The role of E. maritimum (L.) in the dune pollination network of the Balearic Islands

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Abstract

Eryngium maritimum L. (Apiaceae) is a geophyte that inhabits in the dunes of the Mediterranean and Atlantic. In Northern Europe, it is considered a highly endangered species due to reproductive problems, while in the Mediterranean, populations are in a good state of conservation. Although it is a highly entomophilous species, there is little literature on its pollinators. The aim of this study is to analyse the role played by E. maritimum in the dune pollination network of the Balearic Islands. For this purpose, two populations located in the North and South of Mallorca were chosen, in which diurnal transects were carried out to observe and capture pollinators on 15 plant species during the anthesis period of E. maritimum. In parallel, an analysis of the flowering period of 10 of these plant species was carried out to identify periods of competition. A total of 82 pollinator species were found, belonging to 30 different families. Eryngium maritimum is a strongly generalist species, with a total of 46 pollinator species. Functionally, Teucrium dunense and Helichrysum stoechas are functionally the most similar species to E. maritimum. However, analysis of phenology suggests that these three species have been able to decouple their blooms to avoid competition. The present study shows that E. maritimum plays a key role in the dune pollination network, being its anthesis located at the end of the dune flowering season, when there are no functionally similar species in flower.

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Abstract

Eryngium maritimum L. (Apiaceae) is a geophyte that inhabits in the dunes of the Mediterranean and Atlantic. In Northern Europe, it is considered a highly endangered species due to reproductive problems, while in the Mediterranean, populations are in a good state of conservation. Although it is a highly entomophilous species, there is little literature on its pollinators. The aim of this study is to analyse the role played by *E. maritimum* in the dune pollination network of the Balearic Islands. For this purpose, two populations located in the North and South of Mallorca were chosen, in which diurnal transects were carried out to observe and capture pollinators on 15 plant species during the anthesis period of *E. maritimum* . In parallel, an analysis of the flowering period of 10 of these plant species was carried out to identify periods of competition. A total of 82 pollinator species were found, belonging to 30 different families.*Eryngium maritimum* is a strongly generalist species, with a total of 46 pollinator species. Functionally, *Teucrium dunense* and*Helichrysum stoechas* are functionally the most similar species to*E. maritimum* . However, analysis of phenology suggests that these three species have been able to decouple their blooms to avoid competition. The present study

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Keywords

Eryngium maritimum , *pollination network* , *dune* ,

connectance, resilience

Introduction

Pollination is considered one of the most crucial plant-animal interactions, influencing on dynamics and diversity of plant communities (Fantinato et al., 2018b). Widespread declines in pollinators populations had led to a concern about a global pollination crisis (Burkle et al., 2013; Tylianakis, 2013). By reducing pollinator availability and nesting sites due to habitat modifications, cross-pollination levels can be modified influencing plant fruit and seed production (Vanbergen et al., 2014; Traveset et al., 2018). At the same time, anthropization is jeopardizing the sustainability of ecosystems and the ability to resist future environmental changes (Macdougall et al., 2013). Among ecosystems, coastal habitats, such as seashores and dune ridges, are considered some of the most threatened habitats (Gigante et al., 2018), due to habitat loss (Coverdale et al., 2013), global warming (Culbertson et al., 2009) and coastal salination due to an increased sea-level (Chu-Agor et al., 2011). Concretely, coastal dune ecosystems are a hotspot for specialized pollinator species (Cane, 1991), displaying highly specialized species and networks higher risks of extinction (Aizen et al., 2012; Burkle et al., 2013). Understanding plant-pollinator interactions is vital to give light to coevolutionary processes in highly diverse communities (Bascompte & Jordano, 2007) and to evaluate the maintenance of ecosystem's resilience over time (Fantinato et al., 2019). So, polllinators are used as a bioindicator species as the decline of their populations are strongly associated with anthropogenic influence (Biesmejer et al., 2006). At the same time, some attributes of the pollination network (selectiveness, nestedness, connectance) have an ecological meaning in the assessment of habitat resilience to various forms of disturbances (Lázaro et al., 2016; Traveset et al., 2018; Fantinato et al., 2019).

Eryngium maritimum L. is a geophyte from the Apiaceae family that inhabits in sand dunes of the Atlantic and Mediterranean coasts (Isermann & Rooney, 2014). Although it is thought that *E. maritimum* is a generalist species for pollinators (Isermann & Rooney, 2014) and strongly dependent of them due to its low rate of autocompatibility (Cortés-Fernández et al., 2021), its role in the coastal pollination network has never been assessed. In this sense, there is a lack of studies analysing the main pollinators of the species in the Balearic Islands and how the species competes with the other species of the habitat for pollinators. This is particularly important as the species is considered a highly-threatened species in Northern European populations (van der Maarel & van der Maarel-Versluys, 1996; Aviziene et al., 2008), where it displays low fruit and seed set production, and conversely, Balearic populations exhibit high fruit and seed set (Cortés-Fernández et al, 2021), displaying its populations good conservation status.

Eryngium maritimum is a diagnostic species of coastal dunes of the phytosociological class Ammophiletea Br.-Bl. et Tx. ex Westhoff et al. 1946 (Marcenò & Jimenez-Alfaro, 2017). In the Balearic Islands, it develops optimally in embryonic and white dunes, where perennial grasses are not dominant (Llorens et al., 2007). The autofecundation capacity of the species is low, as well as its anemophily, which suggests that the species is strongly entomophilous (Cortes-Fernández, 2021a). It coinhabits with a great variety of plant species which are strongly pollinator-dependent, including members of the Lamiaceae (*Teucrium dunense* Sennen), Leguminosae (*Lotus cytisoides* L.), Asteraceae (*Helichrysum stoechas* (L.) Moench) and Papaveraceae (*Glaucium flavum* Crantz). The best approaches to give light to the dune pollination networks of the Balearic Islands have been carried out in a fixed dune of the North of Mallorca (Son Bosc; Tur et al., 2013; Castro-Urgal et al., 2013; Castro-Urgal & Traveset, 2014; Traveset et al., 2017; Lázaro et al., 2020), which displays a differential floral diversity (*Crucianellion maritimae* Rivas Goday & Rivas-Martinez 1963) than where *E. maritimum* inhabits, and Cala Mesquida (Castro-Urgal & Traveset, 2014), the most representative study carried out in a *E. maritimum* habitat. Unfortunately, for this latest work no species list or network is provided, and so the role of *E. maritimum* in the pollination network is yet unknown.

The main objective of the present study is to analyse *E. maritimum* pollinators and what is its specific role of the species in the dune pollination network of the Balearic Islands. The main hypothesis is that *E. maritimum* is a generalist species and it will play a key role in the pollination network of the habitat. This study will give light to the ecology of the species in the Balearic Islands, continuing a series of studies which analysed its reproductive biology, germination and salinity tolerance in this area (Cortés-Fernandez, 2021a, 2021b, 2022).

Material and methods

Study area

Pollinator surveys were carried out in two different coastal dunes of Mallorca (Balearic Islands, Spain), one located in the North and one in the South of the island (Figure 1). First sampling area was located in Son Serra de Marina (SS, 39.7309N, 3.2382E), in the North of the island. Although the area is relatively well-conserved compared to other areas of the island, it suffers from severe anthropogenic impact mainly due to tourist pression, overall in the drift line zone. On the other hand, the other sampling area was located in Es Trenc (ET, 39.3382N, 2.9903E), in the south of the island. The area is strictly protected, and so interacting with the dunes is completely forbidden. In each area three transects of 50m were carried out, separated 100m with each other, in order to increase the plant diversity available per zone. Each transect consist of a straight line of 50m placed perpendicularly from the coastline. In both areas, vegetation, and so transects, followed a clear sequence from the seashore inland. The sequence starts from therophytes in the drift line zone (Aliance Cakilion maritimae), very altered by the presence of tourism, followed by embryonic dune (*Agropyro-Minuartion peploidis*) and white dune communities (*Ammophilion australis*), which lead to semi-fixed dunes (*Crucianellion maritimae*) landwards (Llorens et al., 2007).

Pollinator surveys

Areas were sampled for 10 weeks, from the beginning of *E. maritimum* flowering in the first week of June and finishing the second week of July, plus two weeks extra (one after and one before) in order two observe pollinator diversity variation. Surveys took place between 08:00–18:00h under favourable weather conditions.

A pollinator survey involved an observer slowly walking (40 min) a transect and recording only those insects that contacted the plant's reproductive structures while actively searching for pollen and/or nectar. Search was limited to those insects belonging to the insect orders most commonly associated with pollination (Coleoptera, Diptera, Hymenoptera and Lepidoptera). Due to the great quantity of pollinators in both areas, only first interaction per session per pollinator-plant species was recorded, in other to construct a presence-absence interaction matrix per session. Insects which were not possible to identify were netted and placed into individually-labelled vials, or captured directly into vials. To minimize our impact on local insect populations, only subsets of individuals from each non-identified species were captured. Insects were frozen and transferred to the laboratory where they were stored until identification.

Pollinators behaviour

Specific observations of *E. maritimum* pollinators were carried out to assess pollinators behaviour and diversity. In each subarea random individuals were selected and observations were made during 20 minutes each transect, with a total observation time of 20*8*4*=640 minutes in each area. For each interaction, the number of visited capitula, its whorl and the total time spend in an individual was recorded.

Phenology

In each sampling area plant surveys were carried out to assess the phenological distribution of plants coinhabiting with *E. maritimum* . Each sampling day a phenological survey was carried out in 10 key species of the habitat, in order to analyse the relationship between flowering and pollinator surveys. To do so, for each species individuals, inflorescences or flowers were followed and flowered units were counted as proposed in Gil (1994).

Network analysis

Three pollination matrices were carried out, one for each population and one for the whole observations. Descriptors for structure and resilience of pollinator interactions were calculated as described by Fantinato et al. (2019) and Traveset et al. (2017) using the *bipartite* R-based package (Dormann et al., 2008). At network level, Connectance (C), Nestedness (N, $NODF$), Specialization Index (H_2 '), Shannon diversity Index (S), Links per species (LP), Vulnerability (V) and number of compartments (NC) were calculated. Connectance is a proportion of the observed links divided by the number of total of possible links (Gomez & Zamora, 2009). Nestedness is the ecological tendency of specialist species to interact with a subset of species that interact with more generalist species (Almeida-Neto et al., 2008; James et al., 2012). Network specialization Index (Bluthgen et al., 2006) is a measure of the network degree of selectiveness, and ranges between 0 (opportunistic, high niche overlap) and 1 (selective, high niche differentiation). Finally, number of compartments reflects the rate of clustering of the network. At species level, Species Strenght (*Str*), Specificity (*Spec*) and Specialization level (*d'*) were considered for analysis. Species strength is the sum of dependencies of a species (Bascompte et al., 2006). Specificity is considered as the coefficient of variation of interactions, and ranges from 0 (low specificity) to 1 (high specificity). Specialization level is, similarly, the level of selectiveness of a species. Using this metric, the degree of selectivity was established based on the*Spec* parameter (highly selective, $Spec > 0.75$; selective, $0.75 > Spec > 0.5$; opportunistic, $0.5 > Spec > 0.25$; highly opportunistic, $Spec < 0.25$), as suggested by Castro-Urgal and Traveset (2013).

For each of the three networks, total number of plant species with interactions (NP) and total number of pollinators (NS) were calculated. Generalized linear mixed effect models were used to compare areas. In order to confirm that our results described patterns that are different from random, models were compared with an appropriate null model (Dormann *et al* ., 2008). To do so, 1000 null versions (null model) of each community matrix were generated using the *shuffle_ web*algorithm implemented in the *bipartite* package with method *r2d* (Dormann *et al* ., 2008).

Results

Pollinator surveys

Our visual survey recorded 353 contacts, involving 82 pollinator (Table S1) and 15 plant species (Table S2). Rarefaction analysis showed that the number of new interactions per session was still growing, but decelerating, at the end of the sampling sessions (Figure S1**).**Diversity of pollinators and Shannon diversity Index indicated than SS was richer in pollinators than ET (Table 1), recording interactions in 16 different plant species in SS, while only 6 in ET. Connectance, Nestedness and Niche Overlap was higher in ET than in SS while Links per species and Vulnerability were lower. Compartment analysis showed that two different compartments were identified considering both populations and ET individually, while SS displayed only one compartment.

Network evaluation indicated that SS web was more complex than ET, displaying more nodes and links (**Figure 2**). In both webs,*E. maritimum* , *T. dunense* and *H. stoechas* displayed the higher diversity of pollinators and interactions. On the other hand, in other plant species like *Ononis natrix subsp. ramosissima*Desf. , *Calystegia soldanella* (L.) R. Br. and*Limbarda chritmoides* (L.) Dumort only one pollinator species was found (**Figure S2**). Although no data about pollinator abundancy was gathered, less pollinators were observed in ET than in SS. On the other hand, the specialization index (H2) indicated that in SS pollinators were more opportunistic than in ET. However, it must be considered that observed versus randomized data suggested that data from ET is not significant enough to indicate clear patterns, contrary to SS and to the full network of both areas (**Table 1**).

Apis mellifera L. was the most opportunistic species of pollinator, visiting 10 of the 15 plant species, while 46 pollinator species were found only visiting one plant species (**Figure S2**). Of the 30 families found, *Apidae* , *Syrphidae* and*Colletidae* were the more diverse families in the network. On the other hand, two families (Satyridae, Bruchinidae) were represented by only one species. Hymenoptera was the most represented class in the network, followed by Diptera and Lepidoptera. Orthoptera was represented only by one interaction, carried out in *P. maritimum* L. and probably accidentally, as a nymph was resting on a stamen. Similarly,

Hemiptera was represented only by one interaction, carried out by *Oxycarenus lavaterae* (Fabricius, 1787) in *E. maritimum* .

Three plant species presented very low levels of selectiveness, *H. stoechas, T. dunense* and *E. maritimum* , while *C. soldanella* , *O. natrix subsp. ramossisima* and *L. chritmoides* presented only 1 interaction and were considered as highly selective (**Table S2**). The vast majority of pollinator species in both populations were highly selective, while high-opportunistic species were proportionally negligible, representing less than 2% of species (**Figure 4; Table S3**). In ET highly selective and selective species were more representative than in SS, where selective and opportunistic species were more represented. Attending at pollinator families, most of them were classified as highly selective, being the only opportunistic families Andrenidae, Apidae, Lycaenidae, Pieridae, Scarabeidae and Syrphidae (**Table S4**). Considering pollinator orders, Coleoptera, Diptera, Hymenoptera and Lepidoptera can be considered as opportunistic (**Table S5)** . On the other hand, Orthoptera and Hemiptera were so unrepresented (N=1) that it is not possible to evaluate selectiveness.

Pollination networks strongly varied among sessions (**Figure S3**). In, first sessions *E. maritimum* was outside of its flowering period and *T.dunense* and *H.stoechas* gathered the vast majority of interactions. Then, T. dunense and especially H. stoechas experimented a decrease while *E. maritimum* began to attract more interactions. In the third session, *E. maritimum* was already the stronger species in terms of pollinator diversity. A slight decrease in pollinator diversity was observed comparing first and last sampling sessions in each area.

Phenology

Seven of the ten species displayed Gauss-like phenological curves, with a definite flowering peak, while *L. cytisoides* , *G. flavum*and *E. pithyusa* presented a diffuse flowering period (**Figure 5**). Considering the most abundant species in the habitat, the flowering period of *E. maritimum* is located after *T. dunense* and *H. stoechas* , being the last species before *P. maritimum* . Observations of the flowering periods between SS an ET during pollinators samples, although not quantitatively evaluated, suggested that plant populations at ET flowered with a delay of, at least, one week respect to SS.

Pollination behaviour

A correlation between time spent in visits and the whorl order was observed, decreasing the time spent in visits in outer whorls (DF =4, F =2.21, P =0.04). Time spent in visits and number of visited capitula was variable among families (**Figure 6**). Apidae pollinators visited more capitula per plant than any other family, while Lycaenidae pollinators spent more time per visits. Data about some families were insufficient to analyse behaviour deeper.

Discussion

Pollinator surveys

Most plant species are generalist rather than specialists (Herrera, 1996; Zamora, 2006), and similarly the great majority of pollinators visit a great variety of plant species (Bosch et al., 2009). Most of the species observed in the present study can be considered as specialists, as their interactions were found in one or a few plant species. However, Petanidou et al. (2008) observed than 90% of species labelled as specialist are indeed generalist when multiple-year data is added. On the other hand, as suggested by Armbruster (2006), generalist pollinators can behave as specialist species in local scale, as a consequence of ecological specialization. The evaluation of the level of specialization is particularly important as more specialized networks are more prone to collapse (Thebault & Fontaine, 2010). Including the interactions found by pollen analysis is known to reduce the proportion of extreme specialist and increase connectance, as pollen remains in the body of pollinators for long period providing a record of visitation history rather than a single sample (Courtney et al., 1982; Bosch et al., 2009).

SS presented a higher number of visits and pollinator richness than ET, which could be related to differences in plant species richness and abundance between populations, that although were not objective of the present

work, were observed in the field. In this sense, floral abundance and plant diversity was higher in SS, factors that have been associated with a high density and abundance of interactions (Bluthgen et al. 2007; Haegen and Kramer, 2010). On the other hand, a high pollinator richness can be considered as an indicator of moderate disturbance levels. As proposed by Connell (1978) in the intermediate disturbance hypothesis (IDH), moderate disturbances levels maintain the highest levels of species richness. In this sense, two possible scenarios emerge. In the first scenario, disturbance is higher in ET than in SS, which is located in the moderate levels, and so species richness decreases in ET. In the second scenario, disturbance in ET is lower than in SS, also presenting lower level of species richness. In sandy dune ecosystems it has been documented that human disturbance increases micro-site diversification (Slaviero et al., 2016) but, at the same time, it increases competition between pollinators and local exclusion of weaker species as a result of a reduction of floral resources availability (Wozjic et al., 2018). However, conclusions derived from IDH should be taken into consideration with caution as it is usually an oversimplification of nature (Fox, 2013).

Although connectance has been widely used as an indicator of resilience (Heleno et al., 2012), the negative relationship between species richness and connectance might be responsible of the differences in connectance between populations rather than responses to human disturbances (Olesen & Jordano, 2002; Fantinato, 2019). Rarefaction curves indicated that more sampling effort would have conducted to a higher species richness in both populations, which would have an impact in connectance values. In this sense, new pollinator observations were carried out in close and similar populations during the study (Rigo, pers. comm.), which could be interpreted as an indicator to increase sampling effort with multiannual data. On the other hand, high values of selectiveness with low values of nestedness are associated with low levels resistence and resilience (Bastolla et al., 2009) as a result of intense disturbances (Revilla et al., 2015; Welti & Joern, 2018), tough not always (Spiesman and Inouye 2013). In the field, more human interaction, and so high levels of disturbance, was observed in ET than in SS, although the last is not protected. So, attending to the indicators and to field observations, more conservation efforts have to be dedicated to avoid dune degradation by anthropization in ET than in SS.

Habitat changes produce different kind of responses depending on the pollinator species (Traveset et al., 2018). Solidary bees, for example, are more susceptible to habitat destruction as they present preferential food resources and nesting sites (Ferreria et al., 2015), while Coleoptera and Dipterans may be less affected as they do not need to return to their nesting sites after foraging (Parsche et al., 2011). However, little is known about how functional pollinator groups change their interaction pattern as a result of disturbances (Lazaro et al., 2016; Traveset et al., 2018). Apidae were the most representative family of pollinators, being generalist and with higher abundances. This is rational considering than bees are generally polylectic, exploiting pollen resources from various species (Minckley & Roulston, 2006), although even oligolectic bees visit various species for nectar. In fact, bees usually alternate visits between a pollen-rich source and a nectar-rich source (Bosch et al., 2009). On the other hand, Hymenoptera was the most represented order of pollinators in the dunes, which is consistent with the observations of previous studies (Castro-Urgal & Traveset, 2014, Fantinato et al., 2018a). Other orders, such as Diptera and Lepidoptera, also played an important role in dune pollination (Gil, 1994). While myophile pollination is known to be usually focused on species with little odourless flowers, psychophyle pollination is carried out preferentially in species with more intense aromas and big tubular flowers (Aguado Martin et al., 2015). In our study, both orders exploited floral resources of a high diversity of plant species, including *E. maritimum* .

An invasive plant species, *Senecio cineraria* DC., was found in our sampling sessions in SS. Attending to the observed interactions, it behaves as a generalist species, although one pollinator species, *Halictus fulvipes* , was only found exploiting its floral resources. Previous studies carried out in a very close area suggested that alien species (in this case *Carpobrotus edulis* (L.) L. Bolus) influence the quantitative component of pollination, influencing negatively (competition) or positively (facilitation; Moragues & Traveset, 2005). So, the present results describe the effect of another alien species, quite abundant in the Balearic Island coasts due to its commercialization as garden plant, producing pollinator species displacements from autochthonous to allochthonous species, altering the structure of coastal networks.

Phenology

A strong phenological variation was present among sampling sessions. For most pollinator species, flowering phenology is the main driver for pollinator distribution rather than flower traits (Bosch et al., 1997), usually presenting short activity periods of pollination (Farre-Armengol et al., 2015). However, a few species presented irregular and long phenological periods (*L. cytisoides* , *G. flavum* and*E. phitysusa*). While *L. cytisoides* and *E. phityusa*are strongly entomogamous, *G. flavum* presents higher levels of autocompatibility (Gil, 1994), which could be related with their irregular phenology and the low pollinator diversity observed in the species, which is particularly visited by coleoptera.

The phenological distribution of species with very low selectiveness (*H. stoechas* , *T. dunense* , *E. maritimum*) suggests that there is a selective pression to decouple flowering between species as to avoid interspecific competition for pollinators. At community level, competition is thought to be the primary selective force moulding flowering schedules (Waser, 1978; Rathcke, 2014). However, when pollinator abundance is optimal, also facilitation among species can occur (Rathcke, 1983), as a sequential mutualism, in which early-flowering species support pollinators of late-flowering species (Waser & Real, 1983), or as a result of synchronous blooms that attract more pollinators that single species alone (Rathcke, 1983). Differences in phenological timing between populations could be related with temperature, as southern coastal populations due to sea currents are colder (Guijarro, 1986; Table S7), which is known to produce a delay in flowering (Gil, 1994, Llorens et al., 2007). On the other hand, the effect of wind is known to have a great impact in pollinators, which enhances the importance of multi-annual data to reduce the potential impact of this variable. On the other hand, more focus should be put on pollinator species abundance in both areas, because attending to our observations strongly varied among sampling sessions.

Pollinator behaviour

Remarkable differences were found between families attending at pollination behaviour. Apidae, the most represented family in both populations, visited more capitula per foraging bout, spending few time per visit, which is consistent with the results of previous studies (Brunet et al., 2009). The high variability observed in the behaviour of Apidae could be attributed to the presence of different functional groups within the family (i.e. bumble-bees, solitary bees and social bees) with usually present different pollination behaviours, spending bumble-bees less time per visit but interacting with more flowers per visit (Brunet et al., 2009). The high values of time per visit observed in Lepidoptera, overall in *Polyommatus celina* , could be attributed to behavioural thermoregulation (Kevan & Shorthouse, 1970), and not really to extensive periods of foraging. In this sense, it must be considered that not all insect visitors may actually be pollinators, and also that pollination is not equally probable among pollinator species, due to differences in carrying capacity, morphology, foraging behaviour and the degree of fidelity (Lindsey, 1984). For example, Coleoptera is known to visit a great variety of plant species, but at the same time is generally considered to have a low effective pollination rate (Thayer et al., 2003; Sayers et al., 2019). However, the evaluation of all these parameters in a single study is prohibitive, and so simplifications, as we did, should be carried out.

The role of E. maritimum

It can be considered as an extreme opportunistic species, presenting pollinators from a great variety of families, which visit flowers for nectar and pollen, which is consistent with previous studies carried out in northern populations (Hegi, 1935; Fitter & Peat, 1994; Westrich, 2001; Zanella et al., 2009). Apiaceae species are known to be visited by a large quantity of insects (Davillla, 2006; Zych et al., 2019) as a result of not presenting floral restrictions accessing to pollen and nectar (Lyndsey, 2014). The species presented the greater species strength and pollinator richness in both populations. This is logical considering that the focus of the study was put on the species, and as a consequence of oversampling, the strength of *E. maritimum* could be overestimated, as the study comprises its whole flowering period. However, a key central role of the species can be defined considering the diversity of pollinators that exploit the floral resources of the species, in a period in which *E. maritimum* is the last species flowered previously to the arrival of cold temperatures. In this sense,*P. maritimum* flowers are not functionally similar, and its known to be strongly

related to evening and nocturnal rather than diurnal pollinators (Eisikowitch & Galil, 1971). So, it can be concluded that conservation of *E. maritimum* is extremely important in terms of pollination, as a vast variety of pollinators depend on the species at the end of the flowering season previously to the decrease in activity due to temperature changes (Mellanby, 1939; Taylor, 1963). Finally, considering the results of the present study, it is improbable that the decrease in fruit and seed set in northern European populations could be attributed to specific pollinator extinctions, as the species behaves as an extremely opportunistic in terms of pollination. However, as suggested by Armbruster (2006), some species can behave as a specialist locally, so replicas of this study in northern populations would be critical to evaluate a potential cause of its decrease in fitness.

Conclusions

1. *Eryngium maritimum* plays a key role in the pollination network
2. It is a widely generalist species
3. It flowers after the other two main generalist species,*H.stoechas* and *T.dunense* , possibly to avoid pollinator competence
4. SS pollination network is more complex than in ET
5. Hymenoptera are the main pollinators of dunes, although Diptera and Lepidoptera also play a major role

Data accessibility

Data are available from the Dryad Digital. Repository: https://doi.org/10.5061/dryad.p8cz8w9s8

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FIGURES AND TABLES

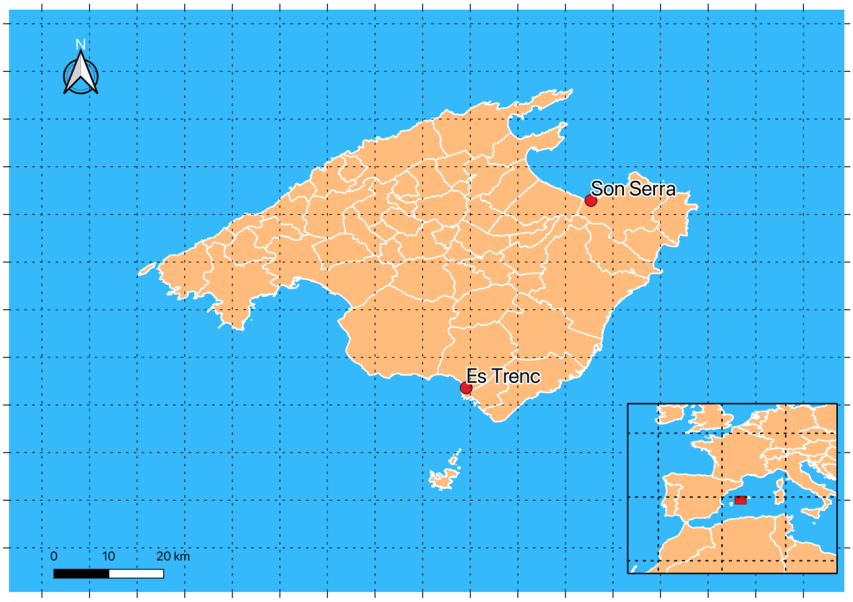


Figure 1 . Map of the studied areas. Red points indicated the sampling areas, each one divided in 3 transects of 50m separated by 100m. Main grid indicates 1x1 km areas, while in secondary map 100x100 km are used.

Figure 2. Pollinator networks of the studied populations (left = Son Serra, right = Es Trenc). Bow width indicates the number of interactions per box. All observed taxons, although some with no interactions, are indicated in both plots to facilitate comparison. For pollinators, genuses are indicated because species are so numerous that decreases readability (See Table S1 for complete results). **Figure 3**. Family (left) and Order (right) pollinator network considering both populations. **Figure 4.** Proportions of species in the different categories of selectivity at each of the study sites. The degree of selectivity is calculated based on the *Specificity index* (highly selective, $Spec > 0.75$; selective, $0.75 > Spec > 0.5$; opportunistic, $0.5 > Spec > 0.25$; highly opportunistic, $Spec < 0.25$). **Figure 5**. Results of the phenological survey of 10 dune species. Colour gradient is used to indicate the flowering peaks. **Figure 6**. Results of the focal observation of pollinators behaviour on *E. maritimum* individuals. For comparison, species have been grouped in families. **Table 1.** Network metrics of the different populations (Son serra - SS, Es Trenc - ET) and both (All). NS= Number of pollinator species, NP= Number of plant species, H2 = Network specialization, C = Connectance, S = Shannon Diversity Index, N = Nestedness, LS = Links per Species, NC = Number of Compartments, NODF= Nestedness based on Overlap, V= Vulnerability. The significance of observed results was tested by constructing 1000 randomized networks with identical margin totals as the empirical networks and comparing the observed and random values using the null model 'r2d' (*P < 0.05).

Population	*NS*	*NP*	*H2*	*C*	*S*	*N*	*LS*	*NC*	*NODF*	*V*
All	82	18	0.20*	0.12*	4.88*	8.25*	1.53*	2*	33.05*	3.16*
Es Trenc	47	8	0.23	0.19	3.97	26.43	1.13	2	16.42	1.83
Son Serra	54	16	0.12*	0.14*	4.57*	11.83*	1.56*	1	33.72*	3.35*

SUPPLEMENTARY FILES

Table S1 . List of the pollinator taxons observed per population

Order	*Family*	*Genus*	*Species*	*Es_ trenc*	*Son_ Serra*
Coleoptera				1	1
	Bruchidae			1	0
		Bruchidius		1	0
	Buprestidae			1	0
		Acmaeodera		1	0
			Acmaeodera convolvuii J.Waltl	1	0
		Anthaxia		1	0
			Anthaxia umbellatarum (Fabrizius, 1787)	1	0
	Coccinellidae			1	1
		Coccinella		1	1
			Coccinella septempunctata L. (1758)	1	1
		Exochomus		1	0
	Mordellidae			1	0
		Mordellistena		1	0
	Oedemerinae			0	1
		Oedemera		0	1

Order	*Family*	*Genus*	*Species*	*Es_ trenc*	*Son_ Serra*
			Oedemera flavipes (Fabricius, 1758)	0	1
	Pentatomidae			1	0
		Graphosoma		1	0
			Graphosoma lineatum (Müller, 1766)	1	0
	Scarabaeidae			0	1
		Oxythyrea		0	1
			Oxythyrea funesta (Poda, 1761)	0	1
		Tropinota		0	1
			Tropinota squalida (Scopoli, 1783)	0	1
	Scraptiidae			1	0
		Anaspis		1	0
	Tenebrionidae			0	1
		Pimelia		0	1
			Pimelia cribra (Solier, 1836)	0	1
Diptera				1	1
	Asilidae			1	0
		Machimus		1	0
	Bombyllidae			1	1
		Exoprosopa		1	1
			Exoprosopa italica (Rossi, 1794)	1	1
		Petrorossia		1	0
			Petrorossia hespera (Rossi, 1790)	1	0
	Calliphoridae			1	1
		Lucilia		1	0
			Lucilia Sericata (Meigen, 1826)	1	0
			Lucilia Silvarum (Meigen, 1826)	1	0
		Stomorhina		1	1
			Stomorhina lunata (Fabricius, 1805)	1	1
	Cloropidae			1	0
		Thaumatomyia		1	0

Order	*Family*	*Genus*	*Species*	*Es_ trenc*	*Son_ Serra*
			Thaumatomyia notata (Meigen, 1830)	1	0
	Conopidae			0	1
		Myopa		0	1
			Myopa extricata Collin, 1960	0	1
	Ephydriidae			1	0
	Muscidae			0	1
	Phoridae			1	0
		Megaselia		1	0
	Pompilidae			1	1
		Dipogon		0	1
			Dipogon variegatus (Linnaeus, 1758)	0	1
	Sarcophagidae			1	1
		Sarcophaga		1	1
	Syrphidae			1	1
		Eristalinus		1	1
			Eristalinus aeneus (Scopoli, 1763)	1	1
			Eristalinus sepulchralis (Linnaeus, 1758)	0	1
			Eristalinus taeniops (Wiedemann, 1818)	0	1
		Eristalis		1	1
			Eristalis tenax (Linnaeus, 1758)	0	1
		Eumerus		0	1
		Paragus		0	1
			Paragus haemorrhous Meigen, 1822	0	1
		Sphaerophoria		1	1
			Sphaerophoria rueppellii (Wiedemann, 1830)	0	1
			Sphaerophoria *taeniata* (Linnaeus, 1758)	1	0
		Syritta		1	0
			Syritta pipiens (Linnaeus, 1758)	1	0
Hemiptera				1	0

Order	*Family*	*Genus*	*Species*	*Es_ trenc*	*Son_ Serra*
	Lygaeidae			1	0
		Oxycarenus		1	0
			Oxycarenus lavaterae (Fabricius, 1787)	1	0
Hymenoptera				1	1
	Andrenidae			1	1
		Andrena		1	1
			Andrena agilissima (Scopoli, 1770)	0	1
			Andrena flavipes Panzer, 1799	1	0
			Andrena morrio Brullé, 1832	1	1
	Apidae			1	1
		Amegilla		1	1
			Amegilla albigena (Lepeletier, 1841)	1	0
			Amegilla quadrifasciata (de Villers, 1789)	0	1
		Antophora		0	1
		Apis		1	1
			Apis mellifera Linnaeus, 1758	1	1
		Bombus		0	1
			Bombus terrestris Linnaeus, 1758	0	1
		Ceratina		1	0
			Ceratina cucurbitina (Rossi, 1792)	1	0
		Megachile		0	1
		Melecta		0	1
			Melecta luctuosa (Scopoli, 1770)	0	1
		Nomada		1	0
			Nomada succinta Panzer, 1798	1	0
		Pseudapis		1	0
			Pseudapis bispinosa (Brullé, 1832)	1	0
		Thyreus		0	1
		Xylocopa		0	1

Order	*Family*	*Genus*	*Species*	*Es_ trenc*	*Son_ Serra*
			Xylocopa violacea (Linnaeus, 1758)	0	1
	Cabronidae			1	1
		Cerceris		1	0
			Cerceris arenaria (Linnaeus, 1758)	1	0
			Cerceris sabulosa (Panzer, 1799)	1	0
		Oxybelus		1	0
		Philanthus		1	1
			Philanthus triangulum (Fabricius, 1775)	1	1
		Stizus		0	1
			Stizus fasciatus (Fabricius, 1781)	0	1
		Tachysphex		1	1
	Colletidae			1	1
		Colletes		1	1
			Colletes abeillei (Pérez, 1903)	1	1
			Colletes succintus (Linnaeus, 1758)	1	0
		Hylaeus		1	1
			Hylaeus annularis (Kirby, 1802)	0	1
			Hylaeus pictus (Smith, 1853)	1	1
			Hylaeus punctatus (Brullé, 1832)	1	0
			Hylaeus taeniolatus (Förster, 1871)	1	0
	Halictidae			1	1
		Ceylalictus		1	0
			Ceylalictus variegatus (Olivier, 1789)	1	0
		Halictus		1	1
			Halictus Fulvipes (Klug, 1817)	0	1
			Halictus scabiosae (Rossi, 1790)	1	1
		Lasioglossum		1	1

Order	*Family*	*Genus*	*Species*	*Es_ trenc*	*Son_ Serra*
			Lasioglossum albocinctum (Lucas, 1849)	0	1
			Lasioglossum nitidulum (Fabricius, 1804)	1	0
		Sphecodes		0	1
			Sphecodes sf. ruficrus	0	1
	Leucospidae			0	1
		Leucospis		0	1
			Leucospis gigas (Fabricius, 1793)	0	1
	Megachilidae			1	1
		Anthidium		0	1
			Anthidium florentinum (Fabricius, 1775)	0	1
		Chalicodoma		0	1
			Chalicodoma sicula (Rossi, 1792)	0	1
		Heriades		1	0
		Osmia		1	0
			Osmia aurulenta (Panzer, 1799)	1	0
			Osmia latreillei (Spinola, 1806)	1	0
		Rhodanthidium		1	1
			Rhodanthidium septemdentatum (Latreille, 1809)	1	1
			Rhodanthidium sticticum (Fabricius, 1787)	0	1
	Pollistidae			1	1
		Bembecinus		0	1
			Bembecinus tridens (Fabricius, 1781)	0	1
		Pollistes		1	1
			Pollistes dominula (Christ, 1791)	1	1
			Pollistes gallicus (Linnaeus, 1767)	1	1
	Pompilidae			1	1
		Entomobora		1	1

Order	*Family*	*Genus*	*Species*	*Es_ trenc*	*Son_ Serra*
			Entomobora fuscipennis (Vander Linden, 1827)	1	0
	Scollidae			1	1
		Dasyscolia		0	1
			Dasyscolia ciliata (Fabricius, 1787)	0	1
	Scollidae	*Megascolia*		1	1
			Megascolia bidens (Linnaeus, 1767)	1	1
			Megascolia maculata (Drury, 1773)	1	1
	Sphecidae			0	1
		Sphex		0	1
			Sphex funerarius (Gussakovskij, 1934)	0	1
	Syrphidae			1	1
		Sphaerophoria		1	1
	Typhiidae			1	0
		Meria		1	0
			Meria tripunctata (Rossi, 1790)	1	0
	Vespidae			1	1
		Ancistrocerus		0	1
			Ancistrocerus kitcheneri (Dusmet, 1917)	0	1
		Eumenes		1	0
			Eumenes coarctatus (Linnaeus, 1758)	1	0
Lepidoptera				1	1
	Lycaenidae			1	1
		Celastrina		0	1
			Celastrina argiolus (Linnaeus, 1758)	0	1
		Polyommatus		1	1
			Polyommatus celina (Austaut, 1879)	1	1
	Noctuidae			0	1
		Autographa		0	1

Order	*Family*	*Genus*	*Species*	*Es_ trenc*	*Son_ Serra*
			Autographa gamma (Linnaeus, 1758)	0	1
		Odice		0	1
			Odice blandula (Rambur, 1858)	0	1
	Nymphalidae			1	1
		Vanessa		1	1
			Vanessa atalanta (Linnaeus, 1758)	0	1
			Vanessa cardui (Linnaeus, 1758)	1	1
	Pieridae			1	1
		Colias		1	1
			Colias Crocea (Geoffroy, 1785)	1	1
		Gonepteryx		0	1
			Gonepteryx cleopatra (Linnaeus, 1767)	0	1
		Pieris		1	1
			Pieris rapae (Linnaeus, 1758)	1	1
		Pontia		1	0
			Pontia daplidice (Linaneus, 1758)	1	0
	Satyridae			0	1
		Pararge		0	1
			Pararge aegeria (Linnaeus, 1758)	0	1
Orthoptera				1	0
	Acrididae			1	0

Table S2 . Plant species metrics of the different populations (Son Serra, Es Trenc) And both (All). *D* = Number of pollinators,*Str* = Species Strength, *Spec* = Specificity, *d'* = Specialization level. Selectiveness is calculated based on the*Specificity index* (highly selective, *Spec* > 0.75; selective, 0.75 > *Spec* > 0.5; opportunistic, 0.5 > *Spec* > 0.25; highly opportunistic, *Spec* < 0.25).

	Es Trenc	Es Trenc	Es Trenc	Es Trenc	Son Serra	Son Serra	Son Serra	Son Serra	Al
Species	*D*	*Str*	*Spec*	*d*	*D*	*Str*	*d*	*Spec*	*D*
Cakile maritima	5	3,33	0,42	0,56	4	1,58	0,46	0,48	9
Calystegia soldanella					1	0,1	0	1	1
Centaurea aspersa					5	1,08	0,06	0,43	5
Cistus salvifolius					4	1,8	0,35	0,48	4
Eryngium maritimum	23	20,53	0,14	0,43	28	16,7	0,25	0,12	46
Euphorbia parallias					3	2,67	0,89	0,6	3
Glaucium flavum					2	1,5	0,82	0,7	2
Helichrysum stoechas	6	3,87	0,38	0,39	11	4,67	0,24	0,27	13
Launaea cervicornis					2	0,45	0,23	0,7	2

	Es Trenc	Es Trenc	Es Trenc	Es Trenc	Son Serra	Son Serra	Son Serra	Son Serra	Al
Limbardia chritmoides	1	1	1	1					1
Limonium	6	3,37	0,38	0,28	5	1,68	0,28	0,43	10
Lotus cytisoides	4	2,53	0,48	0,45	8	4,55	0,46	0,33	11
Ononis natrix					1	0,1	0	1	1
Senecio cineraria					7	2,28	0,15	0,35	7
Teucrium dunense	8	5,37	0,32	0,38	16	8,83	0,34	0,21	17

Table S3 . Pollinator species metrics of the different populations (Son Serra, Es Trenc) And both (All). D = Number of pollinators, *Str* = Species Strength, *Spec* = Specificity,*d'* = Specialization level. Selectiveness is calculated based on the *Specificity index* (highly selective, *Spec*$>$ 0.75; selective, 0.75 $>$ *Spec*$>$ 0.5; opportunistic, 0.5 $>$ *Spec*$>$ 0.25; highly opportunistic, *Spec* $<$ 0.25).

	Es Trenc	Es Trenc	Es Trenc	Es Trenc	Son Serra	Son Serra	Son Serra	Son Serra
Species	*D*	*Str*	*d*	*Spec*	*D*	*Str*	*d*	*Spec*
Amegilla albigena	1	0,2	0,49	1				
Amegilla quadrifasciata					3	0,49	0,26	0,53
Ancistrocerus kitcheneri					1	0,04	0	1
Andrena agilissima					1	0,04	0	1
Andrena flavipes	1	0,17	0,43	1				
Andrena morrio	1	0,04	0	1	5	0,83	0,11	0,37
Anthaxia umbellatarum	1	0,04	0	1				
Anthidium florentinum					1	0,12	0,38	1
Apis mellifera	3	0,46	0,19	0,47	10	3,11	0,16	0,18
Autographa gamma					1	0,06	0,17	1
Bembecinus tridens					1	0,04	0	1
Bombus terrestris					5	0,57	0,06	0,37
Celastrina argiolus					1	0,04	0	1
Ceratina cucurbitina	1	0,04	0	1				
Cerceris arenaria	1	0,04	0	1				
Cerceris sabulosa	1	0,04	0	1				
Ceylalictus variegatus	1	0,04	0	1				
Chalicodoma sicula					1	0,12	0,38	1
Coccinella septempunctata	1	0,17	0,43	1	1	0,09	0,28	1
Colias crocea	1	0,12	0,34	1	1	0,06	0,17	1
Colletes abeillei	3	0,62	0,32	0,47	2	0,13	0,06	0,68
Colletes succintus	1	0,04	0	1				
Dasyscolia ciliata					2	0,1	0	0,68
Dipogon variegatus					1	0,04	0	1
Entomobora fuscipennis	1	0,04	0	1				
Eristalinus aeneus	1	0,12	0,34	1	4	0,44	0,07	0,44
Eristalinus sepulchralis					2	0,15	0,15	0,68
Eristalis tenax					3	0,27	0,1	0,53
Eumenes coarctatus	1	0,04	0	1				
Exoprosopa italica	1	0,17	0,43	1	2	0,38	0,43	0,68
Gonepteryx cleopatra					4	0,58	0,2	0,44
Graphosoma lineatum	1	0,04	0	1				
Halictus fulvipes					1	0,14	0,42	1
Halictus scabiosae	1	0,04	0	1	1	0,04	0	1
Hylaeus annularis					1	0,12	0,38	1

	Es Trenc	Es Trenc	Es Trenc	Es Trenc	Son Serra	Son Serra	Son Serra	Son Serra
Hylaeus pictus	1	0,04	0	1	1	0,09	0,28	1
Lasioglossum albocinctum					2	0,29	0,23	0,68
Lasioglossum nitidulum	1	0,25	0,56	1				
Leucospis gigas					1	0,04	0	1
Lucilia sericata	1	0,04	0	1				
Megascolia bidens	3	0,34	0	0,47	2	0,1	0	0,68
Megascolia maculata	2	0,21	0,06	0,65	2	0,1	0	0,68
Melecta luctuosa					1	0,04	0	1
Meria tripunctata	1	0,04	0	1				
Myopa extricata					1	0,04	0	1
Nomada succinta	1	0,12	0,34	1				
Oedemera flavipes					1	0,25	0,58	1
Osmia aurulenta	1	0,25	0,56	1				
Osmia latreillei	1	1	1	1				
Oxycarenus lavaterae	1	0,04	0	1				
Oxythyrea funesta					5	0,72	0,15	0,37
Paragus haemorrhous					1	0,25	0,58	1
Pararge aegeria					1	0,06	0,17	1
Philanthus triangulum	1	0,12	0,34	1	3	0,19	0	0,53
Pieris rapae	1	0,17	0,43	1	2	0,38	0,43	0,68
Pollistes dominula	1	0,04	0	1	2	0,24	0,19	0,68
Pollistes gallicus	1	0,04	0	1	2	0,7	0,65	0,72
Polyommatus celina	5	0,75	0,03	0,26	4	0,78	0,25	0,44
Pontia daplidice	1	0,17	0,43	1				
Pseudapis bispinosa	2	0,24	0,09	0,65				
Sphaerophoria rueppellii					1	0,25	0,58	1
Sphaerophoria taeniata	1	0,04	0	1				
Sphex funerarius					2	0,24	0,19	0,68
Stizus fasciatus					1	0,04	0	1
Stomorhina lunata					2	0,54	0,34	0,68
Syritta pipiens	1	0,2	0,49	1				
Thaumatomyia notata	1	0,04	0	1				
Tropinota squalida					1	0,5	0,79	1
Vanessa atalanta					1	0,06	0,17	1
Vanessa cardui	2	0,32	0,29	0,65	2	0,1	0	0,68
Xylocopa violacea					1	0,06	0,17	1

Table S4 . Pollinator family metrics. D = Number of pollinators, *Str* = Species Strength, *Spec* = Specificity,*d'* = Specialization level. Selectiveness is calculated based on the *Specificity index* (highly selective, *Spec*$>$ 0.75; selective, 0.75 $>$ *Spec*$>$ 0.5; opportunistic, 0.5 $>$ *Spec*$>$ 0.25; highly opportunistic, *Spec* $<$ 0.25).

Species	*D*	*Str*	*d*	*Spec*	*Specific*
Acrididae	1	1.00	1.00	1.00	Highly selective
Andrenidae	5	0.85	0.13	0.45	Opportunistic
Apidae	11	4.09	0.16	0.29	Opportunistic
Bombyllidae	3	0.29	0.31	0.54	Selective
Bruchidae	1	0.01	0.00	1.00	Highly selective
Buprestidae	1	0.01	0.00	1.00	Highly selective
Cabronidae	3	0.25	0.10	0.72	Selective

Species	*D*	*Str*	*d*	*Spec*	*Specific*
Calliphoridae	2	0.53	0.23	0.73	Selective
Cloropidae	1	0.01	0.00	1.00	Highly selective
Coccinellidae	1	0.12	0.41	1.00	Highly selective
Colletidae	4	0.56	0.14	0.55	Selective
Conopidae	3	0.16	0.07	0.54	Selective
Ephydriidae	1	0.01	0.00	1.00	Highly selective
Halictidae	6	1.60	0.16	0.51	Selective
Leucospidae	1	0.01	0.00	1.00	Highly selective
Lycaenidae	6	0.82	0.08	0.36	Opportunistic
Lygaeidae	1	0.01	0.00	1.00	Highly selective
Megachilidae	2	1.27	0.75	0.70	Selective
Mordellidae	1	0.01	0.00	1.00	Highly selective
Muscidae	1	0.01	0.00	1.00	Highly selective
Noctuidae	1	0.05	0.28	1.00	Highly selective
Nymphalidae	3	0.22	0.14	0.58	Selective
Oedemerinae	1	0.25	0.67	1.00	Highly selective
Pentatomidae	1	0.01	0.00	1.00	Highly selective
Phoridae	1	0.01	0.00	1.00	Highly selective
Pieridae	8	0.85	0.11	0.29	Opportunistic
Pollistidae	3	0.75	0.26	0.61	Selective
Pompilidae	1	0.04	0.07	1.00	Highly selective
Sarcophagidae	1	0.01	0.00	1.00	Highly selective
Satyridae	1	0.05	0.28	1.00	Highly selective
Scarabaeidae	6	1.17	0.28	0.34	Opportunistic
Scollidae	3	0.43	0.18	0.57	Selective
Scraptiidae	1	0.01	0.00	1.00	Highly selective
Sphecidae	2	0.11	0.09	0.68	Selective
Syrphidae	6	1.31	0.16	0.39	Opportunistic
Typhiidae	1	0.01	0.00	1.00	Highly selective
Vespidae	1	0.04	0.07	1.00	Highly selective

Table S5 . Pollinator order metrics of the different populations. D = Number of pollinators, *Str* = Species Strength, *Spec* = Specificity, *d'* = Specialization level. Selectiveness is calculated based on the *Specificity index*(highly selective, $Spec > 0.75$; selective, $0.75 > Spec > 0.5$; opportunistic, $0.5 > Spec > 0.25$; highly opportunistic,$Spec < 0.25$).

Species	*D*	*Str*	*d*	*Spec*	*Specific*
Coleoptera	6	1.59	0.22	0.47	Opportunistic
Diptera	9	2.42	0.07	0.45	Opportunistic
Hemiptera	1	0.01	0.00	1.00	Highly selective
Hymenoptera	15	10.03	0.05	0.42	Opportunistic
Lepidoptera	9	1.94	0.09	0.33	Opportunistic
Orthoptera	1	1.00	1.00	1.00	Highly selective

Table S6 . Pollinator behaviour results of the focal census on*E. maritimum* individuals. Time spent in visits and number of visited capitula are indicated. For some species only one observation is available.

Order	*Family*	*Genus*	*Species*	*Time (s)*	*Capitula*
Coleoptera					2
Diptera				67 ± 2.35	1
Diptera	*Calliphoridae*			2.5 ± 0.5	1
Diptera	*Syrphidae*			3 ± 0	4
Hemiptera					2
Hymenoptera				81.45 ± 21.41	3 ± 0.48
Hymenoptera	*Apidae*	*Amegilla*	*Amegilla quadrifasciata*	5.5 ± 0.5	5
Hymenoptera	*Apidae*	*Bombus*	*Bombus terrestris*	36.78 ± 14.62	5.67 ± 2.4
Hymenoptera	*Apidae*	*Pseudapis*	*Pseudapis bispinosa*	30	2
Hymenoptera	*Cabronidae*			74	3
Hymenoptera	*Cabronidae*	*Cerceris*		14	1
Hymenoptera	*Cabronidae*	*Cerceris*	*Cerceris arenaria*	12	1
Hymenoptera	*Cabronidae*	*Philanthus*	*Philanthus triangulum*	117 ± 23	
Hymenoptera	*Colletidae*			10 ± 4	1.5 ± 0.5
Hymenoptera	*Colletidae*	*Colletes*	*Colletes succintus*	14	2
Hymenoptera	*Halictidae*			14	1
Hymenoptera	*Halictidae*	*Ceratina*	*Ceratina cucurbitina*	20 ± 14	1
Hymenoptera	*Halictidae*	*Halictus*	*Halictus scabiosae*	28.4 ± 7.54	1.2 ± 0.2
Hymenoptera	*Pollistidae*			13	1
Hymenoptera	*Pollistidae*	*Pollistes*	*Pollistes dominula*	16.67 ± 7.69	1
Hymenoptera	*Pollistidae*	*Pollistes*	*Pollistes gallicus*	11	1
Hymenoptera	*Pompilidae*	*Entomobora*	*Entomobora fuscipennis*	10	1
Hymenoptera	*Scollidae*			197 ± 14	6
Hymenoptera	*Scollidae*	*Dasyscolia*	*Dasyscolia ciliata*	65	4
Hymenoptera	*Scollidae*	*Megascolia*	*Megascolia bidens*	32.67 ± 9.4	2.33 ± 0.88
Hymenoptera	*Scollidae*	*Megascolia*	*Megascolia maculata*	32.75 ± 9.7	1.67 ± 0.67
Hymenoptera	*Sphecidae*	*Sphex*	*Sphex funerarius*	20	3
Lepidoptera					
Lepidoptera	*Lycaenidae*	*Polyommatus*	*Polyommatus celina*	281	1
Lepidoptera	*Nymphalidae*	*Vanessa*	*Vanessa cardui*	79	

Table S7 . Climatic data of SS and ES populations. Data collection has been restricted until the end of the fruiting season in final August of 2021. This data complements the analysis of Guijarro (1986), which

suggested that southern dunes are colder than northern Mallorcan dunes. Data source: Wunderground (Code: ISANTA224) and Balearsmeteo (Club Nautico del Sa Rapita de Campos), respectively.

	ES TRENC (ES)	ES TRENC (ES)	ES TRENC (ES)	ES TRENC (ES)	ES TRENC (ES)	ES TRENC (ES)
	Mean T (ºC)	Absolute min. T (ºC)	Mean min. T (ºC)	Absolute max. T (ºC)	Mean max. T (ºC)	Precipiation (mm)
January	10,8	-1,4	6,3	19,4	14,5	29
February	13,1	2,9	8,1	21,5	16,8	2
March	12,7	3,6	8	21,5	16,8	47,2
April	14,5	1,9	10,3	21,9	18,1	8,6
May	18,1	10,6	13,9	27,1	21,4	65,2
June	23,4	14,7	18,2	35	27,5	35
July	25,3	17,3	20,6	33,1	29	0
August	26,3	18,8	21,9	37,8	30,6	10

	SON SERRA DE MARINA (SS)	SON SERRA DE MARINA (SS)	SON SERRA DE MARINA (SS)	SON SERRA DE MARINA (SS)	SON SERRA DE MARINA (SS)	SON SERRA DE MARINA (SS)	
	Mean T (ºC)	Absolute min. T (ºC)	Mean min. T (ºC)	Absolute max. T (ºC)	Mean max. T (ºC)	Precipiation (mm)	Precipiation (mm)
January	10,4	-0,1	5,8	25,3	15,6	66,97	66,97
February	12,8	2,9	7,8	25,1	18,2	3,6	3,6
March	12,8	4,5	7,5	23,8	17,5	40,6	40,6
April	13,8	2	9,6	23,5	19	8,9	8,9
May	17,2	15	13,6	27,9	22,8	51,6	51,6
June	23,8	15	17,3	34	28,1	46,7	46,7
July	26	16,6	20,4	38,1	32,1	8,7	8,7
August	26,1	18	21,6	40,8	31,5	60,9	60,9

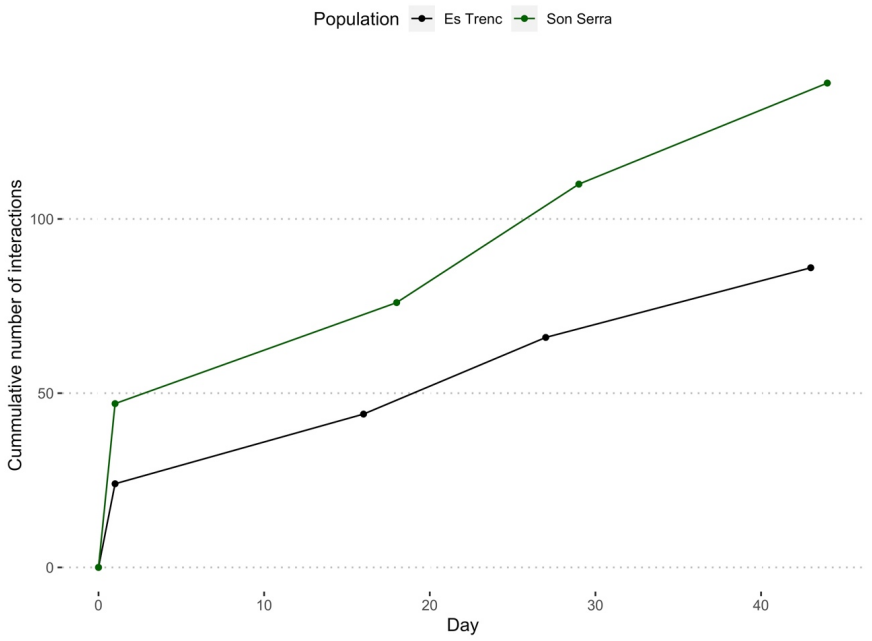


Figure S1 . Rarefaction plot of the cumulative number of new interactions per population per sampling session

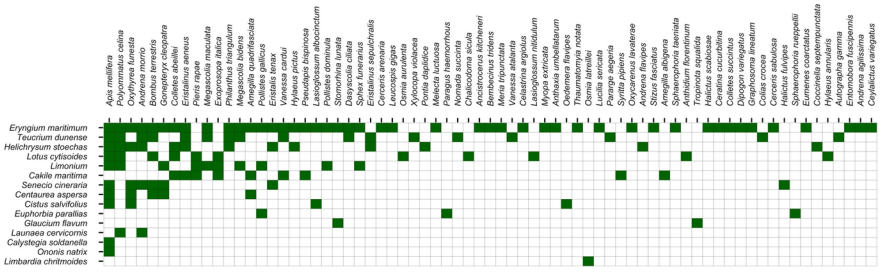
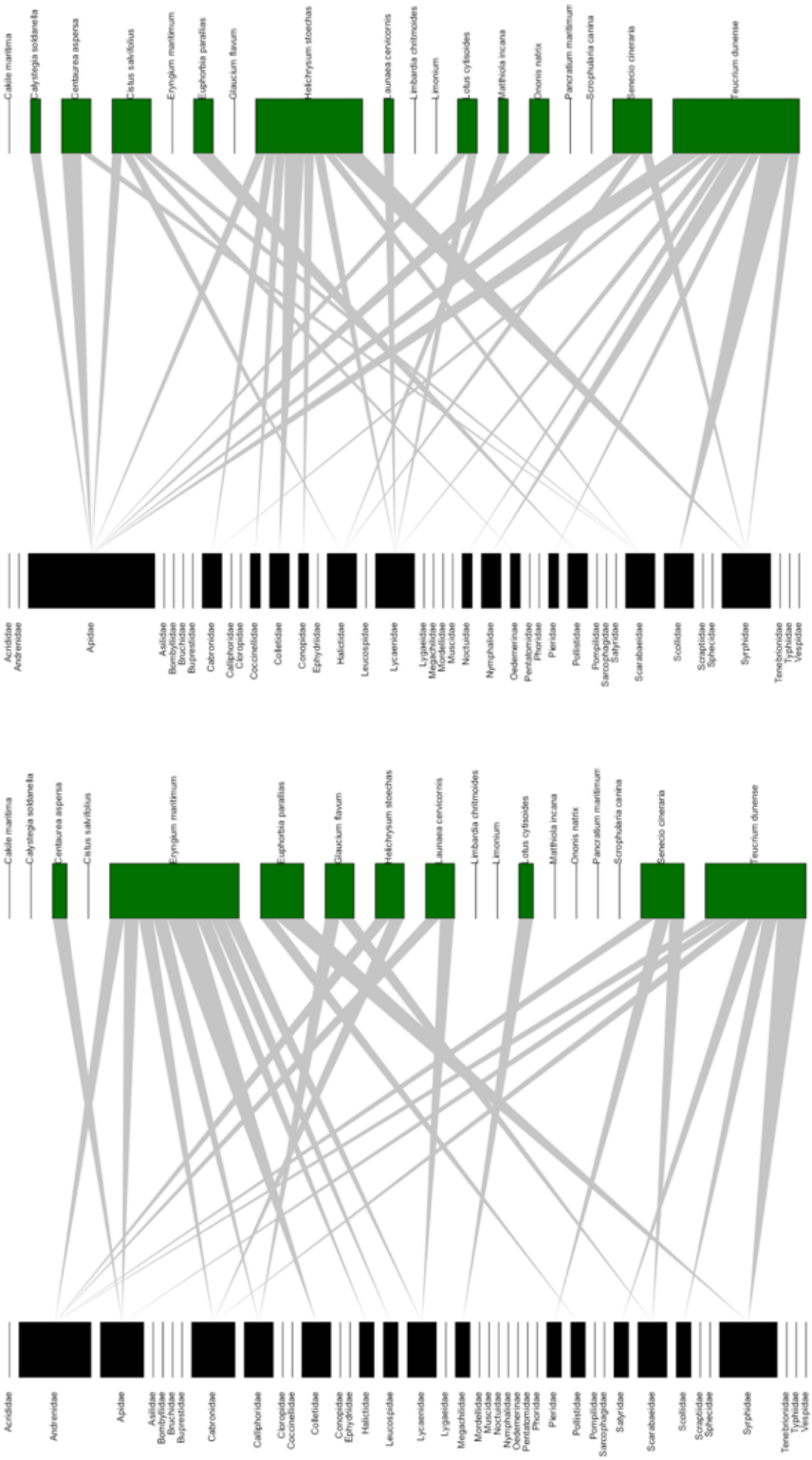
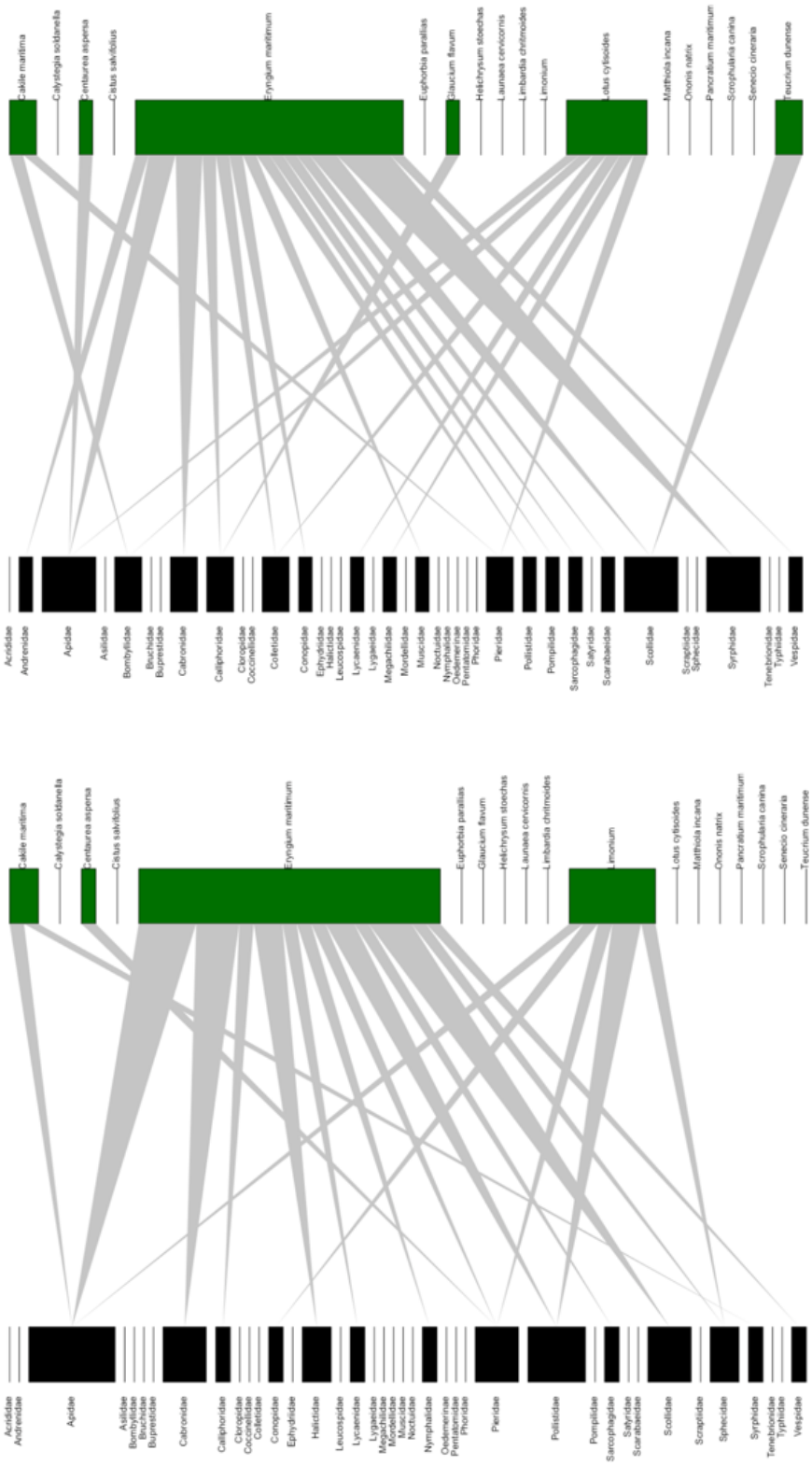
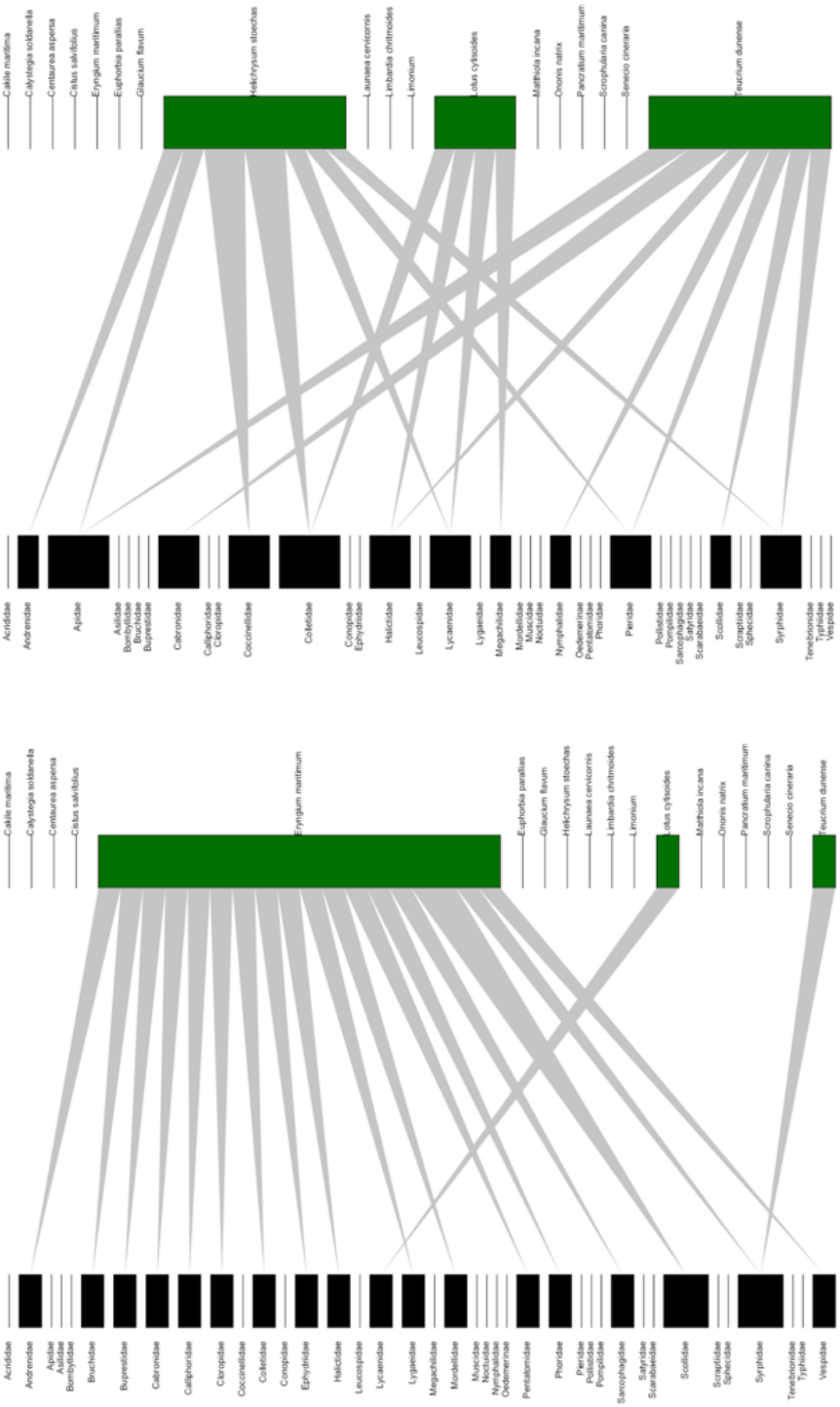


Figure S2 . Matrix of pollinators per plant species. Pollinator species are ordered by diversity of interactions (grade of selectiveness) from left to right.







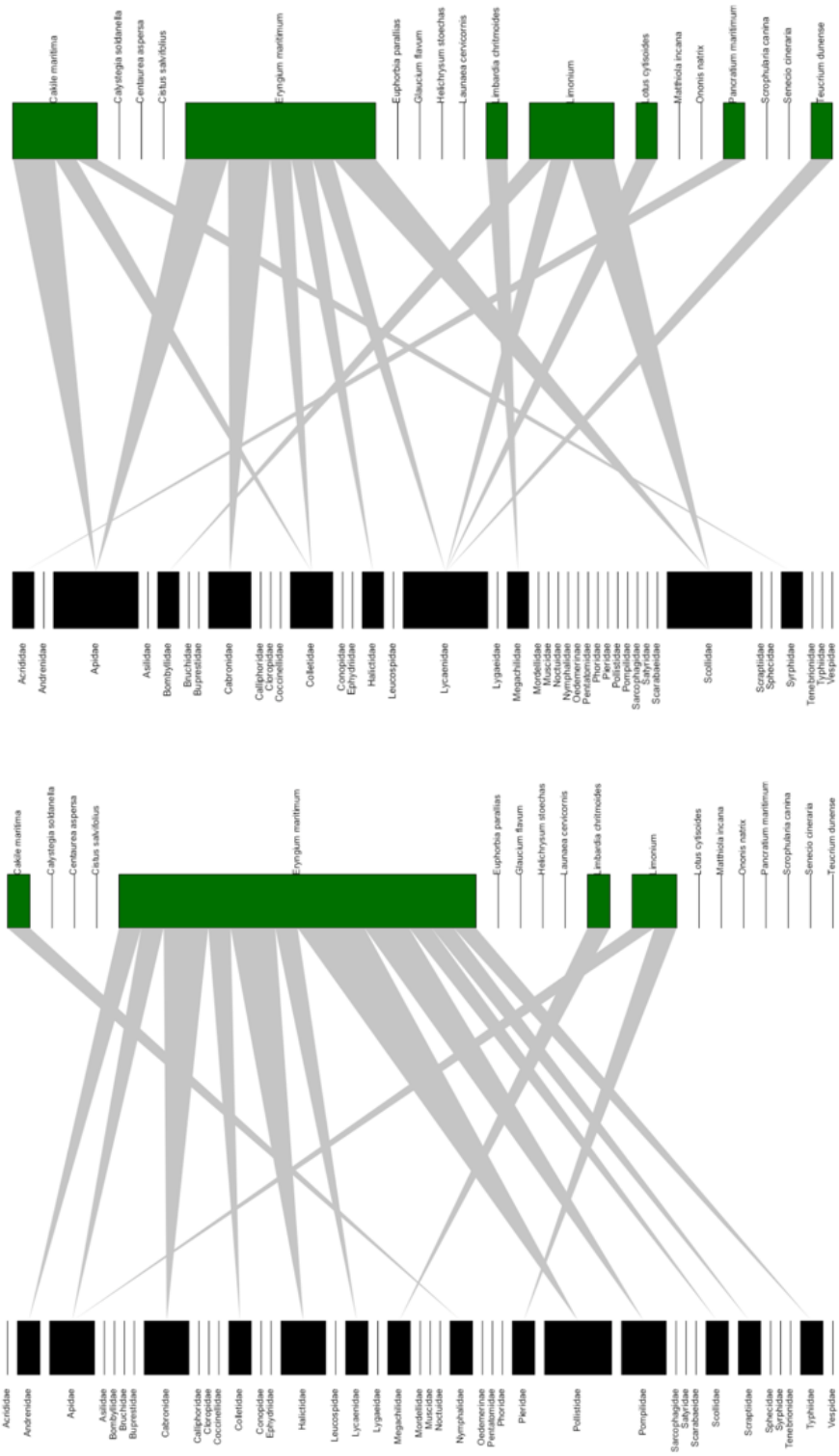


Figure S3 . Pollinator networks by day of sampling (left to right). First row indicates samples in Son Serra de Marina, while second indicates Es Trenc networks. The timing between samples between populations is one week, while between samples of the same population is two weeks.