Unveiling wild bee-plant interaction patterns on a large but largely understudied Mediterranean island (Sardinia, Italy)

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State of the art and objective

The study of plant–pollinator networks offers valuable insights into the mechanisms influencing the structure and stability of bee communities and their ecosystem services, as well as their resilience to anthropogenic disturbances. However, the Mediterranean basin, which hosts one of the world's highest diversities of bees, remains significantly understudied, with many islands particularly overlooked in terms of bee-plant interaction research.

In this work, we present the results of the first comprehensive monitoring of wild bees and their interactions with plants in Sardinia (Italy), the second-largest island in the Mediterranean.

Methods

Four sites were surveyed: two on the island of Asinara (dominated by natural habitats) and two in the Nurra region on the Sardinian mainland (dominated by extensive agroecosystems) (Fig. 1)

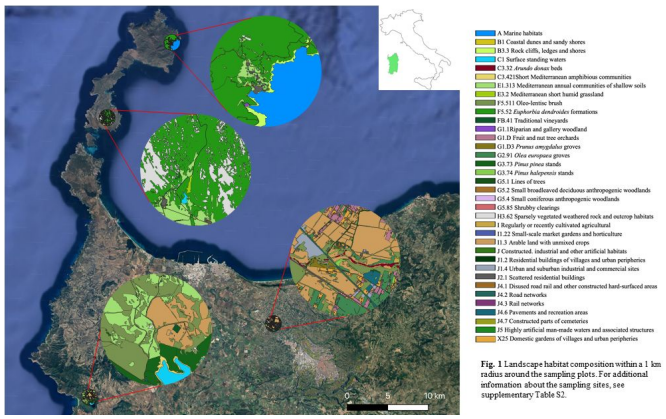

Fig. 1 Landscape habitat composition within a 1 km radius around the sampling plots. For additional information about the sampling sites, see supplementary Table S2.

Results

A total of 129 wild bee species were identified among the 1,491 individuals collected, with the greatest species richness and diversity observed at the Nurra sites, a pattern also found for plant species (Tab.1).

The bipartite network analysis revealed that all four bee-plant ecological networks exhibited high complementarity, were non-nested, modular, and had low connectance and interaction evenness, indicating that despite being species-rich and specialized, they showed low stability and some vulnerability (Tab. 2).

At all sites, species within the networks exhibited moderate specialization, with most acting as peripheral species, consistent with the overall low connectance. In terms of species roles within the network, the majority of species in all four sites are classified as peripheral species, indicating that they have relatively few interactions and are largely restricted to within-module connections. However, the variation in the number of connectors across sites is particularly interesting, with Ottava the most anthropized site, exhibits the highest number of connector species.

This site includes a wide range of habitats, from cultivated and peri-urban areas to seminatural habitats, promoting higher biodiversity and interactions, leading to more species that bridge different modules. In contrast, more pristine sites like Cala d'Oliva and Fornelli, with less habitat diversity, have fewer connector species, reinforcing the idea that anthropogenic landscapes might support more generalist species linking different modules.

Tab 1. Differences in the observed species richness (S), Shannon-Weaver diversity (H') and Gini-Simpson dominance (GS) between pairs of the four studied communities. In bold, the significant comparisons.

Bees	Baratz	Ottava	Cala d'Oliva	Fornelli	Permutation *P*
S	60	86	49	45	Baratz vs. Ottava: 0.64 Baratz vs. Cala d'Oliva: 0.14 Baratz vs. Fornelli: **0.03** Ottava vs. Cala d'Oliva: **0.02** Ottava vs. Fornelli: **0.07** Cala d'Oliva vs. Fornelli: 0.67
H'	3.44	3.475	2.888	3.042	Baratz vs. Ottava: 0.87 Baratz vs. Cala d'Oliva: **0.0002** Baratz vs. Fornelli: **0.002** Ottava vs. Cala d'Oliva: **0.0001** Ottava vs. Fornelli: **0.003** Cala d'Oliva vs. Fornelli: 0.26
GS	0.9471	0.938	0.8723	0.9119	Baratz vs. Ottava: 0.24 Baratz vs. Cala d'Oliva: **0.0001** Baratz vs. Fornelli: **0.0001** Ottava vs. Cala d'Oliva: **0.0001** Ottava vs. Fornelli: **0.0008** Cala d'Oliva vs. Fornelli: **0.02**
Plants	**Baratz**	**Ottava**	**Cala d'Oliva**	**Fornelli**	**Permutation *P***
S	33	53	28	19	Baratz vs. Ottava: 0.08 Baratz vs. Cala d'Oliva: 0.32 Baratz vs. Fornelli: **0.0002** Ottava vs. Cala d'Oliva: **0.0007** Ottava vs. Fornelli: **0.0001** Cala d'Oliva vs. Fornelli: 0.02
H'	2.899	3.213	2.269	2.407	Baratz vs. Ottava: **0.003** Baratz vs. Cala d'Oliva: **0.0001** Baratz vs. Fornelli: **0.0001** Ottava vs. Cala d'Oliva: **0.0001** Ottava vs. Fornelli: **0.0001** Cala d'Oliva vs. Fornelli: 0.20
GS	0.9161	0.9418	0.776	0.8881	Baratz vs. Ottava: **0.0001** Baratz vs. Cala d'Oliva: **0.0001** Baratz vs. Fornelli: **0.0001** Ottava vs. Cala d'Oliva: **0.0001** Ottava vs. Fornelli: **0.0001** Cala d'Oliva vs. Fornelli: **0.0001**

Tab 2. Values of the network-level indices of specialization (H2'), nestedness (NODF), linkage density (LD) and interaction evenness (IE), together with their bootstrapped comparisons with random networks. In bold, the significant comparisons.

Baratz	Observed	Null mean	Lower CI	Upper CI	*t*	*P*
H_2'	0.46	0.14	0.14	0.15	-122.39	**<0.0001**
WNODF	5.68	10.58	10.09	11.07	20.98	**<0.0001**
LD	0.10	0.17	0.16	0.17	27.64	**<0.0001**
IE	4.53	9.04	8.89	9.20	59.88	**<0.0001**
Ottava						
H_2'	0.44	0.13	0.13	0.13	-207.57	**<0.0001**
WNODF	5.86	14.66	14.19	15.13	39.08	**<0.0001**
LD	0.08	0.19	0.18	0.20	18.02	**<0.0001**
IE	6.09	13.22	13.04	13.41	81.27	**<0.0001**
Cala d'Oliva						
H_2'	0.48	0.13	0.12	0.14	-96.96	**<0.0001**
WNODF	9.86	23.10	21.87	24.33	22.53	**<0.0001**
LD	0.15	0.36	0.34	0.37	27.42	**<0.0001**
IE	4.15	8.16	8.01	8.32	52.67	**<0.0001**
Fornelli						
H_2'	0.58	0.16	0.15	0.17	-112.04	**<0.0001**
WNODF	7.49	17.88	17.09	18.67	27.57	**<0.0001**
LD	0.12	0.27	0.25	0.28	19.61	**<0.0001**
IE	3.77	8.36	8.20	8.52	59.53	**<0.0001**

Conclusion

The networks studied, despite sharing common structural traits, exhibited differences shaped by the specific habitats and land-use types of each site. Habitat diversity and moderate human disturbance play key roles in shaping network structure. Simplified landscapes with less habitat heterogeneity, like Cala d'Oliva and Fornelli, support more specialized and less connected networks, whereas heterogeneous and anthropized landscapes, like Ottava, foster higher connectivity and interaction diversity. This aligns with broader ecological trends where environmental factors significantly influence plant-pollinator interaction dynamics.