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ES 404: Networks and Complex Systems

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Abstract

This report investigates key properties of a real-world network using centrality measures, community detection algorithms, assortativity analysis, and clustering coefficients. All computations were performed using Python, and relevant plots are included.

1 Task 1: Network Construction & Preliminaries

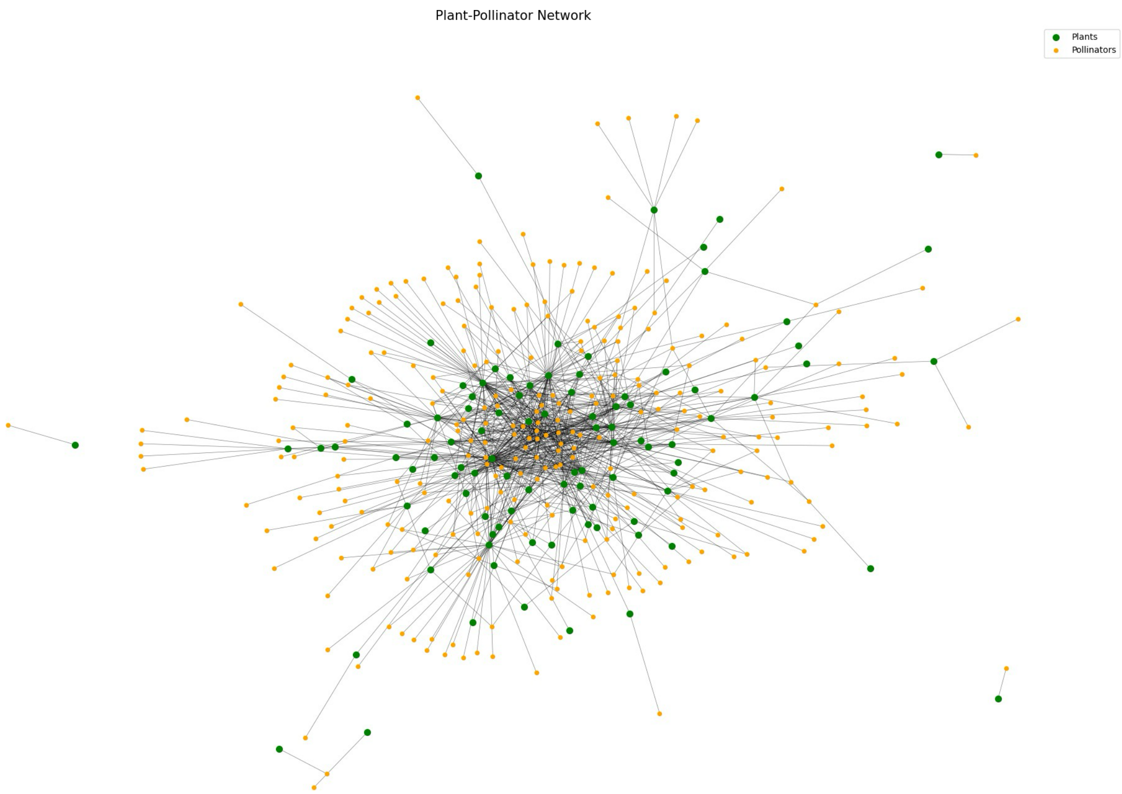

Figure 1: Plant-Pollinator Network

1.1 Dataset Description

The dataset represents a pollination network where:

- **Nodes** represent plant and pollinator species.
- **Edges** represent interactions between plant and pollinator pairs.
- The dataset M_PL_005.csv was obtained from the Web of Life ecological network database.

1.2 Preprocessing

Prior to network construction:

- Null entries were removed.
- The data was converted into an adjacency matrix.
- The dataset was converted into a bipartite network.

1.3 Basic Metrics

- Number of nodes: **N = 371** (96 plants and 275 pollinators)
- Number of edges: **E = 923**

1.4 Degree Distribution

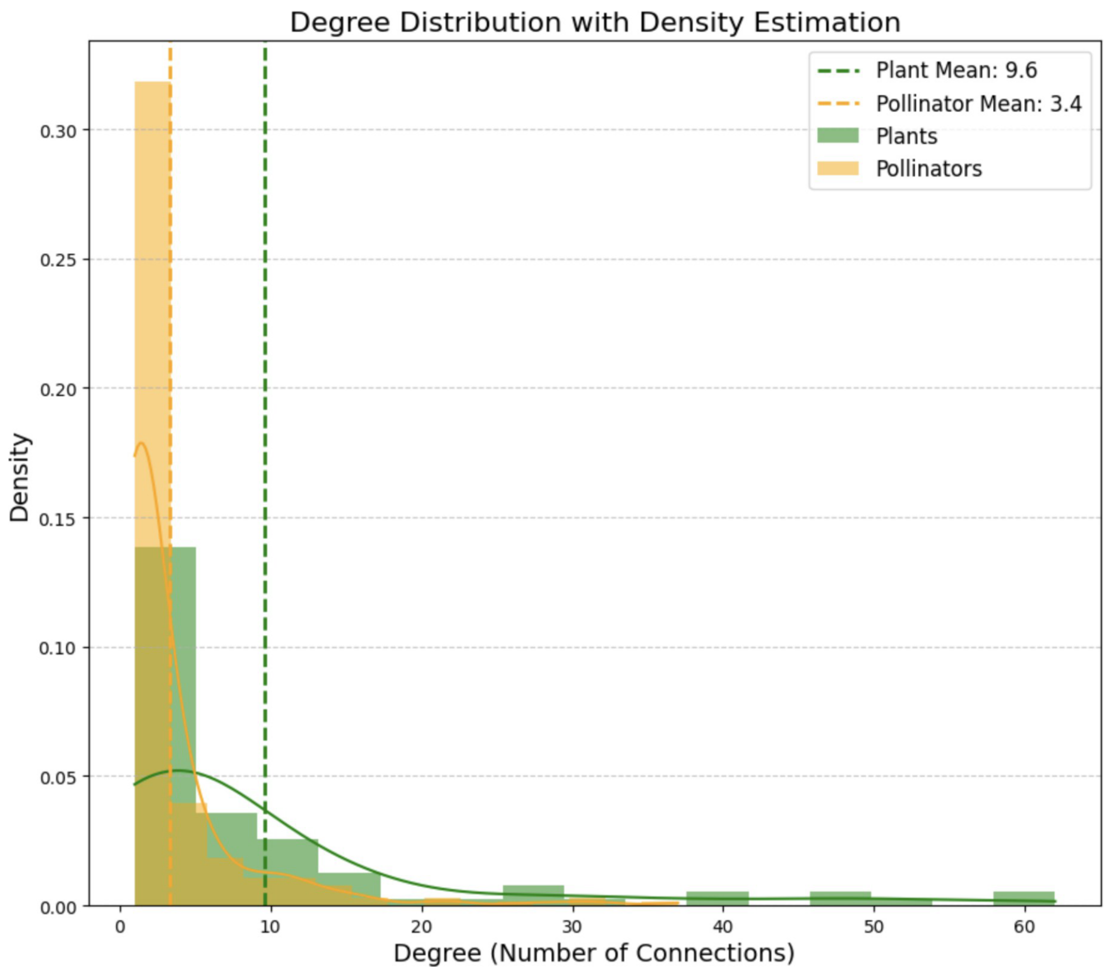

Figure 2: Degree distribution of the network.

Observations: The plant-pollinator network shows a right-skewed degree distribution, where most species—especially pollinators—have few connections, while a few, mainly plants, have many. This reflects the typical structure of asymmetric ecological networks. The green histogram for plants also shows a heavy tail, highlighting the presence of super-generalist plants that interact with many pollinators and play a key role in keeping the network connected. Additionally, the average degree for plants (9.6) is much higher than that for pollinators (3.4), indicating that plants tend to attract multiple pollinators, while many pollinators are specialists with fewer interactions.

2 Task 2: Centrality Measures

2.1 Top Nodes by Centrality

Table 1: Top 10 Plants and Pollinators by Centrality Measures

Centrality Measure	Top 10 Plants	Top 10 Pollinators
Eigenvector	1. Rubus deliciosus (0.2426) 2. Geranium caespitosum (0.2323) 3. Rosa acicularis (0.2311) 4. Pentstemon glaber (0.2167) 5. Chamaenerium angustifolium (0.1938) 6. Pentstemon gracilis (0.1857) 7. Rubus strigosus (0.1662) 8. Monarda fistulosa (0.1422) 9. Mertensia sibirica (0.1343) 10. Carduus hookerianus (0.1121)	1. Bombus edwardsi (0.1996) 2. Bombus occidentalis (0.1861) 3. Bombus hunti (0.1755) 4. Bombus juxtus (0.1699) 5. Bombus bifarius (0.1532) 6. Halictus pulzenus (0.1485) 7. Clisodon terminalis (0.1275) 8. Bombus appositus (0.1206) 9. Andrena madronitens (0.1187) 10. Monumetha albifrons (0.1187)
Katz	1. Rubus deliciosus (0.0820) 2. Geranium caespitosum (0.0804) 3. Rosa acicularis (0.0765) 4. Pentstemon glaber (0.0754) 5. Chamaenerium angustifolium (0.0742) 6. Pentstemon gracilis (0.0701) 7. Prunus demissa (0.0691) 8. Monarda fistulosa (0.0657) 9. Rubus strigosus (0.0647) 10. Mertensia sibirica (0.0647)	1. Bombus edwardsi (0.0703) 2. Bombus occidentalis (0.0678) 3. Bombus hunti (0.0666) 4. Bombus juxtus (0.0649) 5. Bombus bifarius (0.0618) 6. Apis mellifera (0.0614) 7. Halictus pulzenus (0.0598) 8. Bombus flavifrons (0.0586) 9. Bombus appositus (0.0584) 10. Clisodon terminalis (0.0584)
Betweenness	1. Rubus deliciosus (0.1469) 2. Geranium caespitosum (0.1439) 3. Pentstemon glaber (0.1138) 4. Chamaenerium angustifolium (0.1075) 5. Prunus demissa (0.0935) 6. Rosa acicularis (0.0888) 7. Carduus hookerianus (0.0679) 8. Erigeron macranthus (0.0601) 9. Pentstemon gracilis (0.0566) 10. Rubus strigosus (0.0501)	1. Bombus occidentalis (0.1008) 2. Bombus edwardsi (0.0995) 3. Bombus hunti (0.0801) 4. Bombus juxtus (0.0469) 5. Apis mellifera (0.0447) 6. Bombus bifarius (0.0355) 7. Gnophaela vermiculata (0.0263) 8. Halictus pulzenus (0.0243) 9. Clisodon terminalis (0.0213) 10. Bombus flavifrons (0.0201)
Closeness	1. Rubus deliciosus (0.3807) 2. Geranium caespitosum (0.3799) 3. Rosa acicularis (0.3734) 4. Pentstemon glaber (0.3726) 5. Chamaenerium angustifolium (0.3695) 6. Rubus strigosus (0.3626) 7. Pentstemon gracilis (0.3531) 8. Monarda fistulosa (0.3482) 9. Carduus hookerianus (0.3475) 10. Mertensia sibirica (0.3475)	1. Bombus occidentalis (0.4116) 2. Bombus edwardsi (0.4106) 3. Bombus hunti (0.4049) 4. Bombus juxtus (0.3836) 5. Bombus bifarius (0.3803) 6. Halictus pulzenus (0.3730) 7. Bombus appositus (0.3593) 8. Monumetha albifrons (0.3585) 9. Bombus rufocinctus (0.3571) 10. Prosopis elliptica (0.3571)
HITS	1. Rubus deliciosus (0.0471) 2. Geranium caespitosum (0.0451) 3. Rosa acicularis (0.0448) 4. Pentstemon glaber (0.0420) 5. Chamaenerium angustifolium (0.0376) 6. Pentstemon gracilis (0.0360) 7. Rubus strigosus (0.0323) 8. Monarda fistulosa (0.0276) 9. Mertensia sibirica (0.0261) 10. Carduus hookerianus (0.0218)	1. Bombus edwardsi (0.0266) 2. Bombus occidentalis (0.0248) 3. Bombus hunti (0.0234) 4. Bombus juxtus (0.0226) 5. Bombus bifarius (0.0204) 6. Halictus pulzenus (0.0198) 7. Clisodon terminalis (0.0170) 8. Bombus appositus (0.0161) 9. Andrena madronitens (0.0158) 10. Monumetha albifrons (0.0158)

Central Nodes Comparison
Different centrality measures highlight important ecological roles within the pollination network. Eigenvector centrality identifies keystone hubs that help maintain network stability and prevent cascading extinctions. Katz centrality captures species that enhance long-range connectivity, aiding efficient resource flow. Betweenness centrality points to key connectors that link otherwise separate parts of the network, reducing fragmentation. Closeness centrality reflects species that facilitate faster interactions, supporting overall ecosystem efficiency. HITS centrality highlights foundational species that promote generalist interactions, contributing to network resilience and biodiversity.

2.2 Visualizations

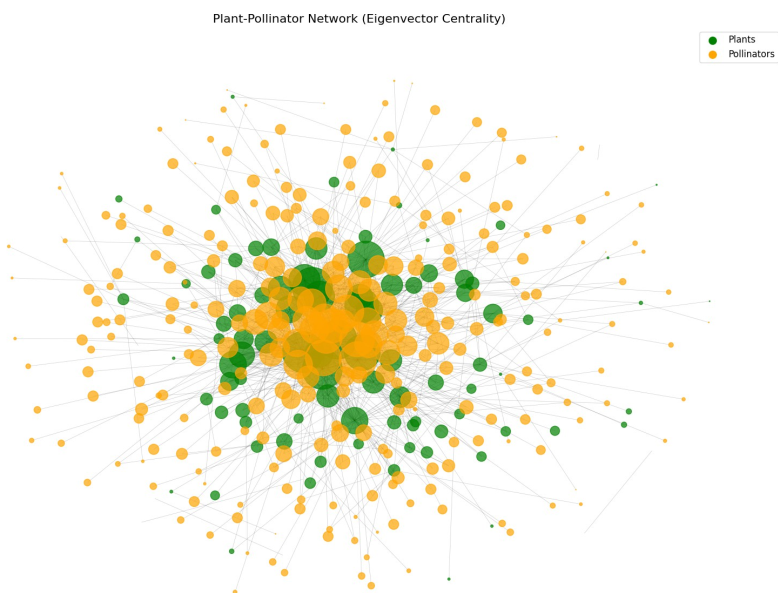

Figure 3: Network visualization sized by eigenvector centrality.

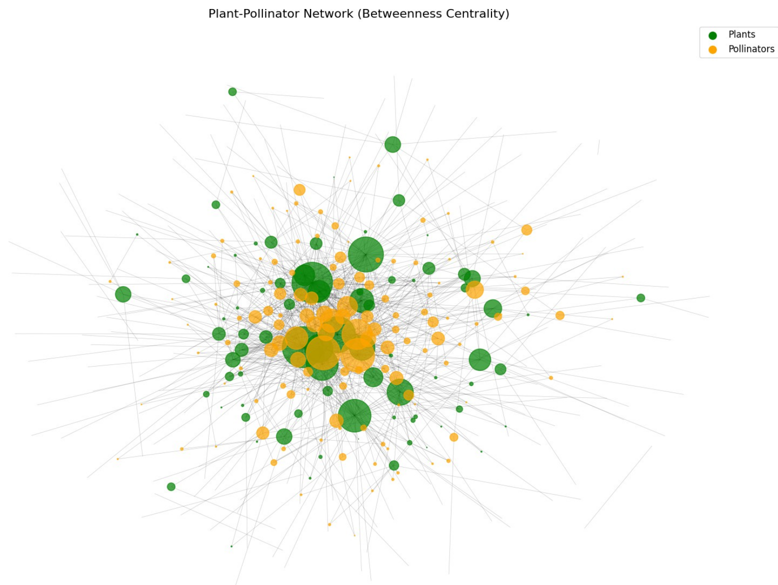

Figure 4: Network visualization sized by Betweenness centrality.

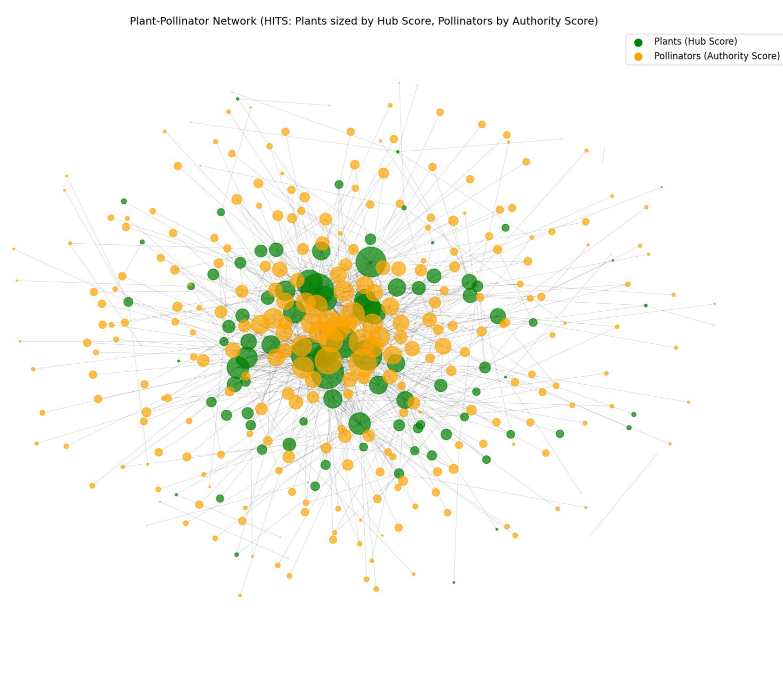

Figure 5: Plants sized by Hub score and Pollinators by Authority score.

2.3 Comparative Analysis

The analysis shows consistent top-ranking species across centrality measures. *Rubus deliciosus* stands out as the most central plant, appearing at the top in all metrics, marking it as a keystone species in the network. *Geranium caespitosum* also ranks highly, highlighting its ecological importance. Among pollinators, *Bombus edwardsi* scores well in Eigenvector, Katz, and HITS centralities, indicating its role as a key hub. *Bombus occidentalis* ranks high in Katz, Betweenness, and Closeness, showing its function as a bridge connecting different parts of the network.

3 Task 3: Community Detection & Modularity

3.1 Method Used

We used the **Louvain algorithm** to detect communities.

3.2 Results

- Number of communities: **18**
- Modularity score: **0.395**

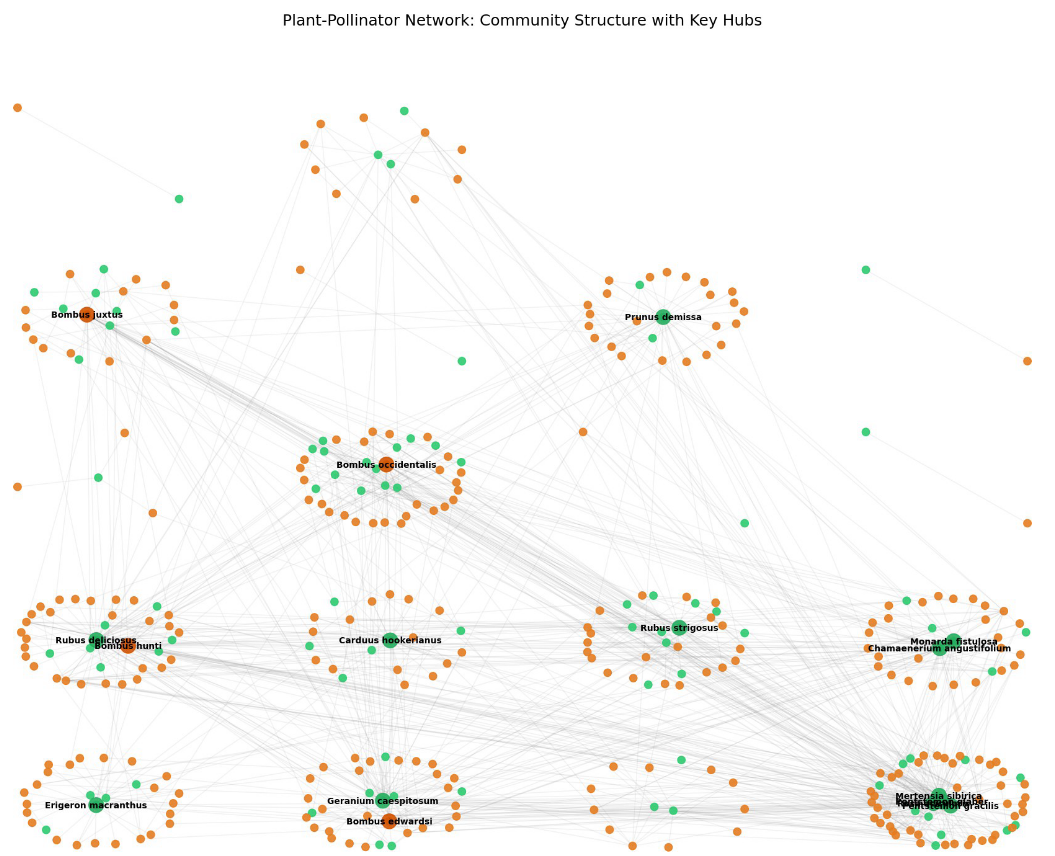

Figure 6: Network colored by detected communities.

Interpretation: The modularity score of **0.395** of the pollination network, calculated using the Louvain method indicating moderate community structure. This suggests that plants and pollinators form distinct modules based on their interactions, but generalist species like Rubus deliciosus and Bombus edwardsi act as bridges, connecting different modules.

Communities insights: The pollination network shows ecologically meaningful community structures, where plants and pollinators interact more within their groups, reflecting specialization and co-evolution. These communities often share traits like flower type or nectar availability. Generalist species such as Rubus deliciosus and Bombus edwardsi act as connectors between communities, helping maintain overall network flow. For conservation, it's important to protect both these generalists and the specialized interactions within each group to support biodiversity and pollination stability.

4 Task 4: Assortativity & Degree-Degree Correlations

4.1 Degree Assortativity

Pearson correlation factor:

- For Plants: -0.15
- For Pollinators: -0.09

4.2 Average Neighbor Degree Plot

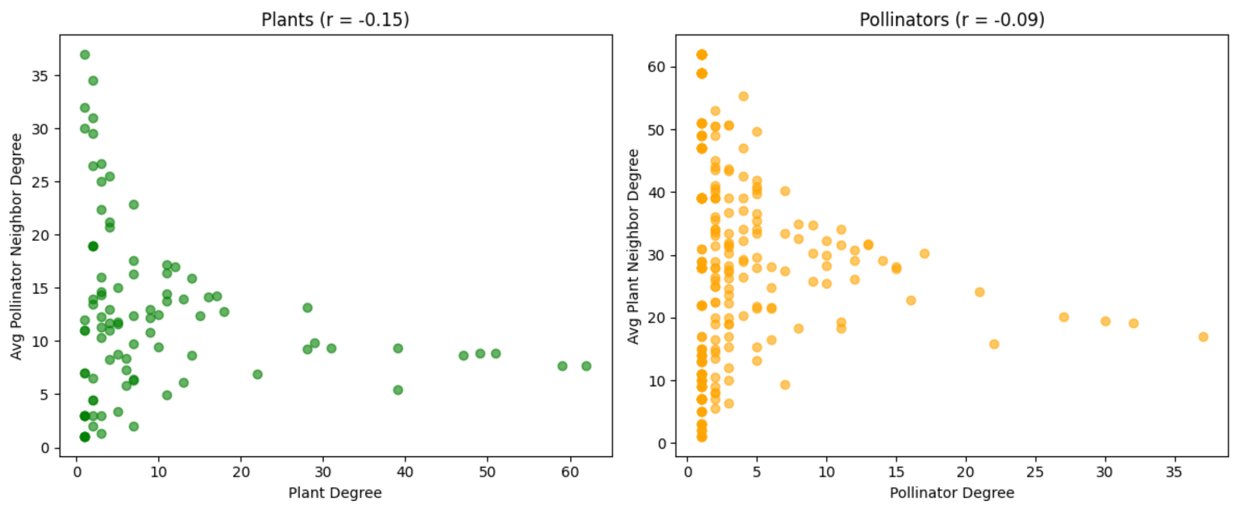

Figure 7: Average neighbor degree vs. node degree.

Interpretation: The **Plant Correlation** is Disassortative (high-degree plants connect to low-degree pollinators) while the **Pollinator Correlarion** is Neutral.

5 Task 5: Clustering Coefficients

5.1 Global clustering coefficient (transitivity):

- Plants: **0.1063**
- Pollinators: **0.2687**

5.2 Local Clustering Coefficients

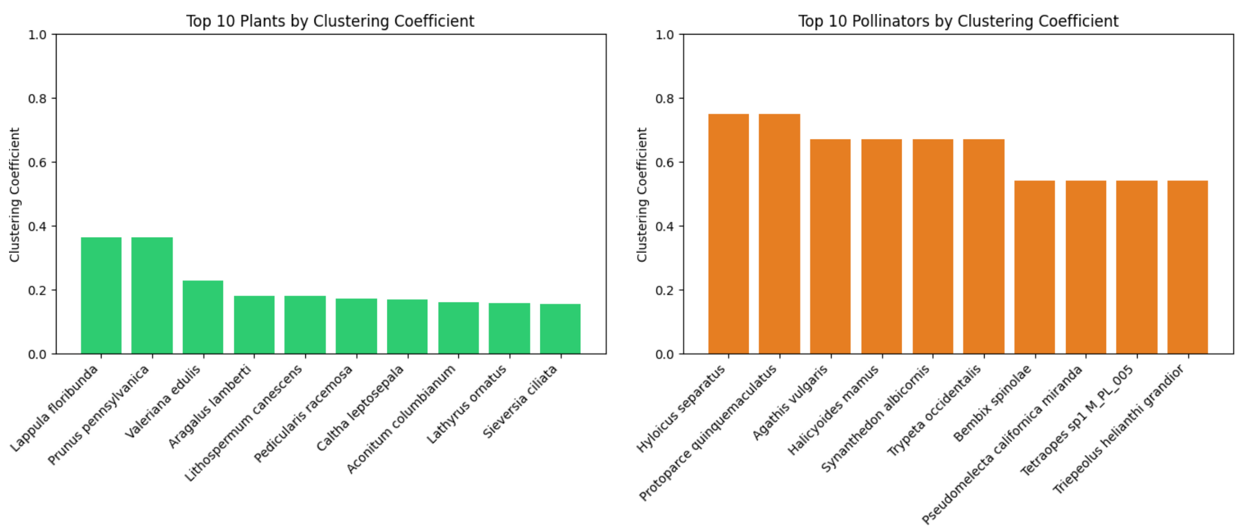

Figure 8: Local Clustering Coefficients

Appendix

- Code provided in attached Jupyter notebook (Pollinations.ipynb)
- Dataset: M_PL_005.csv