Structure et dynamique des communautés écologiques

(ii)

Daily and seasonal dynamic of ecological networks and the spread of perturbation, plant pollinator communities as a study case

Colin Fontaine

Aussois 2021
From aggregated networks to temporal networks
Phenology: an important determinant of the structure of plant-pollinator networks

Insect-flower Relationship in the Primary Beech Forest of Ashu, Kyoto: An Overview of the Flowering Phenology and the Seasonal Pattern of Insect Visits

Makoto Kato, Takehiko Kakinami, Tamiji Inoue and Takao Itino

Pollination specialization and time of pollination on a tropical Venezuelan plain: variations in time and space

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Very few theoretical studies consider the effects of phenology on the stability of mutualistic webs

- Effects on network structure and species persistence
  - Encinas-Viso et al. (2012)

- Effects of species phenological attributes on species persistence
  - Ramos-Jiliberto et al. (2018)
Effects of climate warming on the phenology of many taxa

Parmesan (2007)
Effects of climate warming on the phenology of pollinators

- Knowledge still restricted to few species of flower-visitors outside Lepidoptera
- Need to assess consequences at the scale of ecological communities
Plant response: from species to community

Fitter & Fitter, Science, 2001

Diez et al., Ecology Letters, 2012
Consequences of phenological shifts on plant-pollinator networks
Investigate the potential consequences of climate warming on pollinator assemblages by extending our knowledge on phenological shifts of flower-visitors.

Understand how species phenologies and seasonality determine plant-pollinator networks and their stability.
The data:
Historical and current records of occurrences of potential insect flower visitors

French National Natural History Museum collections + private collections
The data:
Historical and current records of occurrences of potential insect flower visitors

Methods: Estimating phenological shifts

Identifying phenological modes for species with multimodal phenologies using clustering gaussian mixture models (e.g. multivoltine species, queens and workers)
Methods:
Estimating phenological shifts

Coupled models for each species to estimate:

**Shift in mean flight date (MFD)**

\[ Y_k = \mu + (\pi + \alpha \times \text{latitude}_k + \delta \times \text{longitude}_k) \times \text{year}_k + (\rho_1 + \gamma_1 \times \text{longitude}_k) \times \text{latitude}_k + (\rho_2 + \gamma_2 \times \text{longitude}_k^2) \times \text{latitude}_k^2 + (\rho_3 + \gamma_3 \times \text{longitude}_k^3) \times \text{latitude}_k^3 + (\sigma_1) \times \text{longitude}_k + (\sigma_2) \times \text{longitude}_k^2 + (\sigma_3) \times \text{longitude}_k^3 + \theta \times \text{altitude}_k + \epsilon_k \]

**Change in phenology length (SD)**

\[ \log(\sigma^2) = \mu_\sigma + (\rho_\sigma \times \text{latitude}_k + \sigma_\sigma \times \text{longitude}_k + \theta_\sigma \times \text{altitude}_k + \pi_\sigma) \times \text{year}_k \]
Mean flight date shifts

On average
5.8 days earlier in 2016
than in 1960

57% earlier
30% non significant
13% delayed

Strong phylogenetic
signal
Pagel's $\lambda = 0.75$
$pval > 0.05$
$pval < 0.05$
Changes of flight period lengths

On average 1.8 days shorter in 2016 than in 1960

30% shortened
43% non significant
27% lengthened

Duchenne et al. (2020)
Interspecific phenological shift variations depend on mean fly date and location
Intraspecific variations in phenological shift that depend on mean fly date and location

Species with multimodal phenology

Latitude effect on MFD shift (day/year° latitude)
Climate warming and phenological shifts of flower visitor assemblages across Europe

Conclusion

- European flower visitors are flying on average 5.8 days earlier and their phenologies are 3.8 days shorter in 2016 than in 1960

- Substantial heterogeneity in phenological shifts that depends on evolutionary history, seasonal precocity and location

- What consequences?
Changes in the seasonal structure of flower visitor communities
Changes in the average phenology overlaps of flower visitor communities

Changes between 1980 and 2016

within orders

among orders
Which consequences on plant-pollinator networks?

Lower overlap

Lower temporal redundancy and complementarity for plant pollination? Decrease competition pressure among pollinators for resources (nectar/pollen)?
Investigate the potential consequences of climate warming on pollinator assemblages by extending our knowledge on phenological shifts of flower-visitors.

Understand how species phenologies and seasonality determine plant-pollinator networks persistence.
Phenology and indirect effects in mutualistic networks

- High trait similarity
  - High phenology overlap

![Diagram showing interactions between species with high trait similarity and high phenology overlap.](image)

**Trait matching**

**Phenology matching**
Phenology and indirect effects in mutualistic networks

High trait similarity
High phenology overlap

High trait similarity
Low phenology overlap

What are the respective impacts of trait vs phenology matching on species persistence in mutualistic networks?

How do they determine indirect effects between plants and between pollinators?
A model for the dynamics of mutualistic networks

\[
\frac{dF_i}{dt} = .
\]

\[
\frac{dP_j}{dt} = .
\]
A model for the dynamics of mutualistic networks

\[ \frac{dF_i}{dt} = F_i(r_i - \frac{F_i}{K_i}) \]

\[ \frac{dP_j}{dt} = P_j(r_j - \frac{P_j}{K_j}) \]

Intrinsic growth rates $r_i < 0 \Rightarrow$ obligate mutualism

Carrying capacity $K_i \Rightarrow$ intraspecific competition
Interactions depend on trait & phenology matching

\[
\frac{dF_i}{dt} = F_i(r_i - \frac{F_i}{K_i} + \frac{\alpha_f \sum_{k=1}^{n_p} I_{ik} \times P_k}{1 + \beta_f \sum_{k=1}^{n_p} I_{ik} \times P_k})
\]

\[
\frac{dP_j}{dt} = P_j(r_j - \frac{P_j}{K_j} + \frac{\alpha_p \sum_{k=1}^{n_f} I_{kj} \times F_k}{1 + \beta_p \sum_{k=1}^{n_f} I_{kj} \times F_k})
\]

Interaction term saturates with mutualistic partner densities

\(I_{ij}\) defines the interaction probability as a function of trait and phenology matching

Bastolla et al. (2009)
Testing the relative impact of trait and phenological matching

Importance of the trait match
ITM

Importance of the phenological match
IPM

Testing the relative impact of trait and phenological matching

Importance of the trait match
ITM

Importance of the phenological match
IPM
\[
\frac{dF_i}{dt} = F_i(r_i - \frac{F_i}{K_i} + \frac{\alpha_f \sum_{k=1}^{np} I_{ik} \times P_k}{1 + \beta_f \sum_{k=1}^{np} I_{ik} \times P_k + c_f \sum_{k=1}^{nf} \theta_{ik} \times F_k})
\]

\[
\frac{dP_j}{dt} = P_j(r_j - \frac{P_j}{K_j} + \frac{\alpha_p \sum_{k=1}^{nf} I_{kj} \times F_k}{1 + \beta_p \sum_{k=1}^{nf} I_{kj} \times F_k + c_p \sum_{k=1}^{np} \omega_{jk} \times P_k})
\]

Competition for mutualistic interactions depends on phenological overlap.

Competition/interference between plants and between pollinators depends on competition strength \(c_p\) and \(c_f\) as well as on phenological and morphological overlap among interacting partners \(\theta_{ik}\) and \(\omega_{jk}\).

\[
\omega_{jk} = \left\{ M_{p_{jk}}^{1PM} \times \sum_{i=1}^{nf} \left( \frac{F_i \times I_{ij}}{\sum_{i=1}^{nf} I_{ij} \times F_i} \times I_{ik} \right) \right\}_{k \in \{1...np\}}
\]

Phenological overlap of poll \(j\) and \(k\) dependance of poll \(j\) on plant \(i\) interaction of poll \(k\) with plant \(i\)

Phenological overlap among pollinators \((M_p)\)
Testing the relative impact of trait and phenological matching

Effects on species persistence
Relative impact of trait and phenological matching on persistence

Increasing competition

Number of persisting species
Testing the relative impact of trait and phenological matching on indirect interactions

Direct and indirect effects between plants and between pollinators at equilibrium?

Higashi & Nakajima (1995)

\[ T_{ij} = \frac{s_{ij}}{s_{ii}s_{jj} - s_{ij}s_{ji}} \]

\[ S = A^{-1} \]
Testing the relative impact of trait and phenological matching on indirect interactions

Average total effects among pollinators
Average total effects among plants

Importance of the morphological match
Importance of the phenological match
Phenological structure and the dynamics of mutualistic networks
Some preliminary conclusions

- Constraints on morphological matching and phenological matching can have different consequences on the dynamics of mutualistic networks

- When there is competition, the phenological structure of the community can promote species persistence

- In addition to mismatch, phenological changes related to climate warming can change the balance between competition and facilitation within guilds
Investigate the potential consequences of climate warming on pollinator assemblages by extending our knowledge on phenological shifts of flower-visitors.

Understand how species phenologies and seasonality determine plant-pollinator networks and their stability.

Pollination around the clock and the consequences of light pollution.

Eva Knop
What about nocturnal pollination?

Only 168 studies on nocturnal pollination (moth) between 1971 and 2013
rarely at community level
very few pollination effectiveness measures
appears to involve numerous plant families

McGregor et al. (2015)
Quantifying pollination around the clock

Most frequent visitor orders

- diptera
- lepidoptera
- hymenoptera
- coleoptera

On average:
- 79.5% diurnal visits
- 20.5% nocturnal visits

Most visited plants

Plants visited during day and night:
- *Aruncus dioicus*
- *Cirsium oleraceum*
- *Valeriana officinalis*

Plants visited only during day:
- *Centaurea* sp.
- *Daucus carota*
- *Erigeron annuus*
- *Heracleum sphondylium*
What about light pollution?

- artificial light at night affect moth behaviour
- 99% of Europeans live in light-polluted areas
- global annual increase in area of about 6%
Light pollution and nocturnal pollinators

7 ruderal meadows located in Bernese Oberland

2 sampling sites per meadow separated by 500m with one where LED streetlamps were installed

Sampling along 100m transect every 30 min all night between June and September 2015
Light pollution and nocturnal pollinators
Light pollution and plant seed set

5 ruderal meadows located in Bernese Oberland
artificial light vs. control
Light pollution and plant seed set

13% reduction in seed set
Light pollution and diurnal pollinators

Potential for indirect interactions

Height ruderal meadows
Sampling every 30min from 17:00 to 16:59
along 50m transect
four 24h sampling rounds per site
Potential indirect effect from nocturnal to diurnal pollinators
Conclusion

Nocturnal pollination is not neglectable, with 20% of visits being nocturnal.

Artificial light impact nocturnal pollinator with negative consequences for plant pollination.

Nocturnal pollinators are not redundant with diurnal ones.

The architecture of merged diurnal and nocturnal pollination networks tend to favor the spread of artificial light perturbation from nocturnal to diurnal pollinators.
Thank you and thanks to...
Artificial light effects on plant-pollinator networks
Stability of mutualistic networks: a balance between mutualism and competition?

- In connected and in nested networks, positive effects outweigh negative ones, enhancing persistence

Bastolla et al. (2009)
Thank you for your attention
Stability of mutualistic networks: a balance between mutualism and competition?

- In connected and in nested networks, positive effects outweigh negative ones, enhancing persistence

- When competition for resources are included, nestedness enhances persistence only in case of adaptive foraging, leading to niche partitioning
Stability of mutualistic networks: a balance between mutualism and competition?

Network structure (e.g. nestedness) arises from constraints linked with species traits and phenologies.

How do these constraints affect the balance between mutualism and competition in mutualistic webs?
Phenology and indirect effects in mutualistic networks

High trait similarity
High phenology overlap

Trait matching

Phenology matching