Picture: Pedro Jordano

Evolutionary dynamics in networks

The role of indirect evolutionary effects

EEE321 – Ecological Networks

Leandro Giacobelli Cosmo
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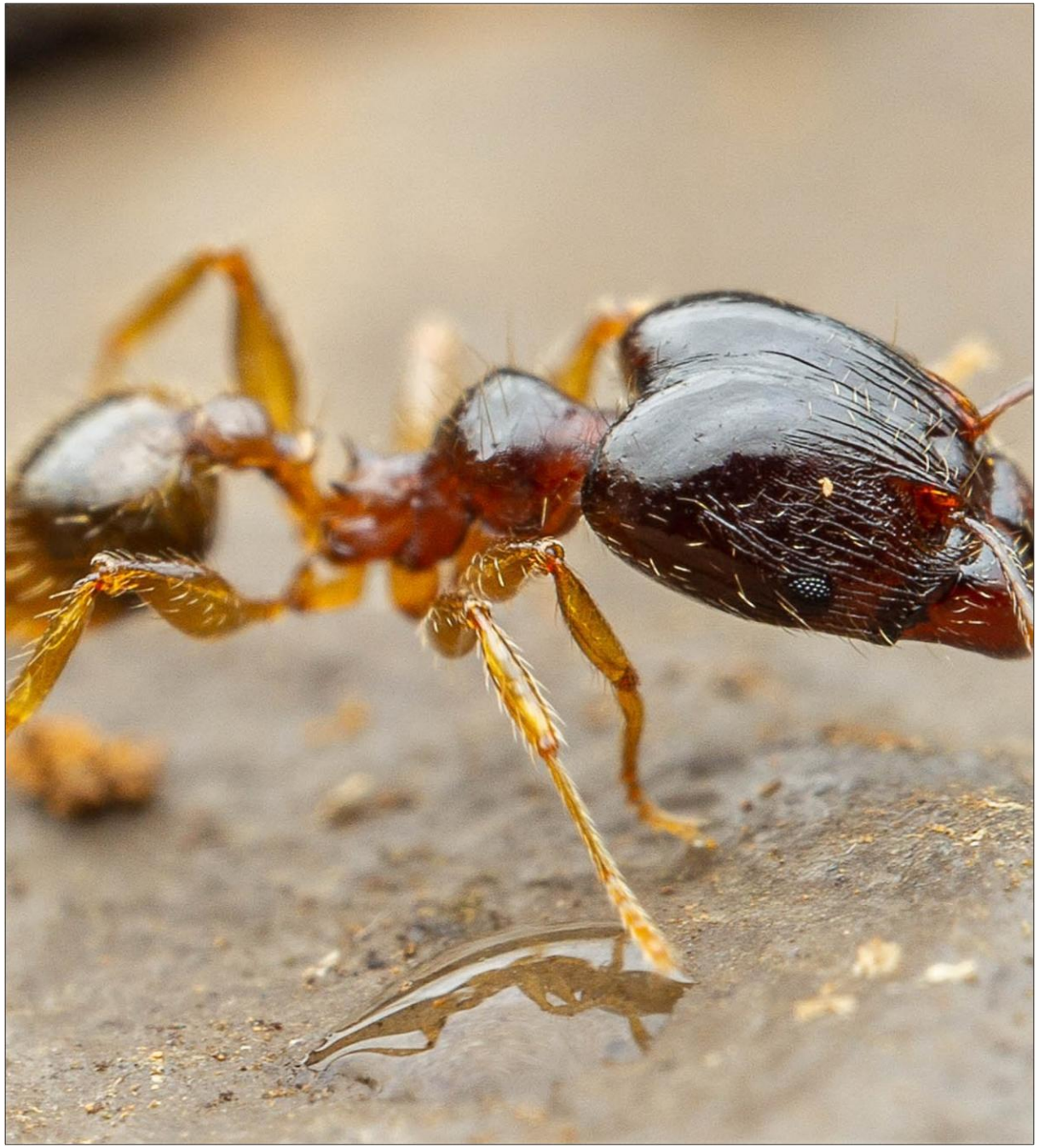

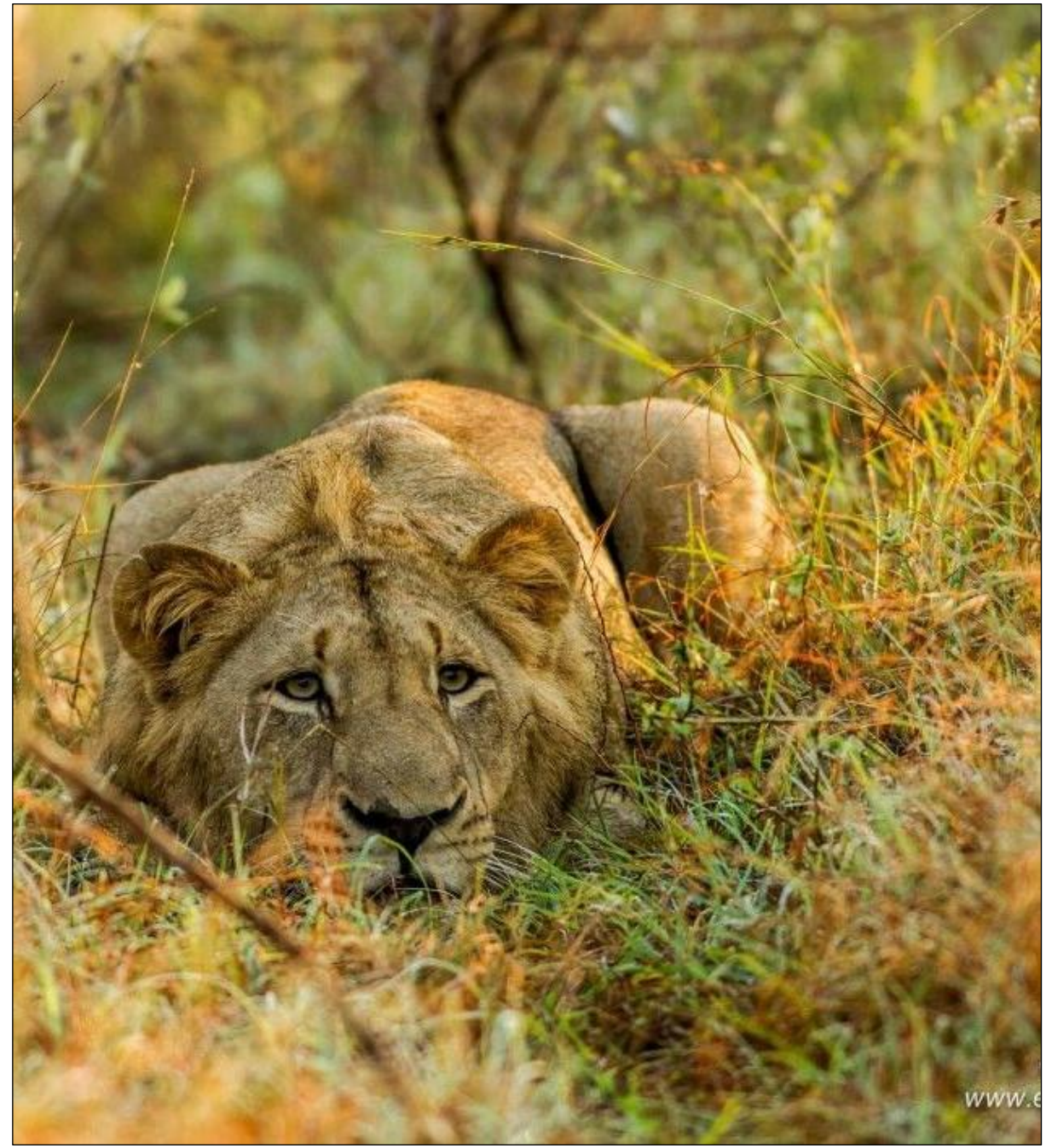

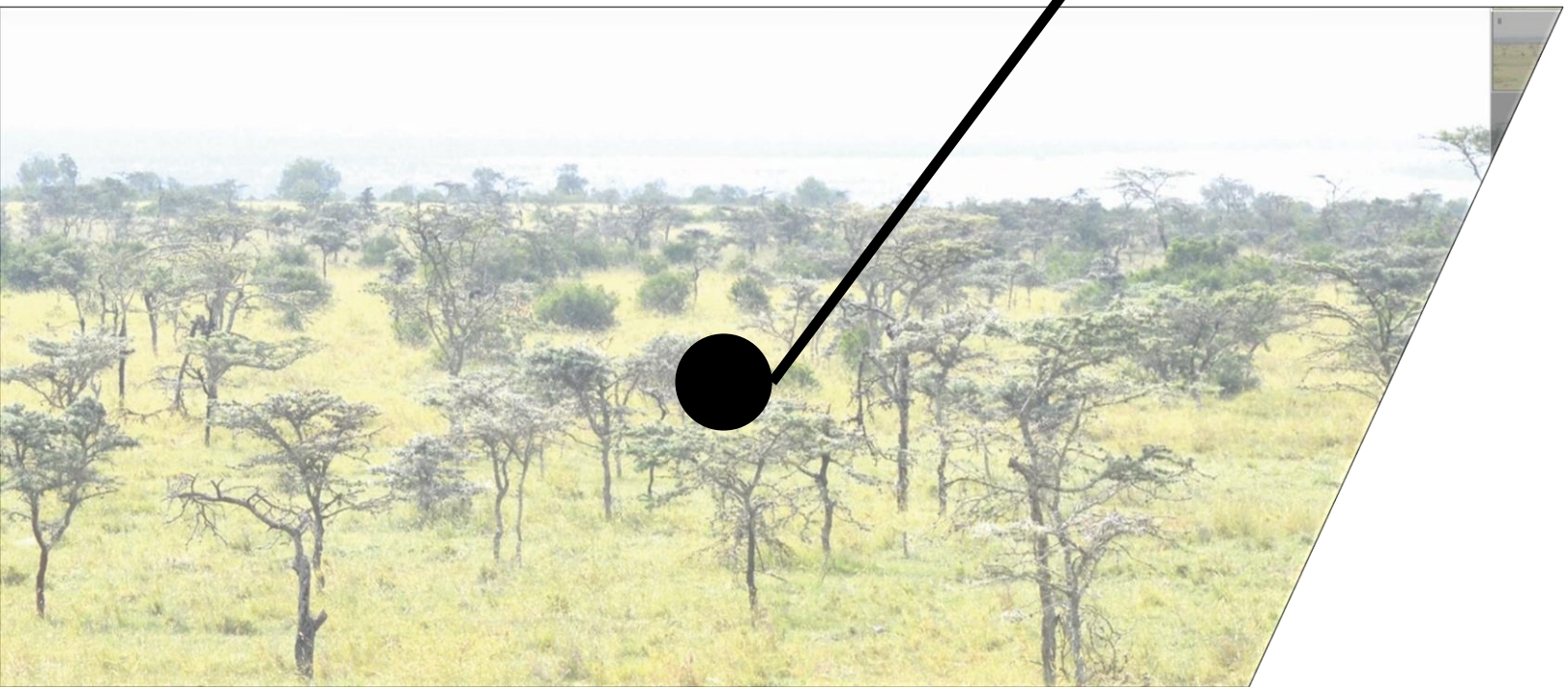

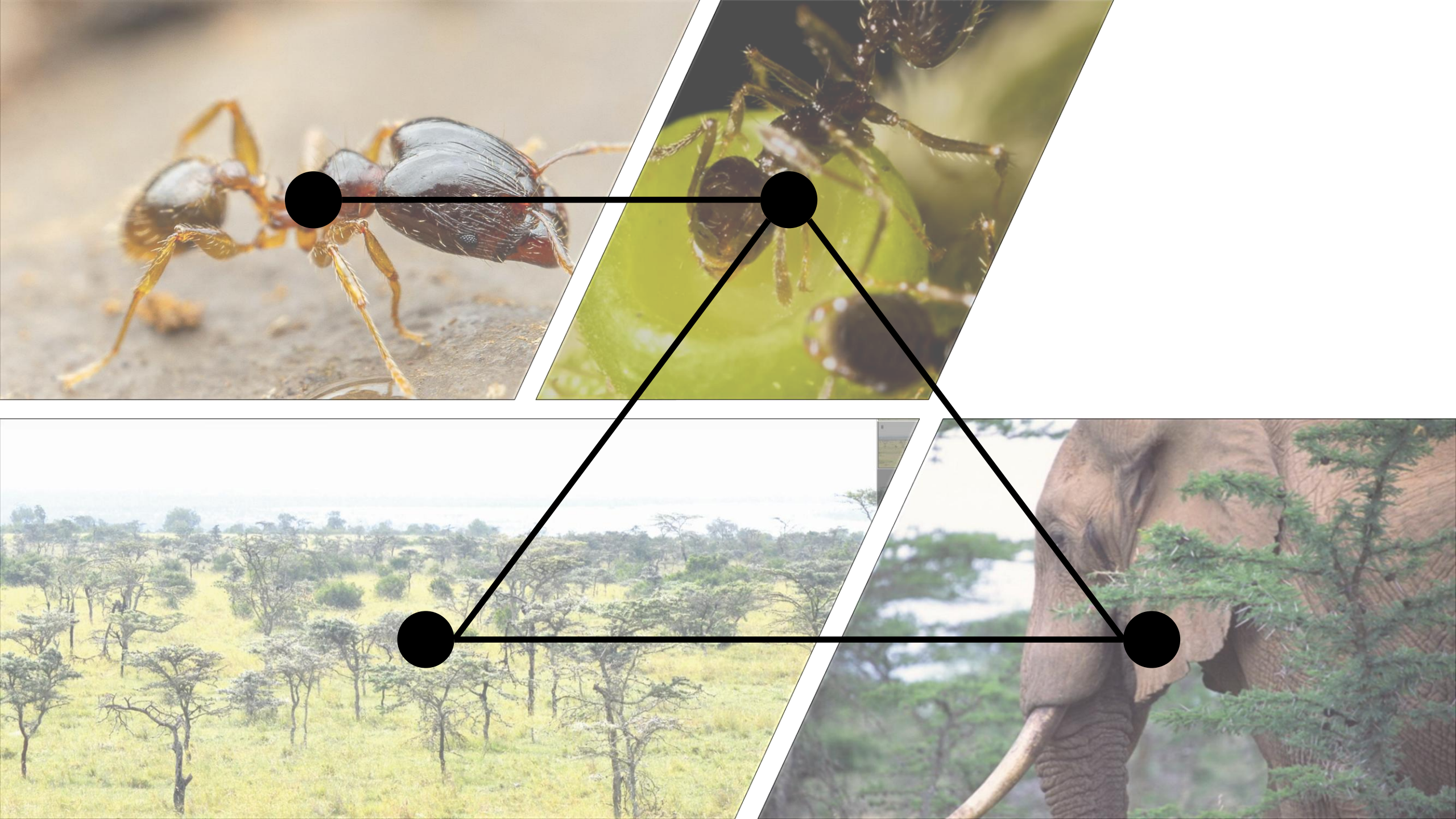

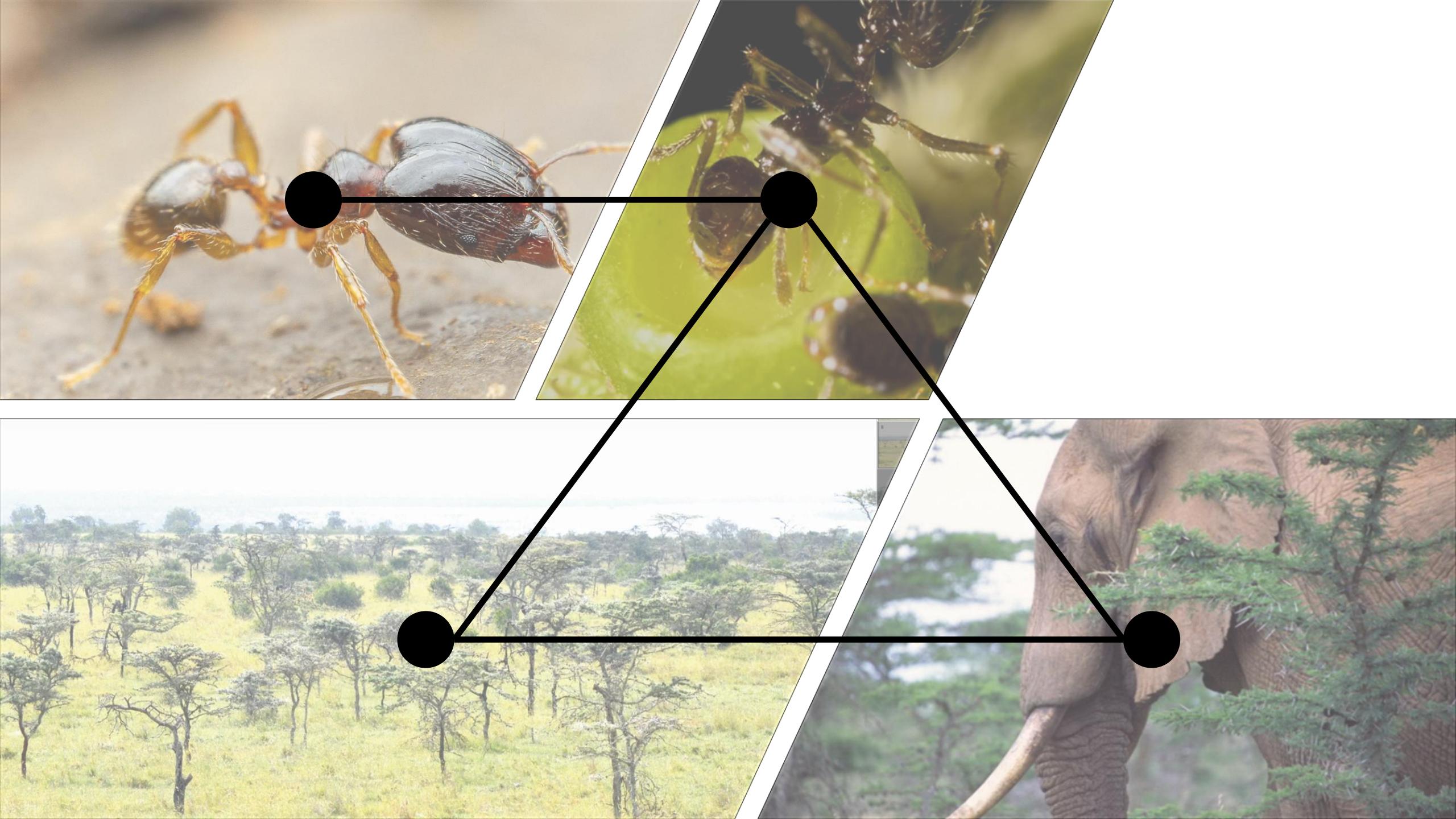

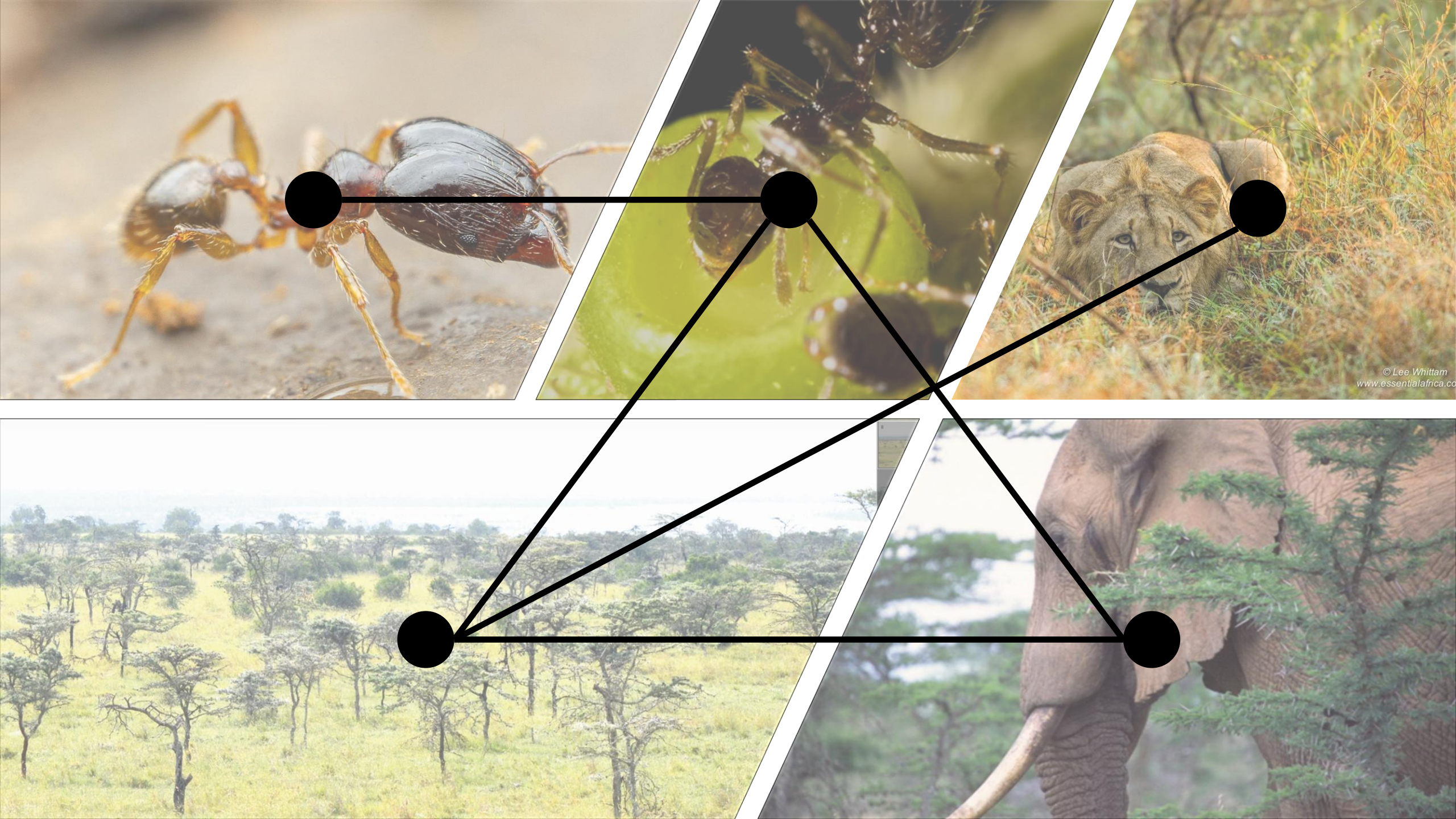
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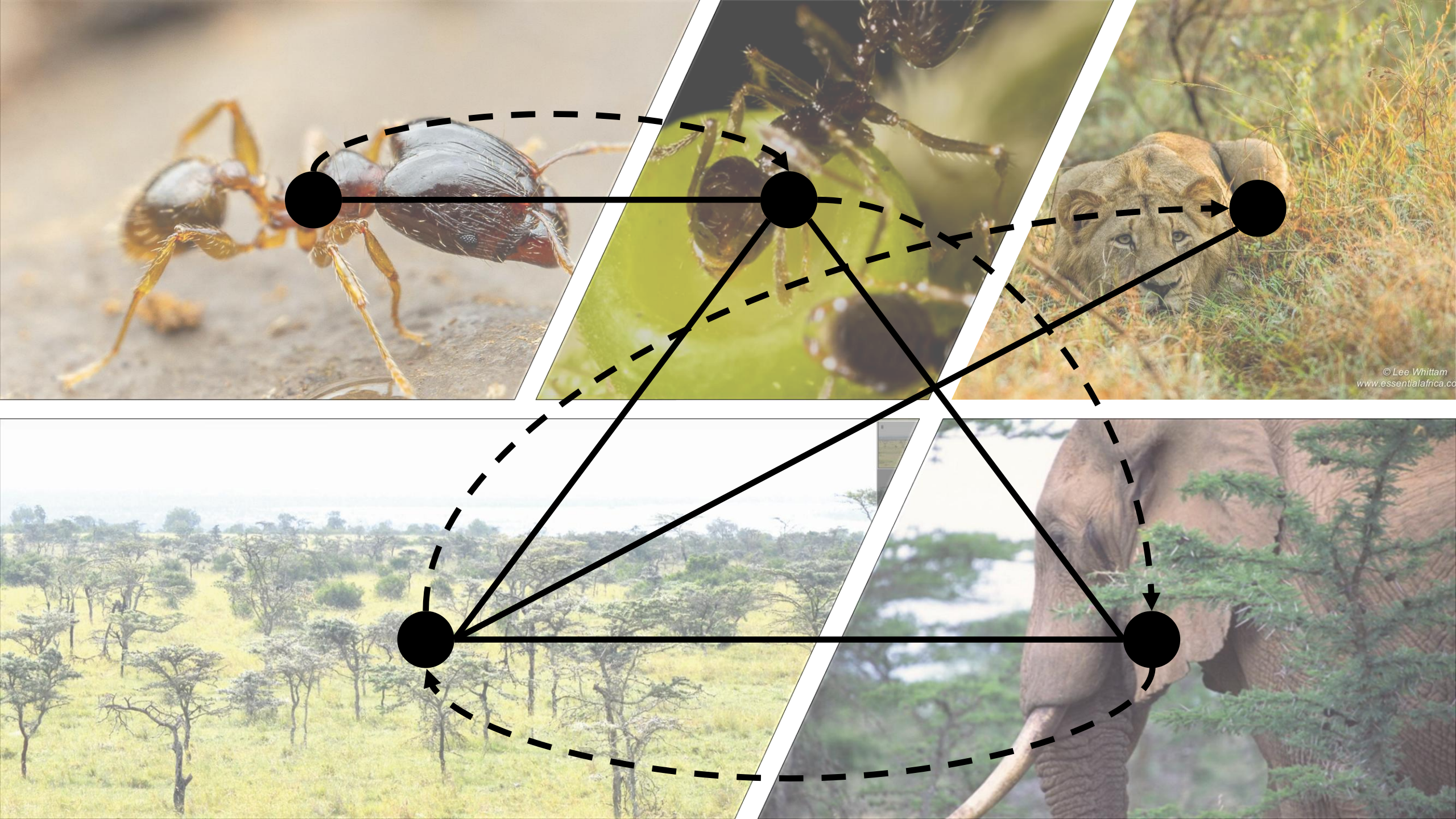
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Disruption of an ant-plant mutualism shapes interactions between lions and their primary prey

DOUGLAS N. KAMARU, TODD M. PALMER, CORINNA RIGINOS, ADAM T. FORD, JAYNE BELNAP, ROBERT M. CHIRA, JOHN M. GITHAIGA, BENARD C. GITUKU, BRANDON R. HAYS, [...], AND JACOB R. GOHEEN +10 authors Authors Info & Affiliations

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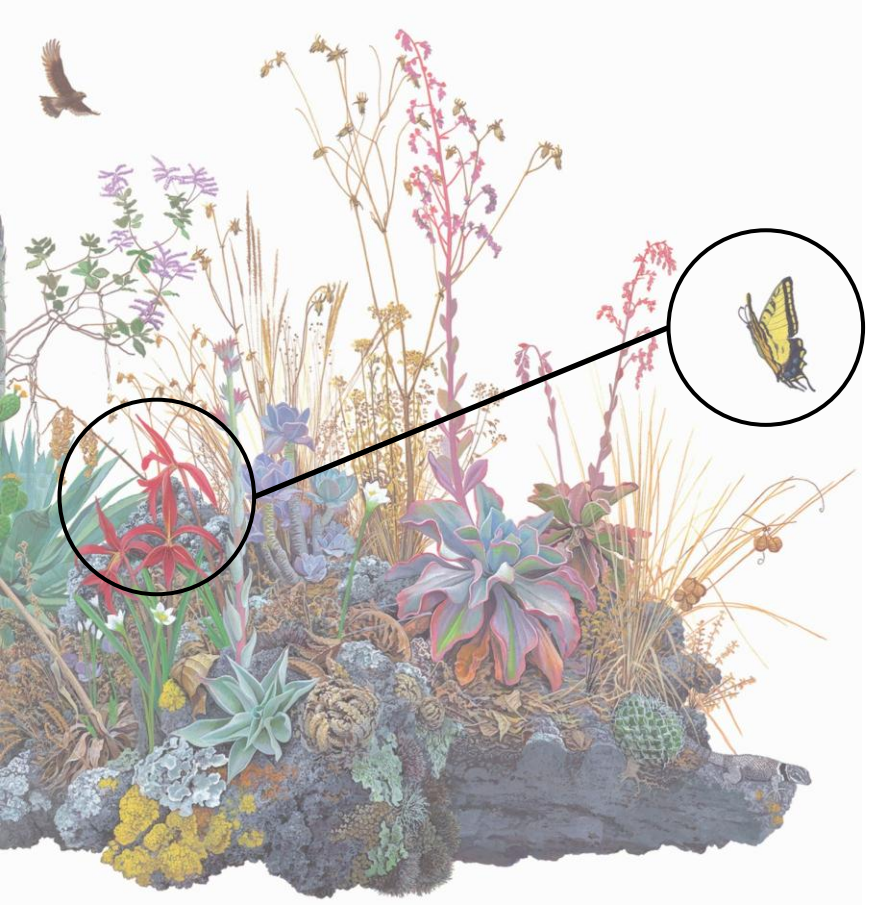
1) Species interact in ecological networks

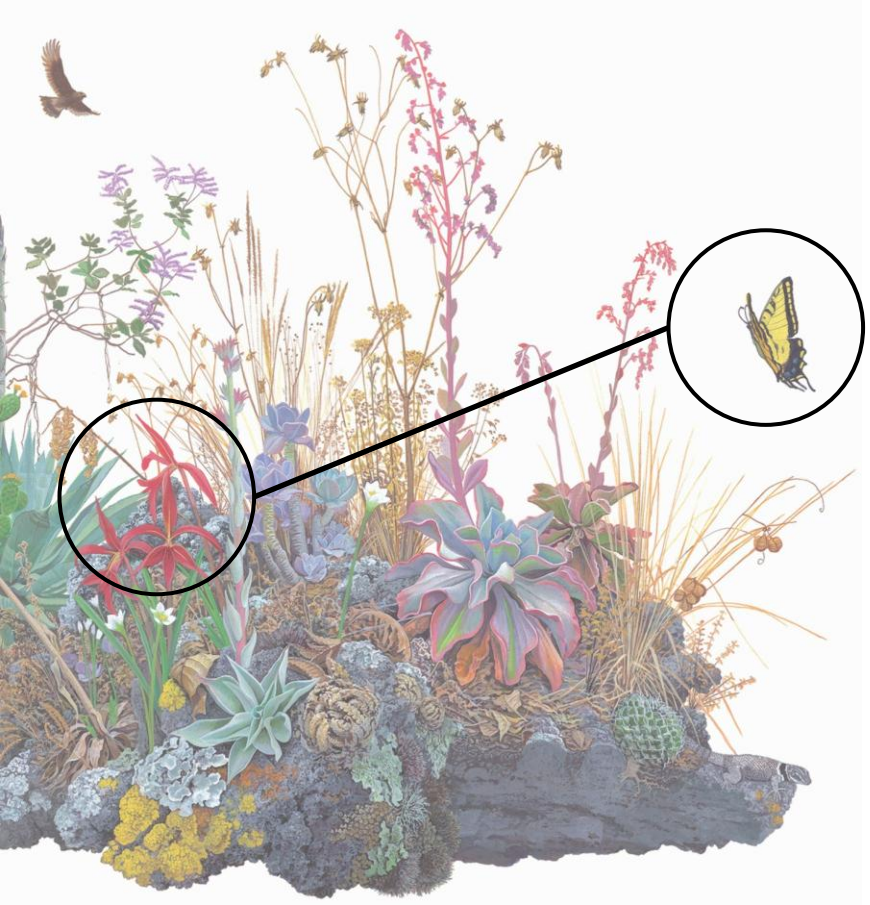
2) In these networks, indirect effects propagate among species

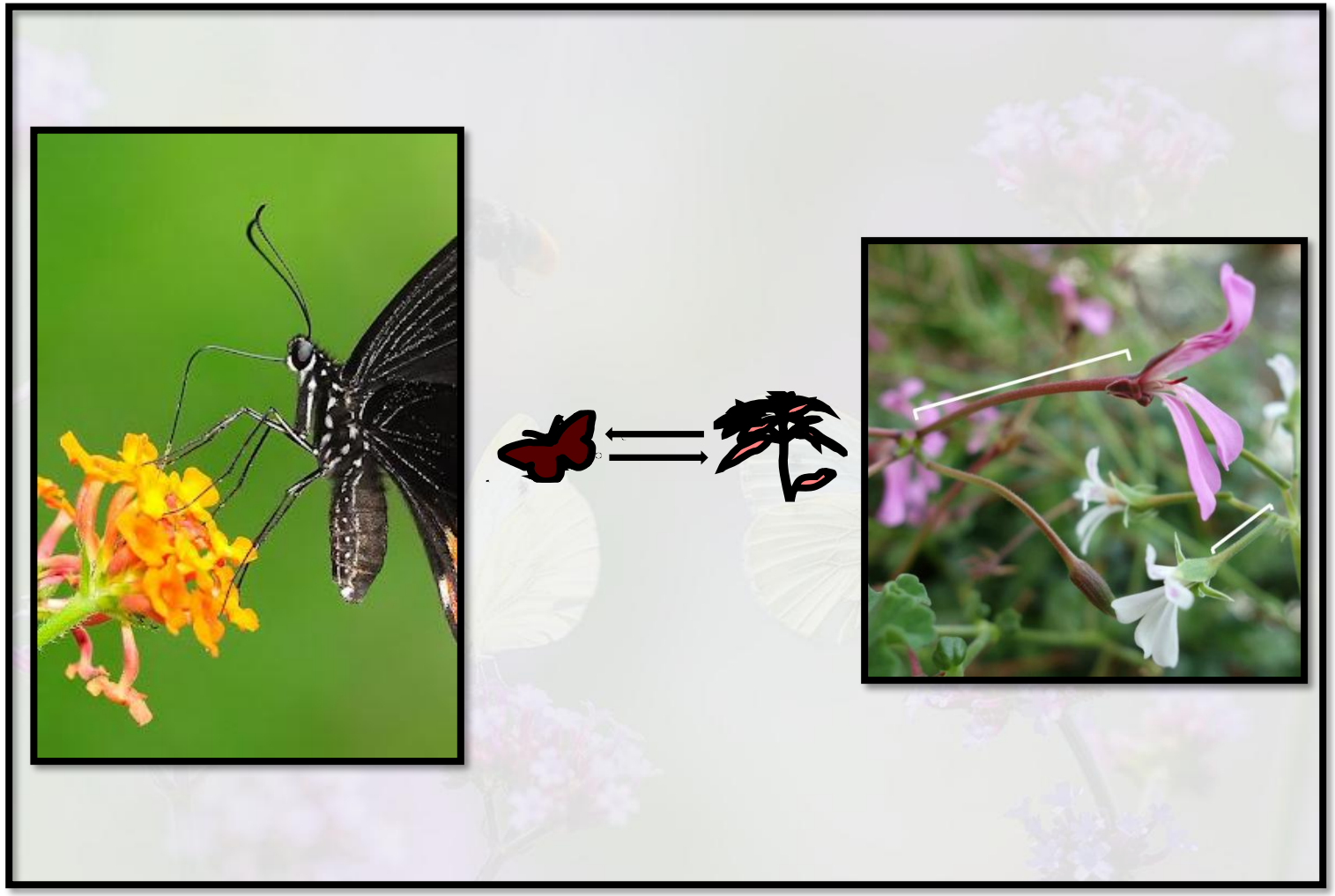
3) Interactions shape the ability of species to survive and reproduce – fitness – either directly or indirectly

Indirect effects that occur in an ecological time scale and through changes in the abundances of species

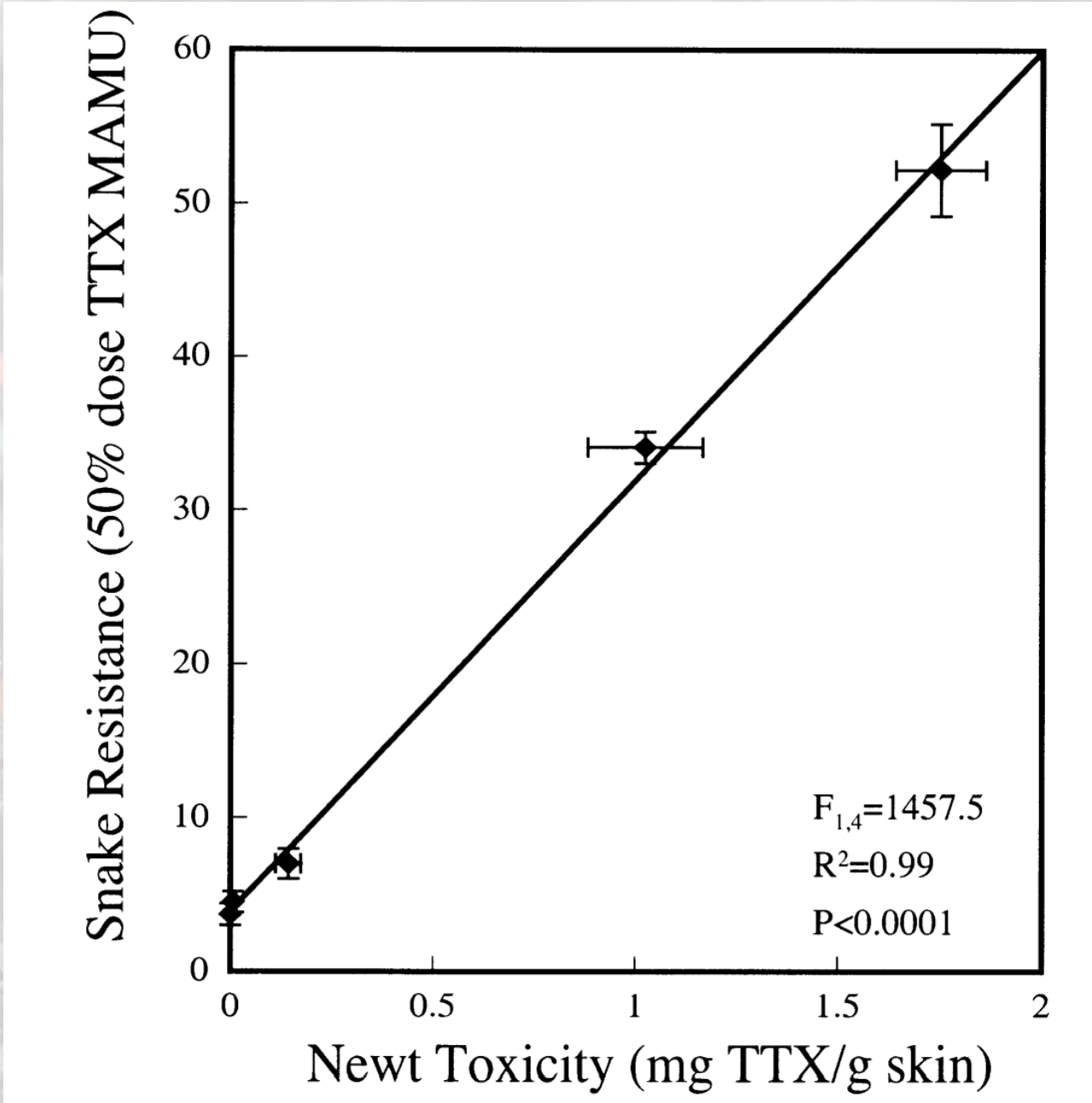


What mediates ecological interactions?

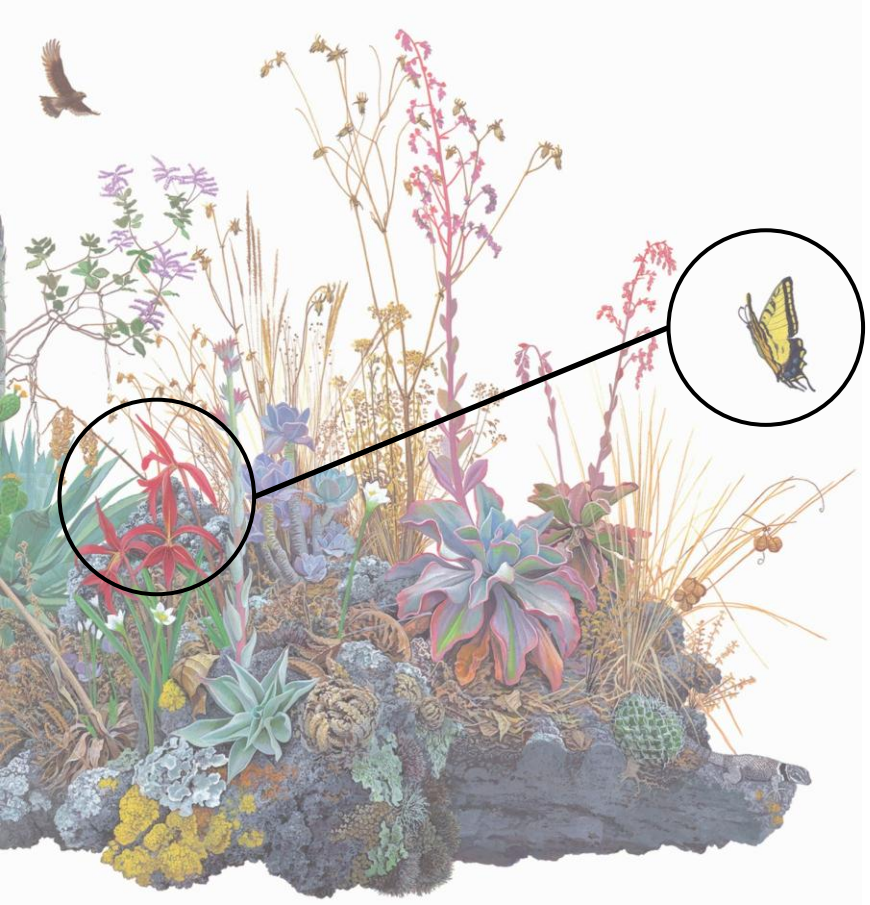


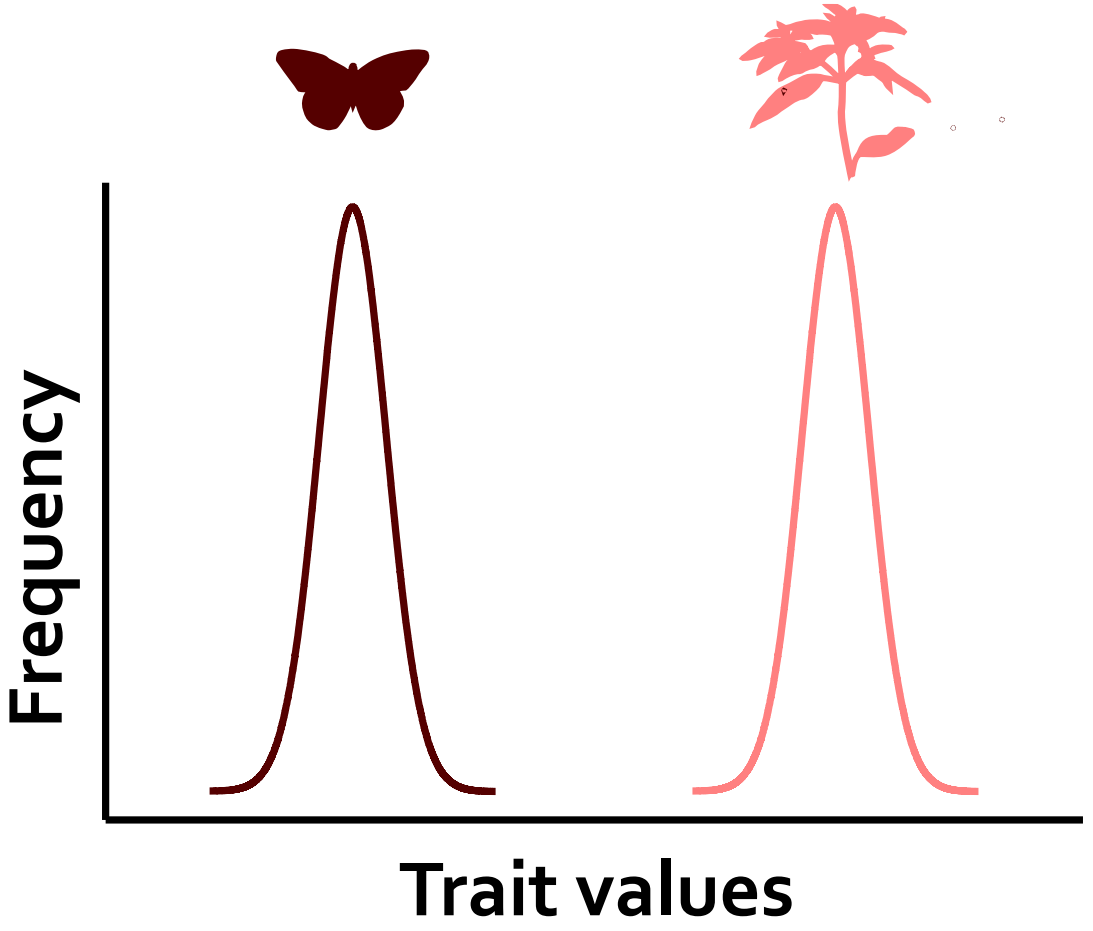


The outcome of interactions depend on species traits

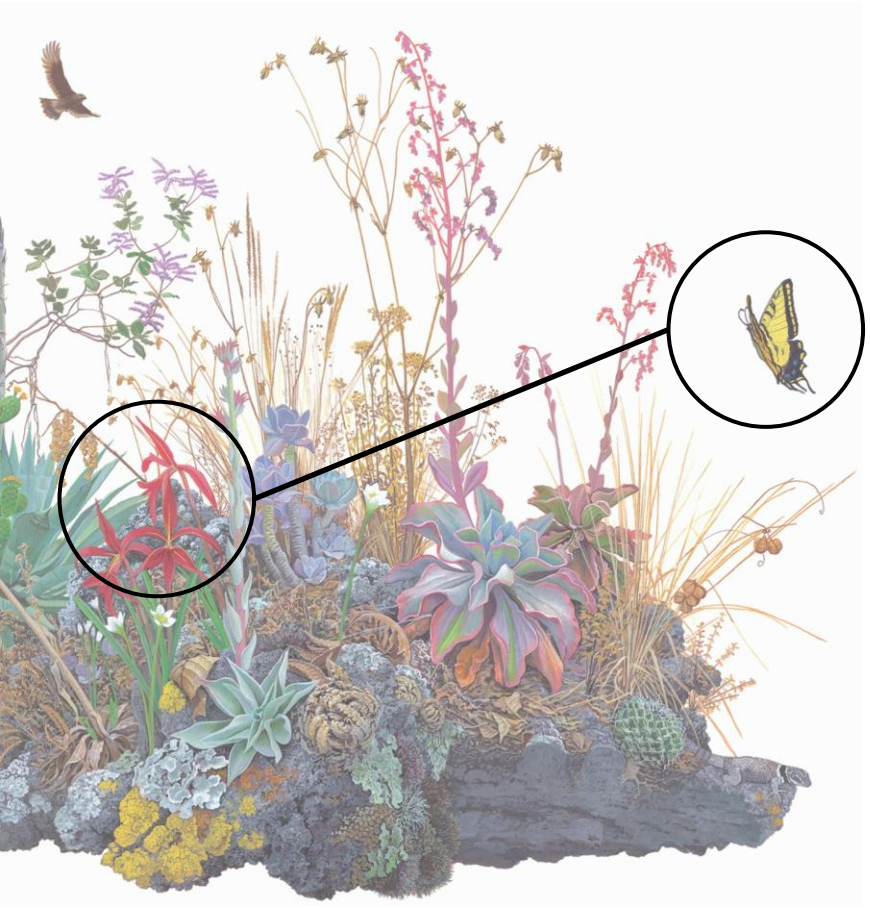


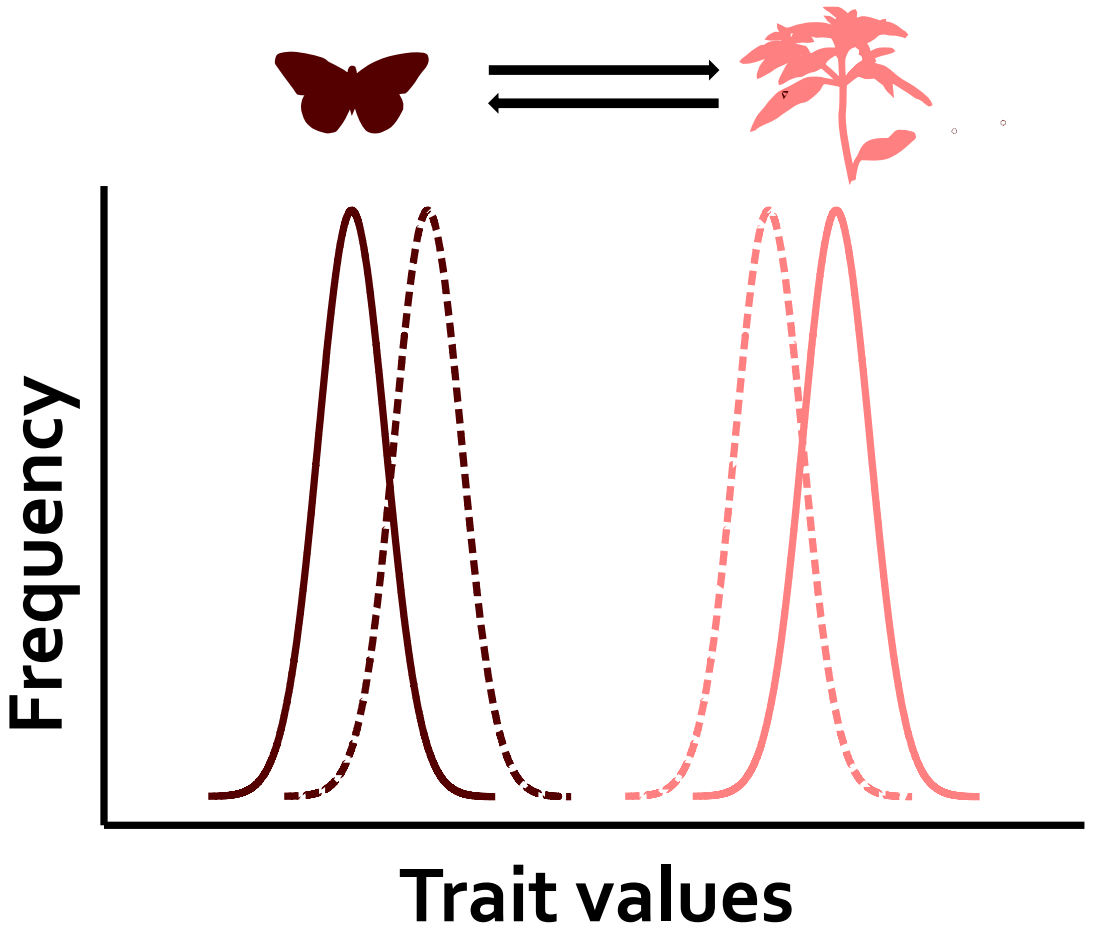
Brodie *et al.* (2002), *Evolution*



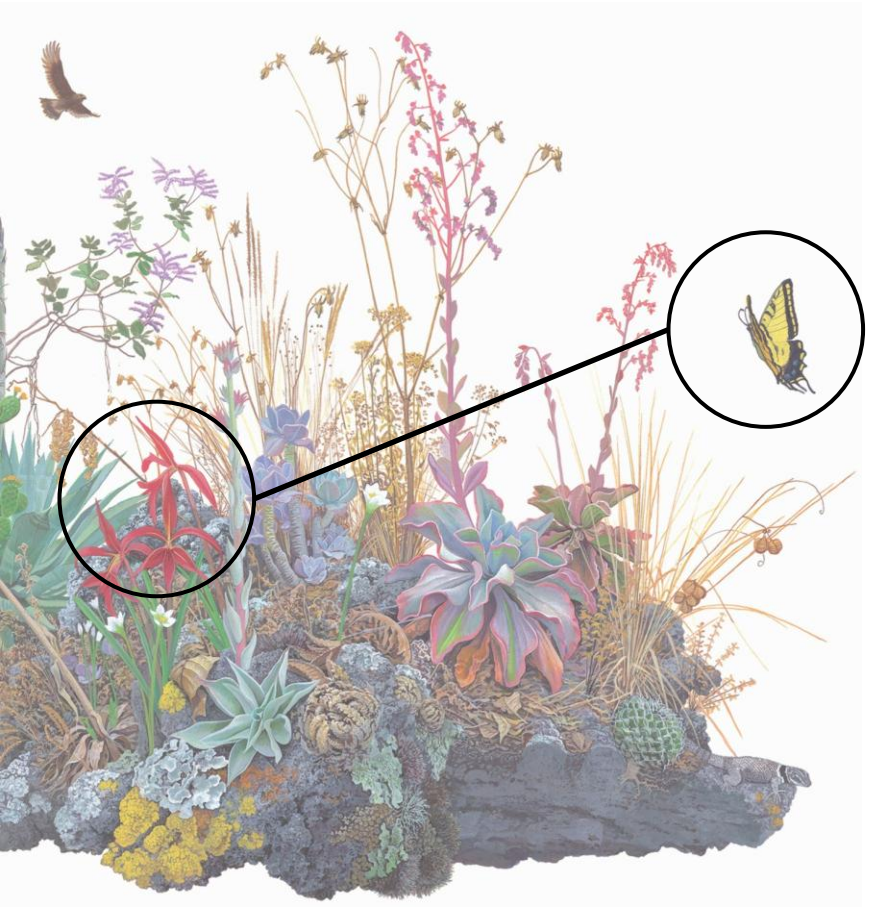


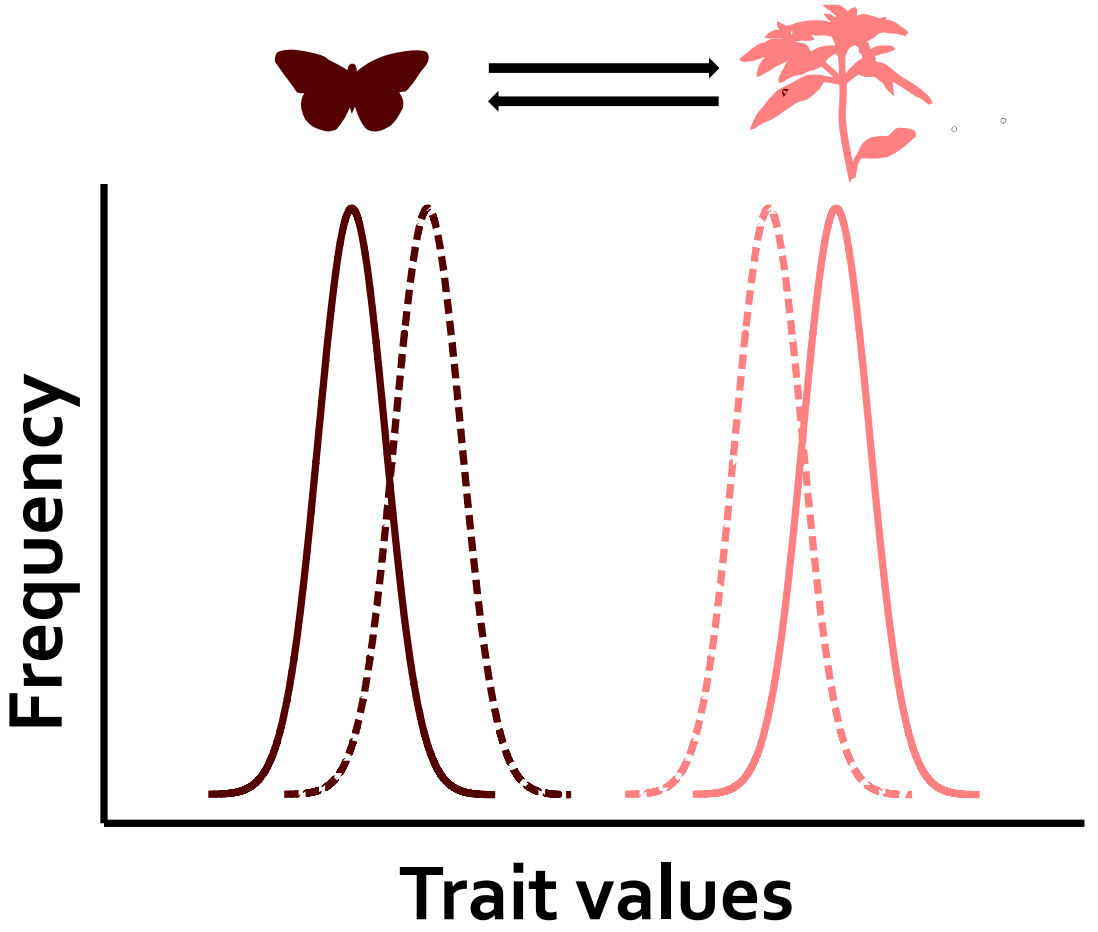
Ecological interactions can be a source of selective pressures that drive the evolution of species traits



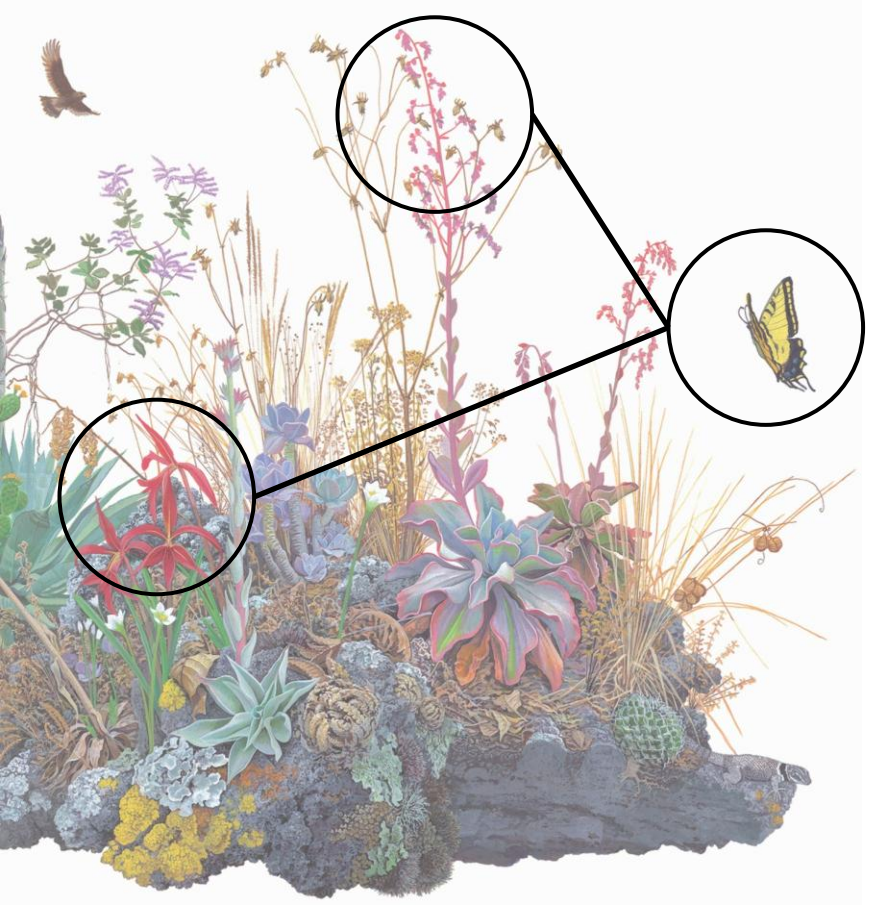


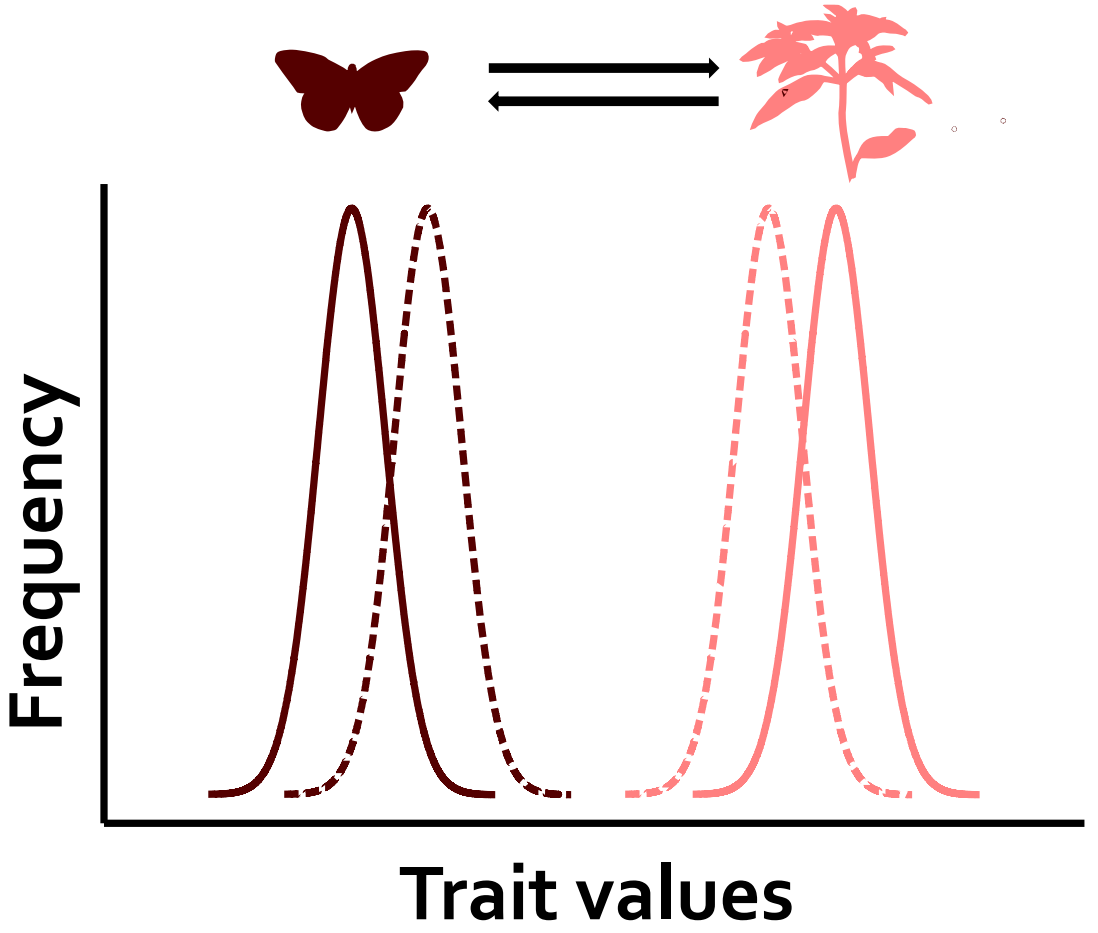
Reciprocal evolutionary changes between interacting species:
coevolution!



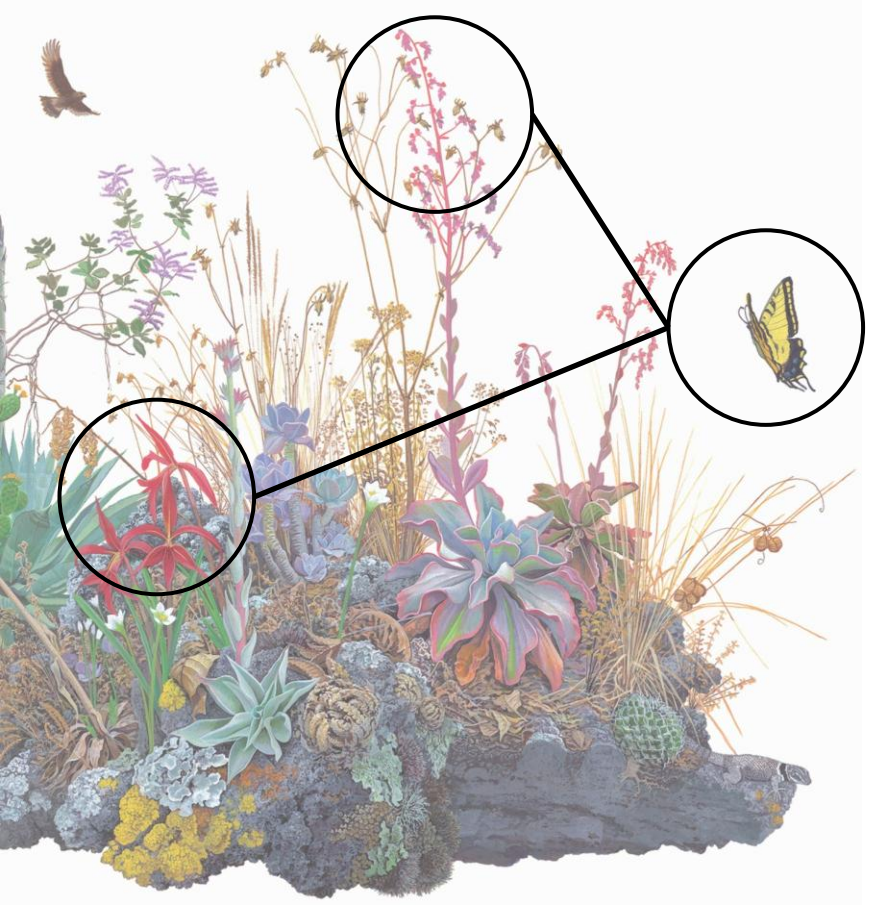


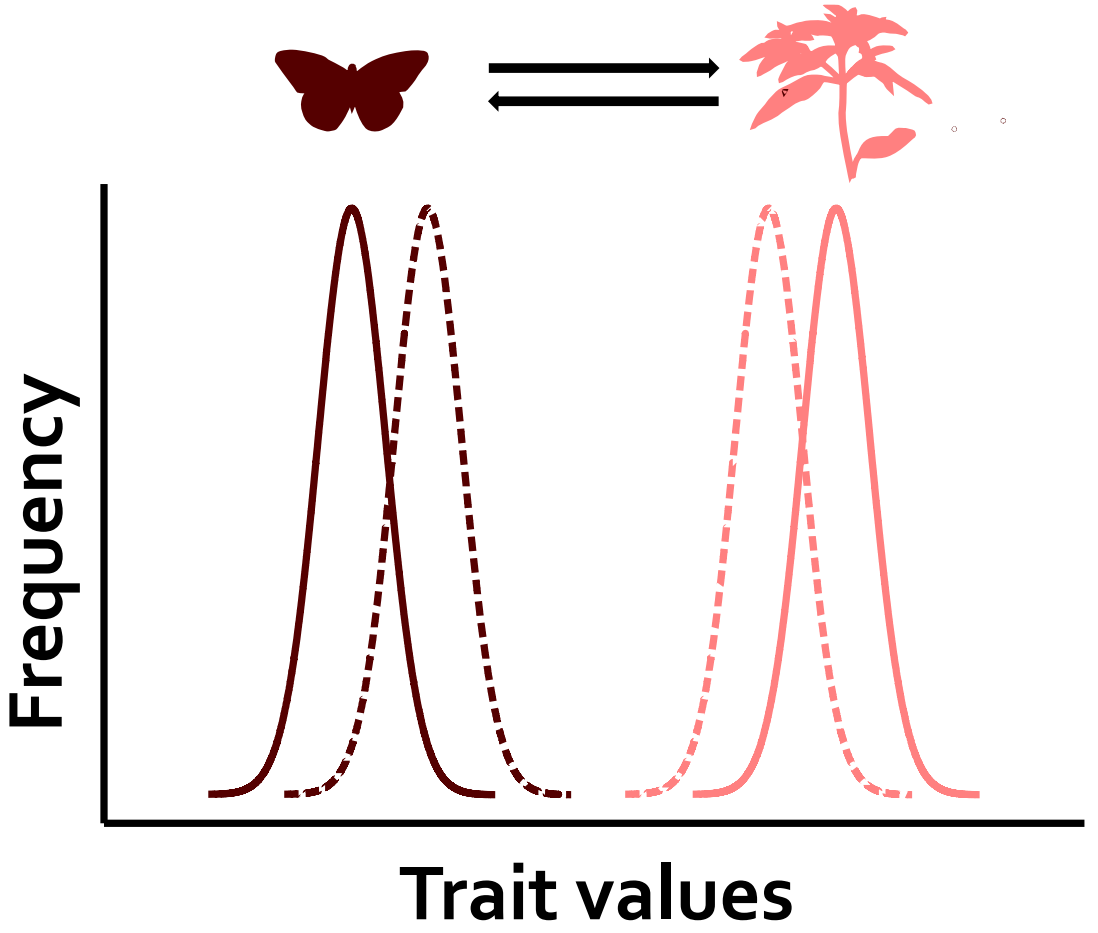
But…



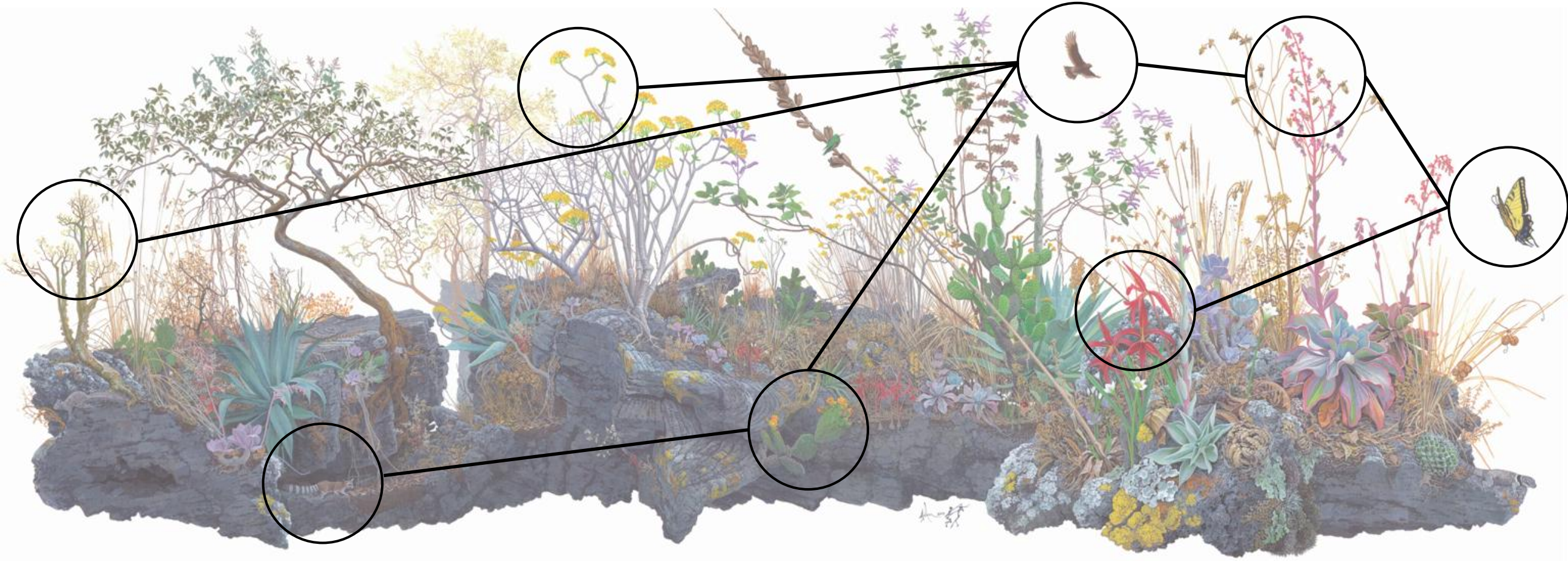


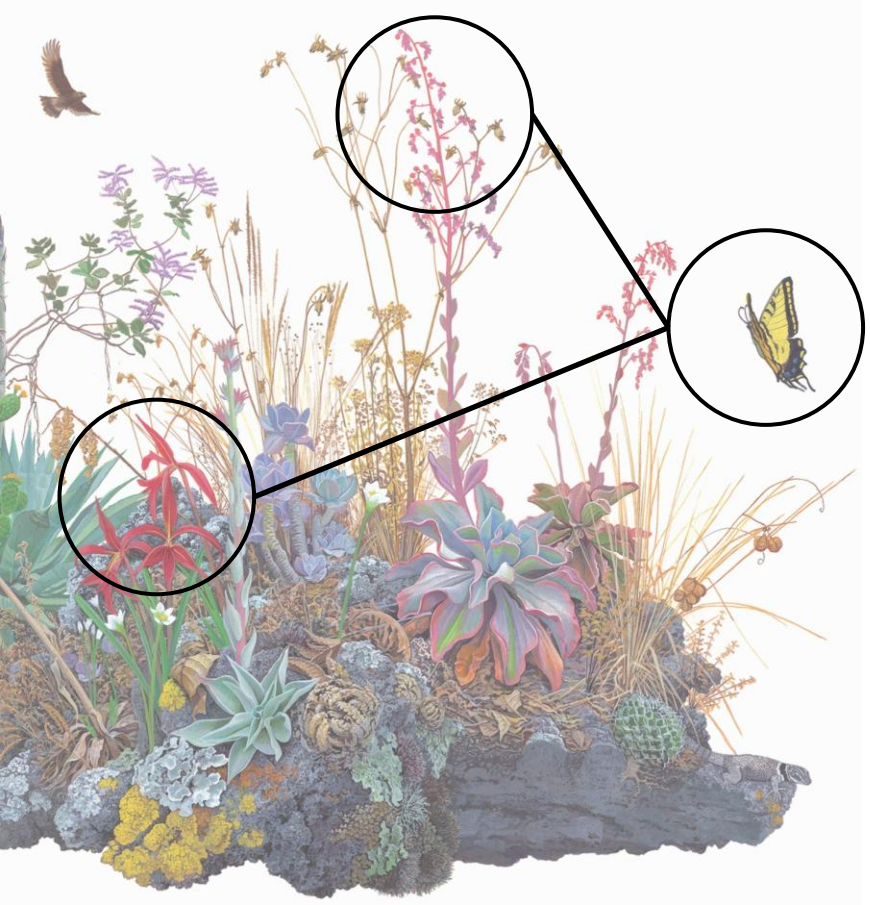
What happens when we have a third interacting species?

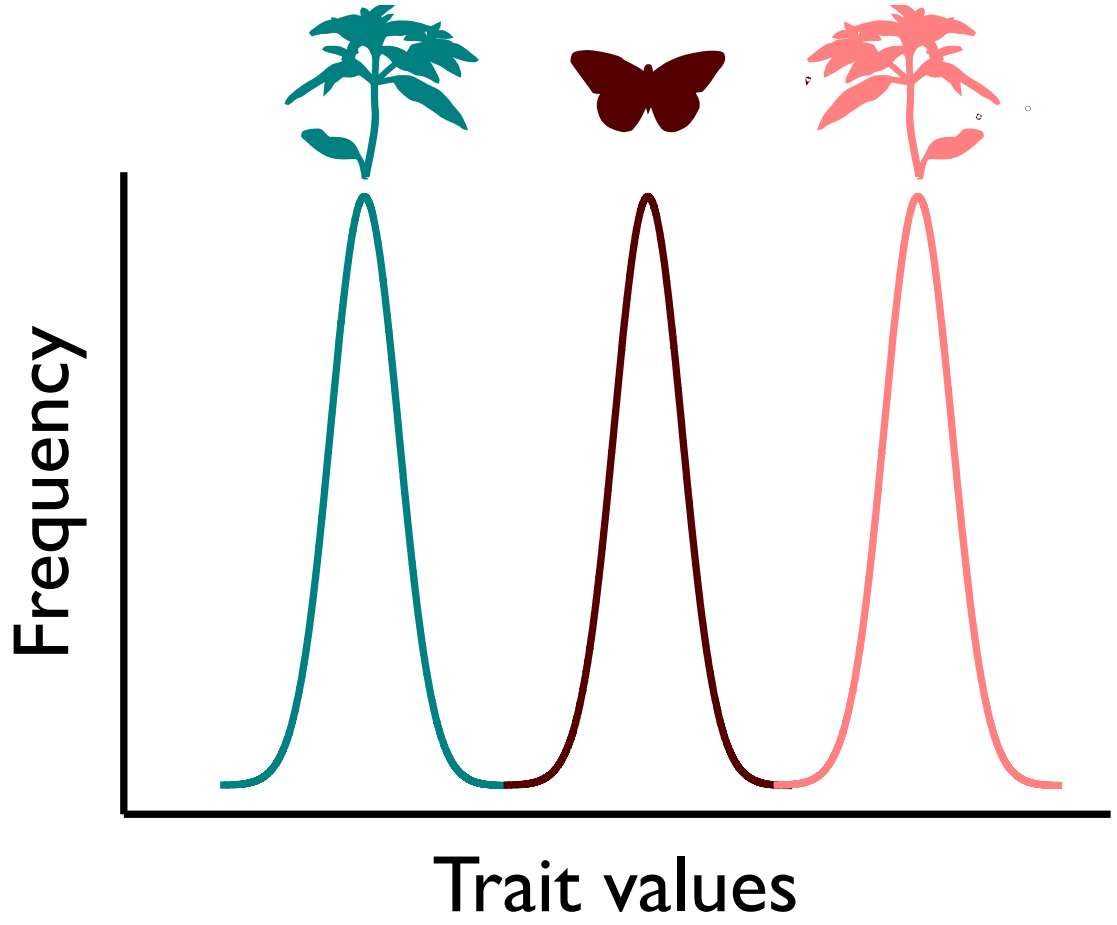




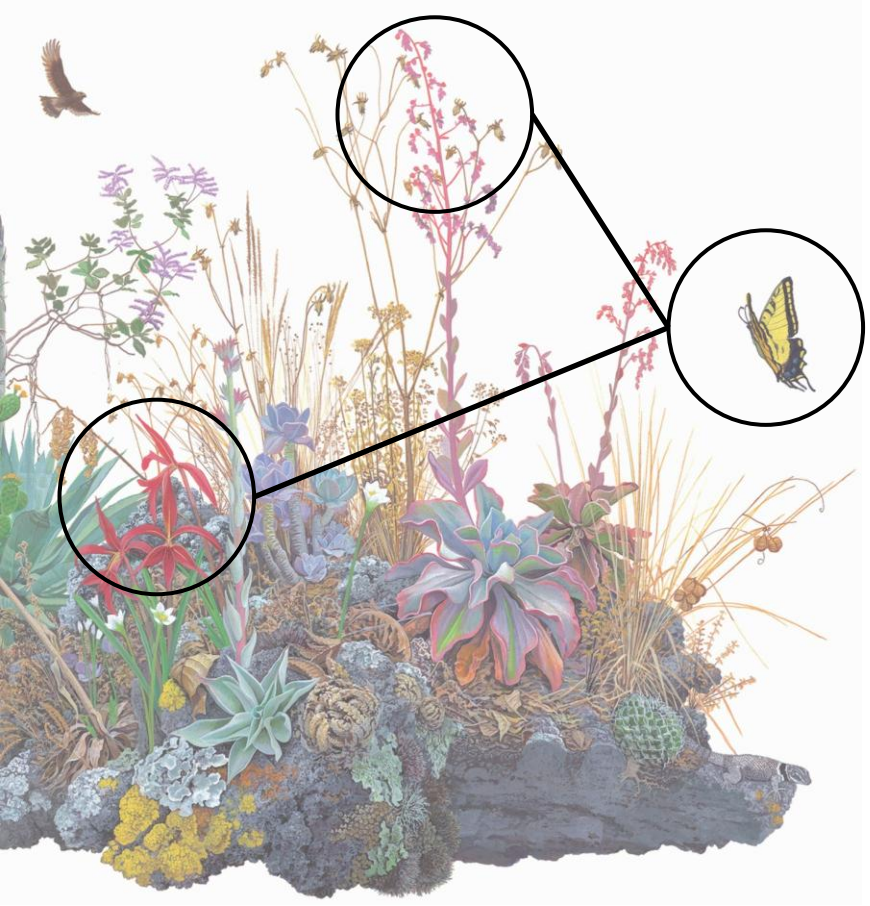
How the structure of ecological networks shape coevolution?

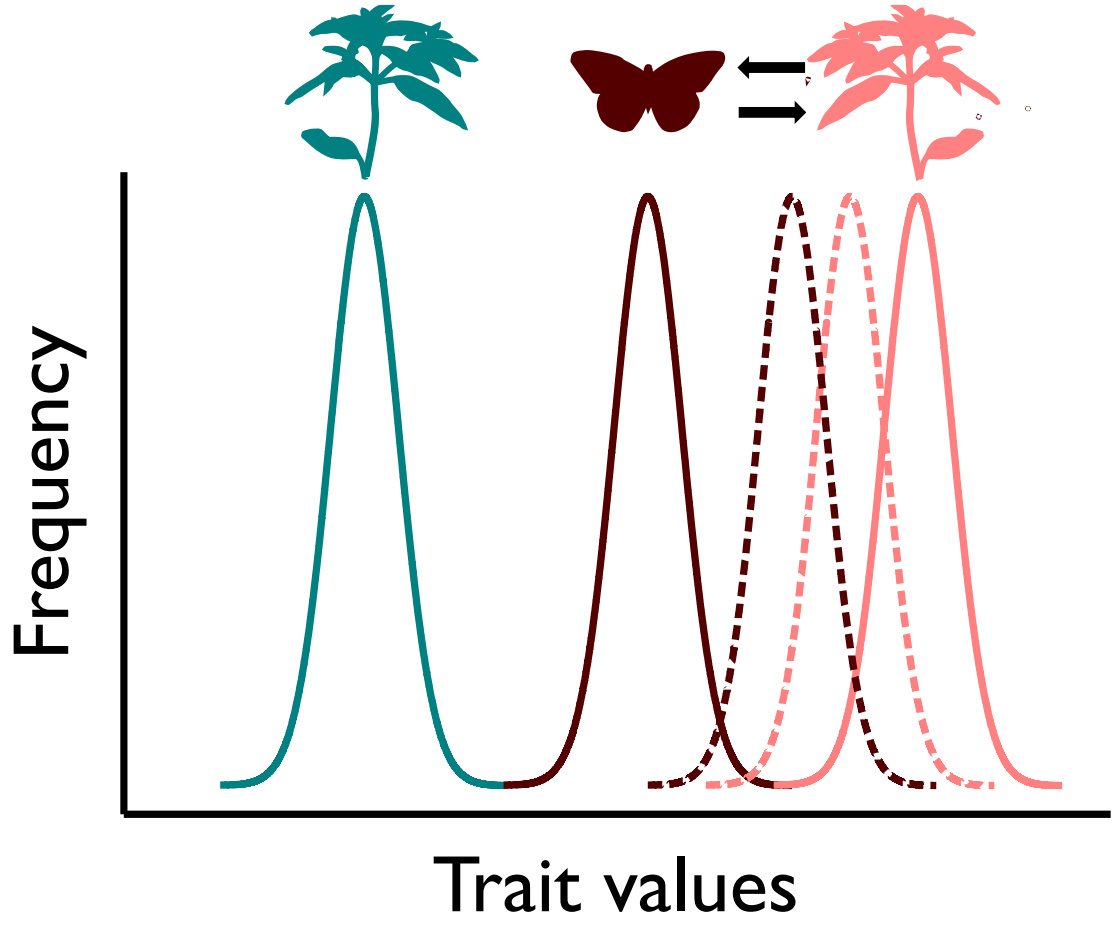




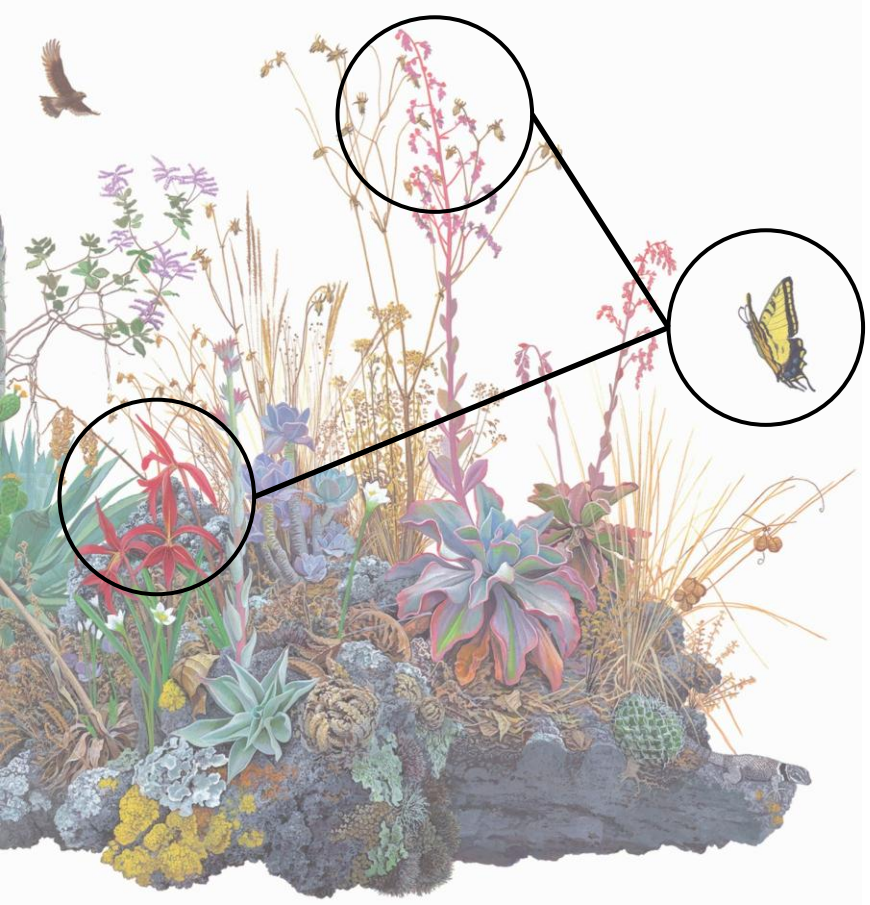


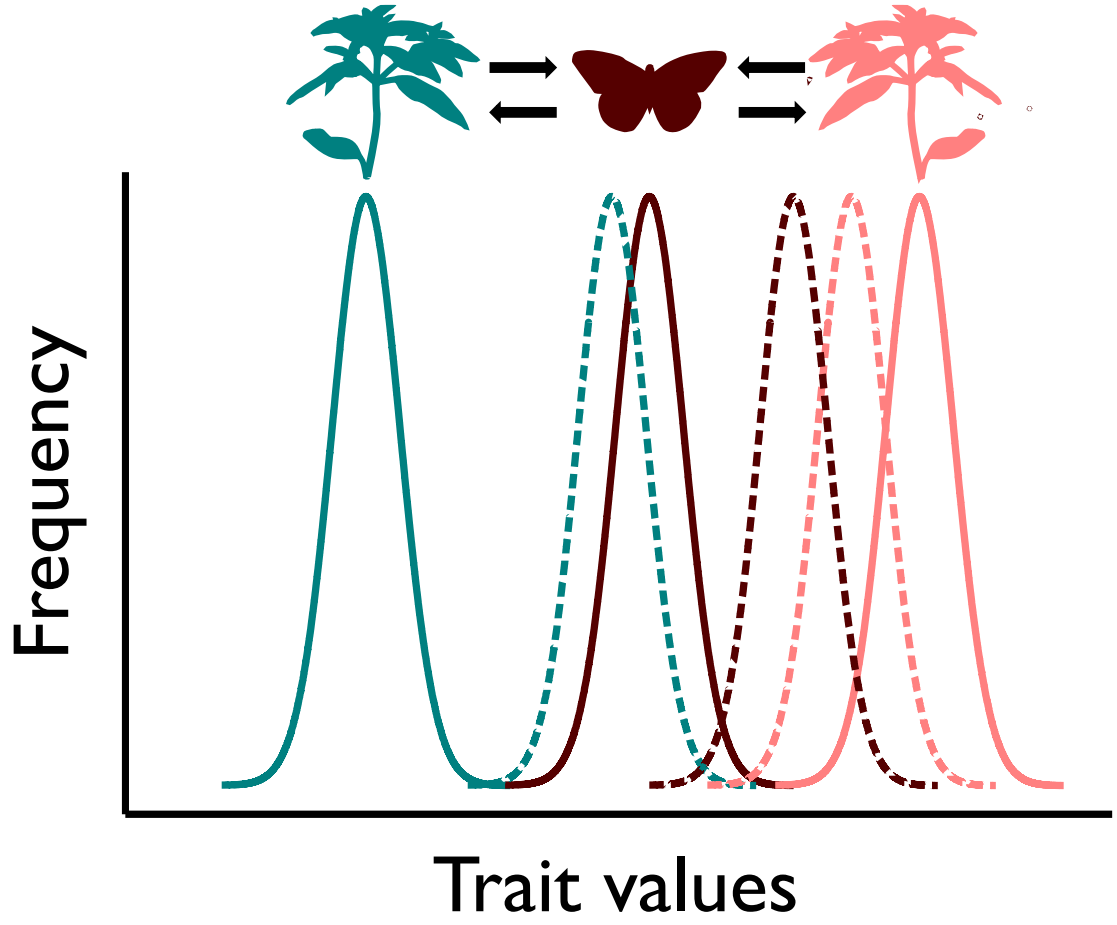
What are the consequences of coevolution among three or more species?



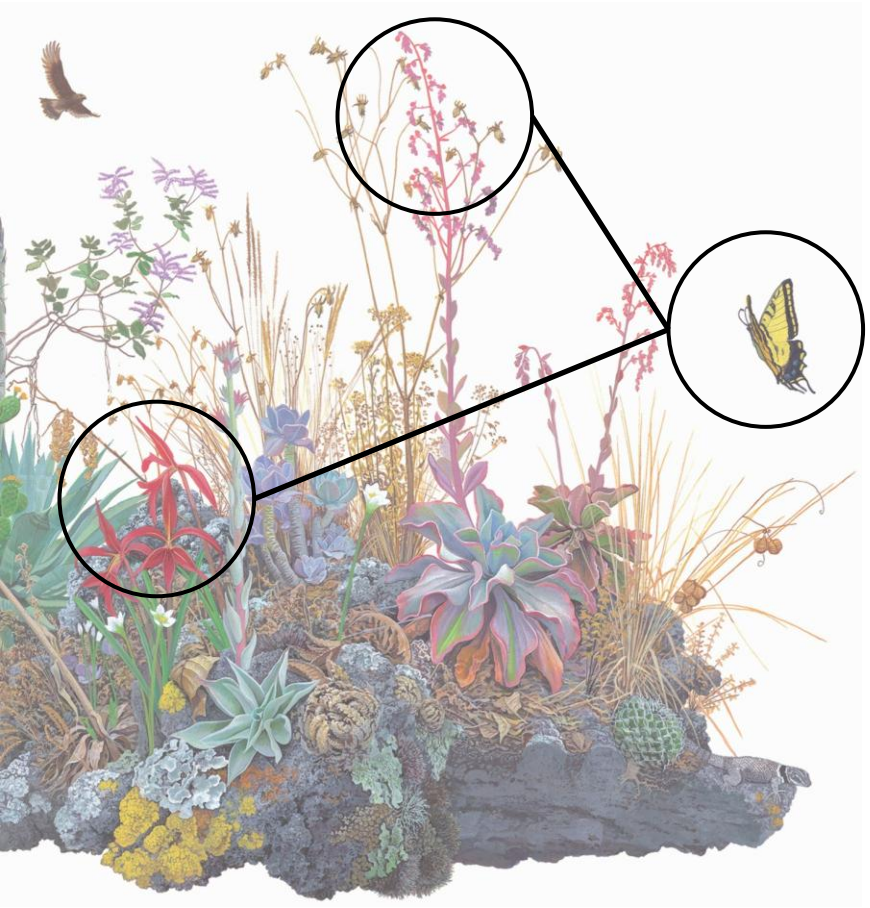


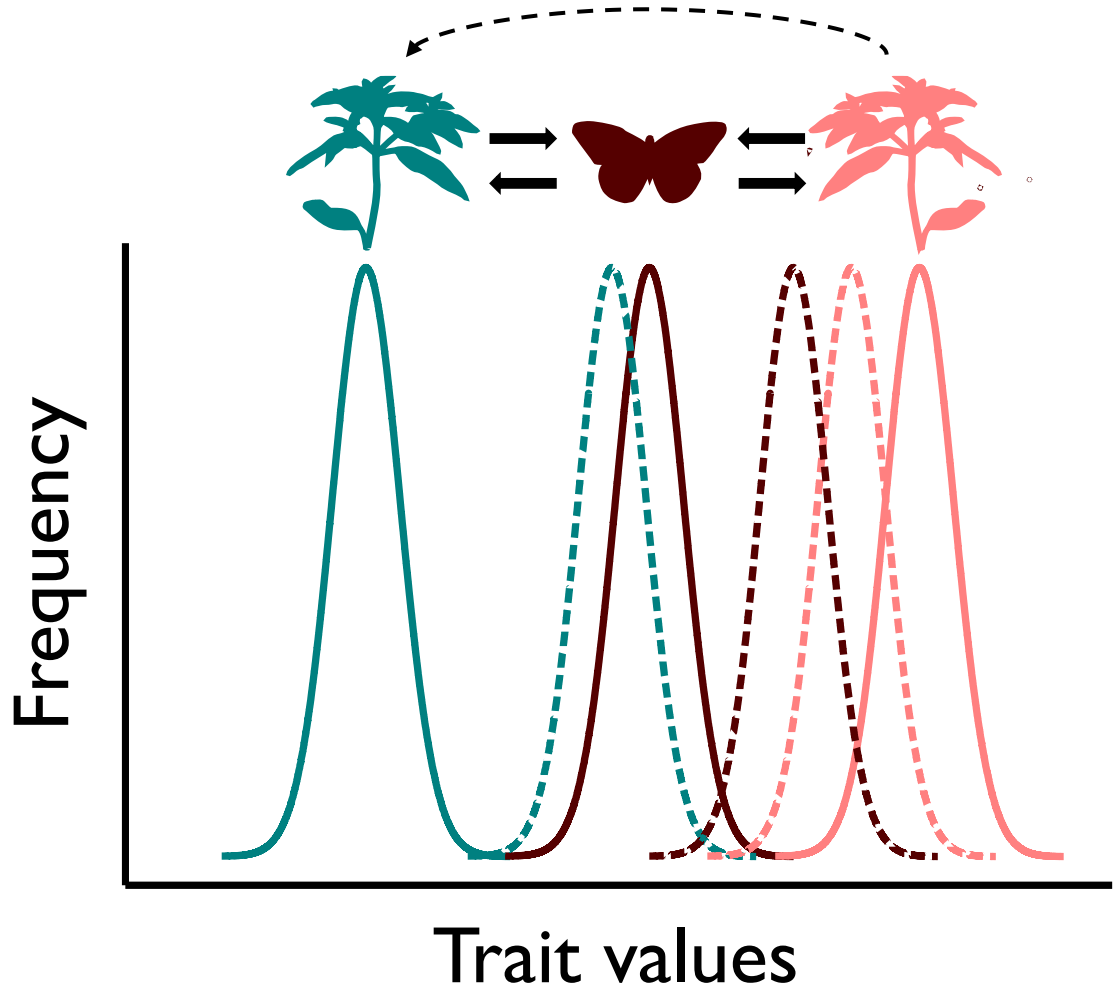
Pairwise interactions: changes in the trait matching between two interacting partners





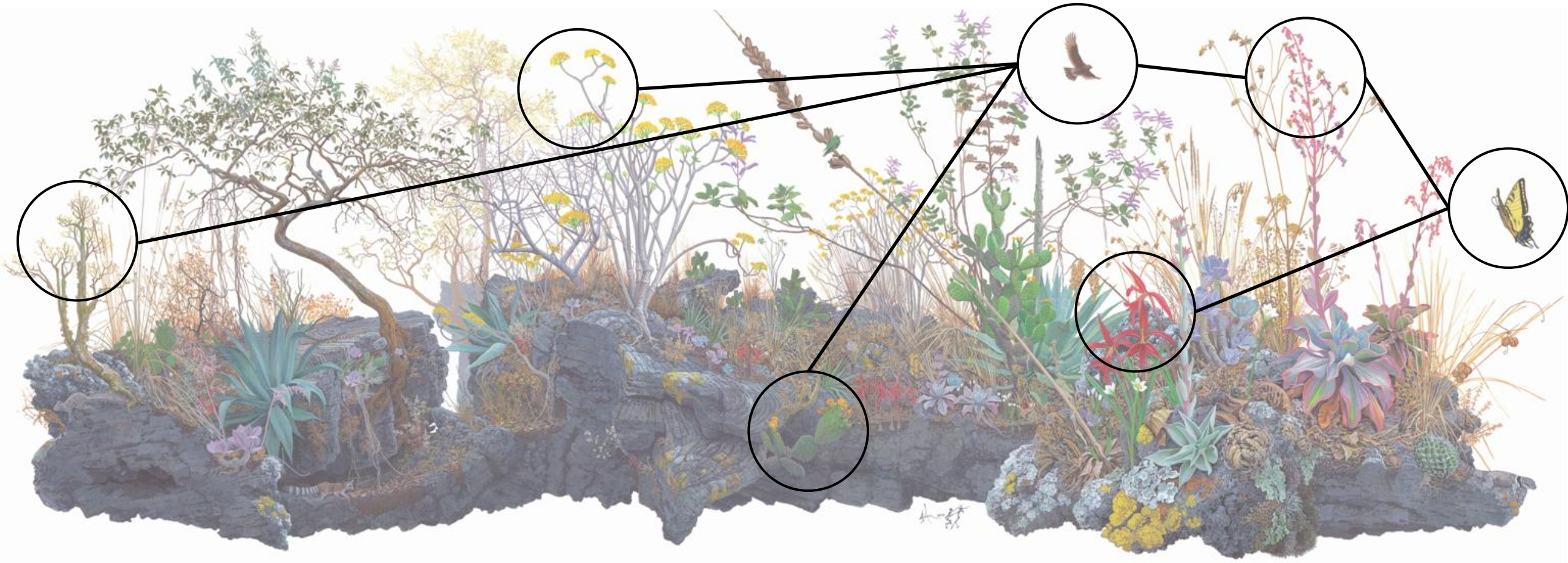
What are the consequences of the first coevolutionary change for a third interacting species?





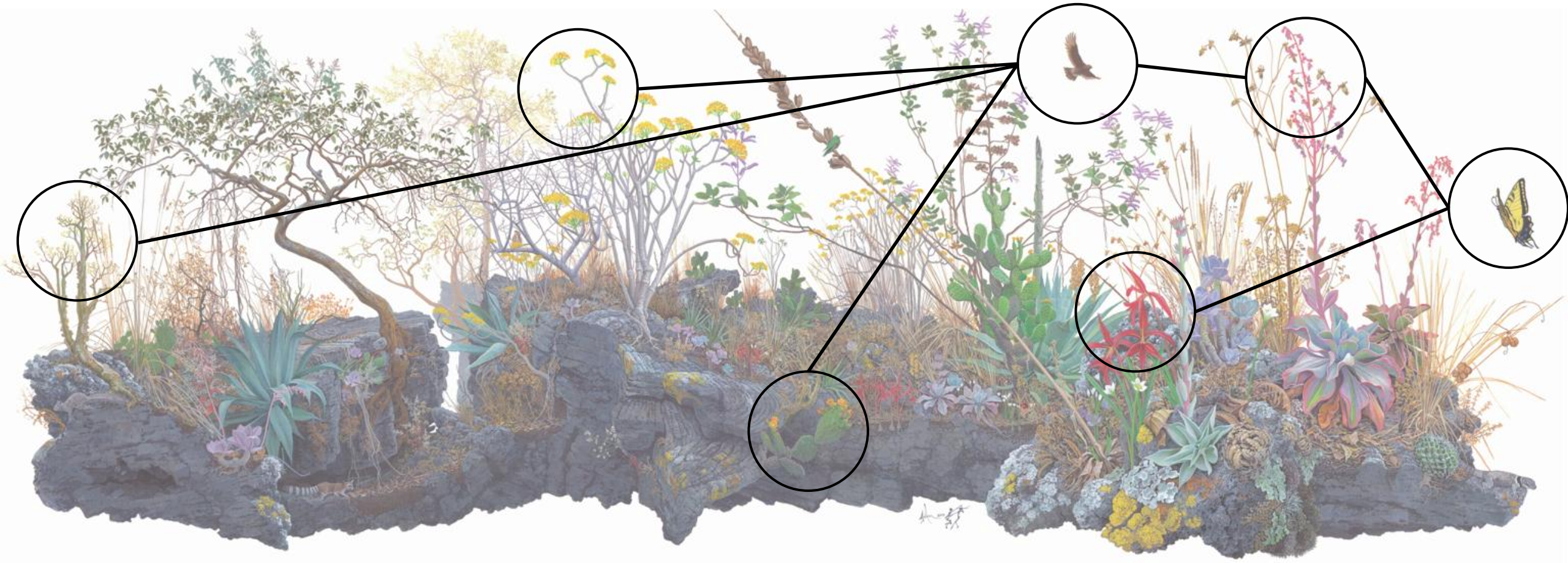
Indirect evolutionary effects emerge from chains of coevolutionary changes

(Art by Aslam Narváez)



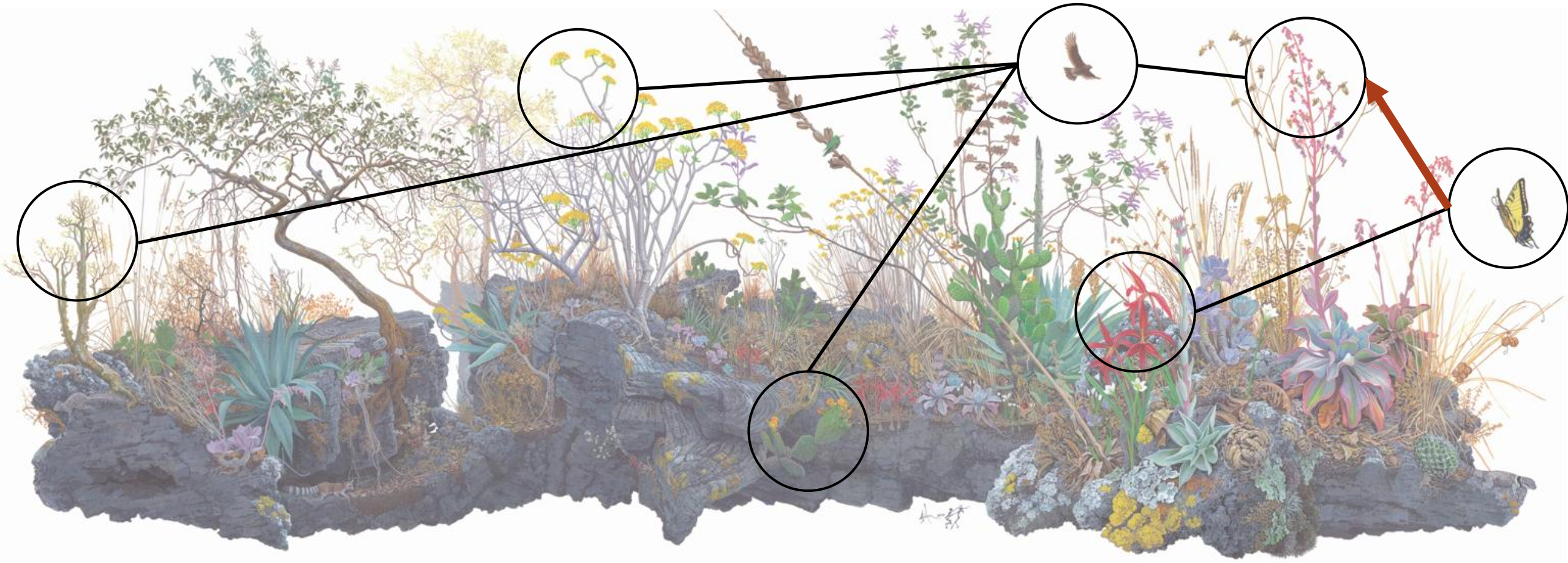
How coevolution operates in networks?

(Art by Aslam Narváez)



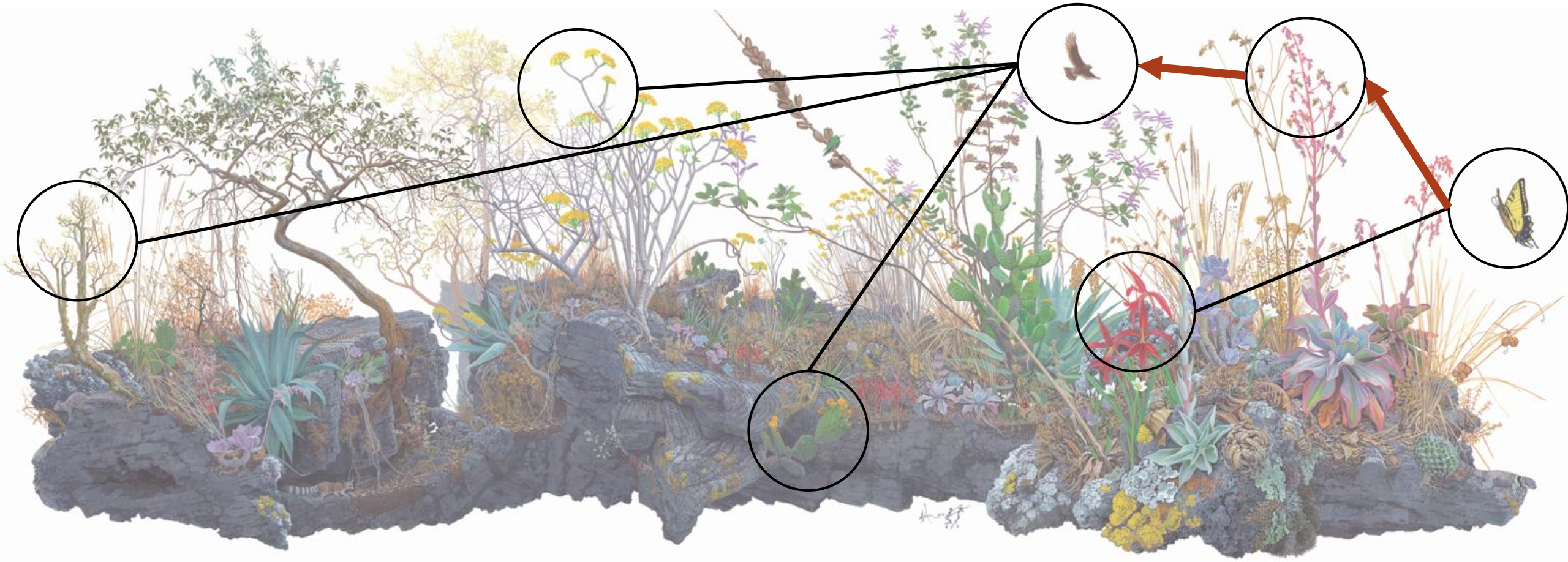
Species may indirectly affect each other's evolution

(Art by Aslam Narváez)



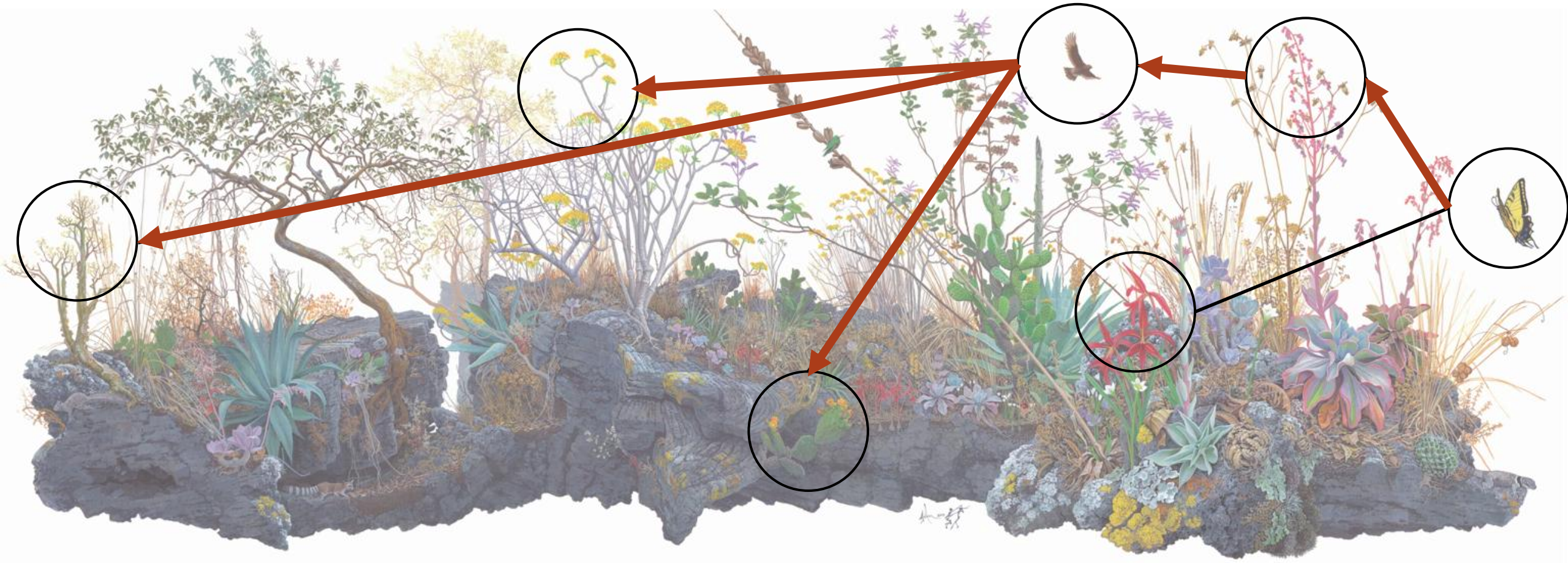
Chains of evolutionary effects

(Art by Aslam Narváez)



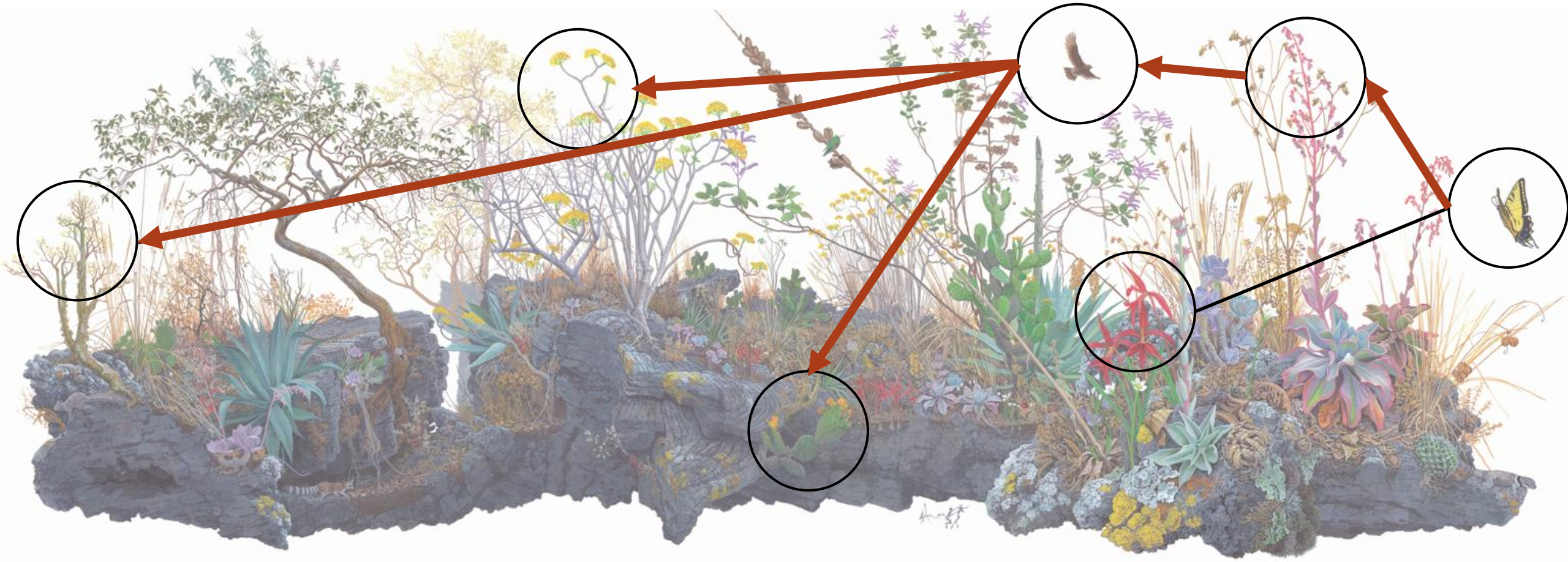
Chains of evolutionary effects

(Art by Aslam Narváez)



Chains of evolutionary effects

(Art by Aslam Narváez)



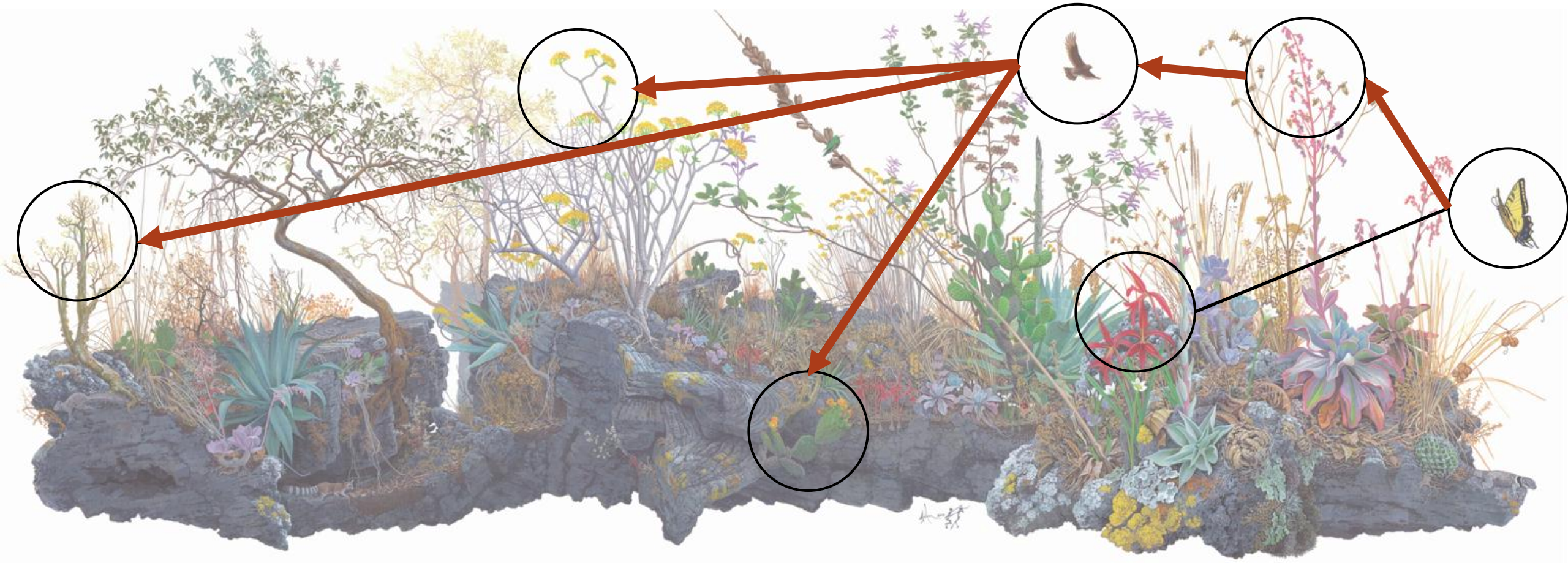
Do these indirect evolutionary effects matter?

Early argument – coevolution in multispecies communities is “diffuse”

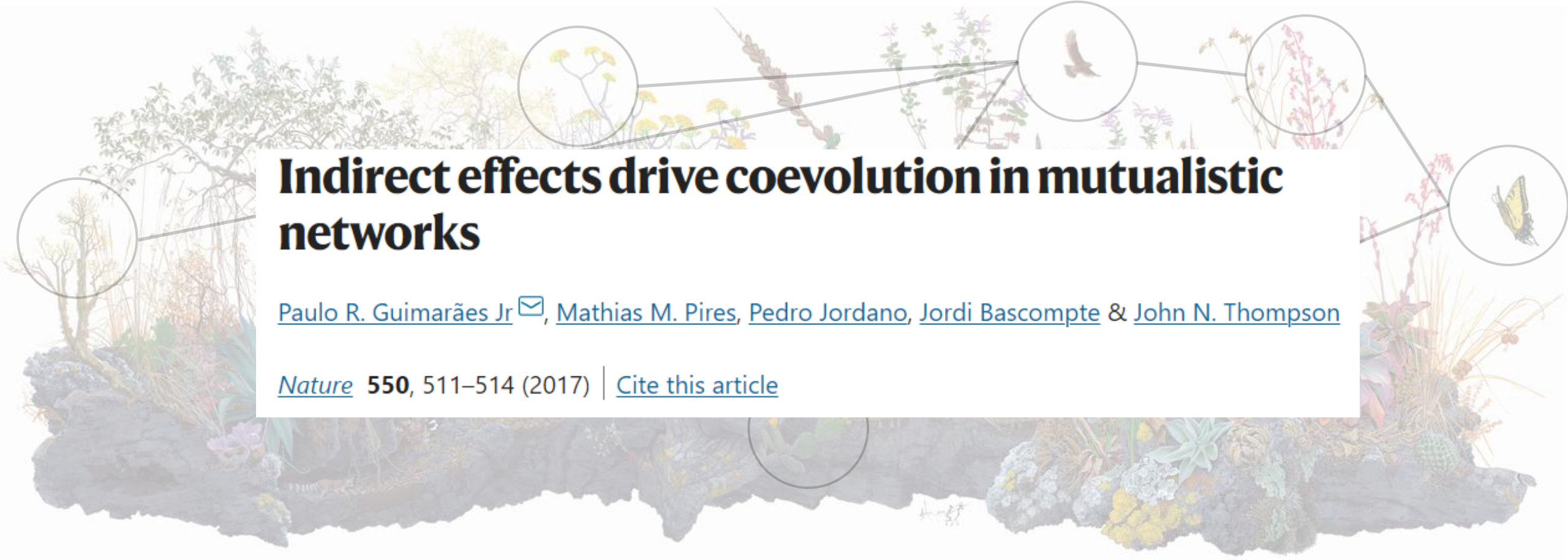
The structure and dynamics of reciprocal selection can not be identified

How important are indirect evolutionary effects?

(Art by Aslam Narváez)



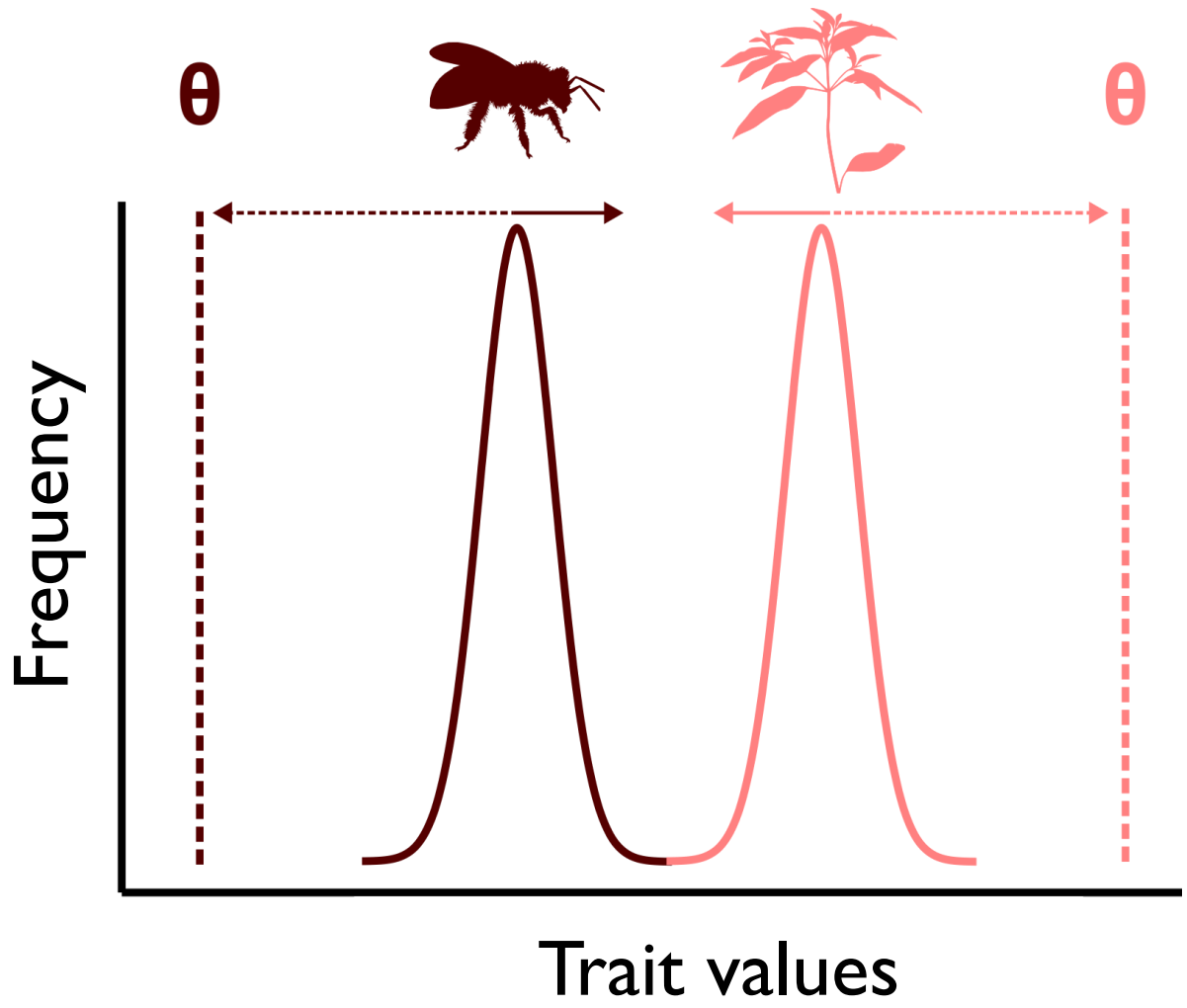
Quantify indirect evolutionary effects



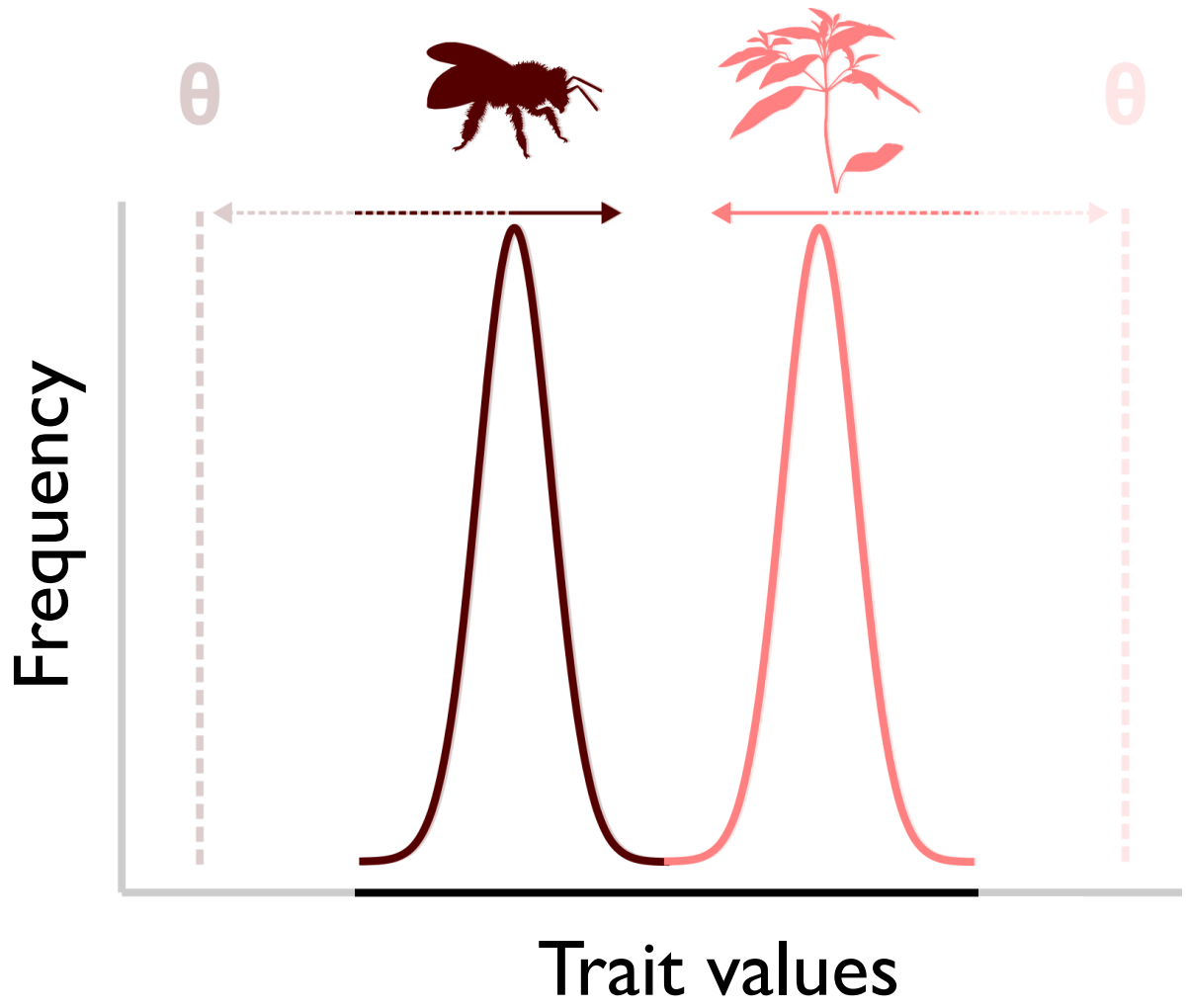
Indirect effects drive coevolution in mutualistic networks

Paulo R. Guimarães Jr ✉, Mathias M. Pires, Pedro Jordano, Jordi Bascompte & John N. Thompson

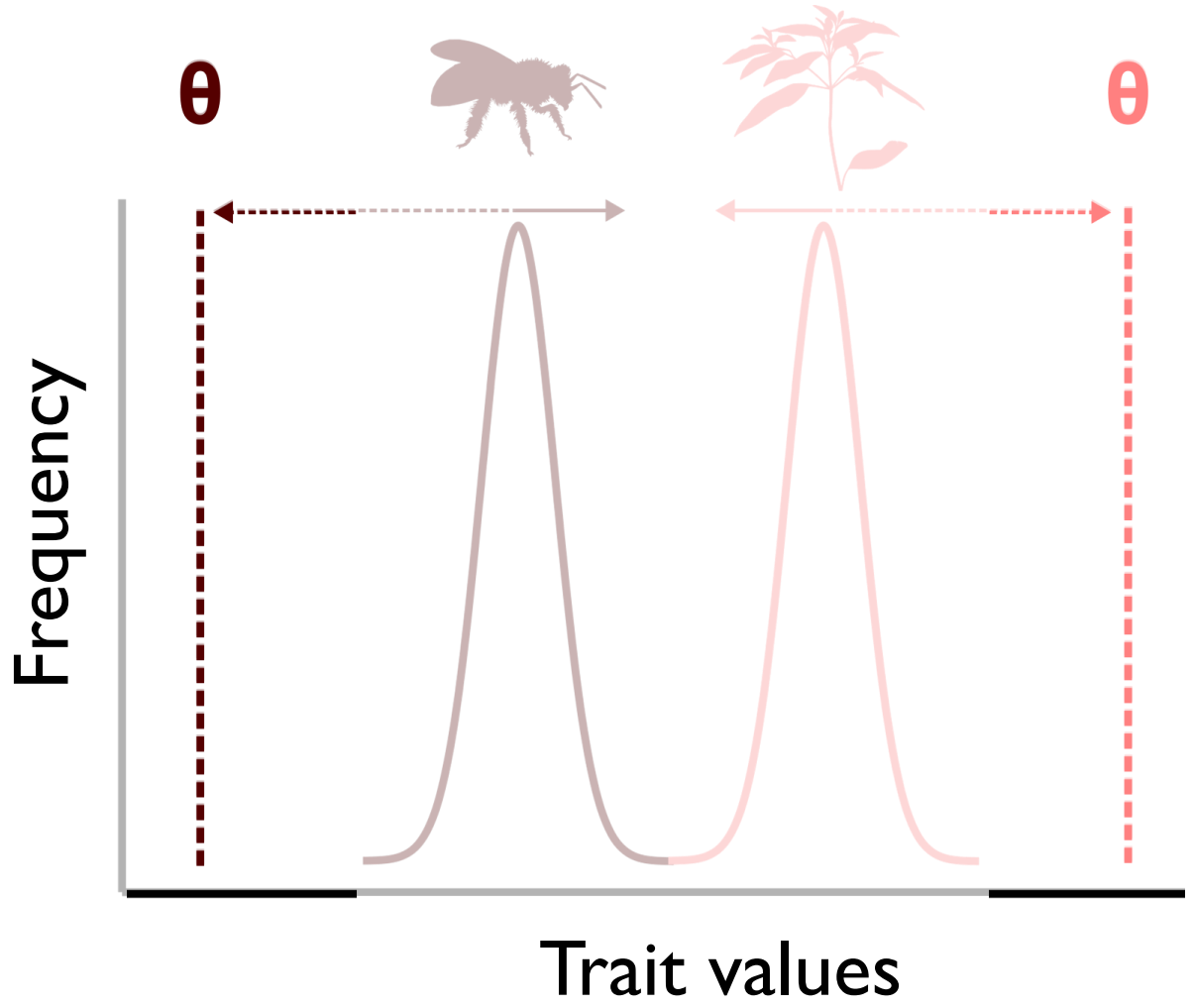
Nature **550**, 511–514 (2017) | Cite this article



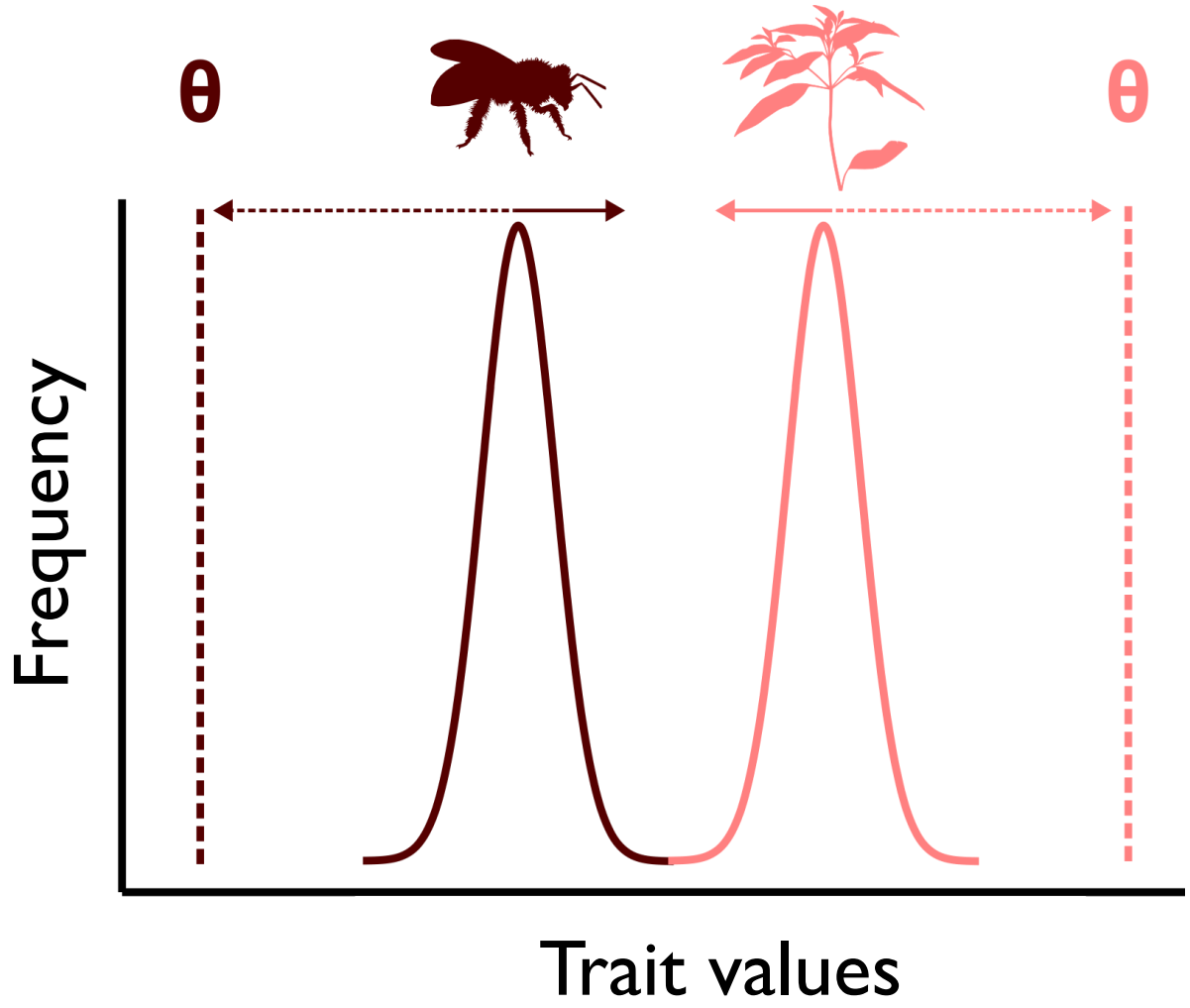
Coevolutionary model – two sources of selective pressures



Selection from mutualistic interactions



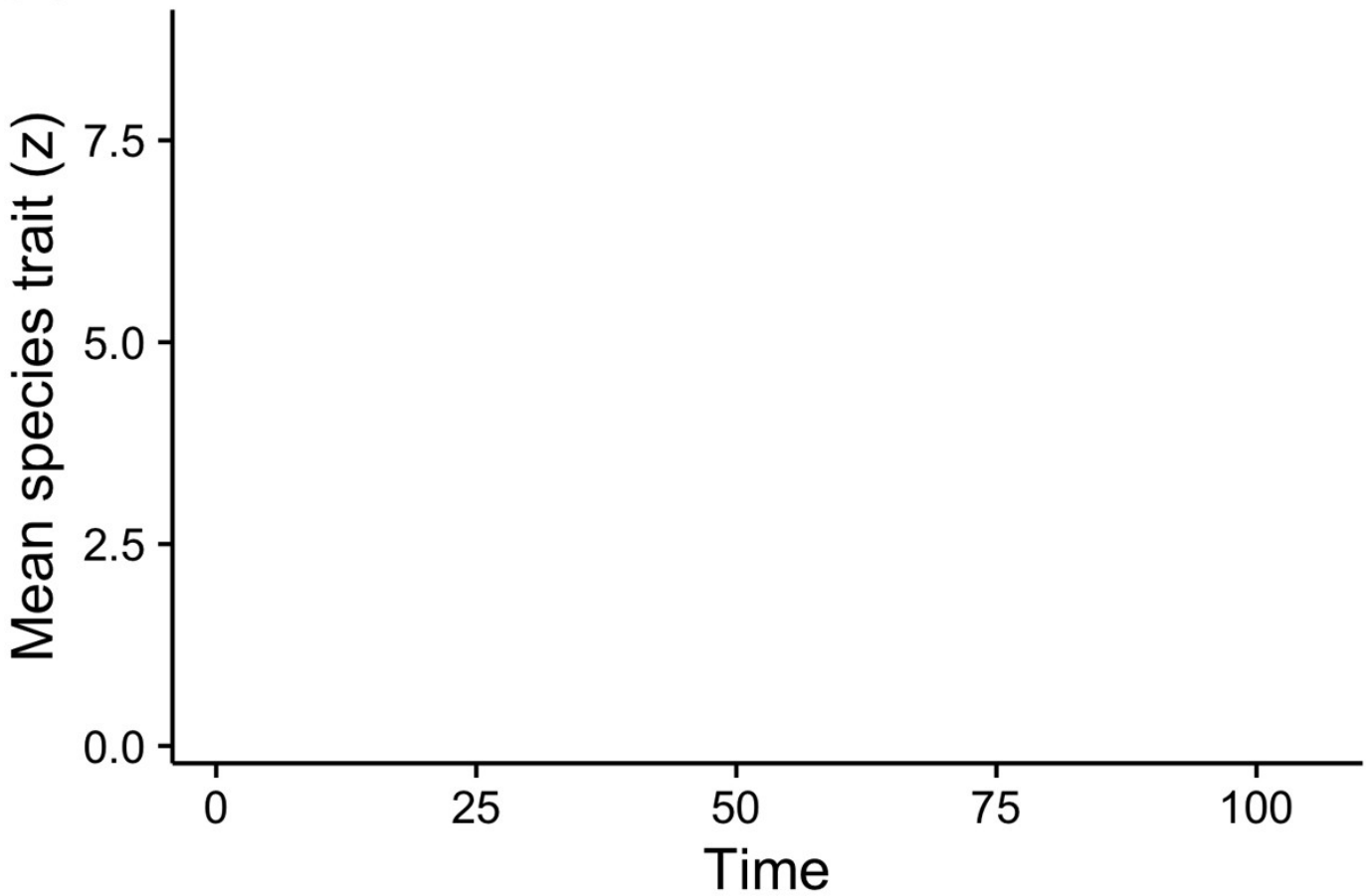
Selection from other sources – environmental optimum

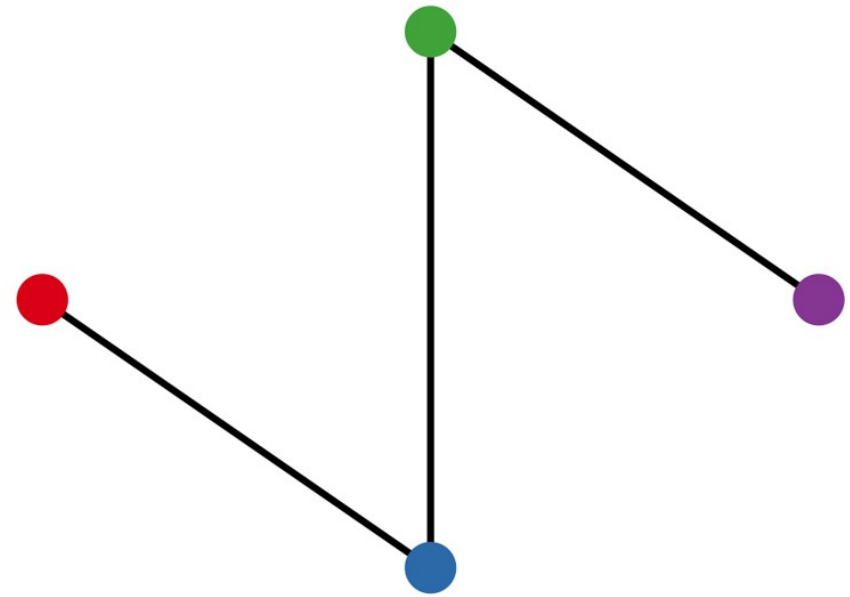


Classical equation (Lande, 1976): $\Delta\bar{z} = h^2\sigma^2 \frac{\partial\, ln(\bar{w}^{(t)})}{\partial\, \bar{z}^{(t)}}$

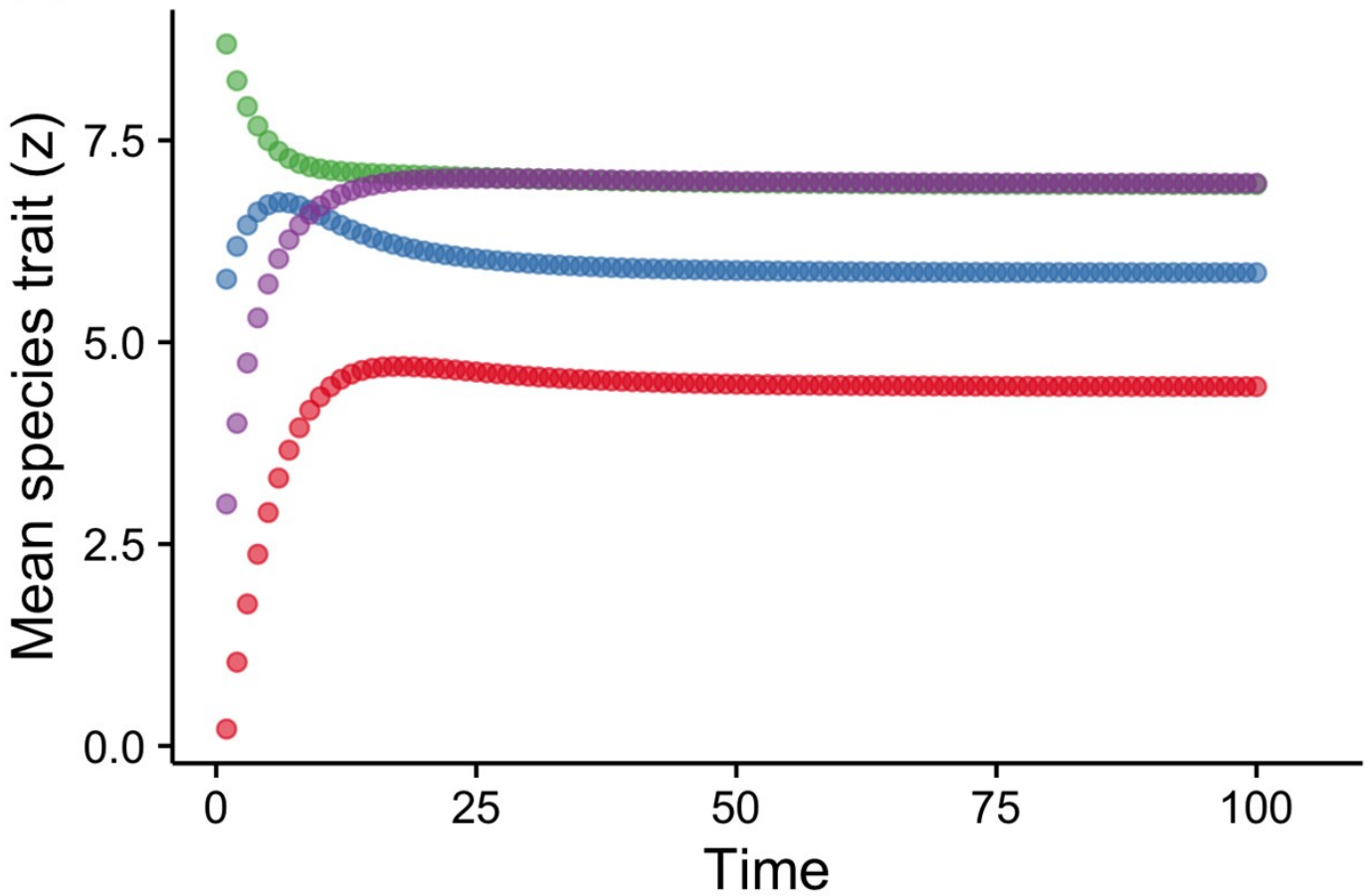
Analytical study

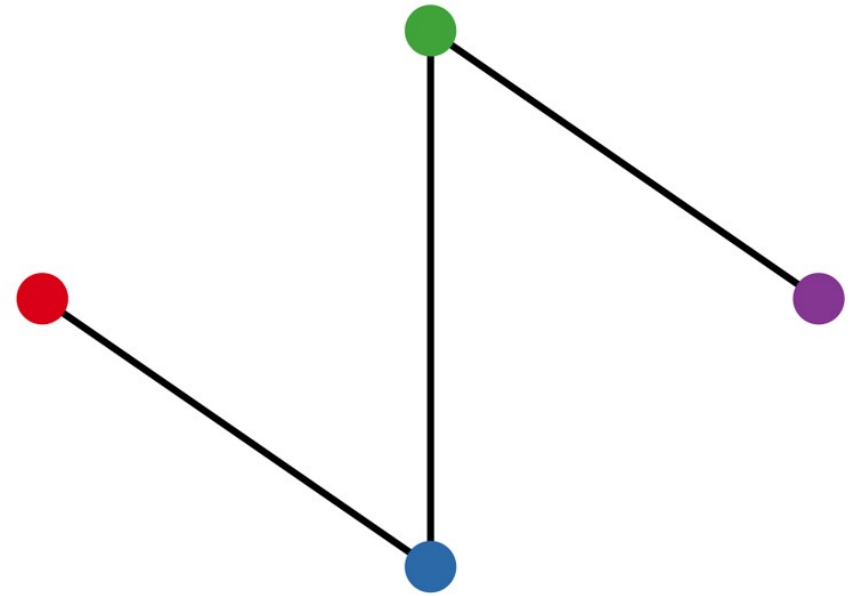
Numerical simulations using empirical networks (Web-of-Life)



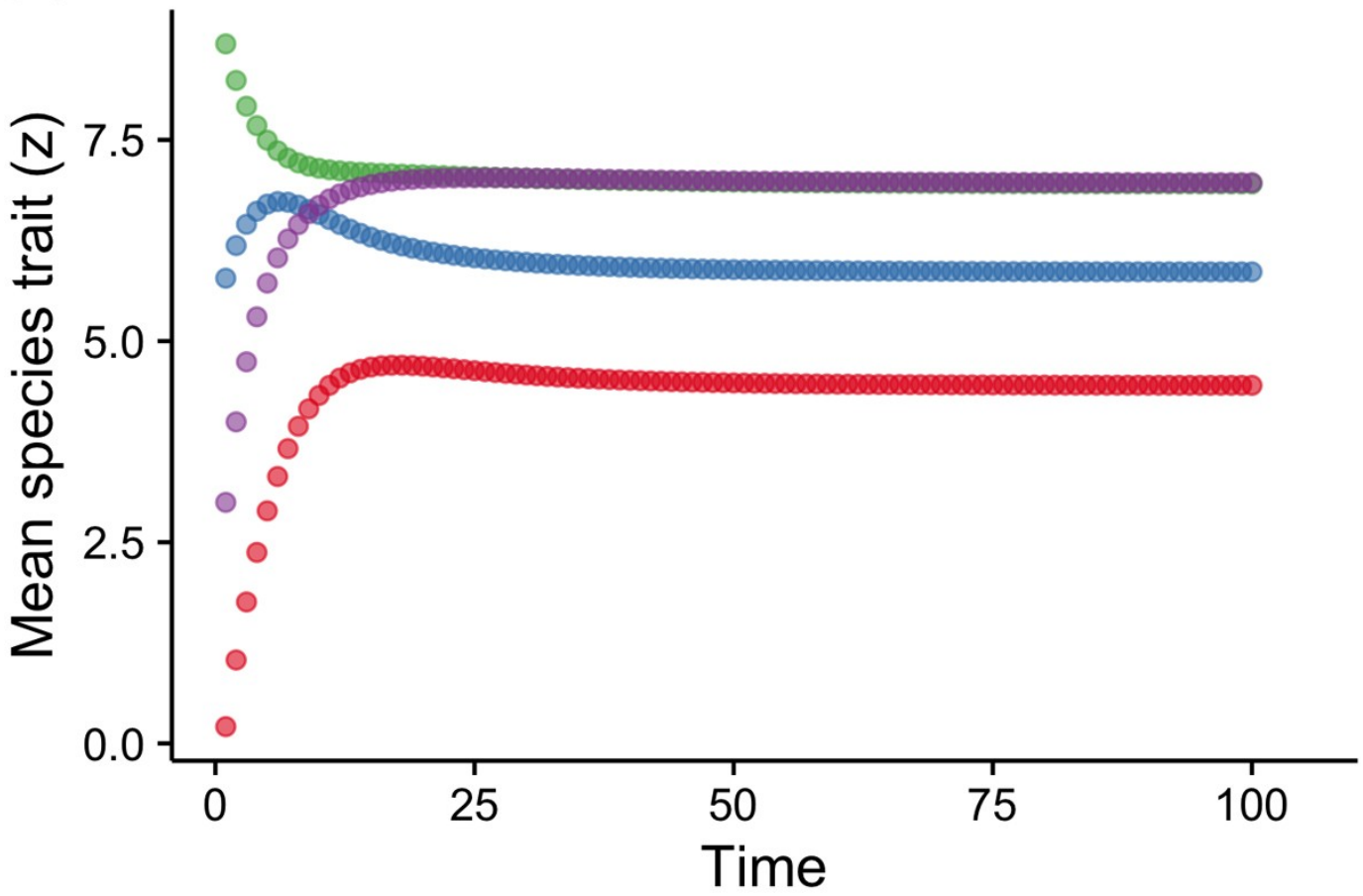


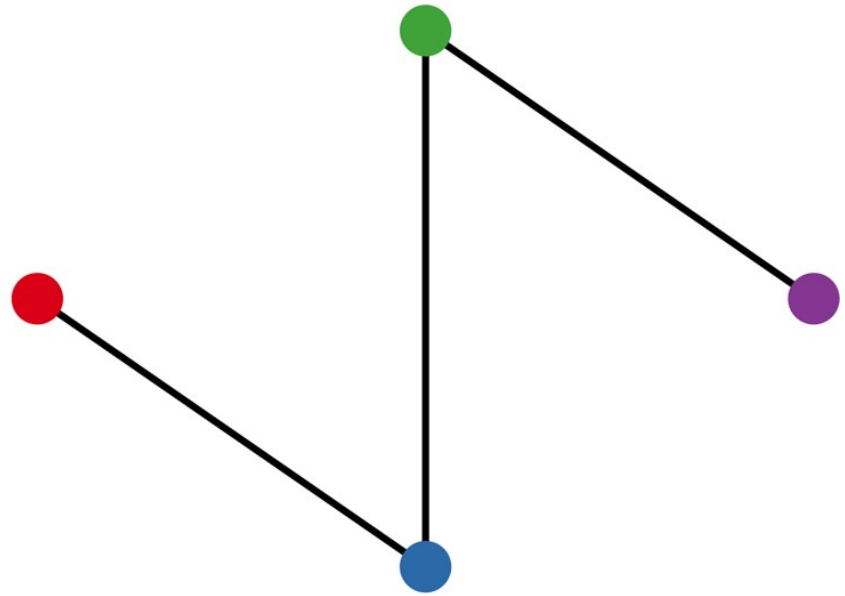
Guimaraes et al. 2017, *Nature*





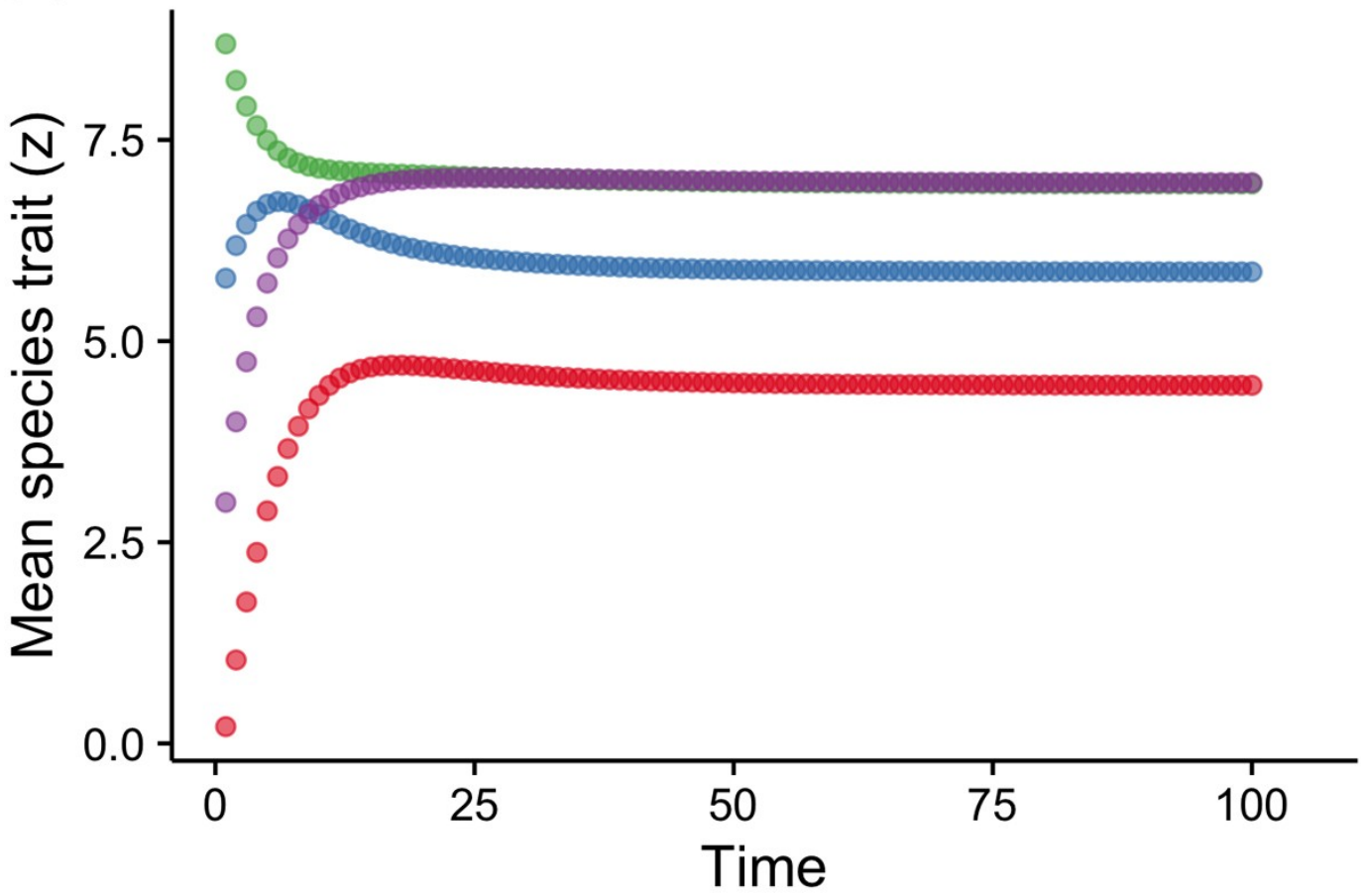
Guimaraes et al. 2017, *Nature*

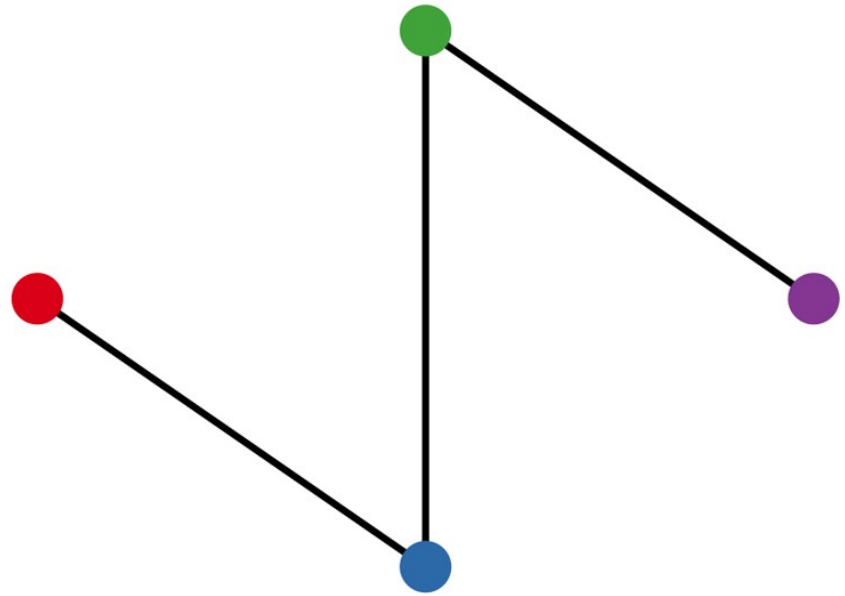




Traits depend on a matrix

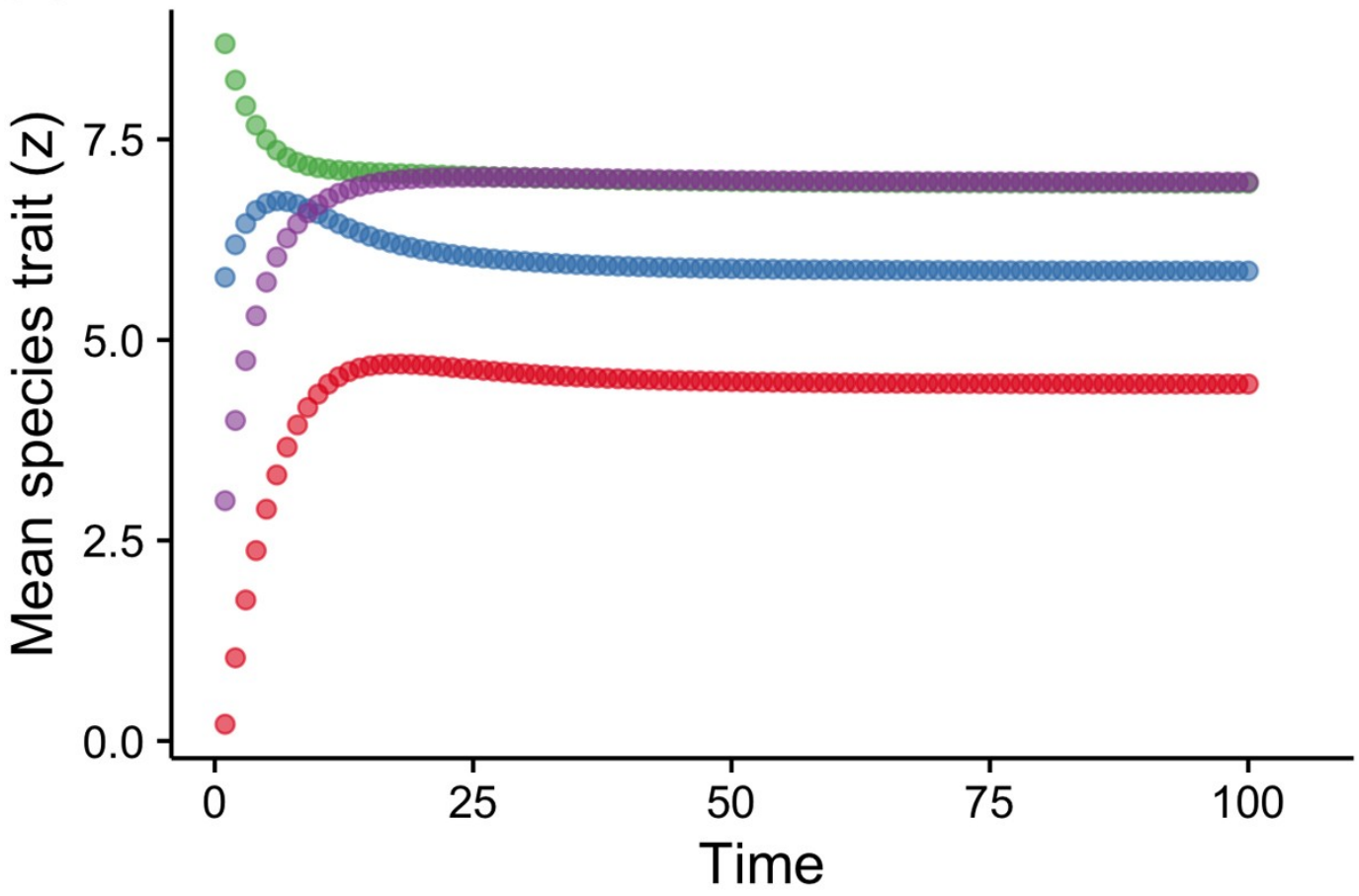
Guimaraes et al. 2017, *Nature*

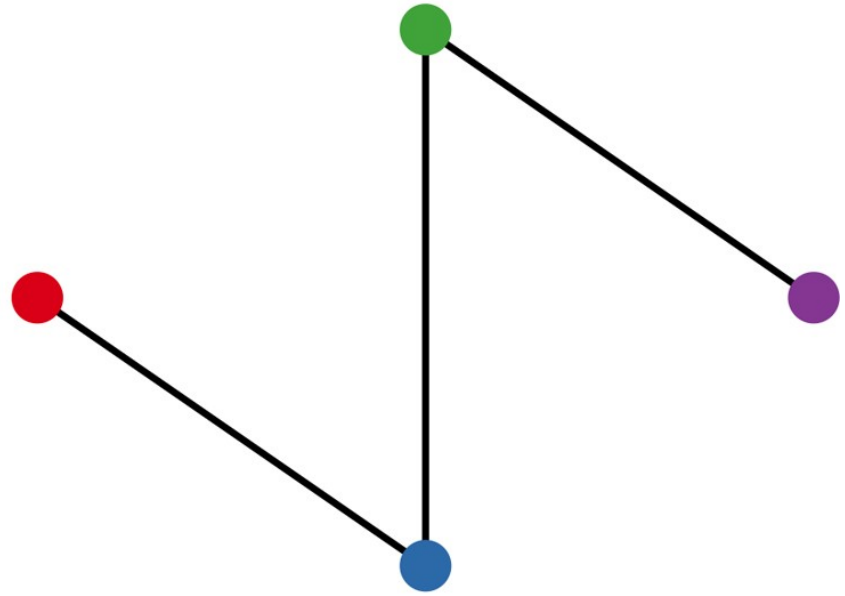




$$T = (I - Q)^{-1}$$

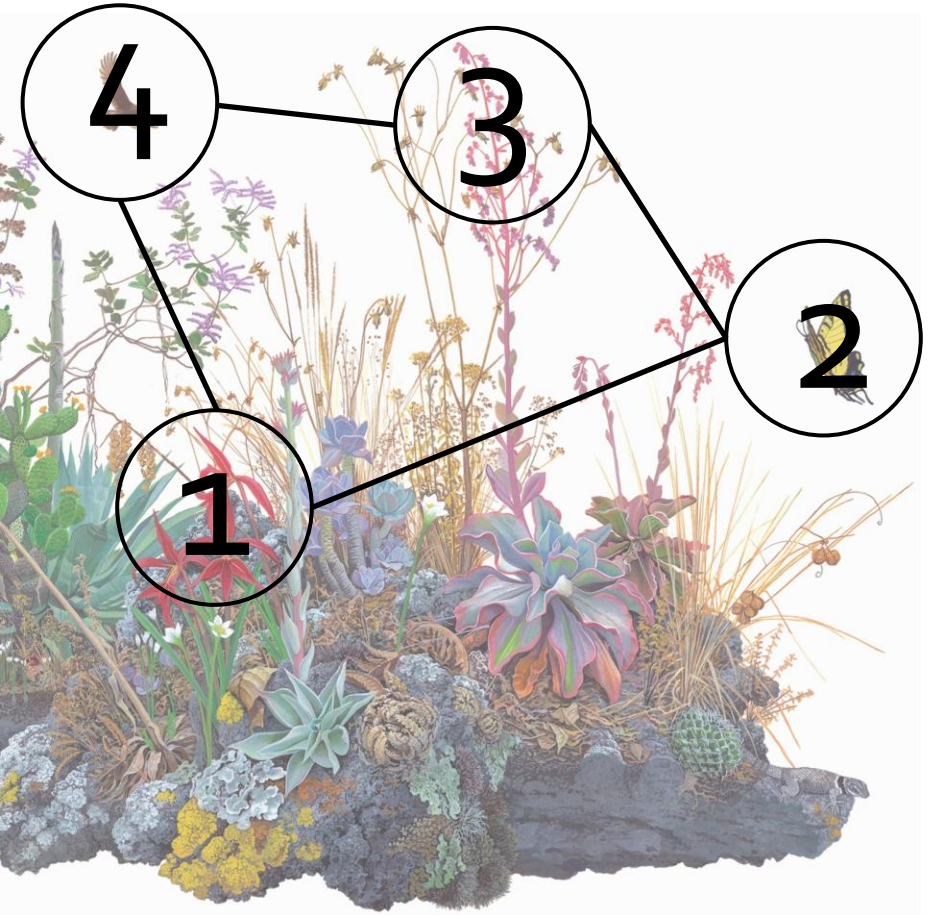
Guimaraes et al. 2017, *Nature*

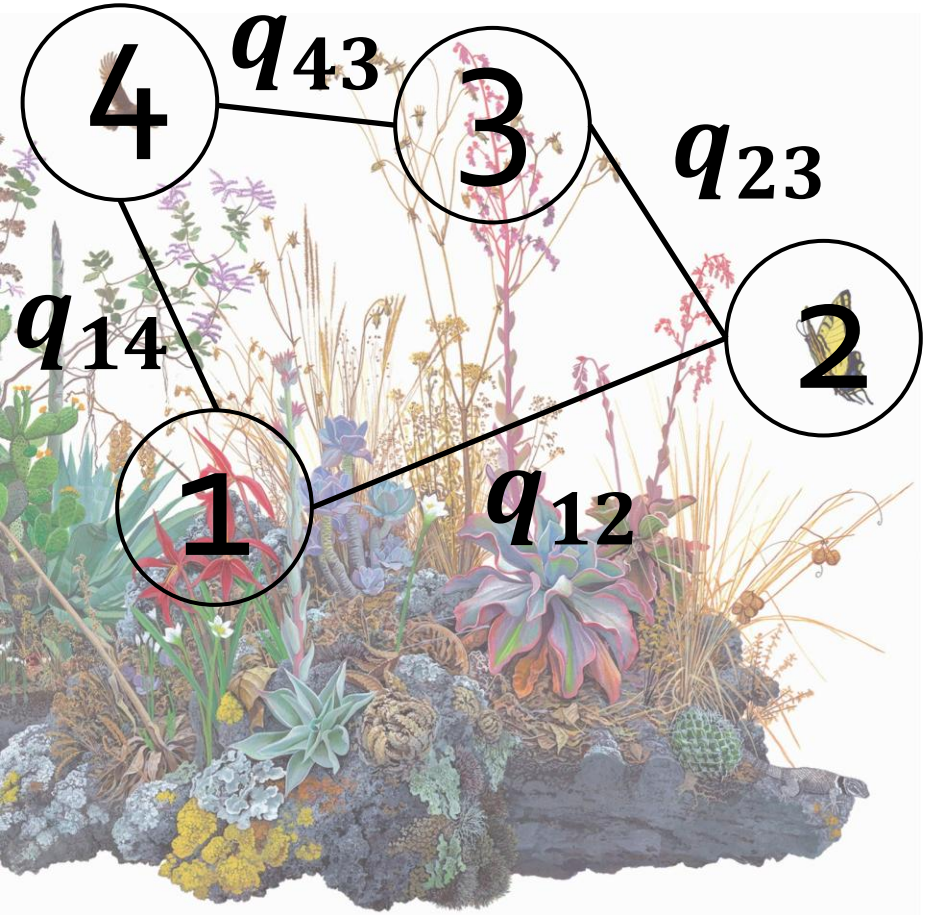


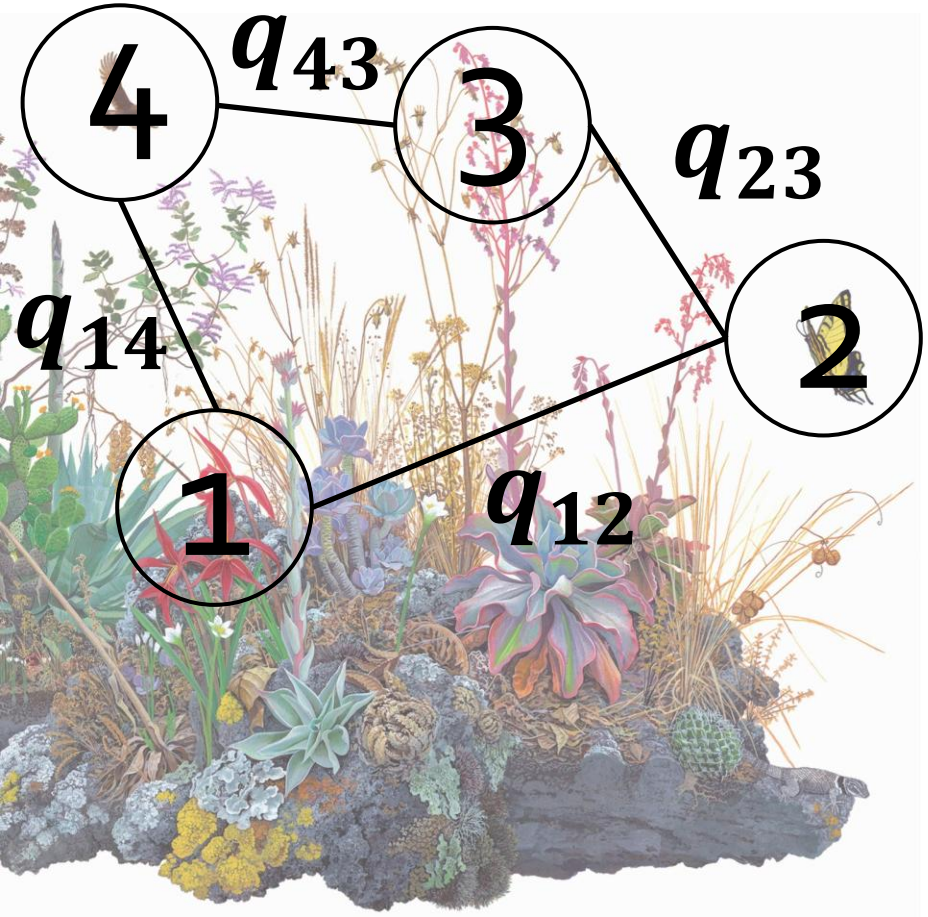


$$(I - Q)^{-1} = Q + Q^2 + Q^3 \ldots$$

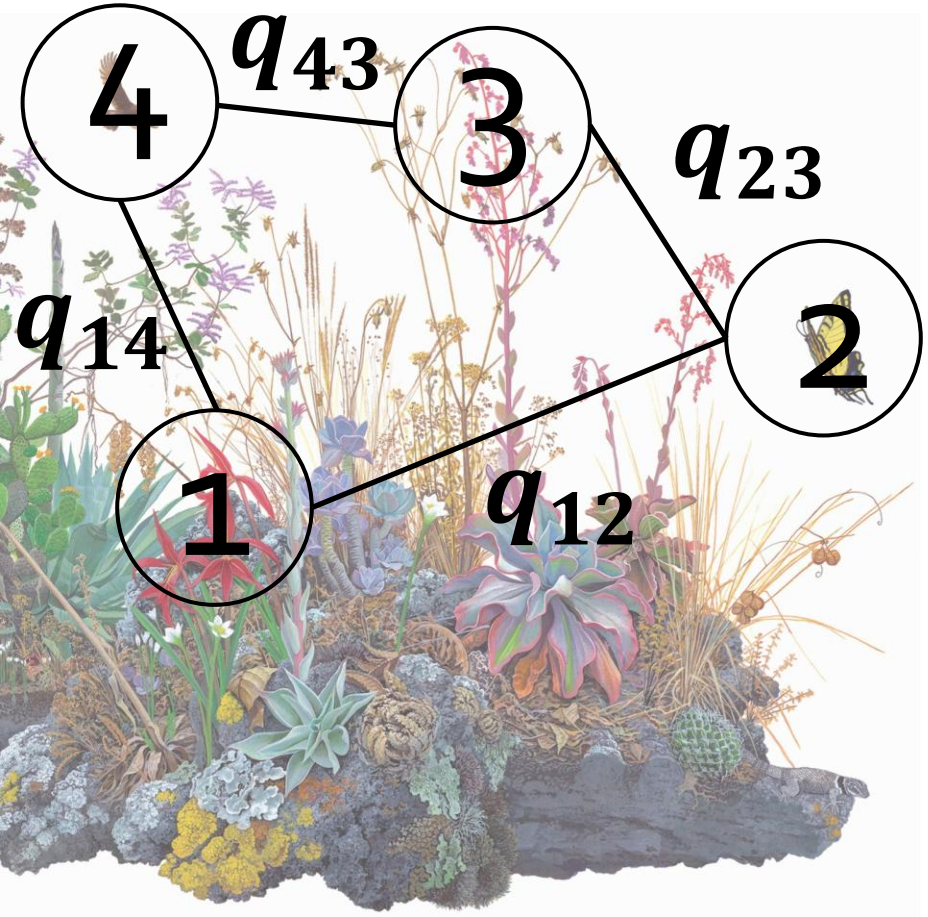
Guimaraes et al. 2017, *Nature*


4
3
2
1


4
q_{43}
3
q_{23}
2
q_{14}
1
q_{12}

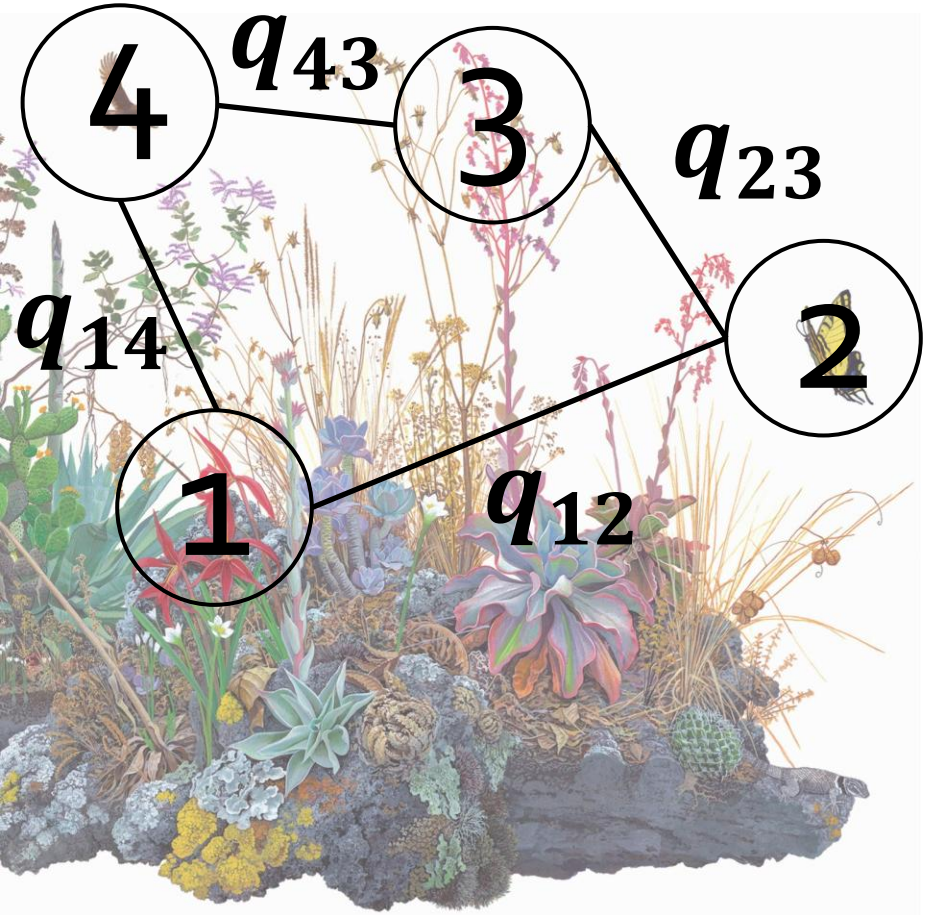


$$Q = \begin{pmatrix} 0 & q_{12} & 0 & q_{14} \\ q_{21} & 0 & q_{23} & 0 \\ 0 & q_{32} & 0 & q_{34} \\ q_{41} & 0 & q_{43} & 0 \end{pmatrix}$$



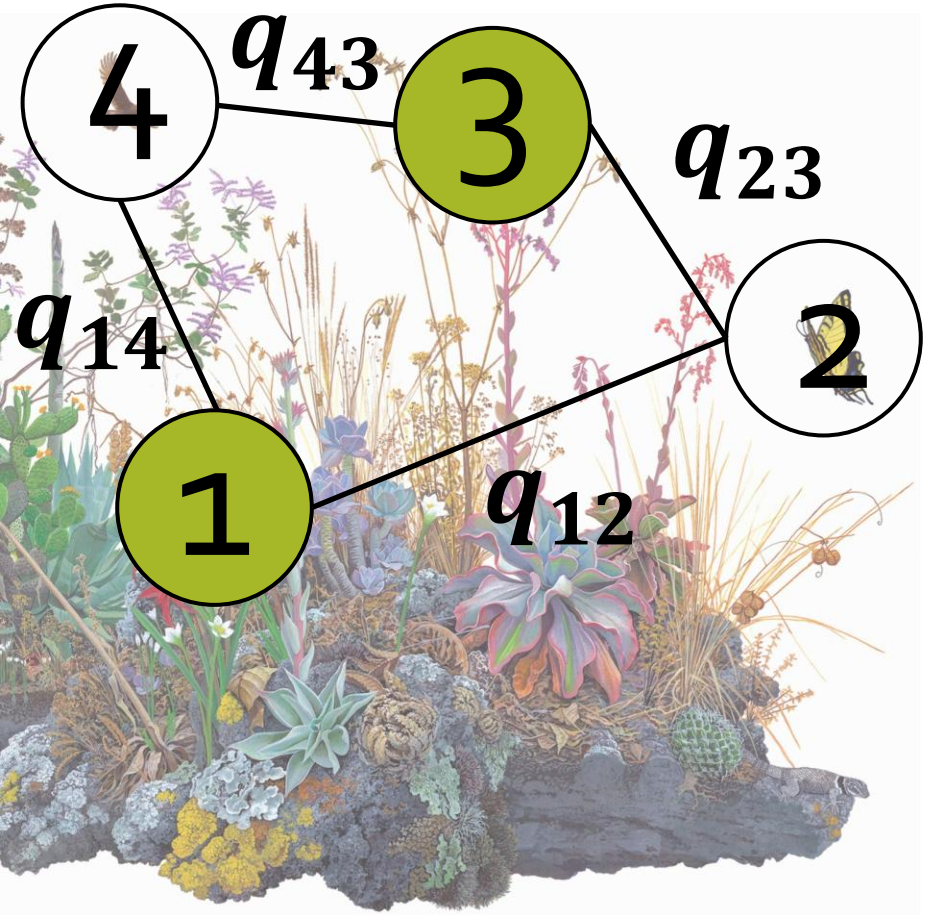
$$Q = \begin{pmatrix} 0 & q_{12} & 0 & q_{14} \\ q_{21} & 0 & q_{23} & 0 \\ 0 & q_{32} & 0 & q_{34} \\ q_{41} & 0 & q_{43} & 0 \end{pmatrix}$$

Matrix Q = Direct evolutionary effects



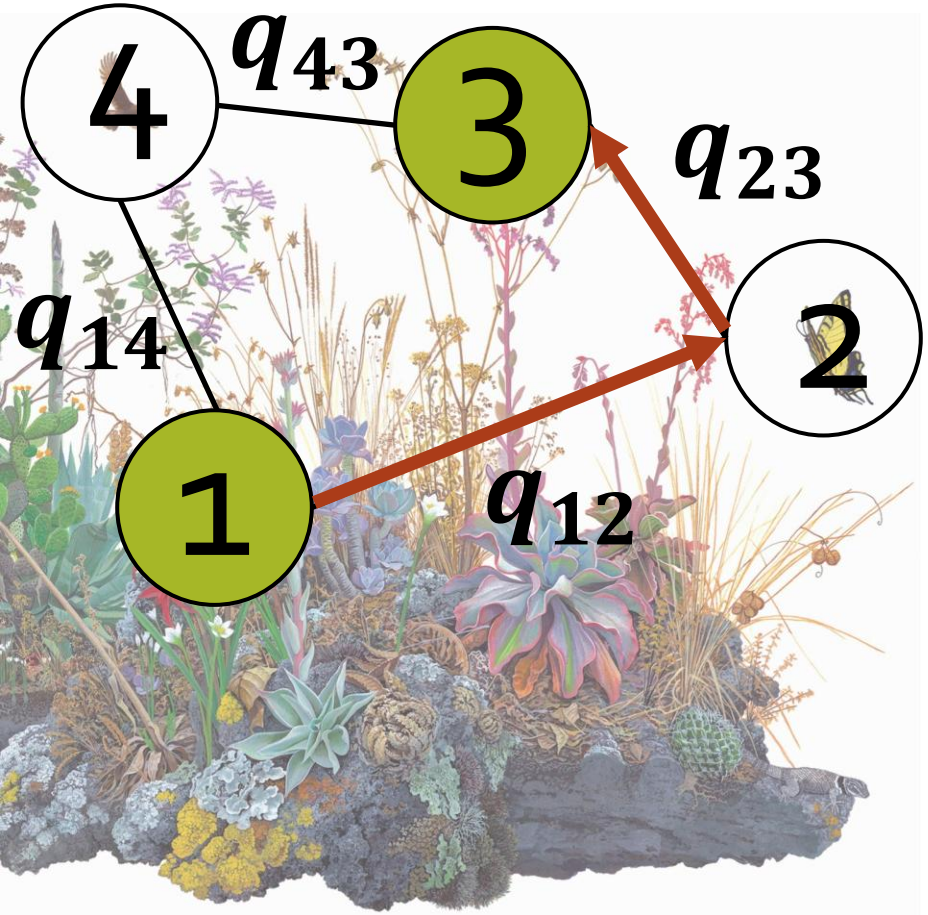
$$Q^2 = ?$$

What is the meaning of Q^2?



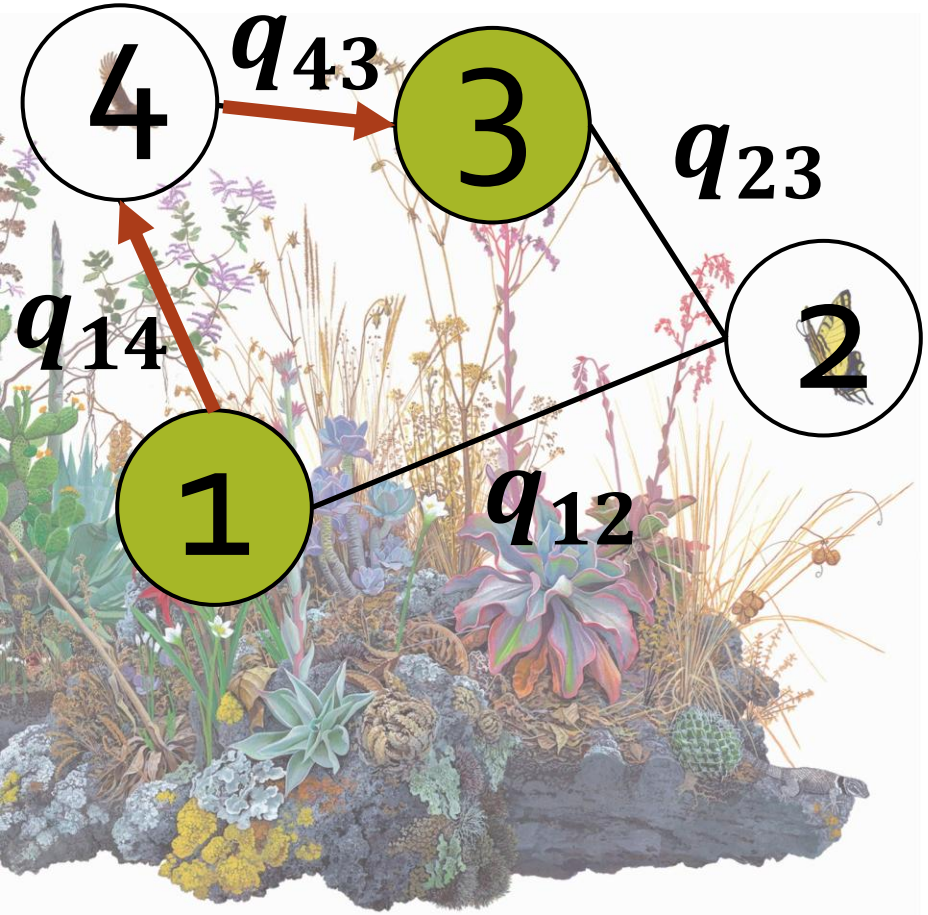
$$Q^2 = ?$$

Q^2 contains the evolutionary effects that come from pathways of length 2



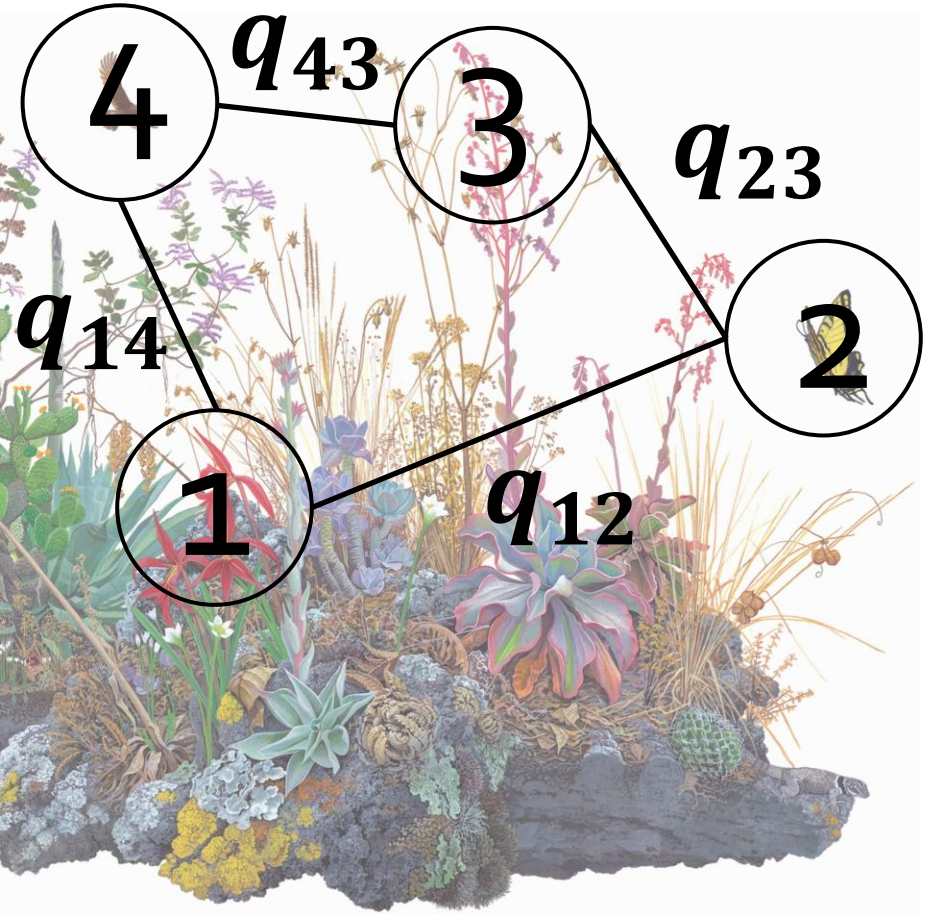
$$Q^2 = ?$$

Q^2 contains the evolutionary effects that come from pathways of length 2



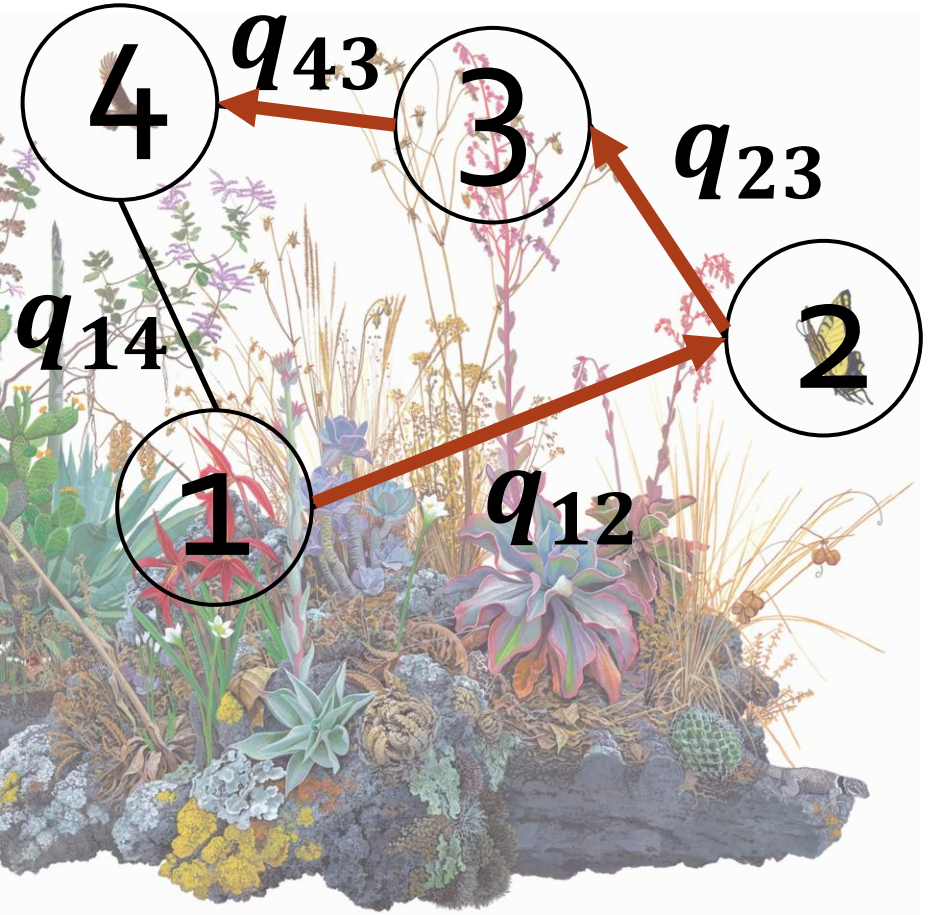
$$Q^2 = ?$$

Q^2 contains the evolutionary effects that come from pathways of length 2



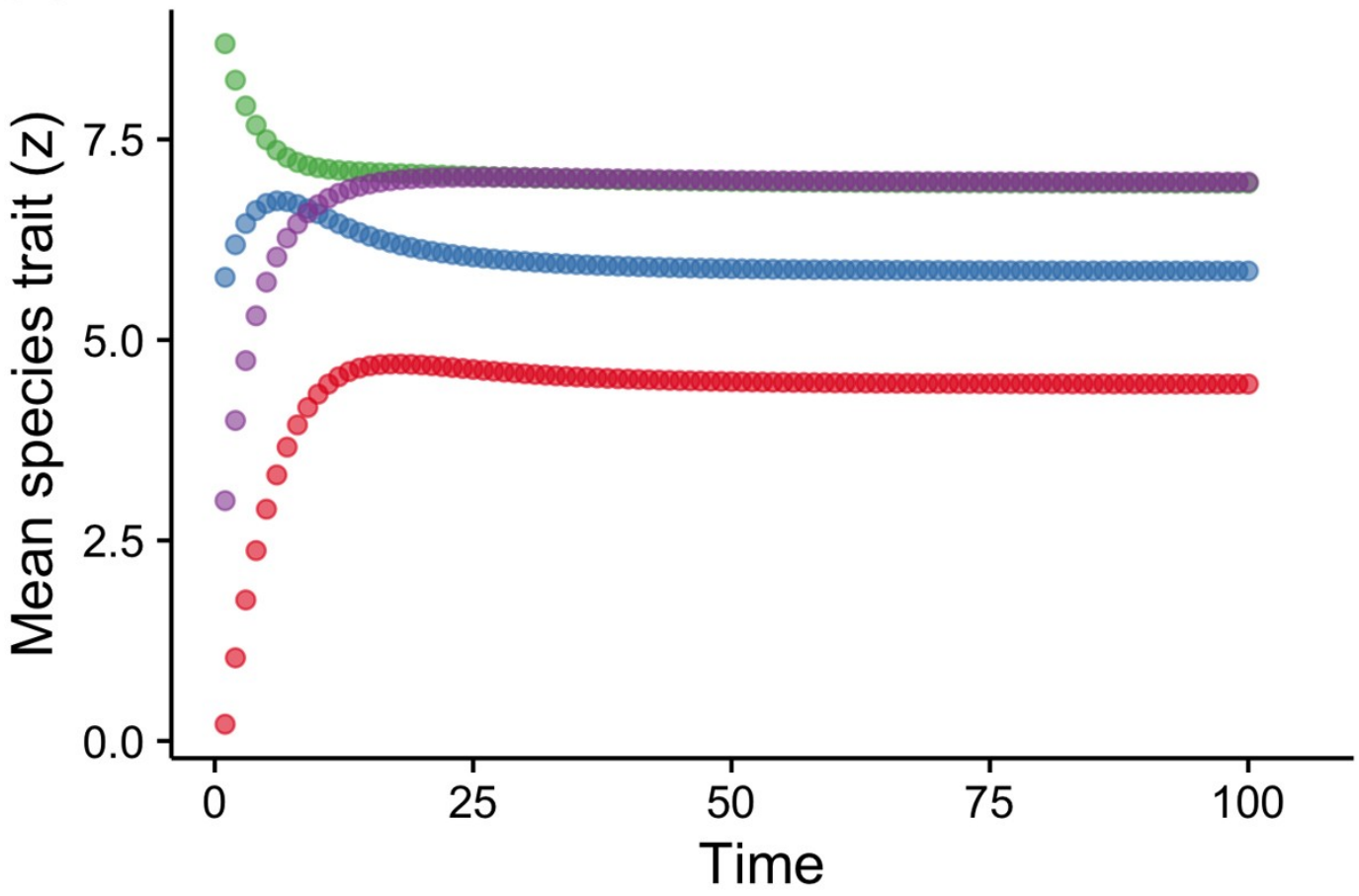
$$Q^3 = ?$$

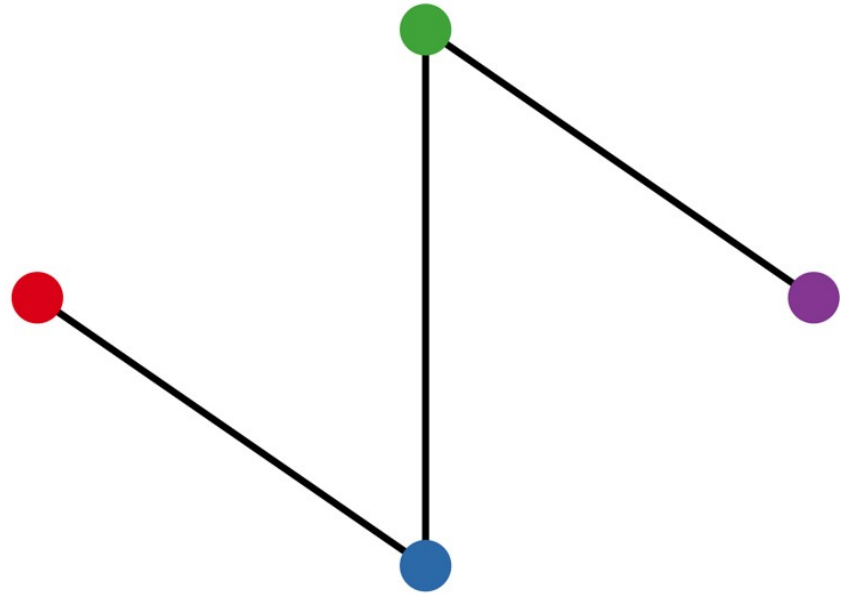
What about Q^3?



$$Q^3 = ?$$

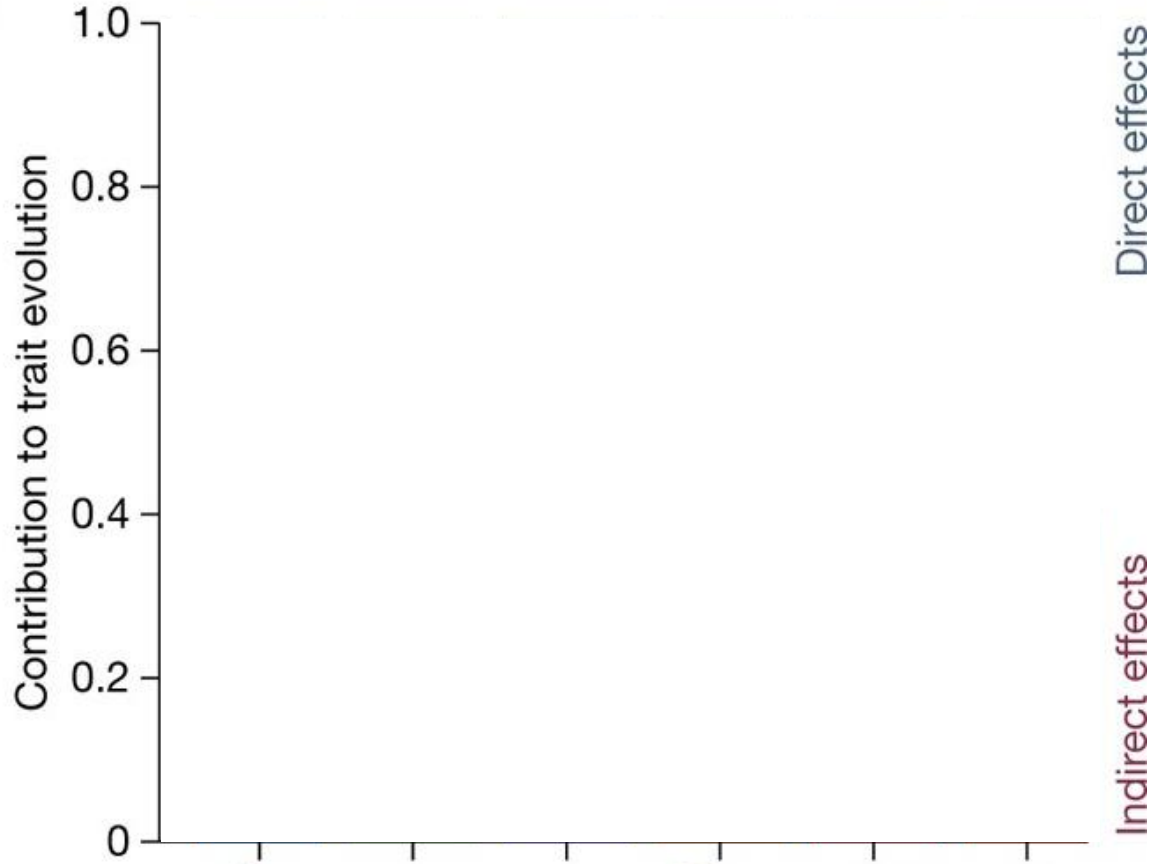
Q^3 contains the evolutionary effects that come from pathways of length 3!



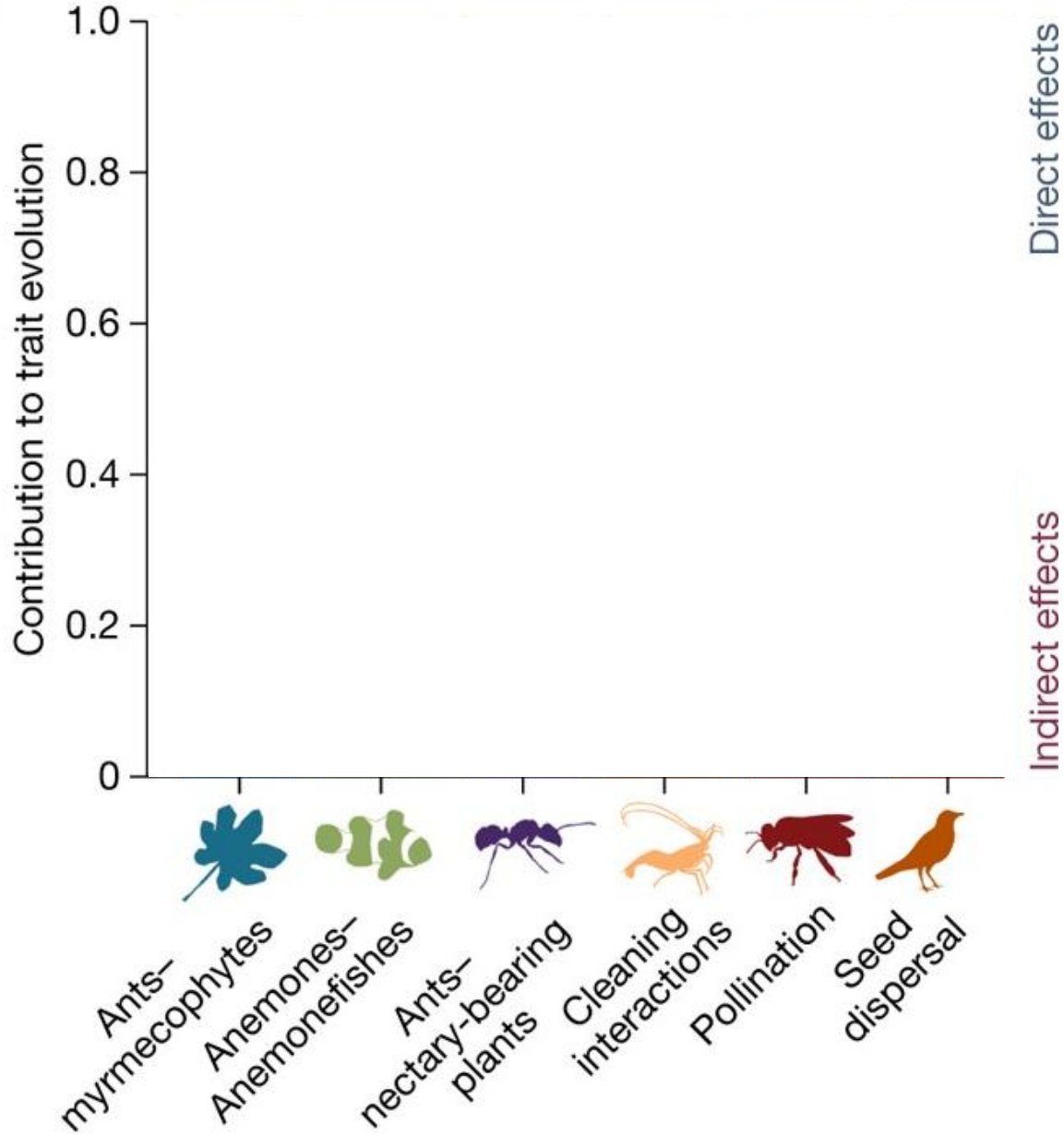


$$(I - Q)^{-1} = Q + Q^2 + Q^3 \ldots$$

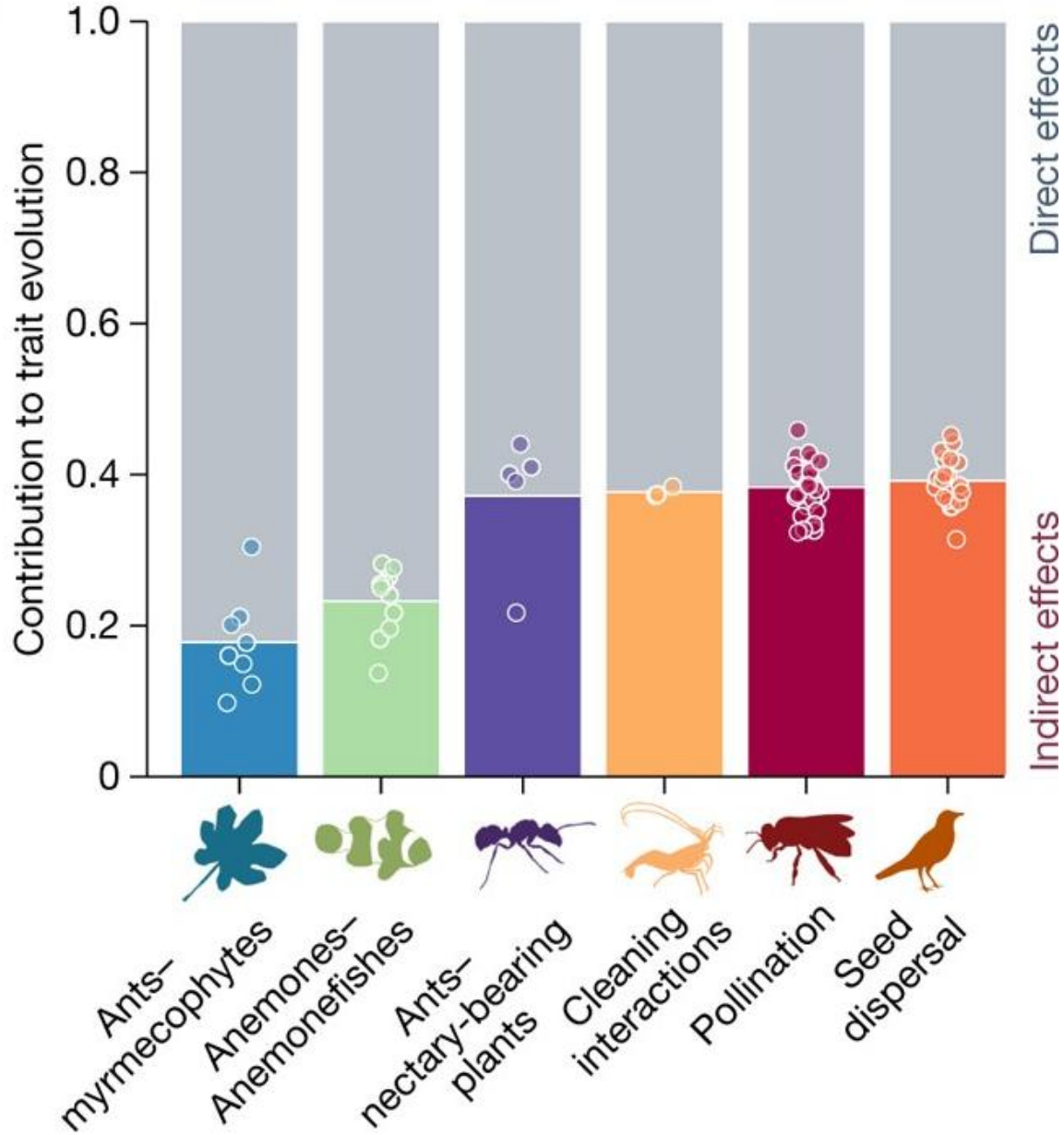
Guimaraes et al. 2017, *Nature*



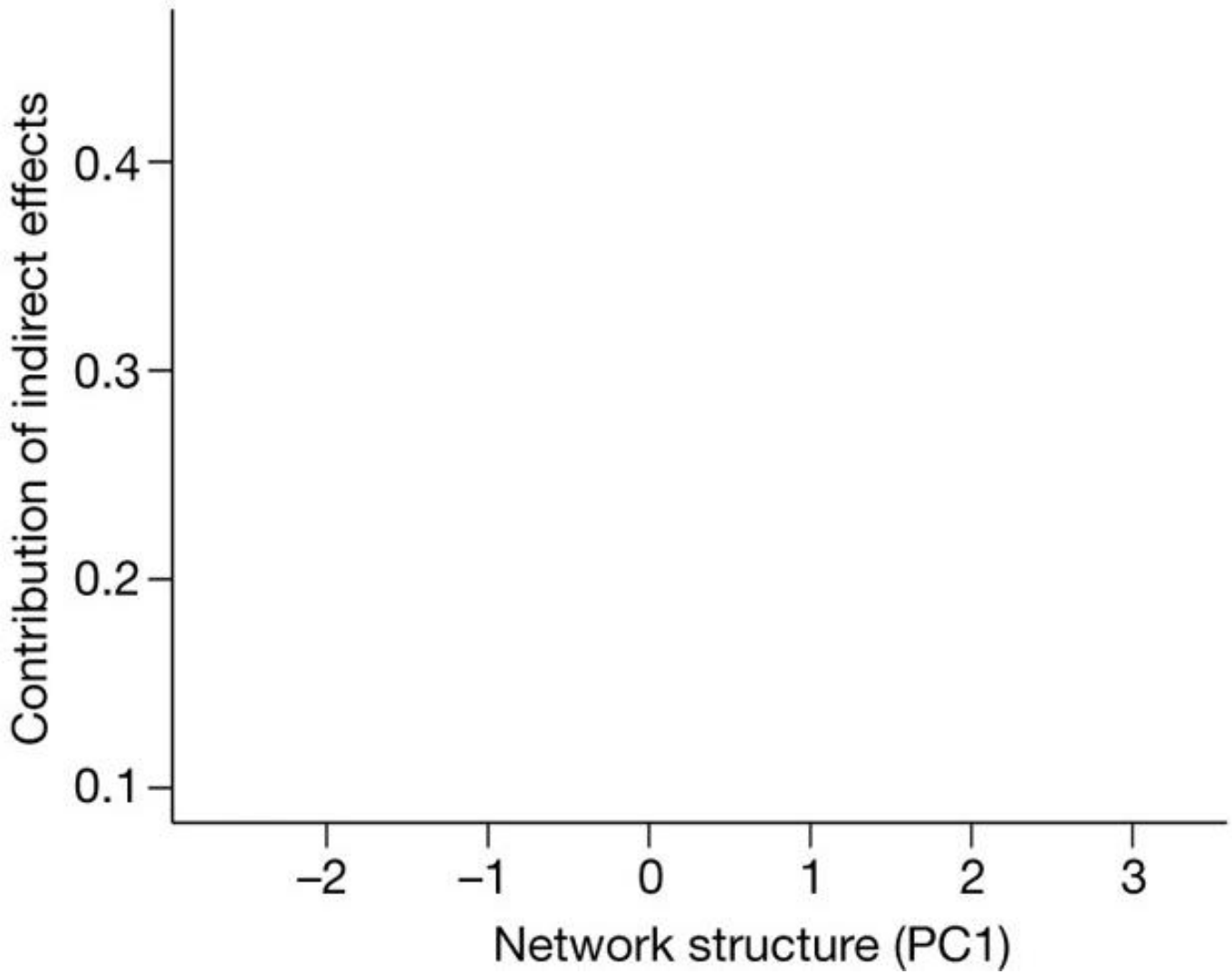
Guimaraes et al. 2017, *Nature*



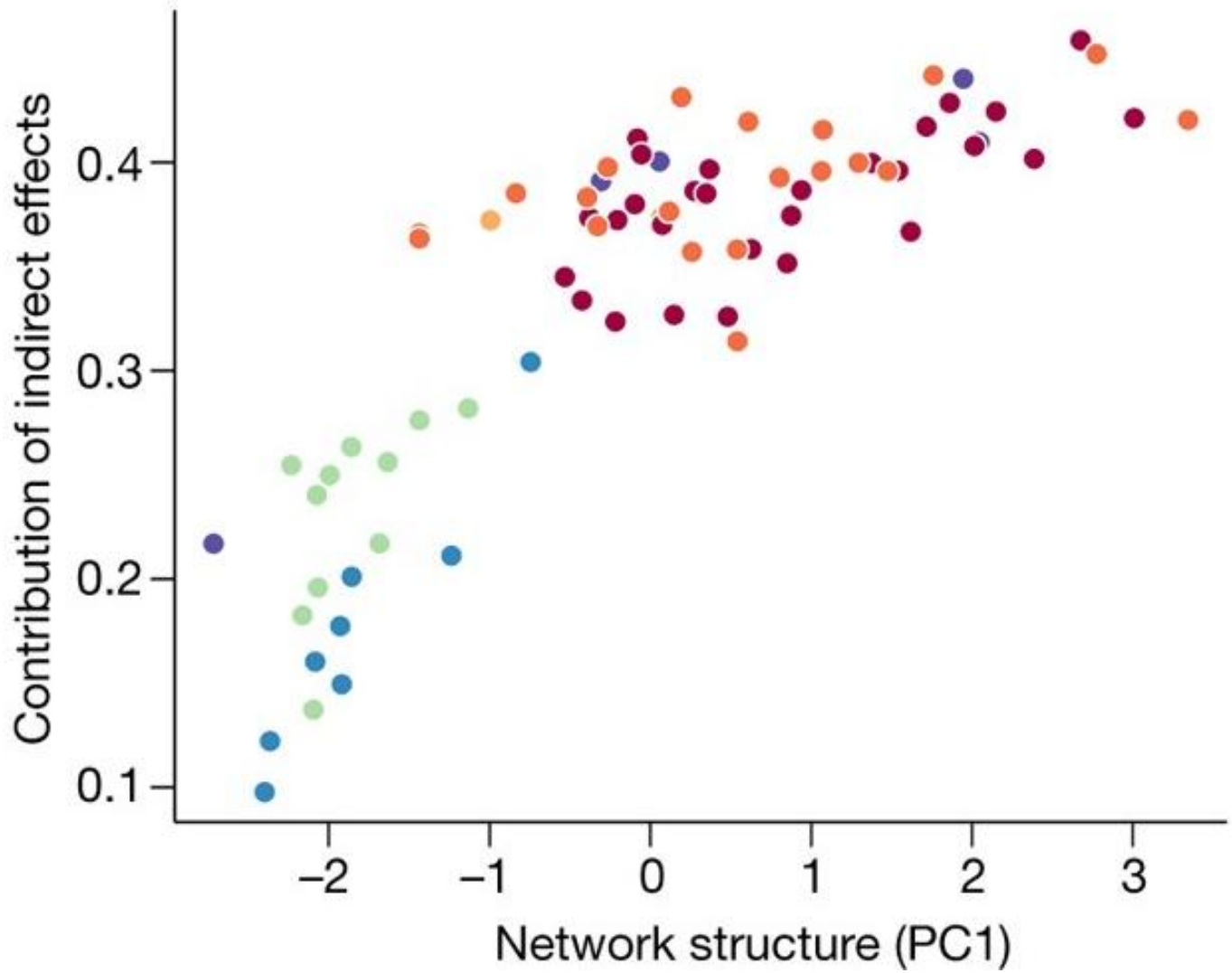
Guimaraes et al. 2017, *Nature*



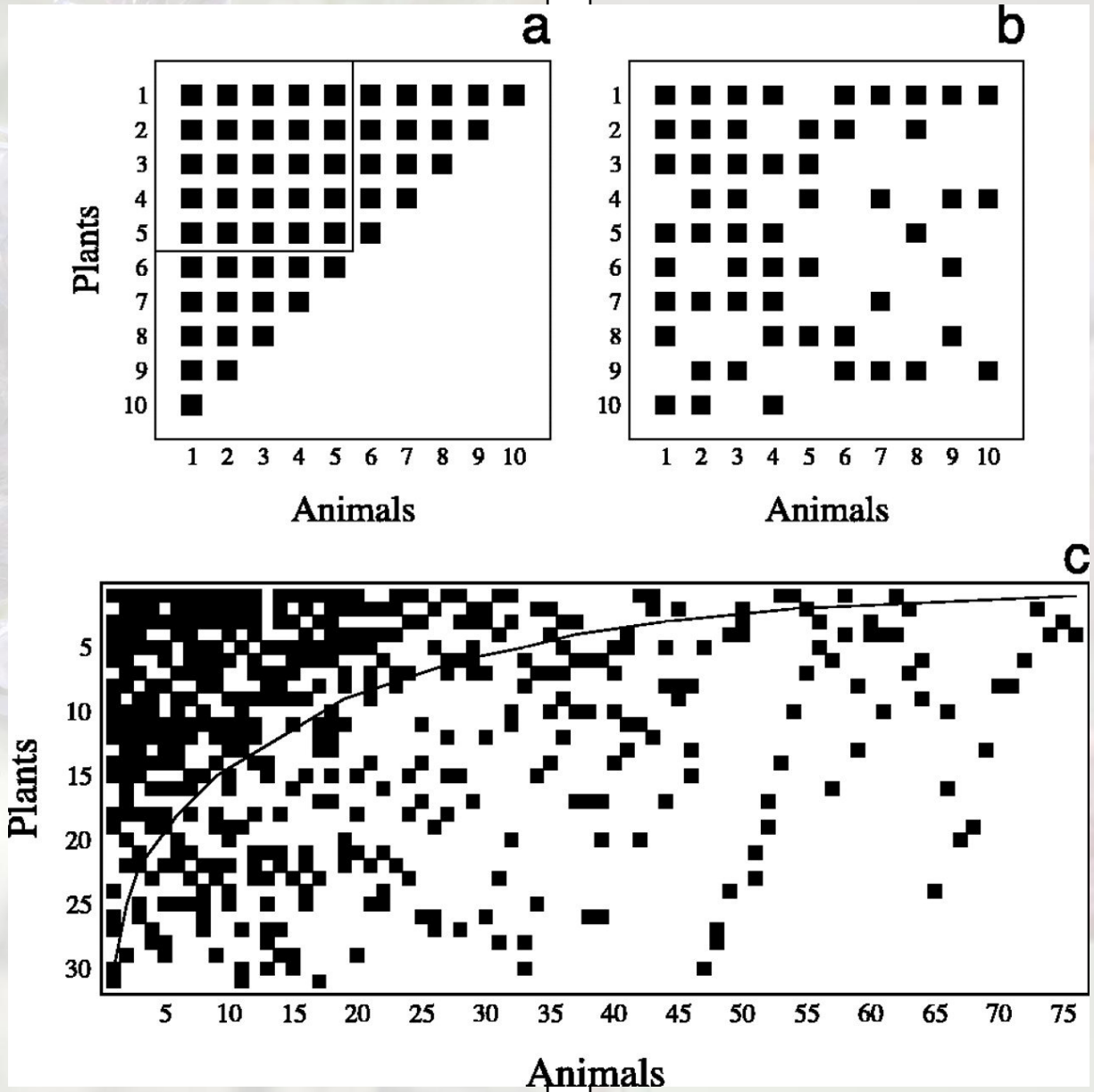
Guimaraes et al. 2017, *Nature*



Guimaraes et al. 2017, *Nature*

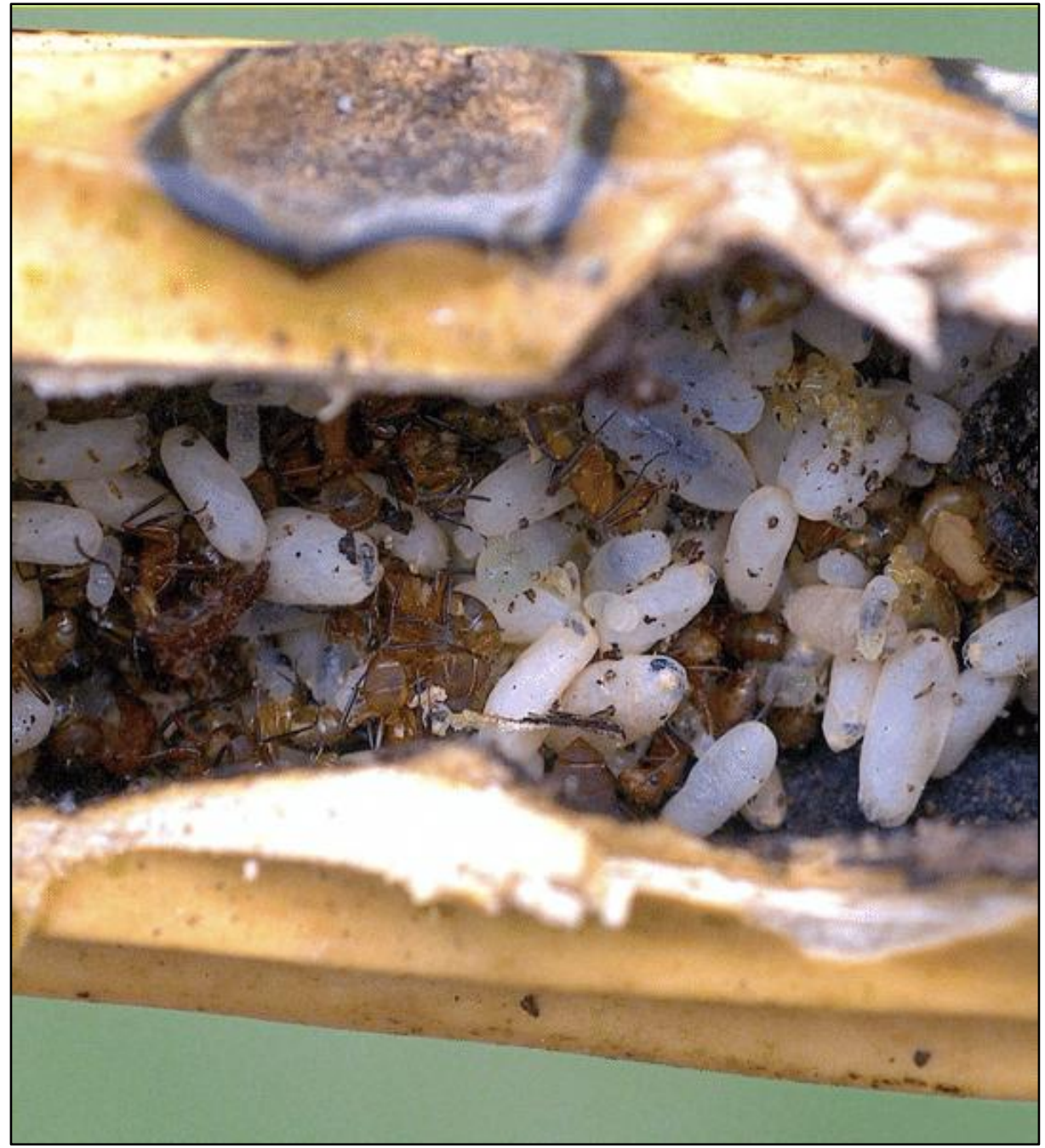


Guimaraes et al. 2017, *Nature*



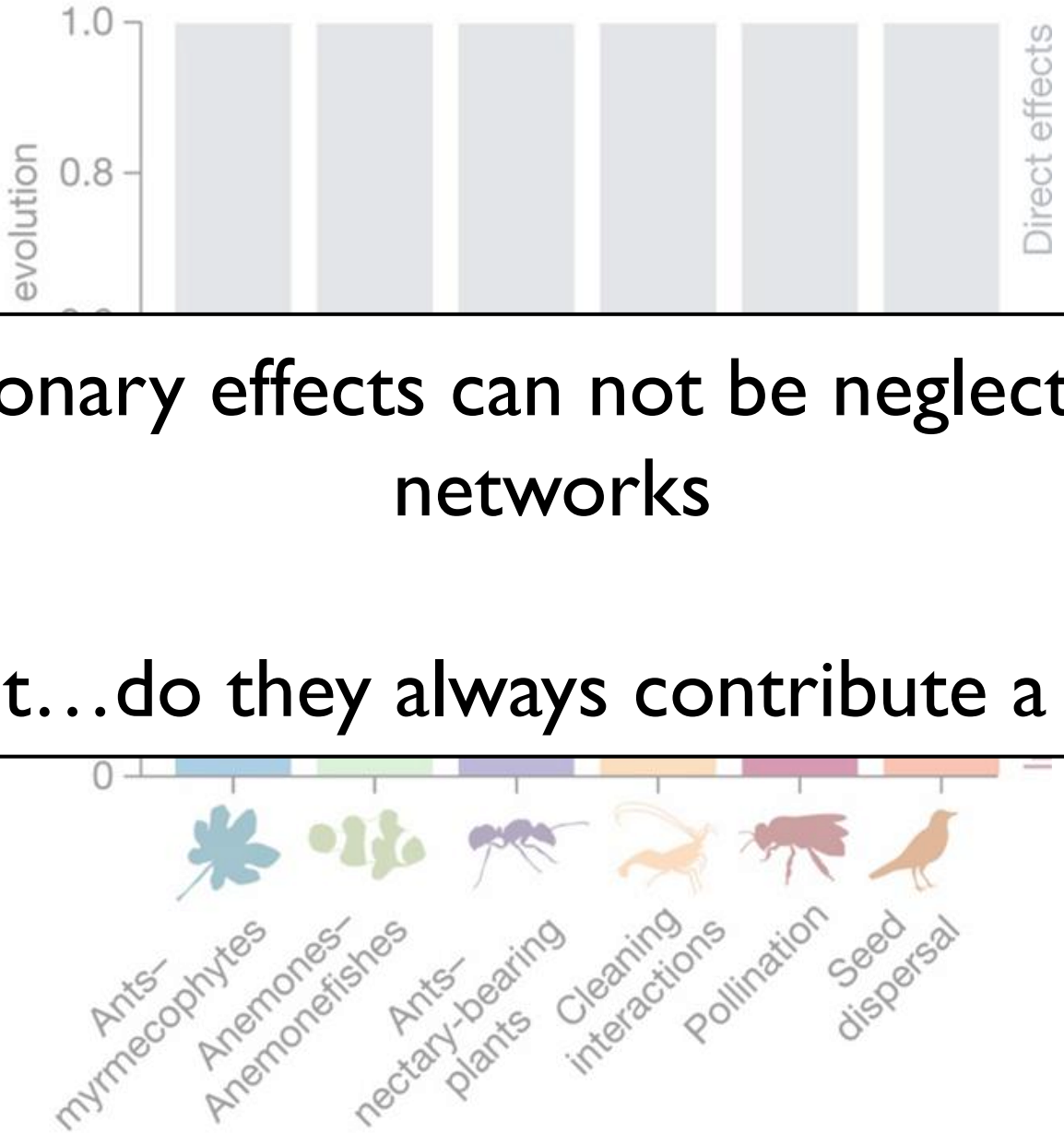
(Bascompte *et al.* 2003)


00129405 © Mark Moffett / Minden / naturepl.com



MYRMECOPHYTES & ANTS	*Cecropia purpuracens*	*Cecropia concolor*	*Cecropia distachya*	*Cecropia ficifolia*	*Pouruma heterophylla*	*Hirtella myrmecophila*	*Hirtella physophora*	*Duroia saccifera*	*Cordia nodosa*	*Cordia aff. nodosa*	*Tococa bullifera*	*Maieta guianensis*	*Maieta poeppiggi*	*Tachigali polyphylla*	*Tachigali myrmecophila*	*Amaioua aff. guianensis*
Camponotus balzanii	11															
Azteca alfari	1															
Azteca isthmica	1	1	1	1												
Azteca aff. isthmica	1			2												
Allomerus D					23											
Allomerus prancei							5									
Allomerus aff. octoarticulata						3	70	27								
Solenops A							3	1								
Allomerus auripunctata								2		2						
Crematogaster B								1	1	1						
Azteca HC										3						
Azteca G										24	11	2				
Crematogaster D										3	2					
Azteca CO										1						
Pheidole minutula											1	93	28			
Crematogaster A							1				7	7	1			
Azteca TO											1					
Crematogaster C											3		3			
Azteca schummani														2	1	
Pseudomyrmex nigrescens														7	16	
Pseudomyrmex concolor														16	18	
Azteca D															1	
Azteca polymorpha															2	
Crematogaster E										1					1	
Azteca Q																3
Unoccupied plants	14	0	0	0	0	0	3	8	0	31	0	5	5	6	5	0

(Fonseca & Ganade *1996*)



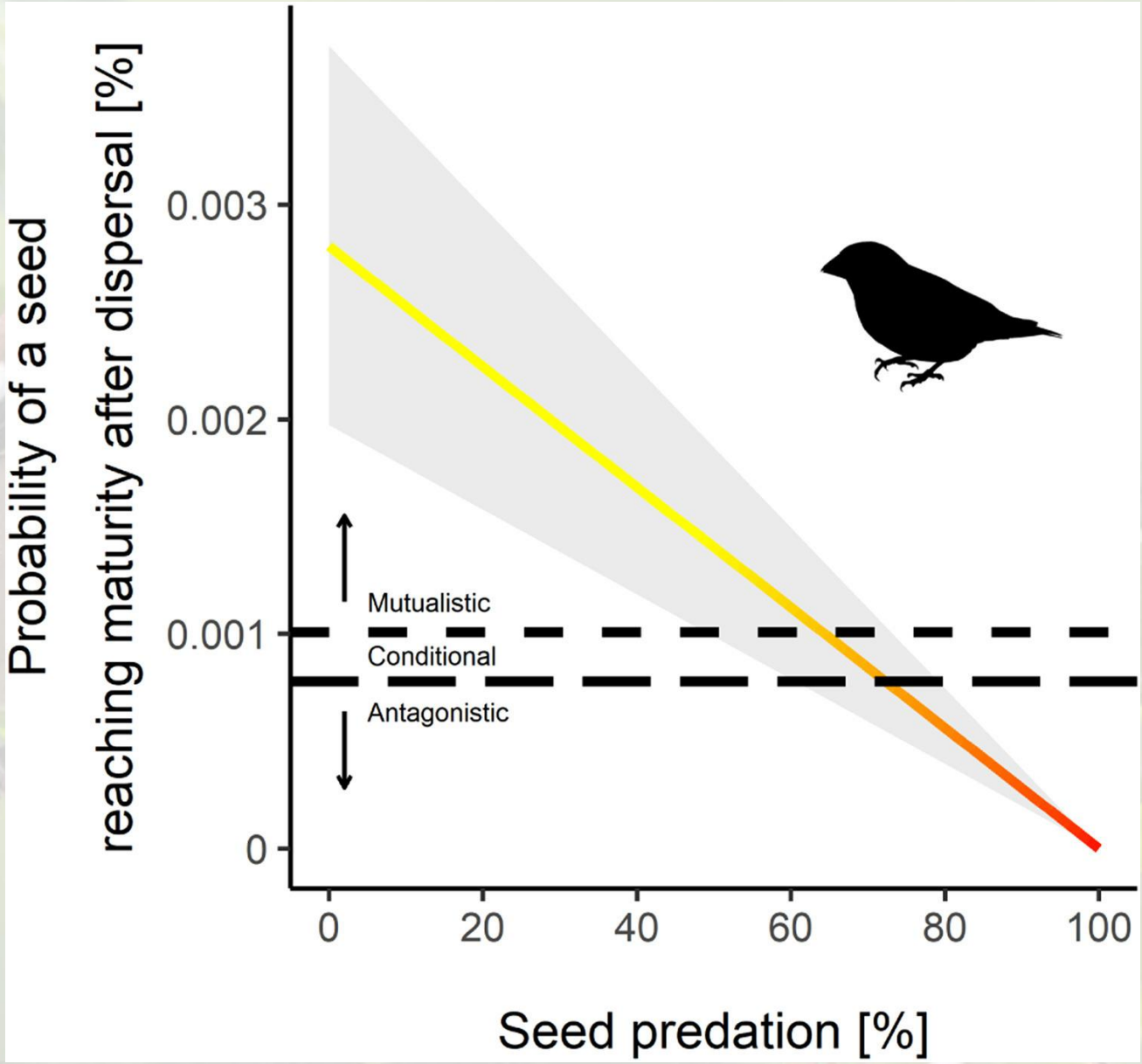
Indirect evolutionary effects can not be neglected in mutualistic networks

But…do they always contribute a lot?

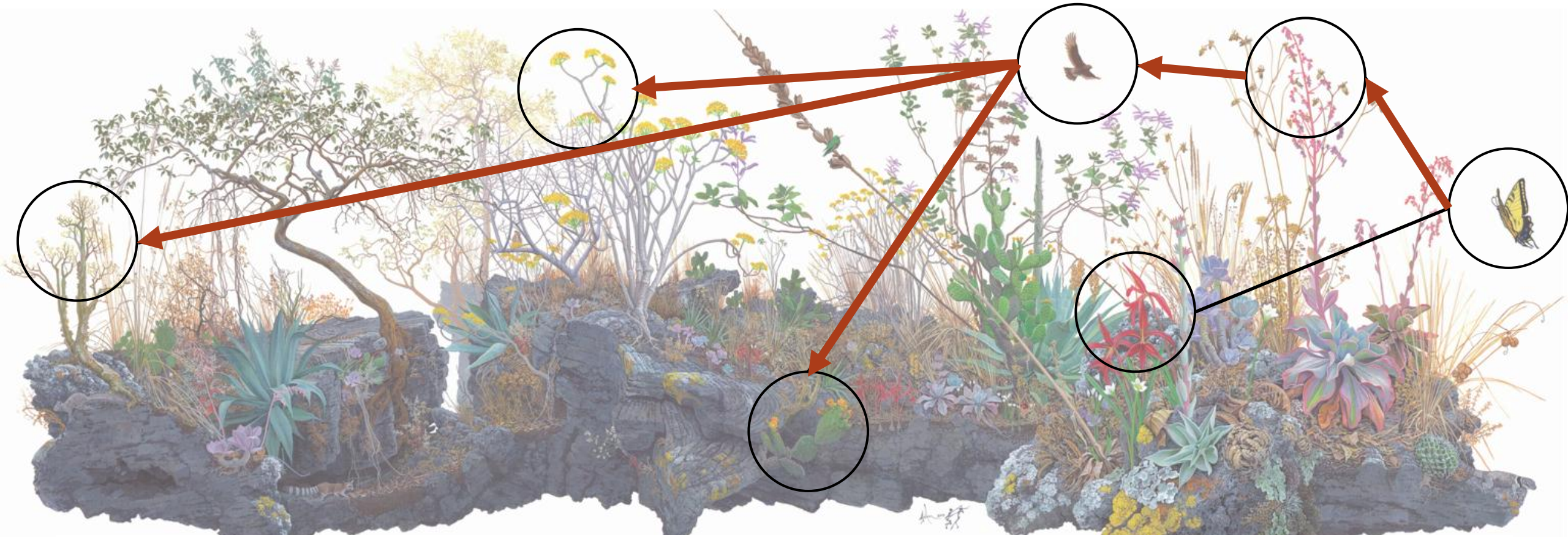
Guimaraes et al. 2017, *Nature*


(Rehling et al. 2024)

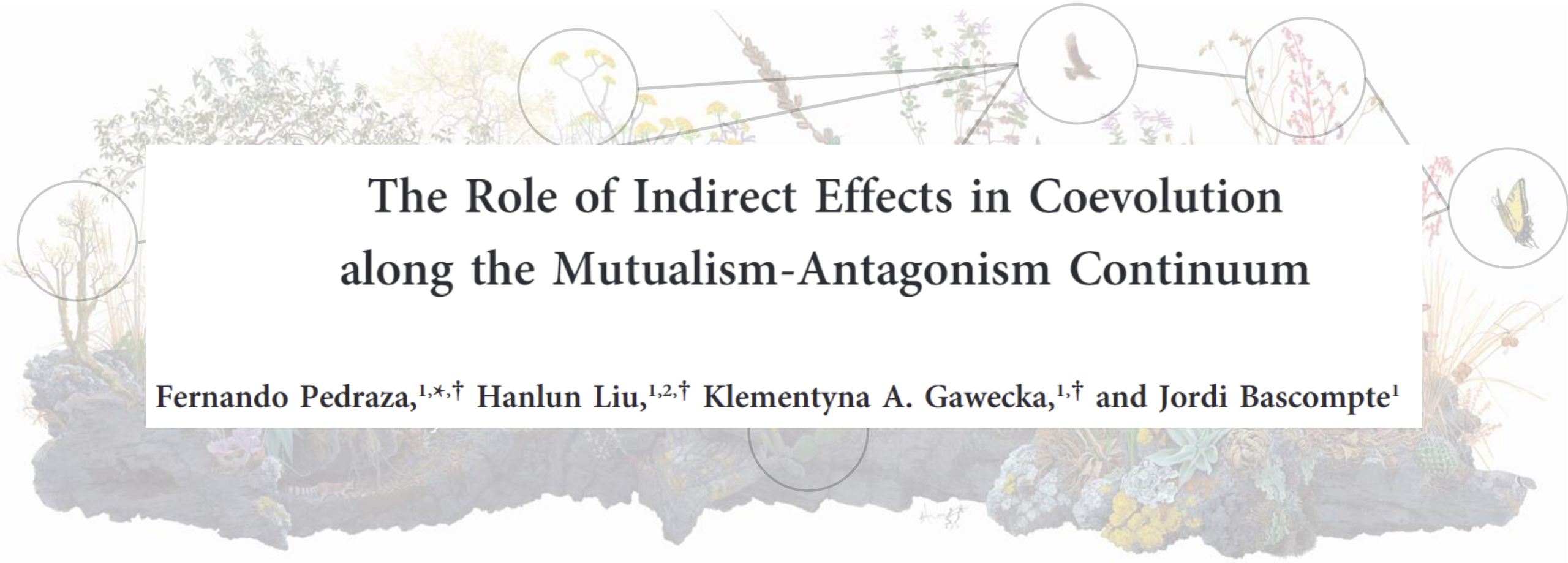
(Rehling et al. 2024)



(Art by Aslam Narváez)

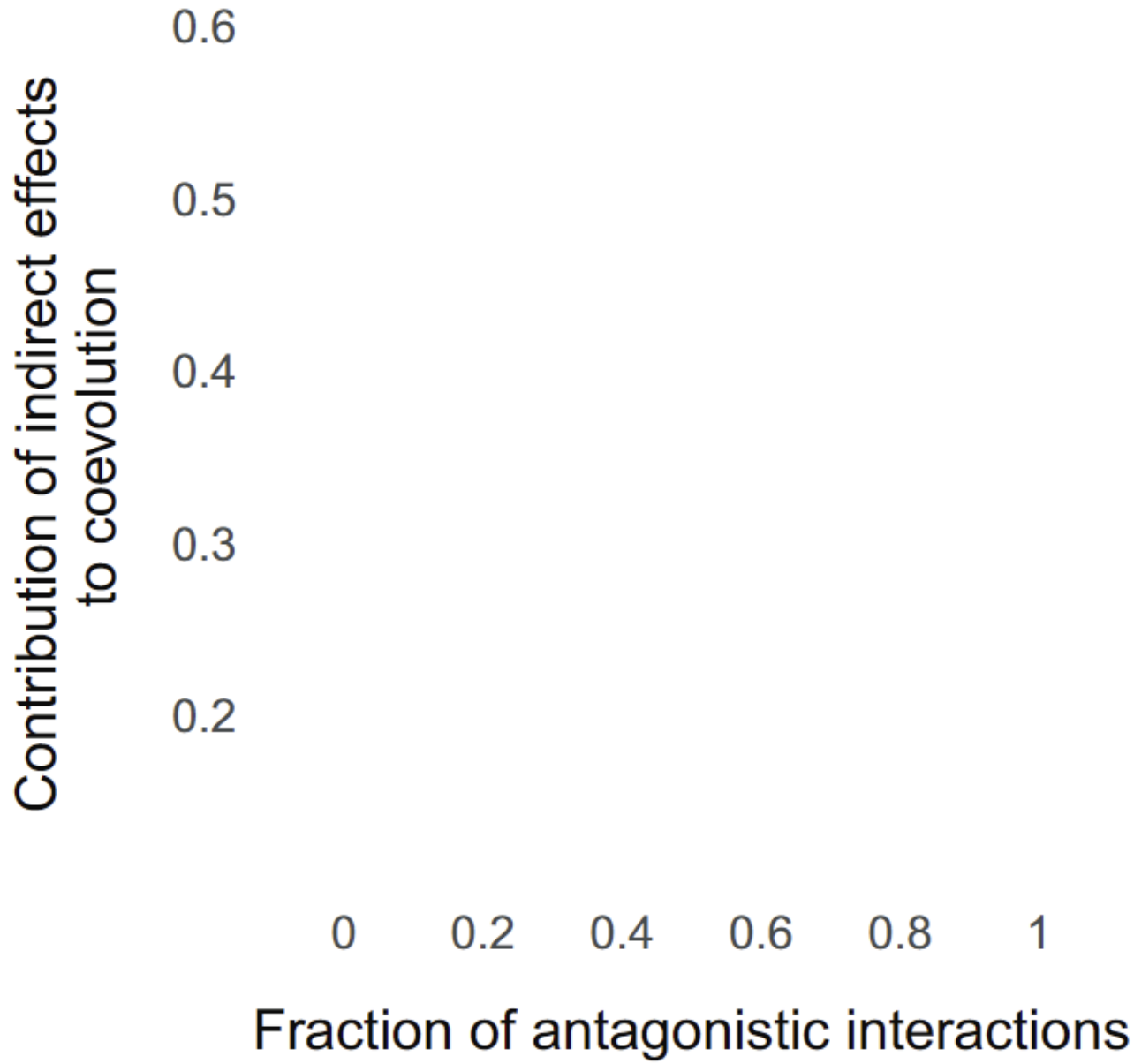


How much indirect evolutionary effects contribute along this mutualism-antagonism continuum?

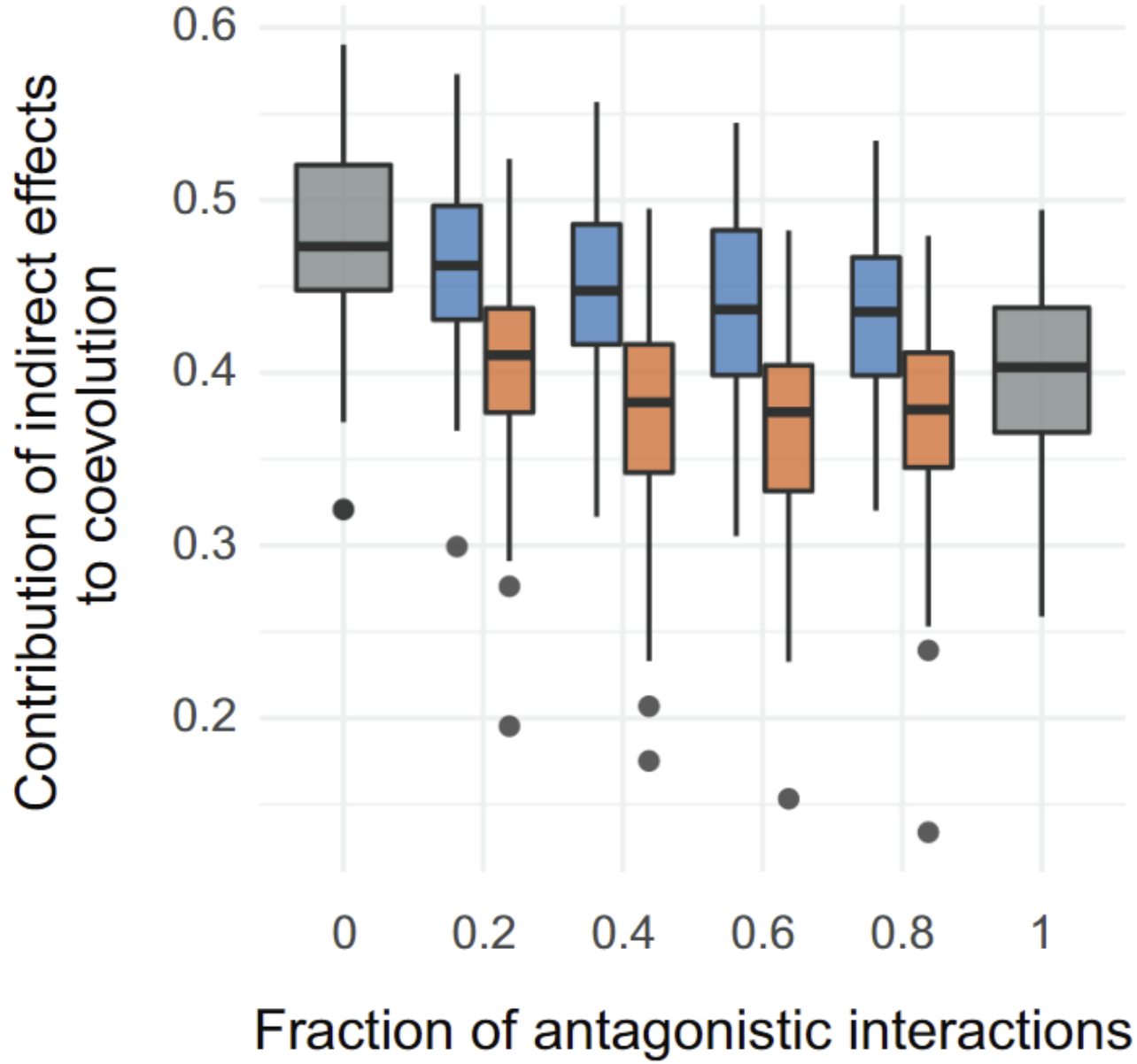


The Role of Indirect Effects in Coevolution along the Mutualism-Antagonism Continuum

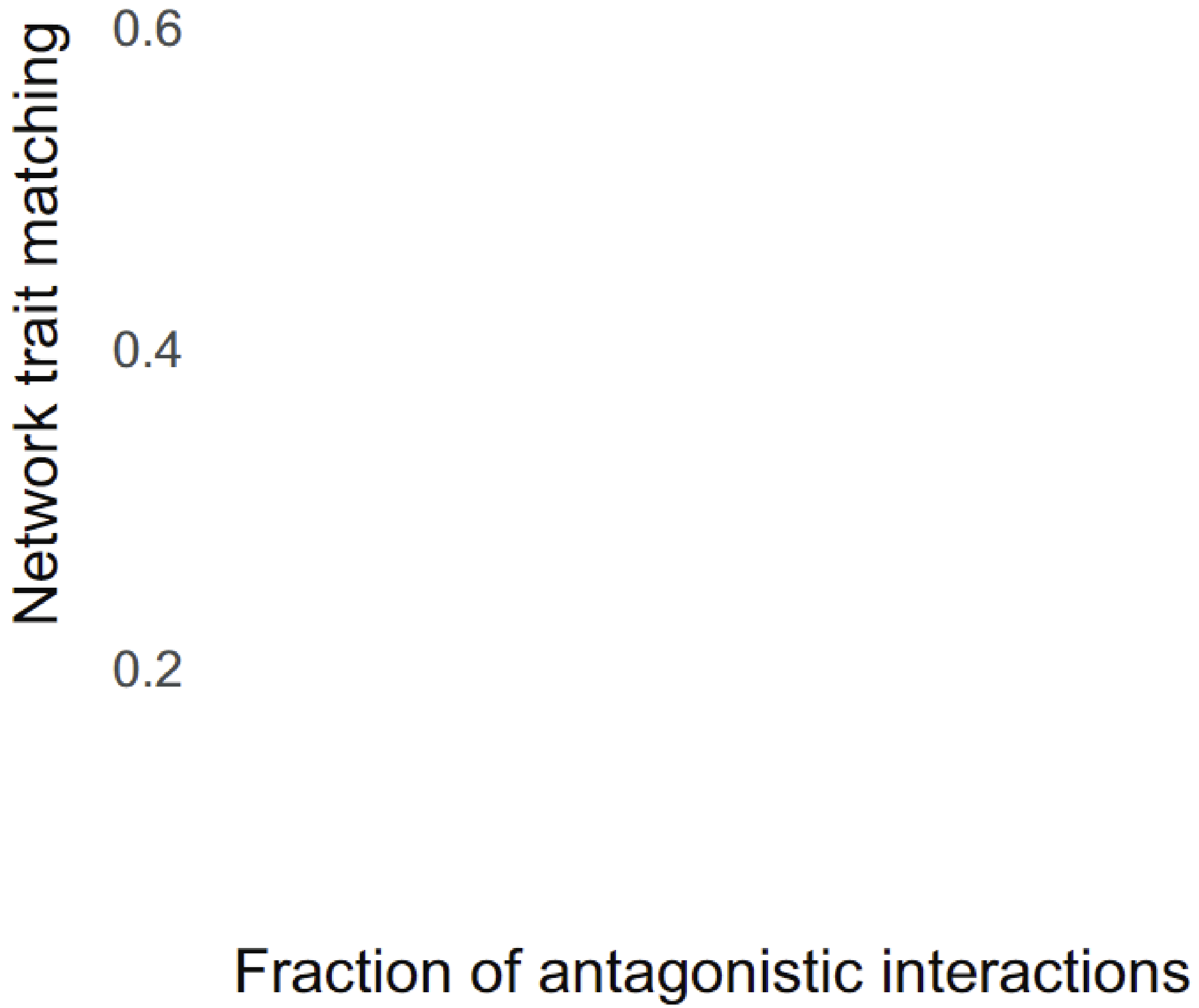
Fernando Pedraza,[1,*,†] Hanlun Liu,[1,2,†] Klementyna A. Gawecka,[1,†] and Jordi Bascompte[1]



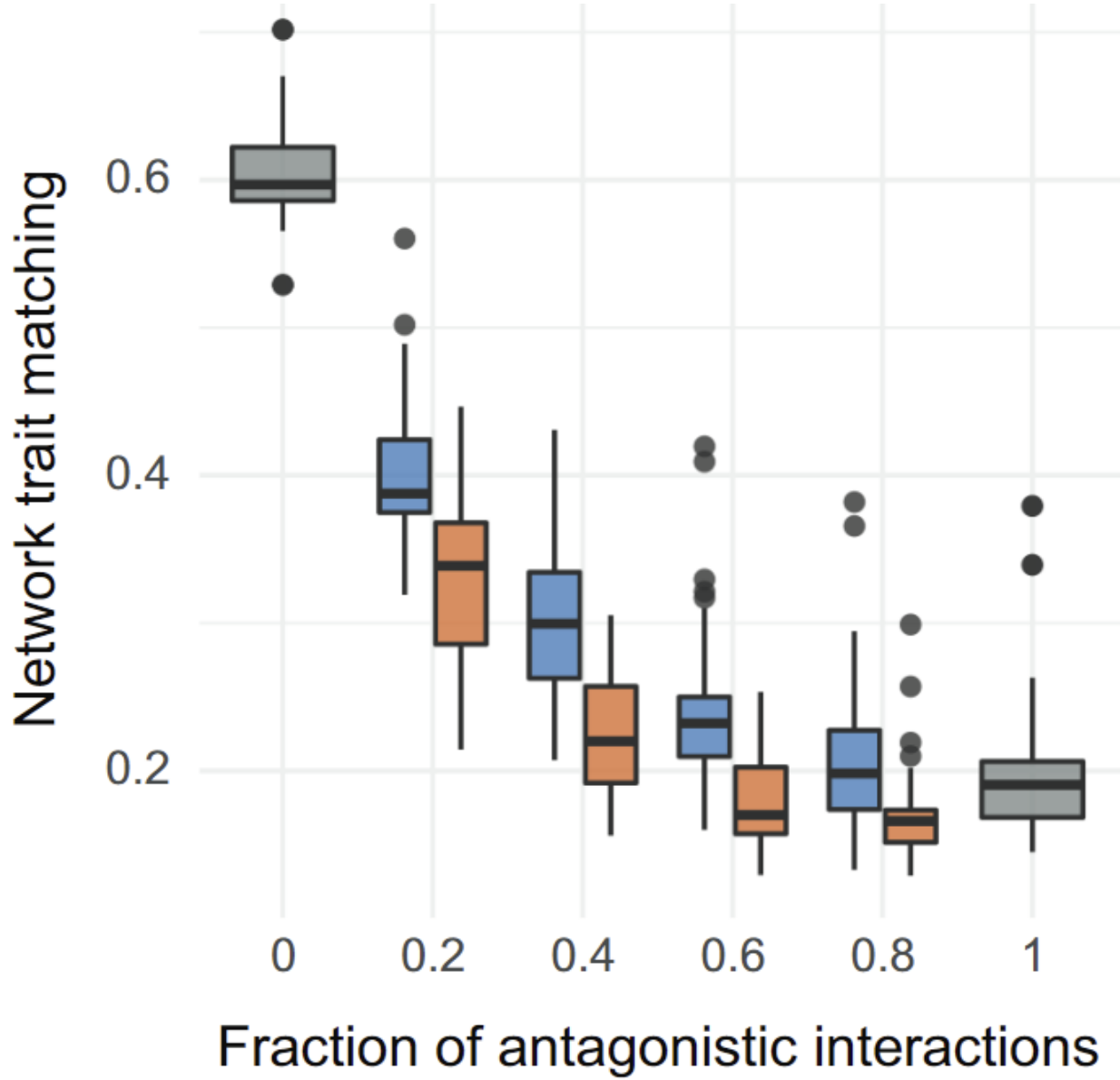
Pedraza et al. 2023, *Am. Nat.*



Pedraza et al. 2023, *Am. Nat.*



Network trait matching
0.6
0.4
0.2
Fraction of antagonistic interactions

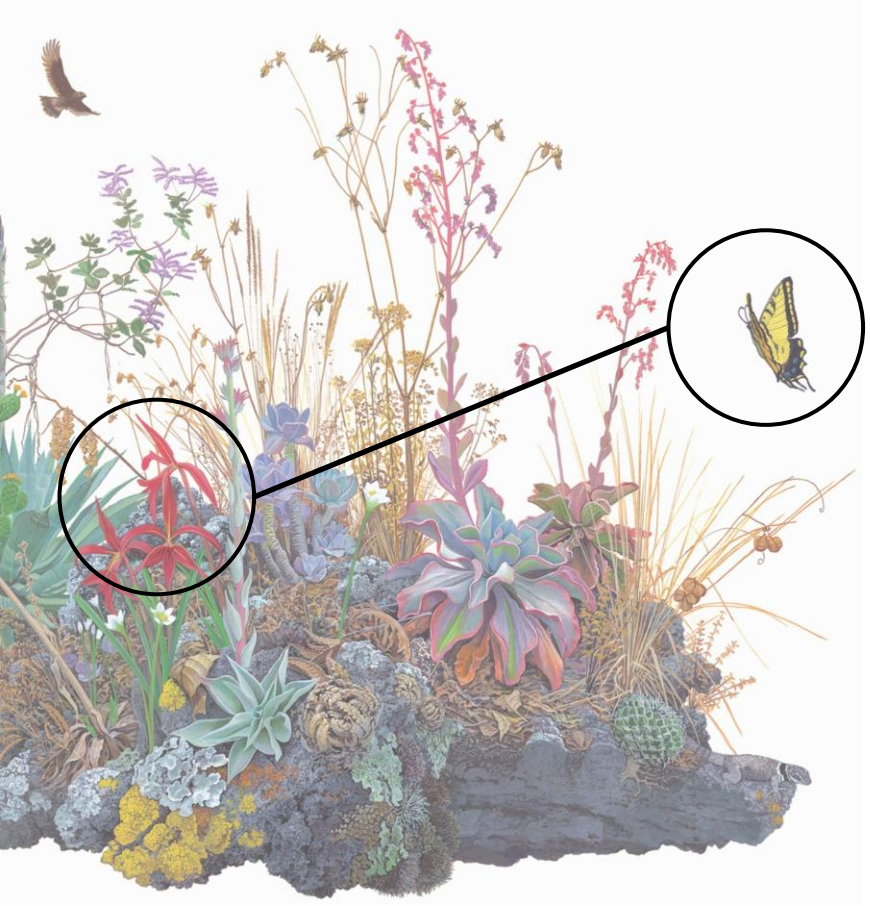

Network trait matching
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1
Fraction of antagonistic interactions

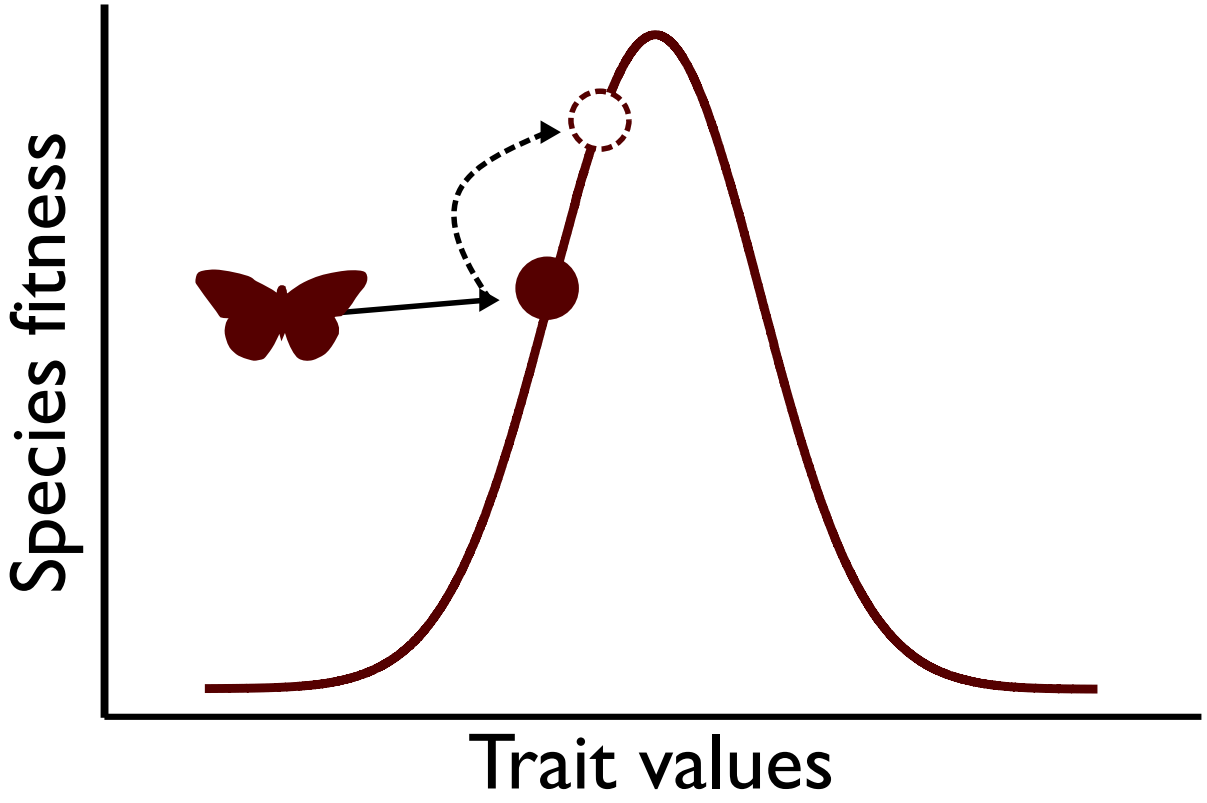
The contribution of indirect effects decreases as we move from mutualisms to antagonisms

Indirect effects shape trait matching at the network scale

But what about the adaptations of each species?

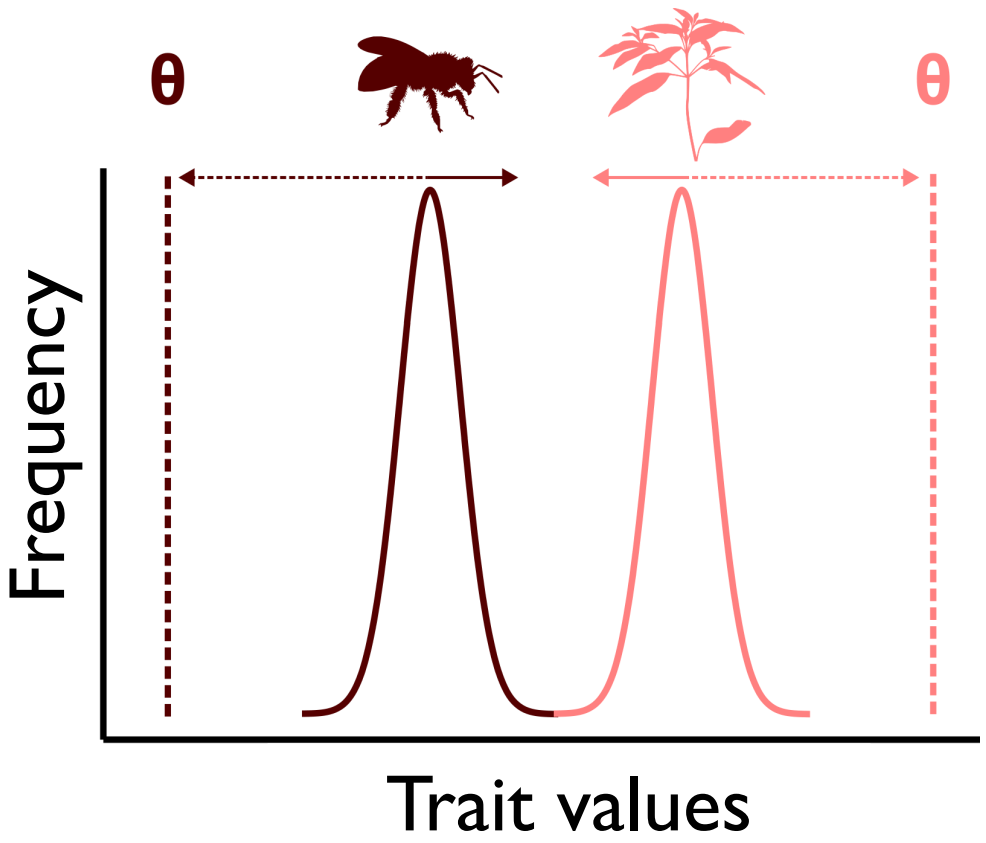
How indirect effects shape the fitness of species?





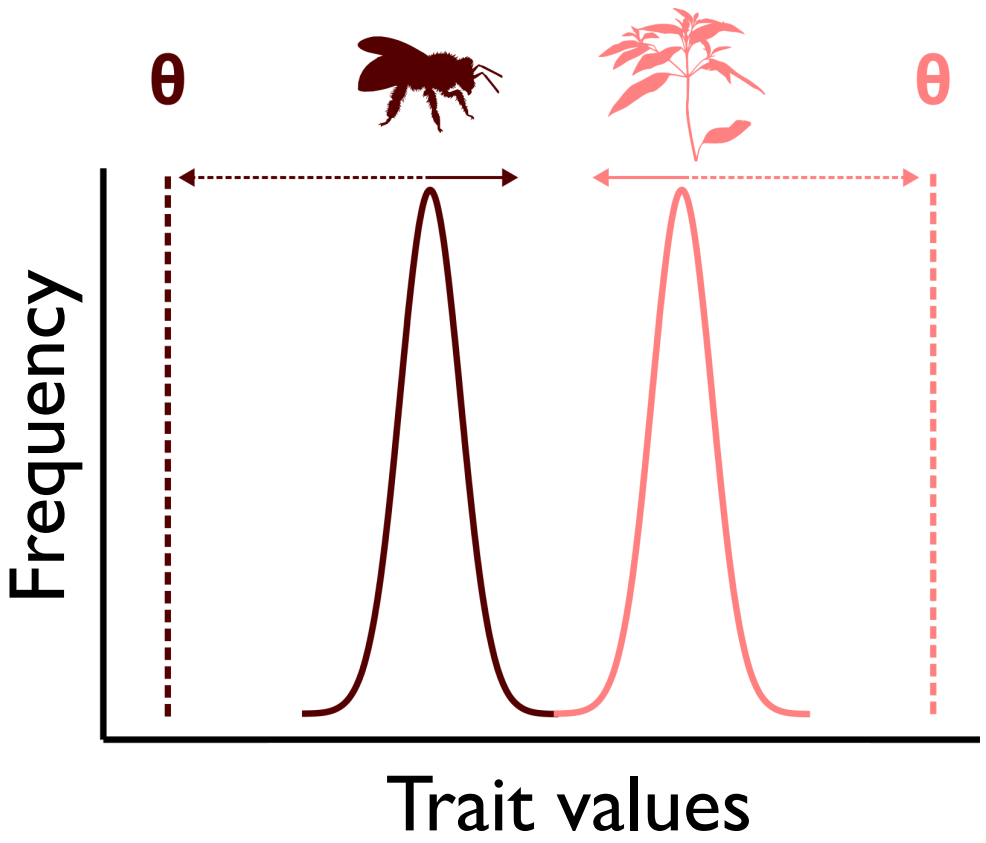
In mutualisms, coevolution is expected to increase the mean fitness of populations – species fitness

$$\Delta\bar{z} = h^2\sigma^2 \frac{\partial\, ln\left(\bar{w}^{(t)}\right)}{\partial\, \bar{z}^{(t)}}$$



Mapping trait values into fitness – fitness landscape of species

$$\Delta\bar{z} = h^2\sigma^2 \frac{\partial\, ln\left(\bar{w}^{(t)}\right)}{\partial\, \bar{z}^{(t)}} \longrightarrow \bar{w}_i = f(\bar{z}_i)$$



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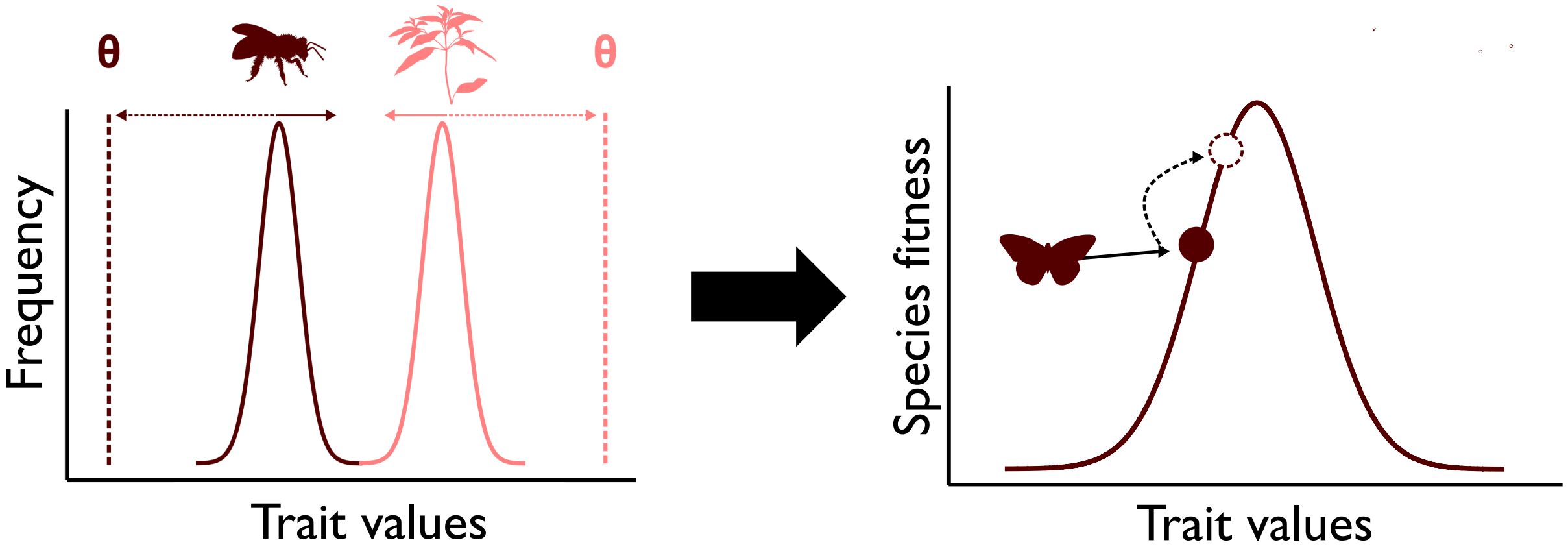

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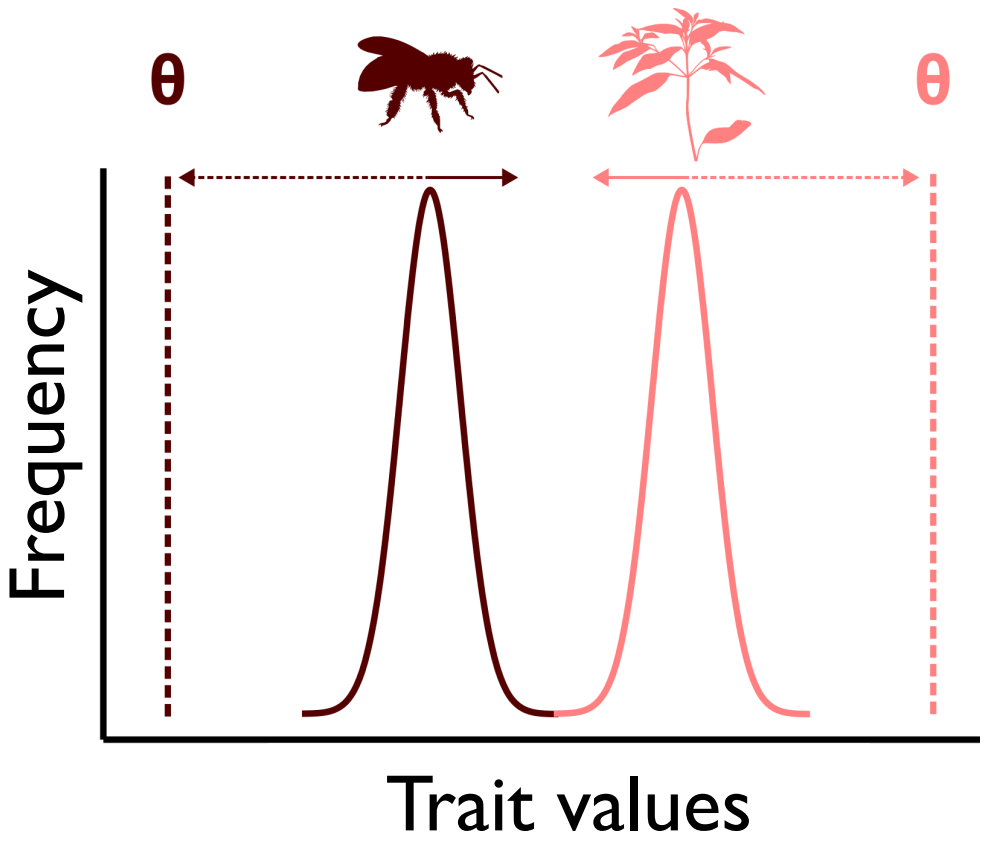
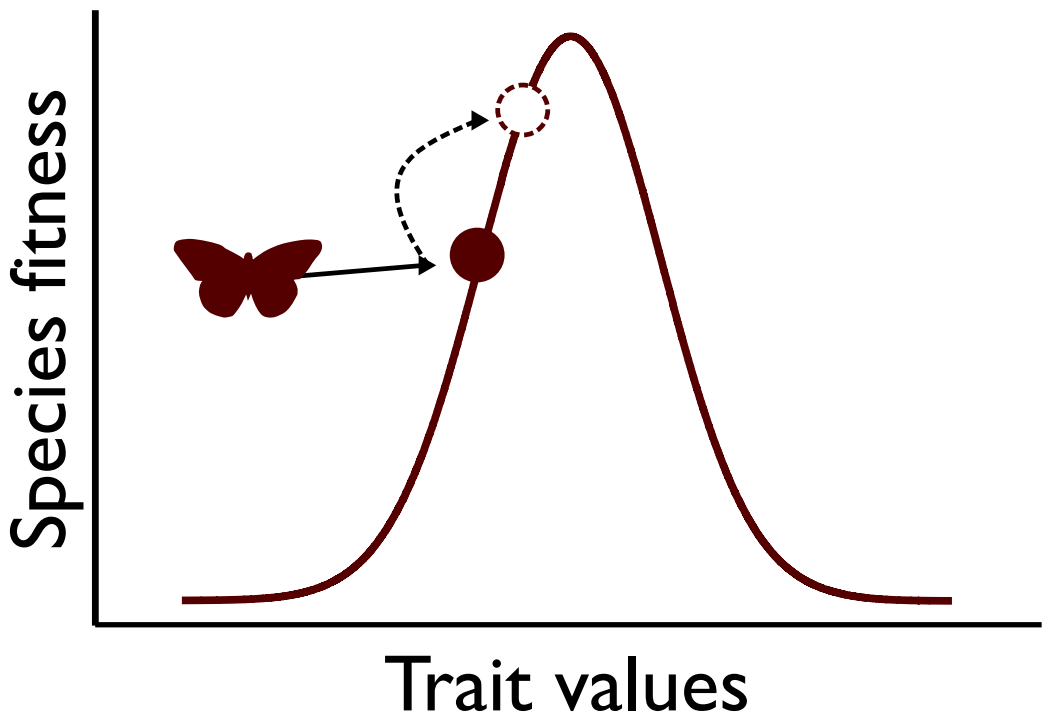
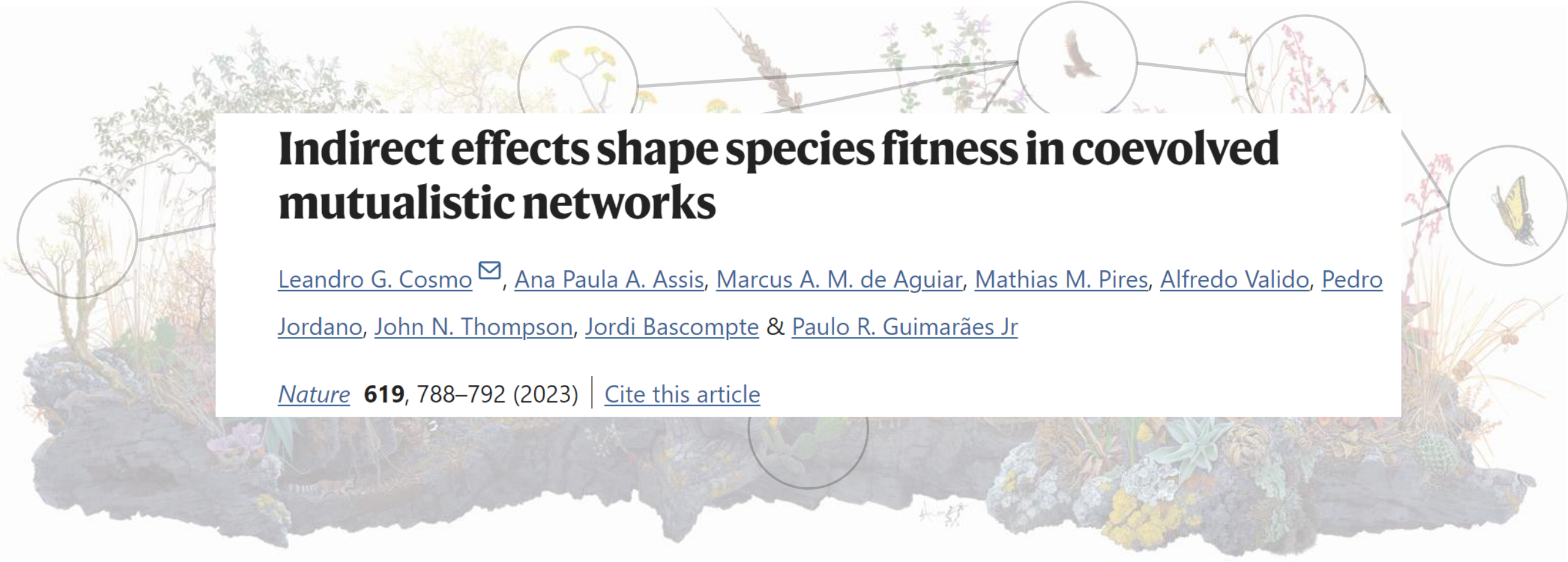




$$ln\overline{W_i} = \varrho_i \left[m_i \int \sum_{j=1, j\neq i}^{N} \frac{a_{ij} e^{-\alpha(\bar{z}_j - \bar{z}_i)^2}}{\sum_{k=1,k\neq i}^{N} a_{ij} e^{-\alpha(\bar{z}_k - \bar{z}_i)^2}} (\bar{z}_j - \bar{z}_i) d\bar{z}_i + (1 - m_i) \int (\theta_i - \bar{z}_i) d\bar{z}_i \right]$$

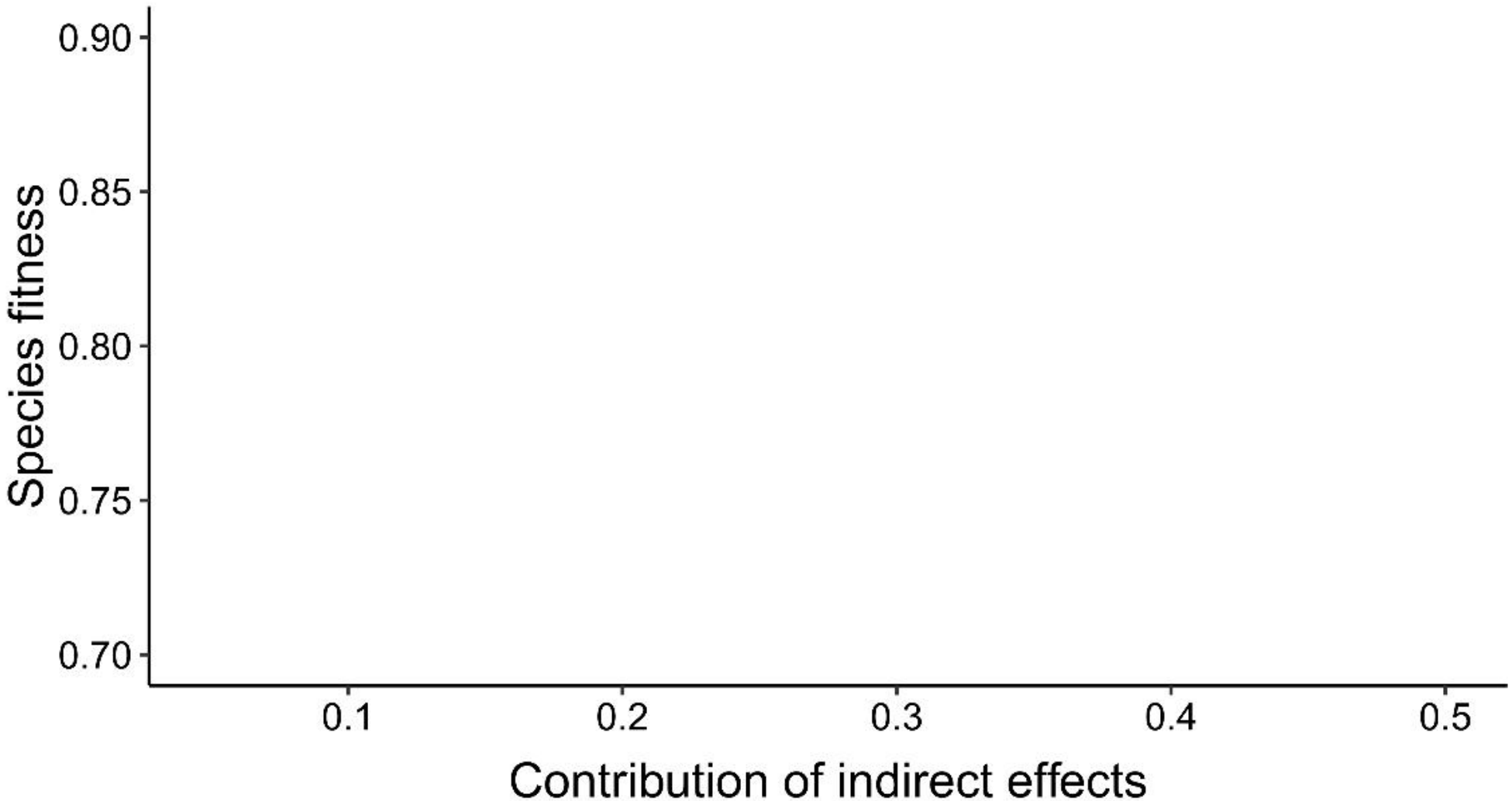


Indirect effects shape species fitness in coevolved mutualistic networks

Leandro G. Cosmo, Ana Paula A. Assis, Marcus A. M. de Aguiar, Mathias M. Pires, Alfredo Valido, Pedro Jordano, John N. Thompson, Jordi Bascompte & Paulo R. Guimarães Jr

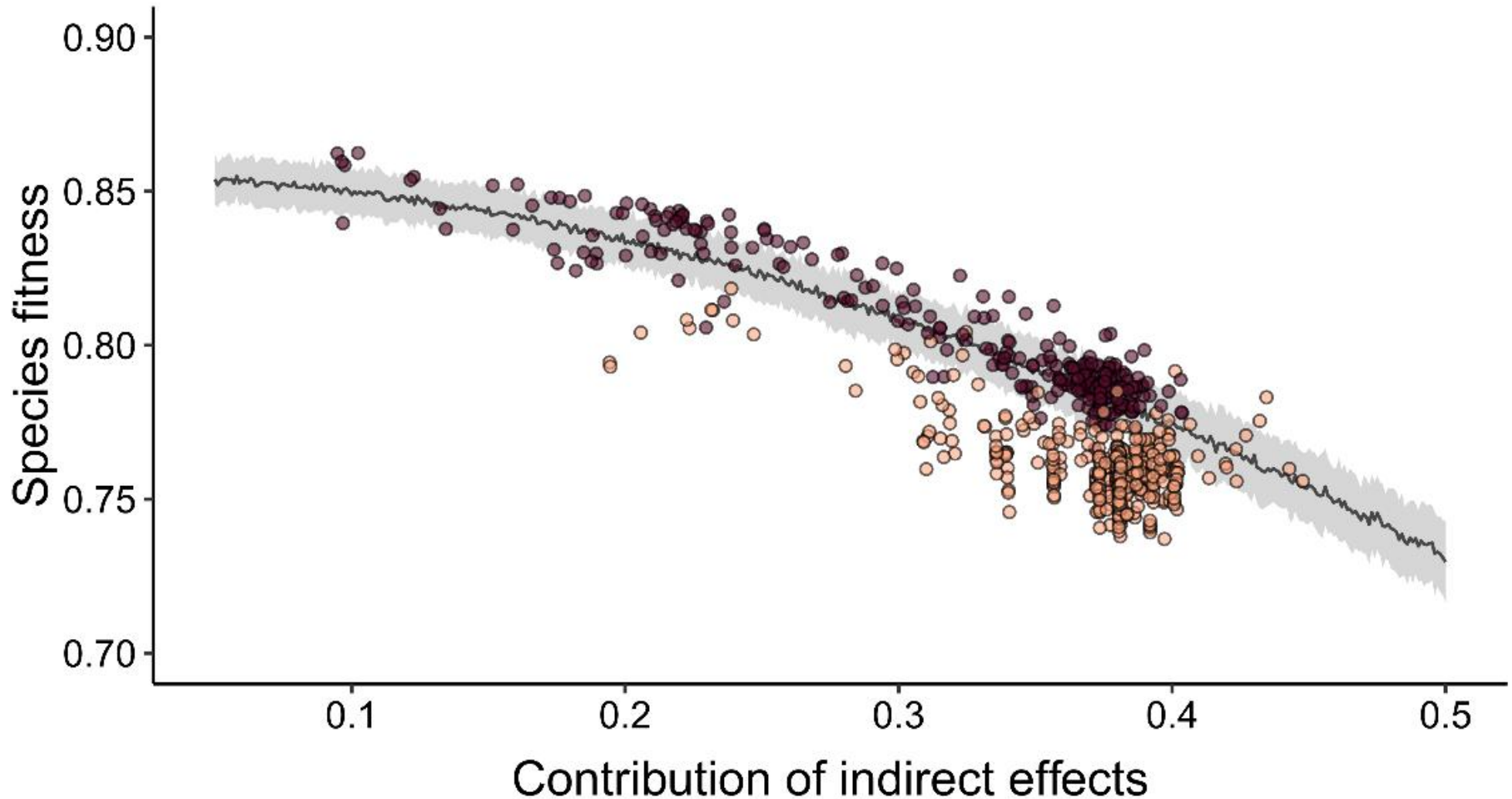
Nature **619**, 788–792 (2023) | Cite this article

$$\overline{w_i}^* \cong e^{-\frac{1}{2}\varrho_i\{m_i[(\langle\theta\rangle-\theta_i)(m_i+F_i)-\theta_i+\langle z\rangle]^2+(1-m_i)(\theta_i-\theta)^2(m_i+F_i)^2\}}$$



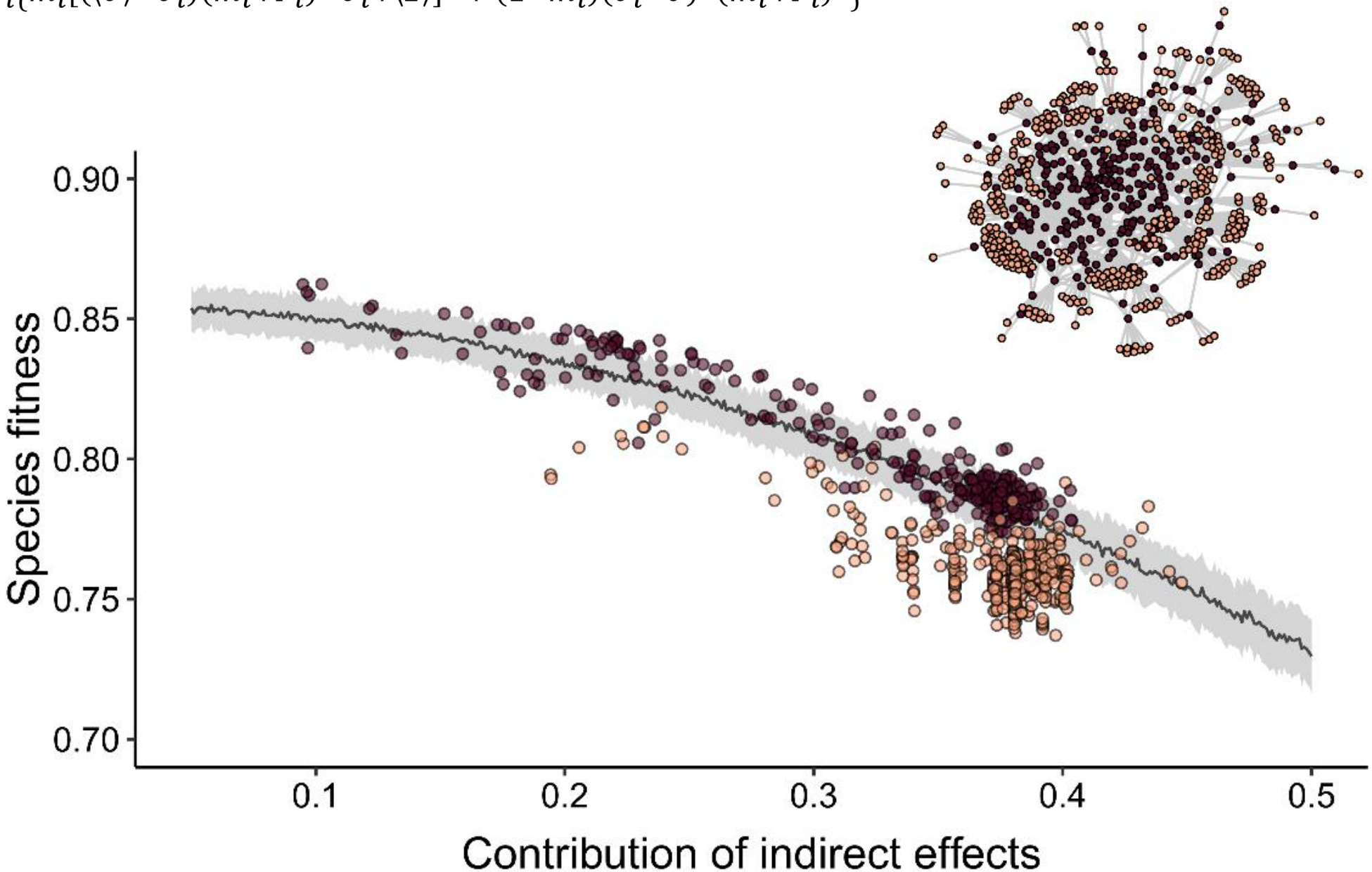
Cosmo et al. 2023, *Nature*

$$\overline{w_i}^* \cong e^{-\frac{1}{2}\varrho_i\{m_i[(\langle\theta\rangle-\theta_i)(m_i+F_i)-\theta_i+\langle z\rangle]^2 + (1-m_i)(\theta_i-\theta)^2(m_i+F_i)^2\}}$$



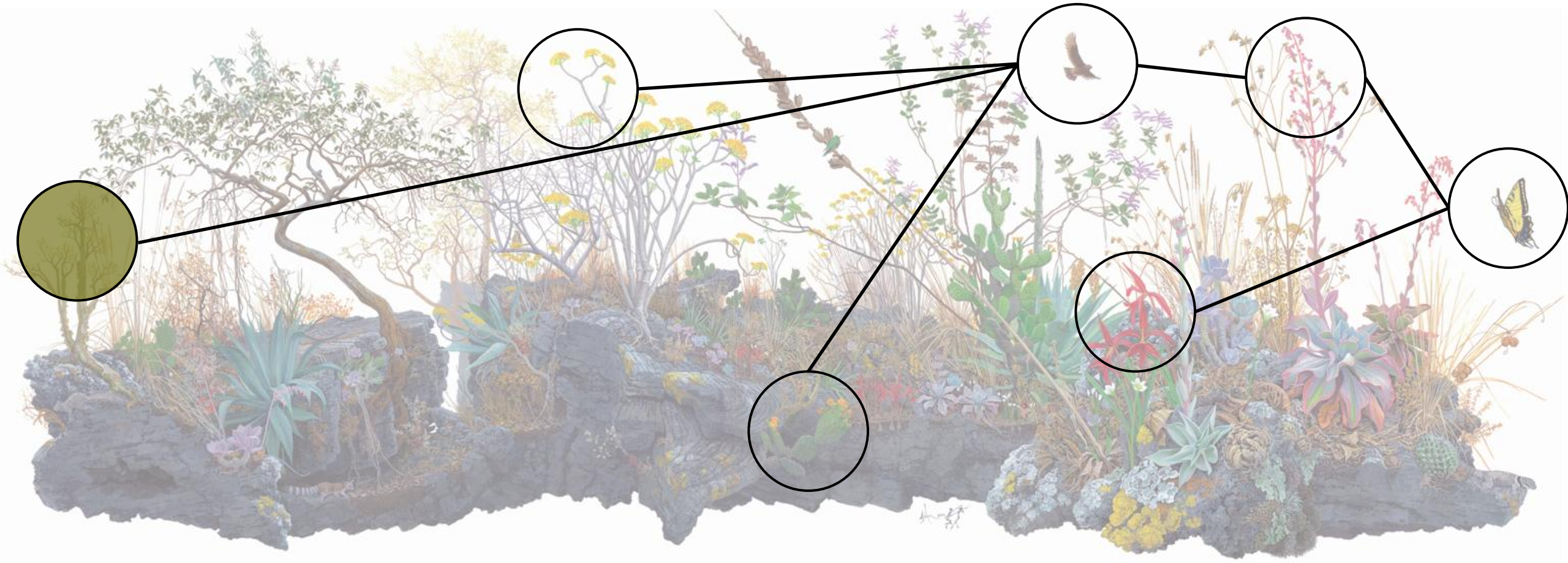
Cosmo et al. 2023, *Nature*

$$\overline{w_i}^* \cong e^{-\frac{1}{2}\varrho_i\{m_i[(\langle\theta\rangle-\theta_i)(m_i+F_i)-\theta_i+\langle z\rangle]^2 + (1-m_i)(\theta_i-\theta)^2(m_i+F_i)^2\}}$$

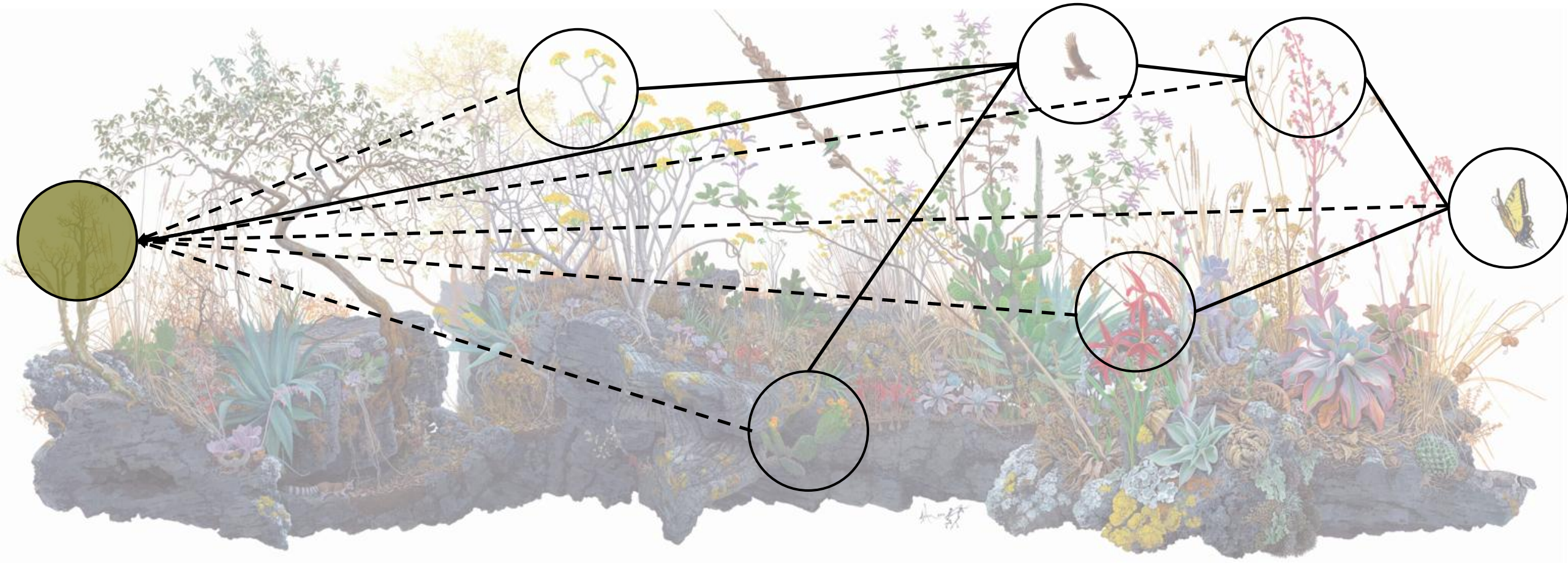


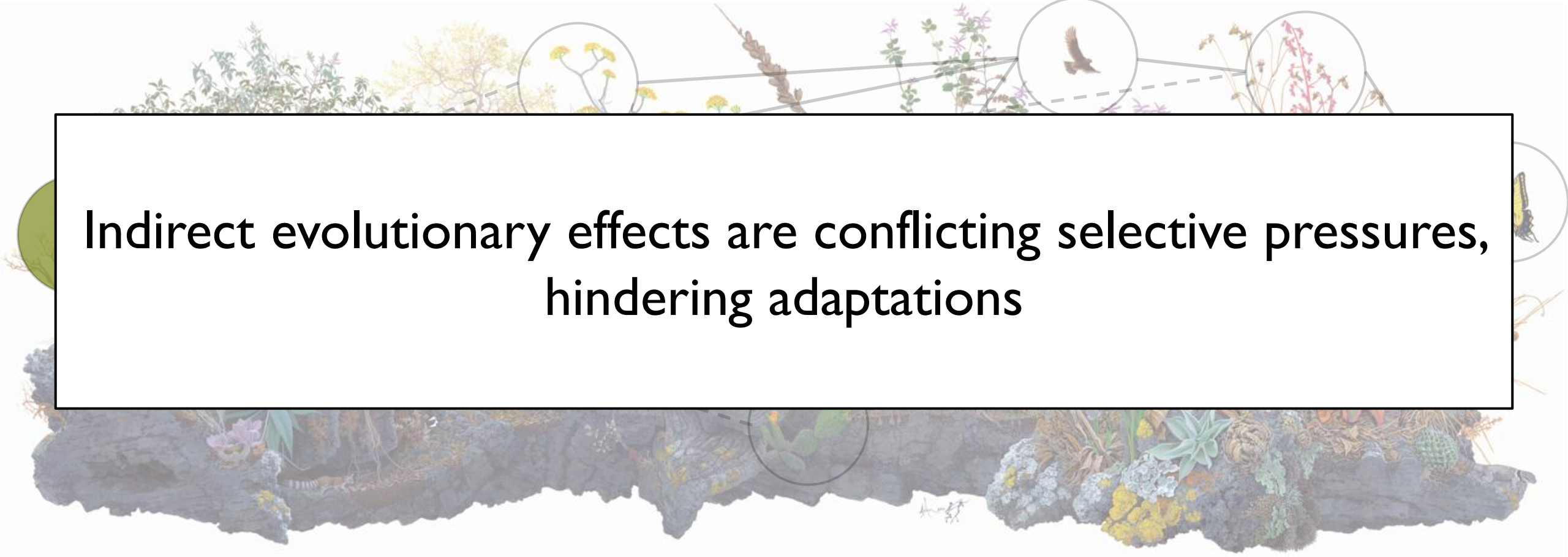
Cosmo et al. 2023, *Nature*

(Art by Aslam Narváez)

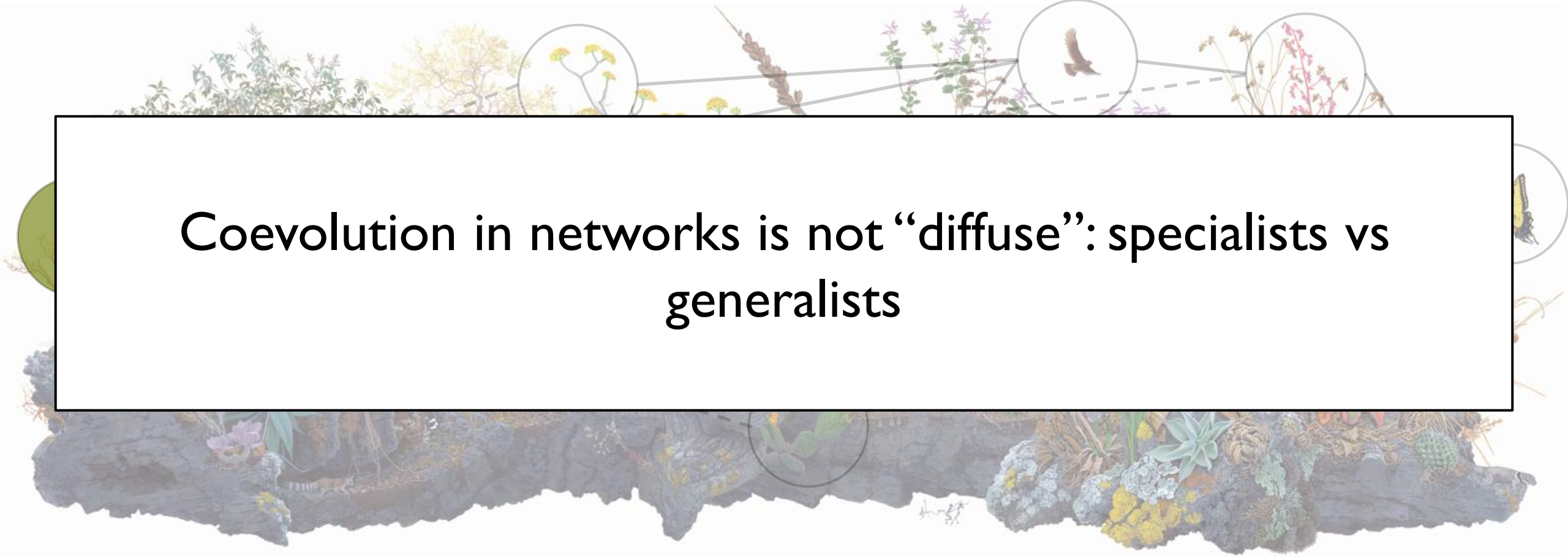


(Art by Aslam Narváez)

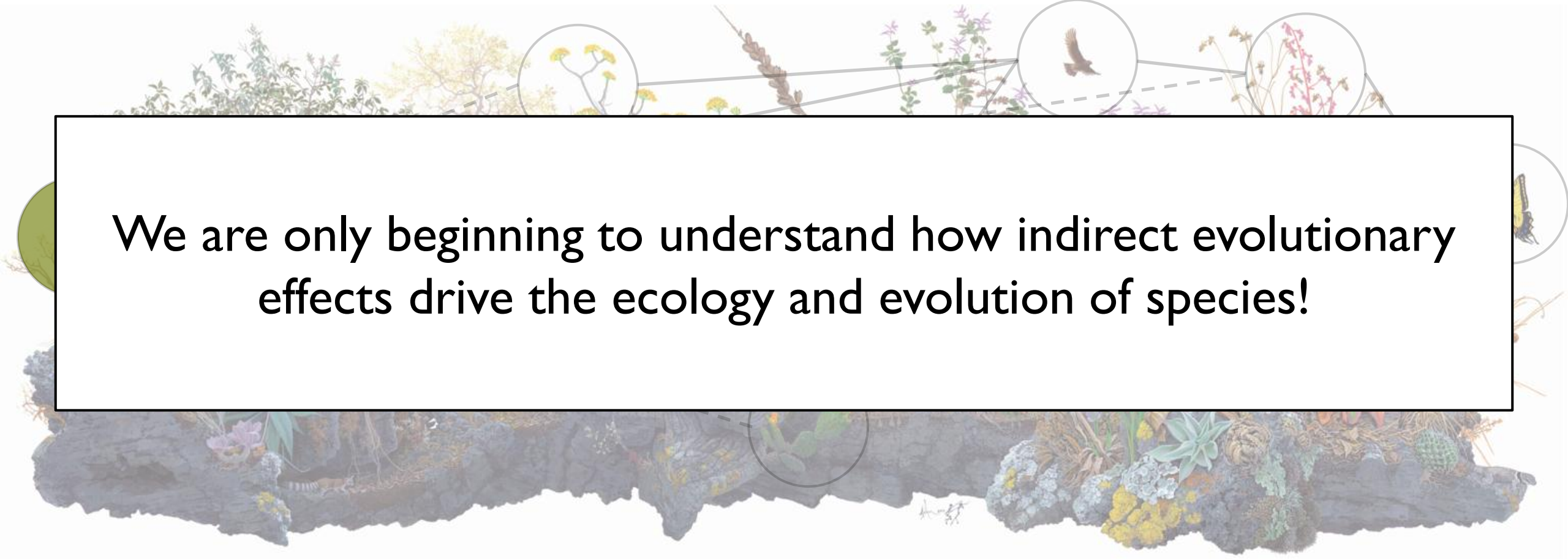




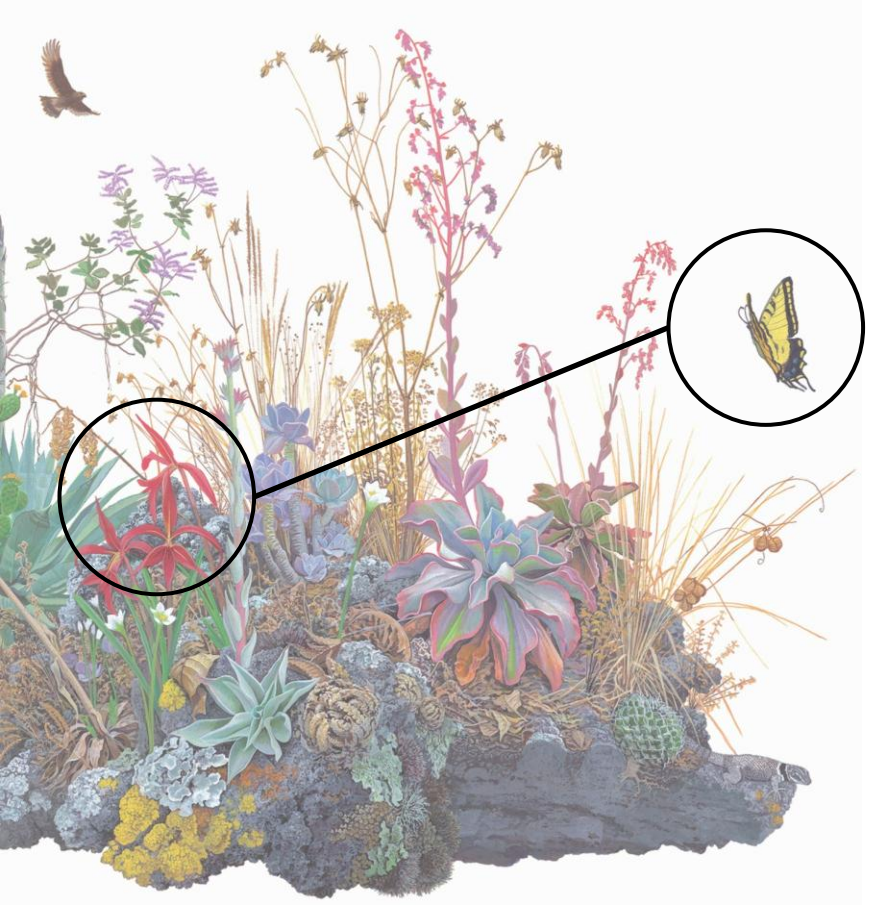
Indirect evolutionary effects are conflicting selective pressures, hindering adaptations

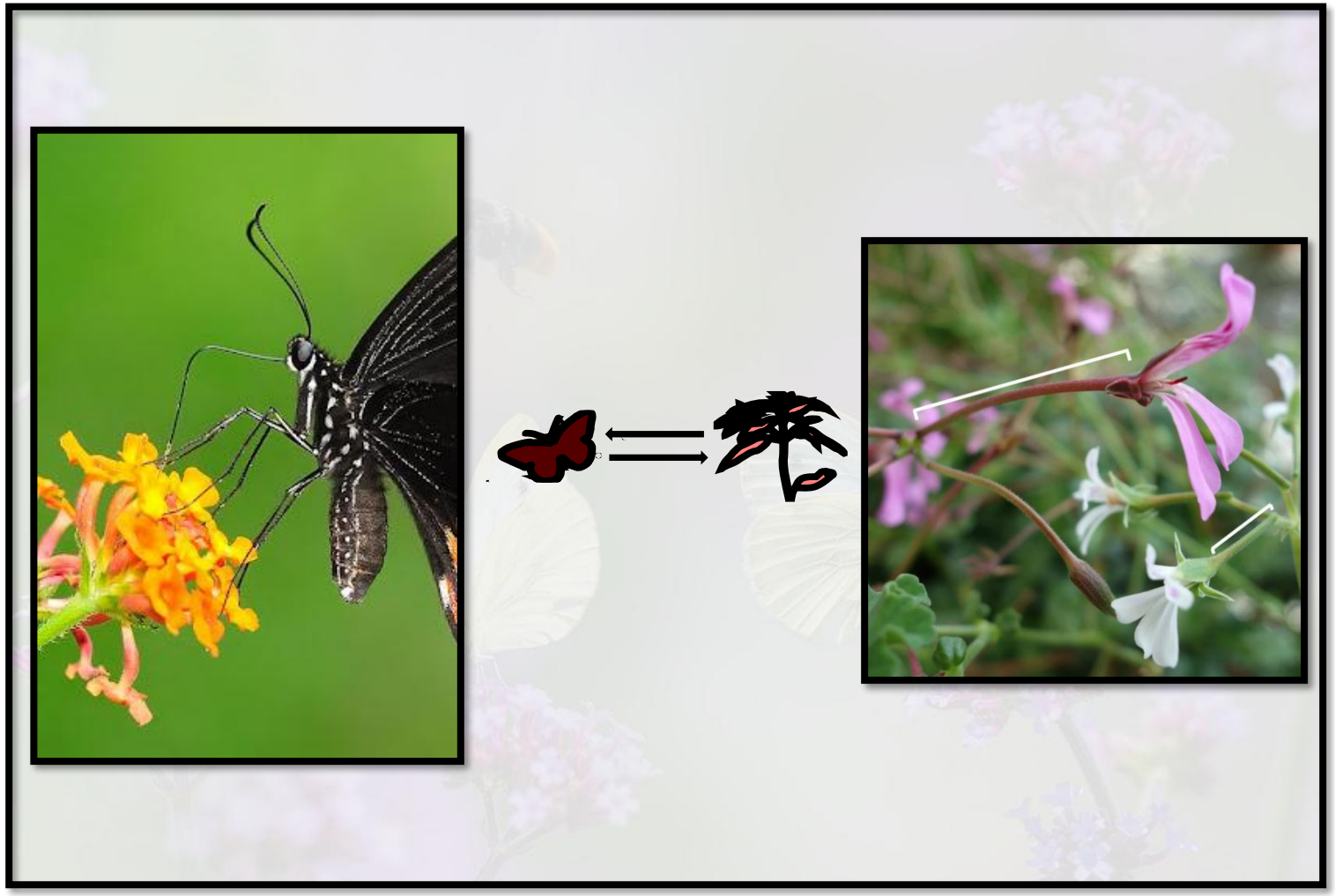


Coevolution in networks is not “diffuse”: specialists vs generalists

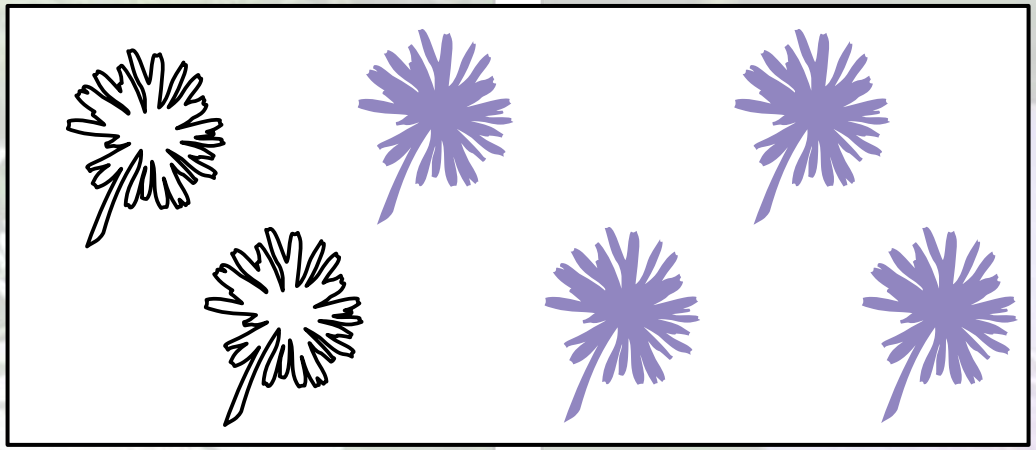


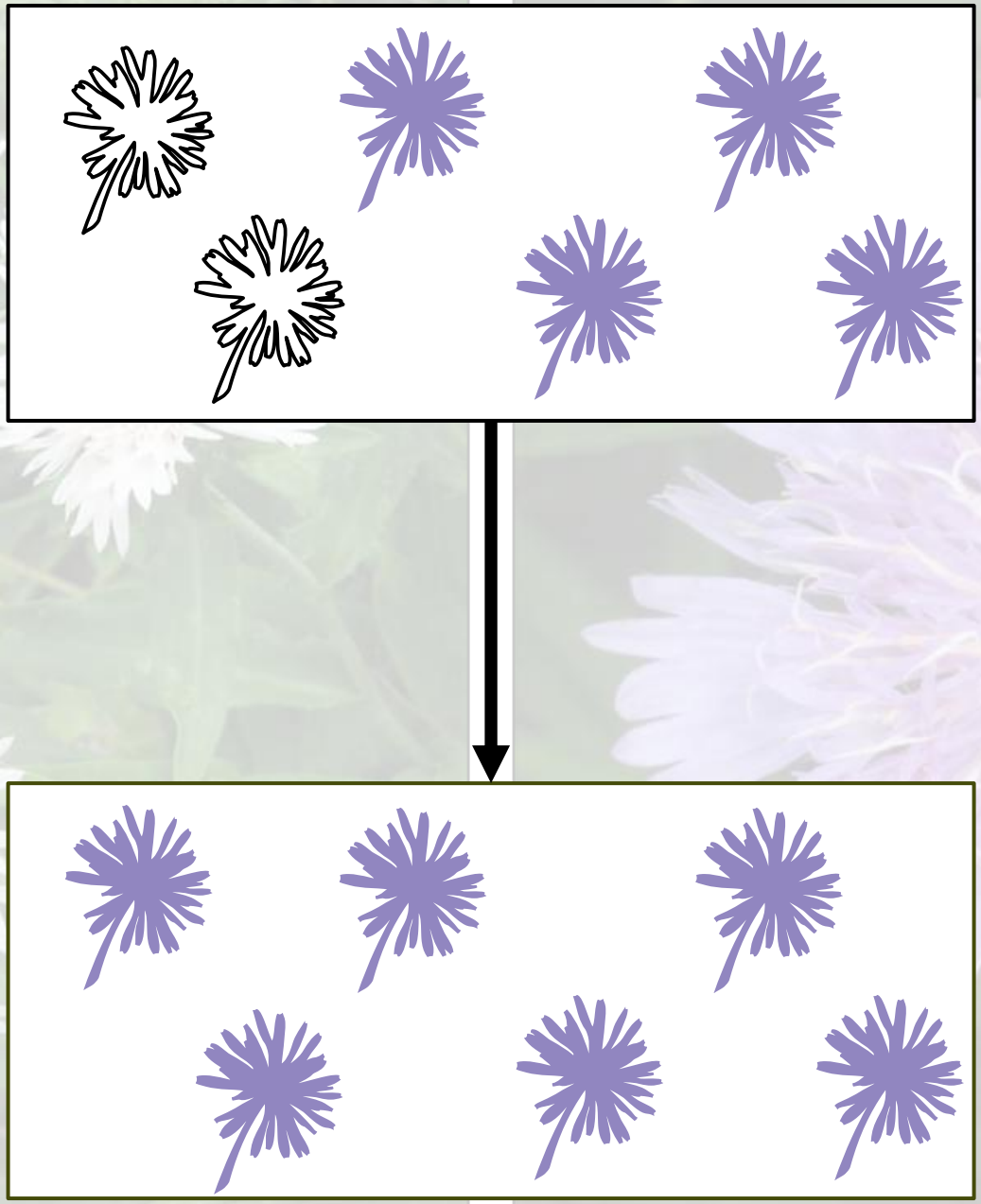
We are only beginning to understand how indirect evolutionary effects drive the ecology and evolution of species!



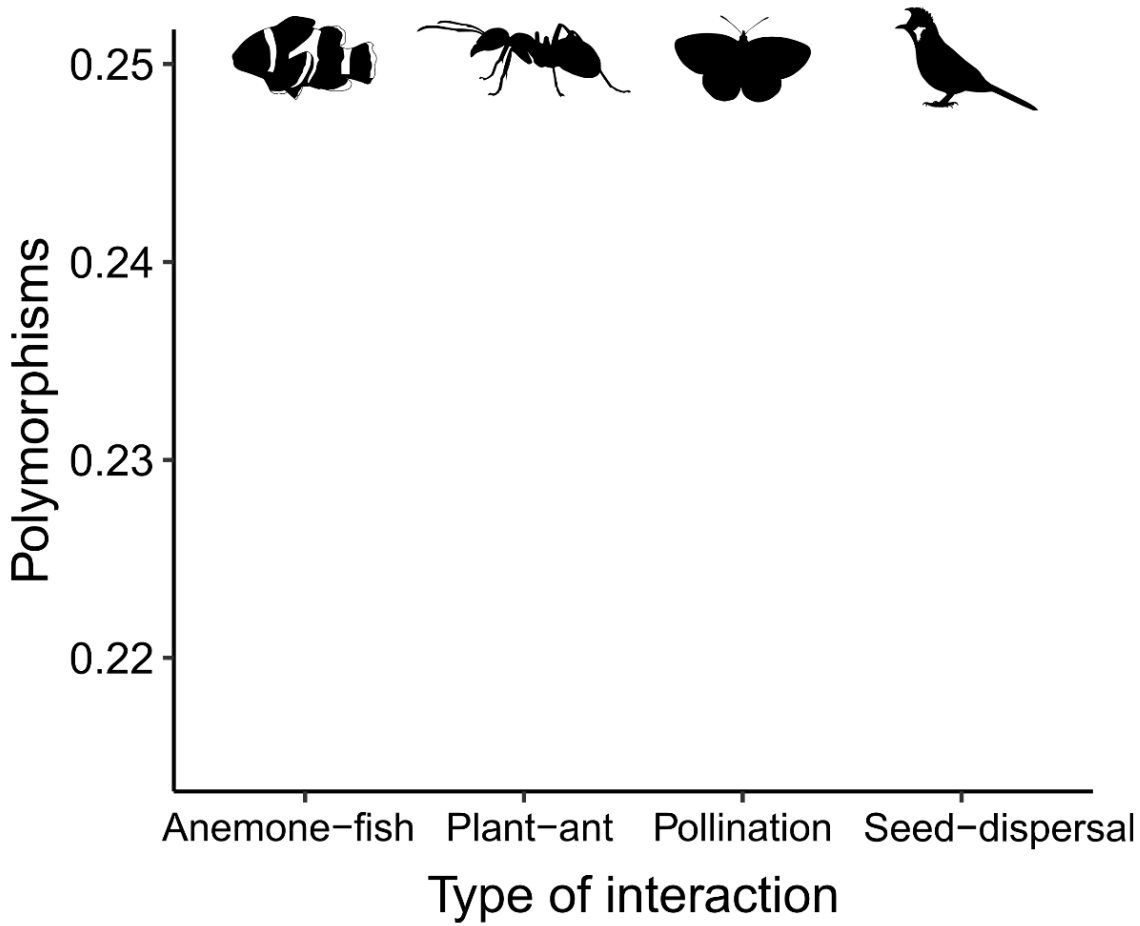


Previous coevolutionary model was limited to continuous traits

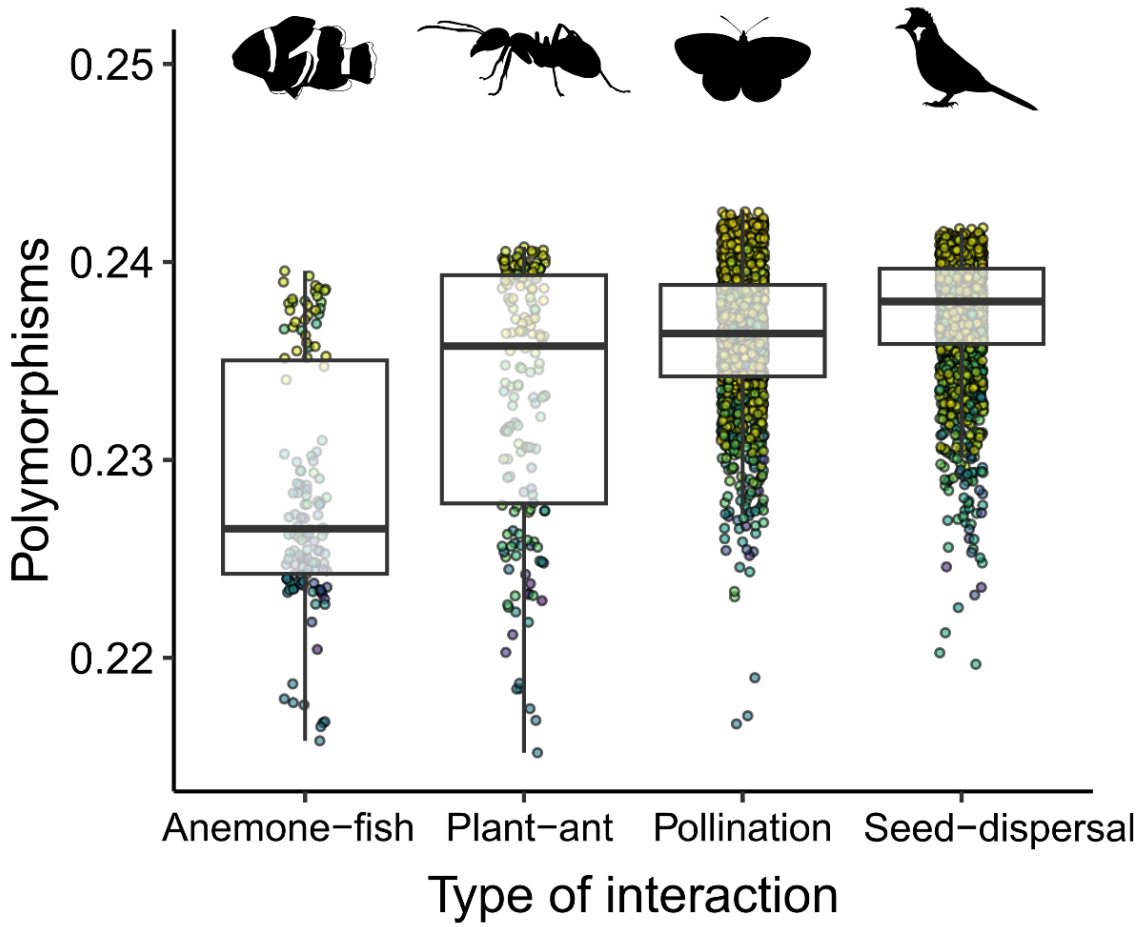




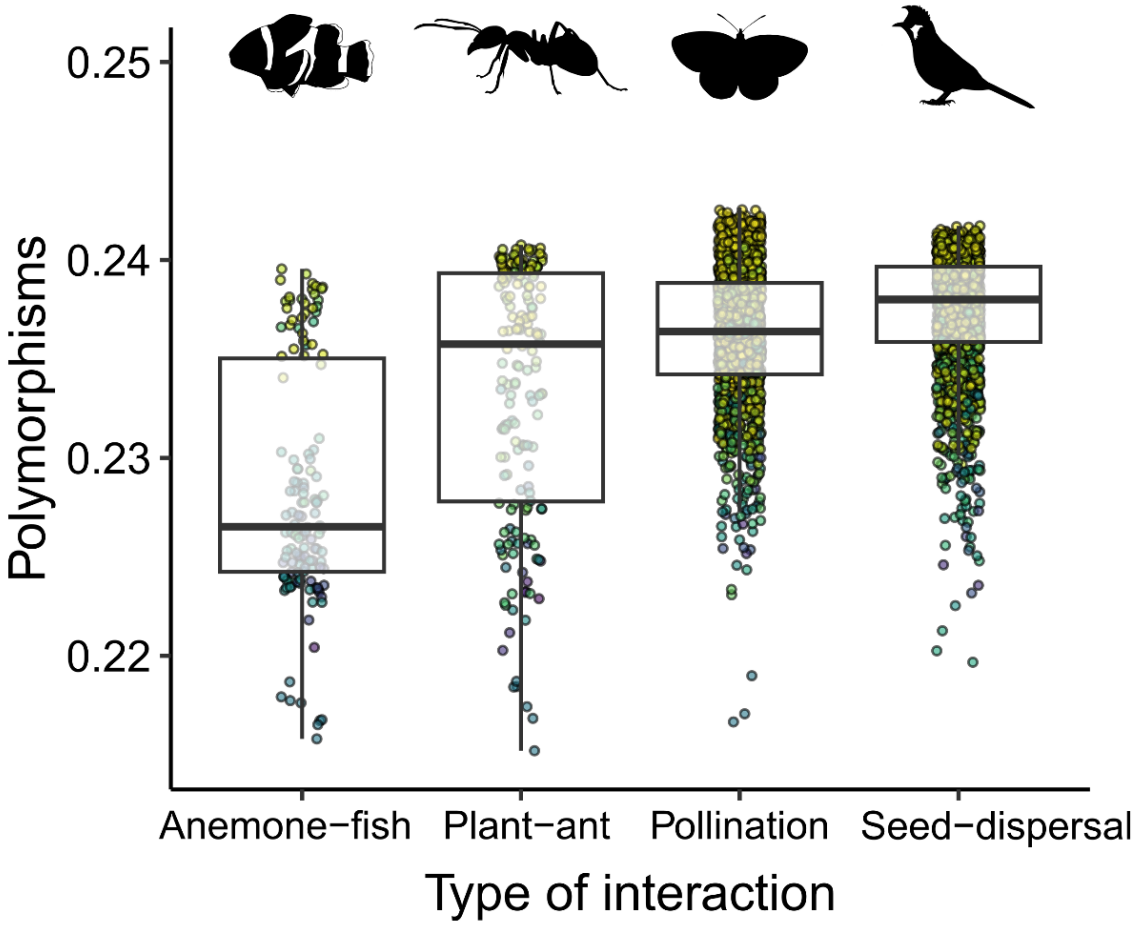
How indirect evolutionary effects can shape the maintenance of polymorphisms within mutualistic species?

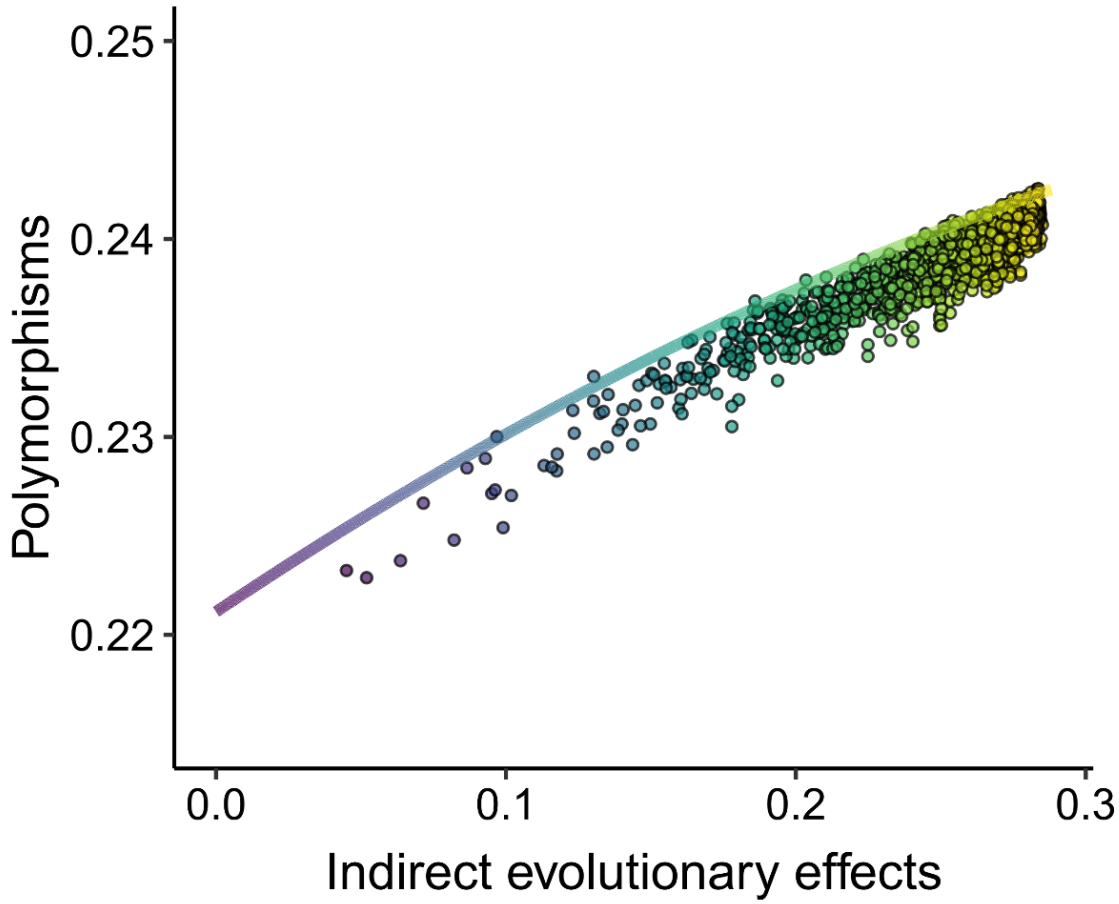


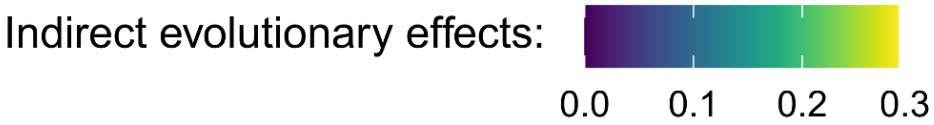
Cosmo, Guimarães and Bascompte, *in review*



Cosmo, Guimarães and Bascompte, *in review*







Cosmo, Guimarães and Bascompte, *in review*

Indirect evolutionary effects are a **source of conflict** that equalize the fitness of the different morphs **within species**

Picture: Pedro Jordano

Evolutionary dynamics in networks

The role of indirect evolutionary effects

EEE321 – Ecological Networks

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