Introduction to networks

Network Analysis in Plant Pathology Research Workshop

Aaron I. **Plex** Sulá and the Garrett Lab

UF IFAS UNIVERSITY of FLORIDA

PLANT PATHOLOGY

GLOBAL FOOD SYSTEMS INSTITUTE

EMERGING PATHOGENS INSTITUTE

APS plant health 2024

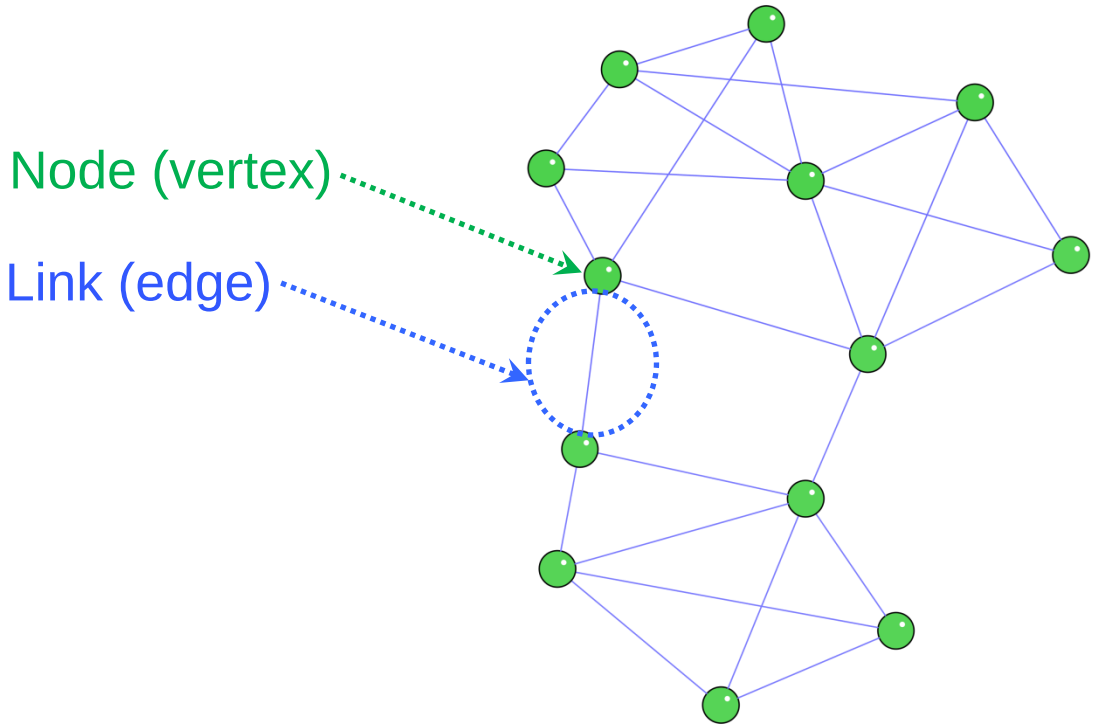
Learning objectives for this presentation

At the end of this lecture, we should be able to…

- **Define what we mean by network**
- **Be familiar with networks in plant pathology**
- **Learn basic metrics in network analysis**
- **Define a network for your pathosystem**

What is a network?

- **Link weight:** level of interaction between at least a pair of nodes.
- **Dynamic nature:** link weights change over space and time.



Infinite possibilities for network model structures

- **Nodes could be**
  - Locations in spatial networks (counties, fields, plants, leaves, cells, organelles, microbes,…)
  - Entities (individual people, species like in food webs or phytobiomes, genes or molecules)
- **Links could be**
  - Strength or likelihood of influence, triggering, information flow, …
  - Dependent on environmental variables

For the system you work, what could nodes represent and what would links represent?

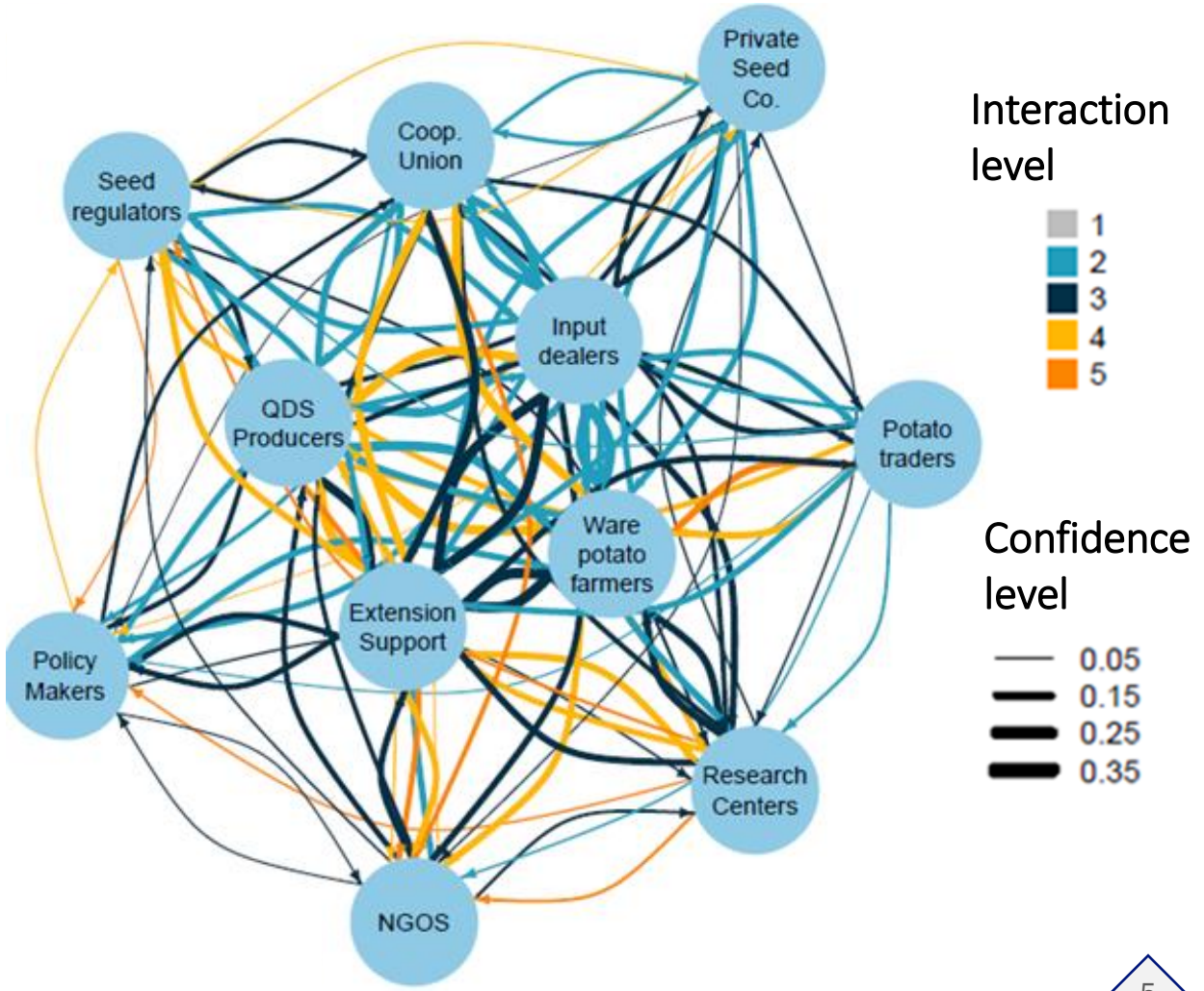
Translating Ethiopian potato seed networks: identifying strategic intervention points for managing bacterial wilt and other diseases

bioRxiv
THE PREPRINT SERVER FOR BIOLOGY

Berea A. Etherton, Aaron I. Plex Sulá, Romaric A. Mouafo-Tchinda, Rogers Kakuhenzire, Haileab A. Kassaye, Frezer Asfaw, Vasilios S. Kosmakos, Richard W. McCoy, Yanru Xing, Jiahe Yao, Kalpana Sharma, Karen A. Garrett

doi: https://doi.org/10.1101/2024.02.12.579952

- **Stakeholder interaction network**
- **Nodes**
  - Potato system stakeholders
- **Links**
  - Interaction and communication level



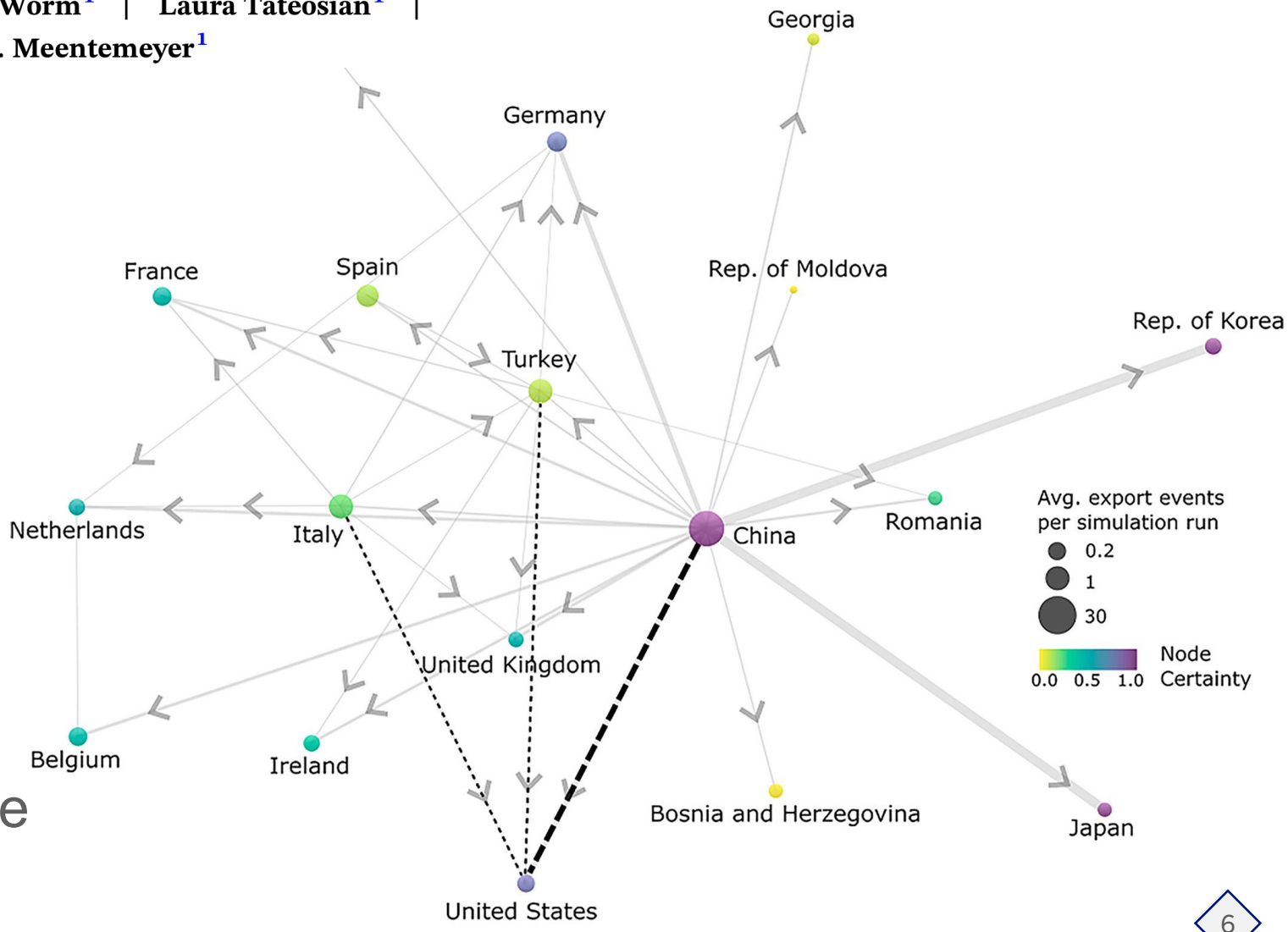
Forecasting global spread of invasive pests and pathogens through international trade

ECOSPHERE
AN ESA OPEN ACCESS JOURNAL

ARTICLE
Emerging Technologies

Kellyn Montgomery[1,2] | Chelsey Walden-Schreiner[1] | Ariel Saffer[1] | Chris Jones[1] | Benjamin J. Seliger[1] | Thom Worm[1] | Laura Tateosian[1] | Makiko Shukunobe[1] | Sunil Kumar[2] | Ross K. Meentemeyer[1]

- **Simulated spotted lanternfly transmission network**
- **Nodes**
  - Countries
- **Link weights**
  - Directional
  - Transmission likelihood
  - Dashed lines emphasize links with the USA.



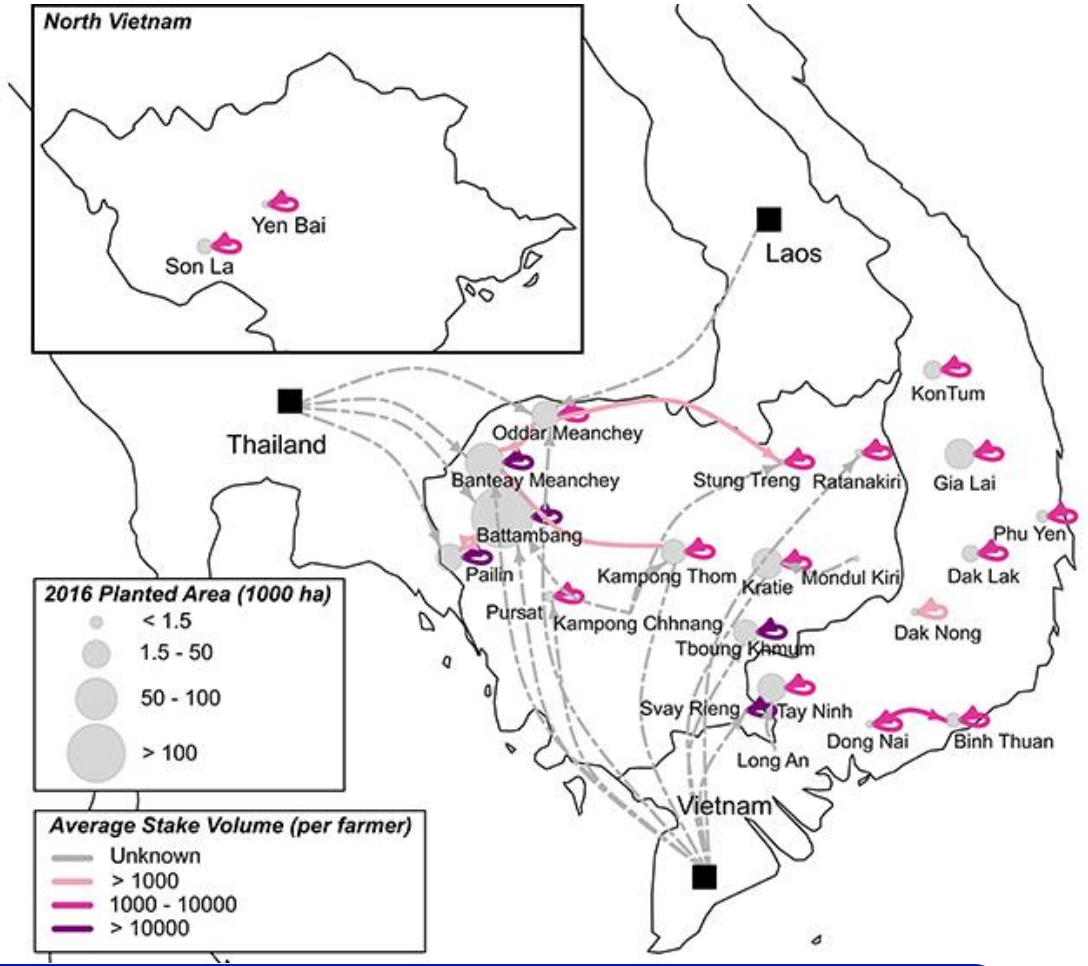
frontiers in Sustainable Food Systems

ORIGINAL RESEARCH
published: 15 November 2018
doi: 10.3389/fsufs.2018.00073

Raising the Stakes: Cassava Seed Networks at Multiple Scales in Cambodia and Vietnam

Erik Delaquis[1], Kelsey F. Andersen[2], Nami Minato[1], Thuy Thi Le Cu[1], Maria Eleanor Karssenberg[3], Sophearith Sok[1], Kris A. G. Wyckhuys[4,5,6], Jonathan C. Newby[1], Dharani Dhar Burra[1], Pao Srean[7], Iv Phirun[8], Niem Duc Le[9], Nhan Thi Pham[10], Karen A. Garrett[2], Conny J. M. Almekinders[3], Paul C. Struik[11] and Stef de Haan[1]

- **Seed exchange network**
- **Nodes**
  - Provinces (grey circles)
  - Countries (black squares)
- **Link weights**
  - Directional exchange of cassava stakes



Phytopathology • 2020 • 110:1578-1587 • https://doi.org/10.1094/PHYTO-01-20-0009-R

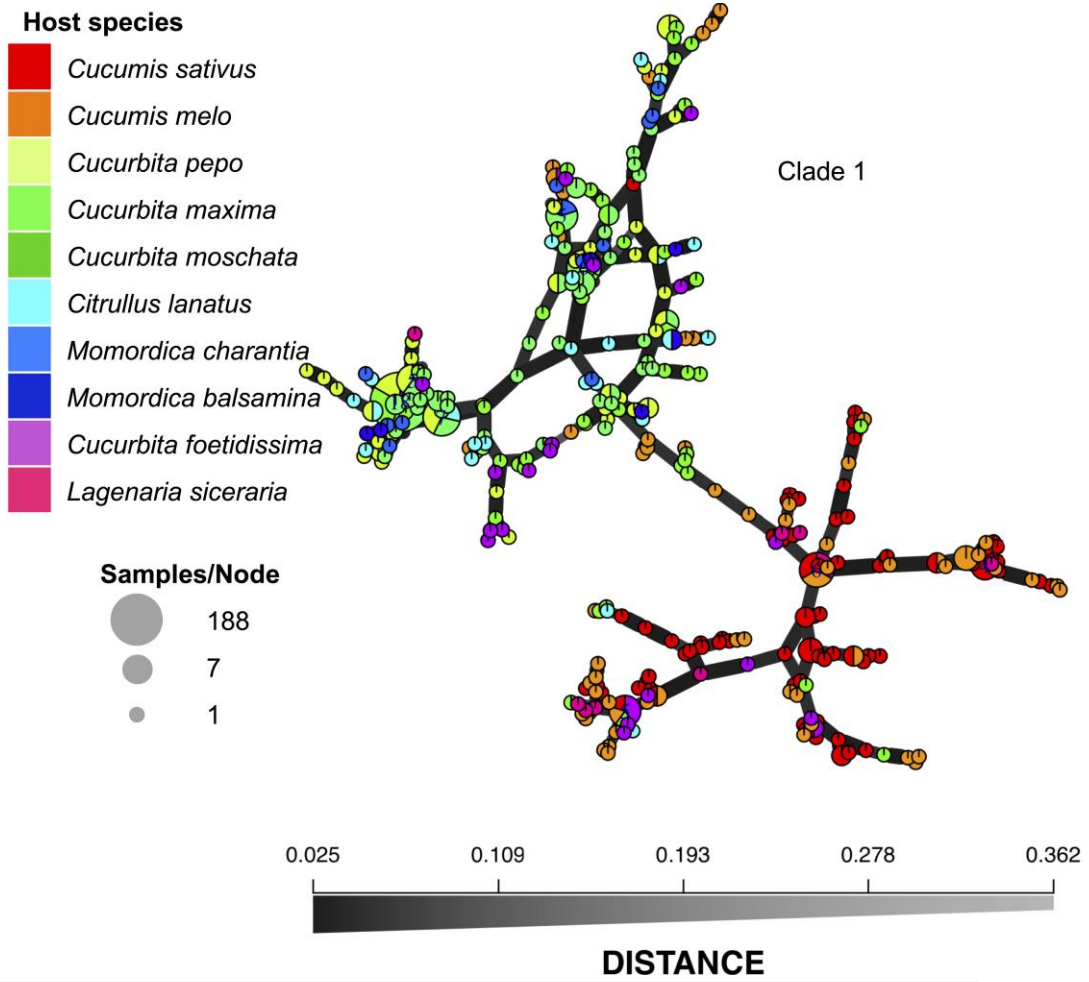
Population Biology

e-Xtra*

Population Analyses Reveal Two Host-Adapted Clades of *Pseudoperonospora cubensis*, the Causal Agent of Cucurbit Downy Mildew, on Commercial and Wild Cucurbits

E. C. Wallace, K. N. D'Arcangelo, and L. M. Quesada-Ocampo†

- **Minimum spanning network**
- **Nodes**
  - Multilocus genotypes (MLGs)
  - Frequency (size)
  - Hosts (color)
- **Link length and brightness**
  - Bruvo's genetic distance



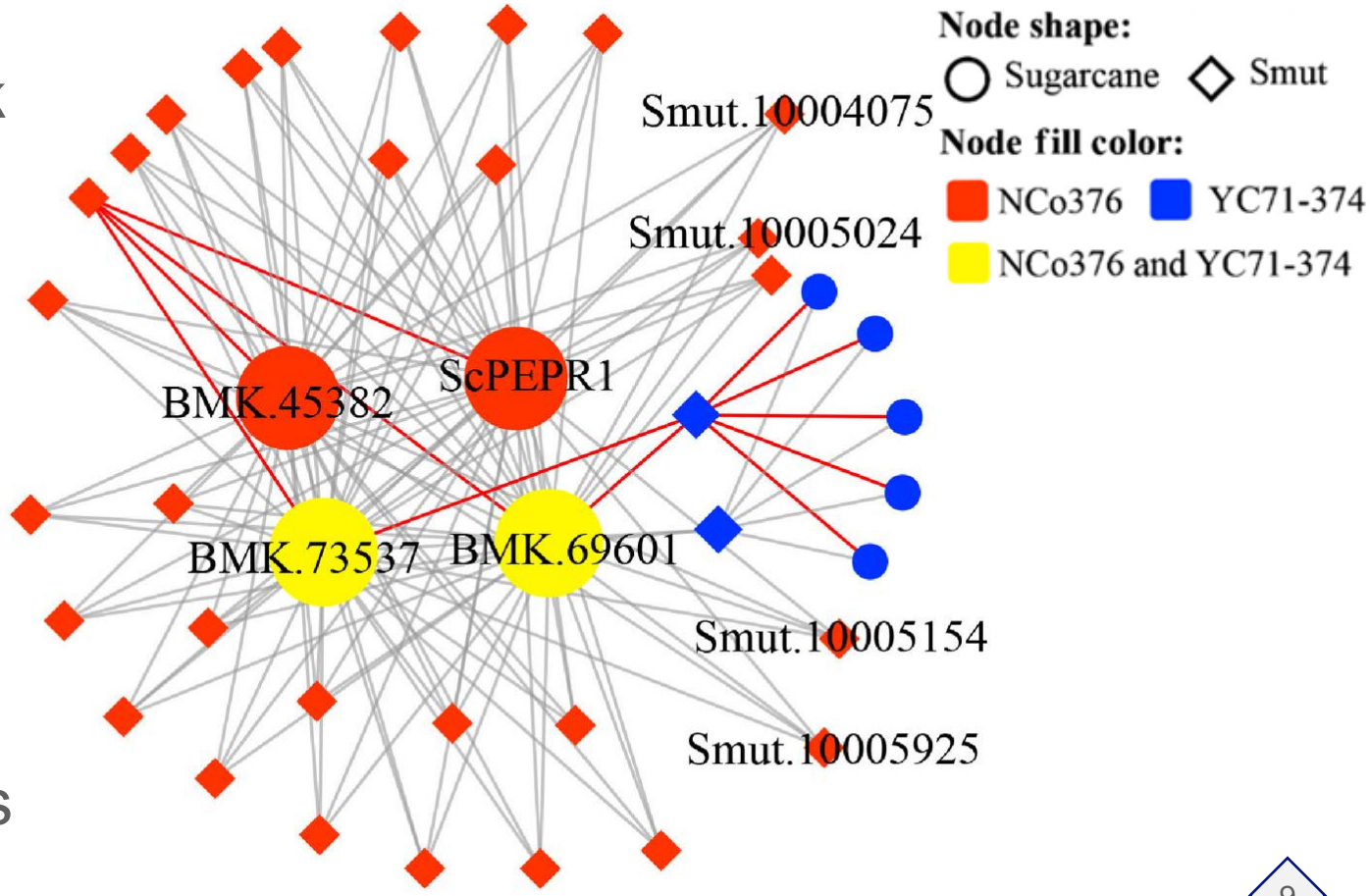
New Phytologist

Research

A sugarcane smut fungus effector simulates the host endogenous elicitor peptide to suppress plant immunity

Hui Ling[1,2*], Xueqin Fu[1*], Ning Huang[2*], Zaofa Zhong[1], Weihua Su[1], Wenxiong Lin[1], Haitao Cui[1] and Youxiong Que[1]

- **Gene co-expression network**
- **Nodes**
  - Sugarcane kinase DEGs (differentially expressed genes)
  - Smut secreted protein genes
- **Link color**
  - Negative and **positive** correlations between genes



Analyzing quantifiable traits of networks

- **Node-level traits**
  - Degree centrality
  - Closeness centrality
  - Betweenness centrality
- **Edge-level traits**
  - Weight, direction
- **Whole-network traits**
  - Network density
  - Cluster identification
  - Network types

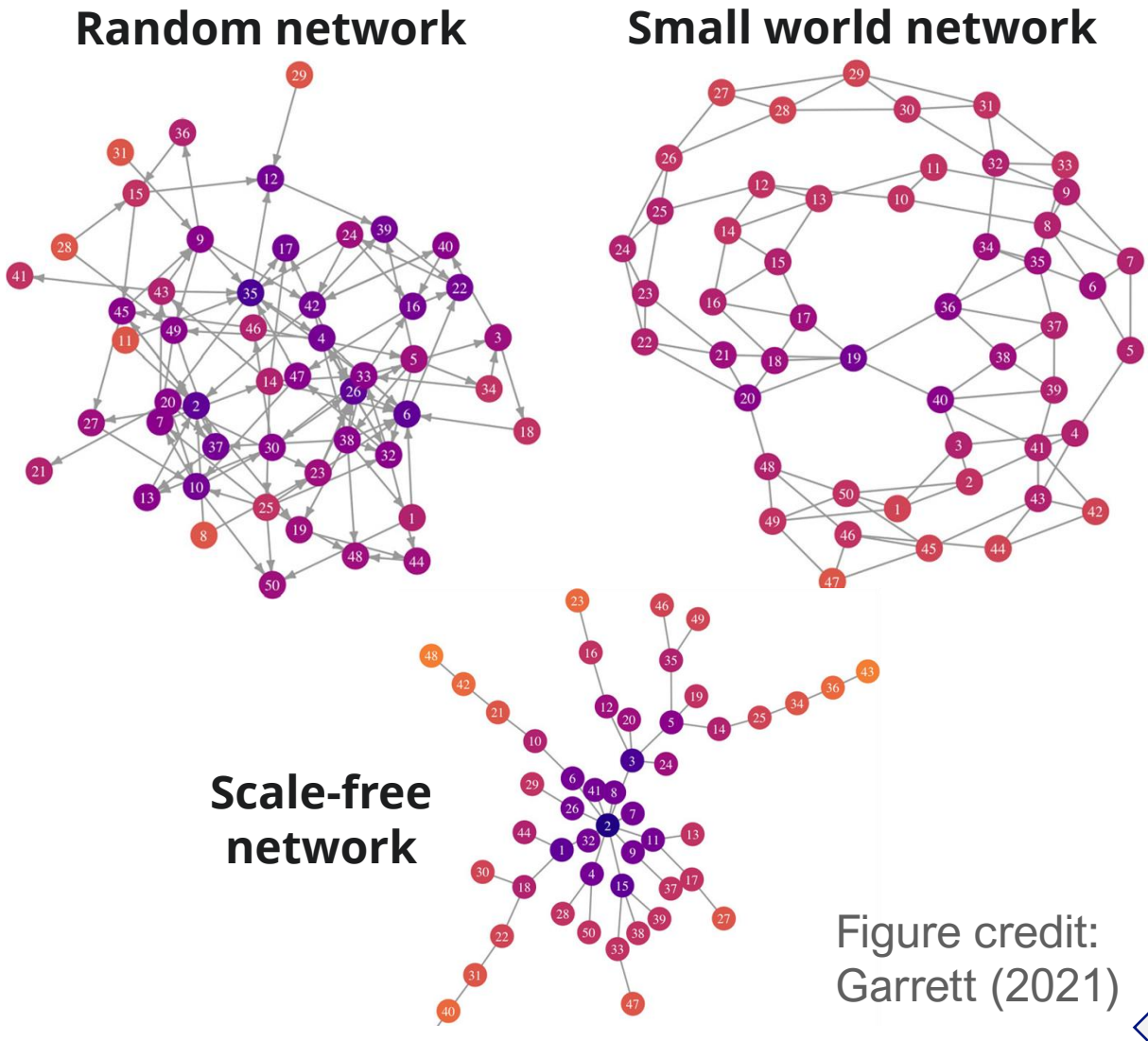
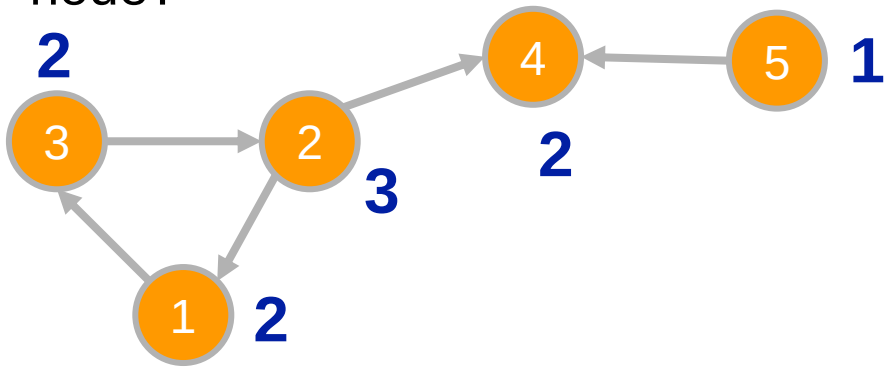


Figure credit: Garrett (2021)

Analyzing traits of networks

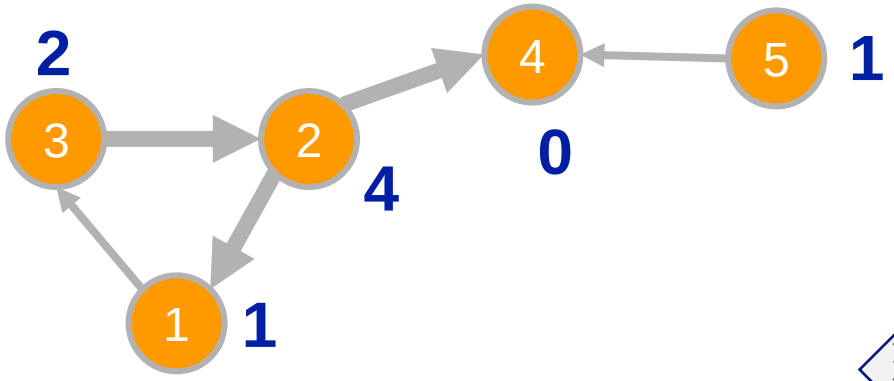
- **Node degree**
  - The number of links a node has to other nodes in the network
  - Both incoming and outgoing links (in- & out-degree)

What is the **total degree** of each node?



- **Node strength**
  - The sum of the weights of links a node has to other nodes in the network
  - Node in- and out-strength

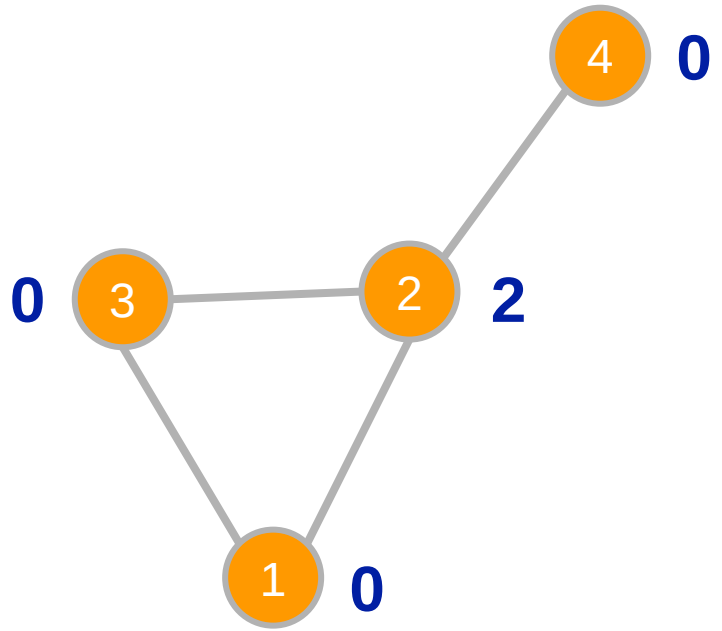
What is the **out-strength** of each node?



Analyzing traits of networks

- **Node betweenness**
  - The number of shortest paths* through the network of which a node is a part
- **Node closeness**
  - The inverse of the average length of the shortest path to and from all the other nodes in the network (“accessibility”).

What is the **betweenness centrality** of each node?

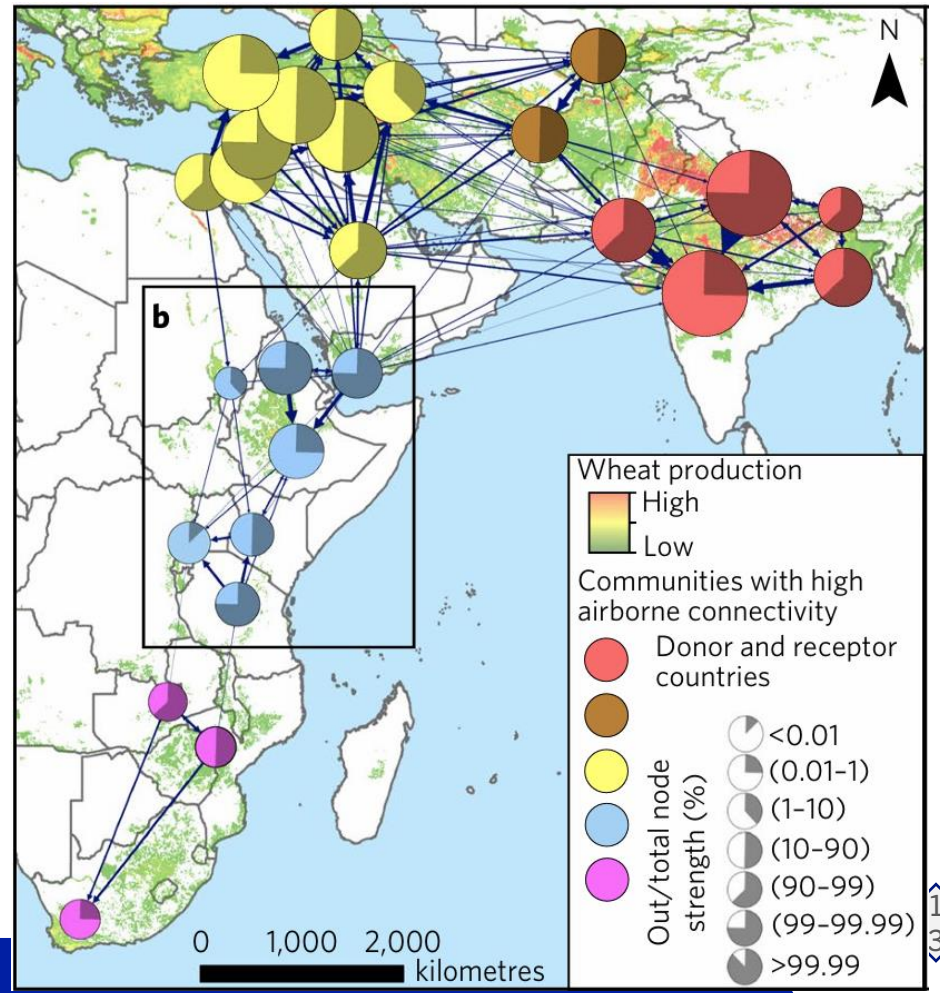


Quantifying airborne dispersal routes of pathogens over continents to safeguard global wheat supply

LETTERS
DOI: 10.1038/s41477-017-0017-5
nature plants

M. Meyer[1*], J. A. Cox[1], M. D. T. Hitchings[1], L. Burgin[2], M. C. Hort[2], D. P. Hodson[3] and C. A. Gilligan[1*]

- **Clusters**
  - A group of nodes that are more connected to each other than they are to the rest of the network.
  - How many ‘communities’ are in the Pgt dispersal network?
- **Others**
  - Network density, transitivity



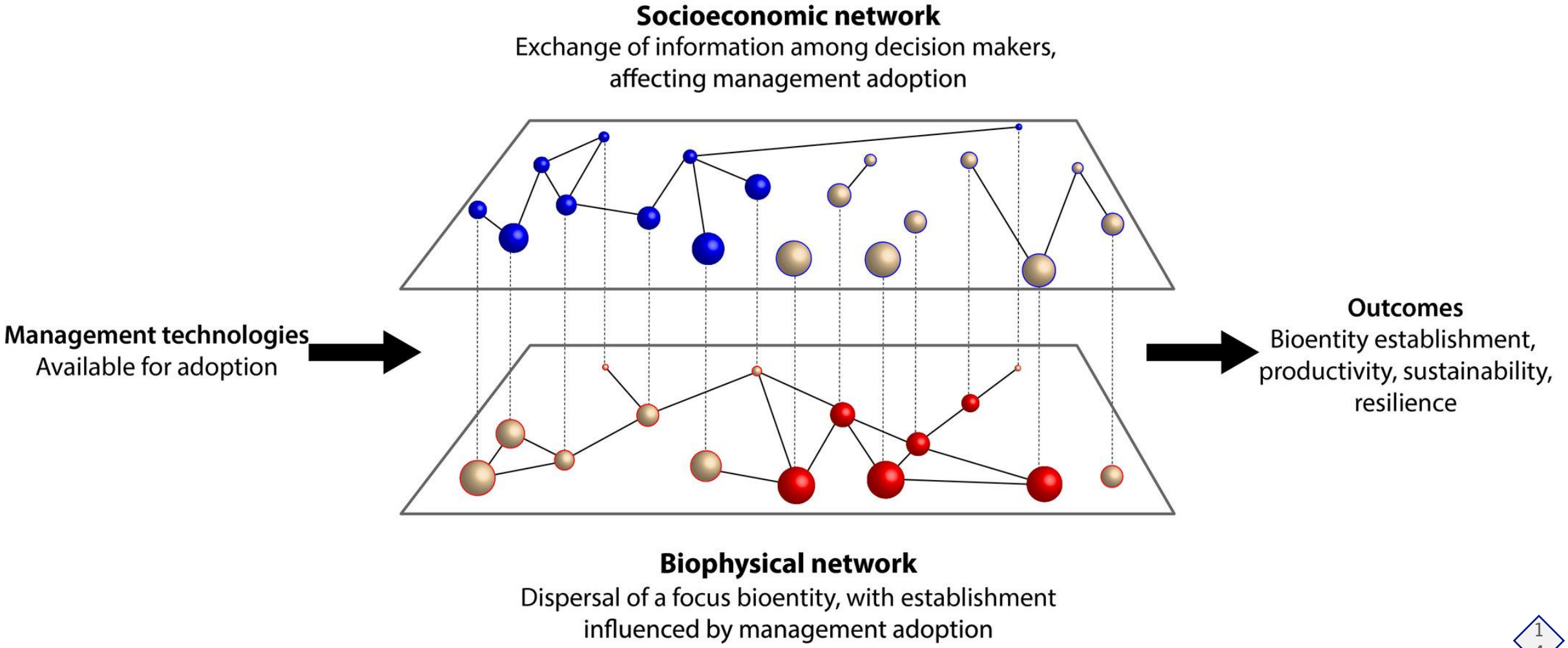
DOI: 10.1111/2041-210X.13655

RESEARCH ARTICLE

Karen A. Garrett

Methods in Ecology and Evolution BRITISH ECOLOGICAL SOCIETY

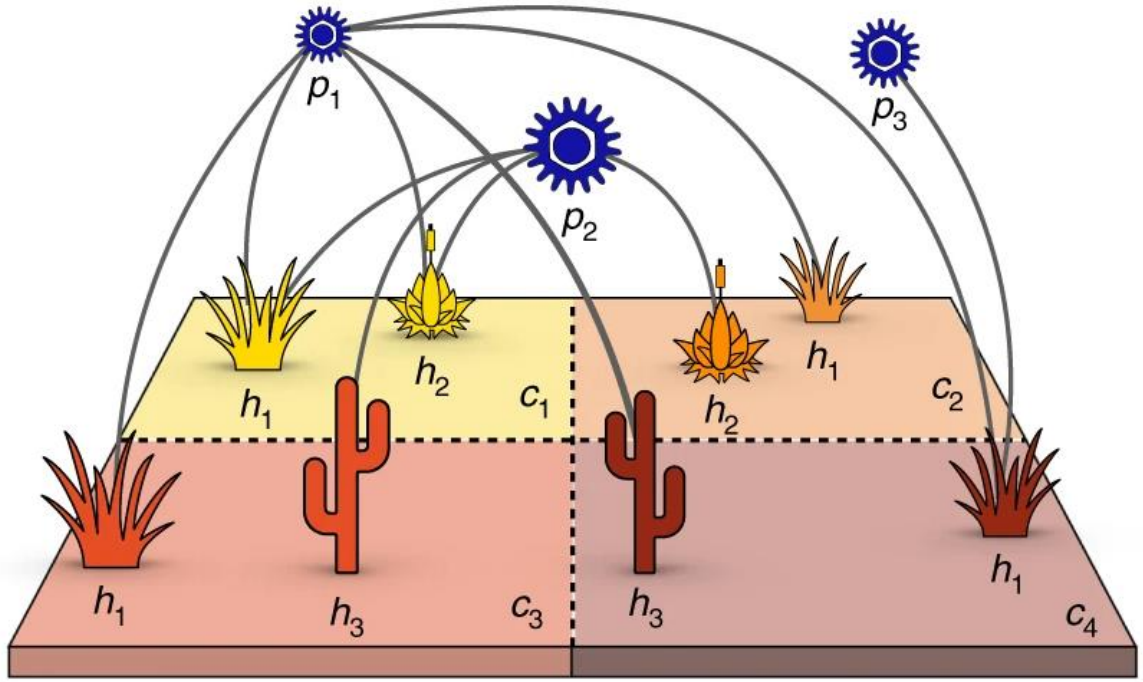
Impact network analysis and the INA R package: Decision support for regional management interventions

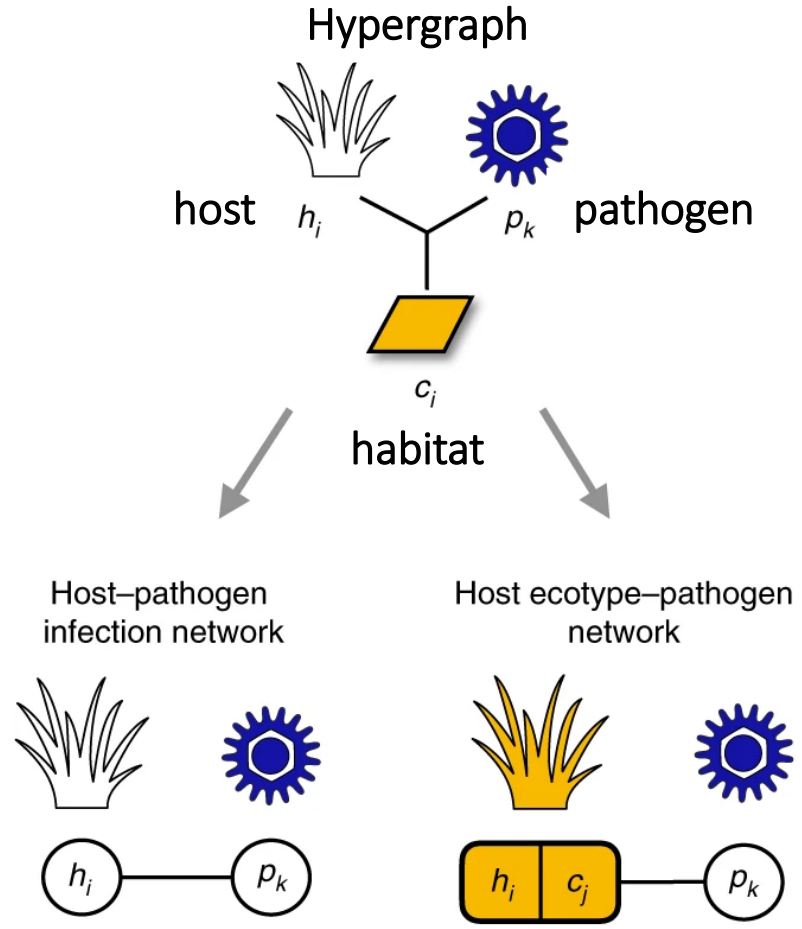


ARTICLES
https://doi.org/10.1038/s41559-020-1130-9
nature ecology & evolution

Coexistence of nestedness and modularity in host–pathogen infection networks

Sergi Valverde[1,2] ✉, Blai Vidiella[3], Raúl Montañez[3], Aurora Fraile[4], Soledad Sacristán[4] and Fernando García-Arenal[4] ✉





GeoHealth

RESEARCH ARTICLE

10.1029/2023GH000885

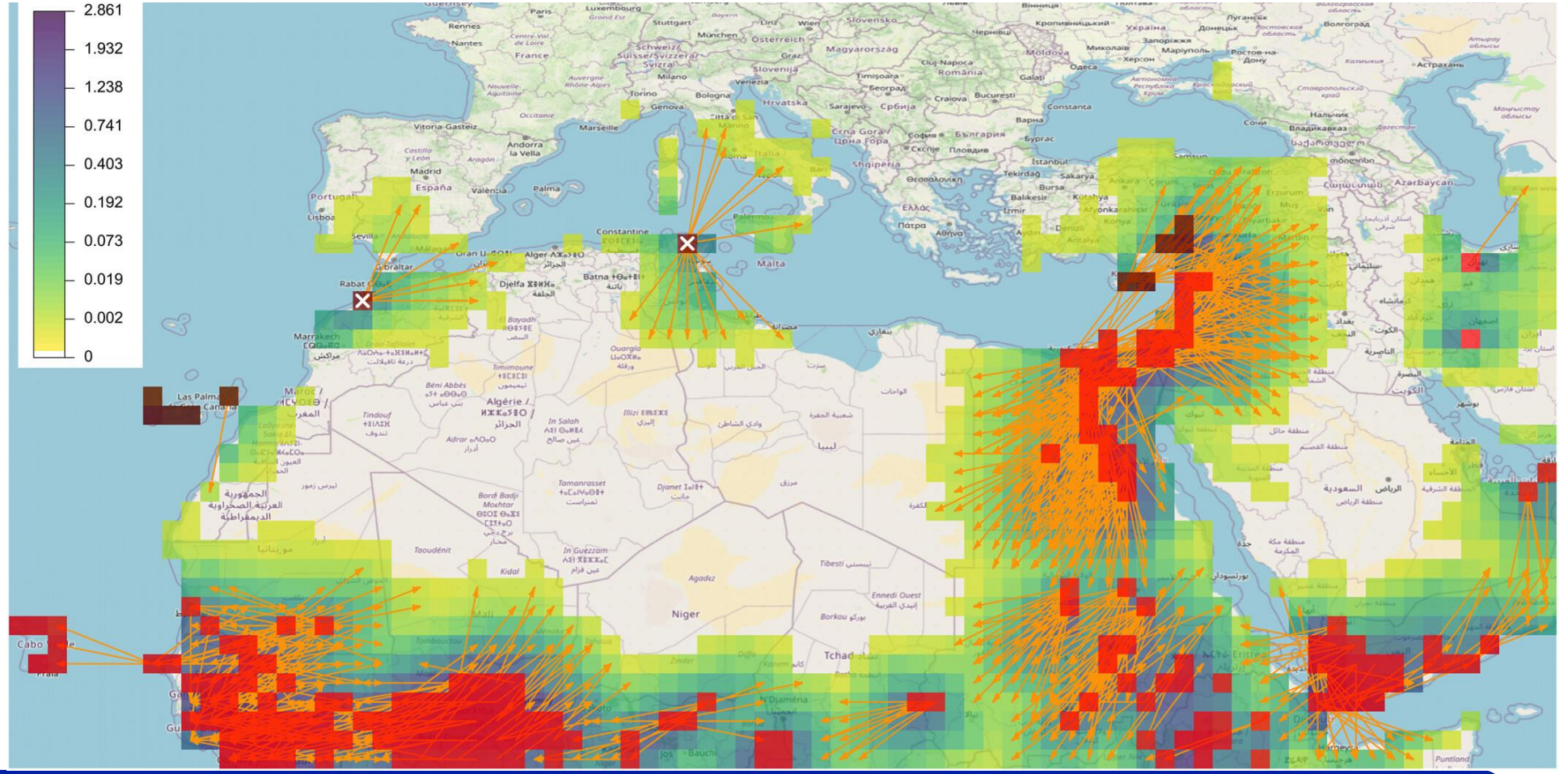
Computing Geographical Networks Generated by Air-Mass Movement

H. Richard[1], D. Martinetti[1], D. Lercier[2], Y. Fouillat[3], B. Hadi[4], M. Elkahky[4], J. Ding[4], L. Michel[5], C. E. Morris[6], K. Berthier[6], F. Maupas[7], and S. Soubeyrand[1]

Key Points:

- The movement of air masses within the troposphere generate air highway

Fall armyworm presence times wind connectivity



Package 'geohabnet'

June 27, 2024

Title Geographical Risk Analysis Based on Habitat Connectivity

Version 2.1.3

Date 2024-06-26

Author Krishna Keshav [aut, cre],
Aaron Plex [aut] (<https://orcid.org/0000-0001-7317-3090>),
Garrett Lab [ctb] (https://garrettlab.com),
Karen Garrett [aut] (<https://orcid.org/0000-0002-6578-1616>),
University of Florida [cph, fnd] (https://www.ufl.edu)

Maintainer Krishna Keshav <kkeshav@ufl.edu>

Repository CRAN

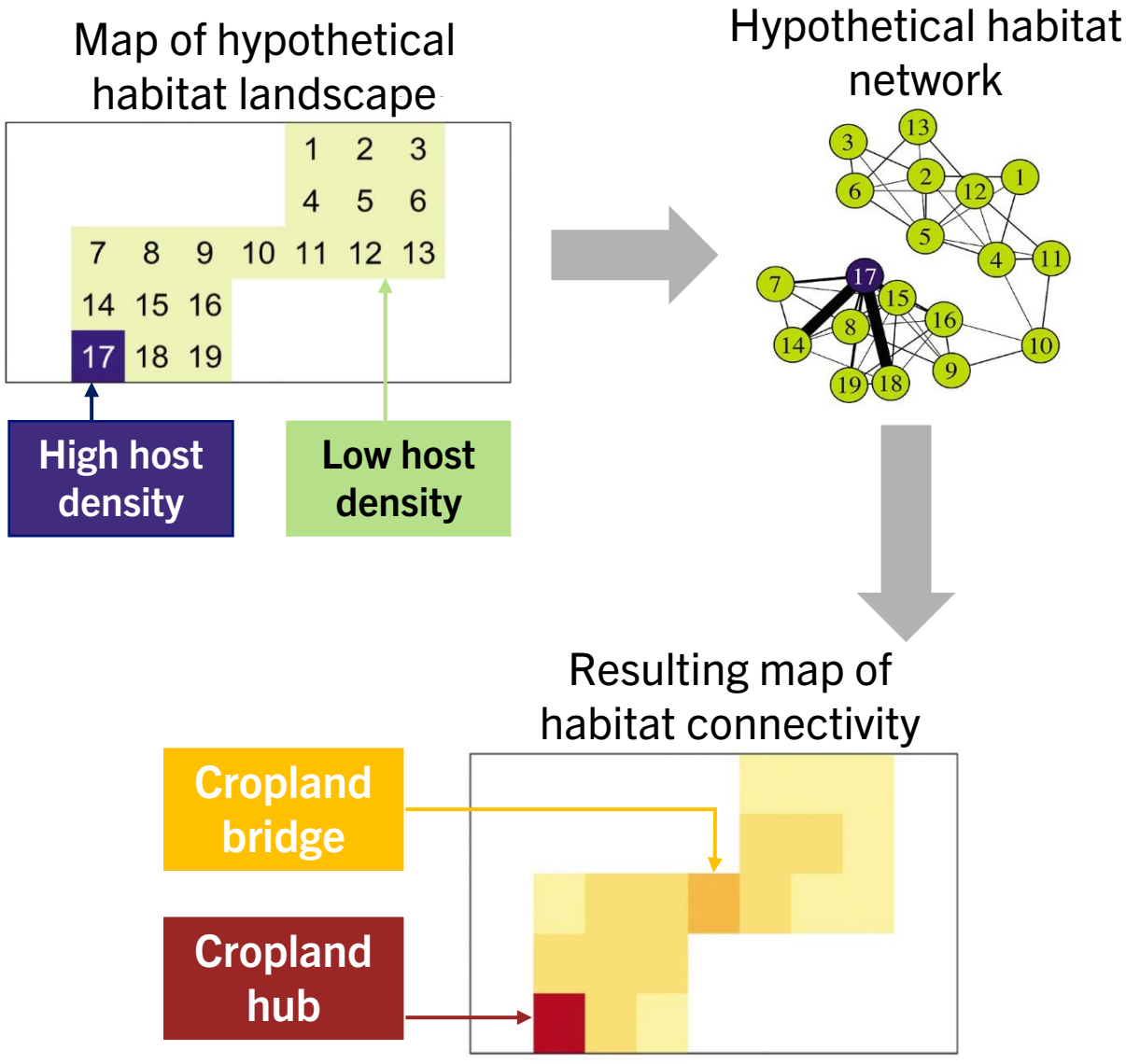
Likely roles of locations in habitat networks

Cropland (habitat) networks

- Geographic locations (nodes)
- Geographic connections (links)

Geographic priorities

- geohabnet



Xing et al. (2020); Margosian et al. (2009)