Smart surveillance and mitigation for plant diseases that threaten food security

Karen A. Garrett

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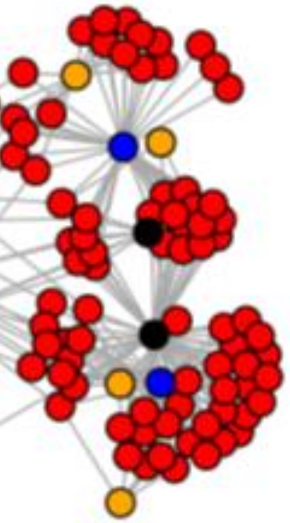
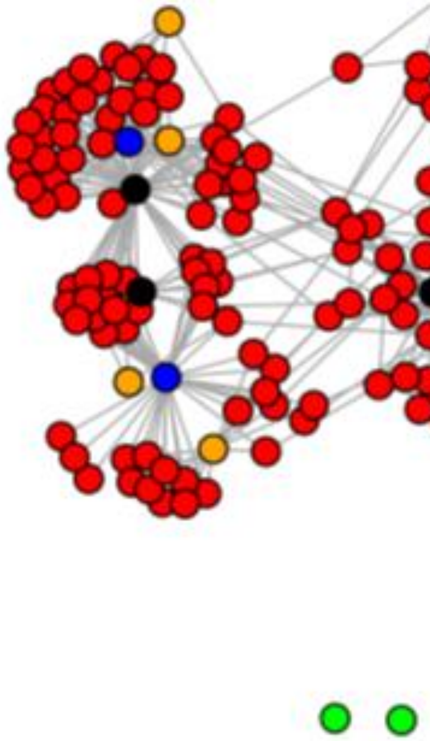




PLANT PATHOLOGY
UF/IFAS

UF IFAS
UNIVERSITY of FLORIDA

Institute for Sustainable Food Systems

Outline

- Intro to network analysis
- Microbiome networks
- Effective altruism & research priorities
- Epidemic networks
- Impact network analysis

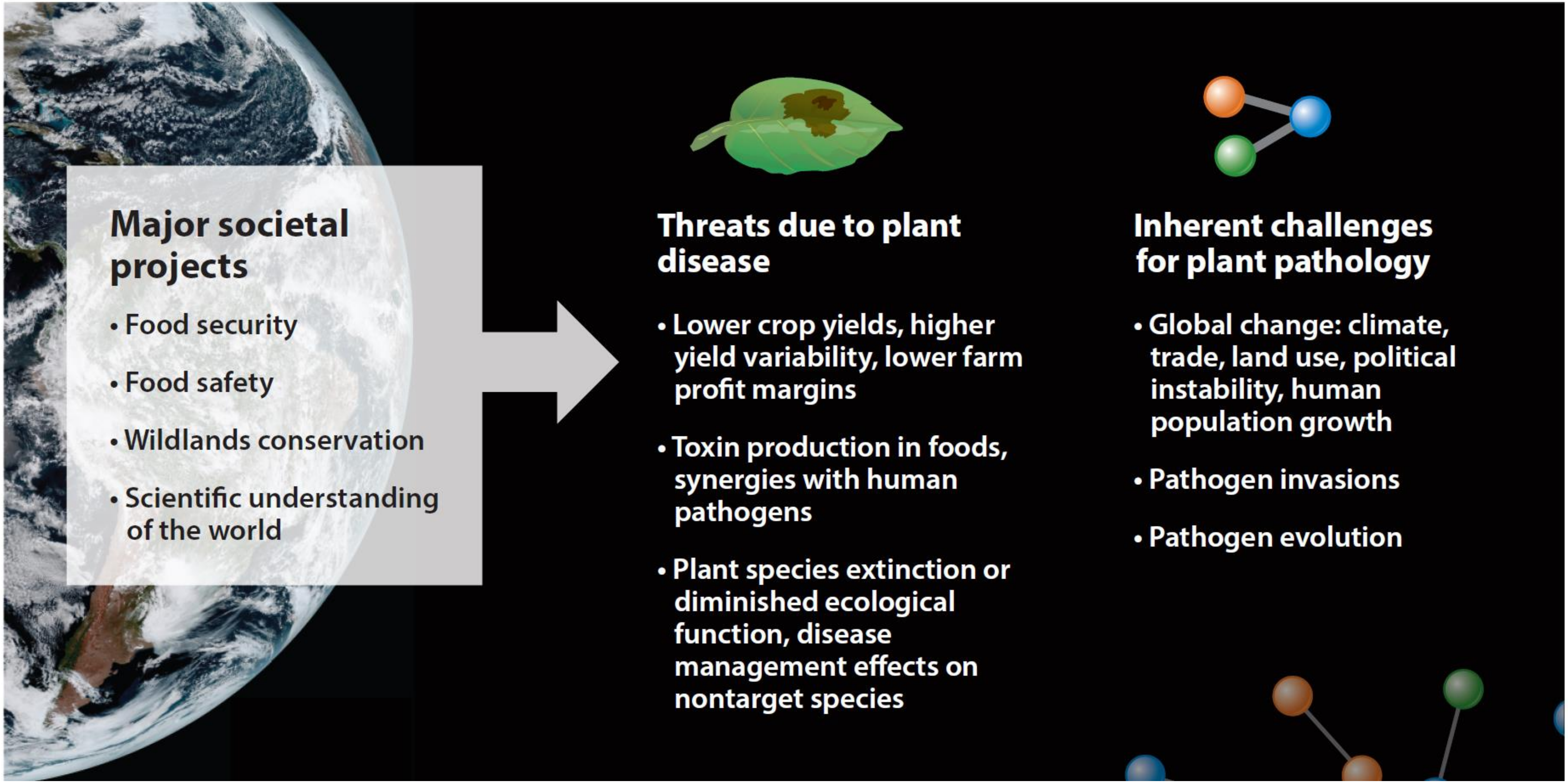
Annual Review of Phytopathology

Network Analysis: A Systems Framework to Address Grand Challenges in Plant Pathology

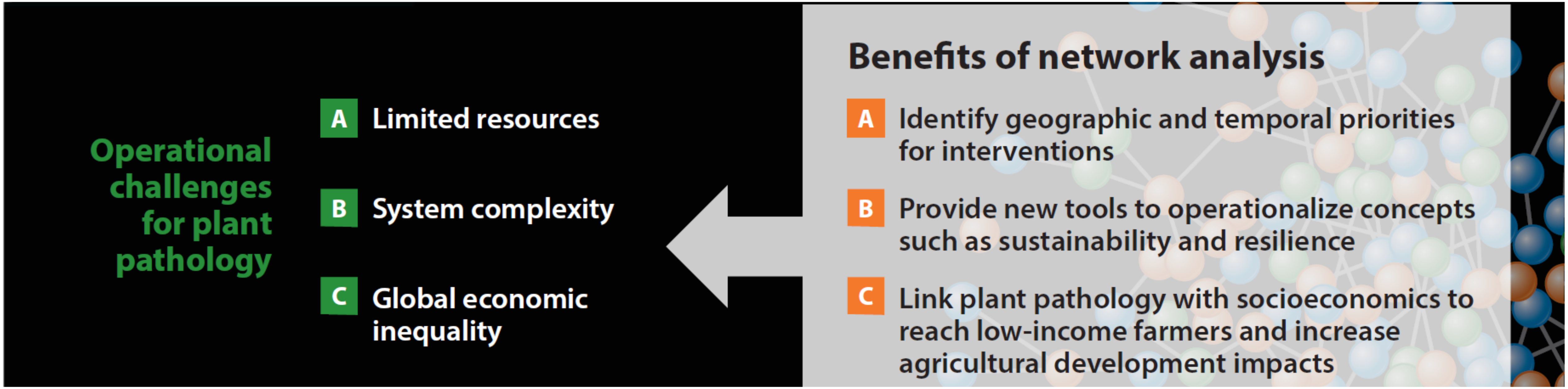
K.A. Garrett,[1,2,3] R.I. Alcalá-Briseño,[1,2,3] K.F. Andersen,[1,2,3] C.E. Buddenhagen,[1,2,3,4] R.A. Choudhury,[1,2,3] J.C. Fulton,[1,2,3] J.F. Hernandez Nopsa,[1,2,3,5] R. Poudel,[1,2,3] and Y. Xing

Annu. Rev. Phytopathol. 2018. 56:559–80

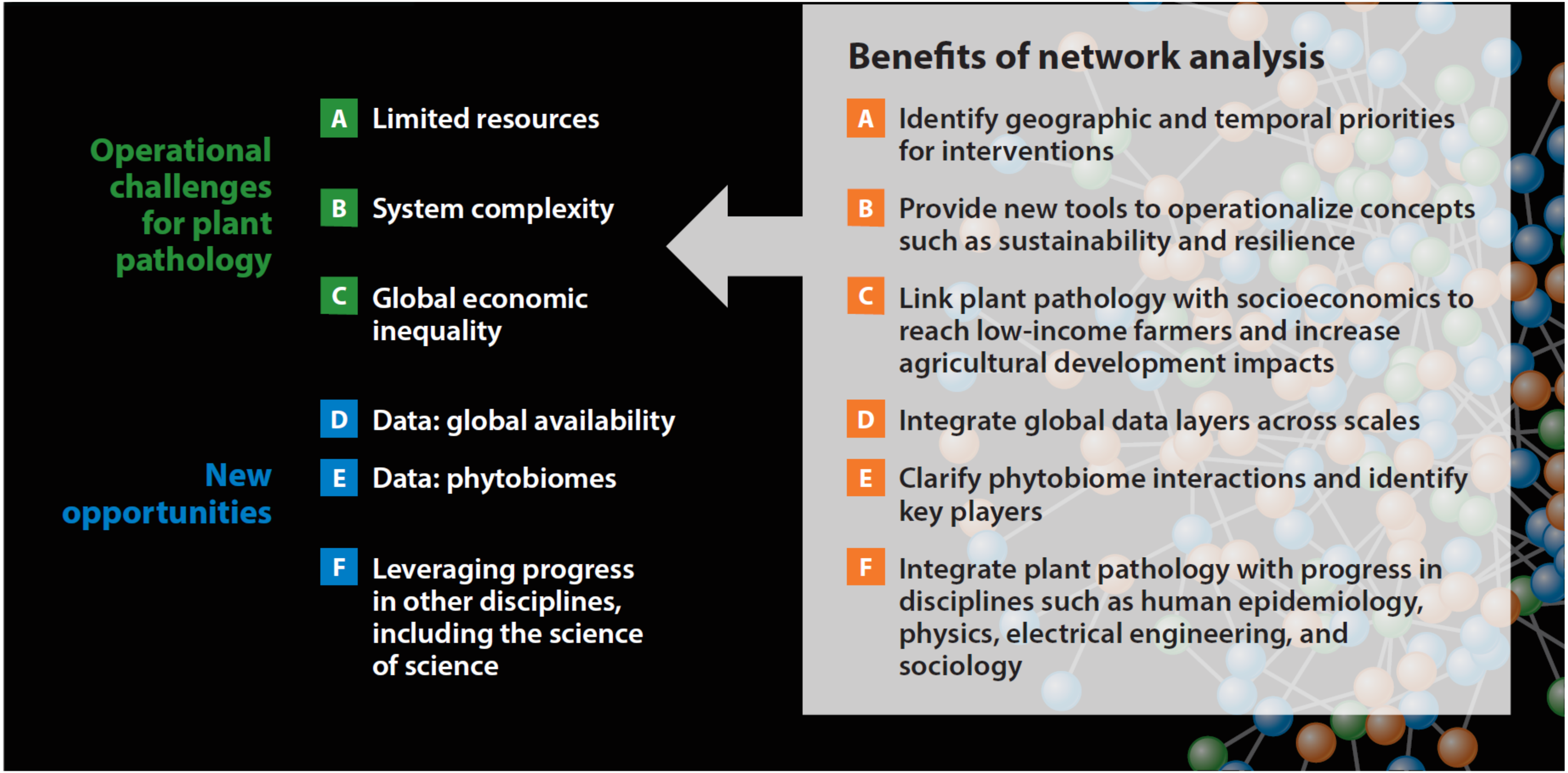
Garrett et al 2018 ARP



Garrett et al 2018 ARP

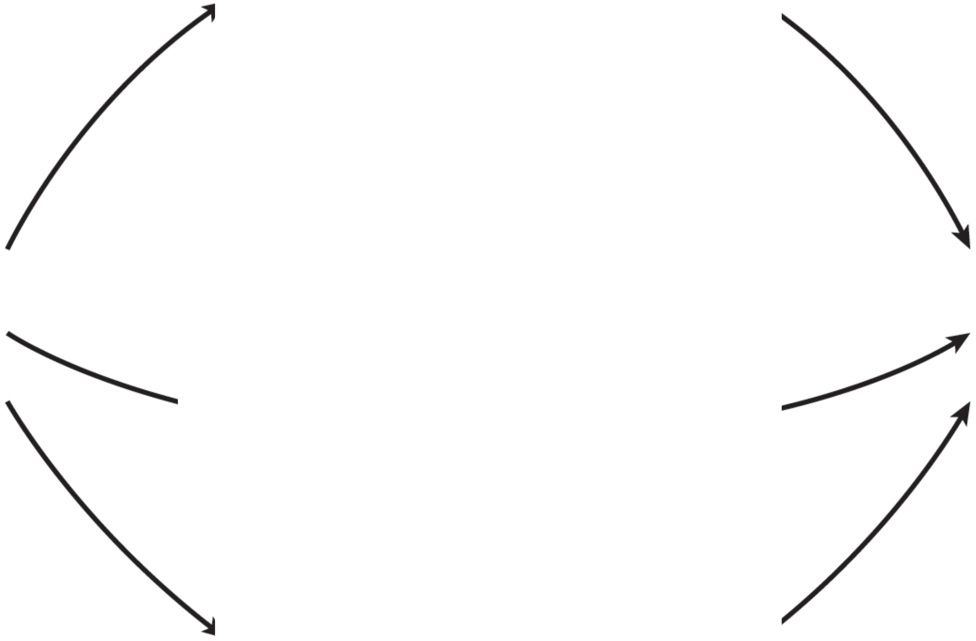


Garrett et al 2018 ARP

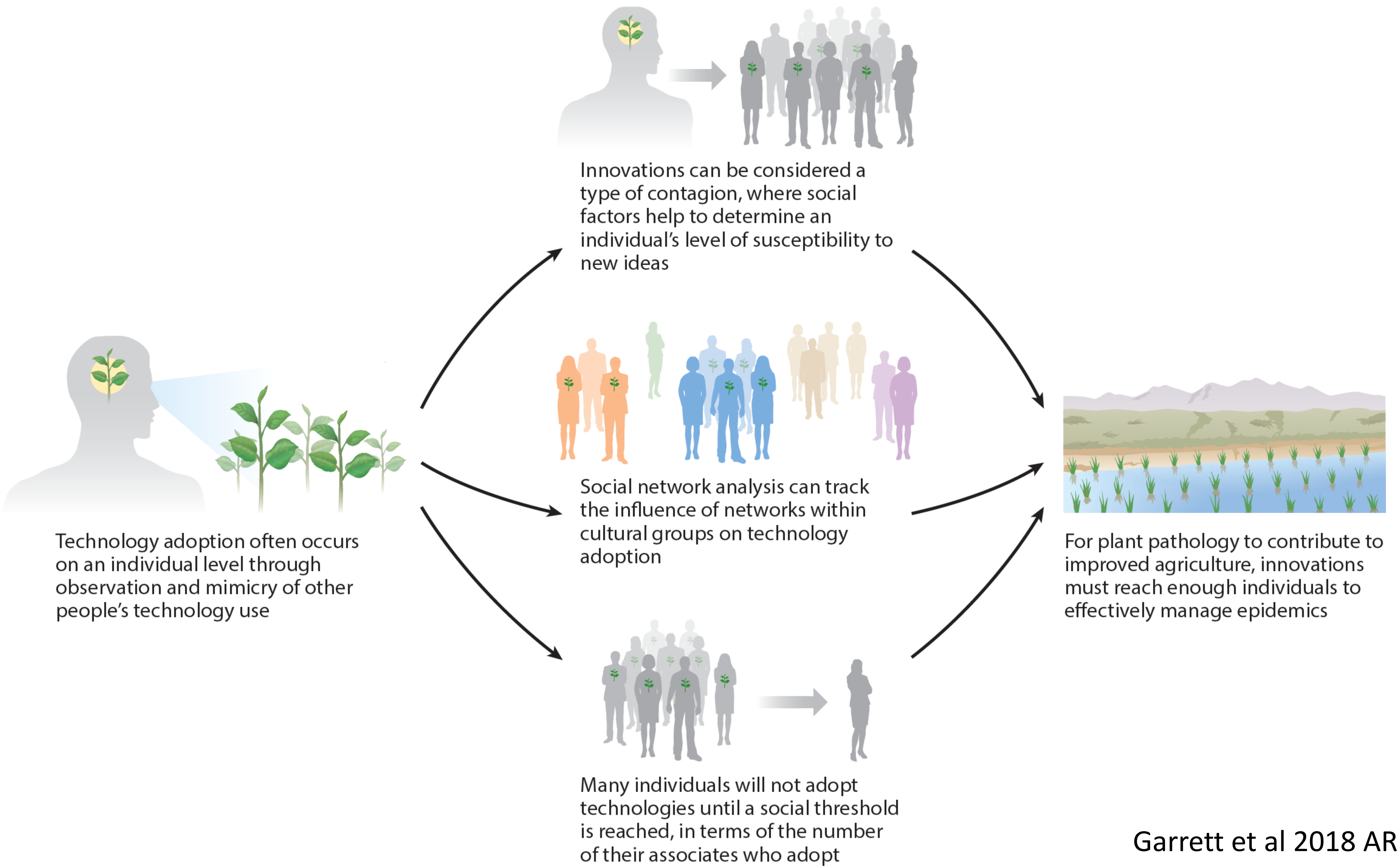


Garrett et al 2018 ARP

Technology adoption often occurs on an individual level through observation and mimicry of other people's technology use

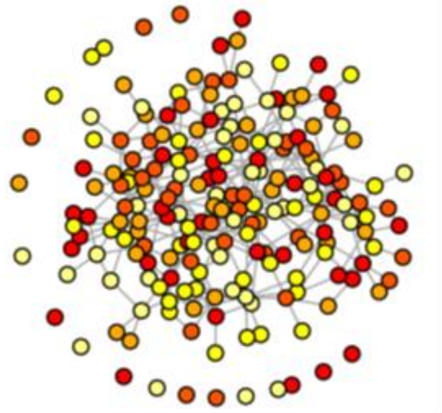


Garrett et al 2018 ARP



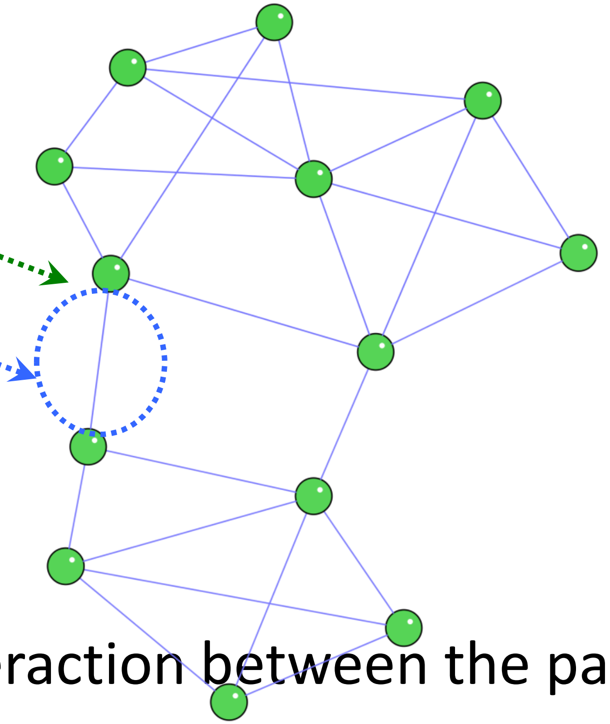
Garrett et al 2018 ARP

Dynamic network models



Node (Vertex)

Link (Edge)

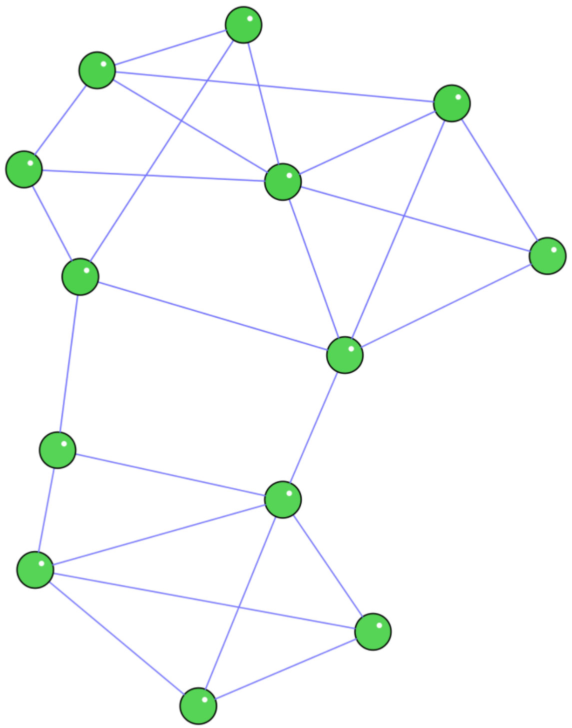


Link weight: Level of interaction between the pair of nodes

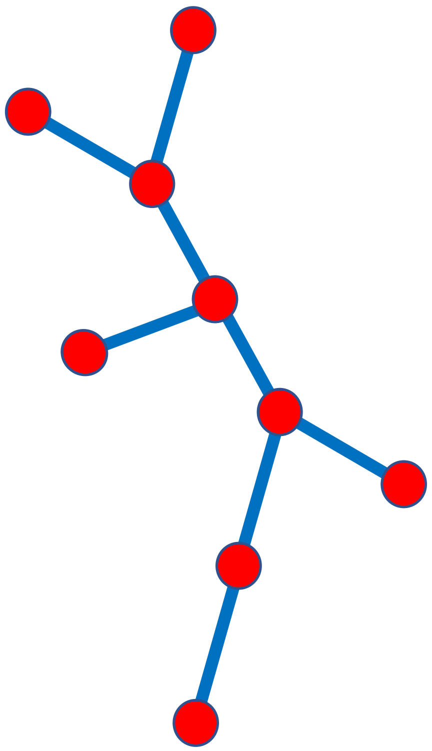
Dynamic nature: Link weights change over time

Infinite possibilities for network model structures

- Nodes could be
  - Locations in spatial networks (counties, fields, plants, leaves, cells, organelles, microbes, …)
  - Entities
    - Individual people
    - Species (perhaps in food webs or the phytobiome)
    - Genes
    - Molecules
- Links could be
  - Strength or likelihood of influence, triggering, information flow, …
  - Dependent on environmental variables



Traits of network nodes



- In a socioeconomic network, nodes are people or human institutions (managers/farmers, extension agents, scientists, …)
- In a biophysical network, nodes are geographic locations (individual plants, farms, storage facilities, wildlands, …)

- Degree centrality – number of links
- Closeness centrality – measure of how readily other nodes can be reached
- Betweenness centrality – importance as a bridge between other nodes
- Centrality of neighbors – importance in terms of importance of neighbors

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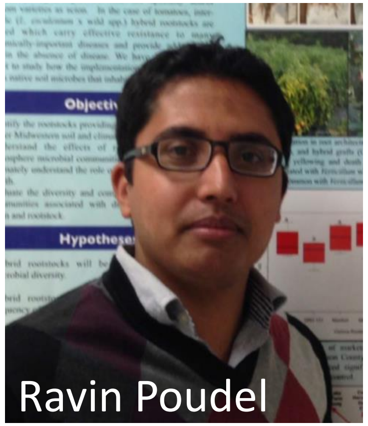
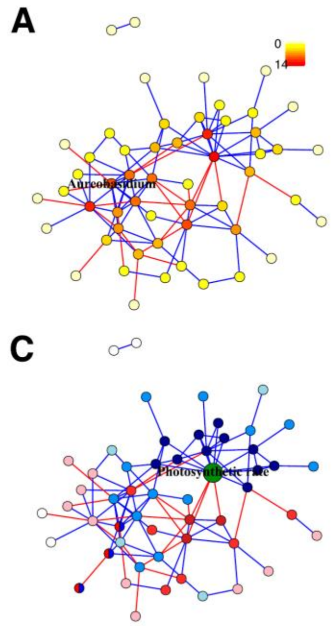


Microbiome systems analysis can mobilize high-throughput sequencing to inform strategies for making the most of microbiomes



Microbiome Networks: A Systems Framework for Identifying Candidate Microbial Assemblages for Disease Management

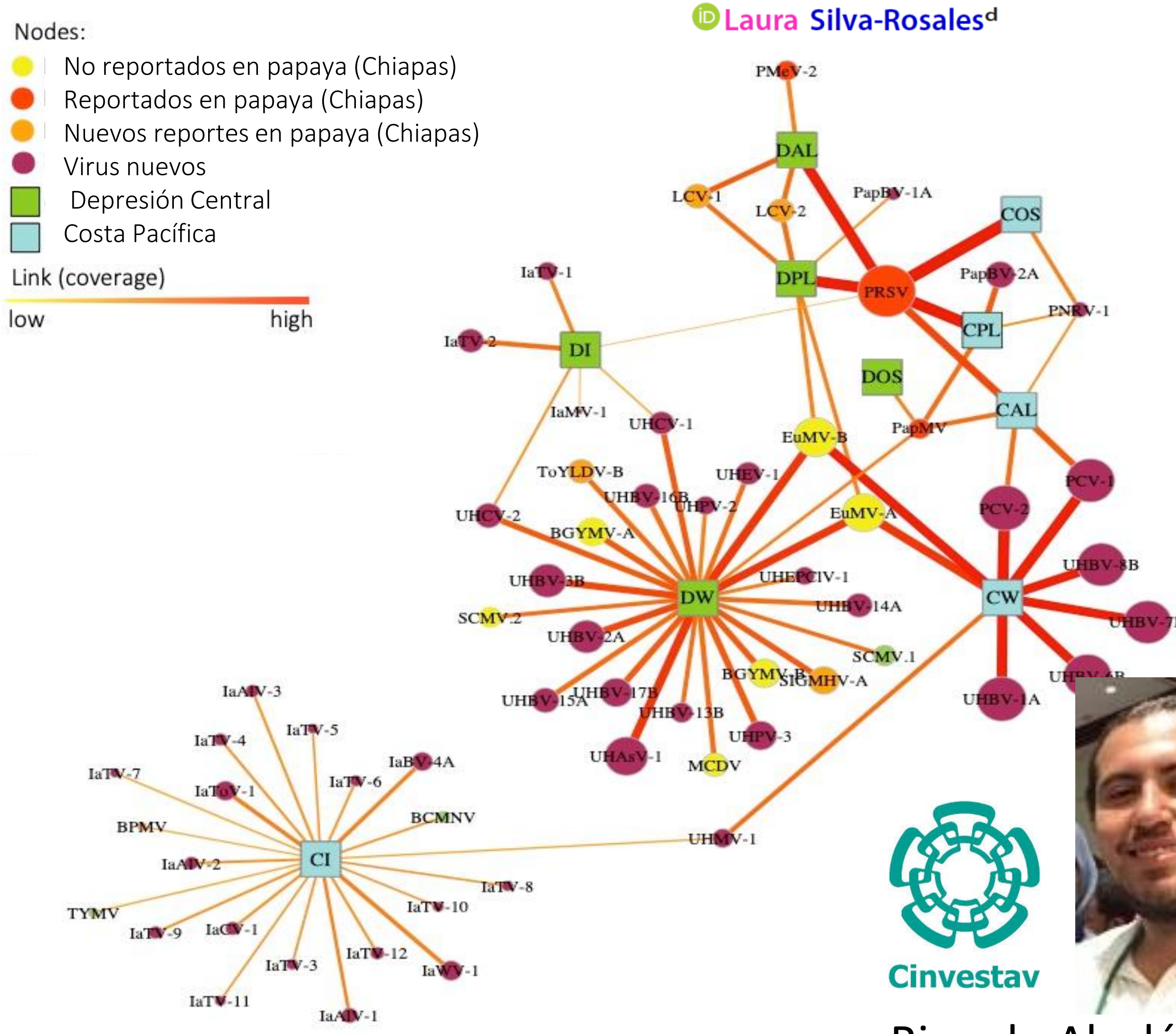
R. Poudel, A. Jumpponen, D. C. Schlatter, T. C. Paulitz, B. B. McSpadden Gardener, L. L. Kinkel, and K. A. Garrett

Phytopathology 2016 [open access link]

Network Analysis of the Papaya Orchard Virome from Two Agroecological Regions of Chiapas, Mexico

Ricardo I. Alcalá-Briseño,[a,b,c,d] Kena Casarrubias-Castillo,[d*] Diana López-Ley,[d] Karen A. Garrett,[a,b,c] Laura Silva-Rosales[d]

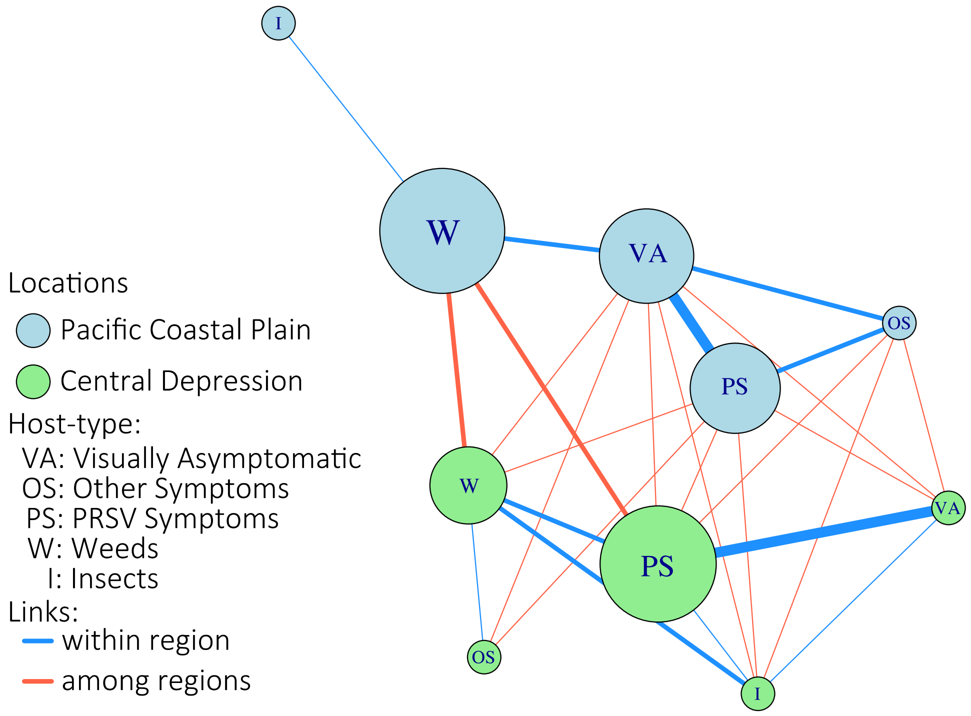
mSystems, publishing Jan 14



Cinvestav

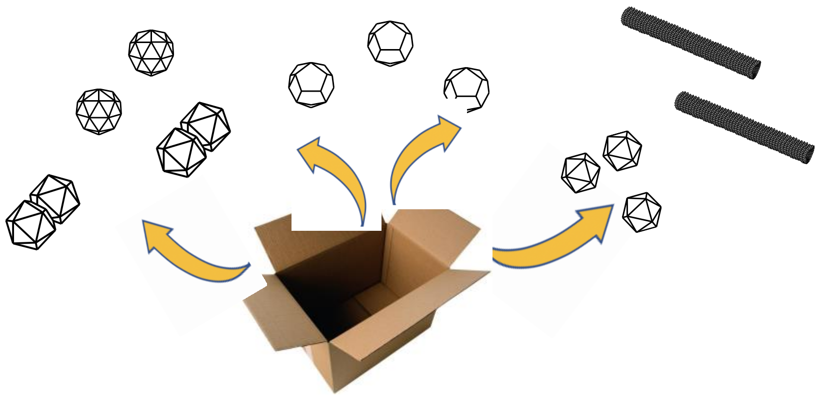
Ricardo Alcalá Briseño

Other sources of viruses in the system

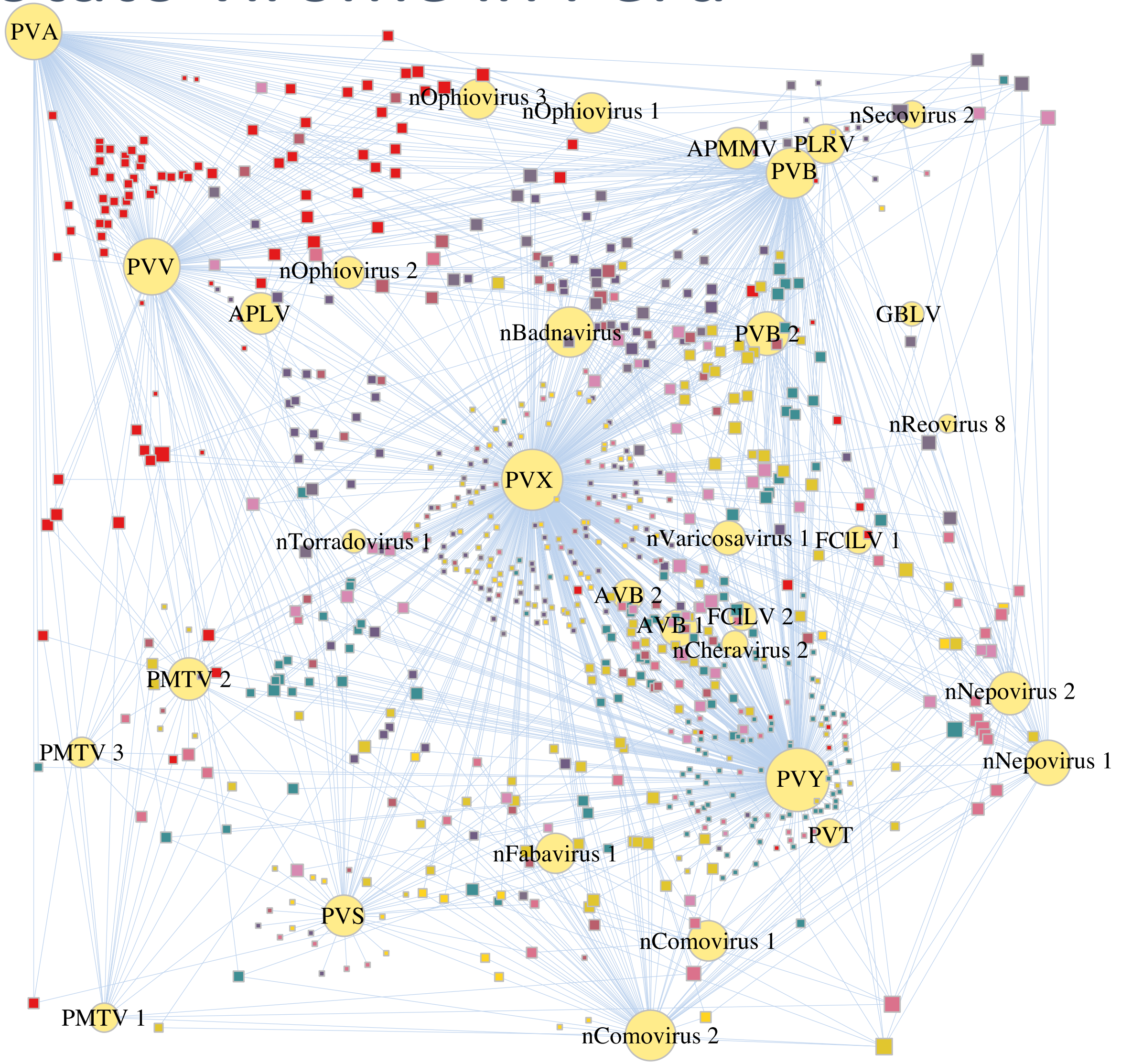


Viromes and phytosanitary standards

- Opening Pandora's box with virome analysis



Potato virome in Peru



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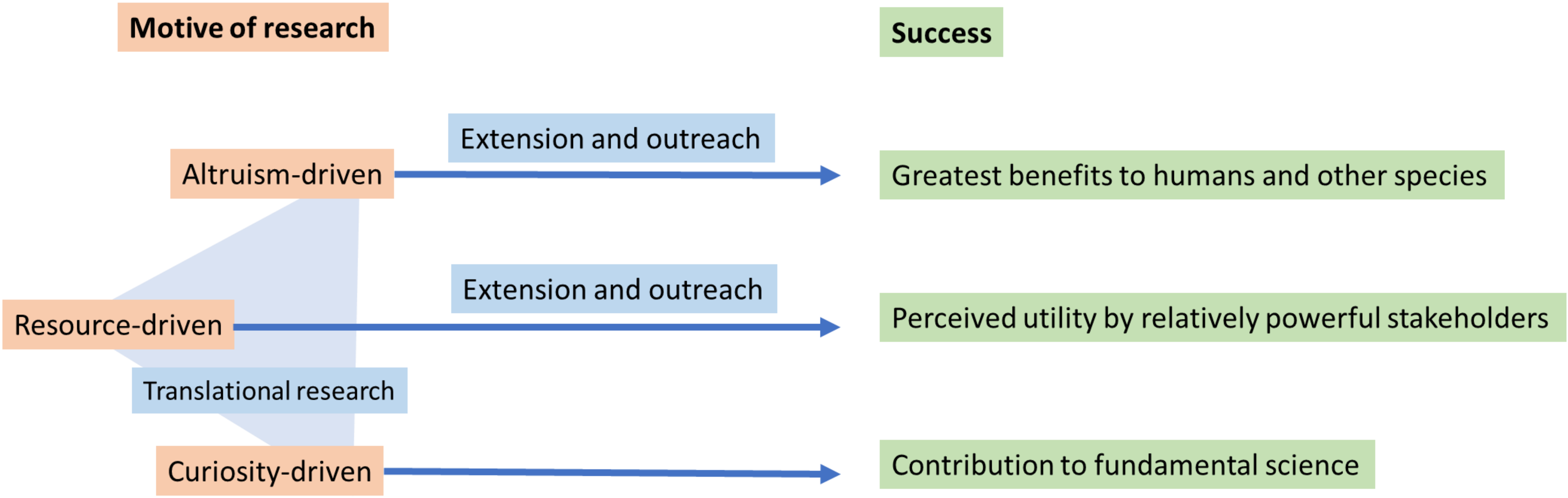
Effective altruism as an ethical lens on research priorities:

- K. A. Garrett, R. I. Alcalá-Briseño, K. F. Andersen, J. Brawner, R. A. Choudhury, E. Delaquis, J. Fayette, R. Poudel, D. Purves, J. Rothschild, I. M. Small, S. Thomas-Sharma, and Y. Xing
- Phytopathology


Motive of research
Success
Extension and outreach
Altruism-driven
Greatest benefits to humans and other species
Extension and outreach
Resource-driven
Perceived utility by relatively powerful stakeholders
Translational research
Curiosity-driven
Contribution to fundamental science

Potential prioritization of research by stakeholders, pathosystems, and experimental questions and techniques

Prioritizing stakeholders

Food security & food safety

- People at greatest risk
- People underserved
- People who will experience the greatest gain
- Greatest number benefiting

Wildlands conservation

- Endangered species
- Biodiversity hotspots
- Systems providing greatest ecosystem services

Prioritizing pathosystems

- Diseases causing the greatest yield loss or quality loss
- Diseases causing the greatest health risks by toxin production
- Systems that would otherwise not receive attention
- Orphan crops and orphan pathosystems
- Geographic locations of greatest importance in epidemic networks

Prioritizing experimental questions and technologies

Examples, see also Table 1

Avoiding the tragedy of the microbiome commons

- Regional microbiomes can be considered a common pool good like air or water, degraded by individuals who manage plant diseases poorly
- Research providing global public goods can support technology spread and durability (Fig. 5)

Value of information (VoI)

- Providing information that will have a substantial effect to improve key decision-making outcomes

Big ethics for big data

- Addressing costs and benefits of data collection and data availability for the range of stakeholders
- Addressing new ethical questions as networking of digital agriculture advances

Doomsday pathogens

- Addressing low-probability existential risks

Garrett et al. 2020 Phytopathology

Avoiding the tragedy of the microbiome commons

Consumption	Access				
	Exclusive			***Non-exclusive***	
Rival	*Private:* e. g., food	Pesticides vulnerable to antibiotic resistance	Formal seed systems Private non-durable resistance genes	*Common pool:* e. g., air, water **Regional microbiome** **Regional pathogen meta-communities** Informal seed systems Public non-durable resistance genes	
Non-rival	*Club/Toll:* e. g., private schools	Pesticides not vulnerable to antibiotic resistance	Private durable resistance genes Private data and models for disease management	Public durable resistance genes Public data and models for disease management	*Public: e. g.,* sunshine

Garrett et al. 2020 Phytopathology


WITH GREAT NODE DEGREE AND BETWEENNESS CENTRALITY COMES GREAT RESPONSIBILITY...

POLICY FORUM

FOOD SECURITY

A global surveillance system for crop diseases

Global preparedness minimizes the risk to food supplies

By **M. Carvajal-Yepes,[1] K. Cardwell,[2] A. Nelson,[3] K. A. Garrett,[4] B. Giovani,[5] D. G. O. Saunders,[6] S. Kamoun,[7] J. P. Legg,[8] V. Verdier,[9] J. Lessel,[10] R. A. Neher,[11] R. Day,[12] P. Pardey,[13] M. L. Gullino,[14] A. R. Records,[15] B. Bextine,[16] J. E. Leach,[17] S. Staiger,[1] J. Tohme[1]**

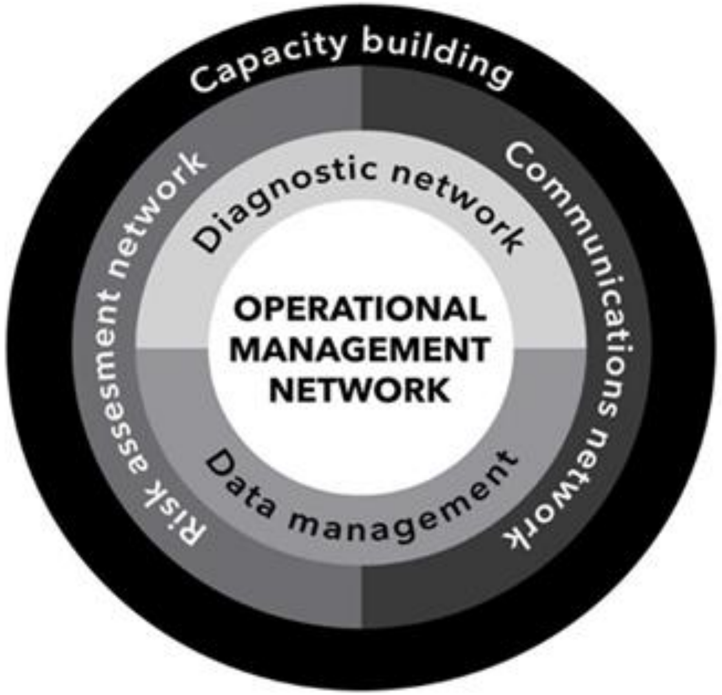
oping and maintaining surveillance systems with well-established network labs for diagnosis and promoting norms for sharing data and information during outbreaks (*5*). In a similar spirit, with the United Nations General Assembly having proclaimed 2020 as the International Year of Plant Health to increase awareness among the public and

fectively screened; thus, actual movement of potential biological invasive species through official entry points is barely constrained (*8*).

General or passive surveillance is aimed at detecting and diagnosing all pests and crop diseases, not just those that are regulated. Passive surveillance personnel either spot diseases during field surveys or re-

[1]International Center of Tropical Agriculture, Cali, Colombia. [2]Oklahoma State University, Stillwater, OK, USA. [3]Department of Natural Resources, Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Enschede, Netherlands. [4]University of Florida, Gainesville, FL, USA. [5]European and Mediterranean Plant Protection Organization–Euphresco, Paris, France. [6]John Innes Centre, Norwich, UK. [7]The Sainsbury Laboratory, University of East Anglia, Norwich, UK. [8]International Institute of Tropical Agriculture, Dar es Salaam, Tanzania. [9]French National Research Institute for Sustainable Development (IRD), CIRAD, University of Montpellier, Interactions Plantes Microorganismes Environnement, Montpellier, France. [10]Gro Intelligence, New York, NY, USA. [11]University of Basel, Basel, Switzerland. [12]Centre for Agriculture and Biosciences International, Wallingford, UK. [13]University of Minnesota, Minneapolis, MN, USA. [14]Torino University, Torino, Italy. [15]United States Agency for International Development, Washington, DC, USA. [16]University of Texas, Austin, TX, USA. [17]Colorado State University, Fort Collins, CO, USA. Email: m.carvajal@cgiar.org; j.tohme@cgiar.org

It would create linkages between general and specific surveillance entities across countries to increase coordination in high-consequence disease detection, allowing optimization of early response and control. It would function through five interconnected networks: (i) diagnostic labs, (ii) risk assessment modeling teams, (iii) data standardization and management specialists, (iv) regular expert communications, and (v) a distributed operations management system, all sharing a cross-cutting capacity-development component. A pilot phase would focus on high-risk diseases



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Connectivity of the American Agricultural Landscape: Assessing the National Risk of Crop Pest and Disease Spread

Peg Margosian

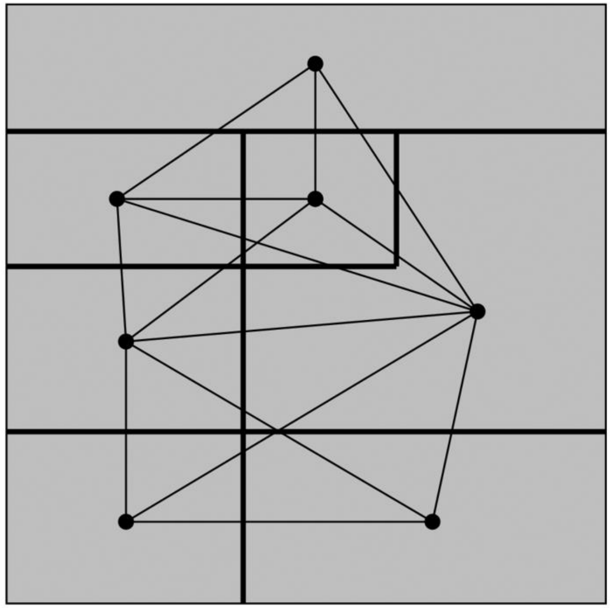
MARGARET L. MARGOSIAN, KAREN A. GARRETT, J. M. SHAWN HUTCHINSON, AND KIMBERLY A. WITH

[open access link]

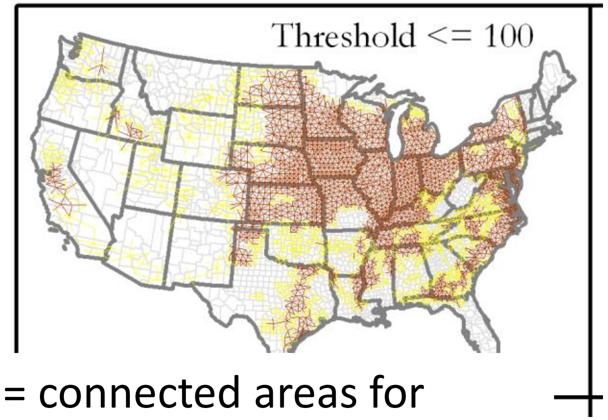
February 2009 / Vol. 59 No. 2 • BioScience 141

Nodes: US counties

Links: measures of likelihood of pathogen movement based on host availability



Maize



Red = connected areas for pathogens that require **at least low** maize density to spread

Red = connected areas for pathogens that require **high** maize density to spread

Sweta
Sutrave

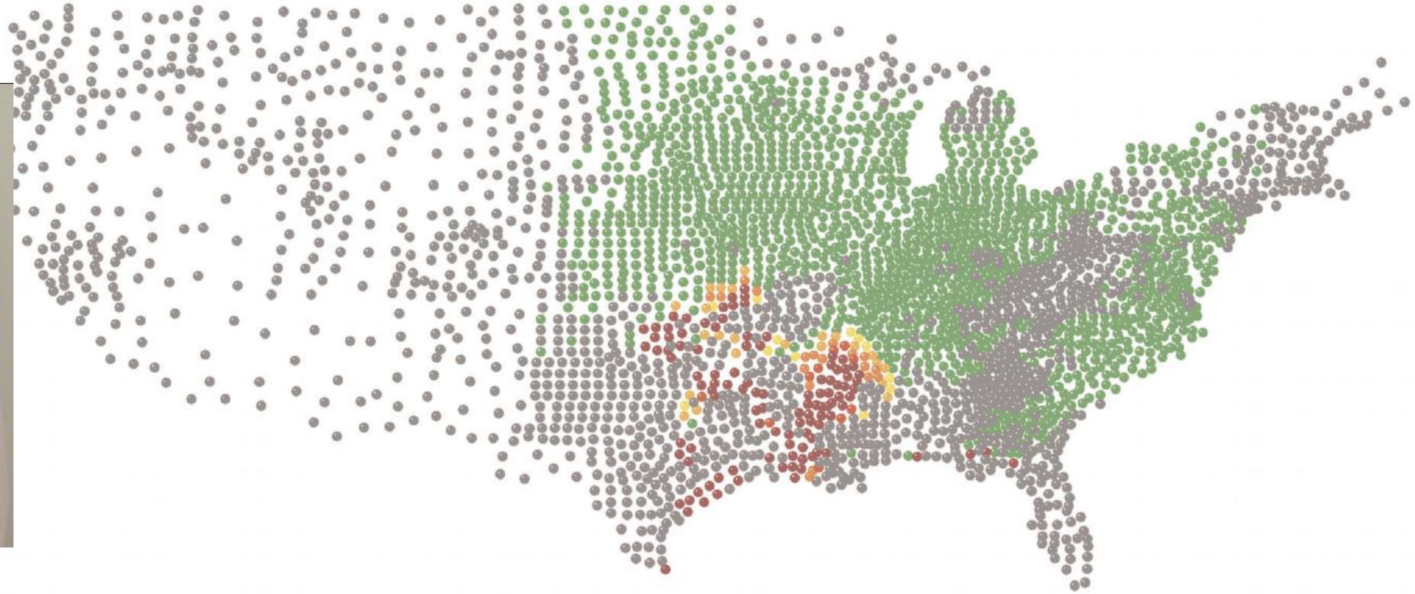


Figure 2. Prediction for soybean rust infection in the United States in September 2007 based on 2007 observations through August. Dark red nodes represent counties which were predicted to be infected with high probability, green nodes represent counties which were predicted to be uninfected with negligible probability of infection, and all other shades from green to dark red represent increasing probability of infection.

Identifying Highly Connected Counties Compensates for Resource Limitations when Evaluating National Spread of an Invasive Pathogen

Sweta Sutrave[1,2], Caterina Scoglio[2], Scott A. Isard[3], J. M. Shawn Hutchinson[4], Karen A. Garrett[1]*

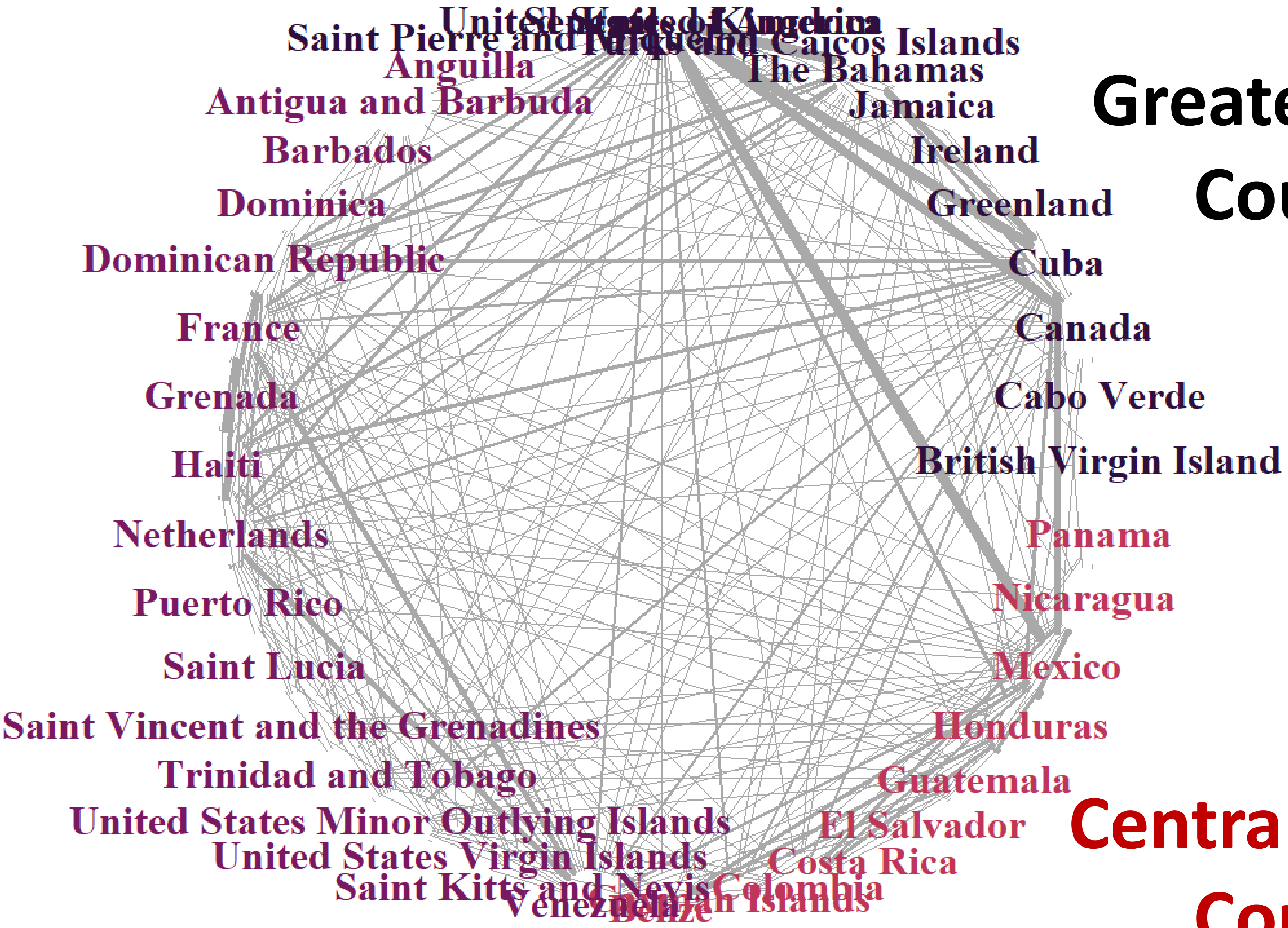
[open access link]

2012

Network of Countries Connected by Hurricanes

Greater Atlantic Countries

Caribbean Countries

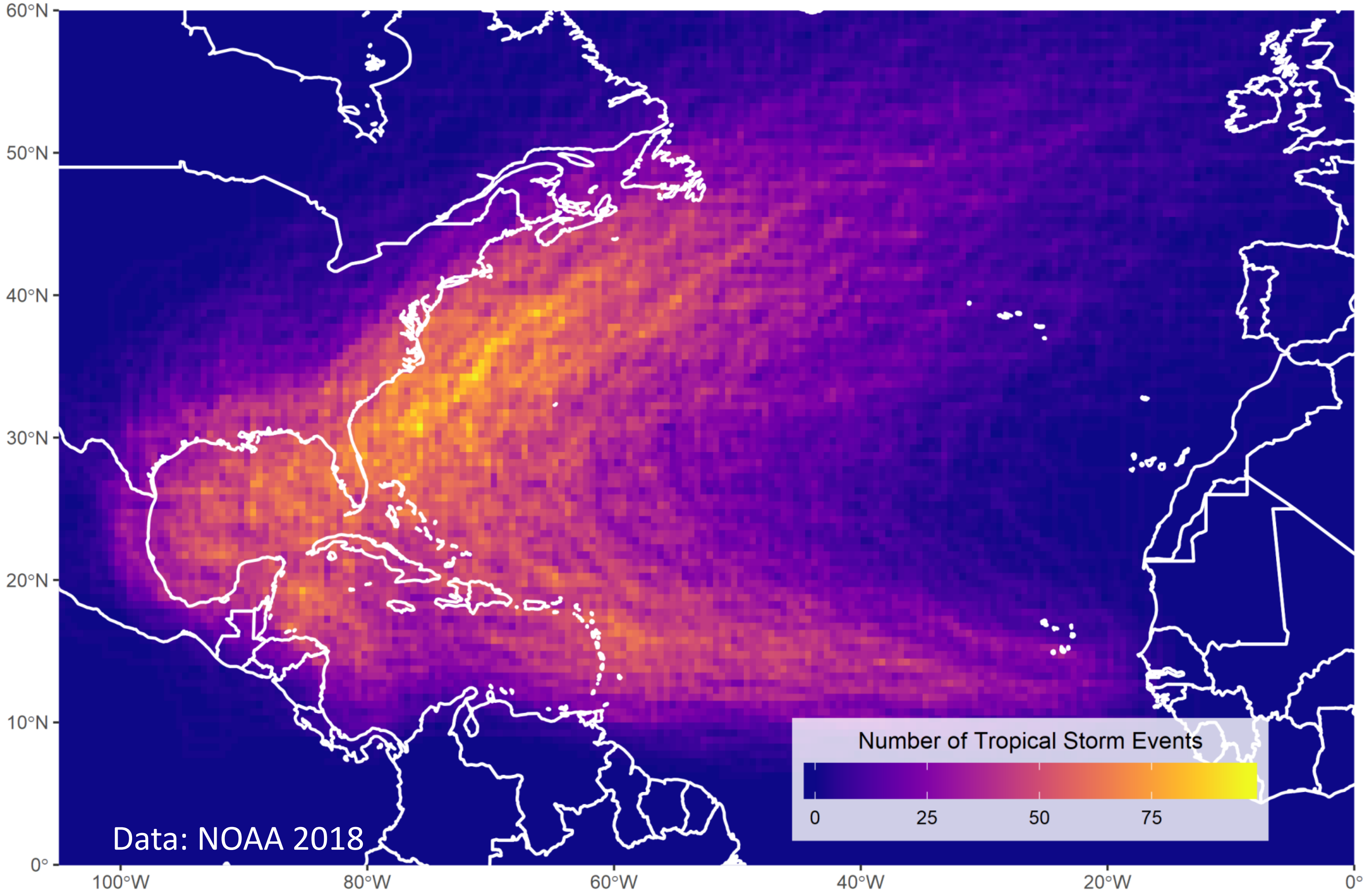


Central American Countries

Robin Choudhury

Choudhury and Garrett

Aggregated Number of Storm Events



Robin Choudhury

Choudhury and Garrett, in revision

Ecological Networks in Stored Grain: Key Postharvest Nodes for Emerging Pests, Pathogens, and Mycotoxins

JOHN F. HERNANDEZ NOPSA, GREGORY J. DAGLISH, DAVID W. HAGSTRUM, JOHN F. LESLIE, THOMAS W. PHILLIPS, CATERINA SCOGLIO, SARA THOMAS-SHARMA, GIMME H. WALTER, AND KAREN A. GARRETT

John Hernandez Nopsa

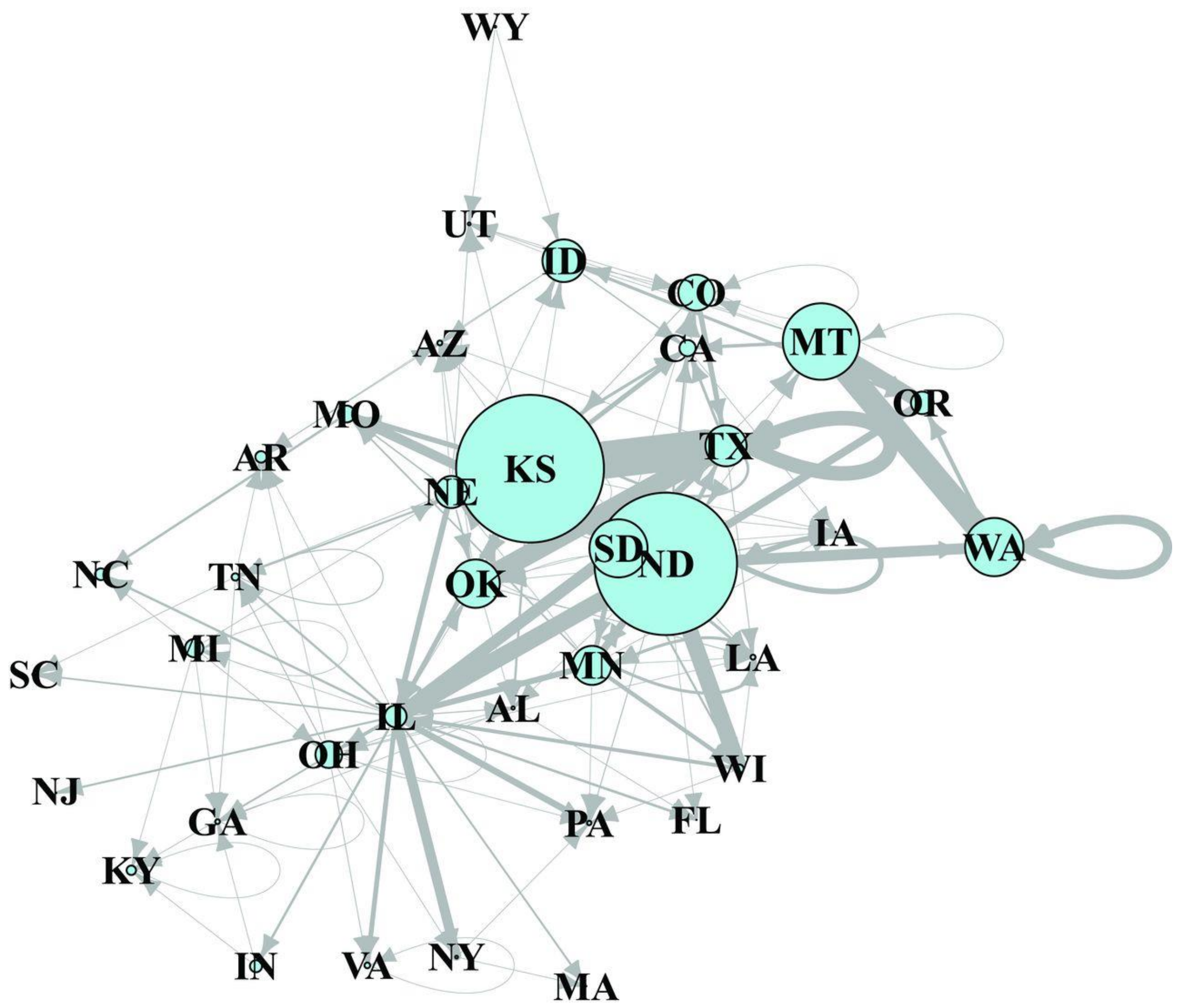
BioScience

An Australian Government Initiative

CRC AUSTRALIA

2015

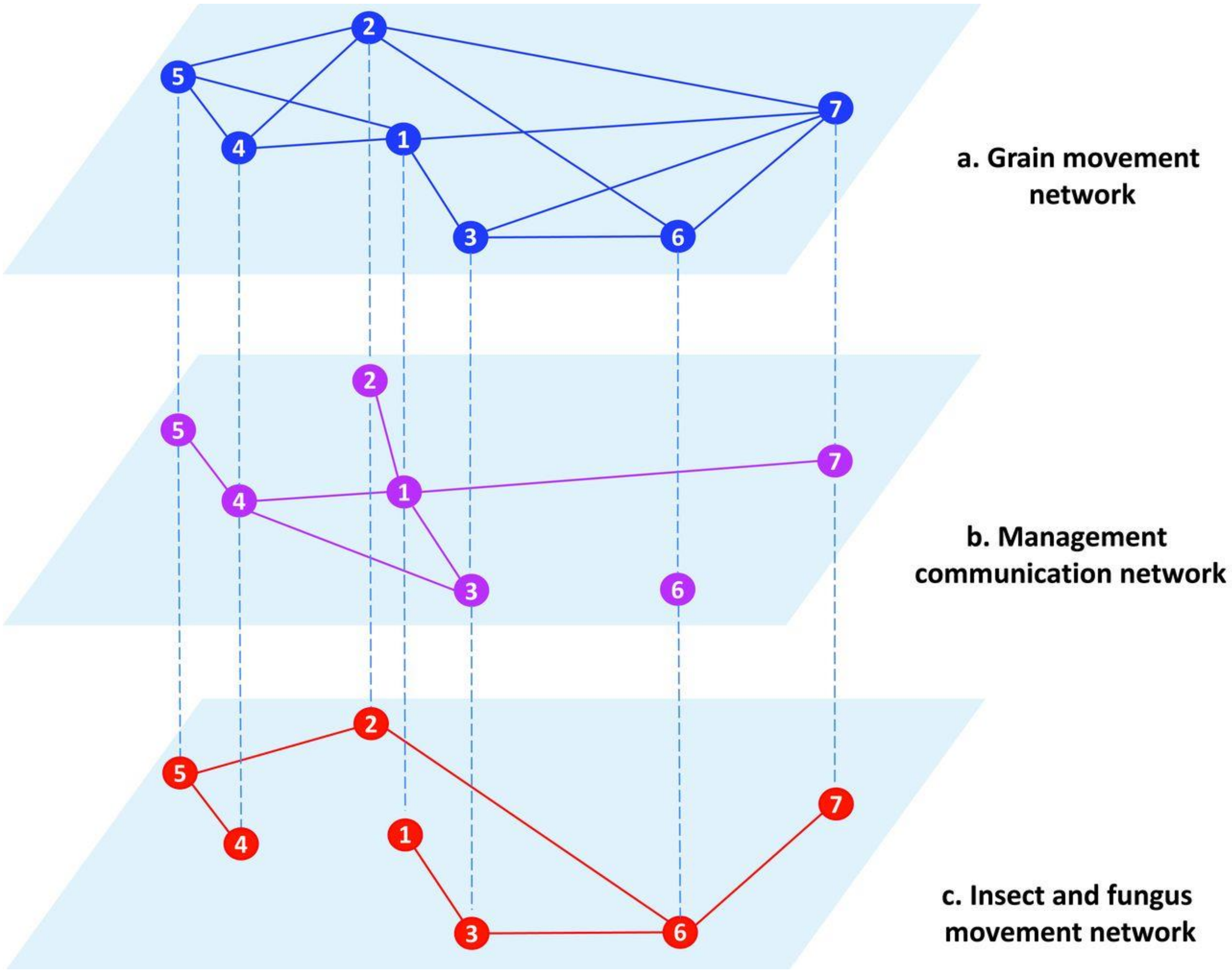
A network depicting both wheat movement (links) and production (nodes) in the United States in 2006–2010



John F. Hernandez Nopsa et al. BioScience 2015;biosci.biv122

BioScience

A hypothetical scenario for a multilayer network in the stored-grain system



John F. Hernandez Nopsa et al. BioScience 2015;biosci.biv122

BioScience

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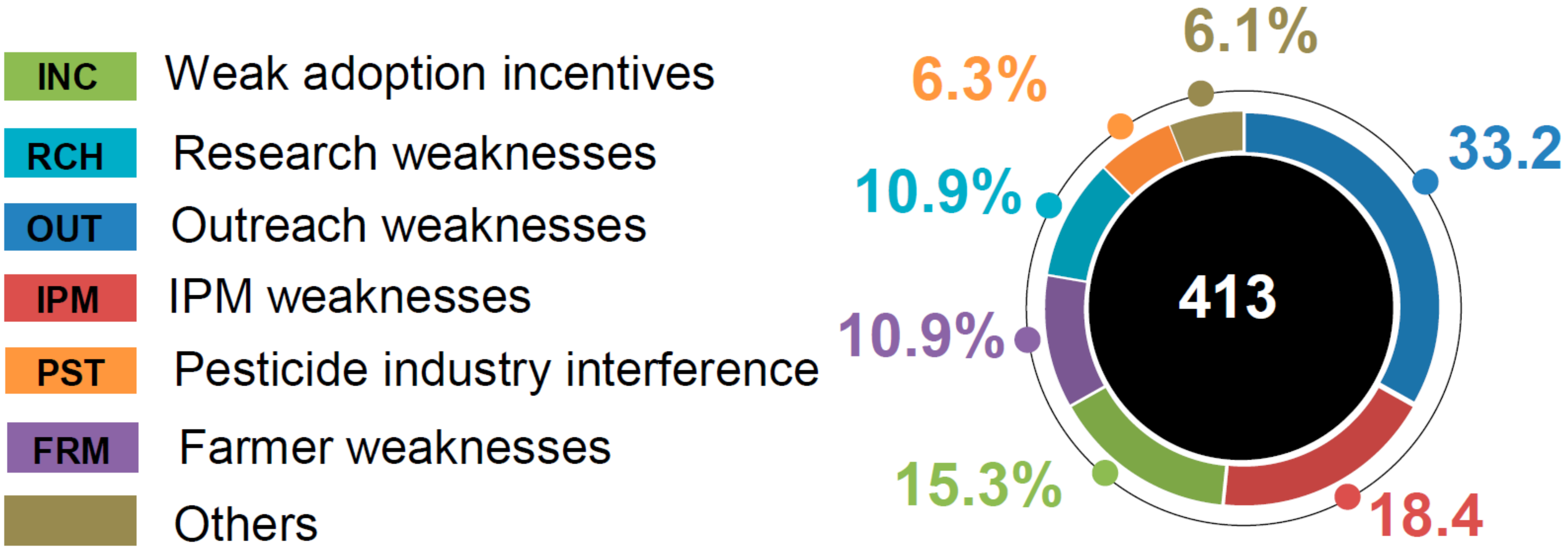
PNAS

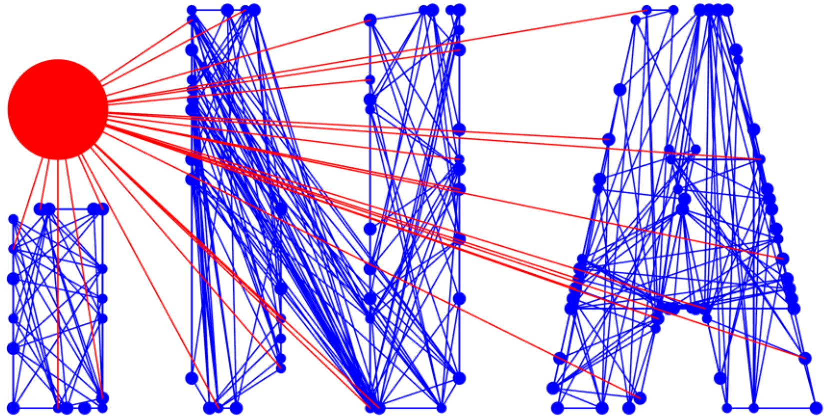
Obstacles to integrated pest management adoption in developing countries

2014

Soroush Parsa[a,1], Stephen Morse[b], Alejandro Bonifacio[c], Timothy C. B. Chancellor[d], Bruno Condori[e], Verónica Crespo-Pérez[f], Shaun L. A. Hobbs[g], Jürgen Kroschel[h], Malick N. Ba[i], François Rebaudo[j,k], Stephen G. Sherwood[l], Steven J. Vanek[m], Emile Faye[j], Mario A. Herrera[f], and Olivier Dangles[f,j,k,n]

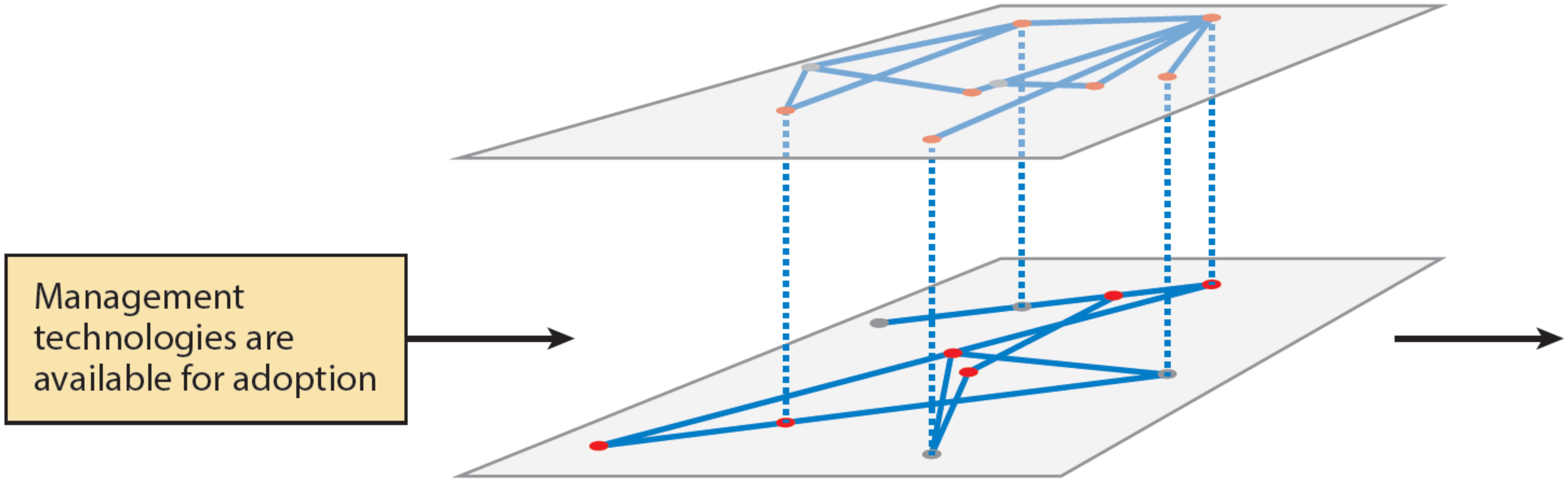


Impact Network Analysis (INA)

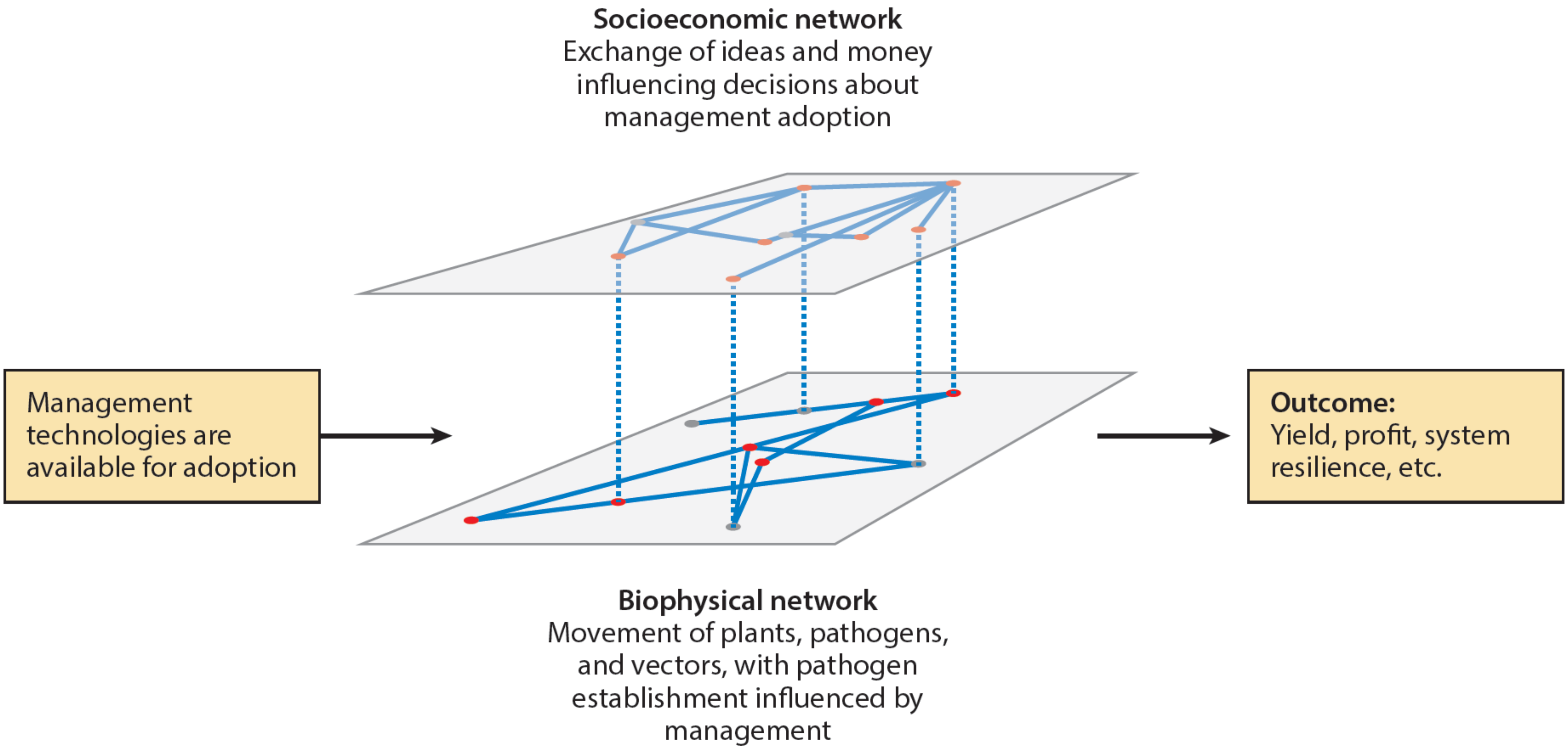


- The Garrett Lab is developing INA as a general platform for evaluating system management strategies (such as crop breeding networks, seed systems, and regional integrated pest and disease management)
- Impact **OF** research products such as information/training, disease resistance, and disease-free seed production technologies
- Impact **ON** spatial ecological processes, such as gene/genotype spread, pathogen invasions or ecosystem services more broadly
- Impact **THROUGH** communication and decision-making networks, and linked biophysical networks

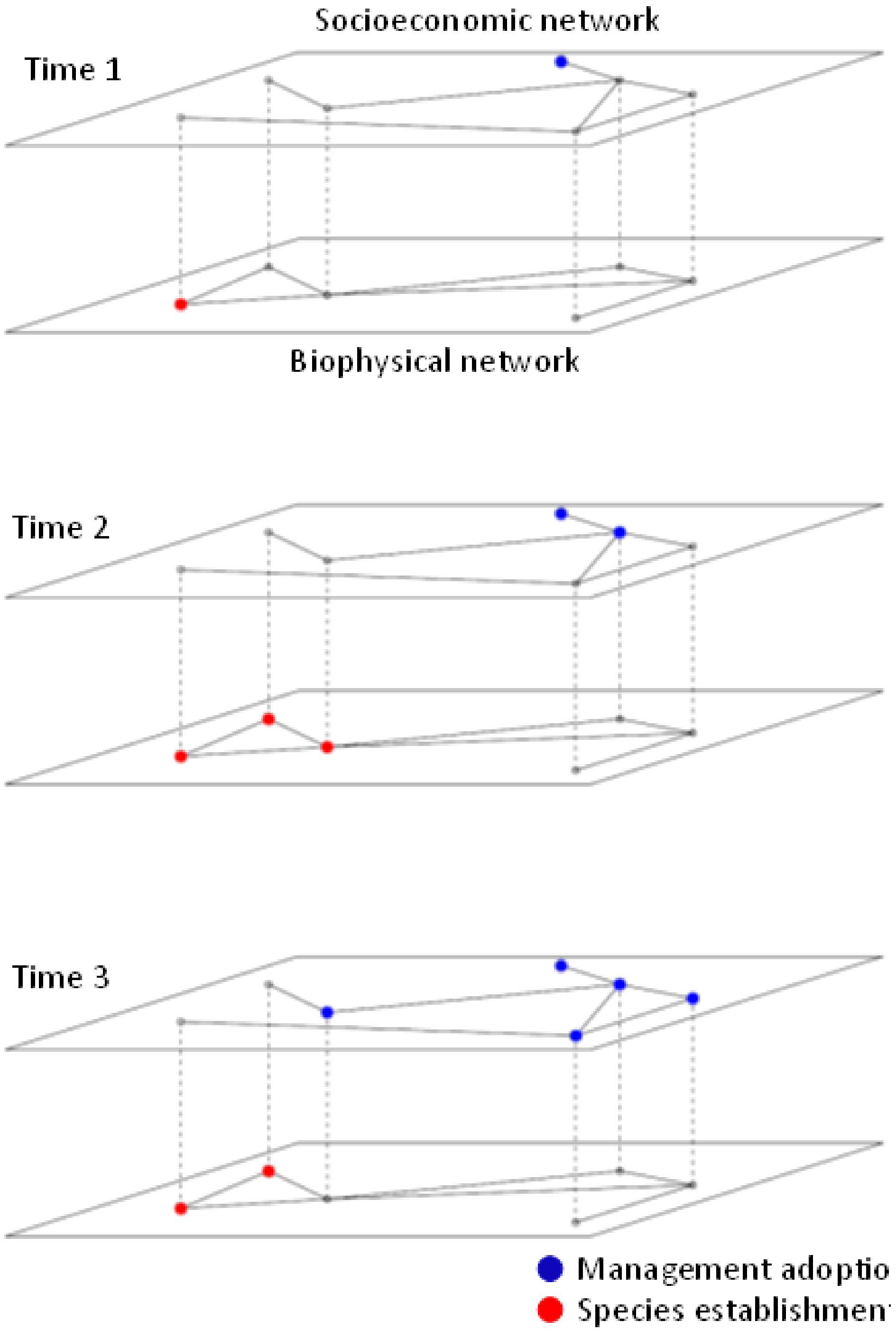
Garrett 2018 PeerJ Preprints



Garrett et al 2018 ARP



Garrett et al 2018 ARP



System over time

- Individuals in the socioeconomic network can influence what happens at individual locations in the biophysical network
- For example,
  - Farmers in the socioeconomic network make decisions about management (e.g., whether to buy good seed) influenced by their associates and prices
  - The decision influences the likelihood of the spread of disease in the biophysical network

Garrett 2018

Impact networks, broadly

Generality Questions like:
How can a change in impact network components compensate for increased risk to maintain system sustainability?

Realism Questions like:
How do changes in network traits, such as changes in mechanisms for interpersonal influence, affect system outcomes?

Precision Questions like:
Which particular communication or land nodes are key control points for transmission through the landscape?

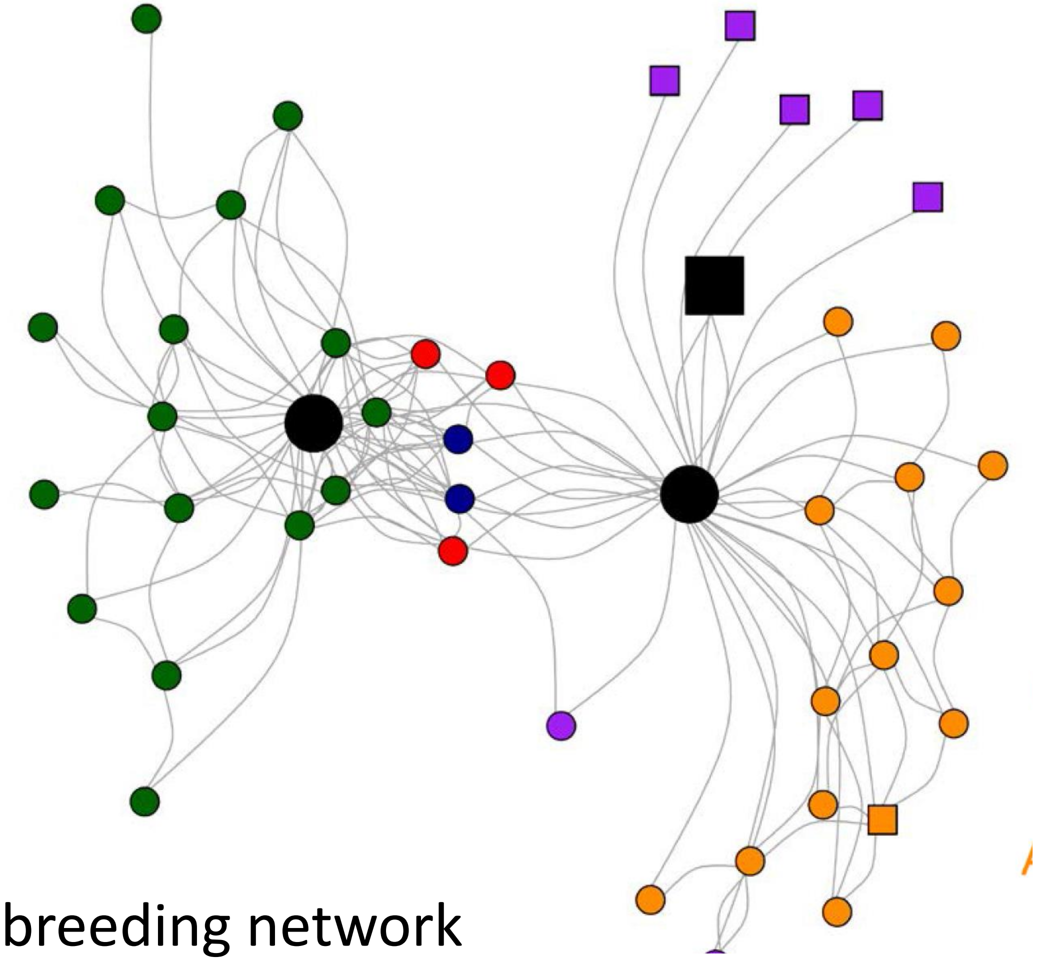
Garrett 2018

Resistance Genes in Global Crop Breeding Networks

K. A. Garrett,† K. F. Andersen, F. Asche, R. L. Bowden, G. A. Forbes, P. A. Kulakow, and B. Zhou

Phytopathology 2017

[open access link]



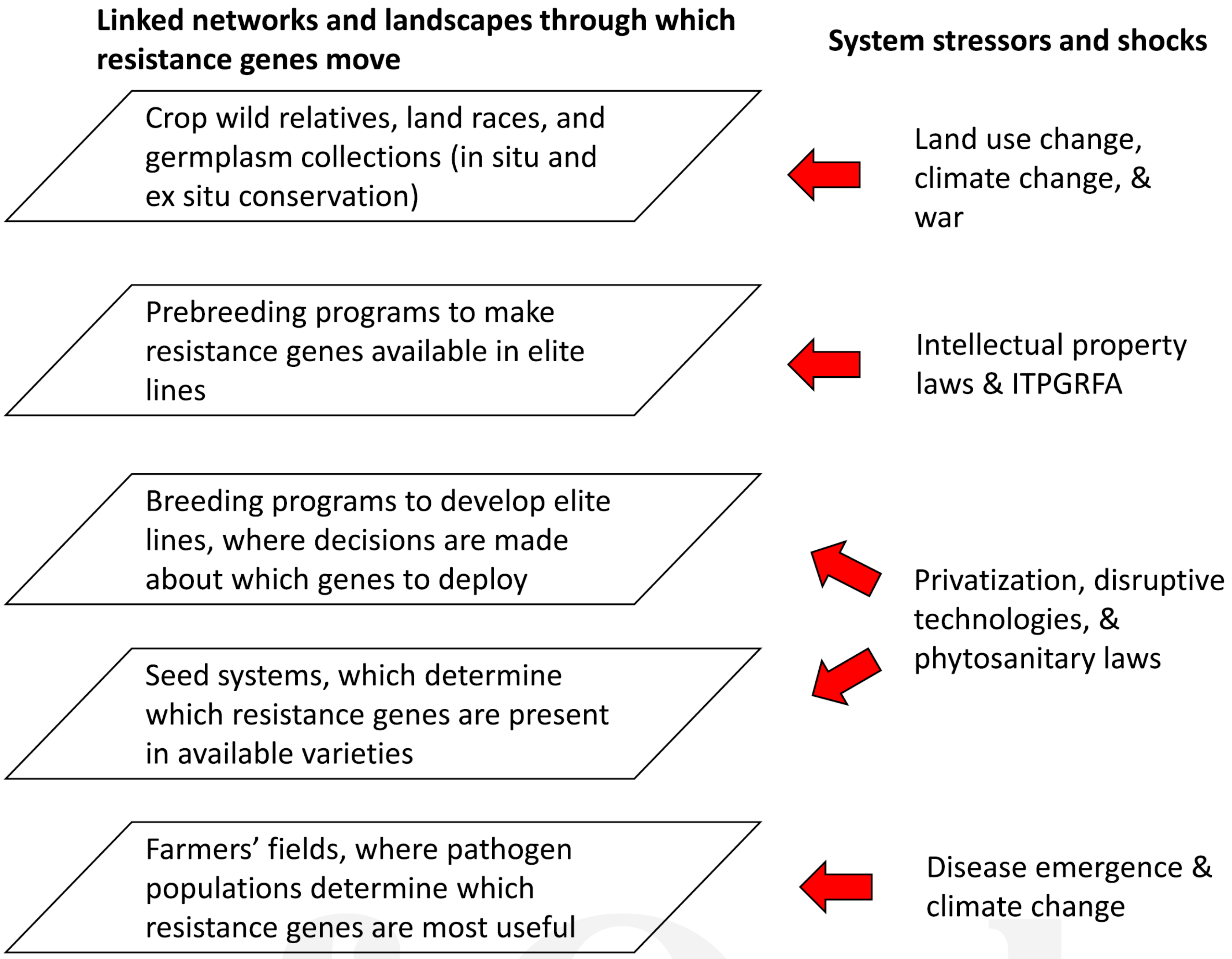
Cassava breeding network

Linked networks and landscapes through which resistance genes move

System stressors and shocks

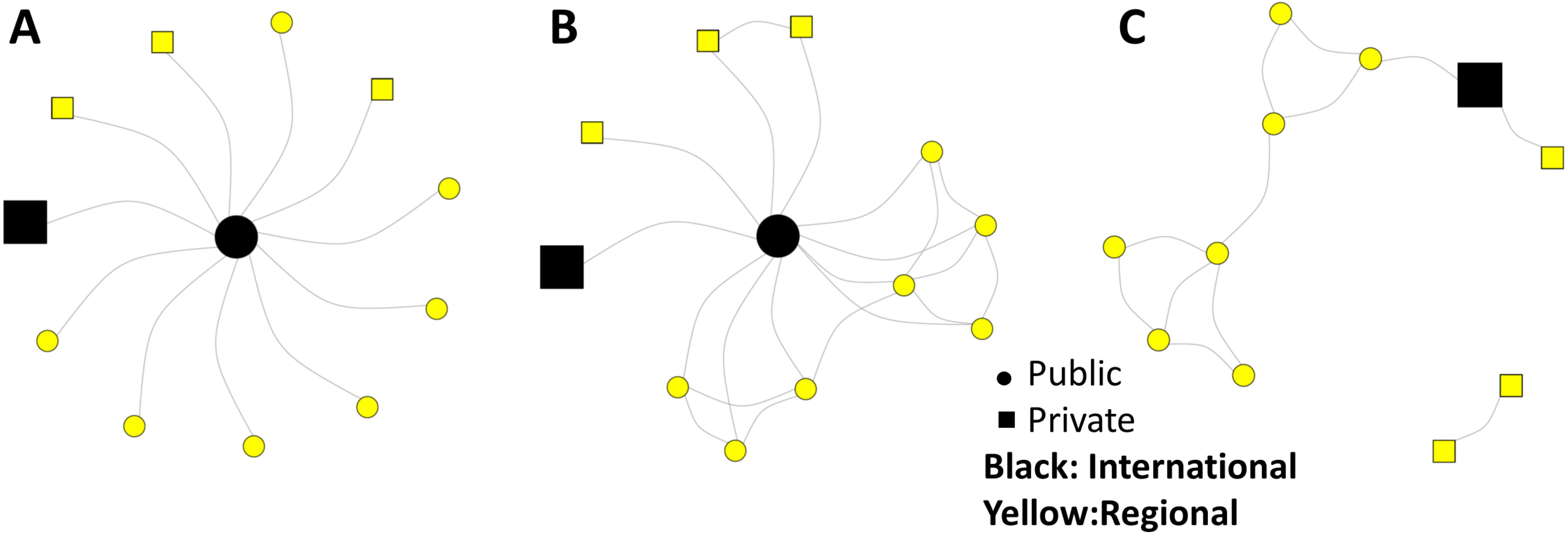
Crop wild relatives, land races, and germplasm collections (in situ and ex situ conservation)

Garrett et al 2017



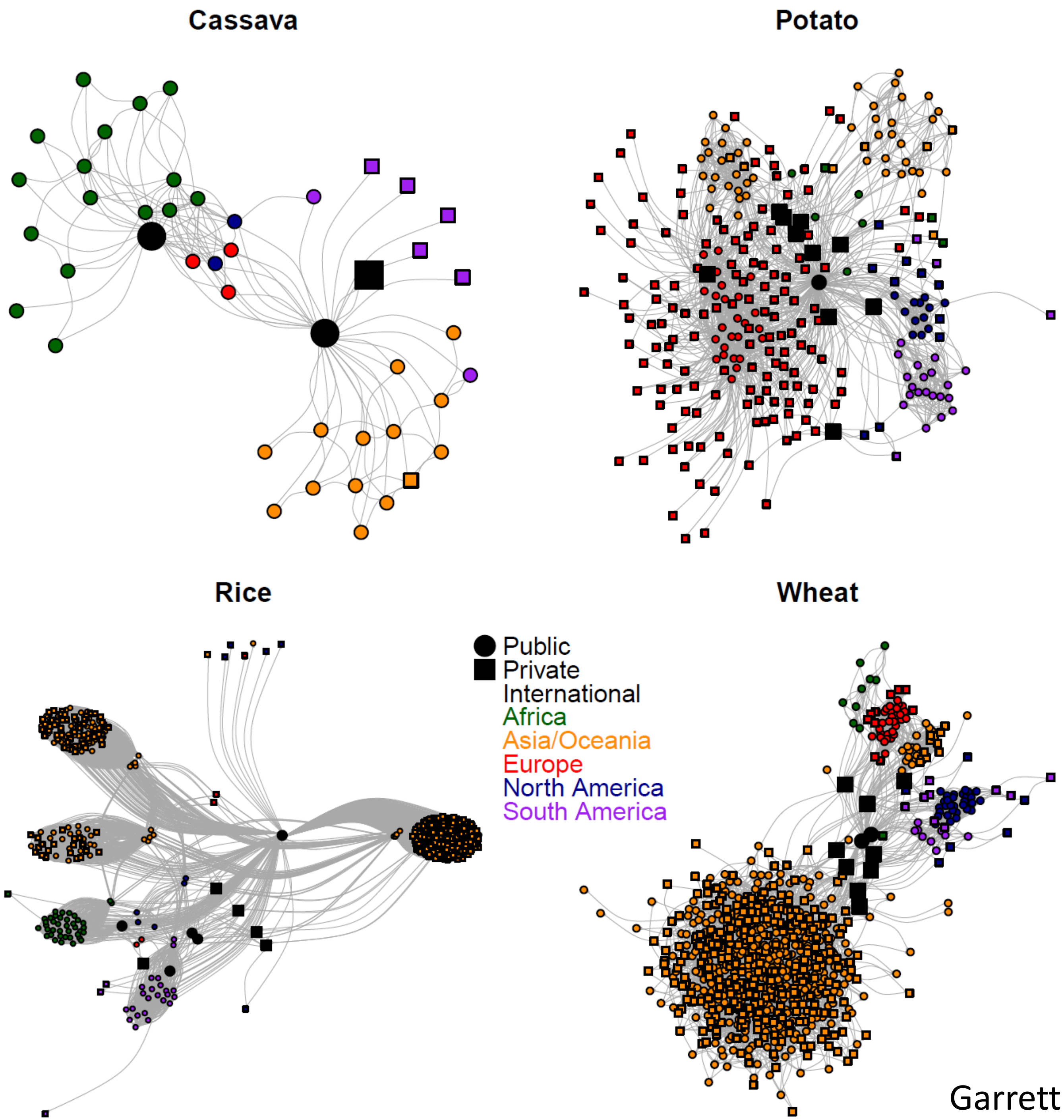
Garrett et al 2017

Three potential scenarios for crop breeding networks



Garrett et al 2017

Can global crop breeding networks adapt to new disease challenges under global change?



Garrett et al 2017

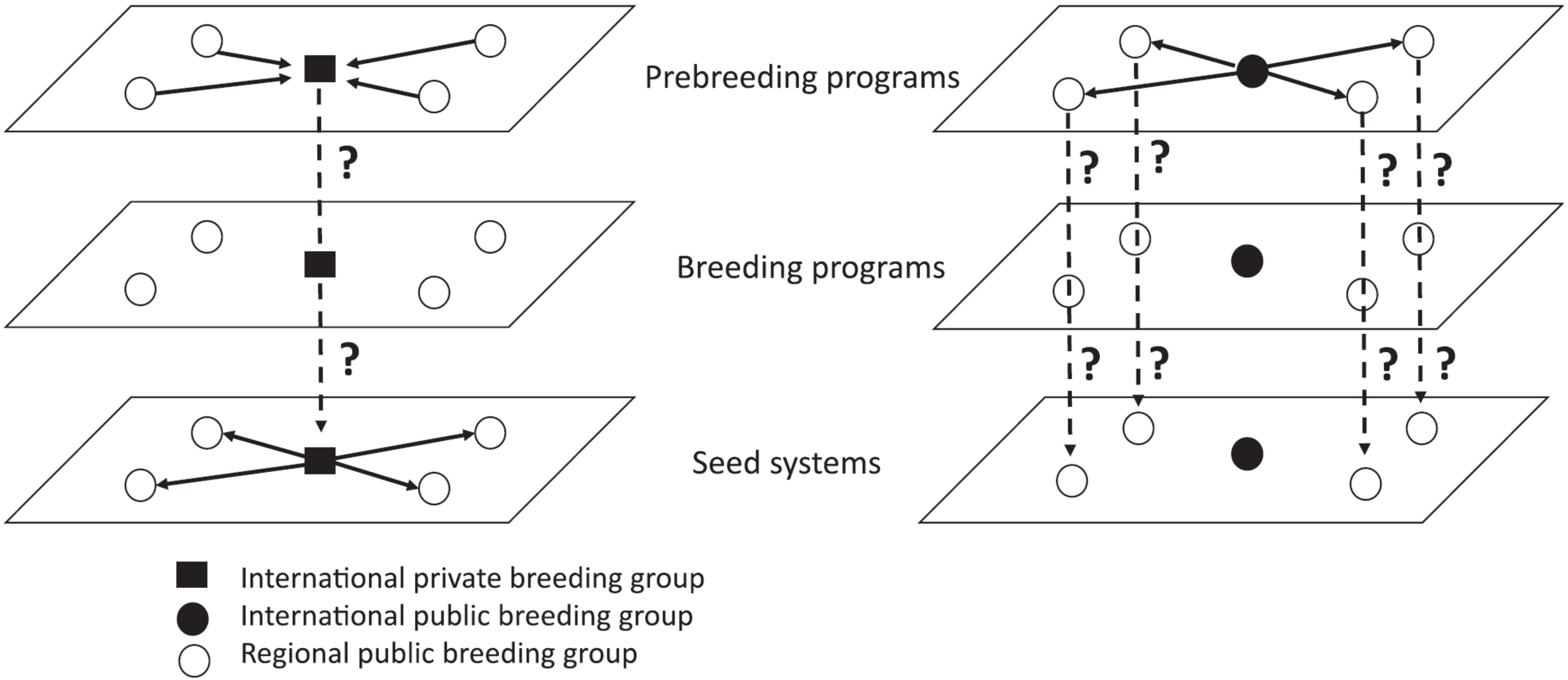
Principles for supporting system resilience (adapted from Biggs et al. 2012)

- Diversity and redundancy
- Management of connectivity
- Management of feedbacks
- Fostering understanding of complex adaptive systems
- Broadening participation
- Promoting polycentric governance systems

Directionality and the likelihood that resistance genes are available to farmers where needed

A. Privatization: If genes are "sequestered" by private breeders, are resistance genes distributed widely enough through seed systems?

B. Public systems: If genes are made available through prebreeding programs, is human capital for plant breeding available to develop regional varieties and distribute seed?



Plant Pathology (2015) Doi: 10.1111/ppa.12439

REVIEW

Seed degeneration in potato: the need for an integrated seed health strategy to mitigate the problem in developing countries

S. Thomas-Sharma[a*], A. Abdurahman[b], S. Ali[c], J. L. Andrade-Piedra[d], S. Bao[e], A. O. Charkowski[f], D. Crook[g], M. Kadian[c], P. Kromann[h], P. C. Struik[b], L. Torrance[i], K. A. Garrett[aj] and G. A. Forbes[g]

Sara Thomas-Sharma

RESEARCH PROGRAM ON Roots, Tubers and Bananas

CGIAR

Table 3 Percentage contribution of formal potato seed system[a] and informal potato seed systems[b] in some developing countries

Country	Formal seed system	Informal seed system	Reference
Afghanistan	0	100	Kadian *et al.* (2007)
Bangladesh	5	95	Ilangantileke *et al.* (2001)
Bhutan	2	98	Kadian *et al.* (2007)
Bolivia	2	98	Hidalgo *et al.* (2009)
China	20	80	Muthoni *et al.* (2013)
Columbia	2–10	90–98	FEDEPAPA (2010), Guzmán-Barney *et al.* (2012)
Ecuador	1–3	97–99	Thiele (1999), ESPAC (2012)
Ethiopia	11[c]	89[c]	Gildemacher *et al.* (2009)
India	20	80	Kadian *et al.* (2007)
Indonesia	6	94	Muthoni *et al.* (2013)
Kenya	0·5[c]	99·5[c]	Gildemacher *et al.* (2009)
Pakistan	5	95	Muthoni *et al.* (2013)
Peru	0·5	99	Hidalgo *et al.* (2009)
Uganda	4[c]	96[c]	Gildemacher *et al.* (2009)

Thomas-Sharma et al. 2016

Epidemic network analysis for mitigation of invasive pathogens in seed systems: Potato in Ecuador

Phytopathology 2017

C. E. Buddenhagen*, J. F. Hernandez Nopsa*, K. F. Andersen, J. Andrade-Piedra, G. A. Forbes, P. Kromann, S. Thomas-Sharma, P. Useche, K. A. Garrett

[open access link]

RESEARCH PROGRAM ON Roots, Tubers and Bananas

CGIAR

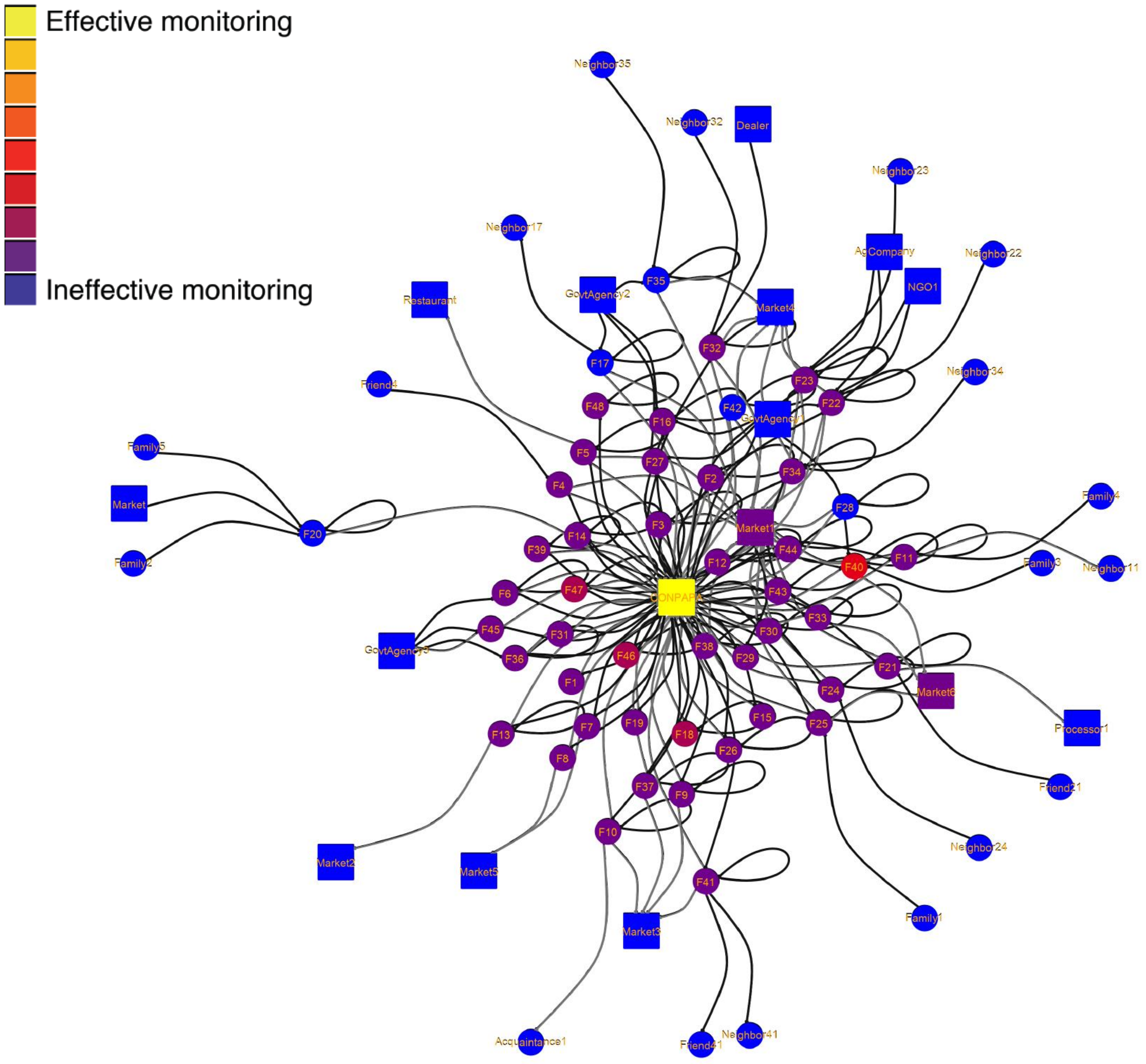
CENTRO INTERNACIONAL DE LA PAPA CIP

UF IFAS UNIVERSITY of FLORIDA

Potato production in Tungurahua Province, Ecuador

Photos: J Hernandez Nopsa

In this analysis, we have survey data for both potato transactions and sources of information for IPM



Scenario analysis indicating how effective monitoring of the spread of a pathogen would be at each node, based on location in network and IPM information sources

Buddenhagen, Hernandez Nopsa, et al. 2017

Modeling Epidemics in Seed Systems and Landscapes to Guide Management Strategies:

The Case of Sweetpotato in Northern Uganda

Kelsey F Andersen[abc], Chris E Buddenhagen[abc], Paul Rachkara[d], Richard Gibson[e], Stephen Kalule[d], David Phillips[e], Karen A Garrett[abc]

[a]Department of Plant Pathology, UF, Gainesville, FL;
[b]Institute for Sustainable Food Systems, UF, Gainesville, FL;
[c]Emerging Pathogens Institute, UF, Gainesville, FL;
[d]Department of Rural Development and Agribusiness, Gulu University, Gulu, Uganda;
[e]Natural Resource Institute, University of Greenwich, United Kingdom

Andersen et al. 2019 Phytopathology

Kelsey Andersen

Sweetpotato vine sellers were surveyed in 2014 in the Gulu Region of Northern Uganda


Photo Credit: Richard Gibson

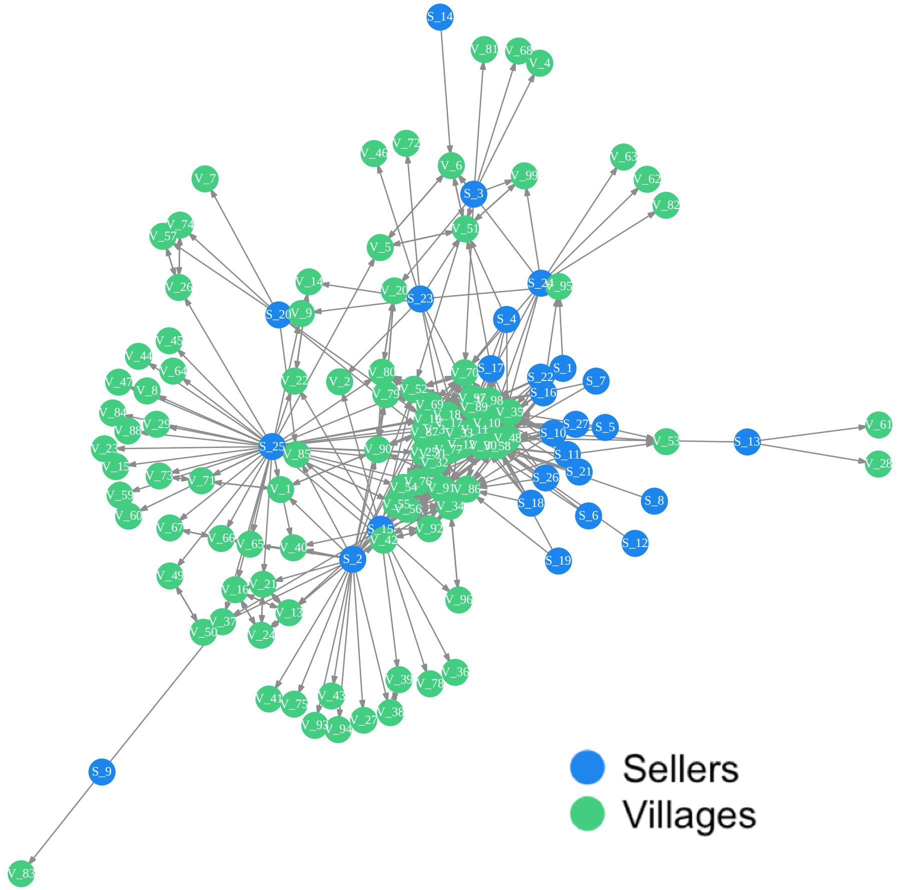
- Seller visited 2x/week
- 27 sellers, sold to farmers form 99 villages
- 878 unique transactions

Estimated village-to-village spread

- A second set of geo-spatially derived links were added to the network based on distance

- Links represent exchange between farmers of neighboring villages

- This network was utilized in experiments to model disease spread in the region



Using network analysis we evaluated a set of questions in simulation experiments

1. What are the optimum surveillance locations to detect disease spread, given equal likelihood of disease introduction at each node?
2. Does the starting position of the epidemic influence epidemic progress and final outcome?
3. How much can disease spread be limited by implementing a quarantine?
4. How do network statistics compare for their utility for selecting quarantine locations?

Andersen et al 2019

Integrating data sources to evaluate risk of cassava mosaic disease: an emerging threat in Southeast Asia

Kelsey Andersen

K. F. Andersen, E. Delaquis, S. de Haan, Cu Thi Le Thuy, N. Minato, J. P. Legg, W. Cuellar, and K. A. Garrett

PLANT PATHOLOGY UF/IFAS

IITA Transforming African Agriculture

CIAT International Center for Tropical Agriculture Since 1967 Science to cultivate change

UF | IFAS UNIVERSITY of FLORIDA

Institute for Sustainable Food Systems

CGIAR RESEARCH PROGRAM ON Roots, Tubers and Bananas

Cassava mosaic disease (CMD)

Cassava is a critical food and industrial crop in tropical countries

Cassava is grown on > 2.5 M acres in Southeast Asia, mostly by smallholder farmers, & acreage has rapidly expanded in the last 10 years

CMD has had major yield impacts for decades on cassava production in Africa and India

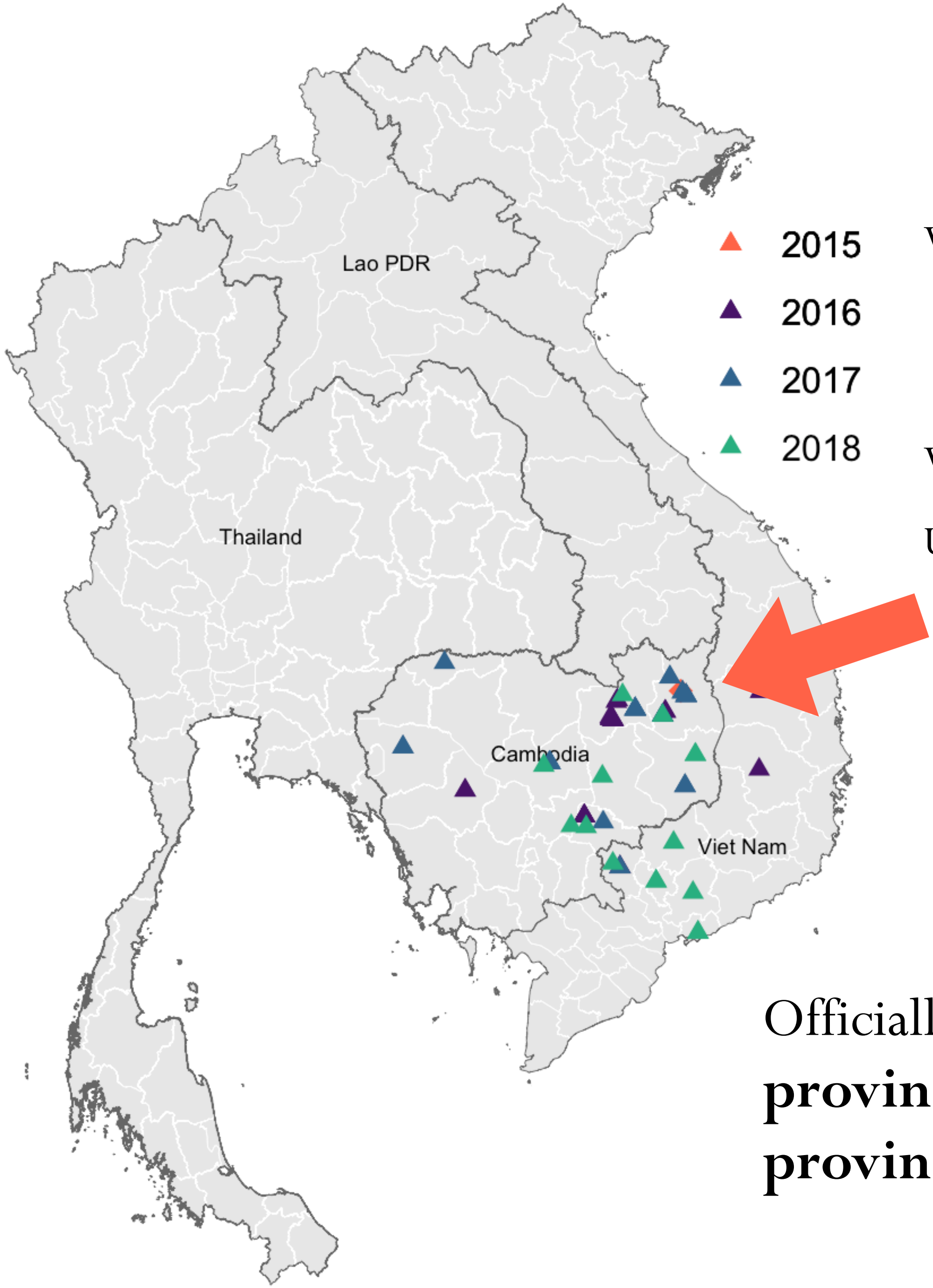
CMD is caused by cassava mosaic viruses

Family Geminiviridae, genus Begomovirus

Vectored by whitefly (*Bemisia tabaci*)

Andersen et al

In 2015, *Sri Lankan cassava mosaic virus* was first reported in Cambodia

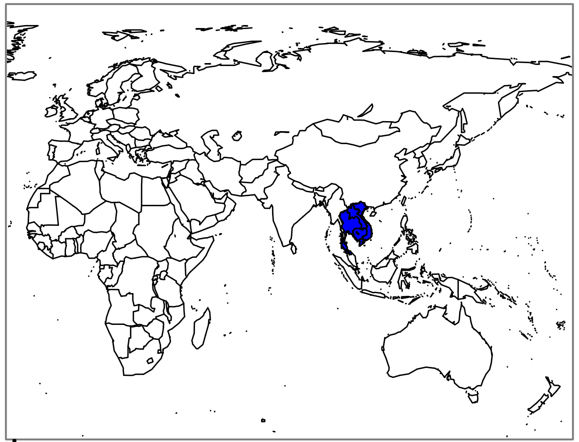


Wang at al. 2015 (Cambodia)

Wang et al. 2018 (China)

Uke et al. 2018 (Vietnam)

Officially reported in **seven provinces** in Cambodia, and **ten provinces** in southern Vietnam.



Andersen et al

Cassava planting material is transported in large volumes across national borders

frontiers in Sustainable Food Systems

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

Check for updates

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]**

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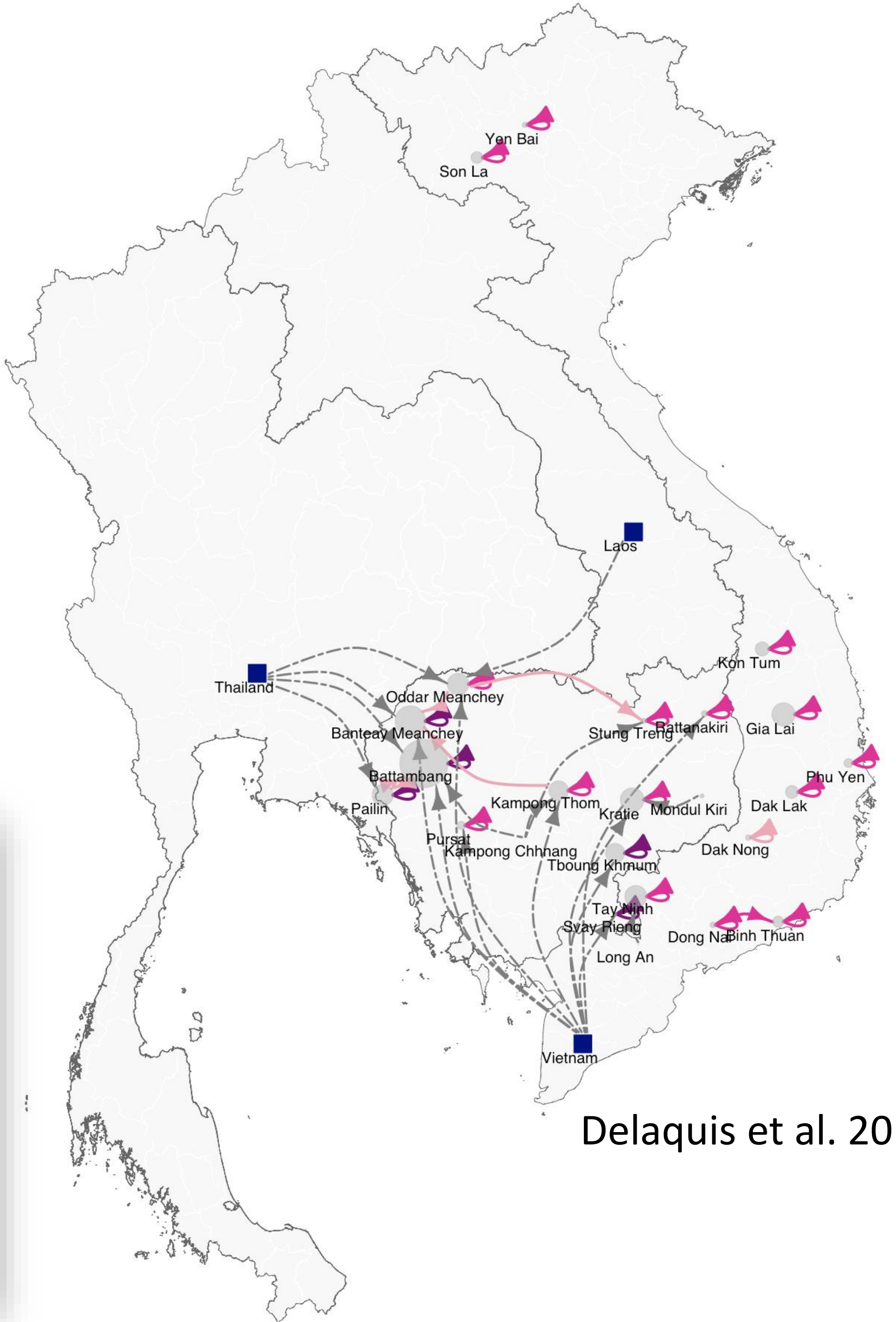
Processing, University of Battambang,
Agriculture, Phnom Penh, Cambodia,
Agricultural Research Center, Dong Na
Wageningen University and Research,

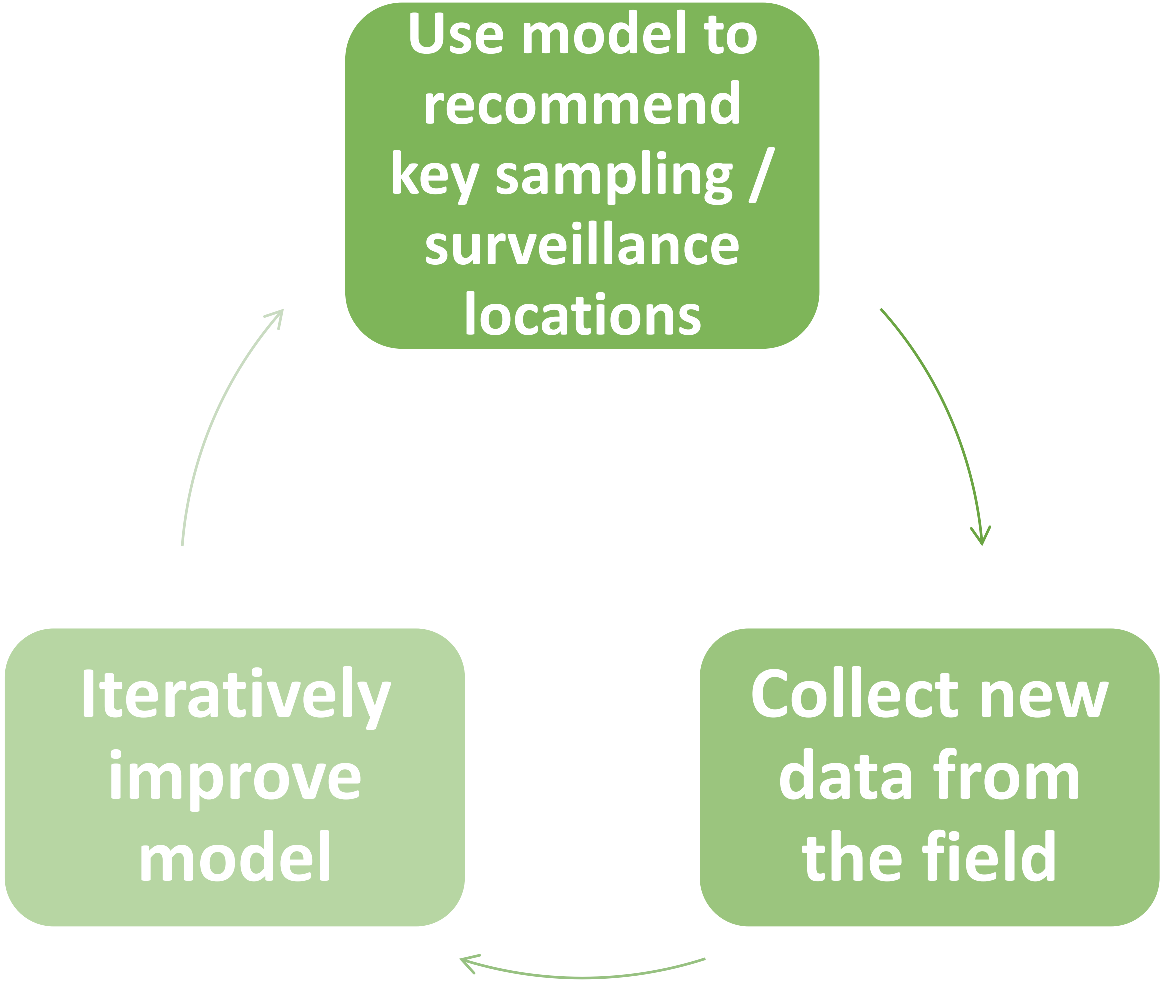
OPEN ACCESS

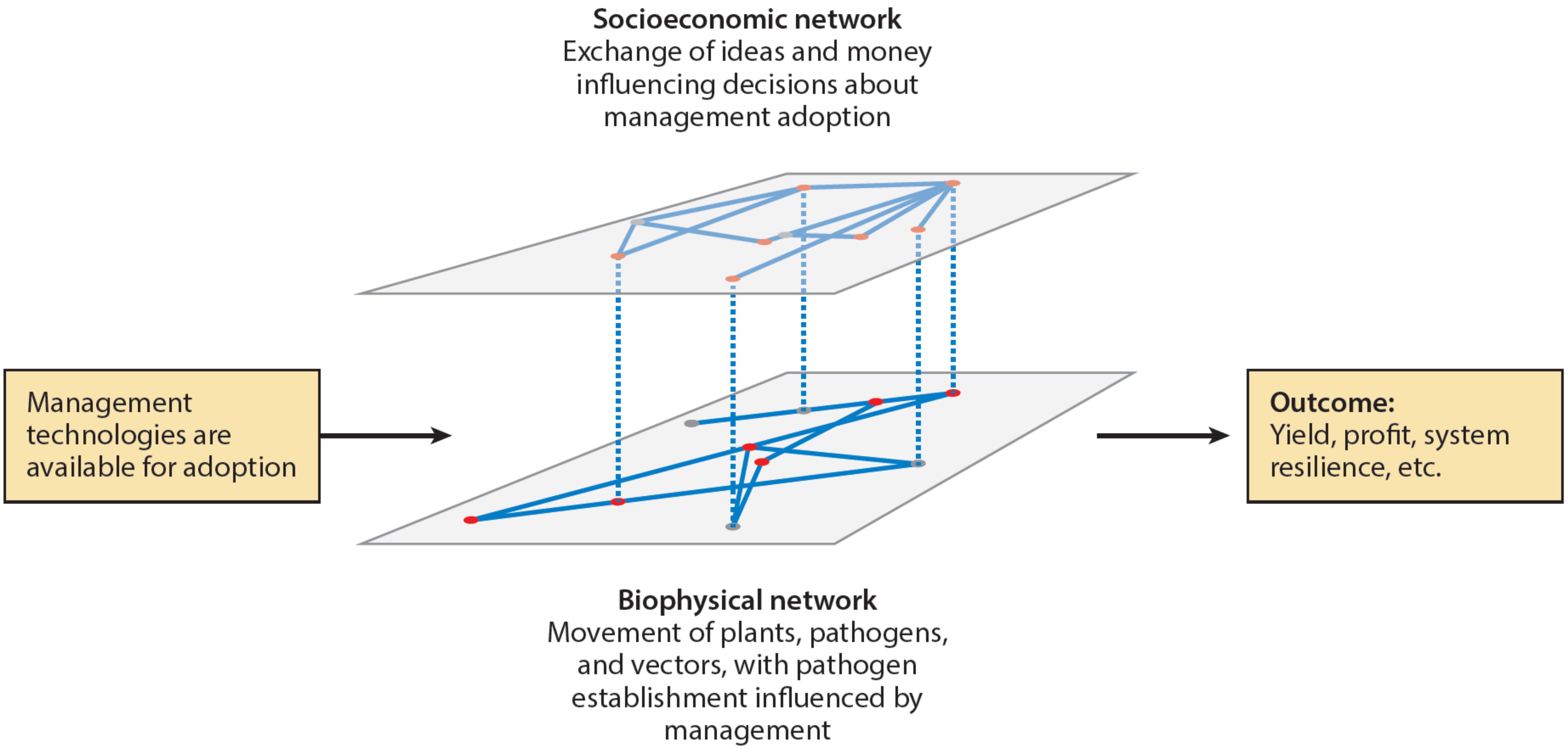


Delaquis et al. 2018

Next steps / model improvement

- Refine risk models with updated data, particularly for Lao PDR and Thailand
- Incorporate whitefly survey data into the model
- Use high risk regions to inform risk-based sampling and surveillance strategies conduced by CIAT and national ministries





Garrett et al 2018 ARP

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谢谢

Thanks for your attention!

Thanks to all the collaborators on our projects

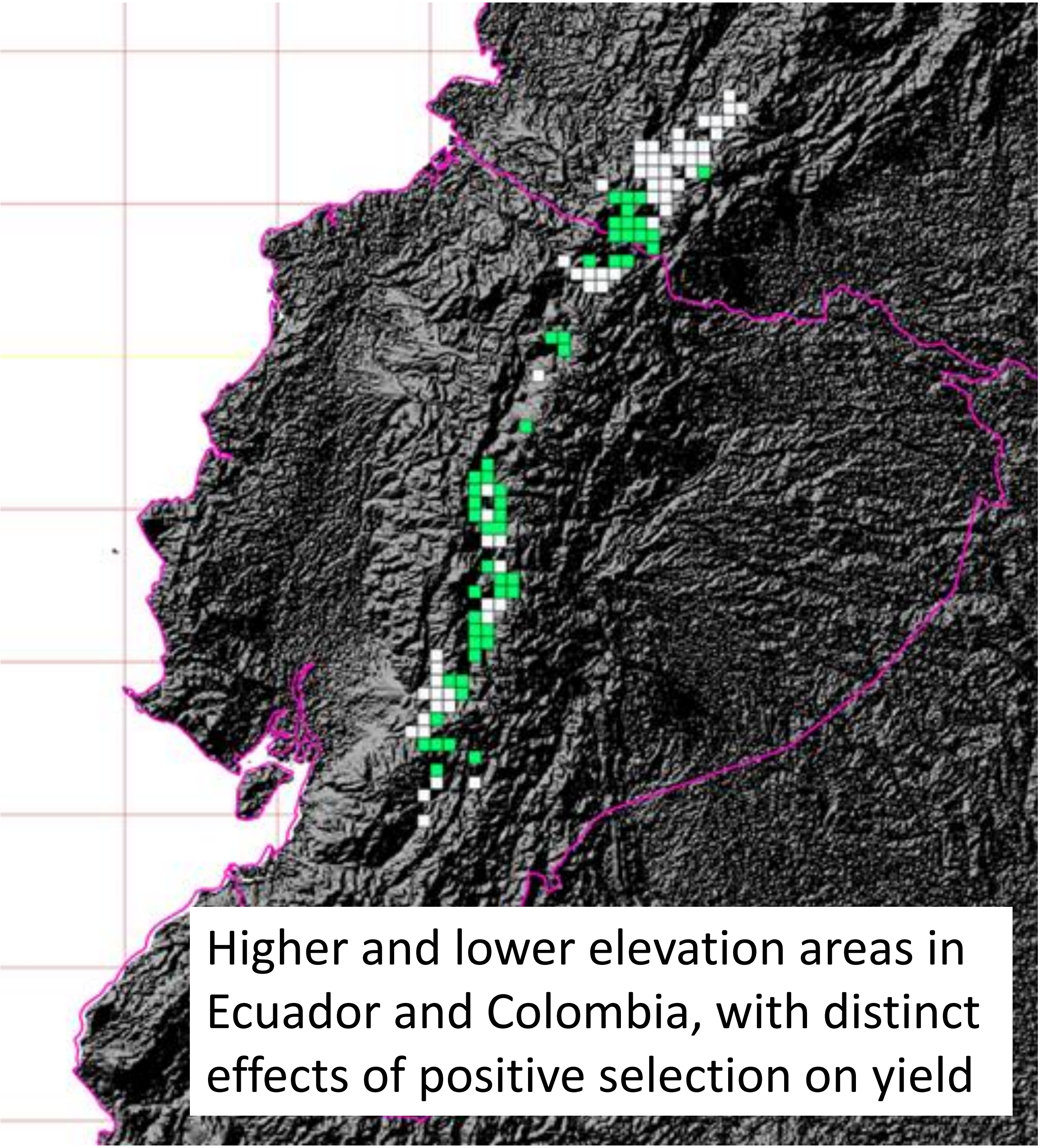
Thanks to our funders

Photo: Pete Garfinkel

Management performance mapping: the value of information for regional prioritization of project interventions

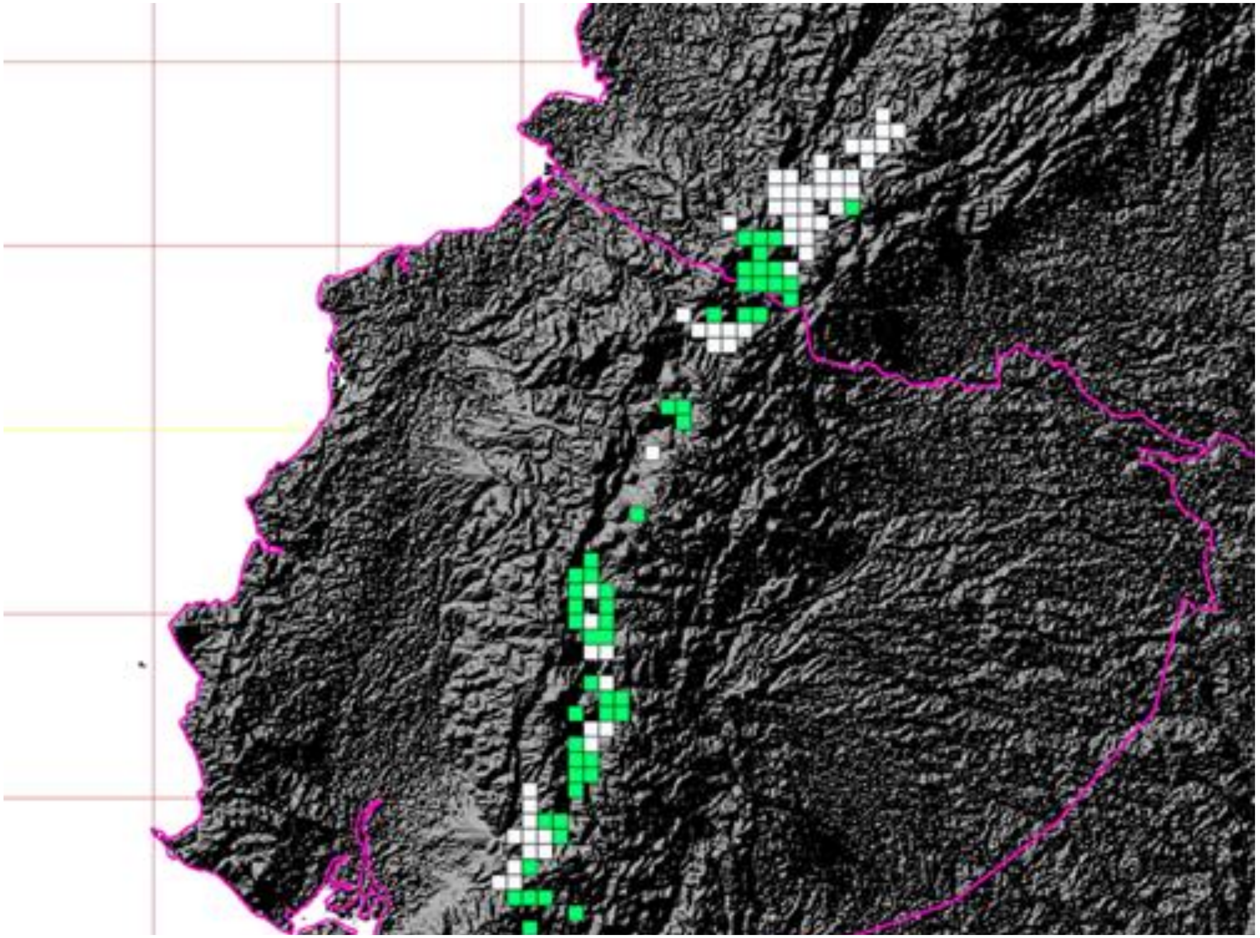
C. E. Buddenhagen, J. Andrade Piedra, G. A. Forbes, P. Kromann, I. Navarrete, S. Thomas-Sharma, Y. Xing, K. A. Garrett

bioRxiv 2018

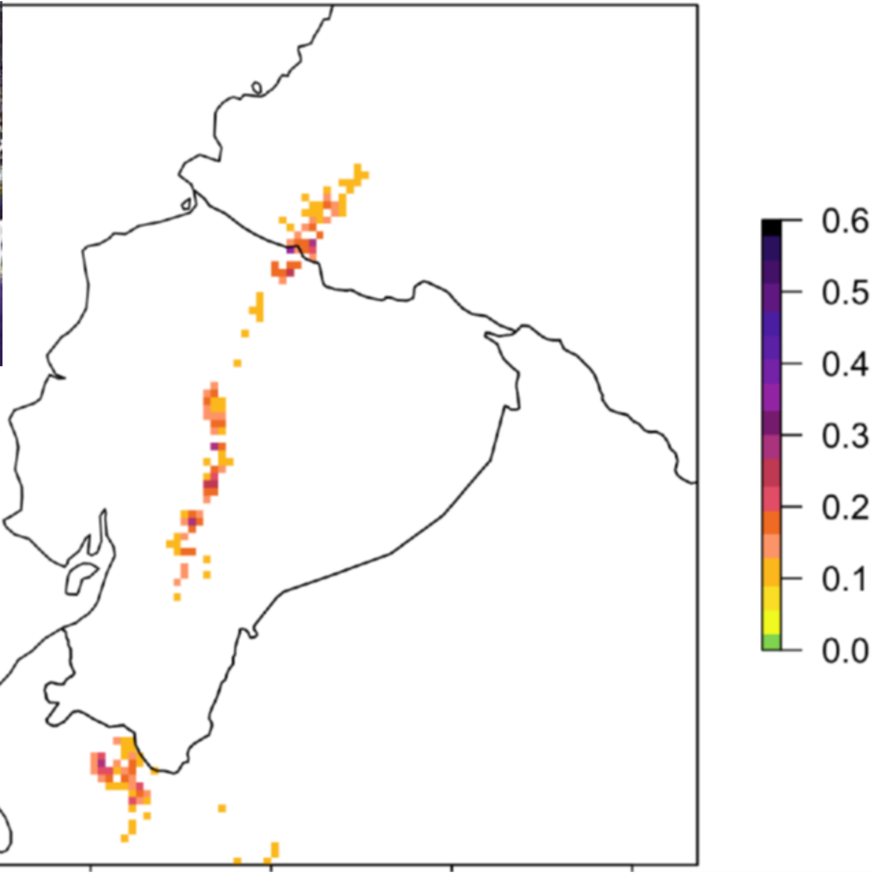


Higher and lower elevation areas in Ecuador and Colombia, with distinct effects of positive selection on yield

Generation of maps of [seed health] management performance for donors/funders deciding on prioritization for investment, extension agents deciding on priorities, etc.



Yanru Xing



- **Management performance mapping for Ecuador and surroundings**, with potato production indicated based on MapSpam estimates. Pixels labelled above (green)
- and below (white) 2895 masl

Benefit of informed site selection: 7.7 t/ha
- Benefit of random site selection: 6.5 t/ha

The potato **cropland connectivity risk index** (CCRI) estimated for Ecuador and southern Colombia, based on the mean from uncertainty quantification

CCRI provides a regional criterion for site selection

Xing et al 2018 bioRxiv