The One Health concept: toward a new *modus operandi* for plant health

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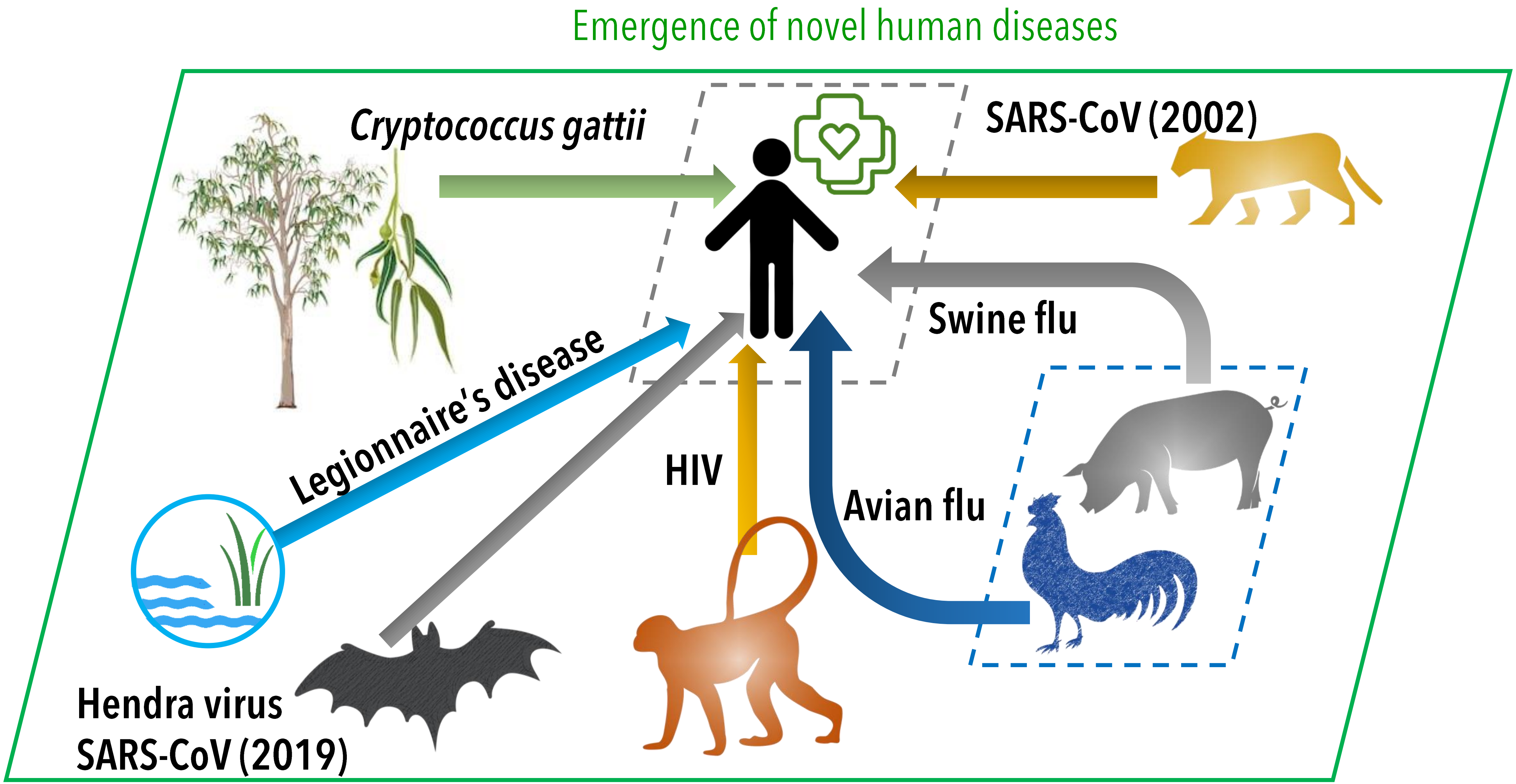
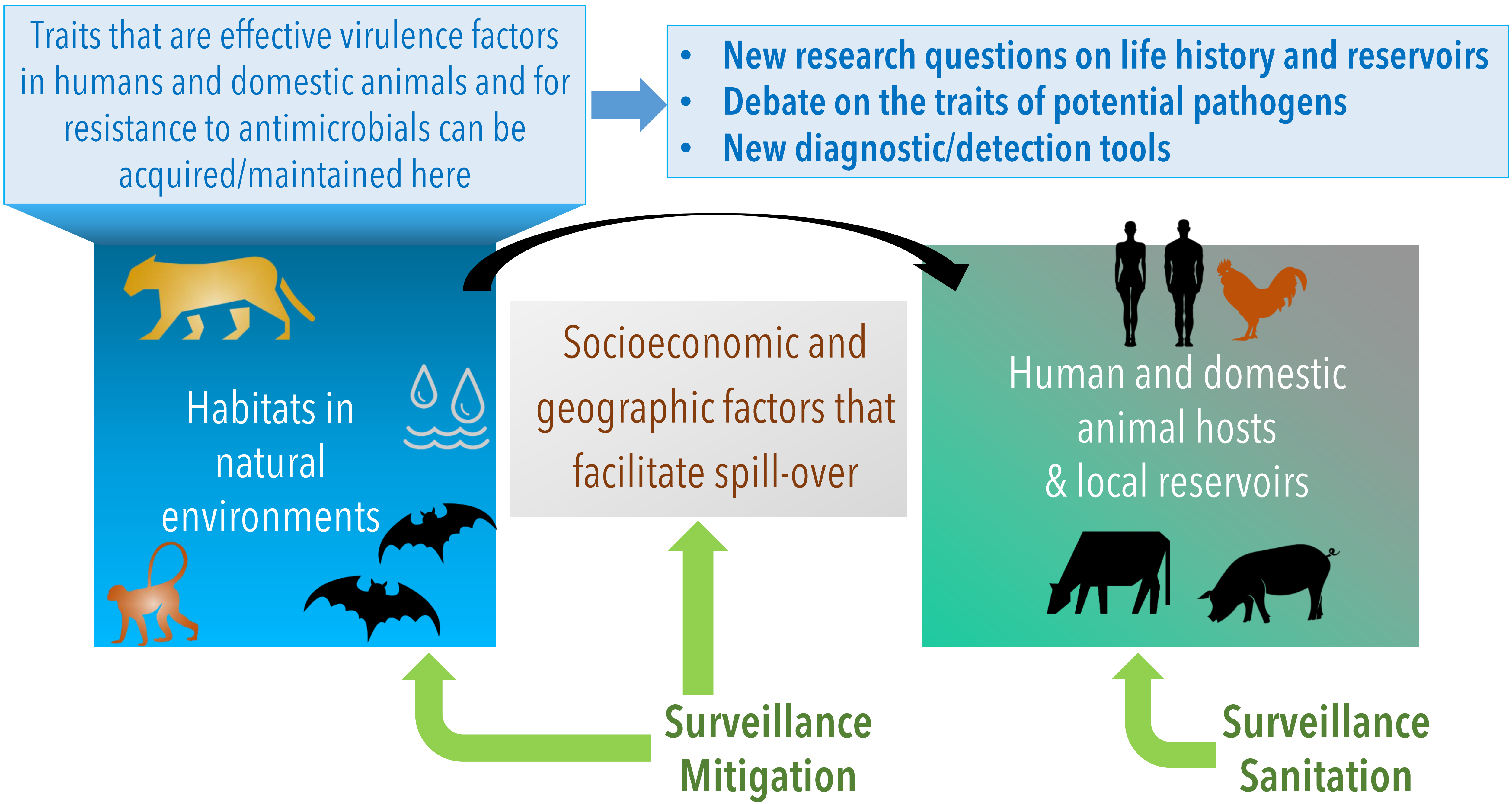
Colloque
Santé globale et nouveaux flux de risques
Impacts des changements climatiques et anthropiques

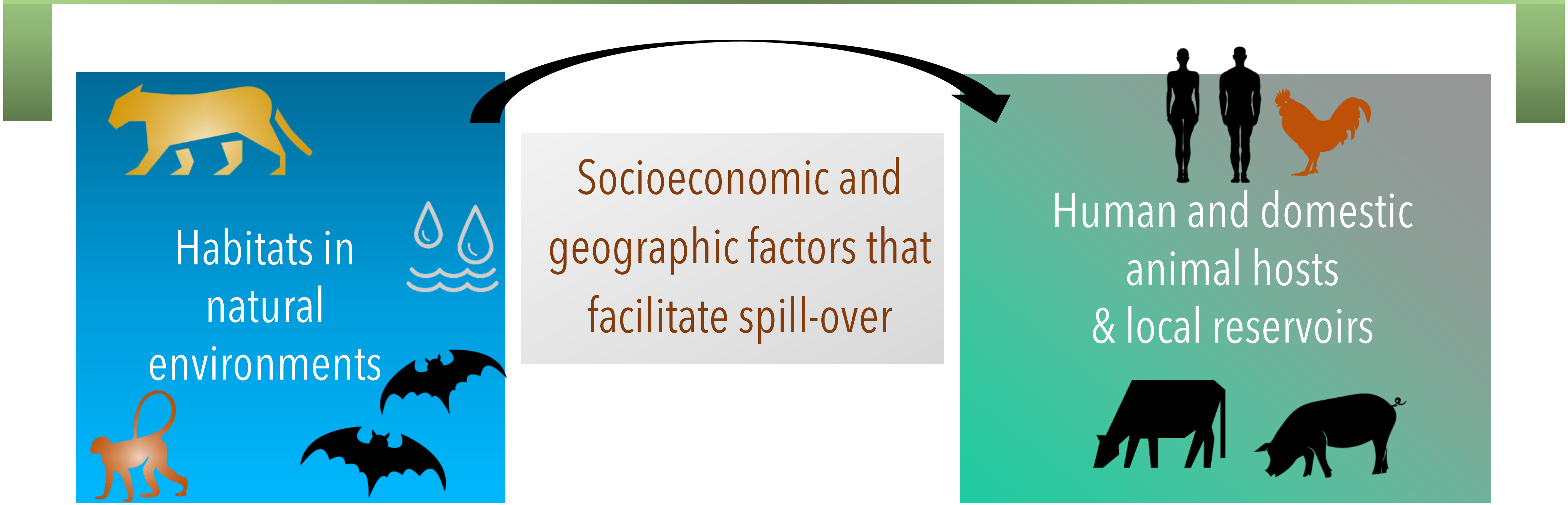
15 December 2020 https://colloque.inrae.fr/sante-globale/


Emergence of novel human diseases
Cryptococcus gattii
SARS-CoV (2002)
Swine flu
Legionnaire's disease
HIV
Avian flu
Hendra virus
SARS-CoV (2019)



Traits that are effective virulence factors in humans and domestic animals and for resistance to antimicrobials can be acquired/maintained here
New research questions on life history and reservoirs
Debate on the traits of potential pathogens
New diagnostic/detection tools
Habitats in natural environments
Socioeconomic and geographic factors that facilitate spill-over
Human and domestic animal hosts & local reservoirs
Surveillance Mitigation
Surveillance Sanitation

the *One Health* framework



What relevance to Plant Health ?

How is One Health relevant to Plant Health ? What new insight ?

? Healthy plants sustain healthy animals

→ not a new idea !

? Holistic approach, everything interconnected

→ Agro-ecology and Integrated Pest Management already profess this.

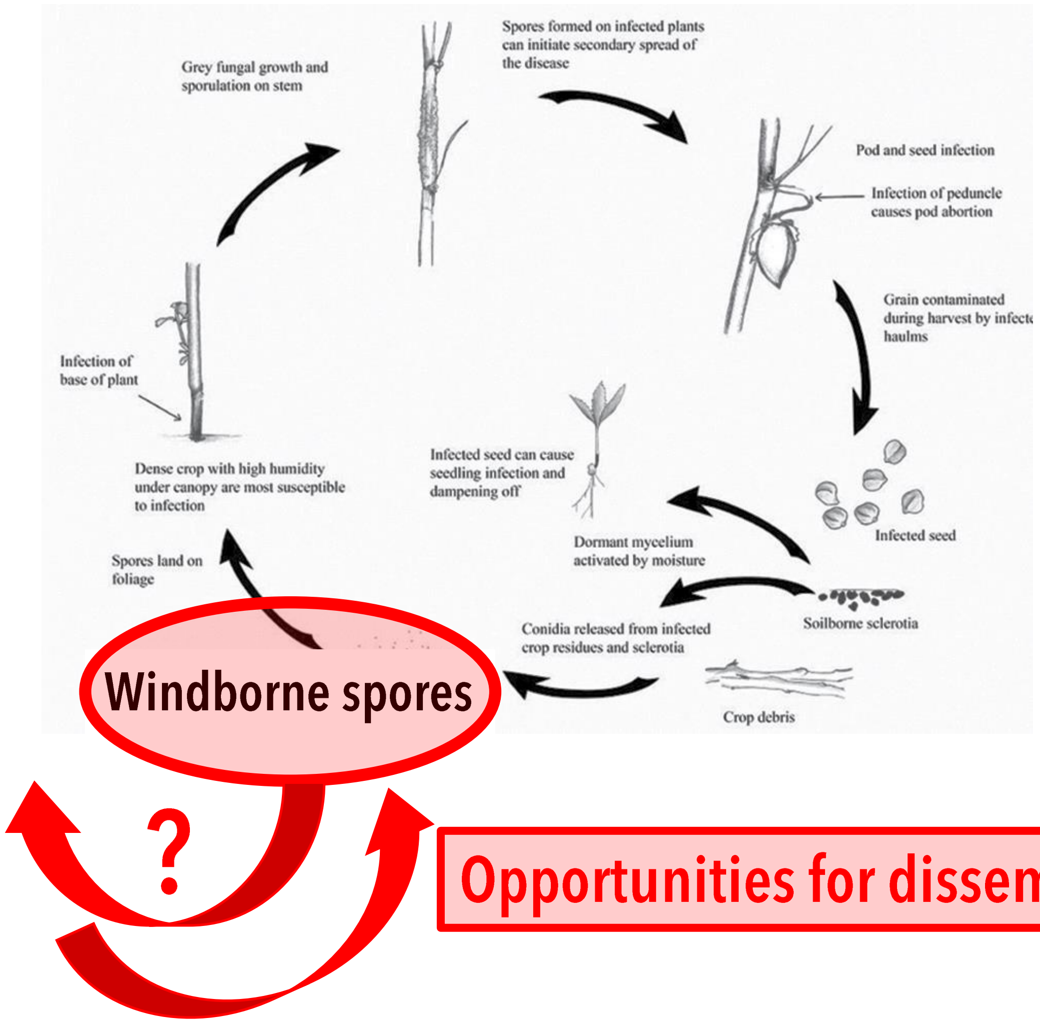
Overcome missing or poorly-developed concepts in plant disease epidemiology and management

- Reservoirs outside of agriculture, on substrates other than plants
- Dual-use virulence factors / Maintenance of virulence factors in non-ag habitats
- Framework for assessing potential risk of microbial lines before they emerge as pathogens
- Spill-over via natural processes operating constantly and at long distances

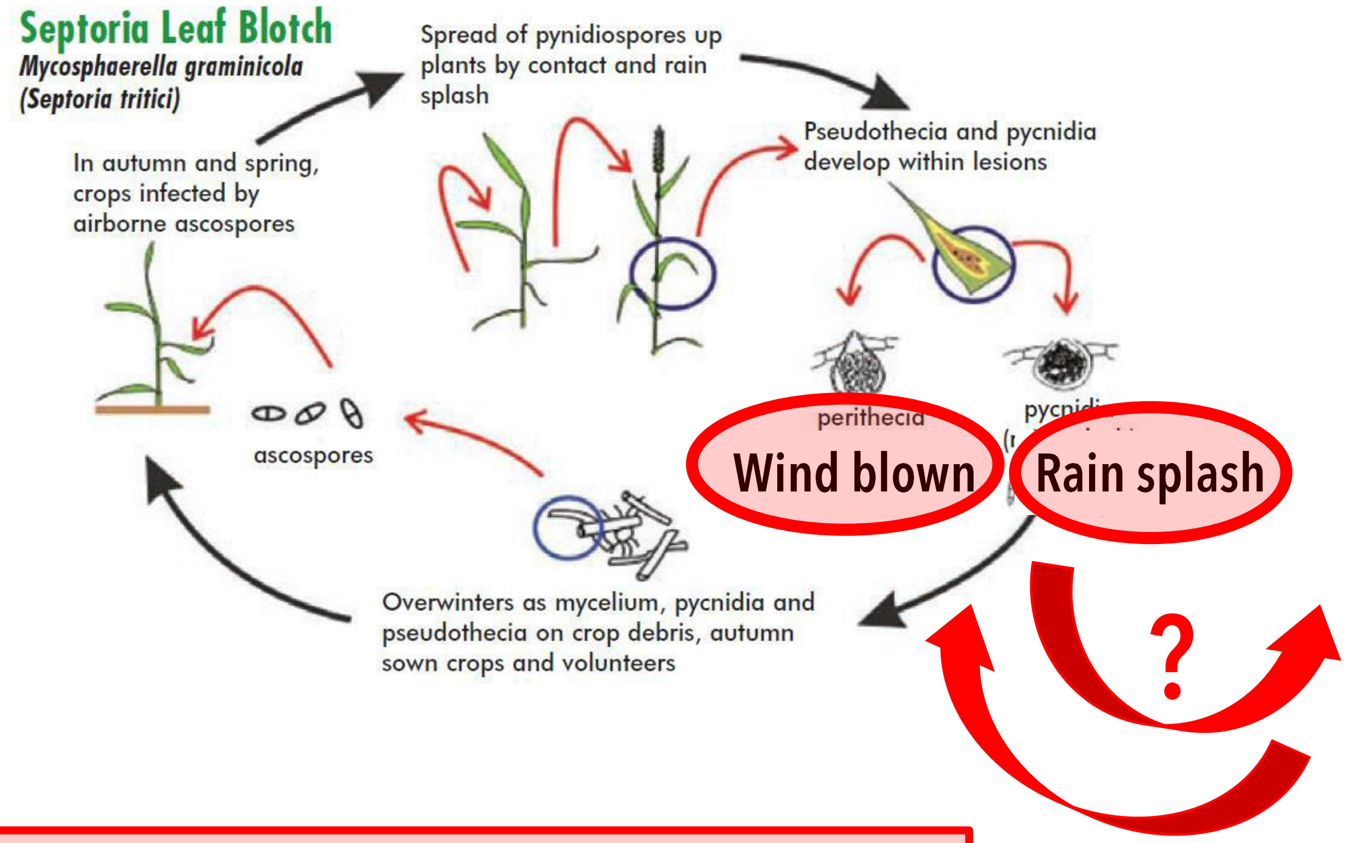
Reservoirs of plant pathogens outside of agriculture

Examples of pathogen life cycles told as incomplete stories of life histories

Botrytis cinerea of chick pea



Mycosphaerella graminicola of wheat



Opportunities for dissemination to/from habitats beyond agriculture

Reservoirs of plant pathogens outside of agriculture

When we look elsewhere – we find plant pathogens !

The case of *Pseudomonas syringae*

Known







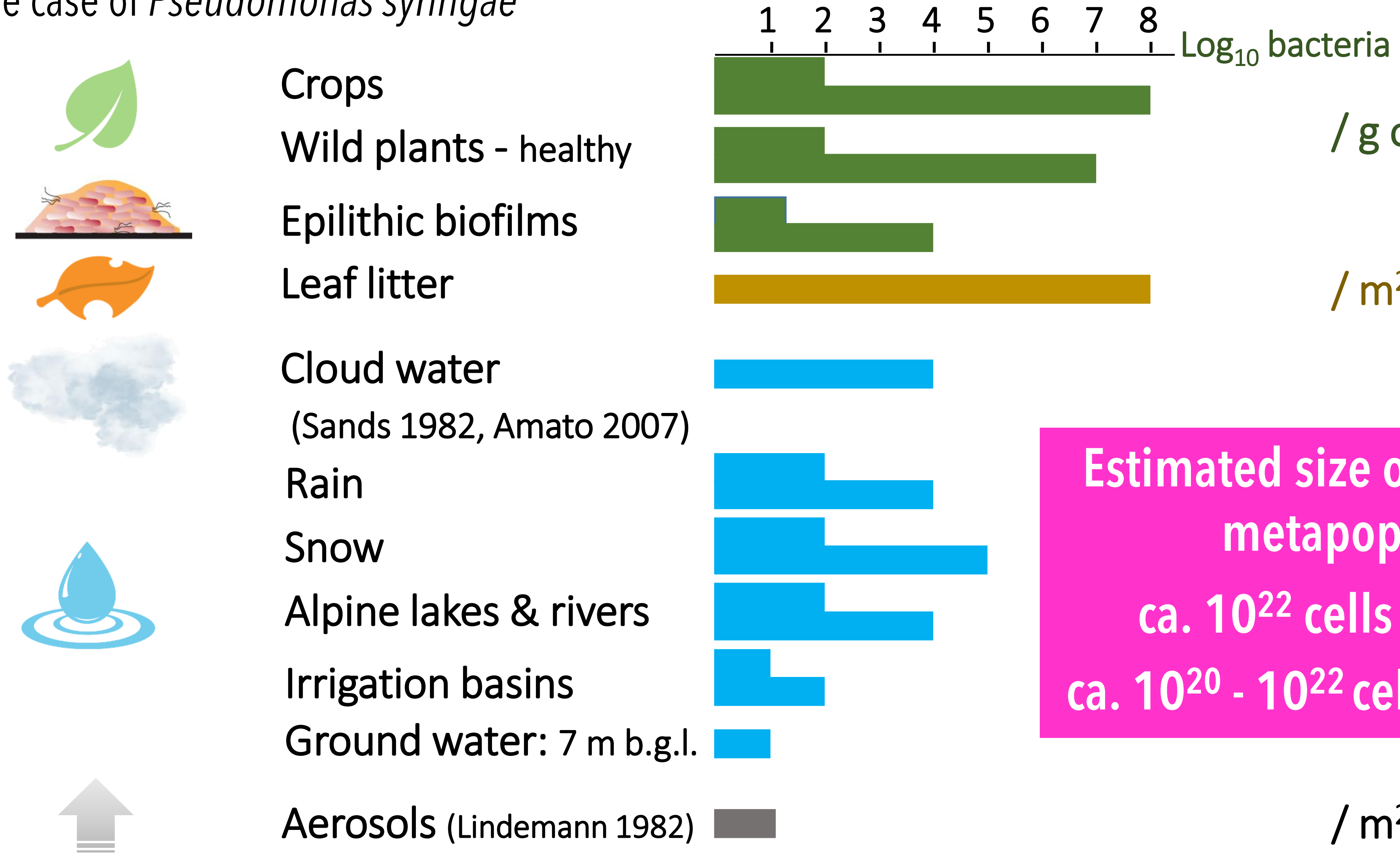
To be discovered





Reservoirs of plant pathogens outside of agriculture

The case of *Pseudomonas syringae*



Estimated size of the planetary metapopulation:

ca. 10^{22} cells on/in plants

ca. 10^{20} - 10^{22} cells in freshwater

Reservoirs of plant pathogens outside of agriculture

Potential pathogens are everywhere

plants tested

cantaloupe

beet

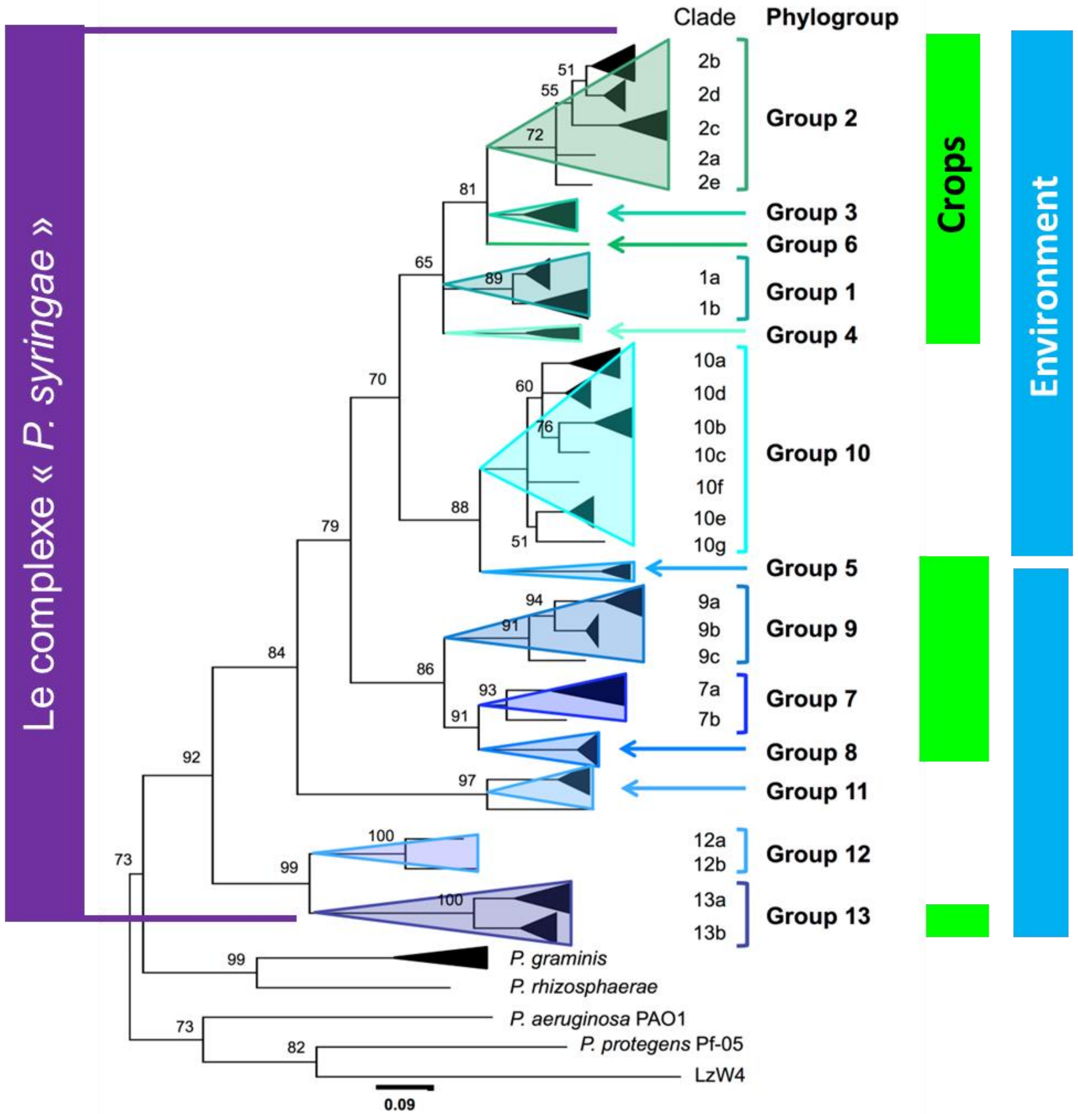
lettuce

Substrates that harbor pathogenic *P. syringae*

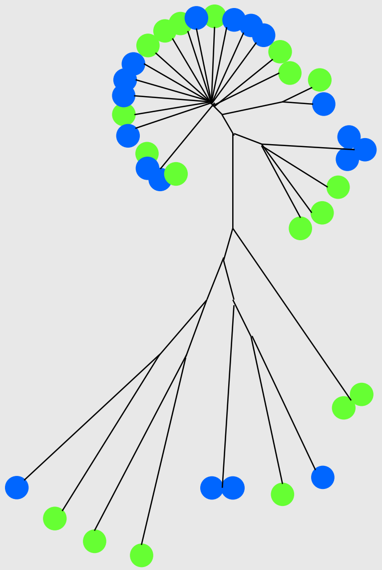
Environment
- Wild alpine plants
- Leaf litter
- Snow pack
- Streams, lakes, rivers
- Ground water
- Cloud water

Agric.
- Irrigation water basins
- Crop plants

Genetic diversity in the environment ≥ in agriculture



Crop & environ'l strains are indistinguishable



Genealogies inferred by *ClonalFrame* for strains in clade 2d from crops and the environment (2293 common genes)

Reservoirs of plant pathogens outside of agriculture

frontiers in Plant Science

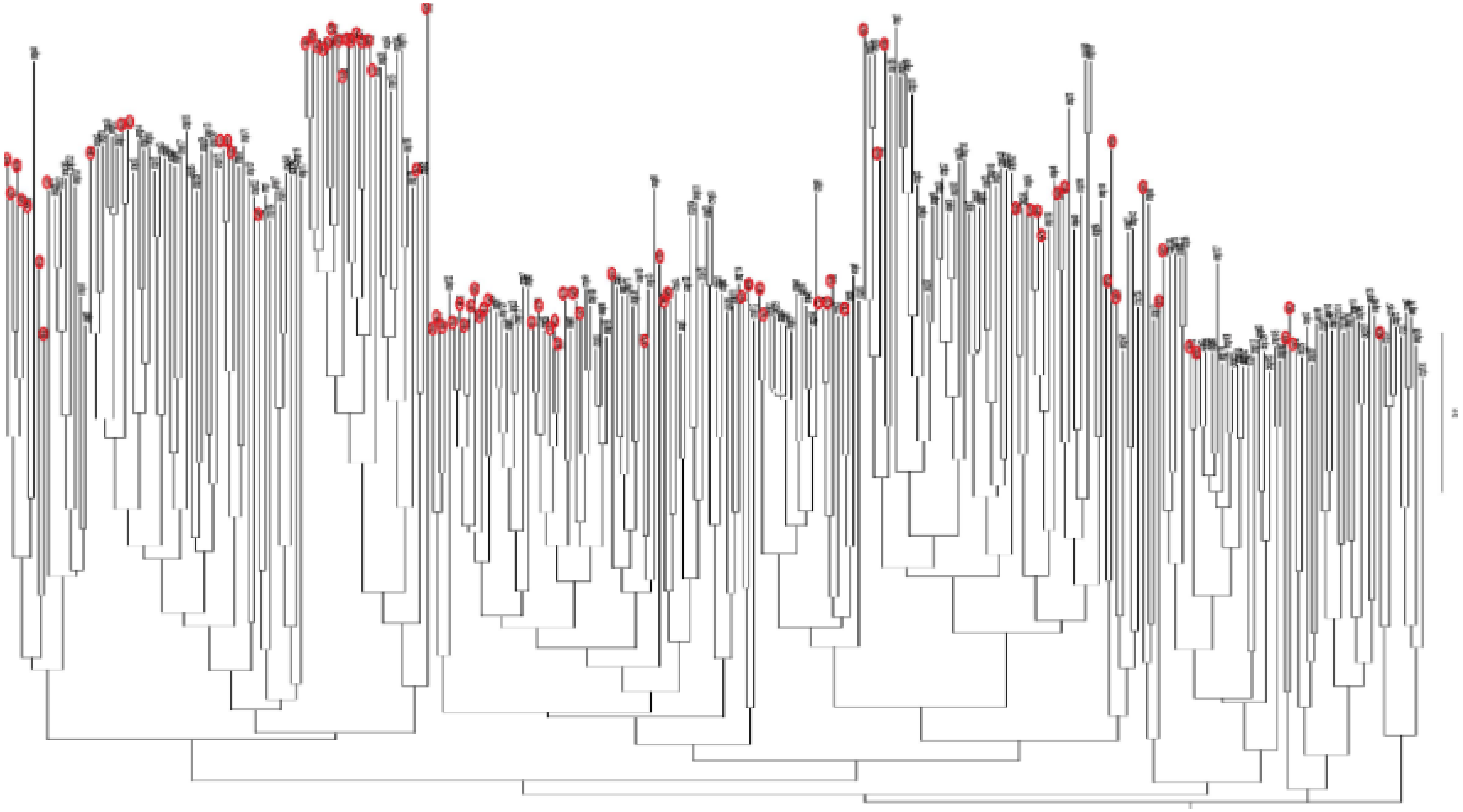
ORIGINAL RESEARCH
published: 05 December 2018
doi: 10.3389/fpls.2018.01820

Striking Similarities Between *Botrytis cinerea* From Non-agricultural and From Agricultural Habitats

Marc Bardin, Christel Leyronas, Claire Troulet and Cindy E. Morris*

Botrytis cinerea
(similar environmental reservoirs as *P. syringae*)

Crop and environmental strains are indistinguishable



NJ tree of genetic distance between strains from non-agricultural habitats (●) and from crops, based on microsatellite markers

Dual-use virulence factors & maintenance of virulence factors outside of agriculture

For human/animal pathogens: Numerous examples of traits that foster environmental fitness and virulence

Organism	Trait or gene	Role in: pathogenic fitness	Role in: environmental fitness
Vibrio cholera	Toxin co-regulated pilus	Virulence factor in humans	Biofilm formation on chitin
Legionella pneumophila	Proteins mimicking cellular functions of eukaryotic proteins; type II & IV secretion systems & effectors, attachment proteins	Virulence factors in macrophages	Parasitism and multiplication in protozoa
Burkholderia cenocepacia	Quorum-sensing regulatory system	Regulation of virulence factors in 'cepacia syndrome'	Regulation of factors involved in nematode killing
Yersinia pestis	Extracellular polysaccharides fostering heme storage	Transmission to human host, protection from f leukocytes.	Colonization of flea esophagus via biofilm formation
Cryptococcus neoformans, *Alternaria fumigatus*	Melanins	Protects µorg against phagocytosis	Protection against oxidation
Alternaria flavus, Histoplasma capsulatum, Aspergillus fumigatus, A. nidulans, numerous bacteria	Siderophores	Virulence factor in humans	Sequestering iron in the environment
Pseudomonas aeruginosa, Stenotrophomonas maltophilia	Efflux pumps	Intrinsic multidrug resistance	Exclusion of lipophilic toxic compounds from cells
Acinetobacter baumannii	Efflux pumps, genetic promiscuity, EPS & biofilm formation, siderophore-like compoundsps	Multidrug resistance, attachment, stimulation of host inflammation, virulence factor in humans	Exclusion of toxic compounds from cells, resistance to desiccation, sequestering of iron

Traits common to many microorganisms, including plant pathogens

Morris et al. 2009: PLoS Pathogens 5(12) : e1000693. doi:10.1371/journal.ppat.1000693

Dual-use virulence factors & maintenance of virulence factors outside of agriculture

For plant pathogens: Many candidates for dual-use virulence factors, but few studies on the role of non-crop habitats as a selective force

Plant pathogens that thrive in non agricultural habitats or survive saprophytically in agricultural contexts in absence of host plants

Bacteria

- *Burkholderia cepacea*
- *Dickyea spp.*
- *Pectobacterium carotovorum*
- *Pantoea agglomerans*
- *Rhodococcus fascians*
- *Streptomyces spp*

Fungi

- *Alternaria spp.*
- *Aspergillus spp.*
- *Cladosporium spp.*
- *Fusarium spp.*
- *Leptosphaeria maculans*
- *Mucorales: Mucor spp. Rhizopus spp.*
- *Pythium spp. (non obligate parasitic oomycetes)*
- *Penicillium spp.*

Morris et al. 2009: PLoS Pathogens 5(12) : e1000693. doi:10.1371/journal.ppat.1000693

Framework for assessing potential risk of microbial lines before they emerge as pathogens

- Management of plant diseases is based on identification, detection, diagnostics of lines of microorganisms that have already caused disease.
- What is the risk posed by environmental strains that are pathogenic when tested in the laboratory?

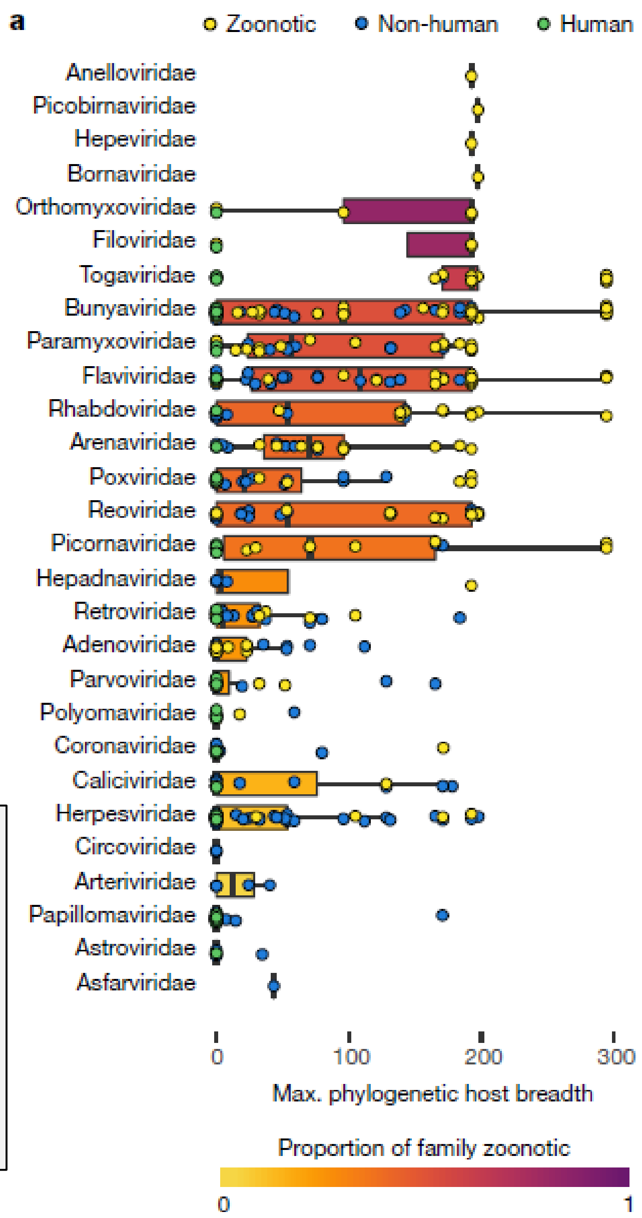
Framework for assessing potential risk of microbial lines before they emerge as pathogens

A framework to predict emergence of new zoonotic diseases

Olival et al. 2017. **Host and viral traits predict zoonotic spillover from mammals.** Nature 546:646–650

The framework consists of an assemblage of traits that prediction zoonotic potential

- Host range breadth (from reports of occurrence)
- Cytoplasmic replication
- Vector-borne



Experimental inoculation of hosts cannot be used to assess zoonotic potential. But, we can inoculate plants to determine their host range. So why isn't Plant Pathology developing a framework to assess and anticipate the risk of new emergences?

Framework for assessing potential risk of microbial lines before they emerge as pathogens

- Management of plant diseases is based on identification, detection, diagnostics of lines of microorganisms that have already caused disease.
- What is the risk posed by environmental strains that are pathogenic when tested in the laboratory?

- The notion of "pathotypes" with rather specific host ranges is a fundamental concept in plant pathology.

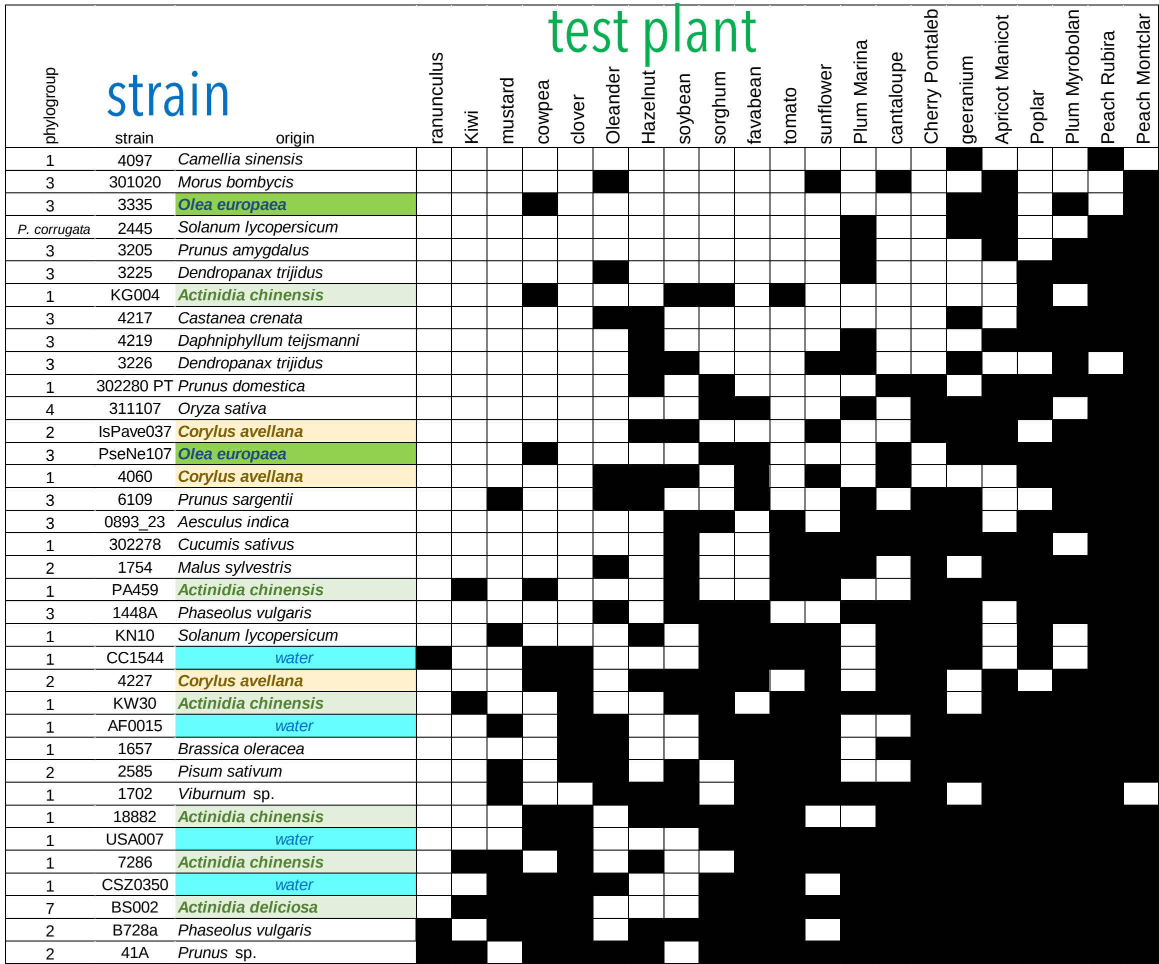
BUT, when tested un comparable conditions:

- Host range of *P. syringae* is an overlapping continuum (nested; no statistically significant modules)

Morris et al. *Phytopathology Research* 1 :4 doi.org/10.1186/s42483-018-0010-6

- Many other pathogens (viruses, fungi, nematodes) show same significantly nested pattern of host range

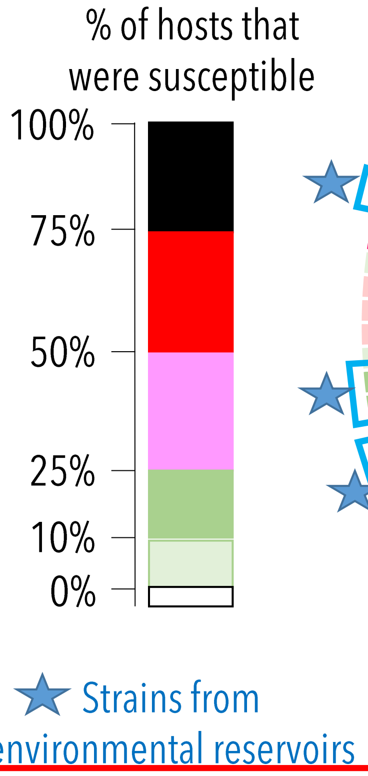
(Moury et al. manuscript in preparation)

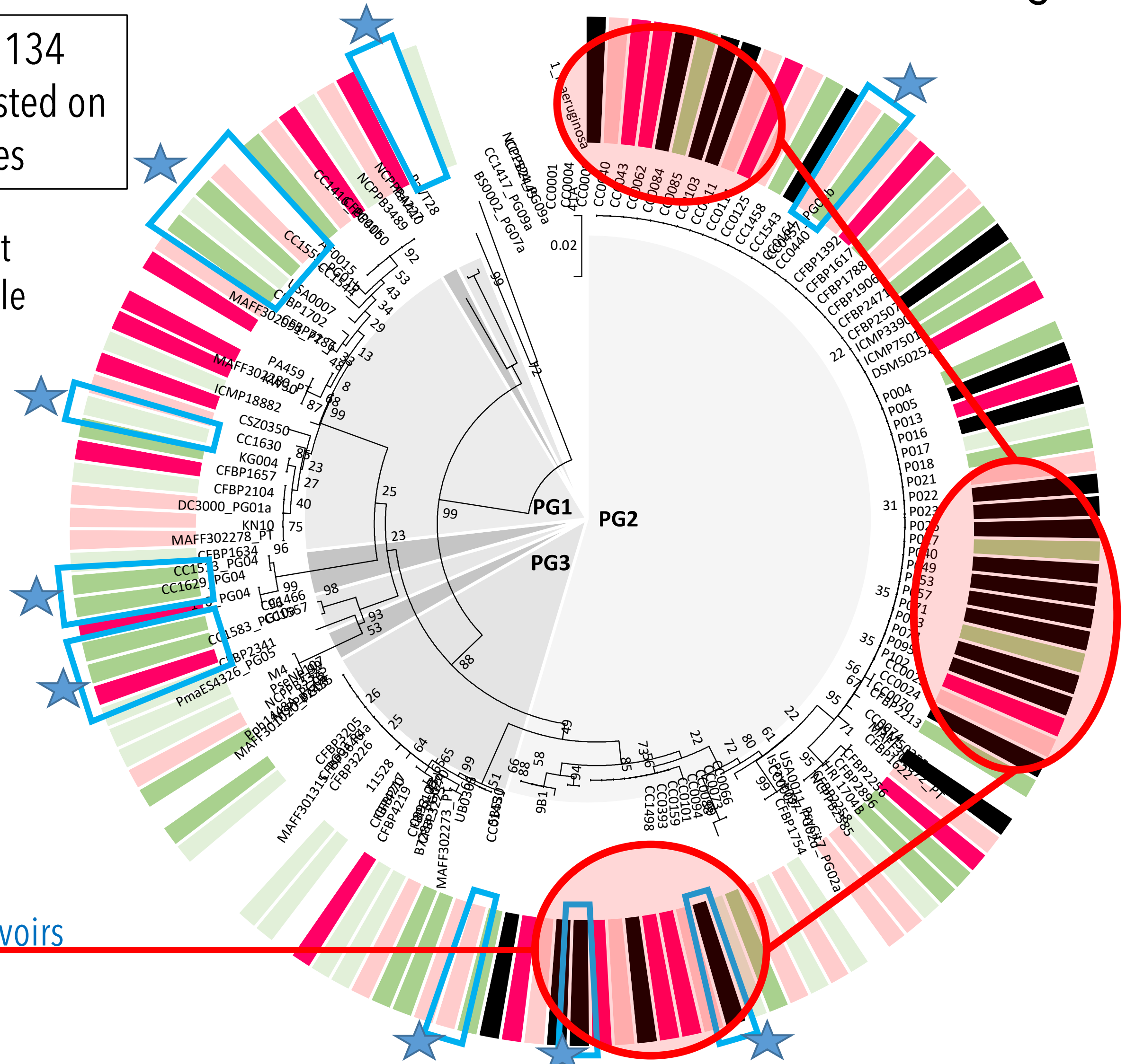


Framework for assessing potential risk of microbial lines before they emerge as pathogens

- In Plant Pathology, the potential for emergence of a given strain could be based on breadth of host range

Host range extent of 134 strains of *P. syringae* tested on 16-22 plant species



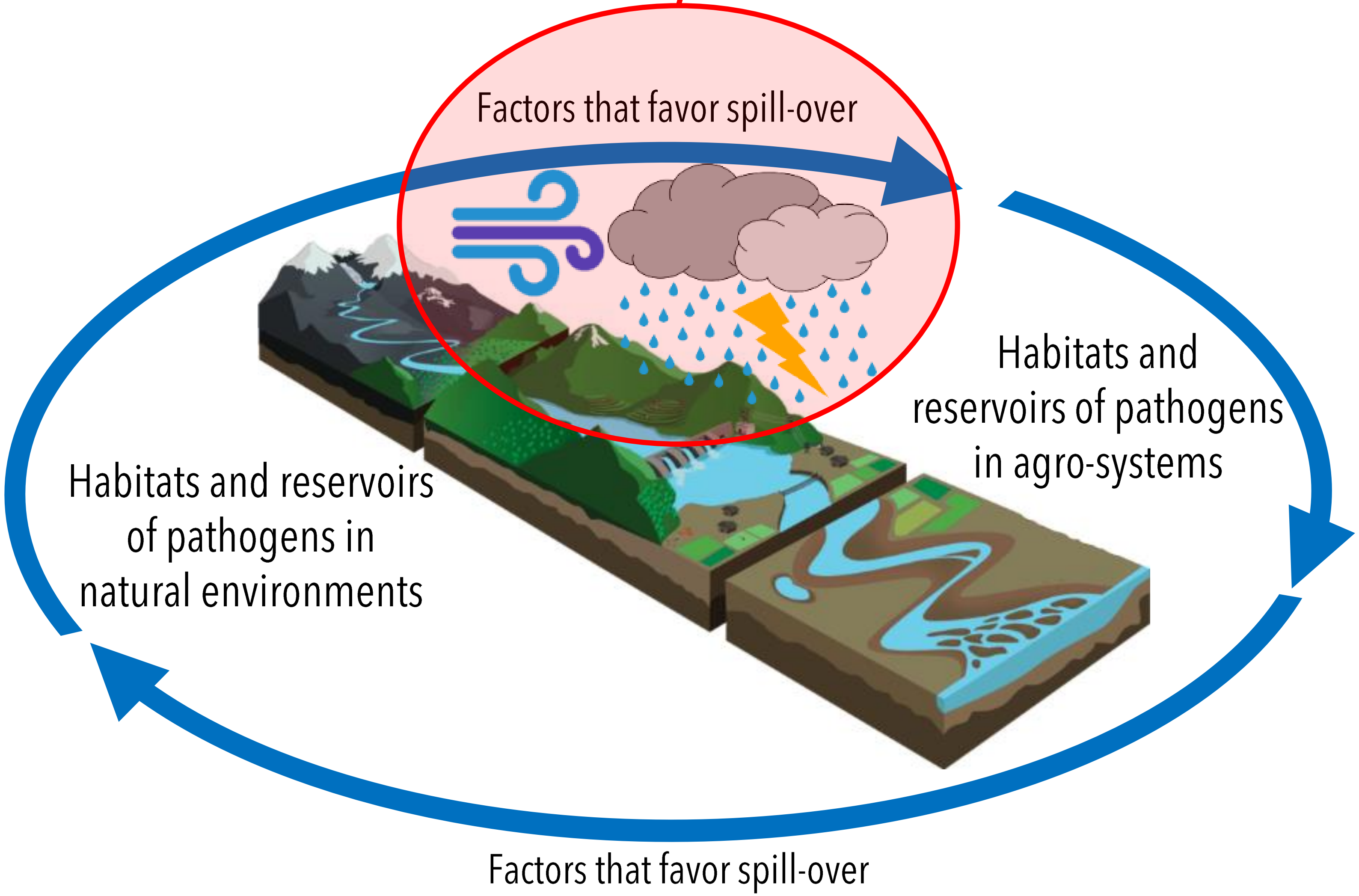


These groups of strains in their respective environmental reservoirs could be surveyed with molecular diagnostics

Morris et al. *Phytopathology Research* 1 :4 doi.org/10.1186/s42483-018-0010-6

Spill-over via natural processes operating constantly and at long distances

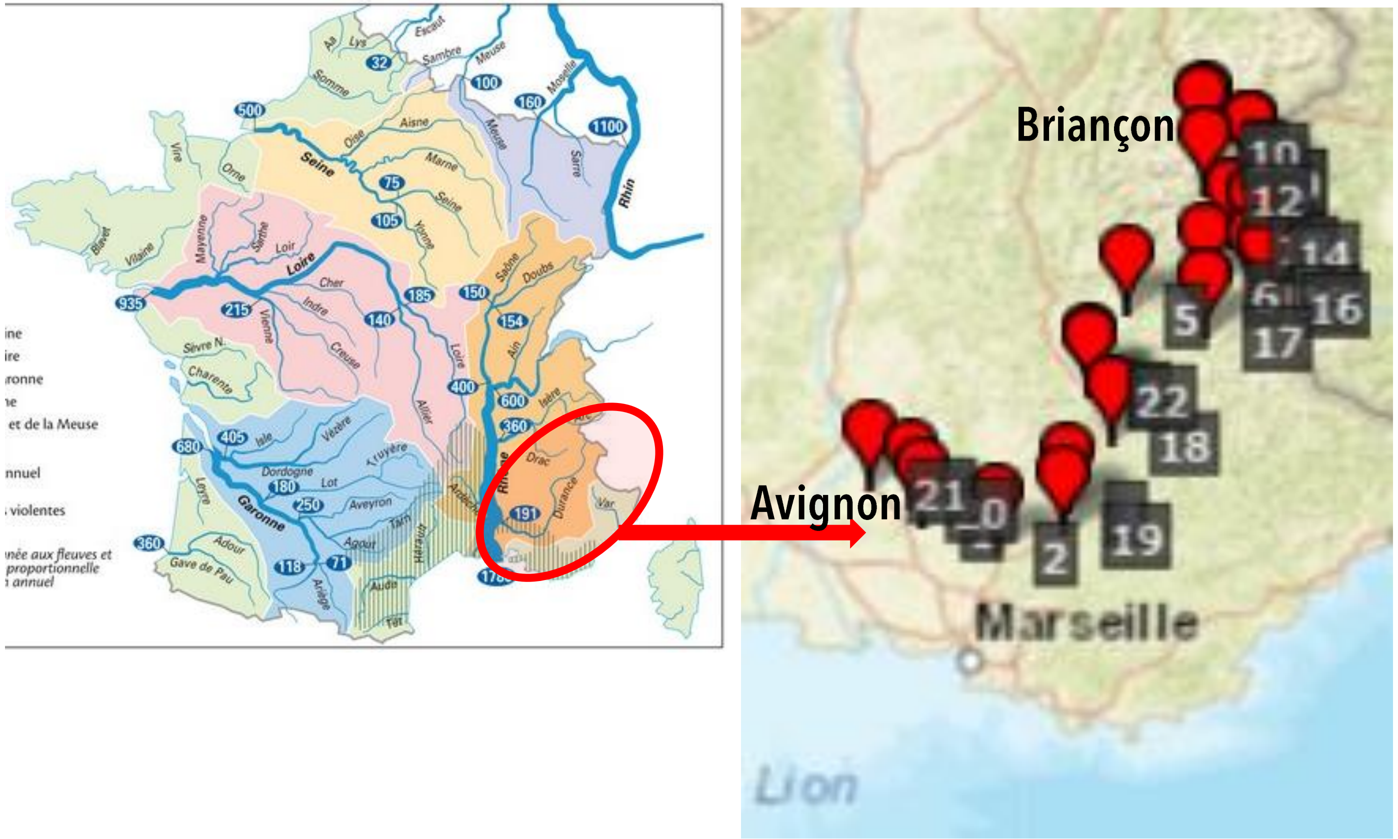
Have these means of dissemination been sufficiently considered in the life history of plant pathogens?



Spill-over via natural processes operating constantly and at long distances

Surface waters

In progress: Characterize the flow of *P. syringae* within the Durance river basin catchment



- 22 sampling sites
- 4 seasons / 2016 & 2017
- Quantify population densities in river water
- Isolate strains for further characterization (>**5000** from this study)

Spill-over …..

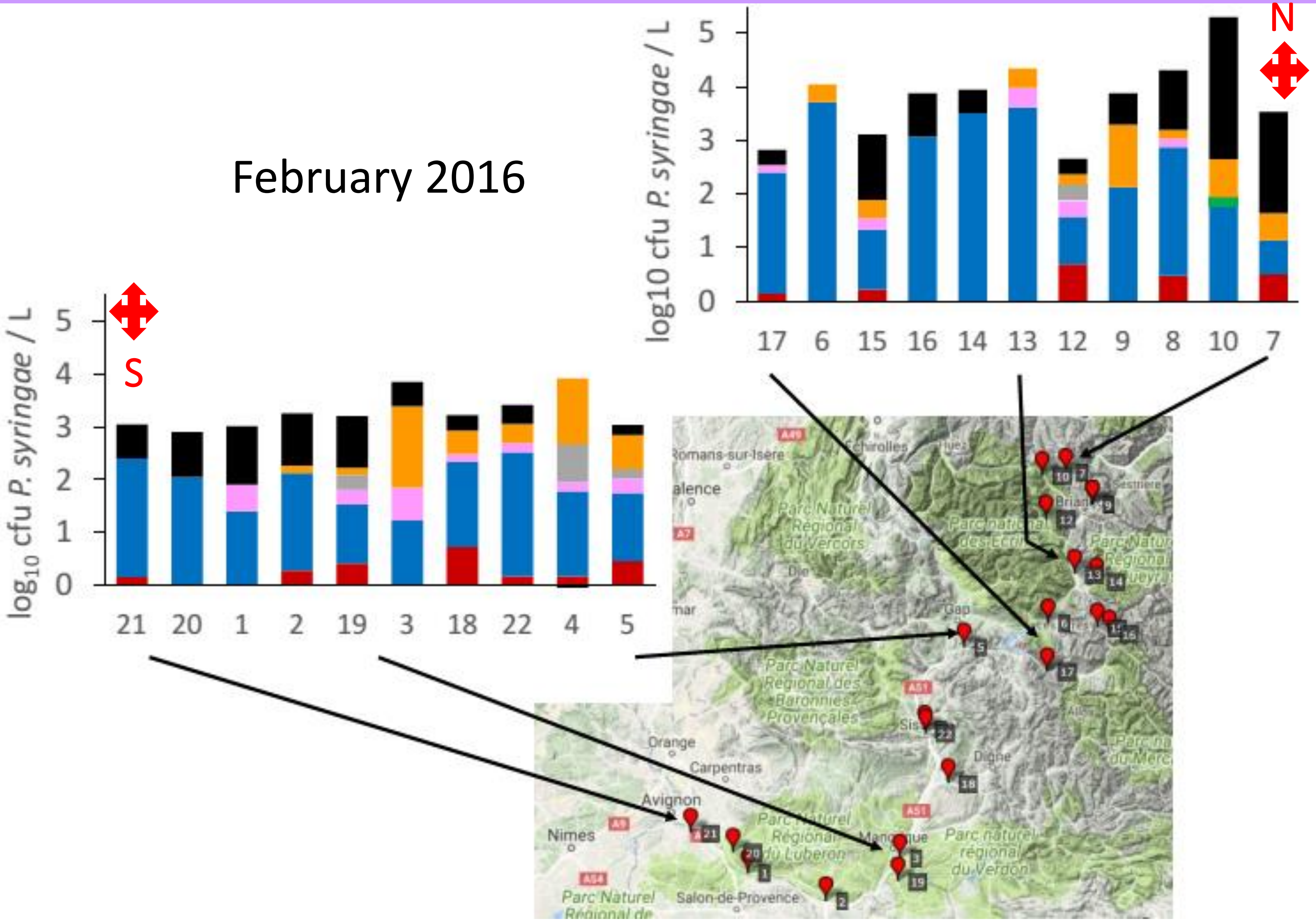
Surface waters

Example results

February 2016

Phylogroups

- PG1
- PG2
- PG4
- PG7/8
- PG9
- PG13
- PG-other



Spill-over via natural processes operating constantly and at long distances

Aerial dissemination

Known long distance aerial trajectories of plant pathogens

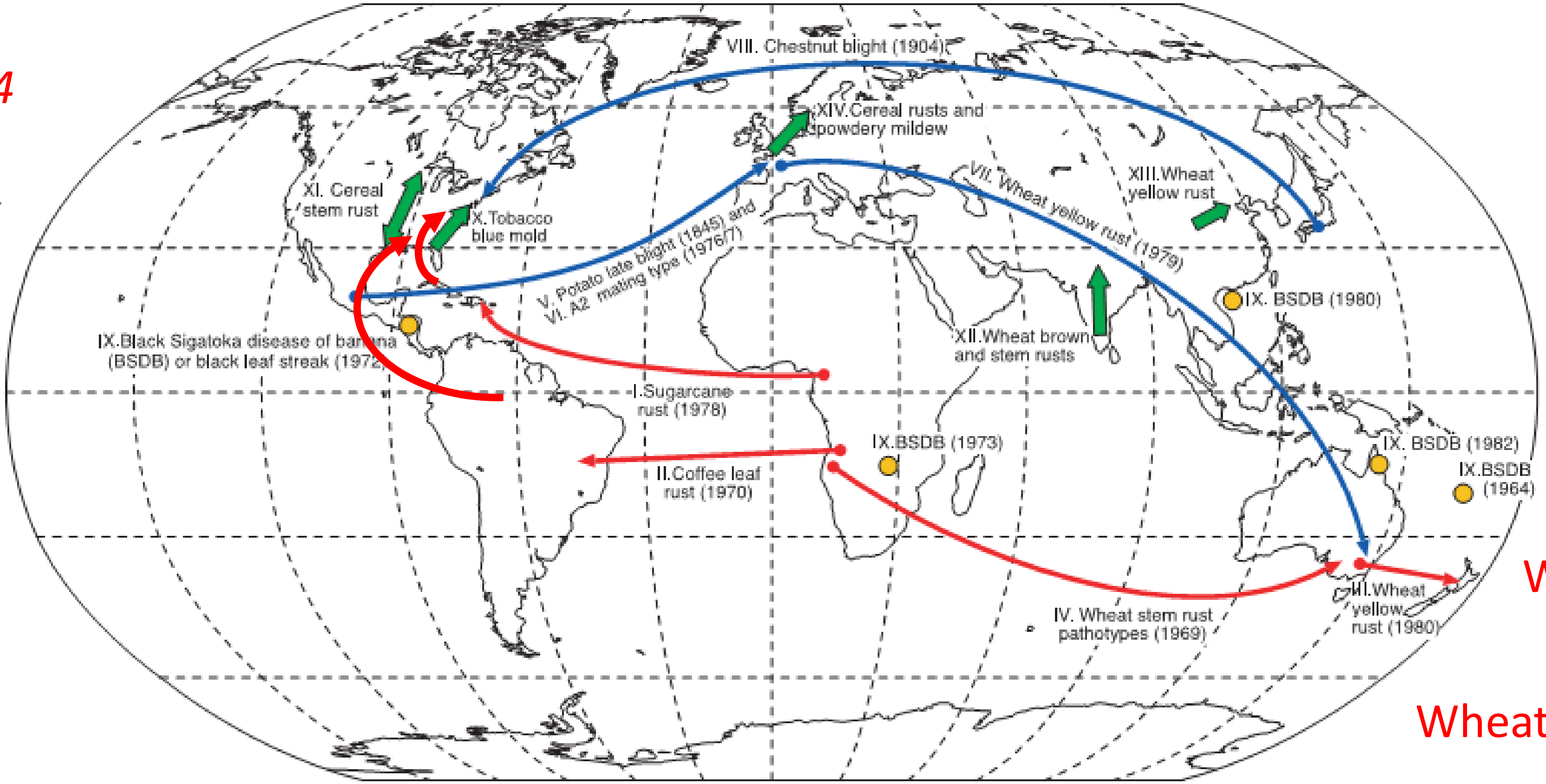
Soybean rust 2004

Isard et al. 2005. *Bioscience*. 55:851–861

Tobacco blue mold 1979

Sugarcane rust 1978

Coffee rust 1970



Wheat yellow rust 1980

Wheat stem rust 1969

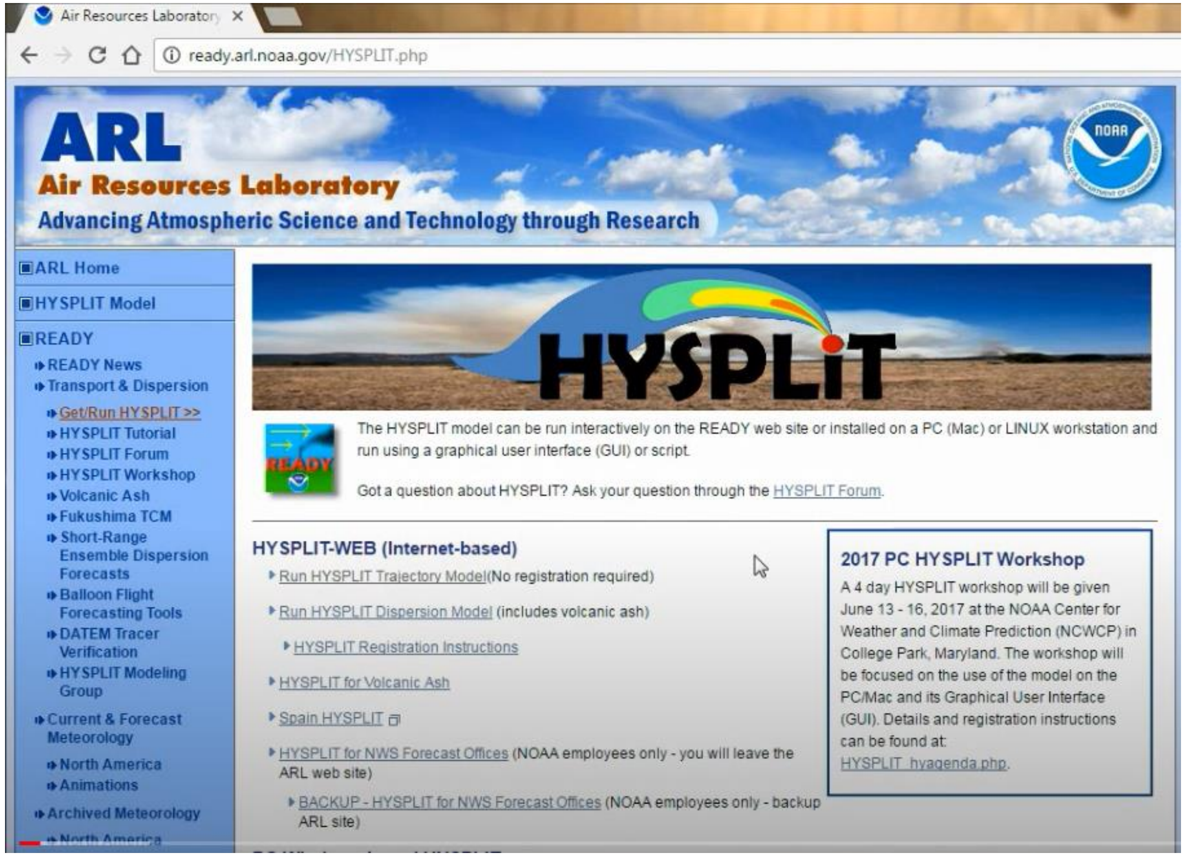
Brown JKM, Hovmøller MS. 2002. *Science* 297:537-541

Spill-over via natural processes operating constantly and at long distances

Aerial dissemination

Concentrations of microorganisms in rain and snowfall …..

….coupled to information about air mass trajectories can give insight about dissemination patterns.



Spill-over via natural processes operating constantly and at long distances

Aerial dissemination

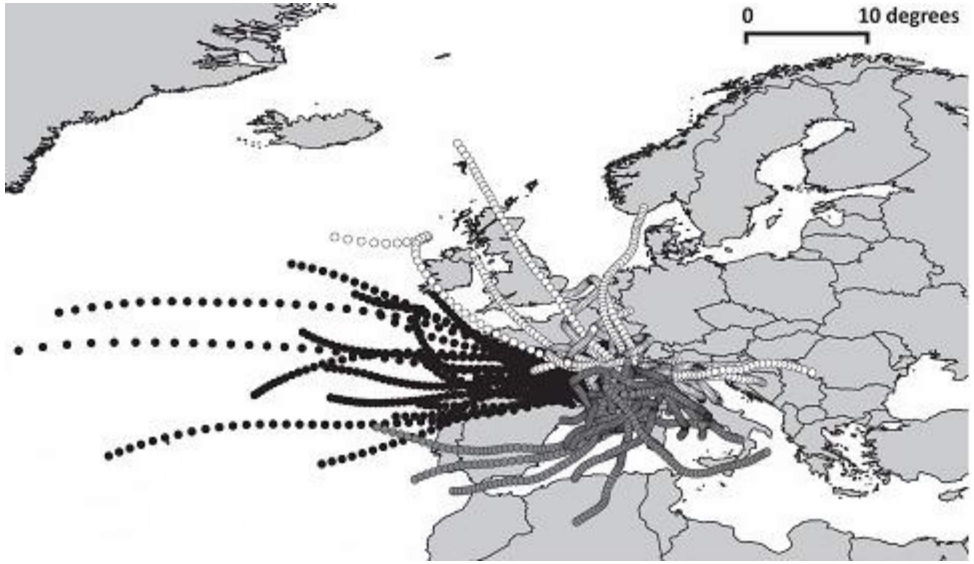
Rain & snowfall carry *P. syringae*, depending on the origin of air masses.

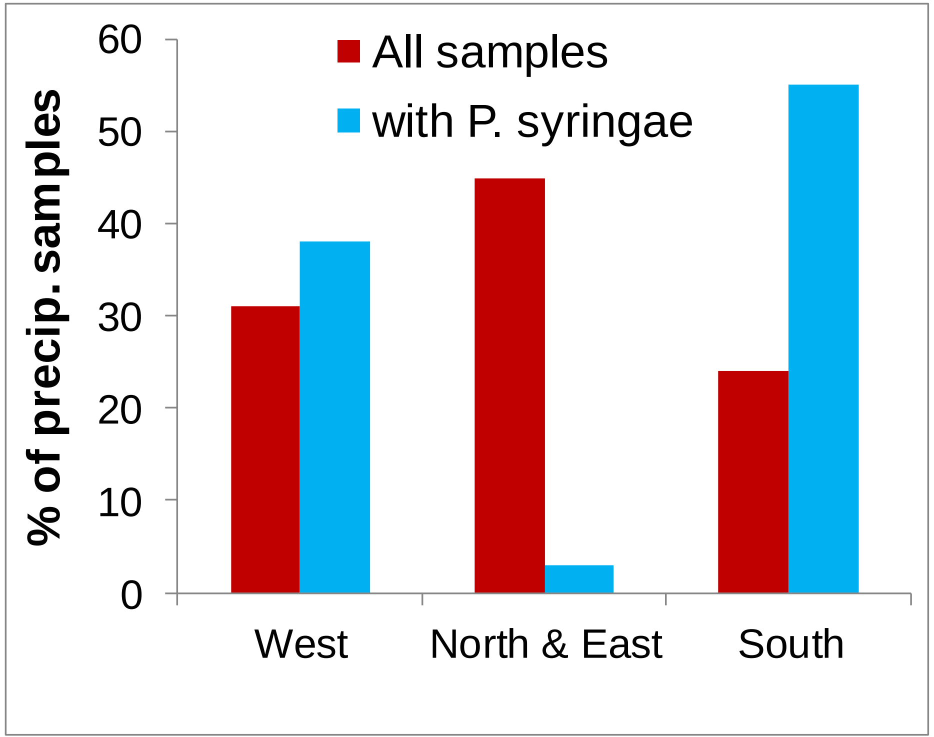
Botryis cinerea is also regularly present in snow and rainfall – at lower concentrations and independent of air mass origin.

In southern France:

	% +	*P. syringae* / L
Rain	65.2	500
Snow	12.3	5000

88 precipitation events 2006 - 2010





	pH*	Conductivity*
Present	6.21	13 µS.cm^{-1}
Absent	5.76	8 µS.cm^{-1}

*Mann Witney U test ($p<0.05$)

Monteil et al. 2014 *ISME J.* doi:10.1038/ismej.2014.55

Spill-over via natural processes operating constantly and at long distances

Aerial dissemination

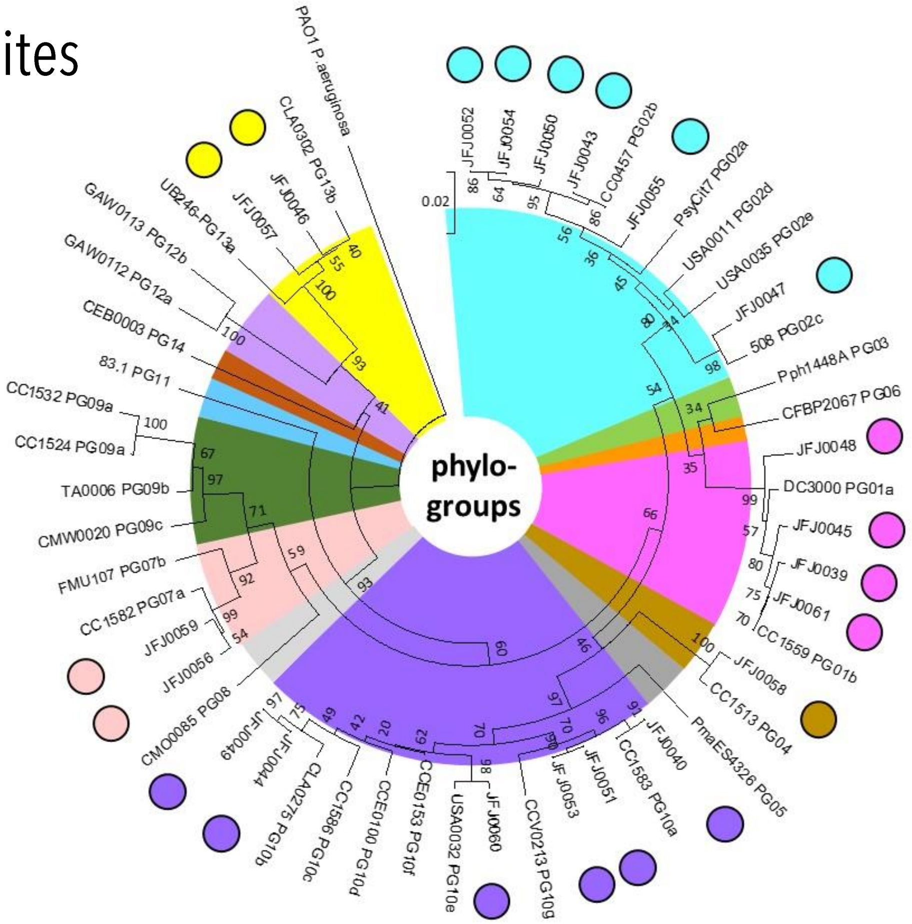
Rain & snowfall – at remote sites

Jungfraujoch, 3580 m altitude

22, 23 May and 22 Oct. 2014

P. syringae in snowfall

up to 45 cells / L snowmelt



Strains from JFJ in 6 phylogroups among the 13 phylogroups of *P. syringae*

Stopelli et al. 2016. *Biogeosciences* 14:1189-1196

Spill-over via natural processes operating constantly and at long distances

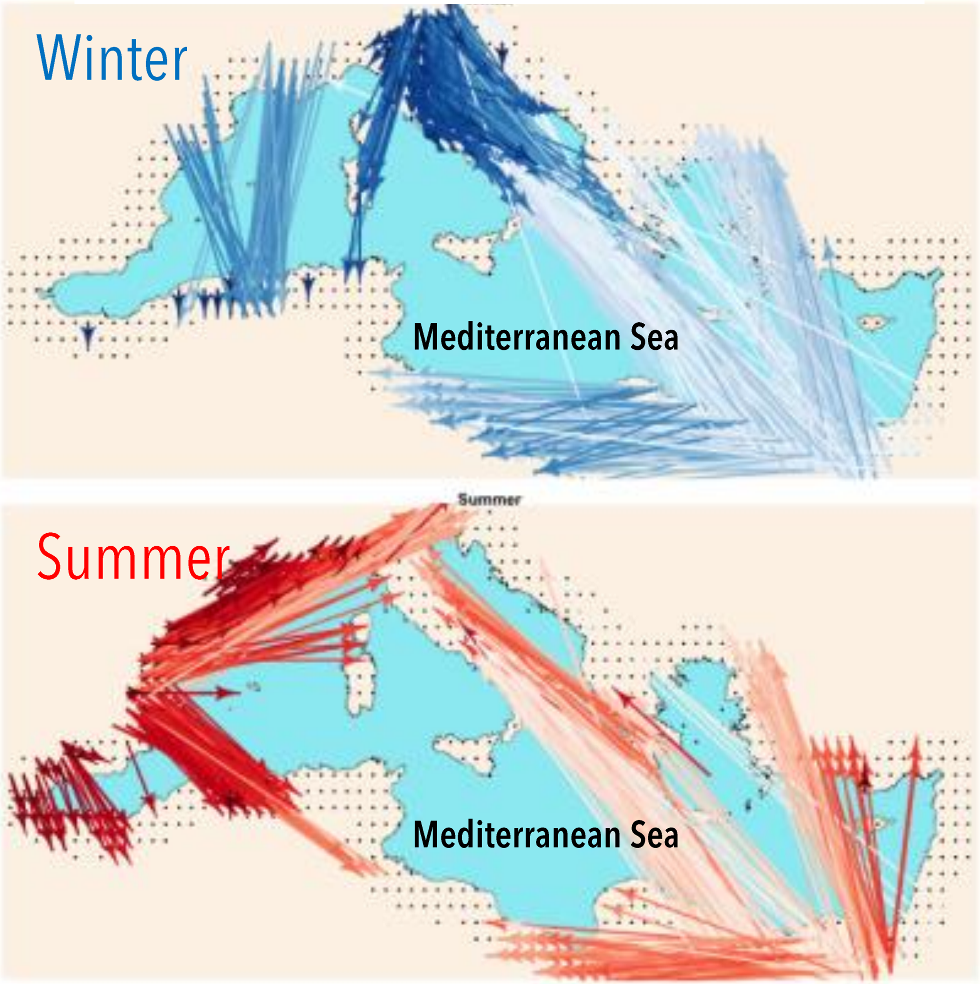
Aerial dissemination

Overall – to experimentally demonstration long distance aerial dissemination pathways is very challenging.

We are tackling this by tracing the probable aerial trajectories based on frequency of air mass movements from historical data via HYSPLIT

Choufany M. Martinetti D., Senoussi R., **Morris C.E.**, Soubeyrand S. **2020.** Spatiotemporal large-scale networks shaped by air mass movements. *Front. Appl. Math. Stat.* (*in press*)

Connectivity via air mass movement



New *modus operandi* for plant health

- Reservoirs outside of agriculture, on substrates other than plants

  Look for them !

- Dual-use virulence factors / Maintenance of virulence factors in non-ag habitats

  New research on more comprehensive questions about the drivers of pathogen evolution.

- Framework for assessing potential risk of microbial lines before they emerge as pathogens

  To anticipate disease emergence, account for pathogenic potential measured in controlled-condition inoculations. Modernize the classification of plant pathogens by "pathotypes".

- Spill-over via natural processes operating constantly and at long distances

  Identify and survey these processes – in addition to surveillance of movement by commerce, transportation.

For more information……..

- Morris C.E., Moury B. 2019. Revisiting the concept of host range of plant pathogens. *Annu. Rev. Phytopathol*. 57:63-90.
- Morris C.E., Lamichhane J.R., Nikolić, I., Stanković S., Moury B. 2019. The overlapping continuum of host range among strains in the *Pseudomonas syringae* complex. *BMC Phytopathology Research* 1 :4 doi.org/10.1186/s42483-018-0010-6
- Bardin M., Leyronas C., Troulet C., Morris C.E. 2018. Striking similarities between *Botrytis cinerea* from non-agricultural and from agricultural habitats. *Frontiers in Plant Science*, 5 Dec 2018, https://doi.org/10.3389/fpls.2018.01820
- Leyronas C., Morris C.E., Choufani M., Soubeyrand S. 2018. Assessing the aerial interconnectivity of distant reservoirs of *Sclerotinia sclerotiorum*. *Frontiers in Microbiology, section Extreme Microbiology* 9 : https://doi.org/10.3389/fmicb.2018.02257
- Carotenuto F., Georgiadis T., Gioli B., Leyronas C., Morris C. E., Nardino M., Wohlfahrt G., Miglietta F. 2017 Measurements and modeling of surface–atmosphere exchange of microorganisms in Mediterranean grassland. Atmos. Chem. Phys. 17, 14919-14936, https://doi.org/10.5194/acp-17-14919-2017
- Stopelli E., Conen F., Guilbaud C., Zopfi J., Alewell C., and Morris C.E. 2017. Ice nucleators, bacterial cells and *Pseudomonas syringae* in precipitation at Jungfraujoch. *Biogeosciences* 14:1189-1196
- Morris C.E., Barny M.A., Berge O., Kinkel L., Lacroix C. 2017. Frontiers for research on the ecology of plant pathogenic bacteria: Fundamentals for sustainability. *Molec. Plant Pathol*. 18 :308-319 doi: 10.1111/mpp.12508
- Monteil C.L., Yahara K., Studholme D.J., Mageiros L., Méric G., Swingle B., Morris C.E., Vinatzer, B.A., Sheppard S.K. 2016. Population genomic insights into the emergence, crop-adaptation, and dissemination of *Pseudomonas syringae* pathogens. *Microbial Genomics* doi: 10.1099/mgen.0.000089
- Stopelli E., Conen F., Morris C.E., Herrmann E., Henne S. Steinbacher M., Alewell C. 2016. Predicting abundance and variability of ice nucleating particles in precipitation at the high-altitude observatory Jungfraujoch. *Atmos. Chem. Phys.* 16 : 8341-8351
- Stopelli E., Conen F., Morris C.E., Herrmann E., Bukowiecki N., Alewell C. 2015. Ice nucleation active particles are efficiently lost from precipitating clouds. *Scientific Reports* 5:16433, DOI: 10.1038/srep16433
- Berge O., Monteil C.L., Bartoli C., Chandeysson C., Guilbaud C., Sands D.C., Morris C.E. 2014. A user's guide to a data base of the diversity of *Pseudomonas syringae* and its application to classifying strains in this phylogenetic complex. *PLoS One* 9(9): e105547. doi:10.1371/journal.pone.010554
- Monteil C.L., Bardin M., Morris C.E. 2014. Features of air masses associated with the deposition of *Pseudomonas syringae* and *Botrytis cinerea* by rain and snowfall. *ISME Journal* 8: 2290-2304. doi: 10.1038/ismej.2014.55
- Morris C.E., Monteil C.L., Berge O. 2013. The life history of *Pseudomonas syringae*: linking agriculture to Earth system processes. *Annu. Rev. Phytopath*. 51:85-104.
- Monteil C.L., Lafolie F., Laurent J., Clement J-C., Simler R., Travi Y., Morris C.E. 2013. Soil water flow is a source of the plant pathogen *Pseudomonas syringae* in subalpine headwaters. *Environ. Microbiol.* doi:10.1111/1462-2920.12296.
- Morris C.E., Sands D.C., Glaux C., Samsatly J., Asaad S., Moukahel A.R., Gonçalves F.L.T., Bigg E.K. 2013. Urediospores of rust fungi are ice nucleation active at > −10 °C and harbor ice nucleation active bacteria. *Atmos. Phys. Chem*. 13:4223-4233.