



General Introduction: The Rise of Invasive Forest Pests and Pathogens

ANDREA VANNINI

STEVE WOODWARD









But...









WHY?



**Main Drivers for Increasing
Invasions**

Main Drivers for Increasing Invasions



Main Drivers for Increasing Invasions



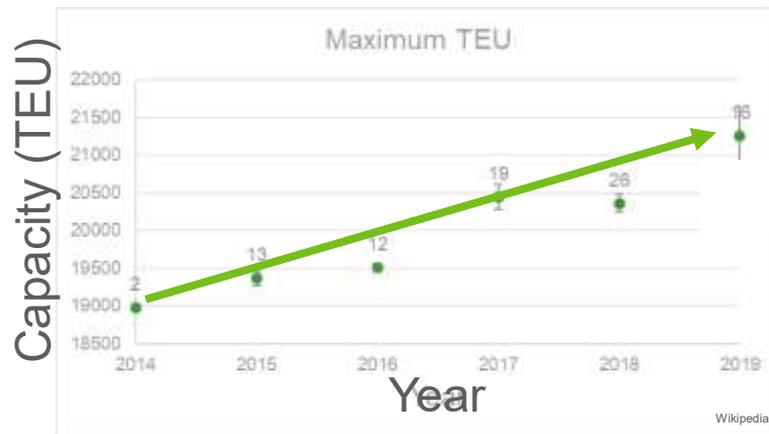
SS Savannah Departed Georgia for London 11th May 1819



Main Drivers for Increasing Invasions

The Clifford J. Rogers Launched: 1955

12% capacity increase in 5 years



MSC GÜLSÜN

THE ^{currently} WORLD'S BIGGEST CONTAINER SHIP



8.35
MILLION
MICROWAVE OVENS

2.94
MILLION
WASHING MACHINES

386
MILLION
PAIRS OF SHOES

IN A
SINGLE VOYAGE
MSC GÜLSÜN
CAN CARRY

8
MILLION
SOLAR PANELS

2.37
MILLION
CAR TYRES

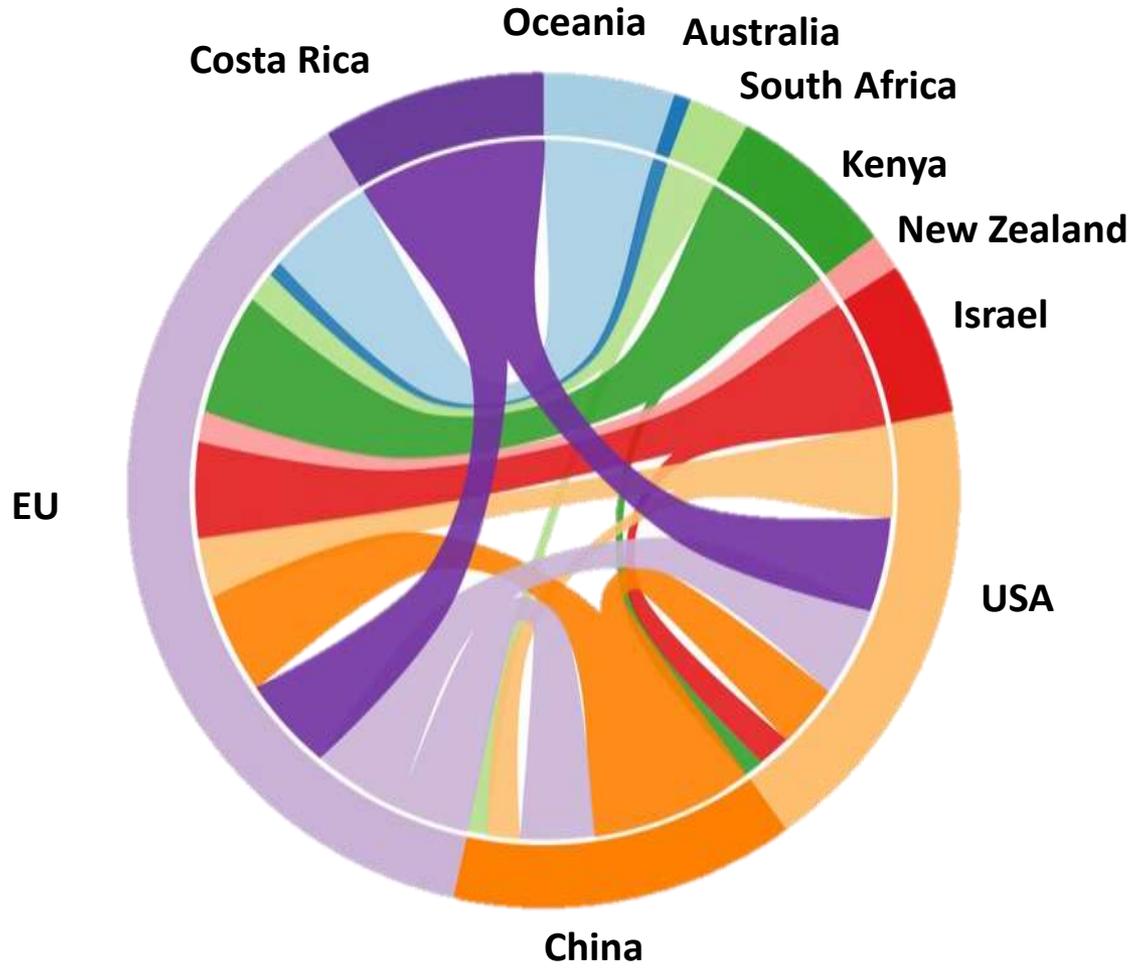
223
MILLION
BANANAS

47,512
CARS



Superseded in January 2025
by the MSC Ilean Class,
capacity 24.346 TEUs

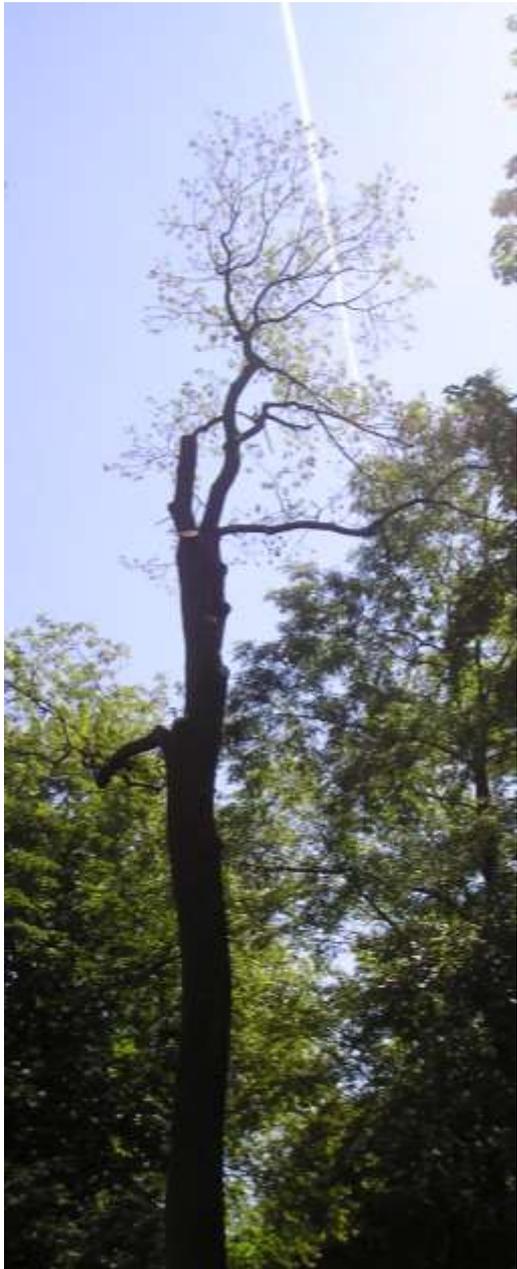
The Complexity of Global Trade



Santini et al., 2018, ISME journal 12: 647-652

Break





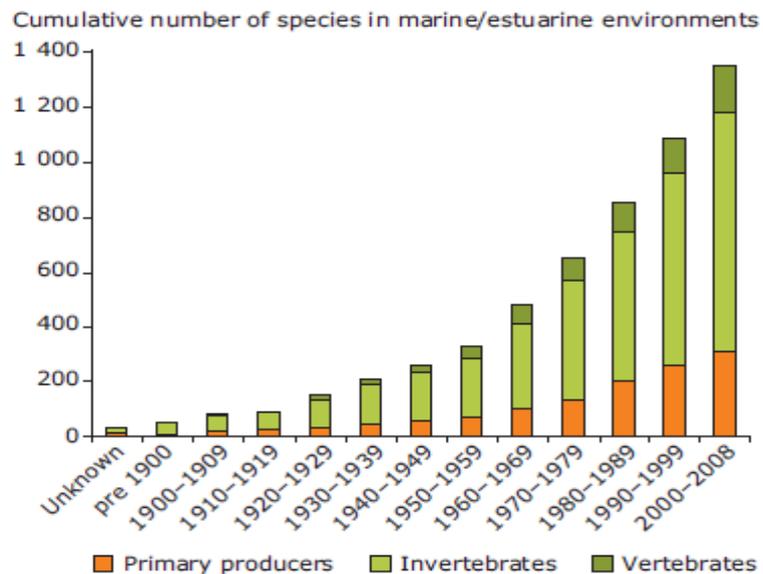
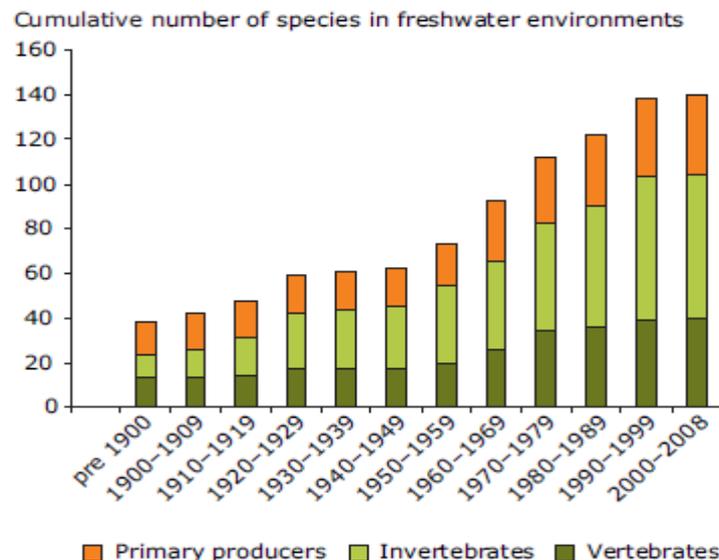
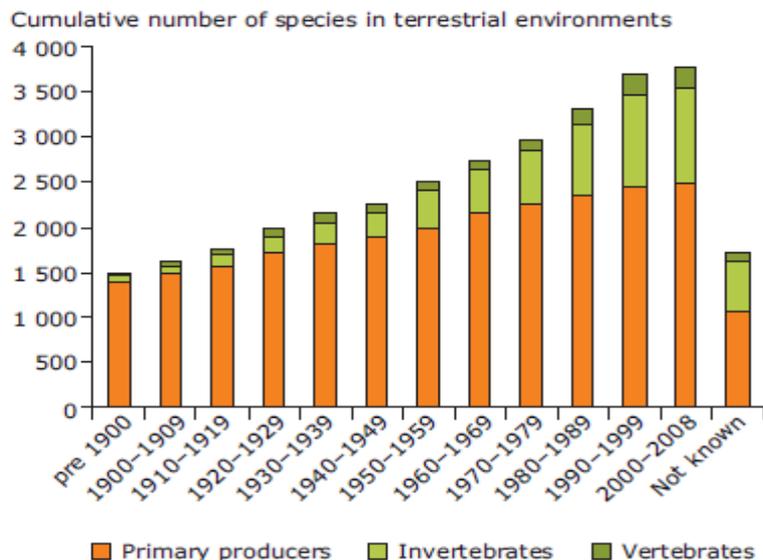
Invasive Forest Pathogens: Definitions, concepts, hypotheses

Andrea Vannini
Steve Woodward

Biological invasions

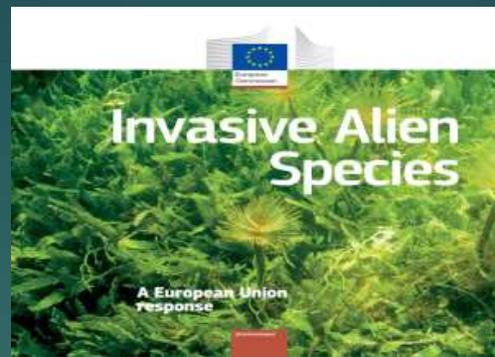
- ▶ Biological invasions by alien (c.f. non-native, non-indigenous, foreign, exotic) species are recognised as significant components in global environmental change: impacts are economic, and on biological diversity and ecosystem function (Wittenberg and Cock 2001).
- ▶ Numerous alien species, many introduced over the last 200 years, became successfully established over large areas of Europe (Hulme 2007).
- ▶ Future global biodiversity scenarios highlight potentially dramatic increases in biological invasions in European ecosystems (Sala *et al.* 2000).
- ▶ Interacting effects through rising atmospheric CO₂ concentrations, warmer temperatures, greater nitrogen deposition, altered disturbance regimes and increased habitat fragmentation will facilitate further invasions (Vilà *et al.* 2006).

Figure 2.1 Cumulative numbers of established alien species in Europe



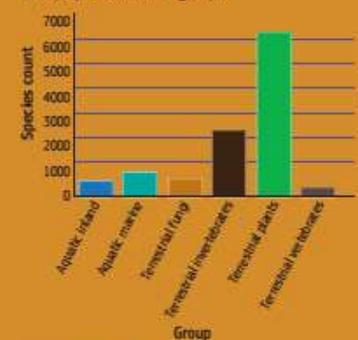
Note: First sentence remains the same, but add the following. The geographic coverage for data from the terrestrial and freshwater environments is: Denmark, Estonia, Finland, Germany, Iceland, Latvia, Lithuania, Norway, Poland, Russia and Sweden. For the marine/estuarine environment, the geographic coverage is all European countries with marine/estuarine waters. Casual records are to some extent included. Casual records < 1920 are excluded, as well as casual records that have later not been found again and therefore assumed extinct.

Source: EEA/SEBI2010; NOBANIS; NEMO database for the Baltic <http://www.corpi.ku.lt/nemo/>, the Black Sea database <http://sfp1.ims.metu.edu.tr/>, Hellenic Centre for Marine Research database, ALIENS database <https://data.aad.gov.au/aadc/biodiversity/>, DAISIE <http://www.europe-aliens.org/>, and experts from France, Spain and Russia made during a dedicated workshop.

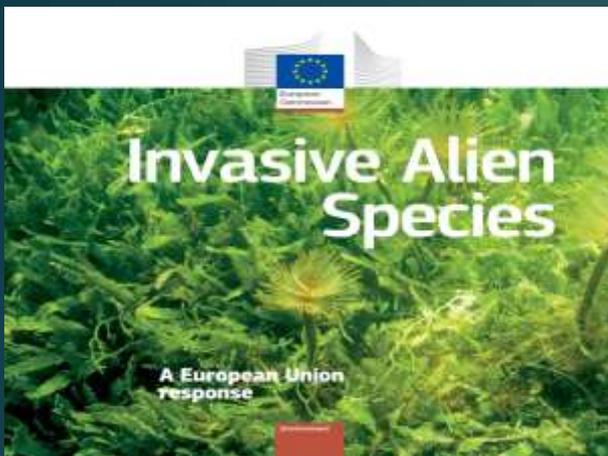


- ▶ Species that have become established outside their native range as a result of human activities
- ▶ Most probably die in the novel environment
- ▶ Some survive, establish and spread
- ▶ Some cause major damage to crops and wider ecosystems
- ▶ Estimates suggest there are over 12,000 invasive alien species present in Europe
- ▶ All Kingdoms of life are represented

Estimated number of alien species in Europe per taxonomic group.



Source: Daisie 2009



Caprobotus edulis

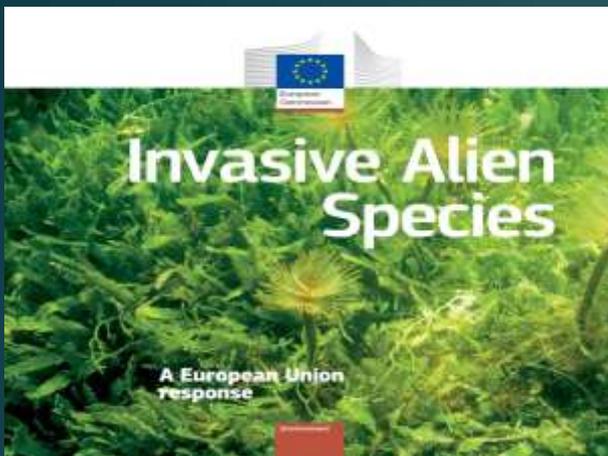
- ▶ Native to the Cape region of South Africa
- ▶ Introduced as an ornamental but escaped and established in the wild



Arion vulgaris -Spanish slug

- ▶ Native in the Iberian peninsula
- ▶ Spread throughout Europe in the horticulture trade





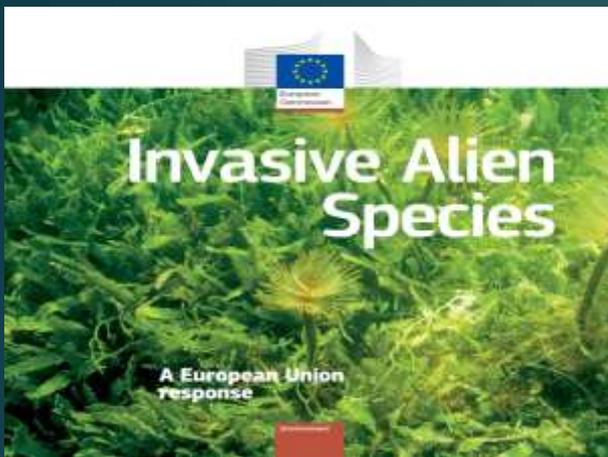
Harmonia oxymiris

- ▶ Native to East Asia
- ▶ Introduced as biological control agent against aphids
- ▶ Voracious predator outcompetes native species

Lithobates catesbeianus –American bullfrog

- ▶ Largest North America frog species
- ▶ Escaped pets spread throughout Europe





Psittacula kramera – rose-ringed parakeet

- ▶ Native to Africa and India
- ▶ Pets escaped and established in the wild



Nyctereutes procyonoides - Raccoon Dog

- ▶ Native in the Iberian peninsula
- ▶ Introduced from Japan for the fur; escaped and spread throughout Europe; vector pathogens, incl. rabies



ONLINE DATABASES OF ALIEN SPECIES

[DAISIE database](#)

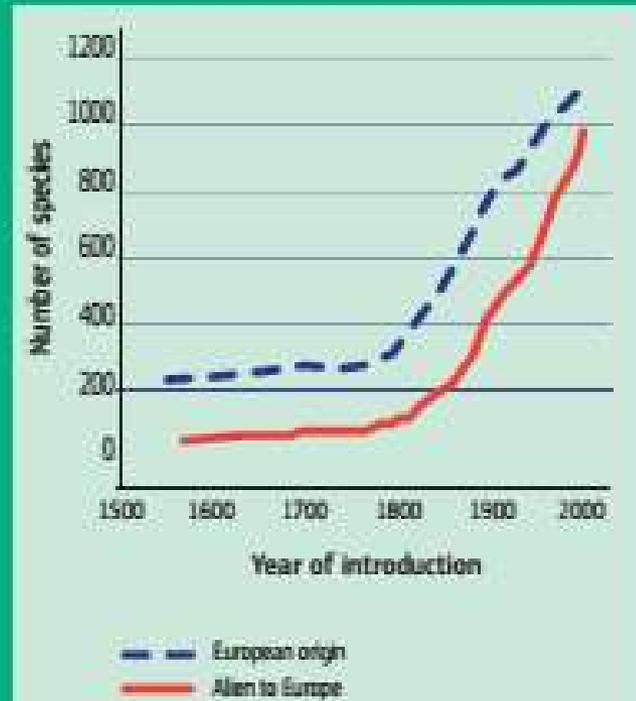
[EASIN database](#)

[NOBANIS database](#)



Modes of introduction

Introduction pathway: is the corridor/commodity through which alien species arrive in a new (naive) environment



Cumulative number of introduced alien plant species to Europe over time:
Source: Lambdon *et al.* 2008

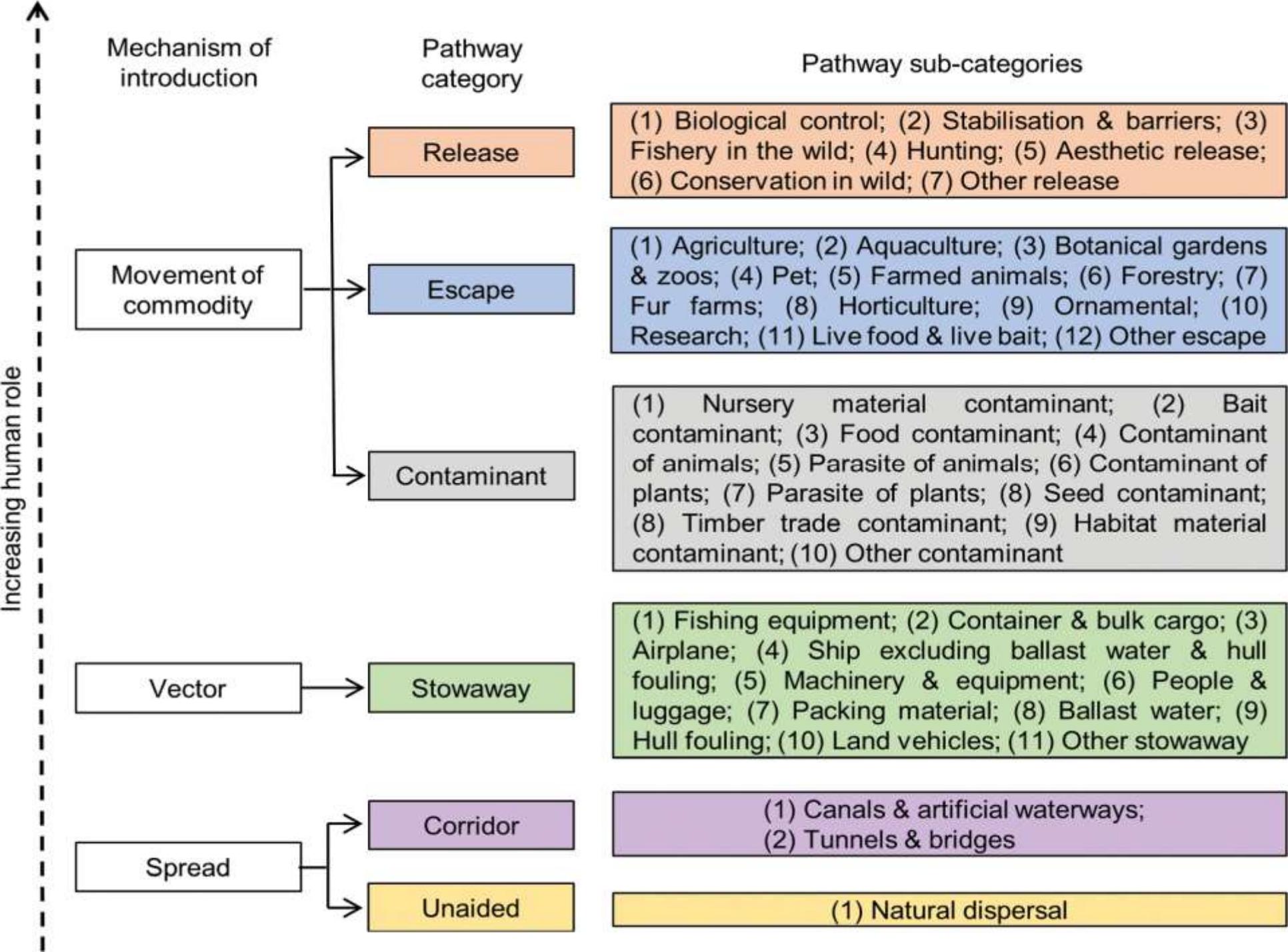
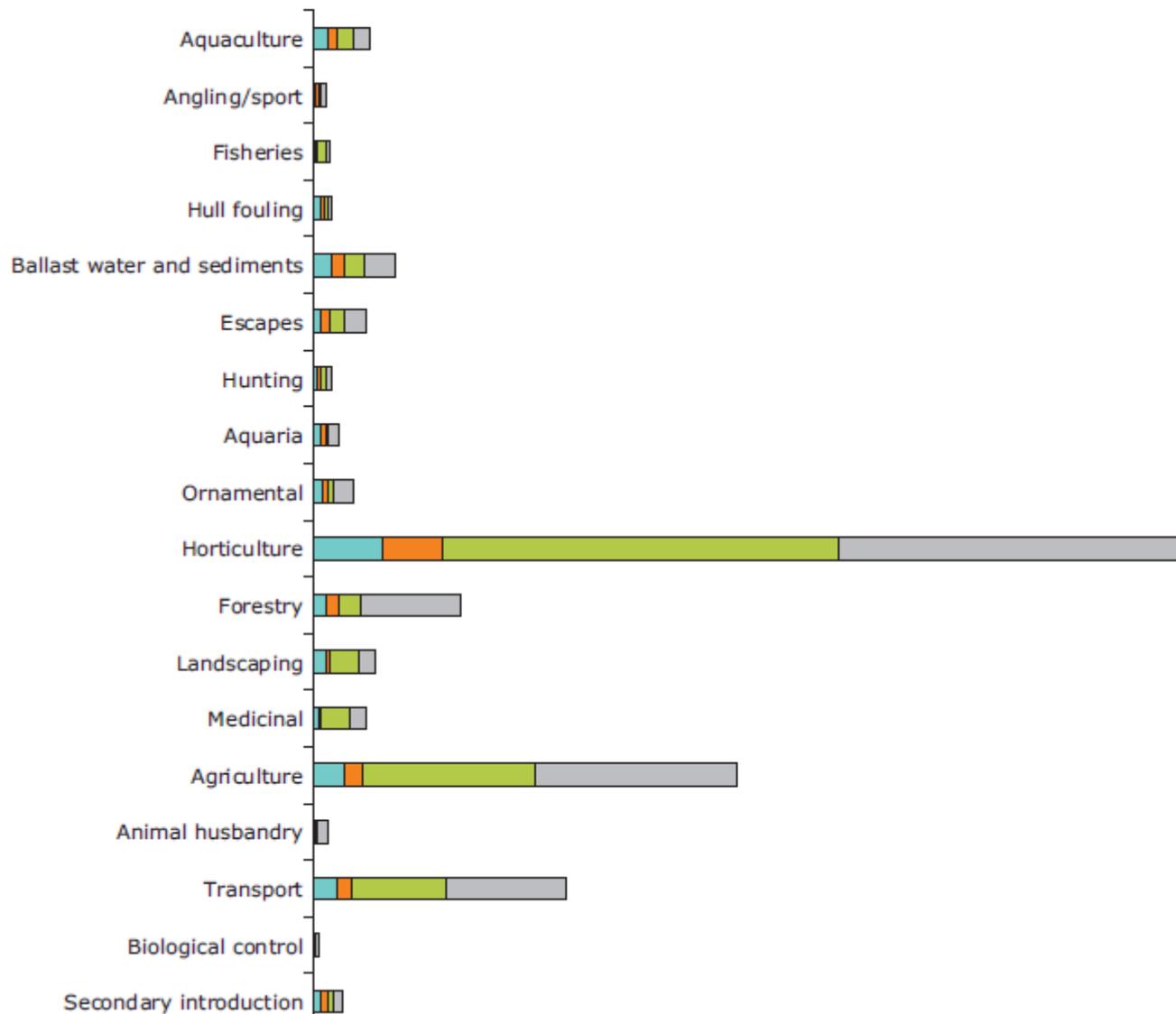
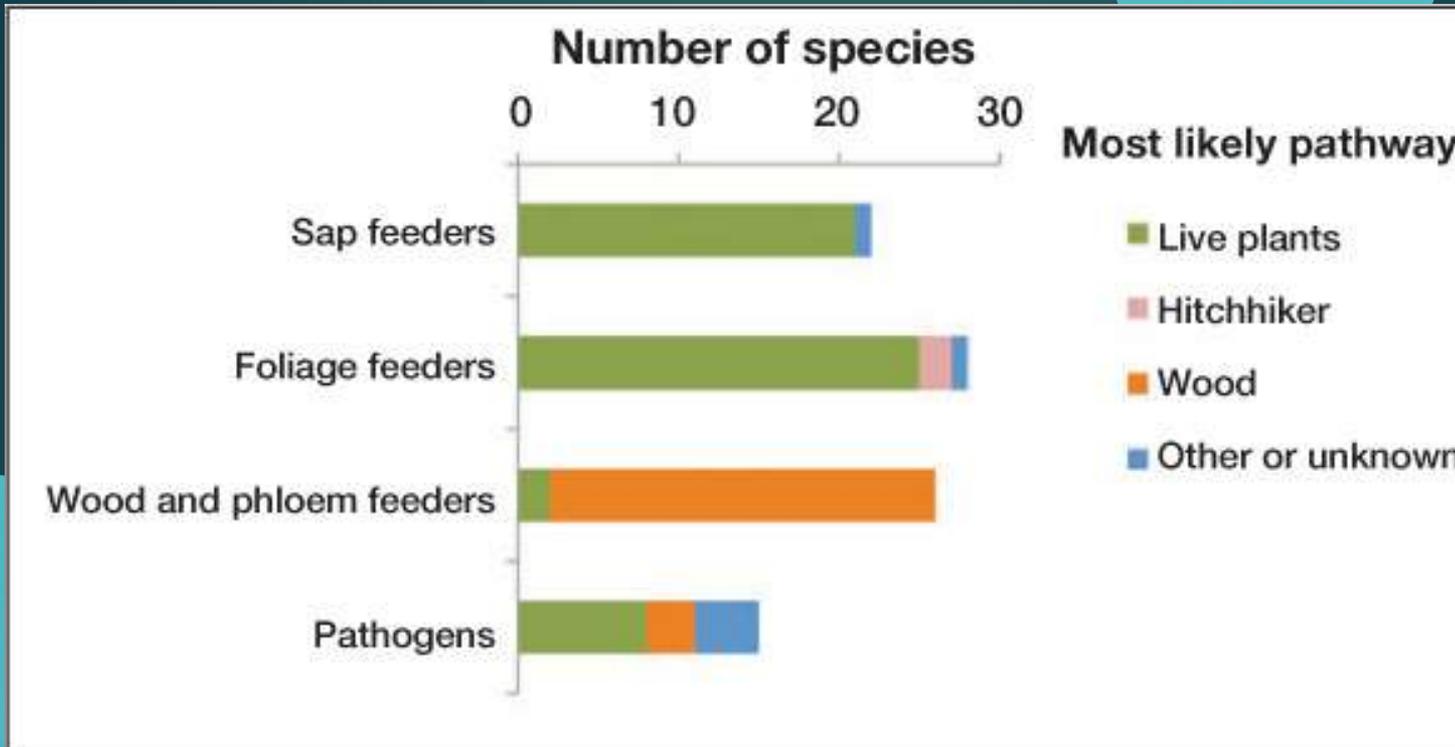


Figure 2.8 Pathways used by alien species in 17 NOBANIS countries, by different levels of invasiveness (based on countries' criteria) (data for 17 countries from NOBANIS)





Main pathways into Europe:
unintentional introductions

Table Liebholt et al., 2012

The Enemy release Hypothesis

'Introduced species have 'lost' their natural enemies during the invasion process'

There is reduced predation and parasitism...

Ref: Agrawal, A. A., Kotanen, P. M., Mitchell, C. E., Power, A. G., Godsoe, W., & Klironomos, J. (2005). Enemy release? An experiment with congeneric plant pairs and diverse above-and belowground enemies. *Ecology*, 86(11), 2979-2989.





The Biotic Resistance Hypothesis

- ▶ Native species may have some resistance against the invasive problems.
- ▶ It appears, however, that ecological interactions rarely enable communities to resist invasion, but may constrain the abundance of invasive species once they have successfully established

▶ Ref: Levine, J. M., Adler, P. B., & Yelenik, S. G. (2004). A meta-analysis of biotic resistance to exotic plant invasions. *Ecology letters*, 7(10), 975-989.



The cost of Invasive Alien Species to society

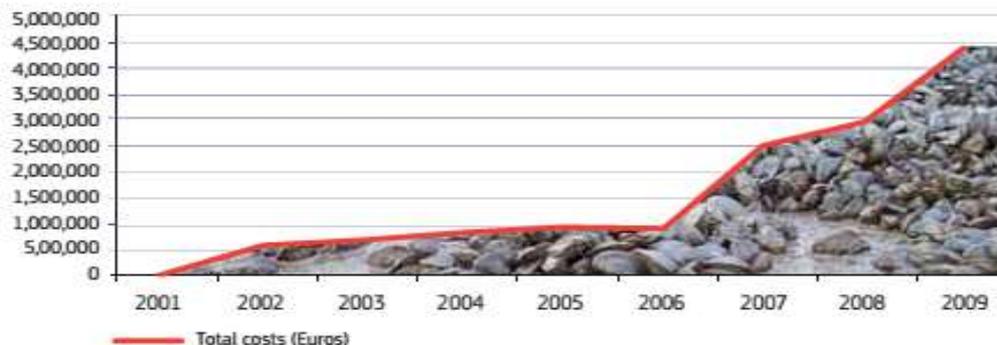
IAS are estimated to have cost the EU at least €12 billion/year over the past 20 years, and the figure is growing all the time. Once an IAS escapes or is deliberately released from their contained environment, substantial human and financial resources are needed in order to repair the damage they cause and take measures to eradicate them, or at least stop them from spreading further.

However, it is also important to recall that not all alien species are problematic or invasive; indeed, some generate significant economic benefits which is why they were introduced into the EU in the first place.

The cost associated with IAS increases exponentially if the species is not eradicated immediately. Without rapid intervention, it will have an opportunity to spread further afield and cause even more damage. Clearly, the sooner the problem is addressed the cheaper it is for all concerned.

The costs and benefits from IAS are also typically distributed unevenly. Those benefitting from bringing IAS into the EU usually have few or no economic incentives to minimise any IAS-related risks, while the costs associated with IAS damage and management are generally met by a much wider cross section of people, including primary producers, public authorities and society.

Evolution of costs of the zebra mussel invasion in the Ebro Delta, Spain, 2001–2009.



Source: Perez y Perez and Chica Moreu, 2009

It pays to tackle IAS as early on as possible

The longer one waits to tackle an IAS, the more expensive it becomes. In the Ebro Delta, the invasion of zebra mussels might have been relatively cost-effective to eradicate had it been done early on.

Now eight years later, the costs have risen dramatically. Over €4 million is being spent every year to repair the damage they cause and prevent the species from spreading. It is no longer feasible to eradicate the species completely from the area as the cost for this has become prohibitive.

Zebra mussel, Dreissena polymorpha.



Invasive Forest Tree Pathogens (IFPs)

- ▶ IFPs include alien, native and cryptic invaders
- ▶ By 2012, 123 European IFPs were described and classified as aliens (42%), species of European origin (28%), cryptogenic species (26%), or hybrids (4%).
- ▶ Ascomycota are the most common group (70%) of IFPs in Europe
- ▶ Oomycetes and Basidiomycota comprise 21% and 9% of the total, respectively
- ▶ Santini et al. (2012)



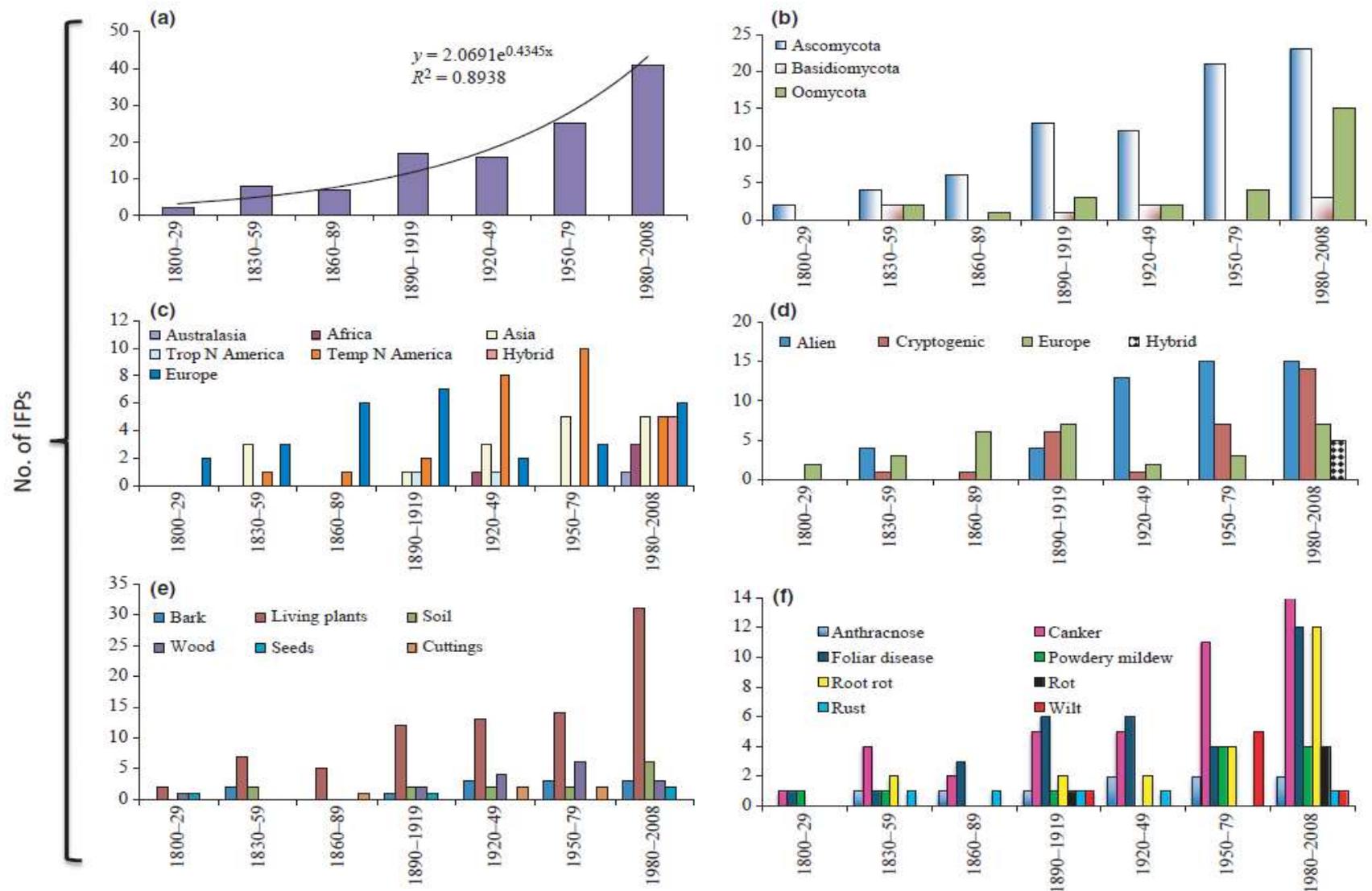
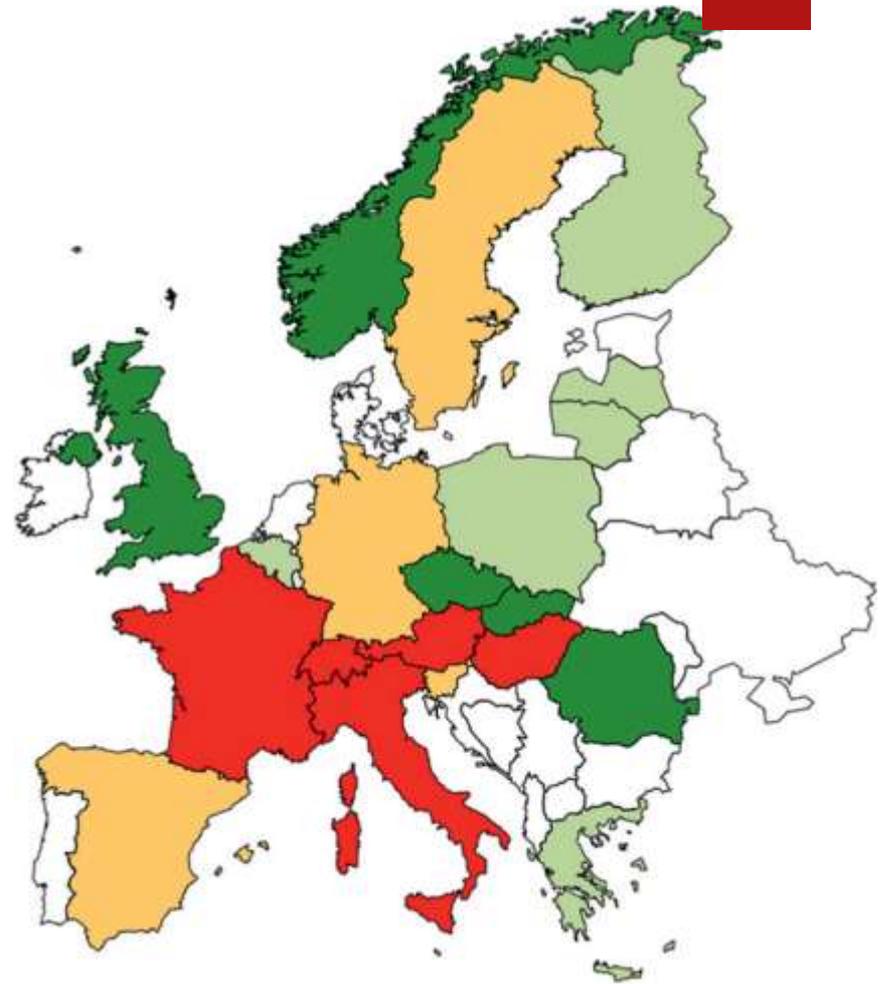
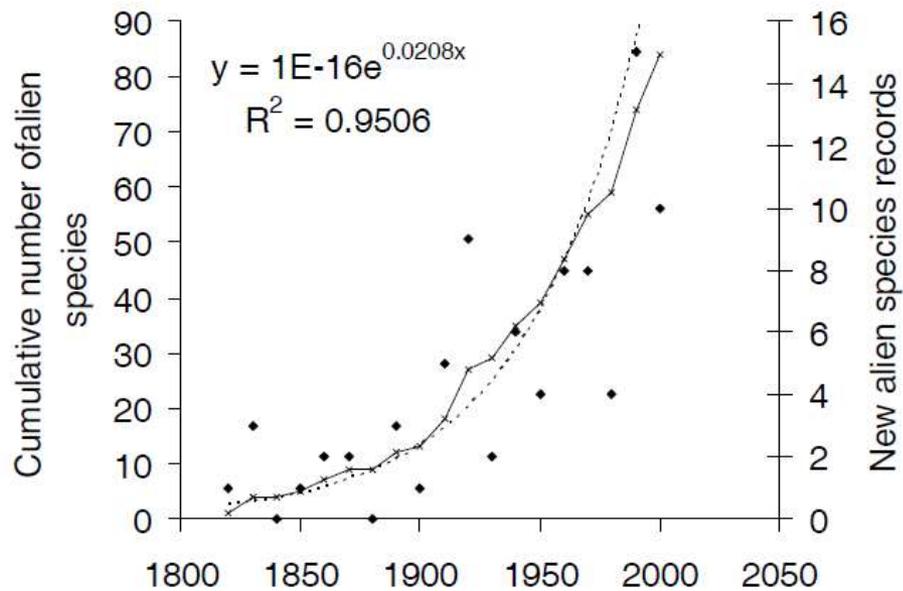


Fig. 1 (a) Total number of alien invasive forest pathogens (IFPs) according to time of arrival in Europe. (b) Taxonomic order of alien IFPs according to time of arrival in Europe. Friedman's statistic = 12.86; adjusted for ties = 13.33; P -value using χ^2 approximation (6 df) = 0.038. (c) Area of origin of alien IFPs according to time of arrival in Europe. Friedman's statistic = 11.11; adjusted for ties = 15.90; P -value using χ^2 approximation (6 df) = 0.014. (d) Status of alien pathogens recorded according to arrival in Europe. Friedman's statistic = 12.64; adjusted for ties = 15.82; P -value using χ^2 approximation (6 df) = 0.015. (e) Most probable substrate on which alien IFPs arrived in Europe, according to time of arrival. Friedman's statistic = 15.79; adjusted for ties = 17.86; P -value using χ^2 approximation (6 df) = 0.007. (f) Diseases caused by alien pathogens grouped according to time of arrival in Europe. Friedman's statistic = 22.67; adjusted for ties = 24.72; P -value using χ^2 approximation (6 df) = 0.000.

▶ Numbers of alien invasive forest pathogens (IFPs) in each country.

▶ Pale green, 1–20;
dark green, 21–30;
pale orange, 31–40;
red, > 41.





Handbook of Alien Species in Europe

INVADING NATURE
 SPRINGER SERIES IN INVASION ECOLOGY
 Volume 3

Series Editor: JAMES A. DRAKE
 University of Tennessee,
 Knoxville, TN, USA

2. The alien fungi of Europe

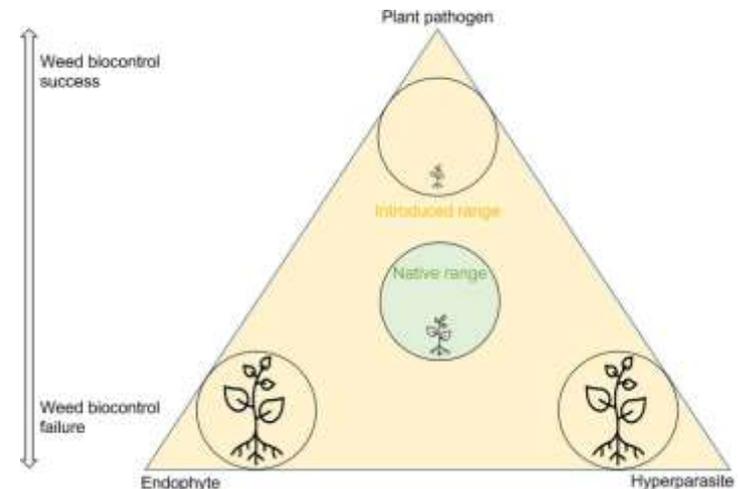
Marie-Laure Desprez-Loustau

Main pathways to Europe: intentional introductions (**release**)

- ▶ Intentional introductions: mycorrhizal fungi; edible mushrooms; biological control fungi among which plant pathogens
- ▶ A few species worldwide, but no documented case of escape or causing negative issues (Barton 2004, Hajek 2007, Schwartz *et al.* 2006).
- ▶ A few species of edible fungi have also been introduced outside their native range into various parts of Europe, e.g. *Agaricus bisporus*, various species of *Pleurotus*.
- ▶ *Lentinula edodes*, Asian shiitake mushroom cultivated in several European countries, has not been reported to occur in natural environments

2. The alien fungi of Europe

Marie-Laure Desprez-Loustau



Main pathways to Europe: unintentional introductions (**contaminants**)

- ▶ Most alien fungi, especially symbionts (including pathogenic and mycorrhizal fungi) entered Europe as contaminants or hitchhikers on their hosts
- ▶ Detailed pathways are rarely documented for alien fungi, but significant number of plant pathogens are obligate parasites (rusts, powdery mildews) and are assumed to have been introduced with a living host plant.
- ▶ Plant trade, especially of ornamentals, is arguably the most important pathway of entry for alien pathogens ([Liebhold et al, 2012](#); [Santini et al., 2012](#); [Jung et al., 2015](#)).
- ▶ e.g., Indirect evidence of the role of trade through nurseries in the spread of *P. ramorum*, was demonstrated by a multilocus genetic analysis (Ivors et al. 2006).

2. The alien fungi of Europe

Marie-Laure Desprez-Loustau

The background of the slide features a dark teal color with a pattern of microscopic plant cells, likely cross-sections of stems, showing vascular bundles. Several large, semi-transparent teal circles of varying sizes are overlaid on the image. A solid red vertical bar is positioned in the top right corner.

Examples: live plants

PLANT TRADE AND *PHYTOPHTHORA* SPP.

Multiple alien *Phytophthora* taxa discovered on diseased ornamental plants in Spain

E. Moralejo^{a*}, A. M. Pérez-Sierra^b, L. A. Álvarez^b, L. Belbahri^c, F. Lefort^c and E. Descals^a

^aInstituto Mediterráneo de Estudios Avanzados, IMEDEA (CSIC-UIB), Miquel Marqués 21, 07190 Esporles, Balearic Islands, ^bGrupo de Investigación en Hongos Fitopatógenos, Instituto Agronómico Mediterráneo, Universidad Politécnica de Valencia, Camino de Vera s/n, 46100 Valencia, Spain; and ^cLaboratory of Applied Genetics, School of Engineering of Lucerne, University of Applied Sciences of Western Switzerland, 150 Route de Prejlige, 1254 Jussy, Switzerland

- ▶ Seventeen spp. of *Phytophthora* identified in a 2001–2006 survey in nurseries & garden centres in Balearic Islands, north and eastern Spain
- ▶ Thirty-five were new host-pathogen combinations
- ▶ Five species unknown to science before January 2001 including *P. hedraiaandra*, *P. niederhauserii*, *P. kelmania* and *P. chlamydospora* and *P. ramorum*.
- ▶ The little-studied *P. hedraiaandra* was isolated in 2002 in Mallorca, 2 years before its formal description by de Cock & Lévesque (2004) from *Viburnum* plants in the Netherlands.

Widespread *Phytophthora* infestations in European nurseries put forest, semi-natural and horticultural ecosystems at high risk of *Phytophthora* diseases

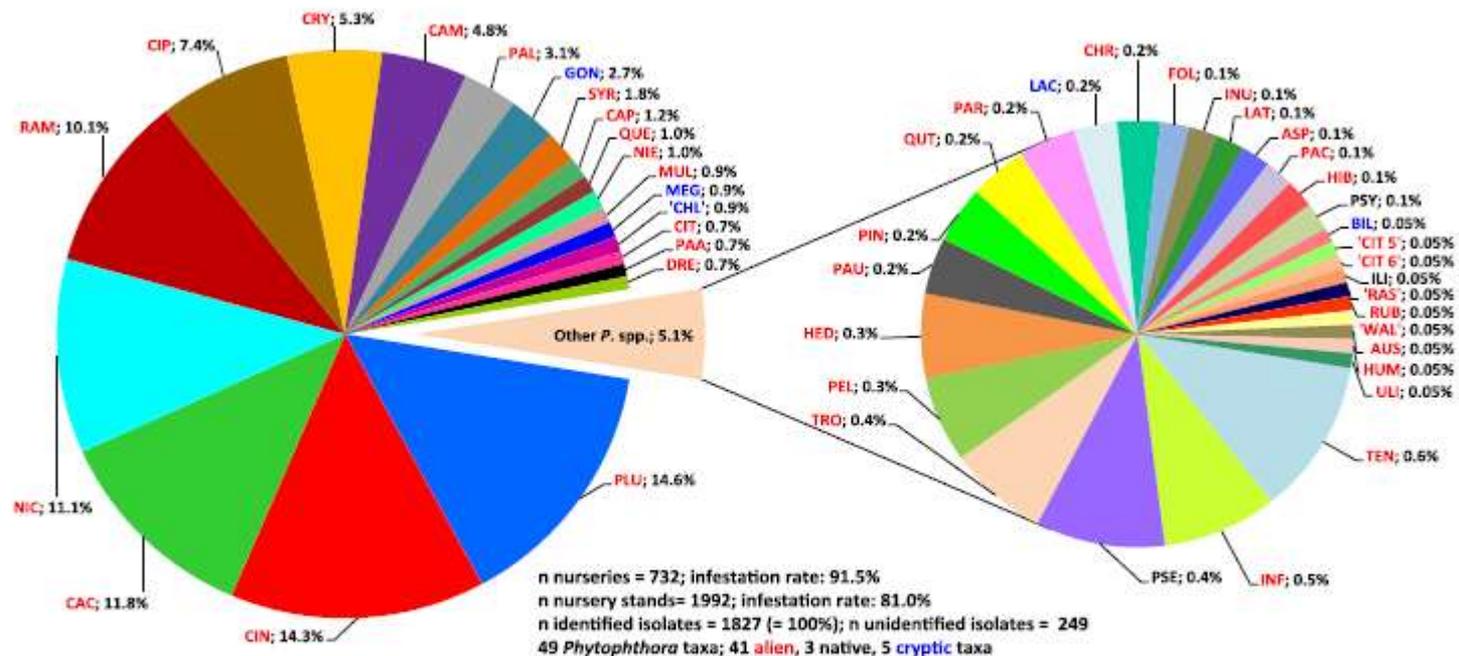


Fig. 1. Diversity and frequency of alien, native and cryptic *Phytophthora* taxa in 1992 fields and container stands of 732 forest, advanced tree, horticultural and ornamental nurseries in 18 European countries. Multiple isolates of a *Phytophthora* taxon from the same nursery stand were considered as one record. Abbreviated *Phytophthora* names are explained in footnote 1 of Table 2.

Phytophthora ramorum: An example of the role of plant trade in the movement of invasive pathogens

MOLECULAR PLANT PATHOLOGY (2008) 9(6), 729–740

DOI: 10.1111/J.1364-3703.2008.00500.X

Pathogen profile

***Phytophthora ramorum*: a pathogen with a remarkably wide host range causing sudden oak death on oaks and ramorum blight on woody ornamentals**

NIKLAUS J. GRÜNWARDL*, ERICA M. GOSS AND CAROLINE M. PRESS

Horticultural Crops Research Laboratory, USDA ARS, Corvallis, OR 97330, USDA

Table 1 Broadly speaking, two distinct disease symptoms can be observed for infections by *P. ramorum*. Sudden oak death is mainly observed in oak and tanoak forests in coastal forests of California and Oregon, but can also be observed on specimen trees in European or American gardens. Ramorum blight is observed in forest, nursery and garden environments in both North America and Europe on trees, ornamentals and woody shrubs. Sudden oak death is the ecologically and economically important disease in North America.

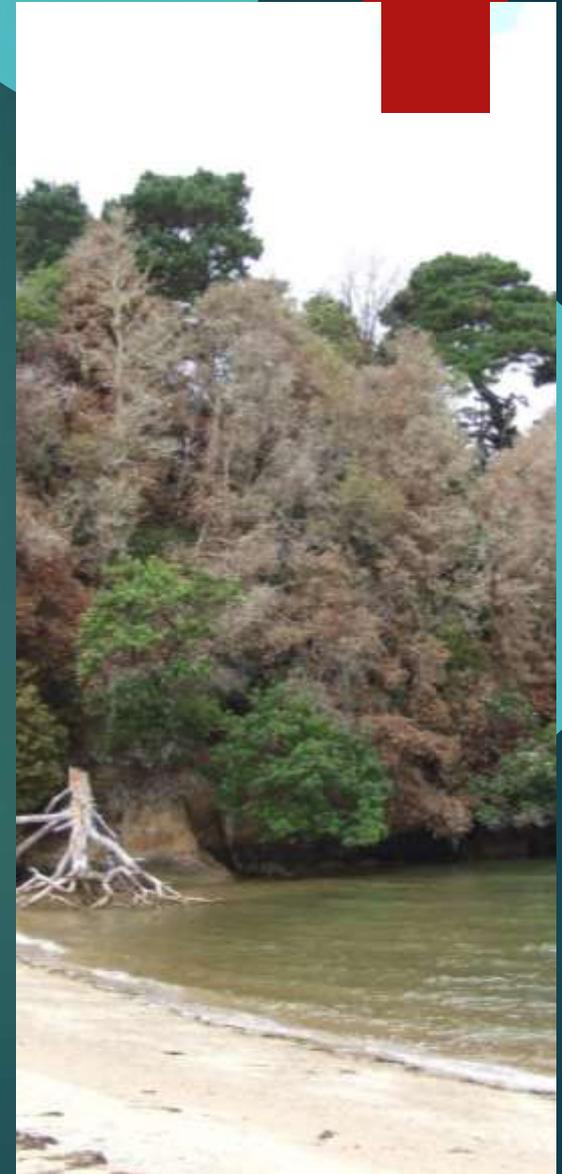
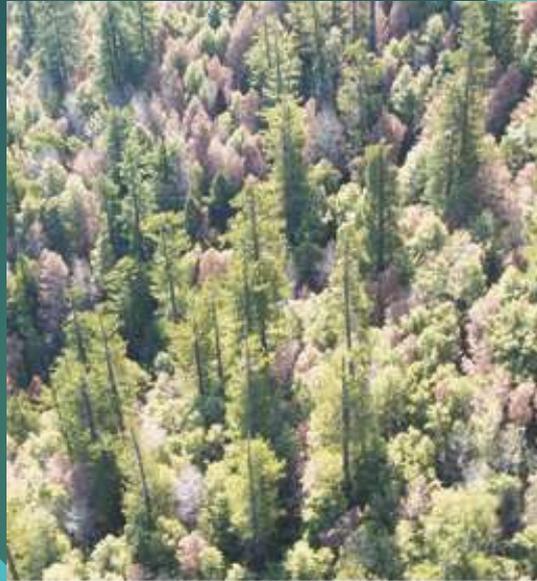
Disease	Symptoms	Host categories	Typical hosts*	Geography and environment
Sudden oak death	Stem cankers; bleeding cankers	Forest trees; garden trees	Coast live oak, tanoak, European beech	North American forests; European gardens
Ramorum blight	Foliar and twig blight; tip and shoot dieback; leaf blight	Ornamental trees and woody shrubs; forest understorey plants	Viburnum, rhododendron, pieris, lilac; coast redwood, Douglas fir, huckleberry, madrone, yew, tanoak, California bay laurel	European nurseries and gardens; North American nurseries and forest

*Only a small selection of typical hosts is presented. For a complete list of hosts refer to section on host range for appropriate references.

▶ (A) Tanoak mortality near Bolinas Ridge, Mt. Tamalpais, Marin County, California. Photo : Janet Klein, Marin Municipal Open Space District.

▶ (B) Attempts to eradicate sudden oak death in Curry County, Oregon, through slash and burn. Photo: Oregon Department of Forestry.

▶ (C) Killing of tan oaks on Shell Beach, California – note that the pines and certain angiosperm trees remain unaffected.



Typical symptoms of
Phytophthora ramorum infection
on different hosts

- ▶ (A) Bleeding cankers on tanoak visible in the exposed inner bark (phloem) after removal of the outer bark: note typical lesions with clearly defined margins;
- ▶ (B) leaf tip necrosis or leaf spots on margins of California bay laurel;
- ▶ (C) *Rhododendron*;
- ▶ (D) leaf necrosis on nursery ornamental rhododendron — arrow marks necrosis on leaf petiole.



Phytophthora ramorum: An example of the role of plant trade in the movement of invasive pathogens

Molecular Ecology (2006) 15, 1493–1505

doi: 10.1111/j.1365-294X.2006.02864.x

Microsatellite markers identify three lineages of *Phytophthora ramorum* in US nurseries, yet single lineages in US forest and European nursery populations

K. IVORS,*†M. GARBELOTTO,†I. D. E. VRIES,‡C. RUYTER-SPIRA,‡B. TE. HEKKERT,‡
N. ROSENZWEIG† and P. BONANTS‡

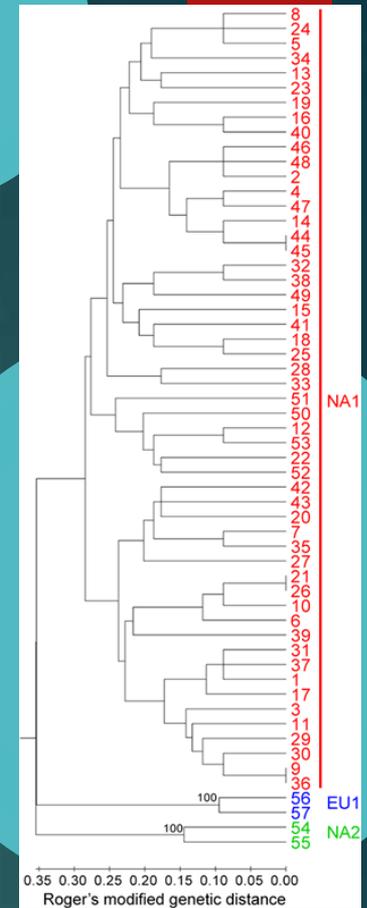
*Department of Plant Pathology, North Carolina State University, 455 Research Drive, Fletcher, NC 28732, USA, †Department of Environmental Science, Policy, and Management — ES, University of California, Berkeley, CA 94720, USA, ‡Plant Research International, PO Box 16, 6700 AA Wageningen, The Netherlands

Abstract

Analysis of 12 polymorphic simple sequence repeats identified in the genome sequence of *Phytophthora ramorum*, causal agent of 'sudden oak death', revealed genotypic diversity to be significantly higher in nurseries (91% of total) than in forests (18% of total). Our analysis identified only two closely related genotypes in US forests, while the genetic structure of populations from European nurseries was of intermediate complexity, including multiple, closely related genotypes. Multilocus analysis determined populations in US forests reproduce clonally and are likely descendants of a single introduced individual. The 151 isolates analysed clustered in three clades. US forest and European nursery isolates clustered into two distinct clades, while one isolate from a US nursery belonged to a third novel clade. The combined microsatellite, sequencing and morphological analyses suggest the three clades represent distinct evolutionary lineages. All three clades were identified in some US nurseries, emphasizing the role of commercial plant trade in the movement of this pathogen.

Keywords: exotic microbe, oomycete, population genetics, SSR, sudden oak death

Received 23 September 2005; revision accepted 29 November 2005



Lineage Current distribution

EU1 Europe, North America

NA1 North America

NA2 North America

Habitat

Gardens, Woodlands, Nurseries

Forests, Nurseries

Nurseries

Mating type

A1 (see #)

A2

A2



Example: live plants

PLANT TRADE AND FUNGAL SPECIES

INVASION MECHANISMS

► Heatmap: abundance of fungal taxa identified to species level by NGS analysis from sentinel nursery plants. Higher intensities of the shading reveal higher abundances of the isolates.

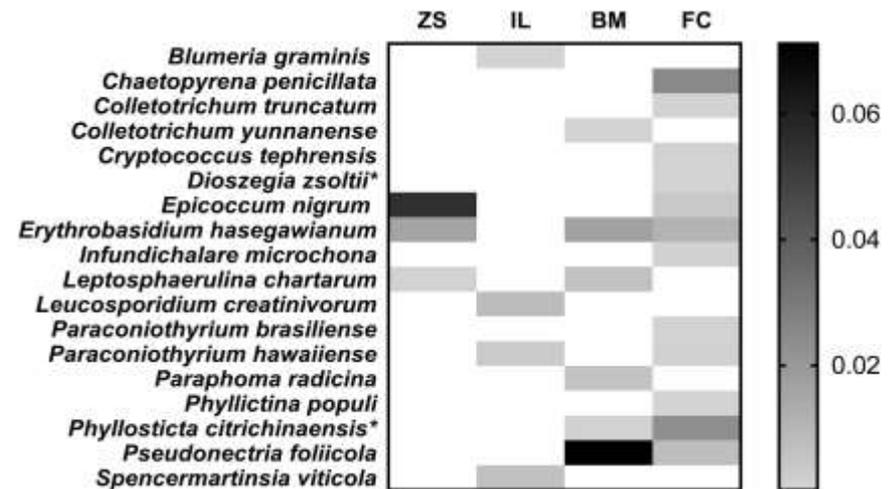
Zelkova schneideriana (ZS); *Ilex cornuta* var. *fortunei* (IC); *Buxus microphylla* (BM); *Fraxinus chinensis* (FC).

*Ambiguous species identification, possible new species.

RESEARCH ARTICLE

The sentinel tree nursery as an early warning system for pathway risk assessment: Fungal pathogens associated with Chinese woody plants commonly shipped to Europe

Anna Maria Vettraino¹, Hong-Mei Lu², Rene Eschen³, Carmen Morales-Rodriguez¹, Andrea Vannini^{1*}



INVASION MECHANISMS

▶ 106 new taxa identified in association with four of the most traded ornamental plants from China

Characterization of the fungal community by NGS analysis

After the quality filtering and removal of singletons, which are considered mostly artefacts [18], 35,872 reads were clustered in 106 OTU's. The majority of OTU's were Ascomycota (76 OTUs, 33,184 reads), followed by Basidiomycota (28 OTUs, 2,676 reads). Other taxa (Entomophthoromycota and Glomeromycota) were represented by less than 0.03% of the sequences



RESEARCH ARTICLE

The sentinel tree nursery as an early warning system for pathway risk assessment: Fungal pathogens associated with Chinese woody plants commonly shipped to Europe

Anna Maria Vettraino¹, Hong-Mei Li², René Eschen³, Carmen Morales-Rodriguez¹, Andrea Vannini^{1*}

Main pathways to Europe: unintentional introductions

Timber, wood packaging and firewood imports are other important pathways

Dutch Elm Disease: *Next slide*

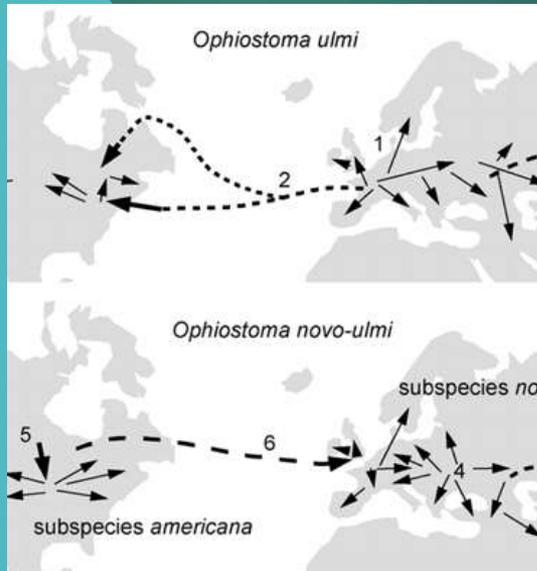
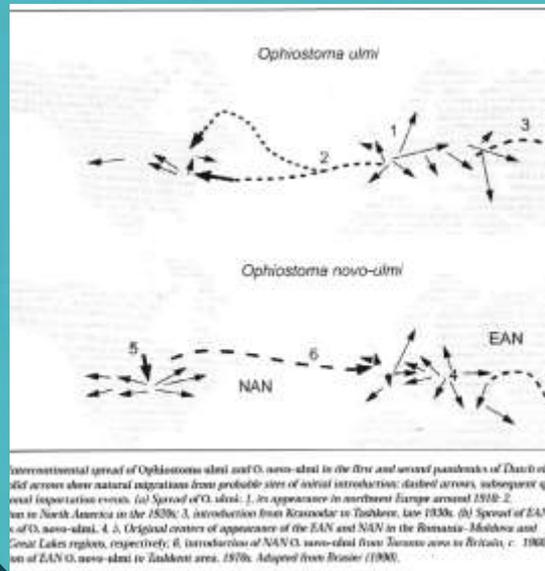
Ceratocystis platani, cause of plane canker stain, was presumably introduced from North America to Europe with military equipment during World War II landings in Provence and Italy, in 1944.

Heterobasidion irregulare probably introduced to Tyrrhenian coast linked to the movement of the US troops in 1944 during World War II (WWII).

Example: wood

WOOD TRADE AND
FUNGAL SPECIES





Timber trade: global movement of Dutch Elm Disease (DED)

Timber trade: *Heterobasidion irregulare* introduced with military wood packaging on the Tyrrhenian coast during the second world war



Heterobasidion irregulare:

- ✓ *Pinus* as main host
- ✓ Spread 1.3 Km/year
- ✓ Invaded habitats mostly unoccupied by native species
- ✓ Hybridization with *H. annosum* s.s.: risk of acquiring adaptive traits

References:

Gonthier et al. *Molecular Ecology* 2007

D'Amico et al. *Forest Pathology*, 2007

Main pathways to Europe: unintentional introductions

- ▶ Seeds: less frequently documented pathways but may have been overlooked.
- ▶ Repeated introductions of pine seeds infected with *Diplodia sapinea* probably explain the high genetic diversity of the introduced fungus in South Africa (Wingfield *et al.* 2001). Seed transmission might also be important for Europe where *D. sapinea* mostly occurs in pine plantations, rarely in native pines.
- ▶ For many saprobes, compost, and more recently wood-chips, seem to be the main pathway. Several mushrooms, hitherto barely if at all present in Europe have been observed in prodigious numbers on wood-chips beds, such as *Stropharia aurantiaca*, presumed to have been introduced from Asia or Australasia (Marren 2006, Shaw *et al.* 2004).

Diplodia pinea
(*Sphaeropsis sapinea*):
an example of seed
trade pathway

- ▶ *Pinus halepensis*
- ▶ *Pinus brutia*
- ▶ *Pinus pinaster*
- ▶ *Pinus pinea*
- ▶ *Pinus nigra*
- ▶ *Pinus sylvestris*
- ▶ *Pinus radiata*



Main pathways to Europe: unintentional introductions

- ▶ Bark and wood beetles; true ambrosia beetles. Many fungi are introduced in new environment as permanent or occasional associates of alien pests and, specifically, beetles, both bark and wood.
- ▶ Permanent associates are represented by symbionts such as those mutualistic species associated with specific insect structures, the mycangia, present in wood boring beetles thus identified as Ambrosia beetles

UNINSPECTED PATHWAYS: trade in finished wood products



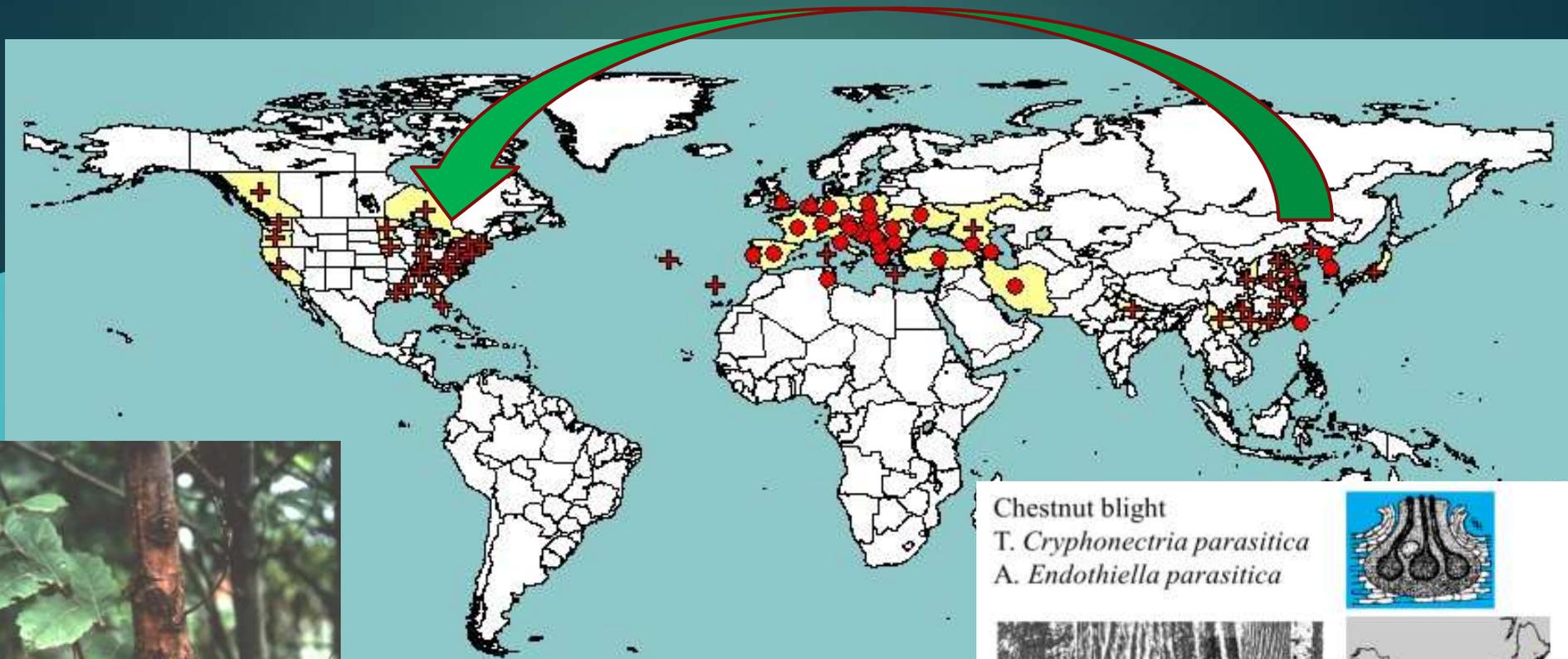
Taxa
<i>Aspergillus niger</i>
<i>Aspergillus</i> sp. 2
<i>Aspergillus</i> sp. 3
<i>Eurotium herbariorum</i>
<i>Eurotium</i> sp. 2
<i>Fusarium oxysporum</i>
<i>Paecilomyces variotii</i>
<i>Paecilomyces</i> sp.2
<i>Penicillium crustosum</i>
<i>Penicillium expansum</i>
<i>Penicillium</i> sp.3
<i>Penicillium</i> sp.4

INVASION MECHANISMS

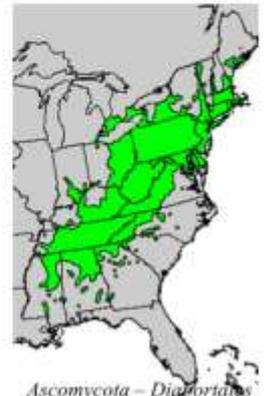


- ▶ **Direct host shift: e.g. *Cryphonectria parasitica*; probably *Ophiostoma ulmi* and *O. novo ulmi*. Most recently *Hymenoscyphus fraxineus***
- ▶ Hybridization with native or additional exotic species: pathogenic to new hosts: e.g. *Phytophthora alni* subsp *alni*, *Heterobasidion irregulare* x *Heterobasidion annosum* s.s.; *Ophiostoma ulmi* x *O. novo ulmi* ; *O. novo ulmi* subsp *novo ulmi* x *O. novo ulmi* subsp *americana*
- ▶ Divergent evolution from native population: polytypic populations: e.g. *Phytophthora lateralis*

INVASION MECHANISMS: direct host shift of *Cryphonectria parasitica* from the co-evolved native Asiatic chestnut species (*Castanea crenata* and *Castanea mollissima*) to American chestnut (*C. dentata*) through trading of infected plant material from Japan.



Chestnut blight
T. Cryphonectria parasitica
A. Endothiella parasitica



INVASION MECHANISMS: direct host shift of *Hymenoscyphus fraxineus* from co-evolved asiatic *Fraxinus* spp. to European *Fraxinus* species

Le ascospore sono la principale fonte di inoculo primario e causa dell'infezione delle lamine fogliari

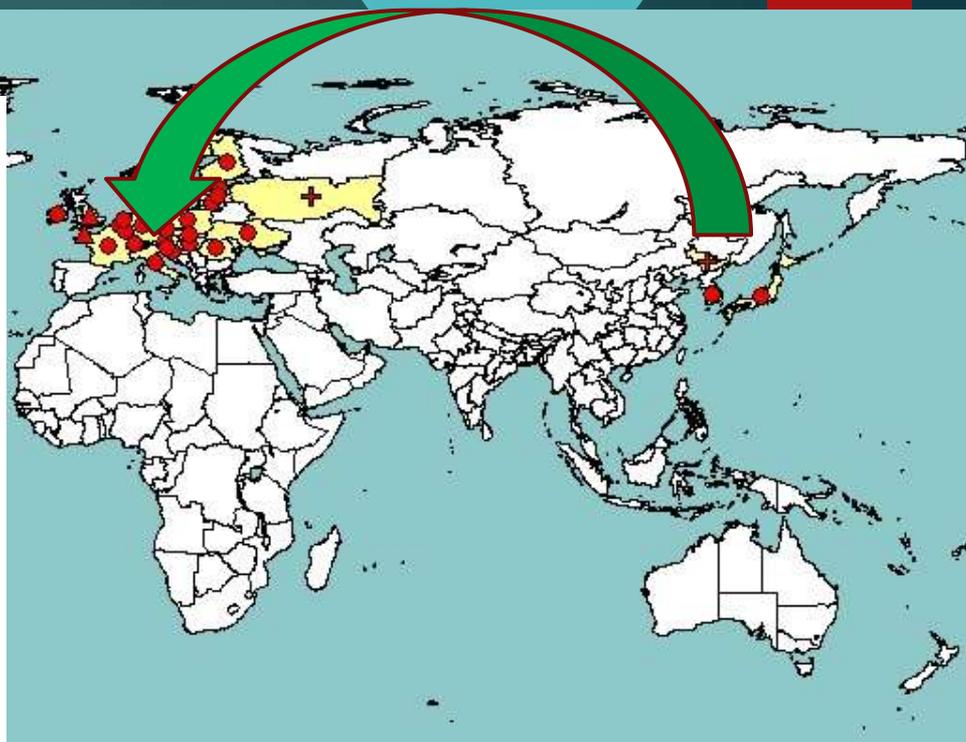
Foglie necrotiche per attacchi primaverili

Necrosi dei rami e del fusto: il patogeno dalle foglie passa ai tessuti legnosi dove causa le necrosi corticali e legnose

Il patogeno sverna nelle foglie sul terreno dove forma in primavera gli apotecii con le ascospore

Chiuma defogliata a causa degli attacchi del patogeno

Ascomycota – Helotiales

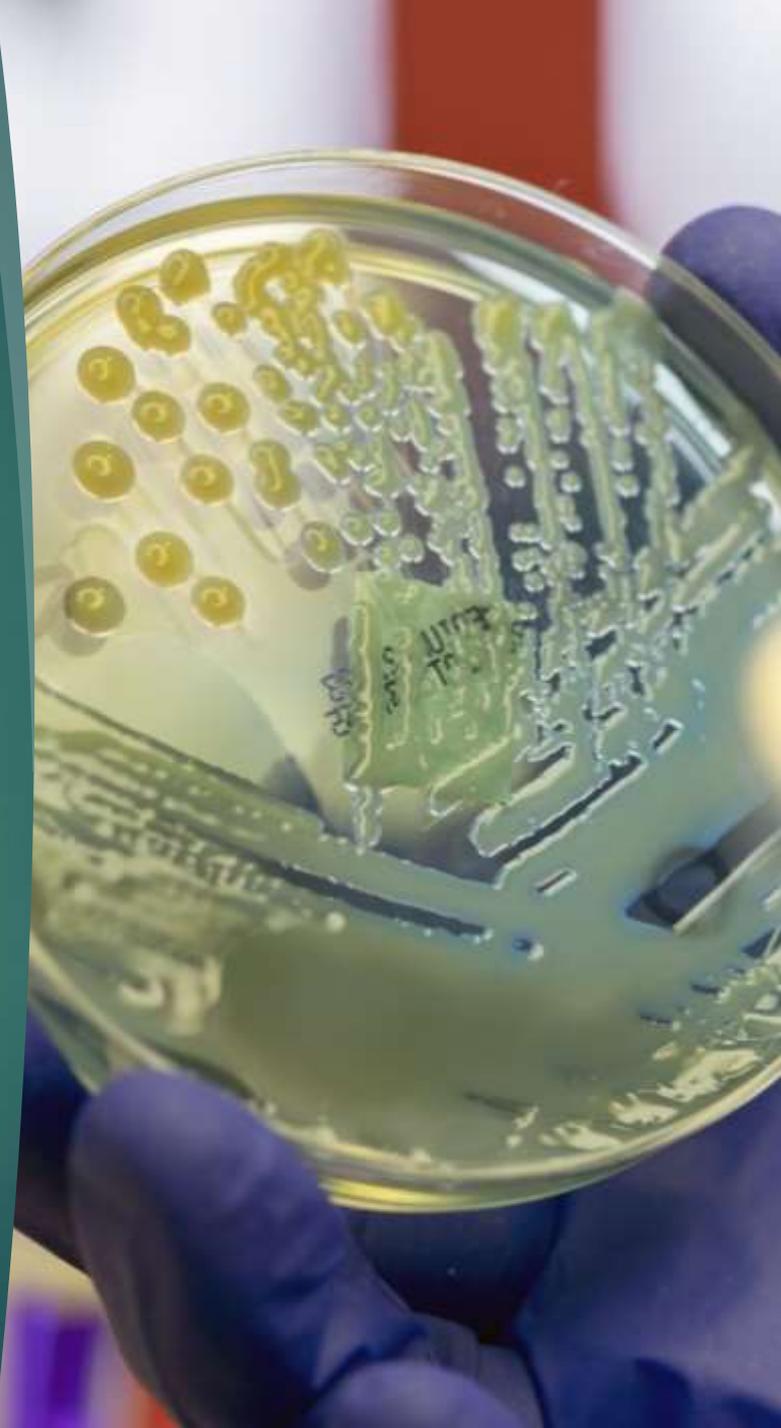


Known distribution of the ash dieback pathogen *Hymenoscyphus fraxineus*. Probable Asian origin. Most likely pathway was trade of live *Fraxinus mandshurica* var. *japonica* from Asia where the pathogen was known as *Lambertiella albida*, a nearly hemi-biotrophic species on native ash species.

Ascomycota – Helotiales

INVASION MECHANISMS

- ▶ Direct host shift: e.g. *Cryphonectria parasitica*; *Phytophthora lateralis*; probably *Ophiostoma ulmi* and *O. novo ulmi*
- ▶ **Hybridization with native or additional exotic species: pathogenic to new hosts:** e.g. *Phytophthora alni* subsp *alni*, *Heterobasidion irregulare* x *Heterobasidion annosum* s.s.; *Ophiostoma ulmi* x *O. novo ulmi* ; *O. novo ulmi* subsp *novo ulmi* x *O. novo ulmi* subsp *americana*
- ▶ Divergent evolution from native population: polytypic populations: e.g. *Phytophthora lateralis*





The highly aggressive *Phytophthora x alni* resulted from successive hybridizations between the exotic (alien) *Phytophthora uniformis* and the possibly native *Phytophthora x multiformis*



UGA2110008

Alder decline (*A. glutinosa*)

Collar necrosis on *A. glutinosa*

(A. Solla, A. Pérez-Sierra, T. Corcobado, M.M. Haque, J.J. Diez & T. Jung, 2009)

Rapid emergence of hybrids between the two subspecies of *Ophiostoma novo-ulmi* with a high level of pathogenic fitness

C. M. Brasier* and S. A. Kirk

Forest Research, Alice Holt Lodge, Farnham, Surrey, GU10 4LH, UK

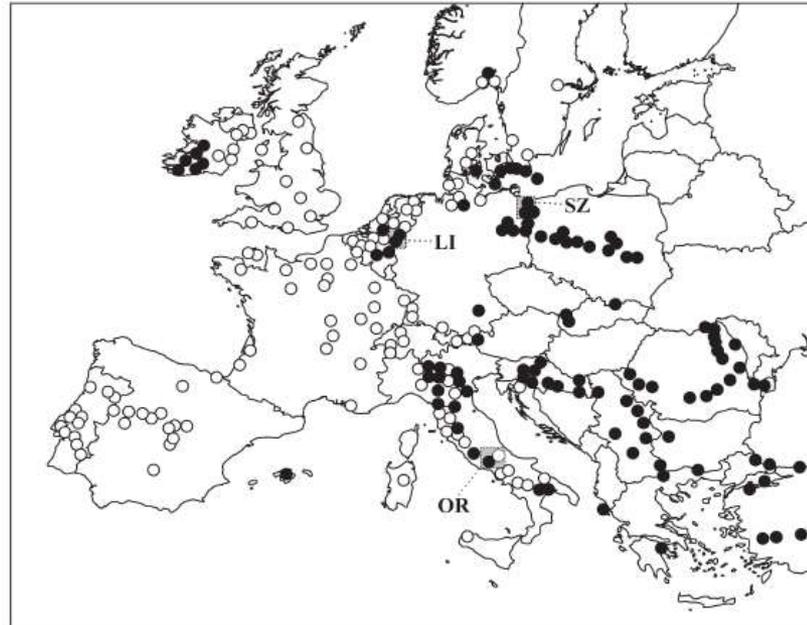


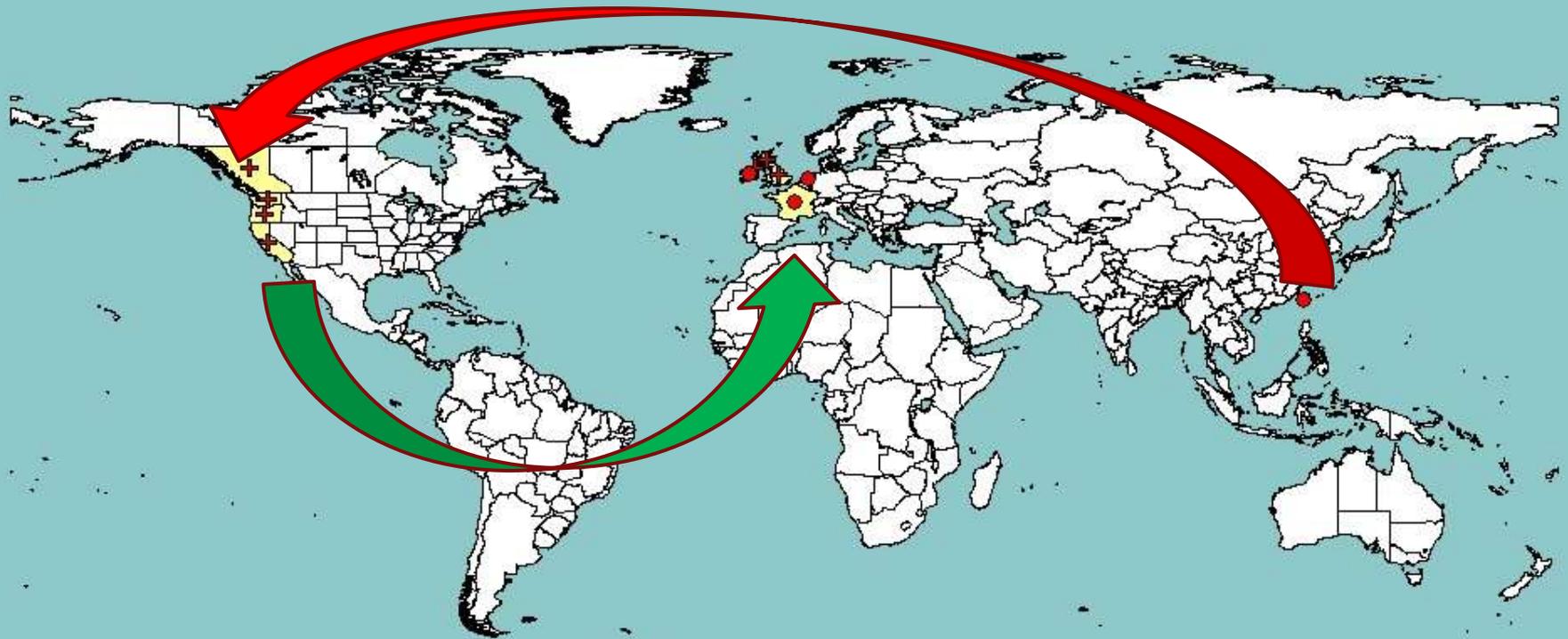
Figure 1 Summary of the known distribution of *Ophiostoma novo-ulmi* subsp. *americana* and subsp. *novo-ulmi* in Europe 1990, based on >2500 samples collected by the authors. Open circles, subsp. *americana*; closed circles, subsp. *novo-ulmi*. Subspecies overlap zones included parts of Ireland, Netherlands, Belgium, Norway, Sweden, Denmark and Germany. LI, Limburg, Netherlands; OR, Orvieto, Italy; SZ, Szczecin (Baltic Ports) Poland. Modified from Brasier & Kirk (2001) omitting central Asia.

INVASION MECHANISMS

- ▶ Direct host shift: e.g. *Cryphonectria parasitica*; probably *Ophiostoma ulmi* and *O. novo ulmi*
- ▶ Hybridization with native or additional exotic species: pathogenic to new hosts: e.g. *Phytophthora alni* subsp *alni*, *Heterobasidion irregulare* x *Heterobasidion annosum* s.s.; *Ophiostoma ulmi* x *O. novo ulmi* ; *O. novo ulmi* subsp *novo ulmi* x *O. novo ulmi* subsp *americana*
- ▶ **Divergent evolution from native population: polytypic populations: e.g. *Phytophthora lateralis***



INVASION MECHANISMS: direct host shift of *Phytophthora lateralis* from the co-evolved Asiatic *Chamaecyparis obtusa* to the US species *Chamaecyparis lawsoniana*

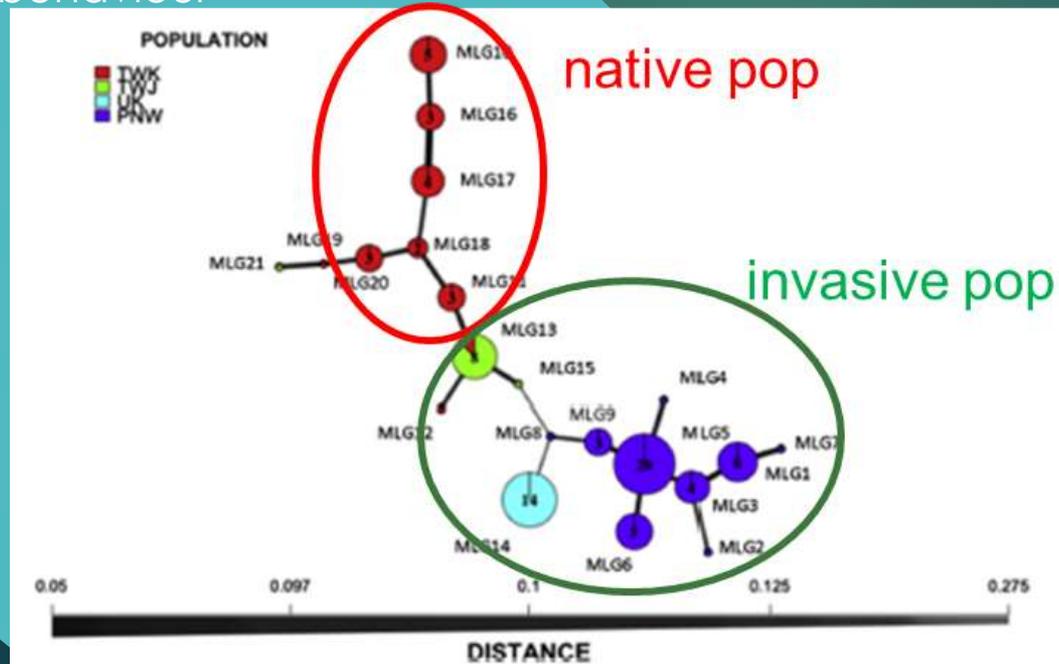


Actual distribution of *Phytophthora lateralis*. Possible asiatic origin. Probable pathway through trade in living *Chamaecyparis obtusa* from Taiwan/Japan where the pathogen was present as nearly hemi-biotrophic species on native *Chamaecyparis* species. EU invasion by introduction of US infected *Chamaecyparis lawsoniana* plants for ornamental use

Divergent evolution: *Phytophthora lateralis* invading USA and Europe

Phytophthora lateralis is one of the most destructive of introduced *Phytophthora* species. First described from roots and root collars of dying ornamental cedars (*Chamaecyparis* spp.) in nurseries and gardens in Oregon and Washington in the Pacific Northwest (PNW) of North America in the 1930s/40s (Tucker & Milbrath 1942) it was later introduced into the native range of *Chamaecyparis lawsoniana* (Lawson Cypress or Port Orford Cedar) in southern Oregon and northern California, where it has since killed many trees of all ages.

Phytophthora lateralis invasive populations in USA and EU differ from the putative native population in Taiwan, resulting in a highest aggressiveness and modified behaviour



Minimum spanning network of multilocus genotypes

Impacts

- ▶ Economic impact
- ▶ Impact on biodiversity
- ▶ Impact on carbon fixation efficiency
- ▶ Impact on landscape, history and traditions
- ▶ Impact on environment



Hotspots of biodiversity

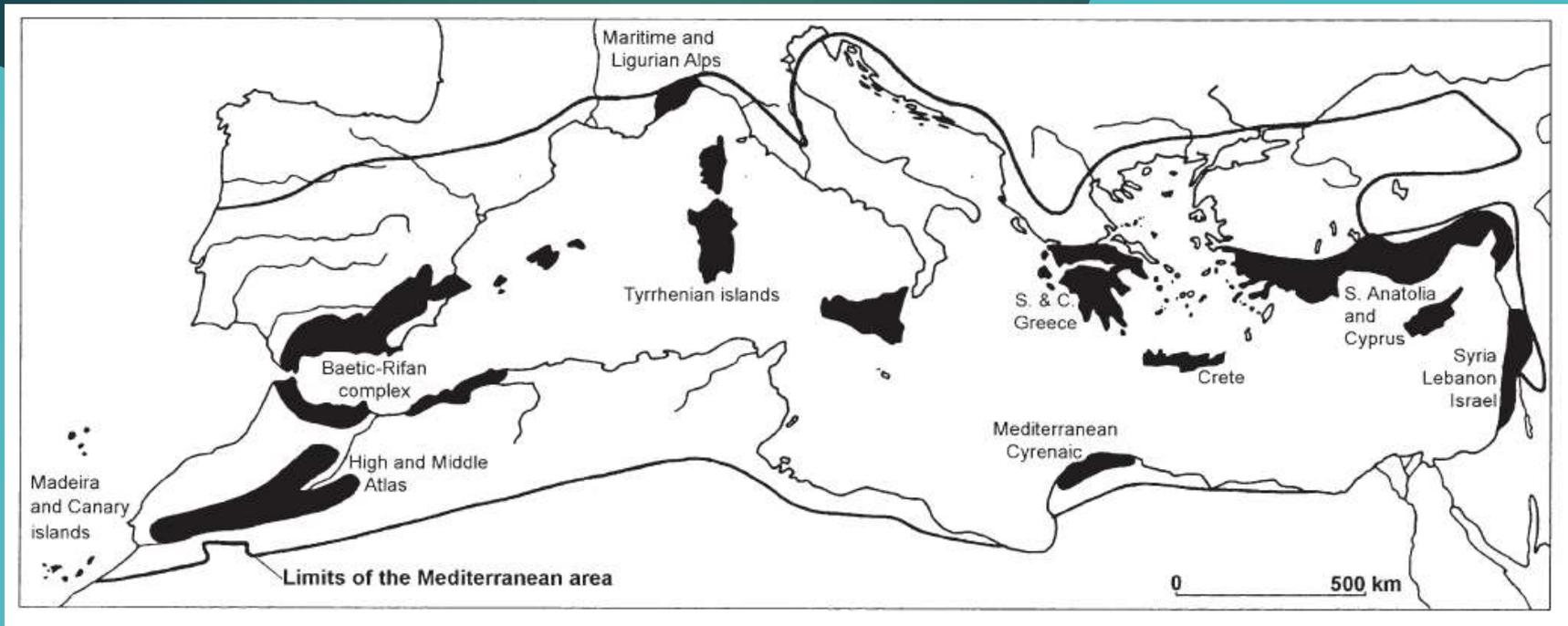
As many as 44% of all species of vascular plants and 35% of all species in four vertebrate groups are confined to 25 hotspots comprising only 1.4% of the land surface of the Earth (Myers et al. 2000 Nature 403, 853-858)



Biodiversity Hotspots in the Mediterranean Basin: Setting Global Conservation Priorities

Conservation Biology, Pages 1510-1513
Volume 13, No. 6, December 1999

FRÉDÉRIC MÉDAIL* AND PIERRE QUÉZEL



Phytophthora cinnamomi – Holm oak and Cork oak forest

Table 1. Plant species surveyed for infection with *Phytophthora cinnamomi*

Family/species (e.g. FRANCO 1971, 1984)	Presence of <i>Phytophthora cinnamomi</i> ¹
<i>Pinaceae</i>	
<i>Pinus pinaster</i> Aiton	+*
<i>Leguminosae</i>	
<i>Genista triacanthos</i> Brot.	+
<i>Ulex</i> spp.	+
<i>Cistaceae</i>	
<i>Cistus crispus</i> L.	+
<i>Cistus ladanifer</i> L.	+
<i>Cistus populifolius</i> L.	+
<i>Cistus salvifolius</i> L.	+
<i>Thymelaeaceae</i>	
<i>Daphne gnidium</i> L.	-
<i>Ericaceae</i>	
<i>Erica arborea</i> L.	-*
<i>Erica lusitanica</i> Rudolphi	-*
<i>Calluna vulgaris</i> (L.) Hull	+*
<i>Arbutus unedo</i> L.	+*
<i>Labiatae</i>	
<i>Lavandula luisieri</i> (Rozeira) Rivas Martinez	-
<i>Lavandula pedunculata</i> (Miller) Cav. subsp. <i>lusitanica</i> (Chaytor) Franco	-*
<i>Phlomis purpurea</i> L.	-
<i>Compositae</i>	
<i>Helichrysum stoechas</i> (L.) Moench	-

¹Species marked with * are listed in Table 1 of ZENTMYER (1980); this list includes an *Erica* 'hisitanica', which is an obvious misprint of 'lusitanica'.

High impact on biodiversity

Reference:

➤ Moreira and Martins, *Forest Pathology*, 2005

Seiridium spp. - cypress

Impact on landscape...history and traditions



“In the Mediterranean region the epidemic of cypress blight is so advanced that it threatens to become another ecological disaster. The devastation of planted and ornamental cypress trees threatens not merely serious economic losses..... cypress is not only a key component of the landscape and an irreplaceable decoration for monument and historical places, but an integral part of the nation’s history and traditions”

Graniti, Annual Review of
Phytopathology, 1998