Co-invasion of invasive trees and their associated belowground mutualists

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Biological invasions are a problem

Diversity and Distributions, (Diversity Distrib.) (2011) 17, 788–809

BIODIVERSITY REVIEW

Trees and shrubs as invasive alien species – a global review

David M. Richardson[1]* and Marcel Rejmánek[2]

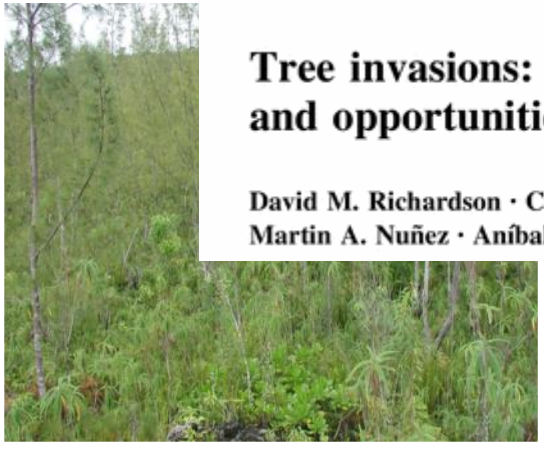
434
tree species

Biol Invasions (2014) 16:473–481
DOI 10.1007/s10530-013-0606-9

ORIGINAL PAPER

Tree invasions: patterns, processes, challenges and opportunities

David M. Richardson · Cang Hui ·
Martin A. Nuñez · Aníbal Pauchard



Main reasons for introduction of invasive tree species:

56% ornamental

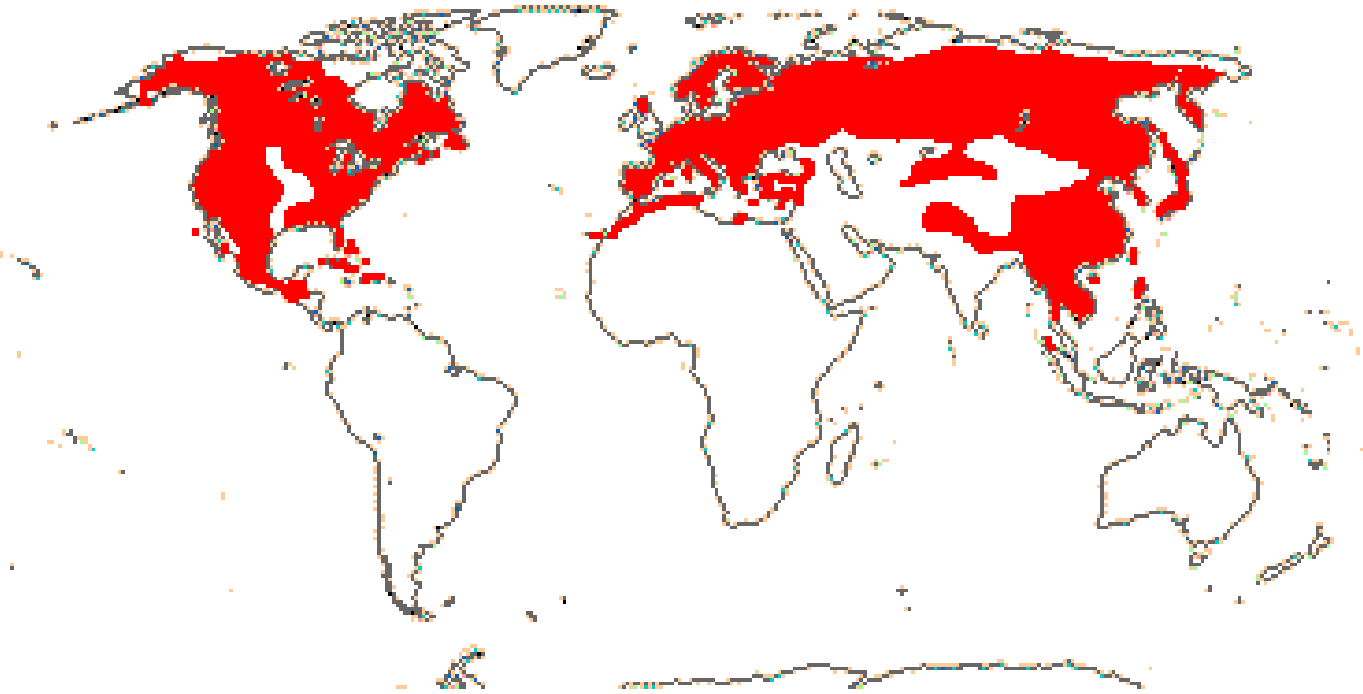
22% forestry

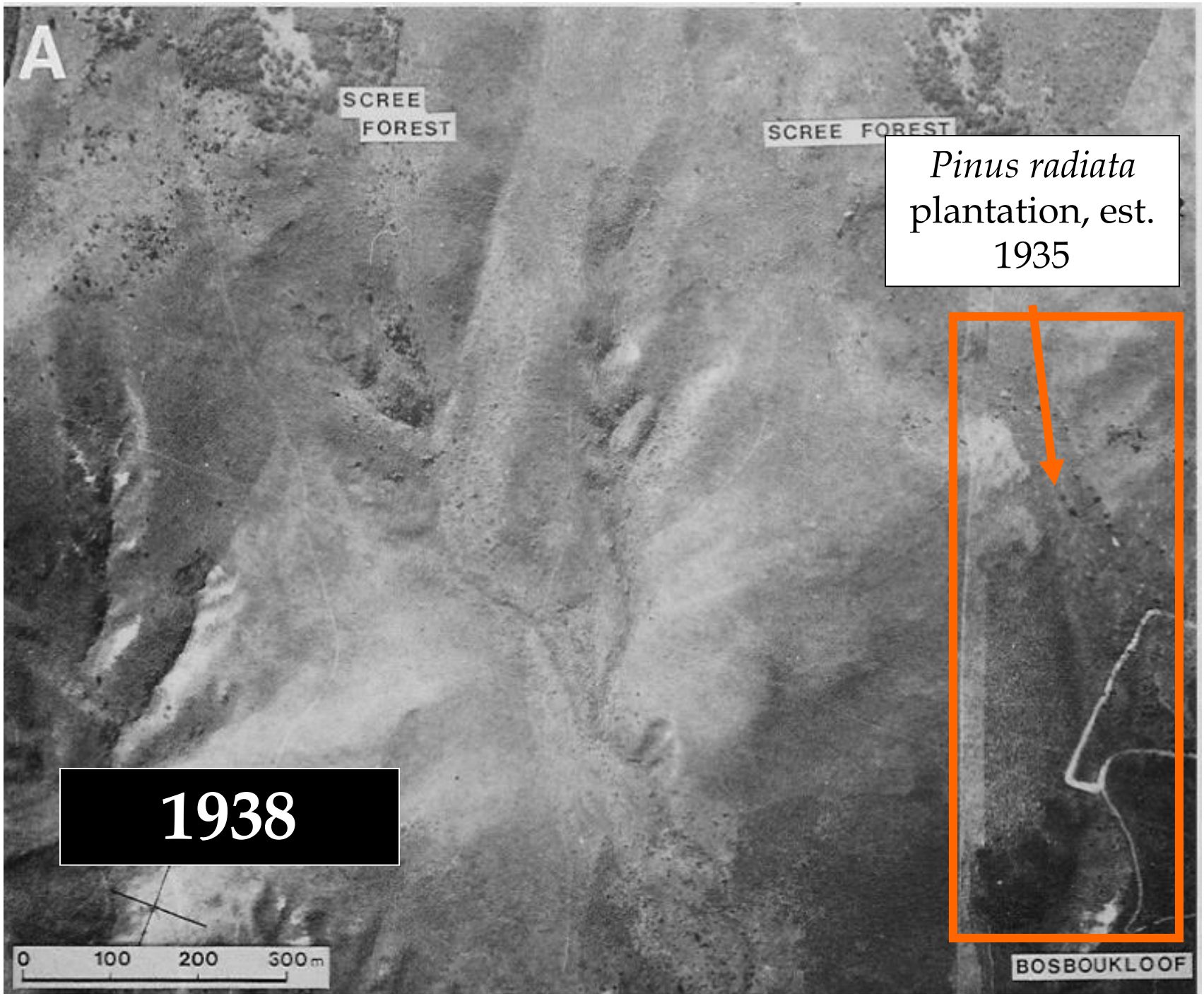
8% agroforestry

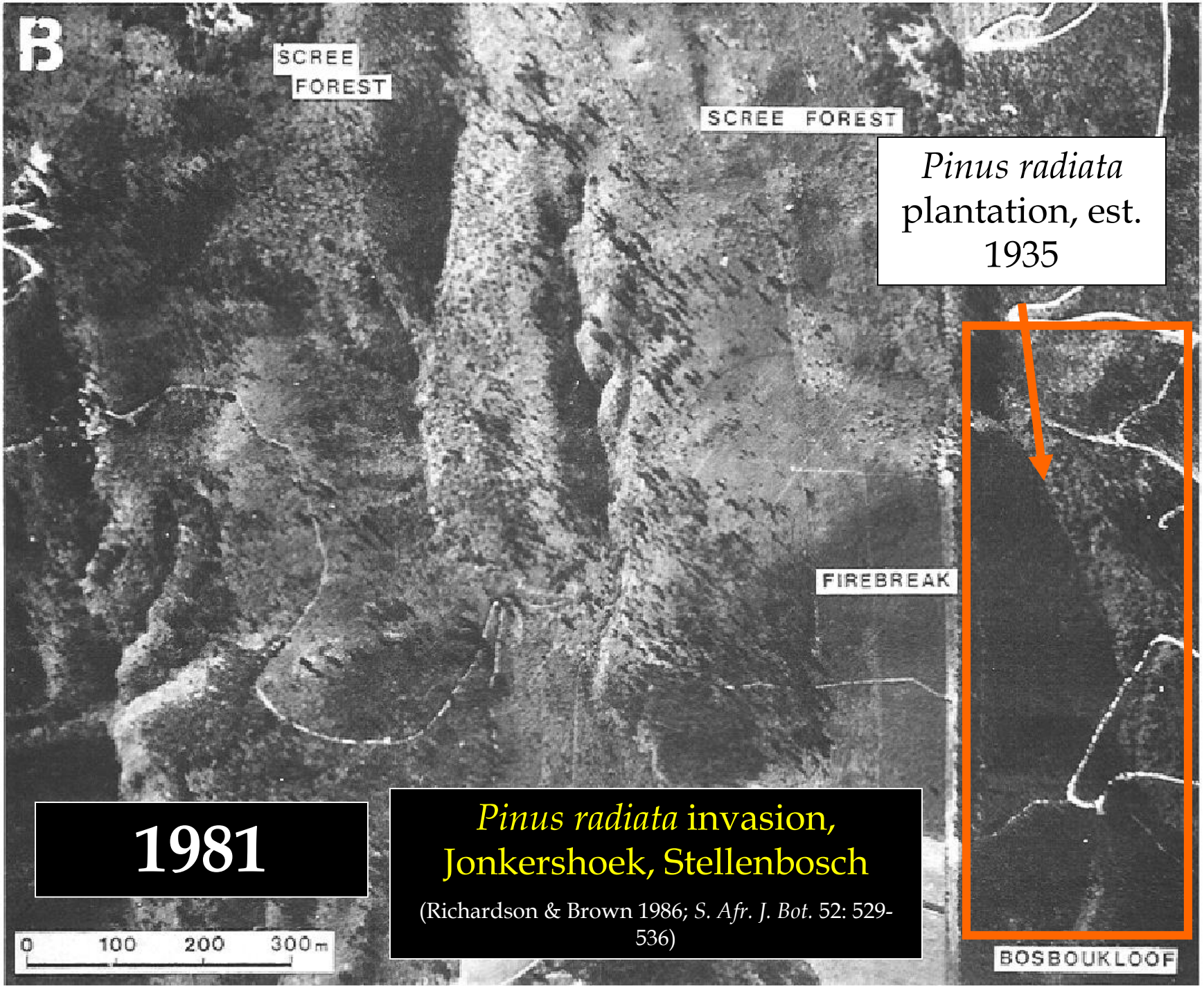
5% sand stabilization

4% fuel wood

Pines are native to the Northern hemisphere and **highly invasive** in the Southern hemisphere

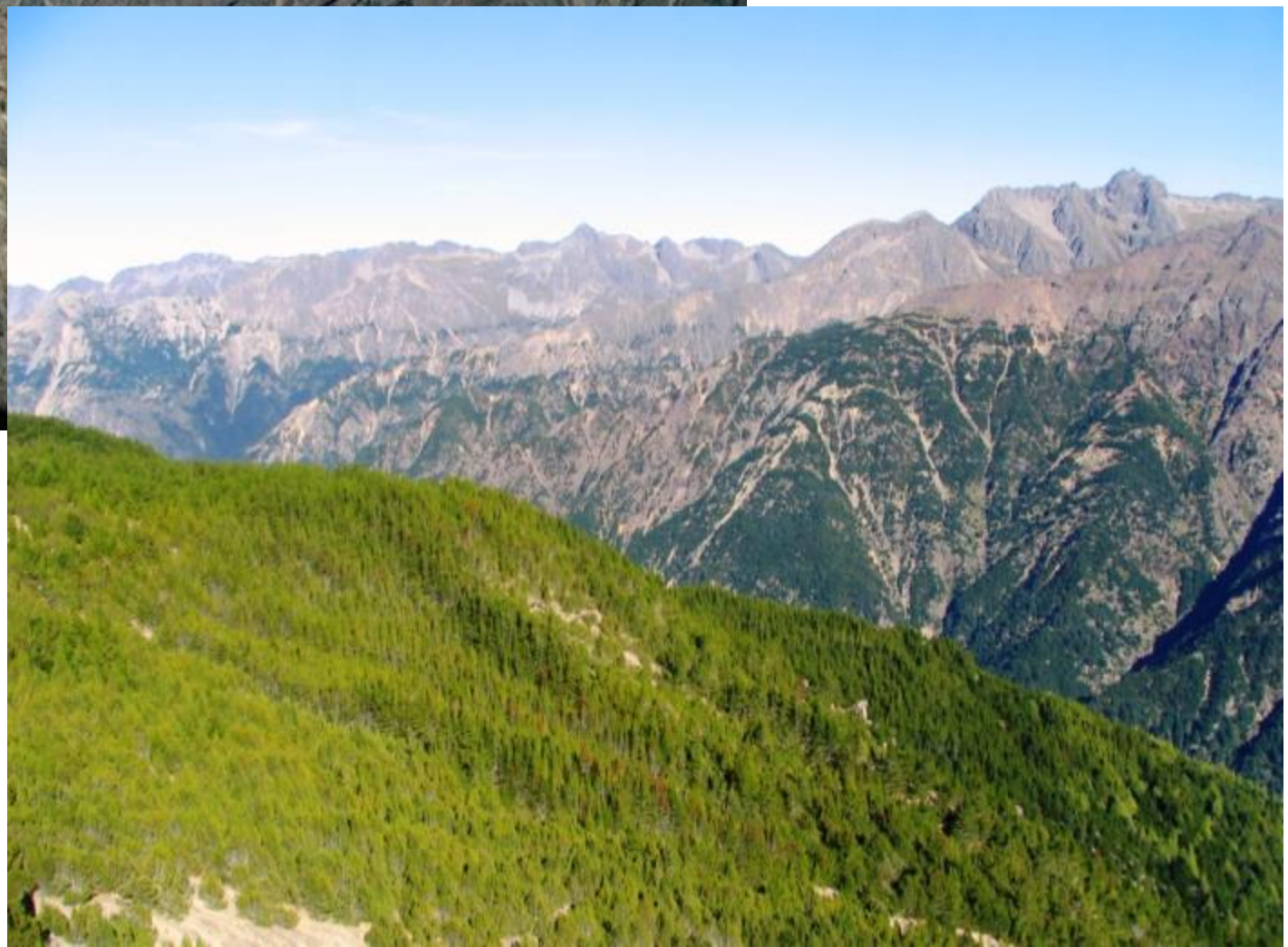


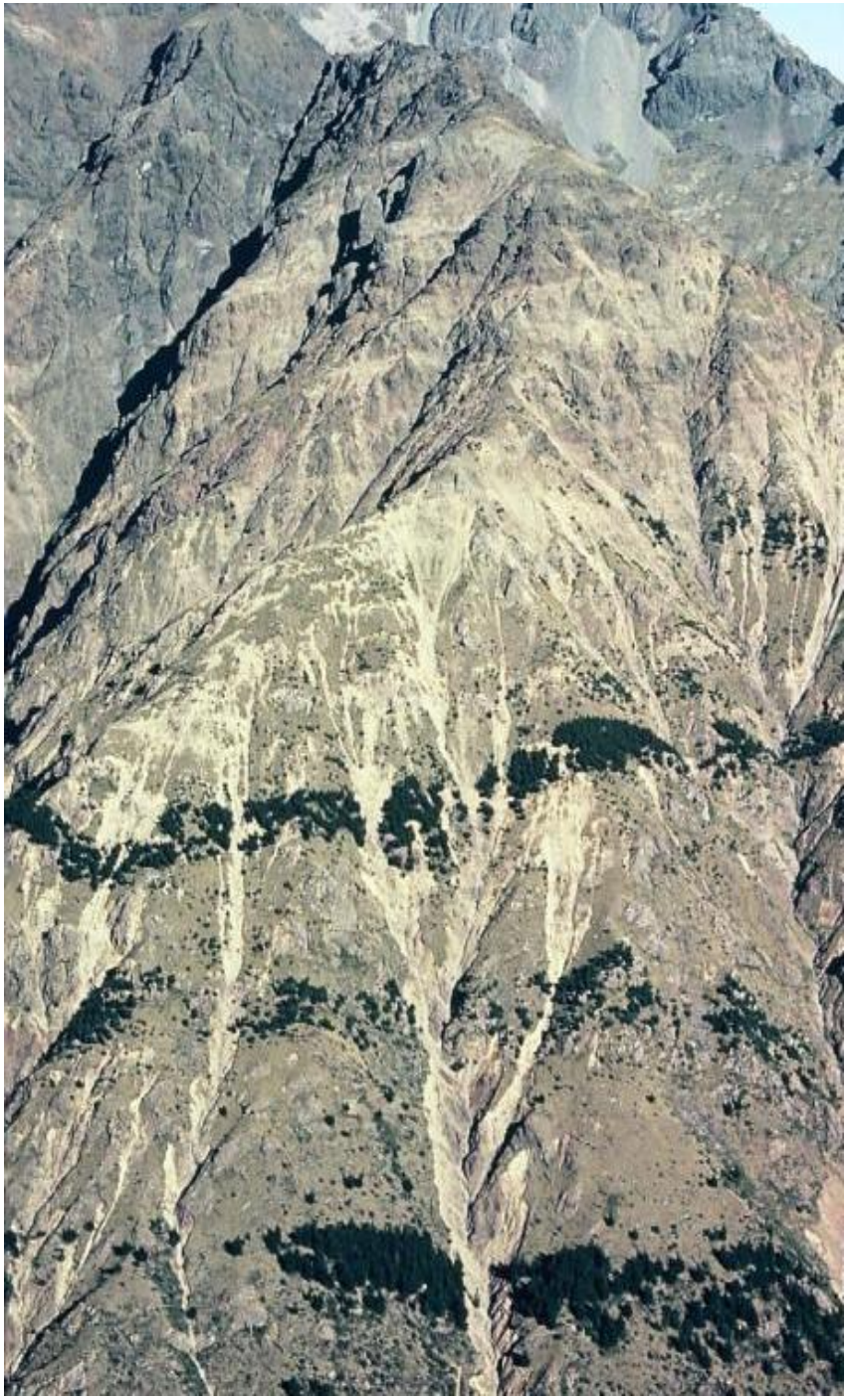

A
SCREE FOREST
SCREE FOREST
Pinus radiata plantation, est. 1935
1938
0 100 200 300 m
BOSBOUKLOOF


B
SCREE FOREST
SCREE FOREST
Pinus radiata plantation, est. 1935
FIREBREAK
BOSBOUKLOOF
1981
Pinus radiata invasion, Jonkershoek, Stellenbosch
(Richardson & Brown 1986; *S. Afr. J. Bot.* 52: 529-536)
0 100 200 300 m

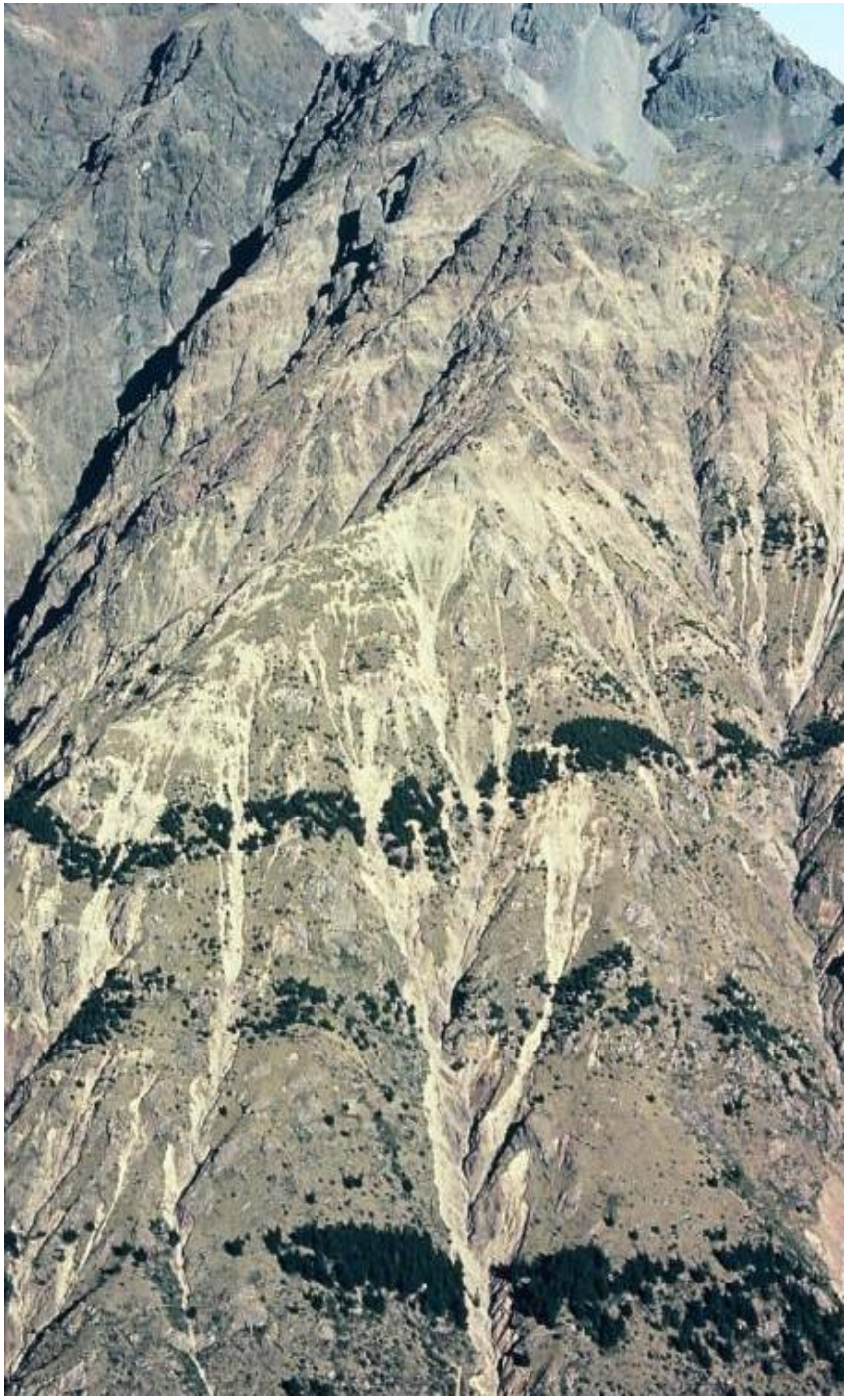
Plantations
in New Zealand

Plantations
in New Zealand

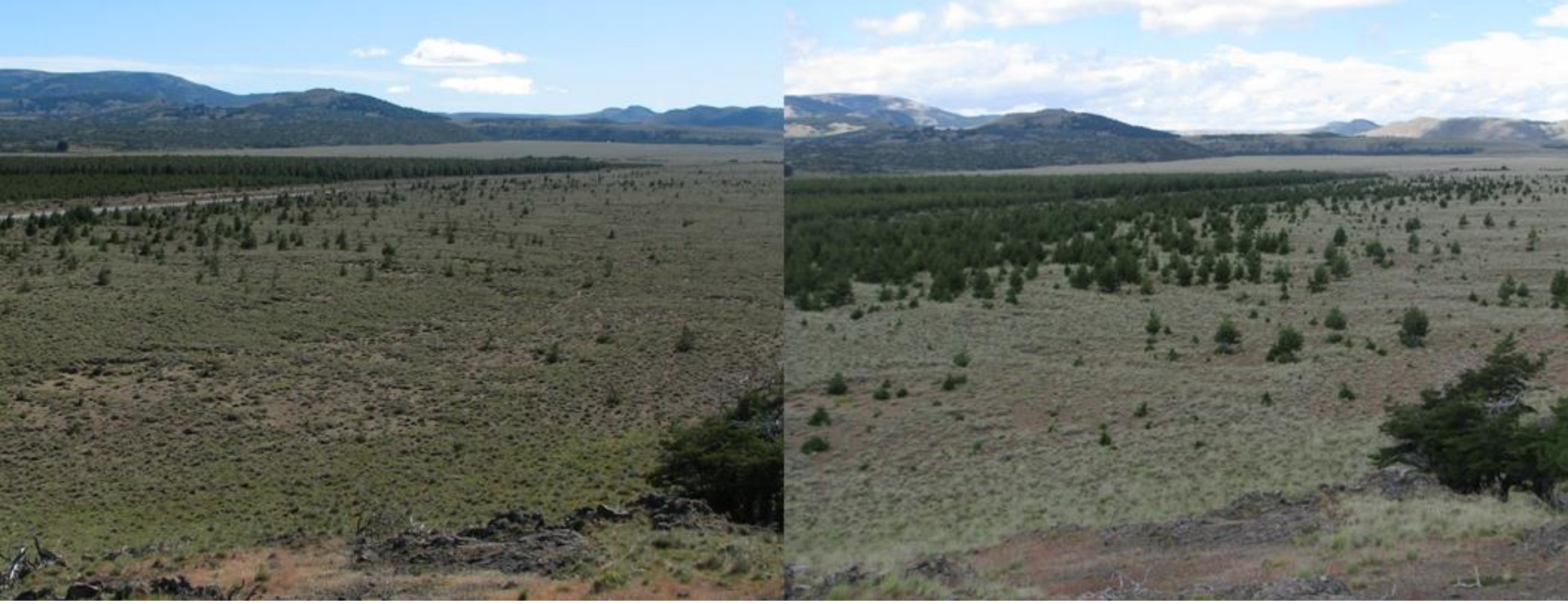




Plantations
in New Zealand



Invasion Pinus contorta: 2007



Invasion Pinus contorta:
2007 2011

Invasion Pinus contorta:
2007 2011 2015

Pinus invasions in the southern hemisphere

P. radiata into forest; Australia

P. pinaster into fynbos; RSA

P. nigra into grassl.; N. Zeal.

P. contorta into grassl.; N. Zeal.

P. radiata into forest; Chile

P. kesiya into grassl; Madagas.

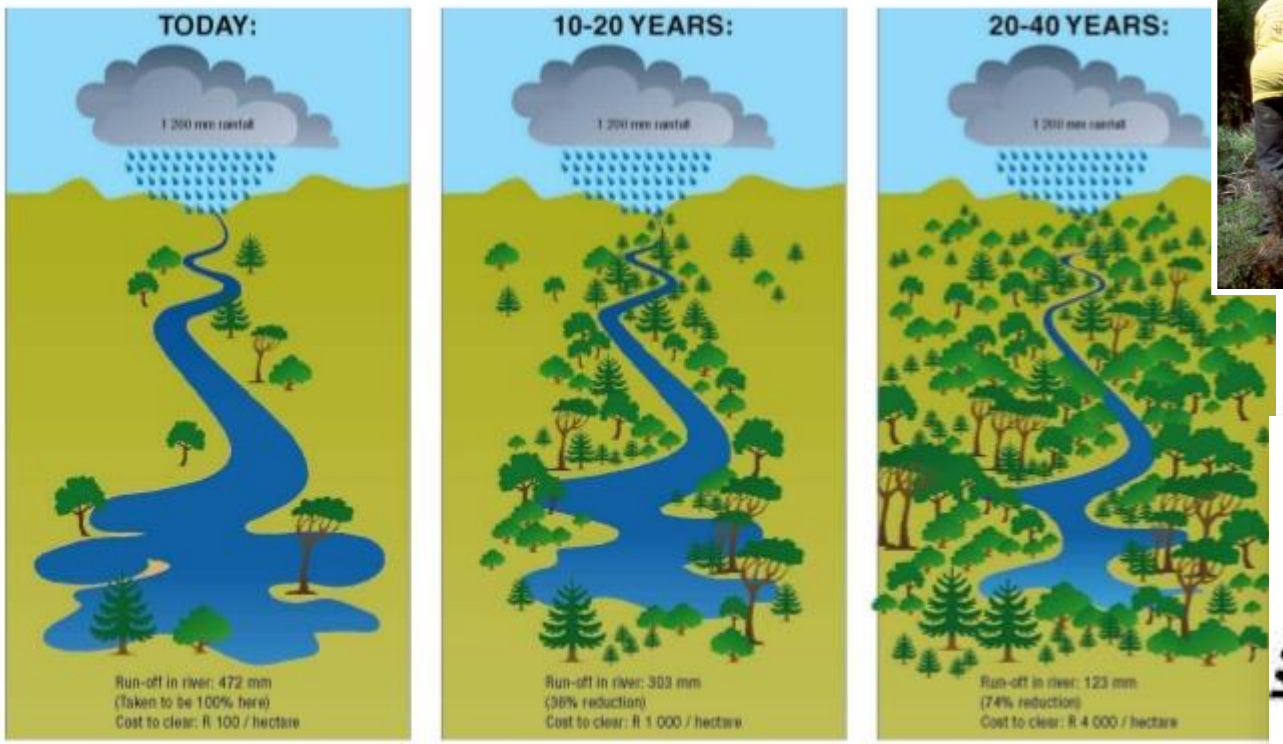
What are the impacts of pine invasions?

- Ecosystem changes caused by the “novel” tree cover.
- Changes in fire regimes.
- Reduction in local diversity by competitive exclusion.
- Economic impacts.
- Change in ecosystem services
- Changes in scenic values.

P. contorta in Chile


2006 2 9

If we do not clear invasive alien plants ...



WORKING FOR WATER

What are the impacts of pine invasions?

- Invasion of open ecosystems and disturbed environments.
- Ecosystem changes caused by the “novel” tree cover.
- Changes in fire regimes.
- Reduction in local diversity by competitive exclusion.
- Economic impacts
- Change in ecosystem services
- Changes in scenic values.

P. contorta in Chile

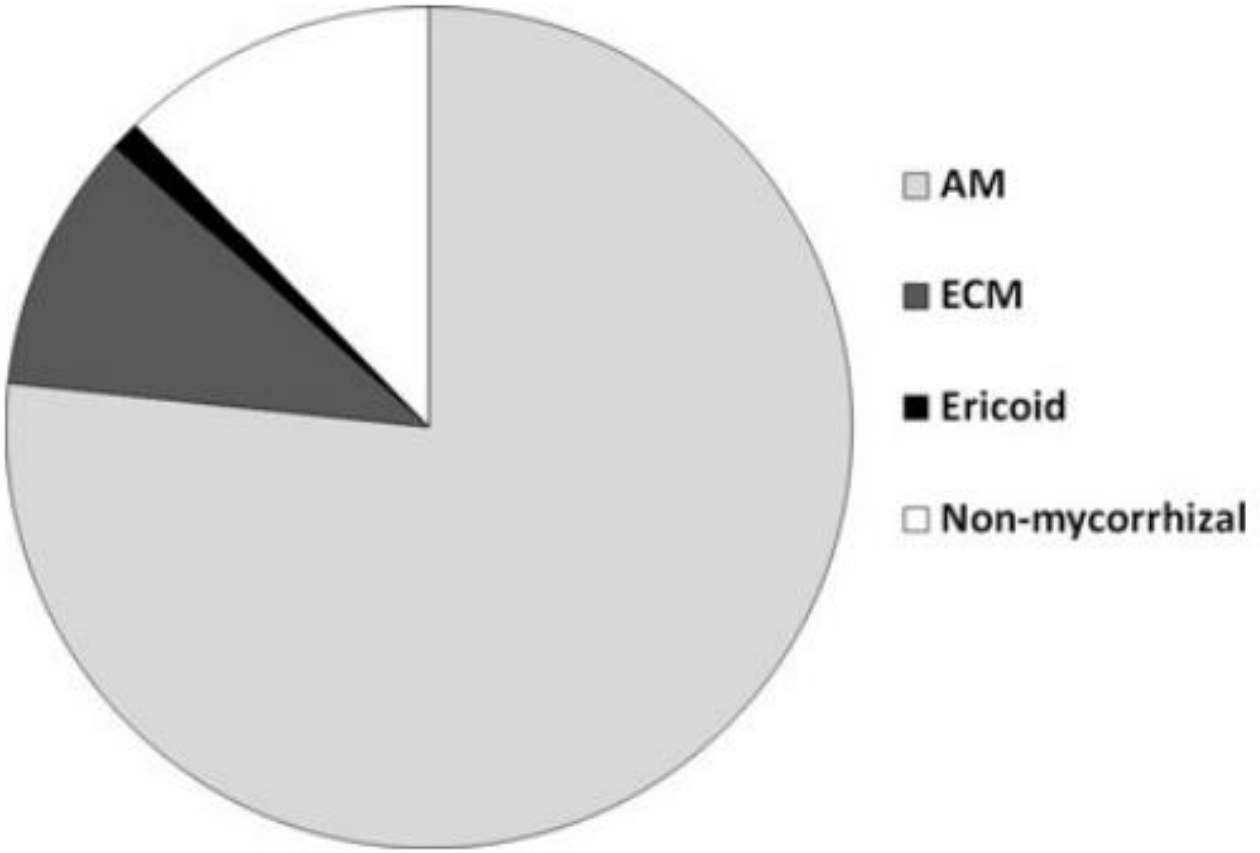
But pines cannot invade alone...

Mycorrhizae

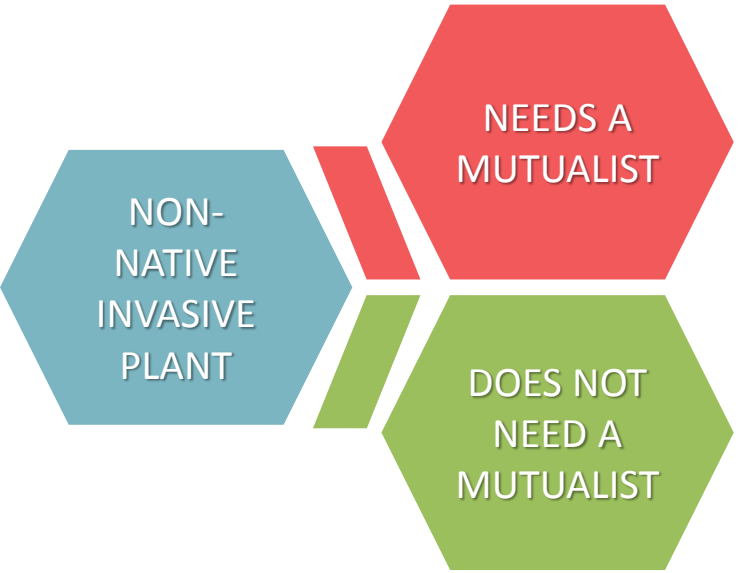
Plant-fungi mutualism

Proportion of invasive trees

M. A. Nuñez, I. A. Dickie



NON-
NATIVE
INVASIVE
PLANT


NON-
NATIVE
INVASIVE
PLANT
NEEDS A
MUTUALIST
DOES NOT
NEED A
MUTUALIST

NON-NATIVE INVASIVE PLANT

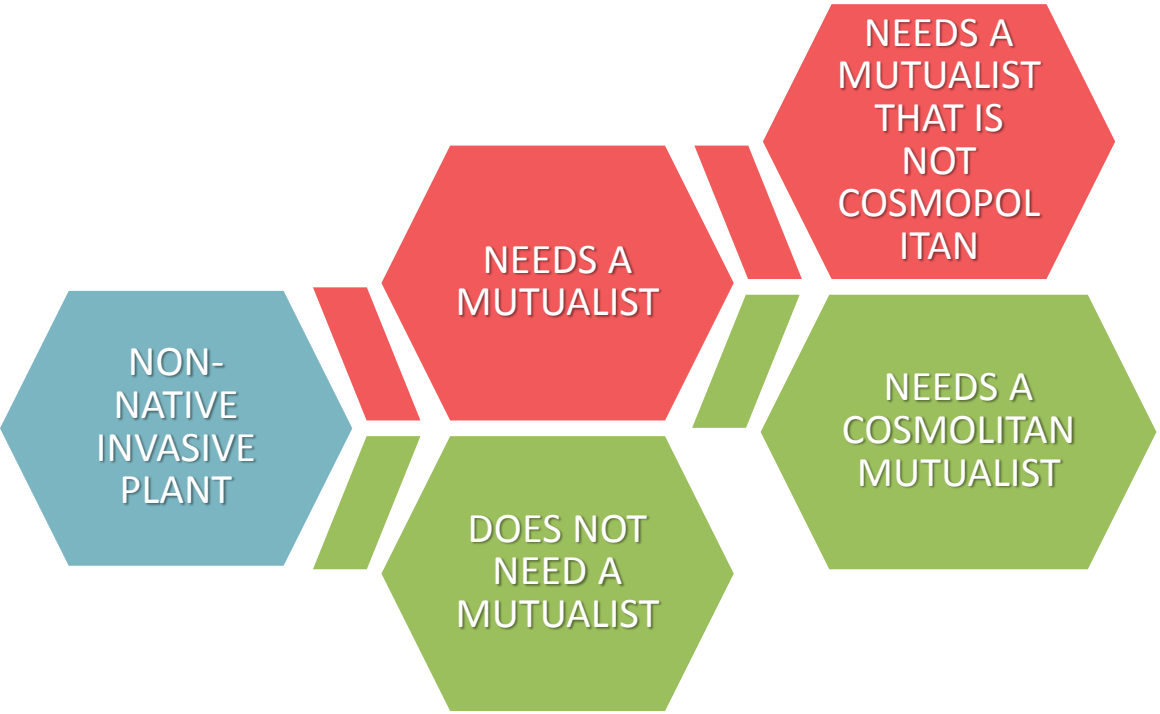
NEEDS A MUTUALIST

DOES NOT NEED A MUTUALIST

Proteaceae; some members of Brassicaceae family. *Tamarix* spp. *Polygonum* spp.

Alliaria petiolata

Embothrium coccineum


NON-NATIVE INVASIVE PLANT
NEEDS A MUTUALIST
NEEDS A MUTUALIST THAT IS NOT COSMOPOLITAN
DOES NOT NEED A MUTUALIST
NEEDS A COSMOLITAN MUTUALIST

NON-NATIVE INVASIVE PLANT

NEEDS A MUTUALIST

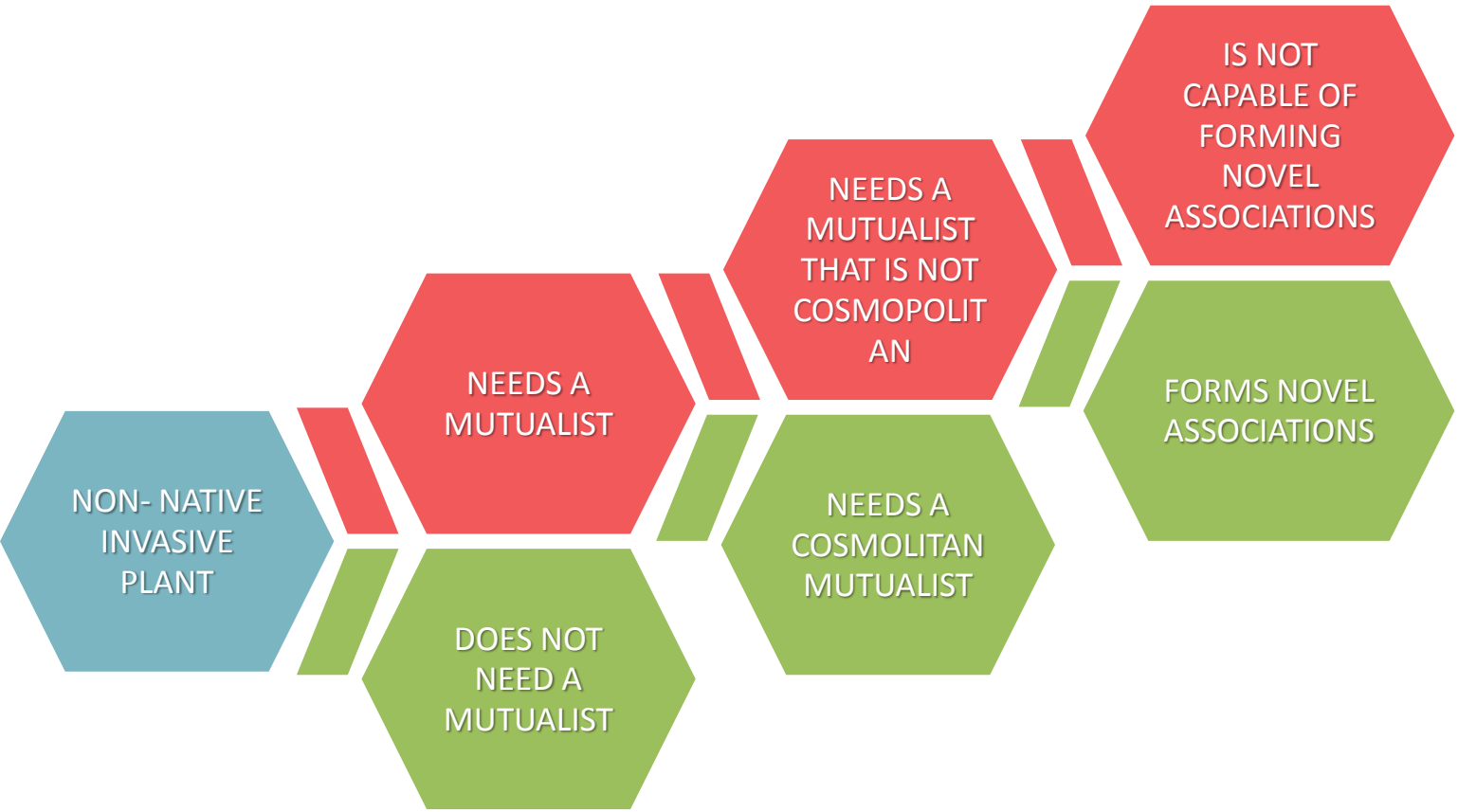
NEEDS A MUTUALIST THAT IS NOT COSMOPOLITAN

NEEDS A COSMOLITAN MUTUALIST

DOES NOT NEED A MUTUALIST

Arbuscular mycorrhizal invasive plants associated with generalist mycorrhizal fungi.

Centaurea stoebe *Trachycarpus fortunei*


NON- NATIVE INVASIVE PLANT
NEEDS A MUTUALIST
DOES NOT NEED A MUTUALIST
NEEDS A MUTUALIST THAT IS NOT COSMOPOLIT AN
NEEDS A COSMOLITAN MUTUALIST
IS NOT CAPABLE OF FORMING NOVEL ASSOCIATIONS
FORMS NOVEL ASSOCIATIONS

NON-NATIVE INVASIVE PLANT

NEEDS A MUTUALIST

DOES NOT NEED A MUTUALIST

NEEDS A MUTUALIST THAT IS NOT COSMOPOLITAN

NEEDS A COSMOLITAN MUTUALIST

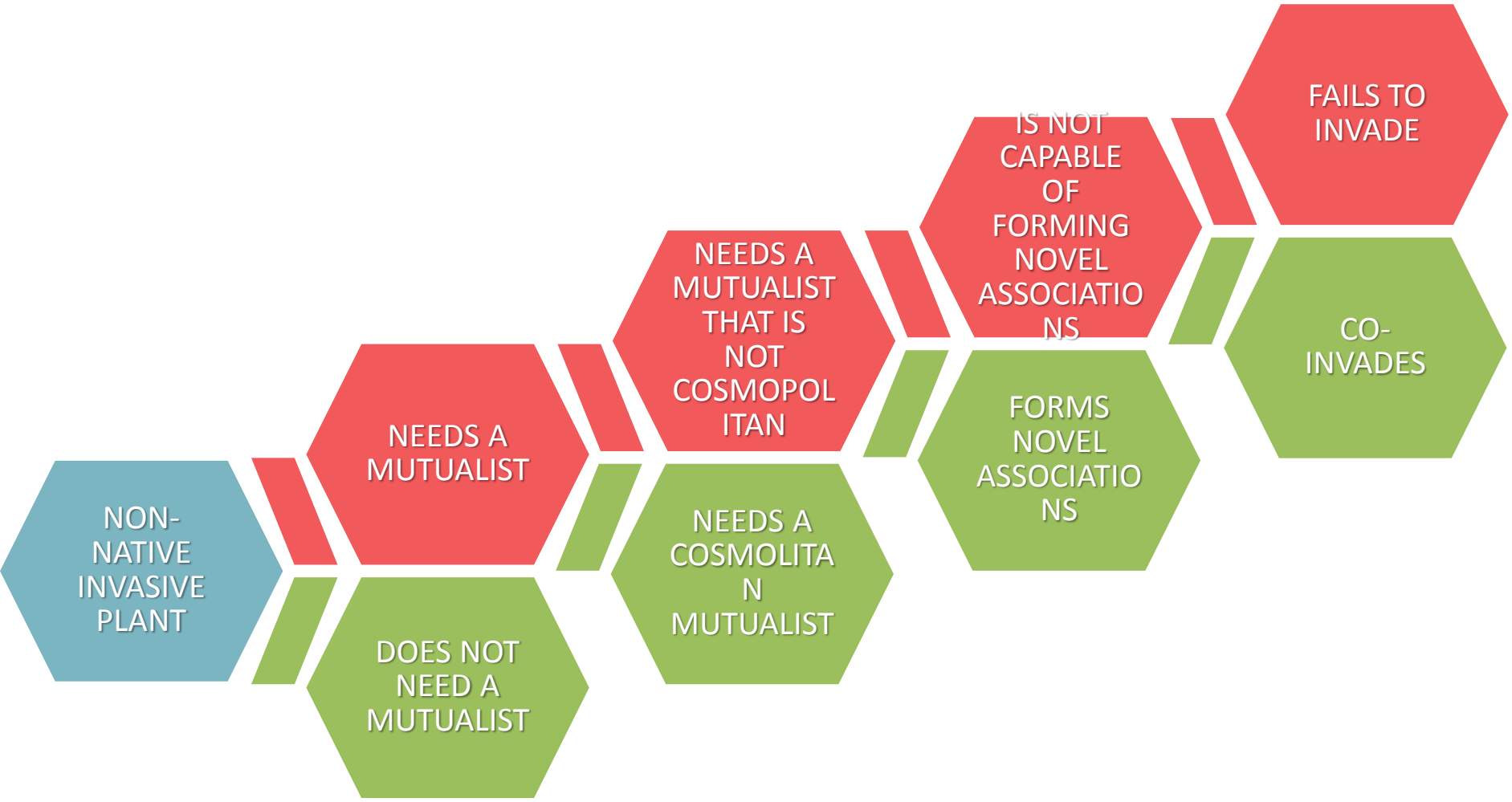
IS NOT CAPABLE OF FORMING NOVEL ASSOCIATIONS

FORMS NOVEL ASSOCIATIONS

N-fixing native symbiont and invasive plants. Some ectomycorrhizal fungi with native plants.

Eucalyptus sp

Nothofagus antarctica


NON-NATIVE INVASIVE PLANT
NEEDS A MUTUALIST
DOES NOT NEED A MUTUALIST
NEEDS A MUTUALIST THAT IS NOT COSMOPOLITAN
NEEDS A COSMOLITAN MUTUALIST
IS NOT CAPABLE OF FORMING NOVEL ASSOCIATIONS
FORMS NOVEL ASSOCIATIONS
FAILS TO INVADE
CO-INVADES

NON-NATIVE INVASIVE PLANT

NEEDS A MUTUALIST

DOES NOT NEED A MUTUALIST

NEEDS A MUTUALIST THAT IS NOT COSMOPOLITAN

NEEDS A COSMOLITAN MUTUALIST

IS NOT CAPABLE OF FORMING NOVEL ASSOCIATIONS

FORMS NOVEL ASSOCIATIONS

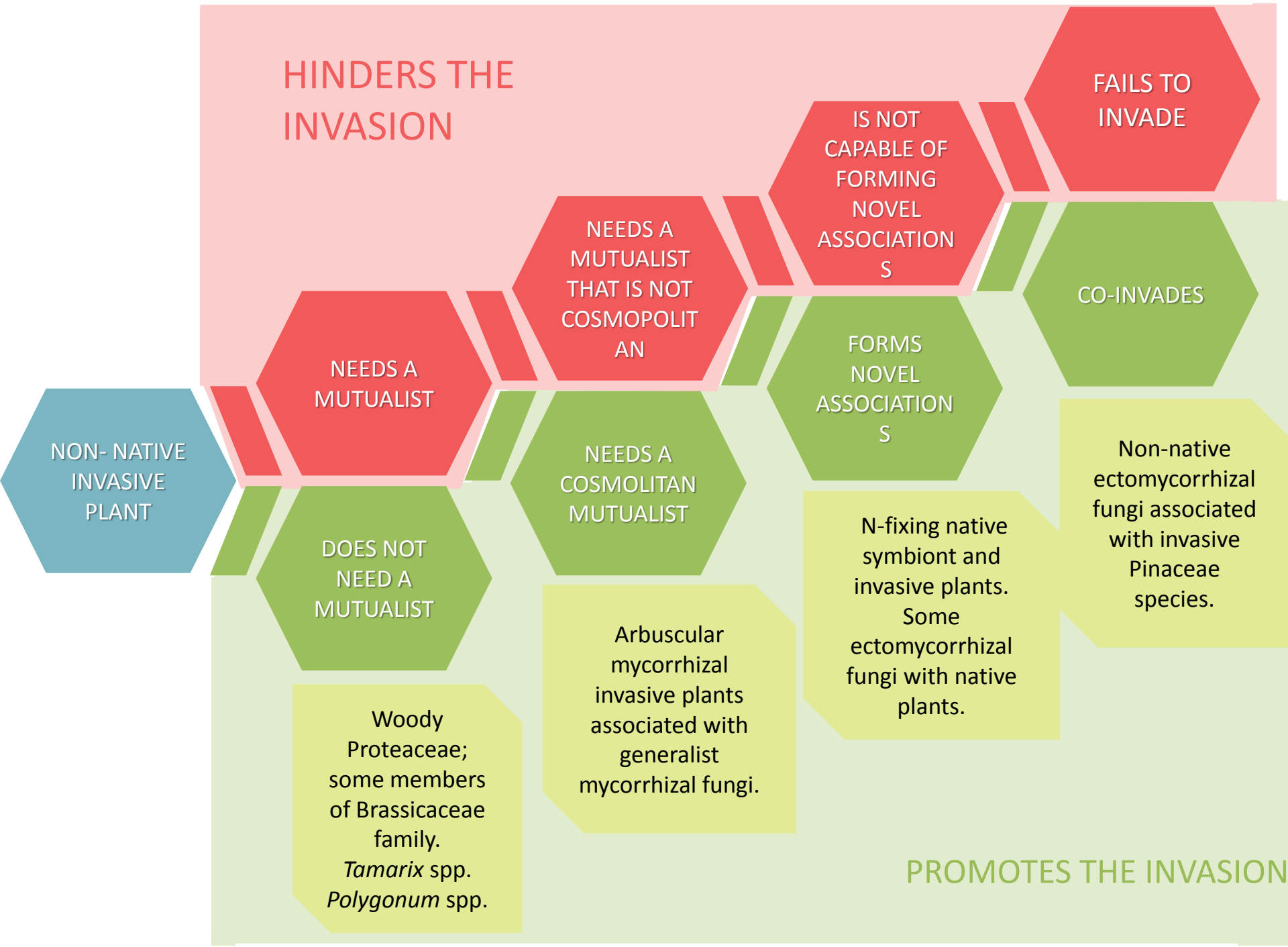
FAILS TO INVADE

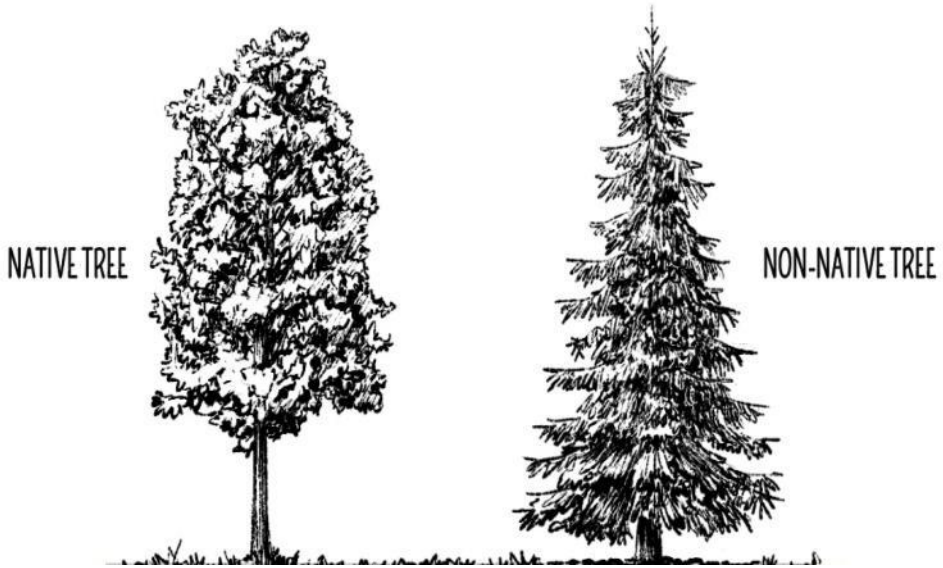
CO-INVADES

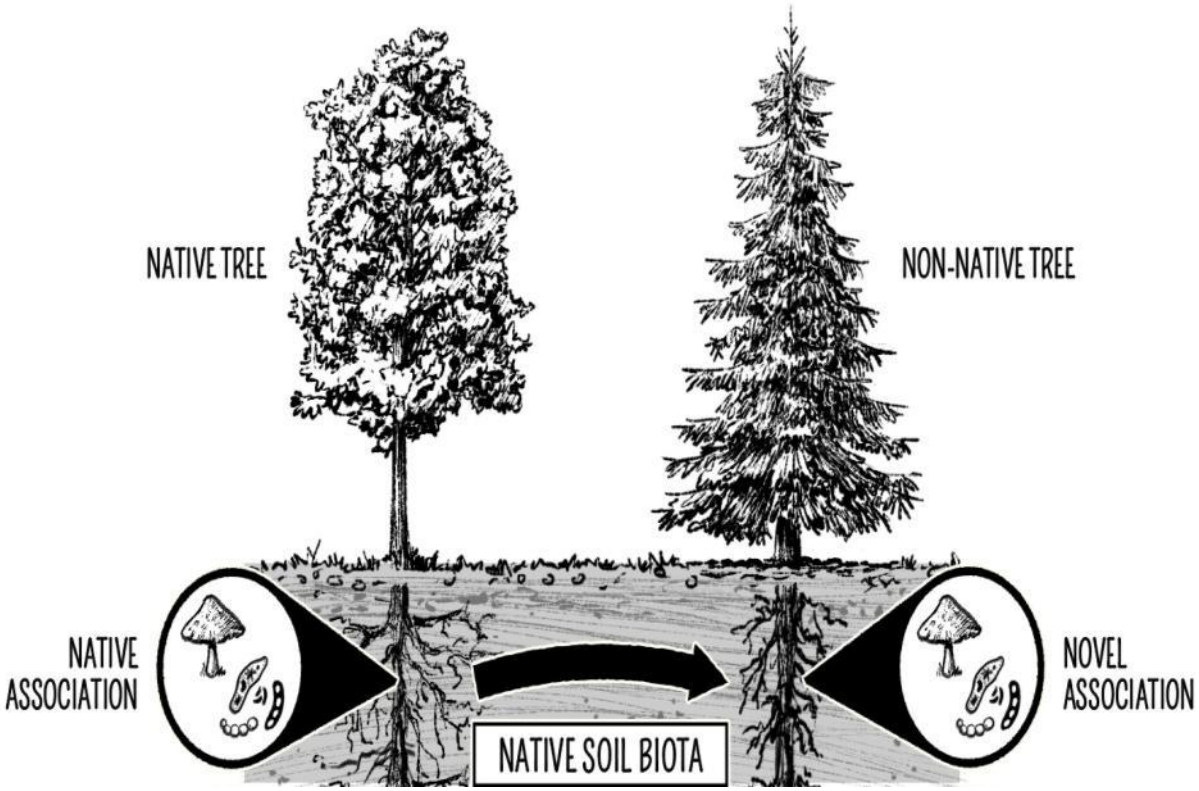
Non-native ectomycorrhizal fungi associated with invasive Pinaceae species.

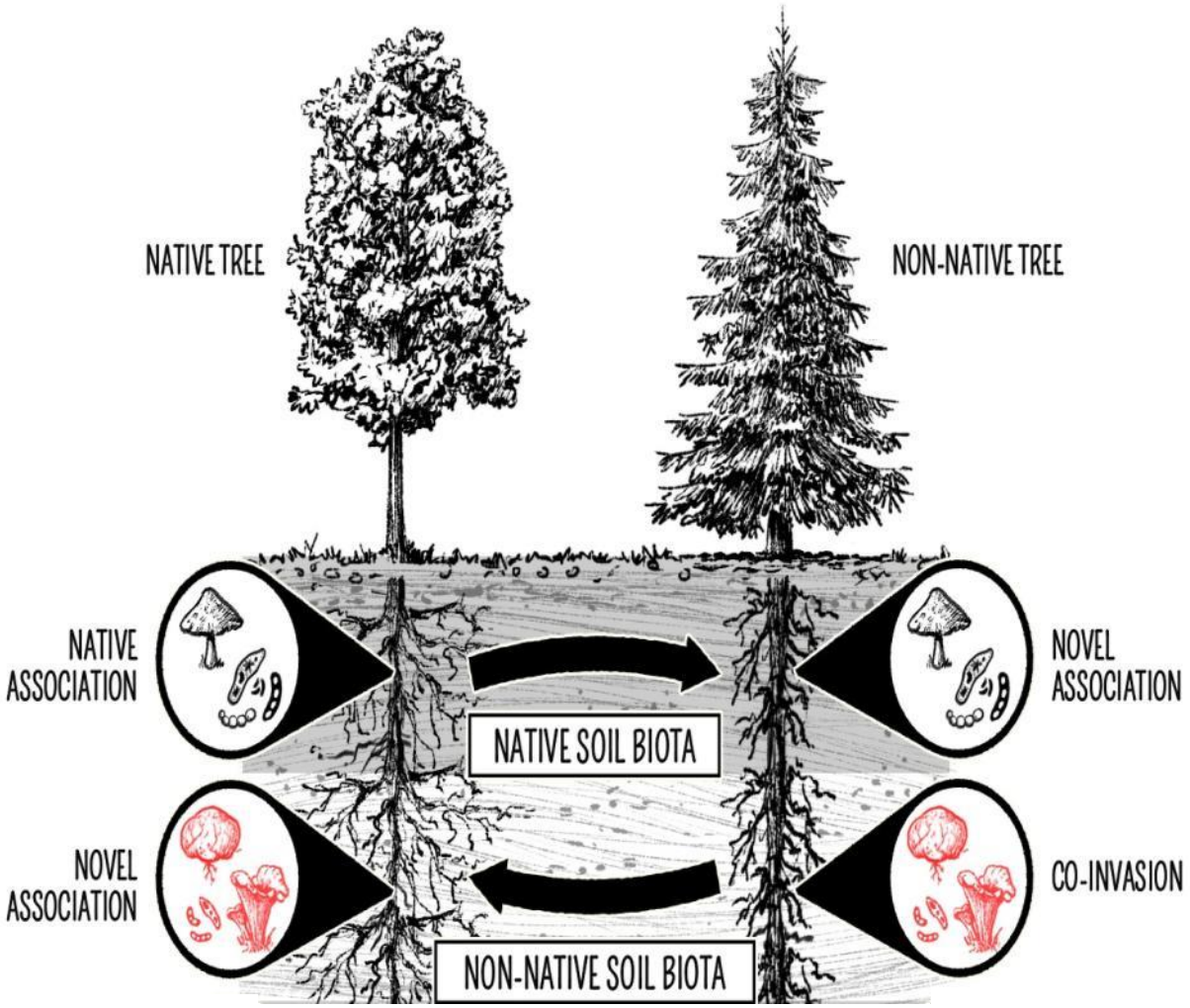
Pinus contorta

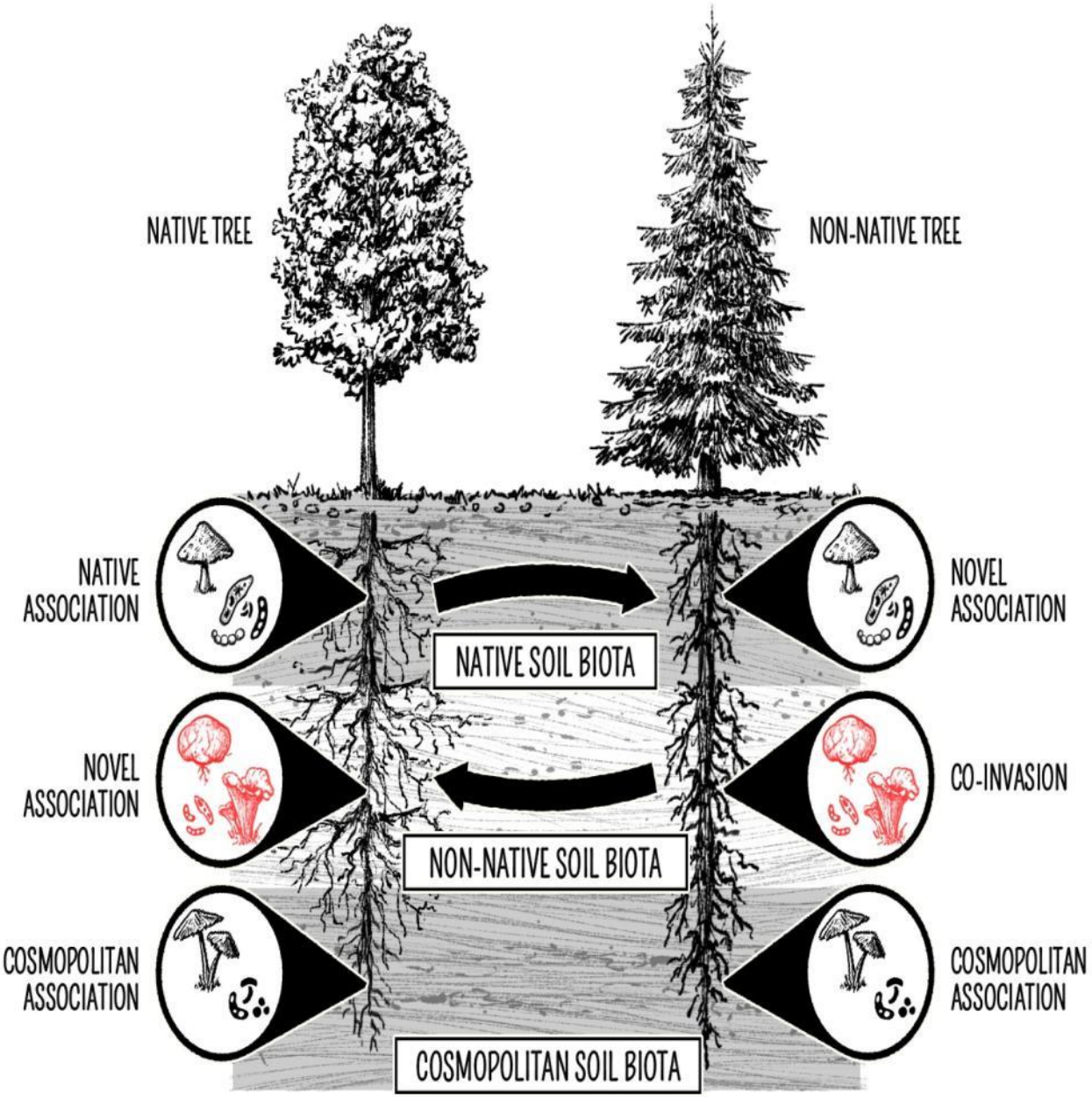
Pseudotsuga menziesii


HINDERS THE INVASION
FAILS TO INVADE
IS NOT CAPABLE OF FORMING NOVEL ASSOCIATIONS
NEEDS A MUTUALIST THAT IS NOT COSMOPOLITAN
NEEDS A MUTUALIST
NON- NATIVE INVASIVE PLANT
CO-INVADES
FORMS NOVEL ASSOCIATIONS
NEEDS A COSMOLITAN MUTUALIST
DOES NOT NEED A MUTUALIST
Non-native ectomycorrhizal fungi associated with invasive Pinaceae species.
N-fixing native symbiont and invasive plants. Some ectomycorrhizal fungi with native plants.
Arbuscular mycorrhizal invasive plants associated with generalist mycorrhizal fungi.
Woody Proteaceae; some members of Brassicaceae family. *Tamarix* spp. *Polygonum* spp.
PROMOTES THE INVASION

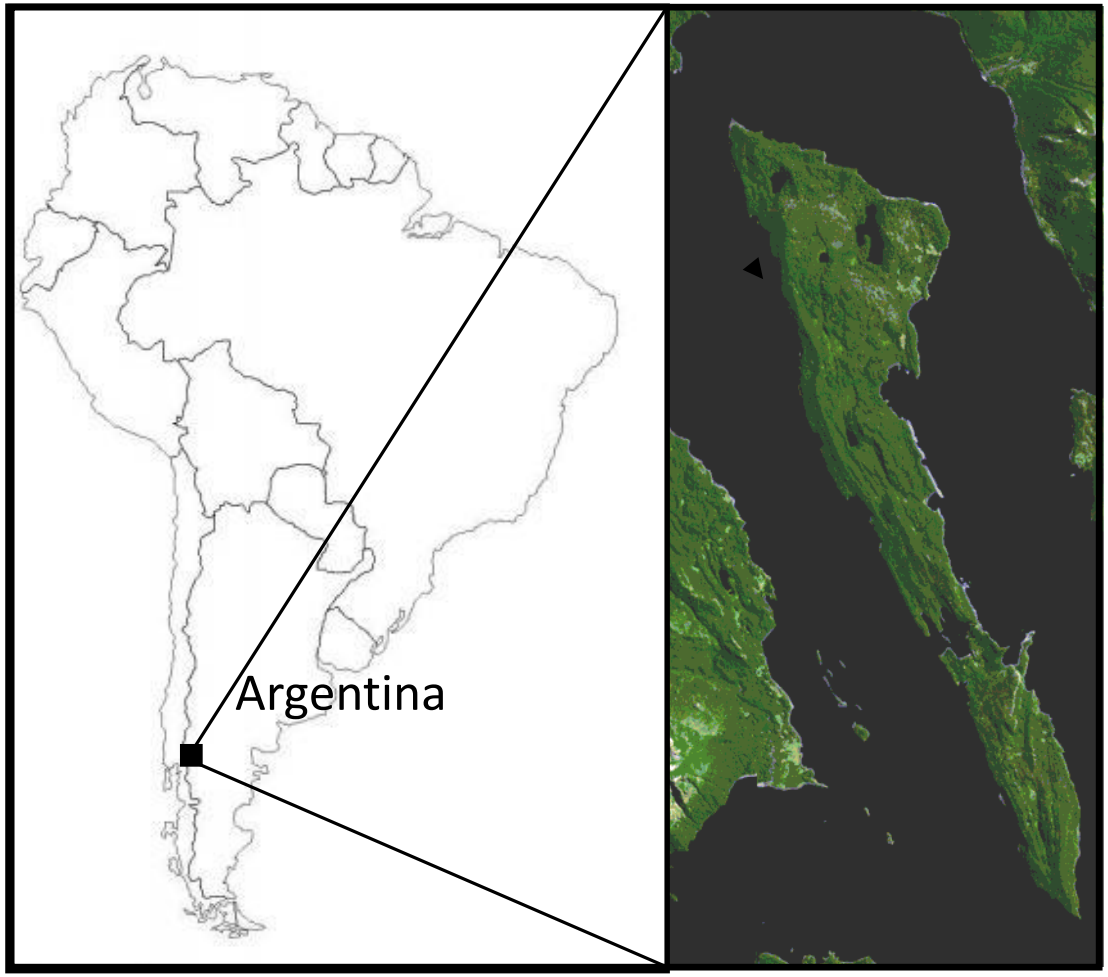

NATIVE TREE
NON-NATIVE TREE


NATIVE TREE
NON-NATIVE TREE
NATIVE ASSOCIATION
NOVEL ASSOCIATION
NATIVE SOIL BIOTA


NATIVE TREE
NON-NATIVE TREE
NATIVE ASSOCIATION
NOVEL ASSOCIATION
NATIVE SOIL BIOTA
NOVEL ASSOCIATION
CO-INVASION
NON-NATIVE SOIL BIOTA


NATIVE TREE
NON-NATIVE TREE
NATIVE ASSOCIATION
NOVEL ASSOCIATION
NATIVE SOIL BIOTA
NOVEL ASSOCIATION
CO-INVASION
NON-NATIVE SOIL BIOTA
COSMOPOLITAN ASSOCIATION
COSMOPOLITAN ASSOCIATION
COSMOPOLITAN SOIL BIOTA

Isla Victoria



1925-1939; 135 exotic species were planted, many of them highly invasive elsewhere

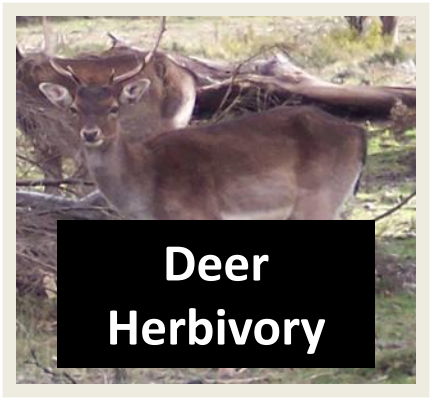
Observed pattern of invasion:

-High densities of exotic trees ***only*** **near plantations** (<50 m)

Invaded forest

Non-invaded forest


Intrinsic invasiveness


Deer Herbivory


Seedling herbivory


Pine Invasion


Seed Predation


Propagule pressure


Mycorrhizal Facilitation

?

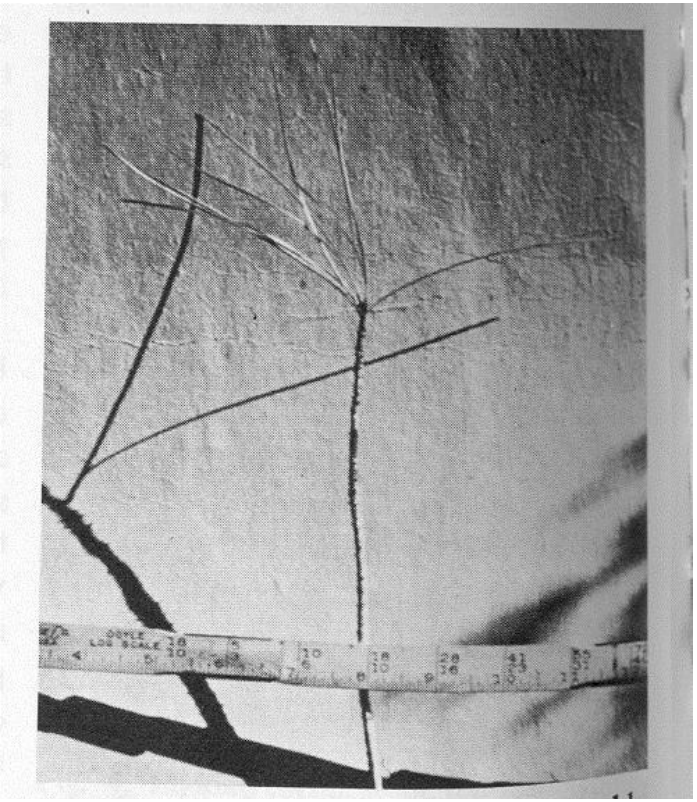
?

?

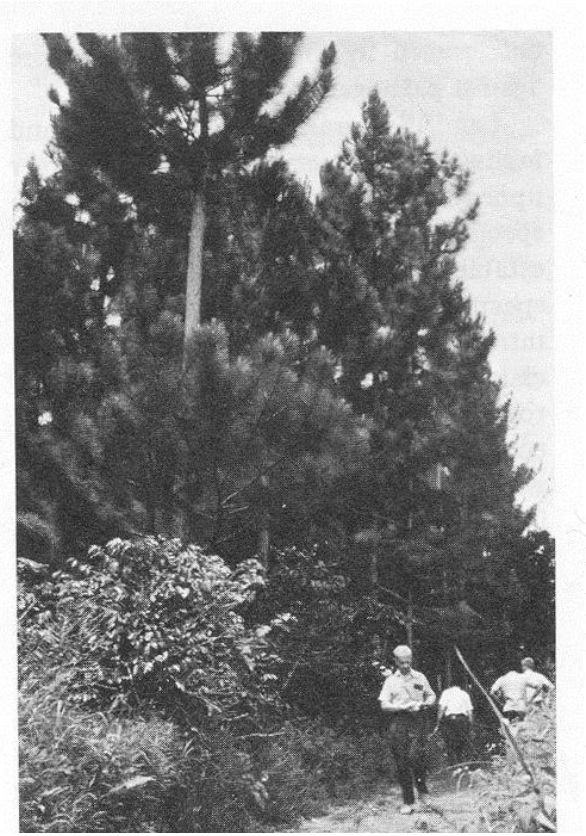
?

?

Many attempts to plant pines failed due to the absence of mycorrhizae

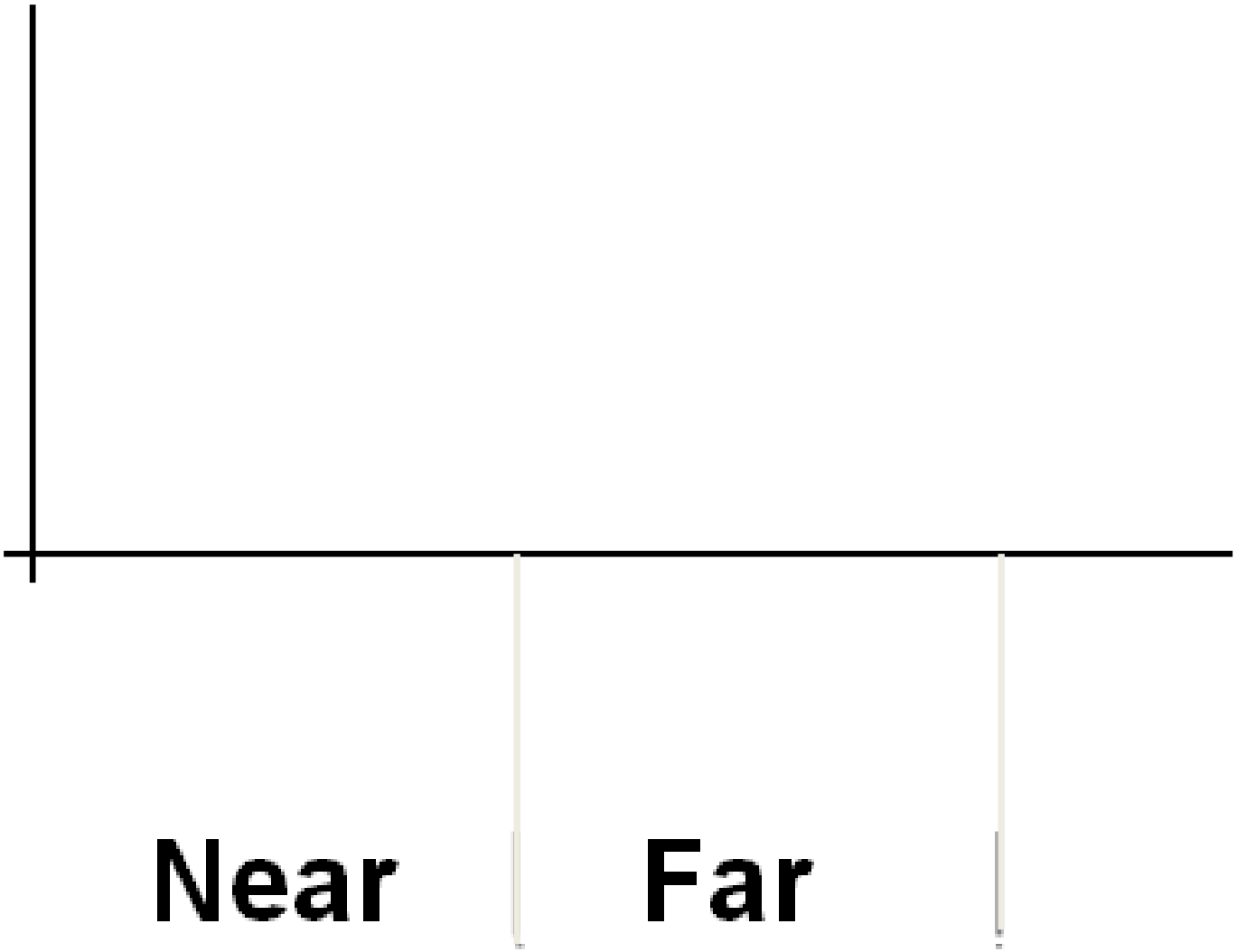


5 year old pine WITHOUT mycorrhizae

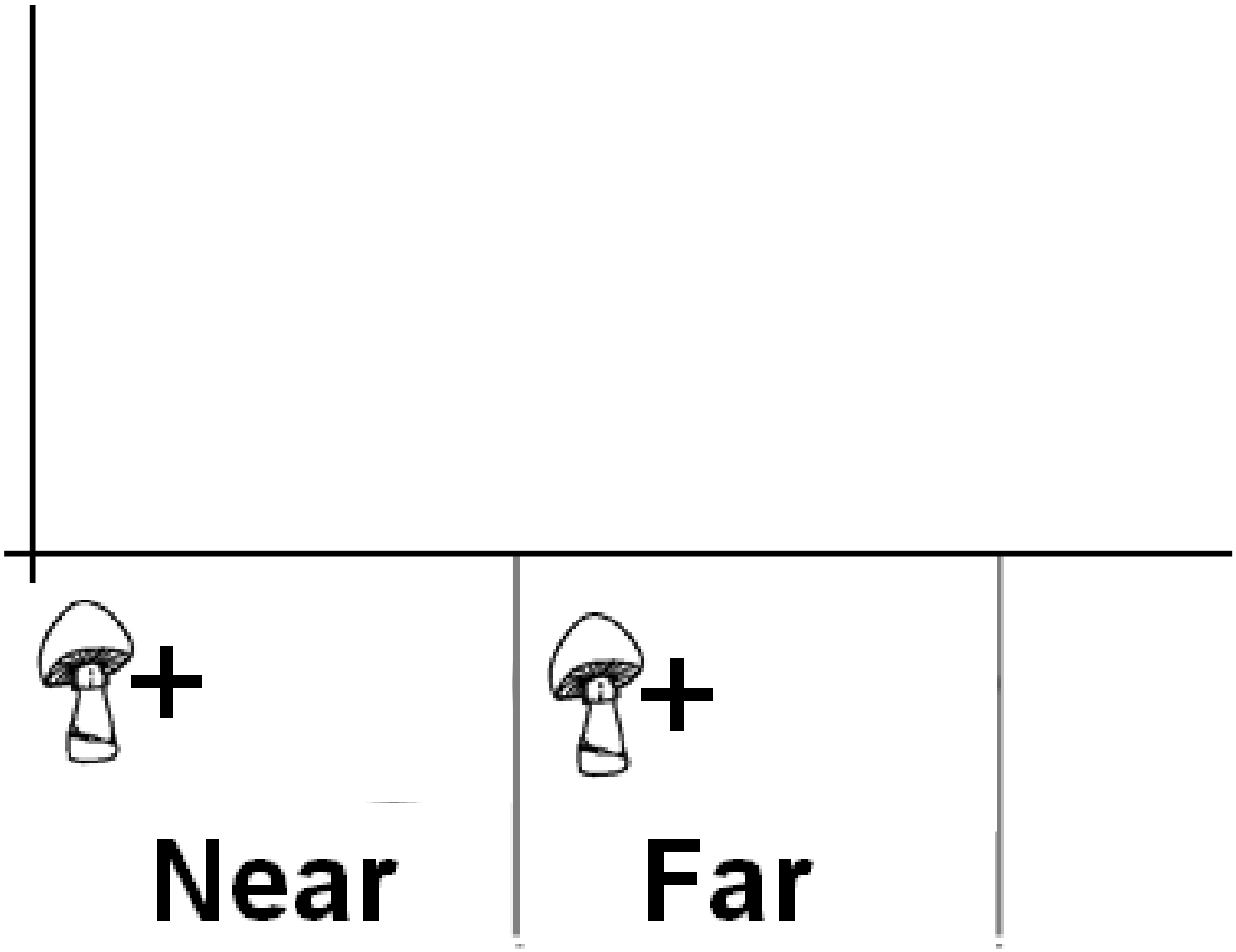


6 year old pine with mycorrhizae

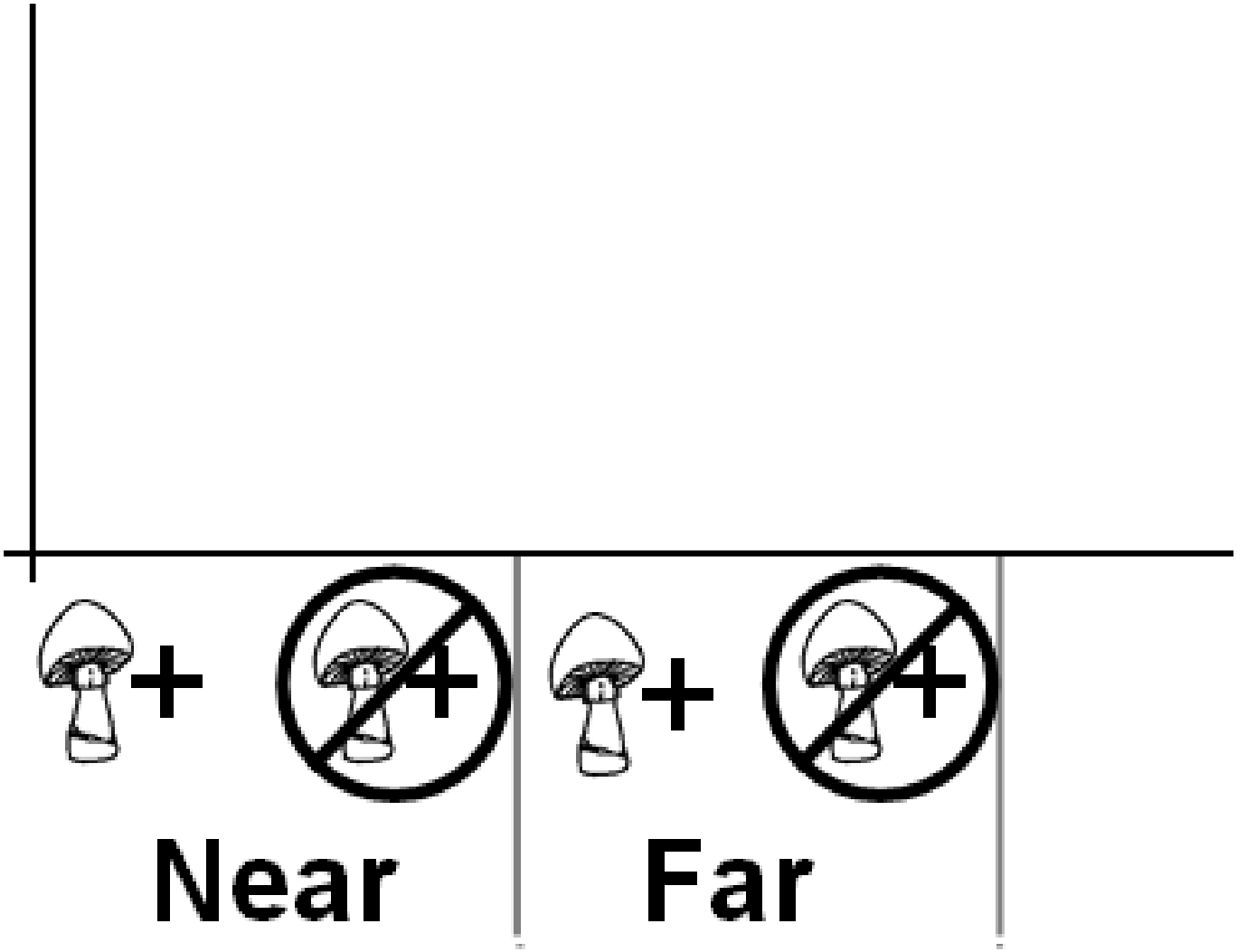
Greenhouse



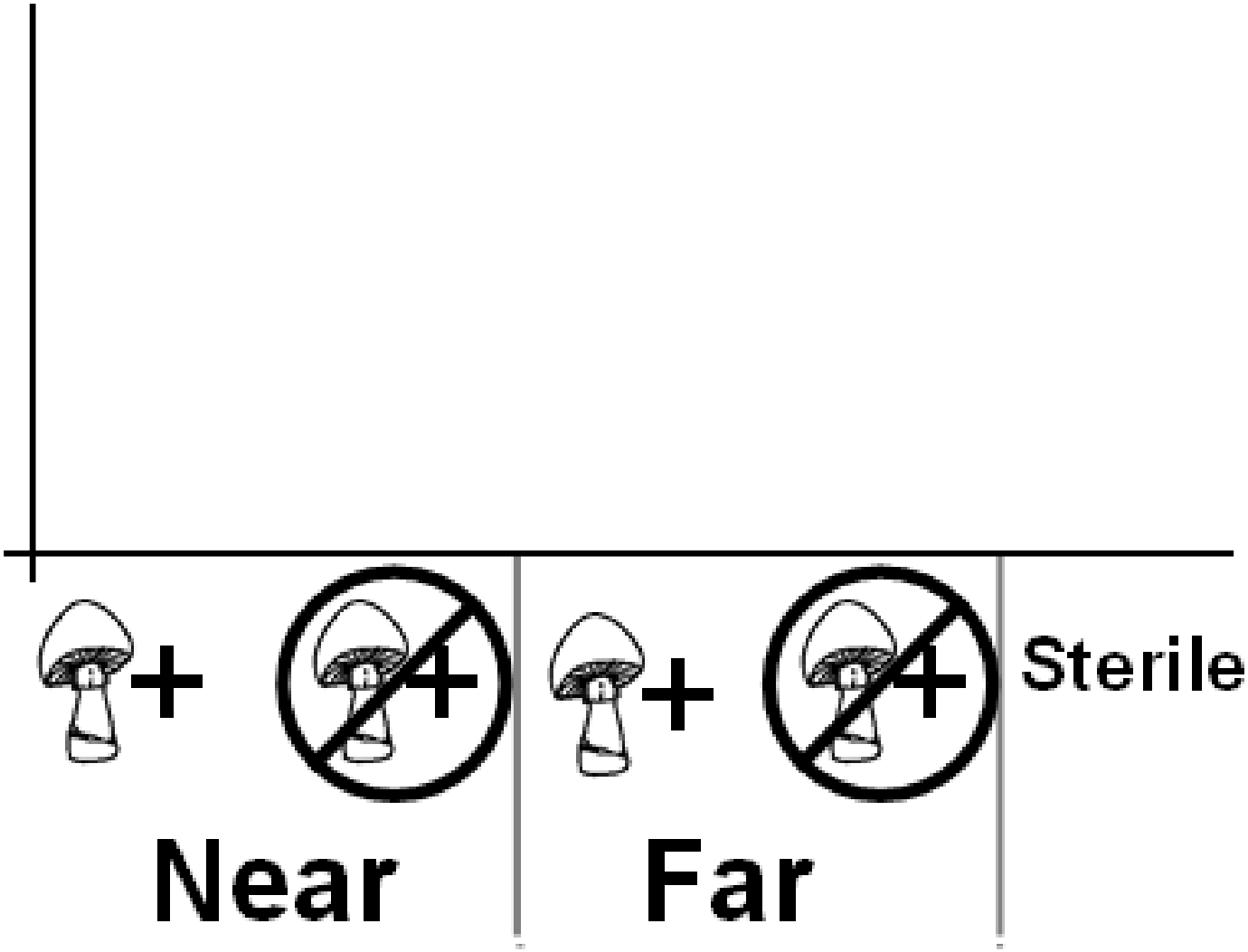
Greenhouse



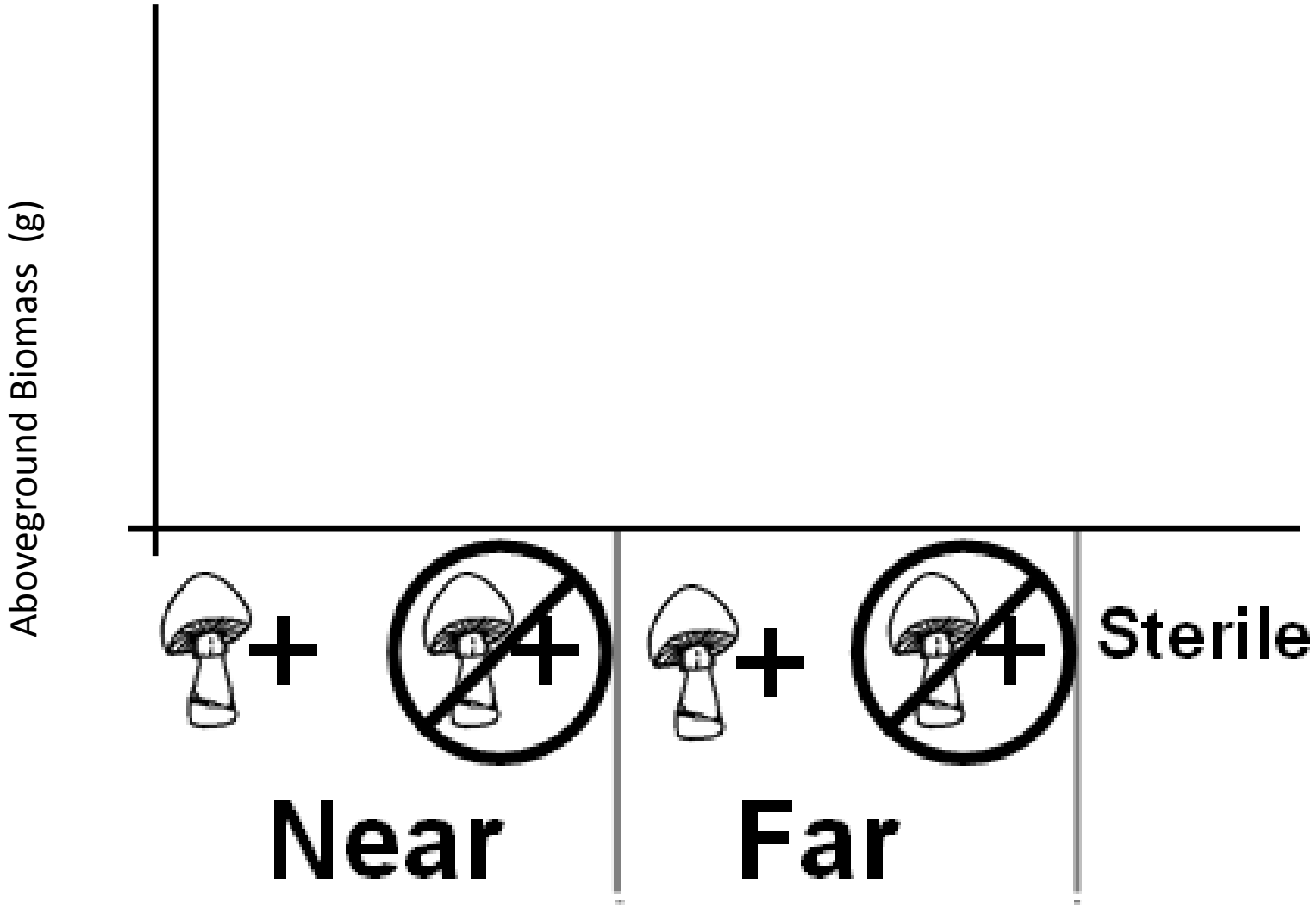
Greenhouse



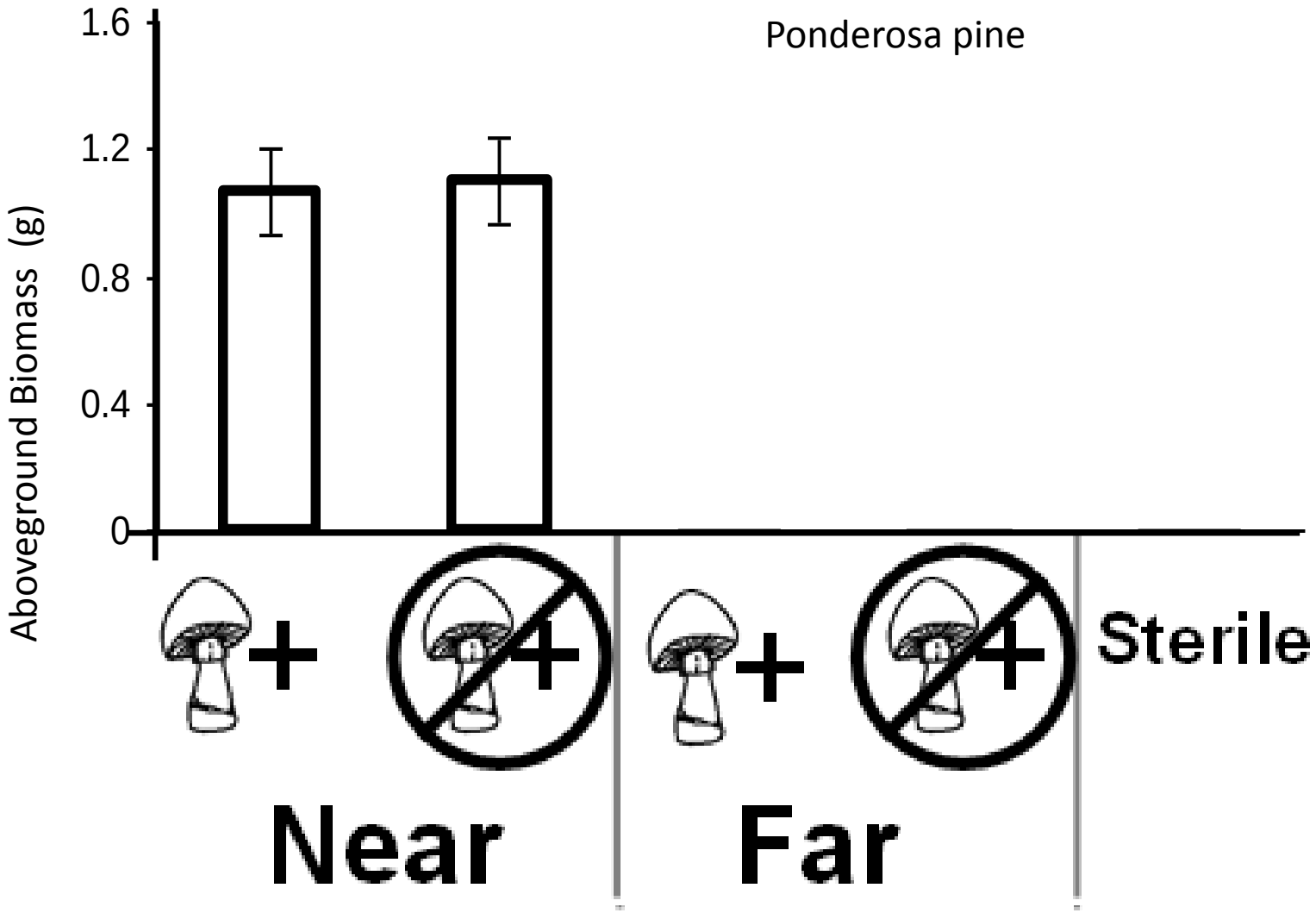
Greenhouse



Greenhouse

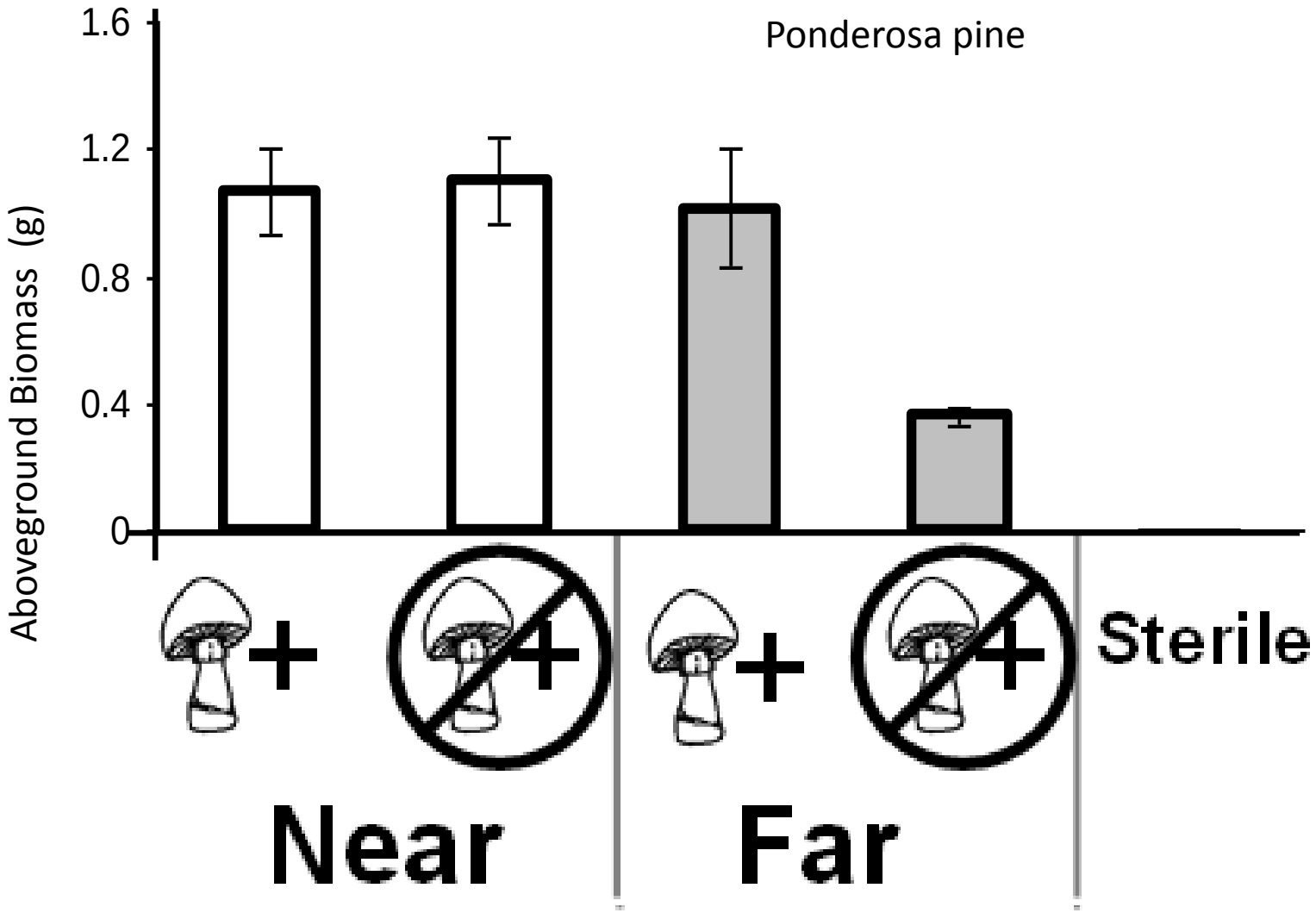


Greenhouse


Ponderosa pine
Aboveground Biomass (g)
1.6
1.2
0.8
0.4
0
Sterile
Near
Far

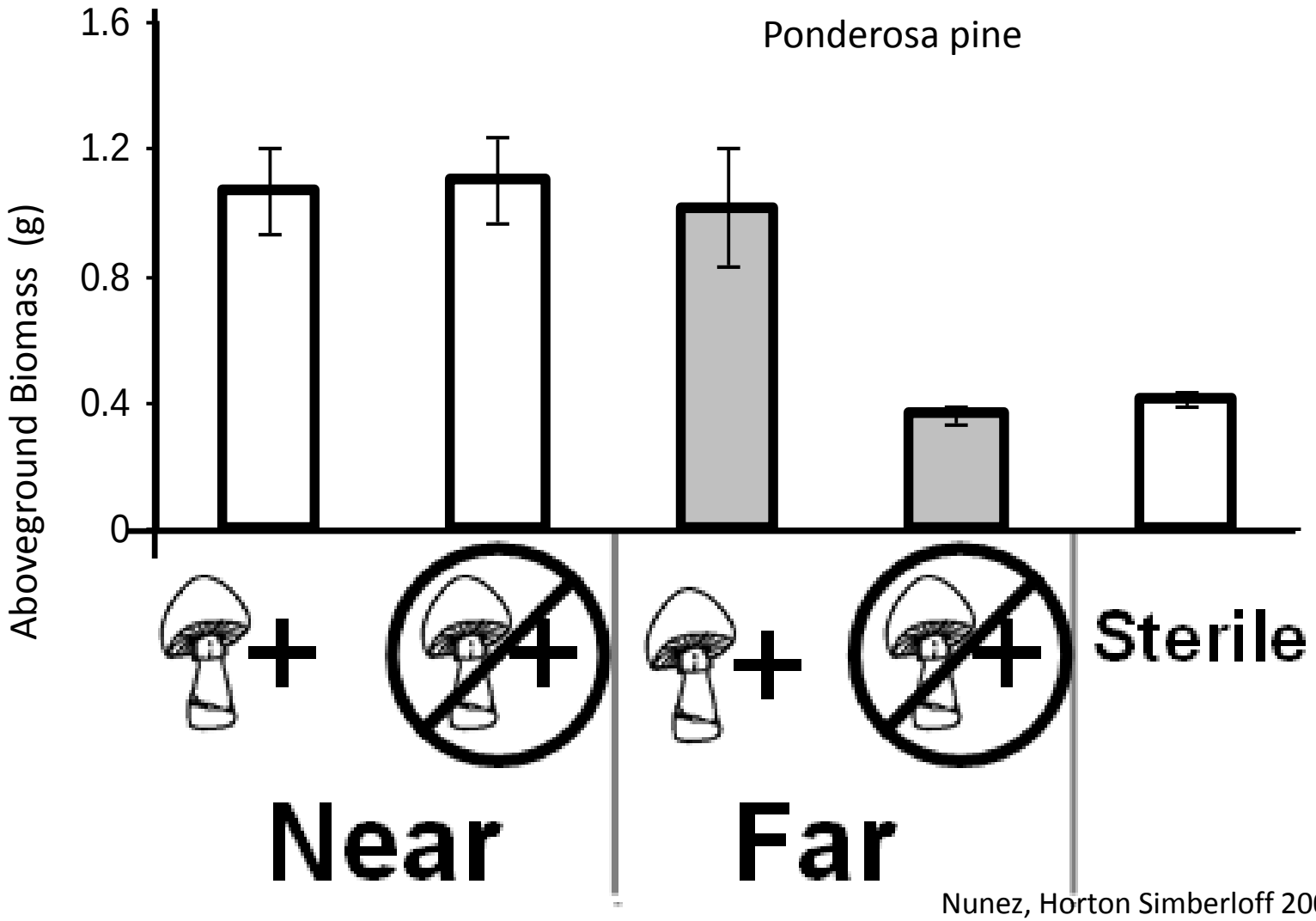
Greenhouse

Inoculum increased the biomass 3x

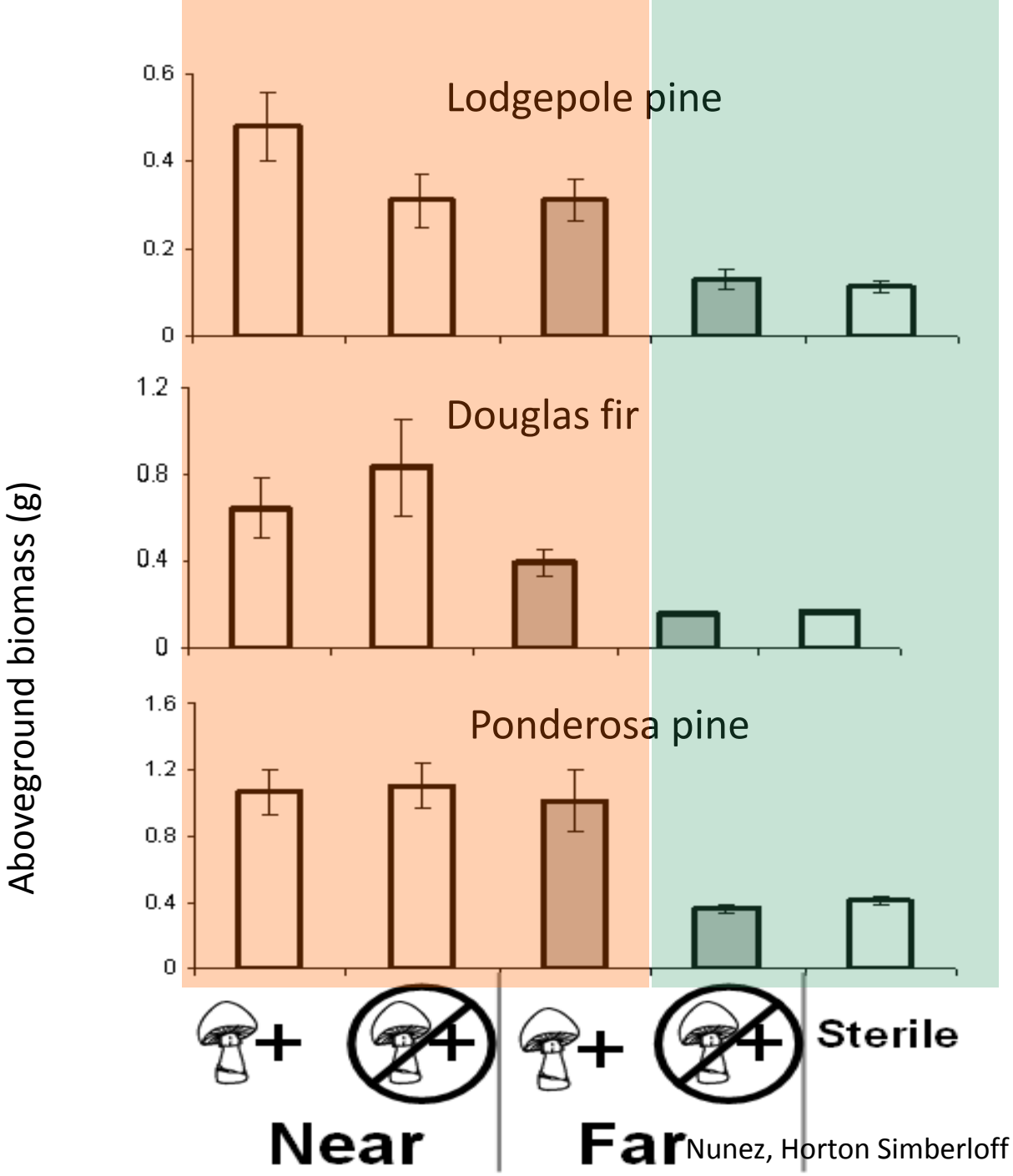


Greenhouse

Inoculum increased the biomass 3x



Nunez, Horton Simberloff 2009, Ecology

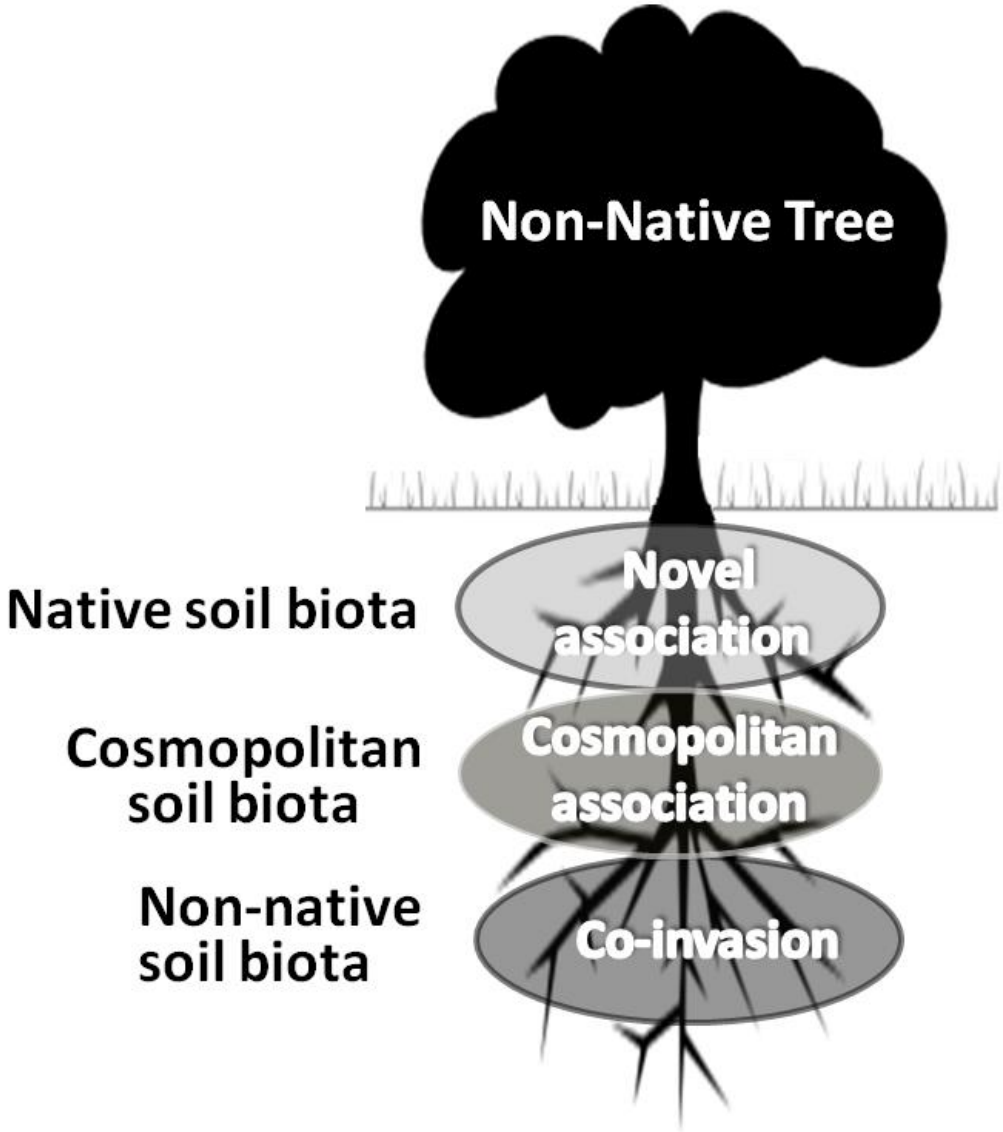


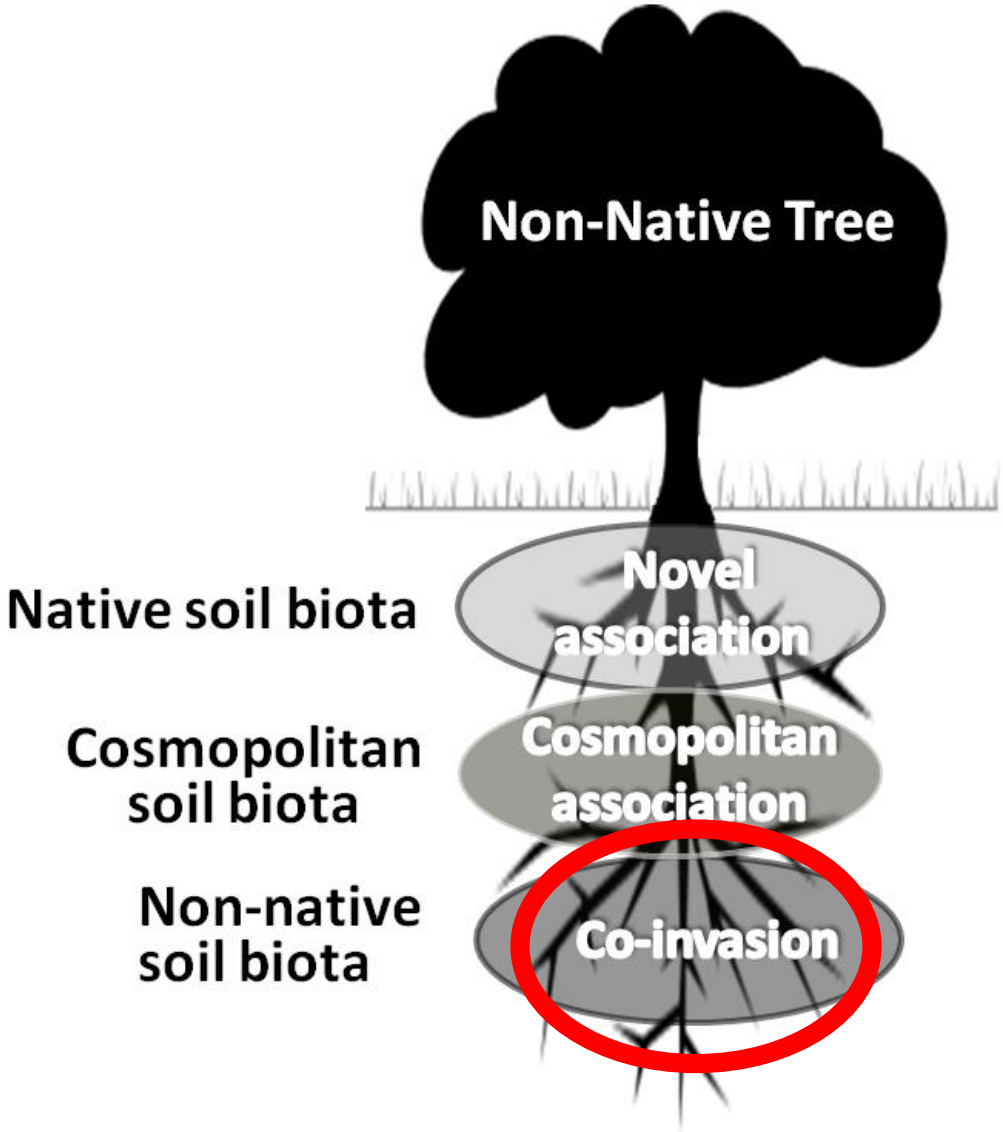
Nunez, Horton Simberloff 2009, Ecology

Morphological & Molecular Analyses

We analyzed fungal colonization using morphological and molecular (RFLPs and sequencing) techniques

Molecular analyses


Non-Native Tree
Native soil biota
Novel association
Cosmopolitan soil biota
Cosmopolitan association
Non-native soil biota
Co-invasion


Non-Native Tree
Native soil biota
Novel association
Cosmopolitan soil biota
Cosmopolitan association
Non-native soil biota
Co-invasion

OTU	Inside plantations	0–50 m	50–750 m	750 m+
Rhizopogon 3	3	11	10	5
Amphinema 1	10	6	2	2
Lactarius quieticolor	1	9	5	2
Suillus luteus	0	2	3	6
Cortinarius 1	3	4	2	0
Suillus lakei	1	4	3	2
Tomentella 1	1	2	2	0
Cortinarius 4	4	0	0	0
Pseudotomentella tristis	0	2	2	0
Leotiomycetes 1	0	1	0	2
Hebeloma 1	2	1	0	0
Hebeloma 2	0	2	0	1
Pyronemataceae 1	3	0	0	0
Rhizopogon 1	0	0	2	0
Melanogaster 1	0	1	1	0
Inocybe 2	0	1	0	1
Inocybe 3	2	0	0	0
Boletus edulis	0	0	1	0
Sebacinaceae 1	0	1	0	0
Tricholoma 1	0	0	1	0
Thelephora terrestris	0	0	1	0
Inocybe 1	0	0	1	0
Cortinarius 2	1	0	0	0
Cortinarius 3	1	0	0	0
Helotiales 7	1	0	0	0
Tomentella 2	1	0	0	0
Russula 1	1	0	0	0

Hayward, Horton, Nuñez, 2015 New Phytologist

OTU	Inside plantations	0–50 m	50–750 m	750 m+
Rhizopogon 3	3	11	10	5
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Suillus lakei	1	4	3	2
Tomentella 1	1	2	2	0
Cortinarius 4	4	0	0	0
Pseudotomentella tristis	0	2	2	0
Leotiomycetes 1	0	1	0	2
Hebeloma 1	2	1	0	0
Hebeloma 2	0	2	0	1
Pyronemataceae 1	3	0	0	0
Rhizopogon 1	0	0	2	0
Melanogaster 1	0	1	1	0
Inocybe 2	0	1	0	1
Inocybe 3	2	0	0	0
Boletus edulis	0	0	1	0
Sebacinaceae 1	0	1	0	0
Tricholoma 1	0	0	1	0
Thelephora terrestris	0	0	1	0
Inocybe 1	0	0	1	0
Cortinarius 2	1	0	0	0
Cortinarius 3	1	0	0	0
Helotiales 7	1	0	0	0
Tomentella 2	1	0	0	0
Russula 1	1	0	0	0

Hayward, Horton, Nunez, 2015 New Phytologist

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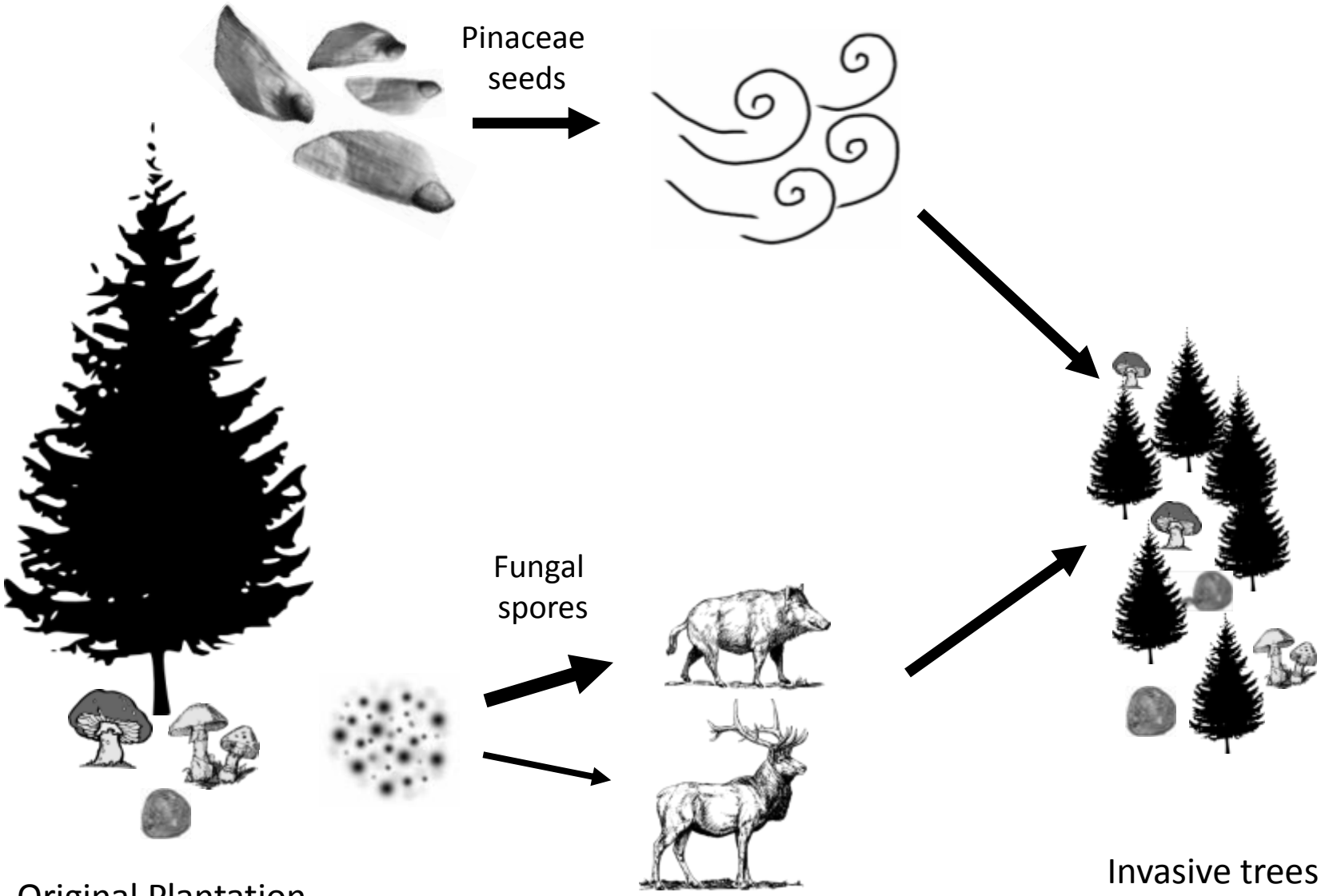
Tomentella 1	1	2	2	0
Cortinarius 4	4	0	0	0
Pseudotomentella tristis	0	2	2	0
Leotiomycetes 1	0	1	0	2
Hebeloma 1	2	1	0	0
Hebeloma 2	0	2	0	1
Pyronemataceae 1	3	0	0	0
Rhizopogon 1	0	0	2	0
Melanogaster 1	0	1	1	0
Inocybe 2	0	1	0	1
Inocybe 3	2	0	0	0
Boletus edulis	0	0	1	0
Sebacinaceae 1	0	1	0	0
Tricholoma 1	0	0	1	0
Thelephora terrestris	0	0	1	0
Inocybe 1	0	0	1	0
Cortinarius 2	1	0	0	0
Cortinarius 3	1	0	0	0
Helotiales 7	1	0	0	0
Tomentella 2	1	0	0	0
Russula 1	1	0	0	0

Rhizopogon sp.*:*



Nuñez et al 2013 PLoS ONE

INVASIONAL MELTDOWN

Invasion of non-pathogenic fungi is a complex phenomena, often ignored and can have very important consequences.

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Invasion of non-pathogenic fungi can be a problem: help invasion of trees, are toxic to humans, decrease local native fungal diversity, and many other not known effects…

Dickie, Nuñez et al 2016

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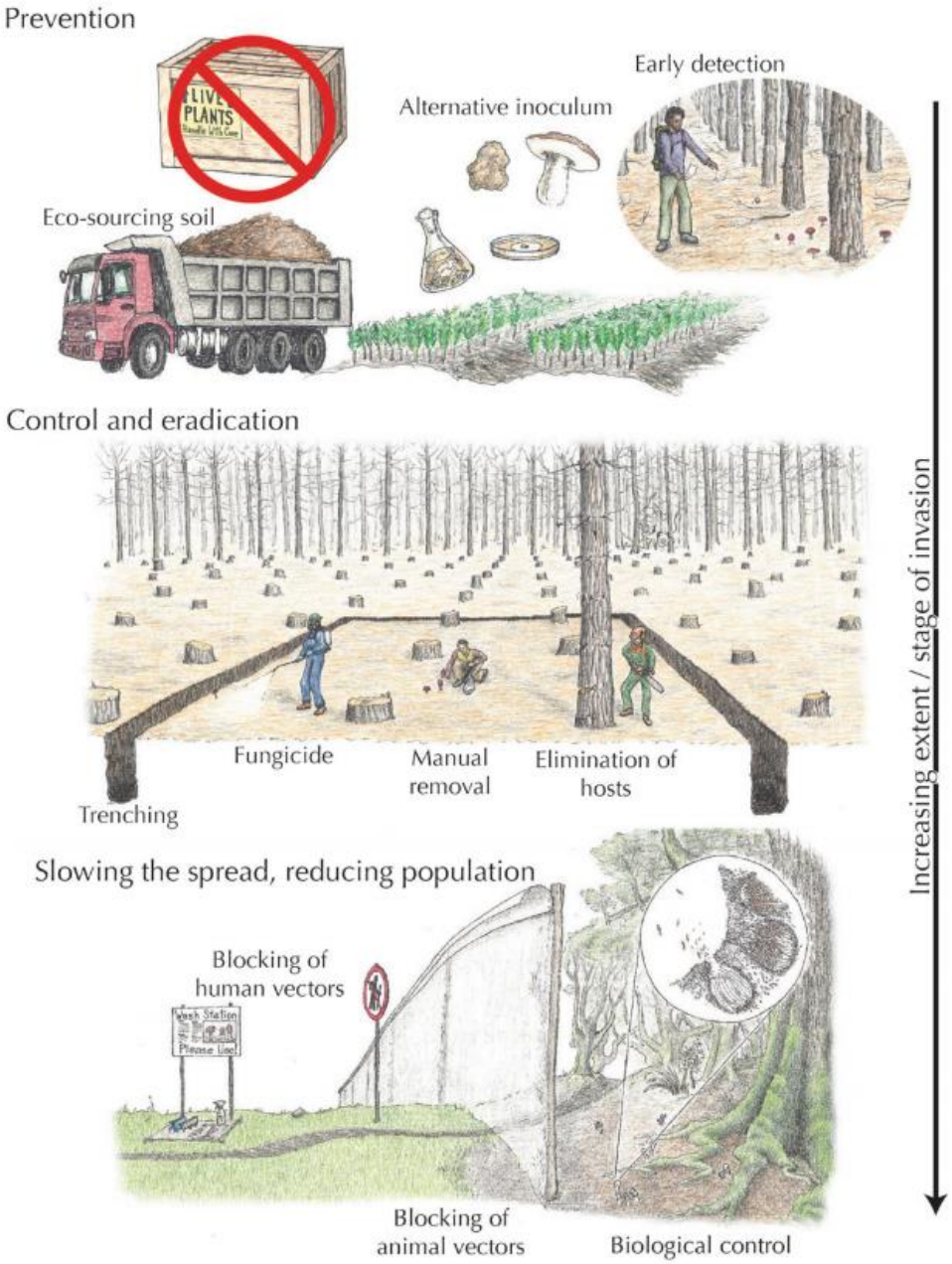
Their control is very difficult once established, there are many alternatives. E.g. native inoculum should be the logical choice for Europe for pinaceaes.



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Thank you!

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- There are ways to minimise the potential impacts of co-invasive mutualists; for example, the introduction of highly invasive non-native soil biota into new areas should be avoided. Also there are some mutualists that mostly spread asexually and seldom produce spores and they could be considered ideal for introduction. As mentioned before, absence of a co-invader may result in limited growth or complete failure of an introduced species, and so in some cases deliberate introduction of a mutualist might be considered desirable. For some introduced tree species that rely mostly on co-invasive mutualists, it could be possible to use native soil symbionts (Moeller et al. 2015), or to minimise introductions of new, non-native symbionts without biosecurity measures (e.g. by restricting movement of soil or trees in pots) Where deliberate introduction of a mutualist is considered, the potential for invasion by the mutualist, and the possible negative effects of that invasion, must be considered. Management of invasive soil biota or the restoration of areas invaded by soil symbionts is a daunting task given their belowground habit, their microscopic size and their ability to persist for long periods (Dickie et al. 2016). Therefore, it is of fundamental importance to control the spread of soil symbionts to avoid the numerous detrimental effects co-invasion can have. Efforts to control the spread of invasive species might be wasted if managers are unaware of co-invasion as a determining factor in whether a plant species becomes invasive or not.

Field experiment

Seedlings grew more near plantation

Inoculation Increases Establishment and Survival

Treatment

Controls

What can disperse these fungi?

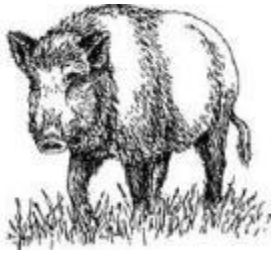
- Wind?
- Rodents are not common around plantations
- Deer and wild boar could be dispersing the fungi…

Exotic deer and pigs

Collected feces from deer and pigs in native forest near plantations
Add 5ml of feces into pots with sterile soil
Plant seeds of *Pseudotsuga menziesii* and *Pinus ponderosa*

Percent of mycorrhizal seedlings

Wild b

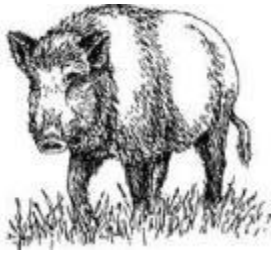


Ponderosa pine	17.5	32.5
Pseudotsuga	15	37.5

Nuñez et al in 2013

Percent of mycorrhizal seedlings

Wild b



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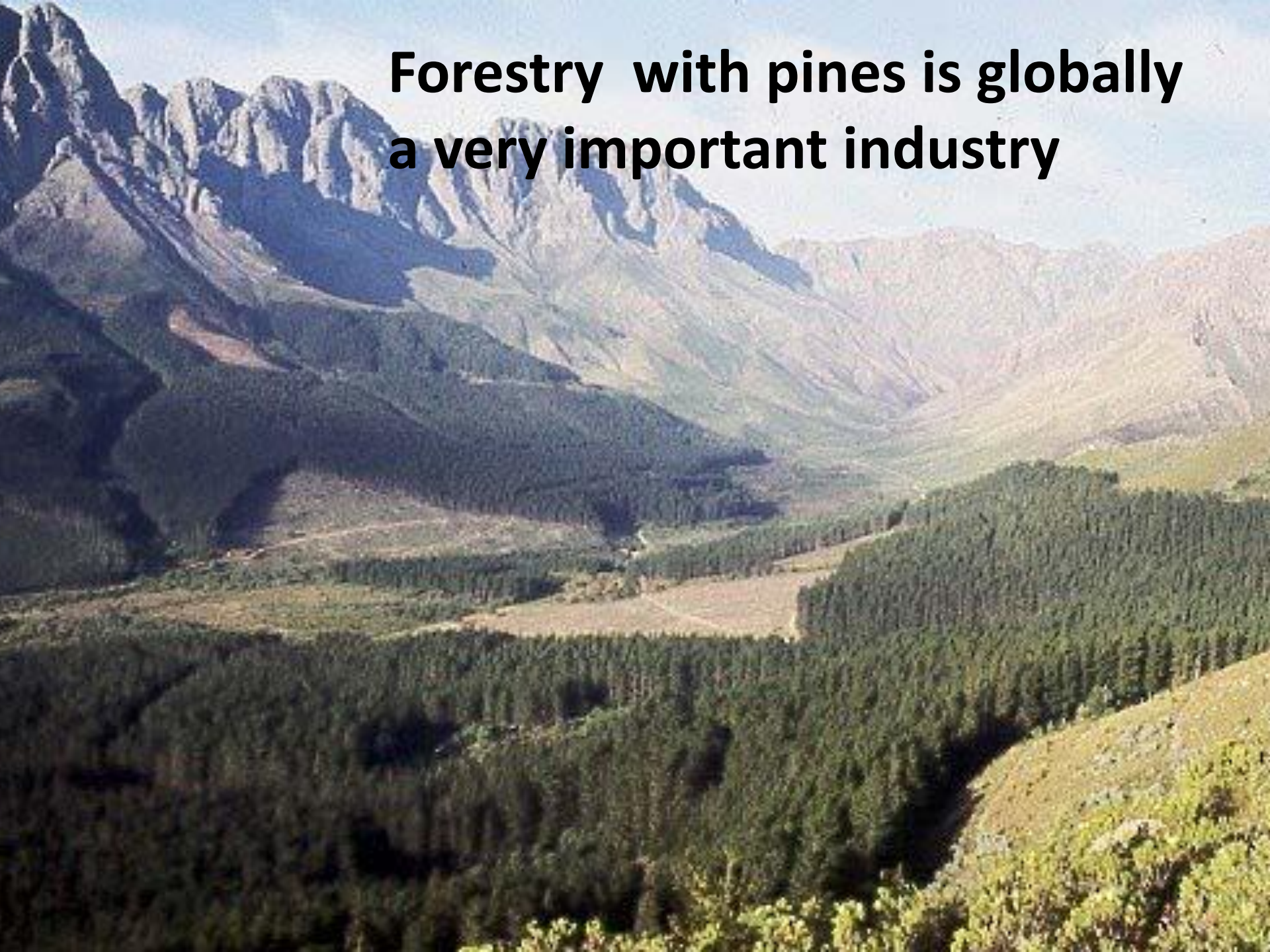
molecular results: Rhizopongon and Suillus are the main species being dispersed

Nuñez et al in 2013


Forestry with pines is globally
a very important industry

Diversity and Distributions, (Diversity Distrib.) (2011) 17, 788–809

BIODIVERSITY REVIEW

Trees and shrubs as invasive alien species – a global review

David M. Richardson[1]* and Marcel Rejmánek[2]

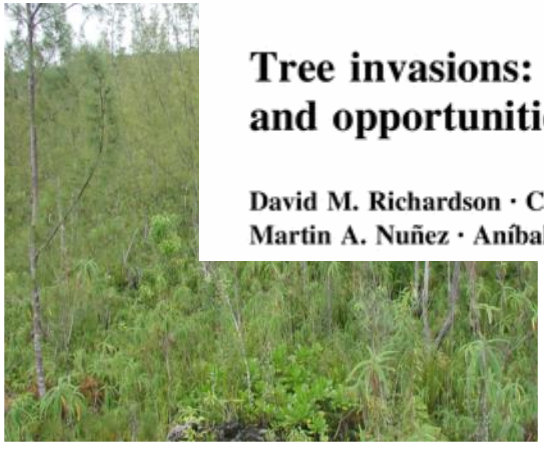
434
tree species

Biol Invasions (2014) 16:473–481
DOI 10.1007/s10530-013-0606-9

ORIGINAL PAPER

Tree invasions: patterns, processes, challenges and opportunities

David M. Richardson · Cang Hui ·
Martin A. Nuñez · Aníbal Pauchard



- Main reasons for introduction of invasive tree species:

- 56% ornamental
- 22% forestry 
- 8% agroforestry
- 5% sand stabilization
- 4% fuel wood

Pine Invasions

- Early seed production
- Small seed size
- Massive seed production
- High seedling growth rates
- Wide climatic tolerance
  - Drought tolerance
  - Freeze tolerance
- Enemy release

… especially in Southern hermisphere…

(Rejmánek & Richardson 1996, Grotkopp et al. 2001, Richardson 2006)