




# Aliens in the Chilean forest

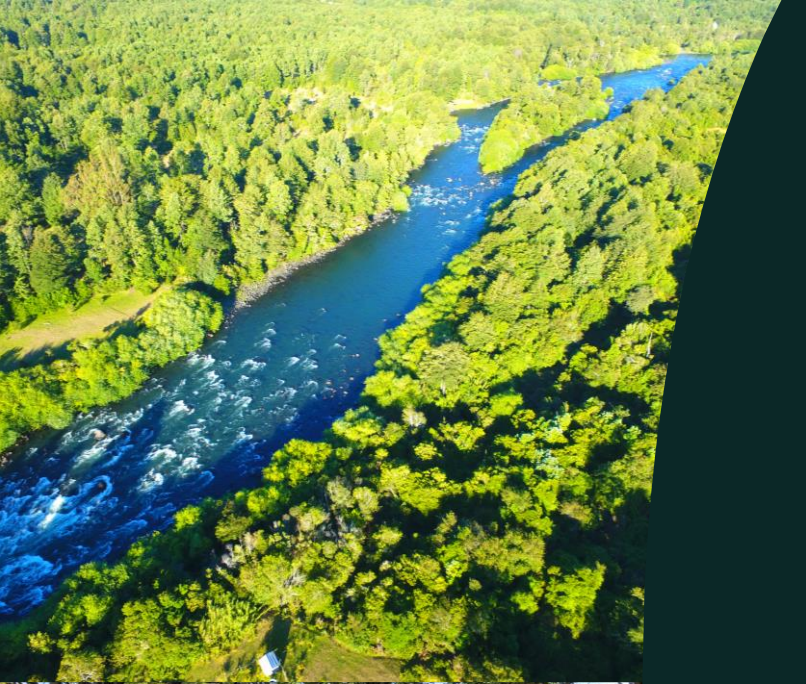
Can timber production be compatible  
with the protection of a biodiversity  
hotspot?

SustainNET webinar 2021



*Pilar Martín Gallego*





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1. The Valdivian temperate forest
2. The forestry industry in Chile
3. The problem
4. Large scale, spatially explicit ecology
5. Using satellite remote sensing
6. Understanding the landscape
7. Forest conservation and forestry sustainability



# The Valdivian temperate forests

- Temperate forests
  - Scarce
  - Large rate of annual forest loss
  - In Chile, less than 11% are protected
- Chile's Valdivian temperate forest ecoregion
  - Isolated
  - Biodiversity hotspot
  - Endemic and culturally relevant *Araucaria araucana* (monkey puzzle tree)
  - Quickly losing habitats
  - Remnants are located in inaccessible areas or are severely degraded by selective logging





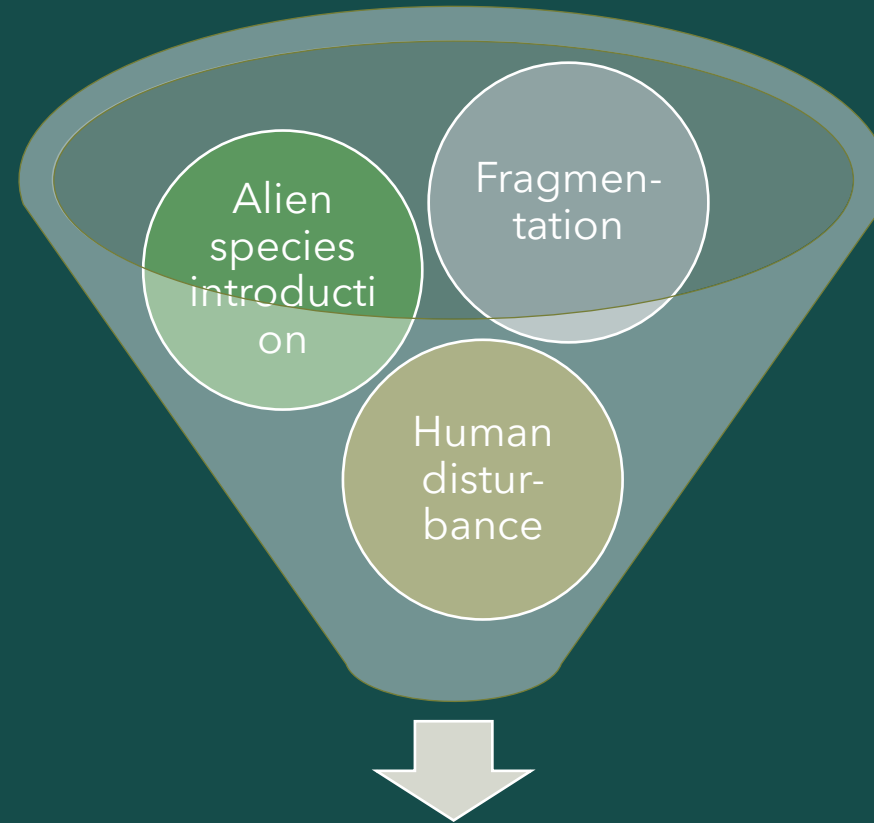
# The forestry industry in Chile

- Boom of the forestry industry – cornerstone of Chile's rapid economic growth
- Large scale expansion of alien (non-native) plantations: Pinaceae and *Eucalyptus* spp.
- Forest subsidies for new productive plantations between 1976 and 2012 – replacement of native forest with alien plantations
- Forestry business model: is it sustainable?
  - Large monoculture plantations: erosion
  - Conversion of native forest: biodiversity, carbon storage
  - Endemic and culturally relevant *Araucaria araucana* forests



# The forestry industry in Chile

- **Alien species** used in forestry are potentially invasive due to their biological characteristics:
  - Easy establishment
  - Fast growth
  - Low shadow tolerance



# The forestry industry in Chile

## CONIFEROUS TREES FROM THE **PINACEAE** FAMILY

- *Pinus contorta*
- *Pinus radiata*
- *Pinus ponderosa*
- *Pinus sylvestris*
- *Pseudotsuga menziesii*  
(shadow tolerant)



## BROADLEAVED TREES FROM THE **EUCALYPTUS** GENUS

- *Eucalyptus globulus*
- *Eucalyptus nitens*



# The problem

Where are the alien trees  
(pines)?





# The problem

Where are the alien trees  
(pines)?







# The problem



Broad scale,  
spatially explicit  
ecological problem





# Using satellite remote sensing

- Understand alien tree invasions a different spatial scales
- Inform forest and conservation management
- Improve the sustainability of the forestry sector



[ontheworldmap.com/chile/chile-political-map.html](http://ontheworldmap.com/chile/chile-political-map.html)



[regiondelaaraucaniaix.blogspot.com/2011/12/mapa-fisico-de-la-region-de-la.html](http://regiondelaaraucaniaix.blogspot.com/2011/12/mapa-fisico-de-la-region-de-la.html)

# Using satellite remote sensing



Sentinel-2

Broad scale alien tree map and model of alien tree spatial distribution



Landsat

Broad scale change analysis: alien tree spread and native forest loss



WorldView-3

Local scale map and early invasion pattern





# Using satellite remote sensing



## Sentinel-2

*Detecting and modelling alien tree presence using Sentinel-2 satellite imagery in Chile's temperate forests*

- Multi season + elevation composites
- Supervised random forest classification (R)
- Landscape metrics (Fragstats)
- Random forest model of *Pinaceae* mean patch area



## Landsat

*Mapping the dynamics of alien plantation spread and native forest loss in Chile using Landsat time series analysis and Google Earth Engine*

- Multi season + elevation composites using image collections (Google Earth Engine (GEE))
- Supervised random forest classification (GEE)
- Land cover change: post-classification comparison



## WorldView-3

*Monitoring alien invasive 'Pinaceae' in Chilean temperate forests using object-based image analysis of WorldView-3 imagery*

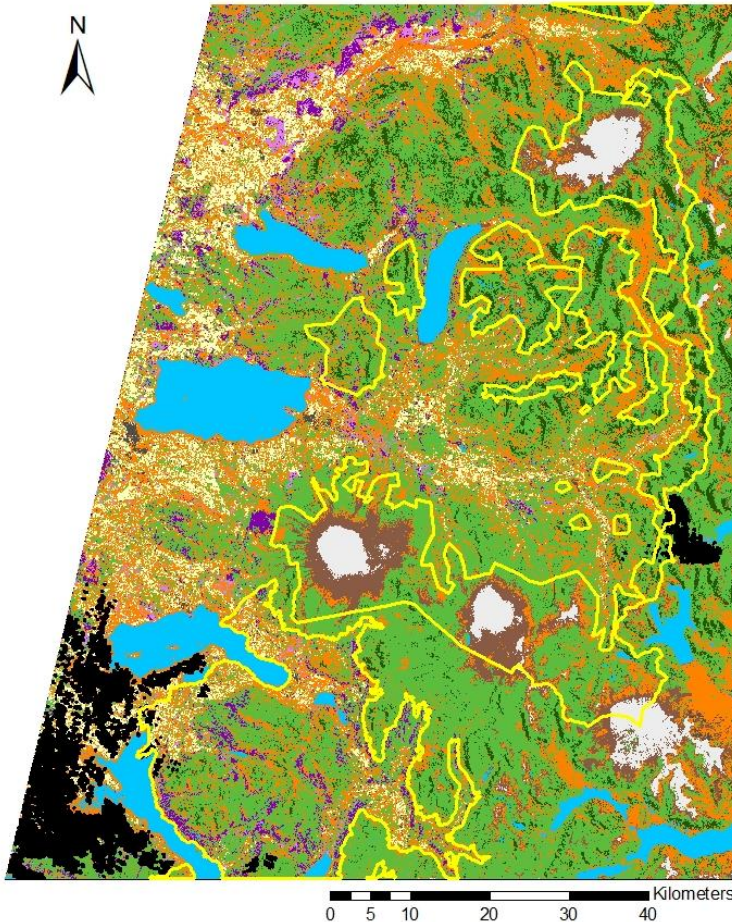
- Very high resolution imagery
- Object-based supervised random forests classification (GEE)
- Landscape structure

# Using satellite remote sensing

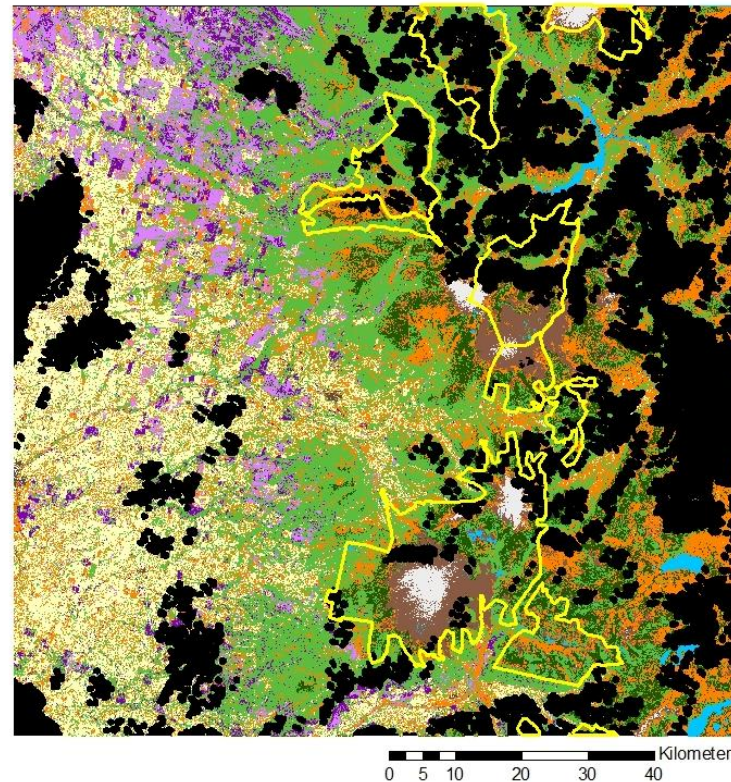
## Can it map invasion? Where are the alien pines? - broad scale

- Moderate resolution imagery (Sentinel-2, Landsat) is useful for broad scale monitoring of deforestation and conversion to alien stands.

VILLARRICA



MALALCAHUELLO



Random forests classifications of Sentinel-2 multi-season + DEM composites.

### Elevation pattern:

- A. araucana* at high elevations
- Pinaceae distribution

Pinaceae km <sup>2</sup>		
	Malal	Villa
Total	343	236
Low	268	147
High	75	90
Parks	4	82



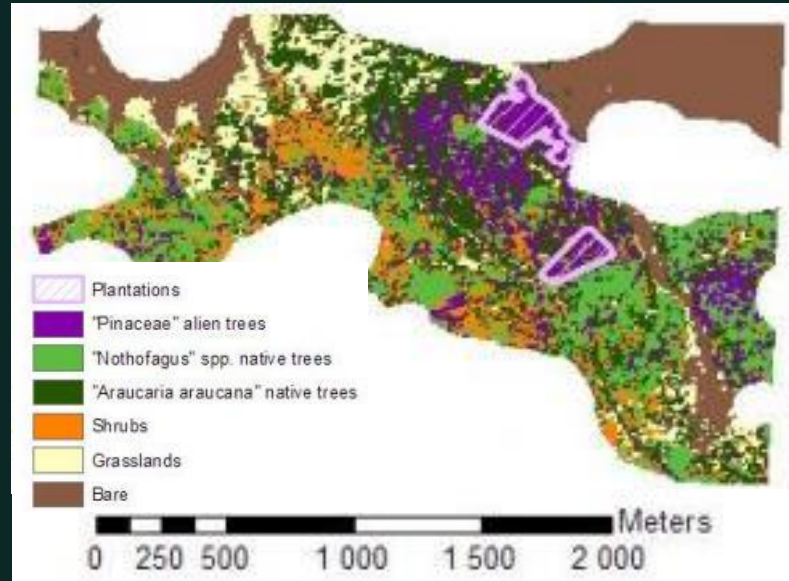
# Using satellite remote sensing

## Can it map invasion? Where are the alien pines? - fine scale

- Very high resolution (VHR) imagery (WorldView-3) can detect early invasion.



### MALALCAHUELLO



Object-based supervised random forests classification of WorldView-3 imagery.

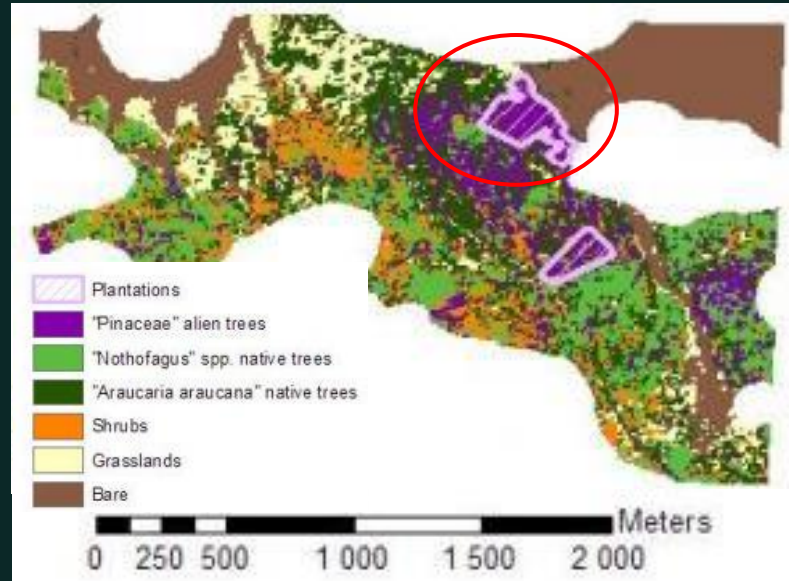
# Using satellite remote sensing

## Can it map invasion? Where are the alien pines? - fine scale

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MALALCAHUELLO



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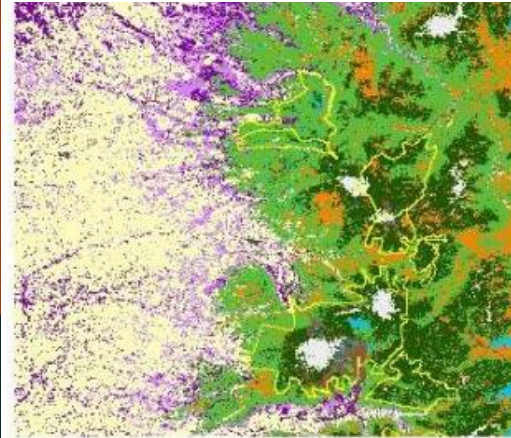
# Using satellite remote sensing

## Where are the alien pines? - Change

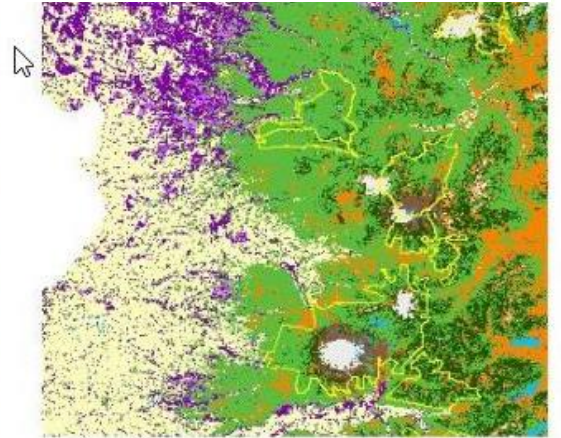
- High dynamism of forest classes.
- Socioeconomic factors greatly impact landscape configuration.
- The end of forest subsidies in 2012 marked an inflection point in land change dynamics. Smallholders shifted to short rotation forestry (alien *Eucalyptus* spp. and native *Nothofagus* spp.).

MALALCAHUJELLO

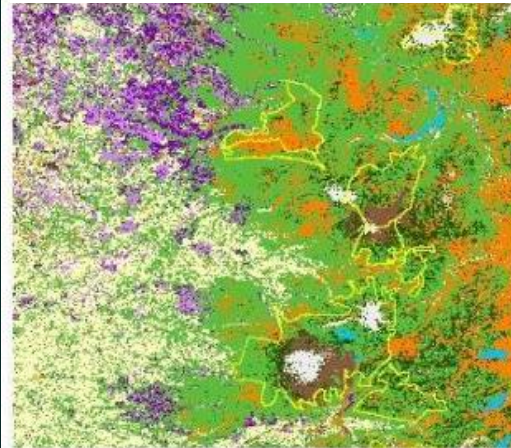
1980s



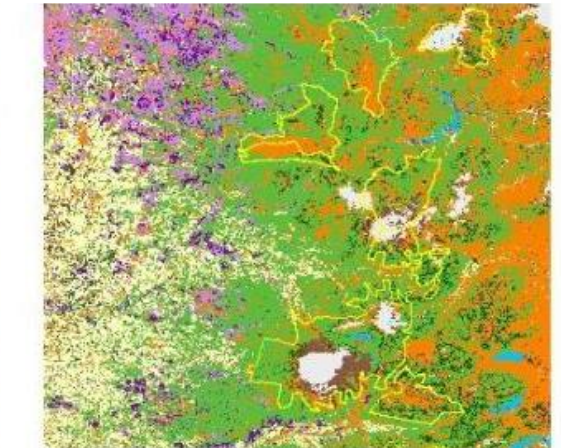
1990s



2000s



2010s

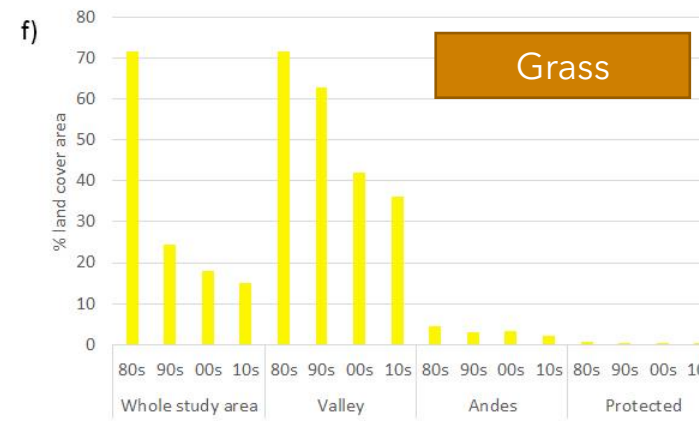
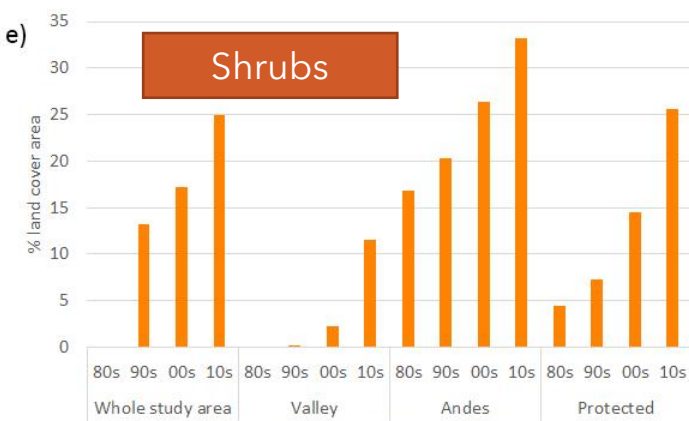
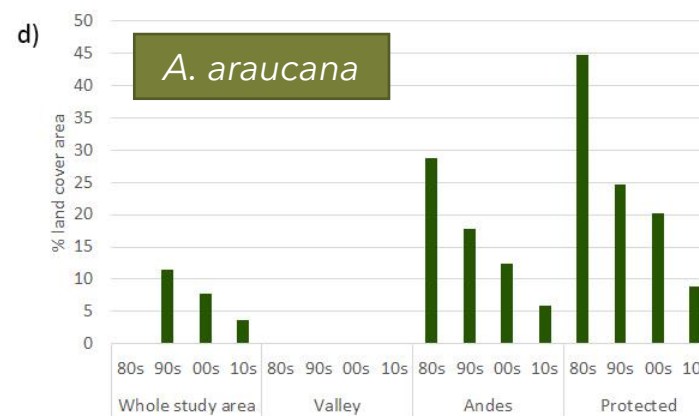
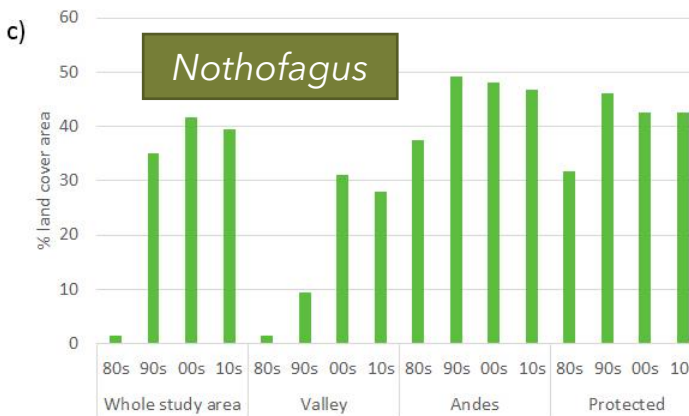
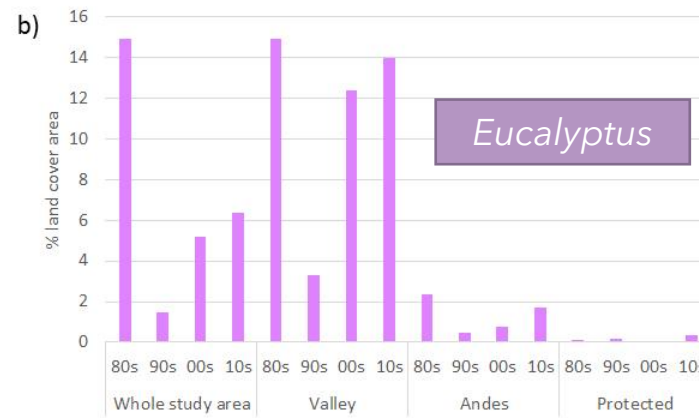
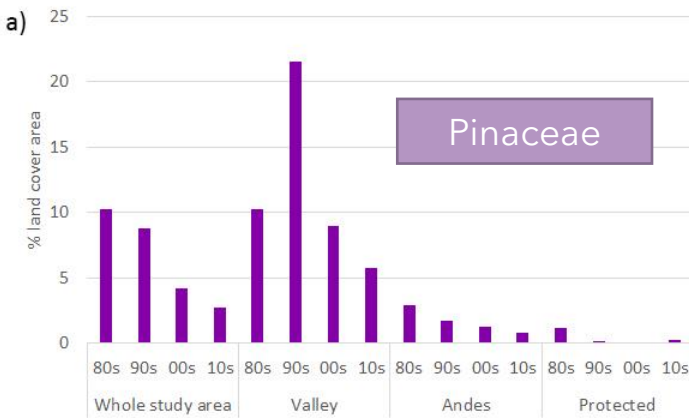


0 5 10 20 30 40 Kilometers

# Using satellite remote sensing

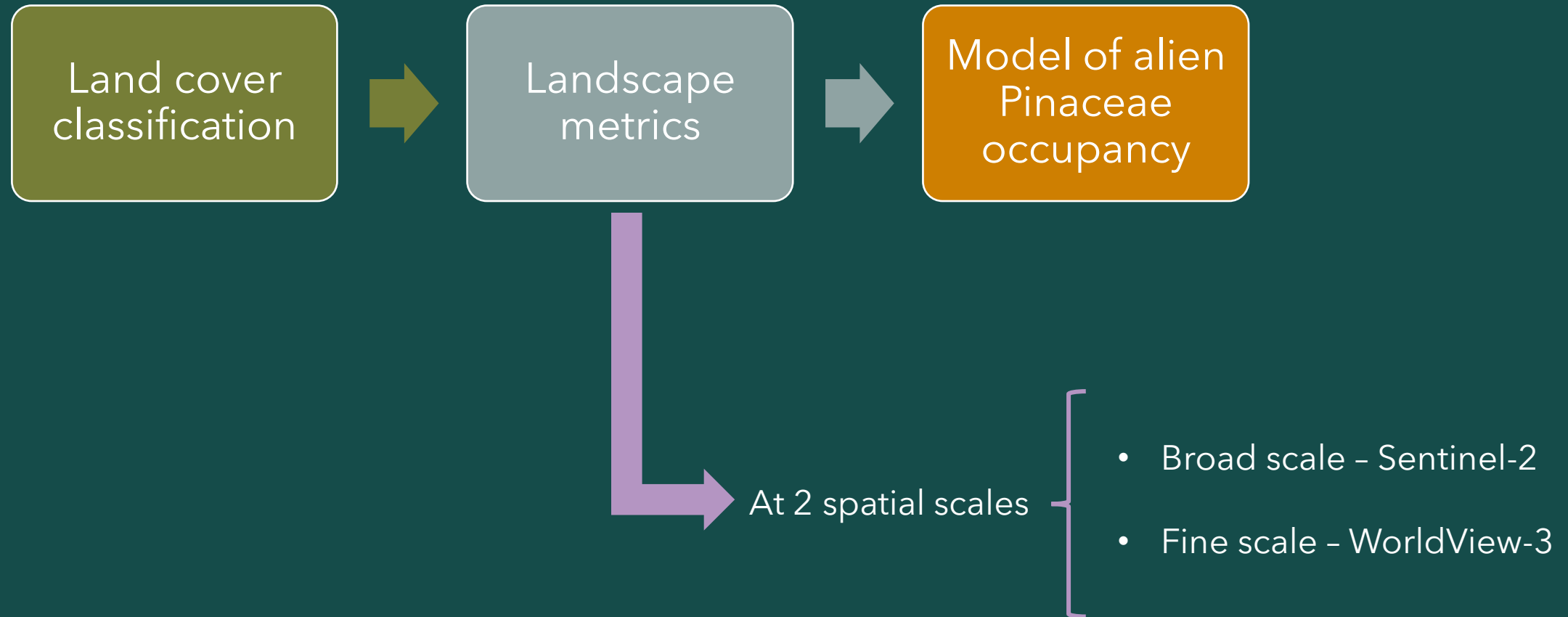
## Where are the alien pines? - Change

- Deforestation of *A. araucana* forests
- Shrub encroachment





# Understanding the landscape





# Understanding the landscape

## Landscape metrics

- To assess forest distribution and fragmentation
- Robust fragmentation index: correlated with aggregation, but not with abundance

Interpreting the combined results to understand the landscape.



# Understanding the landscape

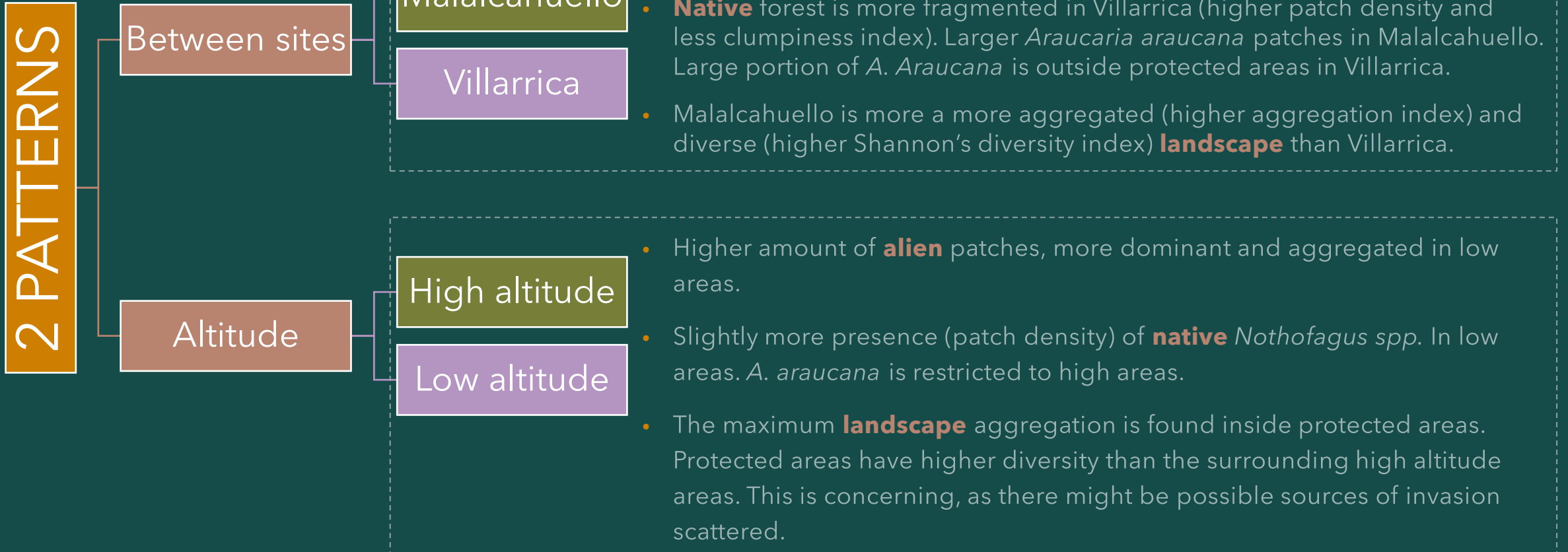
## Selected metrics (Fragstats)

- **Landscape level:**
  - Aggregation index (AI): overall landscape aggregation/connectivity and fragmentation
  - Shannon's diversity index (SHDI): land cover diversity
- **Class level:**
  - Patch density (PD): class fragmentation
  - Mean patch area (AREA\_MN): class fragmentation
  - Largest patch index (LPI): class dominance
  - Perimeter area fractal dimension (PAFRAC): shape complexity. Robust fragmentation index according to literature.
  - Clumpiness index (CLUMPY): class aggregation

Interpreting the combined results to understand the landscape.

# Understanding the landscape

## Broad scale – Sentinel-2

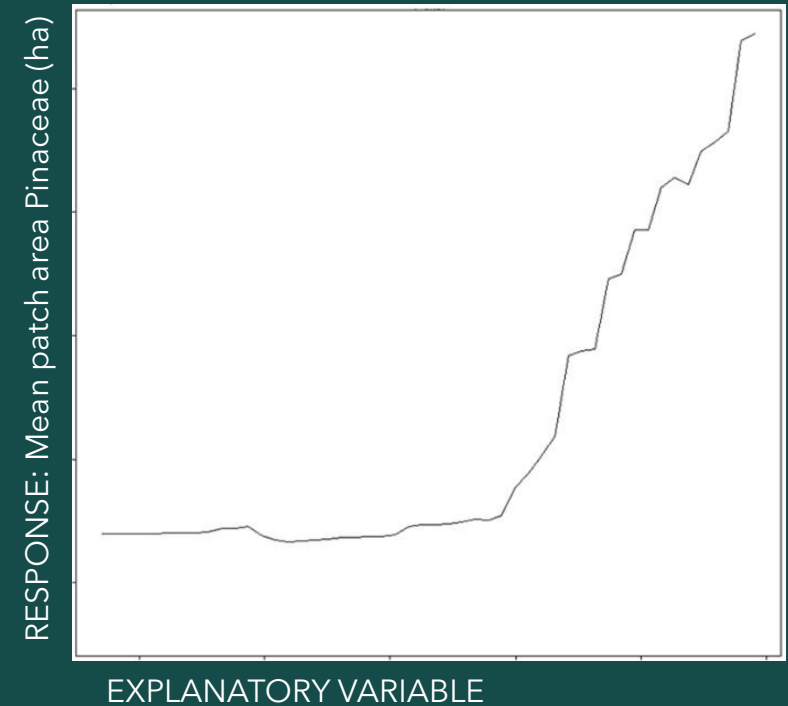




# Understanding the landscape

## Broad scale – Sentinel-2

- **Random forest model** of Pinaceae area
  - Response variable: **Pinaceae mean patch area**
  - Explanatory (predictor) variables: landscape metrics and different geographical parameters (**27 variables**)
  - Iterative method: stepwise removal of explanatory variables
- Random forests algorithm can be used for classification and prediction

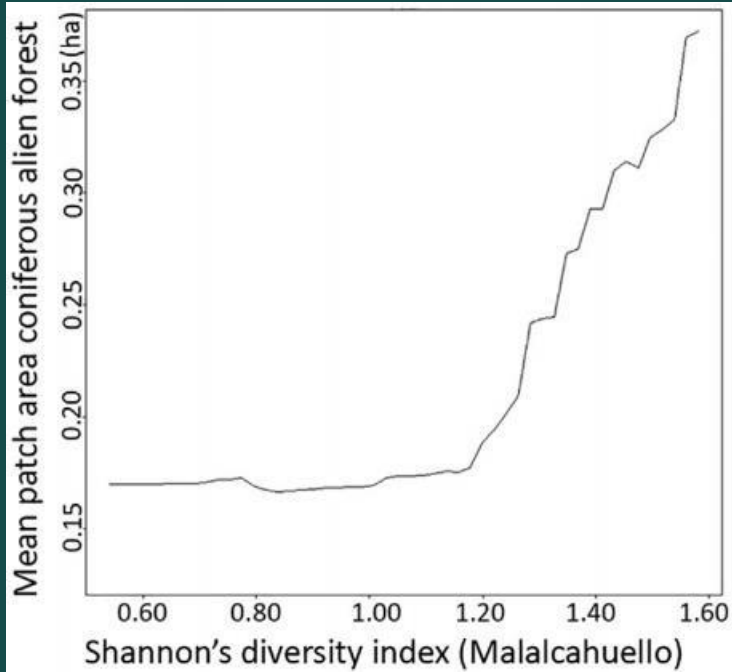


**Partial dependence plots:**  
effect that a variable has on the predicted outcome of the model.

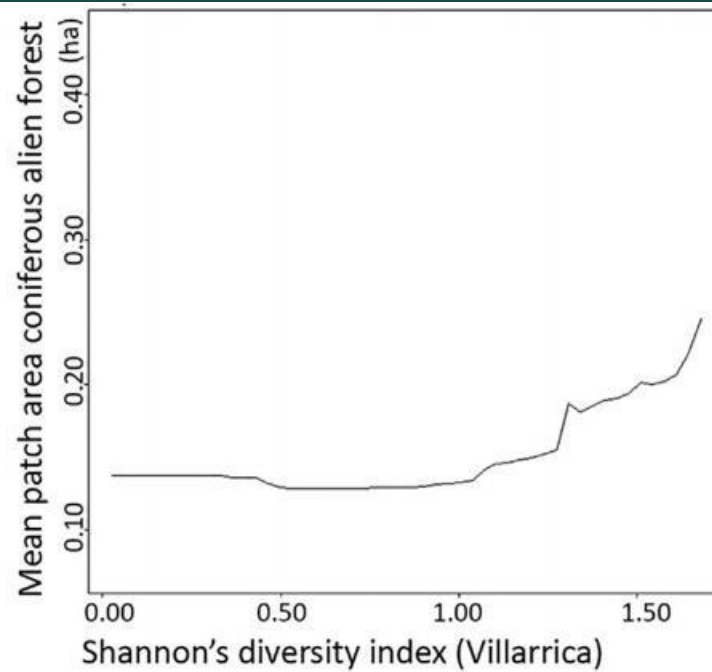
# Understanding the landscape

## Broad scale – Sentinel-2

### SHANNON'S DIVERSITY INDEX



**Malcalahuello**



**Villarrica**

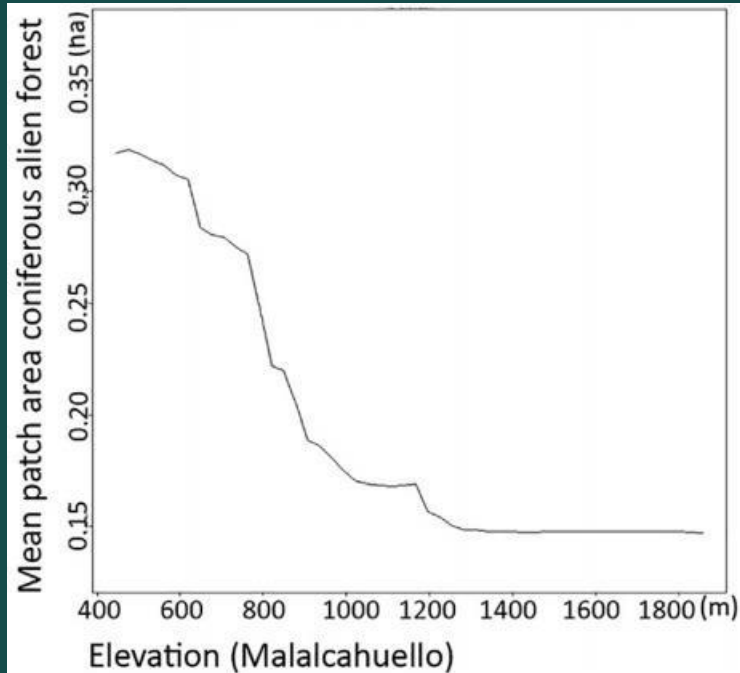
An increase in SHDI is a sign of a more diverse and potentially fragmented landscape.



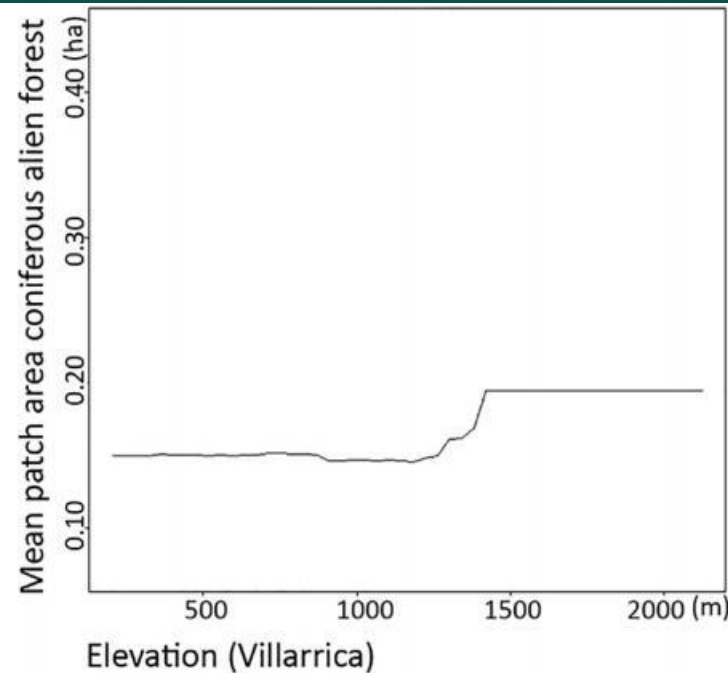
# Understanding the landscape

## Broad scale – Sentinel-2

### ELEVATION



Malalcahuello



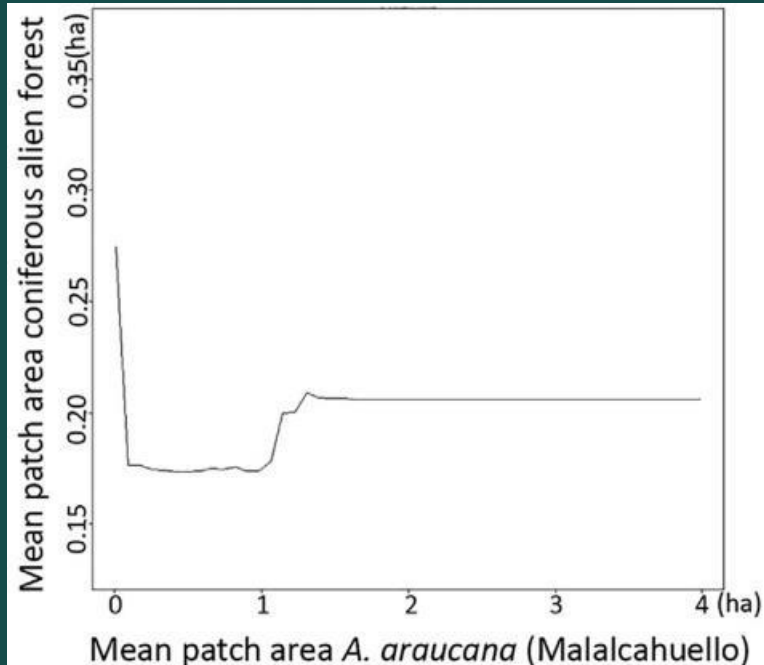
Villarrica

Productive plantations tend to be located in low, accessible areas in Malalcahuello, where the main economic activities are forestry and farming.

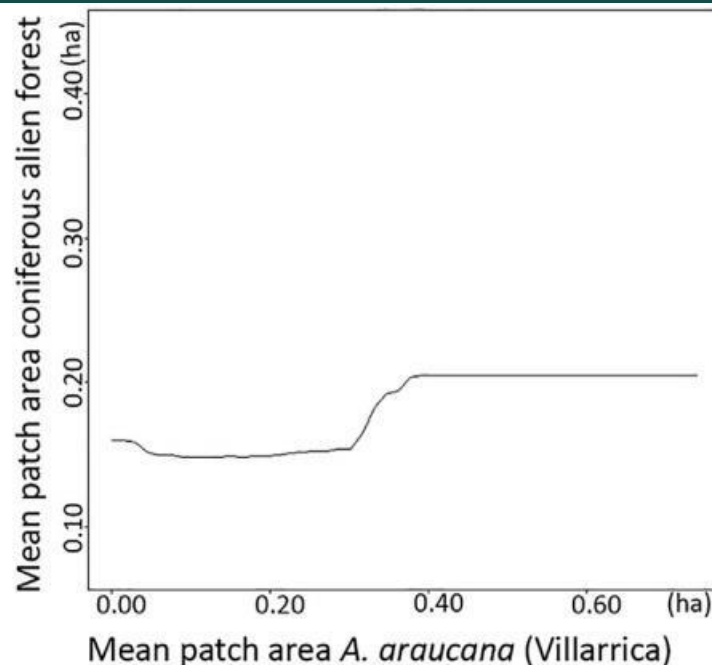
# Understanding the landscape

## Broad scale – Sentinel-2

### MEAN PATCH AREA *A. araucana*



**Malalcahuello**



**Villarrica**



The openness of the native forest constitutes an ideal environment for heliophytes like Pinaceae to colonise.

Threat for *A. araucana* regeneration.

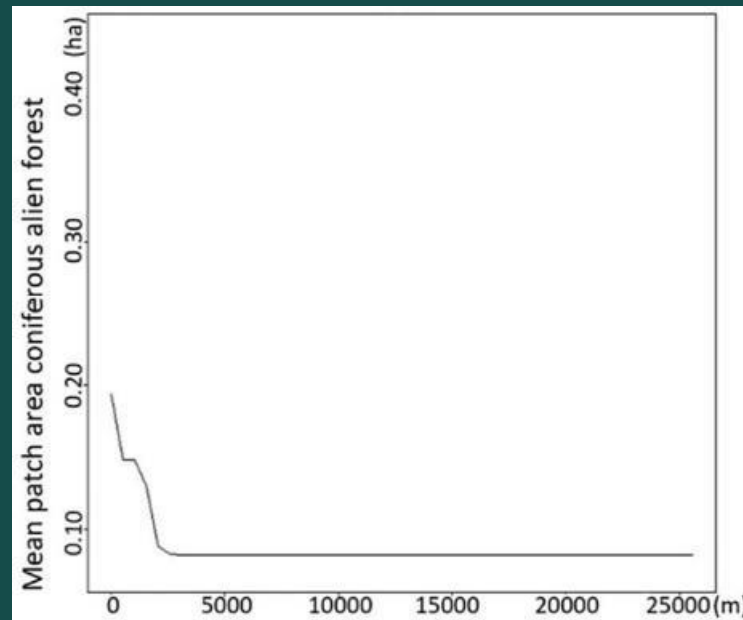




# Understanding the landscape

## Broad scale – Sentinel-2

Villarrica



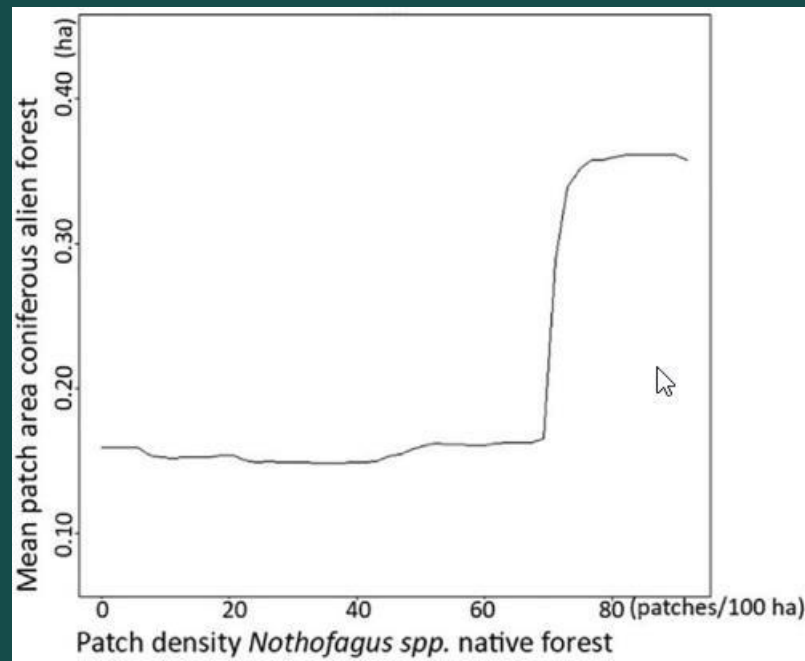
Distance to nearest Pinaceae patch

Distance to seed sources theory is confirmed. Invasion.

# Understanding the landscape

## Broad scale – Sentinel-2

Villarrica



Patch density of *Nothofagus* spp. native forest

Very sharp increase in alien Pinaceae with higher patch density of native *Nothofagus* spp. This did not occur for LPI or AREA\_MN of *Nothofagus* spp. Fragmentation, and not habitat loss, plays a role in the presence of alien species.

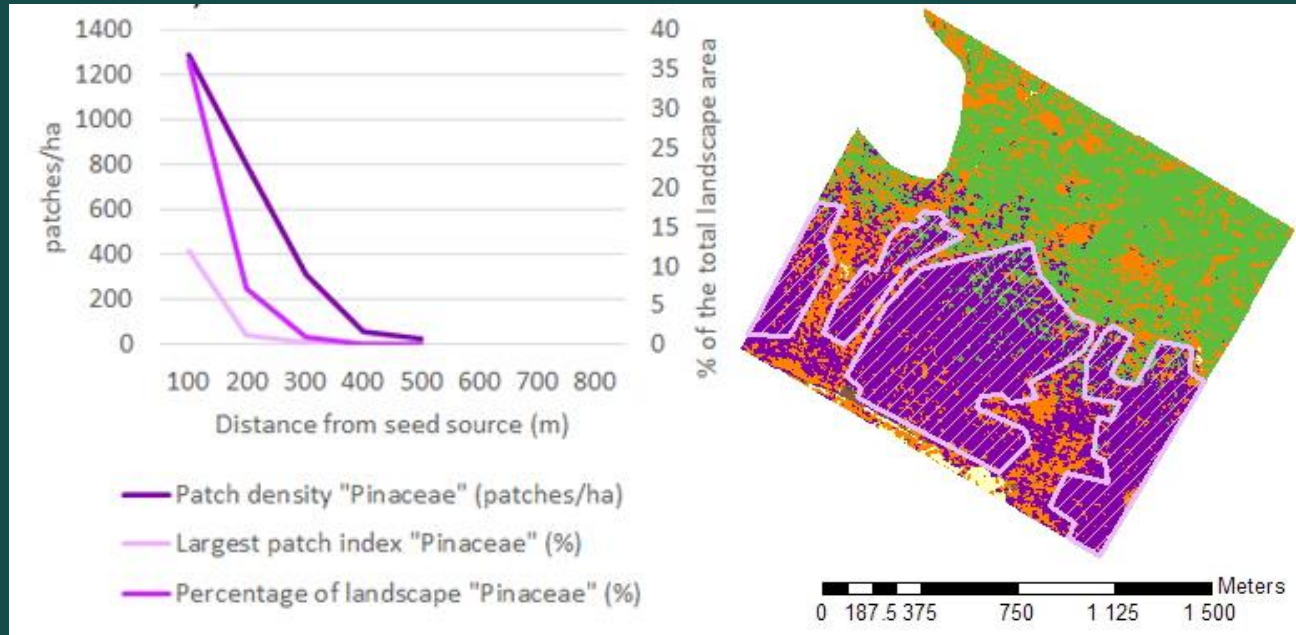


# Understanding the landscape

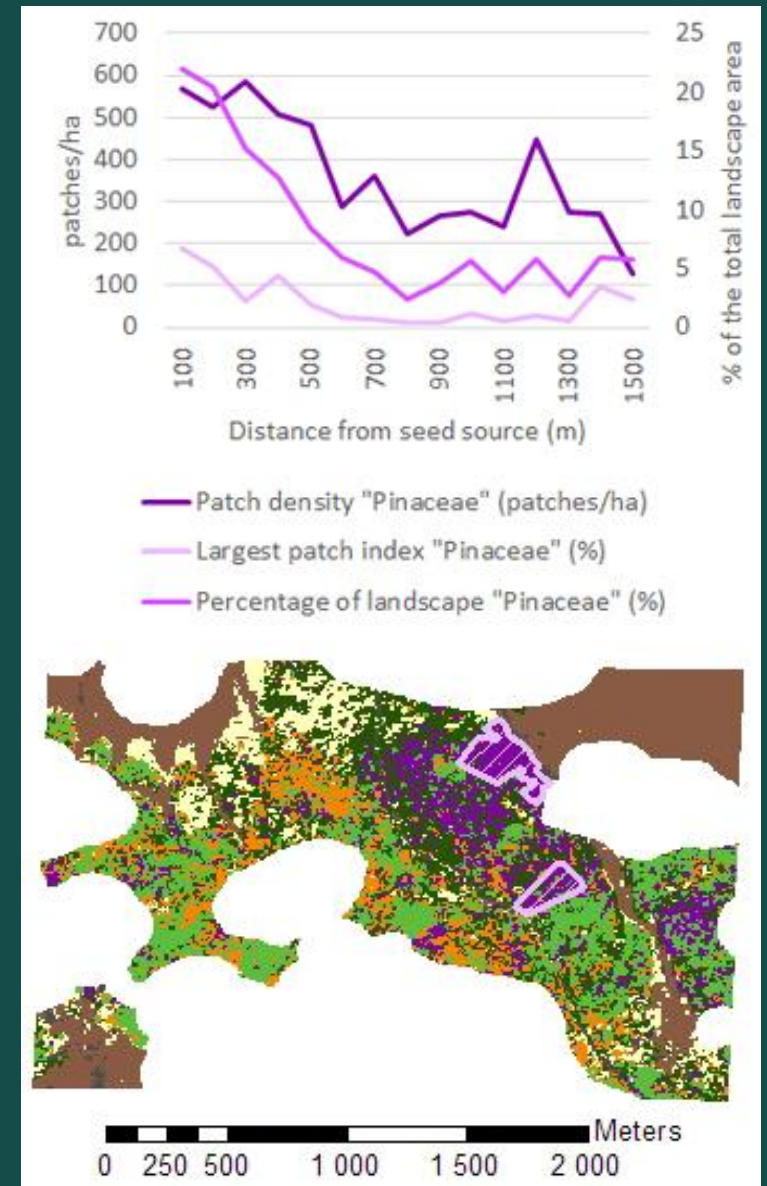
## Fine scale – WorldView-3

- Early Pinaceae invasion is linked to seed source distance (widespread invasion hypothesis)

### Villarrica



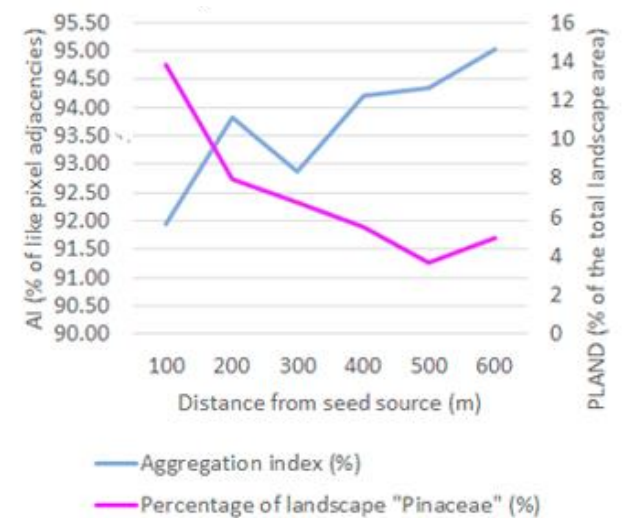
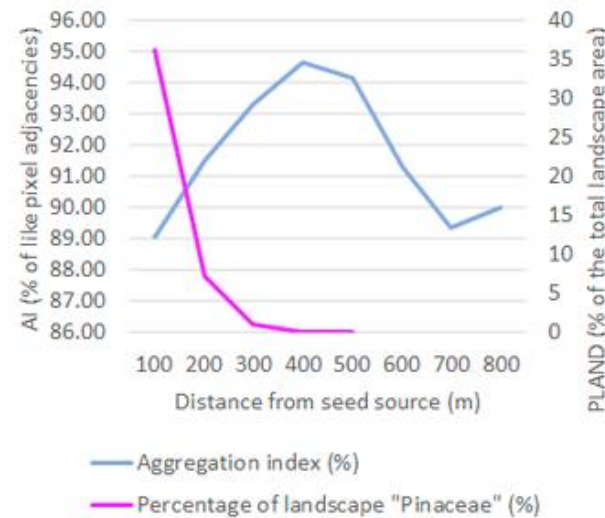
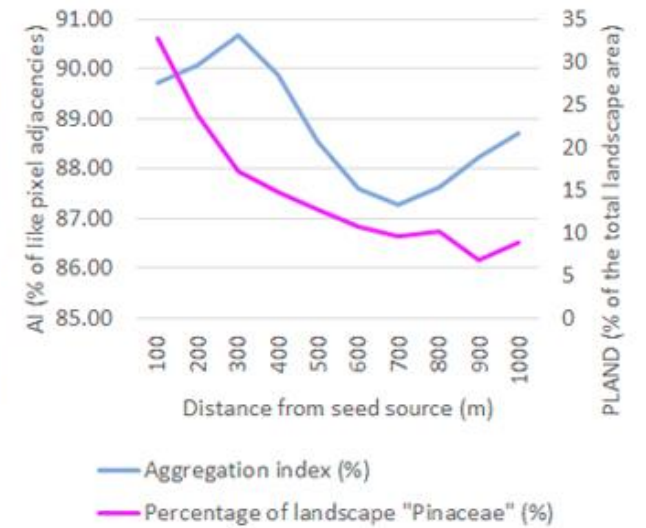
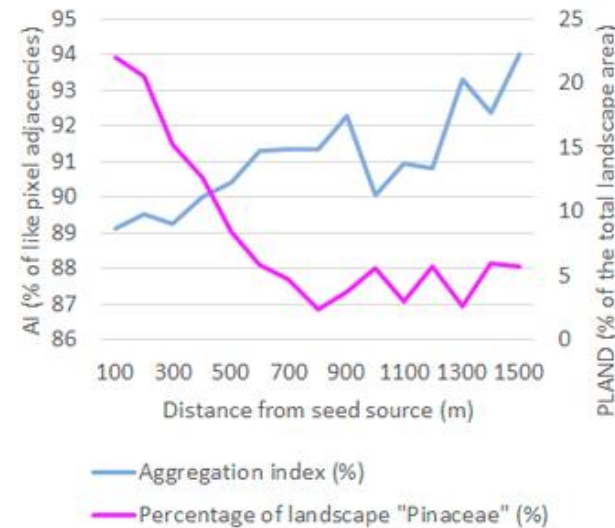
### Malalcahuello



# Understanding the landscape

## Fine scale – WorldView-3

Early Pinaceae invasion is linked to fragmentation.





# Forest conservation and forestry sustainability

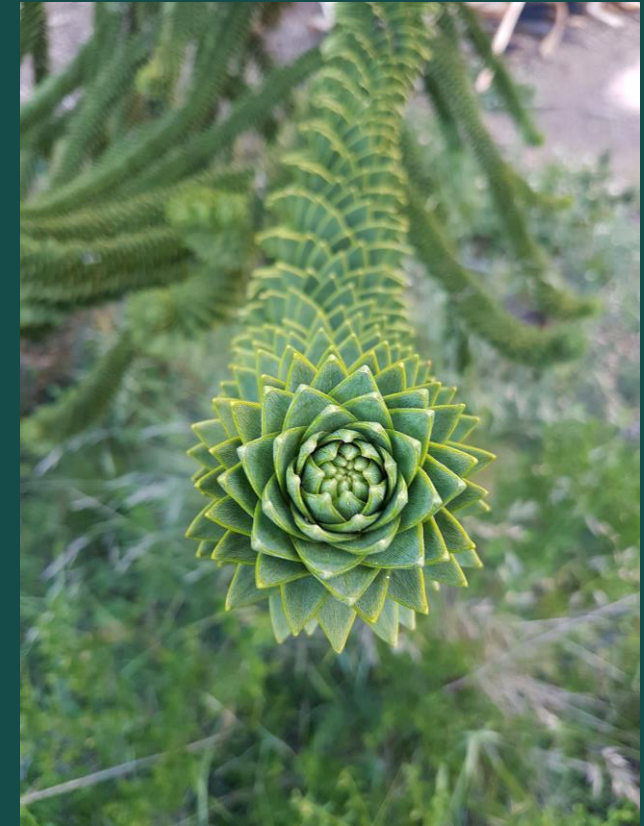
- Protected areas:
  - Only 11.7% of the Valdivian temperate forest is protected.
  - Most of the protected areas are located at high elevations, failing to protect all the variability of forests such as *Nothofagus* spp. forests.
  - Relatively high fragmentation and presence of alien Pinaceae within protected areas.
  - Large proportion of *A. araucana* outside protected areas.





# Forest conservation and forestry sustainability

- General recommendations:
  - Reconsider protected area boundaries.
  - Use remote sensing data to improve the selection of new areas for protection.



# Forest conservation and forestry sustainability

## ZONES WITHIN PROTECTED AREAS

- **Intangible zone:** Unique, fragile, and relatively pristine ecosystems. Only scientific and conservation activities. No vehicles.
- **Primitive zone:** Minimal human disturbance. Low intensity public use. No vehicles.
- **Restoration zone:** Degraded areas or areas with alien species. Requires specific management.
- **Public use zone:** Landscape beauty. Recreational resources. Dense use. Vehicles allowed.
- **Resource management zone:** Sustainable extractive activities are allowed.

## MANAGEMENT RECOMMENDATIONS

- There are Pinaceae trees within intangible and primitive zones. These areas should be included in the restoration zone for active management and eradication.
- Gradual removal of Pinaceae through selective thinning. Subsequent native species reforestation. Clearcuttings must not be used to avoid erosion and alteration of the hydrological regime.
- Resource management zones are sometimes adjacent to primitive or intangible zones. There should be a buffer or transitional area to avoid spread from Pinaceae seed sources.



# Final thoughts

- *Pinaceae* invasions into *A. araucana* forests.
- Long term regeneration of endemic *A. araucana* is compromised.
- Native forest degradation, fragmentation. → Shrub encroachment, alien invasion.
- Protected area management: Eradication, buffer zones, reconsideration of boundaries.

