

Monitoring of forest restoration: A review of approaches and strategies for global assessment

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Context



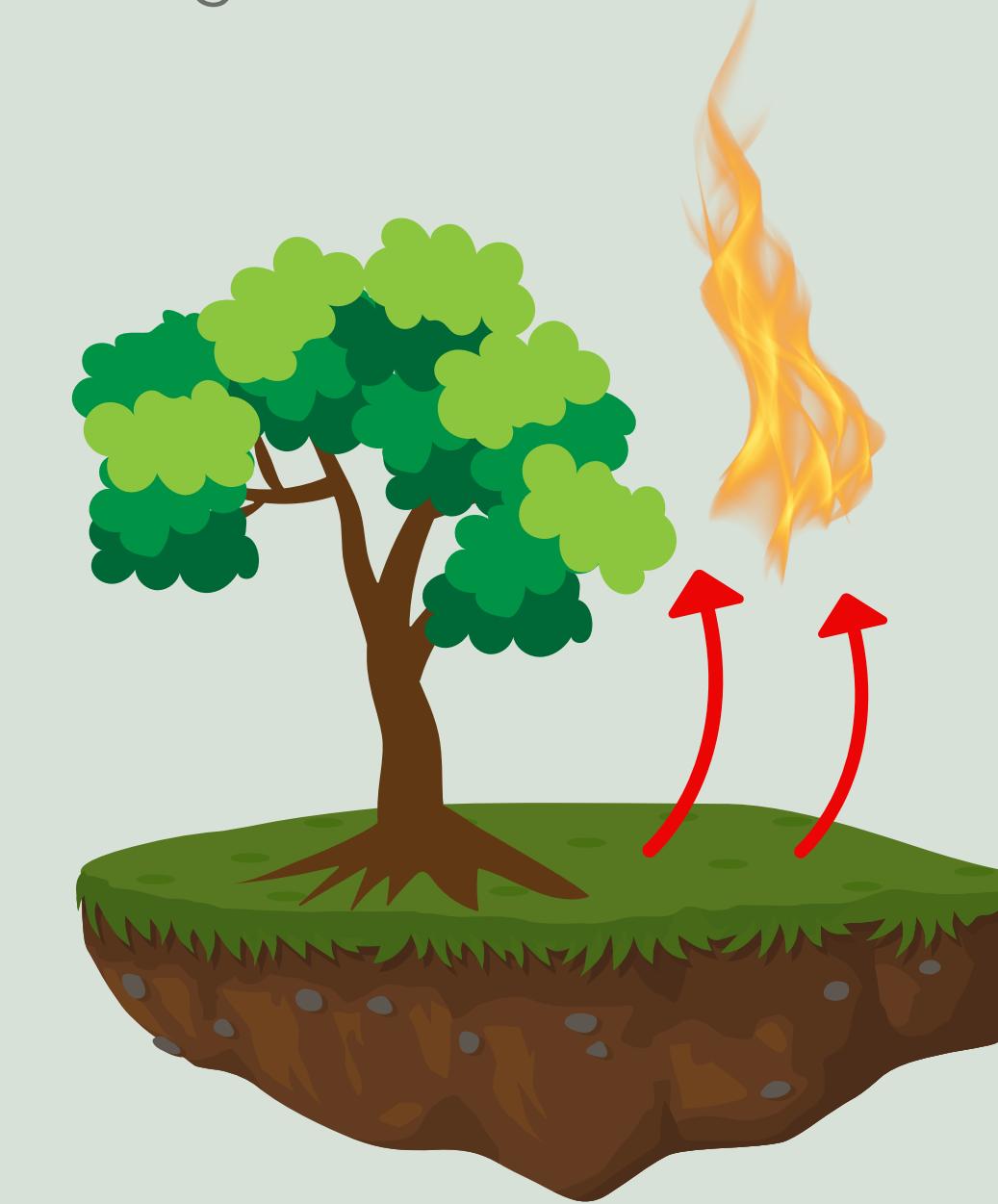
Urgency of Restoration

Degraded areas



Global Importance of Forests

Forests are crucial



Climate change intensifies disturbances



Identify the number of monitoring studies that discuss or apply their results to ecological restoration.

Identify the most widely used tools in the restoration monitoring process.

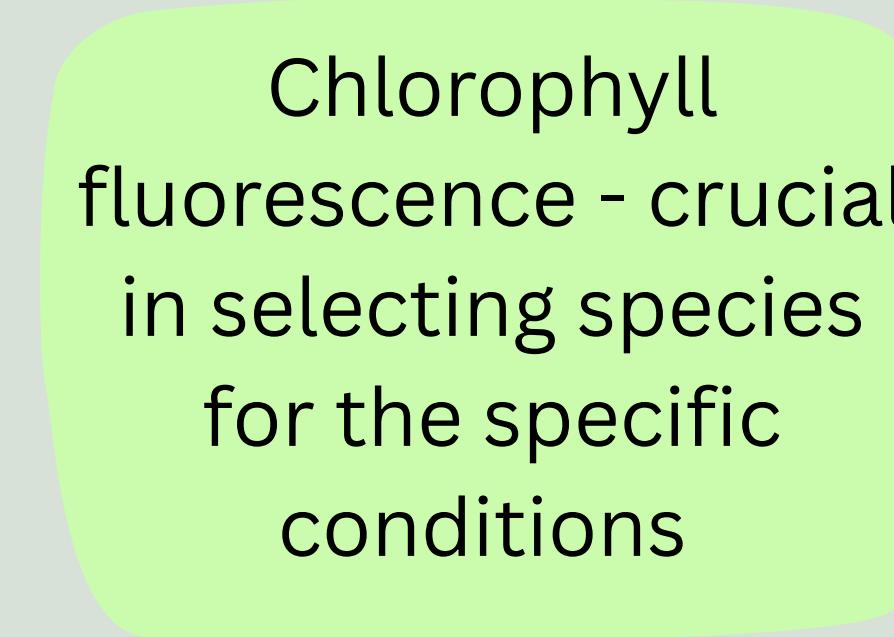
Identify the key parameters most frequently used for monitoring species in forest restoration projects.

Survival rate assessment



key element in
measuring long-term
forest restoration
success

Monitoring plant stress



Chlorophyll
fluorescence - crucial
in selecting species
for the specific
conditions

Search platforms and keywords

Period: Studies from 1995 to 2024 were reviewed.

ScienceDirect

Scopus®

Web of Science™

"Forest restoration" OR "forestry restoration" OR "success restoration" OR "restoration ecology")
AND ("monitor" OR "evaluation") AND ("forest" OR tree)

Restoration monitoring:

- Seedling planting
- Direct seedling
- Natural regeneration
- in situ - remote sensing tools

Inclusion Criteria

- Fauna
- Abiotic components
- Ecosystem services
- Economic/planning aspects
- Reviews

Exclusion Criteria

Total Studies: 2.956 initial studies, 380 were included in this review.

Selection of Studies

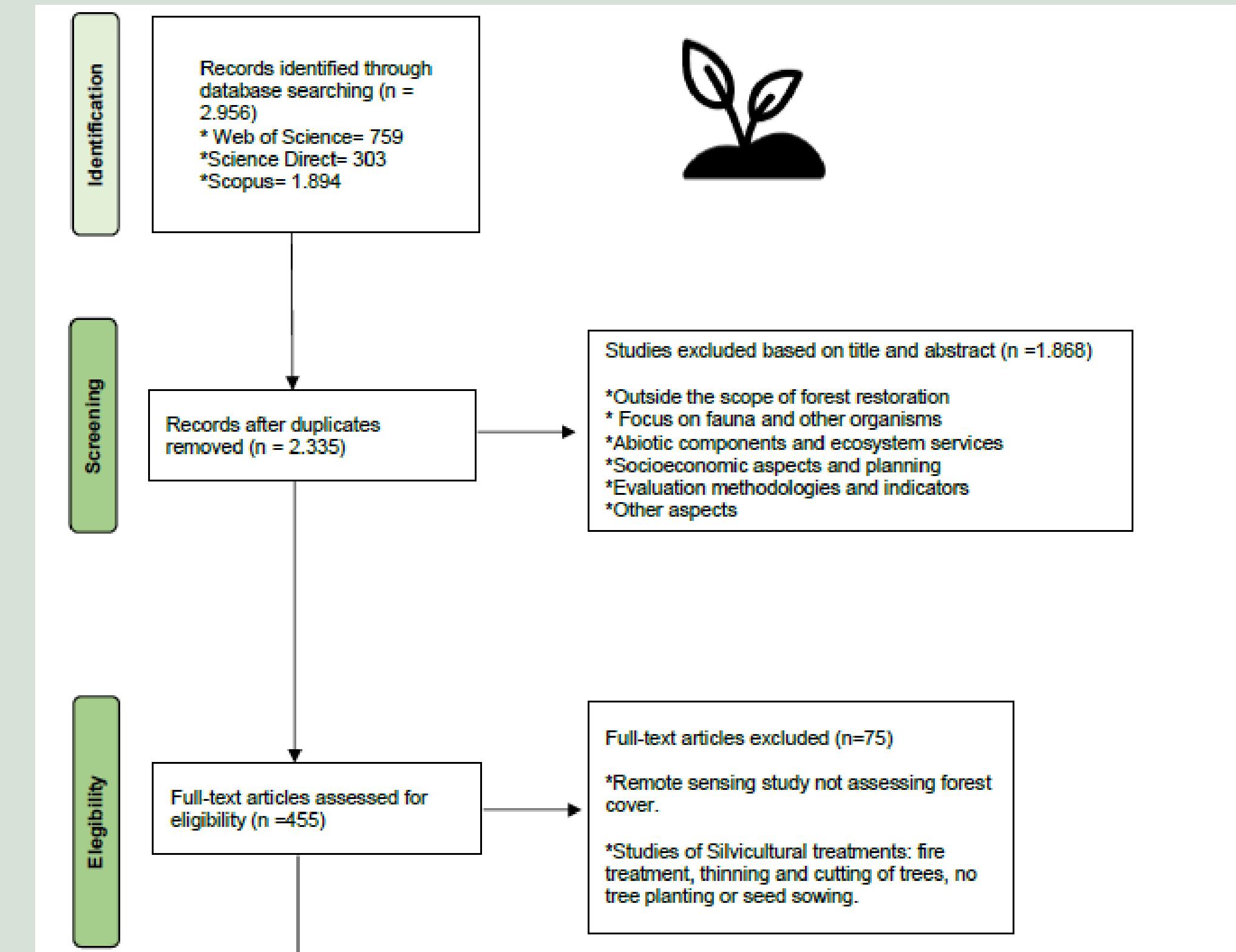
Parsif.al program
(Parsifal Ltd. 2018)

Screening Process=2.956

Initial review based on titles
and abstracts

Automatic identification of
duplicate studies = 2.335

Full reading of selected
studies relevant to the topic
(1868)



Indicators

(1) Type of disturbance: Agricultural and livestock activities, deforestation and land-use change, invasive species and pests, fires and fire management, forest management and silviculture, climate change and extreme natural events, pollution and waste, and urbanization and infrastructure.

(2) Restoration technique: Natural, Seedling planting, and Direct seeding

(3) Cultural treatments: Application of hydrogel, nutrients, and soil amendments prior to tree planting or seed sowing.

(4) Survival: If survival data was reported.

(5) Level of organization: Population, community, and ecosystem

(6) Ontogenetic stage: young, adult, in addition to indicating studies that evaluated natural regeneration

(7) Species information

(8) Number of species evaluated: The following ranges were created: 1–10, 11–20, 21–30, 31–40, 41–50, and >50 years-old.

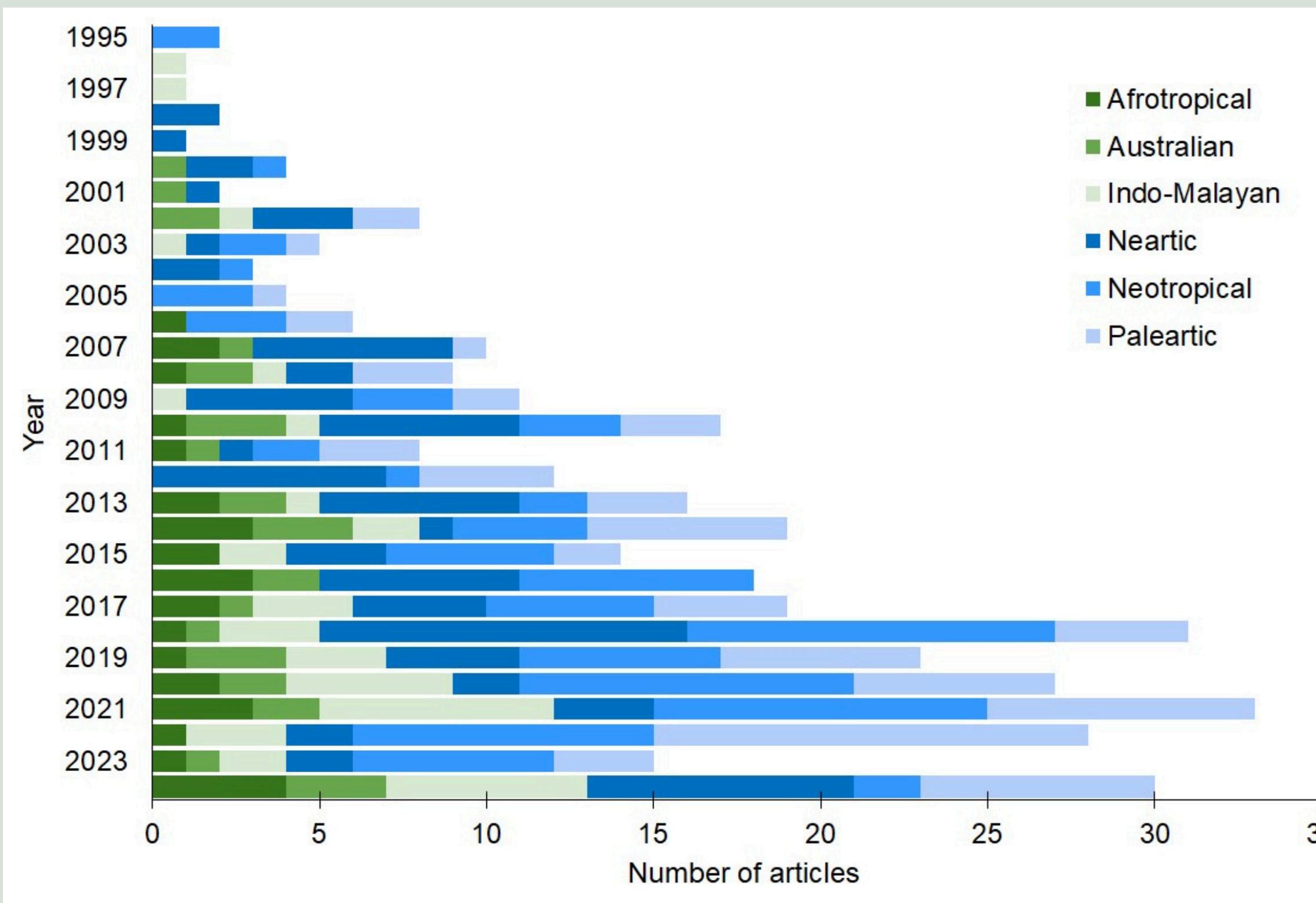
(9) Monitoring scale: remote sensing and in situ

(10) Tree and/or forest component evaluated: leaf, stem and canopy

(11) Stress evaluation in the study: It refers to whether the studies considered the evaluation of any type of stress, specifically through leaf analysis.

(12) Biogeographic Realm: Adopting the methodology of Olson et al. (2001), Neotropical, Nearctic, Palearctic, Indo-Malayan, Australian, and Afrotropical Guerra et al. (2020)

Publication Trends & Biogeographic Realms



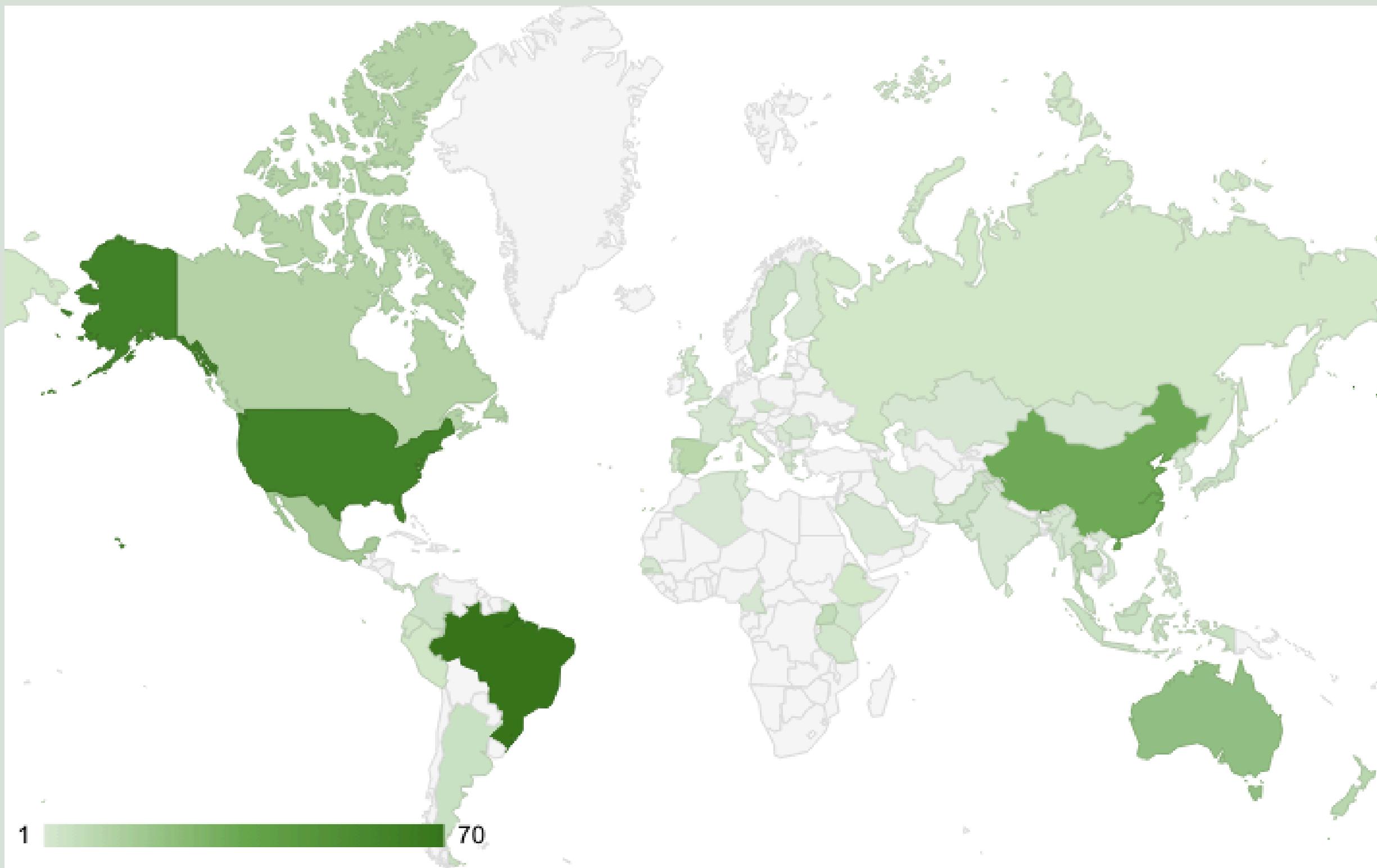
Distribution of 380 studies on the biogeographic realms

The highest number:
2022 and 2024

166 scientific journals,
Restoration Ecology (46)

Neotropical realm (98)
Neartic (91)
Paleartic (84)

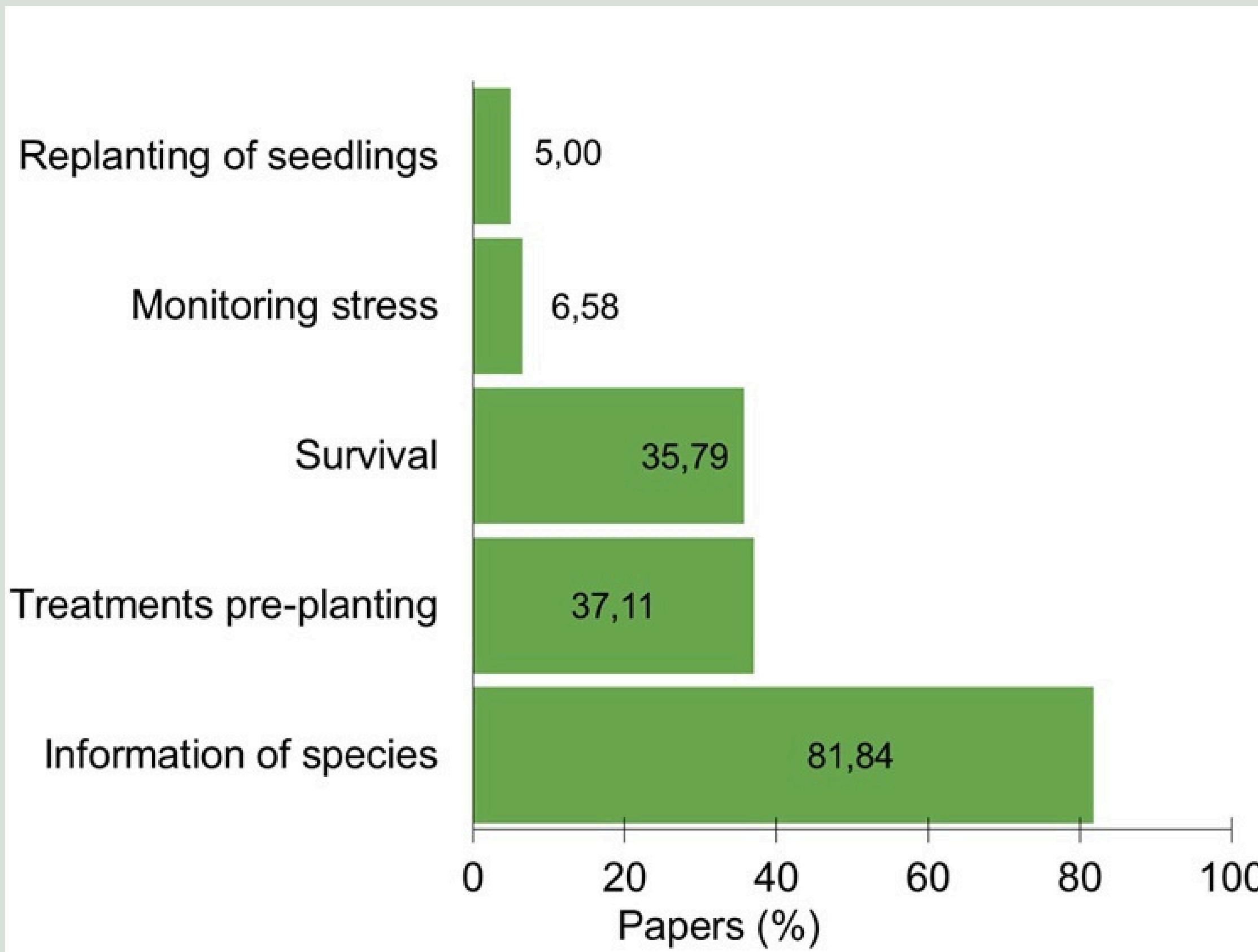
Geographical Distribution



66 countries

Brazil had the highest number
of studies (70)
United States (62)
China (34)

Monitoring Indicators

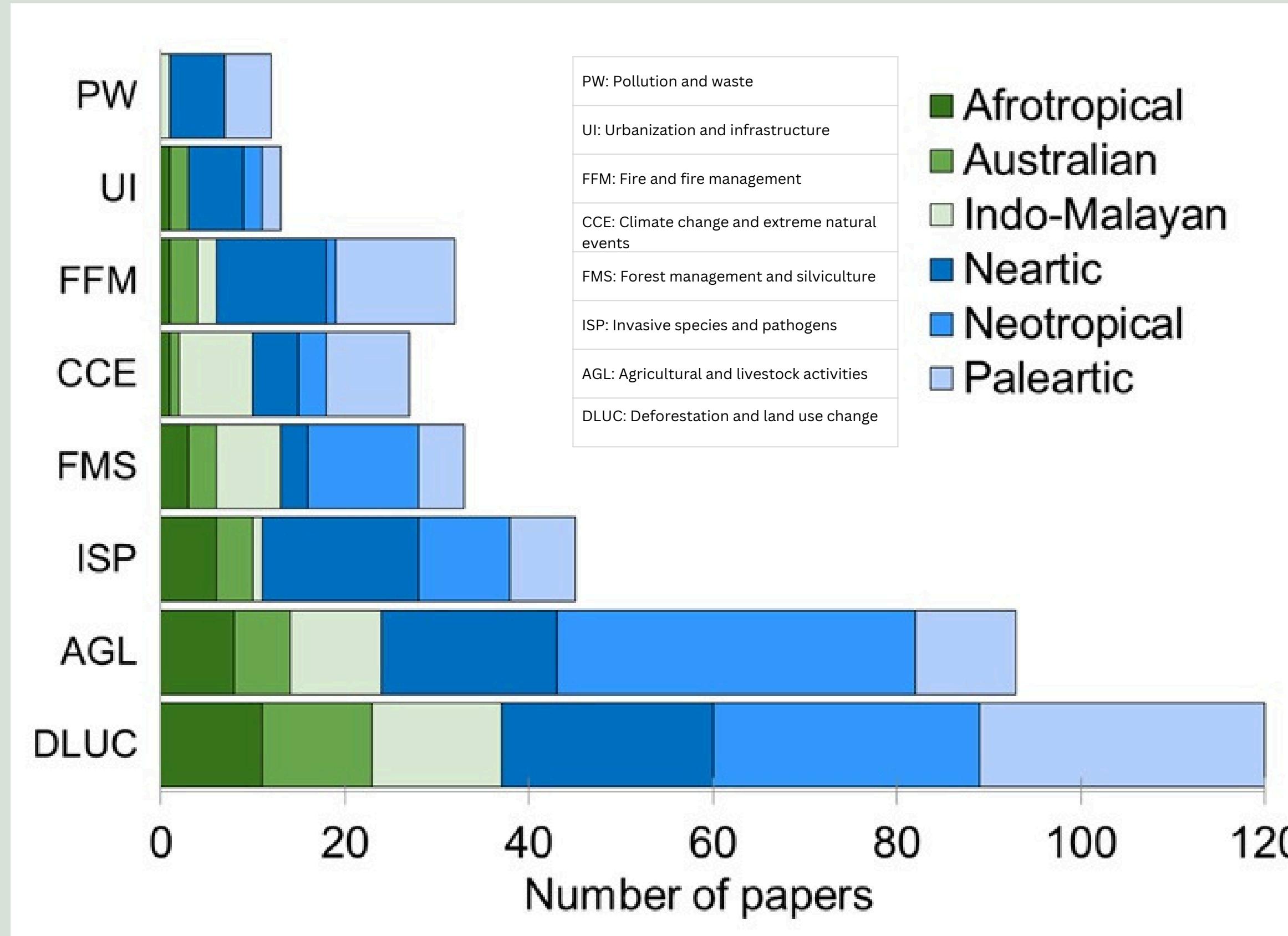


Reported in 298 of 380 studies

Pre-planting Treatments: 139 studies

(site preparation, invasive species removal, and soil improvement)

Types of Disturbance

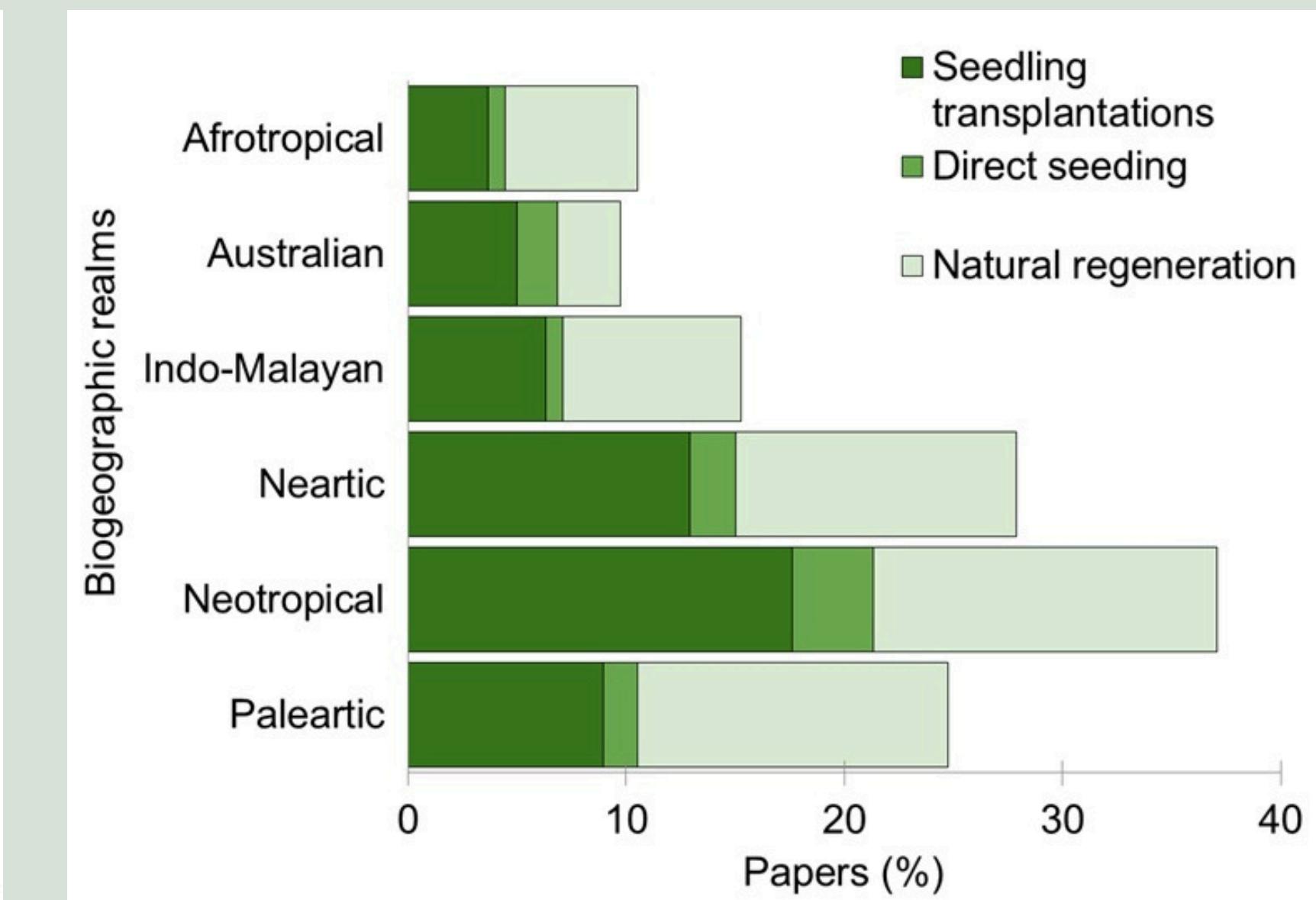
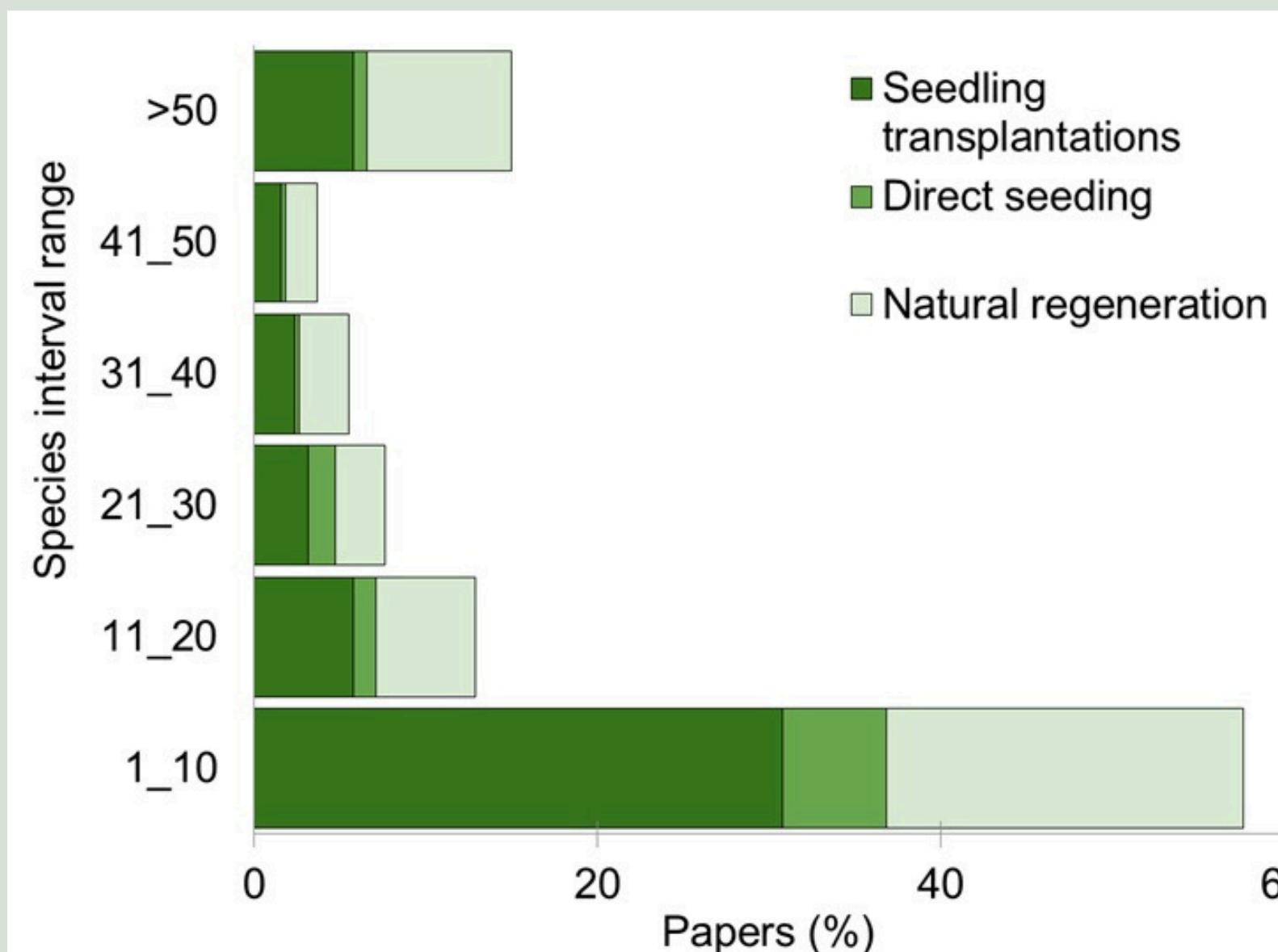


Deforestation and land
use change (120)

Neotropical and Palearctic
realms

Urban infrastructure (13)
pollution and waste (12)

Restoration Techniques

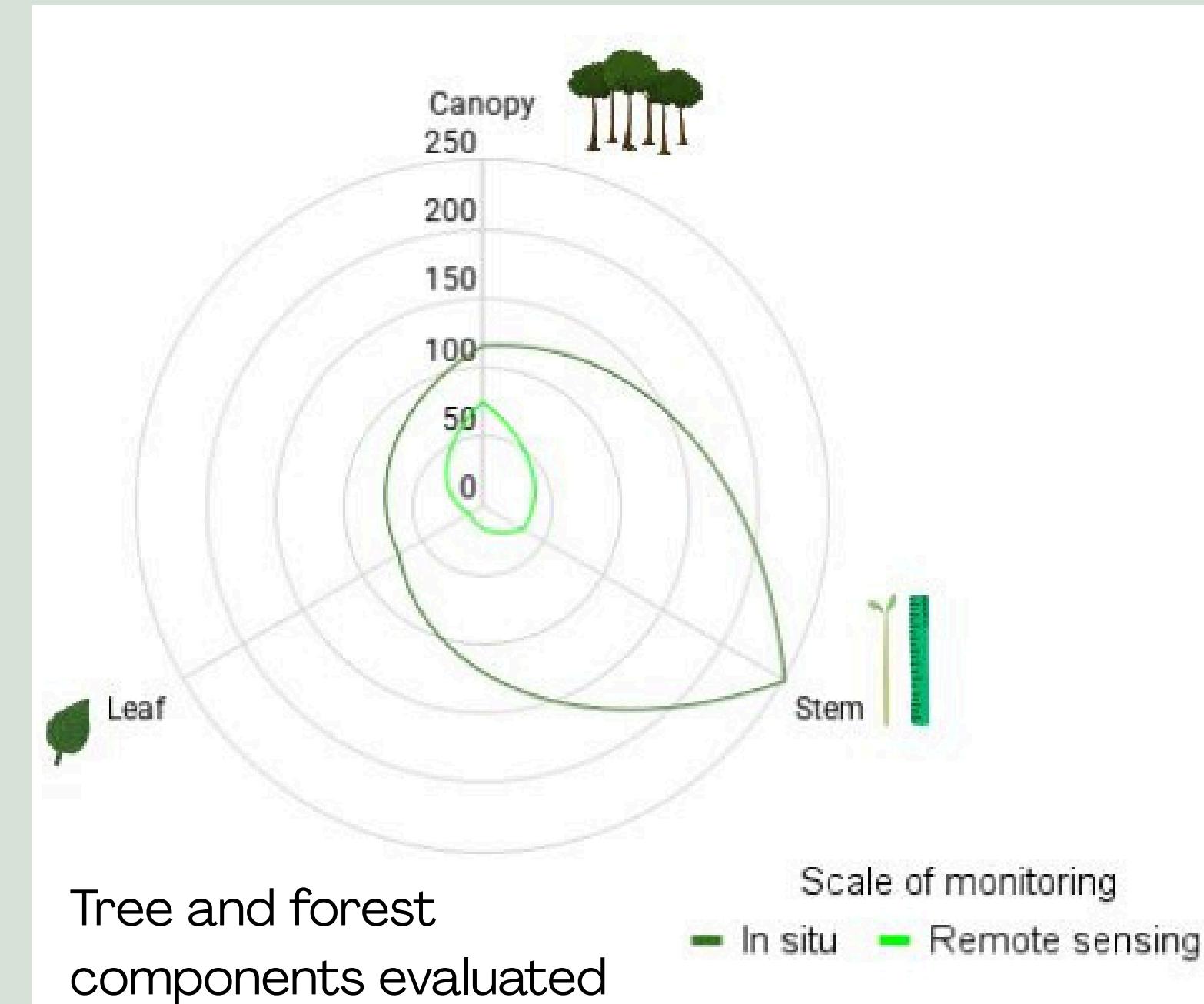
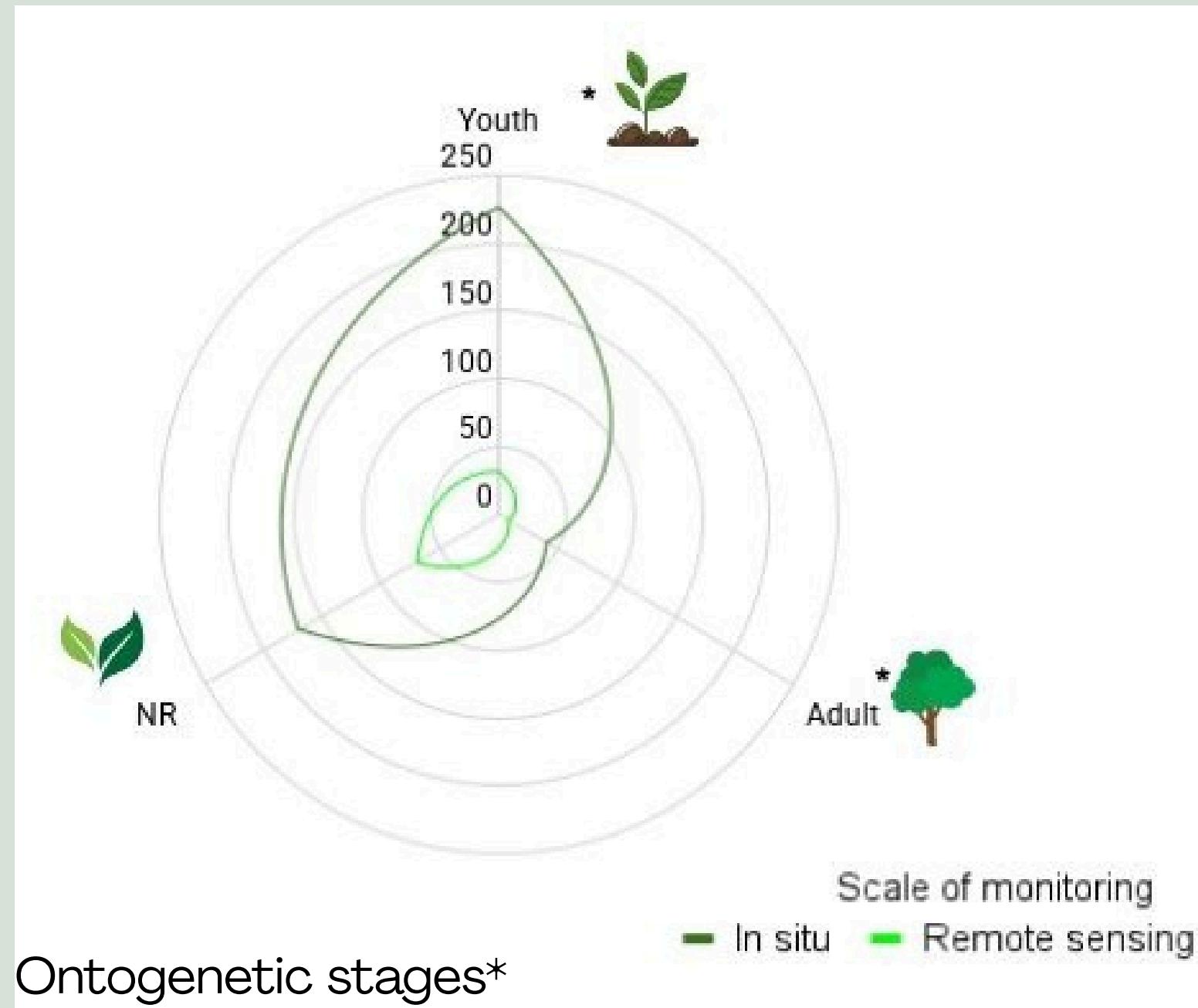


The majority of studies (57.63%) reported evaluating 1-10 species

Natural regeneration - 229 studies

Tree planting - 211 studies

Direct seeding - 10.79%



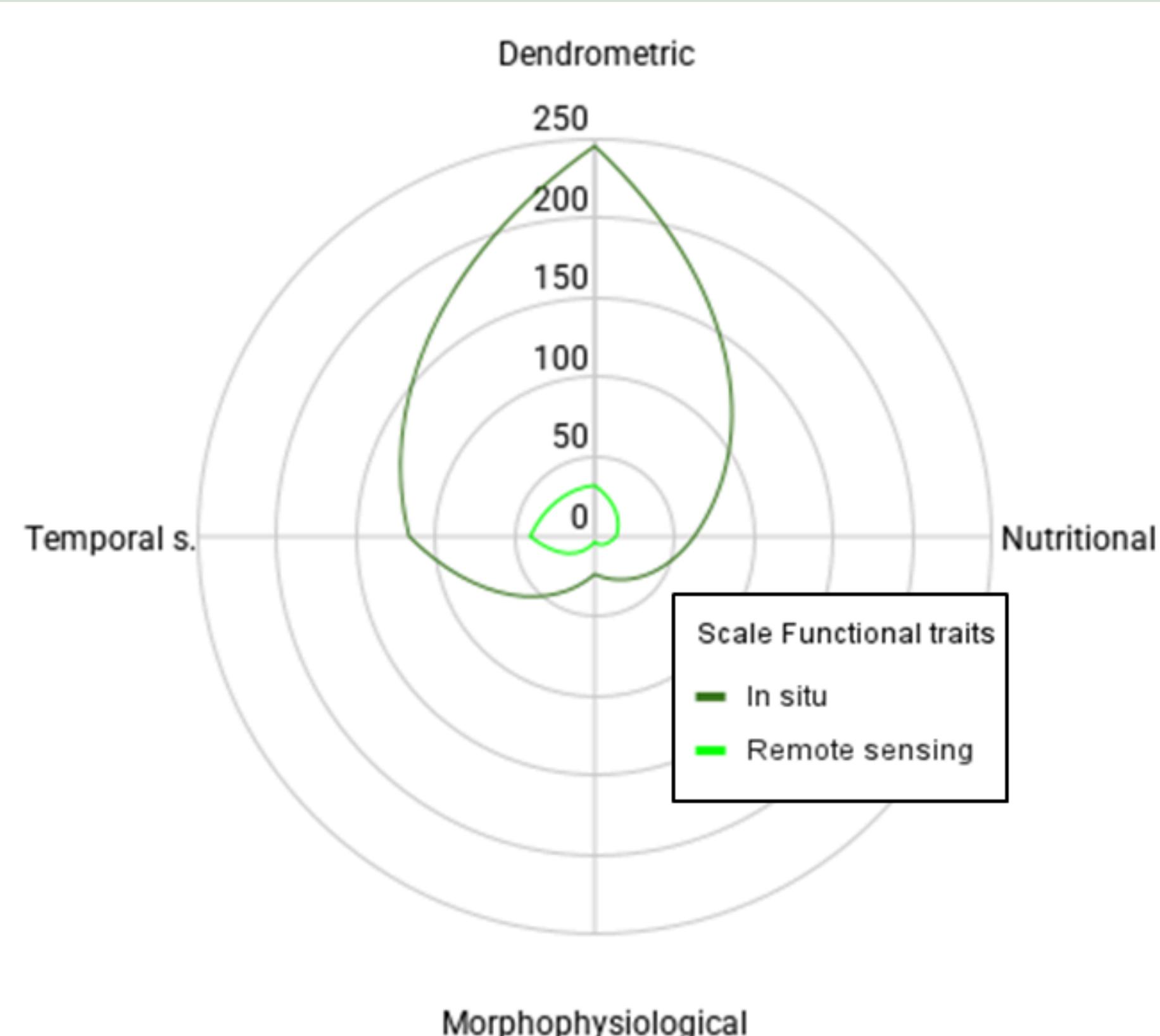
Comparison of monitoring scales in forest restoration

In situ monitoring (329)

Remote Sensing (85)

Stem - in juvenile trees (227)

Leaf - least reported (70; 11 studies)

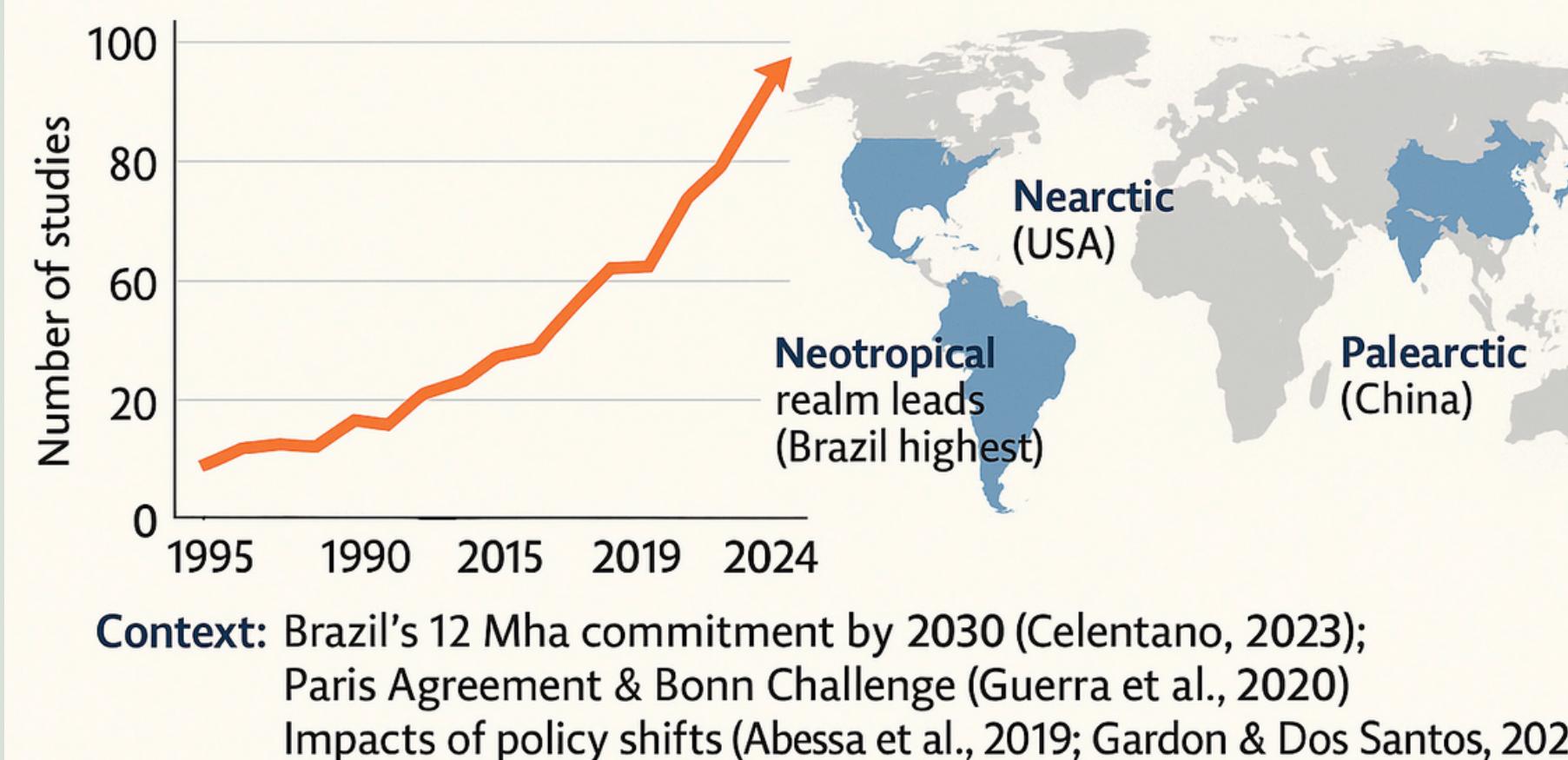


Functional traits in monitoring scale.

Functional Traits:
Dendrometric traits
(H, DBH) -245 studies

Leaf attributes - nutritional classification was the least reported (28)

Discussion



Significant increase
(1995–2024)



1. Tree planting

Most common and effective method for improving canopy and soil.

(Ayu Lestari et al. 2018; Cole et al. 2024; Gardiner et al. 2019; Trimanto et al. 2021).

2. Natural regeneration

Cost-effective, but not always viable in highly degraded areas.

(Alvarez & Williams, 2012; Palomeque et al. 2017; Scheeres et al. 2023).

3. Direct seeding

It was less common due to challenges in native species seed information and commercial availability.

(Prieto et al. 2019; Cole et al. 2024).

Discussion

In situ monitoring

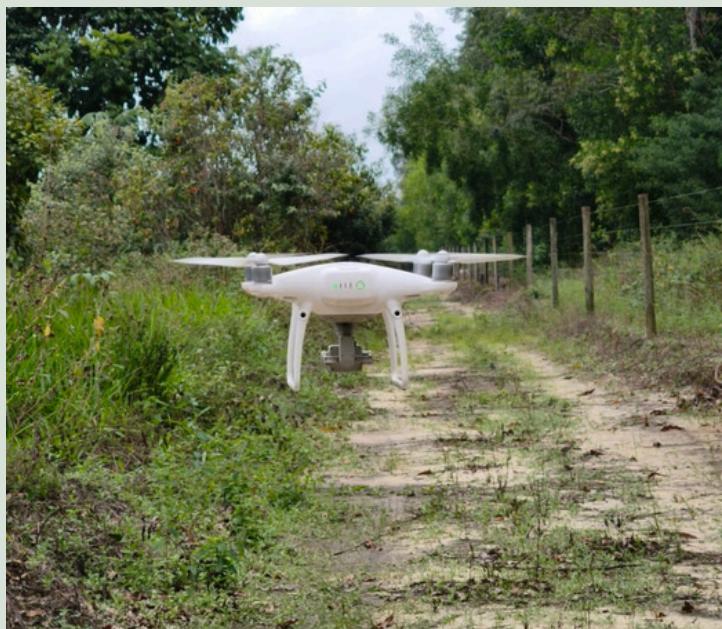
Essential for accuracy

- Time and effort-intensive

(Changsalak & Tiansawat, 2022, Jiao et al. 2021)



Programa Arboretum, 2025



Programa Arboretum, 2025

Remote sensing (RS)

Crucial for large-scale dynamics includes
UAVs
LiDAR, Satellites

(Li et al. 2023; Milodowski et al. 2021; Scheeres et al. 2023; Wasserman et al. 2019)

Discussion



1. Dominance of stem

Easy to measure

(Nuijten et al. 2021; Iizuka et al. 2017)



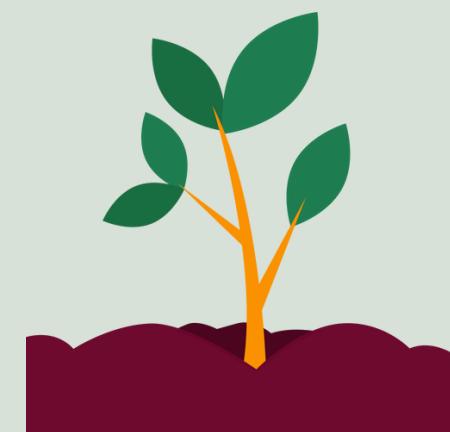
2. Less-evaluated Leaf Traits



• Critical functional traits:

- Photosynthesis
- Stomatal conductance
- Leaf Mass per Area (LMA)
- Chlorophyll fluorescence

(Badano et al. 2011; Ceacero et al. 2011, Schulten et al. 2014)



3. Juvenile stage vulnerability

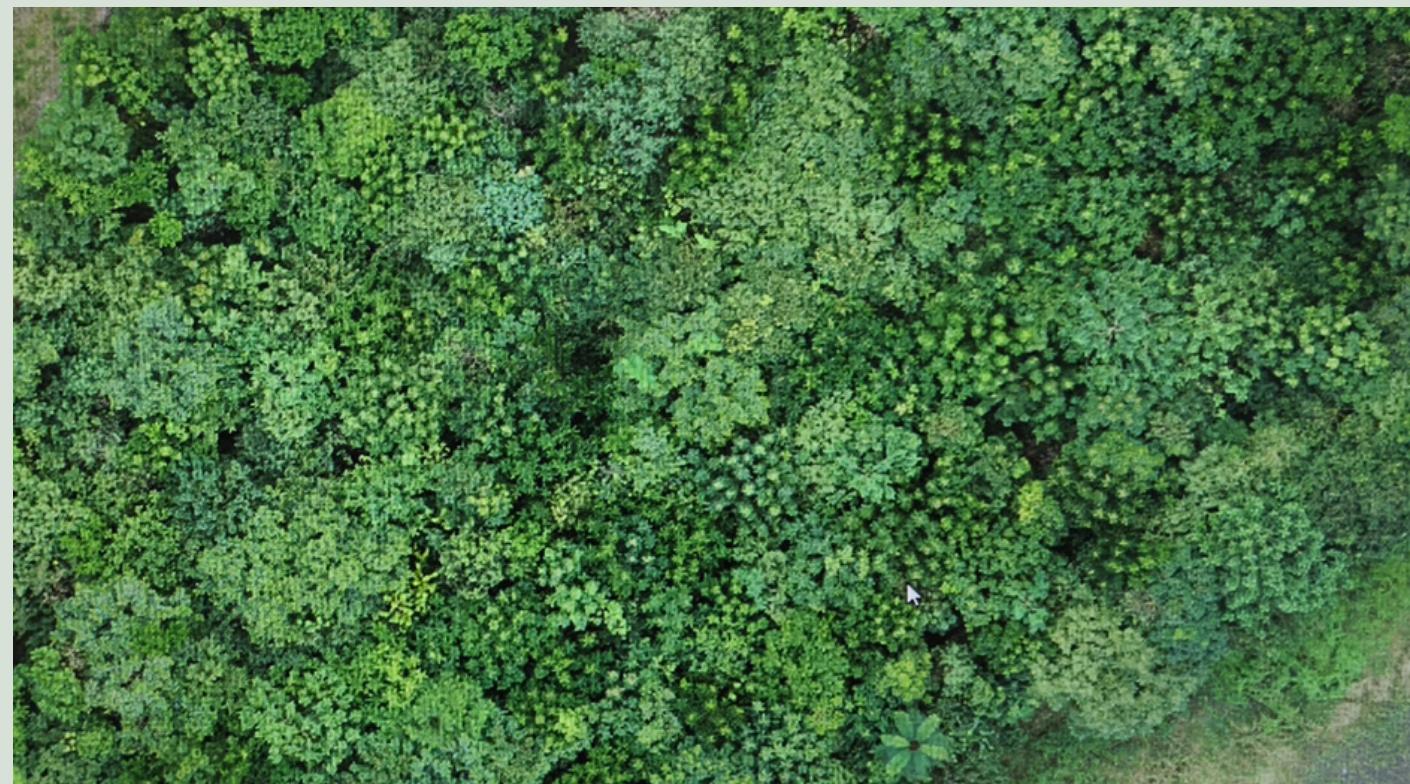
Future research - functional traits: chlorophyll fluorescence (F_v/F_m) for resistant species selecting in extreme conditions.

(Ceacero et al. 2012)

Next steps



Tolerance to severe environmental stress and post-planting survival of tropical trees in Atlantic forest restoration



Remote sensing for monitoring seedling survival in ecological restoration areas of the Atlantic Forest: A case study in Bahia, Brazil.



**“Our land
Our future.
We are Generation Restoration”**

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