Timberline under changing climate

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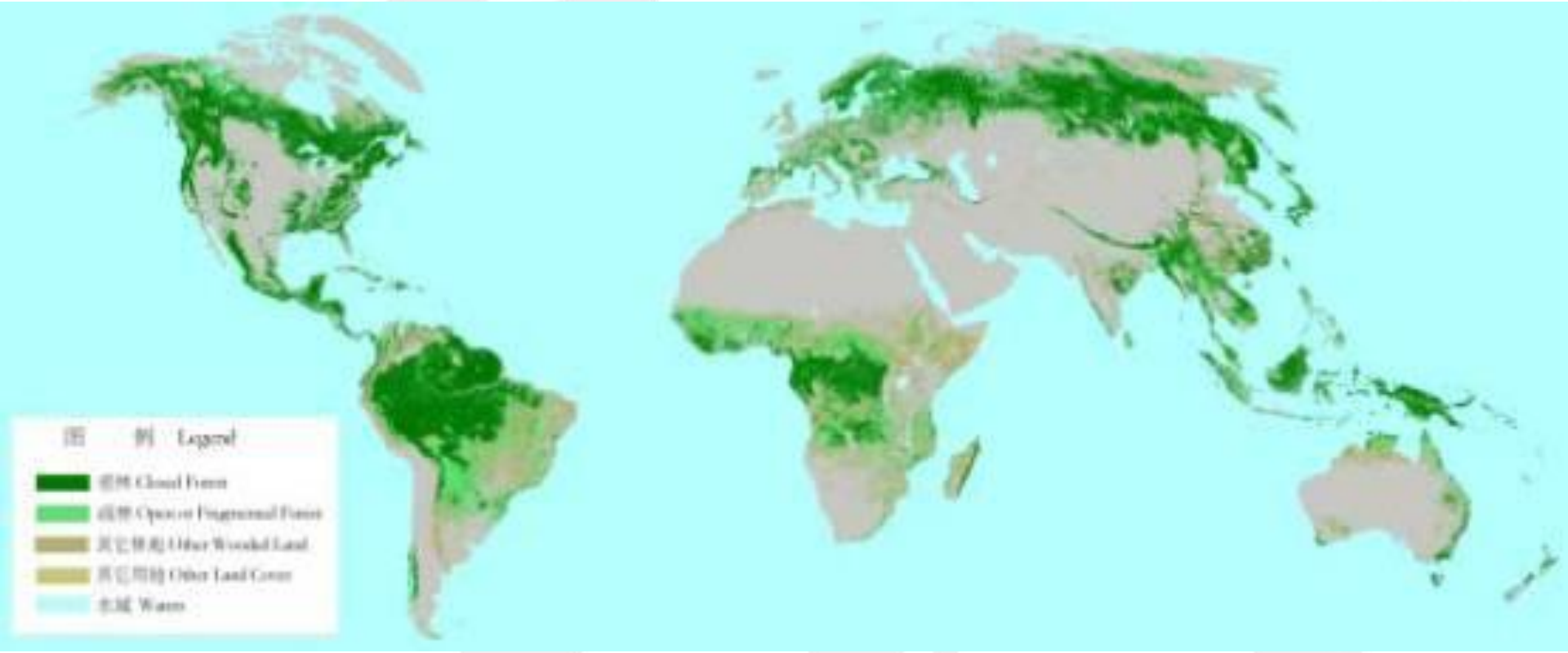
1. Why do we study timberline?

Timberline (TL) = Edge of forest



Four limits of forest distribution:

1. Cold: Arctic TL (Forest-tundra ecotone), Alpine TL (Upper TL)
2. Dry: Dry TL (lower timberline, forest-steppe ecotone)
3. Wet: Wetland TL (Forest-wetland ecotone)

1. Why do we study timberline?

TL is sensitive to climate change

Table 2 Recent latitudinal and altitudinal range shifts

Species*	Location	Observed changes	Climate link
Treeline	Europe, New Zealand	Advancement towards higher altitudes[87–89]	General warming
Arctic shrub vegetation	Alaska	Expansion of shrubs in previously shrub-free areas[90]	Environmental warming
Alpine plants	European Alps	Elevational shift of 1–4 m per decade[24]	General warming

(Walter et al., Nature, 2002)

Little change in the fir tree-line position on the southeastern Tibetan Plateau after 200 years of warming

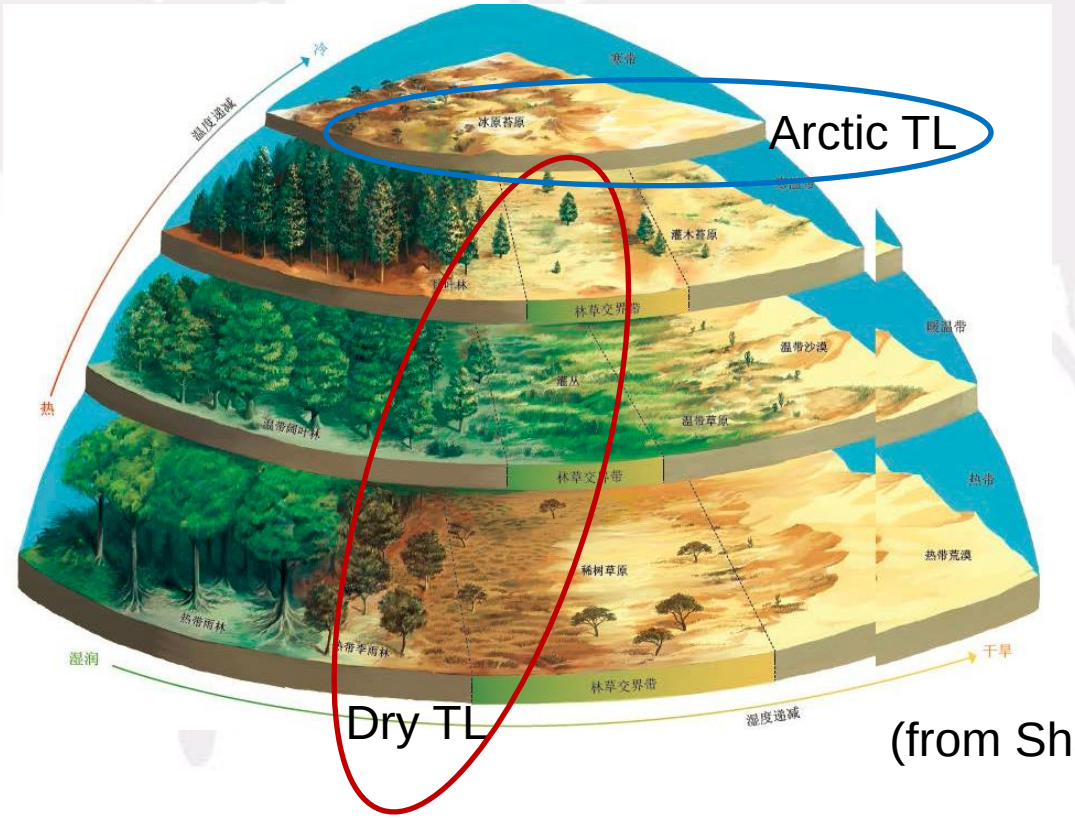
Eryuan Liang[1], Yafeng Wang[1,3], Dieter Eckstein[2] and Tianxiang Luo[1]

(Liang et al., New Phytologist, 2011)

1. Why do we study timberline?

Can vegetation pattern affect TL response to CC?

- Tree height lows down in both arctic and dry TLs.
- Tree density lows down in both arctic and dry TLs.



(from Shan, 2012)

1. Why do we study timberline?

Totally different local environment

Arctic timberline (Courtesy, Epstein)

Alpine timberline

1. Why do we study timberline?

Our purpose of studying TL

- Hypothesis: TL position movement is not the only way of TL response to climate change because: 1) other features of TL vegetation, for example, forest growth and regeneration, patch size, species diversity could also respond; 2) Factors other than temperature also contribute to TL vegetation dynamics.
- We focus on:

  1. What are the common vegetation patterns for various TL?

  2. How are TLs sensitive to climate change?

2. Vegetation pattern and dynamics of dry TL

Three types of vegetation patterns in dry TL

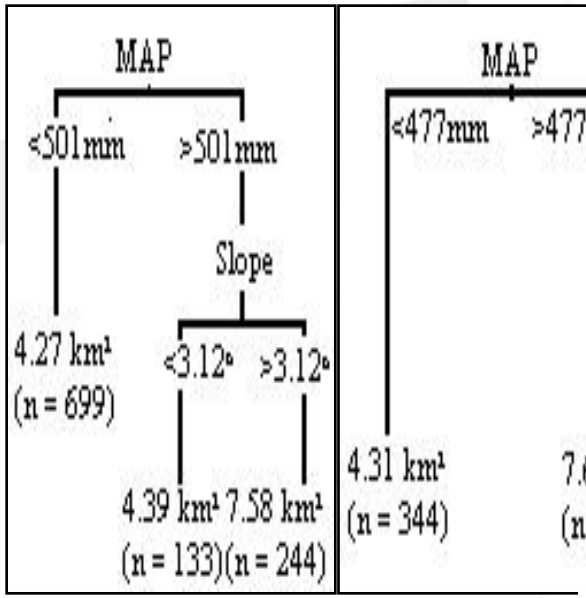
1. Exposure forest-steppe

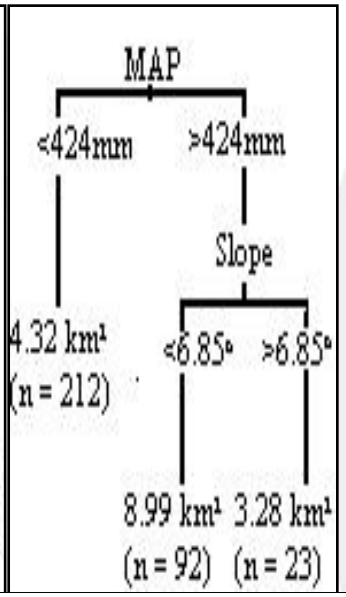
2. Savanna

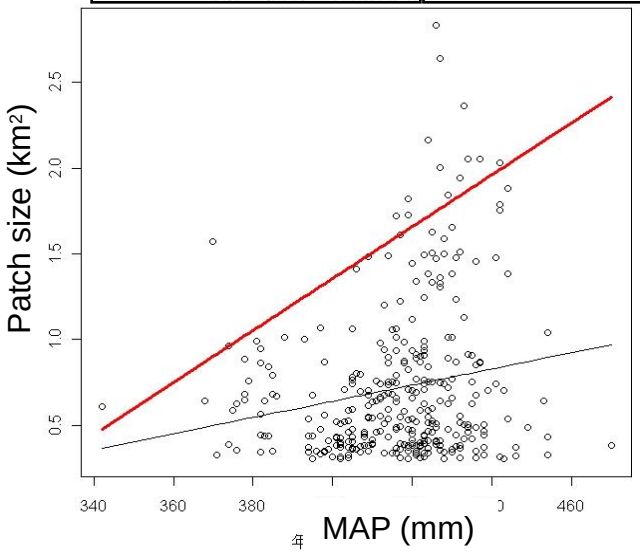
3. River valley forest-steppe

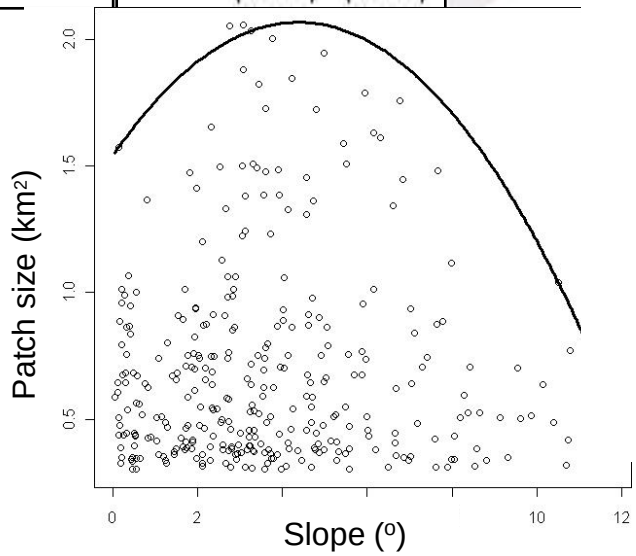
2. Vegetation pattern and dynamics of dry TL

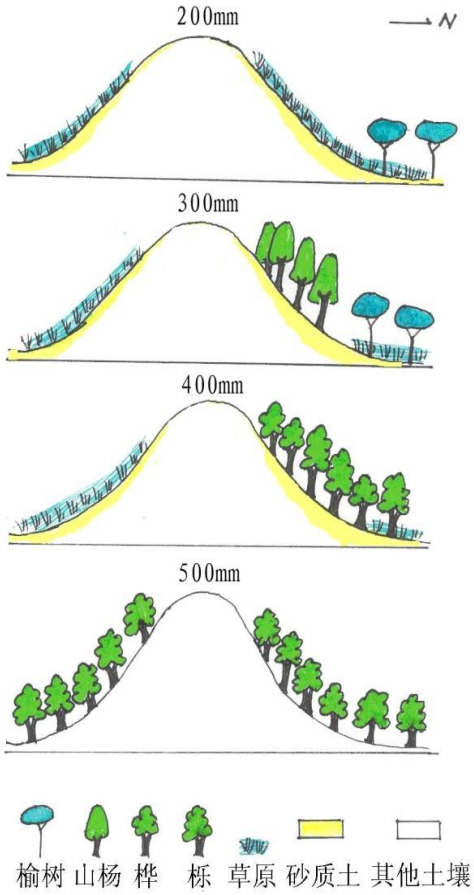
MAP determined forest patch size









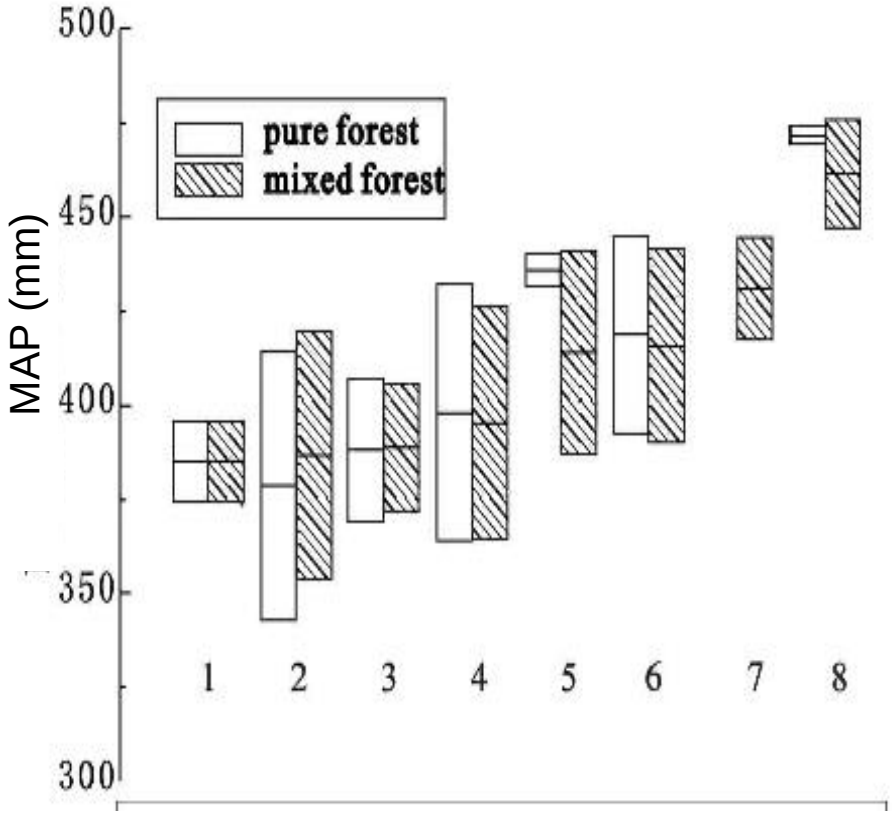


2. Vegetation pattern and dynamics of dry TL

Changes in species distribution along MAP


Chinese pine in dry TL

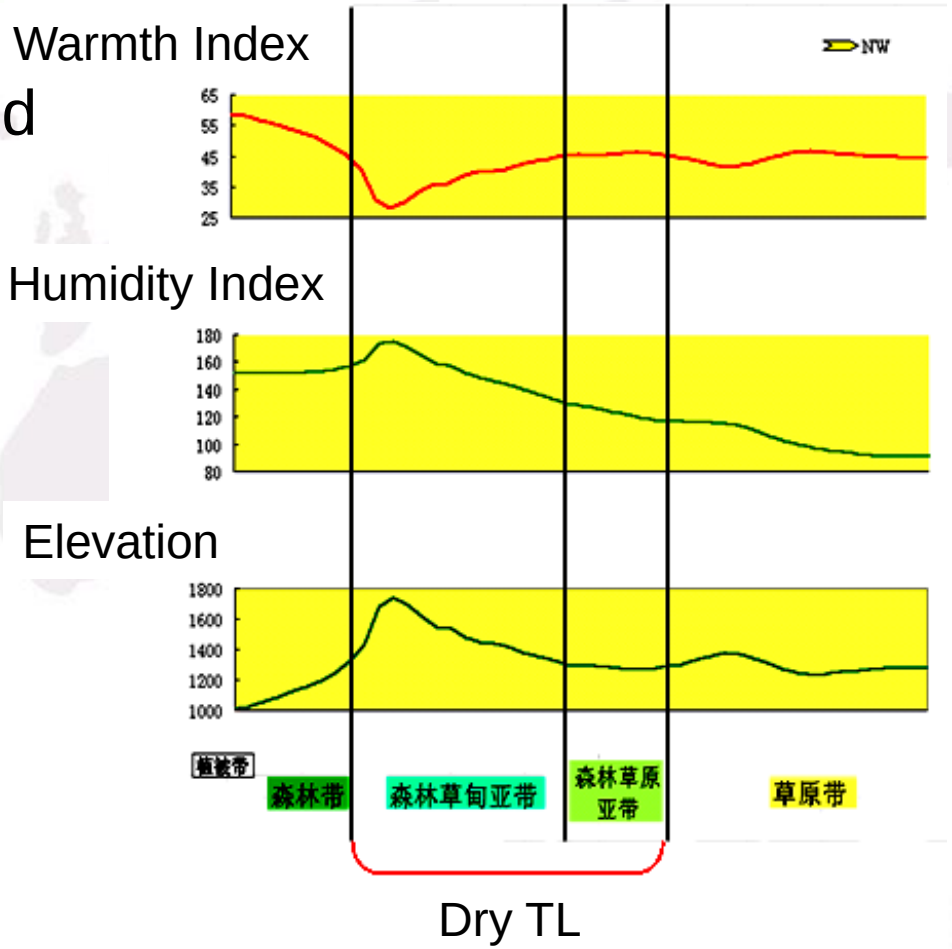
1. *Ulmus pumila*
2. *Populus davidiana*
3. *Pinus tabulaeformis*
4. *Picea meyeri*
5. *Quercus mongolica*
6. *Betula platyphylla*
7. *Betula dahurica*
8. *Larix principis-rupprechtii*



2. Vegetation pattern and dynamics of dry TL

Vegetation differentiation with dry timberline

- 5 zones can be identified
  - Forest zone
  - Forest-meadow zone
  - Forest-steppe zone
  - Savanna forest zone
  - Scrub steppe zone
- Scrub has been commonly regarded as scrub invasion in steppe

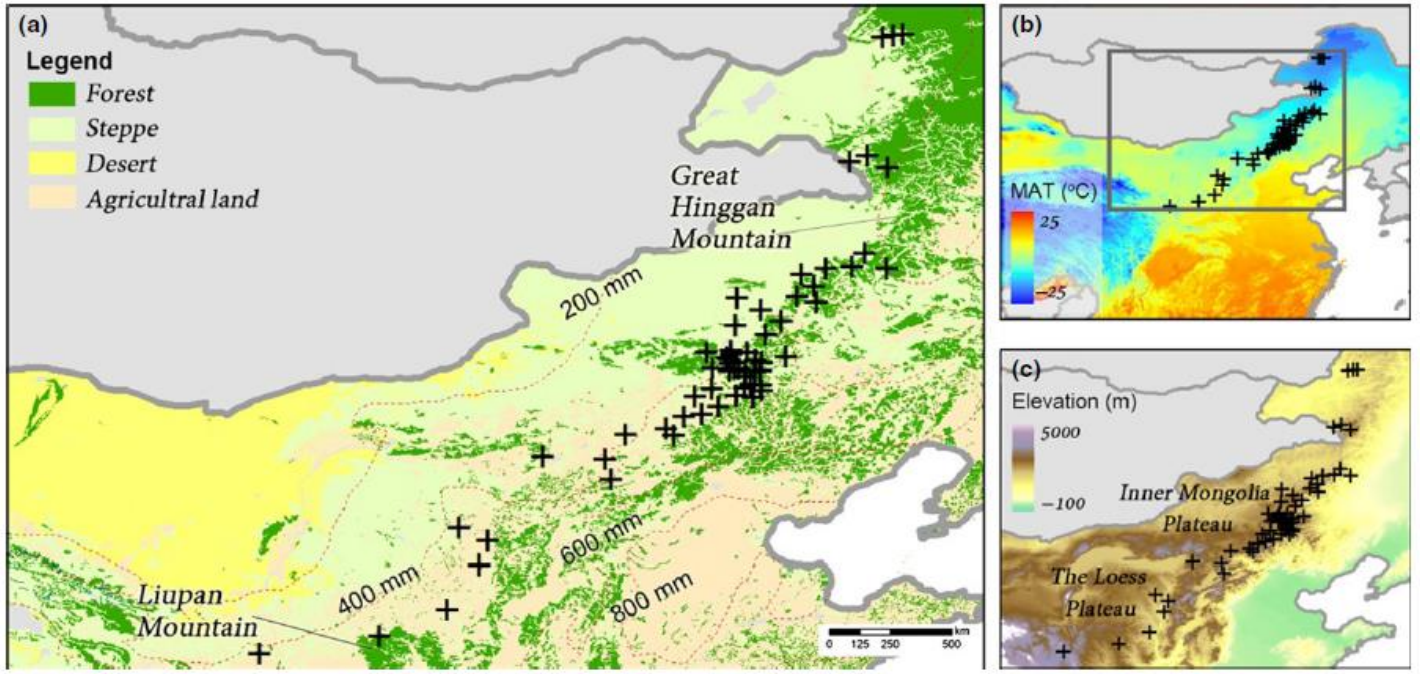


(Liu *et al., Journal of Vegetation Science,* 2000; *Physical Geography*, 2012)

2. Vegetation pattern and dynamics of dry TL

Patterns of species diversity

- Long and narrow dry TL has a great temperature gradient as well as a sharp precipitation gradient. How do they affect species distribution?
- Hypotheses: Isolation effect of patches with size determined by precipitation, or dispersal effect of spatial distance determines species diversity?



Paired-plots of both forest and steppe along the dry TL in northern China

2. Vegetation pattern and dynamics of dry TL

Determinants of species diversity

- Temperature (coupled with spatial distance) rather than precipitation determines species distribution.
- No significant effect of climate on local scale species diversity.

Explanatory factor	Forest		Steppe		Forest and steppe combination	
	Mantel *r*	*P*-value	Mantel *r*	*P*-value	Mantel *r*	*P*-value
(a)						
ΔMAT	**0.3420**	**0.001**	**0.2708**	**0.001**	**0.3395**	**0.001**
ΔMAP	**0.1036**	**0.050**	0.0818	0.097	**0.1657**	**0.011**
GD	**0.3247**	**0.001**	**0.2261**	**0.001**	**0.3591**	**0.001**
ΔPS	0.0524	0.172	–	–	**0.1554**	**0.004**
(b)						
ΔMAT	**0.1577**	**0.012**	**0.1769**	**0.003**	**0.1082**	**0.019**
ΔMAP	−0.0511	0.199	−0.0102	0.431	−0.0765	0.913
GD	**0.1457**	**0.010**	0.0162	0.380	**0.1584**	**0.004**
ΔPS	0.0503	0.170	–	–	**0.1305**	**0.015**

*Bold value indicates significant correlation ($P < 0.05$).

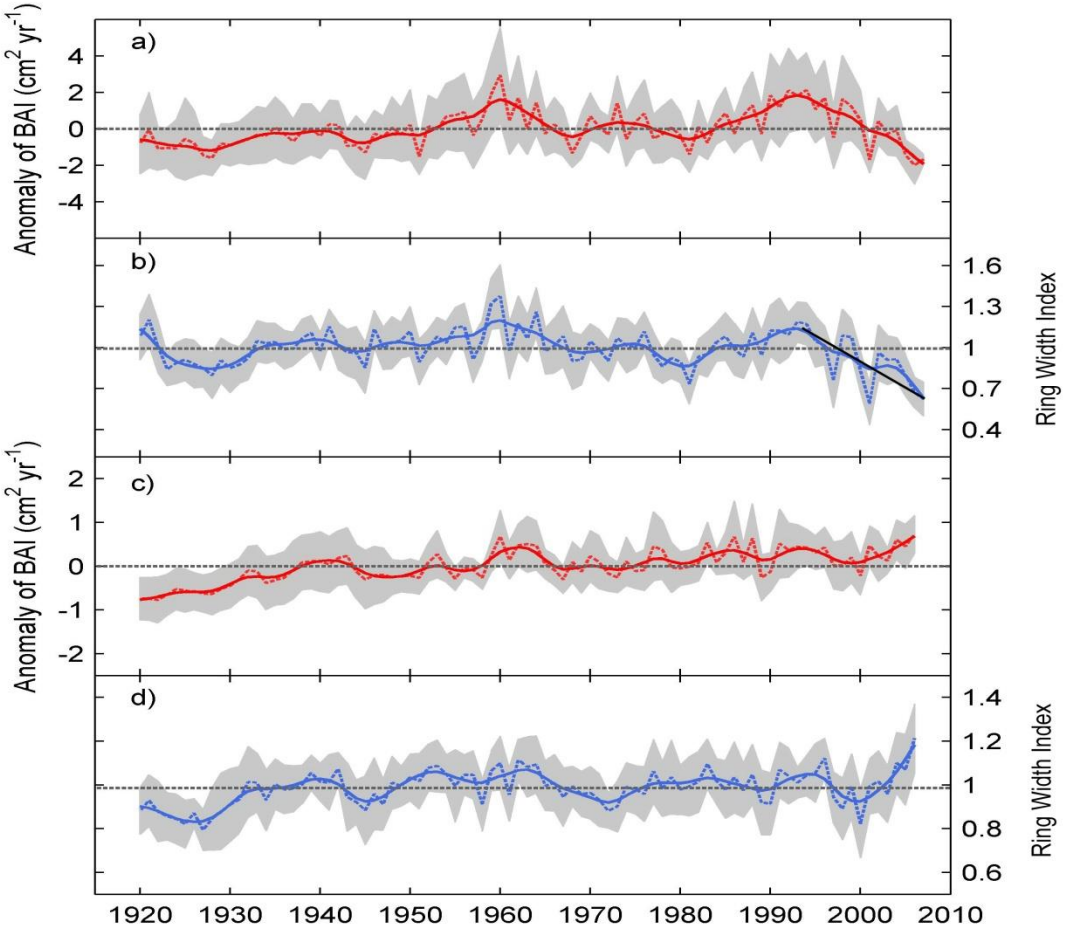
(Liu *et al., Journal of Vegetation Science,* 2014)

2. Vegetation pattern and dynamics of dry TL

Growth decline in dry TL

Dry timberline

Continuous forest

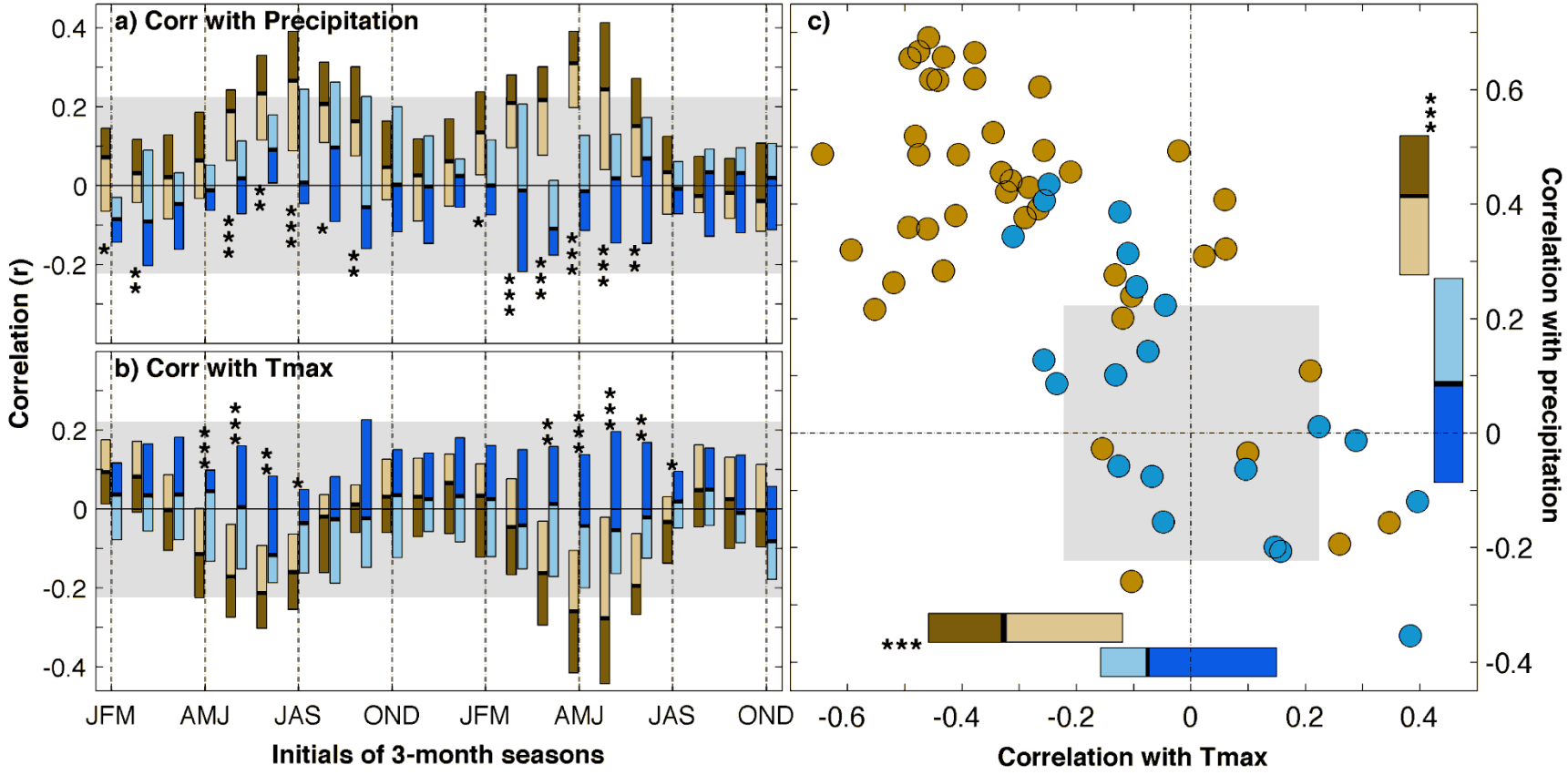


(Liu *et al., Global Change Biology*, 2013)

2. Vegetation pattern and dynamics of dry TL

Drought-limited tree growth

- Dry TL: affected by pre-growing and growing season drought induced by temperature increase and precipitation decrease
- Continuous forest: not affected by drought



2. Vegetation pattern and dynamics of dry TL

Soil moisture and forest mortality

- Insufficient soil moisture during the growing season led to forest mortality.

3. Vegetation pattern and dynamics of alpine TL

Water determines alpine TL species

- TL position: Temperature-determined

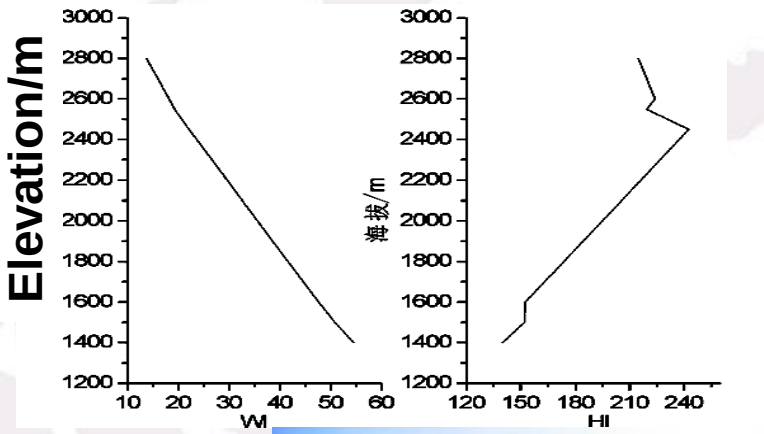
Warmth Index = 15℃·Month

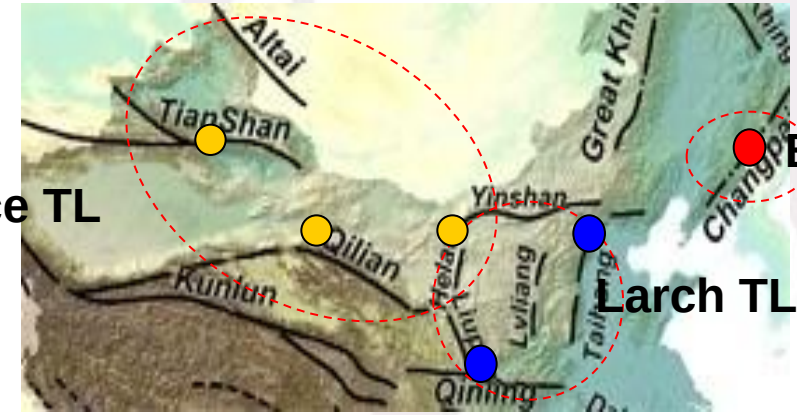
- TL species: Water-determined

Larch TL, Humidity Index < 210

Spruce TL, Humidity Index > 210

Wutai Mt.(3058m)





Spruce TL

Broadleaf TL

Larch TL

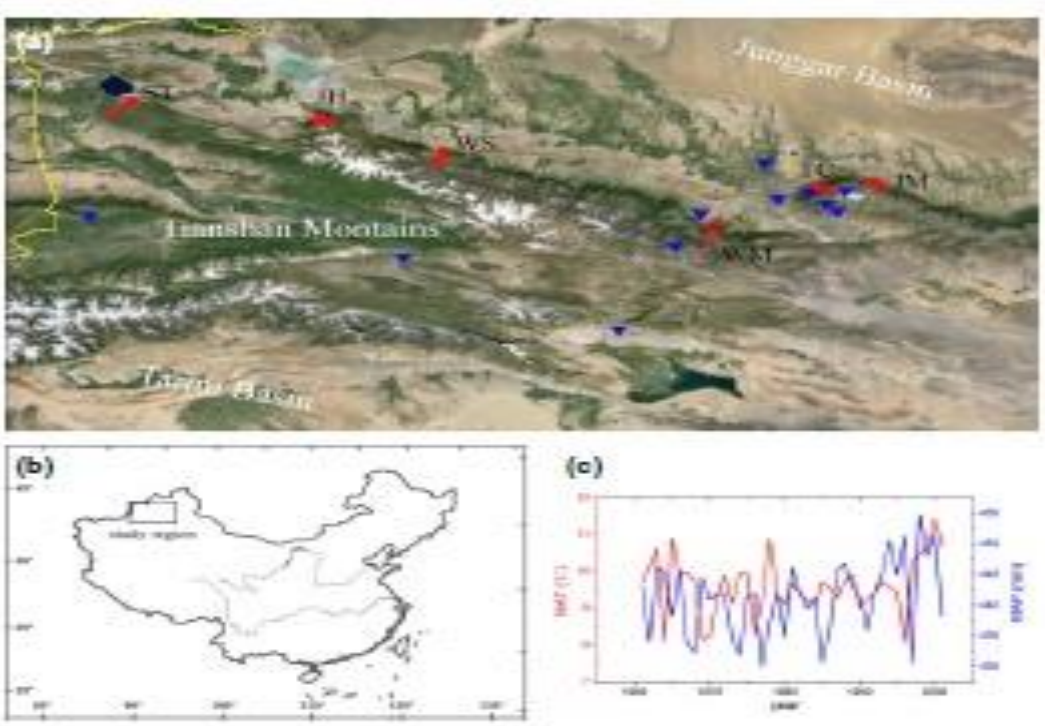
- Pollen analysis: Climate drying determined change from spruce TL to larch TL

(Liu *et al., Mountain Research and Development,* 2002)

3. Vegetation pattern and dynamics of alpine TL

Is tree growth in alpine TL slow?

Hypothesis: Climate warming can accelerate tree-growth faster in the alpine TL than in continuous forest because it is limited by temperature



A case study in Tianshan with sample-total methods on 6 watersheds from alpine TL to continuous forest.

(Qi *et al., Global Change Biology*, 2014)

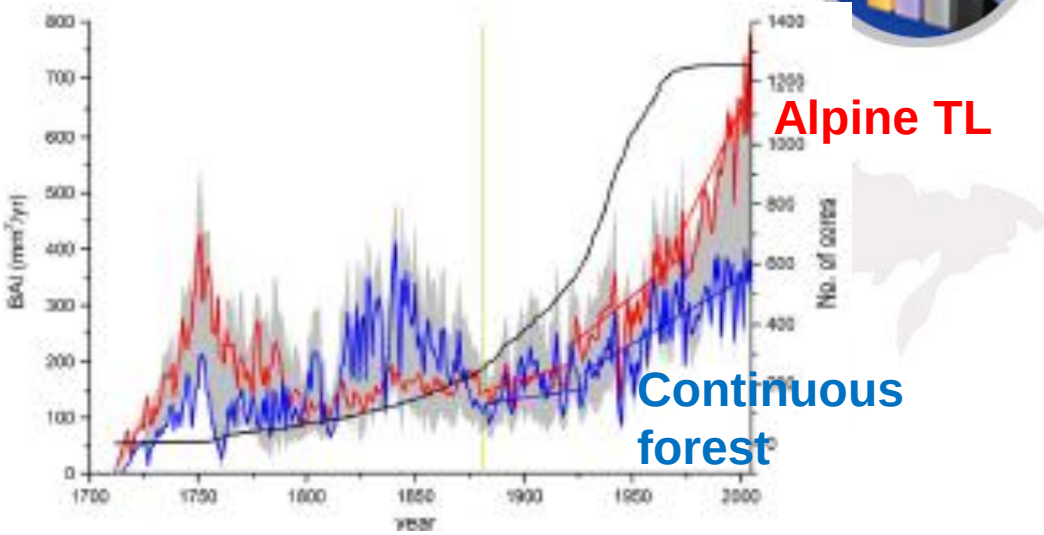
3. Vegetation pattern and dynamics of alpine TL

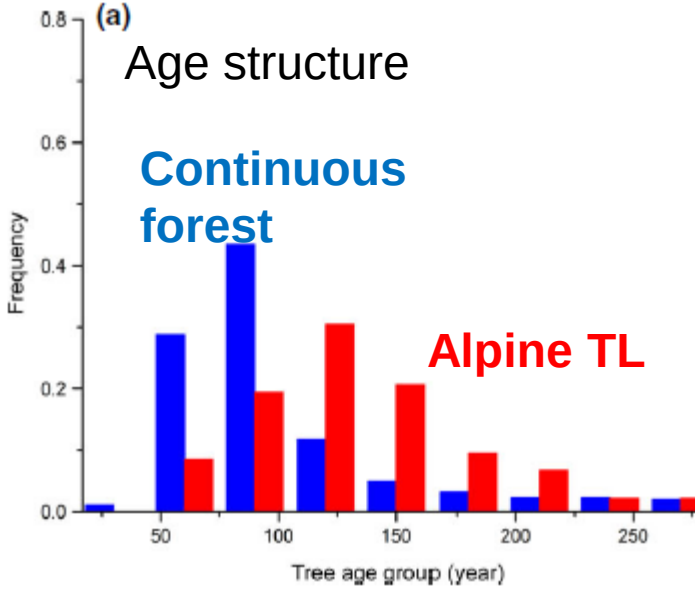
Forest growth in alpine TL

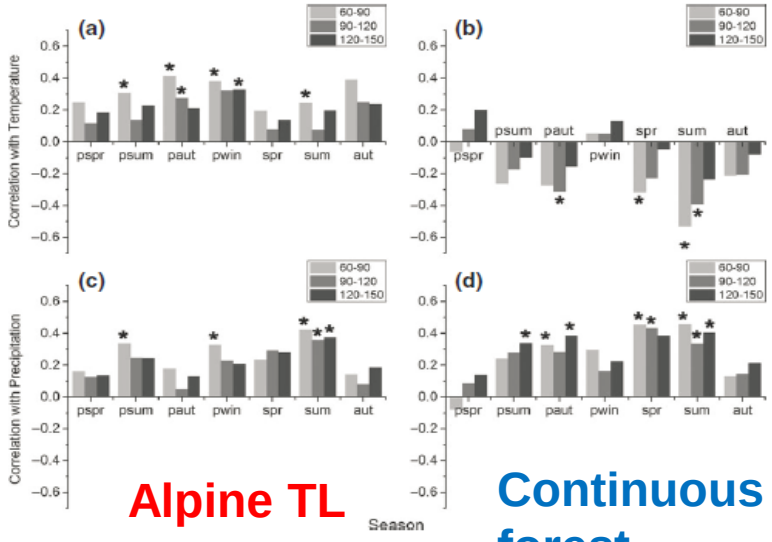
Acceleration is faster in alpine TL than in continuous forest.

Age effect is insignificant.

Water competition might restrict tree growth in continuous forest.







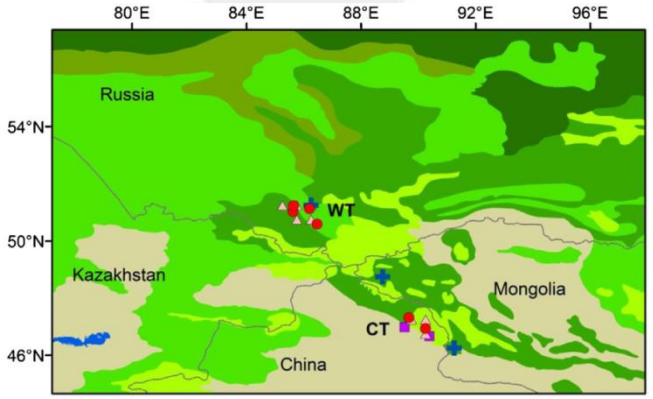
(Qi *et al., Global Change Biology*, 2014)

3. Vegetation pattern and dynamics of alpine TL

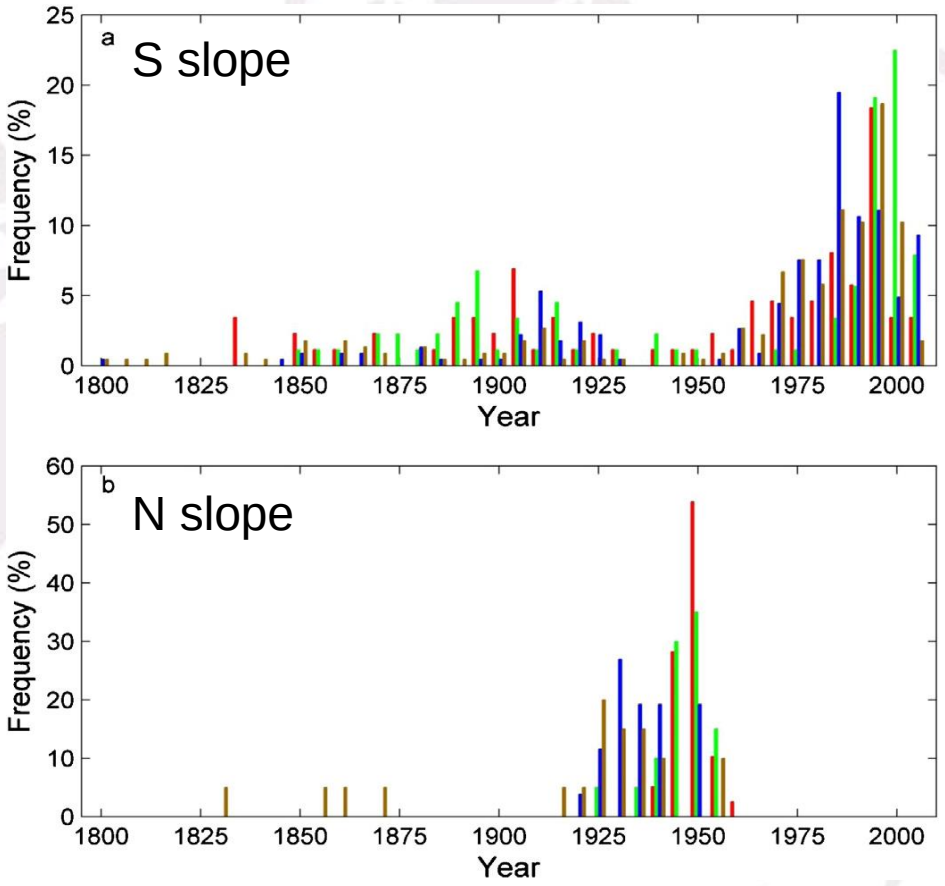
Forest regeneration patterns in alpine TL

Different between low and high altitudes

Different between S and N slopes



Sample-total of 4 sites on S (China) and N (Russia) slopes of Altai Mts.



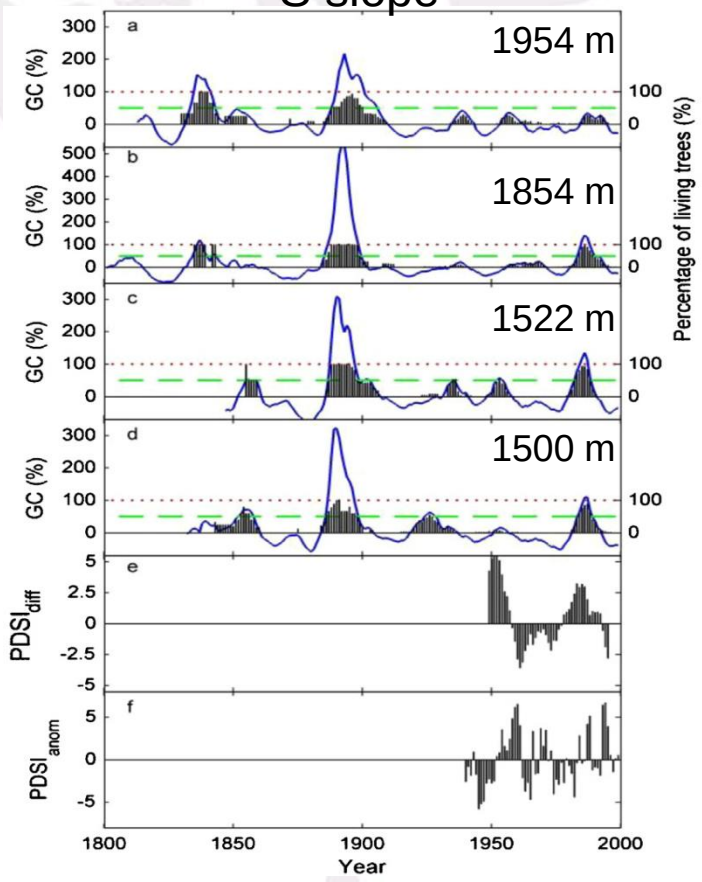
(Wu *et al., Ecological Indicators*, 2014)

3. Vegetation pattern and dynamics of alpine TL

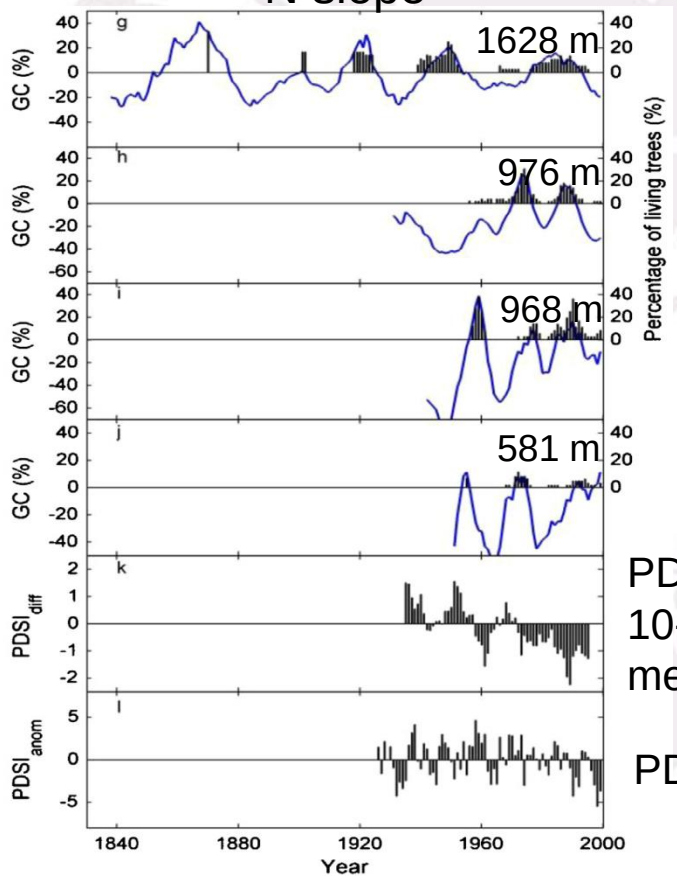
Relationships between forest growth and regeneration

Drought enhanced growth release and regeneration on lower latitudes, but not on higher latitudes

S slope



N slope



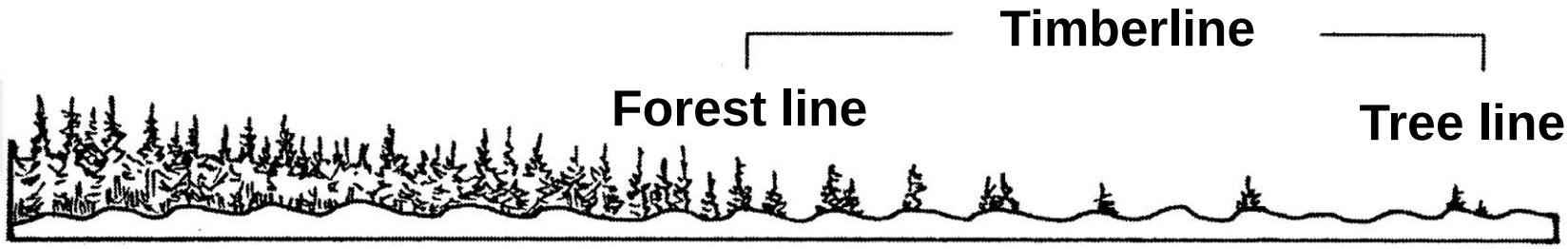
PDSI 10-yr smoothed mean

PDSI

(Wu *et al., Ecological Indicators*, 2014)

4. Common mechanism of TL formation

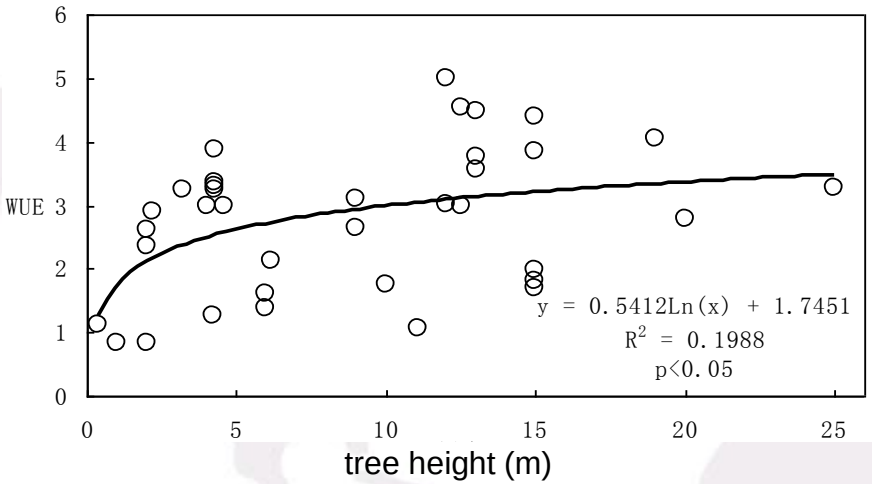
Common features of TLs

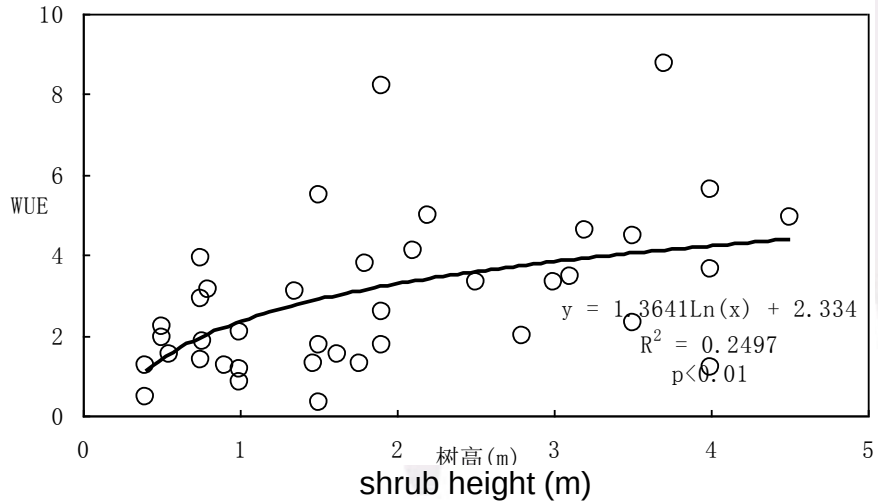


- The common feature of alpine (upper) timberline and dry timberline (lower) is shrub expansion.
- Can clone regeneration under extreme climate determine the tree line position for upper and lower timberlines?

4. Common mechanism of TL formation

Why shrubs replace trees on TL?





A meta-analysis of WUE (=P/T)

A lower height to reach maximum WUE for shrubs than for trees

A greater WUE for shrubs than for trees with the same height.

(He et al., unpublished)

5. Summary

- There are common vegetation patterns for alpine and dry timberline in China.
- Forest growth and regeneration, species diversity and distribution are climate-related.
- Alpine timberline position is determined by temperature, but its species composition is determined by humidity.
- Non-linear responses of timberline vegetation to climate change might be caused by local factors.

5. Summary

To be investigated

- Hypothesis: Timberline is formed as an adaptation to disturbances caused by climatic extremes. High WUE and redundant clone regeneration of shrubs determines the position of timberline.
- We are planning a monitoring network for:

1. Regeneration strategy of TL trees.

2. Soil moisture and water use of TL trees.

3. Effects of plant community features on forest growth and regeneration of TL .

Thank you for your attention!

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