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Dynamics of the subalpine forests in the French Pyrenees over the last two centuries



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Introduction

Material & Methods

Using map comparison to assess forest line dynamics

Forest line is sensitive to temperature (Holtmeier & Broll, 2019). In the context of global warming, a recent upward shift of forest line is observed (Harsch *et al.*, 2009). However, few studies have the necessary temporal depth to determine whether this upward shift only accompanies recent global warming or is part of a longer-term dynamic initiated since the forest minimum in France (ca. 1850).

Our objective here is to describe forest line dynamics from the forest minimum to nowadays, to answer the following questions :

- Can we detect a forest line upward shift since the forest minimum?
- Can we detect an acceleration of the upward shift in the recent period?
- Can we detect a change in the forest line ecotone characteristics along with the upward shift?

The study area is situated in the French Pyrenees and is composed of 125 municipal districts. Forest line elevations were estimated for three maps from 1850 to 2010 thanks to a digital elevation model. Forest line shift was then computed as the difference between two consecutive maps while the upward shift velocity was calculated using the exact dates between two maps. For a subset of 60 districts, we study the ecotone width, defined here as the elevation difference between open and closed forests lines.

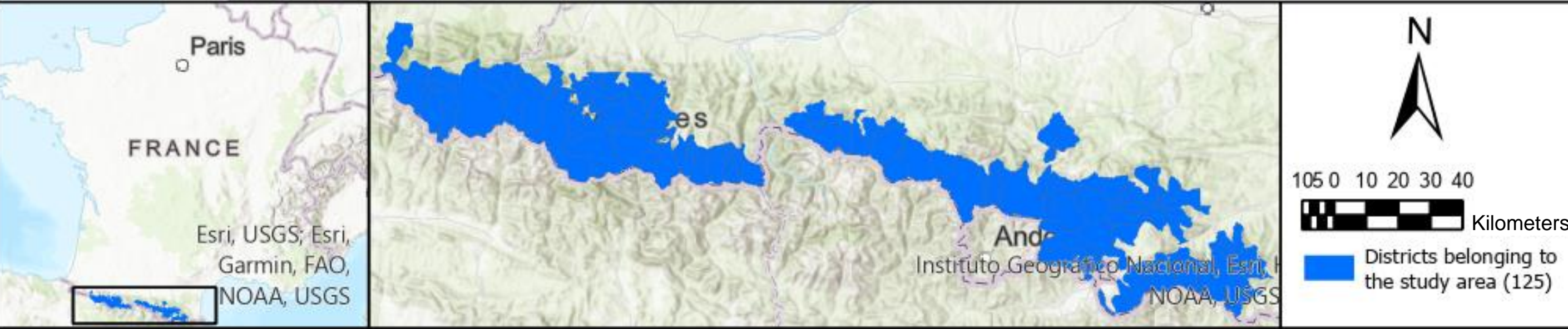
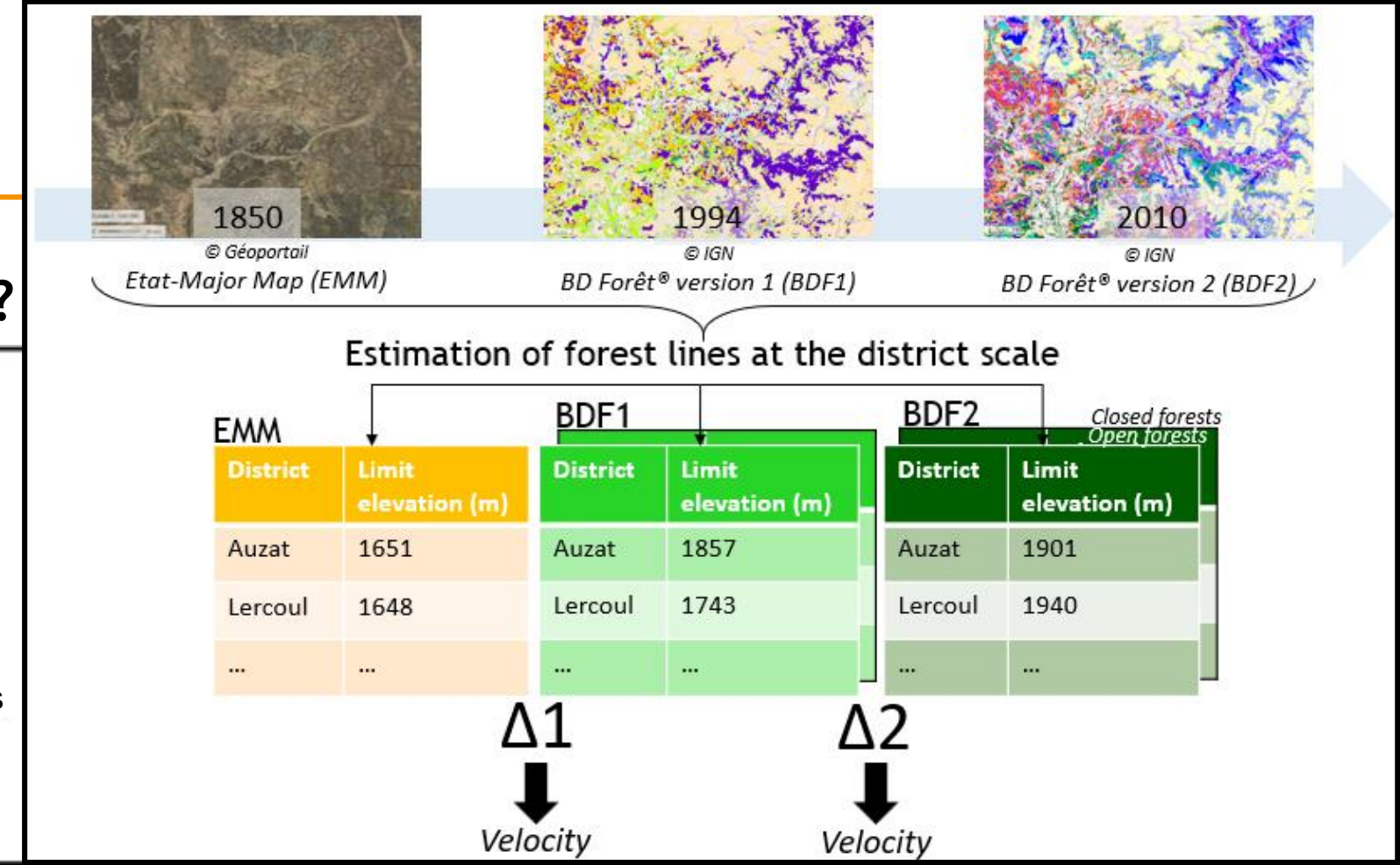


Figure 1: Location of the 125 studied communal districts in the French Pyrenees

Figure 2: Comparison of maps for each studied district

Results Significant forest line upward shift since the forest minimum

- Forest line elevation
- Etat-Major Map (EMM) : 1892 ± 51 m a.s.l.
 - BD Forêt® V1 (BDF1) : 2018 ± 51 m a.s.l.
 - BD Forêt® V2 (BDF2) : 2067 ± 50 m a.s.l.

- ANOVA on mixed effect model and post-hoc tests show a significant forest line upward shift (all p-values < 0,0001)
- This upward shift results from: 1) An abrupt change from low to high elevation groups
2) A gradual upward shift inside low and high elevation groups

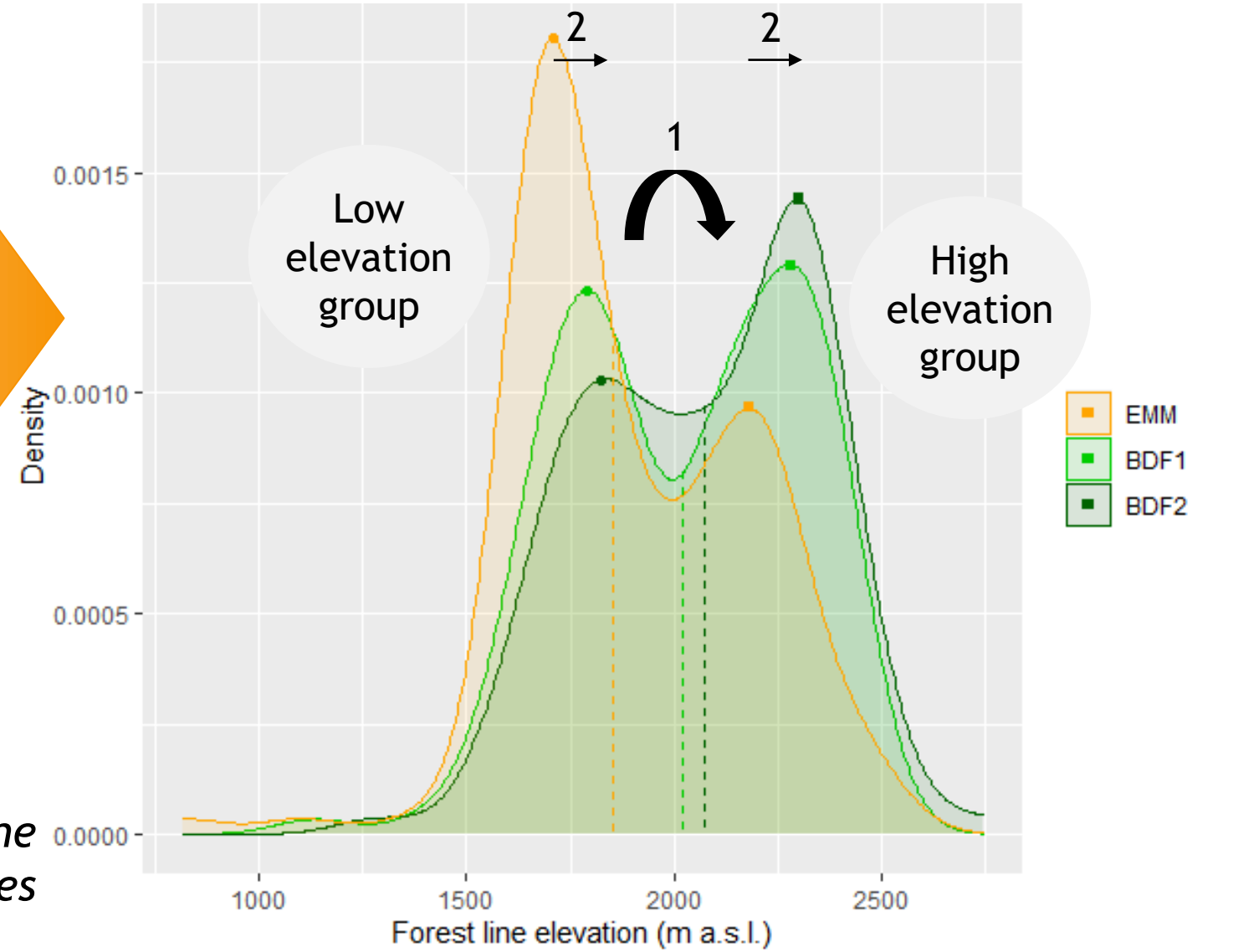


Figure 3: Distribution of forest line elevations in the French Pyrenees



Figure 4: Forest line shift in the French Pyrenees for ancient and recent periods

Forest line upward shift is accelerating in the recent period

- Ancient period (1850-1994) : upward shift of 126 ± 32 m
- Recent period (1994-2010) : upward shift of 49 ± 15 m
- Majority of districts show a forest line upward shift : 82% in ancient period and 76% in recent period

- Ancient period : shift velocity of 9 ± 2 m/decade
- Recent period : shift velocity of 34 ± 10 m/decade

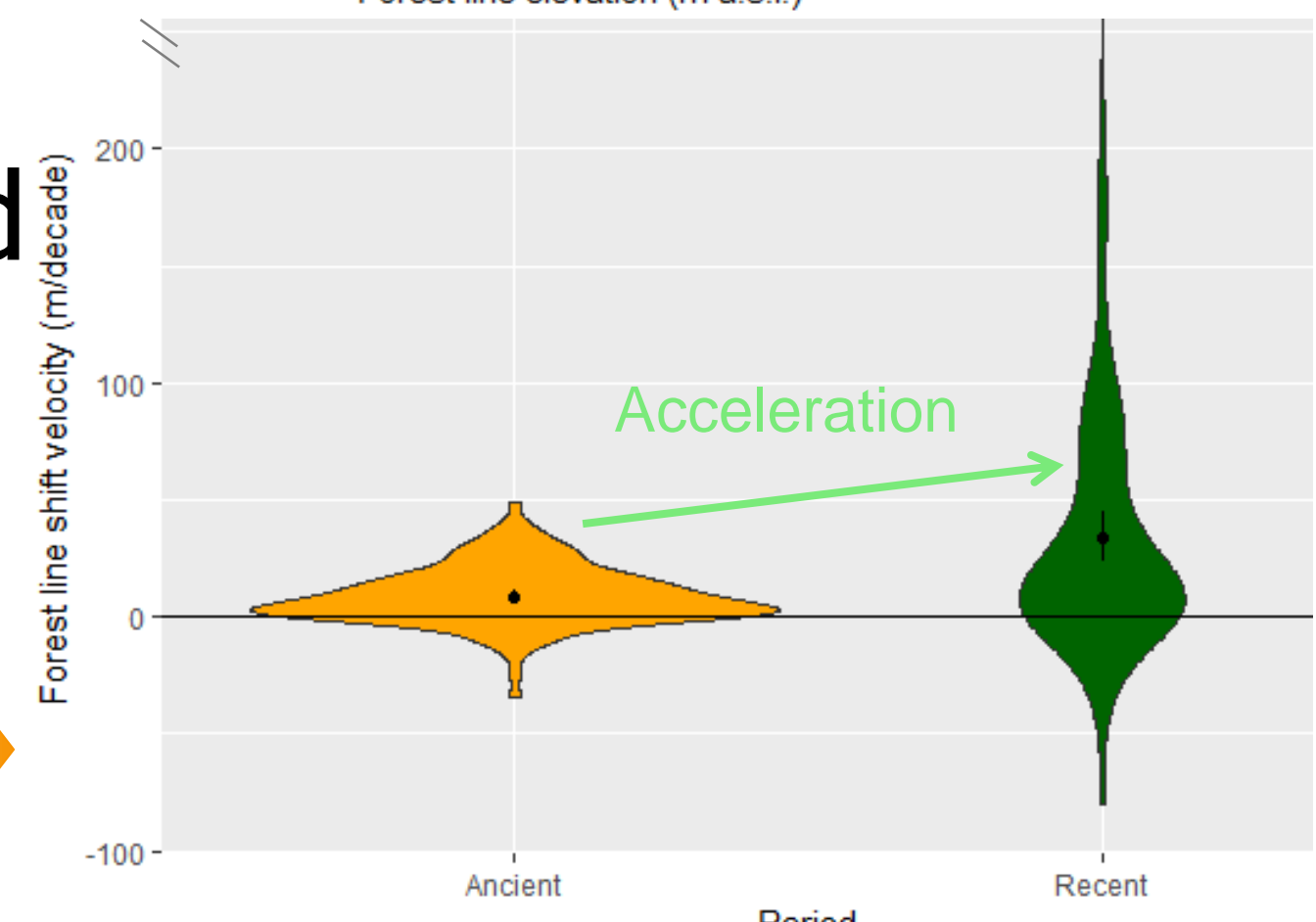
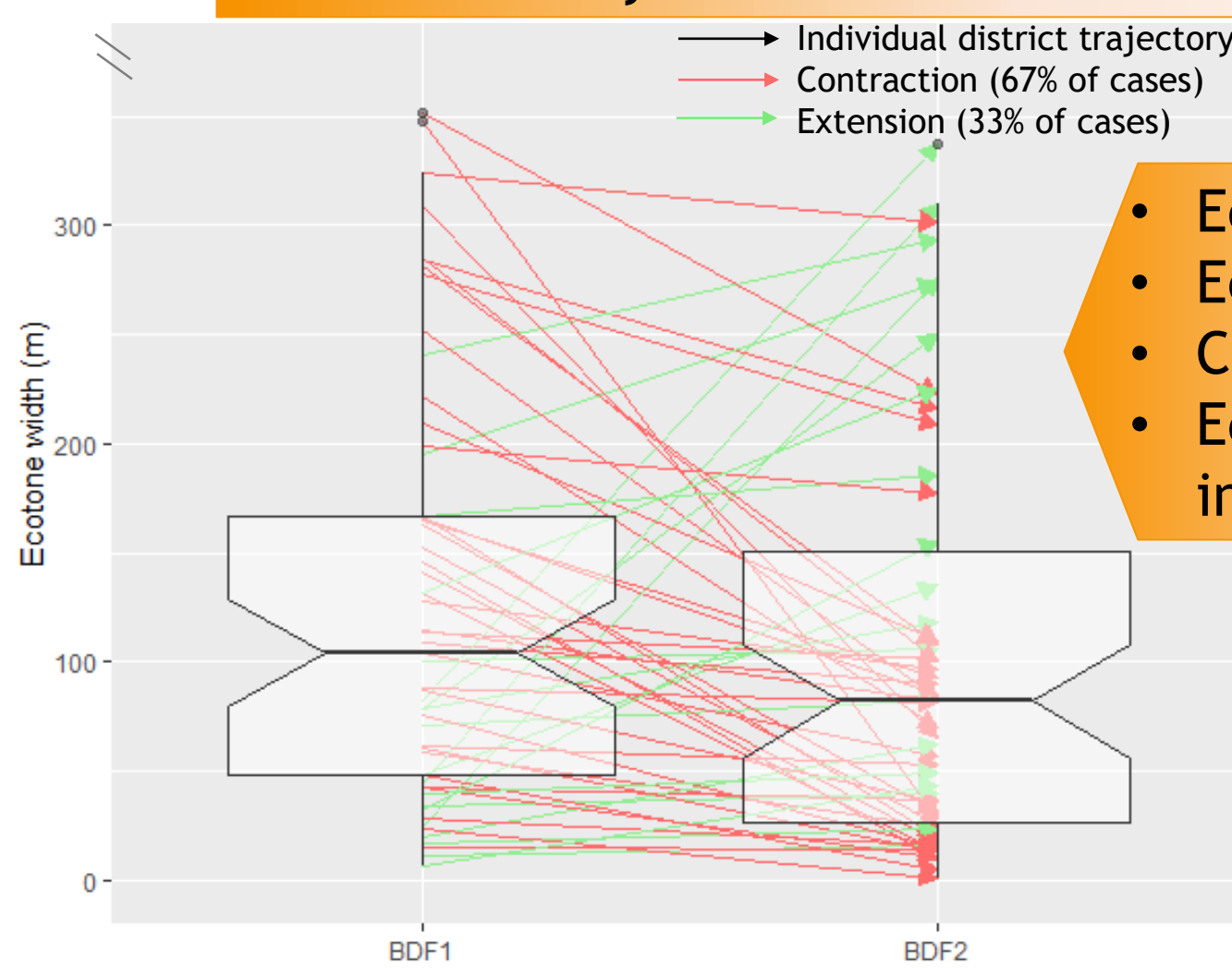


Figure 5: Forest line shift velocity in the French Pyrenees for ancient and recent periods

Faster upward shift of closed forest lines leads to ecotone contraction

- Shift velocity of open forest line : 41 ± 17 m/decade
- Shift velocity of closed forest line : 70 ± 25 m/decade



- Ecotone in BDF1 : 154 ± 38 m
- Ecotone in BDF2 : 114 ± 28 m
- Contraction of 29 m/decade
- Ecotone contraction is observed in 2/3 of the cases

Discussion

In this study, we found a general upward shift of about 175 m since the forest minimum, which is consistent with what is known from literature (Améztegui *et al.*, 2016 ; Feuillet *et al.*, 2020 ; Harsch *et al.*, 2009). However, thanks to the span of the study period, we put in evidence an acceleration of forest line upward shift in the recent period. This suggest an increasing prominent role of global warming. We also observed an ecotone contraction as a result of the faster upward shift of closed forest lines. While forest line upward shift acceleration and ecotone contraction may be a threat for biodiversity, they also represent strong potential sink of carbon for long term sequestration.

Perspectives

The next step will be to analyse the relationship between forest line dynamics and environmental factors.

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