Vegetation Dynamics in Alpine Treeline Ecotones Worldwide 1985-2020

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Introduction

❖***Alpine Treeline Ecotone (ATE),*** an ecological transition zone between montane closed forests and alpine tundra areas in high mountains worldwide[1,2] (see *Fig. 1*), is: ***1)*** an essential habitat for numerous species and relevant to many ecological functions, ***2)*** both a potential at-risk area of and a powerful indicator for climate change[3,4].

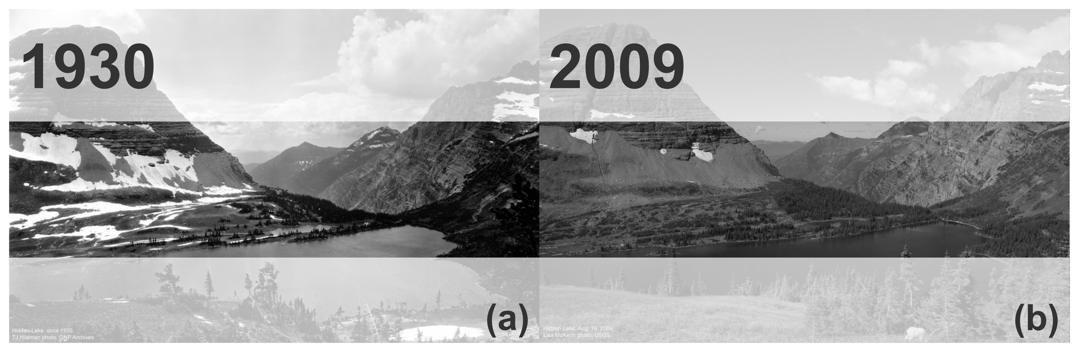

Fig. 1 *Hidden Lake in Glacier National Park, MT in a) 1930 (source: T.J. Hileman photo, courtesy of Glacier National Park Archives), b) 2009 (source: Lisa McKeon photo, courtesy of USGS).*

❖***Elevation-dependent warming:*** high-altitude regions often experience more rapid variations in temperature than the adjacent low land under climate change[5,6].

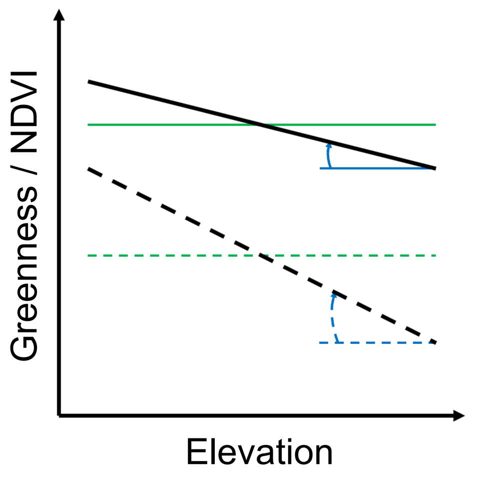

Fig. 2 *Illustration of the estimated greenness indices (i.e., NDVIs) in 1985 (dashed) and 2020 (solid) on a hillslope. Black lines: the estimated NDVI trend line over elevation. Green lines: the average value of NDVI. Blue angles: the estimated elevational gradient of NDVI.*

❖***Research hypotheses: 1)*** most ATEs have become "greener" over the past decades, ***2)*** vegetation productivity in most ATEs has become more homogenized along the elevational gradient.

❖***Research objectives: 1)*** to monitor the variation of NDVI over time in ATEs worldwide from 1985 to 2020, ***2)*** to quantify the temporal dynamics of the elevational gradient of NDVI in ATEs during the 36 years.

Fig. 3 *Illustration of the image pixels of two gridded datasets at 1-km (red) and 3-km (blue) resolutions in Olympic National Park, WA.*

❖***Challenges of using gridded data in mountain research: 1)*** potentially mixed information and concealed patterns of spatially fine environmental variables (see *Grids 6 & 7* in *Fig. 3*), ***2)*** uncertain spatial representativeness for ecological variability in different zones (see *Grids 2-5* in *Fig. 3*), ***3)*** potentially biased data analysis results toward low-lying regions (see *Grid 8* in *Fig. 3*).

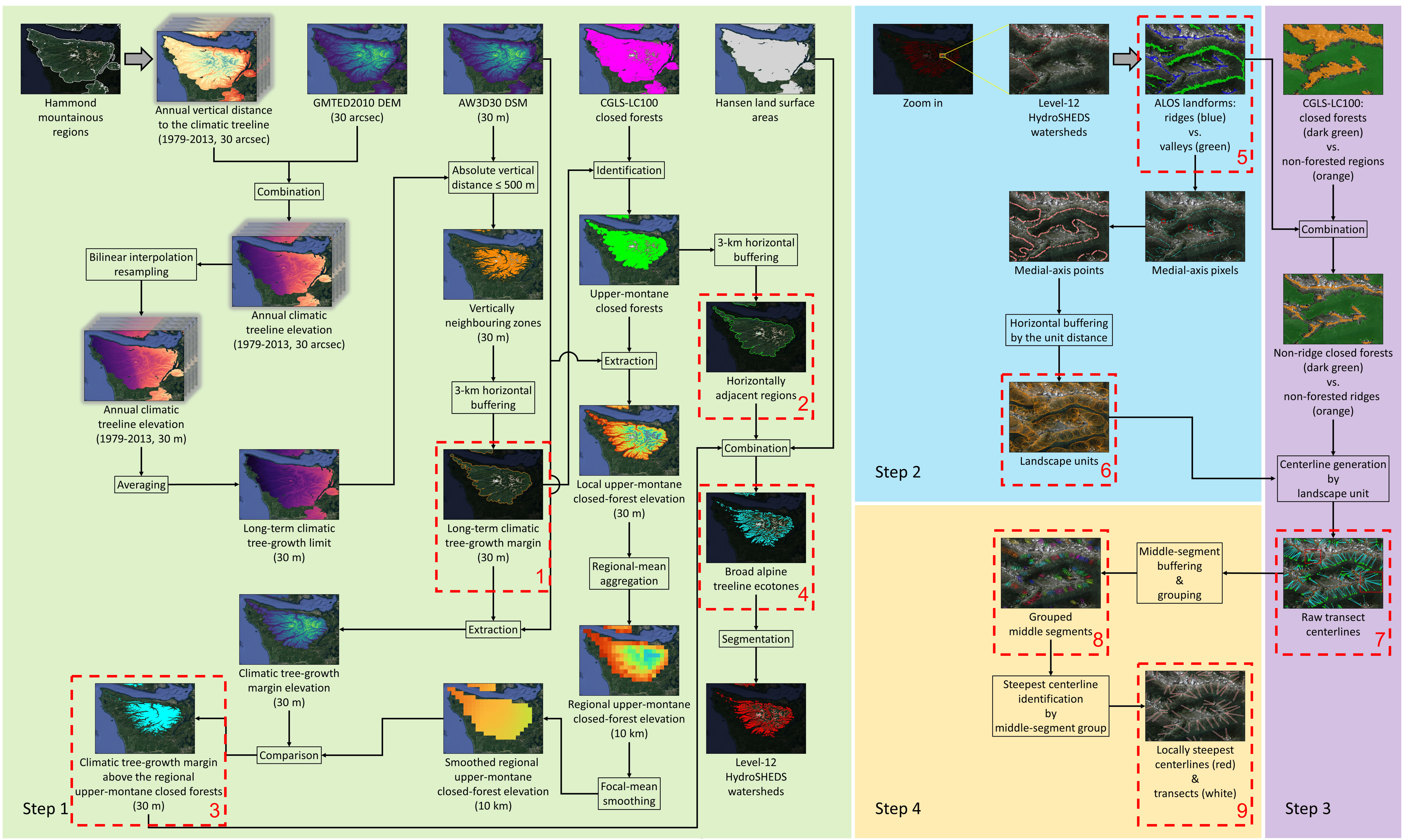

Fig. 4 *Simplified workflow for constructing alpine treeline elevational transects (ATETs) in Olympic National Park, WA.*

Alpine Treeline Elevational Transect (ATET) Construction

❖***Step 1 -- Broad ATE identification:***

1) **Climate-based identification** -- delineate mountainous regions with conditions similar to the climatic limit of tree growth[7-9] worldwide (see *Map 1* in *Fig. 4* and the *blue-shaded regions* in *Mountains B-E* in *Fig. 5*).

2) **Land-cover-based identification** -- determine the climatic tree-growth margin spatially adjacent to (see *Map 2* in *Fig. 4* and *dotted orange polygons* in *Fig. 5*) and regionally higher than[10-12] (see *Map 3* in *Fig. 4* and the *dotted purple line* in *Fig. 5*) the upper-montane closed forests[13] (see *Map 4* in *Fig. 4* and *red polygons* in *Fig. 5*).

❖***Step 2 -- Landscape unit determination:*** define unit areas (see *Map 6* in *Fig. 4*) in the broad ATE based on the ridge and valley landforms[14] (see *Map 5* in *Fig. 4*) to ensure transects are established at the hillside scale.

❖***Step 3 -- Transect centerline construction:*** pinpoint and connect the lowest non-ridge closed forest and the highest non-forested ridge within each landscape unit (see *Map 7* in *Fig. 4*) so that the determined centerlines are oriented along the ecological transition in ATEs.

❖***Step 4 -- Steepest transect selection: 1)*** group the clustered centerlines based on their mid-quarter segments (see *Map 8* in *Fig. 4*), ***2)*** identify and buffer the centerline with the greatest elevation range for each group (see *Map 9* in *Fig. 4*).

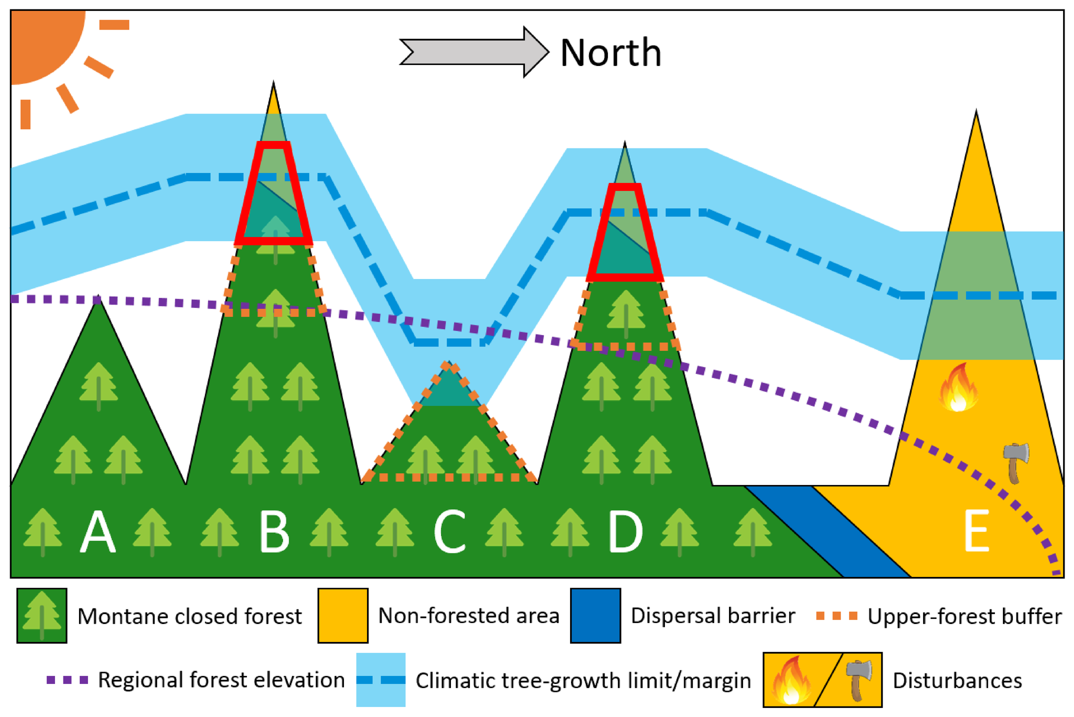

Fig. 5 *Illustration of the broad ATE determination in a mountain range based on the pertinent climatic and land cover information at the local and regional levels. Red polygons indicate the identified broad ATEs.*

Vegetation Productivity Analysis

❖***Annual NDVI estimation by ATET (1985-2020): 1)*** derive and smooth the yearly max. LANDSAT NDVI at each 30-m pixel in the broad ATE, ***2)*** calculate the spatial average NDVI of each ATET (see *green lines* in *Fig. 2*), ***3)*** quantify the elevational gradient of NDVI for each ATET (see *blue angles* in *Fig. 2*) with the non-parametric Theil-Sen (T-S) estimator.

❖***Temporal NDVI dynamics by ATET: 1)*** remove abnormal NDVI values for each ATET through a moving-window approach, ***2)*** **Hypothesis-1 testing** -- estimate the trend of annual average NDVIs over time using the T-S estimator (see the *horizontal axis* in *Fig. 6*), ***3)*** **Hypothesis-2 testing** -- analyze the temporal trend of the yearly elevational gradients of NDVI with the T-S estimator (see the *vertical axis* in *Fig. 6*).

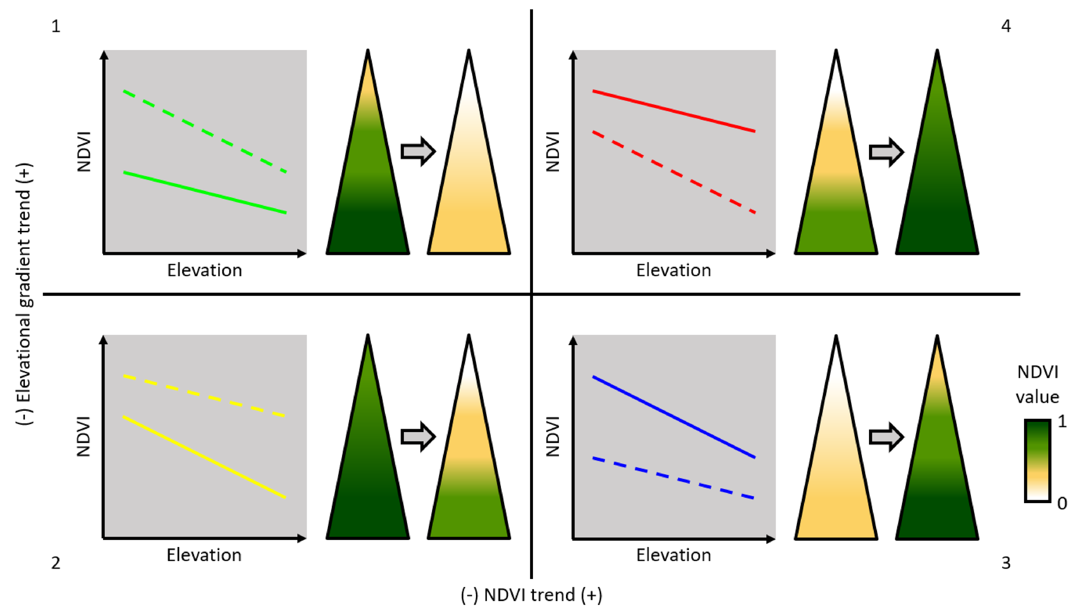

Fig. 6 *Possible scenarios of the temporal dynamics of NDVI and its elevational gradient of each ATET. 1985: the dashed line and the left triangle in each panel. 2020: the solid line and the right triangle in each panel.*

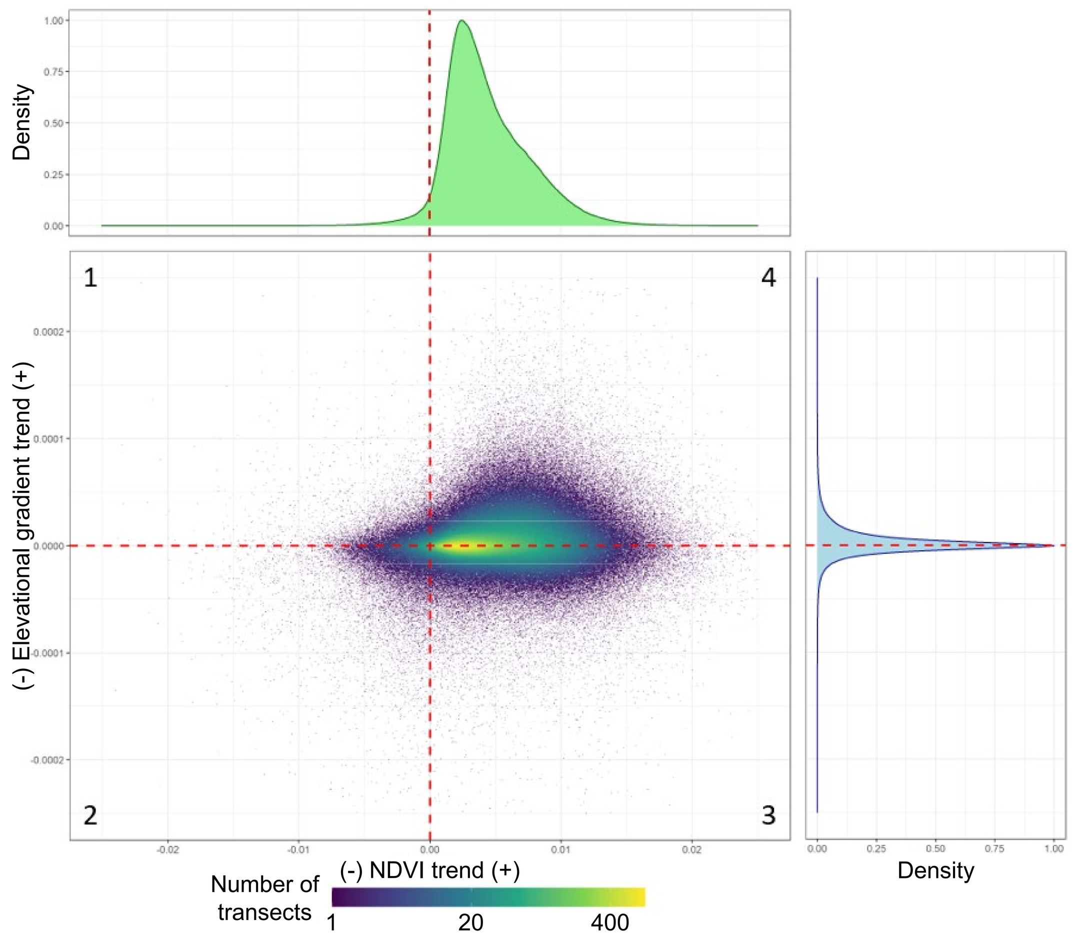

Fig. 7 *Estimated temporal trends of the yearly average values and elevational gradients of NDVIs within each ATET from 1985 to 2020.*

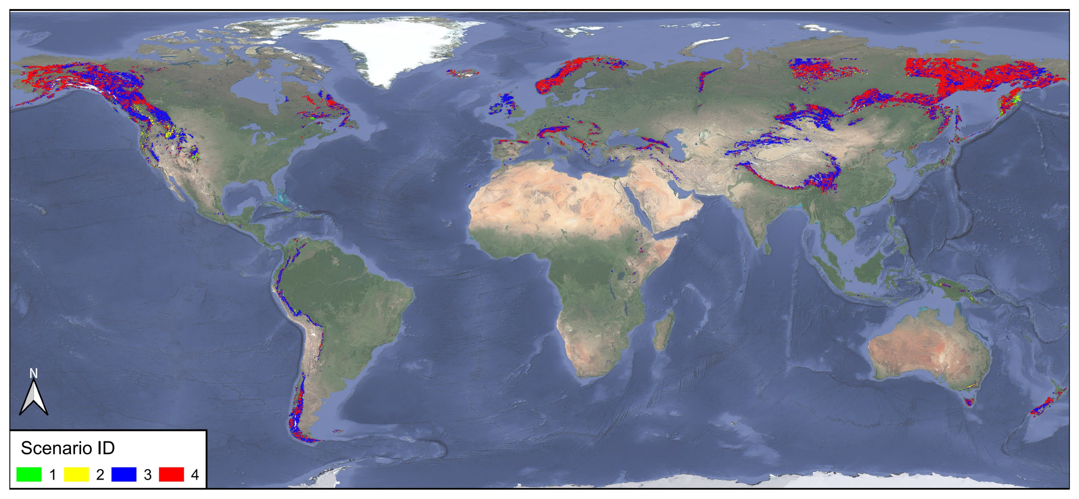

Fig. 8 *Spatial distribution of the possible scenarios of the temporal dynamics of NDVI and its elevational gradient of each ATET from 1985 to 2020. The results are aggregated to the Level-12 HydroSHEDS watersheds for better visualization.*

Conclusions

❖The vegetation productivity of roughly 96.6% ATETs increased from 1985 to 2020 (see *Scenarios 3 & 4* in *Figs. 7 & 8*).

❖In around 52.6% ATETs, vegetation productivity became more homogenized during the study period (see *Scenarios 1 & 4* in *Figs. 7 & 8*).

❖"Greener" and more homogenized ATETs (see *Scenario 4* in *Fig. 8*) were mostly situated within high-latitude regions.

Selected References

1. Körner, C. & Riedl, S. Alpine Treelines: Functional Ecology of the Global High Elevation Tree Limits. (Springer Basel, 2012).
2. Körner, C. The cold range limit of trees. Trends Ecol. Evol. 36, 979–989 (2021).
3. Camarero, J. J., Gutierrez, E. & Fortin, M.-J. Spatial patterns of plant richness across treeline ecotones in the Pyrenees reveal different locations for richness and tree cover boundaries. Glob. Ecol. Biogeogr. 15, 182–191 (2006).
4. Trant, A. J. et al. Complex Changes in Plant Communities across a Subarctic Alpine Tree Line in Labrador, Canada. Arctic 68, 500–512 (2015).
5. Pepin, N. et al. Elevation-dependent warming in mountain regions of the world. Nat. Clim. Chang. 5, 424–430 (2015).
6. Pepin, N. C. et al. Climate changes and their elevational patterns in the mountains of the world. Rev. Geophys. 60, (2022).
7. Paulsen, J. & Körner, C. A climate-based model to predict potential treeline position around the globe. Alpine Botany 124, 1–12 (2014).
8. Karger, D. N. et al. Climatologies at high resolution for the earth's land surface areas. Sci Data 4, 170122 (2017).
9. Karger, D. N. et al. Why tree lines are lower on islands—Climatic and biogeographic effects hold the answer. Glob. Ecol. Biogeogr. 28, 839–850 (2019).
10. Takaku, J., Tadono, T., Tsutsui, K. & Ichikawa, M. VALIDATION OF'AW3D'GLOBAL DSM GENERATED FROM ALOS PRISM. ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences 3, (2016).
11. Takaku, J., Tadono, T., Doutsu, M., Ohgushi, F. & Kai, H. Updates of 'aw3d30' Alos global digital surface model with other open access datasets. ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XLIII-B4-2020, 183–189 (2020).
12. Tadono, T. et al. Generation of the 30 M-Mesh Global Digital Surface Model by Alos Prism. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 41B4, 157 (2016).
13. Buchhorn, M. et al. Copernicus Global Land Cover Layers—Collection 2. Remote Sensing 12, 1044 (2020).
14. Theobald, D. M., Harrison-Atlas, D., Monahan, W. B. & Albano, C. M. Ecologically-Relevant Maps of Landforms and Physiographic Diversity for Climate Adaptation Planning. PLoS One 10, e0143619 (2015).

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