Supplementary Information

Supplementary Tables

Table S1. List of species included in the analyses and their traits. **The species groups were defined using their trait values and knowledge of species ecology. Temperate species have temperature indices above 4.25, and boreal species below 4.25. Pioneer species have shade tolerance below 2.6 and are generally found in disturbed habitats.**

Species name	Vernacular name	Group	Shade tolerance	Temperature index
Abies balsamea	Balsam fir	Boreal	5.0	3.16
Acer pensylvanicum	Striped maple	Temperate	3.5	5.22
Acer rubrum	Red maple	Temperate	3.4	9.28
Acer saccharinum	Silver maple	Temperate	3.6	9.97
Acer saccharum	Sugar maple	Temperate	4.8	6.93
Acer spicatum	Mountain maple	Temperate	3.3	4.52
Alnus incana	Speckled alder	Boreal	1	1.22
Amelanchier sp.	Serviceberry	Temperate	3.4	9.40
Betula alleghaniensis	Yellow birch	Temperate	3.2	4.49
Betula papyrifera	White birch	Pioneer	1.5	3.69
Betula populifolia	Grey birch	Pioneer	1.5	5.58
Carpinus caroliniana	Blue beech	Temperate	4.6	15.90
Carya cordiformis	Bitternut hickory	Temperate	2.1	11.06
Fagus grandifolia	American beech	Temperate	4.8	8.46
Fraxinus americana	White ash	Temperate	2.5	9.54
Fraxinus nigra	Black ash	Temperate	3	4.92
Fraxinus pennsylvanica	Red ash	Temperate	3.1	11.86
Juglans cinerea	Butternut	Temperate	1.9	8.10
Larix laricina	Tamarack	Boreal	1	3.92
Malus sp.	Crab apple	Temperate	2.2	7.96

Species name	Vernacular name	Group	Shade tolerance	Temperature index
Ostrya virginiana	Ironwood	Temperate	4.6	8.91
Picea glauca	White spruce	Boreal	4.2	3.08
Picea mariana	Black spruce	Boreal	4.1	1.68
Picea rubens	Red spruce	Temperate	4.4	4.26
Pinus banksiana	Jack pine	Boreal	1.4	2.99
Pinus resinosa	Red pine	Temperate	1.9	5.54
Pinus strobus	Eastern white pine	Temperate	3.2	6.85
Populus balsamifera	Balsam poplar	Pioneer	1.3	4.25
Populus deltoides	Cottonwood	Pioneer	1.8	8.12
Populus grandidentata	Large tooth aspen	Pioneer	1.2	6.14
Populus tremuloides	Trembling aspen	Pioneer	1.2	4.22
Prunus pensylvanica	Pin cherry	Pioneer	1	4.01
Prunus serotina	Black cherry	Temperate	2.5	4.69
Prunus virginiana	Chokecherry	Temperate	2.6	7.79
Quercus alba	White oak	Temperate	2.9	12.95
Quercus bicolor	Swamp white oak	Temperate	3	9.51
Quercus macrocarpa	Bur oak	Temperate	2.7	6.72
Quercus rubra	Red oak	Temperate	2.8	9.67
Salix sp.	Willow	Pioneer	1.5	13.32
Sorbus sp.	Mountain-ash	Pioneer	2.6	2.31
Thuja occidentalis	White cedar	Temperate	3.5	4.30
Tilia americana	Basswood	Temperate	4	5.34
Tsuga canadensis	Eastern hemlock	Temperate	4.8	6.87
Ulmus americana	American elm	Temperate	3.1	10.67
Ulmus rubra	Red elm	Temperate	3.3	12.37
Ulmus thomasii	Rock elm	Temperate	3.2	7.80

Table S2. 21 original disturbance types and their reclassification into natural disturbances and harvest, with three levels of intensity. Sites with tree planting were excluded from the study.

	Original disturbance types	Reclassification	Disturbance level
1	Improvement cutting	Harvest	Moderate
2	Strip cutting	Harvest	Moderate
3	Checkerboard clear-cutting	Harvest	Moderate
4	Diameter-limit cutting	Harvest	Moderate
5	Selection cutting	Harvest	Moderate
6	Partial cutting	Harvest	Moderate
7	Diameter-limit cutting with crop tree release	Harvest	Moderate
8	Commercial thinning	Harvest	Moderate
9	Partial cutting with light outbreak	Harvest	Moderate
10	Partial burn	Natural	Moderate
11	Light outbreak	Natural	Moderate
12	Partial windfall	Natural	Moderate
13	Partial ice storm	Natural	Moderate
14	Partial decline	Natural	Moderate
15	Final strip cutting	Harvest	Major
16	Harvesting with protection of regeneration	Harvest	Major
17	Clearcutting	Harvest	Major
18	Total burn	Natural	Major
19	Severe outbreak	Natural	Major
20	Total windfall	Natural	Major
21	Total decline	Natural	Major
-	Seeding	Plantation	x
-	Planting	Plantation	x
-	Planting bare-rooted seedlings	Plantation	x
-	Container planting	Plantation	x

Table S3. List of R packages used for analyses.

Packages	Uses	References
adespatial	Forward selection (`forward.sel`), temporal beta diversity (`tbi`)	Dray *et al.* (2018)
FD	Functional composition (`functcomp`)	Laliberté *et al.* (2014)
raster	Manipulation of spatial data	Hijmans (2018)
sf	Manipulation of spatial data	Pebesma (2018)
stats	Linear regressions (`lm`)	R Core Team (2018)
vegan	Variation partitioning (`varpart`)	Oksanen *et al.* (2019)
zoo	Rolling average (`rollmean`)	Zeileis & Grothendieck (2005)

Supplementary Figures

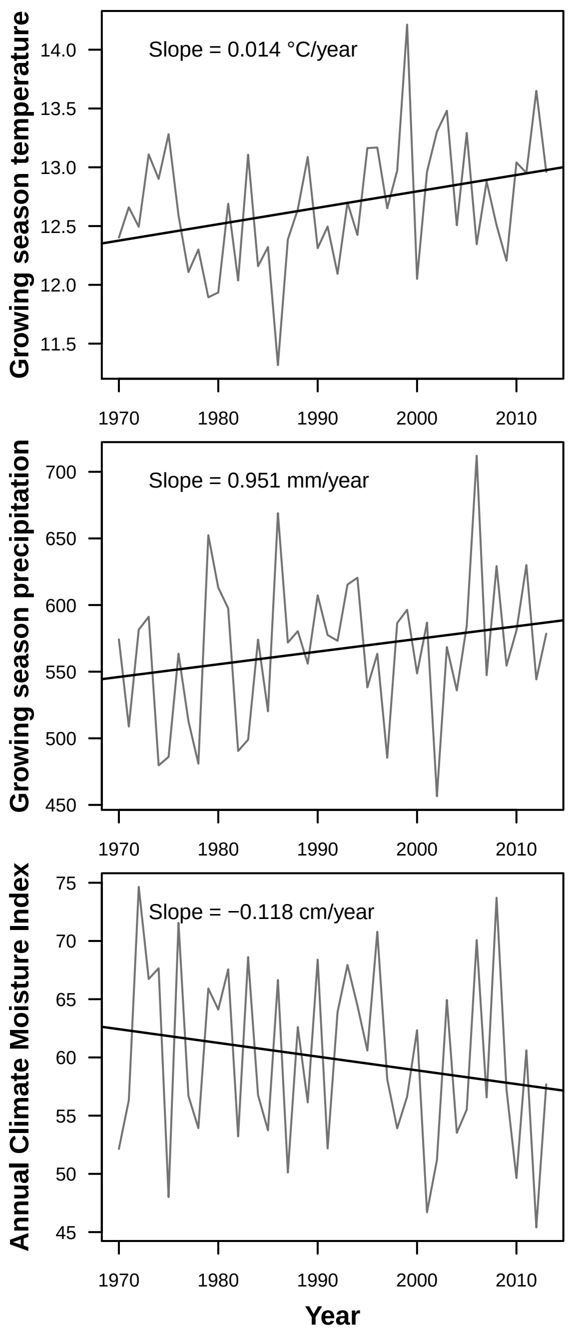

Figure S1. Temporal trends in growing season temperatures (top), total growing season precipitation (middle) and annual climate moisture index (bottom). Grey lines represent averaged climate values across the 6281 studied forest plots. Straight black lines show the fitted least-squared linear regression lines.

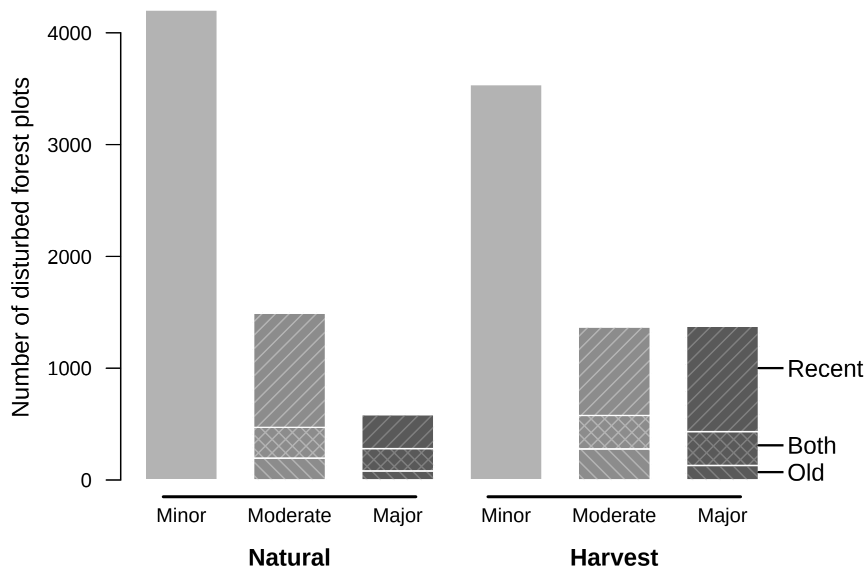

Figure S2. Frequency of forest plots by disturbance type (natural disturbances and harvest), level of intensity (minor, moderate, major) and timing (old refers to disturbances that occurred before the study period whereas recent disturbances occurred during the study period). The three columns in each disturbance type sum to $n = 6281$ forest plots, but many forest plots have been disturbed by more than one type of disturbance during the study period.

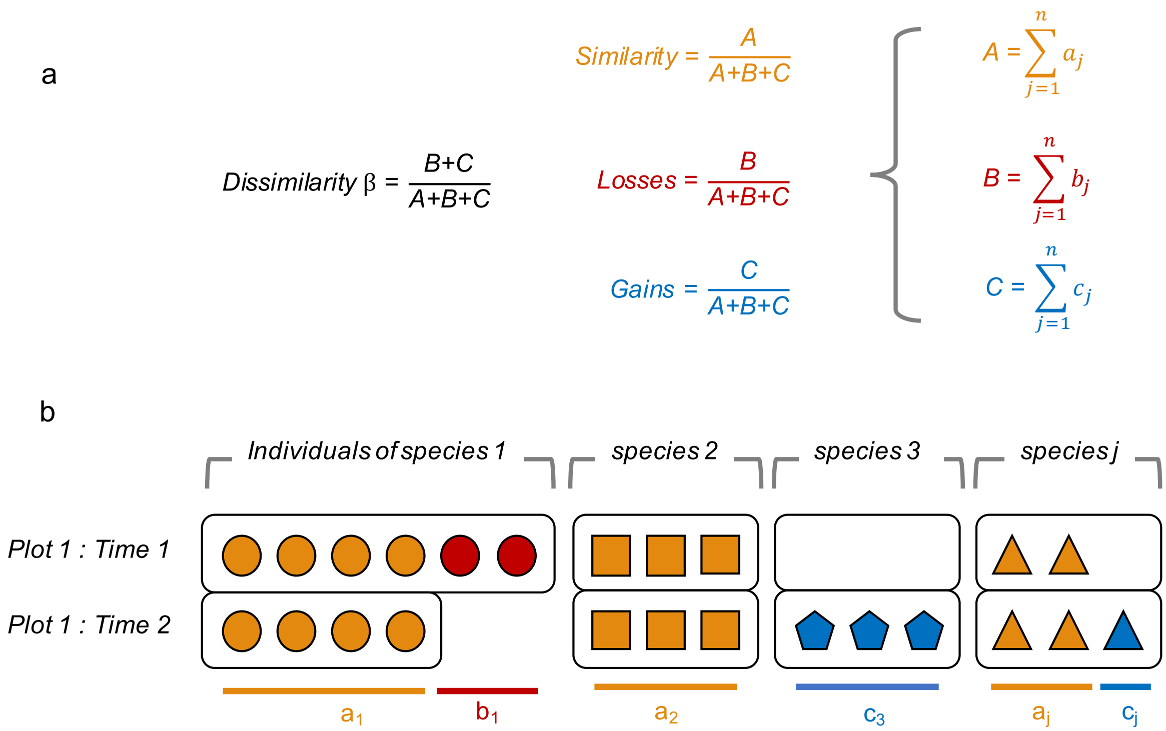

Figure S3. Equations to compute the temporal ß diversity index, as well as its components, using the Ružička coefficient for abundance data (a) and an example (b) where the tree composition of a single forest plot is compared between two surveys, t_1 and t_2. In the example, each of the n species is represented by a symbol. The symbols in yellow represent the abundance of a species that is common to the two survey (component A; note that it can be different individuals of the same species). The symbols in red represent the abundance of a species that is lost between t_1 and t_2 (component B). The symbols in blue represent the abundance of a species that is gained between t_1 and t_2 (component C). In this example, $A = 4 + 3 + 2 = 9$, $B = 2$, and $C = 3 + 1 = 4$, therefore $\beta = 2 + 4/(9 + 2 + 4) = 0.4$.

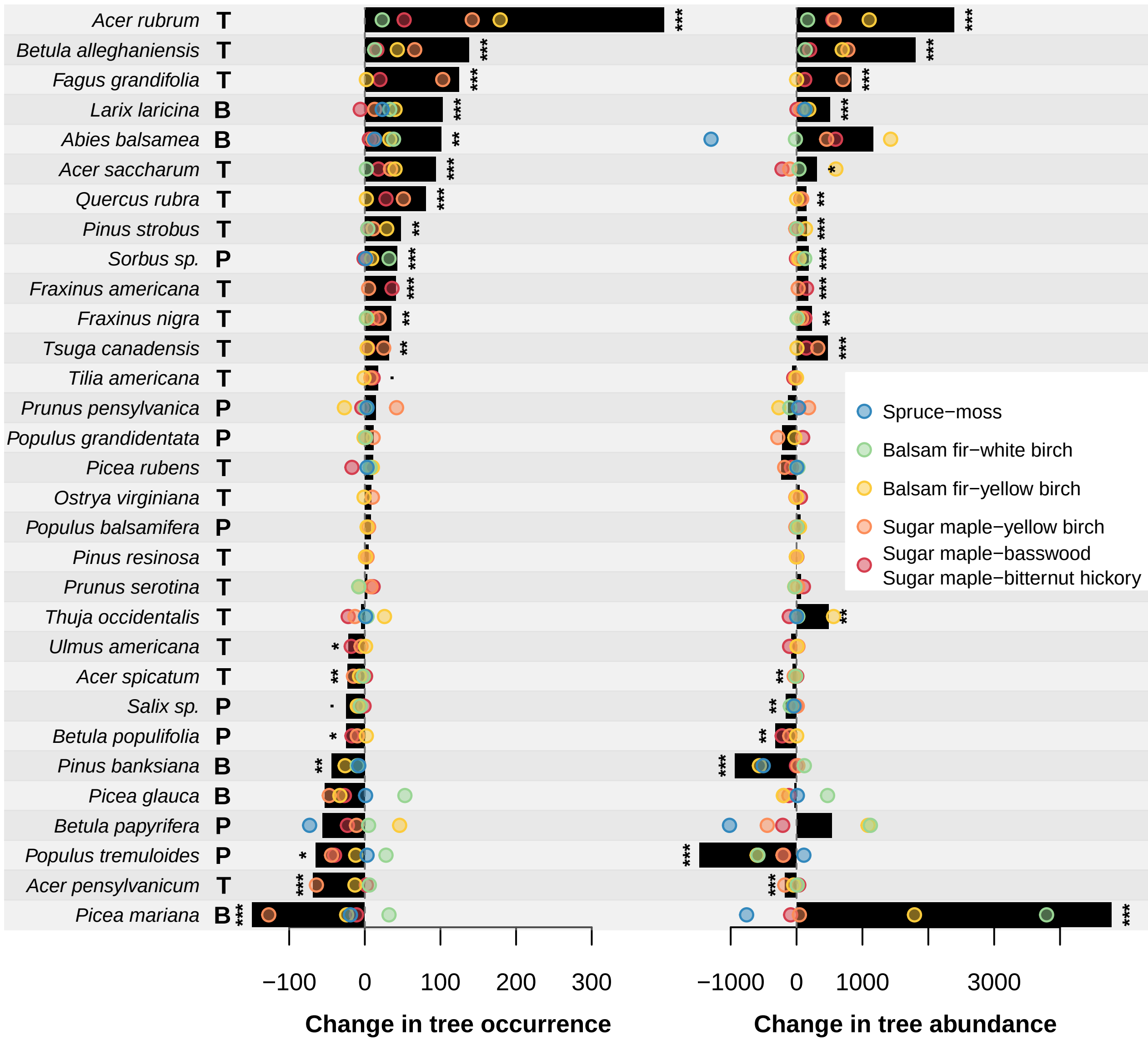

Figure S4. Species temporal changes for Québec forests and for each bioclimatic domain. Changes in species occurrence (left) and species abundance (right). Only the species occupying more than 20 plots are shown. The bars represent the mean changes across the study area, while the colored points represent the mean changes by bioclimatic domain. Stars represent the levels of the significance of the p-value (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$) associated with Wilcoxon signed-rank tests used to determine whether individual species changes in occurrence and abundance were significant. An increase in occurrence indicates that the species has spread regionally, while an increase in abundance indicates that the species has spread locally and/or regionally. Letters next to species names correspond to (T)emperate; (P)ioneer and (B)oreal species.

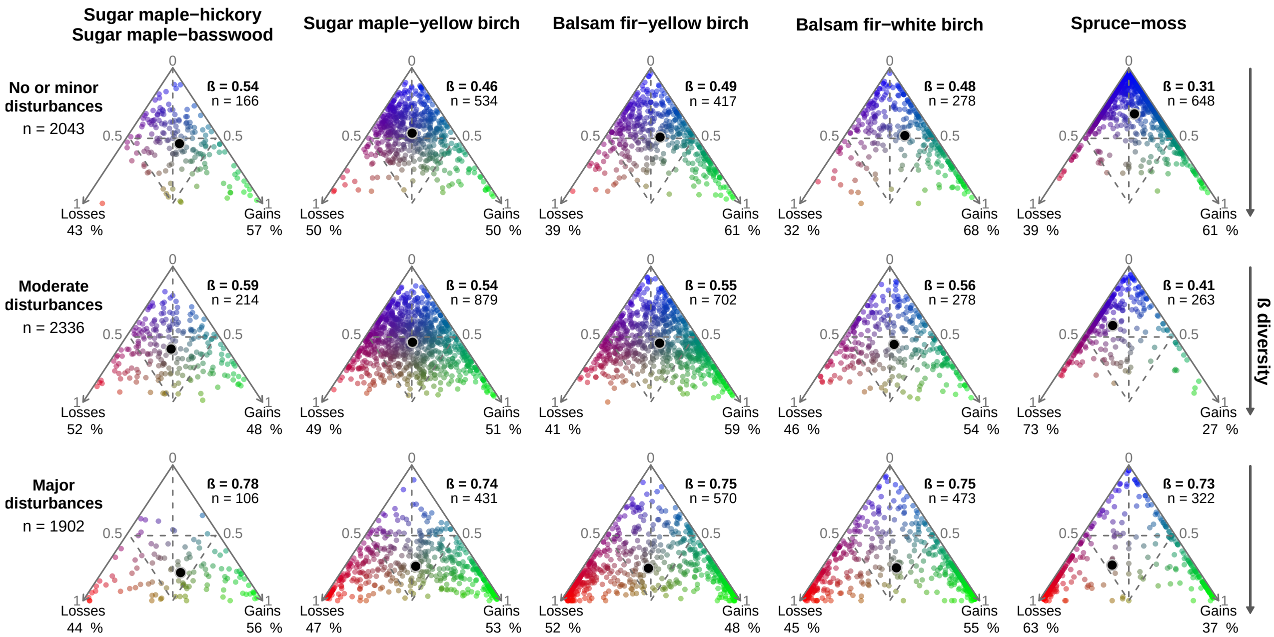

Figure S5. Triangular diagrams of gains and losses in tree abundance by bioclimatic domains and disturbance levels. Each point represents a forest plot and the large black point represents the centroid. At the upper tip of the triangle, similarity is high (ß = 0; blue colors). At the base of the triangle, dissimilarity is high (ß = 1). On the left, forests in red are dominated by losses, while on the right, forests in green are dominated by gains. The similar distributions of gain and loss values in the ternary diagrams suggests that there is no major difference in temporal ß diversity patterns among domains.

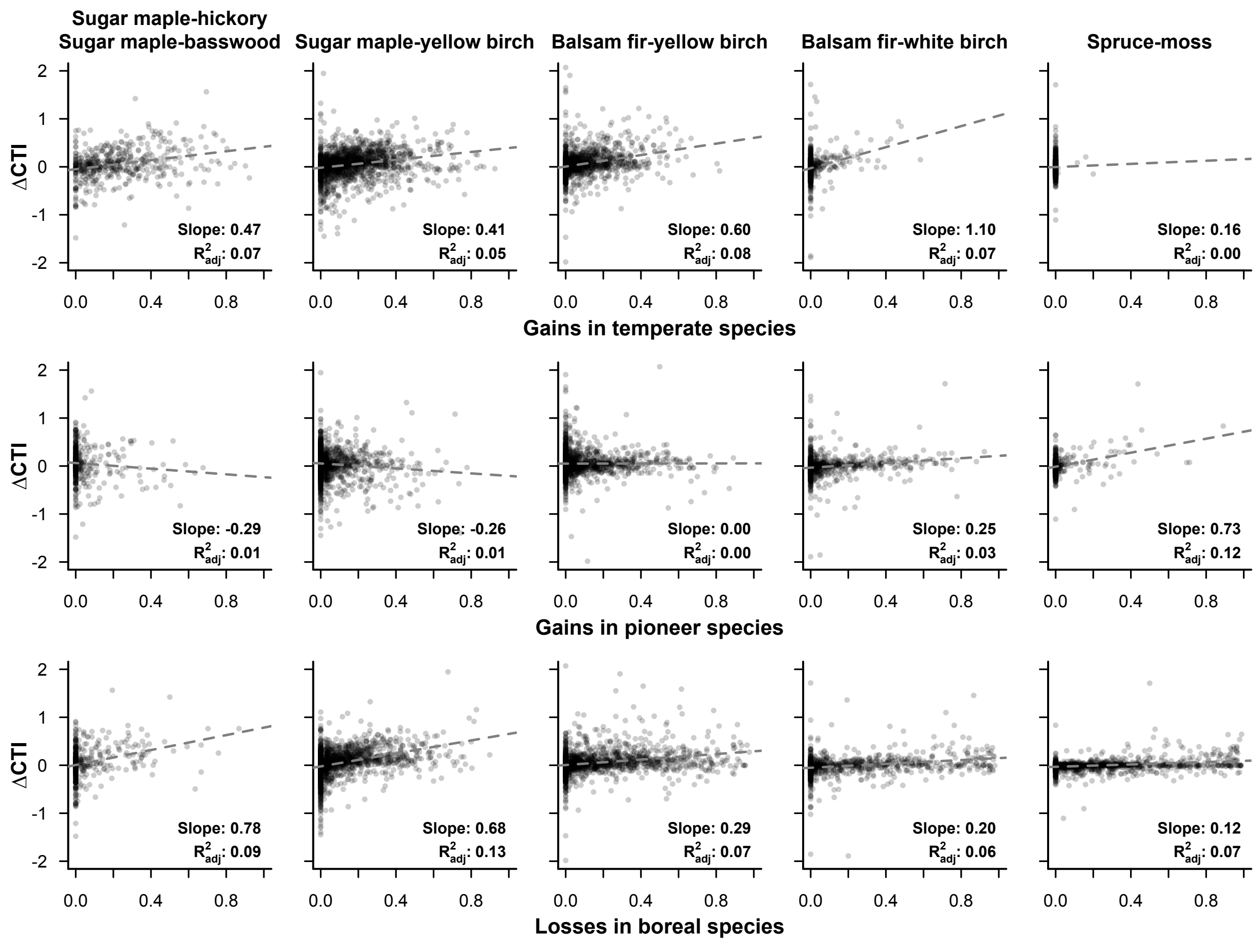

Figure S6. Relations between change in Community Temperature Index (ΔCTI) and gains in temperate (top), gains in pioneer (middle) and losses in boreal species (bottom). In each panel, the slope and adjusted R^2 of a linear regression model are shown.

References

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