

Appendix 1: Sensitivity analysis of the vegetation model

The sensitivity analysis of the parameters of the vegetation model on the dominance of different biomes at equilibrium has been conducted as follows. Each parameter was drawn from a normal distribution resulting in a realistic range of variation (See Table A1). Each parameter randomization was given by a dimension of a Latin-hypercube in order to maximize the total explored parameter space. 10 000 sets of parameters were generated randomly and the model was solved at equilibrium for each of those sets. We assessed the importance of each parameter on two different response variables. The first model focused on the dominance of Boreal versus Temperate forest as a categorical response variable. A second model had the proportion of open vegetation as response variable. We used random forest algorithms to fit the models as they are flexible. Parameters importance were ranked according to the mean decrease Gini index for the categorical response variable and node purity for the continuous variable. Importance measures are reported into the two following graphs.

Vegetation parameter	μ	σ	minimum	maximum
$a_T = a_B$	1/20	0.01	$\sim 1/80$	$\sim 1/10$
c	0.5	0.1	~ 0.1	~ 0.9
$1/d_T$	250	50	~ 50	~ 450
$1/d_T$	250	50	~ 50	~ 450
k	0.5	0.1	~ 0.1	~ 0.9

Table. A1 Variability of vegetation parameters for the sensitivity analysis.

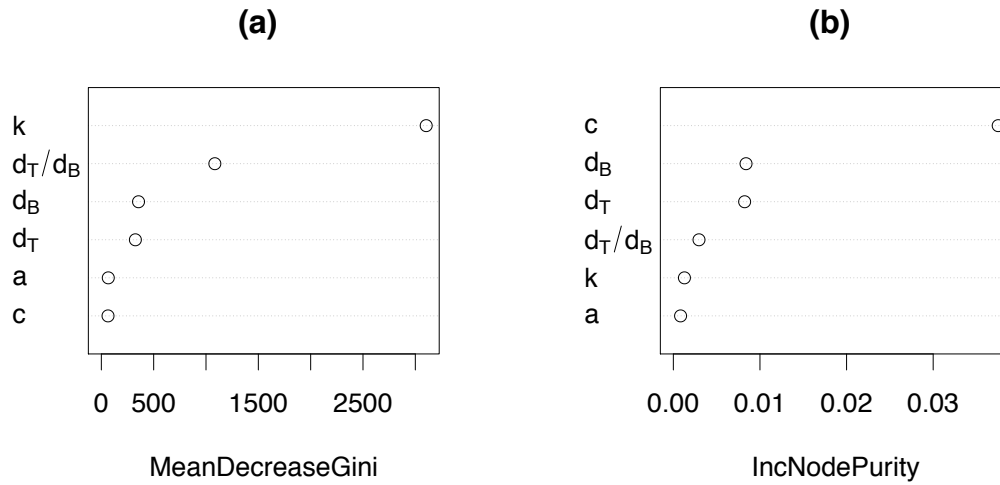


Fig. A1. Sensitivity of the vegetation states at equilibrium to the vegetation parameters Both the Gini index and the node purity are used as measures of the importance of variables (a) Importance of the different parameters for the dominance of Boreal vs. Temperate mature trees. (b) Importance of the different parameters to determine the proportion of open vegetation.

Appendix 2: Computation of browser impacts on the vegetation dynamics

Total resource consumption

The total intakes are used to compute herbivore gains in equations 3 and 4. They are, for summer and winter respectively:

$$I_s = \frac{G_s(R, T, B, H)}{e_s}$$

$$I_w = \frac{G_w(R, T, B, H)}{e_w}$$

Resource consumption attributed to type R

The consumption of seedlings and sapling in summer, U_s , and winter, U_w , are only proportions ϕ_s and ϕ_w of the total intakes:

$$U_s = \phi_s \cdot I_s$$

$$U_w = \phi_w \cdot I_w$$

In presence of grazing, I_s is reduced by the grazed proportion:

$$U_s = \phi_s \cdot I_s \cdot \left(1 - \frac{F_{sG}}{F_s}\right)$$

In a passive scenario, we assume that the consumption of each vegetation type is proportional to its available biomass:

$$\phi_{s0} = \frac{u_R \cdot R \cdot f}{(u_R \cdot R + u_T \cdot T) \cdot f}$$
$$\phi_{w0} = \frac{u_R \cdot R \cdot (1 - f)}{(u_R \cdot R + u_T \cdot T) \cdot (1 - f) + u_B \cdot B}$$

If we consider an active selection of the vegetation patch R over mature stands, the proportions ϕ_s and ϕ_w will be modified as follows:

$$\phi(p_R) = \frac{p_R \cdot \phi_0}{p_R \cdot \phi + (1 - \phi) \cdot (1 - p_R)}$$

where p_R is the additional parameter describing the preference of regeneration patches over mature stands.

Herbivore impacts

The impact of browsers depends on the ratio between the amount of biomass consumed and the available biomass. P_R is the herbivory impact on seedlings and saplings and is computed as follows:

$$P_R = \frac{U_s + U_w}{u_R \cdot R}$$

To compute the specific impacts on temperate or boreal stand development, we assume that the type of vegetation (temperate or boreal) available in state R is proportional to the amount of corresponding mature tree stands in the landscape, thus:

$$w = \frac{T + \epsilon}{B + T + 2 \cdot \epsilon}$$

where ϵ is a negligible quantity added to avoid dividing by 0 when $B + T = 0$. We assume that the proportion of consumed temperate seedlings and saplings is dependent on both their availability and their preference by browsers:

$$q = \frac{p \cdot w}{p \cdot w + (1 - w) \cdot (1 - p)}$$

The same applies for boreal trees. P_T and P_B are the specific impacts on temperate and boreal regeneration, respectively, computed as follows:

$$P_T = \frac{q}{w} \cdot P_R$$

$$P_B = \frac{1 - q}{1 - w} \cdot P_R$$

Appendix 3: Parameter variations along the climatic gradient

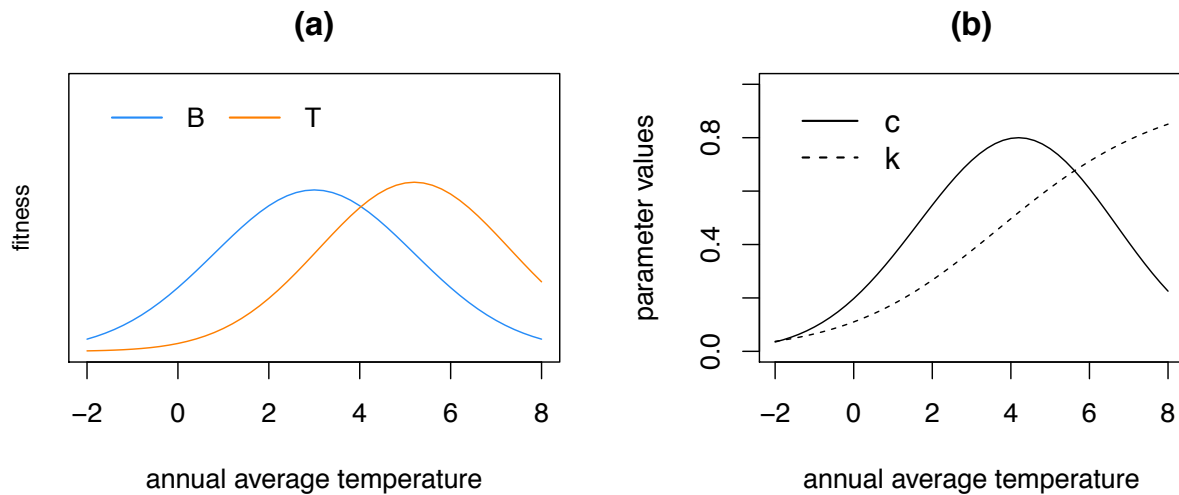


Fig. A3. Parameter variation along the gradient (a) Success of boreal trees (blue), temperate trees (orange) along the gradient. These curves were chosen to depict the succession of the two species niches along the gradient. The fitness of boreal trees is distributed around a mean of 3°C, with a standard deviation of 2.2°C. The fitness of temperate trees is distributed around a mean of 5.2°C, with a standard deviation of 2.1°C. (b) The parameter c (tree colonization rate) is a linear combination of temperate and boreal trees' fitnesses. The parameter k (performance of temperate trees relative to boreal trees) is derived from the ratio between the fitnesses of temperate trees and boreal trees.

Appendix 4: Parameterization of the influence of browsers

Parameters c_0 and a_0 are modified by herbivory pressures P_R , P_T and P_B . The general form of the multiplicative function is the same for the two parameters and is given by:

$$\frac{1}{1 + e^{r \cdot (P-h)}}$$

where P is the herbivory pressure. This function allows the herbivory impact to stay limited at low herbivore density and saturate at high herbivore density. The two parameters r and h were chosen so that browsers have a significant impact on vegetation when their density is 1 individual per km², and may revert the vegetation dominance at 5 individuals per km².

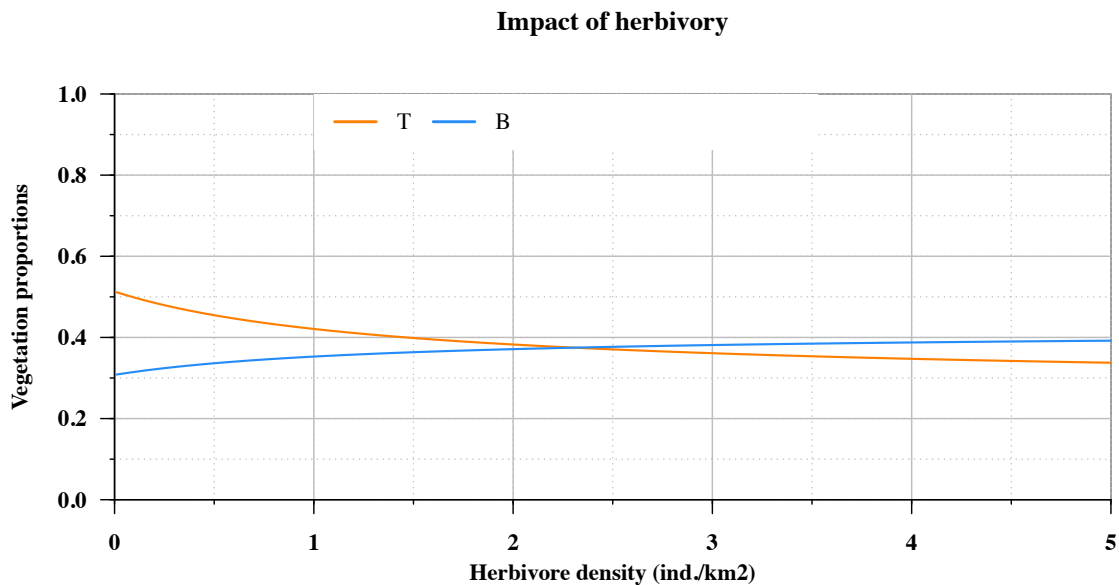


Fig. A4. Impact browsers on vegetation. Individuals were considered weighing 375 kg on average. Here, $c = 0.7$ and $k = 0.4$, which corresponds to an intermediate climate (ca. 3°C).

Appendix 5: Effect of an active preference of regeneration stands by browsers

We present here the main results for a preference of seedlings and saplings over mature trees, at equal available biomass to the herbivore, i.e. $p_R = 0.8$ instead of 0.5.

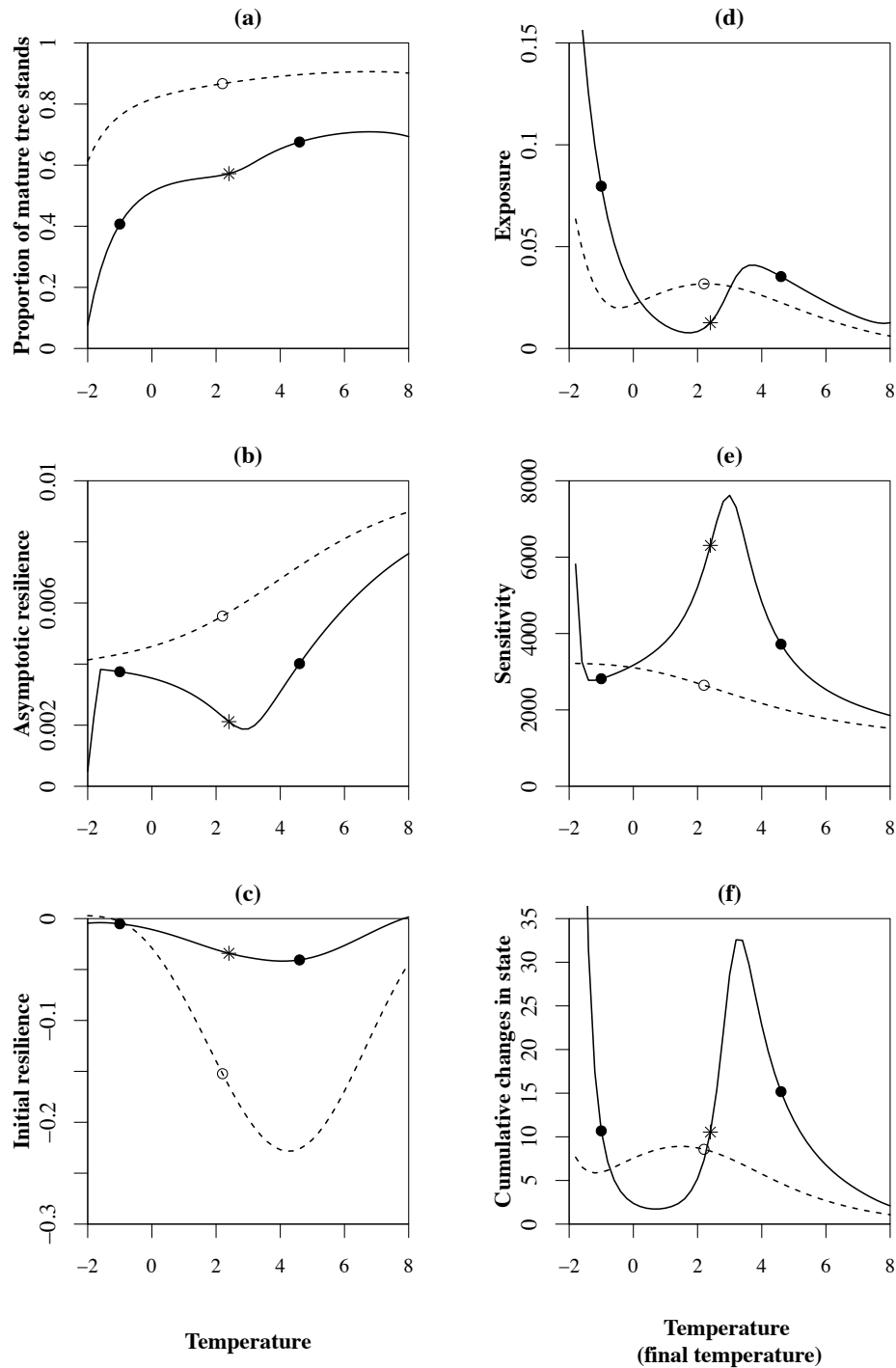


Fig. A5a. Ecosystem response along the increasing temperature gradient, with or without plant-herbivore interactions. (a) Proportion of mature tree stands at equilibrium along the increasing temperature gradient, (b) asymptotic resilience R_∞ (c) initial resilience $-R_0$, (d) exposure ΔN (e) sensitivity Δt , and (f) cumulative changes in vegetation state during the transient period $\int N dt$. For the five measures (b – f), dashed lines indicate values without browsers, and solid lines indicate values when including plant-herbivore interactions. The circles, solid when herbivores are included and open otherwise, indicate the change in dominant vegetation type from open (V) to boreal (B) and then from boreal (B) to temperate (T). The asterisk indicates climatic conditions with maximum herbivore population biomass.

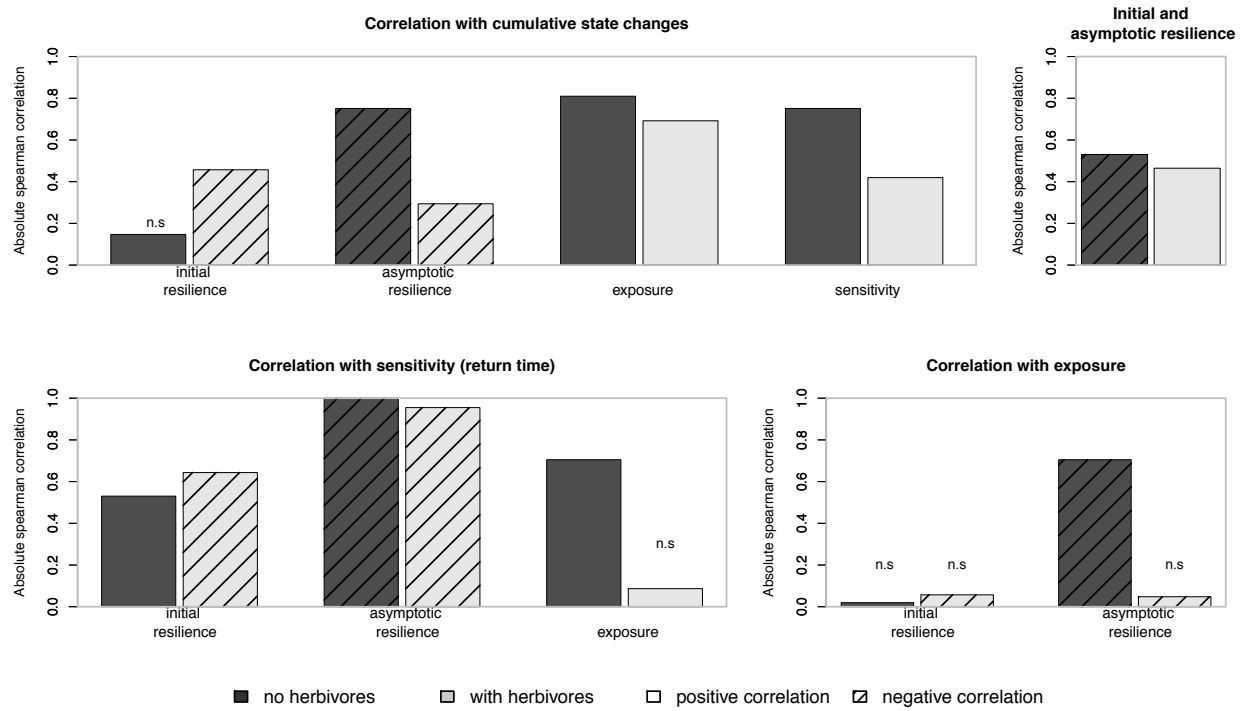


Fig. A5b. Correlations among descriptors, in presence and absence of browsers. Spearman rank correlations were computed from all values along the climatic gradient. Dark grey bars indicate correlations in absence of browsers whereas light grey ones are computed in presence of plant-herbivore interactions. Stripped bars indicate negative correlations. Not statistically significant correlations (p -values >0.05) are labeled “n.s”.

Appendix 6: Variation for a mixed-feeding herbivore

We present here the main results for a mixed-feeding animal, with a summer diet composed at most of 50% of grasses (i.e. $pG = 1$), and grass productivity put to $50\,000\text{ kg.km}^{-2}.\text{year}^{-1}$. This productivity value is consistent with **Tieszen, L.L. 2013. NPP Tundra: Point Barrow, Alaska, 1970-1972, R1. Data set. Available on-line [http://daac.ornl.gov]** from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, USA. doi.10.3334/ORNLDAAC/580.

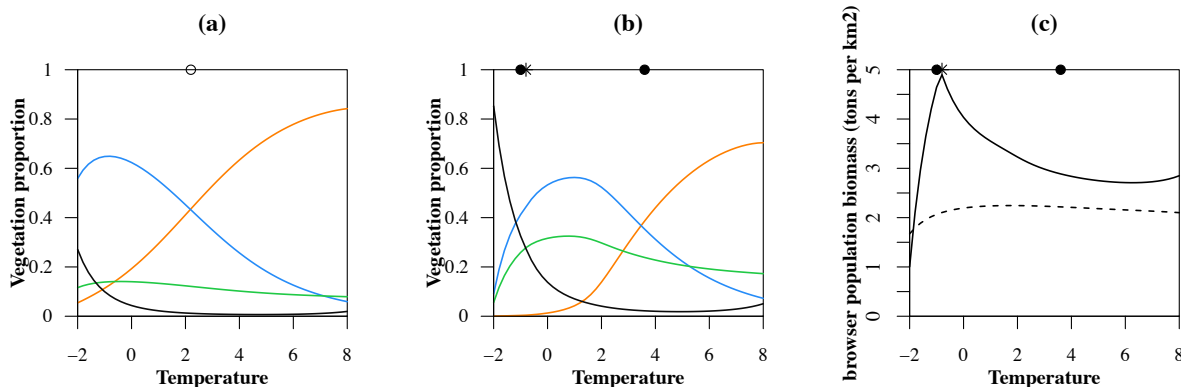


Fig. A6a. Changes in ecosystem state at equilibrium along the temperature gradient. Proportion of open vegetation V (black), mature boreal tree stands B (blue), mature temperate tree stands T (orange), and seedlings and saplings R (green). (a) Changes in vegetation proportions without plant-herbivore interactions in the system. (b) Changes in vegetation proportions with plant-herbivore interactions. (c) Changes in browser biomass. An asterisk indicates where the browser biomass reaches its maximum population biomass. The dashed line indicates the carrying capacity for the browser population in absence of feedback on the vegetation. The open (no browsers) and closed (with browsers) circles indicate transitions in vegetation type dominance from open (V) to boreal (B) and then from boreal (B) to temperate (T).

The maximum biomass for a mixed-feeding herbivore population was observed with a landscape having enough open vegetation V containing grasses, and regeneration stands R, but still a maximum of boreal mature forest B (Fig. A6a). Such mixed-feeding herbivore as parameterized here also have a larger impact on the shift of the transition between open and forest ecosystems.

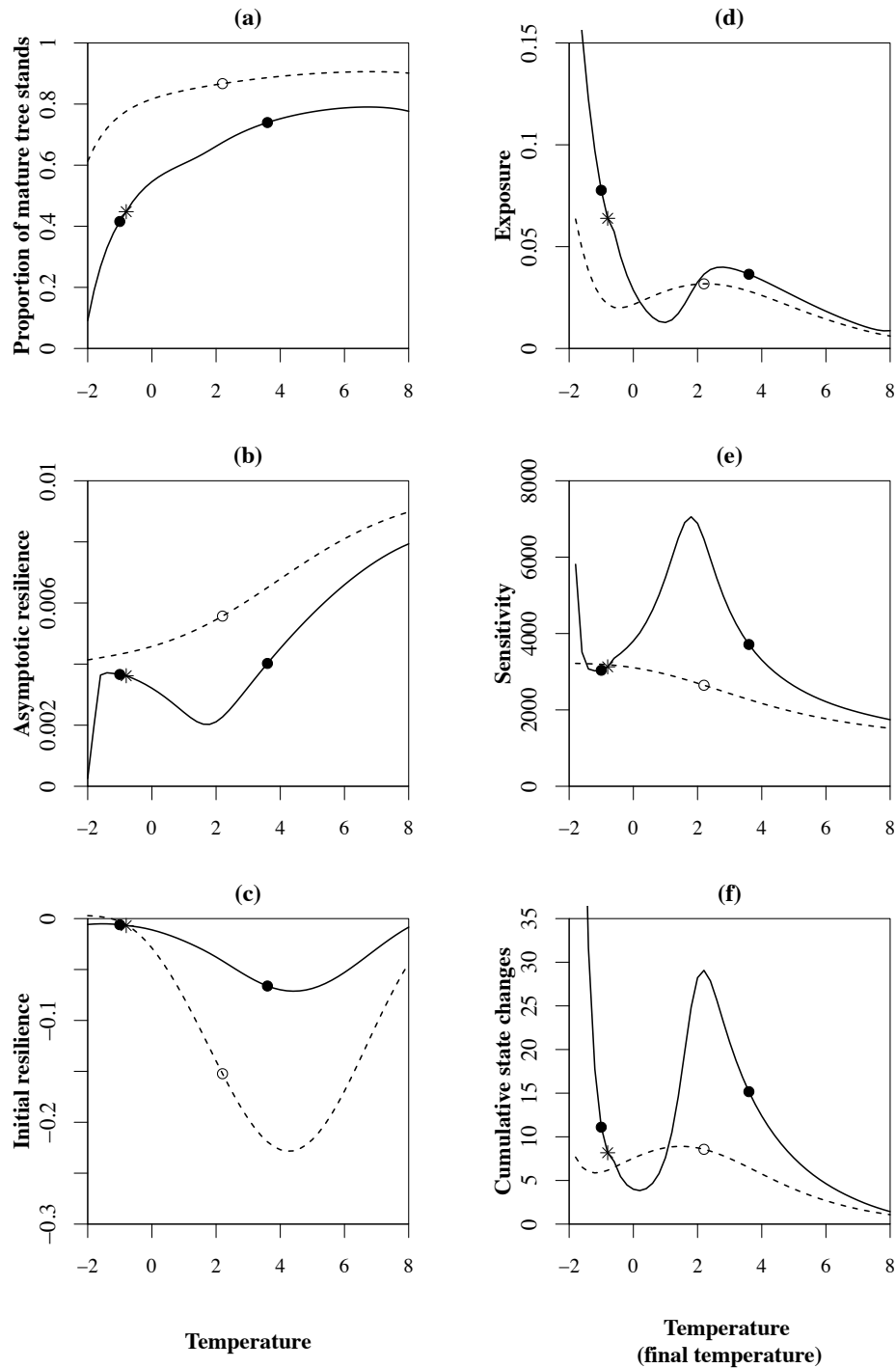


Fig. A6b. Ecosystem response along the increasing temperature gradient, with varying plant-herbivore interactions Black lines refer to the basic analysis. Orange lines represent the addition of a decreasing energy cost along the temperature gradient. Blue lines represent a decreasing impact of herbivory on seedling mortality along the temperature gradient. Red lines represent the variation of the growing season length along the gradient (a) Proportion of mature tree stands at equilibrium along the increasing temperature gradient. (b) Asymptotic resilience (c) Initial resilience (d) Exposure (e) Sensitivity (return time) (f) Cumulative state changes during the transient period.

Appendix 7: Variation of additional parameters along the climatic gradient

Vegetation-herbivore interactions may be mediated by additional factors along the temperature gradient (Louthan et al. 2006). At warmer temperatures, the metabolic energy cost of the herbivore may decrease, or herbivory may induce less plant mortality. To test how these additional factors impact our conclusions, we allowed two groups of parameters to vary along the increasing temperature gradient. The decrease in energy cost was modeled by a decrease of the biomass conversion factors e_w and e_s from 200% to 10% of their original values. The reduction of plant mortality due to herbivory was modeled by increasing h_S , h_T , and h_B from 10% to 200% of their original values. In addition, we varied the length of the growing season along the gradient, from 65 days to 185 days to see if it could impact our conclusions.

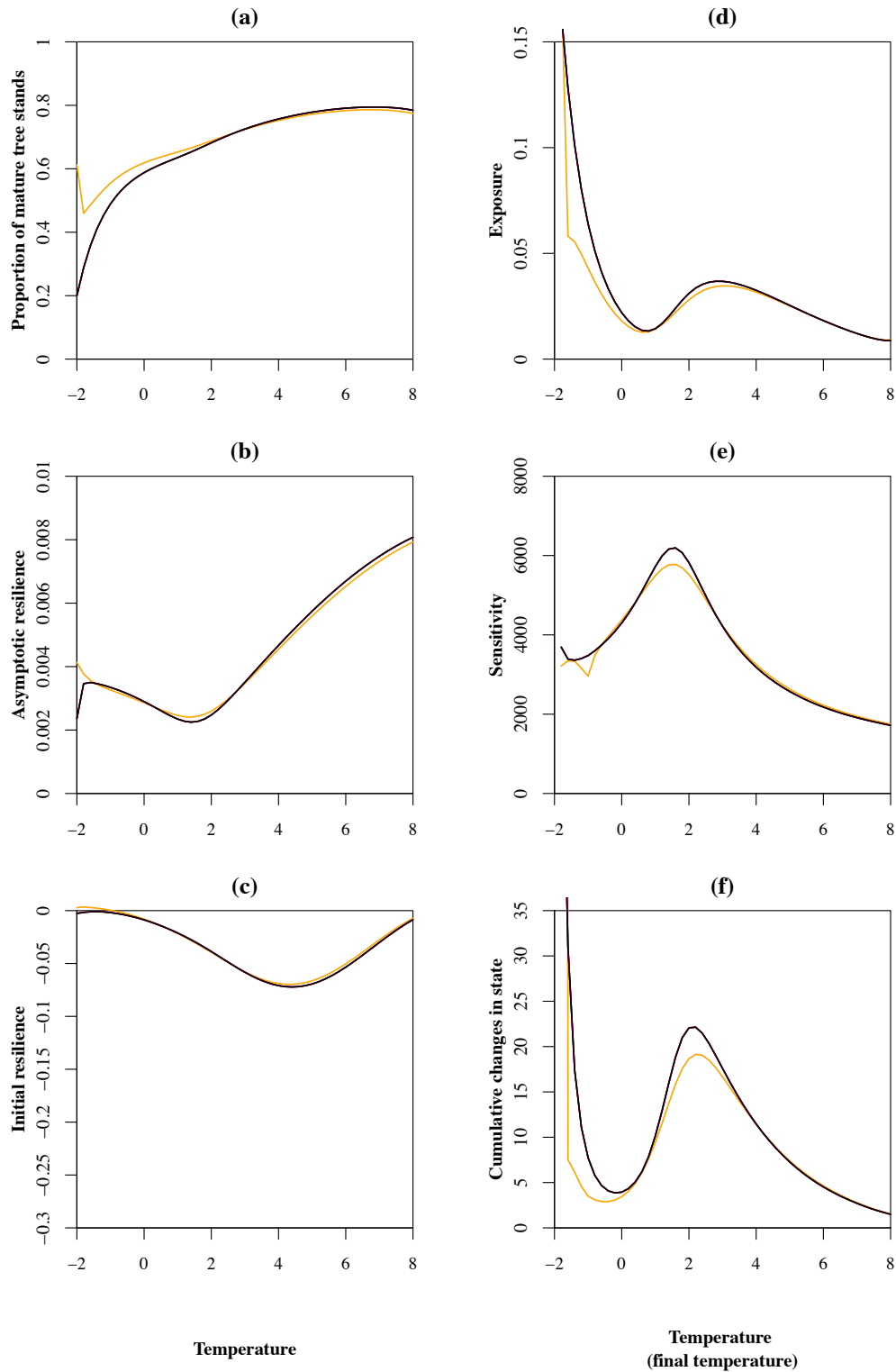


Fig. A7. Ecosystem response along the increasing temperature gradient, with varying plant-herbivore interactions Black lines refer to the basic analysis. Orange lines represent the addition of a decreasing energy cost along the temperature gradient. Blue lines represent a decreasing impact of herbivory on seedling mortality along the temperature gradient. Red lines represent the variation of the growing season length along the gradient (a) Proportion of mature tree stands at equilibrium along the increasing temperature gradient. (b) Asymptotic resilience (c) Initial resilience (d) Exposure (e) Sensitivity (return time) (f) Cumulative state changes during the transient period.