Interactions among resource partitioning, sampling effect, and facilitation on the biodiversity effect: A modeling approach

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SUPPLEMENTAL INFORMATION

1. Model description

1.1. Components

The components of our model are two life forms, grasses and shrubs, and three soil layers. In the Patagonian steppe, grasses are shallow rooted and perennial, and shrubs are deep rooted and deciduous. We divided one meter of soil depth into top, mid, and bottom layers, with 0-5, 5-35, and 35-100 cm depth. Evaporation takes place from the top layer (Paruelo et al. 1991), while the mid layer represents the layer with highest grass root biomass (Soriano et al. 1987) and the bottom layer has the most shrub root biomass (Fernandez and Paruelo 1988; Golluscio et al. 2006). Soil is coarse textured with high proportion of sand and pebbles (Sala et al. 1989) that yields a low water-holding capacity. Therefore, we used a soil-water-holding capacity of 1 mm H_2O cm soil^{-1} for the entire soil profile. We calculated wilting (Ww_y, mm H_2O, eq. 1) and saturation (Ws_y, mm H_2O, eq. 2) points for each y layer as

$$Ww_y = h_y\, wil_y \qquad \text{eq. 1}$$

$$Ws_y = h_y\, sat_y \qquad \text{eq. 2}$$

where h_y (cm) is the height of the y layer and wil_y (mm H_2O cm^{-1}) and sat_y (mm H_2O cm^{-1}) are wilting and saturation constants. Water available in the y layer (Wa_y, mm H_2O) is the difference between amount of water on y layer (W_y, mm H_2O) and Ww_y:

$$Wa_y = W_y\ Ww_y \qquad \text{eq. 3}$$

Wa_y is zero or positive.

1.2. Water flow

The water balance of the top layer (dW_{L5}/dt, mm H_2O day^{-1}, eq. 4) was simulated by inputs in precipitation (*PPT*, mm H_2O day^{-1}) and outputs through evaporation (*Ev*, mm H_2O day^{-1}, eq. 5) and percolation (P_{L5}, mm H_2O day^{-1}, eq. 8).

$$dW_{L5}|dt = PPT - Ev - P_{L5} \qquad \text{eq. 4}$$

Precipitation was the only water input into the system; we did not consider run-on nor runoff because of the flat topography and coarse soil texture (Paruelo and Sala 1995). Evaporation was the product between evaporation constant (α_{ev}, day^{-1}) and water available in the top soil layer (Wa_{L5}).

$$Ev = \alpha_{ev}\ Wa_{L5} \qquad \text{eq. 5}$$

In the mid (*L35*) and bottom (*L100*) layers, the water balance (eqs. 6 and 7) was simulated by inputs as percolation from the soil layer above (P_{L5}, or P_{L35}), and outputs as percolation to the layer below (P_{L35}, or P_{L100}) and as uptake by shrubs and grasses ($U_{SH\text{-}y}$ $U_{GR\text{-}y}$, mm H_2O day^{-1}, eqs. 9 and 10).

$$dW_{L35}|dt = P_{L5} - P_{L35} - U_{SH\text{-}L35} - U_{GR\text{-}L35} \qquad \text{eq. 6}$$

$$dW_{L100}|dt = P_{L35} - P_{L100} - U_{SH\text{-}L100} - U_{GR\text{-}L100} \qquad \text{eq. 7}$$

The model simulates water movement (P_y, mm H_2O day^{-1}) by saturated flow and did not represent unsaturated flow. Therefore, water moved downward but not upwards. Unsaturated flow in this coarse-texture soil is very small and consequently not including this flow should not result in a significant error (Paruelo and Sala 1995). Percolation (P_y, eq. 8) from layer *y* was proportional (by constant α_{per}, day^{-1}) to the difference between water in the layer (W_y) and the saturation point of the layer (Ws_y). P_y is either zero or positive.

$$P_y = \alpha_{per} (W_y - Ws_y) \qquad \text{eq. 8}$$

Plants transpired the same amount of water that they uptake (eqs. 9 and 10). We simulated shrub water uptake from soil layer y ($U_{SH\text{-}y}$, mm H_2O day^{-1}) as an asymptotic function of the water content of layer y using the following equation:

$$U_{SH-y} = \frac{Wa_y Br_{SH-y} \delta_{SH}}{Wa_y + (Ws_y - Ww_y)/2} \qquad \text{eq. 9}$$

$U_{SH\text{-}y}$ also increased with shrub-root biomass in layer y ($Br_{SH\text{-}y}$, g m^{-2}), and a constant regulated absorption rate (δ_{SH}, mm H_2O day^{-1} g^{-1} m^{2}). In the denominator of eq. 9, a constant number equivalent to 50% of potential water available [($Ws_y - Ww_y$)/2] and Wa_y, gave the hyperbolic shape of the curve. Shrubs absorbed water from spring to early autumn reproducing the phenology of green biomass in the Patagonian Steppe. We simulated grass-water uptake ($U_{GR\text{-}y}$, mm H_2O day^{-1}) from soil layer y with a similar equation but modified by a temperature factor (eq. 10).

$$U_{GR-y} = \left(\frac{Wa_y Br_{GR-y} \delta_{GR}}{Wa_y + (Ws_y - Ww_y)/2} \right) \left(\frac{(T - Ts)}{(T - Ts) + Tm} \right) \qquad \text{eq. 10}$$

In the Patagonian Steppe, grass species are perennial and active all year around, but winter activity is constrained by low temperatures. The temperature correction factor reduced water uptake to 80% of the maximum capacity at 24 ^{o}C, to 17% at 5^{o}C, and to 0% below 4 ^{o}C (Ts = 4 ºC, and Tm = 5 ºC). Root biomass of life form f in each layer y ($Br_{f\text{-}y}$, g m^{-2}) of eqs. 9 and 10, depended on the root to shoot ratio (γ_f, no units), the root proportion in layer y ($root_{f\text{-}y}$, no units), and the plant aboveground biomass (B_f, g m^{-2}, eq. 11)

$$Br_{f\text{-}y} = root_{f\text{-}y}\, \gamma_f\, B_f \qquad \text{eq. 11}$$

Weather inputs were daily values of mean air temperature and precipitation, recorded during 19 years at the experimental station INTA Río Mayo, (45° 41' S, 70° 16'W).

1.3. Biomass production

Daily changes in aboveground plant biomass (*dB/dt*, eq. 12) were simulated as the difference between aboveground net primary production ($ANPP_f$, g m^{-2} day^{-1}, eq. 13) and senescence (S_f, g m^{-2} day^{-1}, eq. 14) per life form *f*.

$$dB_f|dt = ANPP_f - S_f \qquad \text{eq. 12}$$

$ANPP_f$ increased with water use efficiency (WUE_f, g m^{-2} mm H_2O^{-1}) and the amount of water transpired (Wt_f, mm H_2O day^{-1}, eq. 13)

$$ANPP_f = WUE_f \;\; Wt_f \qquad \text{eq. 13}$$

Wt_f equals the total water uptake by life form *f* (the sum of water uptake from mid and bottom soil layers). Senescence of green biomass was seasonal; shrubs lost all their aboveground green biomass at the end of the growing season (May), while grasses had a progressive litter production until the start of the new season (end of September). For both life forms, senescence was directly proportional to a constant ε_f (day^{-1}) and live biomass (B_f, g m^{-2})

$$S_f = \varepsilon_f \;\; B_f \qquad \text{eq. 14}$$

The biomass for shrubs at the beginning of the current growing season was a fix fraction (0.05) of past year biomass produced, while for grasses, biomass was the balance between biomass produced in the growing season minus biomass lost in autumn and winter.

2. <u>*Simulations*</u>

2.1. Biodiversity gradient

We estimated the biodiversity effect as the difference between observed and expected ANPP (eq 15) (Loreau and Hector 2001). The expected value (second term in eq. 15) was the product of the proportion of life form *f* in the mixture (term in brackets) and its ANPP as monoculture. For example, if the proportion of grasses was 50% at the end of autumn, the expected value in the mixture was half of grasses ANPP growing as a monoculture.

$$\text{Biodiversity effect} = \sum ANPP_{f.Mix} - \sum\left(\frac{B_{f.Mix}}{B_{SH.Mix} + B_{GR.Mix}}\right) ANPP_{f.Mono} \qquad \text{eq. 15}$$

Mix and *Mono* suffixes indicate values obtained from mixtures and monocultures respectively. Finally, we estimated sampling effect (eq. 16) (Loreau and Hector 2001).

$$\text{Sampling effect} = 2 * \text{cov}\left(\frac{ANPP_{f.Mix}}{ANPP_{f.Mono}} - \frac{B_{f.Mix}}{B_{SH.Mix} + B_{GR.Mix}}, ANPP_{f.Mono}\right) \qquad \text{eq. 16}$$

2.2. Resource partitioning gradient

We defined resource partitioning as the mean fraction of root non-overlap between life forms (eq. 17)

$$\text{root overlap} = 1 - [\sum(root_{SH\text{-}y} - root_{GR\text{-}y})^2 / 2]^{1/2} \qquad \text{eq. 17}$$

Supplemental Information References

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Supplemental Information Figures

Figure S1: Influence of increased WUE for grasses and root overlap on niche complementarity. Niche complementarity was estimated using Loreau and Hector (2001) method. Root overlap (RO) and increased grass WUE simulated resource partitioning (RP) and facilitation (F) gradients. Lines depict simulations with the same root overlap and same increased WUE for grasses. Niche complementarity was expressed as a fraction of ANPP.