Supplement to "(A bit) Earlier or later is always better: Phenological shifts in consumer-resource interactions"

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Within year and across years dynamics

The middle row of Figure 2 in the main text show stable phenologies of adult resources and adult consumers, after several years of interaction, when the system attains an equilibrium, i.e. when the number of offspring produced at the end of each year stabilizes, as seen in the bottom row of the same figure. Figure 1 of this supplement displays the consumer-resource dynamics of the adult phases within the years, i.e. the adult abundance phenologies, and the corresponding offspring production per day, i.e. the phenology or reproduction, over several consecutive years, for the case with $\Delta\mu = 0$ and $\sigma_i = 10$ (with all the other parameters as in Table 1 in the main text). We can see that phenologies change and oscillate as their final shape is progressively achieved. The long-term dynamics of the system corresponds to the net number of offspring produced at day 365, i.e. the result of integrating the offspring differential equations each year. This is represented by a thicker black line running along the τ axis.

As shown in Figure 3 of the main text, some systems do not achieve a long-term equilibrium but persistent oscillations. Figure 2 of this supplement shows the within year dynamics in one of such scenarios, during 50 consecutive years, when $\Delta\mu = -10$ and $\sigma_i = 5$ (with all the other parameters as in Table 1 in the main text). We can see in this example that the phenologies of the resources and consumers vary periodically.

Finally, Figure 3 of this supplement shows the dynamics in a system in which $\Delta\mu = 0$ and the abundance phenology of the consumer is very short ($\sigma_2 = 2.5, m_2 = 1$) compared with the resource ($\sigma_1 = 10, m_1 = 0.1$) (with all the other parameters as in Table 1 in the main text). This simulates an ephemeral consumer, that recruits during 2 weeks. The consumer shapes the abundance phenology of resource and turn it bimodal (but recruitment $\rho_1(t)$ is still unimodal), causing a biphasic dynamics in resource reproduction. Yet, the long-term dynamics is stable, as in the first figure of this supplement.

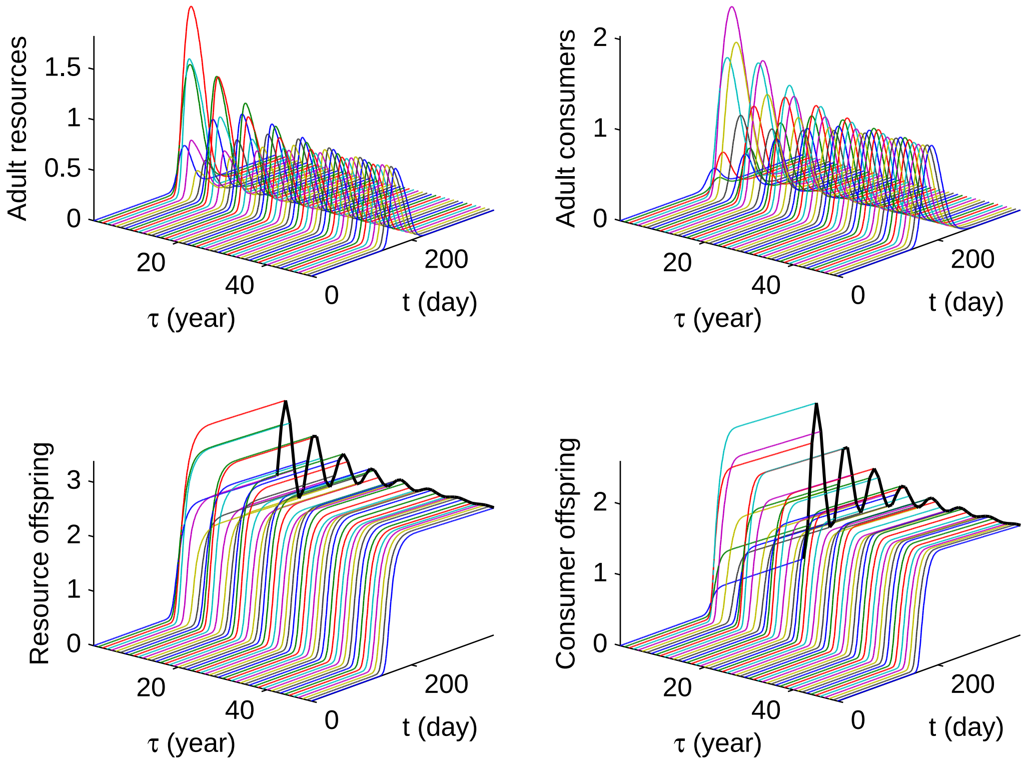

Figure 1: Dynamics *within years* (color lines) and *across years* (thick black line) in a long-term stable system (abundances are in a $\log_{10}(y + 1)$ scale).

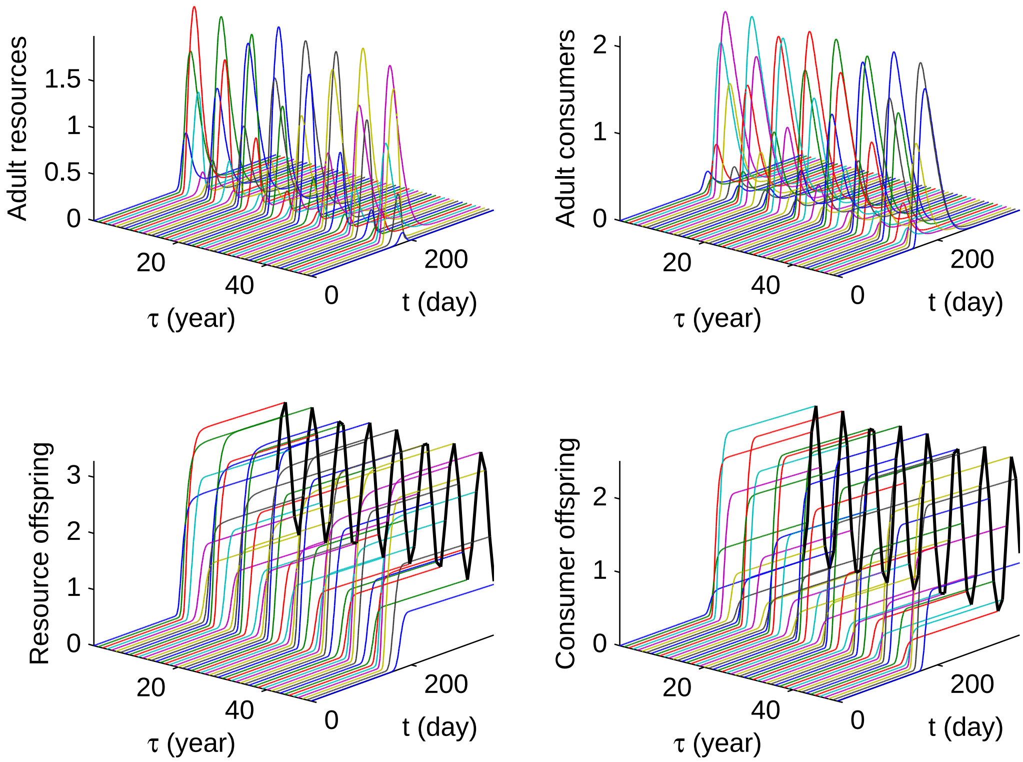

Figure 2: Dynamics *within years* (color lines) and *across years* (thick black line) in a persistently oscillating system (abundances are in a $\log_{10}(y+1)$ scale).

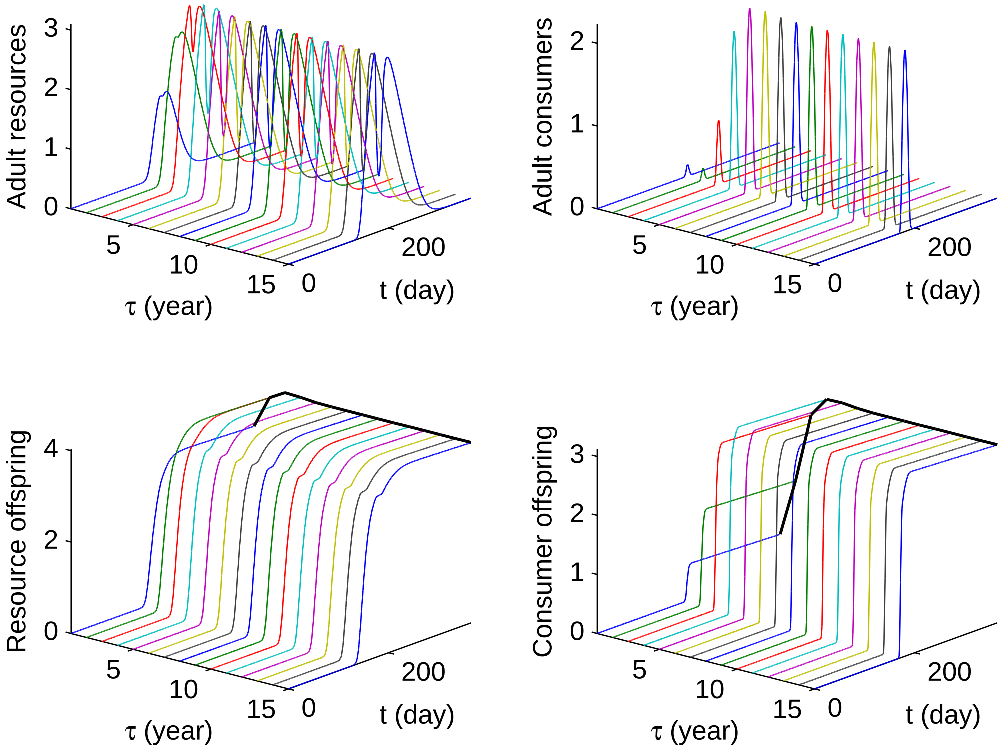

Figure 3: Dynamics *within years* (color lines) and *across years* (thick black line) with an ephemeral consumer (abundances are in a $\log_{10}(y+1)$ scale).

Robustness analysis

To check the robustness of our results we performed additional simulations in all community modules. All the parameters of the ODEs were changed (typically doubled or halved) with respect to their default values (Table 1 in the main text), some of the symmetry assumptions are dropped, and the form of the recruitment rate distribution (ρ) was changed. The following figures show the average of offspring abundances over the last 20 simulated years, of runs lasting 300 years. Like in the main text, the mean of the recruitment date of species 1 is at day $\mu_1 = 180$, the horizontal axis is the shift of species 2 with respect to species 1 ($\mu_2 - \mu_1$) and the vertical axis is the shift of species 3 with respect to species 1 ($\mu_3 - \mu_1$). Abundances are plotted as contours in this phenological space increasing from blue to red, using white to represent abundances smaller than 1 (extinction). The changes are:

- Figure 4: consumer mortalities increased from $m_i = 0.1$ to 0.2 (resources not changed)
- Figure 5: consumer mortalities decreased from $m_i = 0.1$ to 0.05 (resources not changed)
- Figure 6: offspring loss rates increased from $d_i = 0.001$ to 0.01 (all species)
- Figure 7: resource birth rates increased from $b_i = 2$ to 4
- Figure 8: resource birth rates decreased from $b_i = 2$ to 1
- Figure 9: resource self-limitation coefficient increased from $c = 0.01$ to 0.02
- Figure 10: resource self-limitation coefficient decreased from $c = 0.01$ to 0.005
- Figure 11: consumer efficiencies increased from $e_i = 0.2$ to 0.4
- Figure 12: consumer efficiencies decreased from $e_i = 0.2$ to 0.1
- Figure 13: standard deviation of the recruitment rates increased from $\sigma_i = 10$ to 20 (all species)
- Figure 14: standard deviation of the recruitment rates decreased from $\sigma_i = 10$ to 5 (all species)
- Figure 15: standard deviation of the consumer recruitment rates increased from $\sigma_i = 10$ to 20 (resources not changed)
- Figure 16: standard deviation of the consumer recruitment rates decreased from $\sigma_i = 10$ to 5 (resources not changed)
- Figure 17: asymmetry is introduced by halving the consumption rate upon species 3 (a_{3i}, apparent competition module) or by species 3 (a_{i3}, all other modules), from 0.3 to 0.15
- Figure 18: recruitment distributions were changed from normal to uniform, with $\rho_i(t) = 1/20$ for $\mu_i - 10 \leq t \leq \mu_i + 20$, and $\rho_i(t) = 0$ elsewhere

Some of these figures can be used to infer abundances when only one resource and one consumer are considered, like in Figure 1 of the main text. To see this, consider narrow strips along the top or the bottom in the graphs of the resource competition module (the dashed boxes in Figure 4b serve as illustration); they correspond to phenological shifts between species 1 and 2, when species 3 is absent or extinct (its box is in white).

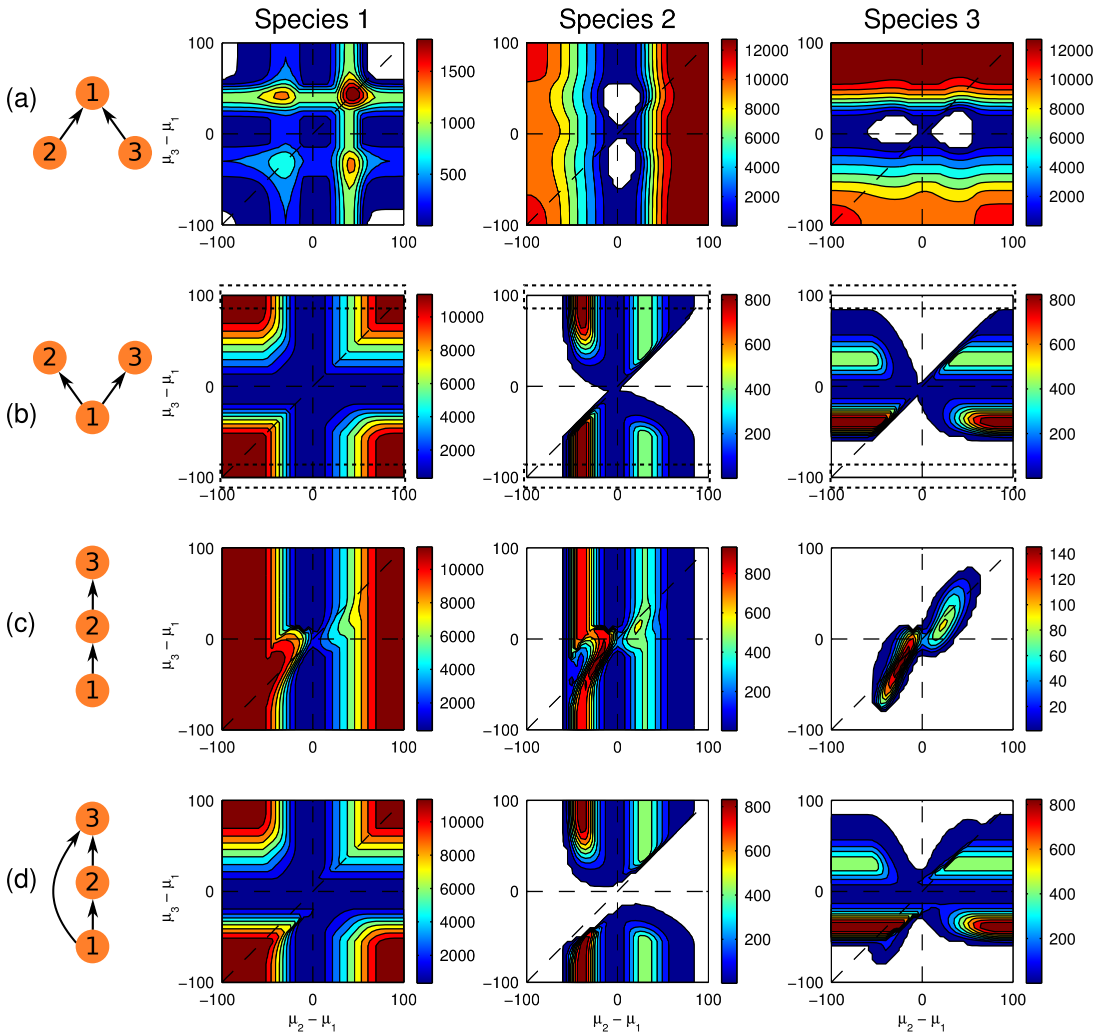

Figure 4: With increased consumer mortality

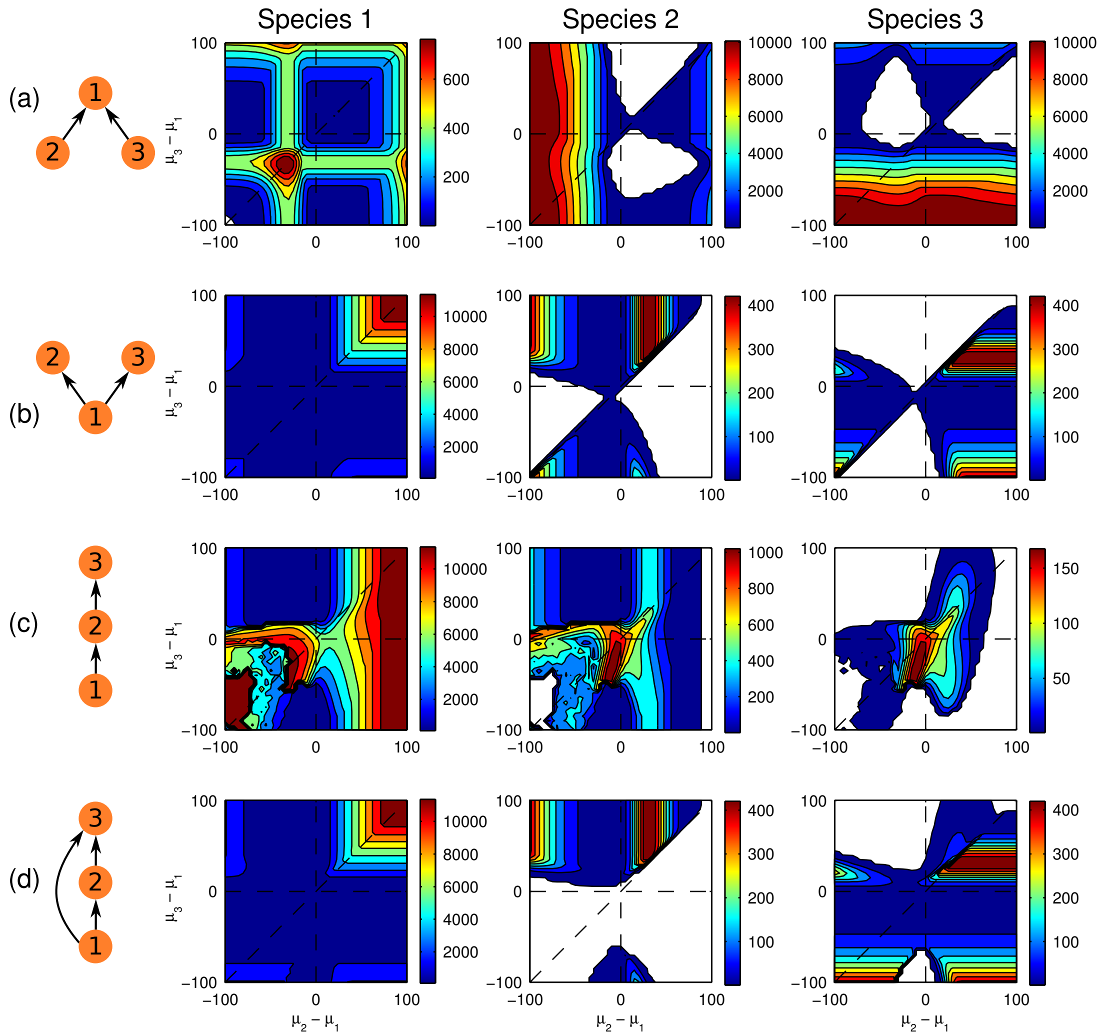

Figure 5: With decreased consumer mortality

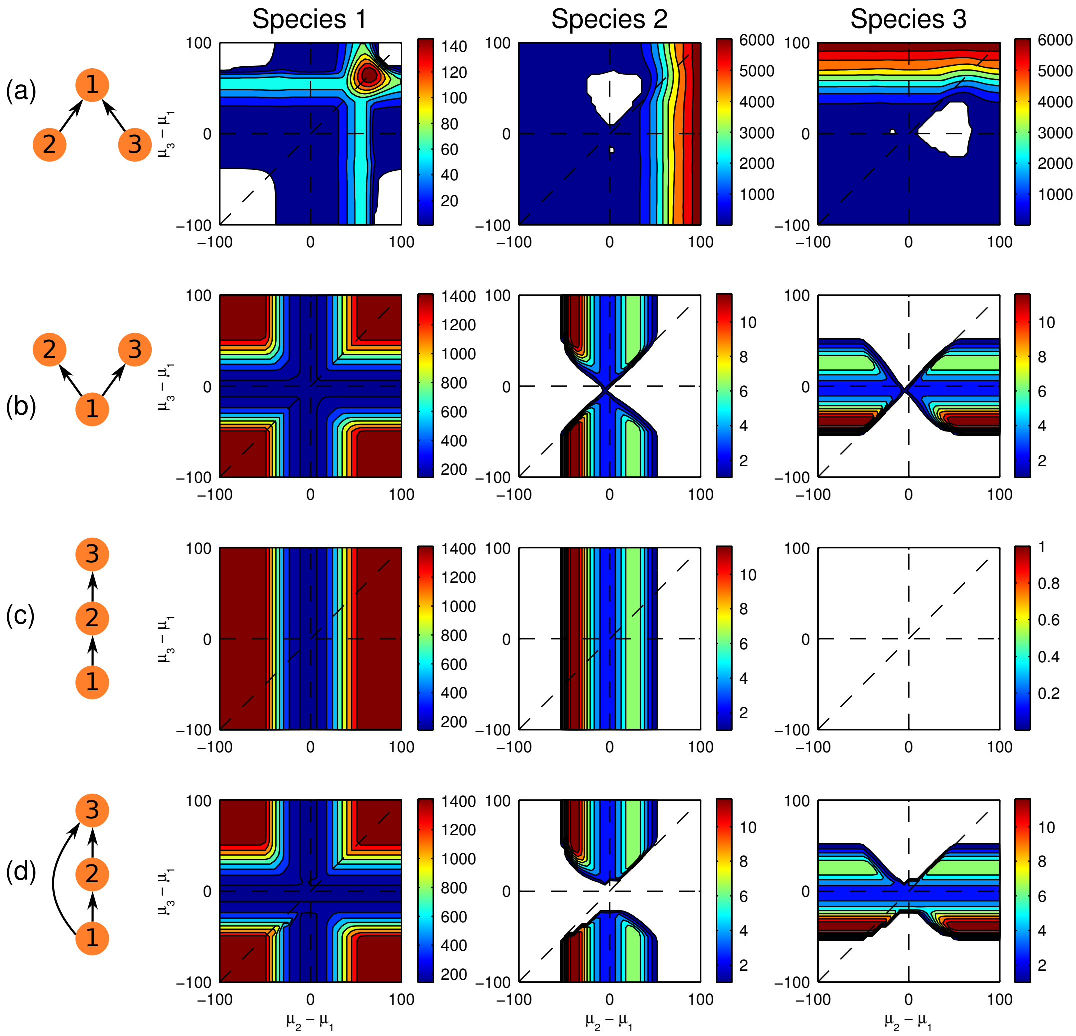

Figure 6: With increased offspring mortality

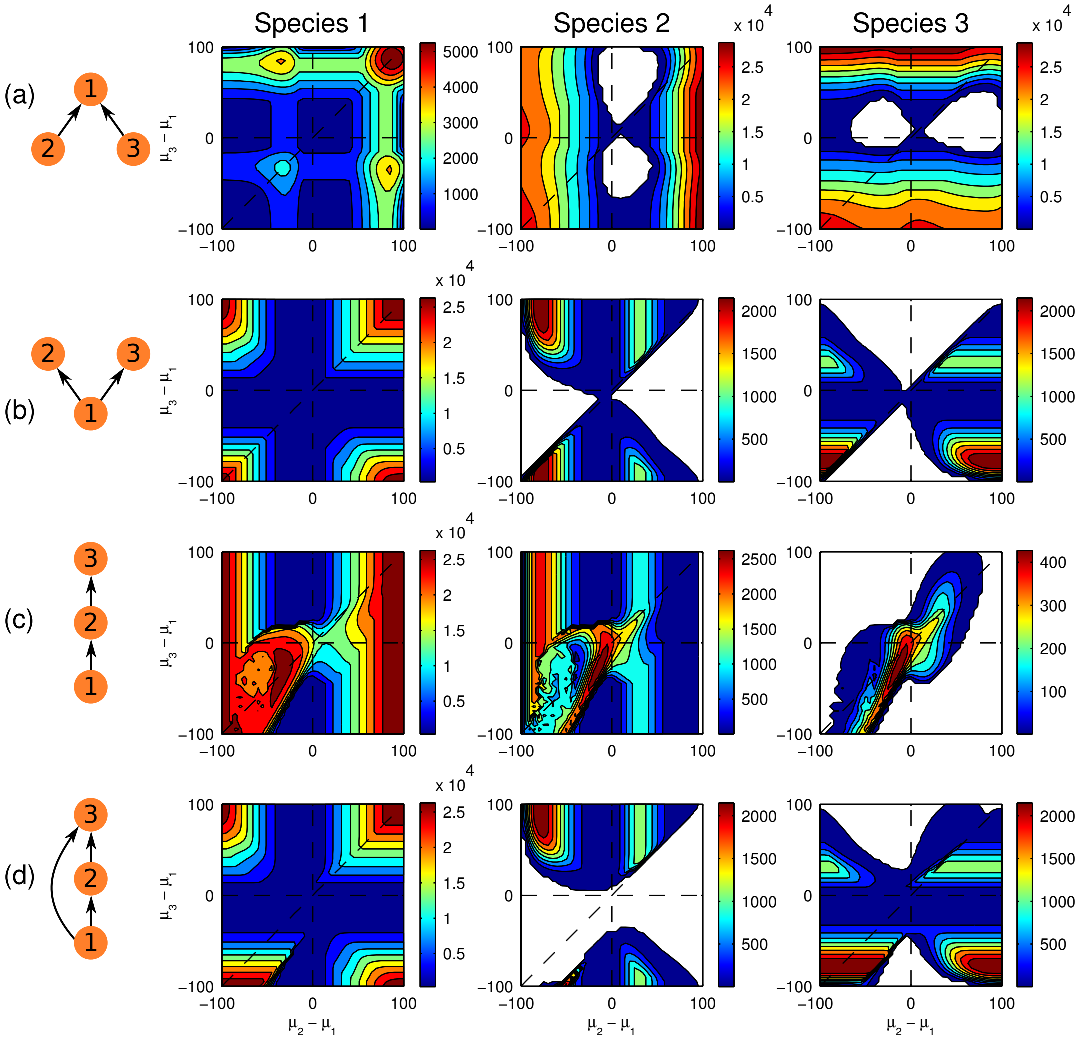

Figure 7: With increased resource reproduction rate

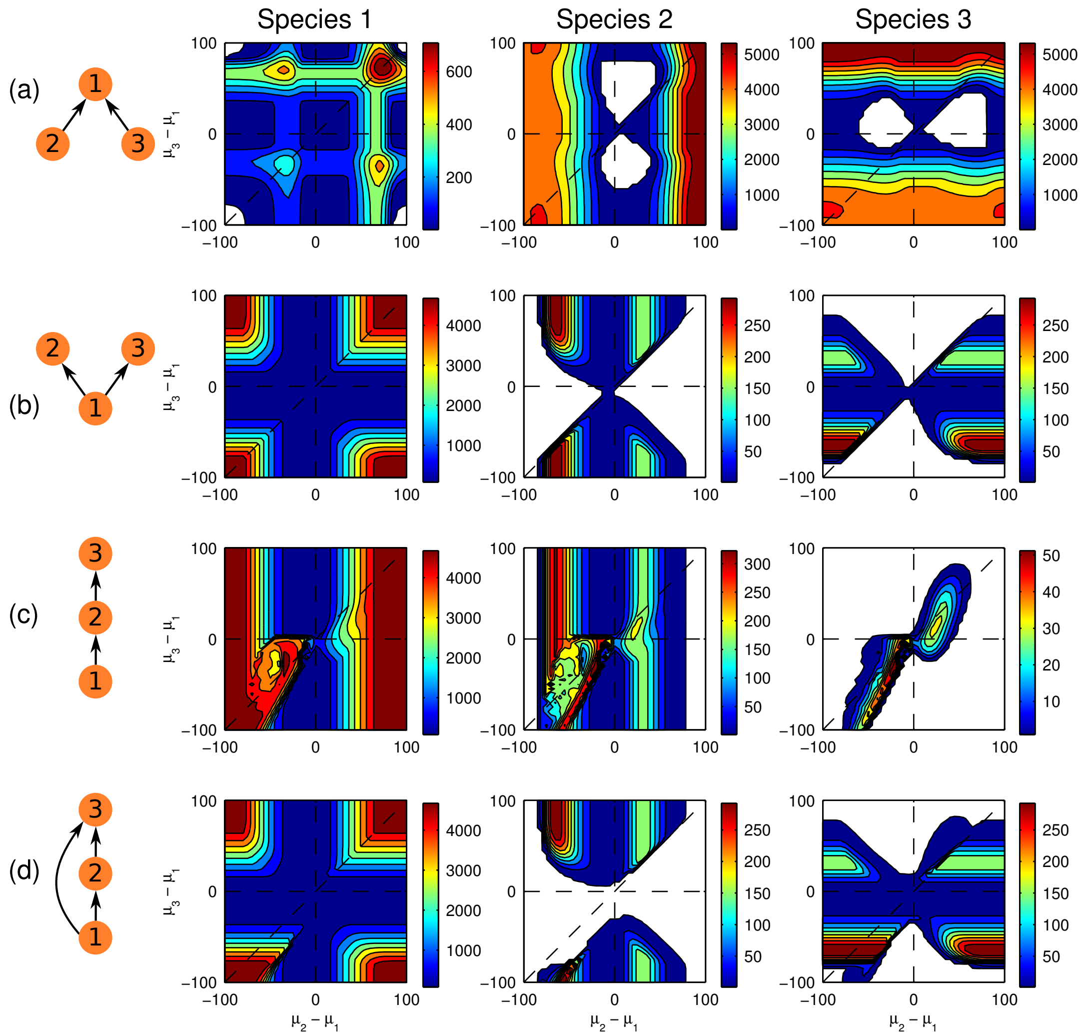

Figure 8: With decreased resource reproduction rate

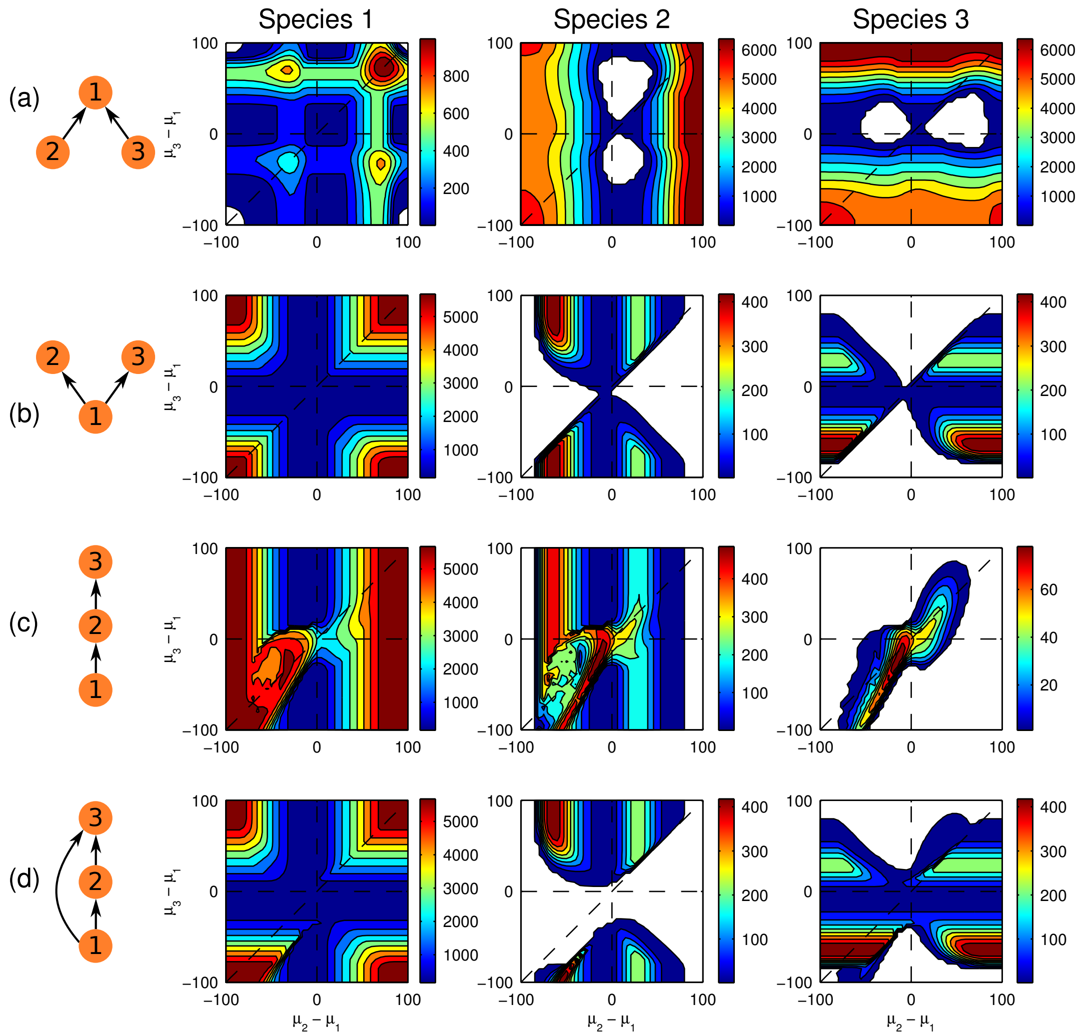

Figure 9: With increased resource self-limitation

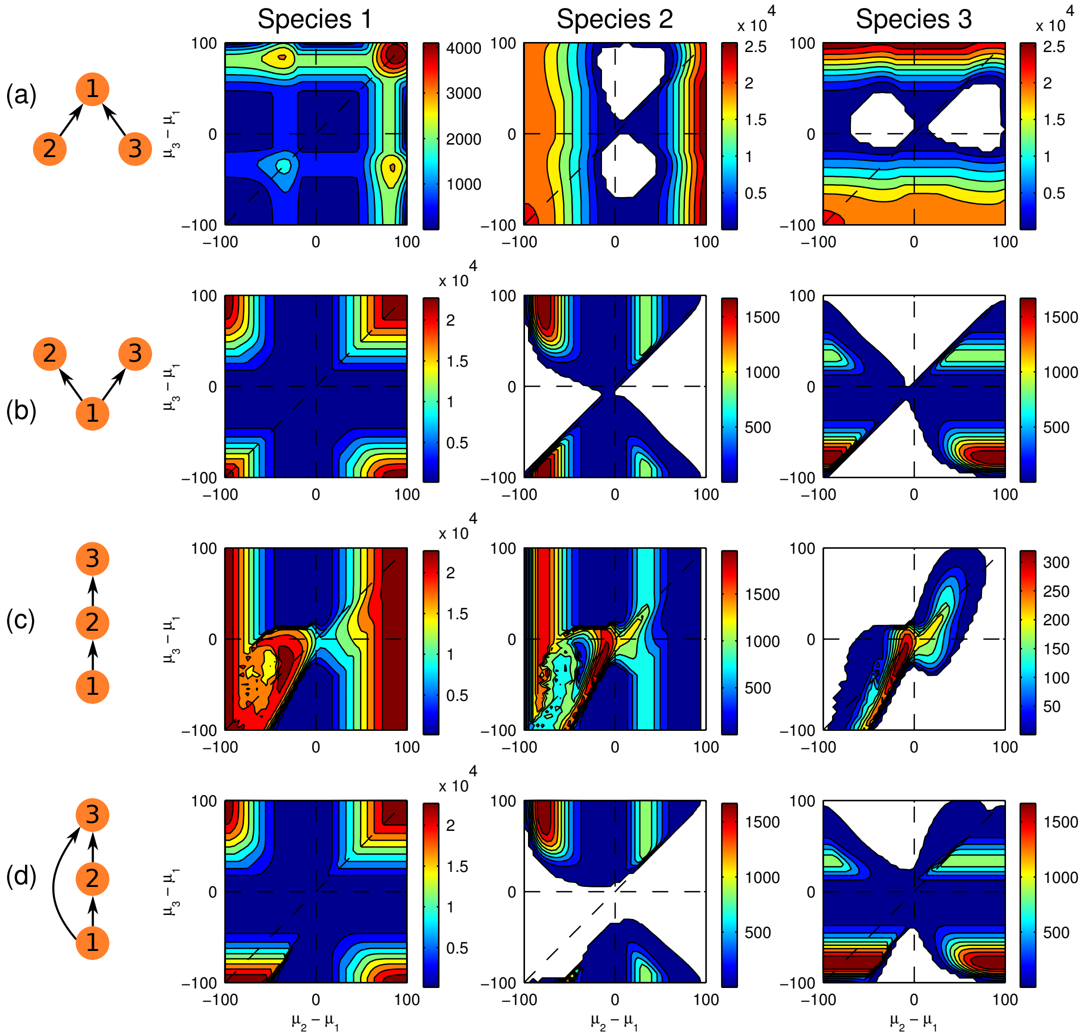

Figure 10: With decreased resource self-limitation

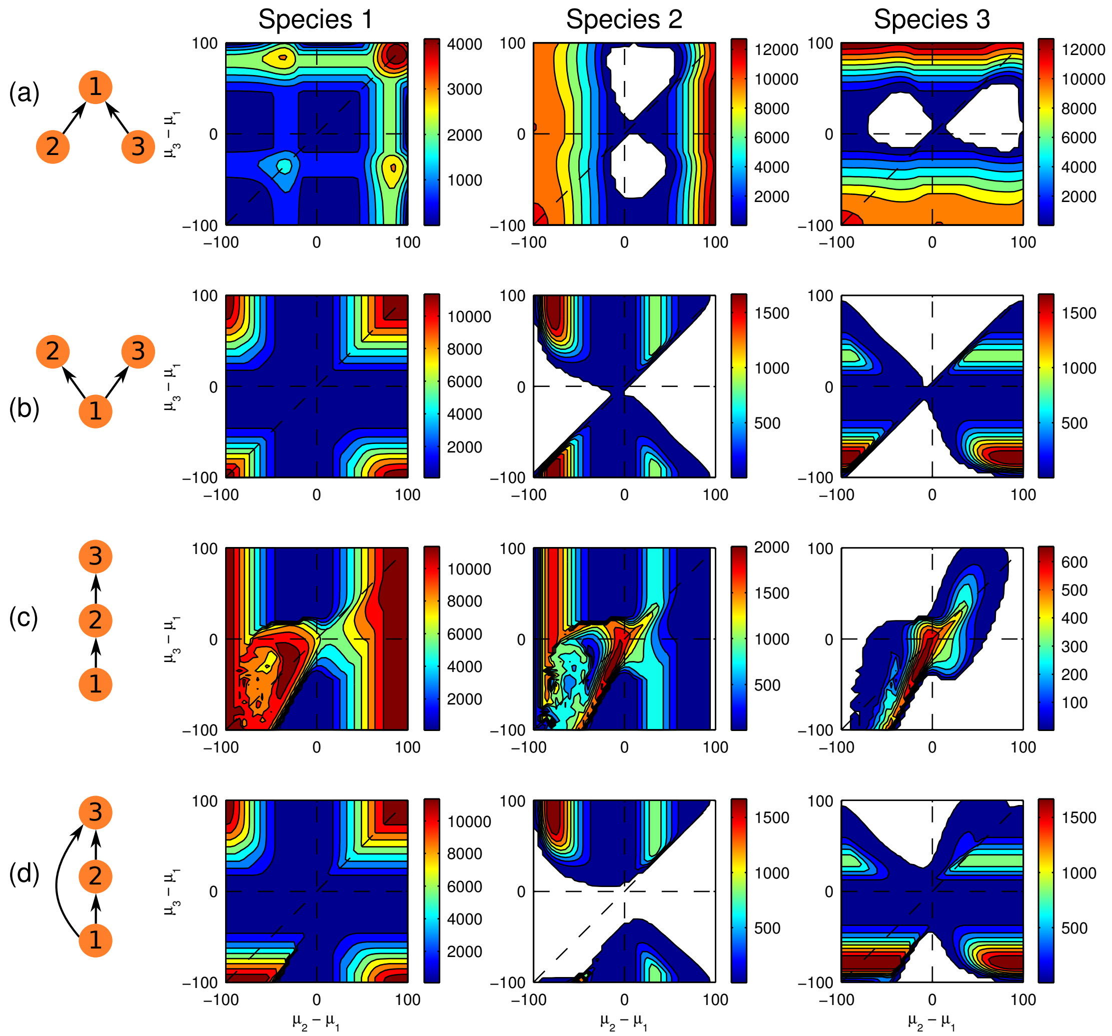

Figure 11: With increased consumer efficiency

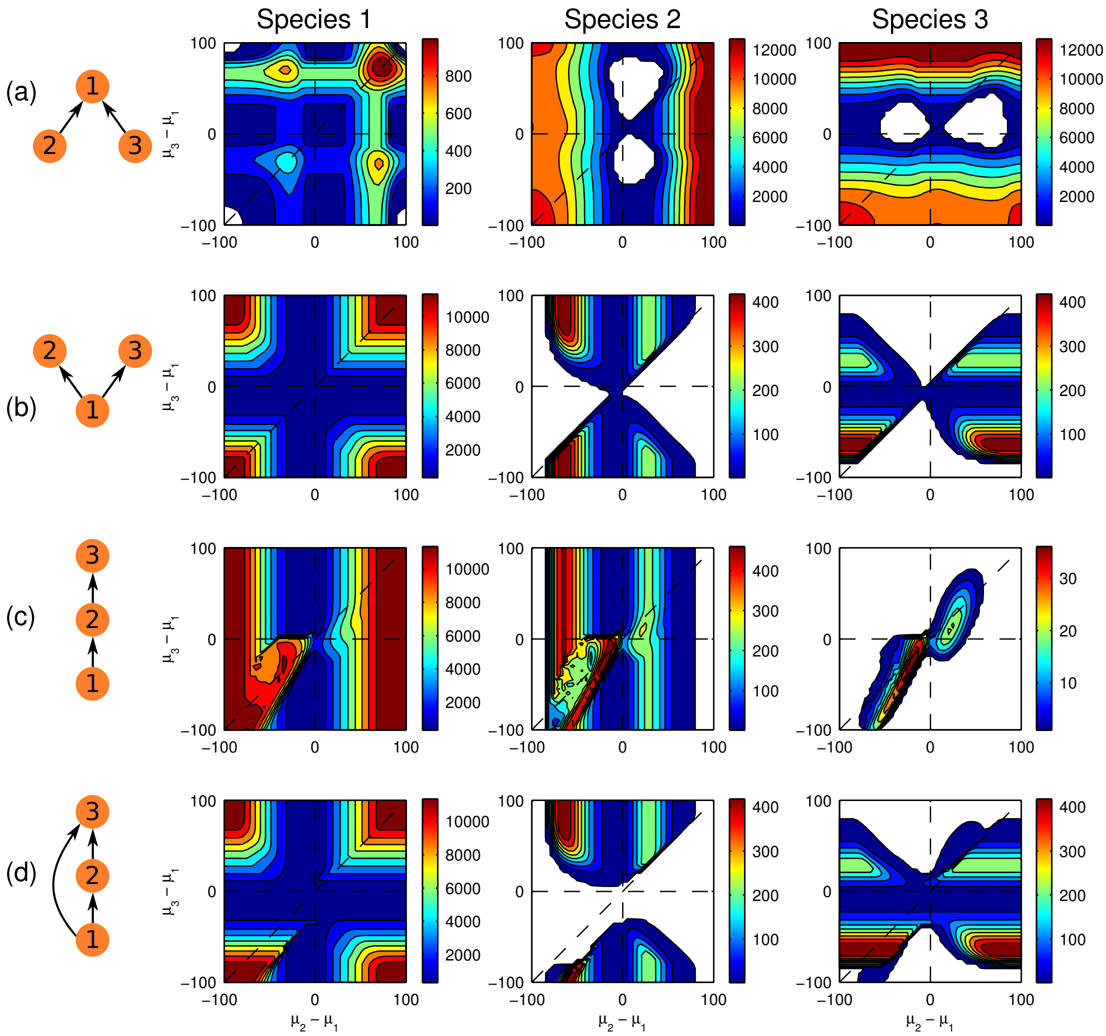

Figure 12: With decreased consumer efficiency

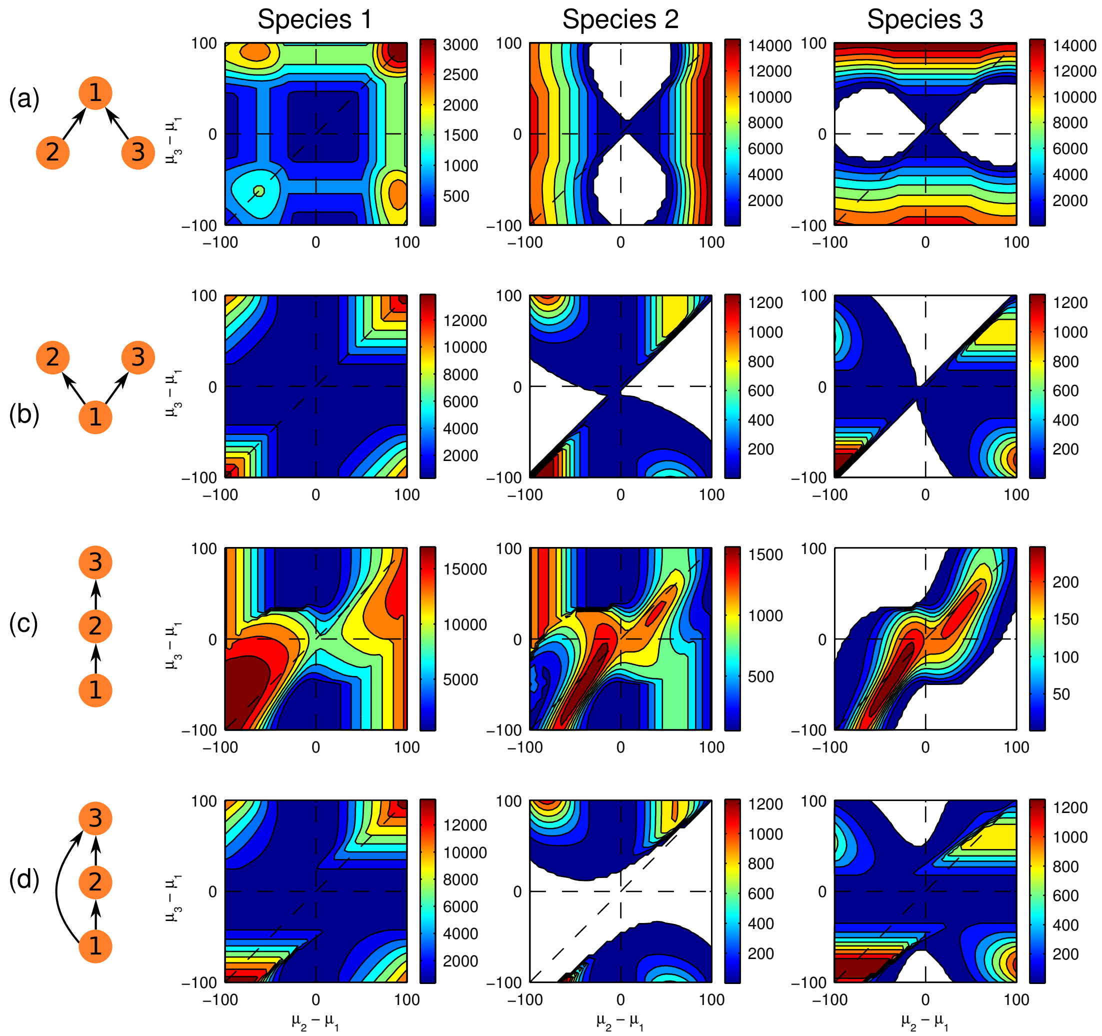

Figure 13: With increased recruitment spread

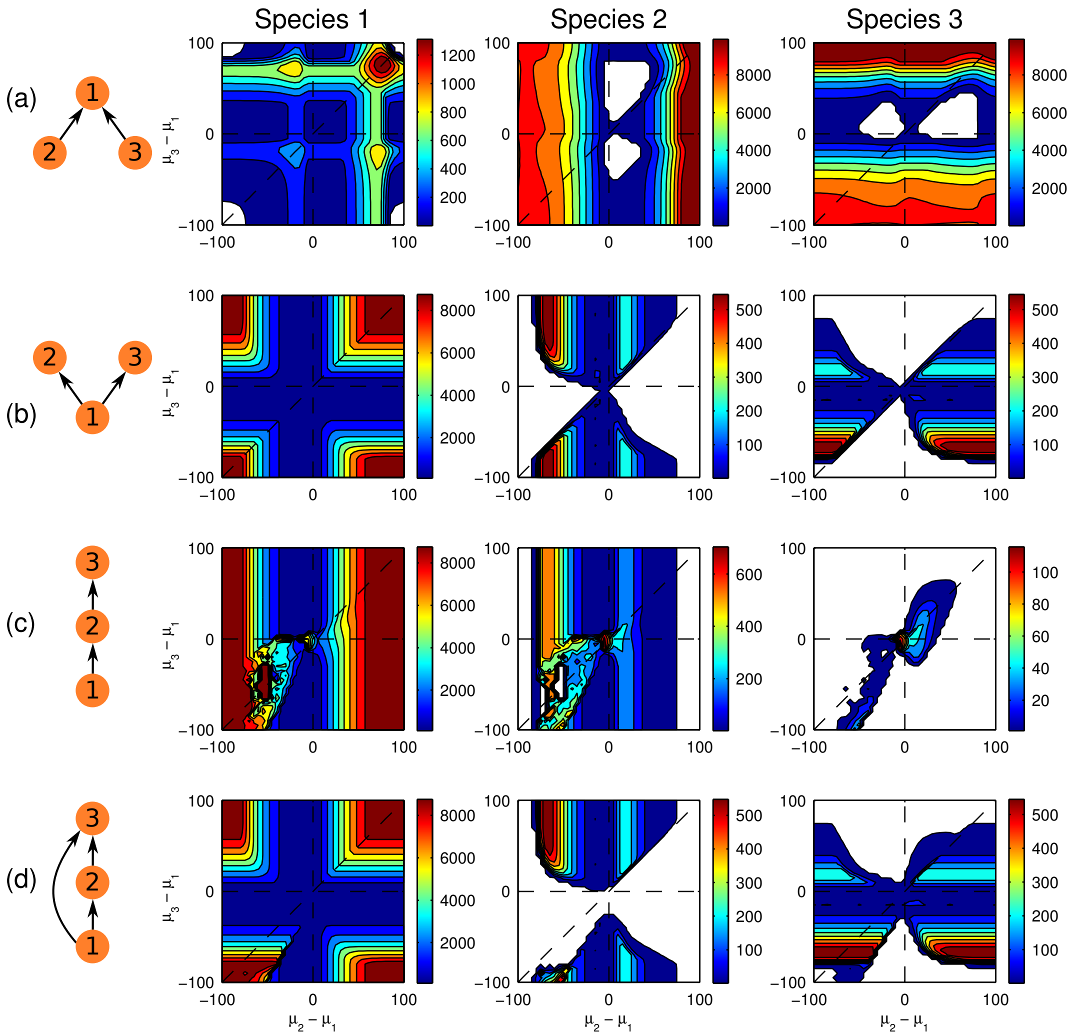

Figure 14: With decreased recruitment spread

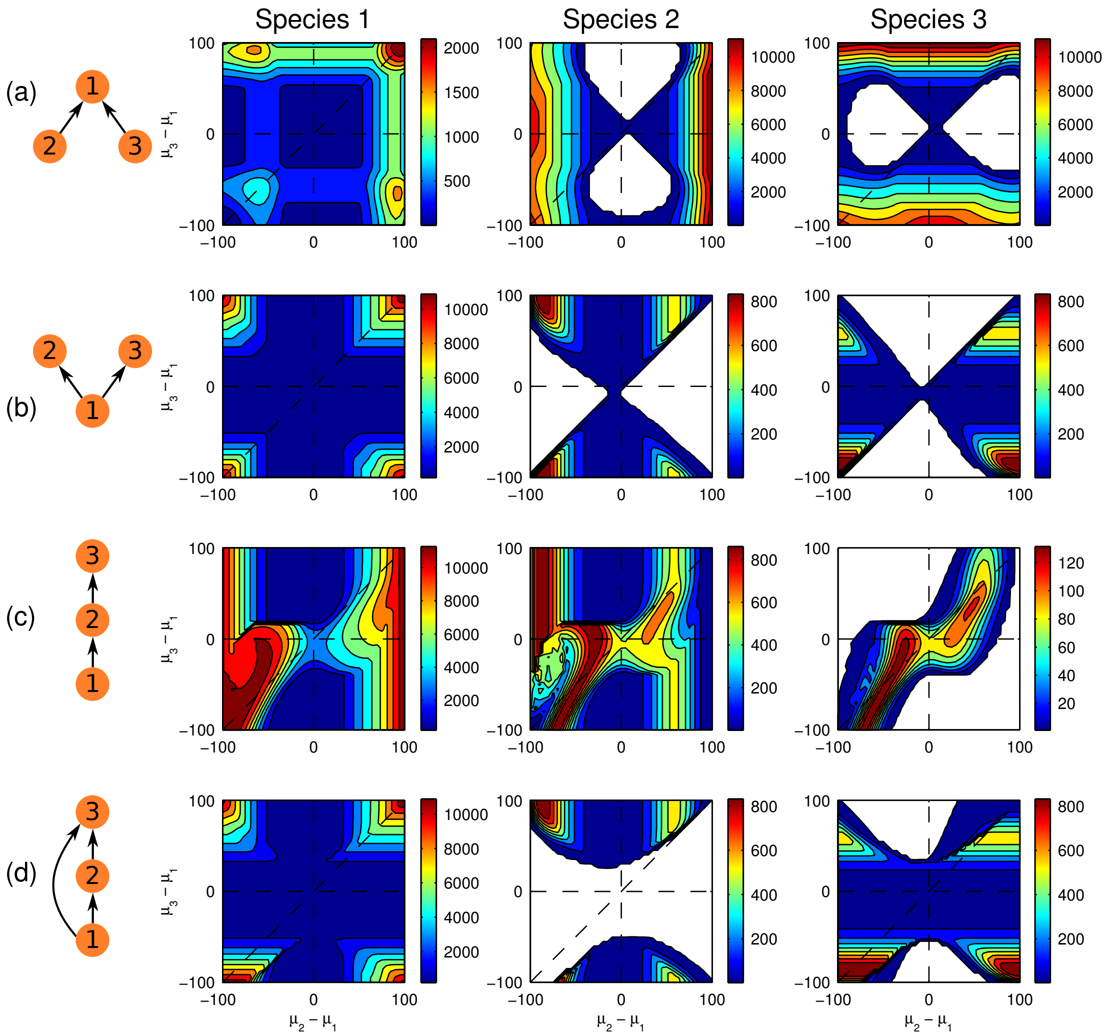

Figure 15: With increased recruitment spread only for consumers

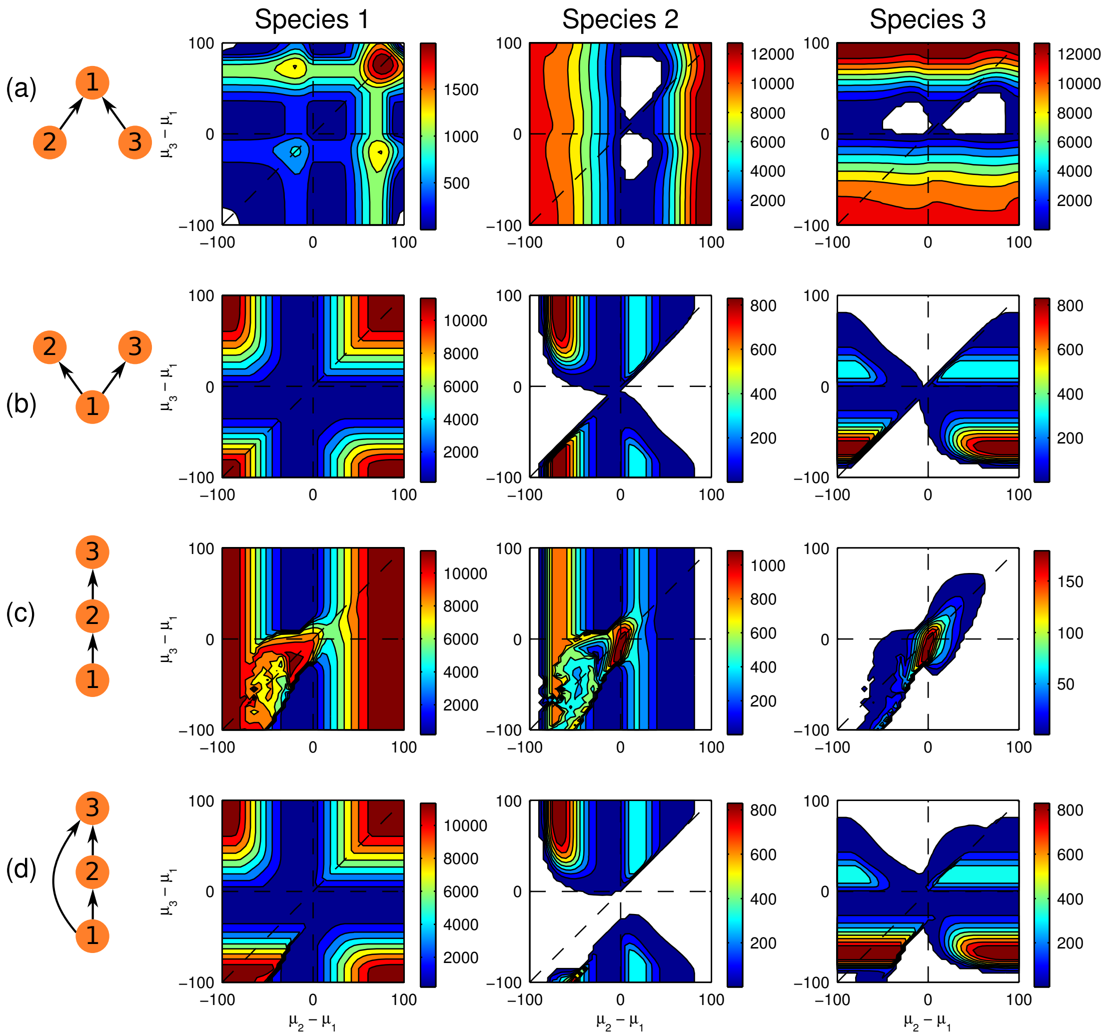

Figure 16: With decreased recruitment spread only for consumers

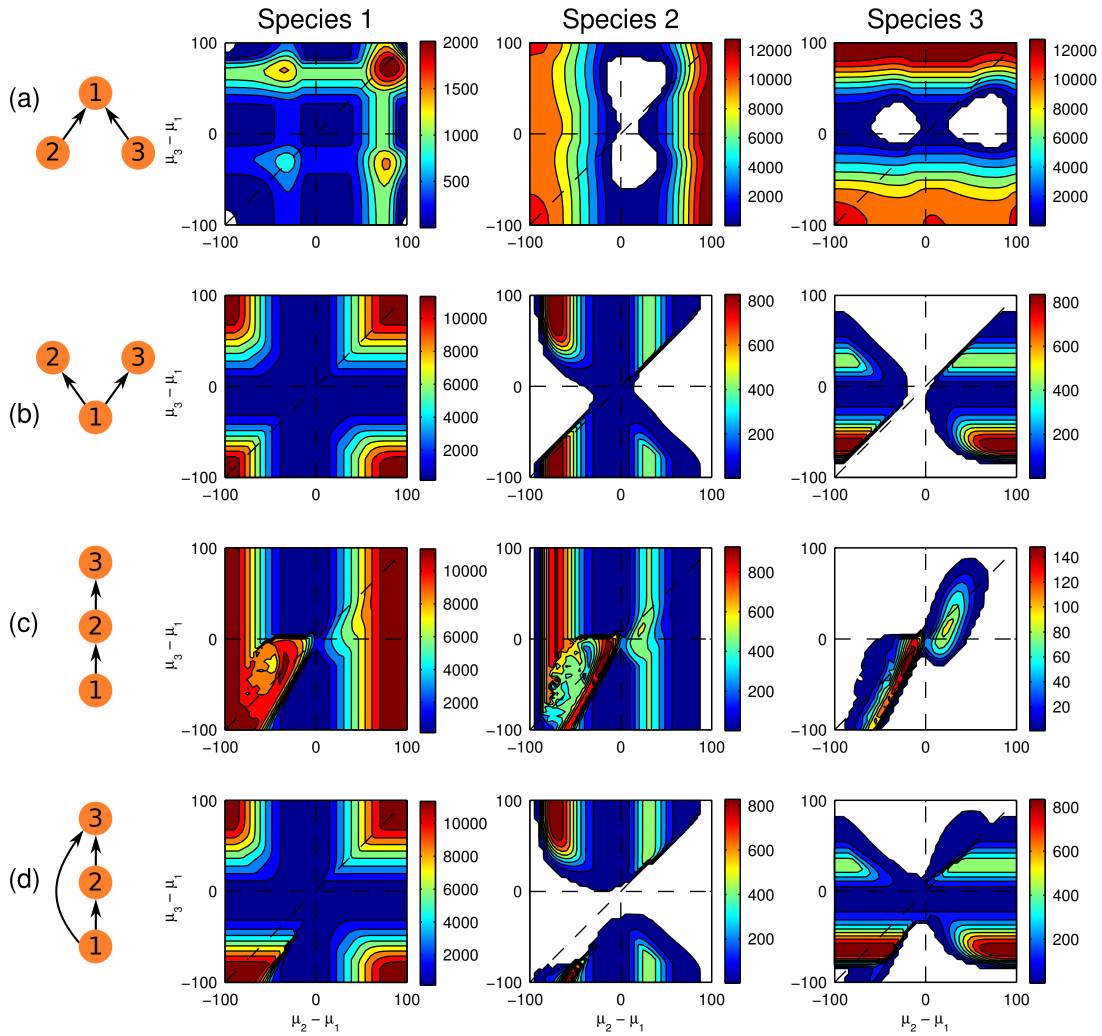

Figure 17: With asymmetry in consumption rates

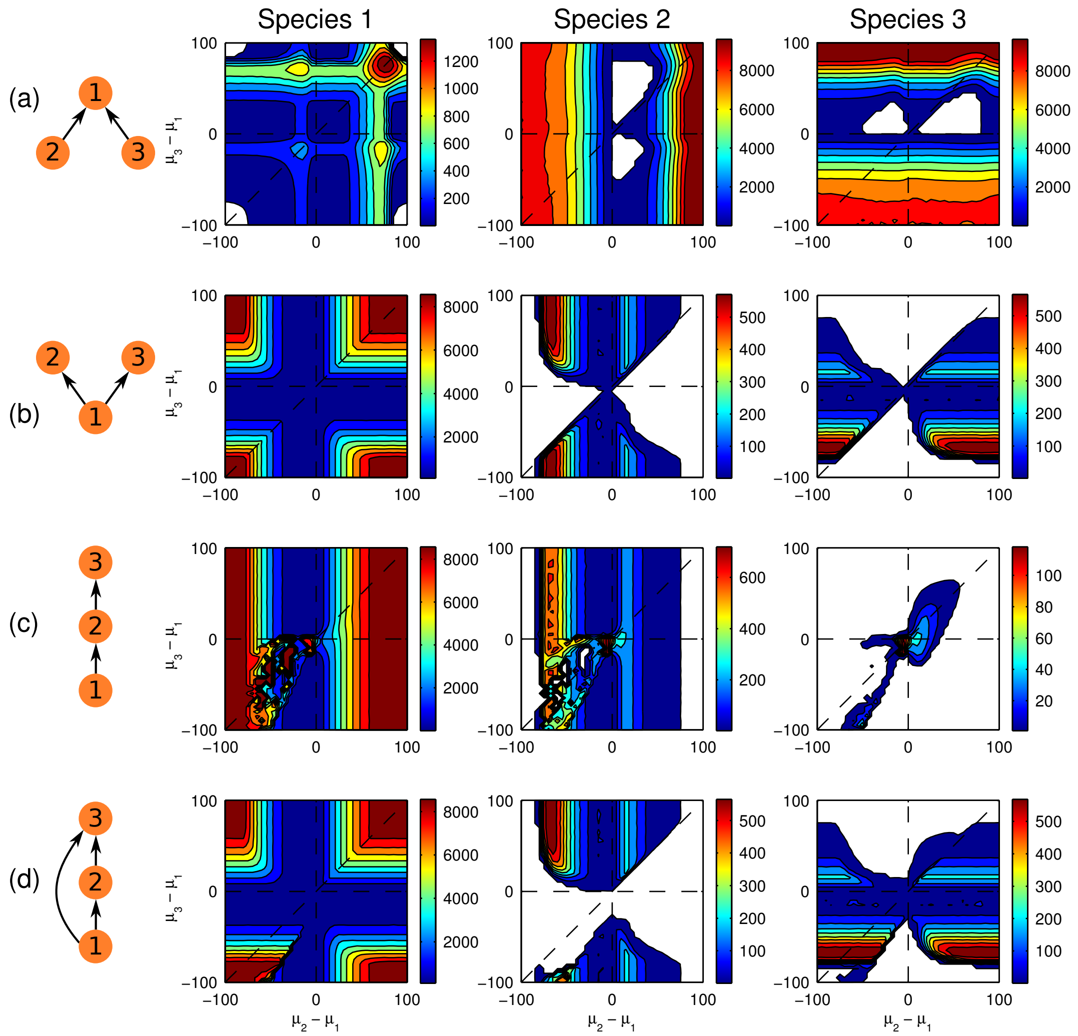

Figure 18: With uniformly distributed recruitment