

Summary

Introduction

- climate change
- adaptation, phenotypic plasticity, predict adaptation
- tree demography success or extinction?

Materials and Methods

Basic explanation of the models. We modeled a stage-structured population in two stages: immatures and matures. The demography is given by a transition matrix, with...

Under constant environment, no plasticity

Using [Lande \(2009\)](#), under weak selection we have:

$$\Delta \bar{z} = \frac{d \ln \bar{\lambda}(\bar{z})}{d \bar{z}} = \frac{1}{\bar{\lambda}(\bar{z})} \frac{d \bar{\lambda}(\bar{z})}{d \bar{z}} \quad (1)$$

And we have:

$$\begin{aligned} \bar{\lambda}(\bar{z}) &= \sum_{i,j} v_i u_j \bar{a}_{ij} \\ &= v_I u_I \bar{a}_{II} + v_I u_M \bar{a}_{IM} + v_M u_I \bar{a}_{MI} + v_M u_M \bar{a}_{MM} \end{aligned}$$

With \bar{a}_{ij} the expected values of the coefficient of the transition matrix. Thus,

$$\begin{aligned} \bar{\lambda}(\bar{z}) &= v_I u_I [\bar{f}_1(\bar{z}) m s_0 + (1 - m) \bar{s}_I(\bar{z})] + v_I u_M s_0 \bar{f}_2(\bar{z}) \\ &\quad + v_M u_I m s_M + v_M u_M s_M \end{aligned} \quad (2)$$

$$\frac{d \bar{\lambda}(\bar{z})}{d \bar{z}} = v_I u_I \left[\frac{d \bar{f}_1(\bar{z})}{d \bar{z}} m s_0 + (1 - m) \frac{d \bar{s}_I(\bar{z})}{d \bar{z}} \right] + v_I u_M s_0 \frac{d \bar{f}_2(\bar{z})}{d \bar{z}} \quad (3)$$

Because f_i and s_I are gaussians we can write the population means \bar{f}_i and \bar{s}_I easily.

$$\bar{f}_1(\bar{z}) = f_1(\theta_f) \sqrt{\frac{\omega_f}{\omega_f + P_I}} \exp \left(-\frac{(\bar{z} - \theta_f)^2}{2(\omega_f + P_I)} \right) \quad (4a)$$

$$\bar{f}_2(\bar{z}) = f_2(\theta_f) \sqrt{\frac{\omega_f}{\omega_f + P_M}} \exp \left(-\frac{(\bar{z} - \theta_f)^2}{2(\omega_f + P_M)} \right) \quad (4b)$$

$$\bar{s}_I(\bar{z}) = s_I(\theta_s) \sqrt{\frac{\omega_s}{\omega_s + P_I}} \exp \left(-\frac{(\bar{z} - \theta_s)^2}{2(\omega_s + P_I)} \right) \quad (4c)$$

Thus we can derive these expression with respect to \bar{z} :

$$\begin{aligned} \frac{\partial \bar{f}_1(\bar{z})}{\partial \bar{z}} &= f_1(\theta_f) \sqrt{\frac{\omega_f}{\omega_f + P_I}} \frac{\partial \exp \left(-\frac{(\bar{z} - \theta_f)^2}{2(\omega_f + P_I)} \right)}{\partial \bar{z}} \\ &= f_1(\theta_f) \sqrt{\frac{\omega_f}{\omega_f + P_I}} \exp \left(-\frac{(\bar{z} - \theta_f)^2}{2(\omega_f + P_I)} \right) \frac{\theta_f - \bar{z}}{\omega_f + P_I} \\ &= \bar{f}_1(\bar{z}) \frac{\theta_f - \bar{z}}{\omega_f + P_I} \end{aligned} \quad (5)$$

We obtain similar formulas for $\overline{f_2}$ and $\overline{s_I}$. Plugging (5) into (3) we have:

$$\frac{d\overline{\lambda}(\overline{z})}{d\overline{z}} = v_I u_I \left[\frac{\theta_f - \overline{z}}{\omega_f + P_I} m s_0 + (1 - m) \frac{\theta_s - \overline{z}}{\omega_s + P_I} \right] + v_I u_M s_0 \frac{\theta_f - \overline{z}}{\omega_f + P_M} \quad (6)$$

Using (6) into (1) gives us after rearranging: We have for variations of phenotype, under weak selection:

$$\Delta\overline{z} = (\theta_f - \overline{z}) \left[\frac{v_I u_I G_I s_0 m \overline{f_1}}{\lambda(P_I + \omega_f)} + \frac{v_I u_M G_M s_0 \overline{f_2}}{\lambda(P_M + \omega_f)} \right] + (\theta_s - \overline{z}) \left[\frac{v_I u_I G_I \overline{s_I} (1 - m)}{\lambda(P_I + \omega_s)} \right] \quad (7)$$

Within the square brackets, we see weighting average of fecundity and survival. Thus, we define them as γ_f and γ_s such as:

$$\gamma_f = \frac{v_I u_I s_0 m \overline{f_1}}{\lambda(P_I + \omega_f)} + \frac{v_I u_M \frac{G_M}{G_I} s_0 \overline{f_2}}{\lambda(P_M + \omega_f)} \quad (8a)$$

and

$$\gamma_s = \frac{v_I u_I \overline{s_I} (1 - m)}{\lambda(P_I + \omega_s)} \quad (8b)$$

We end up having a simpler expression for $\Delta\overline{z}$ under constant environment:

$$\begin{aligned} \Delta\overline{z} &= -G_I [\gamma_f (\overline{z} - \theta_f) + \gamma_s (\overline{z} - \theta_s)] \\ \Delta\overline{z} &= -G_I \gamma (\overline{z} - \theta_v) \end{aligned} \quad (9)$$

with

$$\gamma = \gamma_f + \gamma_s \quad (10)$$

$$\theta_v = \frac{\frac{\gamma_f}{\gamma_s} \theta_f + \theta_s}{\frac{\gamma_f}{\gamma_s} + 1} \quad (11)$$

Under varying environment, without plasticity

From [Engen et al. \(2011\)](#), we derived equations for mean variation of phenotype on our model.

We supposed an auto-correlated fluctuating environment ϵ_t influencing optimums θ_i such as:

$$\begin{cases} \theta_i(t) = \overline{\theta}_i + \alpha_i \epsilon_t \\ \epsilon_{t+1} = (1 - \rho) \overline{\epsilon} + \rho \epsilon_t + \xi \end{cases} \quad (12)$$

with α_i the dependence factor of the optimum on the environment, ρ the auto-correlation coefficient of the environment, $\overline{\epsilon}$ the expected environment and ξ a gaussian noise vector with variance σ_ξ^2 and mean 0. We chose $\overline{\epsilon} = 0$ to simplify the calculations so that $\epsilon_{t+1} = \rho \epsilon_t + \xi$, we can see that:

$$\begin{aligned} \theta_i(t+1) &= \overline{\theta}_i + \alpha_i \epsilon_{t+1} \\ &= \overline{\theta}_i + \alpha_i (\rho \epsilon_t + \xi) \\ &= \overline{\theta}_i + \alpha_i \rho \left(\frac{\theta_i(t) - \overline{\theta}_i}{\alpha_i} \right) + \alpha_i \xi \\ \theta_i(t+1) &= \overline{\theta}_i (1 - \rho) + \rho \theta_i(t) + \alpha_i \xi \end{aligned} \quad (13)$$

The auto-correlation in the environment ϵ_t causes θ_i to be auto-correlated with the same correlation coefficient ρ .

Using the same approach as in a constant environment, under weak selection, we end up having a similar equation than (7) but with optimum depending on environment:

$$\Delta \bar{z}_t = (\theta_f(t) - \bar{z}_t) \left[\frac{v_I u_I G_I s_0 m \bar{f}_1}{\lambda_t(P_I + \omega_f)} + \frac{v_I u_M G_M s_0 \bar{f}_2}{\lambda_t(P_M + \omega_f)} \right] + (\theta_s(t) - \bar{z}_t) \left[\frac{v_I u_I G_I \bar{s}_I (1 - m)}{\lambda_t(P_I + \omega_s)} \right] \quad (14)$$

Plugging (12) in (14) we obtain

$$\Delta \bar{z}_t = (\bar{\theta}_f + \alpha_f \epsilon_t - \bar{z}_t) \left[\frac{v_I u_I G_I s_0 m \bar{f}_1}{\lambda_t(P_I + \omega_f)} + \frac{v_I u_M G_M s_0 \bar{f}_2}{\lambda_t(P_M + \omega_f)} \right] + (\bar{\theta}_s + \alpha_s \epsilon_t - \bar{z}_t) \left[\frac{v_I u_I G_I \bar{s}_I (1 - m)}{\lambda_t(P_I + \omega_s)} \right] \quad (15a)$$

Defining the same γ_f , γ_s and θ_v as in (8a), (8b) and (11), respectively:

$$\begin{aligned} \Delta \bar{z}_t &= G_I [(\bar{\theta}_f + \alpha_f \epsilon_t - \bar{z}_t) \gamma_f + (\bar{\theta}_s + \alpha_s \epsilon_t - \bar{z}_t) \gamma_s] \\ &= -G_I [\gamma_f (\bar{z}_t - \theta_f) + \gamma_s (\bar{z}_t - \theta_s)] - G_I \epsilon_t (\gamma_f \alpha_f + \gamma_s \alpha_s) \\ \Delta \bar{z}_t &= \Delta \bar{z} + G_I \epsilon_t (\gamma_f \alpha_f + \gamma_s \alpha_s) \end{aligned} \quad (15b)$$

$$\begin{aligned} &= -G_I \gamma (\bar{z}_t - \theta_v) + G_I \epsilon_t (\gamma_f \alpha_f + \gamma_s \alpha_s) \\ &= -G_I \gamma \left(\bar{z}_t - \theta_v - \epsilon_t \frac{\gamma_f \alpha_f + \gamma_s \alpha_s}{\gamma} \right) \\ \Delta \bar{z}_t &= -G_I \gamma (\bar{z}_t - \theta_v - \alpha_v \epsilon_t) \end{aligned} \quad (15c)$$

With α_v a weighted component between α_f and α_s , defined in similar fashion as θ_v in (11):

$$\begin{aligned} \alpha_v &= \frac{\gamma_f \alpha_f + \gamma_s \alpha_s}{\gamma} \\ &= \frac{\gamma_f \alpha_f + \gamma_s \alpha_s}{\gamma_f + \gamma_s} \\ \alpha_v &= \frac{\frac{\gamma_f}{\gamma_s} \alpha_f + \alpha_s}{\frac{\gamma_f}{\gamma_s} + 1} \end{aligned} \quad (16)$$

Estimating variance of \bar{z}_t

Taking (15c) we can estimate variance of \bar{z}_t . Using the same process as Engen et al. (2011). Indeed, (15c) has the form:

$$\Delta A_t = -D A_t + e_t \quad (17)$$

with $A_t = \bar{z}_t - \theta_v$, $D = G_I \gamma$ and $e_t = D \alpha_v \epsilon_t$. (17) has a stationary solution:

$$A_{t+1} = (1 - D)^{t+1} A_0 + \sum_{r=0}^t (1 - D)^r e_{t-r} \quad (18a)$$

If we consider the evolution of A_t over a long time, (18a) becomes, because $(1 - D) < 1$:

$$A_t = \sum_{r=0}^{\infty} e_{t-r} (1 - D)^r \quad (18b)$$

We want to estimate how will \bar{z}_t move away from the mean because of environmental fluctuations, that is why we compute its variance. From (18a):

$$\begin{aligned}
\text{Var}(A_t) &= \text{Var} \left[\sum_{r=0}^{\infty} e_{t-r} (1-D)^r \right] \\
&= \sum_{r=0}^{\infty} \text{Var} [e_{t-r} (1-D)^r] \\
&= \sum_{r=0}^{\infty} \text{Var} [\epsilon_{t-r} D \alpha_v (1-D)^r] \\
&\stackrel{\text{def}}{=} \sigma_{\epsilon}^2 D^2 \alpha_v^2 \sum_{r=0}^{\infty} (1-D)^{2r} \\
\text{Var}(A_t) &= \sigma_{\epsilon}^2 D^2 \alpha_v^2 \frac{1}{1 - (1-D)^2} \\
\text{Var}(\bar{z}_t) &\stackrel{\text{def}}{=} \sigma_{\epsilon}^2 G_I^2 \gamma^2 \alpha_v^2 \frac{1}{G_I \gamma (2 - G_I \gamma)} \\
\text{Var}(\bar{z}_t) &\stackrel{\gamma \rightarrow 0}{=} \frac{1}{2} G_I \gamma \sigma_{\epsilon}^2 \alpha_v^2
\end{aligned} \tag{19}$$

Results

Subheading1

Subheading2

Discussion

Authors Contributions and Acknowledgments

References

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- Lande, R. (2009). Adaptation to an extraordinary environment by evolution of phenotypic plasticity and genetic assimilation. *Journal of Evolutionary Biology* 22, 1435--1446.