Seasonality and the evolutionary divergence of plant parasites

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Niche theory and speciation workshop
Lake Balaton, August 2011

Biotrophic plant parasites

- **feed, grow and reproduce on their living host plant**
- cause massive damage to staple food crops

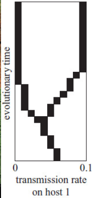
Potato late blight caused the "great famine" in Ireland (1845-1852)

- **ubiquitous coexistence of related plant parasite species**[1]

[1] Brasier (1987)

Which ecological bases for evolutionary diversification?

- Resource heterogeneity can promote evolutionary divergence[2]



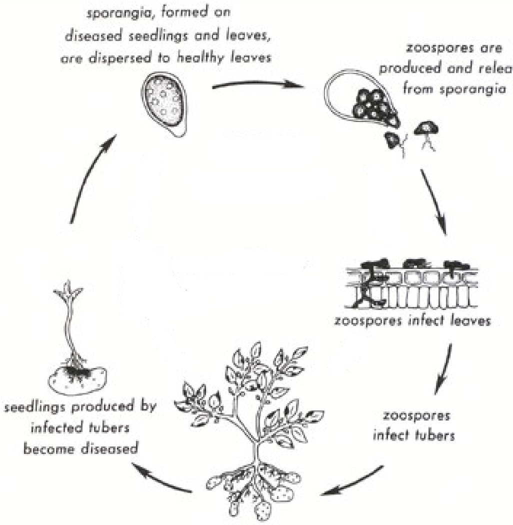
- **Can seasonality promote evolutionary divergence as well?**

[2]Gudelj *et al.* (2004)

Biotrophic parasites life cycle. *P. infestans* example:

During early spring

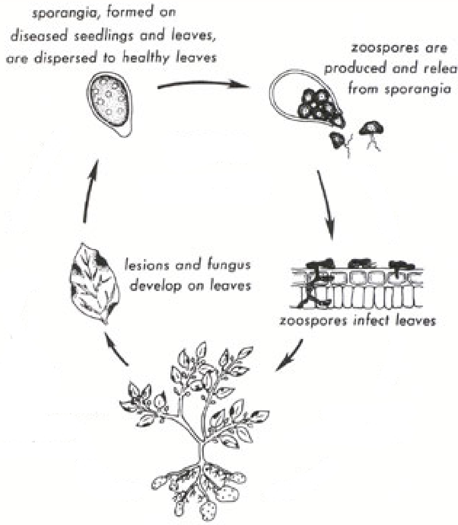
- **Primary infections**: seedlings infection by **inoculum from previous seasons**



Biotrophic parasites life cycle. *P. infestans* example:

During the **season**

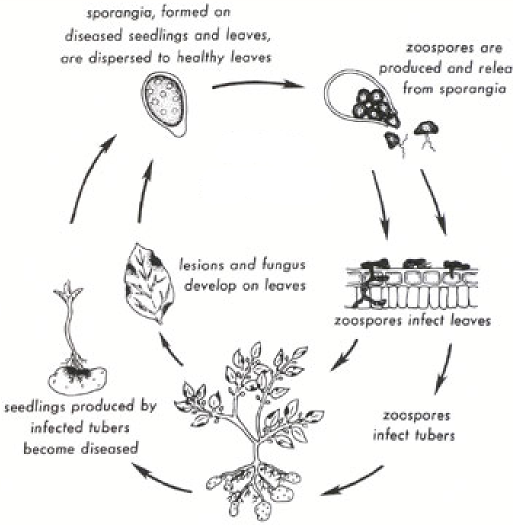
- **Secondary infections**: host-to-host infections through **inoculum from the current season**



Biotrophic parasites life cycle. *P. infestans* example:

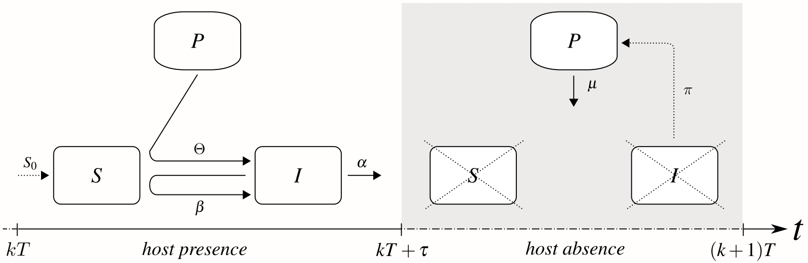
Two **complementary** transmission routes:

- **between** season
- **within** season



Full model

- Two **time windows**:



This is a 3-dimensional nonlinear continuous×discrete model.

- Assuming **fast** primary infections yields a 2-d compact form[3]

[3]Mailleret *et al.*, *Theor. Ecol.* (2011)

Compact model

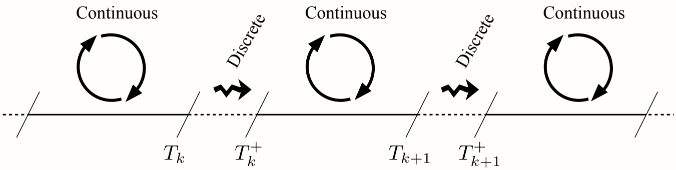
- Within season **continuous part**:

$$\dot{S} = -\sum_i \beta_i S I_i \,, \qquad \text{Susceptible/healthy hosts}$$
$$\dot{I}_i = \beta_i S I_i - \alpha I_i \,. \qquad \text{Infected/infectious hosts, } r \text{ or } m$$

- Between season **discrete part**:

$$\begin{aligned} S(T_k^+) &= S_0 \exp\left(-\sum_i F_i(T_k)\right), \\ I_i(T_k^+) &= S_0 \left[1 - \exp\left(-\sum_i F_i(T_k)\right)\right] \times \frac{F_i(T_k)}{\sum_i F_i(T_k)}, \end{aligned} \qquad (1)$$

with $F_i(T_k) \propto I_i(T_k) \exp(-\mu_i(T-\tau))$.



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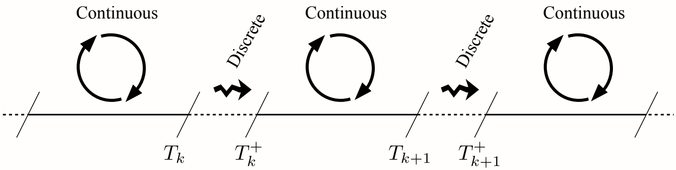
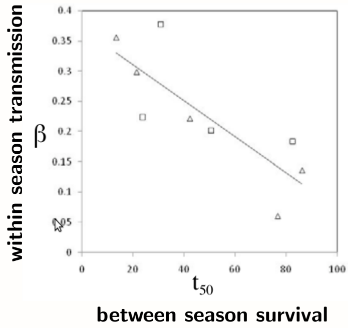


Evolutionary trade-off

- Biological evidence[4] of a **negative relationship** between

Gosme *et al.* (2009), take-all of wheat



- To **capture** this, let $\mu_i = f(\beta_i)$, **with** $f' > 0$.

[4] Abang *et al.* (2006), Carson (1998).

Adaptive Dynamics

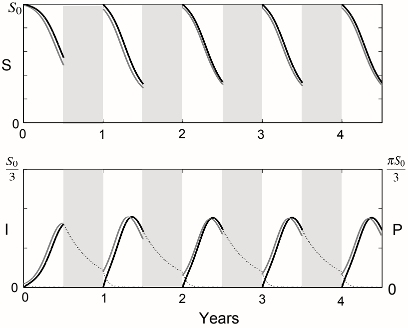
A framework to address phenotypic **evolution**

- consider a **resident** population at ecological “equilibrium,”
- **challenge** it with a small **mutant** sub-population

Assuming the resident is at a T-periodic equilibrium $(S_r^\circ(\cdot), I_r^\circ(\cdot))$,

let

$$\bar{S}_r = \frac{1}{\tau}\int_0^\tau S_r^\circ(t)\mathrm{d}t\,.$$



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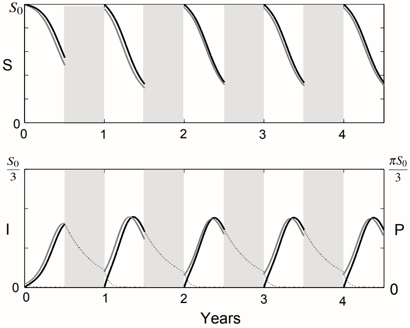


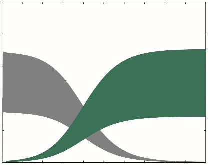
Invasion fitness

The mutant invasion criterion reads:

$$s(\beta_r, \beta_m) = (\beta_m - \beta_r)\bar{S}^\circ(\beta_r)\tau - [f(\beta_m) - f(\beta_r)](T - \tau)$$

- *i.e.* the mutant can invade provided

$$s(\beta_r, \beta_m) > 0.$$



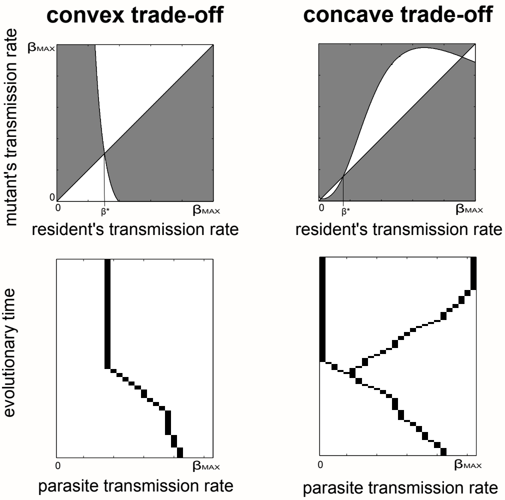
We are interested in **singular traits** $\beta^\star$ s.t.

$$\mathrm{D}_2 s(\beta^\star, \beta^\star) = 0\,.$$

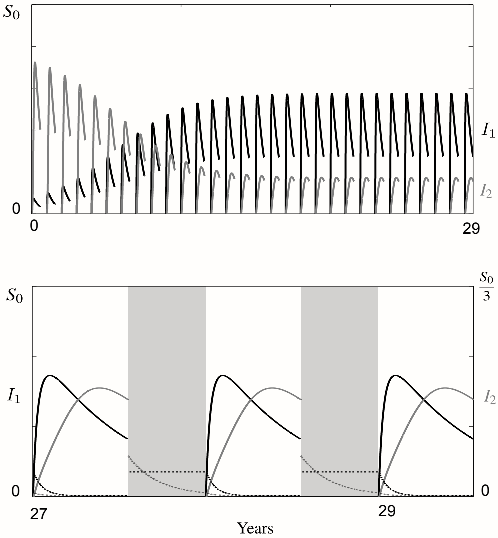
One necessary condition for a branching point to occur reads

$$\mathrm{D}_{22} s(\beta^\star, \beta^\star) = -f''(\beta^\star)(T - \tau) > 0\,.$$

Pairwise Invasibility Plots and evolutionary dynamics



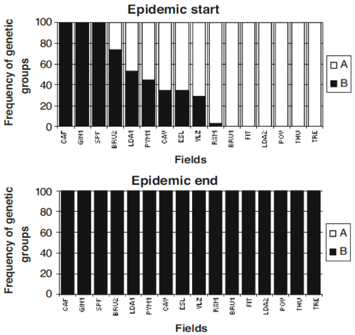
Ecological dynamics at the dimorphic evolutionary endpoint



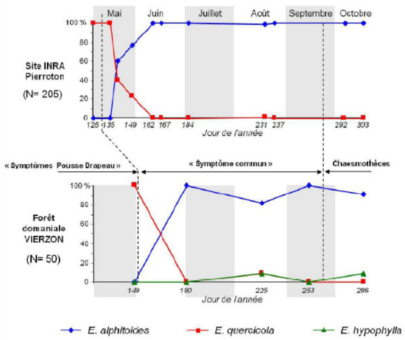
Evolution can promote temporal niche differentiation

- Biological evidence in several cryptic species complexes

Montarry *et al.* (2007), grapevine powdery mildew



Feau *et al.* (2011), oak powdery mildew



- **Can reproductive isolation arise from time partitioning?**

Thank you for your attention

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References:

- Mailleret L, Castel M, Montarry J, Hamelin FM. From elaborate to compact seasonal plant epidemic models and back: is competitive exclusion in the details? *Theoretical Ecology*, In Press.
- Hamelin FM, Castel M, Poggi S, Andrivon D, Mailleret L. Seasonality and the evolutionary divergence of plant parasites. *Ecology*, in press.