

ELECTRONIC APPENDIX

This is the Electronic Appendix to the article

**Pathogen adaptation to seasonal forcing
and climate change**

by

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Proc. R. Soc. B ([doi:10.1098/rspb.2004.3043](https://doi.org/10.1098/rspb.2004.3043))

Electronic appendices are refereed with the text; however, no attempt is made to impose a uniform editorial style on the electronic appendices.

Online material

Online appendix

The analytical derivation of $S(x,t)$ is intractable in this system for all but the full generalist strain, which is discussed here. For a generalist strain x , there is no sensitivity to the seasonal driver, such that $c(x) = 0$. The transmission of the pathogen at any point in the year is then $\beta_{\max}(x)$, and the equilibrium fraction of susceptibles in the host population is independent of time and easily solved with eq. 1:

$$\frac{S^*(x)}{N} = \frac{\alpha}{\beta_{\max}(x)}. \quad (\text{A1})$$

The invasion fitness of a mutant strain y into a host population with a resident generalist strain x can then be evaluated by substituting the expression (A1) into the general fitness function (eq. 3):

$$f(y, x) = \int_{t=0}^{\infty} \alpha \left(\frac{\beta_s(y, t)}{\beta_{\max}(x)} - 1 \right) dt \quad (\text{A2})$$

This expression can be further simplified by summing only from $t = 0$ to $t = 1$, since the only time-dependent variable is $\beta_s(y,t)$, which has an annual cycle. Simplifying, we have:

$$f(y, x) > 0 \text{ iff } \int_{t=0}^1 \beta_{s,y}(t) dt > \beta_{\max,x} \quad (\text{A3})$$

that is, a slightly specialized mutant strain can invade only if its average transmission rate is greater than the resident's (constant) transmission rate.

Substituting in the expression for $\beta_s(y,t)$, we have:

$$\int_{t=0}^1 (c(y)(P_m - A \cos(2\pi t) - P_{opt}))^2 + \beta_{\max}(y) dt > \beta_{\max}(x) \quad (\text{A4})$$

When $P_m = P_{opt}$, we can integrate and simplify to:

$$\beta_{\max}(y) - \beta_{\max}(x) > -\frac{A^2}{2} c(y) \quad (\text{A5})$$

A specialist y can therefore invade when seasonal temperature fluctuations are low enough (small A), or if the decrease in $c(y)$ is compensated by a substantially larger

increase in $\beta_{\max}(y)$. The importance of the trade-off between sensitivity to climate fluctuations c and maximum transmission rate β_{\max} is thereby highlighted.

Online supplemental figure and text

The shape of the trade-off between β_{\max} and c affects the type of evolutionary singular strategy. When the shape of the trade-off curve between β_{\max} and c is convex (i.e. weak, with $\gamma = 0.85$), the evolutionary singular point is a continuously stable strategy (Figure S1a). When the shape of the trade-off becomes slightly concave ($\gamma = 1.03$), the evolutionary singular point, once reached, is a fitness minimum, resulting in evolutionary branching into two strains, one with higher and one with lower sensitivity to climatic variation (Figure S1b). Further increases in the strength (i.e. concavity) of the trade-off ($\gamma = 1.3$) result in a PIP configuration that leads to the evolution of either the generalist or the extreme specialist phenotype via repellor dynamics (Figure S1c). These results are in agreement with the types expected from a geometric analysis of convergence stability and evolutionary stability (de Mazancourt and Dieckmann 2004). At a value between $\gamma = 1.03$ and $\gamma = 1.3$, the trade-off shape becomes more concave than the local attainability boundary (the boundary delineating the phenotypes attainable by small evolutionary steps), converting the type of evolutionary singular strategy from an evolutionary branching point to an invisable repellor (de Mazancourt and Dieckmann 2004).

Figure S1. Pairwise invasibility plots (PIPs) for the seasonal phenotype, measured by a pathogen's sensitivity to climatic variability c . a) The evolutionary singular strategy is

continuously stable when $\gamma = 0.85$. b) The evolutionary singular strategy is an evolutionary branching point when $\gamma = 1.03$ c) The evolutionary singular strategy is an invincible repellor when $\gamma = 1.3$ In all PIPs, invasion fitness values $f(y,x)$ are positive in the black areas and negative in the white areas, and are obtained through numerical simulation of eq. 4. Climate fluctuations are given by $P_m = 210$, $A = 210$, and eq. 5. Both β_{\max} and c values for the specialist and generalist phenotypes are given in Figure 1. The epidemiological parameters in these simulations and the P_{opt} are given in Figure 2.

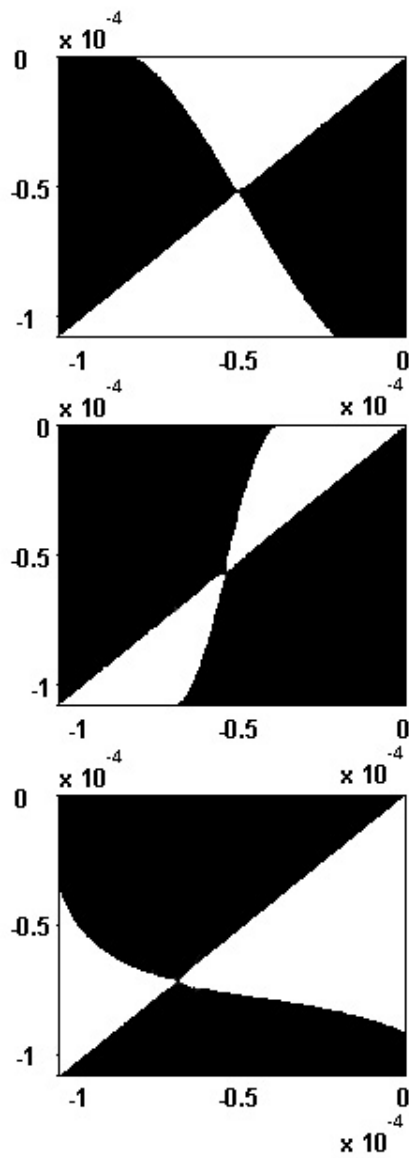


Figure S1

References

de Mazancourt, C. and U. Dieckmann (2004). Trade-off geometries and frequency-dependent selection. The American Naturalist **164**(6): 000-000.