Complex responses to movement based control: when moving cattle helps

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Background: movement based control

Livestock disease is often spread **between** herds by **movement** of infected animals

Interventions include quarantine, testing all animals in transit, and **restricting** cattle movement

R_0 is often used when examining disease spread, but it says little about **between-group transmissions** …

- … in this case household models have been used to calculate a threshold R_*, but usually consider disease spread by **contact** rather than **movement**, which we show makes an important difference

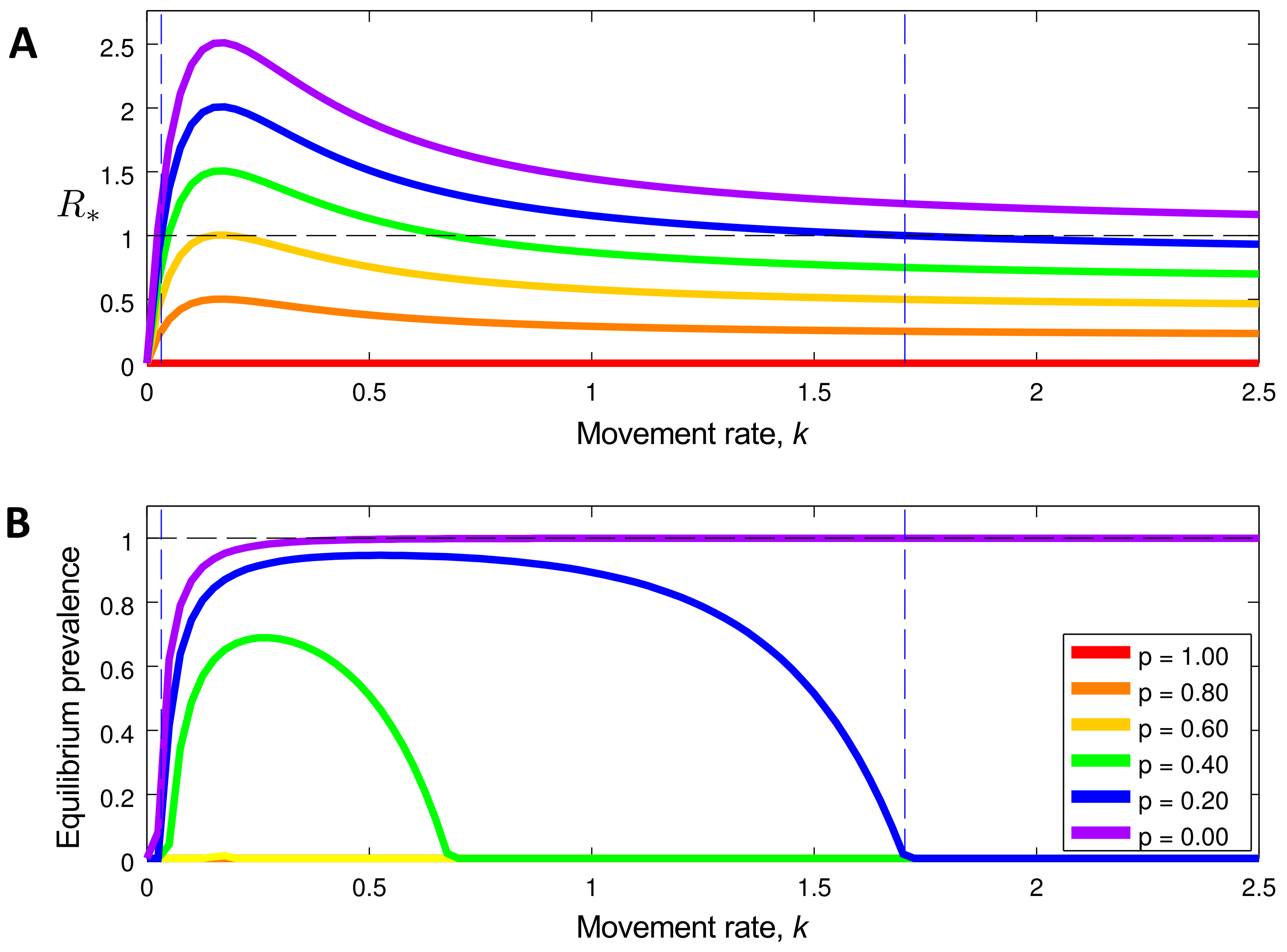
How disease spreads between groups

- **Next Generation Matrix**[1] techniques, used to calculate R_0 are extended to derive an expression for R_*

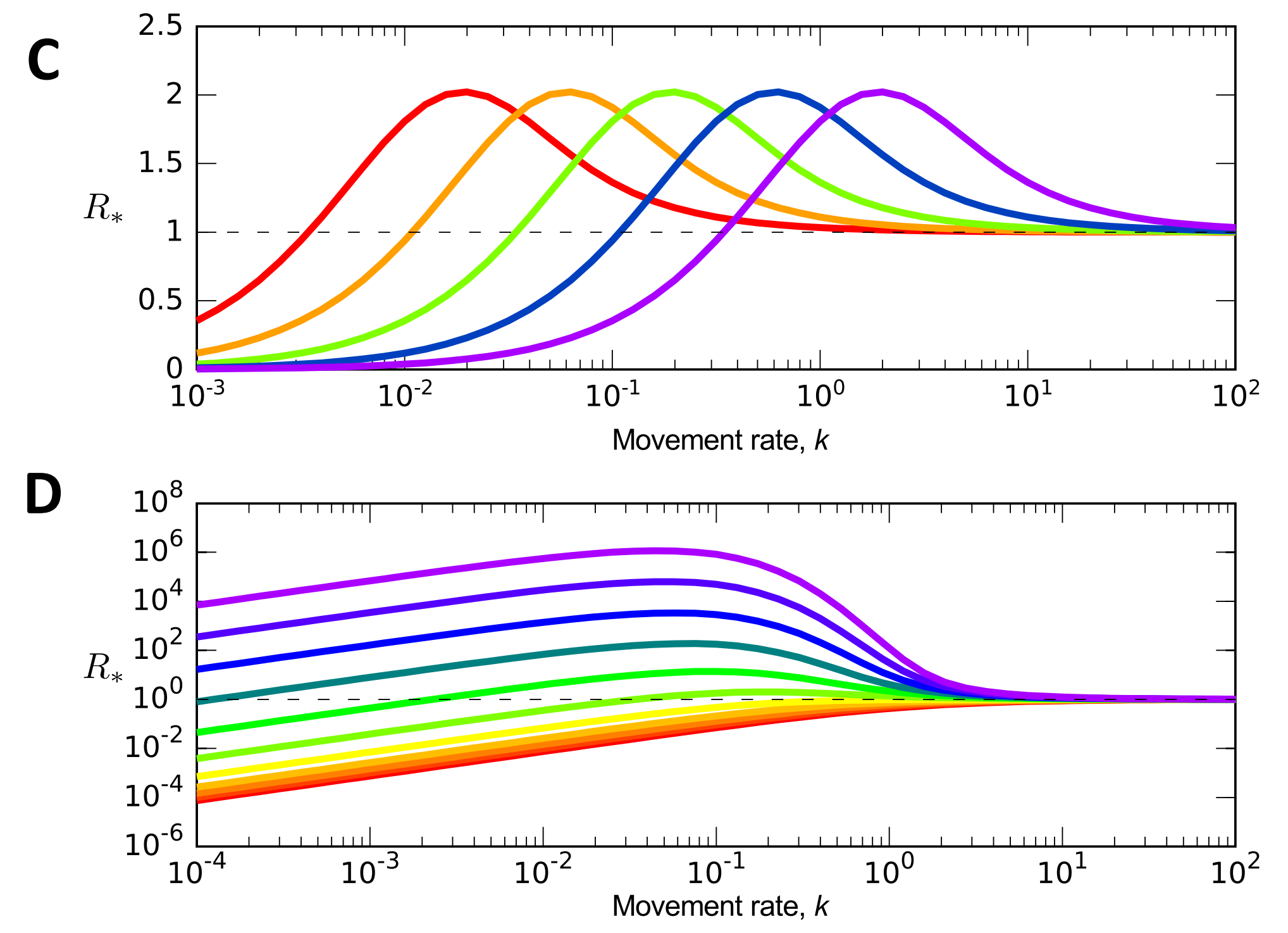
$$\kappa N P_{\text{pos}} T_{\text{inf}}$$

- where κ is the *per capita* movement rate, N is the herd size, P_{pos} is the average prevalence during the expected time T_{inf} until the herd recovers from the disease
- We use models to explore the behaviour of R_*, how it is affected by **disease intervention**, **heterogeneity**, and how it determines the expected between-herd **prevalence**. We consider R_* in a variety of important and real but characteristically different diseases: *Map* (Johne's disease), *E.coli* O157, Bovine Herpes Virus (BHV), and Bovine Viral Diarrhoea Virus (BVDV).

How R_* behaves: thresholds and control



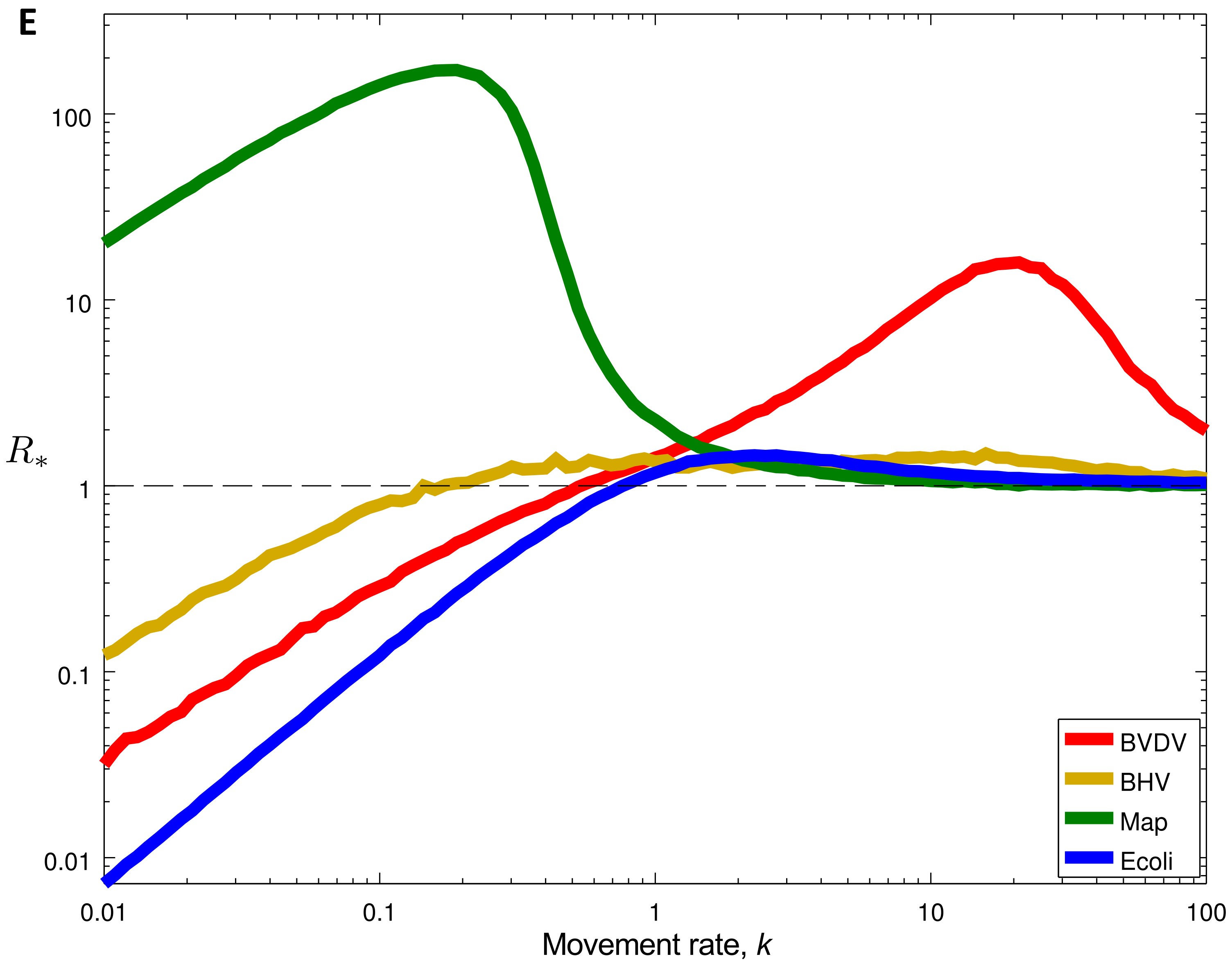
- R_* is 0 when there is no movement. When movement is high, $R_* \rightarrow 1$, as the primary infective becomes increasingly likely to move before it recovers, dies, or creates any secondary infectives
- The disease can persist only if $R_* > 1$, but a high R_* does not imply a high between-herd prevalence (see **B**, purple curve)
- If intervention successfully prevents a proportion p of infectives from arriving at another group, then R_* is reduced by a factor $1-p$.
- R_* is maximised for intermediate movement rate (see **A**) …
- **… therefore disease is hardest to control at intermediate movement rates**
- p must be $\geq 1-1/R_*$ to prevent disease persistence (c.f. R_0 and minimum vaccination coverage)

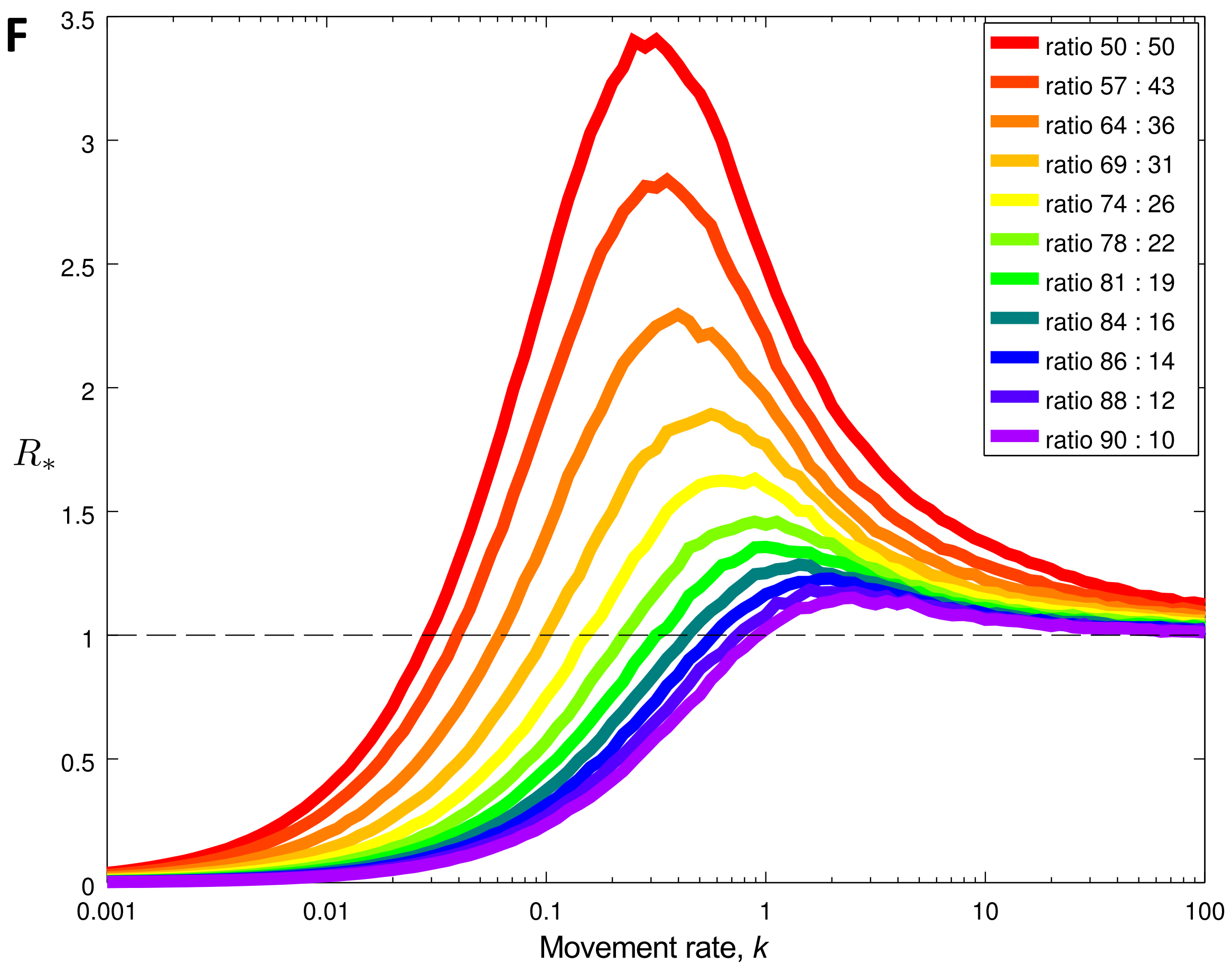


- Faster diseases have maximum R_* at higher movement rates than slower diseases with the same R_0 (see **C**)
- Higher R_0 leads to higher R_*, but has little effect on where it is hardest to control (see **D**)

Application to important livestock diseases, and the role of supershedders

- BVDV would be harder to control with higher movement rates
- *Map* is harder to control at lower movement rates because it persists within the herd for such a long time (movement based control is not a feasible way to handle *Map*)
- BHV and *Ecoli* both have low R_*, and should respond well to movement based disease control.





- *E.coli* O157 is characterised by heterogeneous shedding, with regular shedders and super shedders
- This gives rise to the 80-20 rule: 80% of the infection is caused by 20% of the infectives (see **F**, green curve)
- Varying the regular to supershedder ratio, but keeping R_0 fixed shows that heterogeneity in disease transmission **reduces** R_* (see **F**)

Key observations

- R_* is a useful metric for predicting the level of disease intervention needed to prevent disease persistence
- Transmission heterogeneity plays an important role in persistence
- R_* is maximised by different movement rates for different diseases, and therefore **hardest to control** at different movement rates.
- If reducing cattle movements were used to help to reduce BVDV transmission, it could **inadvertently** make *Map* considerably **more difficult** to control.

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[1] Diekmann, O., Heesterbeek, J. & Roberts, M. (2010). The construction of next-generation matrices for compartmental epidemic models. *J. R. Soc. Interface* **7**: 873—885.

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