evolution of virulence

27 February 2022

Definitions

- **virulence**
  - (broad): decrease in a host's fitness caused by a parasite.
  - (narrow): *per capita* rate of parasite-induced host mortality
- **resistance**: host's ability to resist or minimize infection
- **tolerance**: host's ability to support parasite infection without losing fitness
- **case mortality** (CM): fraction of hosts killed by infection
- Parasite-host interaction complicates the definition of virulence (assumes that a more virulent parasite is more virulent for *all* host genotypes/species)
- conceptually:
  - parasite load depends on balance between parasite *within-host reproduction rate* and host's *parasite clearance rate*
  - virulence depends on parasite load and per-copy parasite *pathogenicity* and host *tolerance*
  - this establishes the terms of the arms race, but these components can't be separated if we look at a single host-parasite pair (parasite virulence is often confounded with host tolerance)
- all in an arms race rather than RQ context

Classical dogma

- Parasites evolve lower virulence over time "for the good of the species". Group-selectionist *but* some evidence?
  - syphilis; first seen in Europe in 1495 (the "Great Pox") (Knell 2004)
    - origins? (previously misdiagnosed; evolved increased virulence; from Africa; from the New World)
    - virulence decreased rapidly over 50 years (maybe even 5-7 years?)
  - *virgin-soil epidemics*: smallpox, etc. [Crosby (1976); ostler_disease_2020] (probably *not* virulence: lack of genetic resistance, previous exposure, societal breakdown, effects of colonization?)

- sampling bias?
  - biocontrol examples always select for maximal virulence
  - mild introductions may not be noticed

Tradeoff theory

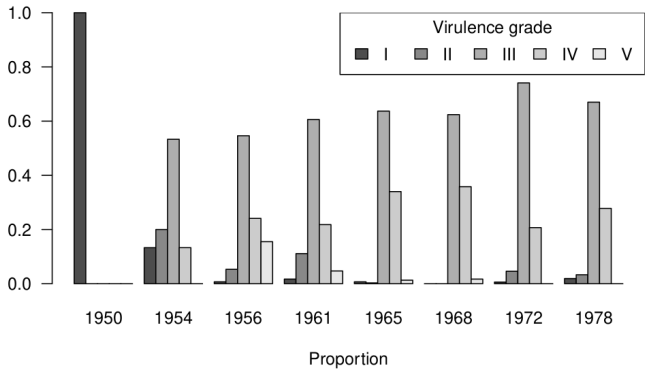
- Intermediate virulence evolves due to host-level selection (group theory returns); a tradeoff between transmission *rate* (infections/host/time) and virulence (*defined as mortality/time*) leads to maximum R_0 (total transmission per generation) at **intermediate** virulence.
- conceptually, mediated by parasite replication rate or load

Example: myxomatosis

Viral disease; mild in Brazilian rabbits (*Sylvilagus brasiliensis*), virulent in European rabbits (*Oryctolagus cuniculus*). Mosquito- and flea-borne. Introduced (several times) in Australia to control introduced rabbits, finally spread 1950-1951. Case mortality originally >99%, populations initially decreased by 90%. CM initially dropped to 90%, then further. Resistance: test by infecting laboratory rabbits that haven't evolved. CM of grade III strain drops from 90% to about 50% as populations experience more epizootics. At the same time mean virus grade drops from I to III, then rebounds.

Evidence for tradeoff theory: Higher grades (higher case mortality) also have faster mortality (<13 days to >50 day survival as CM goes from >99% to <50%). Skin virus *titer* is also higher (and increases faster with time) for higher grades. Mosquito infection probability is proportional to skin titer. (Some biological complications.)

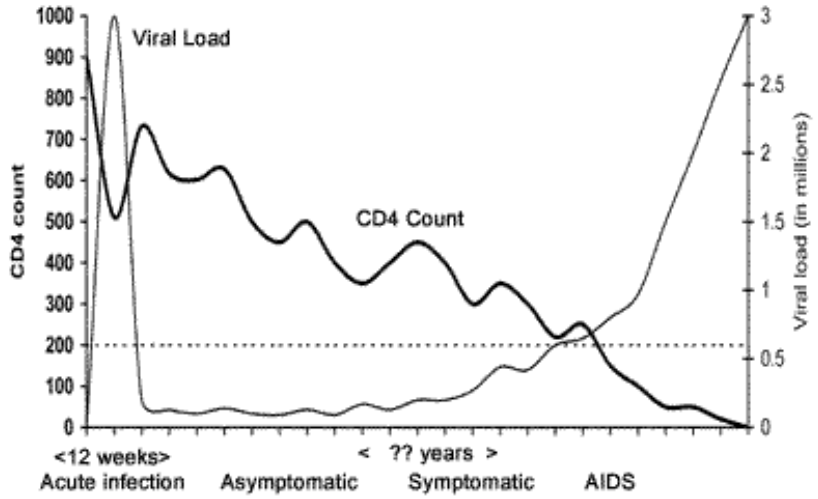
Myxomatosis grades over time (Fenner et al., 1956)



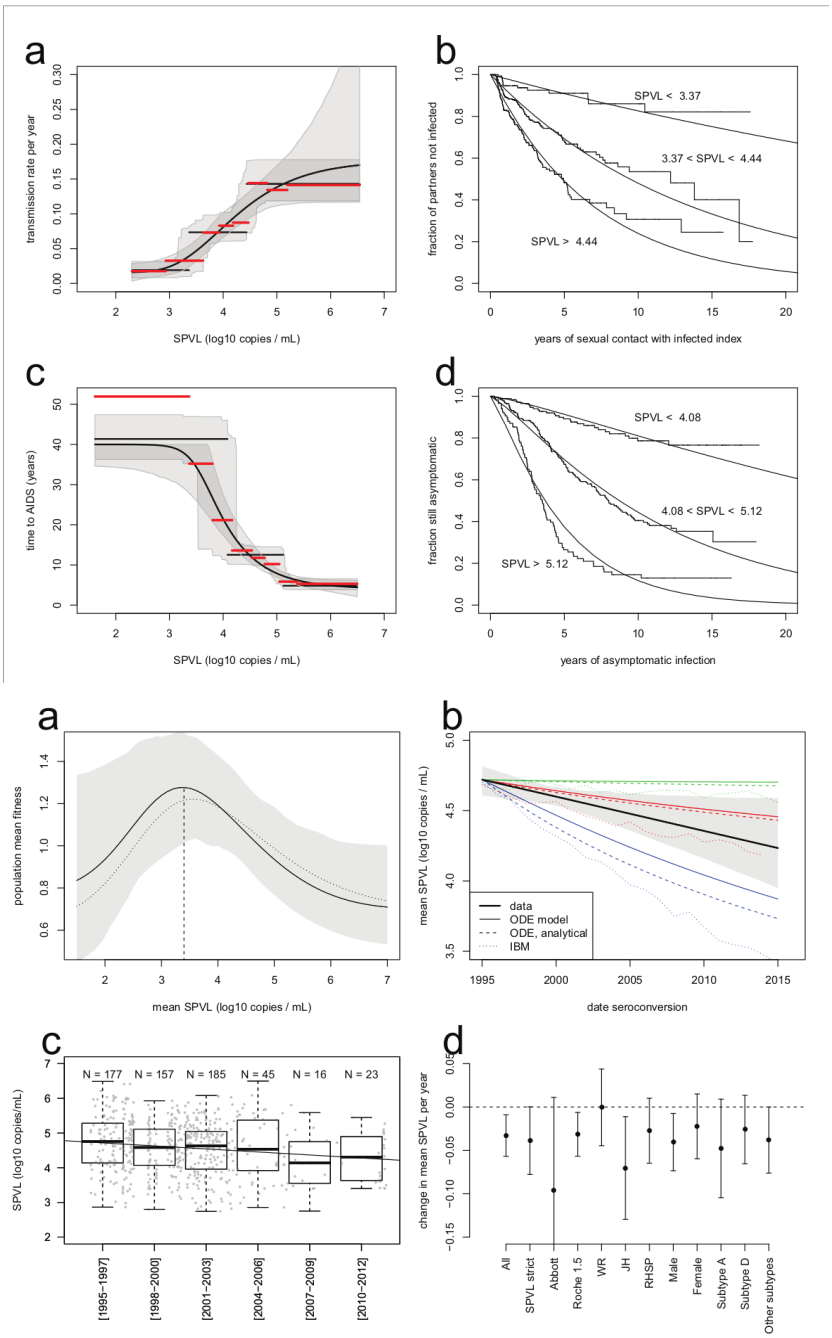
Bottom line: myxomavirus probably still reduces populations somewhat, but the Australians continue to look for other biocontrol solutions (calicivirus, rabbit haemhorrhagic disease).

Example: HIV

- Correlations among
  - *setpoint viral load*
  - *time to progression* or *rate of CD4 decline* (mechanisms still poorly understood! within-host evolution for diversity, virulence, immune escape? immune aging?? accumulation of opportunistic infections?)
  - *transmission probability* (as measured in *serodiscordant couples*; *Rakai cohort*)
- probably no longer ethically measurable



https://www.thebodypro.com/article/course-hiv-disease

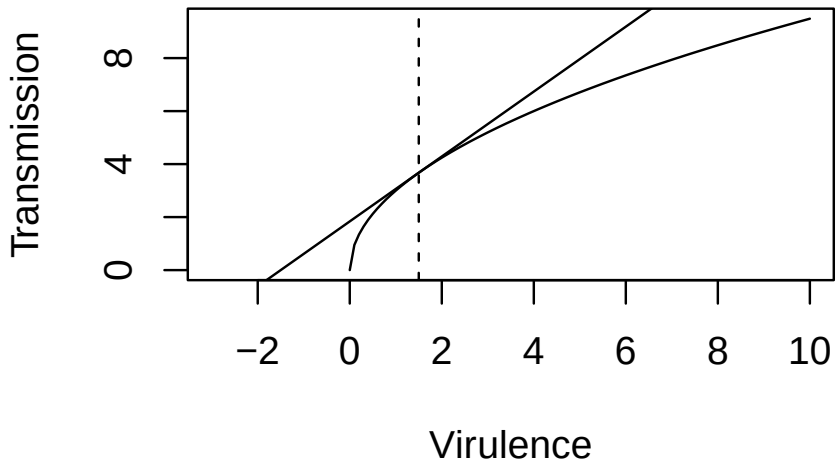


- highly variable [

Theory

- if there is a tradeoff, we would expect expect strong effects of **transmission mode**
  - vector-borne > direct

  - high virulence for "necrotransmission" (via dead hosts: anthrax, chronic wasting disease)
  - horizontal transmission > vertical
  - needle-borne > STD?
  - environmental (water-borne, e.g. cholera) > direct
- does higher overall transmission rate (due to population density, poor hygiene, etc.) select for higher transmission?
- **facultative** parasites (e.g. soil-borne microbes with a **facultative** stage) should be more virulent
- "curse of the pharaoh": effect of resting stages? (Bonhoeffer, Lenski, and Ebert 1996)
- spatial restriction should? decrease virulence (Kamo and Boots 2006)
- Maximizing R_0:



- "Virulence" could be effect of host mortality, or rapid clearance.
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Within-host competition

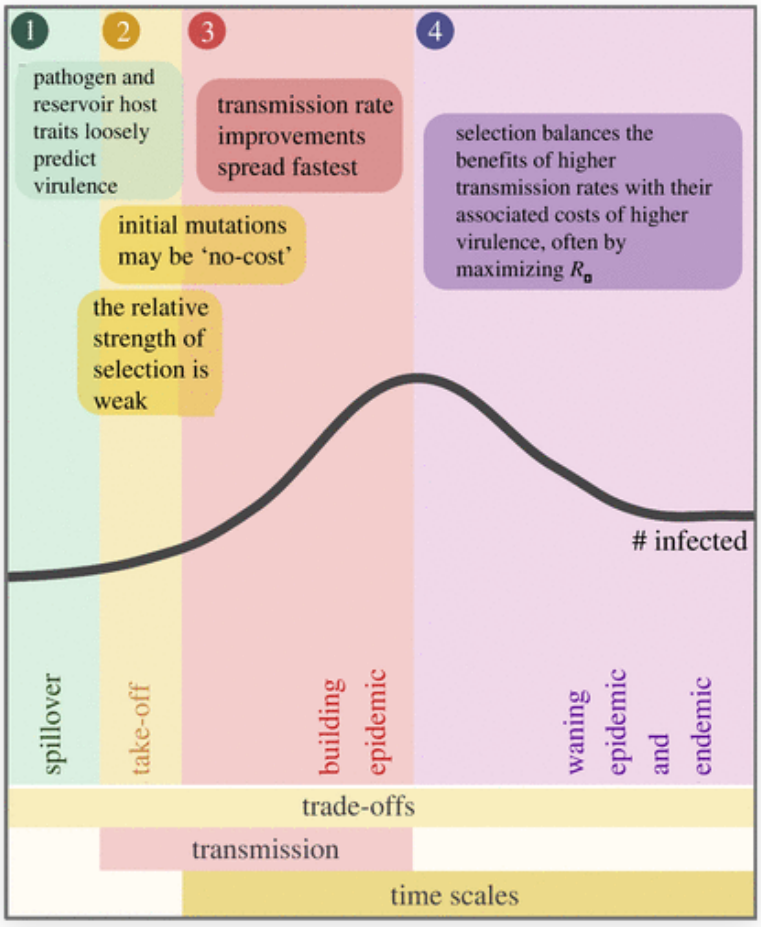
- basic tradeoff theory assumes one infection/strain per host
- effects of mutation, **superinfection**: within-host competition

Short-sighted evolution

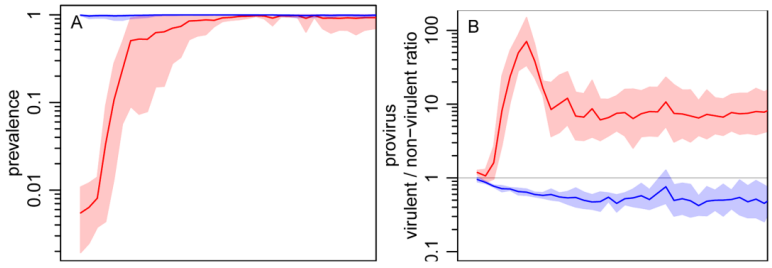
- sometimes evolution is just stupid (Levin and Bull 1994)
- meningitis-producing, paralytic polio strains (central nervous system tropism)
- HIV [most transmission probably occurs during acute phases]

Epidemic vs. endemic phases; transient virulence

(Frank 1996; Bolker, Nanda, and Shah 2010; Visher et al. 2021; Day and Proulx 2004; Berngruber et al. 2013)



Experimental evolution: phages started as endemic or epidemic



Effects of imperfect vaccines

- evolution due to **risk compensation** (Massad et al. 2006)?
- evolution of higher virulence in unvaccinated people due to

"leaky" vaccination (Gandon et al. 2001)?

- mouse malaria: (Mackinnon and Read 2004; Mackinnon, Gandon, and Read 2008); consistent with "arms race" upregulation of replication
- increased virulence in Marek's disease: reduced host generation time or effects of leaky vaccine? (Atkins et al. 2013)

Mackinnon, Gandon, and Read (2008):

> a cautionary approach to the widespread use of anti-replication or anti-disease vaccines seems justified. Ideally, this means combining such vaccines with transmission-blocking vaccines, bednets, drugs, housing improvements and other transmission-reducing measures

Atkins, Katherine E., Andrew F. Read, Nicholas J. Savill, Katrin G. Renz, AFM Fakhrul Islam, Stephen W. Walkden-Brown, and Mark E. J. Woolhouse. 2013. "Vaccination and Reduced Cohort Duration Can Drive Virulence Evolution: Marek's Disease Virus and Industrialized Agriculture." *Evolution* 67 (3): 851–60. https://doi.org/10.1111/j.1558-5646.2012.01803.x.

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