Density dependence

The dependence of a per capita life history parameter on population size or density

Vandermeer and Goldberg p7-19; p28-29

Continuous time

- Logistic growth model can be derived assuming
  – r is proportional to food available
  – Food available is proportional to population size

  See vandermeer and Goldberg p. 14-17

$$\frac{dN(t)}{dt} = rN(t)\left(1 - \frac{N(t)}{K}\right)$$

Logistic growth (continuous time)

$$\frac{dN(t)}{dt} = rN(t)\left(1 - \frac{N(t)}{K}\right)$$

- r: intrinsic growth rate at low population size (1/time)
- K: carrying capacity (number)
- $N(t)$: size of the population at time, t.

Equilibrium points

- Values of $\mathrm{N(t)}$ such that $$\frac{dN(t)}{dt} = 0$$

- Equilbria can be unstable
- Stability of equlibrium can be determined by a line-arrow diagram

Logistic growth (continuous time)

- N(t) = 0 is stable when $r < 0$
- N(t) = K is stable when $r > 0$
- Per capita growth rate decreases linearly

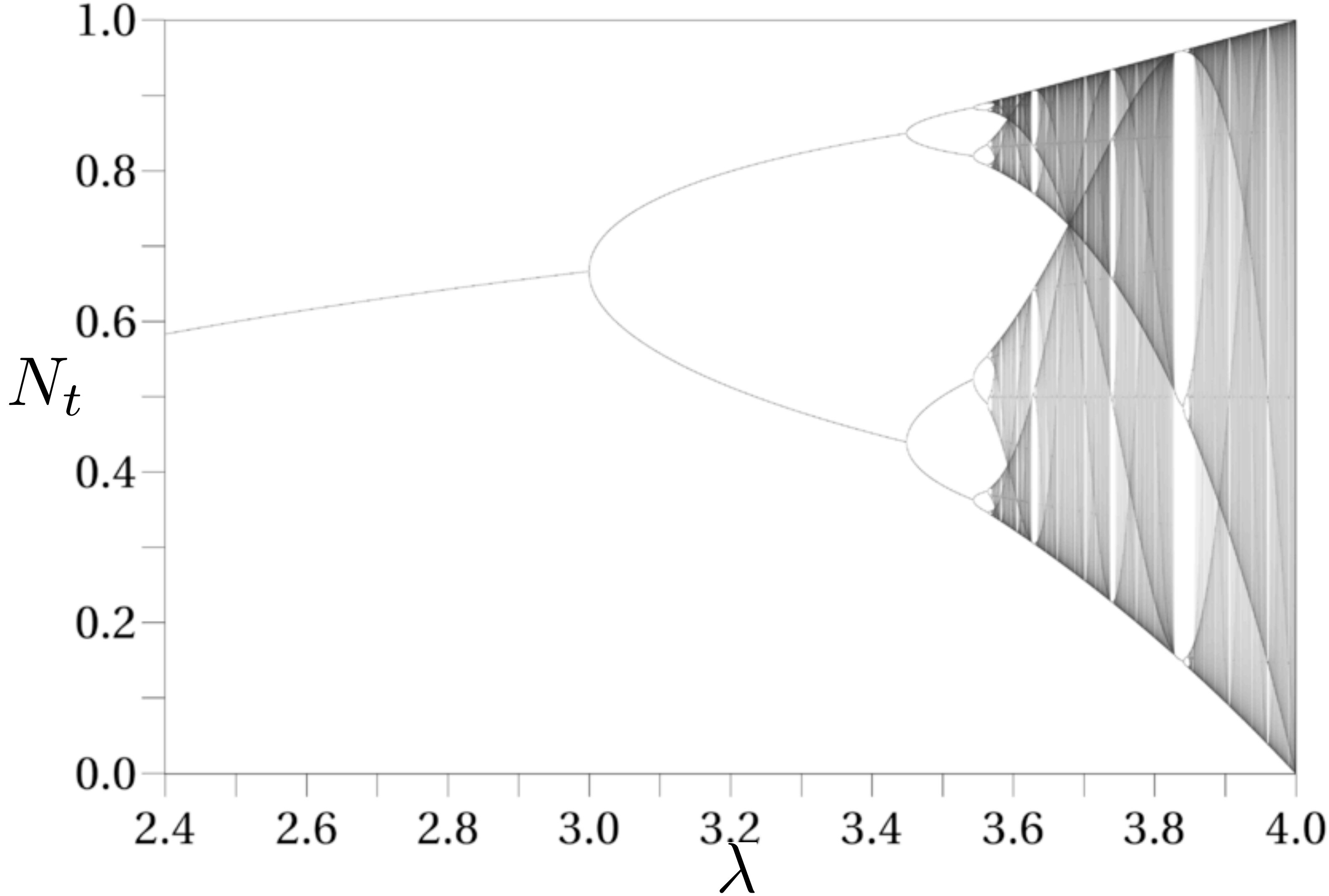
$$\frac{dN(t)}{dt}\frac{1}{N(t)}$$

Logistic growth (discrete time)

$$\text{May: } N_{t+1} = \lambda N_t \left(\frac{K - N_t}{K} \right)$$

- As from p28 vandermeer and Goldberg. This model has historical significance, but..
- … this is a poor population model because population size can be negative:

  i.e. find N_1 and N_2 for N_0 = 70, K = 100, and λ=5
- K is not the carrying capacity for this model: the positive equilibrium is $K(\lambda-1)/\lambda$
- Turchin: *Complex Population Dynamics* has a good discussion of discrete time models with density dependence

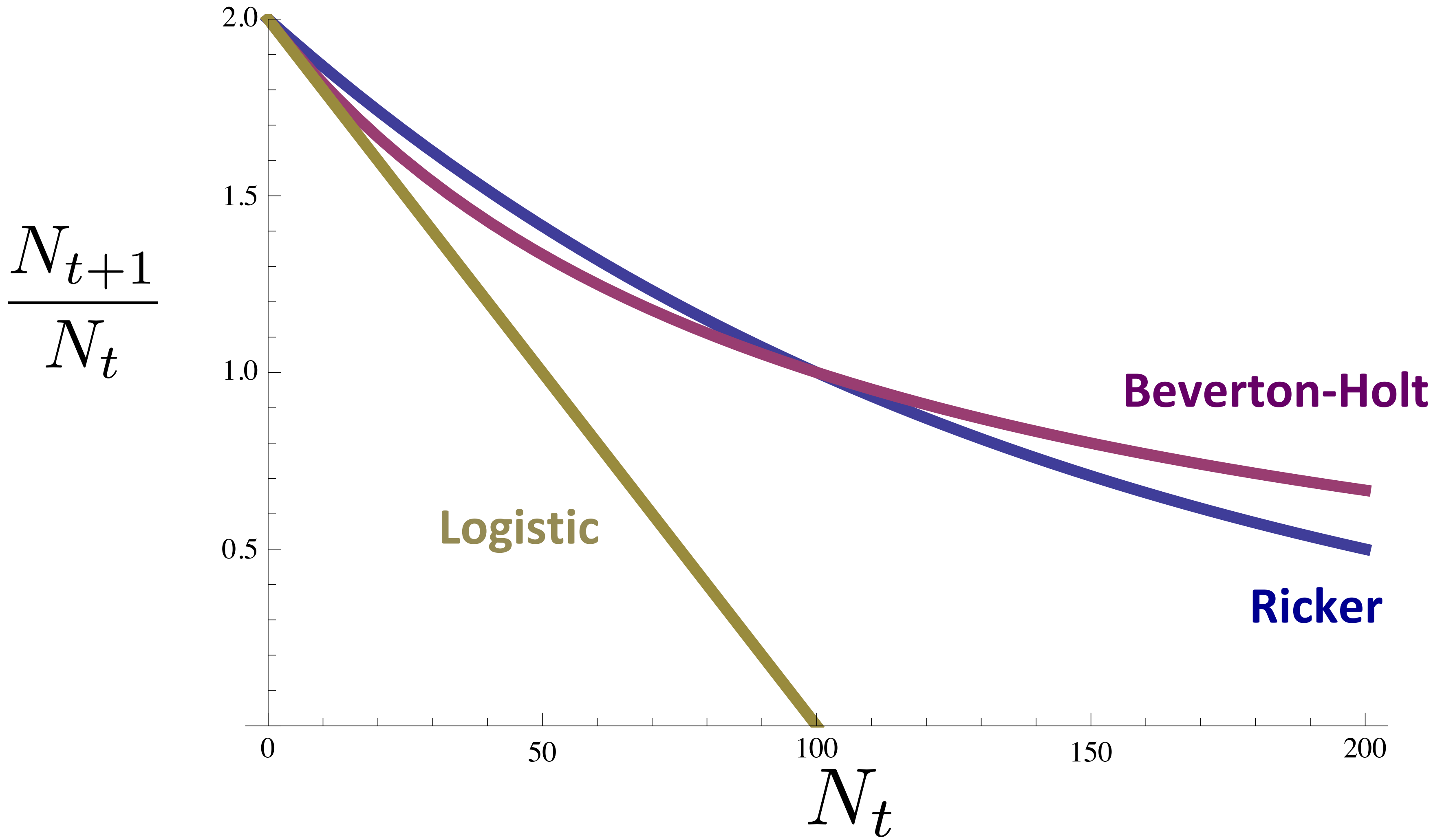

1.0
0.8
0.6
0.4
0.2
0.0
N_t
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
λ

Logistic growth (discrete time)

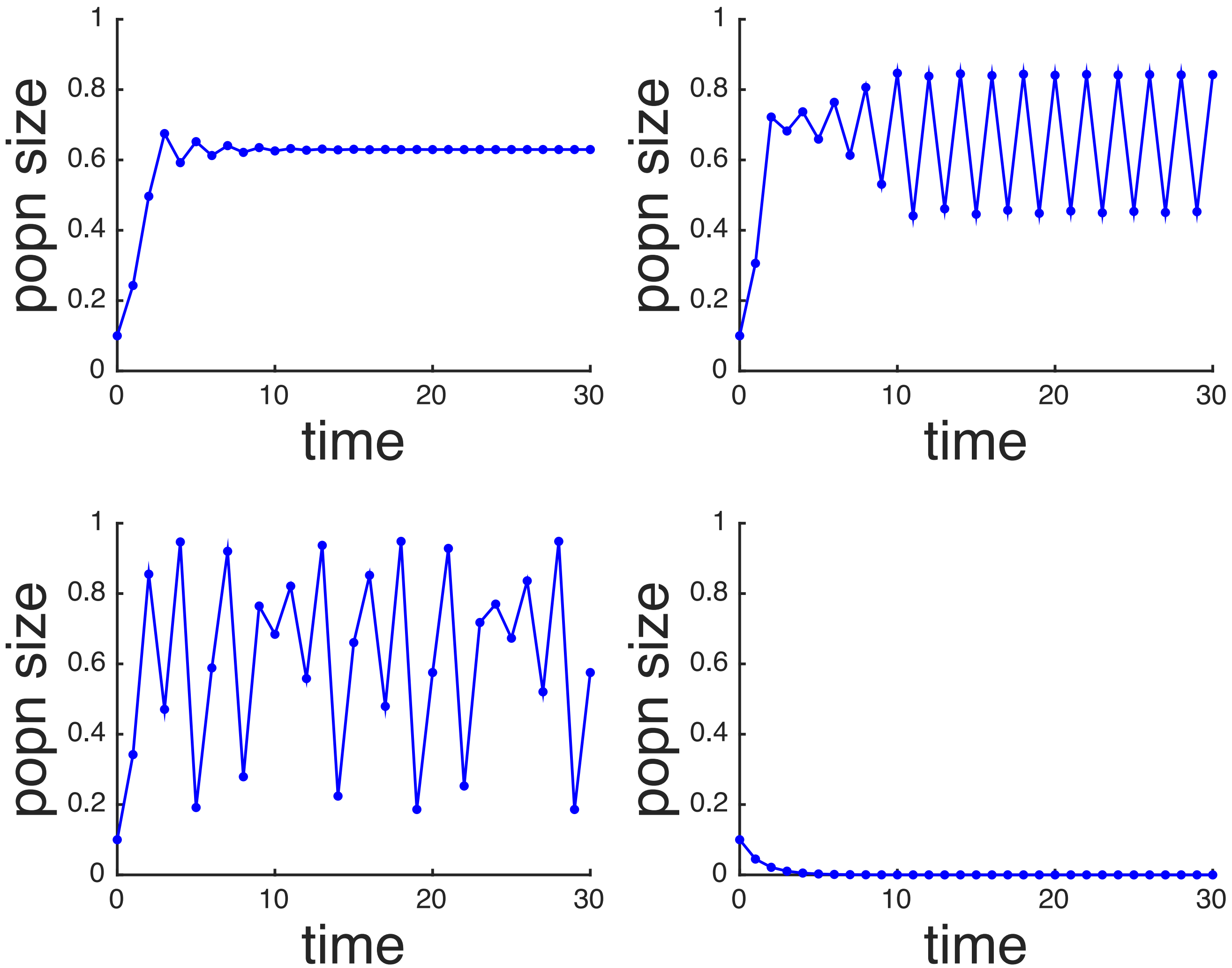
$$\text{Alternative formulation: } N_{t+1} = N_t + \lambda N_t \left(\frac{K - N_t}{K} \right)$$

- K is the carrying capacity, but negative values are still possible

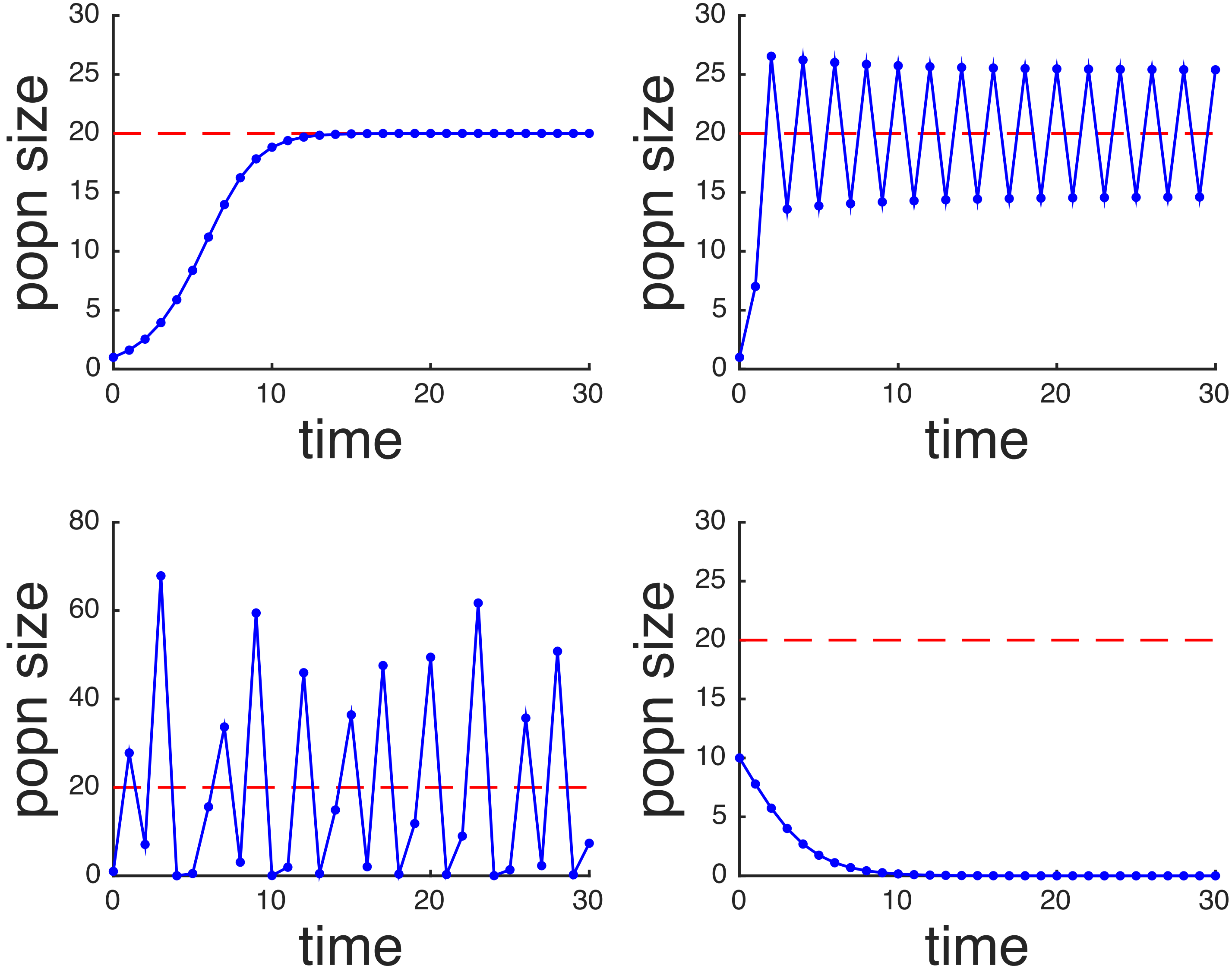
Density dependence for discrete time models of population growth



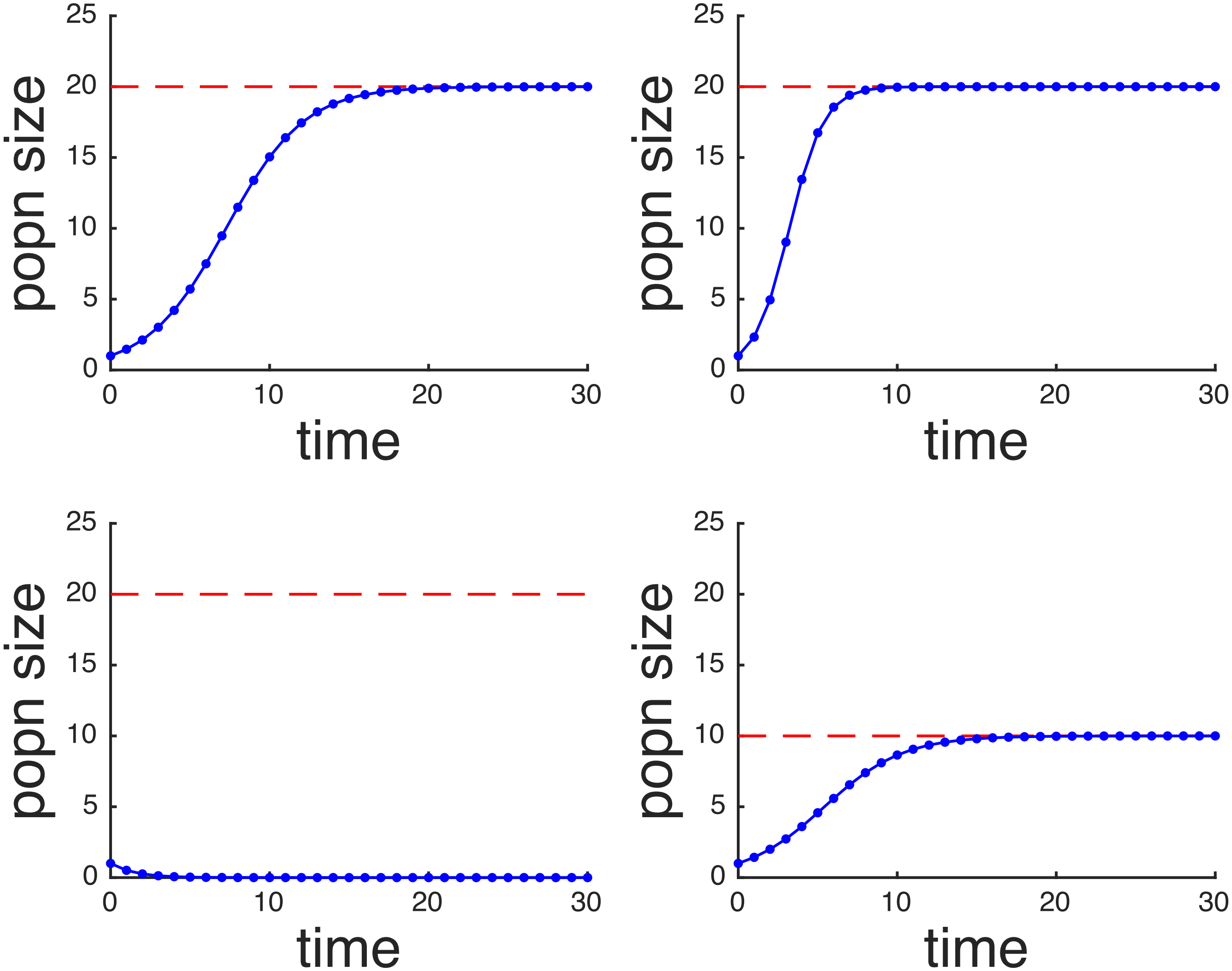
Logistic map dynamics



Ricker model dynamics



Beverton-Holt model dynamics

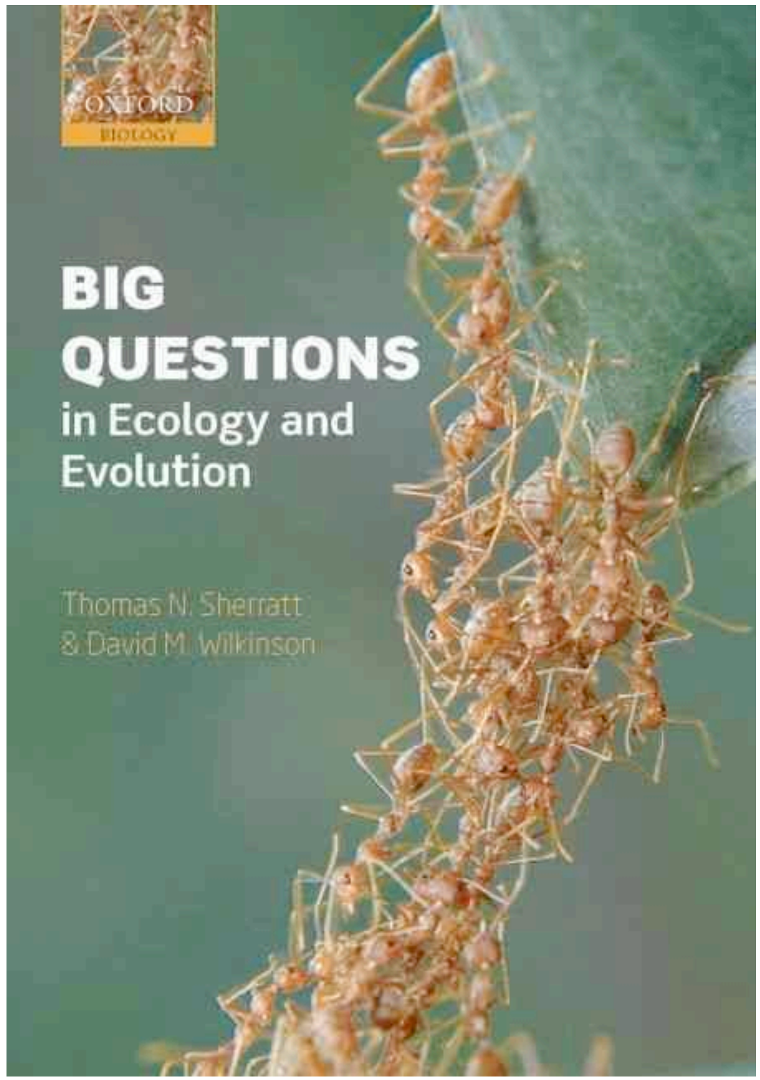


Models	Dynamics
Geometric (DT exponential)	a
CT exponential	a
CT logistic growth	a,b
Alternative DT logistic map	a,b,c,d
Ricker	a,b,c,d
Beverton-Holt	a,b

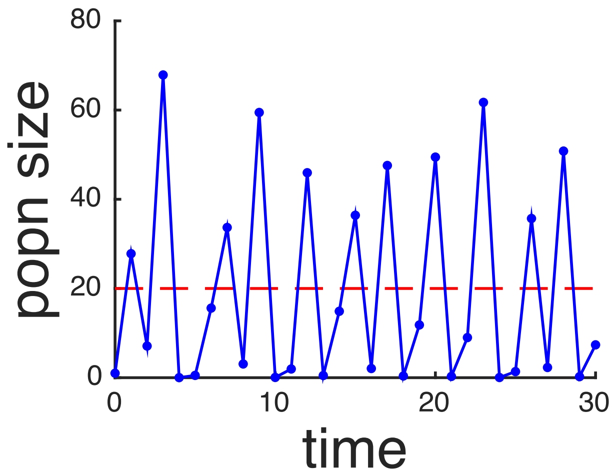
a. Equilibrium at 0; b. Equilibrium at K;

c. Periodic cycles; d. Chaos

Do biological populations exhibit chaotic dynamics?

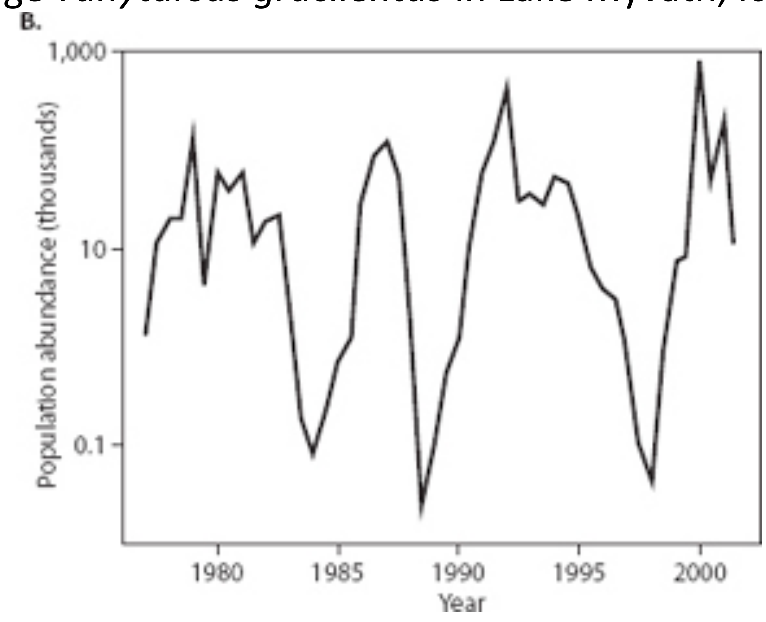


How to identify chaos?



The midge *Tanytarsus gracilentus* in Lake Myvatn, Iceland

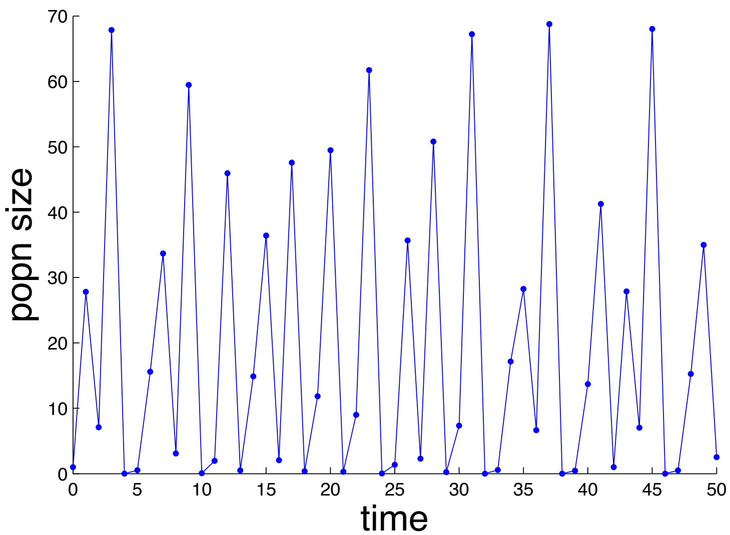
Photo credit: Kenneth Chang



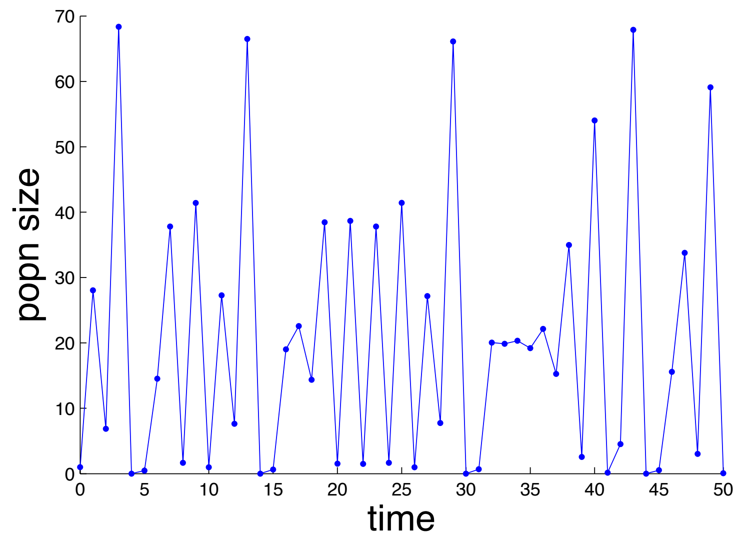
Definition of chaos

- ‘a trajectory is chaotic if it is bounded in magnitude, neither periodic or approaches a periodic state, and is sensitive to initial conditions’ Cushing et al. 2002. Chaos in ecology. Academic Press.
- Extreme sensitivity to initial conditions – butterfly effect

Initial population size N_0 = 1



Initial population size N_0 = 1.01



Ricker model: r = 3.5, K=20

Photo credit: Fir0002/Flagstaffotos

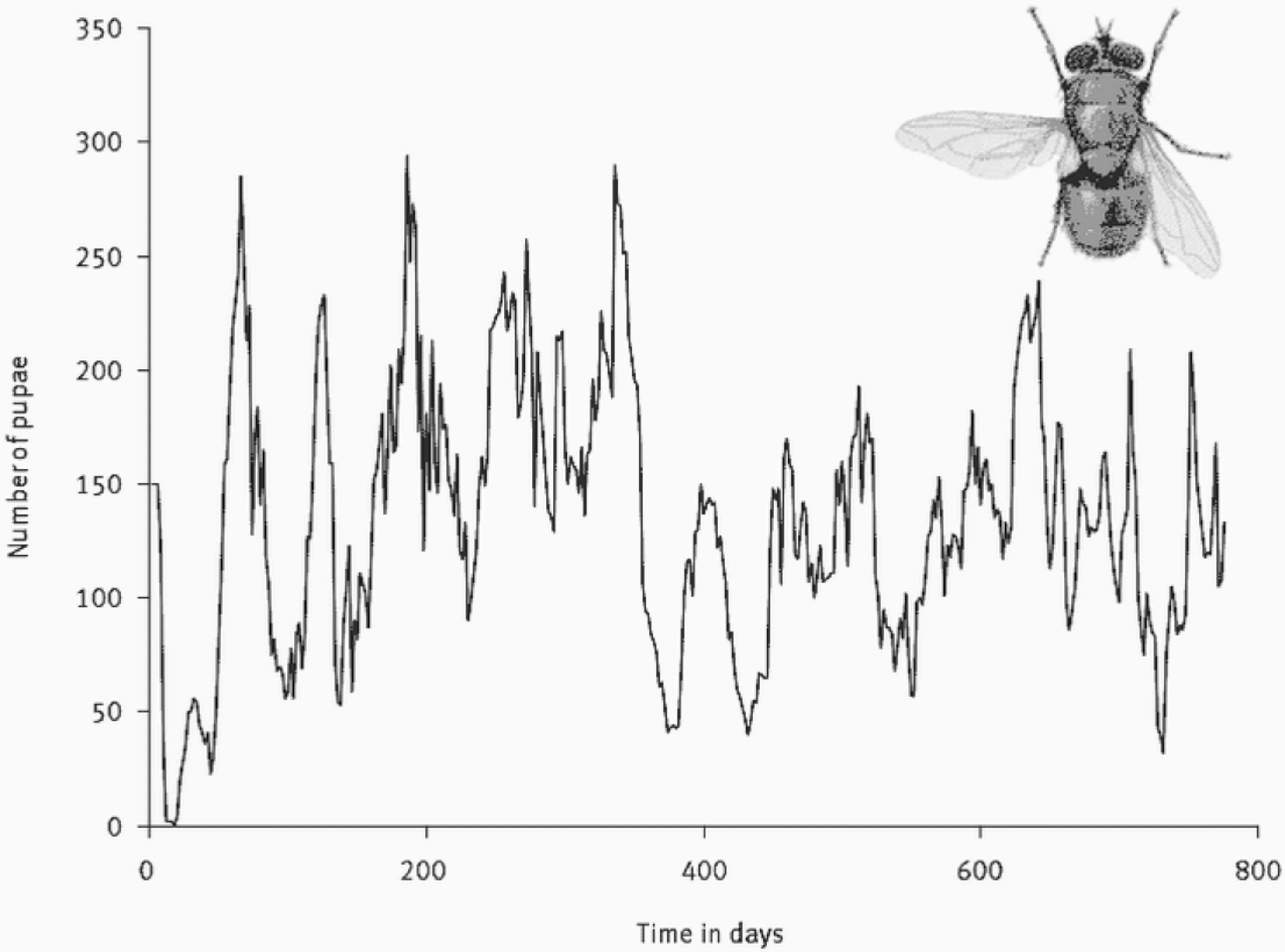


Figure 6.1 The number of pupae of the green bottle (sheep blowfly), in a laboratory population monitored every two days for two years. Data kindly made available to researchers by Robert Smith and colleagues (see http://mcs.open.ac.uk/drm48/chaos/).[1]

Patterns of Dynamical Behaviour in Single-Species Populations

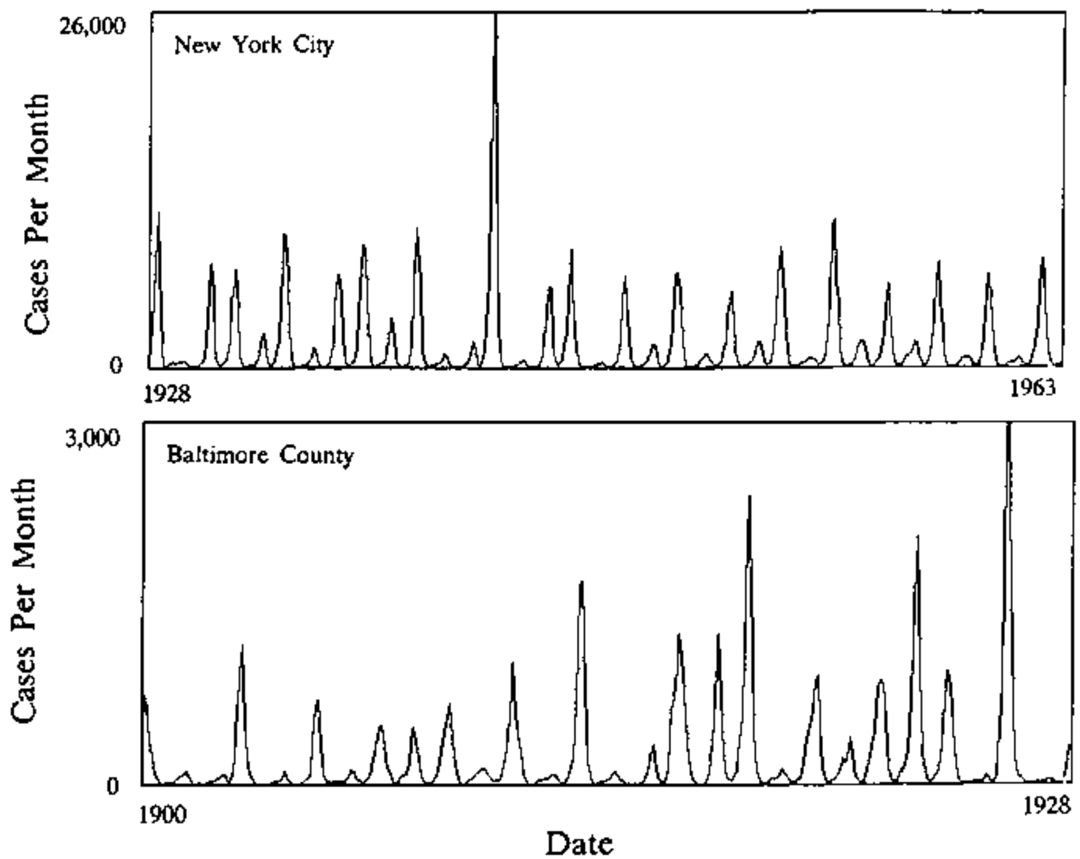
M. P. Hassell; J. H. Lawton; R. M. May

The Journal of Animal Ecology, Vol. 45, No. 2 (Jun., 1976), 471-486.

- 28 insect data sets
- Only the laboratory study of blowflies by Nicholson had parameters in the chaotic regime
- Could be a laboratory artifact: not subject to natural mortality from parasitic wasps

Photo credit: Andre Karwath

- 27 (Thomas et al. 1980) and 25 (Mueller and Ayala 1991) genetically distinct fruit fly populations
- No evidence of chaos

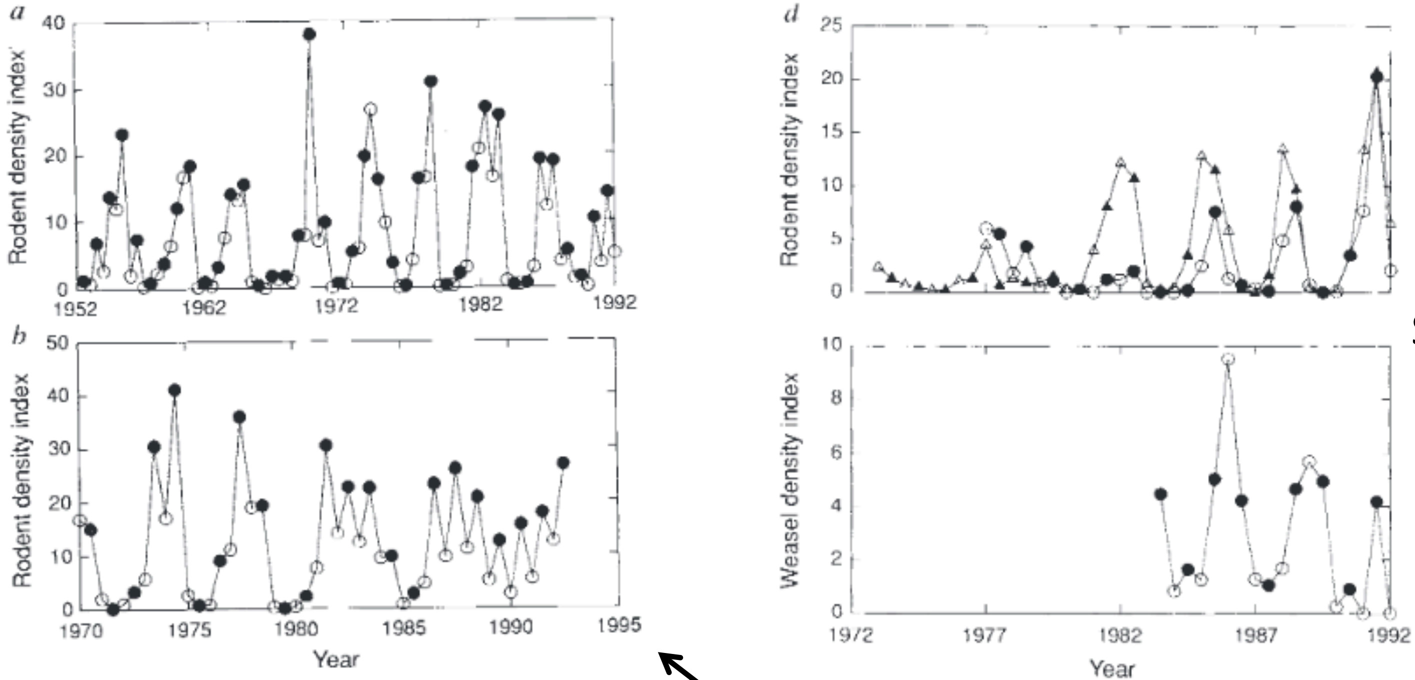


Source: Hedrich (1933)

- Measles in NYC and Baltimore, 1928-1963
- Analyses find the dynamics are chaotic
- Doubts: birth rates have changed over time, amount of seasonal forcing required to generate chaos more than observed

Photo credit: Fer boei

- *Microtus* voles in western Finland
- Time series shows ‘chaos superimposed’ on top of a more regular signal.



Since 1984, 3 yr cycles

Multiannual cycles absent since 1980

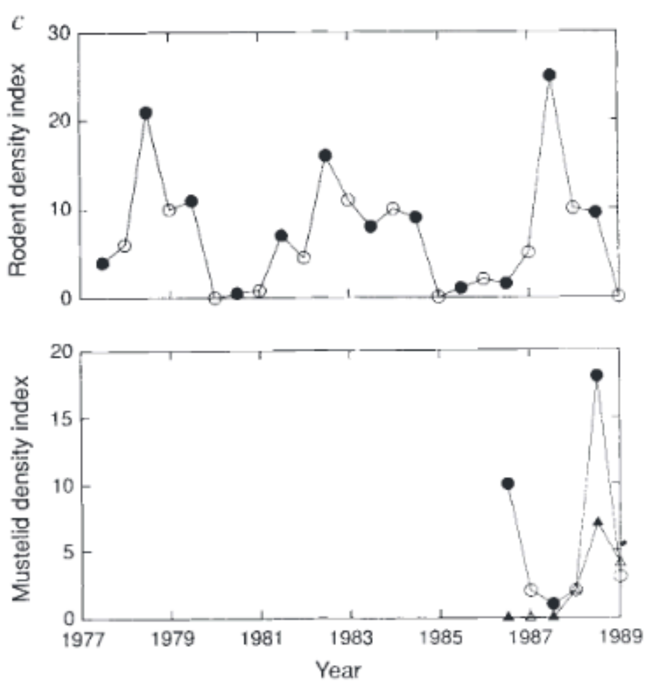
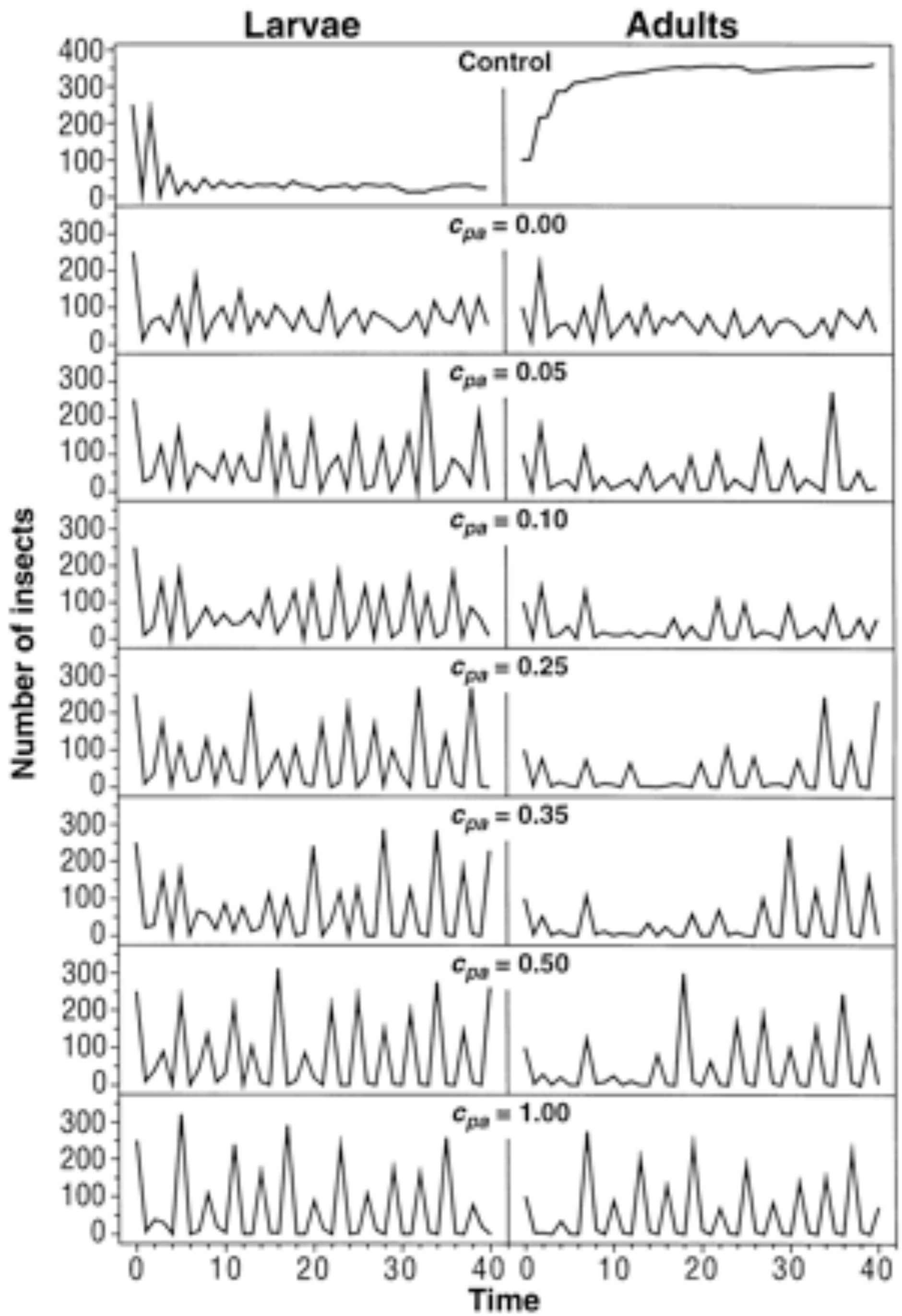


FIG. 2 Four examples of observed long-term rodent dynamics. *a*, Kilpisjärvi, Finnish Lapland, pooled density of 5 vole species[30,31] (H.H., unpublished results); *b*, Pallasjärvi, Finnish Lapland, pooled density of 5 vole species in old taiga forest (H.H., unpublished results); *c*, Iesjavri basin, Norwegian Lapland; upper panel, pooled data for 3 vole species; lower panel, the least weasel and the stoat[9]; *d*, Alajoki western Finland; upper panel, *Microtus* densities at 2 study sites separated by 14 km; lower panel, the least weasel densities[8,26]. Open symbols give spring densities, filled symbols autumn densities.

Hanski et al. 1993 Nature

Flour beetles (*Tribolium castaneum*)

- Artificially manipulated adult mortality and the pupae to adult recruitment rate to generate chaos
- Criticism: forced the system to match the model not other way around

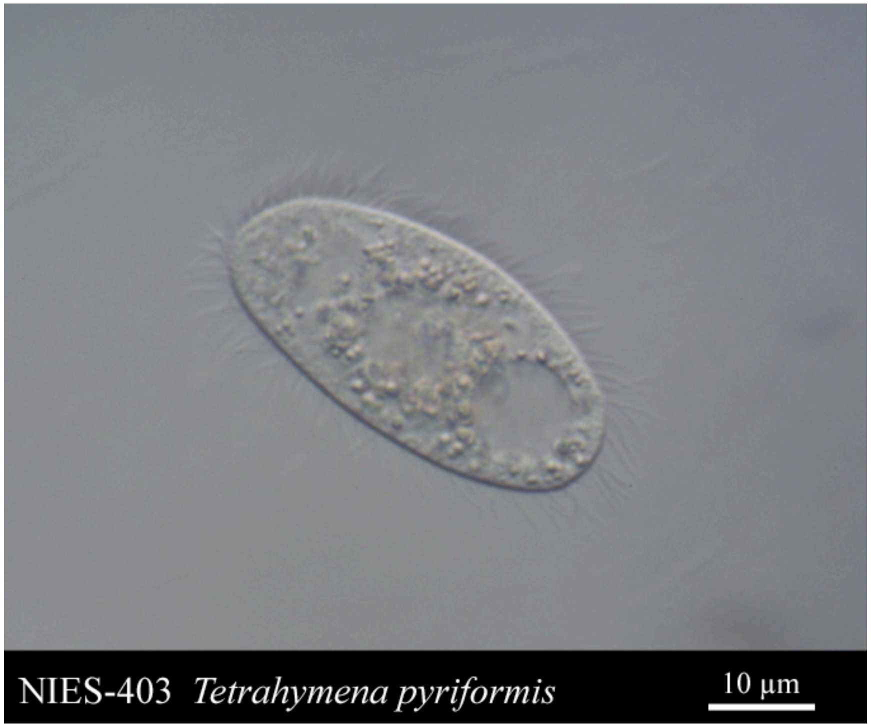


Equilibrium

chaos

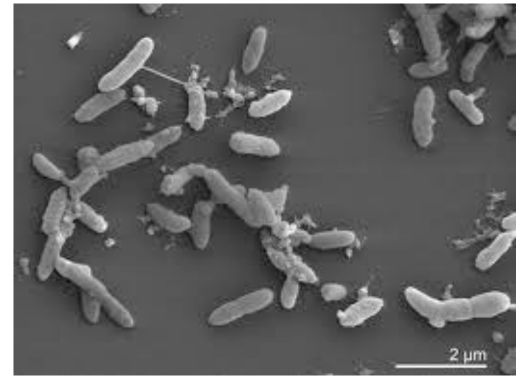
period-3 cycle

Costantino et al. 1997



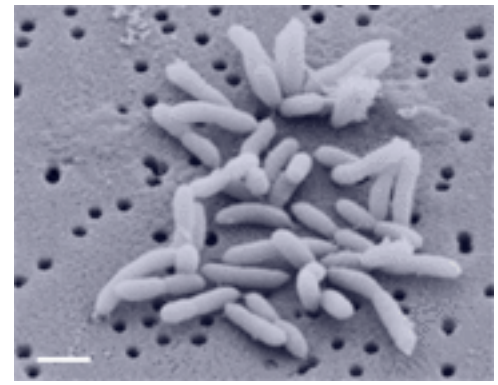
source: www8.umoncton.ca

Pedobacter



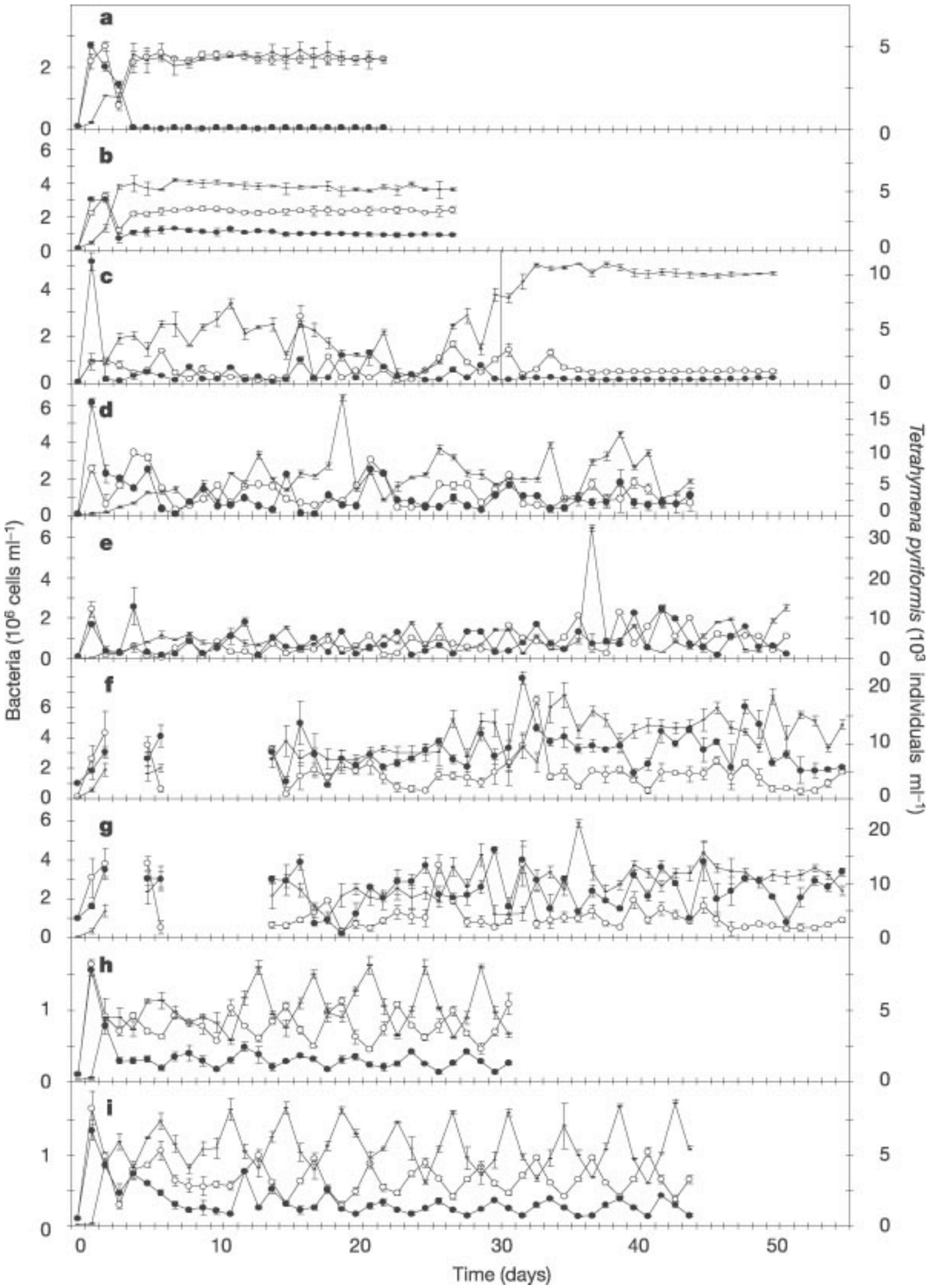
Source: http://bacmap.wishartlab.com/organisms/937

Brevundimonas



Source: https://microbewiki.kenyon.edu/index.php/Brevundimonas_diminuta

- Laboratory experiments with bacteria-eating ciliate predator and two species of bacteria
- Evidence of chaotic dynamics



Source: Becks et al. 2005. Nature.

Summary

- “we cannot rule out the possibility … [of chaos in nature] …but the case is looking increasingly shaky, at least for multicellular organisms.

- Data sets are short term and noisy.