Interactions

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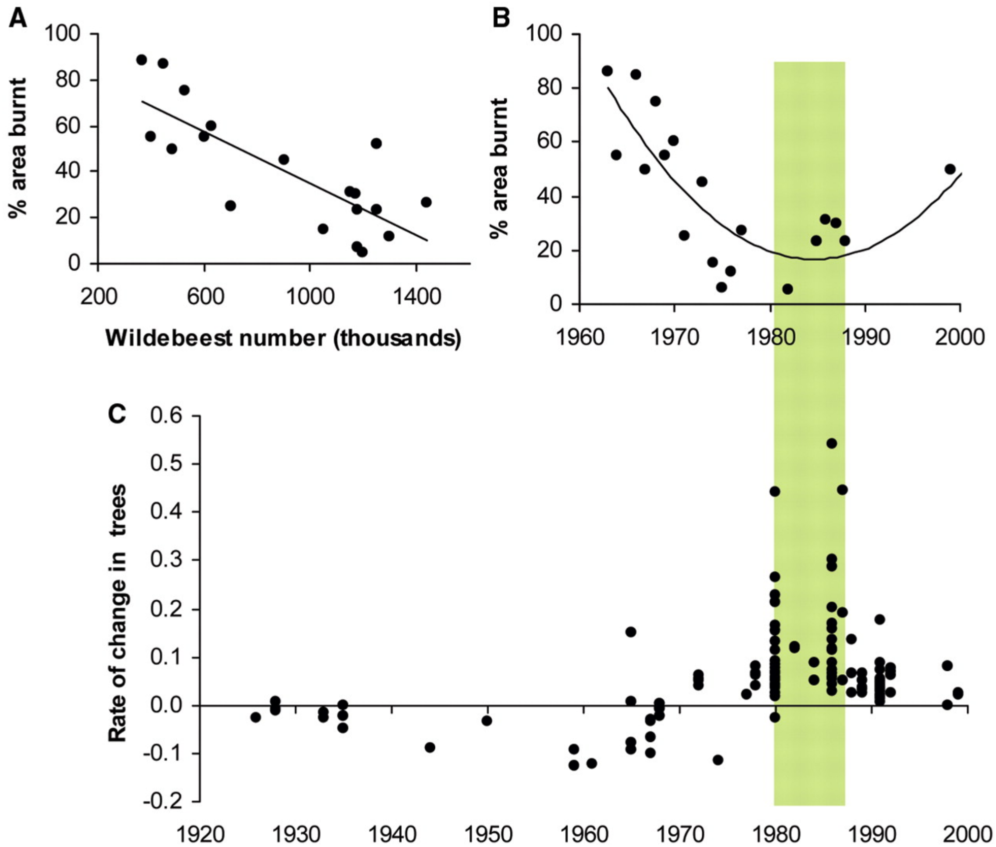
The network of interactions

It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us. *On the Origin of Species (1859) by Charles Darwin*

If you look at the world in a certain way, everything is connected to everything else. *Foucault's Pendulum (1988) by Umberto Eco*

Interactions at play in the Serengeti

Tree growth (Packer et al. Science 2005)



The players: Trees

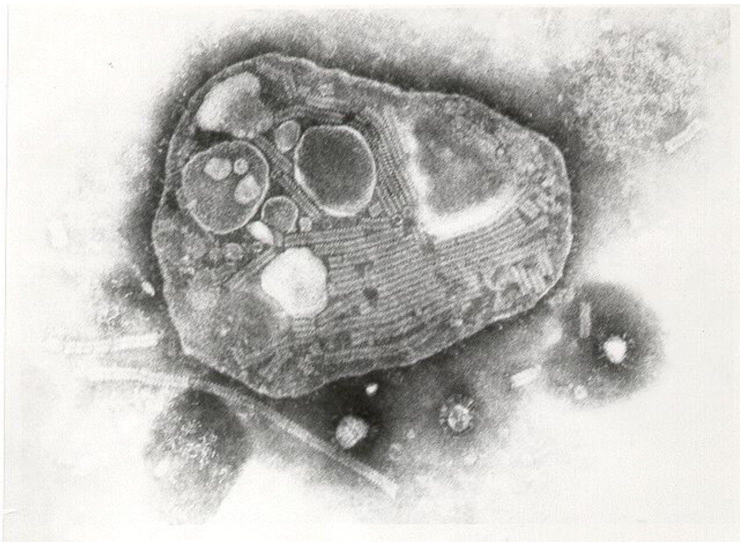
The players: Elephants

The players: Grass

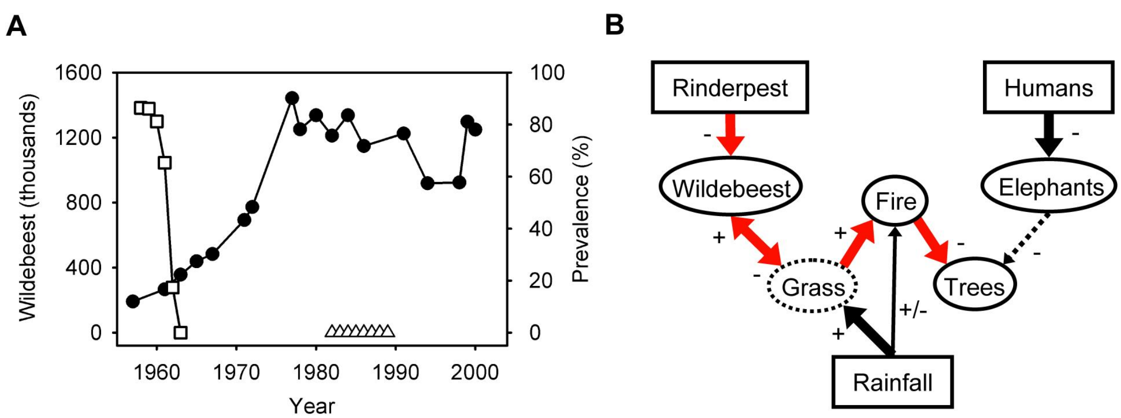
The players: Fire

The players: Wildebeest

The players: A virus?!



Interactions at play in the Serengeti



Holdo et al., 2009

Types of interaction between species

- *Competition (-, -)*
- *Antagonism (+, -)*, e.g., consumption, parasitism.
- *Mutualism (+, +)*, e.g., pollination, seed-dispersal, symbiosis
- *Amensalism (-, 0)*
- *Commensalism (+, 0)*

Network structure

Ecological communities can be described by networks in which the nodes are the populations, and the edges connecting the nodes stand for ecological interactions.

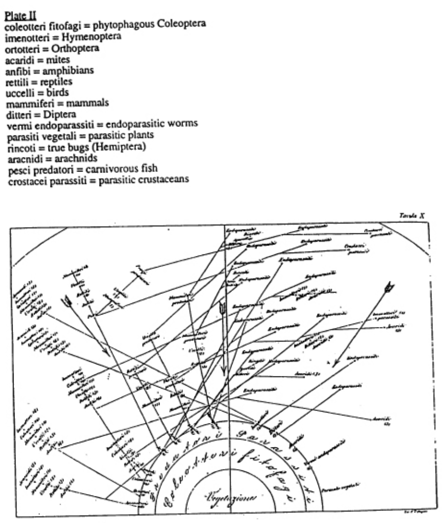
Networks commonly found in the ecological literature

- Food webs (who eats whom?)
- Pollination networks (plant-animal; bipartite)
- Herbivory (bipartite)
- Parasitism (parasite/parasitoid-host; bipartite)

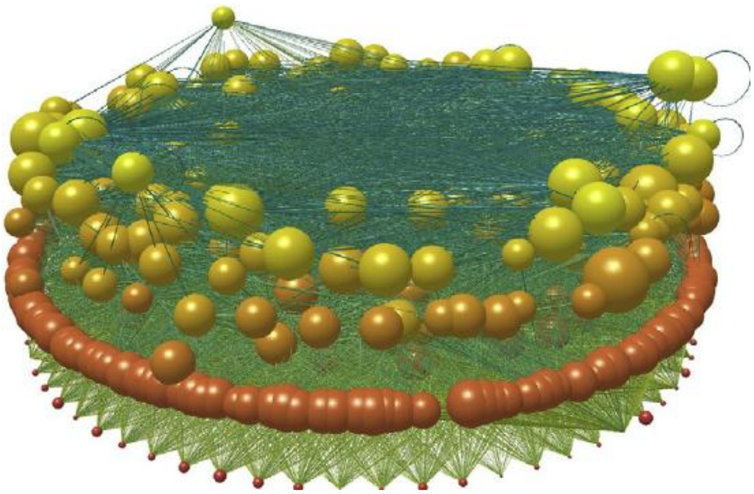
Lorenzo Camerano: the first food web

"In 1880, Lorenzo Camerano, then a 24-year-old assistant in the laboratory of the Royal Zoological Museum of Torino, Italy, published a paper 'On the equilibrium of living beings by means of reciprocal destruction'[. . .]. This pioneering paper contains an early, perhaps the first, graphical representation of a food web as a network of groups of species linked by feeding relations." (Joel Cohen, 1994)

Lorenzo Camerano: the first food web

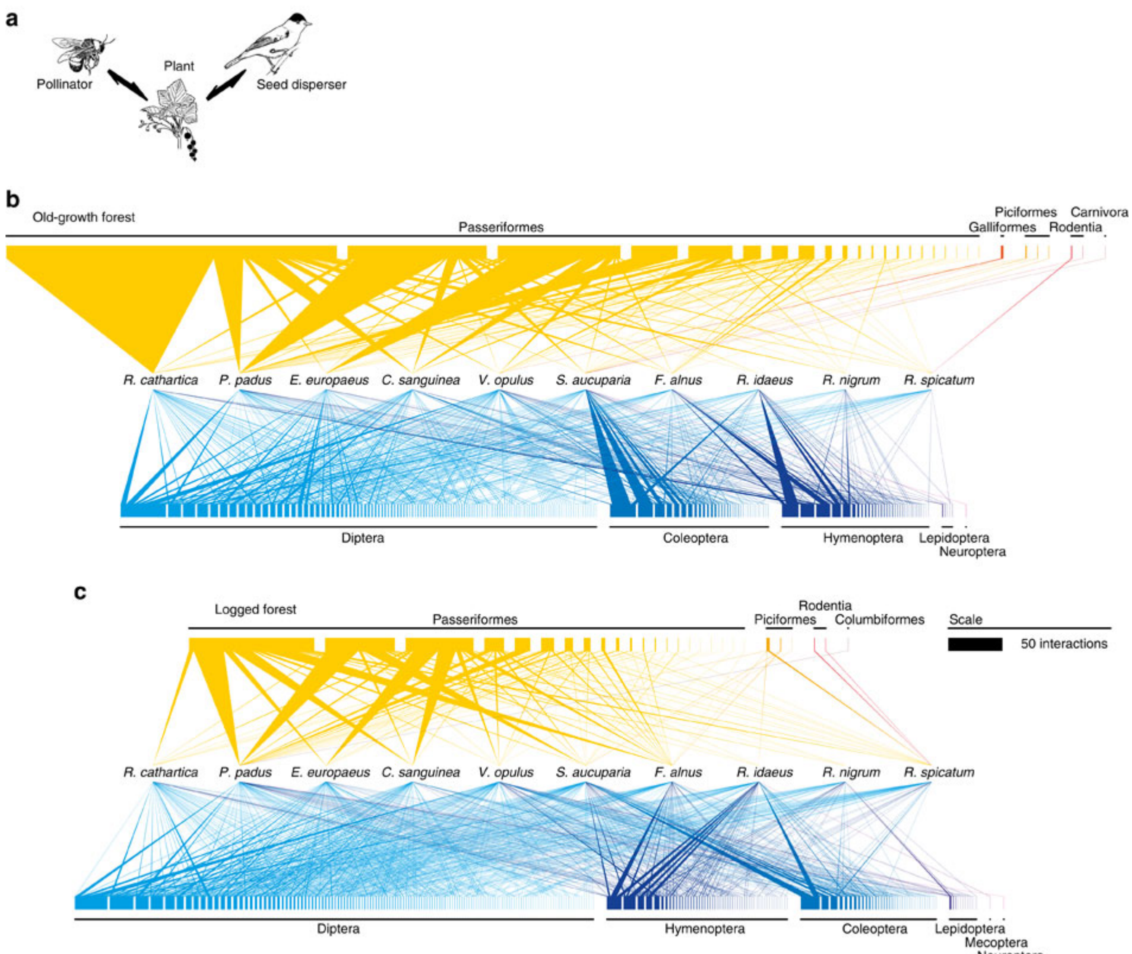


Modern food web



488 species; 16,200 feeding interactions

Plant, pollinator, seed disperser network



Lotka-Volterra Equations

Clearly, consumers and resources influence each others.

Can we build a mathematical model describing the dynamics of the species?

In 1926, in a short paper in Nature, Vito Volterra published an influential model, which is the progenitor of most models used today.

Turns out, the same equations had been published the year before by Alfred J. Lotka, an Polish-born mathematician, physicist and statistician working in the US.

Volterra, 1926

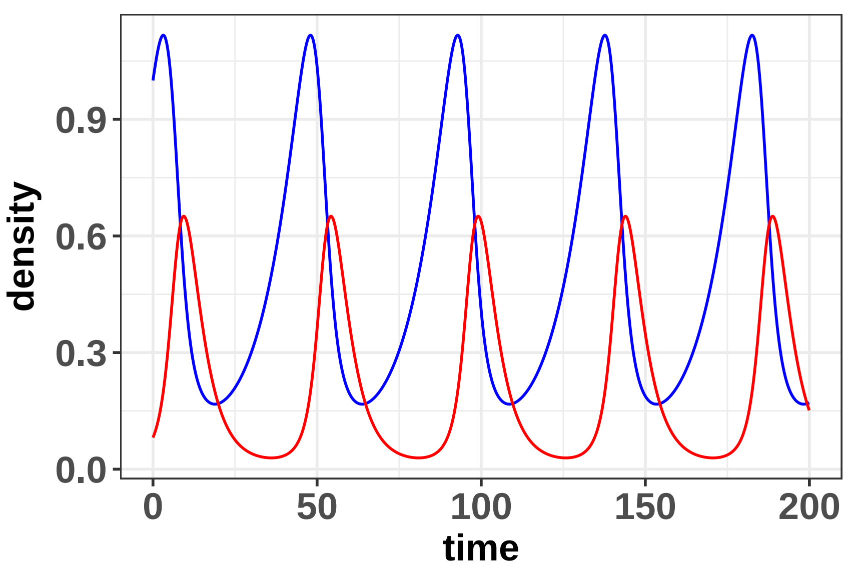
"The first case I have considered is that of two species, of which one, finding sufficient food in its environment, would multiply indefinitely when left to itself, while the other would perish for lack of nourishment if left alone; but the second feeds upon the first, and so the two species can co-exist together."

In modern notation, we would write:

$$\frac{dX}{dt} = X(a - bY)$$

$$\frac{dY}{dt} = Y(-d + bX)$$

Dynamics

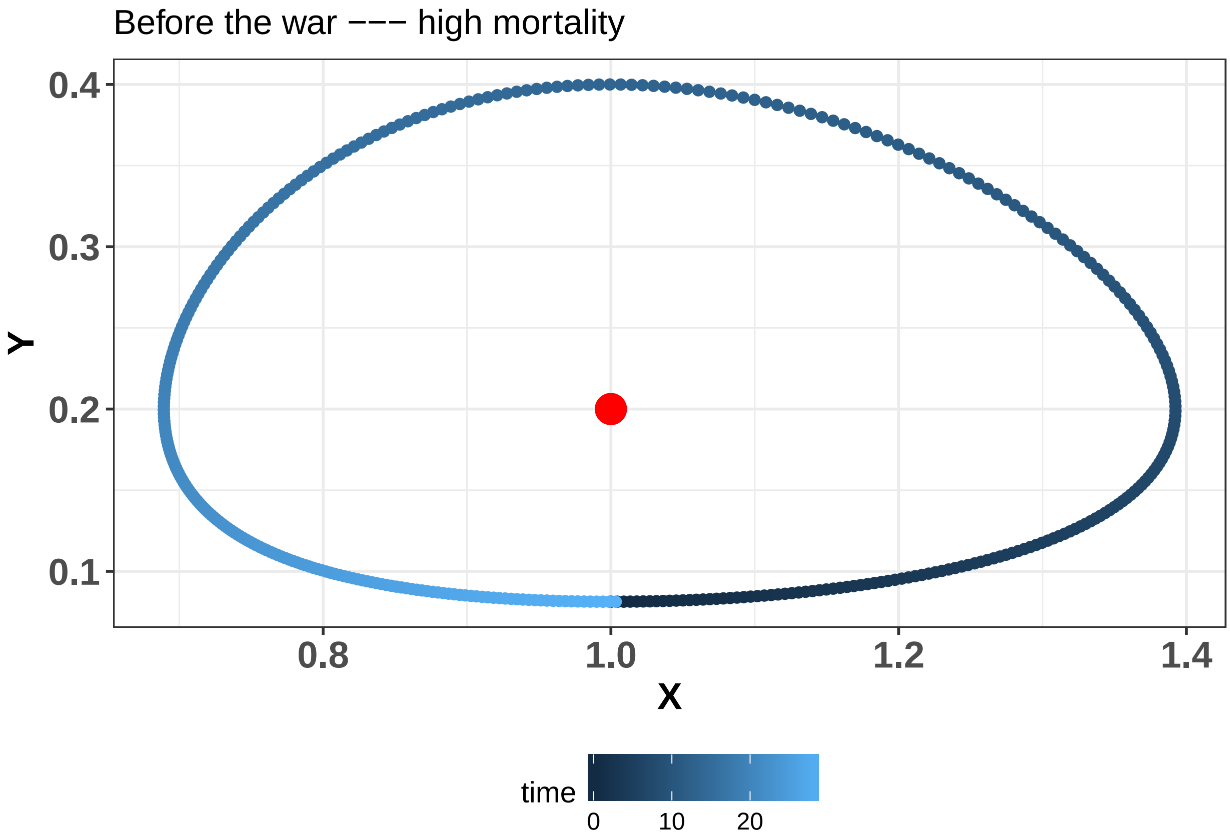


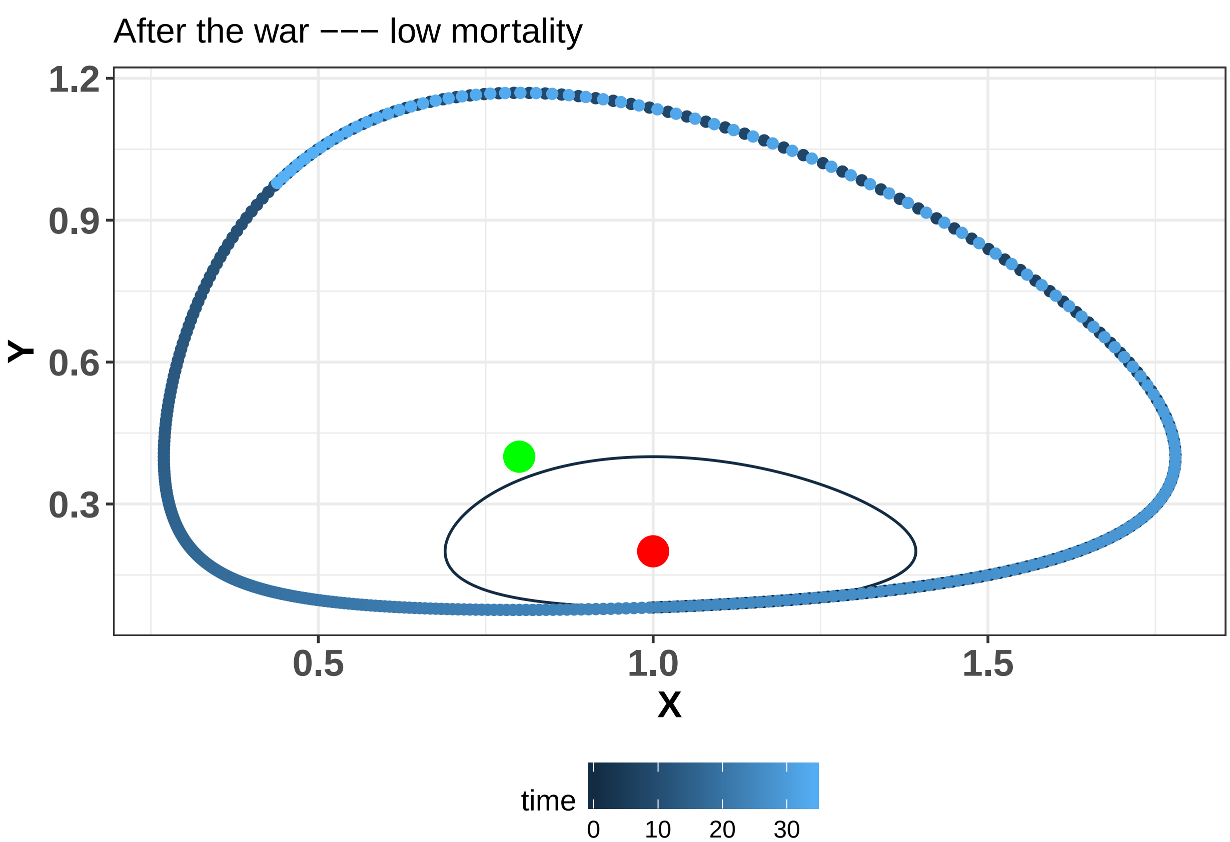
Volterra effect

Volterra was inspired by an observation of his son-in-law Umberto D'Ancona. He had noticed that the landings of predatory fish in Trieste, Fiume and Venice immediately after WWI had increased with respect to before the war, while that of herbivorous and planktivorous fish had not.

During WWI, the Adriatic sea was covered with mines, as it was bordered by opposing forces. As such, fishery had halted, releasing the fish population from high mortality.

But why would the number of predators increase, while that of prey stay about constant?





LV Competition

$$\frac{dX_1}{dt} = X_1 \left(r_1 - A_{1,1}X_1 - A_{1,2}X_2\right)$$
$$\frac{dX_2}{dt} = X_2 \left(r_2 - A_{2,2}X_2 - A_{2,1}X_1\right)$$

$A_{1,1}$: intra-specific competition species 1 (crowding)

$A_{1,2}$: inter-specific competition — effect of species 2 on growth of species 1

if $A_{1,1} > A_{1,2}$ adding a conspecific decreases growth more than adding heterospecific

Qualitative analysis

- Determine the **equilibria**
- Determine the isoclines of null growth (**nullclines**)
- Assess the **stability of equilibria graphically**
- Assess the **stability using invasibility**
- State the principle of **competitive exclusion**

Equilibria

$$\frac{dX_1}{dt} = X_1 \left(r_1 - A_{1,1}X_1 - A_{1,2}X_2\right)$$
$$\frac{dX_2}{dt} = X_2 \left(r_2 - A_{2,2}X_2 - A_{2,1}X_1\right)$$

Setting both equations to zero, we find:

$(X_1^*, X_2^*) = (0,0)$ Trivial equilibrium (no populations!)

$(X_1^*, X_2^*) = \left(\frac{r_1}{A_{1,1}}, 0\right)$ Species 1 to carrying capacity; species 2 extinct

$(X_1^*, X_2^*) = \left(0, \frac{r_2}{A_{2,2}}\right)$ Species 2 to carrying capacity; species 1 extinct

$(X_1^*, X_2^*) = \left(\frac{r_1 A_{2,2} - r_2 A_{1,2}}{A_{1,1}A_{2,2} - A_{1,2}A_{2,1}}, \frac{r_2 A_{1,1} - r_1 A_{2,1}}{A_{1,1}A_{2,2} - A_{1,2}A_{2,1}}\right)$

Most interesting equilibrium — possibility of coexistence! (However, not always present… more on this later)

Graph