Interspecific Interactions

“Populační ekologie živočichů“

Stano Pekár

Types of interactions

Effect of species 1 on fitness of species 2

Effect of species 2 on fitness of species 1

	Increase	Neutral	Decrease
Increase	+ +		
Neutral	0 +	0 0	
Decrease	+ -	- 0	- -

+ + .. **mutualism** (plants and pollinators)

0 + .. **commensalism** (saprophytism, parasitism, phoresis)

- + .. **predation** (herbivory, parasitism)**, mimicry**

- 0 .. **amensalism** (allelopathy)

- - .. **competition**

Model of competition

- based on the logistic model of Lotka (1925) and Volterra (1926)

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

- assumptions:

- all parameters are constant
- individuals of the same species are identical
- environment is homogenous, differentiation of niches is not possible
- only exact compensation is present

species 1: N_1, K_1, r_1

species 2: N_2, K_2, r_2

$$\frac{dN_1}{dt} = N_1 r_1\left(1 - \frac{N_1 + N_2}{K_1}\right)$$

$$\frac{dN_2}{dt} = N_2 r_2\left(1 - \frac{N_1 + N_2}{K_2}\right)$$

- total competitive effect (intra + inter-specific)

$(N_1 + \alpha N_2)$ where α .. coefficient of competition

$\alpha = 0$ .. no interspecific competition

$\alpha < 1$ .. species 2 has lower effect on species 1 than species 1 on itself

$\alpha = 0.5$ .. one individual of species 1 is equivalent to 0.5 individuals of species 2)

$\alpha = 1$ .. both species has equal effect on the other one

$\alpha > 1$ .. species 2 has greater effect on species 1 than species 1 on itself

species 1: $$\frac{dN_1}{dt} = N_1 r_1 \left(1 - \frac{N_1 + \alpha_{12} N_2}{K_1}\right)$$

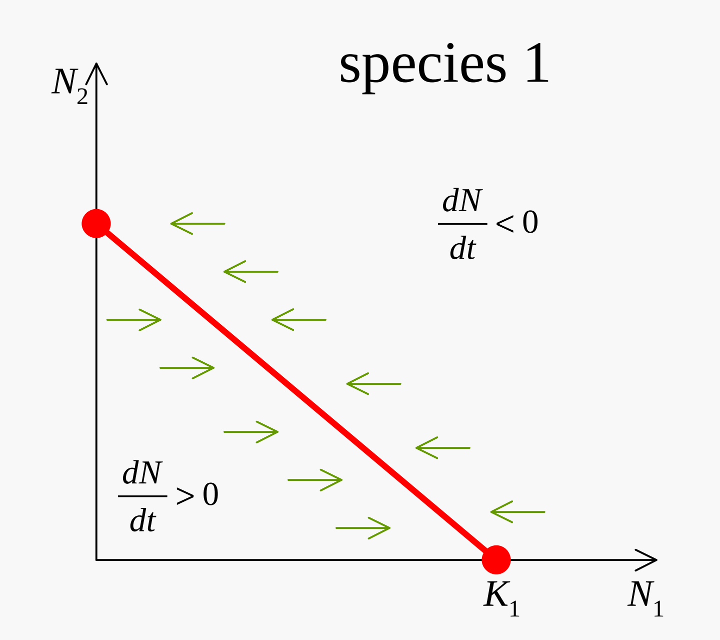
species 2: $$\frac{dN_2}{dt} = N_2 r_2 \left(1 - \frac{\alpha_{21} N_1 + N_2}{K_2}\right)$$

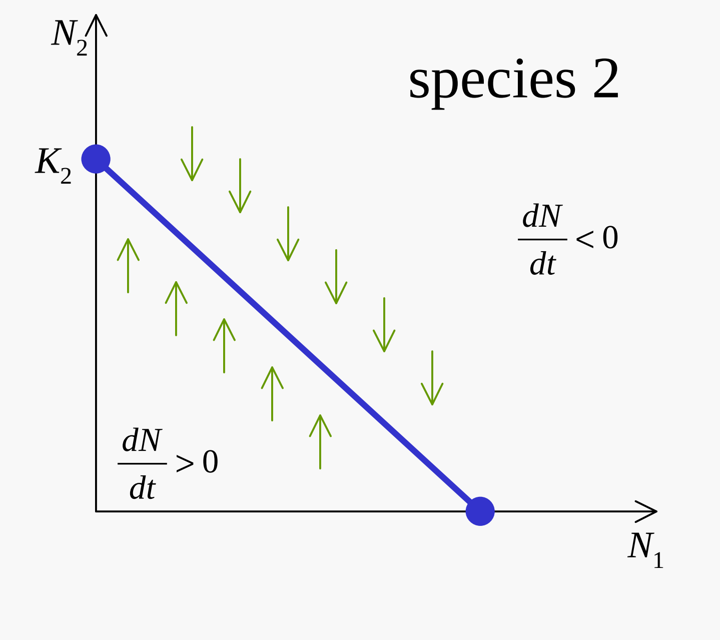
- if competing species use the same resource then interspecific competition is equal to intraspecific

Analysis of the model

- examination of the model behaviour on a phase plane
- used to describe change in any two variables in coupled differential equations by projecting orthogonal vectors
- identification of isoclines: a set of abundances for which the growth rate is 0

$$\frac{dN}{dt} = 0$$





Isoclines

- species 1

$$r_1 N_1 (1 - [N_1 + \alpha_{12} N_2] / K_1) = 0$$
$$r_1 N_1 ([K_1 - N_1 - \alpha_{12} N_2] / K_1) = 0$$

if $r_1, N_1, K_1 = 0$

and if $K_1 - N_1 - \alpha_{12} N_2 = 0$

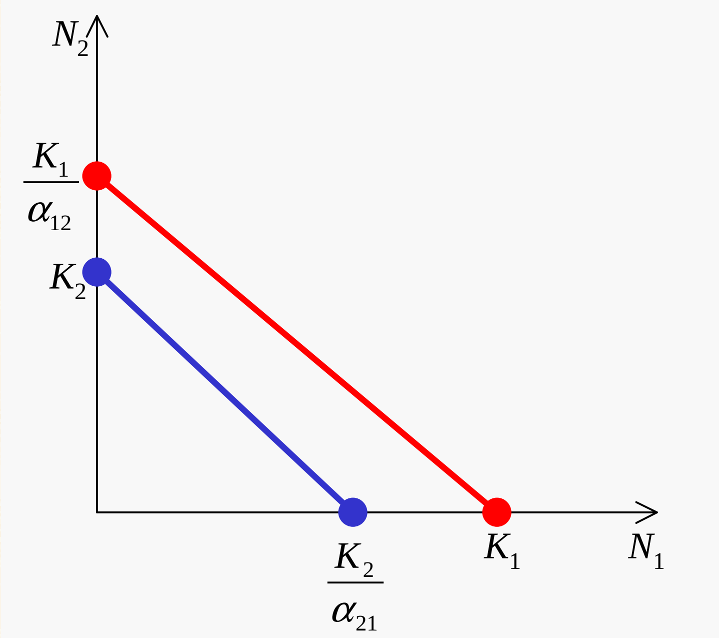
then $N_1 = K_1 - \alpha_{12} N_2$

if $N_1 = 0$ then $N_2 = K_1/\alpha_{12}$
if $N_2 = 0$ then $N_1 = K_1$

- species 2

$$r_2 N_2 (1 - [N_2 + \alpha_{21} N_1] / K_2) = 0$$
$$N_2 = K_2 - \alpha_{21} N_1$$

if $N_2 = 0$ then $N_1 = K_2/\alpha_{21}$
if $N_1 = 0$ then $N_2 = K_2$



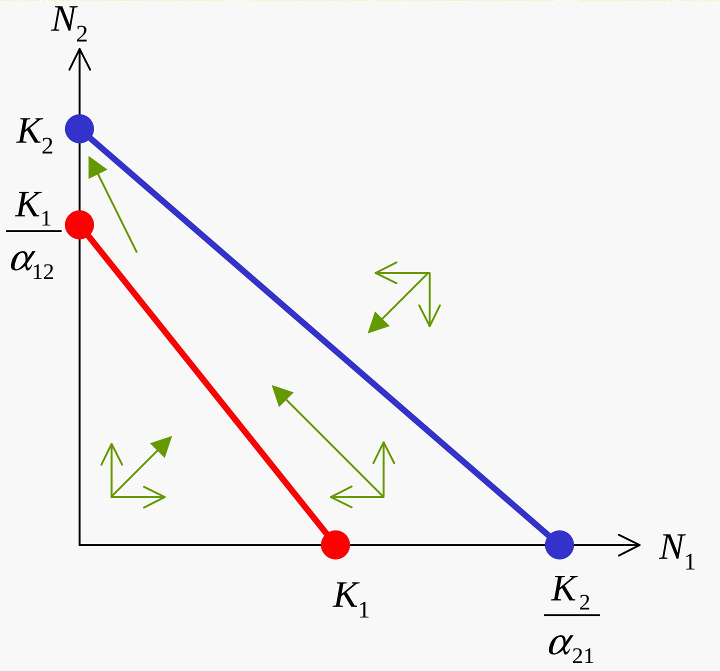
- above isocline i_1 and below i_2 competition is weak
- in-between i_1 and i_2 competition is strong

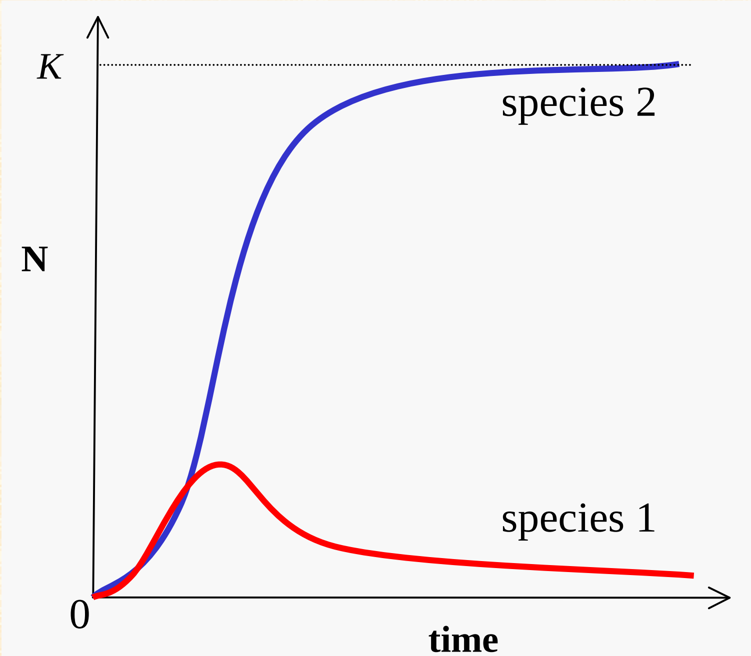
1. Species 2 drives species 1 to extinction

- *K* and α determine the model behaviour
- disregarding initial densities species 2 (stronger competitor) will outcompete species 1 (weaker competitor)

$$K_2 > \frac{K_1}{\alpha_{12}} \qquad K_1 < \frac{K_2}{\alpha_{21}}$$

$$K_1 = K_2 \qquad r_1 = r_2$$
$$\alpha_{12} > \alpha_{21} \qquad N_{01} = N_{02}$$



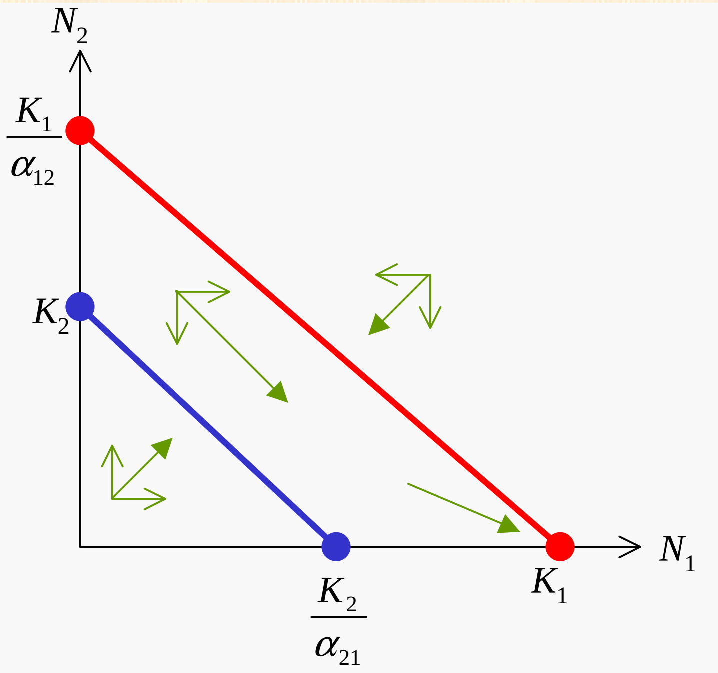


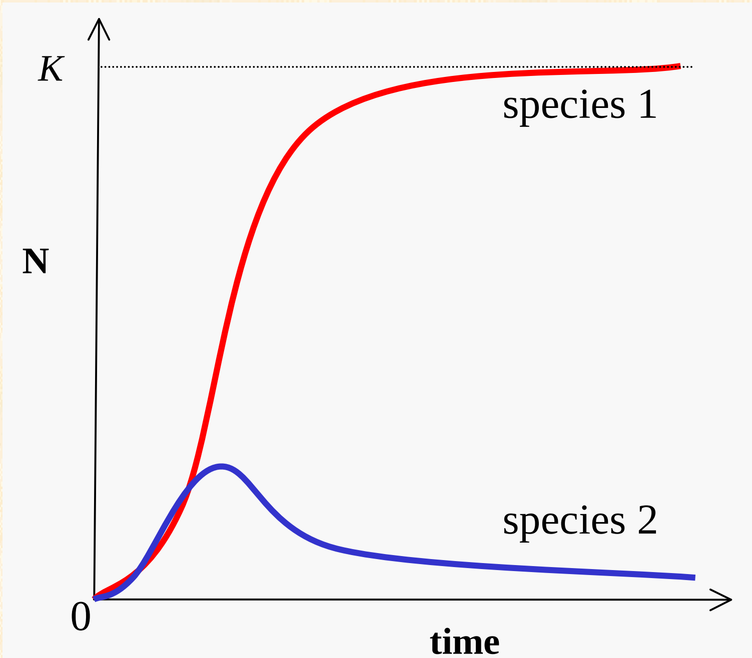
2. Species 1 drives species 2 to extinction

- species 1 (stronger competitor) will outcompete species 2 (weaker competitor)

$$K_1 > \frac{K_2}{\alpha_{21}} \quad K_2 < \frac{K_1}{\alpha_{12}}$$

$$r_1 = r_2 \qquad K_1 = K_2$$
$$N_{01} = N_{02} \qquad \alpha_{12} < \alpha_{21}$$



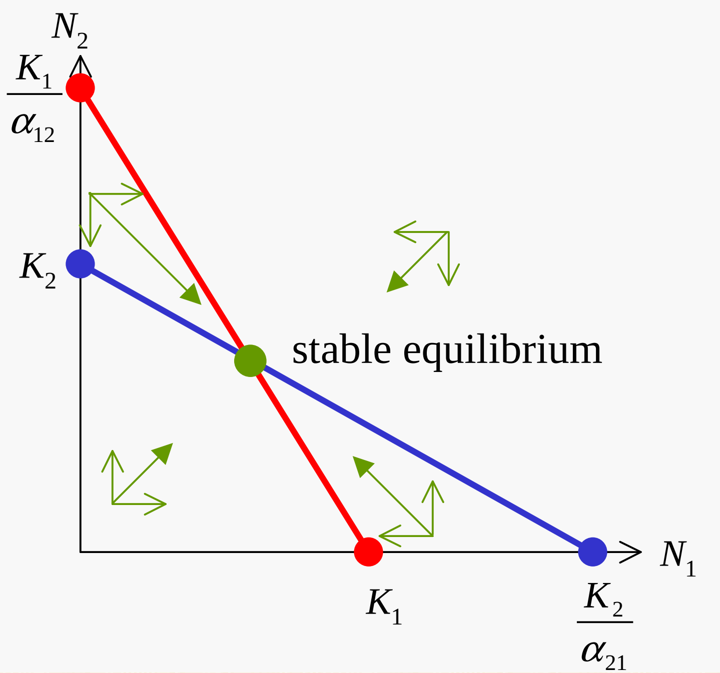


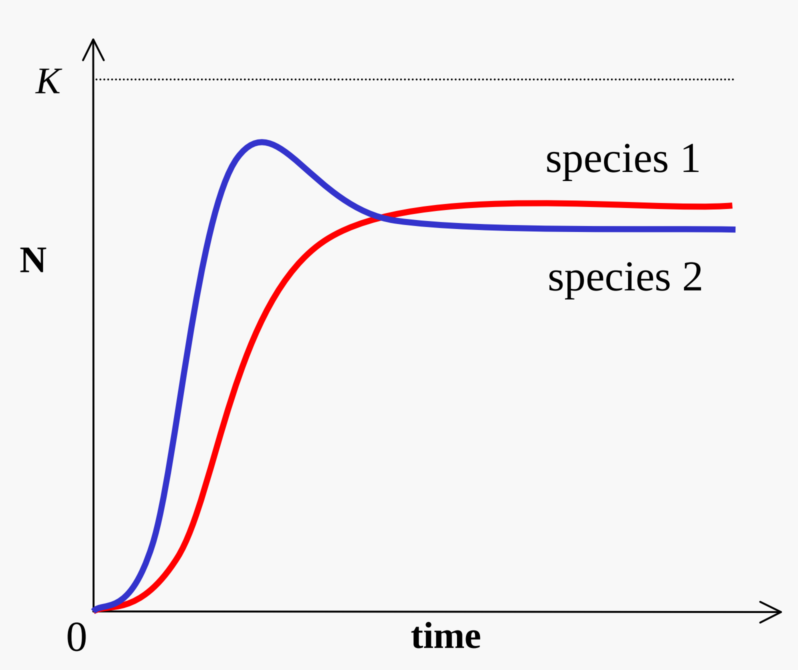
3. Stable coexistence of species

- disregarding initial densities both species will coexist at stable equilibrium (where isoclines cross)
- at at equilibrium population density of both species is reduced
- both species are weak competitors

$$K_1 < \frac{K_2}{\alpha_{21}} \qquad K_2 < \frac{K_1}{\alpha_{12}}$$

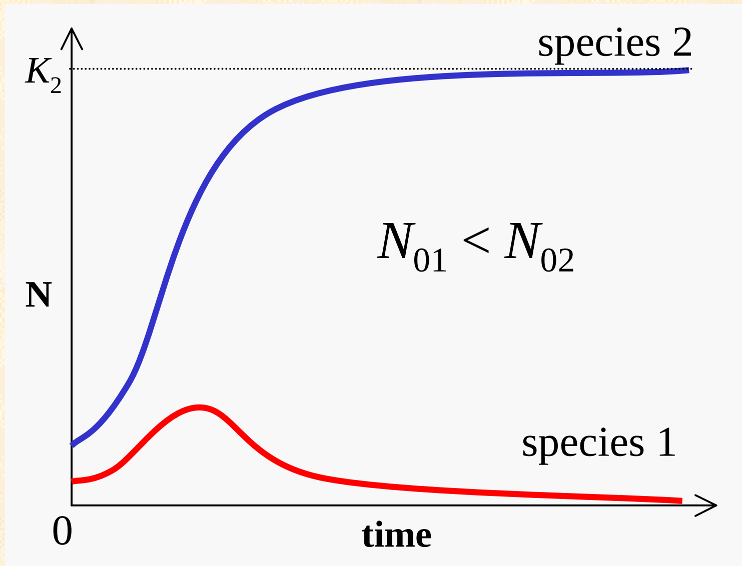
$$r_1 < r_2 \qquad K_1 = K_2$$
$$N_{01} = N_{02} \qquad \alpha_{12}, \alpha_{21} < 1$$



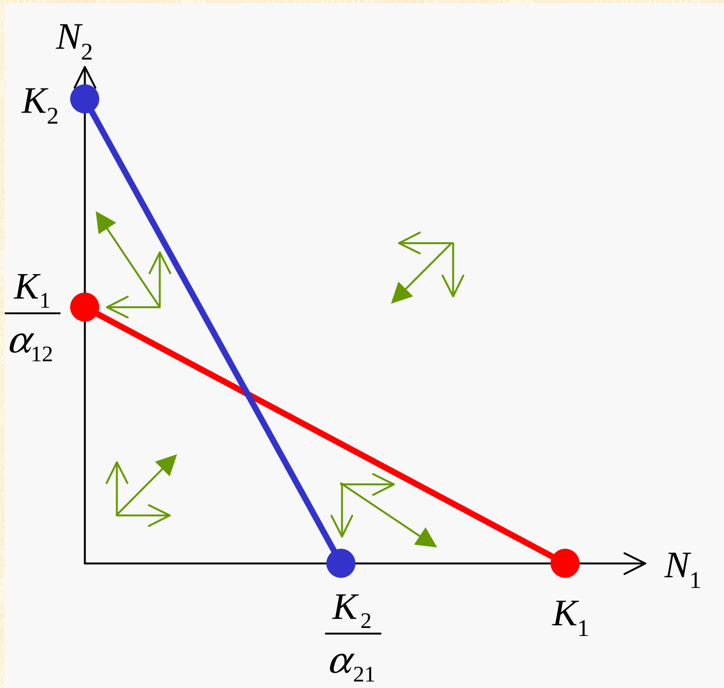


4. Competitive exclusion

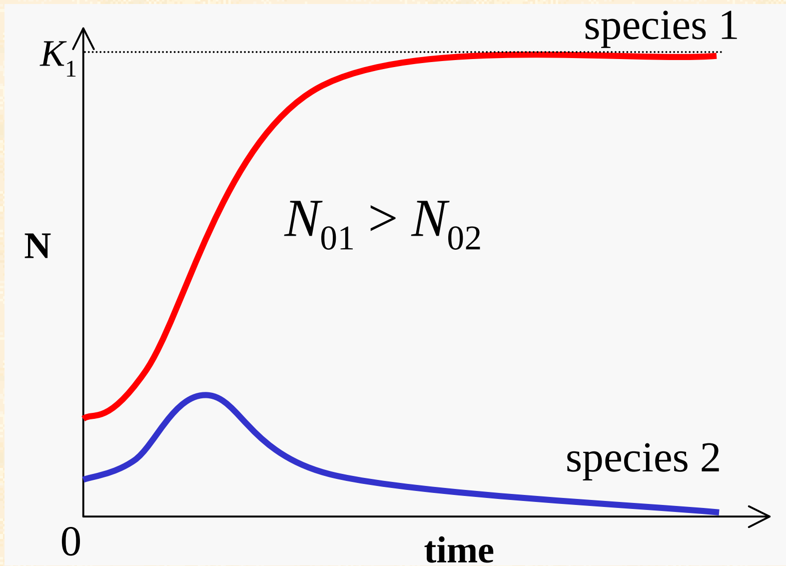
- one species will drive other to extinction depending on the initial conditions
- coexistence for a short time
- both species are strong competitors



$$K_1 > \frac{K_2}{\alpha_{21}} \qquad K_2 > \frac{K_1}{\alpha_{12}}$$



$$r_1 = r_2$$
$$K_1 = K_2 \qquad \alpha_{12}, \alpha_{21} > 1$$



Test of the model

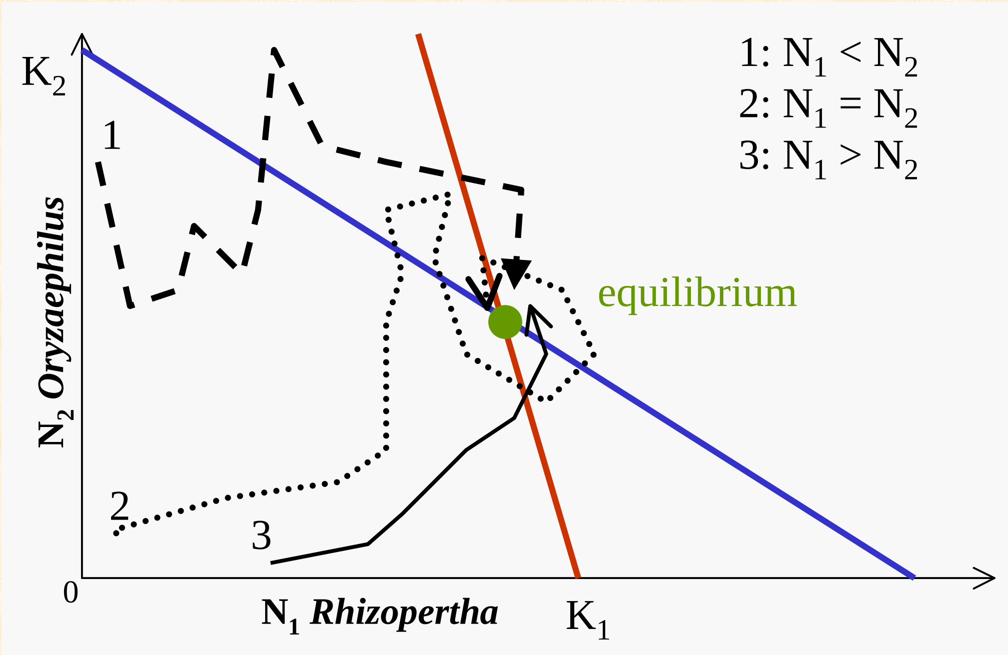
- when *Rhizopertha* and *Oryzaephilus* were reared separately both species increased to 420-450 individuals (= K)

- when reared together *Rhizopertha* reached $K_1 = 360$, while *Oryzaephilus* $K_2 = 150$ individuals

- combination resulted in more efficient conversion of grain ($K_{12} = 510$ individuals)

- three combinations of densities converged to the same stable equilibrium

- prediction of Lotka-Volterra model is correct



Crombie (1947)

Model for discrete generations

- solution of the differential model:

$$N_{1,t+1} = N_{1,t} e^{r_1\left(\frac{K_1 - N_{1,t} - \alpha_{12} N_{2,t}}{K_1}\right)}$$

$$N_{2,t+1} = N_{2,t} e^{r_2\left(\frac{K_2 - N_{2,t} - \alpha_{21} N_{1,t}}{K_2}\right)}$$

- multiple regression analysis is used to estimate parameters from abundances

$$\ln\left(\frac{N_{1,t+1}}{N_{1,t}}\right) = r_1 - N_{1,t}\frac{r_1}{K_1} - N_{2,t}\frac{r_1\alpha_{12}}{K_1}$$

$$\ln\left(\frac{N_{2,t+1}}{N_{2,t}}\right) = r_2 - N_{1,t}\frac{r_2}{K_2} - N_{1,t}\frac{r_2\alpha_{21}}{K_2}$$

$$\ln\left(\frac{N_{1,t+1}}{N_{1,t}}\right) = a + bN_{1,t} + cN_{2,t}$$

$$\ln\left(\frac{N_{2,t+1}}{N_{2,t}}\right) = a + bN_{2,t} + cN_{1,t}$$

$$r = a \qquad \alpha = -\frac{Kc}{r} \qquad K = -\frac{r}{b}$$

Excercise 16

Two species of *Tribolium* beetles were kept together in a jar with flour. The species breed in discrete periods. Their densities were recorded once a week. The following abundances were observed:

A: 10, 6, 5, 4, 3, 4, 6, 8, 10, 12, 15, 16
B: 20, 18, 16, 11, 6, 6, 5, 3, 2, 2, 1, 1

1. Estimate r_1, r_2, K_1, K_2, α_{12}, α_{21}.
2. Simulate the dynamics using difference model system for a period of 20 years. Use estimated values of parameters and initial densities of 20 individuals.

```
a<-c(10,6,5,4,3,4,6,8,10,12,15,16)
b<-c(20,18,16,11,6,6,5,3,2,2,1,1)
a1<-a[-1]/a[-12]
b1<-b[-1]/b[-12]

coef(lm(log(a1)~a[-12]+b[-12]))
0.60443/0.02992
20.20154*0.04106/0.60443

coef(lm(log(b1)~b[-12]+a[-12]))
0.399980/0.005052
79.1726*0.011438/0.399980

N12<-data.frame(N1<-numeric(1:20),N2<-numeric(1:20))
N12[,1]<-20
N12[,2]<-20
for(t in 1:20) N12[t+1,]<-{
N1<-N12[t,1]*exp(0.6*(20.2-N12[t,1]-1.4*N12[t,2])/20.2)
N2<-N12[t,2]*exp(-0.4*(79.2-N12[t,2]-2.3*N12[t,1])/79.2)
c(N1,N2)}
matplot(N12, type="l",lty=1:2)
legend(1,80,c("N1","N2"),lty=1:2)
```

Excercise 17

Two species of spiders, *Pardosa* and *Pachygnatha*, occur together and were found to feed in the field on the following prey:

Druh	Collembola	Hemiptera	Ensifera	Diptera	Isopoda
Pardosa	0.61	0.15	0.12	0.07	0.05
Pachygnatha	0.93	0.05	0.01	0	0.01

1. Estimate and plot niche breadth (*D*) for each species.
2. Estimate niche overlap (a_{12}, a_{21}) for each species.

$$D = \frac{1}{\sum_{k=1}^{n} p_k^2}$$

$$a_{12} = \frac{\sum p_{1k} p_{2k}}{\sum p_{1k}^2} \qquad a_{21} = \frac{\sum p_{1k} p_{2k}}{\sum p_{2k}^2}$$

```
Par<-c(0.61,0.15,0.12,0.07,0.05)
Pach<-c(0.93,0.05,0.01,0,0.01)
both<-rbind(Par,Pach)
barplot(both,beside=T,legend.text=c("Par","Pach"))
1/sum(Par^2)
1/sum(Pach^2)

a12<-sum(Par*Pach)/sum(Par^2); a12
a21<-sum(Par*Pach)/sum(Pach^2); a21
```

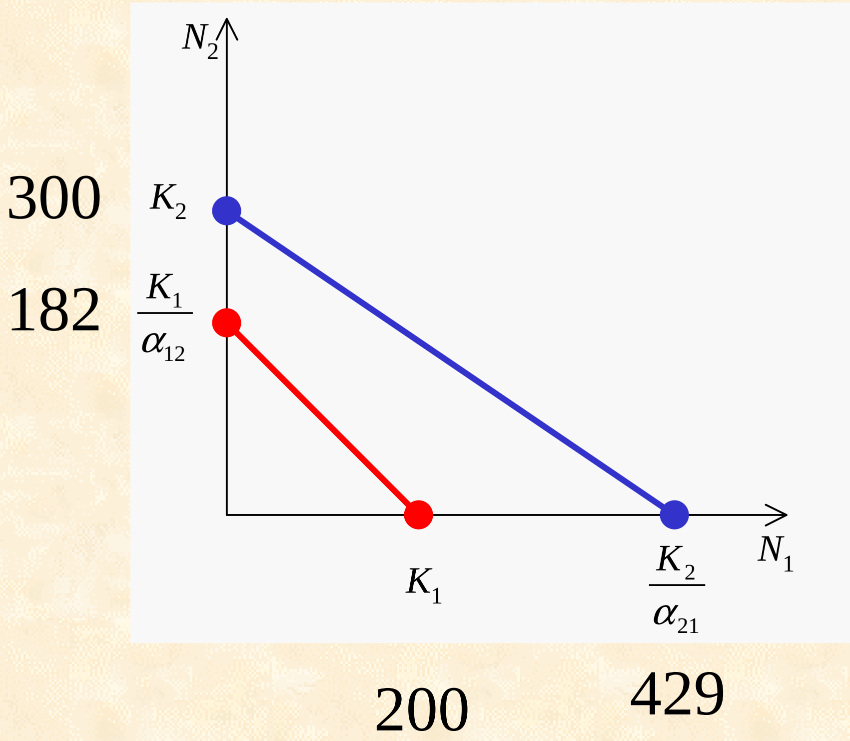
Excercise 18

An invasive ant species is spreading and may replace a native ant species as both have similar niches. The following parameters are know for the native (1) and invasive (2) species.

$r_1 = 0.2$	$r_2 = 0.9$
$K_1 = 200$	$K_2 = 300$
$\alpha_{12} = 1.1$	$\alpha_{21} = 0.7$

Simulate the population dynamic using differential model system for the period of 30 years. The initial densities are N_{01}=200 and N_{02}=10.

How to achieve stable coexistence?



```
comp<-function(t,y,param){
N1<-y[1]
N2<-y[2]
with(as.list(param),{
dN1.dt<-r1*N1*(1-(N1+a12*N2)/K1)
dN2.dt<-r2*N2*(1-(N2+a21*N1)/K2)
return(list(c(dN1.dt,dN2.dt)))})}

N1<-200;N2<-10
param<-c(r1=0.2,r2=0.9,a12=1.1,a21=0.7,K1=200,K2=300)
time<-seq(0,30,0.1)
library(deSolve)
out<-data.frame(ode(c(N1,N2),time,comp,param))
matplot(time,out[,-1],type="l",lty=1:2,col=1)
legend("right",c("N1","N2"),lty=1:2)

N1<-200;N2<-10
param<-c(r1=0.2,r2=0.9,a12=0.5,a21=0.7,K1=200,K2=300)
time<-seq(0,30,0.1)
library(deSolve)
out<-data.frame(ode(c(N1,N2),time,comp,param))
matplot(time,out[,-1],type="l",lty=1:2,col=1)
legend("right",c("N1","N2"),lty=1:2)
```