Effects of harvesting and competition on the spatial synchrony scales of population fluctuations

FRANCISCO J. CAO

(OUT OF EQUILIBRIUM DYNAMICS GROUP, UCM, SPAIN)

Previous general expertise

Model building to solve physical and biological problems (grasp the main ingredients)

Compute the dynamics of this models (in particular for stochastic models)

Compare stochastic models with data

In particular

Modeling of DNA replication by polymerases (PNAS, NARS)

Modeling of microorganism nutrient uptake rates (Marine Ecology Progress Series)

Recent contributions

Spatial correlation of population fluctuations

- Effects of harvesting:
  - Proportional harvesting increases the spatial correlation length of the harvested species
  - Harvesting with and stronger or weaker density dependence than the growth rate will decrease or increase the spatial correlation length of the harvested species (respectively)
- Effects of competition:
  - Uncorrelated environmental noise: both species increase their spatial correlation length.
  - Completely correlated environmental noise: usually increases the spatial correlation length of one species decreasing it for the other. Leading in general to a increase in the differences of spatial correlation length of the two competing species.

One species dynamics in fluctuating environment

(Lande, Engen, Saether book pages 93-96)

Defining the deviation from deterministic population equilibrium as

$$\epsilon(z,t) = \frac{N(z,t)}{K} - 1$$

The evolution equation is given by (assumes linear behavior)

$$d\epsilon(z,t) = -(r+m)\epsilon(z,t)dt + mdt\int \epsilon(z-x,t)f(x)dx + \sigma_e dB(z,t)$$

Giving the following interesting relation

$$l_p^2 = l_e^2 + \frac{ml_m^2}{r}$$

between the population correlation length l_p, the environmental fluctuations correlation length l_e, and the migration characteristic distance l_m.

This expression shows that population correlation length is increased by migration if the return to the equilibrium population is slow (small value of r)

Two competing species dynamics

(Gotelli book chapter 5)

Evolution equations for a two competing species model

$$\frac{dN_1}{dt} = r_1 N_1 \frac{K_1 - N_1 - \alpha_1 N_2}{K_1}$$
$$\frac{dN_2}{dt} = r_2 N_2 \frac{K_2 - N_2 - \alpha_2 N_1}{K_2}$$

where terms due to species competition are marked in red

When $\frac{1}{\alpha_2} > \frac{K_1}{K_2} > \alpha_1$, there is a **stable coexistence** with equilibrium values

$$\hat{N}_1 = \frac{K_1 - \alpha_1 K_2}{1 - \alpha_1 \alpha_2}$$

$$\hat{N}_2 = \frac{K_2 - \alpha_2 K_1}{1 - \alpha_1 \alpha_2}$$

Effects of harvesting

Proportional harvesting

$$\frac{dN_1}{dt} = r_1 N_1 \frac{K_1 - N_1 - \alpha_1 N_2}{K_1} - \beta_1 N_1$$
$$\frac{dN_2}{dt} = r_2 N_2 \frac{K_2 - N_2 - \alpha_2 N_1}{K_2} - \beta_2 N_2$$

Displaces the deterministic equilibrium, reducing effective carrying capacity $K_i^* = K_i\left(1 - \frac{\beta_i}{r_i}\right)$

Reduces effective growth rate $r_i^* = r_i - \beta_i = r_i\left(1 - \frac{\beta_i}{r_i}\right)$

Proportional harvesting increases the population synchrony scales

(This is consistent with our more recent results for one-species. These other results show that if harvesting depends more strongly on population density than the growth rate the population synchrony scale can be reduced, while if harvesting has a weaker density dependence the scale is increase, as is the case for proportional harvesting.)

Spatial population correlation lengths

We have obtained analytical expression for all the spatial population correlation lengths ($l_{11}^2, l_{22}^2, l_{12}^2$), at leading order in the competition coefficient, for example we have

$$l_{11}^2 = l_{e11}^2 + \frac{m_1 l_{m1}^2}{r_1^*}\left(1 + \alpha_1^* \Phi_{11}^{(1)}\right)$$

where $r_i^* = r_i - \beta_i$, $\alpha_1^* = \frac{\alpha_1 K_2^*}{K_1^*}$, $K_i^* = K_i\left(1 - \frac{\beta_i}{r_i}\right)$,

and $\Phi_{11}^{(1)}$ is the competition sensitivity, for which we have an explicit analytical expressions.

$$\Phi_{11}^{(1)} = 1 - 2\frac{J_{e12}}{J_{e11}}\frac{1}{\left(1 + \frac{r_2^*}{r_1^*}\right)^2}\left[1 + \frac{m_2 l_{m2}^2}{m_1 l_{m1}^2} - (r_1^* + r_2^*)\frac{l_{e11}^2 - l_{e12}^2}{m_1 l_{m1}^2}\right]$$

Spatial population correlation lengths

Particular cases

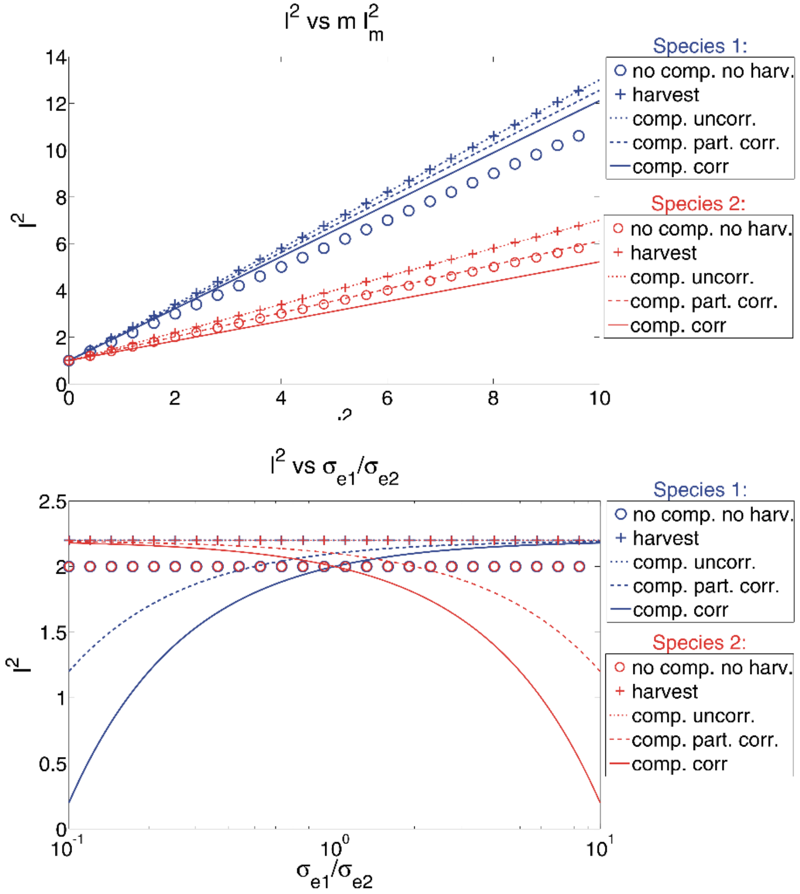
- No harvesting and no competition: the Moran effect with migration correction is recovered

$$l_{11}^2 = l_{e11}^2 + \frac{m_1 l_{m1}^2}{r_1}$$

- Harvesting without competition: **proportional harvesting always increases correlation length** (continues to be true for mild competition, i.e., α_i^* small)

$$l_{11}^2 = l_{e11}^2 + \frac{m_1 l_{m1}^2}{r_1^*}$$

with $r_i^* = r_i - \beta_i$



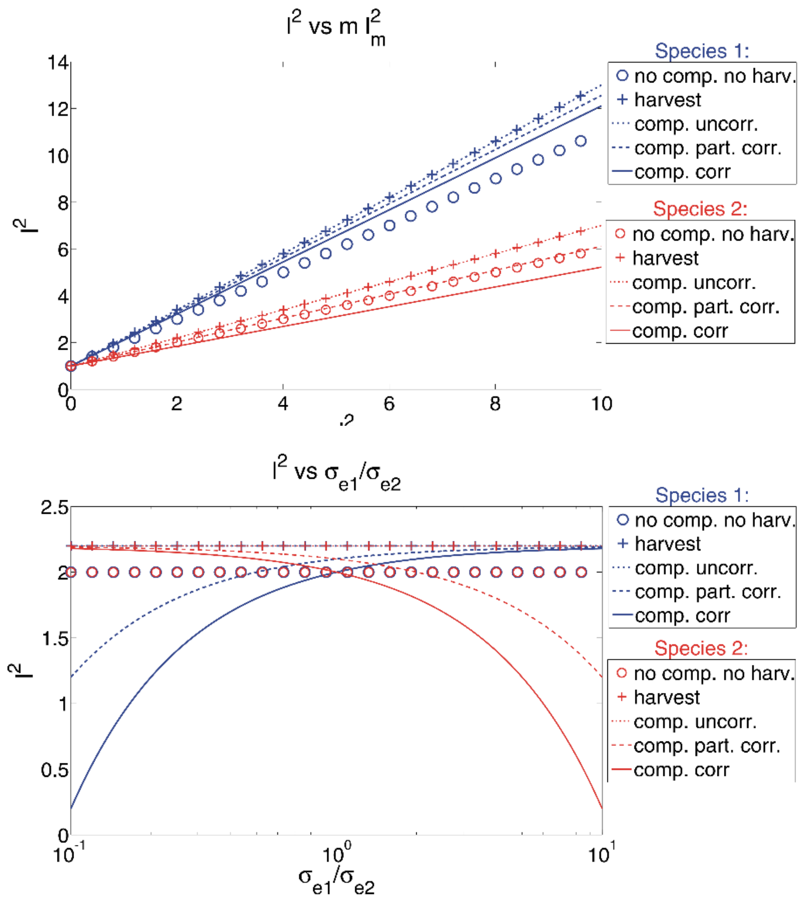
Spatial population correlation lengths

Particular cases

- **Uncorrelated environmental noises:** i.e., when both species are affected by **different environmental variables**.

Competiton increases the correlation length for both species. (See dotted line in plot compared with line with circles.)

$$l_{11}^2 = l_{e11}^2 + \frac{m_1 l_{m1}^2}{r_1^*}(1+\alpha_1^*)$$



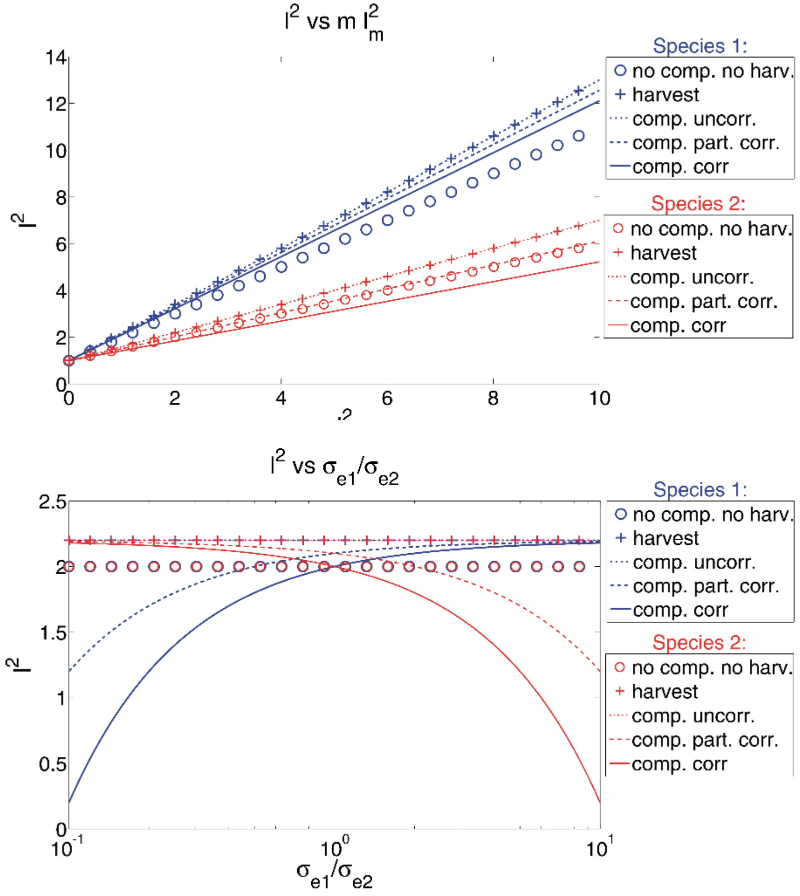
Spatial population correlation lengths

Particular cases

- **Correlated environmental noises**: i.e., when both species are **affected similarly by the environment**.

Competition generally increases the correlation length of one species and decreases it for the other. (See solid line in plot compared with line with circles.)

$$l_{11}^2 = l_{e11}^2 + \frac{m_1 l_{m1}^2}{r_1^*}\left(1 + \alpha_1^* \Phi_{11}^{(1)}\right)$$



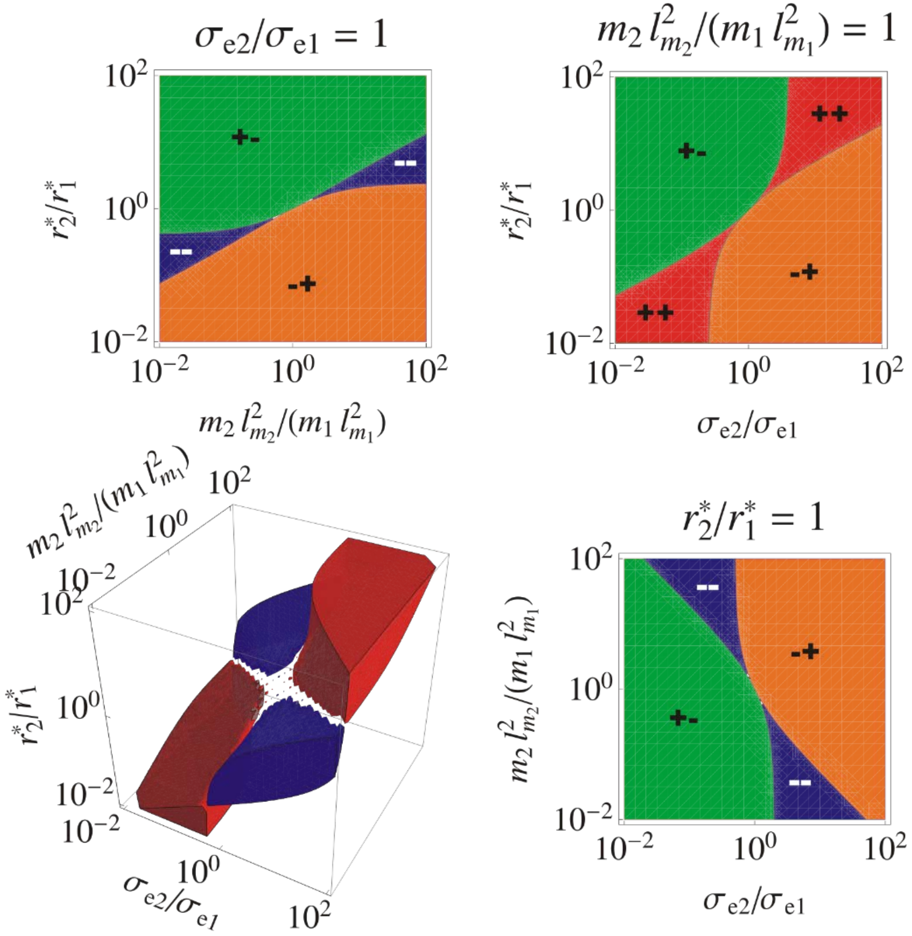
Spatial population correlation lengths

Particular cases

- **Correlated environmental noises**: i.e., when both species are **affected similarly by the environment.**

Competition generally increases the correlation length of one species and decreases it for the other. (See solid line in plot compared with line with circles.)

$$l_{11}^2 = l_{e11}^2 + \frac{m_1 l_{m1}^2}{r_1^*}\left(1 + \alpha_1^* \Phi_{11}^{(1)}\right)$$

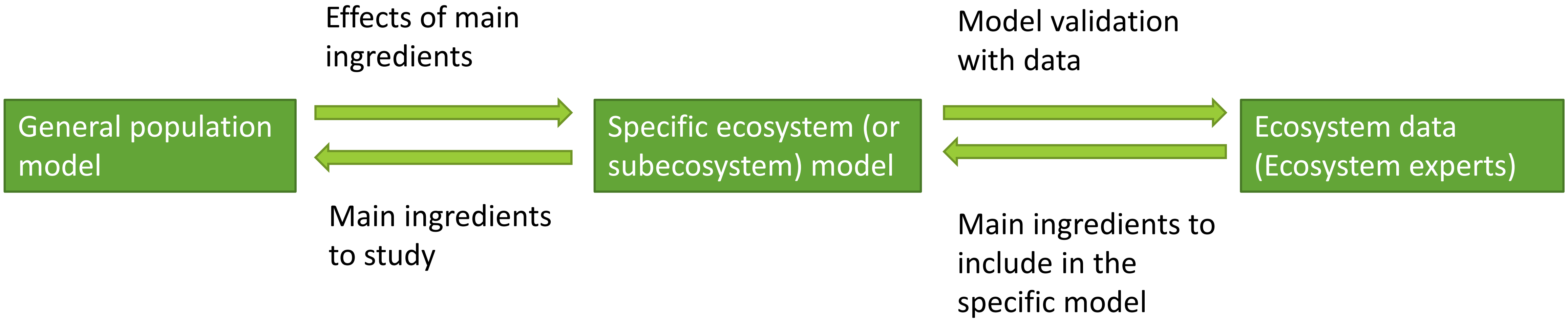


Reduced description of a subecosystem

Some of the species and their interactions are considered as our subecosystem

The other species and environmental factors (temperature, rain, …) as our environment. Their mean values determine growth rate and carrying capacity. Their fluctuations give contributions to stochastic environmental fluctuations.

From models to data and viceversa



Main ingredients can be for example harvesting, competition, predator-prey interaction.

Subecosystem refers to a description including only some of the species of the ecosystem

Results in

deeper understanding of specific ecosystems

Deeper understanding of population dynamics (with potential applications to other ecosystems)

Implications for ecosystems in the Norwegian SUSTAIN project

Several of the ecosystems included in SUSTAIN have abundant spatial and temporal information of several species, in particular

- Barents Sea
- Svalbard

  our results could serve to understand the dynamics of these ecosystems, in particular the spatial and temporal synchrony of their population dynamics.

  Conversely, these ecosystems could provide illustration of our theoretical results.

Conclusions

Spatial correlation of population fluctuations

- Effects of harvesting:
  - Proportional harvesting increases the spatial correlation length of the harvested species
  - Harvesting with and stronger or weaker density dependence than the growth rate will decrease or increase the spatial correlation length of the harvested species (respectively)
- Effects of competition:
  - Uncorrelated environmental noise: both species increase their spatial correlation length.
  - Completely correlated environmental noise: usually increases the spatial correlation length of one species decreasing it for the other. Leading in general to a increase in the differences of spatial correlation length of the two competing species.

These theoretical results will be compared with data for different ecosystems included in the Norwegian SUSTAIN Project.