METAPOPULATION MODELLING : A TOOL FOR CONSERVATION BIOLOGY

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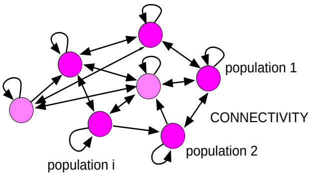
▶ Existence of alternate dispersive/sedentary stages in species life cycle may lead to meta-population functioning



Dispersive stage frequent during reproduction of sedentary adult

- terrestrial plants : pollen, seeds
- marine benthic invertebrates
- some fishes

but also dispersive adults can be constrained by reproduction in specific habitat

- some insects
- amphihaline fishes
- jellyfish

Does losses during dispersive phase endanger population persistence at a regional scale (the metapopulation scale)?

▶ The early metapopulation model of Levins (1969)

Assumptions

- infinite number of patches of the same size and quality = highly fragmented habitat
- describe p the fraction of patch occupied by one species (not abundance)
- dispersal and extinction are spatially homogeneous

$$\frac{dp}{dt} = \underbrace{mp(1-p)}_{colonization} - \underbrace{ep}_{extinction}$$

Metapopulation equilibrium p^*

$$\iff \frac{dp}{dt} = 0$$

$$\Rightarrow p^* = 1 - e/m$$

$p^* > 0$ if and only if $m > e$

▶ Hanski and Ovaskainen model (2000, 2003)

Assumptions

- finite number of patches but still highly fragmented habitat
- describe p_i the probability of species presence in each patch i with area A_i
- dispersal and extinction are spatially structured

$$\frac{dp_i}{dt} = \underbrace{C_i(t)(1-p_i)}_{colonization} - \underbrace{\mu_i p_i}_{extinction}$$

assuming $\mu_i = e/A_i$ and
$C_i(t) = c\sum_{j\neq i}\exp(-\alpha d_{ij})p_j(t)A_j$
with

- c colonisation parameter
- α average distance of migration
- e extinction parameter

Metapopulation viability
$\Rightarrow$ leading eigenvalues of
$M = [\exp(-\alpha d_{ij})A_iA_j]$ is larger than e/c.

Hastings and Botsford model (2006)

Assumptions

- finite number of patches
- describe $N(t) = [N_i(t)]$ the abundance of species adult in each patch i
- dispersal and survivorship are spatially structured

$$N(t+1) = CN(t)$$

where C a matrix defined by:

$$C_{ij} = b_j t_{ij} a_i + s_{ij} \delta_{ij}$$

with:

- b_j recruitment success in patch j
- t_{ij} propagule exchange rate from patch i to patch j
- a_i propagule production rate in patch i
- s_{ii} adults survivorship rate in patch i

Metapopulation viability
$\Rightarrow$ leading eigenvalues of C is larger than 1.

▶ Age-structured metapopulation models (M2 Belharet, 2011)

Assumptions

- finite number of patches
- describe $N(t) = [N_i(t)]$ the abundance of a species juveniles and adults in each patch i
- dispersal is spatially structured
- sexual maturation and maturation are spatially uniform

Two stages in each patch i,

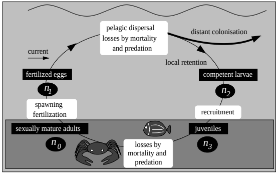
$$\frac{\partial J_i}{\partial t} = -cJ_i - m_J J_i + (\omega M[T(\tau).A].rU)\delta(t,\tau$$

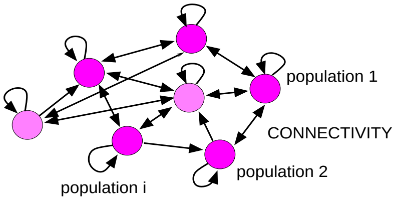
$$\frac{\partial A_i}{\partial t} = +cJ_i - m_A A_i$$

with:

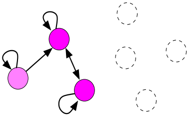
- c_J sexual maturation rate of juveniles
- T_{ij} propagule exchange rate from patch i to patch j
- ω propagule production rate
- r recruitment rate
- m_J, m_A, M juveniles, adults and larvae mortality rates

▶ Benthic species reproducing with planktonic larval dispersal: connectivity-driven resilience ?

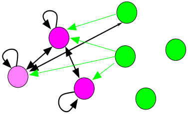




- Antropogenic stresses > Habitat loss



- Climatic stresses > Recruitment failure



▶ Meta-population dynamics modelling: adapted from Hastings and Botsford (2006)

Assumptions

- describe $A(t) = [A_i(t)]$ the abundance of species adult in each patch i
- finite number of patches
- connectivity and survivorship are spatially structured
- density dependence and stochastic connectivity

$$A(t + \Delta t) = min(G(t)A(t), A_{max})$$

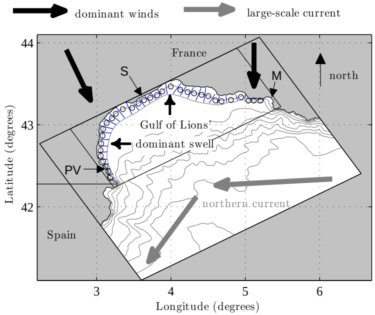
where G a matrix defined by:

$$G_{ij} = a_i C_{ij}(t) b_j + s_{ij}\delta_{ij}$$

with:

- a_i propagule production rate in patch i
- C_{ij} propagule exchange rate from patch i to patch j
- b_j recruitment success in patch j
- s_{ii} adults survivorship rate in patch i
- A_{max} carrying capacity

▶ Application to soft-bottom polychaetes in the Gulf of Lions: Connectivity matrix

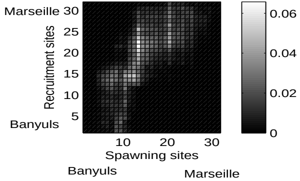


Weather forecast model (Météo-France ALADIN)

> Coastal circulation model (CNRS-INSU SYMPHONIE)

Lagrangian larval dispersal modelling

- neutrally buoyant larvae with PLD = 3-5 weeks
- 32 spawning sites along the 20 m isobath
- 20 spawning periods of 10 days: January to April (100 days) in 2004 and 2006



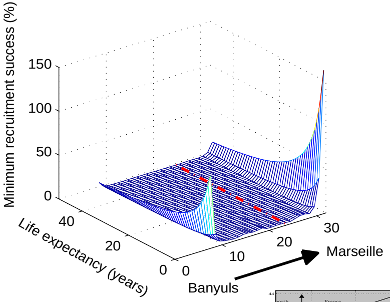
▶ Application to soft-bottom polychaetes in the Gulf of Lions: Demographic parameters

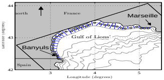
- survivorship is spatially uniform : $s_{ij} = ln(0.01)/L_E$ where L_E is species life expectancy
- propagule production rate is spatially uniform over the region: $a_i = 3.75\ 10^3$ larvae per adult
- recruitment success is spatially uniform over the region: $b_j = R$
- site carrying capacity is based on adult size L: $A_{max} = 10/L^2$

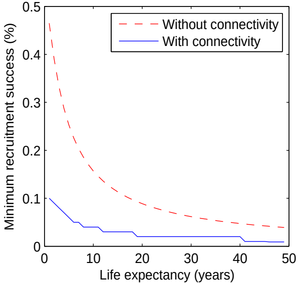
▶ Minimum recruitment success R for persistence

Without connectivity:
the closed populations hypothesis

With connectivity:
the metapopulation hypothesis



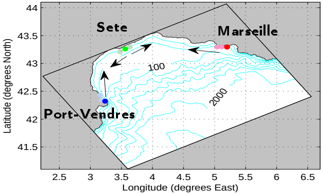


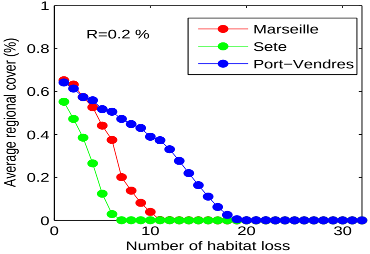


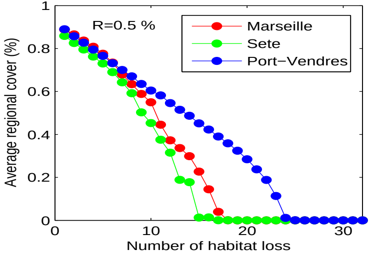
Minimum recruitment success R required for species persistence at the regional scale is reduced by a factor 5 on average by connectivity

▶ Regional resilience of a short living species to anthropogenic stress

Oil spill starting in the main regional ports and destructing habitat while spreading

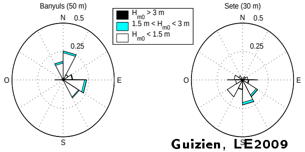




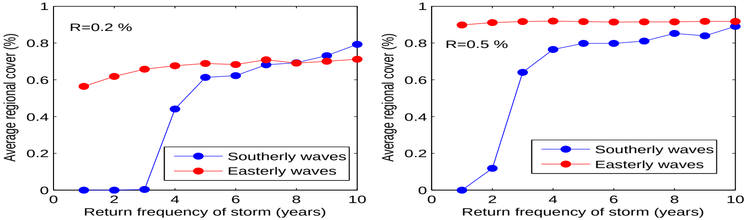


▶ Regional resilience of a short living species to climatic stress

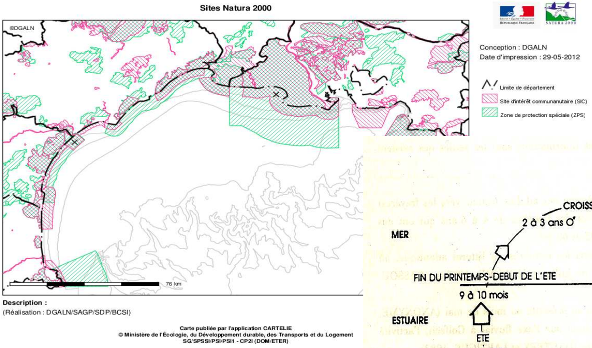
Storm swell with different origins causes recruitment failure at different frequency

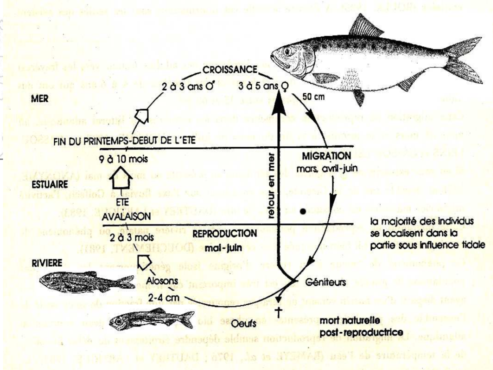


Guizien, LE2009

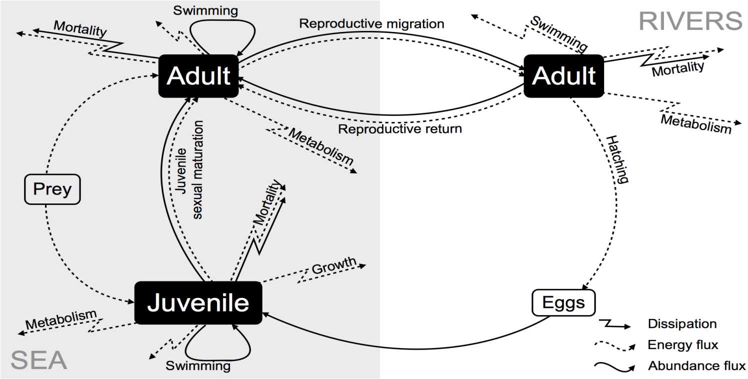


▶ Amphihaline species reproducing in rivers : is the river the essential habitat ?



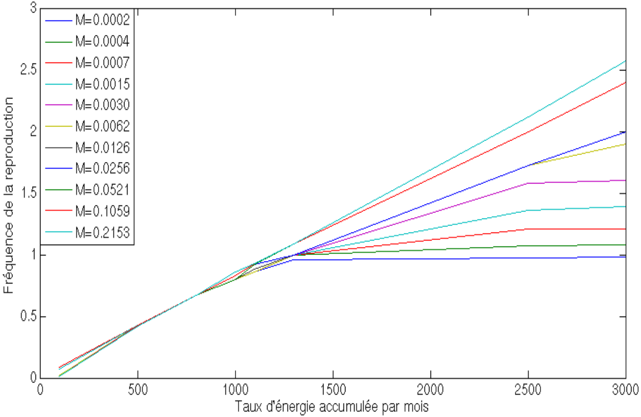


▶ Coupled meta-population / DEB model

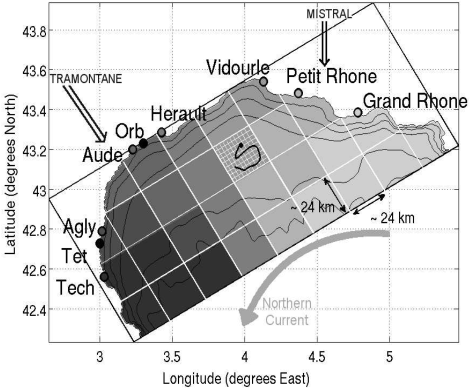


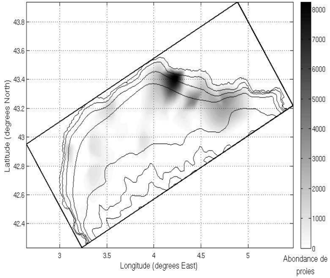
Dynamic Energy Budget model : balance between energy loss due to counter-current swim and energy gain when feeding

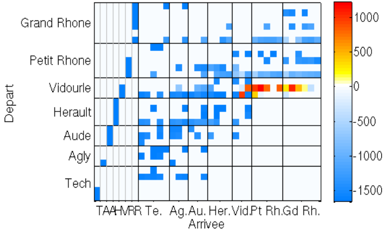
▶ Annual reproduction requires energy gains during dispersal whatever larval mortality



▶ Application to the Gulf of Lions: *Alosa fallax*

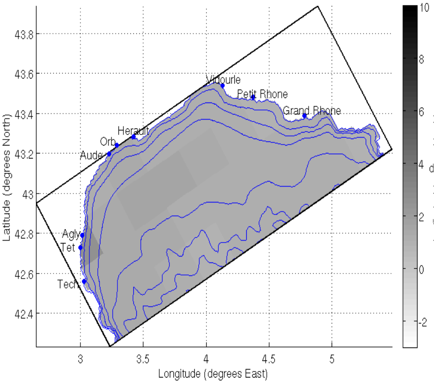




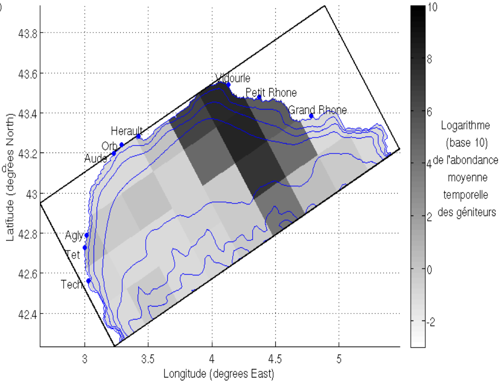


▶ Fish behaviour and essential habitats

Passive behaviour



Active behaviour



▶ Take home messages

- connectivity enhances resilience populations at regional scale
- connectivity can spatially structure species vulnerability to extreme stresses like habitat desctruction and recruitment failure
- new essential habitats identification benefits from metapopulation point of view

Thank for your attention