STUDYING BIODIVERSITY BY AN INTEGRATIVE APPROACH OF POPULATION GENETICS AND COMMUNITY ECOLOGY:

A WAY TO BETTER PREDICT THE FATE OF OUR MARINE FORESTS IN A CHANGING OCEAN?

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Evolutionary Biology and Ecology of Algae
EBEA – UMI 3614 – CNRS, UPMC, PUCCh, UACH

ISYEB seminar - June 30th 2015
The forces maintaining species and genetic diversity are similar (1976)
The forces maintaining species and genetic diversity are similar (1976)

Janis Antonovics

<table>
<thead>
<tr>
<th></th>
<th>Genetic diversity</th>
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<tbody>
<tr>
<td></td>
<td><em>Within &amp; among populations</em></td>
<td><em>Within &amp; among communities</em></td>
</tr>
<tr>
<td>Drift</td>
<td>Random fluctuations in the abundance of genes</td>
<td>Random fluctuations in the abundance of species</td>
</tr>
<tr>
<td>Migration</td>
<td>Movement of genes among localities</td>
<td>Movement of species among localities</td>
</tr>
<tr>
<td>Selection</td>
<td>Favours a genotype over others</td>
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Empirical data show species genetic diversity correlation

Test of SGDC (species genetic diversity correlation) across islands in 14 datasets
Empirical data show species genetic diversity correlation


Test of SGDC (species genetic diversity correlation) across islands in 14 datasets

Genetic diversity of *Urocyon littoralis*

Channel Islands, CA
Data for 6 islands

Species diversity of terrestrial mammals

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Empirical data show species genetic diversity correlation

Test of SGDC (species genetic diversity correlation) across islands in 14 datasets

Positive SGDC in 13 out of 14 datasets explained by island area
Empirical data show species genetic diversity correlation

Most of the studies published report positive SGDC

Lamy et al. 2013

Genetic diversity of *Aplexa marmorata*

SGDC across 57 pond sites in Guadeloupe
Positive effect of site connectivity on both genetic and species diversity
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He et al. 2008

Genetic diversity of *Banksia attenuata*

Species diversity of shrub trees

SGDC across 27 dunes in SW Australia
Positive effect of water availability on both genetic and species diversity

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EMPIRICAL DATA SHOW SPECIES GENETIC DIVERSITY CORRELATION

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Positive SGDC explained by parallel effects of neutral processes (drift, migration) or environmental filters on both diversity levels
EMPIRICAL DATA SHOW SPECIES GENETIC DIVERSITY CORRELATION

A few studies report negative or no SGDC

Karlin et al. 1984

Genetic diversity of *Desmognathus fuscus*

Species diversity of *Desmognathus*

Negative SGDC across 27 sites in Eastern USA explained by interspecific intrageneric competition
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Genetic diversity of one flora species
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No SGDC for this multi-species study of high-mountain flora (the Alps and the Carpathians) explained by past climate influence on species distribution & diversity
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SGDC vary among organisms and/or spatial extent under study
SPECIES GENETIC DIVERSITY CORRELATION: PARALLEL PROCESSES

Habitat
- Area
- Connectivity
- Heterogeneity
- Environment

Parallel effects:
- drift
- migration
- selection

Genetic diversity
- correlation +
- correlation +
- correlation ?

Species diversity
**SPECIES GENETIC DIVERSITY CORRELATION: PARALLEL PROCESSES**

**Habitat**
- Area
- Connectivity
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**Parallel effects**
- Drift
- Selection
- Migration

**Genetic diversity**
- Correlation +
- Correlation +
- Correlation ?

**Species diversity**

--- SGDC + by parallel effects of drift among habitats of different area (e.g. Vellend 2003) ---

**Populations/communities size**

**Drift**

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SPECIES GENETIC DIVERSITY CORRELATION: PARALLEL PROCESSES

SGDC + by parallel effects of migration among habitats of different connectivity (e.g. Lamy et al. 2013)
SPECIES GENETIC DIVERSITY CORRELATION: PARALLEL PROCESSES

SGDC + by parallel effects of selection among habitats of different water availability (e.g. He et al. 2008)
SPECIES GENETIC DIVERSITY CORRELATION: CAUSAL EFFECTS

- Genetic diversity
- Species diversity

Habitat
- Area
- Connectivity
- Heterogeneity
- Environment

Parallel effects
- correlation -
- correlation +

Causal effects
- competition
- facilitation

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**SPECIES GENETIC DIVERSITY CORRELATION: CAUSAL EFFECTS**

SGDC - by competition effects of species diversity on genetic diversity among habitats of different species richness (e.g. Karlin et al. 1984)
**SPECIES GENETIC DIVERSITY CORRELATION: CAUSAL EFFECTS**

**Habitat**
- Area
- Connectivity
- Heterogeneity
- Environment

**Parallel effects**

**Genetic diversity**

**Causal effects**
- competition
- facilitation

**Species diversity**

SGDC + by facilitation effects of plant genotypic diversity on consumers species diversity via increasing productivity and resource specialisation (e.g. Crutsinger et al. 2006)

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**Genotypic diversity**

**Productivity & specialisation**

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1) Identifying processes impacting biodiversity at intra and inter-specific levels

- Genetic diversity
- Species diversity

anthropogenic pressures → conservation measures
1) Identifying processes impacting biodiversity at intra and inter-specific levels

- Genetic diversity
- Species diversity

Anthropogenic pressures
Conservation measures

2) Use one level of diversity as a surrogate for the other

- Genetic diversity
- Species diversity
Kelp forests of Brittany

Large brown algae forming underwater marine forests in cold to temperate rocky shores

Ecosystem engineers providing habitat, food and protection to other organisms
Kelp forests of Brittany

Large brown algae forming underwater marine forests in cold to temperate rocky shores

Ecosystem engineers providing habitat, food and protection to other organisms

In Brittany two species dominate the subtidal zone:

\textit{Laminaria hyperborea}

\begin{itemize}
  \item subtidal
  \item Norway to Portugal
\end{itemize}

\textit{Laminaria digitata}

\begin{itemize}
  \item low intertidal/high subtidal
  \item Norway to Southern Brittany
\end{itemize}

Photo Yann Fontana

Photo Marine Robuchon
Kelps forests of Brittany are under pressure

1) Climate change
Cold-water species
Temperature impacts survival, growth & reproduction
Mean temperature has increased by 0.7 ° during the last 20 years in Brittany (Gallon, Robuchon et al. 2014, JOB)
Exacerbated pressure for Laminaria digitata
Kelps forests of Brittany are under pressure

1) Climate change
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Exacerbated pressure for *Laminaria digitata*

2) Harvesting
*Laminaria hyperborea* harvested by the Norwegian comb since 2006
*Laminaria digitata* harvested by the scoubidou since 1960’s
LOOKING FOR SGDC IN KELP FORESTS OF BRITTANY

20 sites sampled in 4 regions along the Brittany coastline during the winter 2011
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1) Genetic diversity of *L. hyperborea* and *L. digitata*

Genotyping (microsatellites) of 30 to 50 specimens/site/species (Robuchon et al. 2014, *Mol. Ecol.*)
20 sites sampled in 4 regions along the Brittany coastline during the winter 2011

1) Genetic diversity of *L. hyperborea* and *L. digitata*

Genotyping (microsatellites) of 30 to 50 specimens/site/species (Robuchon et al. 2014, *Mol. Ecol.*)

2) Species diversity of algal communities living beneath *L. digitata* and *L. hyperborea*

Integrative identification of specimens sampled in 3 0.1 m² quadrats/site/species (Robuchon et al. 2015, *Genetica*)
Calculation of equivalent diversity metrics at both diversity levels by site

<table>
<thead>
<tr>
<th>Genetic diversity</th>
<th>Species diversity</th>
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<tbody>
<tr>
<td>Allelic richness</td>
<td>Species richness</td>
</tr>
<tr>
<td>AR</td>
<td>SR</td>
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**α**
- Gene diversity\(^1\)
  \[ \text{He} = 1 - \sum p_i^2 \]
- Simpson diversity\(^2\)
  \[ 1 - \lambda = 1 - \sum p_i^2 \]

**β**
- Genetic structure/differentiation\(^3\)
  \[ F_{ST} = \sigma_a^2 / (\sigma_a^2 + \sigma_b^2 + \sigma_w^2) \]
- Community structure/differentiation\(^4\)
  \[ F_{STC} = \sigma_a^2 / (\sigma_a^2 + \sigma_b^2) \]

Where \( \sigma_a, \sigma_b \) and \( \sigma_w \) are the components of variance of allel (resp. species) frequencies among populations (resp. localities), among individuals within populations (resp. localities), within individuals (resp. = 0)

\(^1\) Nei, 1978; \(^2\) Simpson, 1949; \(^3\) Weir & Cockerham, 1984; \(^4\) Evanno et al. 2009
Correlation tests between species and genetic diversity carried out

2 kelp species
Correlation tests between species and genetic diversity carried out

2 kelp species

3 metrics

AR versus SR
He versus 1-\(\lambda\)
\(F_{ST}\) versus \(F_{STC}\)
Looking for SGDC in kelp forests of Brittany

Correlation tests between species and genetic diversity carried out

2 kelp species

3 metrics
AR versus SR
He versus 1-\(\lambda\)
\(F_{ST}\) versus \(F_{STC}\)

5 spatial scales
Brittany  St Malo Bay  Morlaix Bay  Iroise Sea  Southern Brittany
SGDC in kelp forests of Brittany: variation among species

Pearson correlation tests between species and allelic richness, all sites of Brittany

\[
p < 0.01, R = 0.57
\]

all sites: \( p > 0.05 \)
SGDC in Kelp Forests of Brittany: Variation Among Species

Pearson correlation tests between species and allelic richness, all sites of Brittany

- All sites: $p < 0.01$, $R = 0.57$
- Without Southern Brittany: $p < 0.01$, $R = 0.72$

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Range limit effect?
SGDC IN KELP FORESTS OF BRITTANY: VARIATION AMONG METRICS

Pearson correlation tests for *L. digitata*, all sites of Brittany

- All sites: $p > 0.05, R = 0.49$
- Without Southern Brittany: $p < 0.01, R = 0.72$

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**He versus $1-\lambda$**

- All sites: $p < 0.05, R = 0.46$
- Without Southern Brittany: $p < 0.01, R = 0.72$

**AR versus SR**

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SGDC in kelp forests of Brittany: variation among metrics

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Pearson correlation tests between species and allelic richness for *L. hyperborea*

- All sites: $p < 0.01$, $R = 0.57$
- St Malo Bay: $p < 0.05$, $R = 0.88$
- Morlaix Bay: $p > 0.05$
- Iroise Sea: $p > 0.05$
- Southern Brittany: $p > 0.05$

Scale-dependant processes?
Pearson correlation tests between species and allelic richness for *L. hyperborea*

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Scale-dependant processes?
## SGDC in Kelp Forests of Brittany: Summary

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#### Within regions:

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<tr>
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<td>AR vs SR</td>
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A MAJORITY OF POSITIVE SGDC: PREVALENCE OF NEUTRAL PROCESSES?

Brittany: 8 out of 9 positive SGDC

Genetic diversity characterised by neutral markers
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Brittany: 8 out of 9 positive SGDC

Genetic diversity characterised by neutral markers

Parallel action of neutral processes on both species and genetic diversity
(Etienne & Olf 2004; Vellend 2010)

Habitat
- Area
- Connectivity
- Heterogeneity
- Environment

Parallel effects
- drift
- selection
- migration

Genetic diversity

Causal effects
- competition
- facilitation

Species diversity
<table>
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<tr>
<th>All sites: no SGDC between AR and SR</th>
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VARIATION OF SGDC PATTERNS: WHAT DO THEY REVEAL?

All sites: no SGDC between AR and SR  
All sites: SGDC + between He and 1-ʎ

Without Southern Brittany: SGDC + between AR and SR

In Southern Brittany, environmental filters seem to affect *Laminaria digitata* negatively. For instance, reproduction is affected by high temperatures (Oppliger et al. 2014, PLoS ONE).

---

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**Species diversity**
VARIATION OF SGDC PATTERNS: WHAT DO THEY REVEAL?

Brittany: 8 out of 9 positive SGDC

Intra-region: 1 out of 21 positive SGDC

Processes vary with scale
**Variation of SGDC Patterns: What Do They Reveal?**

Brittany: 8 out of 9 positive SGDC

Intra-region: 1 out of 21 positive SGDC

**Processes vary with scale**

Neutral processes seem to dominate at large scale

**Habitat**
- Area
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**Parallel effects**
- drift
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**Genetic diversity**

**Species diversity**

**Causal effects**
- competition
- facilitation

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VARIATION OF SGDC PATTERNS: WHAT DO THEY REVEAL?

Brittany: 8 out of 9 positive SGDC
Intra-region: 1 out of 21 positive SGDC

Processes vary with scale
Neutral processes seem to dominate at large scale
Deterministic processes seem to play an important role at small scale

Genetic diversity
Species diversity

Causal effects
- competition
- facilitation

Parallel effects
- drift
- selection
- migration

Habitat
- Area
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Drift and migration act in parallel on both species and genetic diversity

> Conservation measures aiming at preserving an important diversity at both intra and inter specific levels should
Drift and migration act in parallel on both species and genetic diversity

>> Conservation measures aiming at preserving an important diversity at both intra and inter specific levels should

1) Reduce drift
e.g. by protecting large areas of kelp forests
IMPLICATIONS FOR PREDICTING THE FATE OF OUR MARINE FORESTS

Drift and migration act in parallel on both species and genetic diversity

>> Conservation measures aiming at preserving an important diversity at both intra and inter specific levels should:

1) Reduce drift
e.g. by protecting large areas of kelp forests

2) Promote migration
e.g. by reducing the impact of kelp harvesting on connectivity

Photo Wilfried Thomas
**Implications for predicting the fate of our marine forests**

*L. digitata* populations at their southern range limit are vulnerable to climate change. Conservation measures aiming at preserving those populations should be strict to maintain them as well as the rich community living beneath their canopy.
**Implications for Predicting the Fate of Our Marine Forests**

*L. digitata* populations at their southern range limit are vulnerable to climate change

>> Conservation measures aiming at preserving those populations should be strict to maintain them as well as the rich community living beneath their canopy

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*L. digitata* in Southern Brittany
Low genetic diversity
Alteration of reproduction
**Implications for Predicting the Fate of Our Marine Forests**

*L. digitata* populations at their southern range limit are vulnerable to climate change

>> Conservation measures aiming at preserving those populations should be strict to maintain them as well as the rich community living beneath their canopy

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**L. digitata** in Southern Brittany
Low genetic diversity
Alteration of reproduction

---

**Sacchorhiza polyschides** in Southern Portugal
Low density
Low connectivity
(Assis et al. 2014)
The relative importance of neutral and deterministic processes seem to vary across scales. A better understanding of how the different processes vary across scales would help to improve the robustness of conservation measures.
The relative importance of neutral and deterministic processes seem to vary across scales.

>> A better understanding of how the different processes vary across scales would help to improve the robustness of conservation measures.

Disentangling the processes of community assembly across scales with ecophylogenetics (Kraft & Ackerly 2010; Mouquet et al. 2012; Cadotte et al. 2013)
The relative importance of neutral and deterministic processes seem to vary across scales.

A better understanding of how the different processes vary across scales would help to improve the robustness of conservation measures.

Disentangling the processes of community assembly across scales with ecophylogenetics (Kraft & Ackerly 2010; Mouquet et al. 2012; Cadotte et al. 2013)

Phylogenies

Species traits
Construction of a species trait database for European seaweed species (EMODnet project)

Le Gall et al. 2010
Verbruggen et al. 2010
Silberfeld et al. 2011

Distribution
Habitat
Life -history
Morpho-functionality