



Are ground-dwelling and flying beetles distinctly influenced by the structural and the compositional heterogeneity of the boreal forest ?

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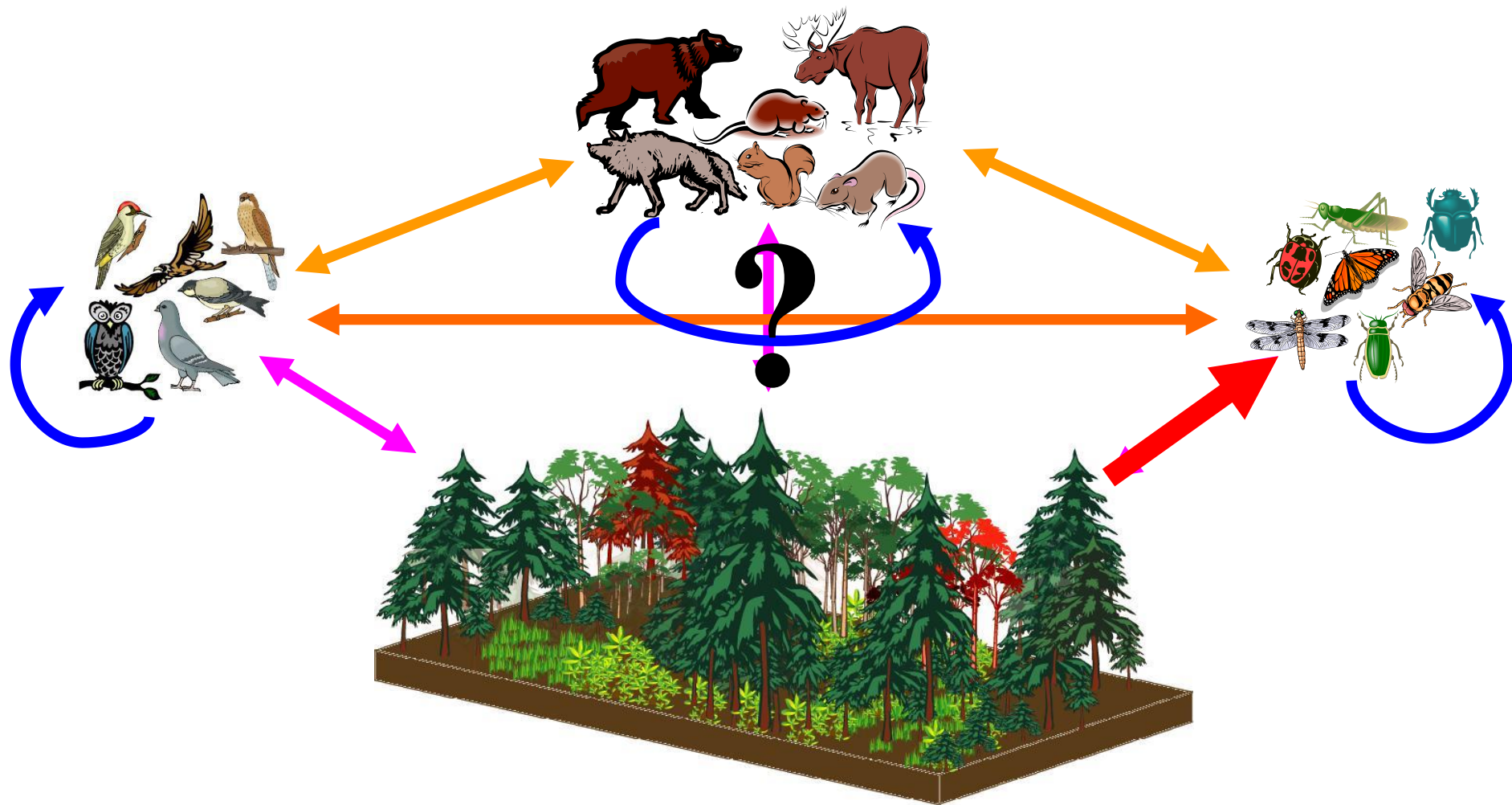
Introduction



CCMF, 1995, 2003; CSNF, 1998, 2003; Ministère des Ressources Naturelles, 1996; Nilsson et al., 2005



Introduction



Nilsson et al., 2001; Thompson et al., 2003

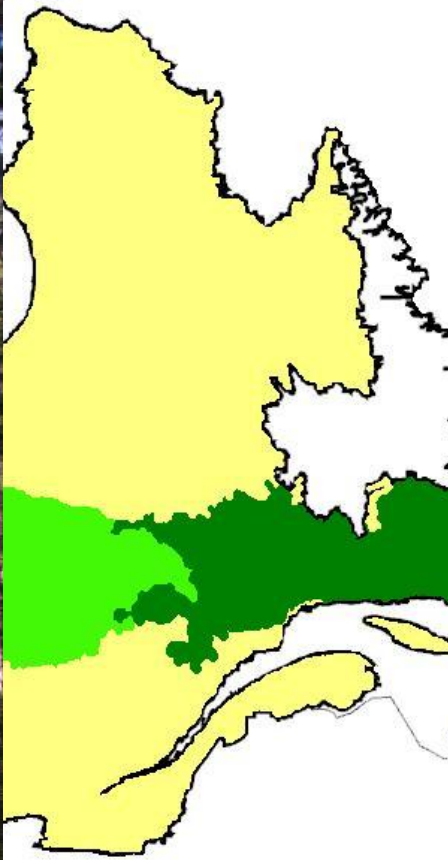


Understanding the influence of habitat heterogeneity at multiple spatial scales on beetle richness

- Is there a type of heterogeneity that has greater influence on species richness?
- At which spatial scale, from stand to landscape, does heterogeneity have the greatest influence on beetle richness?



Western spruce-moss



Eastern spruce-moss



Regular structure

Irregular structure

Bergeron et al., 2003; Bohlman et al., 2004





A favourable area to study how habitat heterogeneity
shapes biodiversity patterns in the boreal forest

Nilsson et al., 2001; Thompson et al., 2003



Insects = 80% of the animal diversity

In forest ecosystems, beetles are:

- well-represented
- most diversified
- well-known



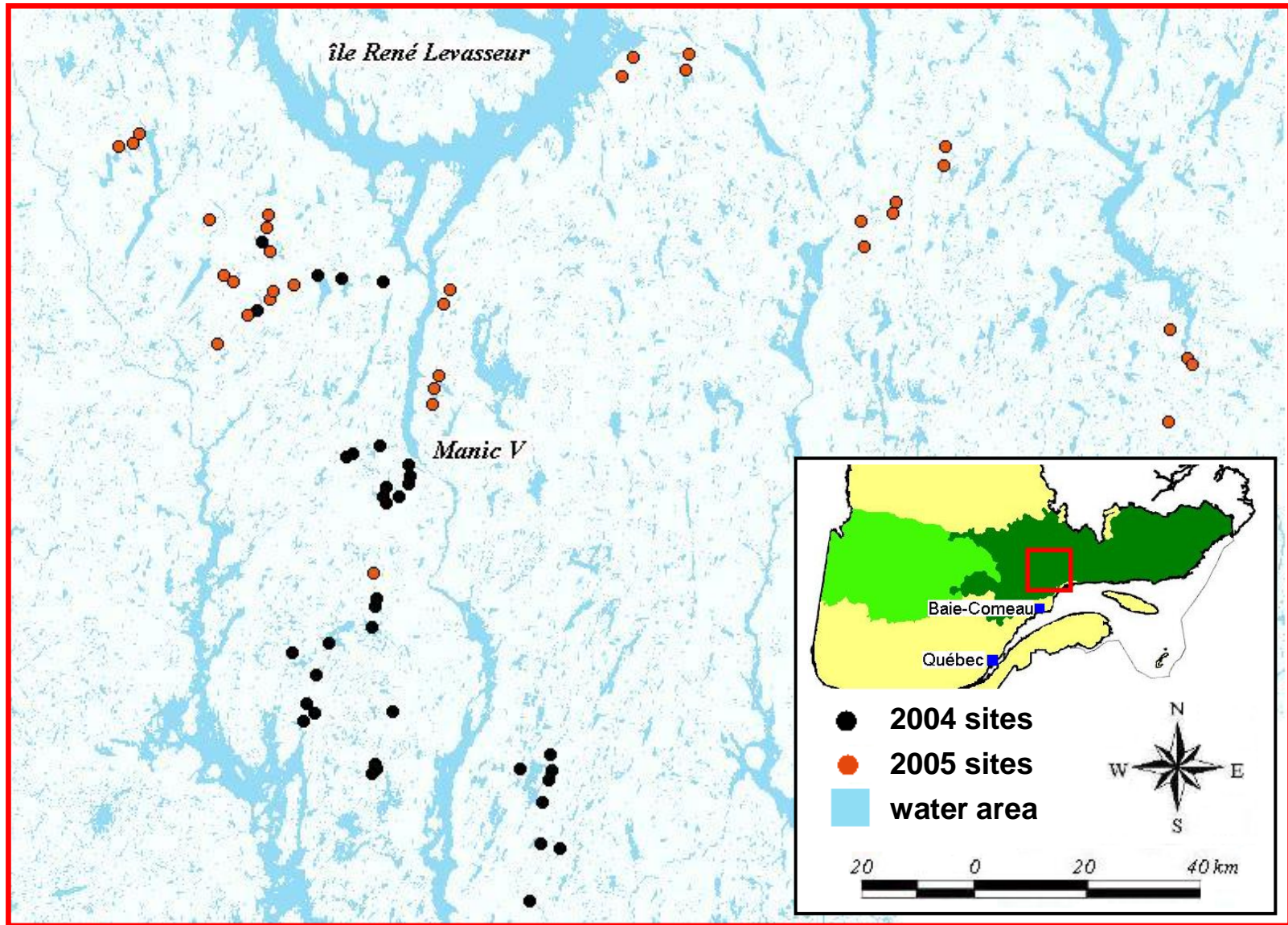
Habitat heterogeneity is rather poorly documented:

- beetles
- natural ecosystems

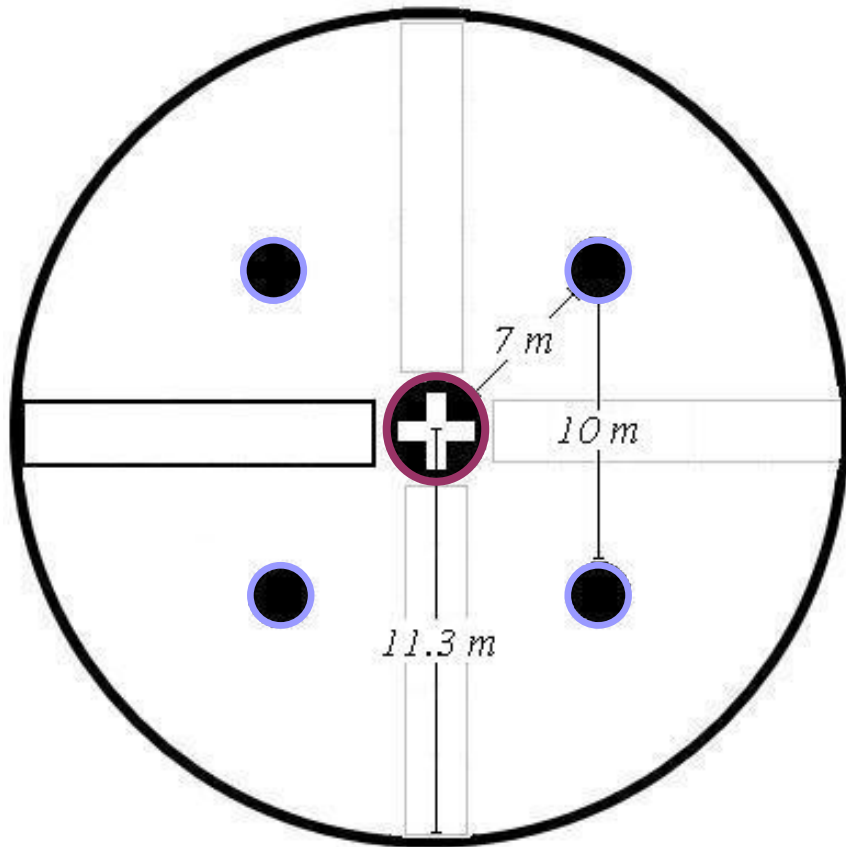
Zerm et al., 2001; Brose, 2003; LaSaus et al., 2004

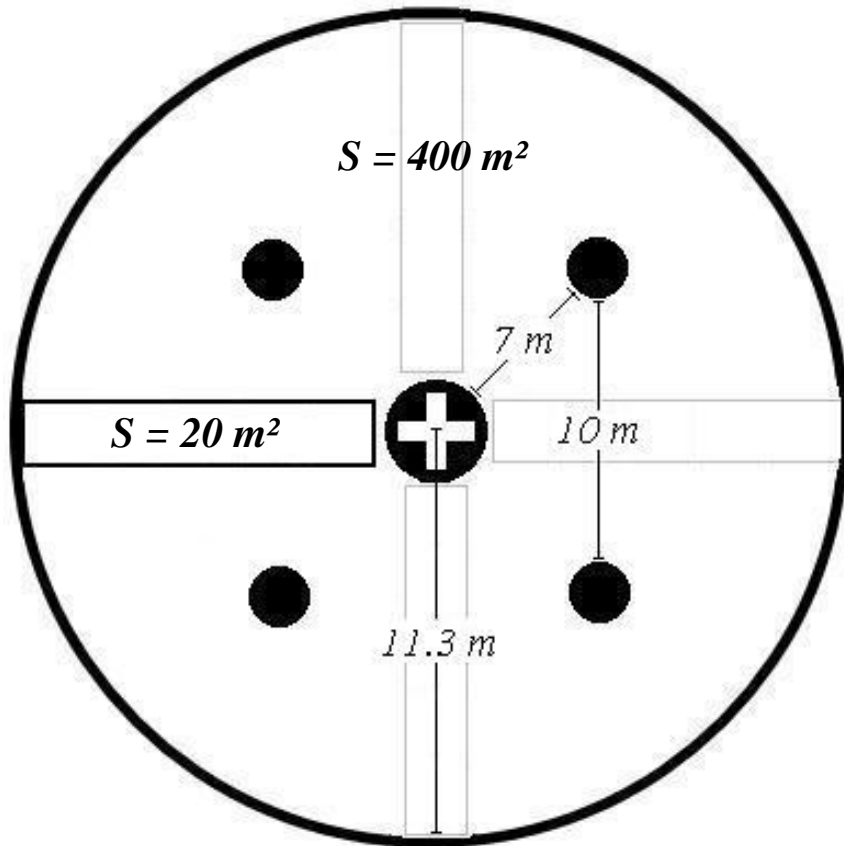


Methods: experimental design



Methods: experimental design





Attributes

- Steam ≥ 9 cm DBH
- CWD ≥ 9 cm base
- Steam < 9 cm DBH



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Habitat heterogeneity hypothesis

Habitat heterogeneity hypothesis = recognized as fundamental to the study of **species richness - heterogeneity** relationship



MacArthur et MacArthur, 1961



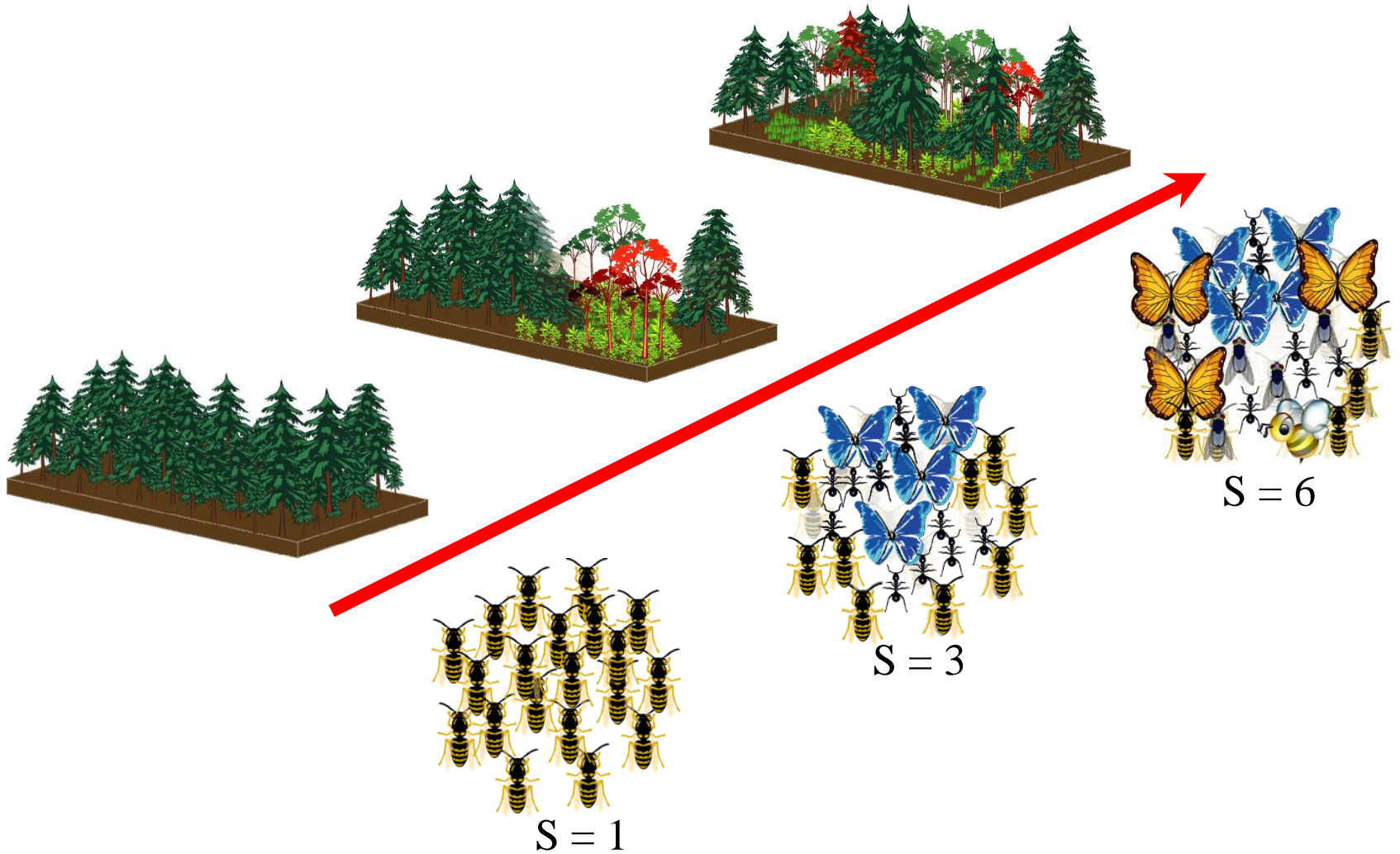
Habitat heterogeneity hypothesis



Lawton, 1983; Meko, 1970; Beal, 1961; Elser & Bazzaz, 1974



Habitat heterogeneity hypothesis



MacArthur et MacArthur, 1961; Downing 1991; Huston, 1994; Kuuluvainen 2001



Heterogeneity influences species at many scales



The study of biodiversity patterns should include two or more scales

Wiens 1989; Niemelä 1990, 1997; McLaughlin et Roughgarden 1993; Roslin 1999; Hamer et Hill 2000;
e.g. Niemelä et al 1996; Salzman et al 2000; Gros 2000; Mouch, Magara et al; Hoban et al 2005



The habitat heterogeneity hypothesis



Structural heterogeneity indices

- of standing trees
 - S = richness of diameter class
- of coarse woody debris
 - S = richness of diameter class



Compositional heterogeneity indices

- of standing trees
 - S = richness of trees species
- of coarse woody debris
 - S = richness of trees species

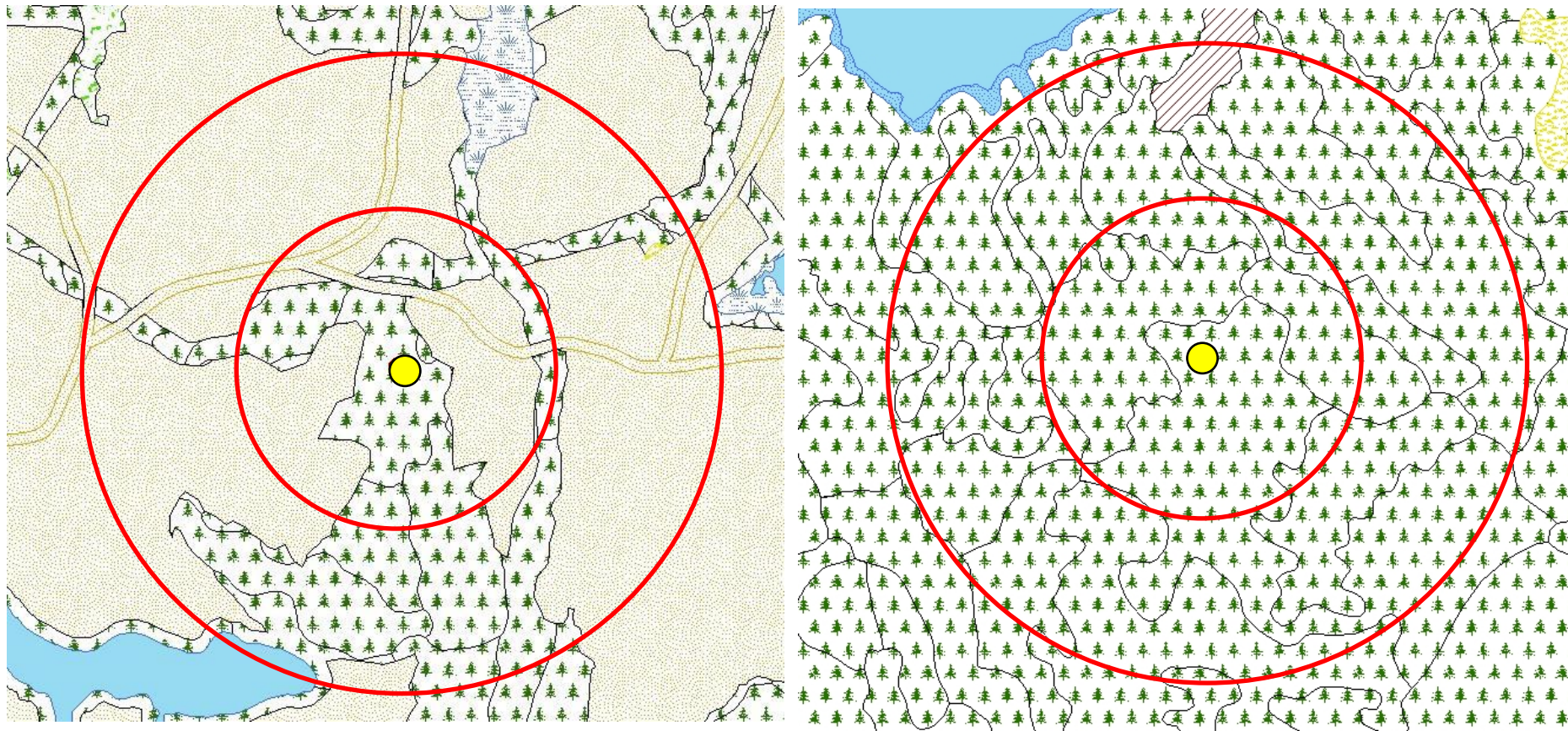


- 4 heterogeneity indices;
- 8 variables associated with dominant attributes:








| | Basal area | composition | volume |
|------------------------|------------|-------------|--------|
| black spruce | X | X | X |
| balsam fire | X | X | X |
| steam: 9 < DBH < 20 cm | X | X | X |
| steam: DBH > 20cm | X | X | X |



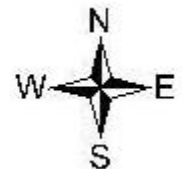
Landscape scale

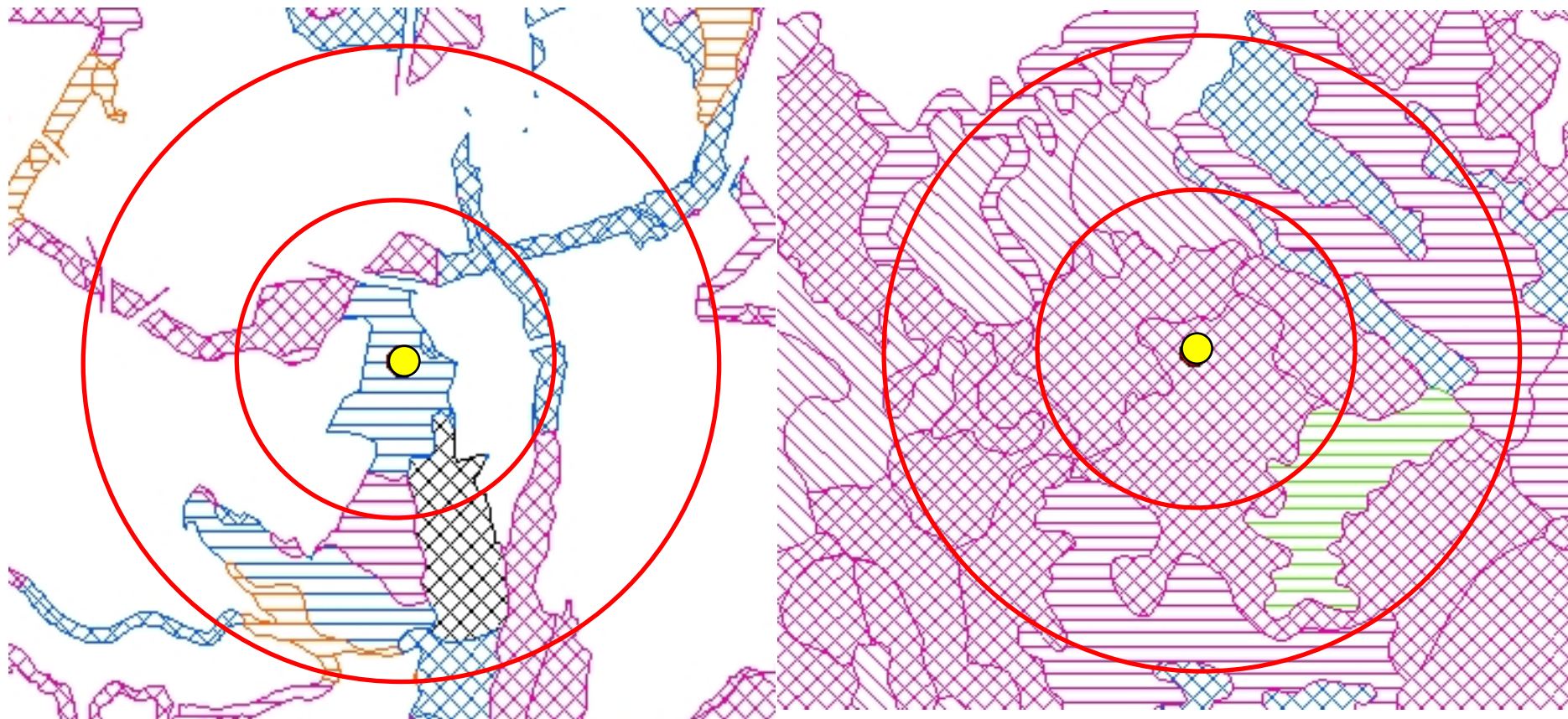


Légende

- | | | | |
|--|---|--|---|
|  Eau |  Denude Humide |  Resineux |  Coupe |
|  Inondable |  Denude Sec |  Chablis totale | |

0 105 210 420 630 Mètres





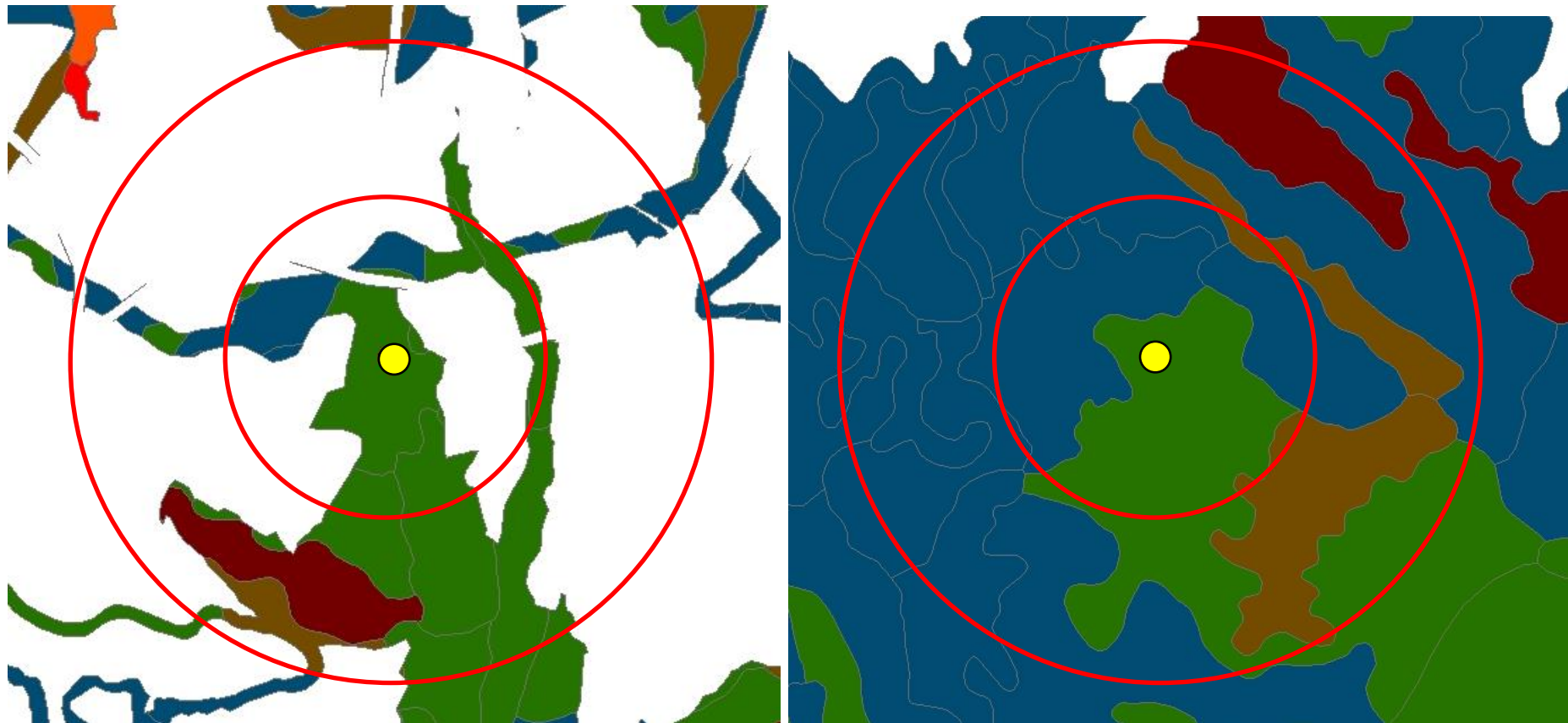
Légende

| | | | | | | | | | |
|--|-------|--|-------|--|--------|--|--------|--|--------|
| | EqJ_A | | EqV_A | | InqJ_A | | InqV_A | | EtgJ_C |
| | EqJ_B | | EqV_B | | InqJ_B | | InqV_B | | EtgJ_D |
| | EqJ_C | | EqV_C | | InqJ_C | | InqV_C | | |
| | EqJ_D | | EqV_D | | InqJ_D | | InqV_D | | |

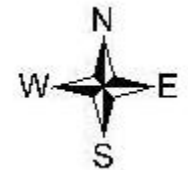
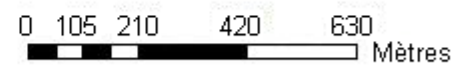
0 105 210 420 630 Mètres



Landscape scale: composition



Légende



- 2 heterogeneity indices;
- 4 variables associated with dominant attributes:

| | area | |
|------------------------------|-------|-------|
| | 400 m | 800 m |
| spruce stand (EE) | X | X |
| balsam fire stand (ES+SE+SS) | X | X |
| old even-aged stand | X | X |
| old uneven-aged stand | X | X |

composition

structure





| Models | Delta AICc | Akaike weights |
|---|------------|----------------|
| latitude spstand sabstand essence ₄₀₀ SX ₄₀₀ | 0.0 | 0.587 |
| latitude spstand sabstand | 2.2 | 0.194 |
| latitude spstand epnstand sabstand | 2.9 | 0.139 |
| latitude spstand sabstand essence ₈₀₀ SX ₈₀₀ | 5.6 | 0.036 |
| latitude spstand epnstand sabstand essence ₈₀₀ ee ₈₀₀ SX ₈₀₀ | 7.4 | 0.014 |



| Models | Delta AICc | Akaike weights |
|--|------------|----------------|
| latitude spstand ststand epnstand tigesmoy | 0.0 | 0.199 |
| latitude spstand ststand essence ₄₀₀ structure ₄₀₀ | 0.1 | 0.191 |
| latitude spstand ststand stlog essence ₄₀₀ structure ₄₀₀ | 0.9 | 0.129 |
| latitude spstand epnstand | 2.1 | 0.070 |
| latitude spstand ststand | 2.3 | 0.063 |



| Variables | |
|--------------|------------|
| latitude | + |
| spstand | + |
| sabstand | + |
| epnstand | - |
| ststand | |
| tigesmoy | |
| splog | |
| stlog | |
| cwdmoy | |
| cwdgros | |
| essence(i) | +400 & 800 |
| sx(i) | -400 + 800 |
| ee(i) | |
| structure(i) | |



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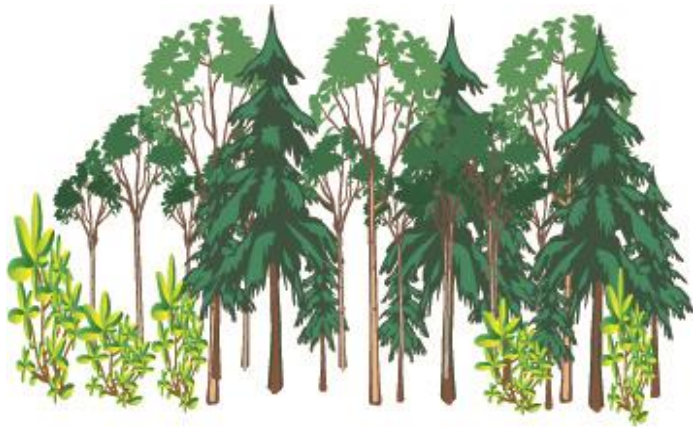
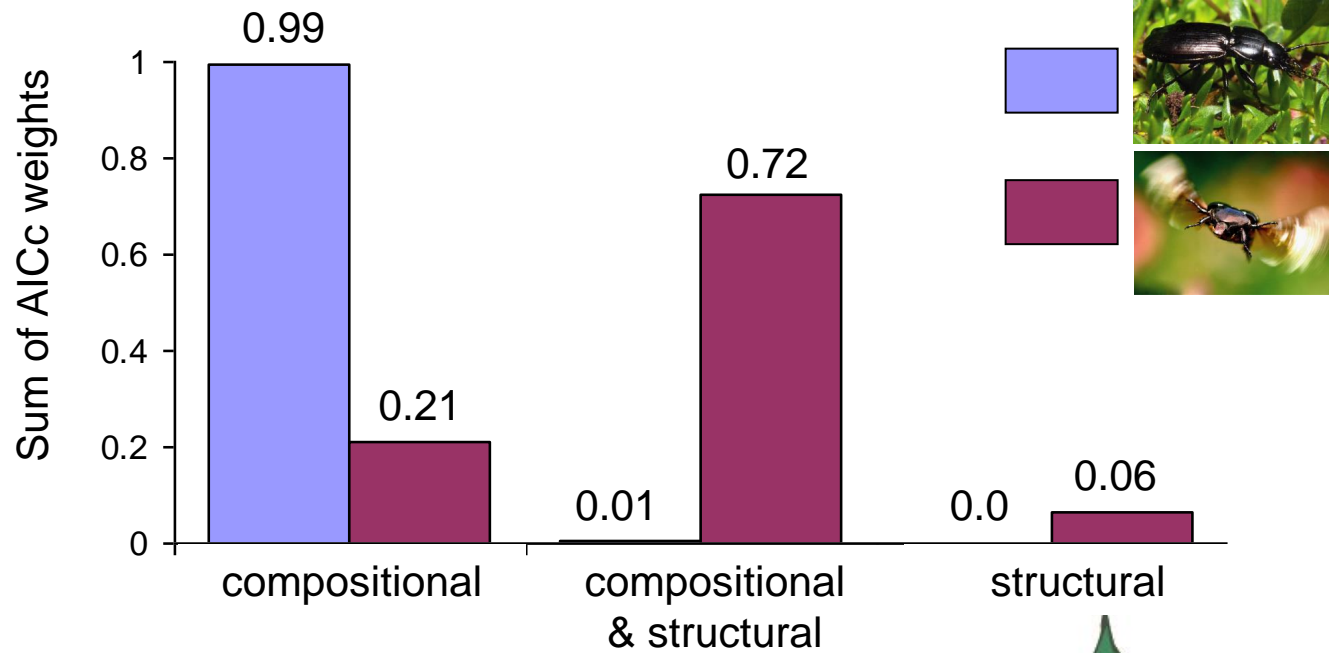


Structural vs compositional heterogeneity

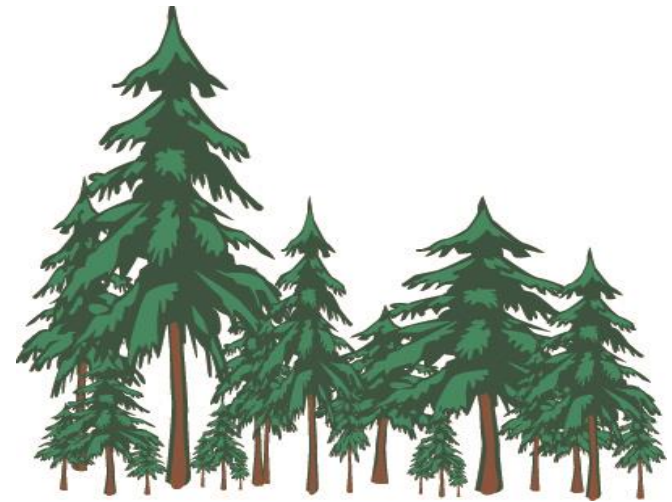
| Dep. var. | Models | K | Δ AICc | AICc weight |
|----------------------|---|---|---------------|-------------|
| S_{pitfall} | latitude spstand sabstand essence ₄₀₀ sx ₄₀₀ | 6 | 0.00 | 0.5493 |
| S_{pitfall} | latitude spstand sabstand | 4 | 2.04 | 0.1984 |
| S_{pitfall} | latitude spstand epnstand sabstand | 5 | 2.52 | 0.1561 |
| S_{pitfall} | latitude spstand sabstand essence ₈₀₀ sx ₈₀₀ | 6 | 5.38 | 0.0374 |
| S_{pitfall} | latitude epnstand sabstand | 4 | 6.42 | 0.0221 |
| S_{pitfall} | latitude spstand epnstand sabstand essence ₈₀₀ ee ₈₀₀ sx ₈₀₀ | 8 | 7.06 | 0.0161 |
| S_{pitfall} | latitude spstand epnstand essence ₄₀₀ ee ₄₀₀ | 6 | 7.93 | 0.0104 |
| S_{pitfall} | latitude spstand sabstand essence ₈₀₀ sx ₈₀₀ | 6 | 9.42 | 0.0050 |
| S_{pitfall} | latitude spstand ststand essence ₄₀₀ structure ₄₀₀ | 6 | 11.48 | 0.0018 |
| S_{pitfall} | latitude spstand ststand epnstand tigesmoy | 6 | 11.52 | 0.0017 |
| S_{pitfall} | latitude spstand ststand stlog essence ₄₀₀ structure ₄₀₀ | 7 | 13.46 | 0.0007 |
| S_{pitfall} | latitude spstand ststand splog essence ₄₀₀ structure ₄₀₀ | 7 | 13.74 | 0.0006 |
| S_{pitfall} | latitude spstand splog essence ₄₀₀ | 5 | 16.22 | 0.0002 |
| S_{pitfall} | latitude tigesmoy tigesgros | 4 | 17.09 | 0.0001 |
| S_{pitfall} | latitude spstand ststand | 4 | 18.37 | 0.0001 |
| S_{pitfall} | latitude spstand epnstand | 4 | 19.24 | 0.0000 |
| S_{pitfall} | latitude spstand ststand stlog | 5 | 19.88 | 0.0000 |
| S_{pitfall} | latitude tigesmoy tigesgros eqv ₄₀₀ inqv ₄₀₀ | 6 | 20.15 | 0.0000 |
| S_{pitfall} | latitude spstand ststand splog | 5 | 20.36 | 0.0000 |
| S_{pitfall} | latitude tigesmoy tigesgros eqv ₈₀₀ inqv ₈₀₀ | 6 | 21.48 | 0.0000 |
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| S_{pitfall} | latitude essence ₄₀₀ structure ₄₀₀ | 4 | 21.72 | 0.0000 |
| S_{pitfall} | latitude spstand epnstand essence ₈₀₀ ee ₈₀₀ | 6 | 21.73 | 0.0000 |
| S_{pitfall} | latitude ststand stlog | 4 | 22.30 | 0.0000 |
| S_{pitfall} | latitude essence ₄₀₀ structure ₄₀₀ ee ₄₀₀ eqv ₄₀₀ | 6 | 22.46 | 0.0000 |
| S_{pitfall} | latitude ststand tigesmoy | 4 | 22.65 | 0.0000 |
| S_{pitfall} | latitude spstand ststand stlog essence ₈₀₀ structure ₈₀₀ | 7 | 22.73 | 0.0000 |
| S_{pitfall} | latitude ststand cwdmoy | 4 | 22.78 | 0.0000 |
| S_{pitfall} | latitude ststand cwdgros | 4 | 22.95 | 0.0000 |
| S_{pitfall} | latitude ststand stlog structure ₈₀₀ | 5 | 23.11 | 0.0000 |
| S_{pitfall} | latitude spstand ststand splog essence ₈₀₀ structure ₈₀₀ | 7 | 23.23 | 0.0000 |
| S_{pitfall} | latitude ststand stlog structure ₄₀₀ | 5 | 23.28 | 0.0000 |
| S_{pitfall} | latitude spstand splog essence ₈₀₀ | 5 | 24.20 | 0.0000 |
| S_{pitfall} | latitude ststand tigesmoy cwdmoy | 5 | 24.83 | 0.0000 |
| S_{pitfall} | latitude spstand splog | 4 | 25.58 | 0.0000 |
| S_{pitfall} | latitude essence ₈₀₀ structure ₈₀₀ | 4 | 30.75 | 0.0000 |
| S_{pitfall} | latitude essence ₈₀₀ structure ₈₀₀ ee ₈₀₀ eqv ₈₀₀ | 6 | 31.67 | 0.0000 |



Structural vs compositional heterogeneity



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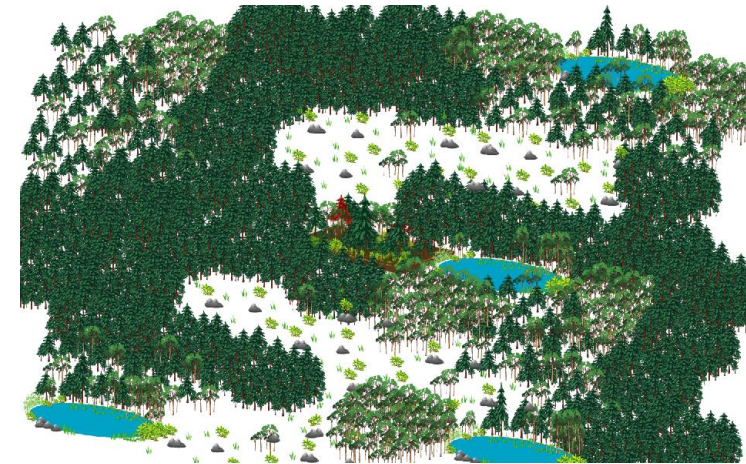
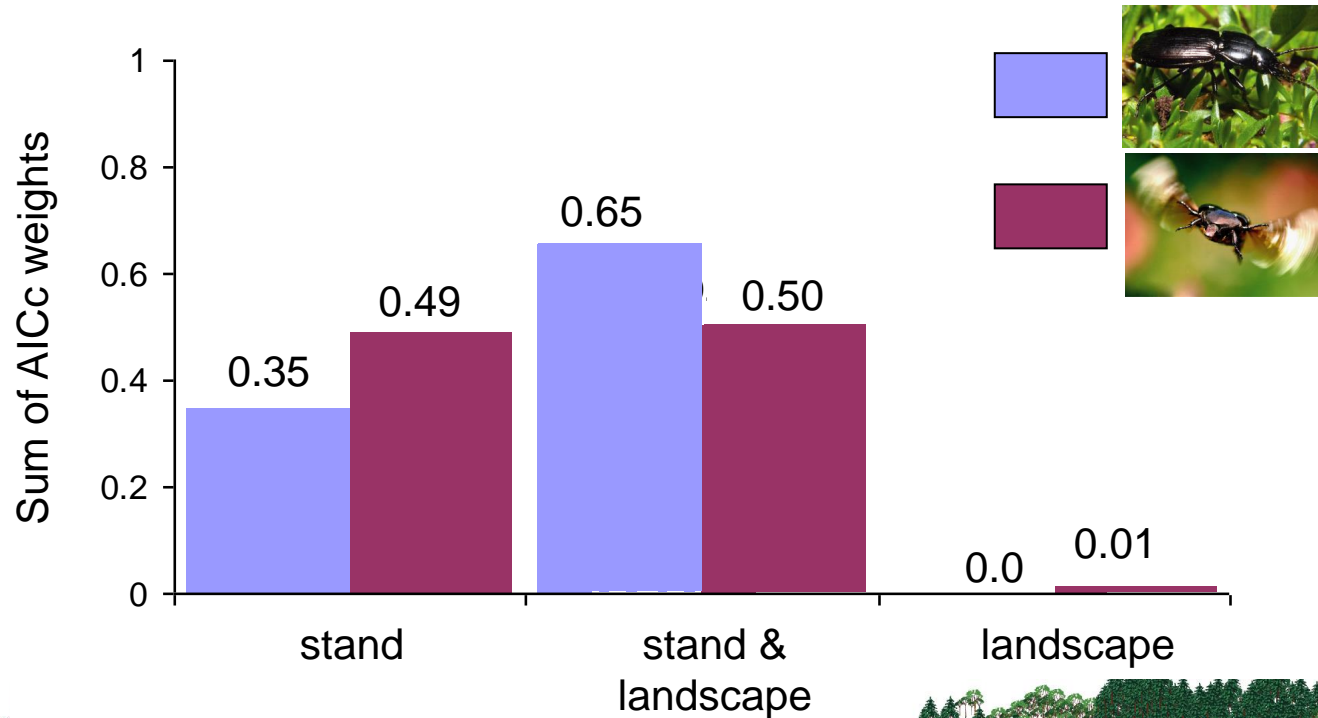


Stand vs landscape heterogeneity

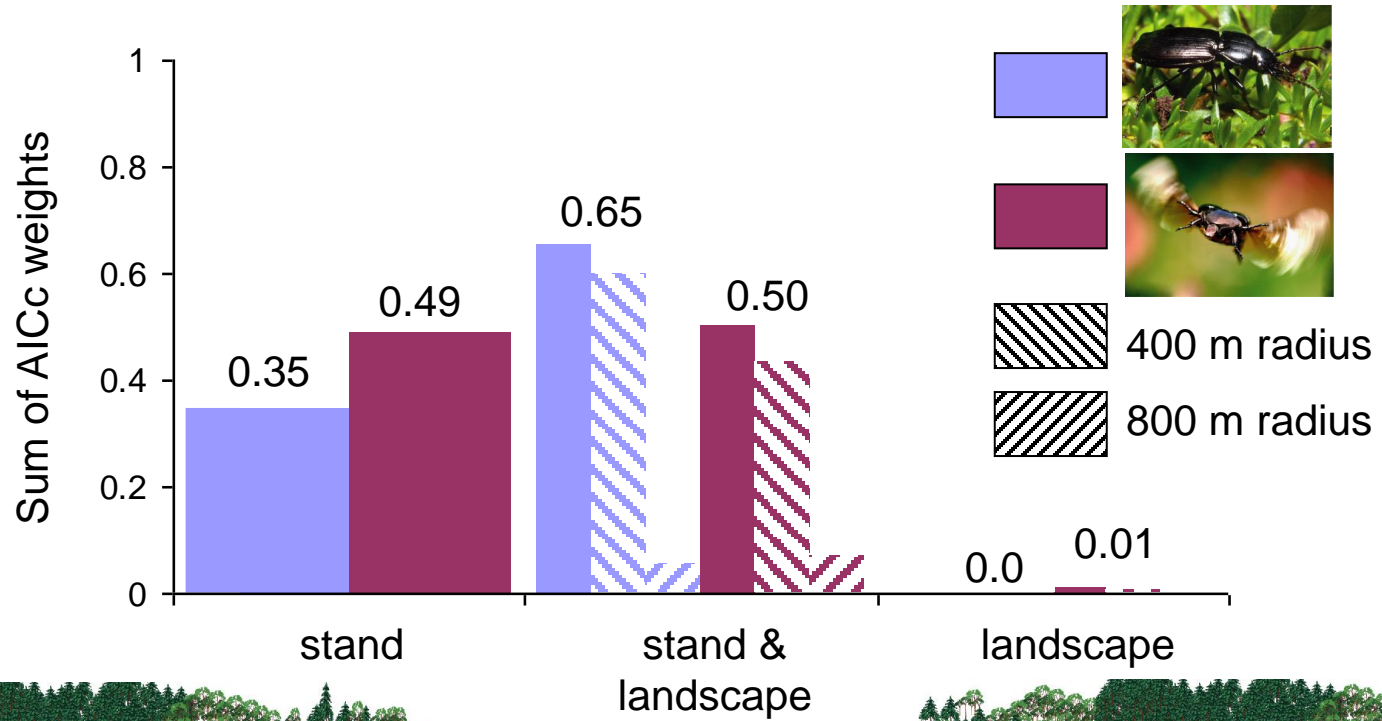
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Stand vs landscape heterogeneity



Stand vs landscape heterogeneity



>



Habitat heterogeneity hypothesis is relevant to explain beetle diversity patterns in boreal forest

Ground-dwelling and flying beetles are influenced by **different types of heterogeneity**



« The creation and/or maintenance of stand structural complexity is essential for biodiversity conservation in all forests... »

Lindenmayer et al., 2006.



Habitat heterogeneity hypothesis is relevant to explain beetle diversity patterns in boreal forest

Ground-dwelling and flying beetles are influenced by **different types of heterogeneity**

- composition > structure

Local scales explain most of the variation for both functional groups

- stand > landscape
- 400 > 800 m

The conservation of beetle diversity in the boreal forest of eastern Québec

would benefit from high **diversity of tree species** at the **stand level**

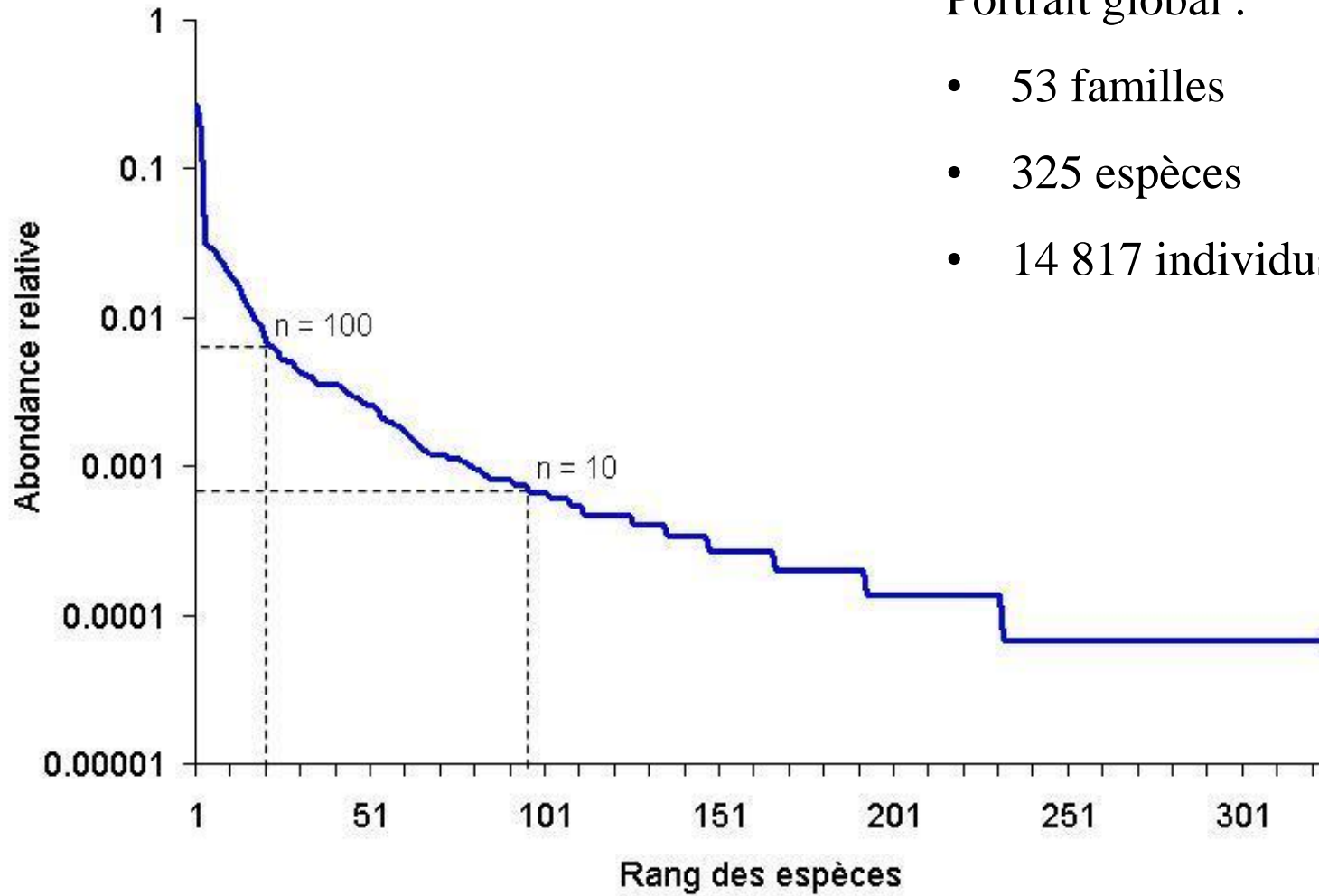


BRUGEROLLE Sophie, DUBUC Yves, ETCHEVERRY Pierre,
GERMAIN Carole, HODSON James, LEMAITRE Jérôme, MARQUIS
Valérie, PELLETIER George, PLANTE Isabelle... and many others.

Beetle pictures: www.koleopterologie.de



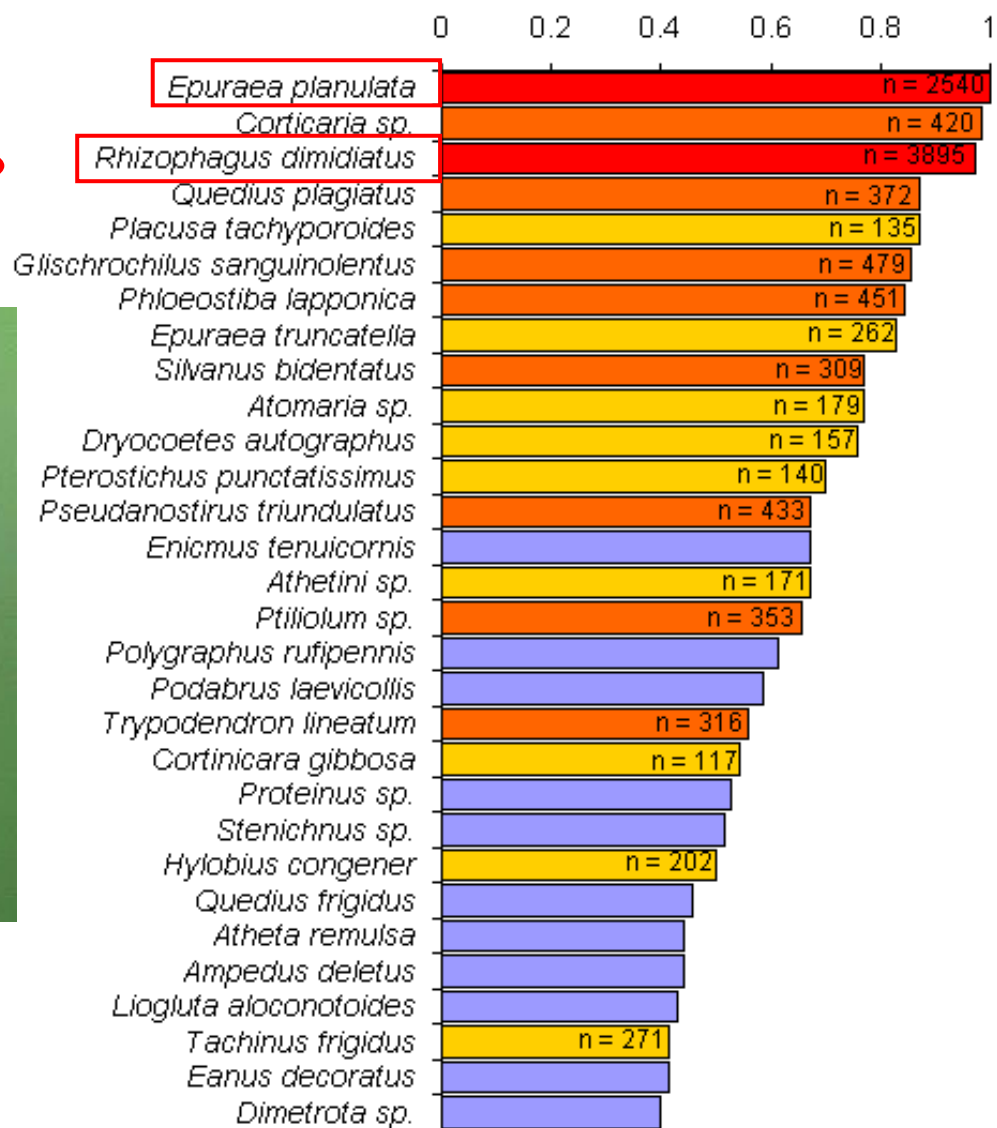
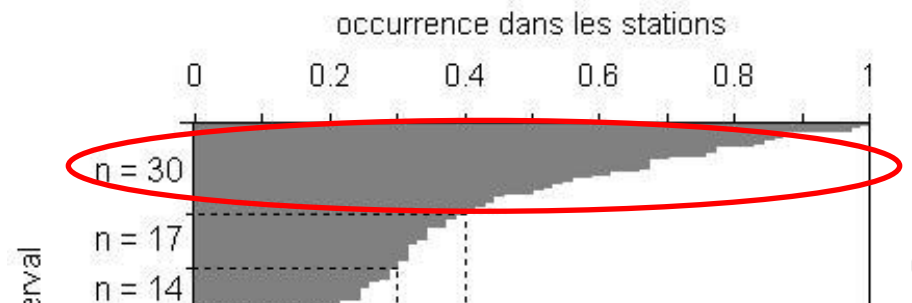


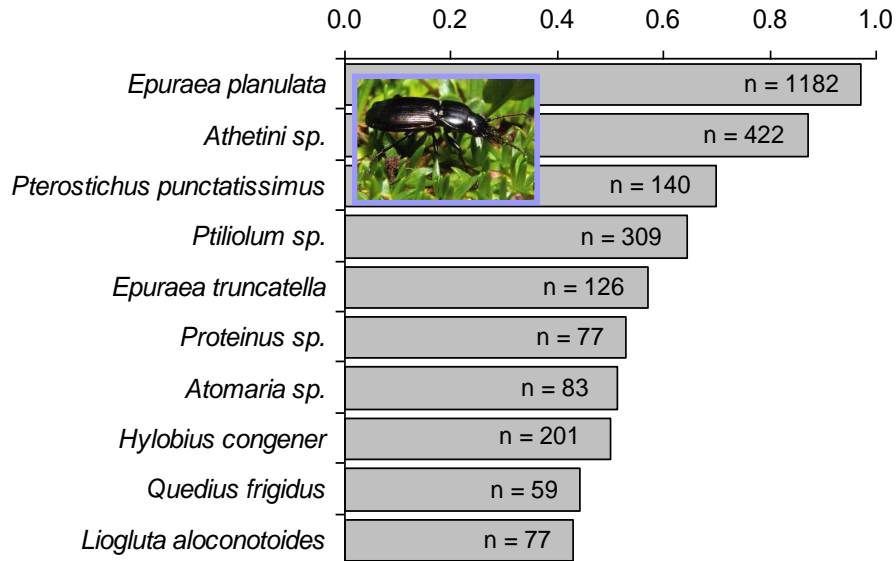


Portrait global :

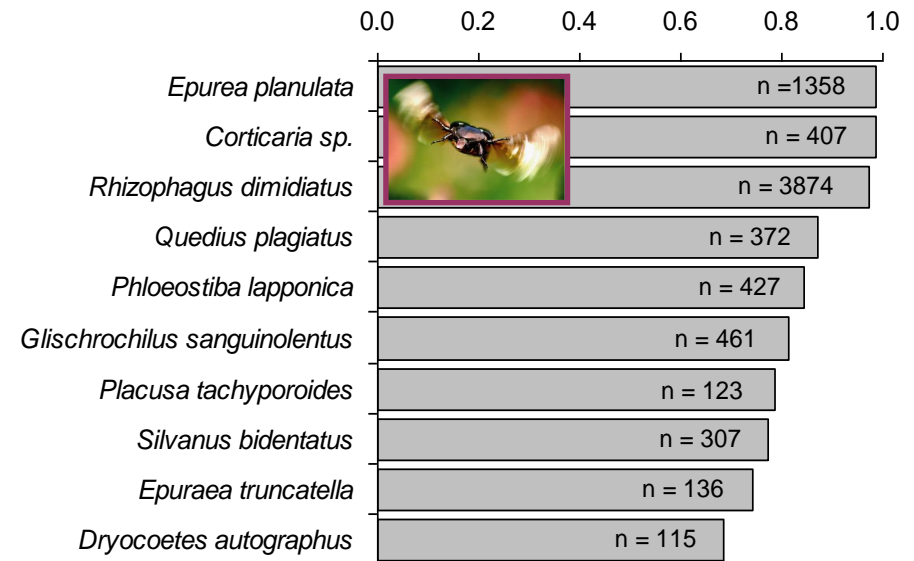
- 53 familles
- 325 espèces
- 14 817 individus







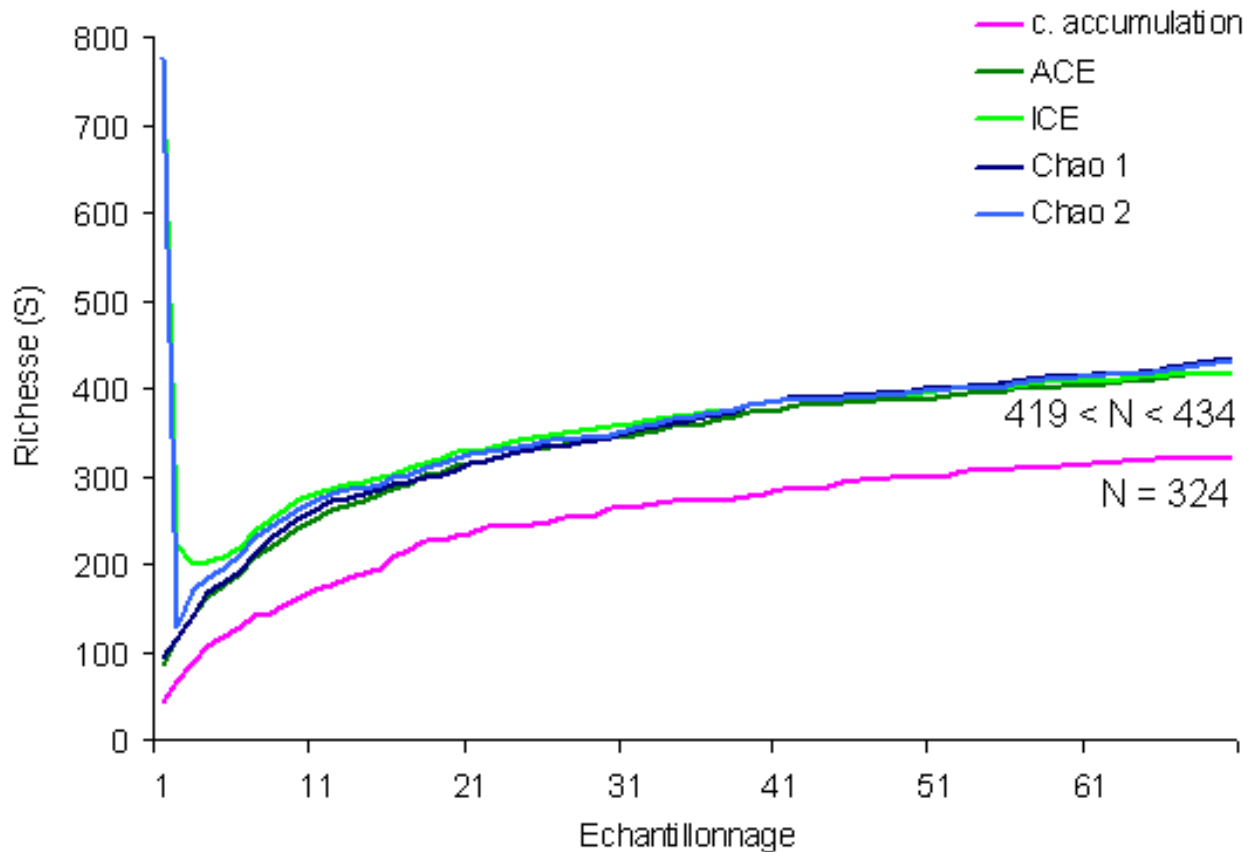
- 133 espèces
- 4 236 individus



- 251 espèces
- 10 583 individus



Notre échantillonnage est-il représentatif de la richesse totale en espèces de coléoptères forestiers de la Côte-Nord ???



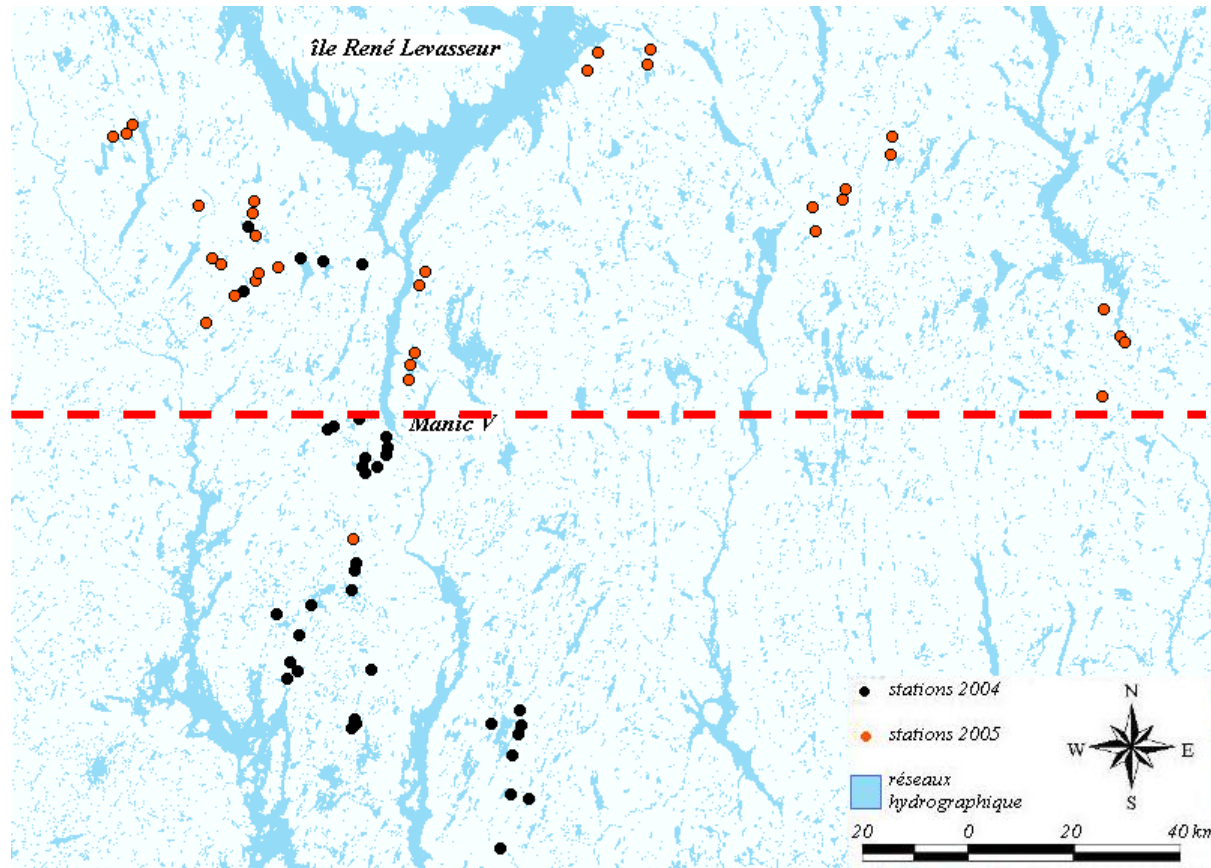
- 74.6 et 77.3% de la richesse totale;

Magurran, 2004; Colwell's, 2005



Autres variables :

- année ou latitude ???

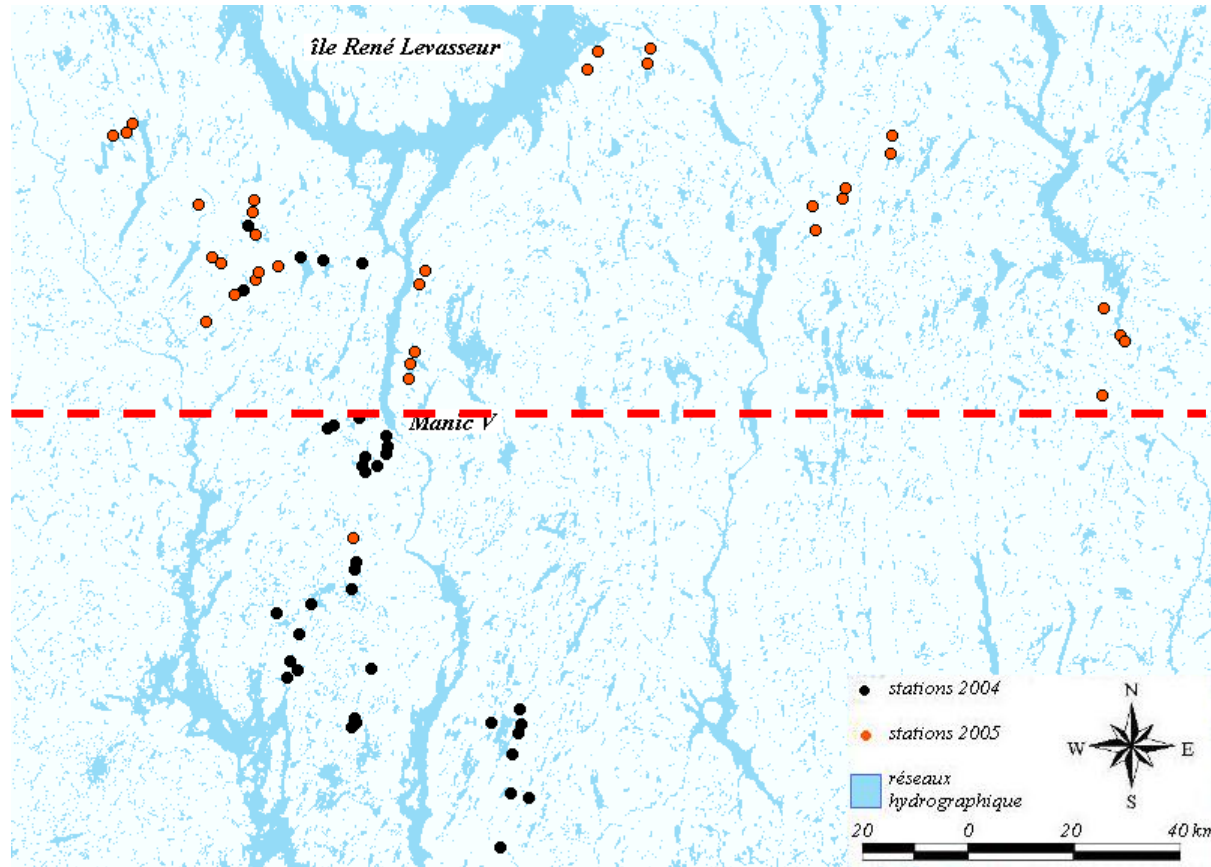


$r = 0.744$



Autres variables :

- ~~année~~ ou latitude



$r = 0.744$



Processus de construction des modèles :

- pour toutes les variables indépendantes, vérification :
 - distribution **homogène** des résidus
 - **normalité** dans la distribution des résidus

transformation $\sqrt{\quad}$ ou $\sqrt{x + 0.5}$ des variables associées aux attributs du peuplement

- construction **a priori** des modèles de régression multiple
- comparaison des modèles et sélection basée sur le **critère d'information d'Akaike**



Autres considérations :

- **ajustement** du modèle **complet**
- contrôle de la **multicollinéarité** (élimination des modèles avec indice VIF > 2)

Graham, 2003



Analyses d'autocorrélation spatiale



Étude **multi-échelles** implique un contrôle de l'**autocorrélation spatiale**

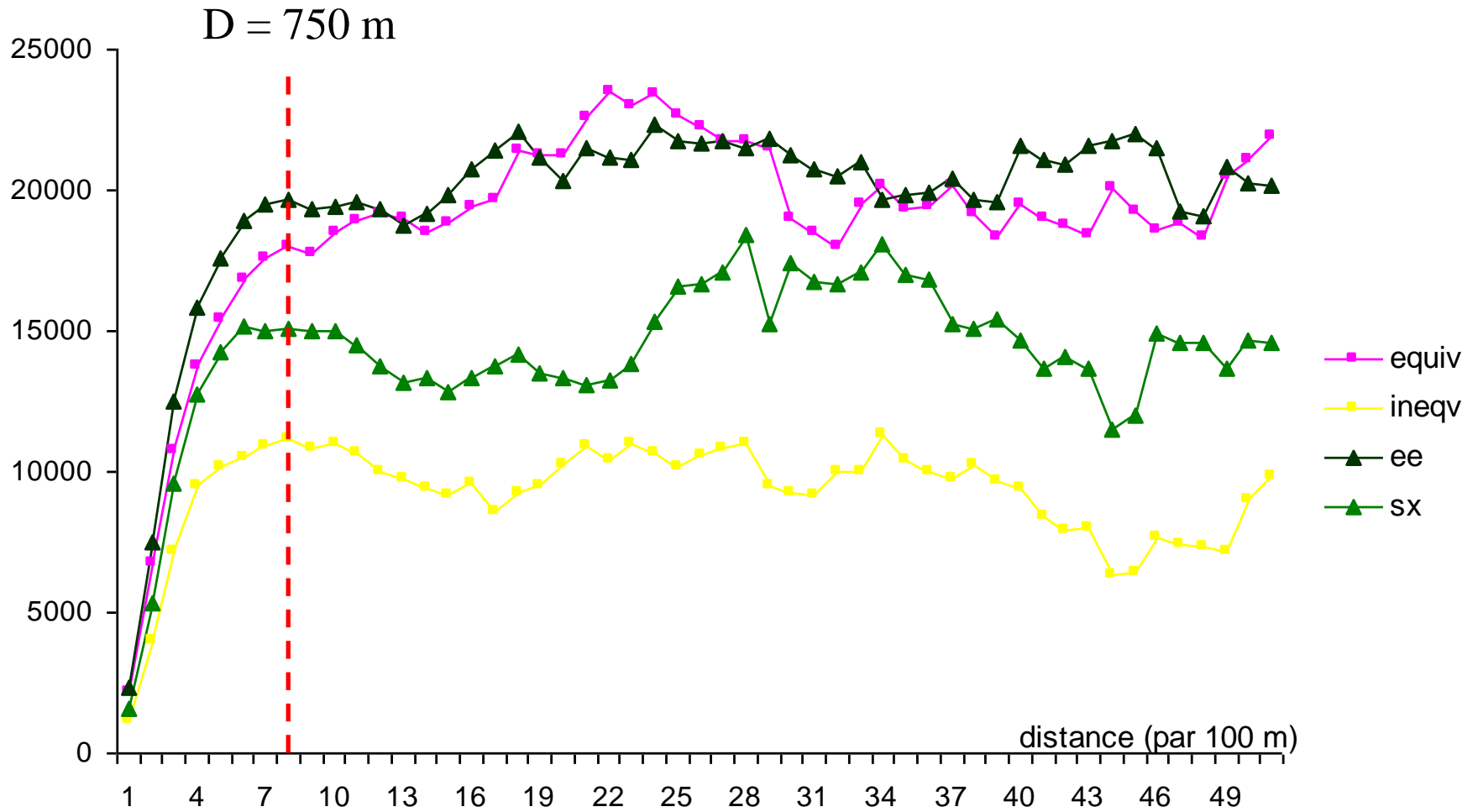
- distance minimale entre les stations = 2 km;
- forêt boréale irrégulière de la Côte-Nord : distance à partir de laquelle **l'hétérogénéité des valeurs est indépendante** de la localisation ???

Utilisation du **variogramme** pour nos variables du paysage

Lichstein et al, 2002; Diniz et al, 2003



Modéliser l'hétérogénéité de l'habitat

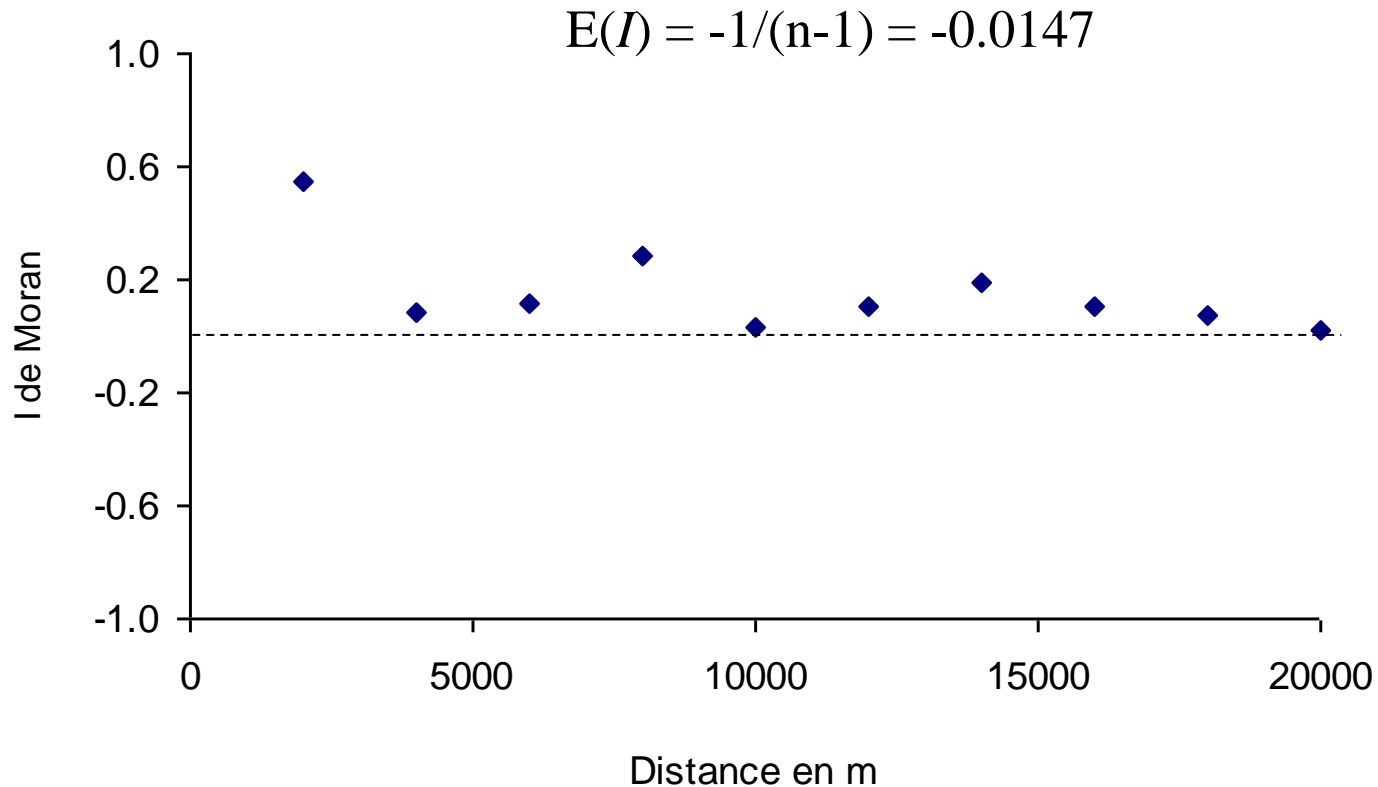


Étude **multi-échelles** implique un contrôle de l'**autocorrélation spatiale**

- distance minimale entre les stations = 2 km;
- forêt boréale irrégulière de la Côte-Nord : distance à partir de laquelle l'**hétérogénéité des valeurs est indépendante** de la localisation = **750 m**
- utilisation de l'indice ***I* de Moran** pour déterminer l'indépendance spatiale de la **richesse** et des **résidus** associés aux régressions multiples.



Correction de Bonferroni
 $= \alpha/k = 0.005$



Absence d'autocorrélation spatiale

