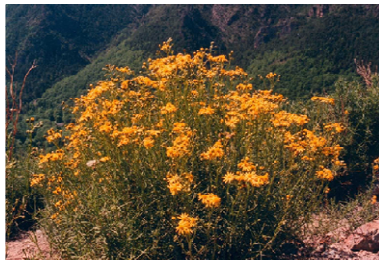
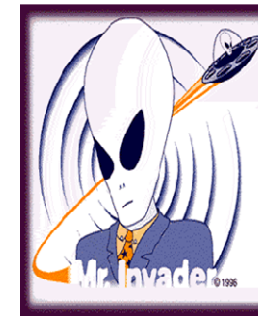


Rôle de l'évolution dans la prolifération des espèces

Arnaud Estoup ⁽¹⁾ et Ruth A. Hufbauer ^(1, 2)

⁽¹⁾ Centre de Biologie pour la Gestion des Populations (CBGP), INRA, France

⁽²⁾ Colorado State University, USA



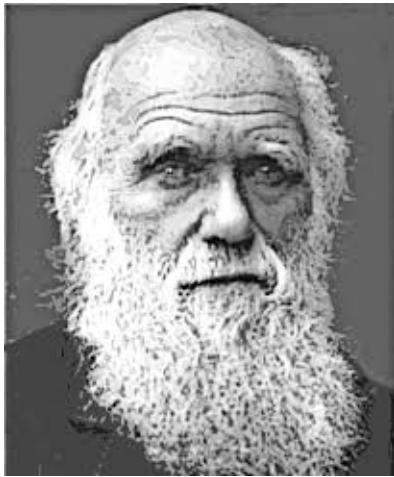
Introduction

- Les espèces qui pullulent
 - introduites
 - locales



- Mêmes processus sous-jacents?
- Cas des espèces introduites (envahissantes)

Le rôle de l'évolution dans la prolifération des espèces introduites est un sujet de recherche majeur des 20 dernières années



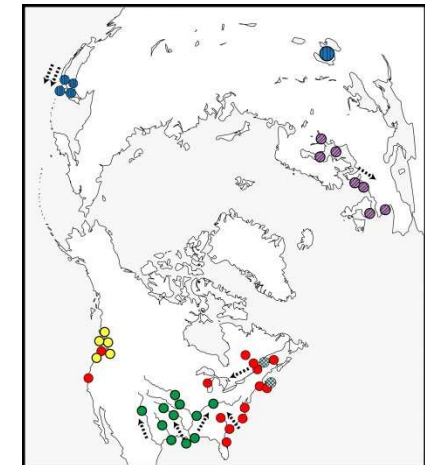
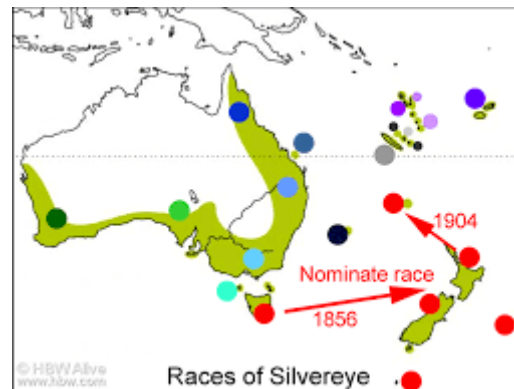
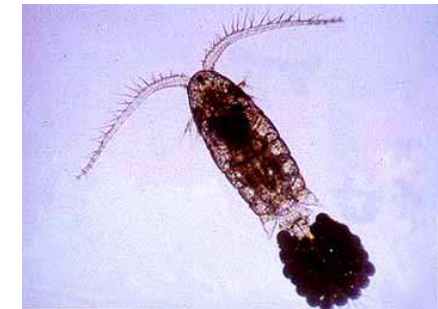
Pinsons de Darwin



Zosterops lateralis



Copépode marin *Eurytemora affinis*: invasions des eaux douces



Trois questions principales :

1/ Est-ce que l'évolution facilite les espèces à devenir envahissantes?

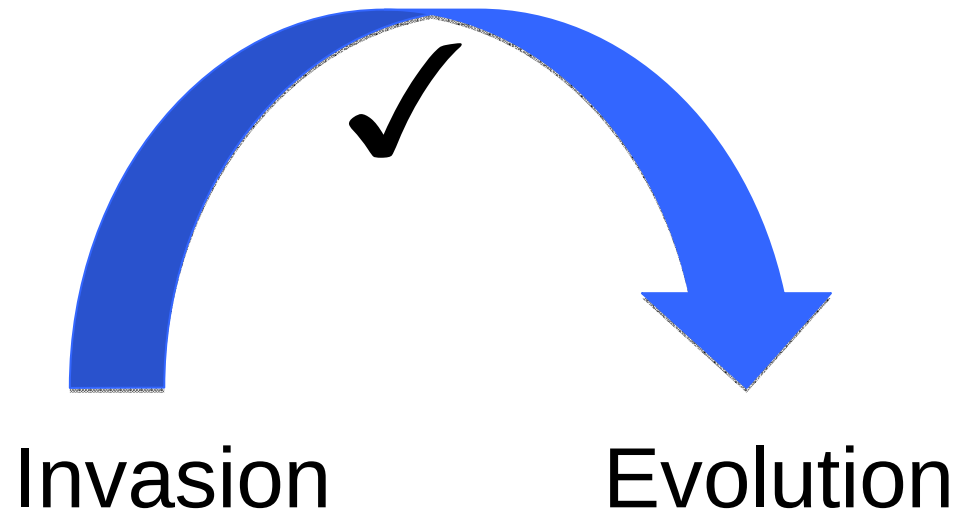
2/ Quel est le rôle de l'Homme dans les processus évolutifs liés aux invasions?

3/ Existe-t-il un paradoxe génétique chez les espèces envahissantes?

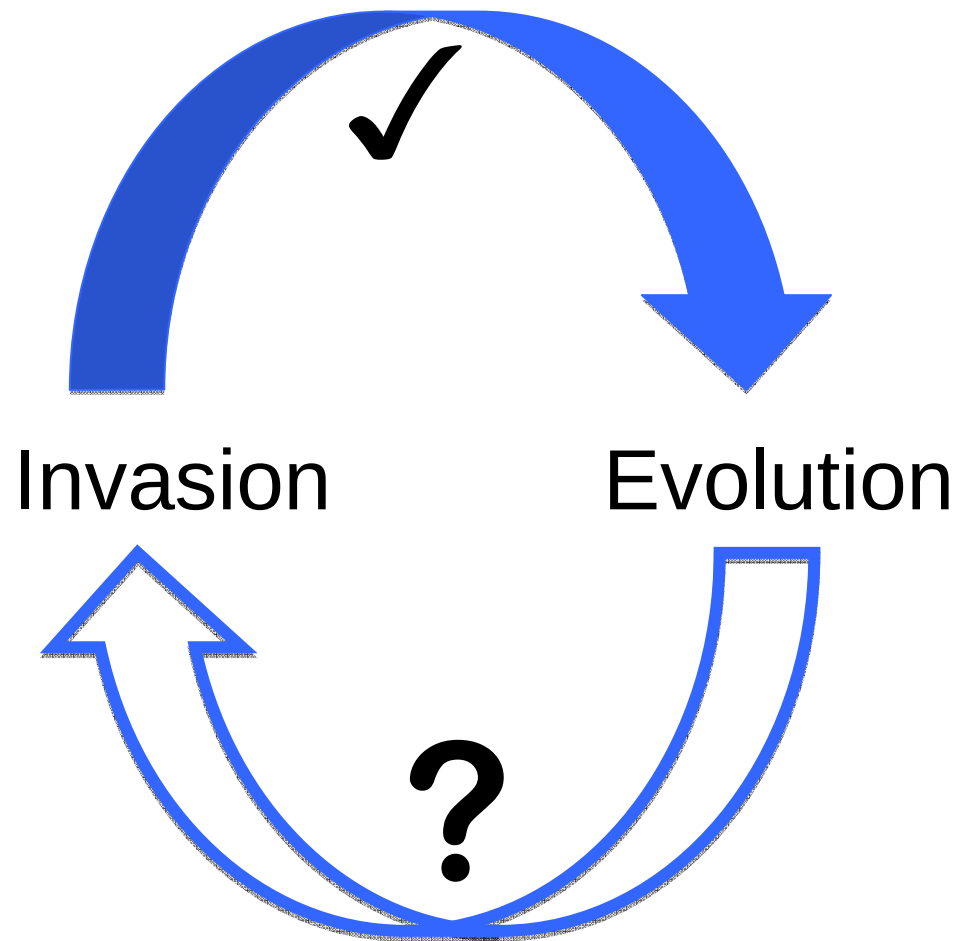
Question 1/: Est-ce que l'évolution facilite les espèces à devenir envahissantes?



Question 1/: Est-ce que l'évolution facilite les espèces à devenir envahissantes?



Question 1/: Est-ce que l'évolution facilite les espèces à devenir envahissantes?



Evolution adaptative facilite l'invasion si:

1/ La taille de population augmente

2/ La population s'étend plus rapidement dans l'espace

Espèce modèle : *Tribolium castaneum*

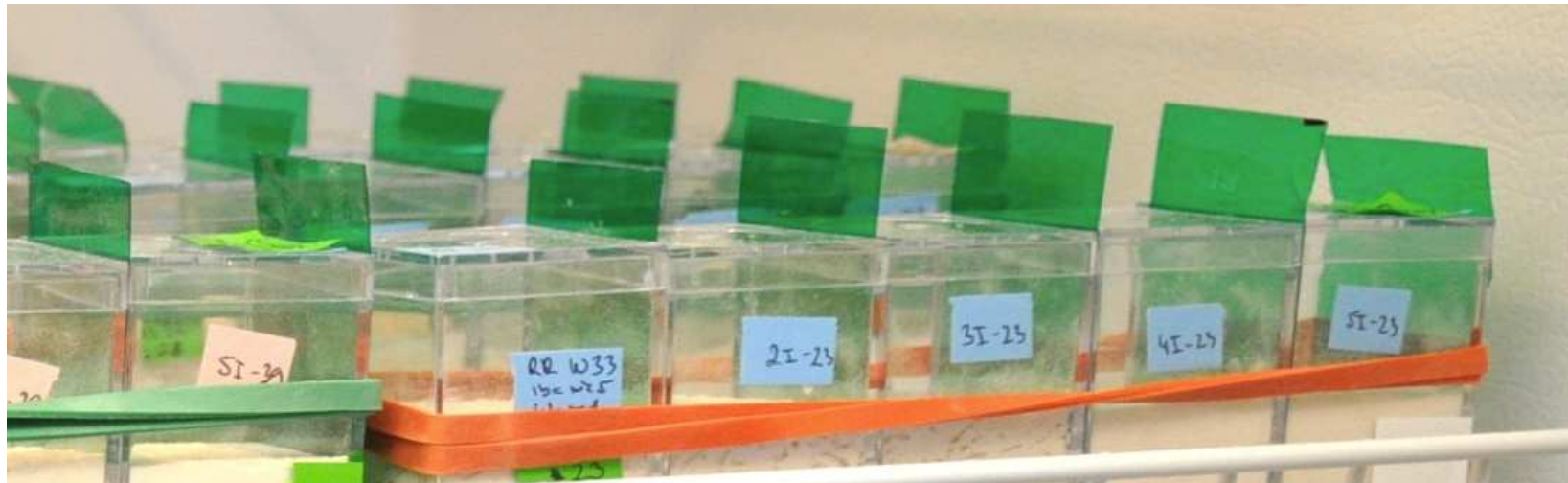


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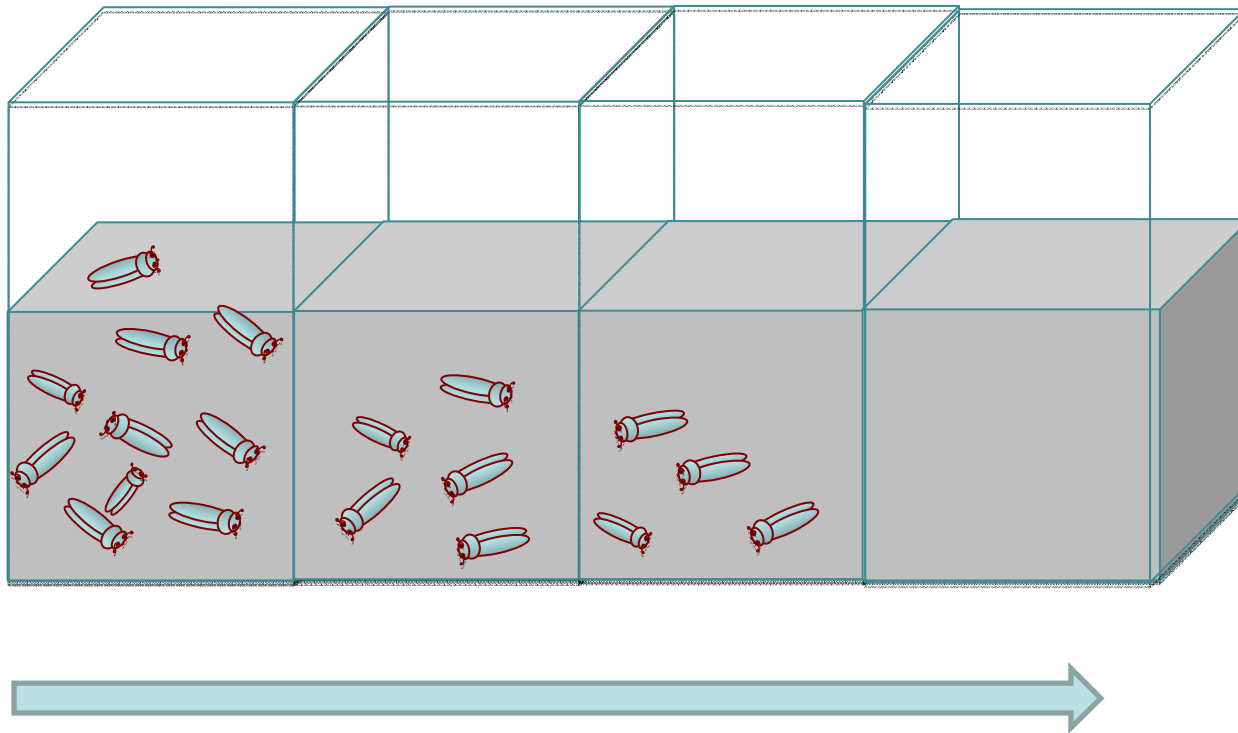
Espèce modèle : *Tribolium castaneum*



Expérience en laboratoire



Reproduction, dispersion, comptage

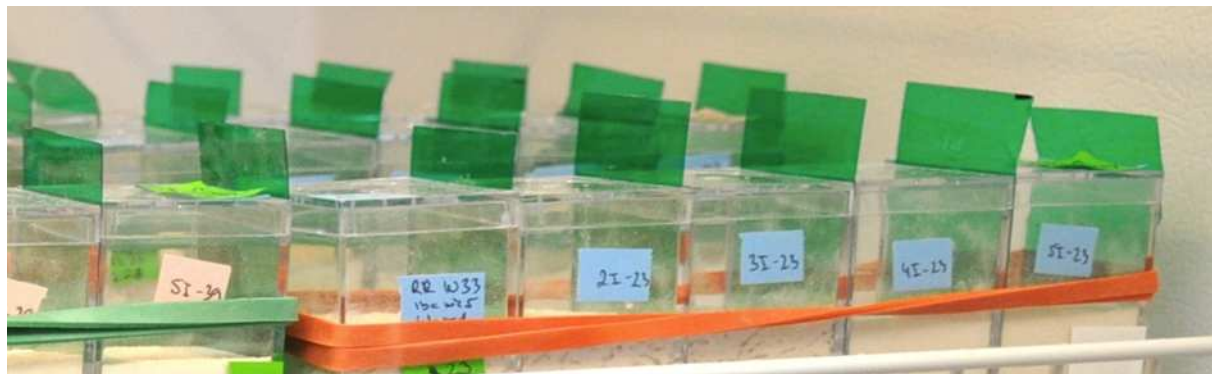
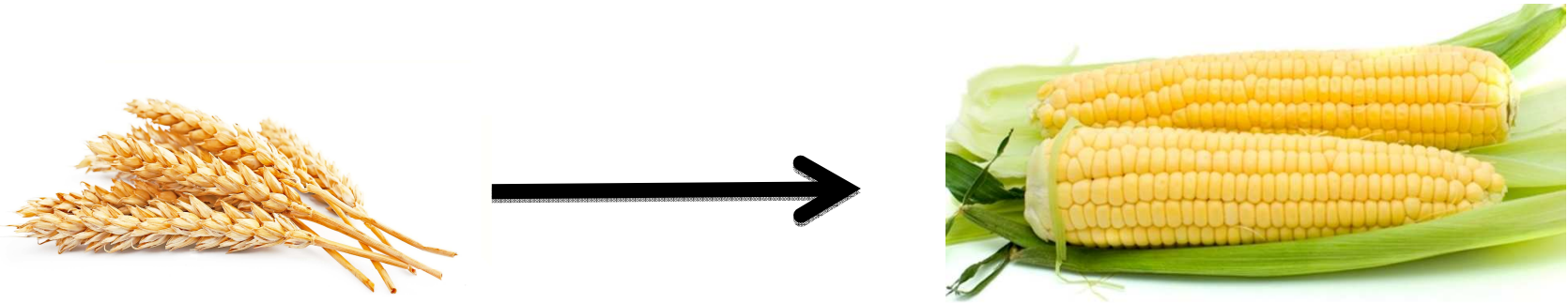


Deux traitements expérimentaux

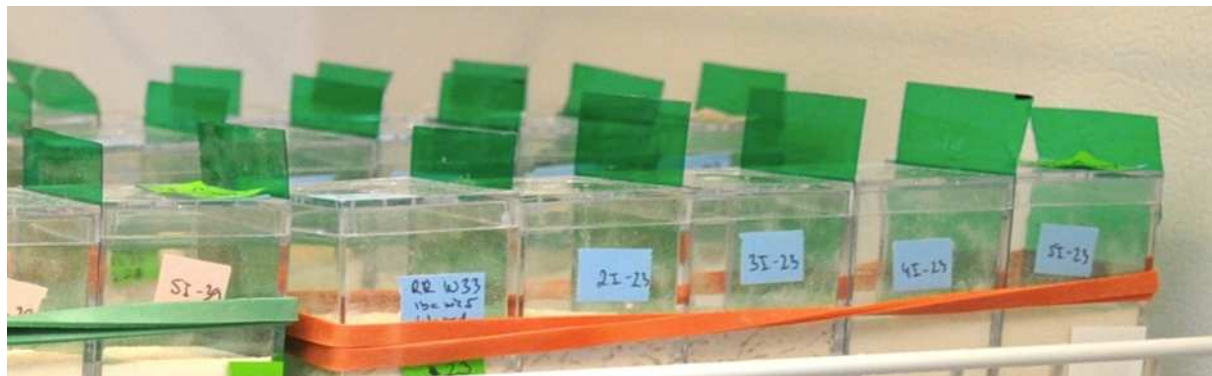
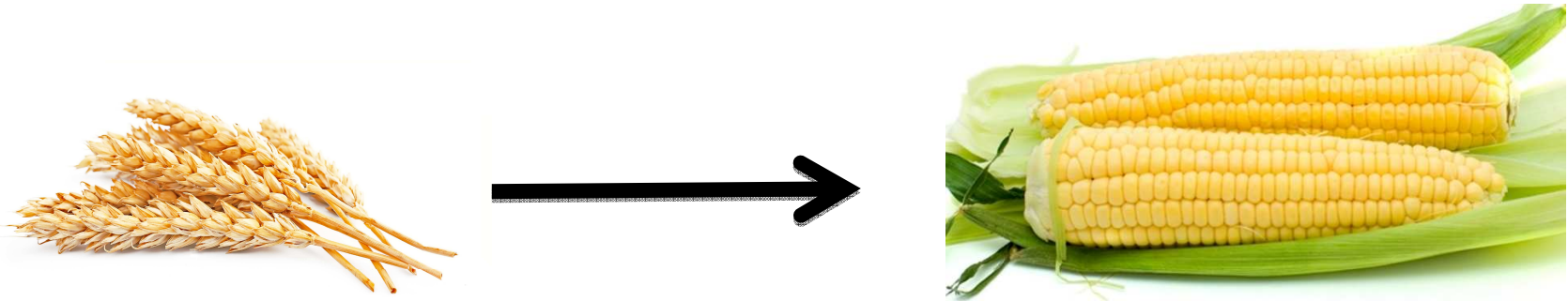
1/ Evolution **possible**

2/ Evolution **non possible** →
remplacement des individus par ceux
d'une population externe

Environnement nouveau

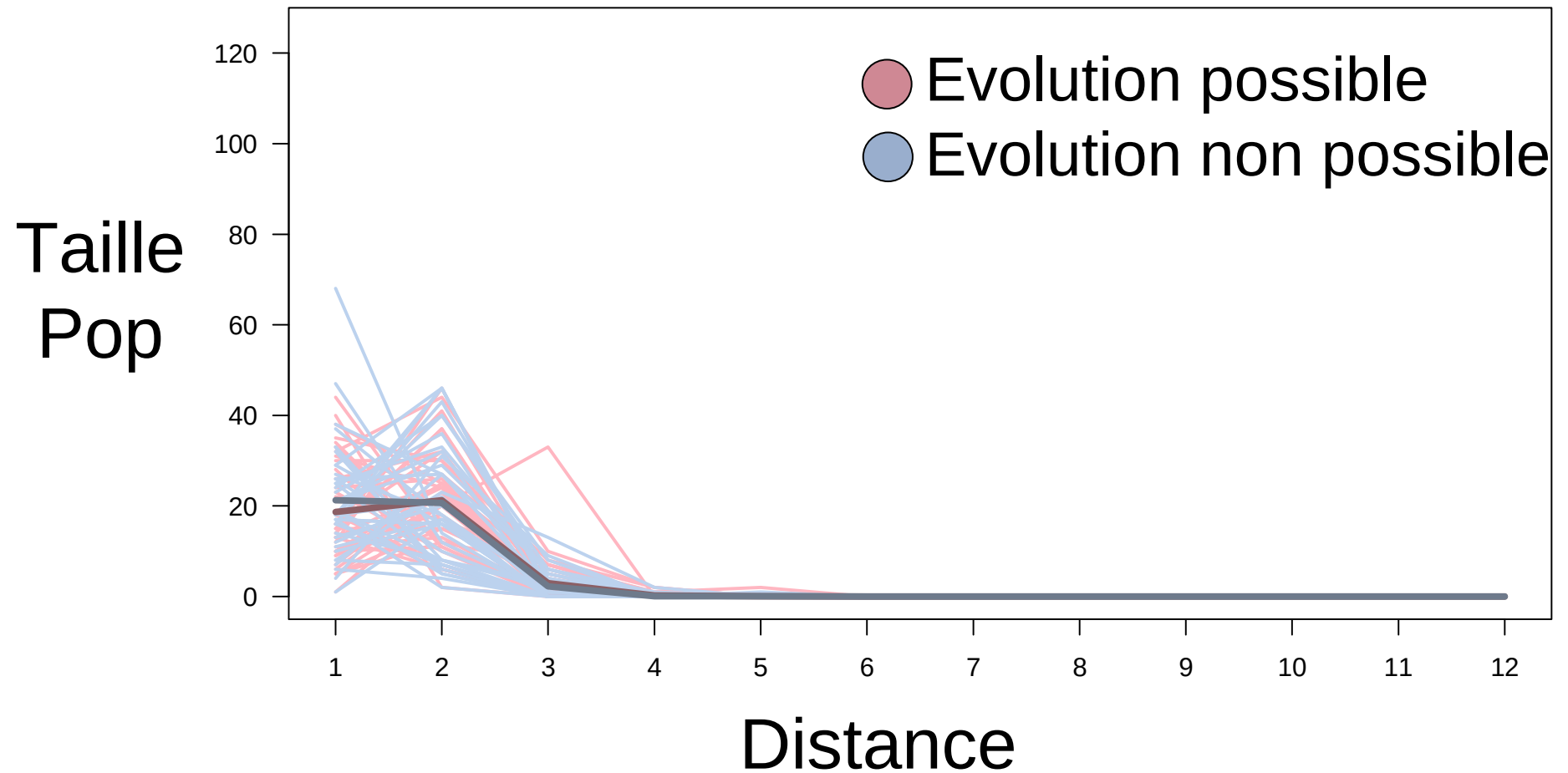


Environnement nouveau

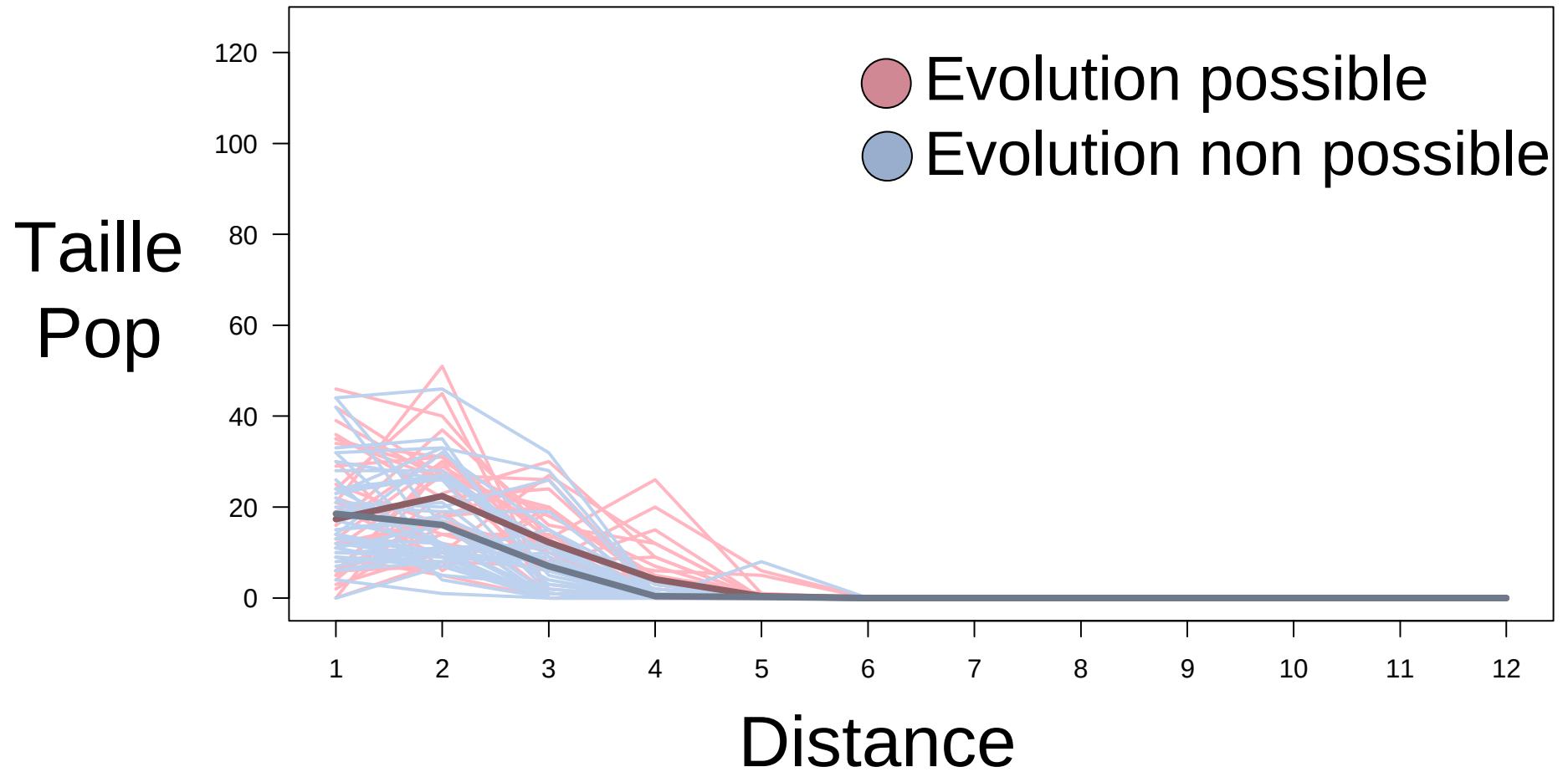


Generation 0 = 20 ind.

Generation 1

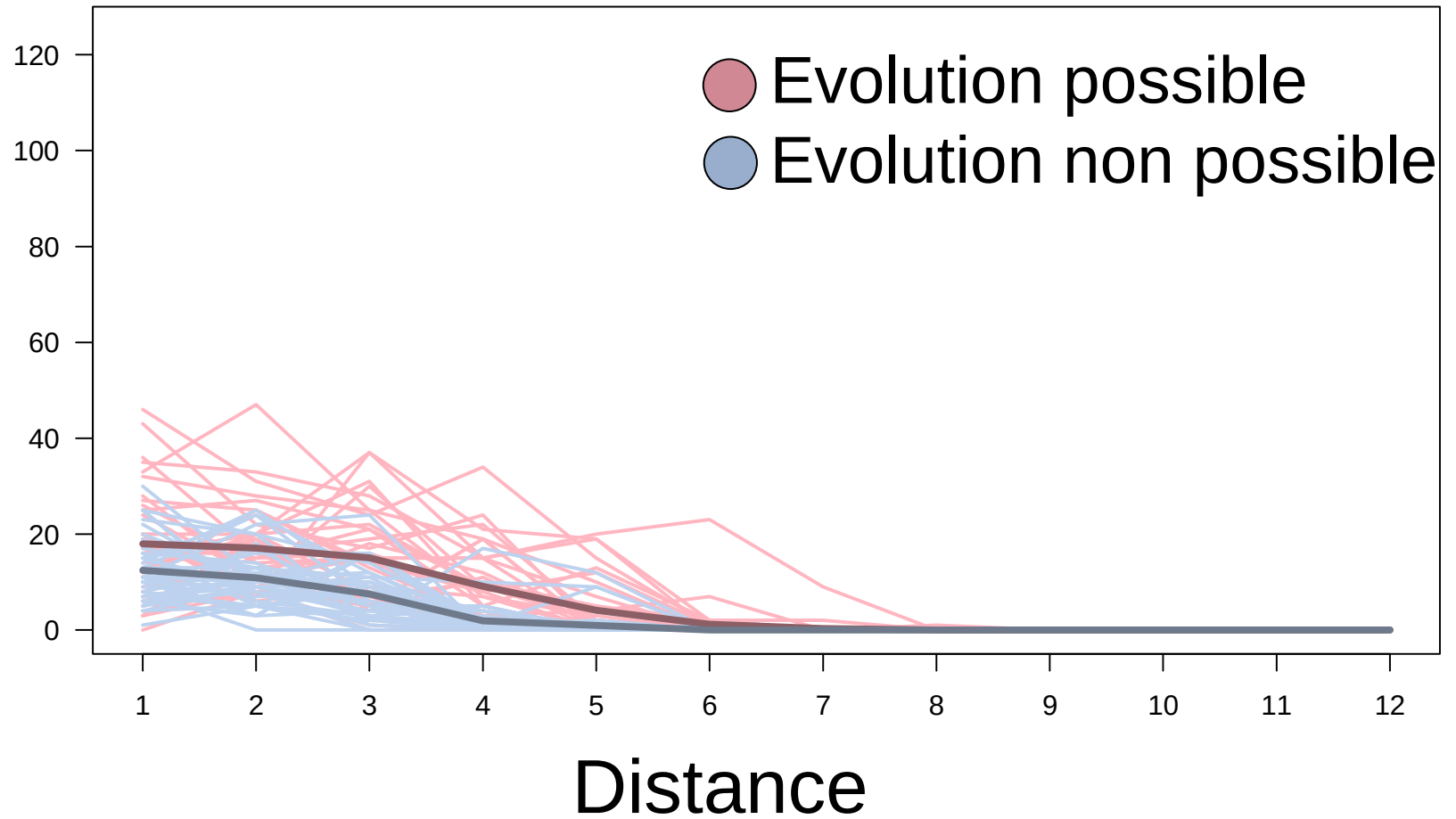


Generation 2



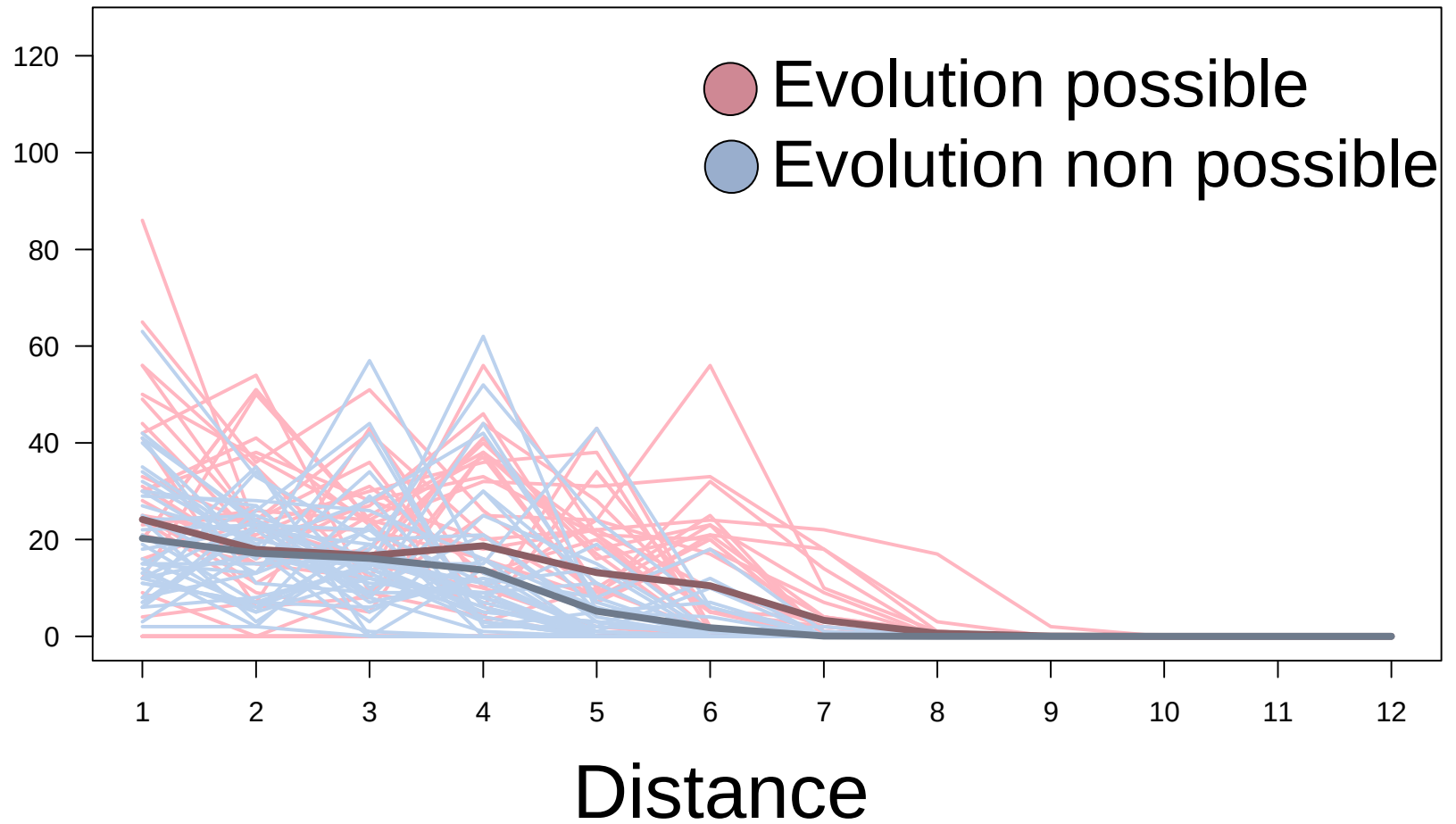
Generation 3

Taille
Pop



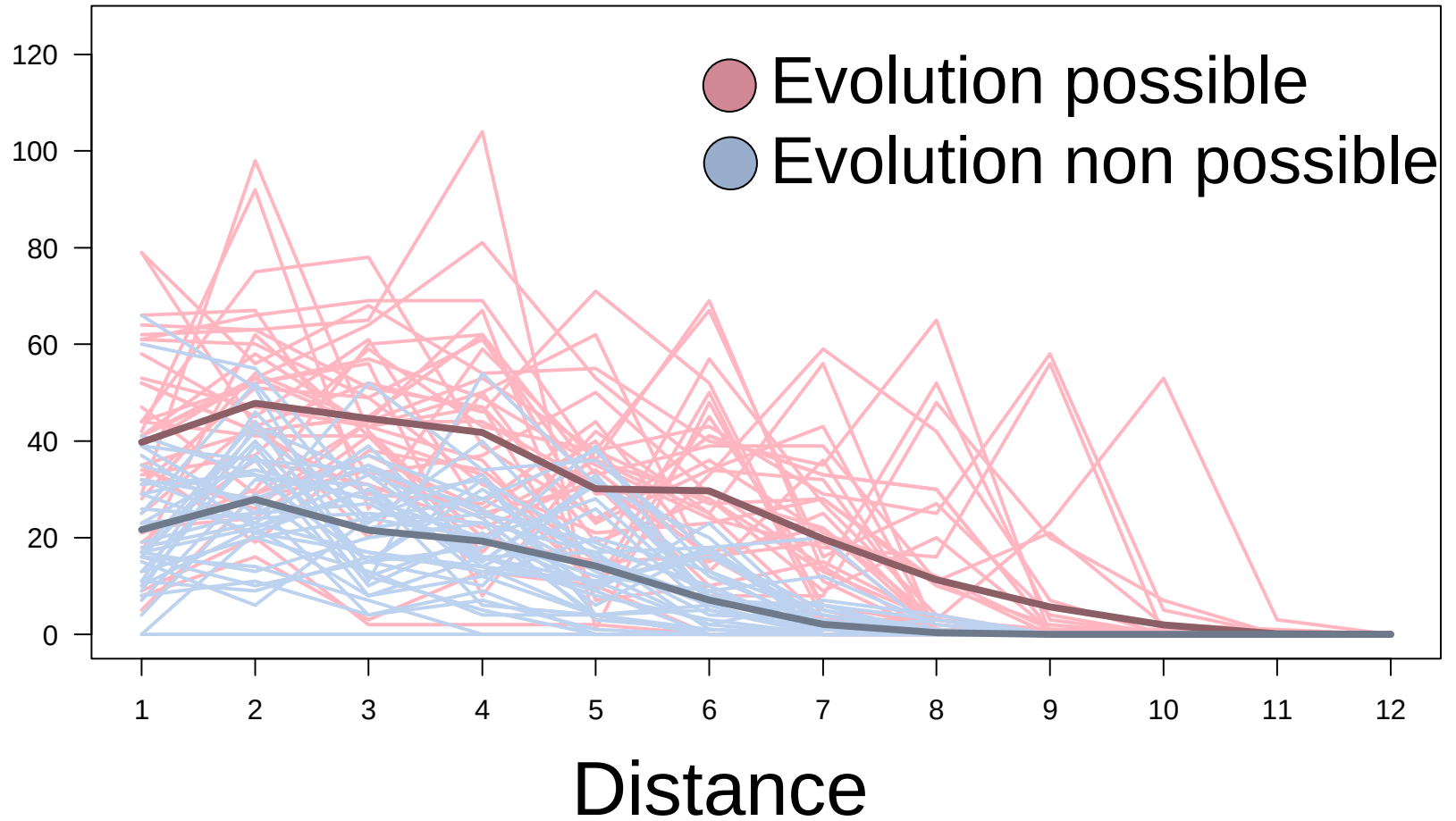
Generation 4

Taille
Pop



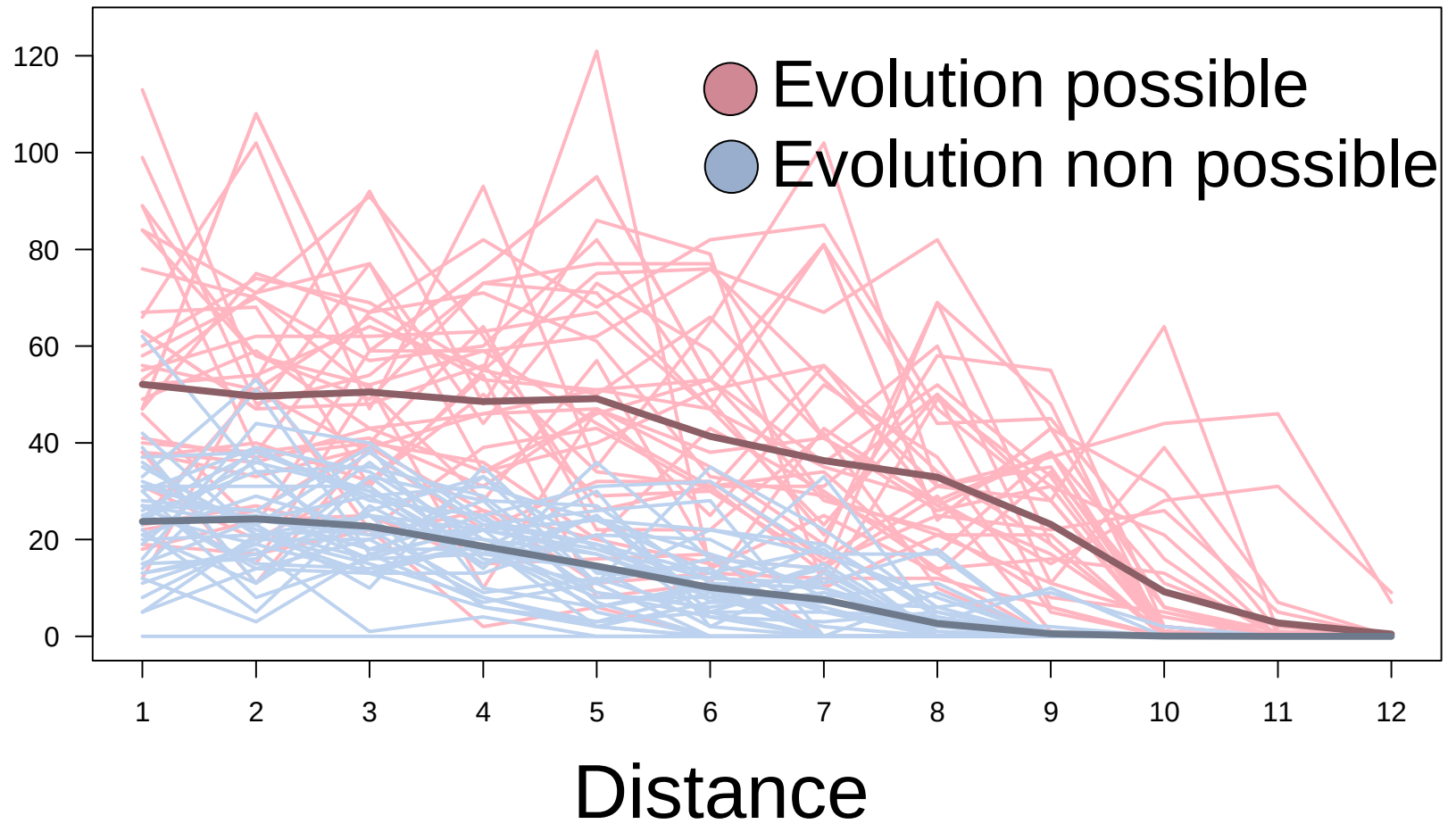
Generation 5

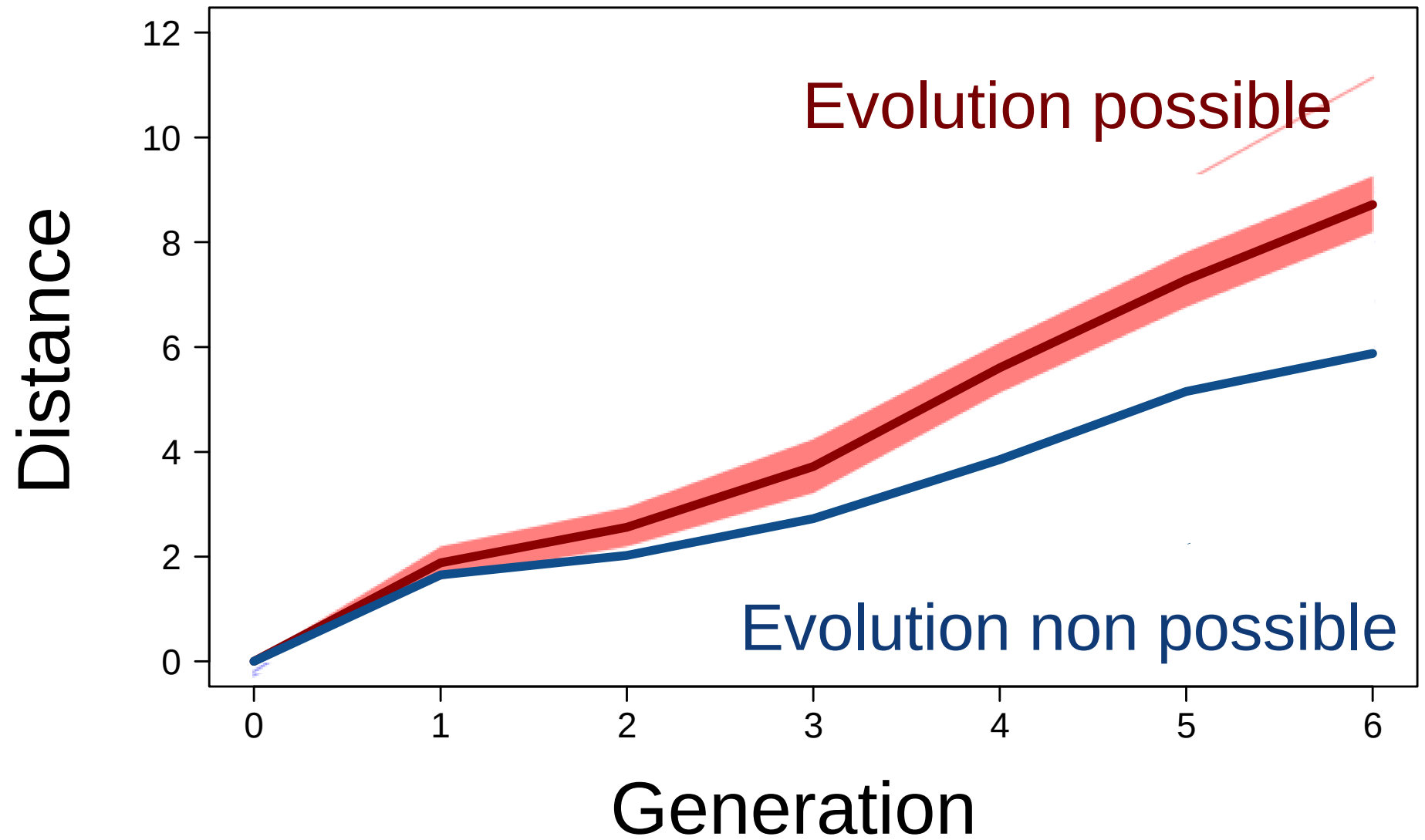
Taille
Pop

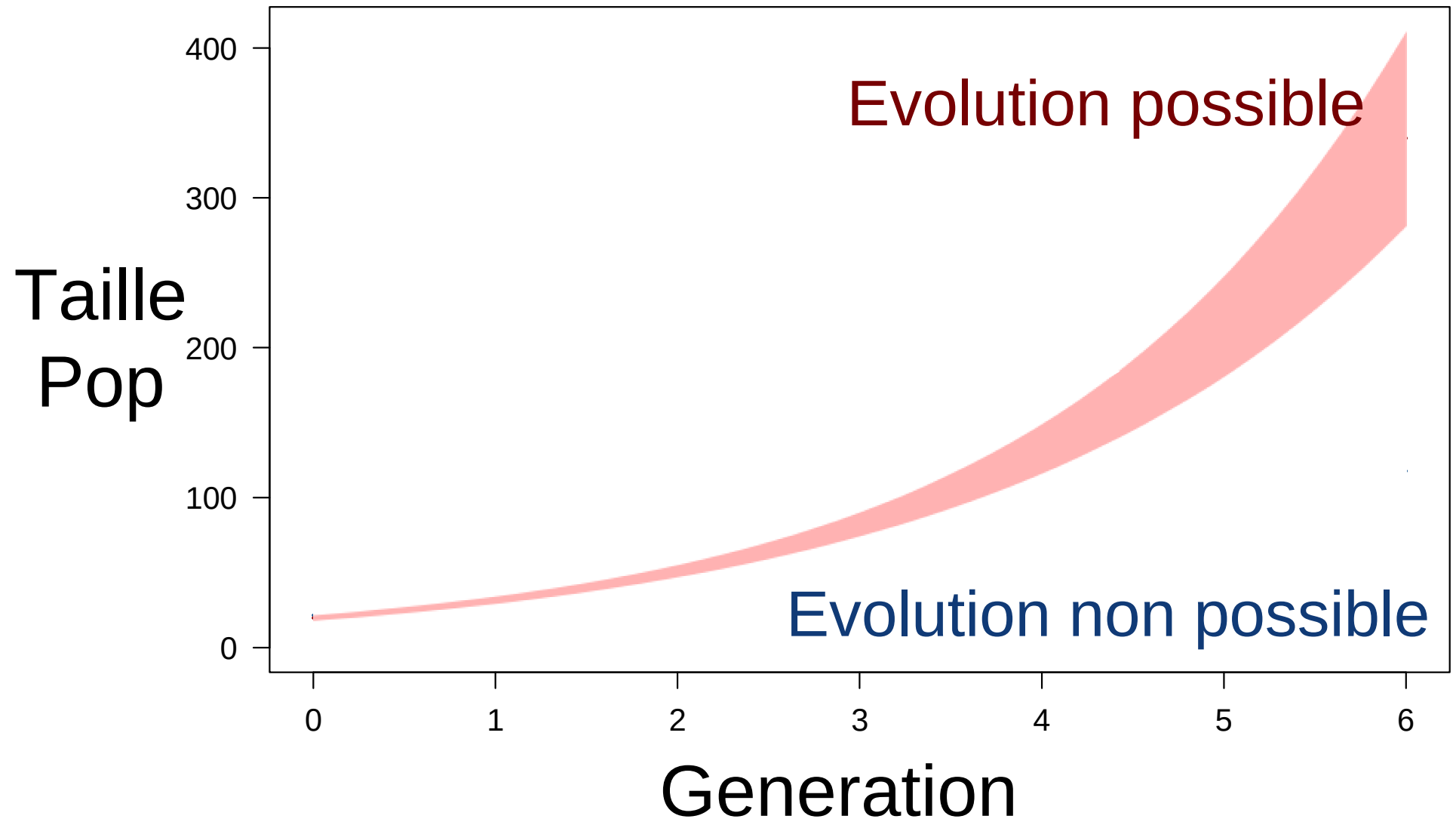


Generation 6

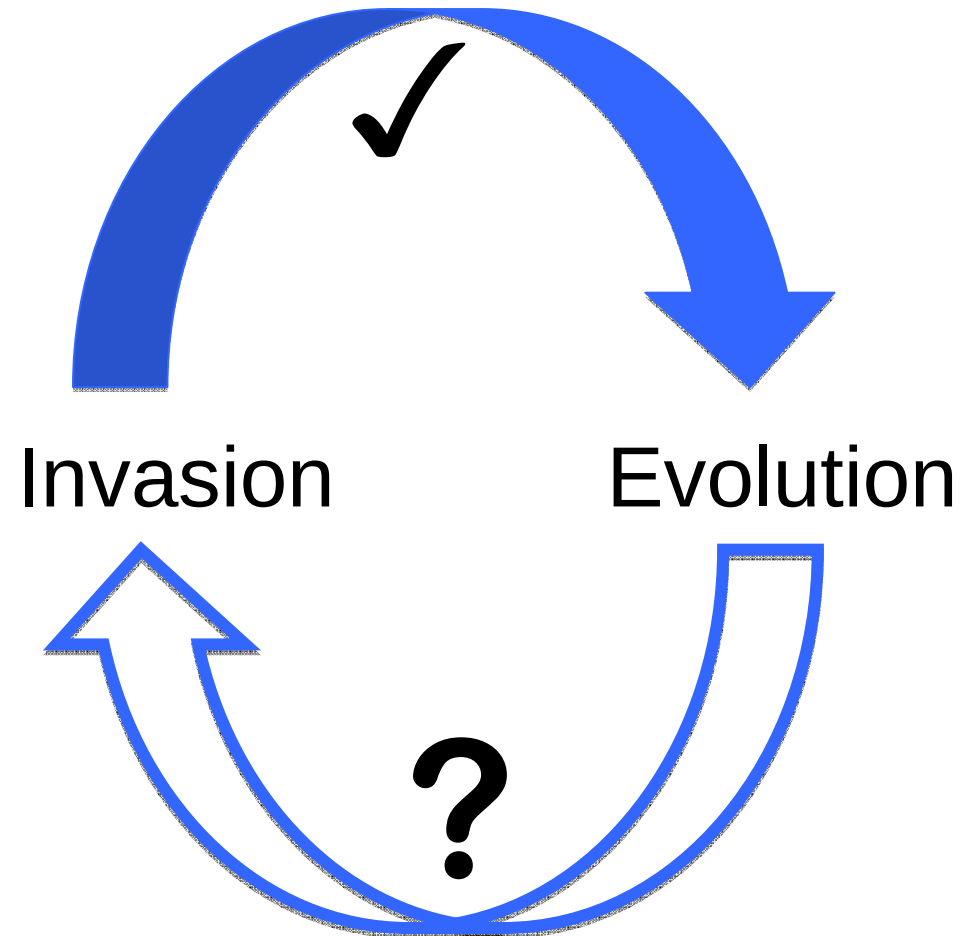
Taille
Pop



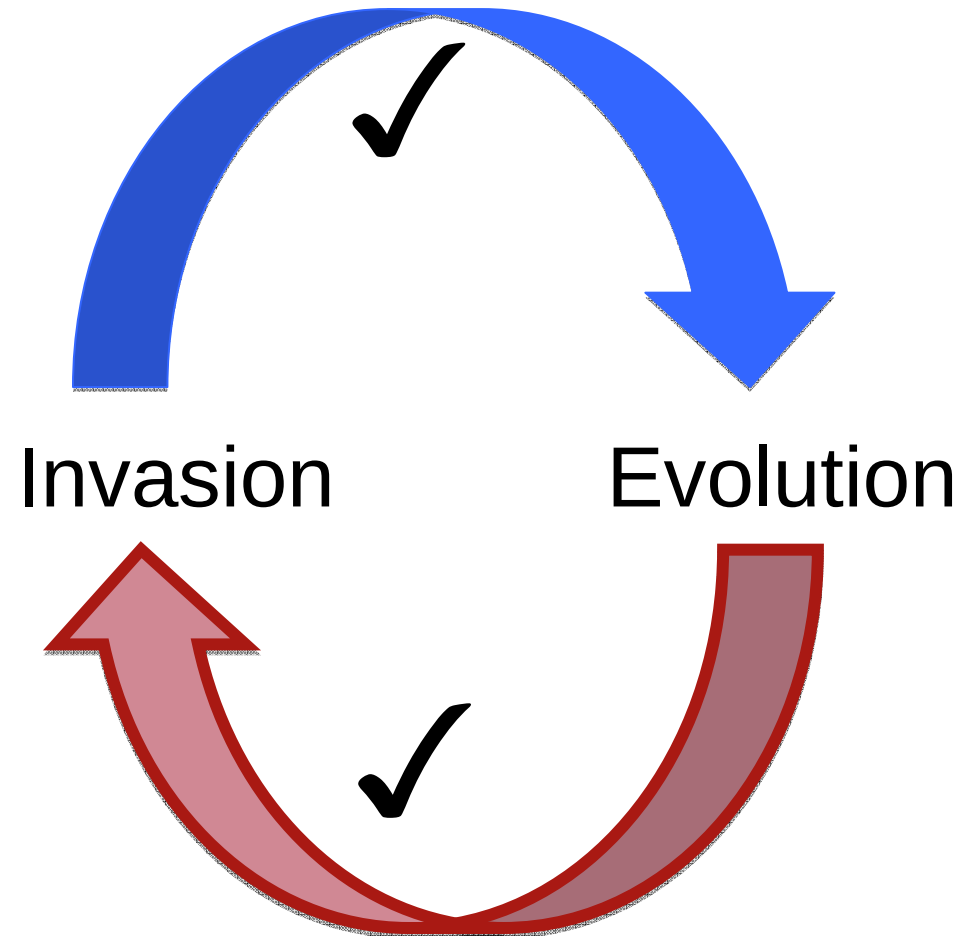




Question 1/: Est-ce que l'évolution facilite les espèces à devenir envahissantes? OUI !!!



Question 1/: Est-ce que l'évolution facilite les espèces à devenir envahissantes? OUI !!!



Question 2/: Quel est le rôle de l'Homme dans les processus évolutifs liés aux invasions?

- **Beaucoup plus qu'un simple vecteur de transport !!!**
- **Zones perturbées écologiquement** par l'activité humaine situées à proximité des zones d'habitats naturels (cf. dans la zone native)

Evolutionary Applications

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Evolutionary Applications ISSN 1752-4571

PERSPECTIVE

Anthropogenically induced adaptation to invade (AIAI): contemporary adaptation to human-altered habitats within the native range can promote invasions

Ruth A. Hufbauer,^{1,2} Benoît Facon,² Virginie Ravigné,³ Julie Turgeon,^{2,4} Julien Foucaud,⁵ Carol E. Lee,⁶ Olivier Rey² and Arnaud Estoup²

¹ Department of Bioagricultural Science and Pest Management, Graduate Degree Program in Ecology, Colorado State University, Ft. Collins, CO, USA

² UMR CBGP (INRA-IRD-CIRAD, Montpellier SupAgro), Campus International de Baillarguet, Montpellier/Lez Cedex, France

³ CIRAD, UMR BGPI, Campus International de Baillarguet, Montpellier Cedex 5, France

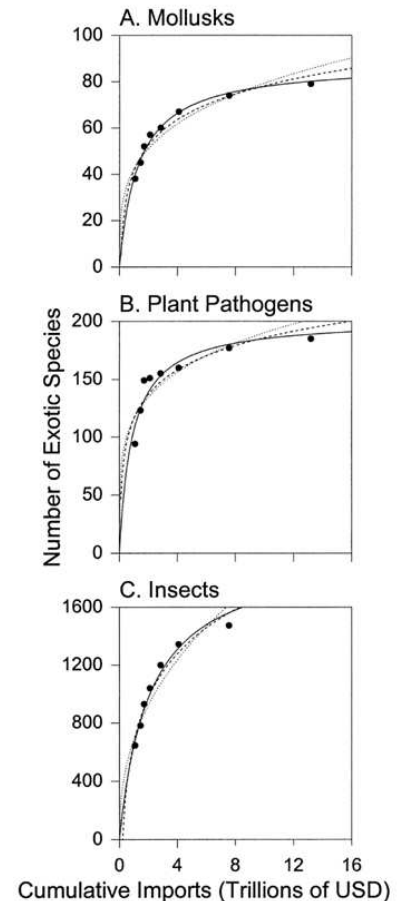
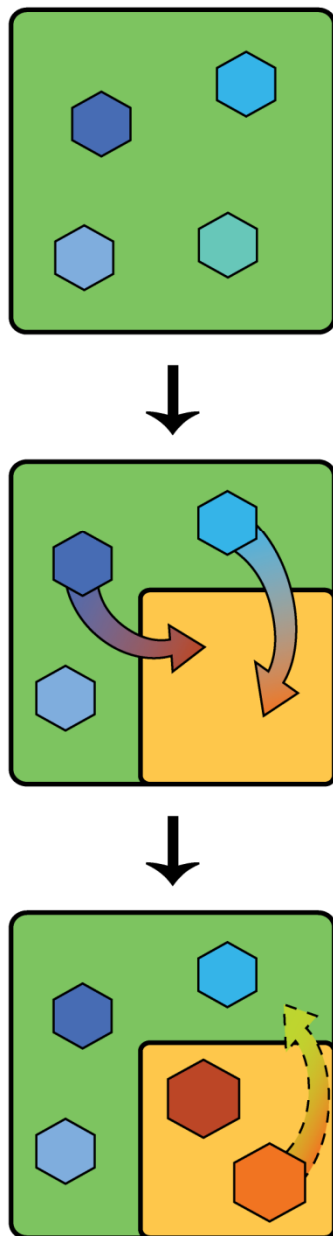
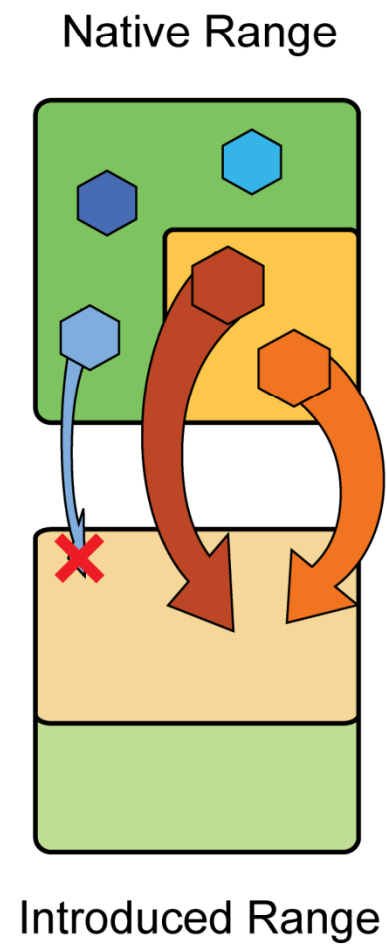


Figure 1. Relationship between U.S. merchandise imports and the accumulation of exotic (a) mollusks, (b) plant pathogens, and (c) insects since 1920 (10-year increments). Lines show the different species-accumulation models in Table 1 (dotted, log-log species-area; dashed, log-linear species-area; solid, Michaelis-Menten). USD are 1999 U.S. dollars.

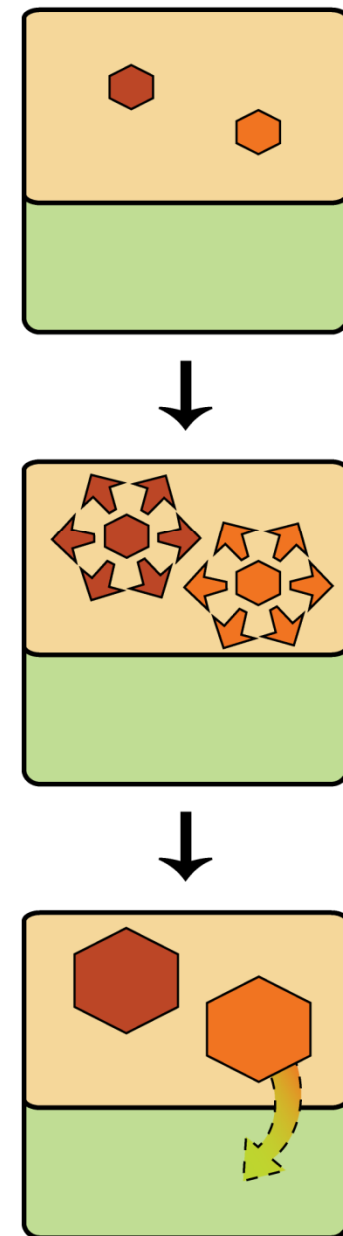
(A) Within the Native Range



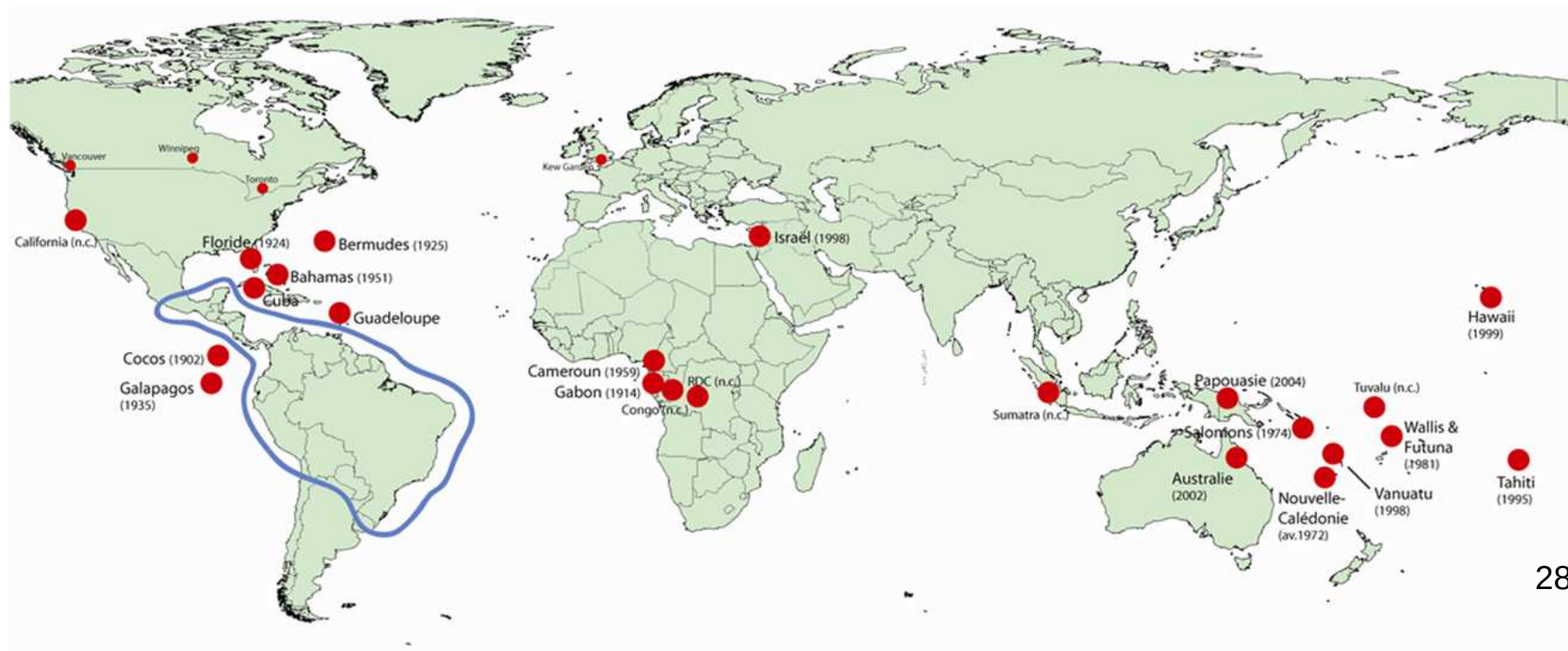
(B) Transport



(C) Within the Introduced Range



Une illustration: la petite fourmi de feu *Wasmania auropunctata*





**A. Habitats naturels
(forêt primaire)**



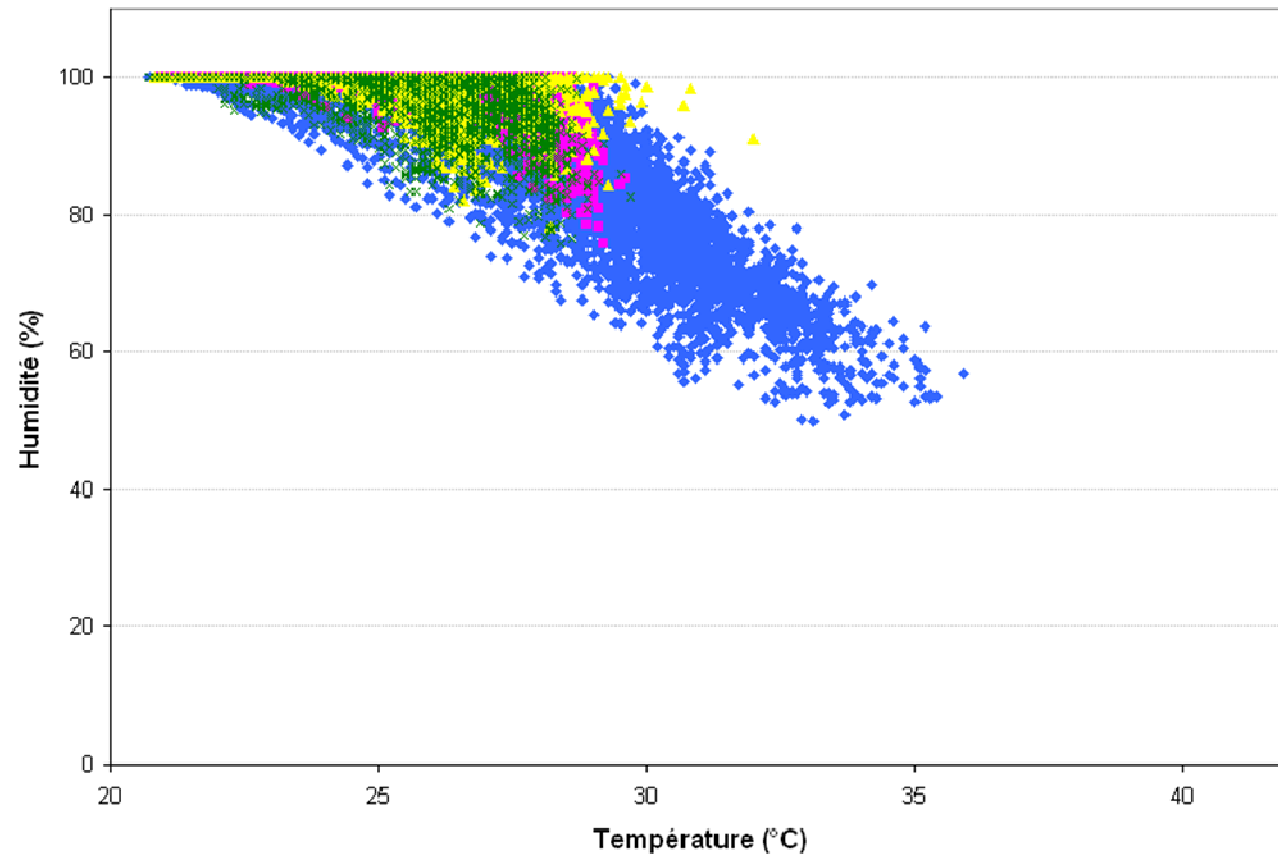
**B. Habitats perturbés
(milieux anthropisés)**



Habitat
Anthropisé

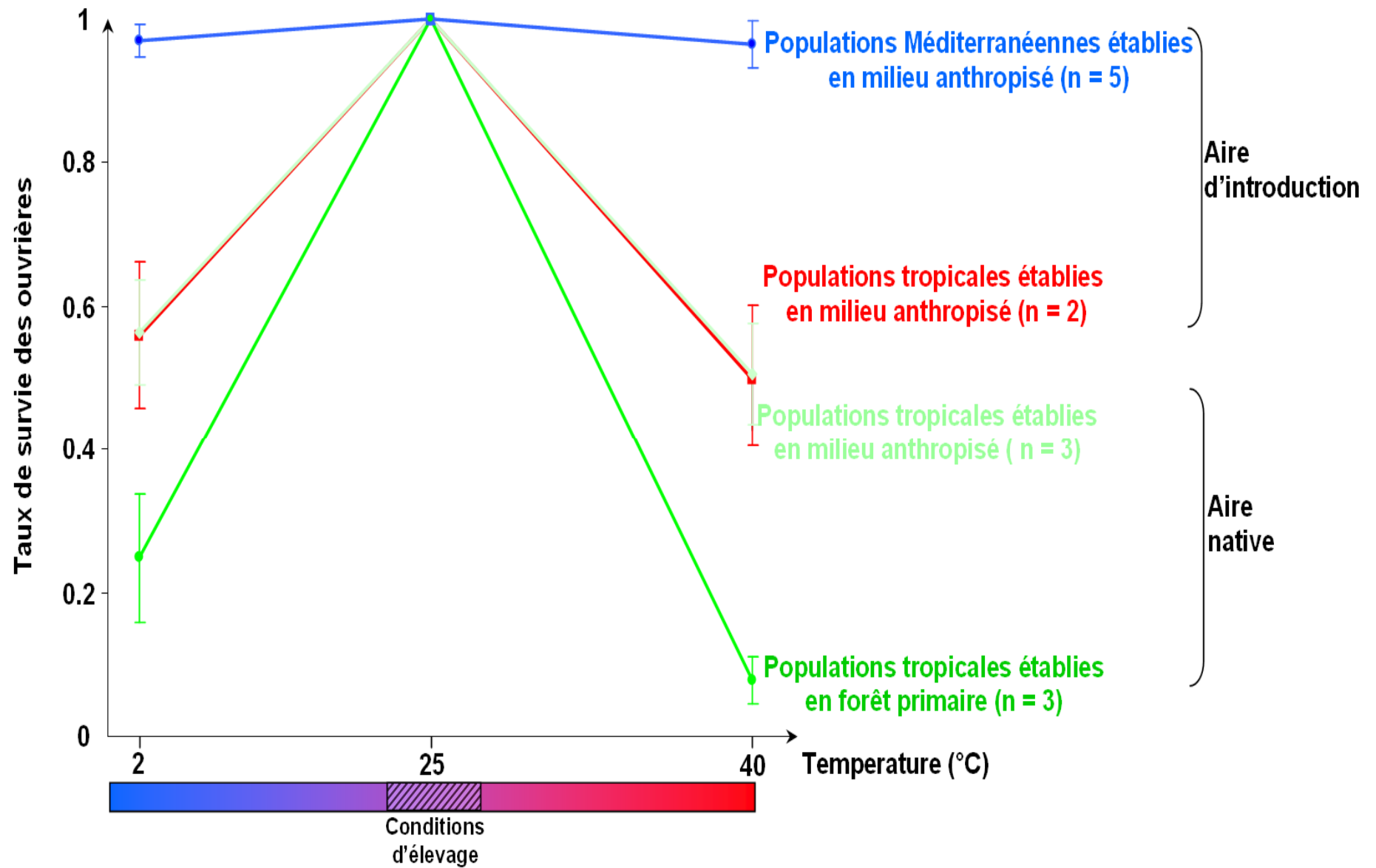


Habitat
naturel

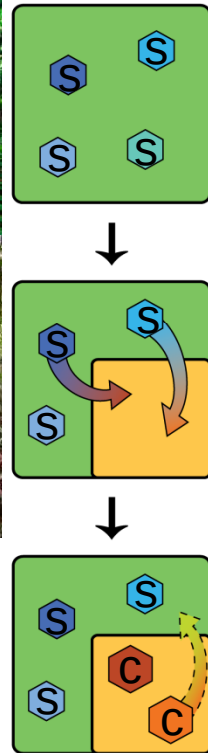
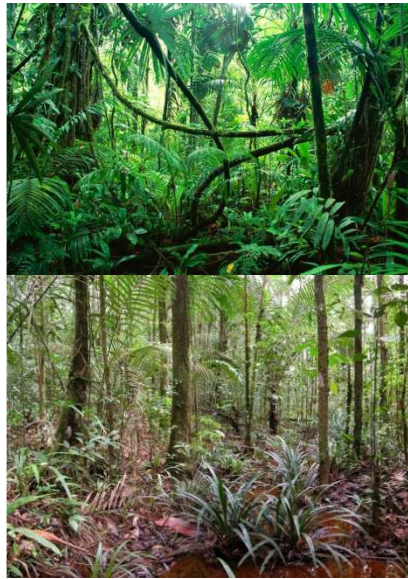


Environnement

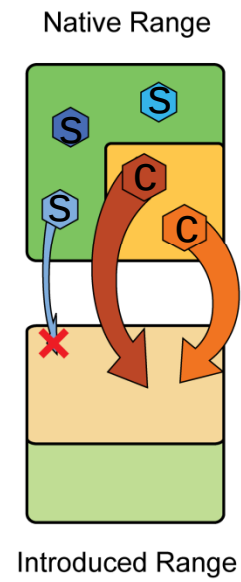
- = Naturel
- ▲ = Naturel
- ✕ = Naturel
- ◆ = Anthropisé



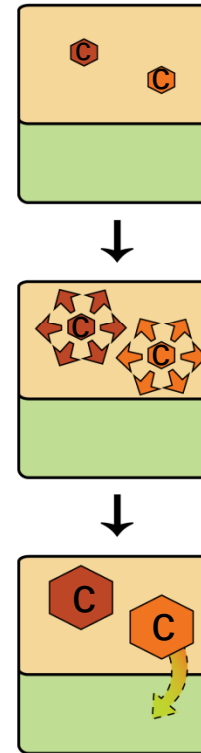
(A) Within the Native Range



(B) Transport

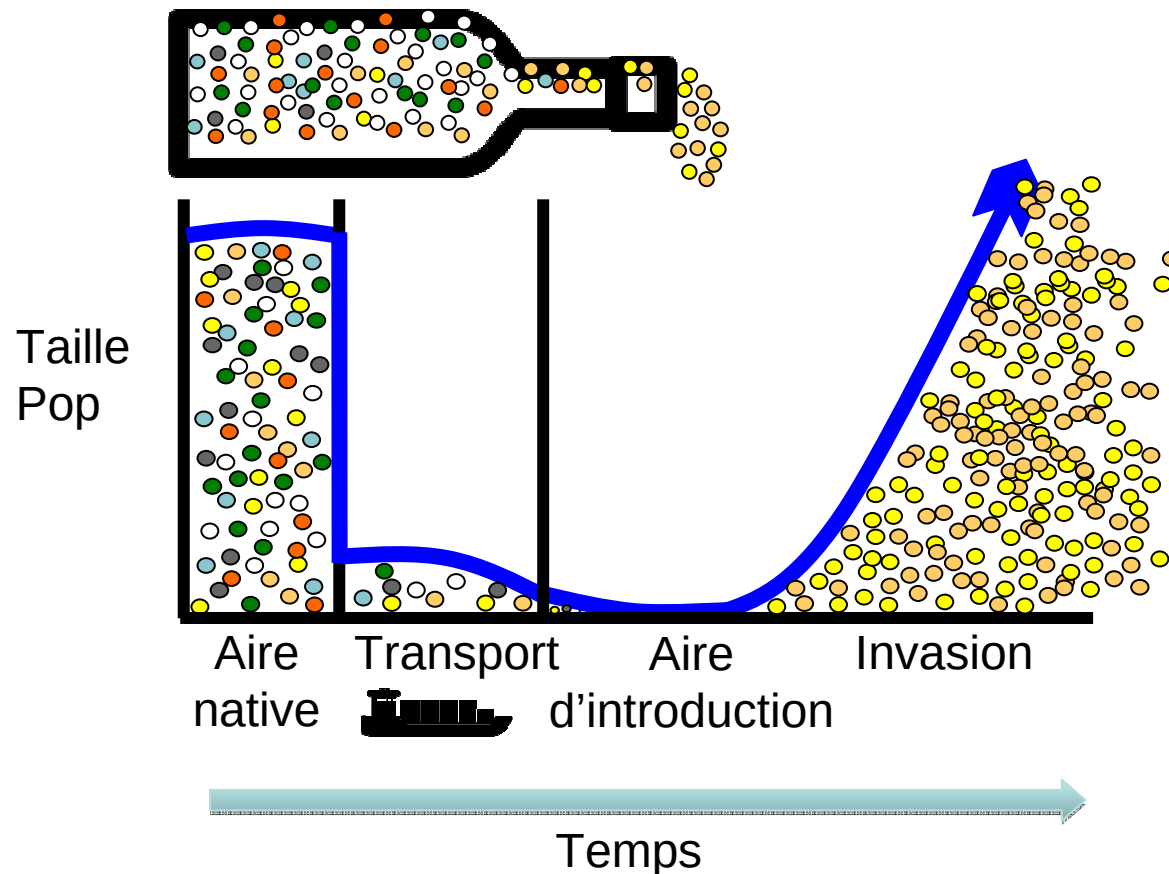


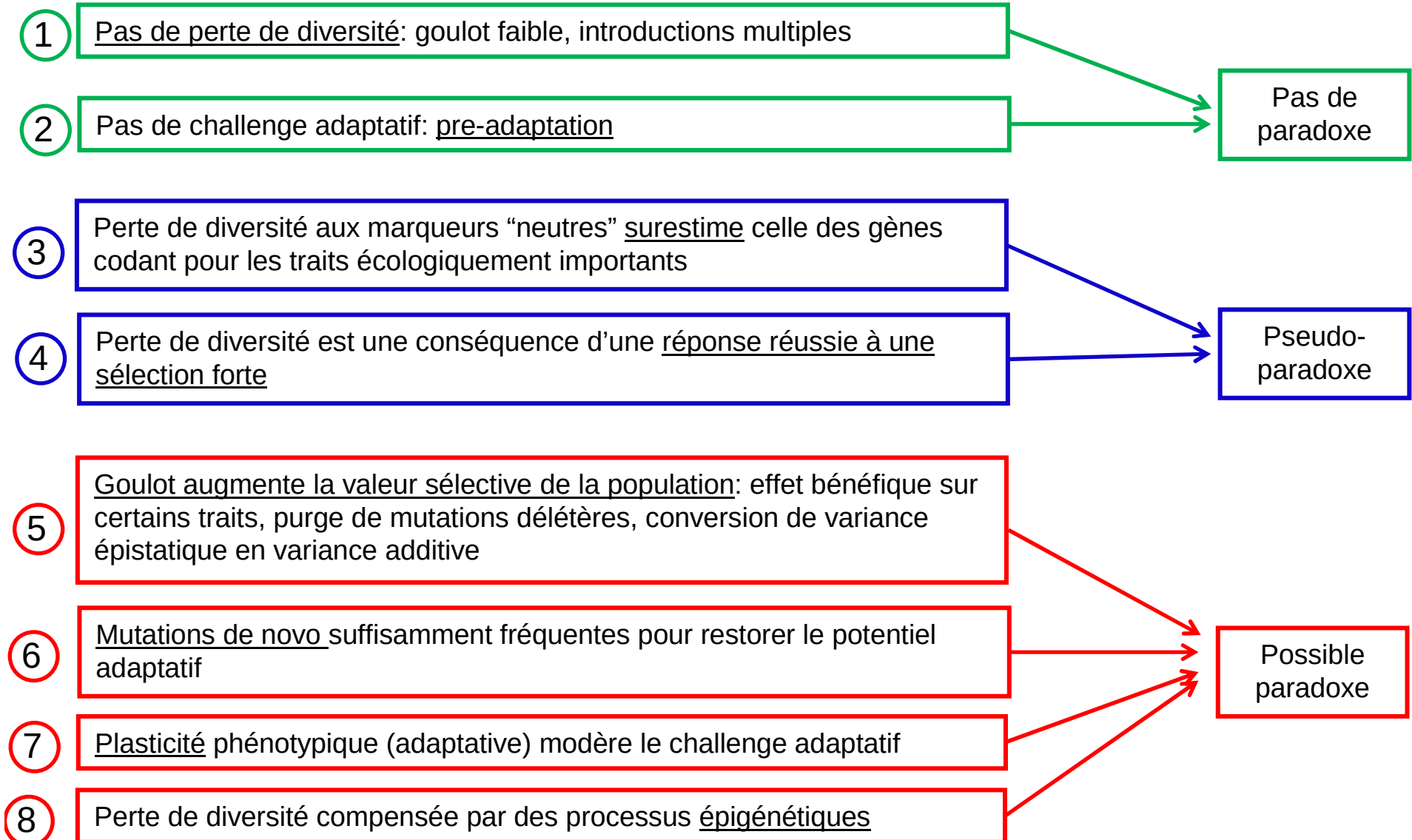
(C) Within the Introduced Range



QUESTION 3/: Existe-t-il un paradoxe génétique chez les espèces envahissantes?

Goulot d'étranglement → faible diversité génétique → faible potentiel d'évolution + faible capacité de reproduction





Pas de perte de diversité: goulot faible, introductions multiples

Pas de challenge adaptatif: pre-adaptation

Pas de
paradoxe

Perte de diversité aux marqueurs "neutres" surestime celle des gènes codant pour les traits écologiquement importants

Perte de diversité est une conséquence d'une réponse réussie à une sélection forte

Pseudo-
paradoxe

5

Goulot augmente la valeur sélective de la population: effet bénéfique sur certains traits, purge de mutations délétères, conversion de variance épistatique en variance additive

Mutations de novo suffisamment fréquentes pour restaurer le potentiel adaptatif

Plasticité phénotypique (adaptative) modère le challenge adaptatif

Perte de diversité compensée par des processus épigénétiques

Possible
paradoxe

Une illustration: la coccinelle asiatique *Harmonia axyridis*

Goulot augmente la valeur sélective de la population: effet
bénéfique sur certains traits, purge de mutations délétères,
conversion de variance épistatique en variance additive

Possible
paradoxe

Current Biology 21, 1–4, March 8, 2011 ©2011 Elsevier Ltd All rights reserved DOI 10.1016/j.cub.2011.01.068

Report

Inbreeding Depression Is Purged in the Invasive Insect *Harmonia axyridis*

Benoît Facon,^{1,*} Ruth A. Hufbauer,² Ashraf Tayeh,¹
Anne Loiseau,¹ Eric Lombaert,³ Renaud Vitalis,⁴
Thomas Guillemaud,³ Jonathan G. Lundgren,⁵
and Arnaud Estoup¹

¹Institut National pour la Recherche Agronomique,
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Campus International de Baillarguet, CS 30 016, 34988
Montferrier/Lez cedex, France

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Université de Nice Sophia-Antipolis, Centre National de la
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National de la Recherche Scientifique, UMR Centre de Biologie
pour la Gestion des Populations, Campus International de
Baillarguet, CS 30 016, 34988 Montferrier/Lez cedex, France

⁵United States Department of Agriculture, Agricultural
Research Service, North Central Agricultural Research
Laboratory, Brookings, SD 57006, USA

[5, 6]. We lack the ability to say whether positive effects of bottlenecks are theoretical curiosities or whether they truly influence the dynamics of natural populations [7]. One mechanism by which bottlenecks can have positive effects is through the purging of deleterious mutations that lead to inbreeding depression [8]. Theory states that for purging to occur, the reduction in population size should be of intermediate intensity (i.e., ranging from 40–300 individuals, depending upon intensity of selection) and the mutations leading to inbreeding depression should be strongly deleterious and highly recessive [3, 7]. Such purging of deleterious mutations has been demonstrated empirically in artificially bottlenecked populations [4, 9, 10], but given the conditions imposed, high rates of extinction have been observed. This makes it difficult to directly extrapolate to natural populations [7]. To date, studies documenting a purge of deleterious mutations during bottlenecks are scarce and rely on indirect evidence [5].

The ability of invasive species to dominate novel ecosystems has been considered puzzling given that they typically pass through bottleneck in population size during introductions ([2], although see [11]). Such bottlenecks have been seen as detrimental to invasion success; the implicit assumption



By Geoff Marsh

A KILLER ladybird has landed in Britain – and it could mean the end for our own beloved red and black insect.

The most invasive ladybird on the planet – the Harlequin – has already caused havoc in America and parts of Continental Europe, decimating native insect populations.

Now scientists have found it in Britain and are warning that it could annihilate native ladybirds and other insects, including butterflies.

Ladybird expert Dr Michael Majerus, of Cambridge University, is urging anyone who spots the

The killer ladybird

This foreign invader could wipe out our native insects



Although there is an invasive ladybug that can cause problems, regular ladybugs do not cause this problem.

The ladybird killers fly in

Native species threatened by voracious insect that even bites people. David Derbyshire reports

A LONELY species of ladybird with the potential to wipe out half of Britain's native species has arrived in the country. The invasive Harlequin, also known as the multi-spotted ladybird, was first spotted in 2003. It is a native of Central Europe and is a voracious predator of other ladybirds. It is also known to bite humans, causing a painful allergic reaction.

The Harlequin is a large, oval-shaped insect with a light-colored body and dark spots. It is a voracious predator of other ladybirds, and it is also known to bite humans, causing a painful allergic reaction. The Harlequin is a native of Central Europe and is a voracious predator of other ladybirds. It is also known to bite humans, causing a painful allergic reaction.

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L'INVASION DES COCCINELLES

Mercredi 10 octobre 2007

03 20 78 40 40 - www.lavoixdunord.fr

67^e ANNÉE - N° 19705 - 0,95 €

Marching in, the mother of all ladybirds

Our ladybirds in peril from foreign invaders

By Rachel Porter
The Harlequin is a ladybird that is native to Central Europe. It is a voracious predator of other ladybirds, and it is also known to bite humans, causing a painful allergic reaction. The Harlequin is a native of Central Europe and is a voracious predator of other ladybirds. It is also known to bite humans, causing a painful allergic reaction.

By Rachel Porter
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Spot of bother: A harlequin ladybird

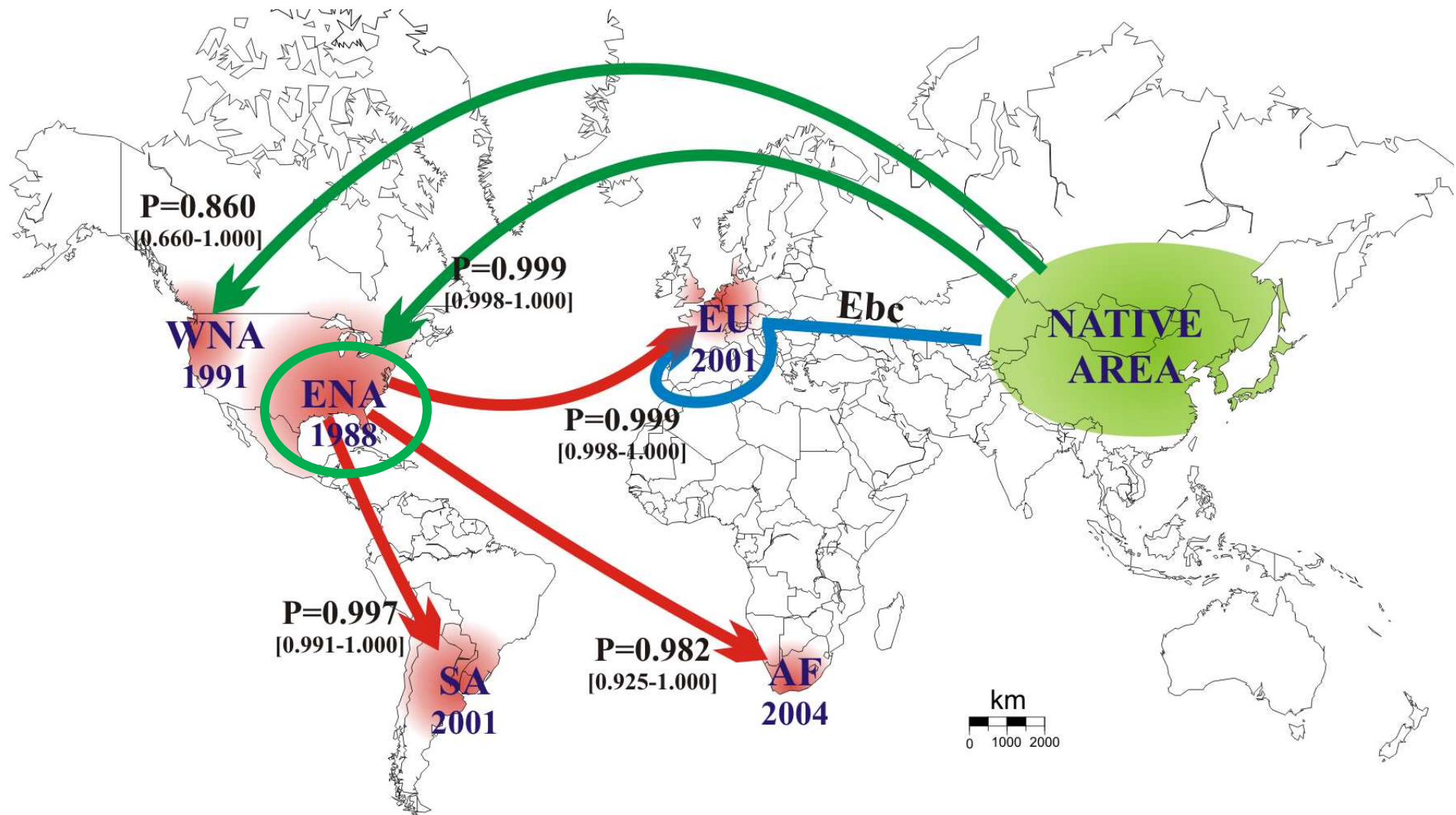
Impacts négatifs de *Harmonia axyridis* dans l'aire envahie

Une des 100 pires espèces envahissantes en Europe

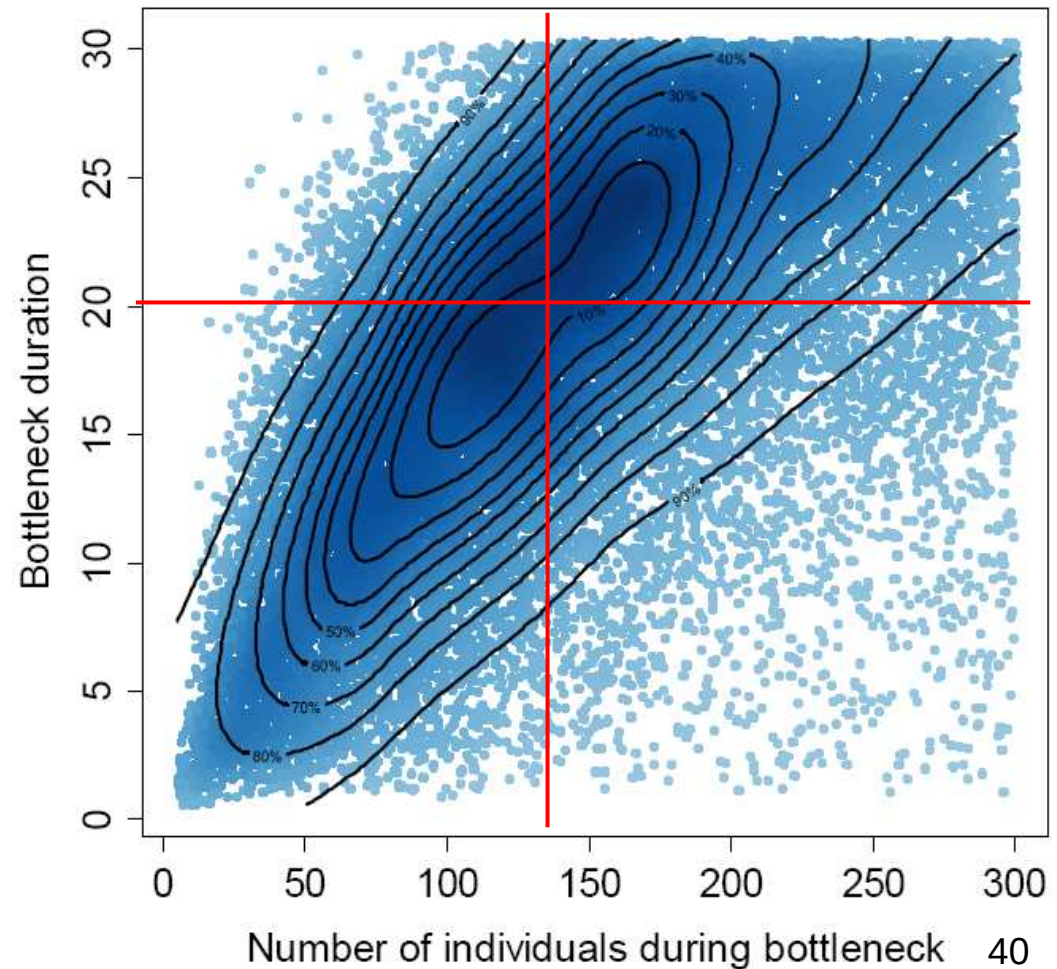
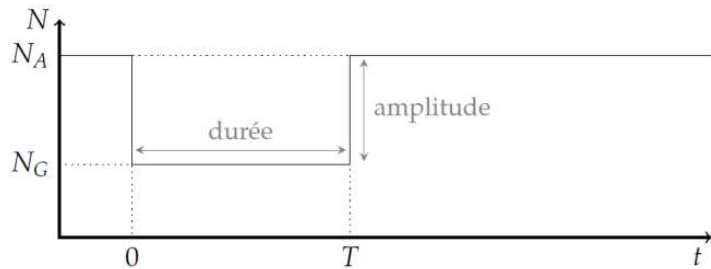
- **Impacts sociétaux:**
pullulation/agrégation
+ pbl allergie
- **Impacts écologiques:**
prédation + compétition
- **Impacts agronomiques:**
production de vin → se nourrit (occasionnellement) sur raisin



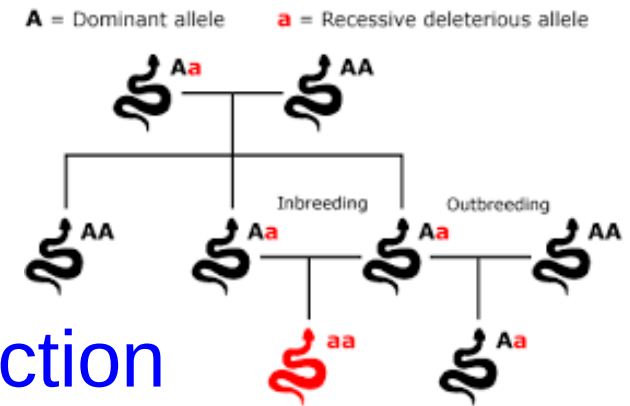
Routes d'invasion de *Harmonia axyridis*



Goulot d'étranglement dans les populations envahissantes (notamment ENA)

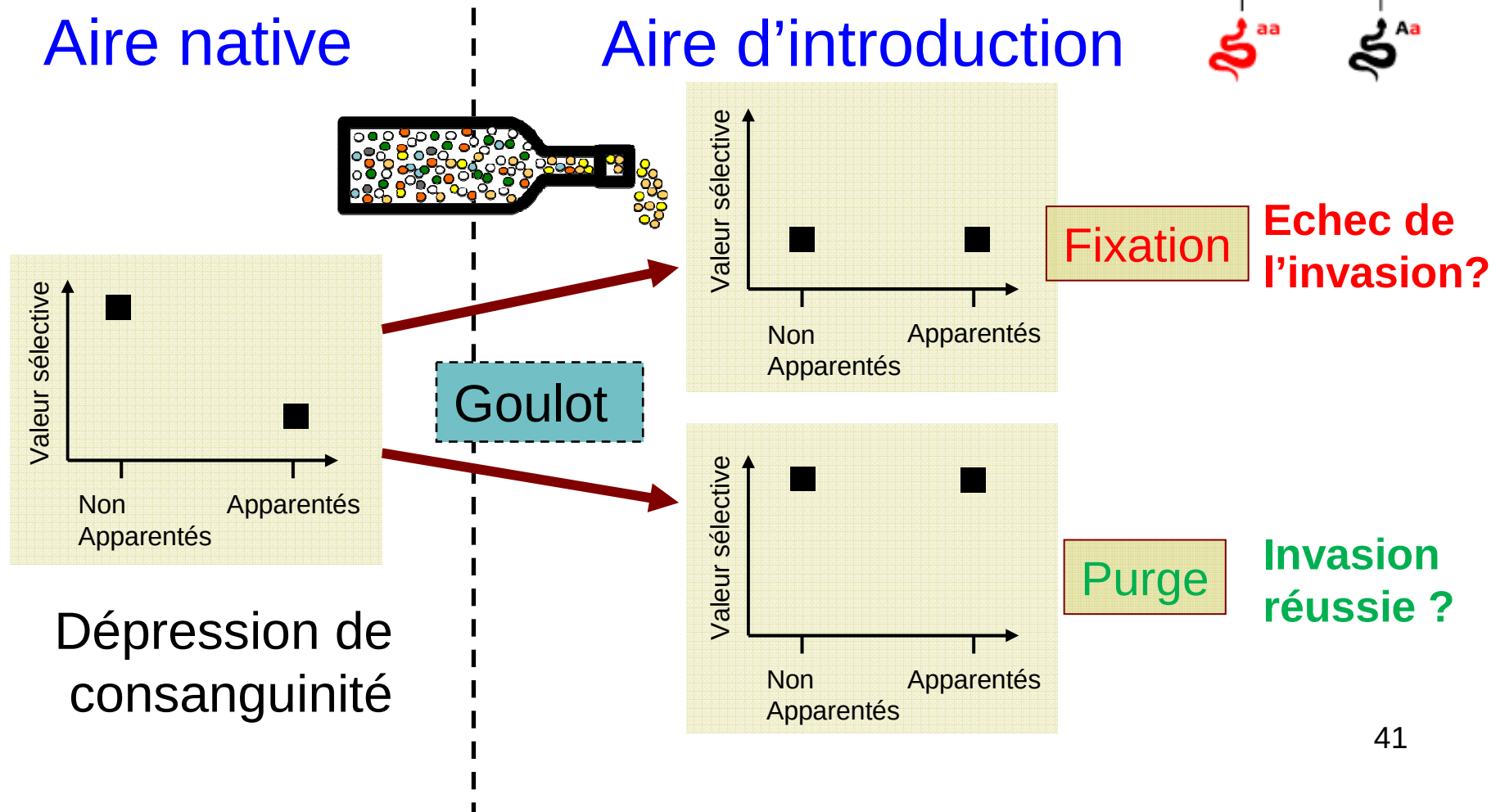


Goulot et fardeau génétique: principaux attendus

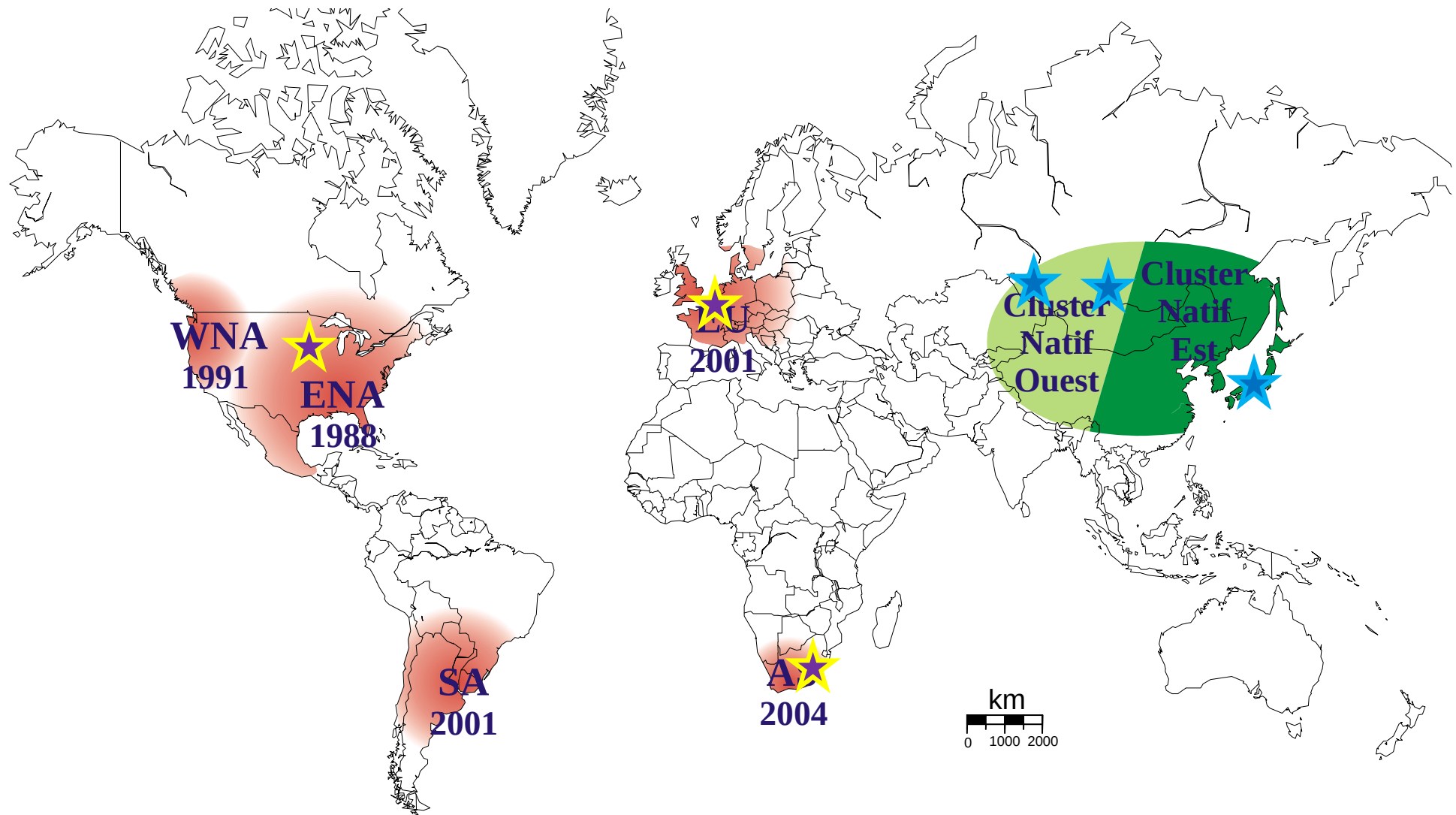


Aire native

Aire d'introduction

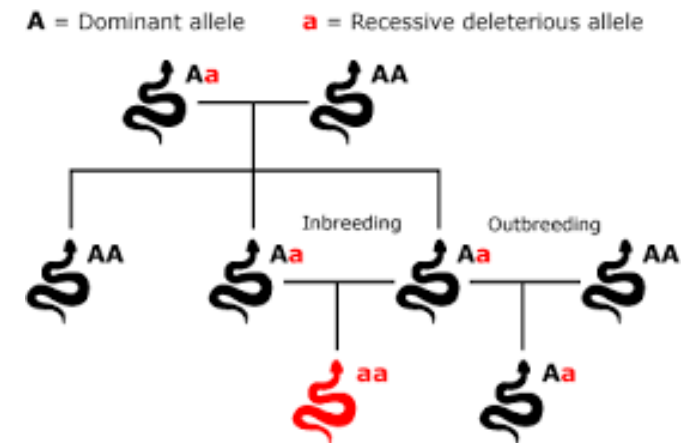
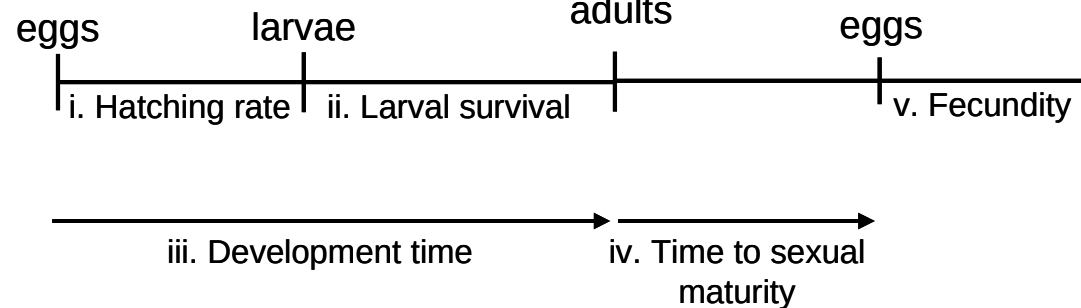


Collecte sur terrain de populations (vivantes)

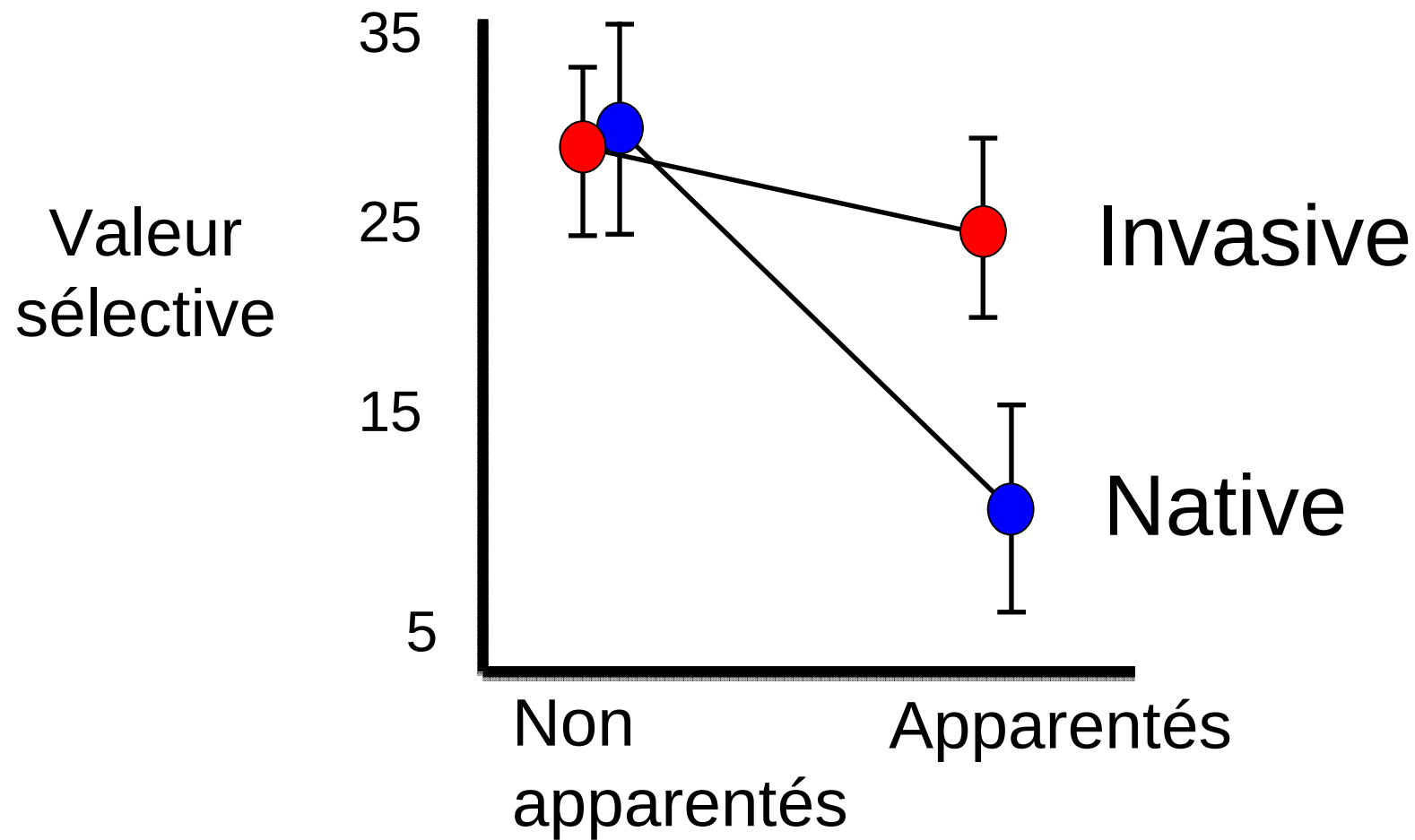


LABORATOIRE: étude du fardeau génétique

- Deux types de croisements expérimentaux:
 - Frère X sœur (apparentés)
 - Mâle X femelle non-apparentés
- Mesure de la valeur sélective:



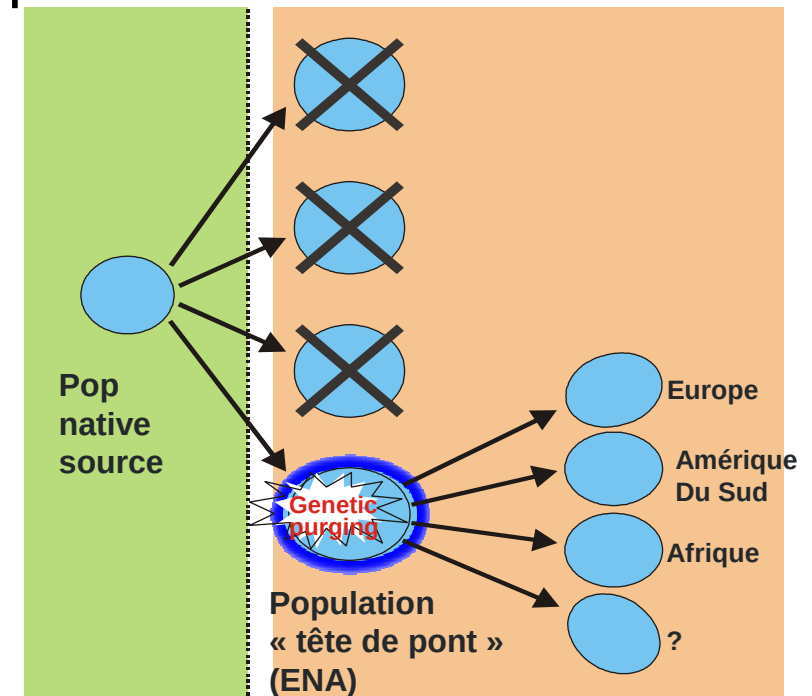
Valeur sélective = mesure globale « performance de cycle de vie »



Dépression de consanguinité **FORTE** dans les pops **natives**...et **ABSENTE** dans les pops **envahissantes**
→ **Purge génétique** dans les pops **envahissantes**

→ Première démonstration expérimentale d'une purge génétique dans les populations d'une espèce envahissante

- Premières générations de l'invasion (faible N_e) + expansion spatiale
- Mécanisme évolutif pertinent lorsque aucun challenge adaptatif évident
- Population(s) « tête de pont » = purge réussie?

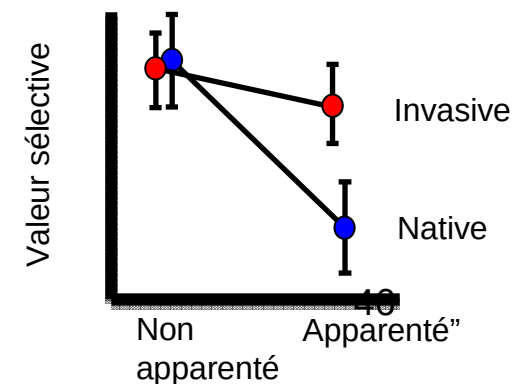
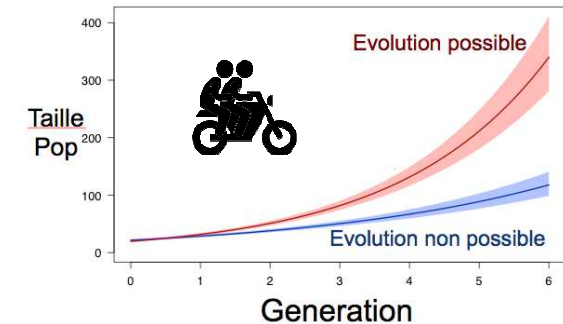


Conclusion

1/ L'évolution facilite les espèces à devenir envahissantes, elle est **un conducteur (+ passager)** des invasions

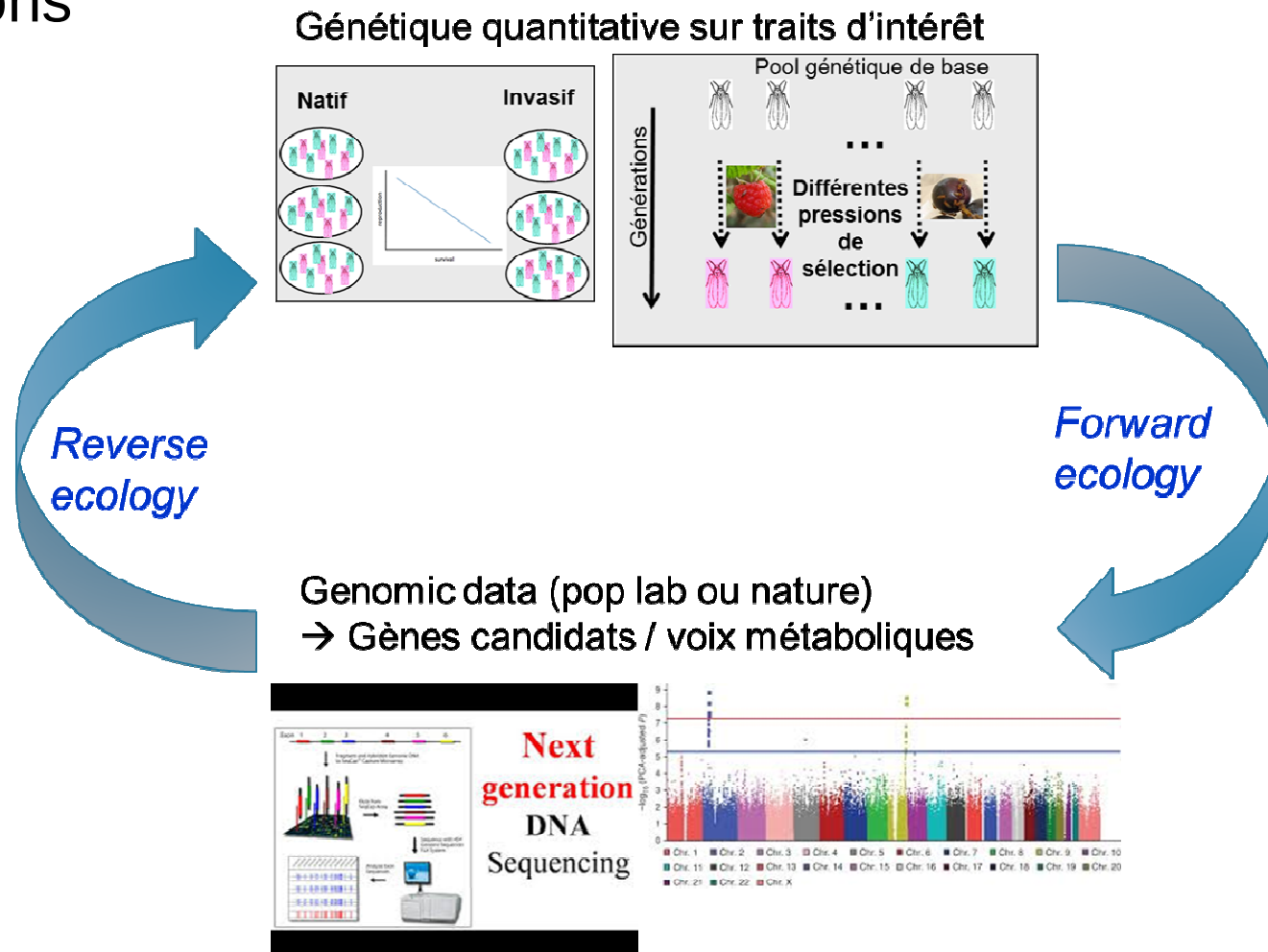
2/ Rôle essentiel de l'Homme dans les processus évolutifs associés aux invasions par la **détérioration / homogénéisation des milieux** notamment dans l'aire native (+ vectorisation)

3/ Il n'existe que rarement un paradoxe génétique chez les espèces envahissantes, sachant qu'il y a une **grande diversité des situations et des mécanismes évolutifs mis en jeux**



Une perspective: analyse fine des génomes via les nouvelles technologies de séquençage (NGS)

→ Gènes des traits quantitatifs qui ont évolués via des mécanismes de sélection naturelle au cours des invasions / proliférations



Un travail collectif !

Principaux collaborateurs: B. Facon, J. Foucaud, M. Gautier, B. Melbourne, M Szucs, M Vahsen, C Weiss-Lehman, E. Lombaert, T. Guillemaud, V. Ravigné, R. Vitalis, J. Orivel, O. Rey, J. Turgeon, Anne Loiseau, J-M Cornuet, C. Tayeh, G. Laugier, C. Lee, W. Su, J. Lungren, R. Koch, I. Zakharov, P. De Clerk, L Lawson Handley,...

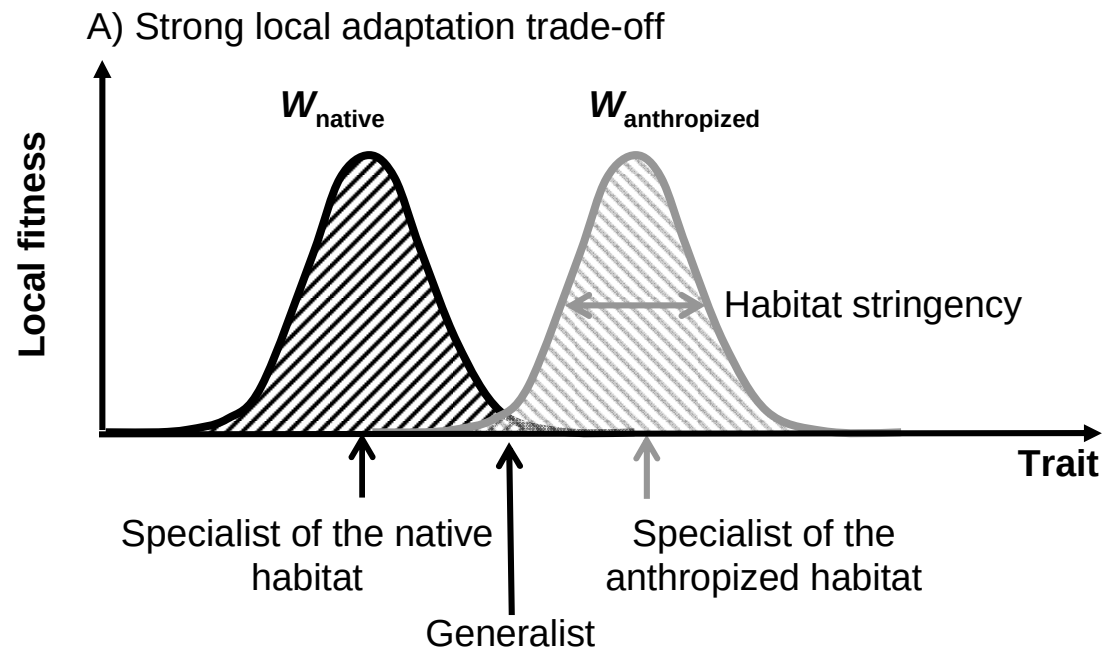
MERCI POUR VOTRE ATTENTION !



Références bibliographiques associées au séminaire

- Estoup A, Ravigné V, Hufbauer RA, Vitalis R, Gautier M, Facon B (2016) Is there a genetic paradox of biological invasion? Annual Review of Ecology, Evolution, and Systematics, 47, 51-72. doi: 10.1146/annurev-ecolsys-121415-032116.
- Facon B, Hufbauer RA, Tayeh A, Loiseau A, Lombaert E, Vitalis R, Guillemaud T, Lundgren J, Estoup A (2011) Inbreeding depression is purged in the invasive insect *Harmonia axyridis*. Current Biology. 21:424-427.
- Foucaud J, Fournier D, Orivel J, Delabie JHC, Loiseau A, Le Breton J, Kergoat GJ, Estoup A (2007). Sex and clonality in the little fire ant. Molecular Biology and Evolution, 24, 2465-2473.
- Foucaud J, Fournier D, Orivel J, Delabie JHC, Loiseau A, Le Breton J, Estoup A (2009) Reproduction system, social organization, human disturbance and invasive success in native populations of the little fire ant, *Wasmannia auropunctata*. Molecular Ecology, 18, 5059-5073.
- Fournier D, Estoup A, Orivel J, Foucaud J, Jourdan H, Le Breton J, Keller L (2005) Clonal reproduction by males and females in the little fire ant, Nature, 435, 1167-1168. [contribution égale pour F.D. et E.A.].
- Hufbauer, RA, M Szűcs, E Kasyon, C Youngberg, M Koontz, C Richards, T Tuff, BA Melbourne. 2015. Three dimensions of rescue can avert extinction in a changing environment. PNAS 112: 10557–10562. DOI: 10.1073/pnas.1504732112
- Lombaert E, Guillemaud T, Cornuet J-M, Malausa T, Facon B, Estoup A (2010) Bridgehead effect in the worldwide invasion of the biocontrol harlequin ladybird. PLoS ONE, 5, e9743, doi:10.1371/journal.pone.0009743.
- Lombaert E, Guillemaud T, Lundgren J, Koch R, Facon B, Grez A, Loomans A, Malausa T, Nedved O, Rhule E, Staverlokk A, Steenberg T, Estoup A (2014) Complementarity of statistical treatments to reconstruct worldwide routes of invasion: the case of the Asian ladybird *Harmonia axyridis*. Molecular Ecology, 23, 5931–6205. DOI: 10.1111/mec.12989
- Szűcs, M, BA Melbourne, T Tuff, C Weiss-Lehman, RA Hufbauer. 2017. Genetic and demographic founder effects have long-term fitness consequences for colonizing populations. Ecology Letters. *On line early*. DOI: 10.1111/ele.12743
- Orivel, J Grangier, J Foucaud, J Le Breton, F-X Andrès, H Jourdan, JHC. Delabie, D Fournier, P Cerdan, B Facon, A Estoup, A Dejean (2009) Ecologically heterogeneous populations of the invasive ant *Wasmannia auropunctata* within its native and introduced ranges. Ecological Entomology, 34, 504-512.
- Rey O, Estoup A, Vonshak M, Loiseau A, Blanchet S, Calcaterra L, Chifflet L, Rossi J-P, Kergoat G, Foucaud J, Orivel O, Leponce M, Schultz T, Facon B (2012) Where do adaptive shifts occur during invasion? A multidisciplinary approach to unravelling cold adaptation in a tropical ant species invading the Mediterranean area. Ecology letters, 15, 1266-1275.
- Steenberg T, Estoup A (2014) Complementarity of statistical treatments to reconstruct worldwide routes of invasion: the case of the Asian ladybird *Harmonia axyridis*. Molecular Ecology, 23, 5931–6205. DOI: 10.1111/mec.12989
- Szűcs M, B Melbourne, T Tuff, RA Hufbauer. 2014. The roles of demography and genetics in the early stages of colonization. Proceedings of the Royal Society B 281: 20141073. DOI: 10.1098/rspb.2014.1073
- Weiss-Lehman, C, RA Hufbauer, BA Melbourne. 2017. Rapid trait evolution drives increased speed and variance in experimental range expansions. Nature Communications. 8:14303 | DOI: 10.1038/ncomms14303

Matériel supplémentaire (optionnel): facteurs affectant le potentiel d'adaptation aux habitats anthropisés (altérés) au sein de l'aire native et attendus en terme de stratégie d'histoire de vie



B) Two ways for a local adaptation trade-off to be weak

