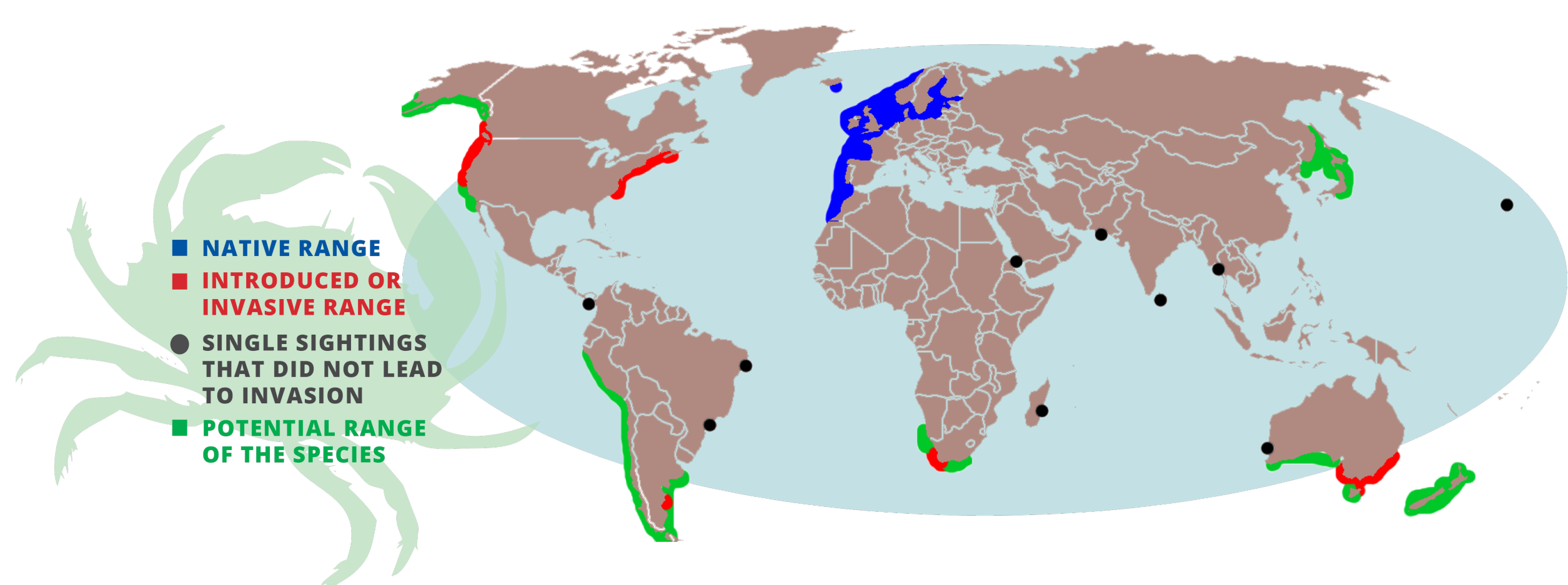


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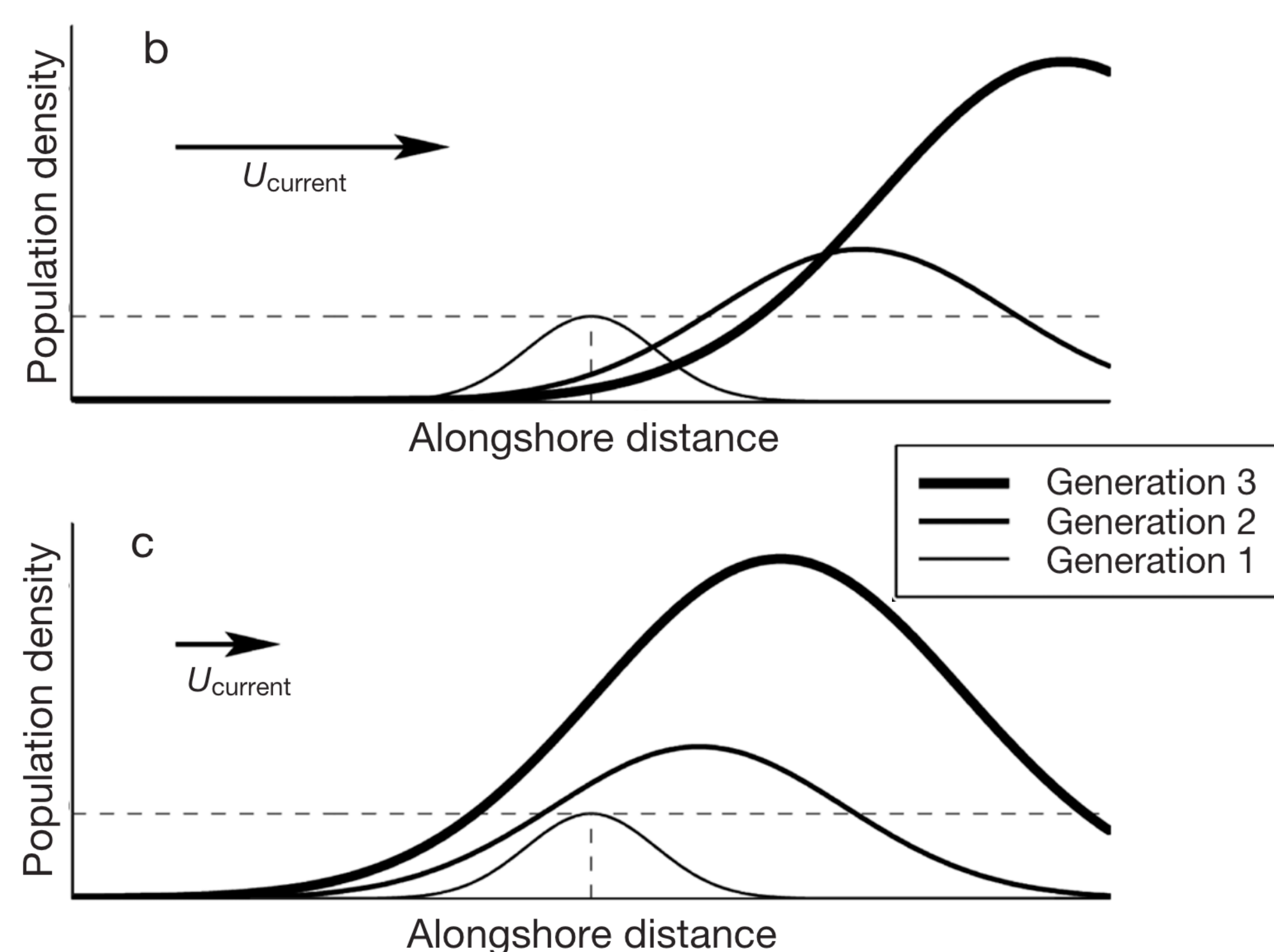
## Introduction

Marine invasions are a pressing threat to ecologies globally, but it is poorly understood what circulation conditions make them more likely!



## How do currents limit invasibility?

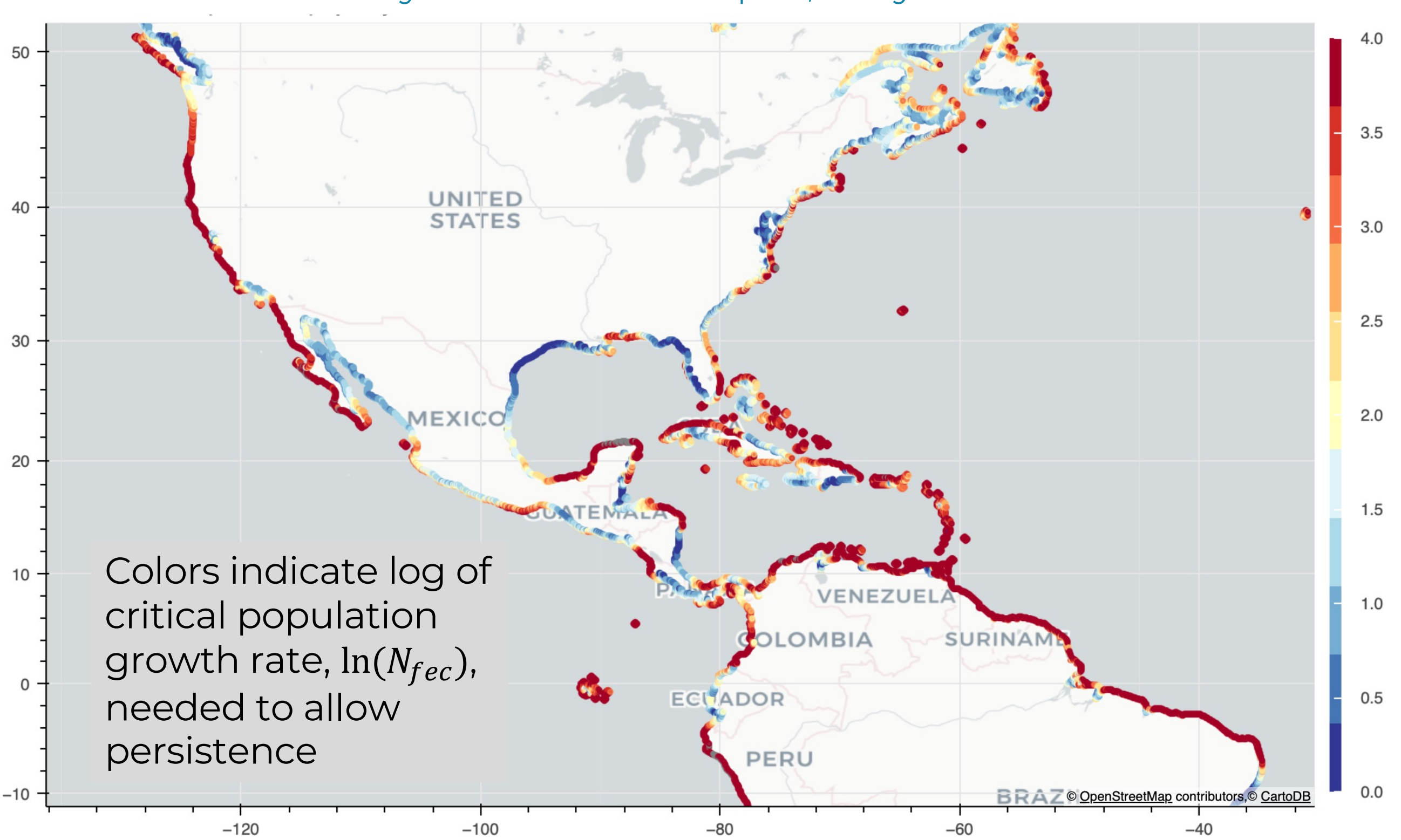
For an invading species to succeed, it must have a greater reproductive capacity than native species. But if larvae are planktonic, the mean currents make it harder to invade by sweeping larvae downstream! (Byers & Pringle 2006)



For an invasion to succeed, the reproductive advantage over competitors  $N_{fec}$  must be enough that the stochastic larval transport  $L_{diff}$  returns enough larvae upstream to compensate for the mean downstream transport  $L_{adv}$ .

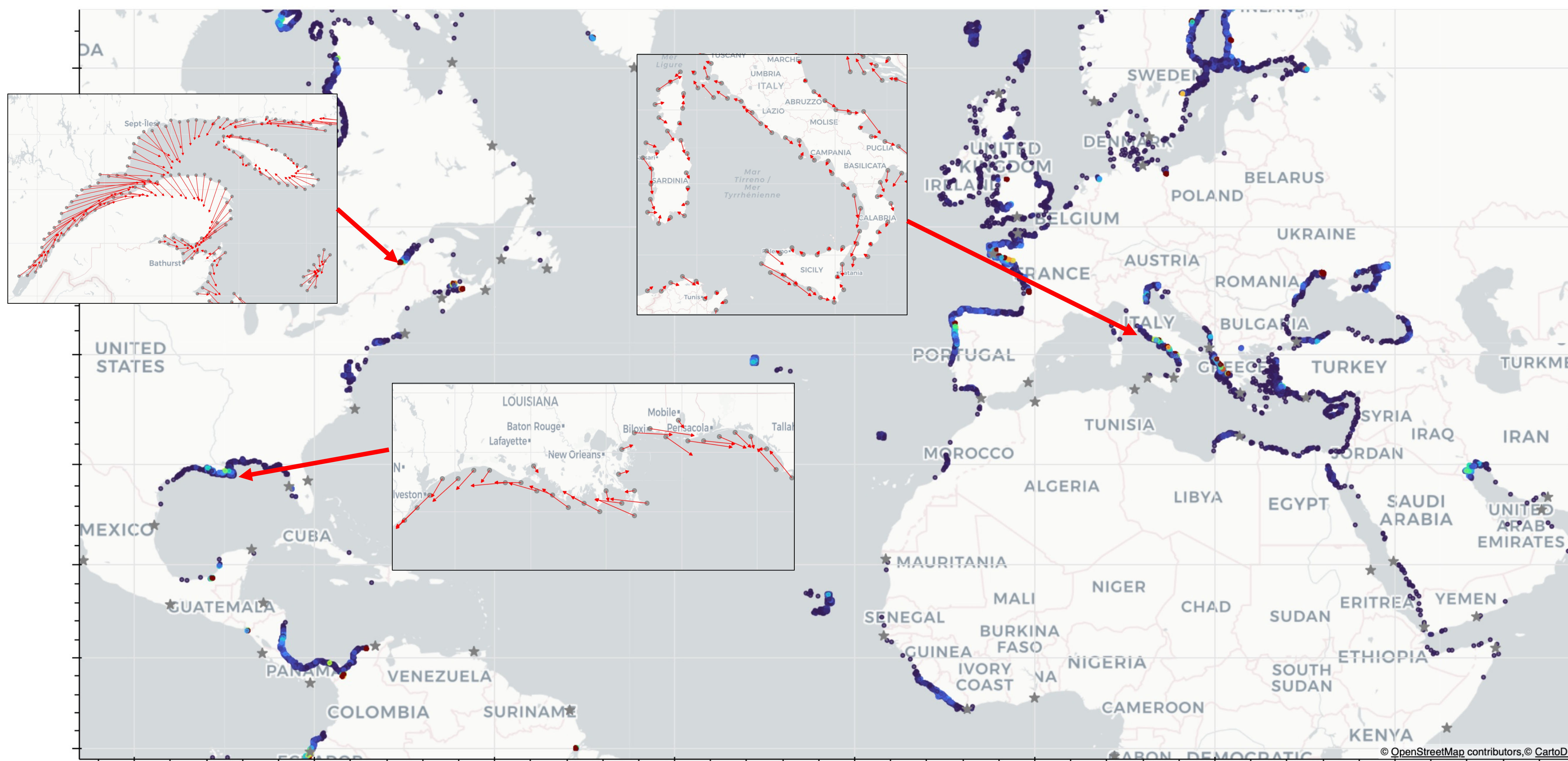
$$\ln(N_{fec}) > \frac{L_{adv}^2}{2L_{diff}^2} - \ln(\text{fraction larvae returned to habitat})$$

This can be a severe constraint for typical ocean larval transport. Shown is  $\ln(N_{fec})$  for surface drifting larvae with a duration of 30 days released in April, May and June.



## What is the effect of spatially varying currents?

Parameterize larval connectivity with Lagrangian pathways calculated from Mercator 1/12<sup>th</sup> degree global ocean model runs. Introduce different novel species of equal competitive ability in each model grid-point and either 1) integrate forward in time and see which species persist or 2) (more efficiently) integrate backwards in time and track origin of species which inhabit global coastal ocean. Either produces a map of locations where an introduced species can persist with no or small reproductive advantage over native species. These are the locations most vulnerable to introduced species for a given larval dispersal strategy. (That last clause does a lot of work ☺). Map below for 30 day larval duration, surface larvae, April-June release.

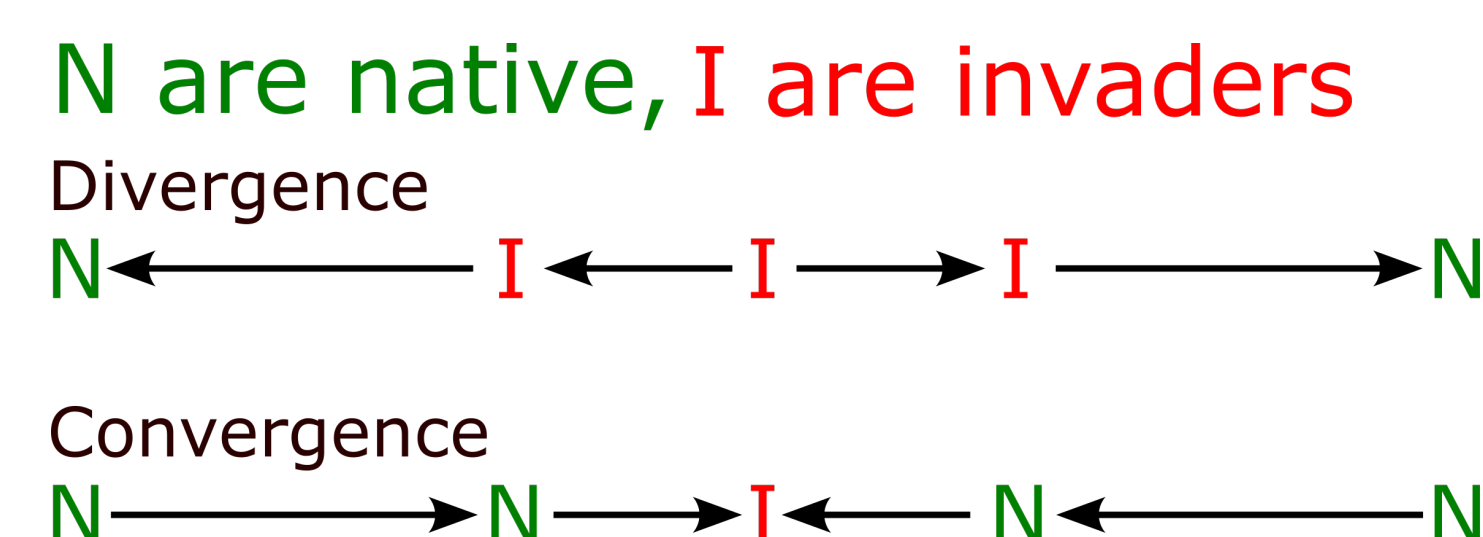


Arrows in insets are mean larval dispersal for 14 day larval durations (reduced duration to reduce clutter). (NOT EXACTLY CURRENTS!)

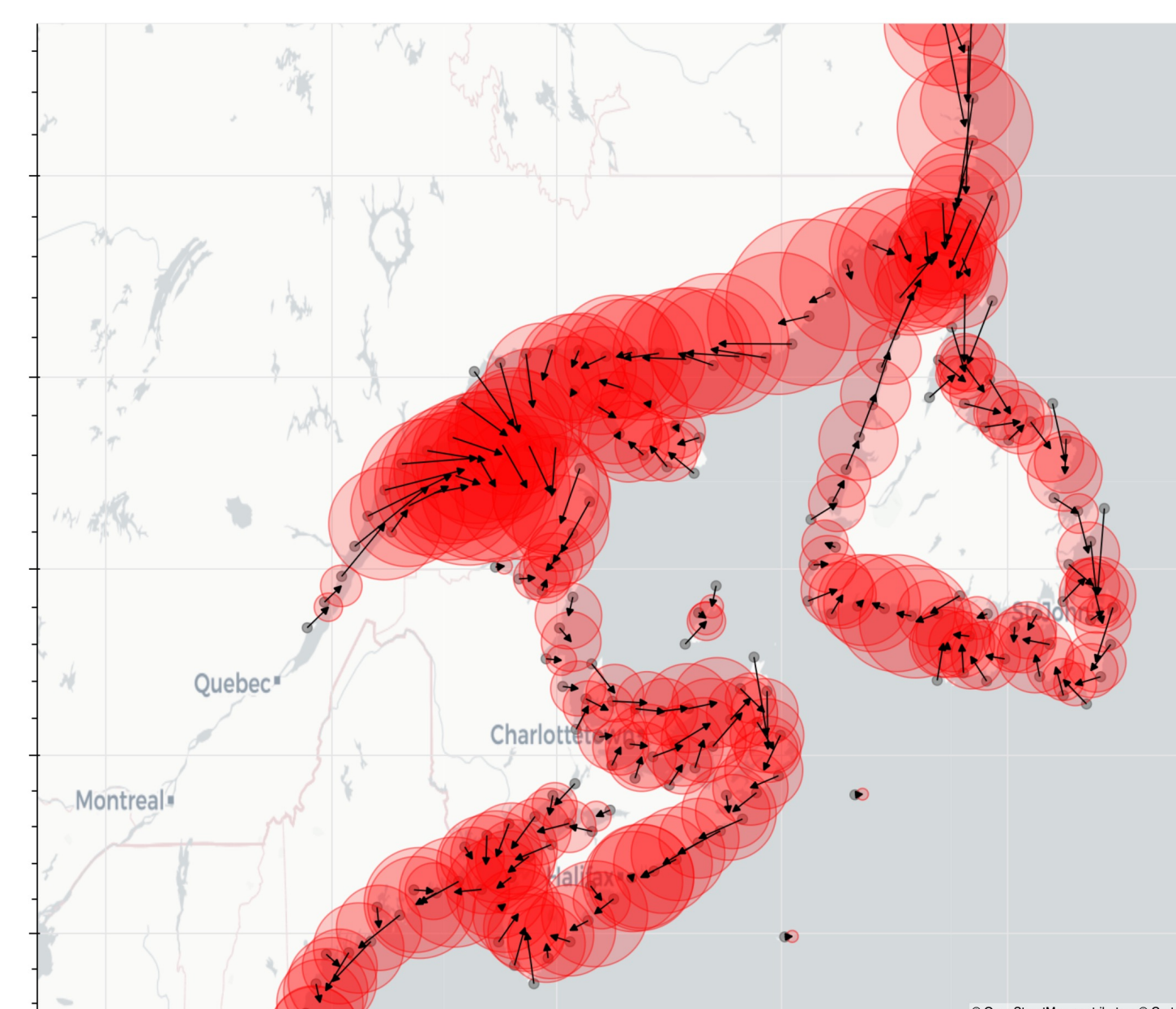
## Why divergence enhances invasibility?

The ability of an introduced species to persist at a place comes down to one thing: can it return more surviving larvae to that place than the native species it competes with?

Diverging larval transport shelters larvae from competition with larvae from elsewhere. Converging increases larval pressure.



But (!) there must be enough larvae produced that some return to the center of the divergence. This requires some variability in larval dispersal.



Above, the standard deviation of larval dispersal distance is shown by a red circle, and the mean by an arrow. The variability allows persistence, as described by Byers & Pringle (2006).

## Precomputed Lagrangian paths available!

Software and data for precomputed Lagrangian pathways are available at <https://github.com/JamiePringle/EZfate>. Pathways are being computed over the summer. Software in R, so everyone can join in... (Ask if you want Zarr with Python code).

## Global Interactive versions of the plots!

[https://oxbow.sr.unh.edu/data/GordonConference\\_2023/](https://oxbow.sr.unh.edu/data/GordonConference_2023/)



## Epilogue & Acknowledgements

This work shows where invasive species can be introduced. To know where they might end up, see Will Lush's poster:



This work was done in collaboration with Will Lush, Jeb Byers (biogeography) and John Wares (genetics; ask me how to use these ideas to understand ocean metapopulation dynamics, genetic diversity and phylogeography). NSF OCE-1947954