The evolution of range shifts: understanding and predicting species' responses to changing environments

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Abstract

The uneven spatial and temporal distribution of biodiversity is shaped by complex ecological and evolutionary processes, yet we still lack a predictive understanding of why some populations thrive under environmental change while others decline or disappear. In an era marked by rapid biodiversity redistribution—including range contractions, expansions, and biological invasions characterized by small population size—this knowledge is urgently needed to forecast species responses and inform conservation strategies. What determines whether a population or species will adapt, migrate, or go extinct when faced with novel conditions?

This PhD project tackles these questions by investigating the evolutionary mechanisms behind successful and failed range shifts in *Littorina saxatilis*, a marine snail that offers a powerful, easily accessible, and naturally replicated model for studying range-edge evolution. The research will focus on a recent—and likely human-mediated—introduction in the Venice Lagoon (Italy), the first confirmed alien species in the Mediterranean Sea. Strikingly, this population is now declining toward extinction, offering a rare opportunity to compare its trajectory with its source population and other successful or failing colonizations.

Using an integrative multidisciplinary approach, the project will combine genomics, morphometrics, behaviour, demography, and environmental data to uncover the drivers of colonization success. Key activities include:

- Sampling modern and historical specimens and data across the species' range;
- Conducting phenotypic and behavioural analyses to assess trait changes;
- Generating whole-genome data to explore adaptation, diversity loss, demographic shifts, and colonization routes;
- Performing genotype-phenotype-environment associations to identify critical factors in range-shift outcomes.

By disentangling the roles of evolutionary background, erosion of genetic diversity, fast-track adaptation, and environmental changes in shaping the fate of marginal populations, this research will advance our understanding of biodiversity dynamics in changing ecosystems. The findings will not only shed light on fundamental evolutionary processes but also provide actionable insights for predicting and managing species responses to global change.

Results will be widely disseminated through scientific publications, stakeholder engagement, and public outreach, fostering broader awareness of biodiversity challenges and strengthening resilience against the ongoing biodiversity crisis.