

Can common sole keep up with a changing ocean?

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1 Background

The North Sea and Celtic Sea are among the fastest-warming seas in the Atlantic[1], and fish distributions are already shifting[2]. How well a population copes depends not only on how much its environment changes, but on its genetic variation.

Genomic offset uses today's links between genotypes and the environment (genotype-environment association, GEA)[3] to predict how well populations will match future climates.

Common sole (*Solea solea*) is one of the UK's most commercially valuable fish[4]. As a warm-water species near the cooler edge of its range[5], its response to warming is hard to predict, and populations may differ in how well they cope.

Which sole populations are most genetically mismatched to future climate conditions?

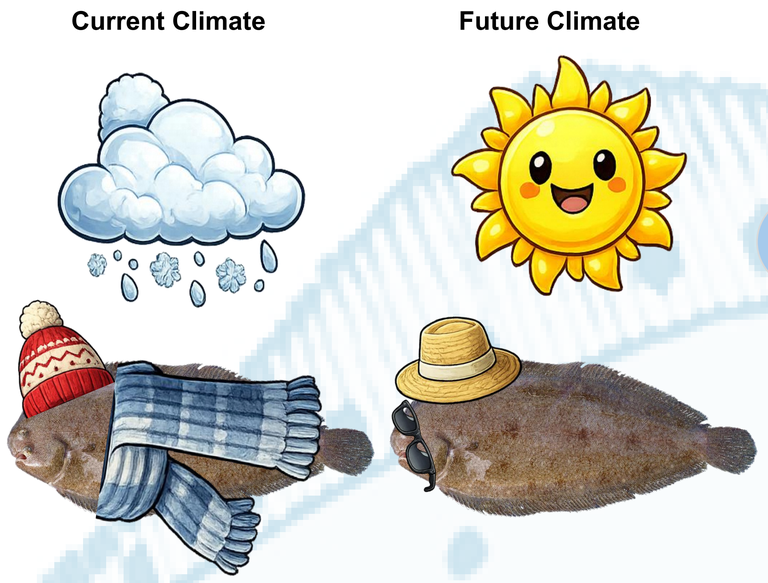


Figure 1. Genomic offset: dressed for today, but ready for tomorrow?

2 Aims & Objectives

Analyse neutral population structure in sole	Strong population structure confounds GEA and requires conditioning on it[3]
Run a genotype-environment association test	To see how genotypes are associated with current environmental variables
Use the current associations to calculate genomic offset	Determine which populations have genotypes mismatched to their projected future conditions

3 Methods

Quality Controlled Data[6] (245 Individuals)

↓

Variant Calling
29,902,430 SNPs (n = 242)

↓

Filtering (missingness, MAF)
20,384,853 SNPs (n = 235)

Retain Outlier Regions	Linkage Pruning (neutral SNPs)
6,717 SNPs (n = 186, 17 sites)	4,079,709 SNPs (n = 186)

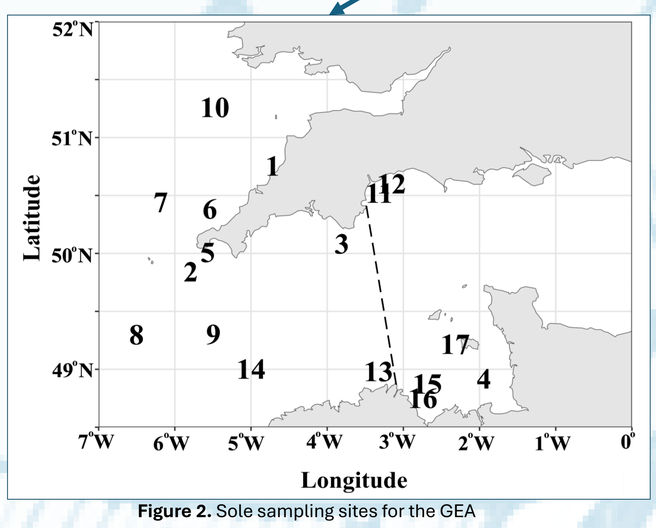


Figure 2. Sole sampling sites for the GEA

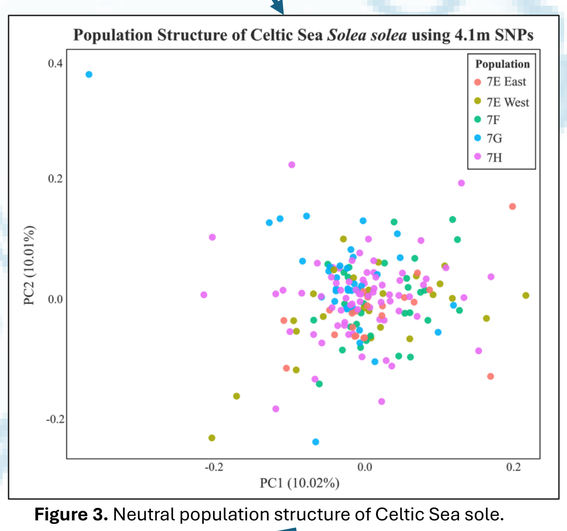


Figure 3. Neutral population structure of Celtic Sea sole.

Current and future environment at each site

No neutral structure → No conditioning needed!

Redundancy Analysis (RDA): Genotype ~ Current Environment
Mean Temperature • Oxygen Range • Velocity Range • Max. Salinity

Genomic offset: same model but future environment
Difference between a site's current and future association score = **offset!**

4 Results

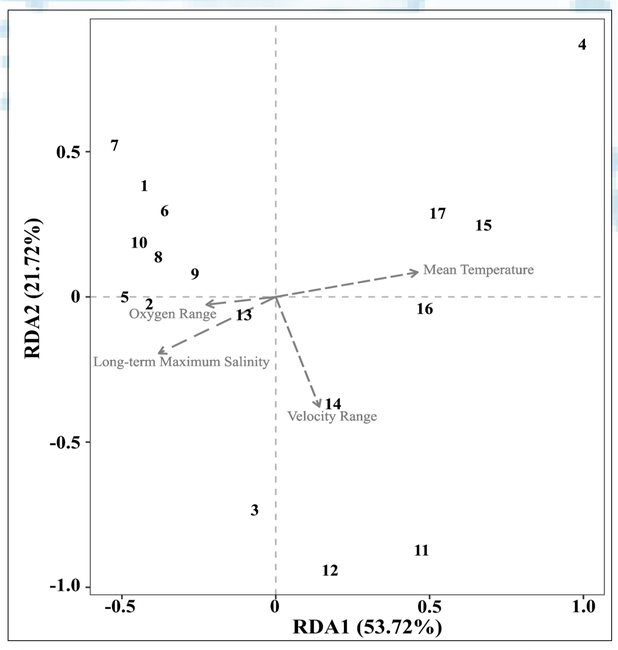


Figure 4. Redundancy analysis of outlier allele frequencies in the 17 Celtic Sea sampling sites. Numbers are sampling groups; arrows show the four environmental variables.

- The outlier regions were significantly associated with the environment (F = 1.64, p = 0.002).
- Sites on the right of RDA1 had the warmest water and the smallest oxygen range.
- The outlier regions contain *troponin C* (*tnnc2.2*), a muscle-contraction gene whose function is temperature-sensitive in fish[7].
- An association was also found in an independent NE Atlantic dataset (F = 2.73, p = 0.001)

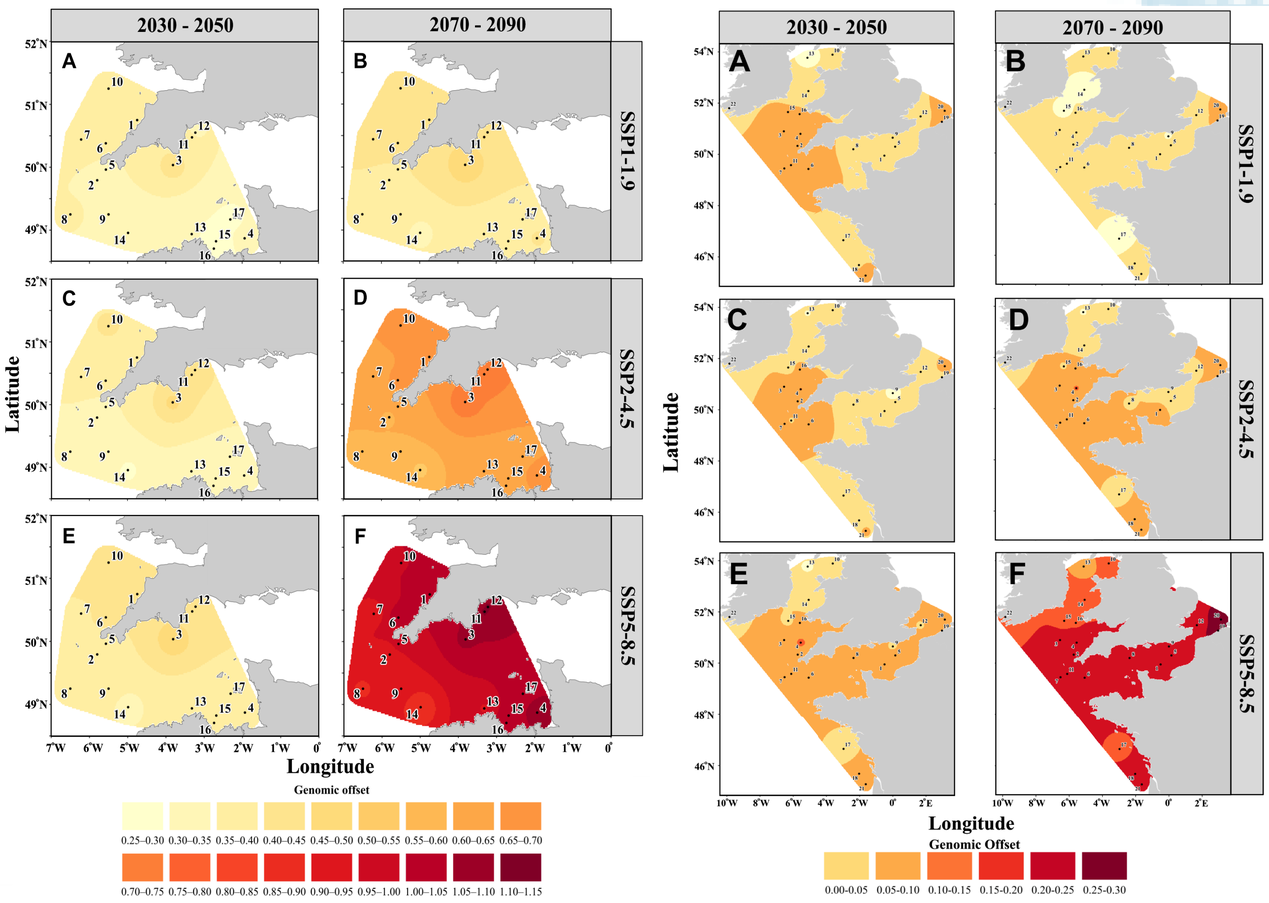


Figure 5. Genomic offset for (a) the Celtic Sea and (b) the NE Atlantic, for 2030–2050 and 2070–2090 under three emission scenarios. Darker colours = greater predicted mismatch with future climate. Colour scales differ between maps.

- Genomic offset increased with higher emissions and later time periods.
- Offset showed no consistent geographic gradient.
- The entrance to the English Channel is a region of high offset.
- Offset magnitudes were uncertain; rankings are more reliable than absolute values.

5 Discussion

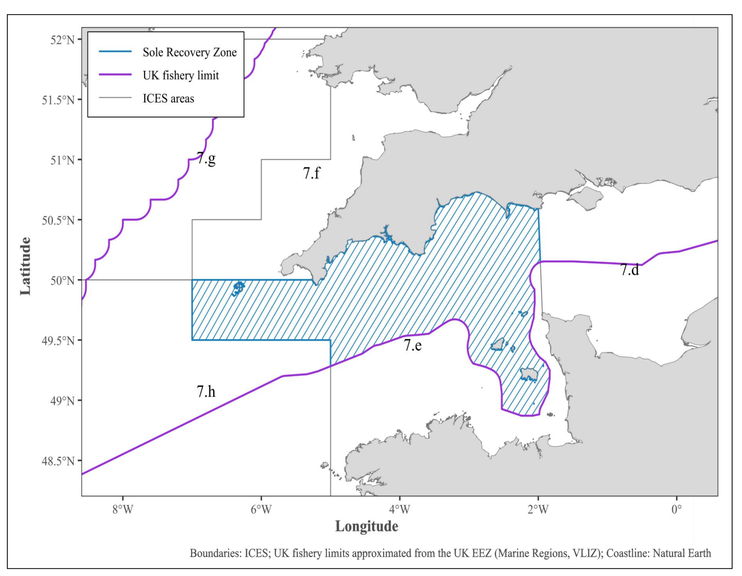


Figure 6. The Sole Recovery Zone (hatched), where fishing effort for sole is restricted.

- The high-offset Channel entrance lies largely within the Sole Recovery Zone[8].
- Existing management areas could be used to monitor genetic change.
- In the cooler part of their range, sole may benefit from slow warming[9,10], but rapid warming could outpace adaptation.
- Offset is a prediction of mismatch, not of decline.

Next steps: Genomic offset in European plaice, which prefer cooler water[10], to compare climate vulnerability across flatfish.

1. Kessler et al. (2022) doi:10.1016/j.pocean.2022.102902 **2.** Perry et al. (2005) doi:10.1126/science.1111322 **3.** Capblancq & Forester (2021) doi:10.1111/2041-210X.13722 **4.** MMO (2025) UK Sea Fisheries Statistics 2024. gov.uk **5.** Rijnsdorp et al. (2009) doi:10.1093/icesjms/fsp056 **6.** Ciezarek et al. (2026) doi:10.64898/2026.06.10.731368 **7.** Gillis & Tibbits (2002) doi:10.1016/S1095-6433(02)00046-6 **8.** MMO (2026) Sole Recovery Zone 2026–2027. gov.uk **9.** Maltby et al. (2020) doi:10.1111/1365-2664.13724 **10.** Teal et al. (2008) doi:10.3354/meps07367