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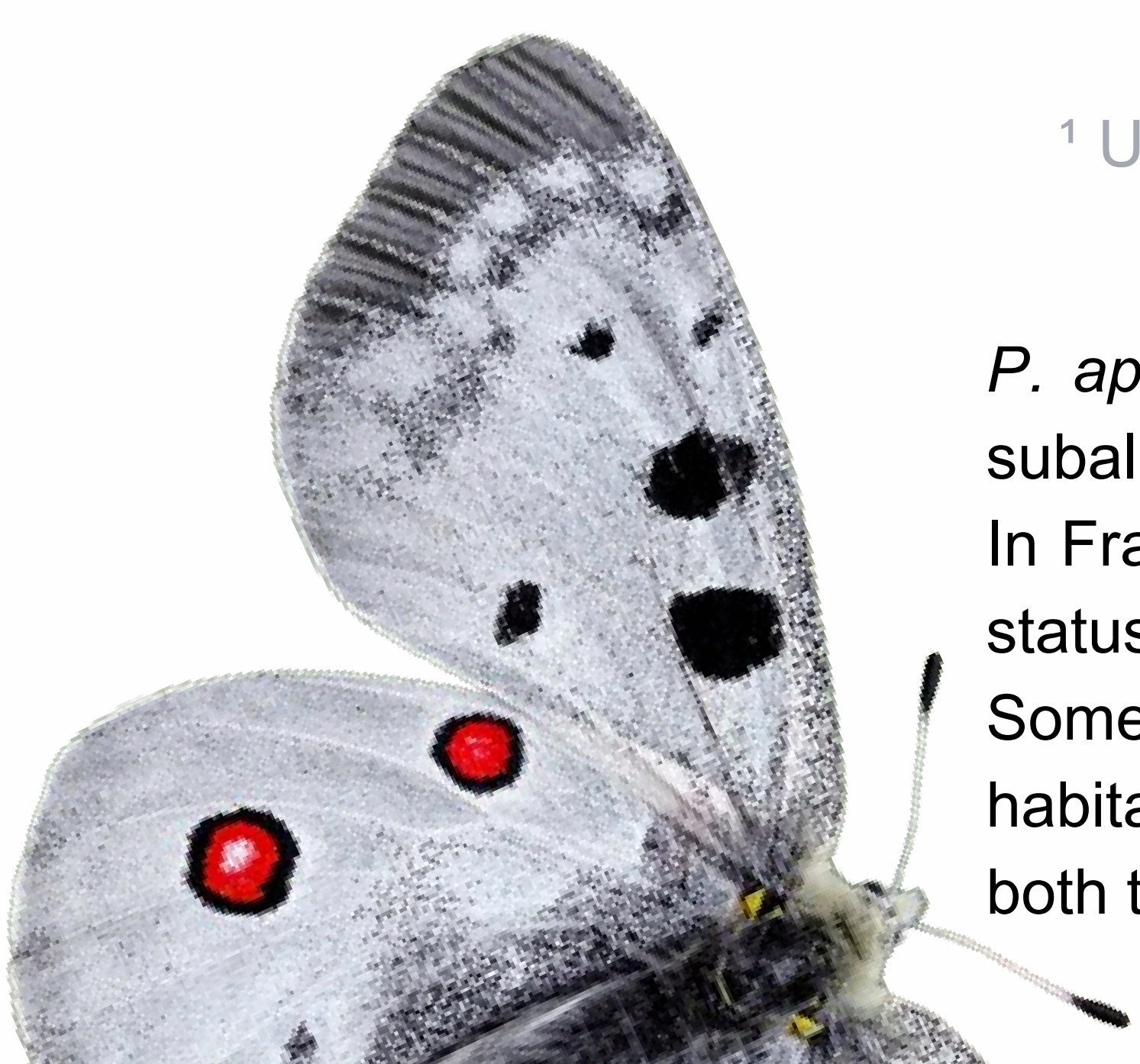
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Impacts of environmental changes on demographic history and genetic structure of the iconic butterfly *Parnassius apollo* populations in France: implications for conservation

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Apollo's caterpillar on *Sedum* sp.



P. apollo (Papilionidae) is an emblematic mountain butterfly, with isolated and small populations distributed in open and, subalpine habitats across Eurasia. The caterpillars develop on species of Crassulaceae (*Sedum* sp. and *Sempervivum* sp.). In France, *P. apollo* is present in the three main mountain ranges (Pyrenees, Massif Central and Alps). Although it has the status of least concern (LC) in France, *P. apollo* is experiencing a decline in its populations, particularly in low altitudes. Some local extinctions have been reported (Vosges, Causse of Larzac, Forez). Sources of its decline are climate change, habitat closure and also overgrazing. The aim of this project is therefore to precise **conservation actions** for *P. apollo* at both the national and local levels.

PhD objectives

- Identify the **genetic structure** of populations between massifs and within each massifs, and calculate **genetic diversity metrics**
- Analyze **population size changes** over time and their links to climate change
- Identify **vulnerable populations** to climate change
- Identify **landscape features** structuring its dispersal
- Guide **conservation strategies**

Sampling and genetic diversity

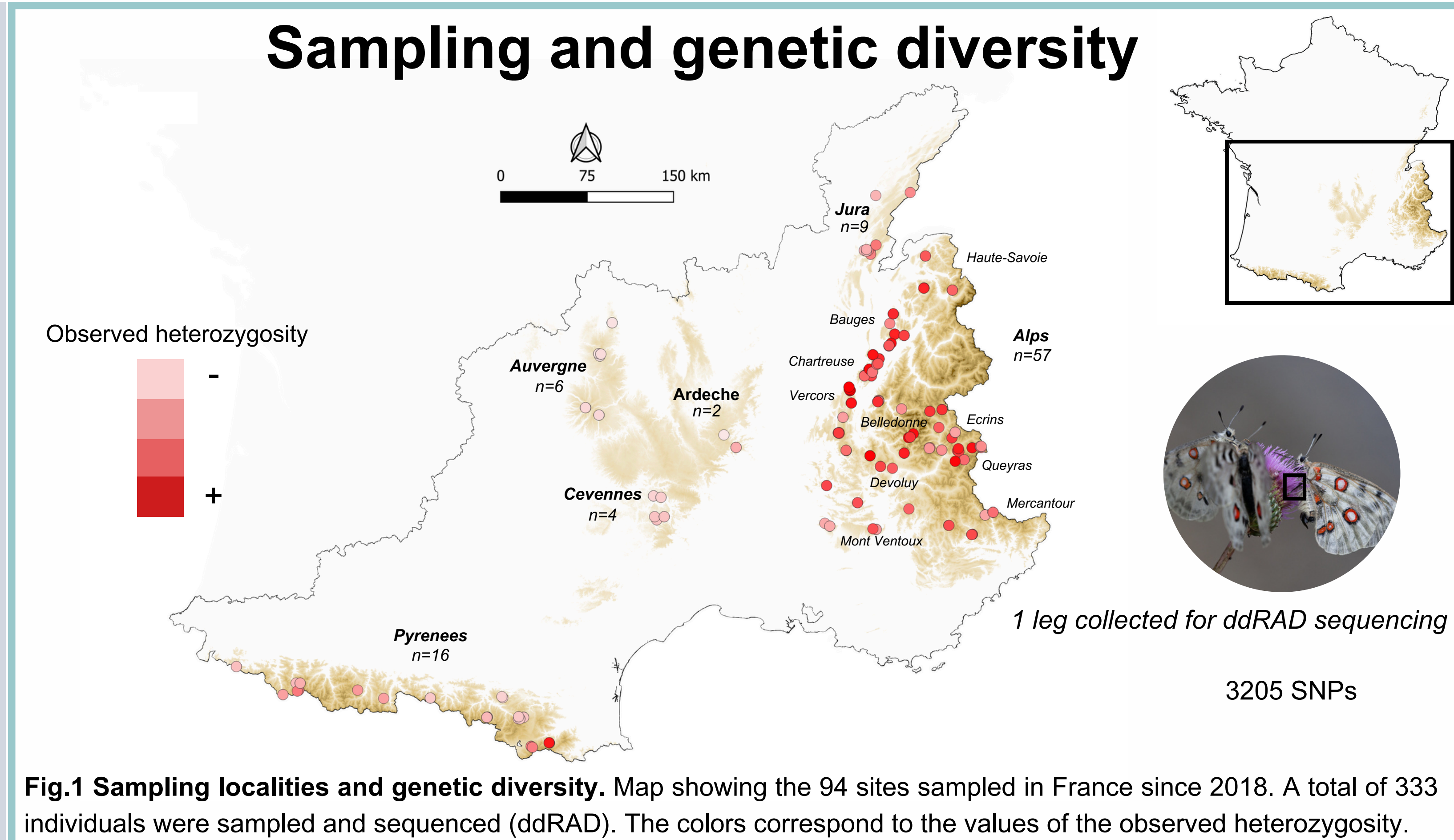


Fig.1 Sampling localities and genetic diversity. Map showing the 94 sites sampled in France since 2018. A total of 333 individuals were sampled and sequenced (ddRAD). The colors correspond to the values of the observed heterozygosity.

Genetic structure

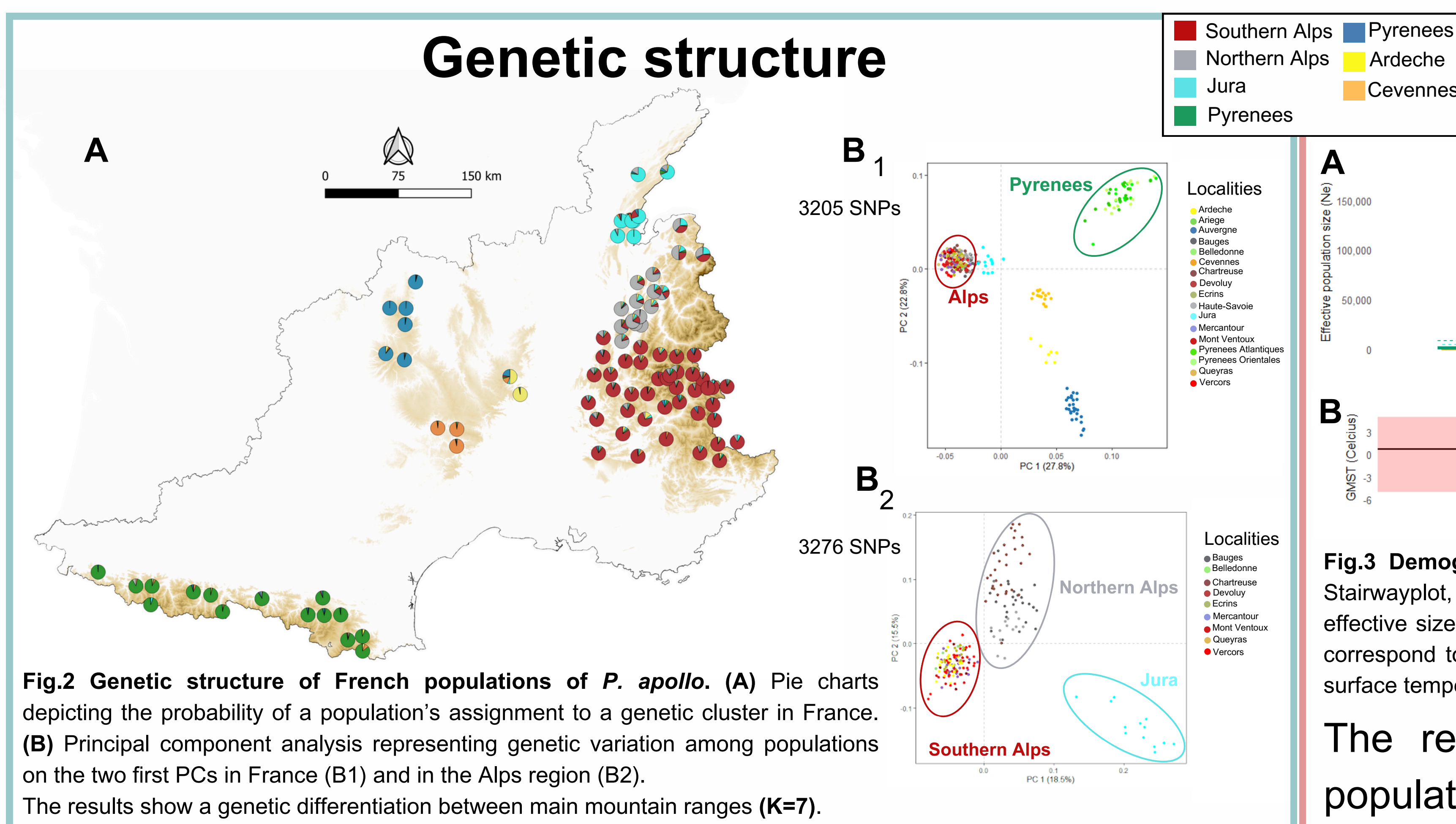


Fig.2 Genetic structure of French populations of *P. apollo*. (A) Pie charts depicting the probability of a population's assignment to a genetic cluster in France. (B) Principal component analysis representing genetic variation among populations on the two first PCs in France (B1) and in the Alps region (B2). The results show a genetic differentiation between main mountain ranges (K=7).

Demographic inferences

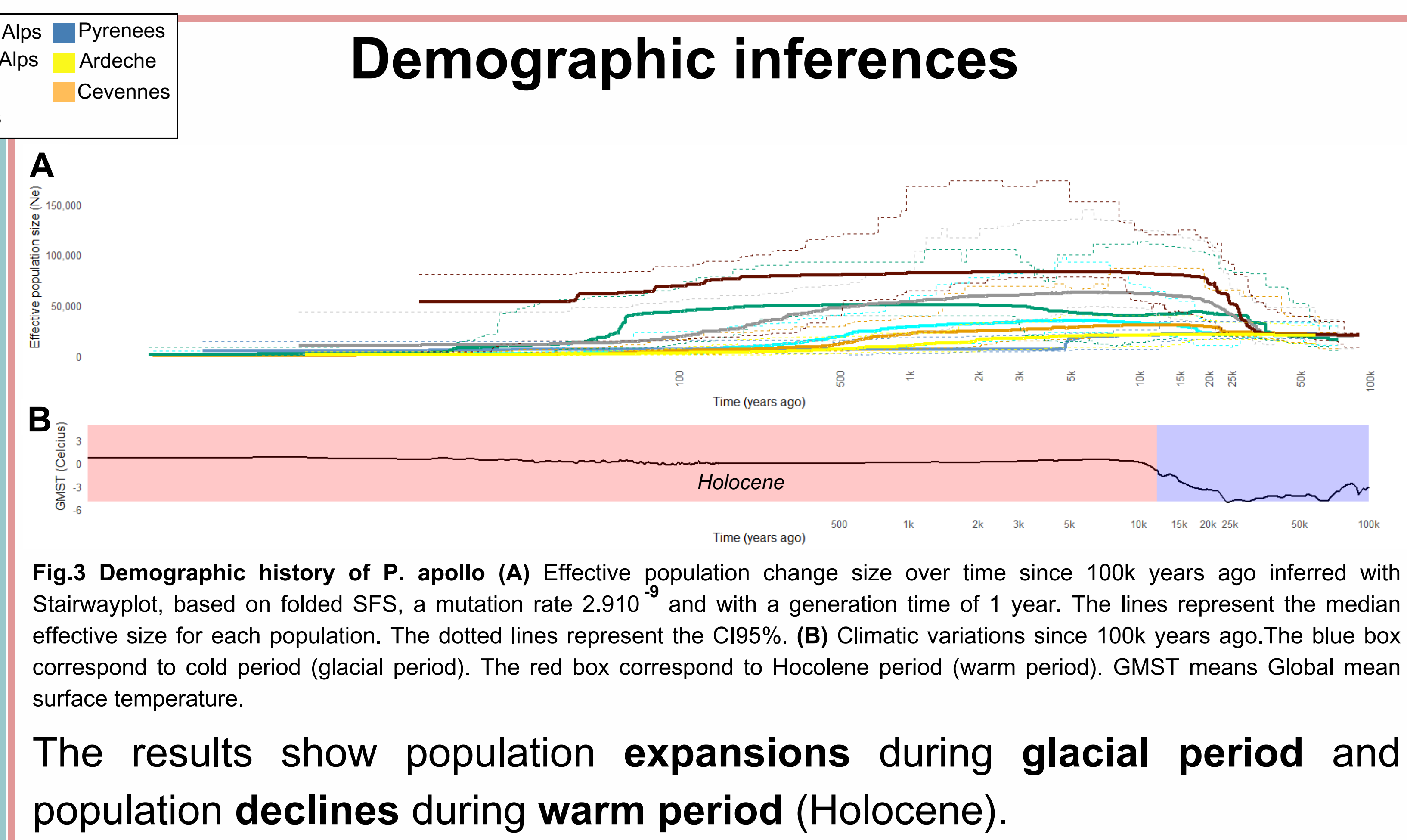


Fig.3 Demographic history of *P. apollo* (A) Effective population change size over time since 100k years ago inferred with Stairwayplot, based on folded SFS, a mutation rate 2.910^{-9} and with a generation time of 1 year. The lines represent the median effective size for each population. The dotted lines represent the CI95%. (B) Climatic variations since 100k years ago. The blue box correspond to cold period (glacial period). The red box correspond to Holocene period (warm period). GMST means Global mean surface temperature.

The results show population **expansions** during **glacial period** and population **declines** during **warm period (Holocene)**.

Vulnerability to climate change

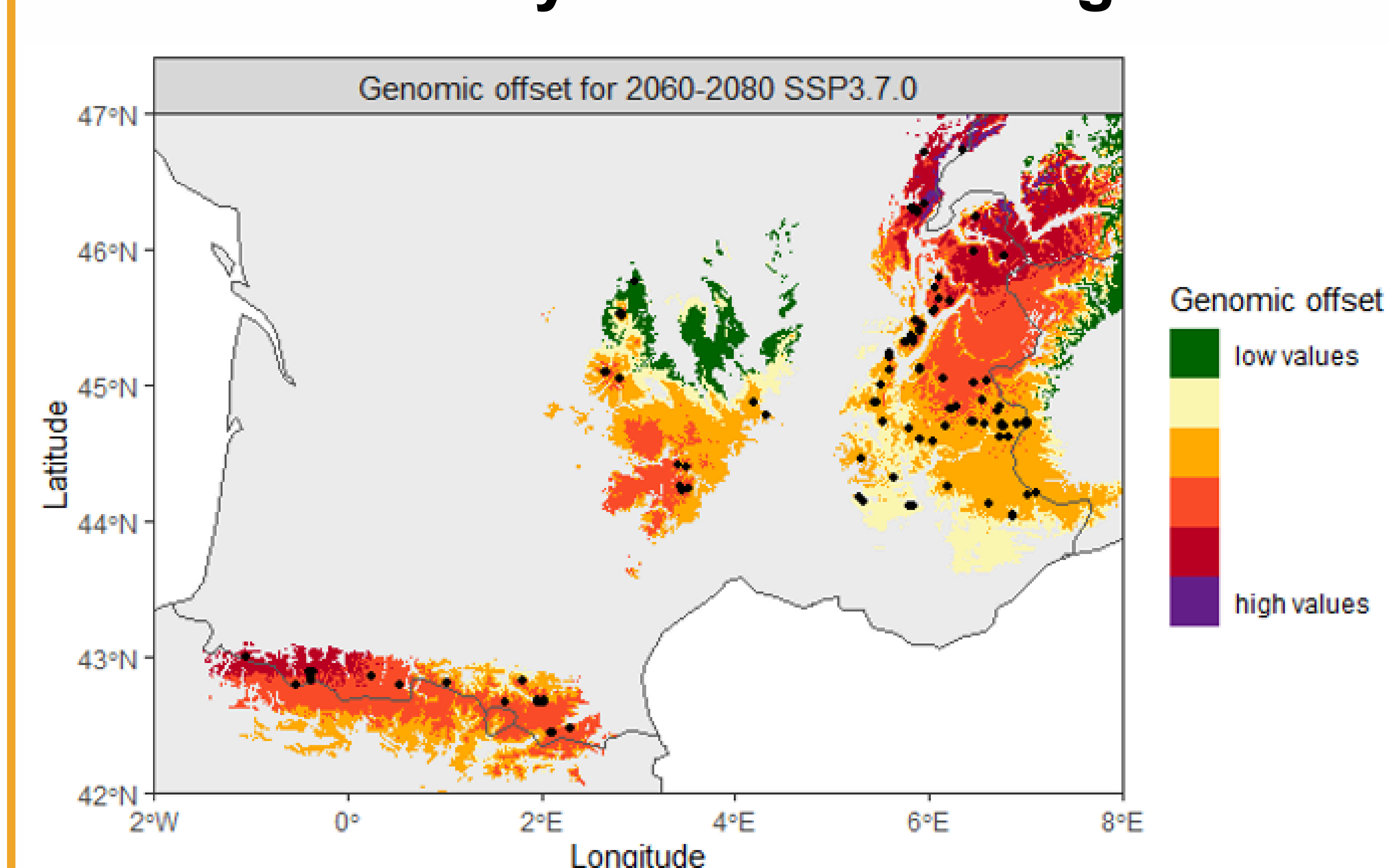


Fig.4 Projection of the difference between the current and future (2060-2080) genetic composition (genomic offset) of *P. apollo* populations within their distribution range in France. The black dots represent the various sampled localities. The colors indicate the values of genomic offset. The red areas correspond to populations potentially maladapted to their future habitat.

Genomic variation associated to climatic variation have identified populations putatively adapted to **dry** and **warm** conditions, and populations adapted to **cold** and **wet** conditions. Moreover, projection of the genomic composition required under future climatic conditions have identified the most **vulnerable populations** (with the highest genomic offset in figure 4)

Perspectives

Experimental tests of local adaptation hypothesis :

Thermal stress tolerance on eggs from different populations in the Alps

- warm temperatures
- cold temperatures

Comparison of **egg hatching rates** (survival rates) between the South Alps populations (warm) and the North Alps populations (cold).

Other PhD perspectives

- Through a **museomic approach**, a HyRAD method will be used to sequence historical DNA from museum specimens of *P. apollo*, in order to obtain information on past genetic diversity.
- Study landscape connectivity of *P. apollo* at different scales, through a **landscape genetics approach**.



historical samples from Grenoble museum

