

Diversity of strategies to study the genetic/genomic basis of adaptation

Day 5 – Lecture

(slides adapted from Anna Tigano's lecture)

Approaches to study local adaptation

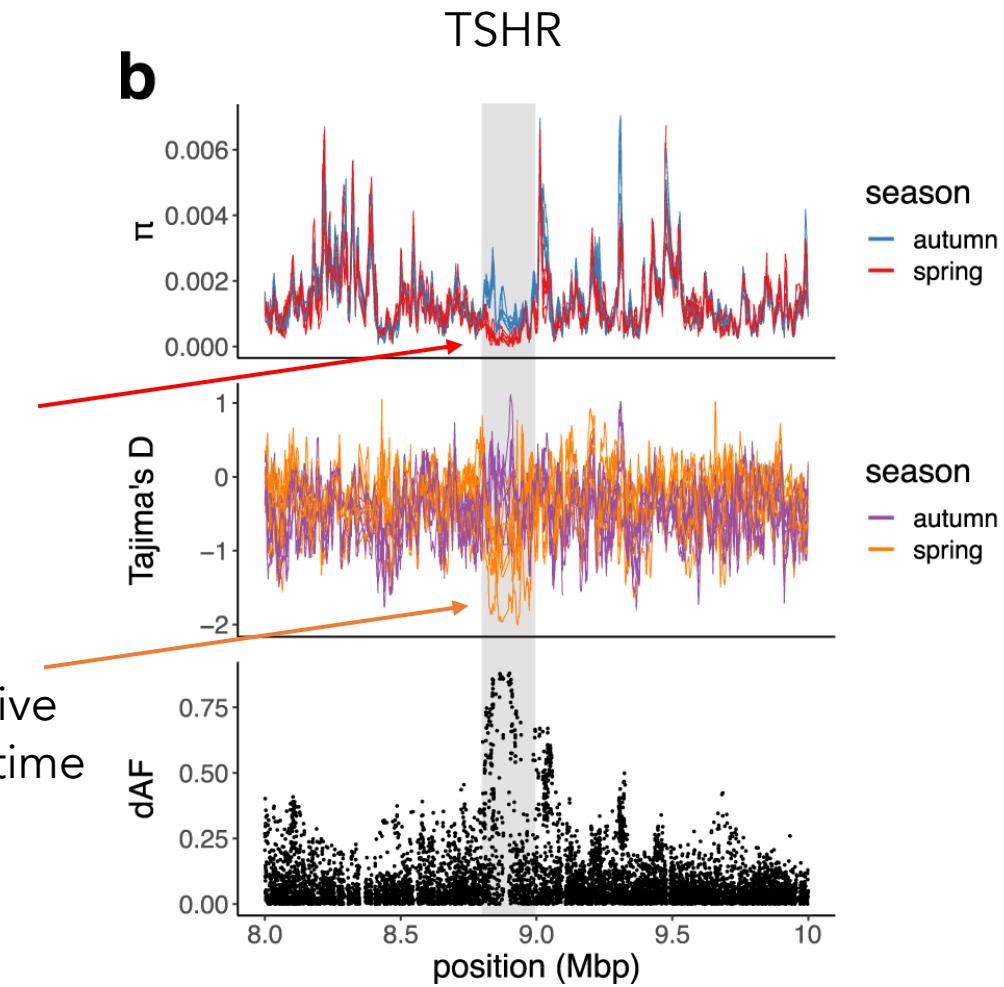
- Local adaptation / population genomics
- Comparative genomics
- Trait-focused genetics/genomics
 - GWAS
 - QTL
- Multi-omics
 - Transcriptomics
 - Epigenomics
 - Proteomics
- Functions and experiments
 - Experimental evolution/selection
 - Candidate genes
 - Common garden
 - Gene-editing

Local adaptation & population genomics

- Site frequency spectrum
 - Tajima's D

Atlantic herring
Spring vs Autumn spawning

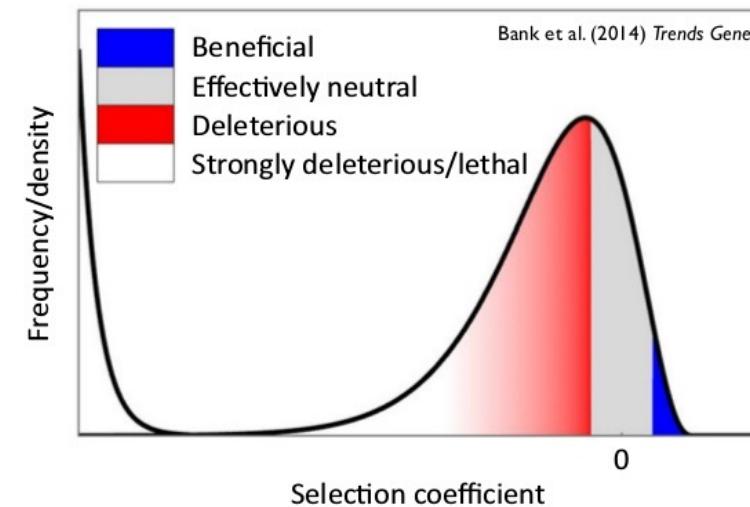
Low diversity
Signature of selective sweep in spawning time gene



Local adaptation & population genomics

- Site frequency spectrum
 - Tajima's D
 - Distribution of fitness effects

Distribution of fitness effects (DFE)
of new mutations

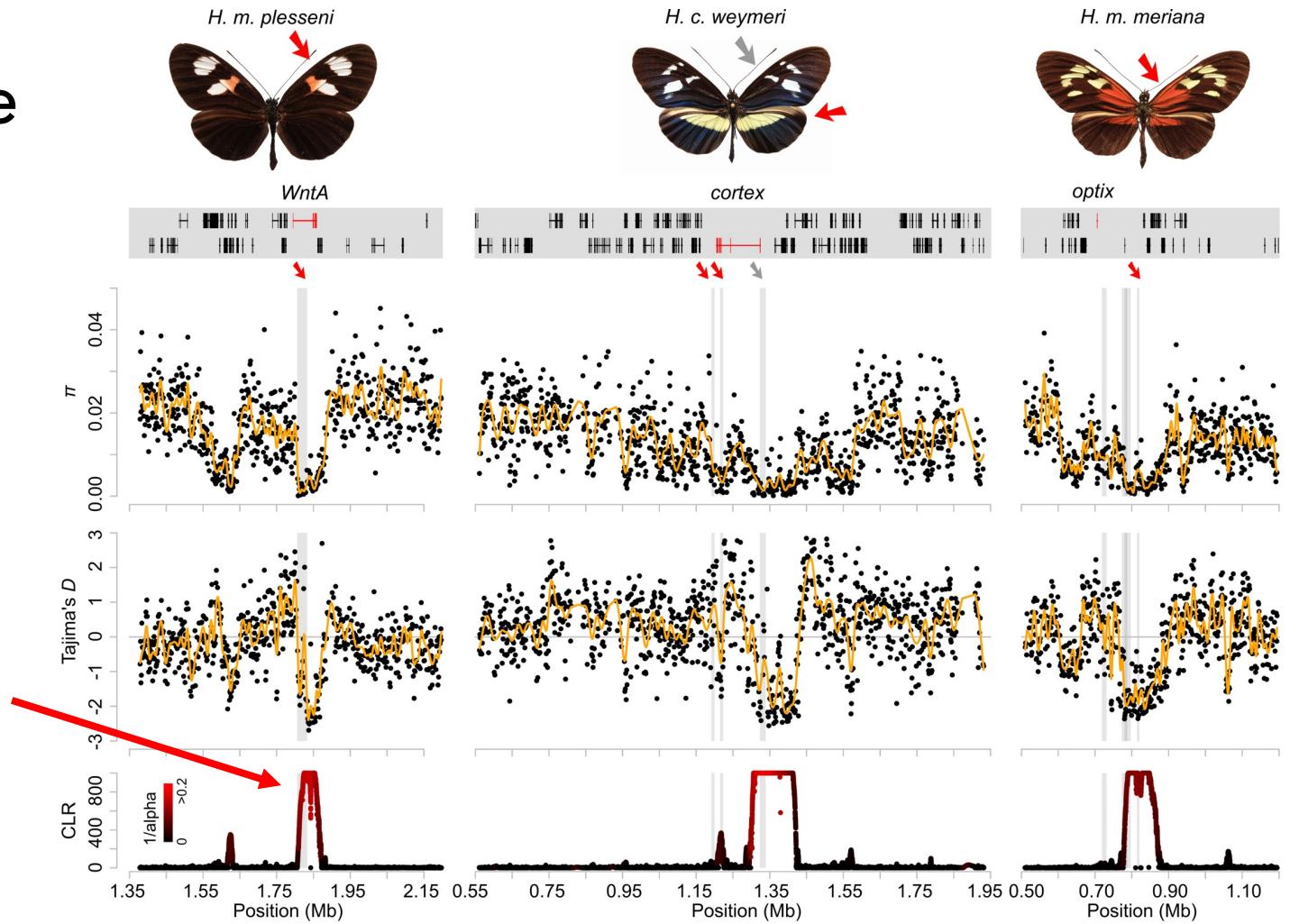


polyDFEv2.0 Tataru et al 2017 Genetics

Local adaptation & population genomics

- Signatures of selective sweeps
 - SweepFinder*

SweepFinder
Low pi (diversity)
Low Tajima's D



Local adaptation & population genomics

- Extended haplotype homozygosity

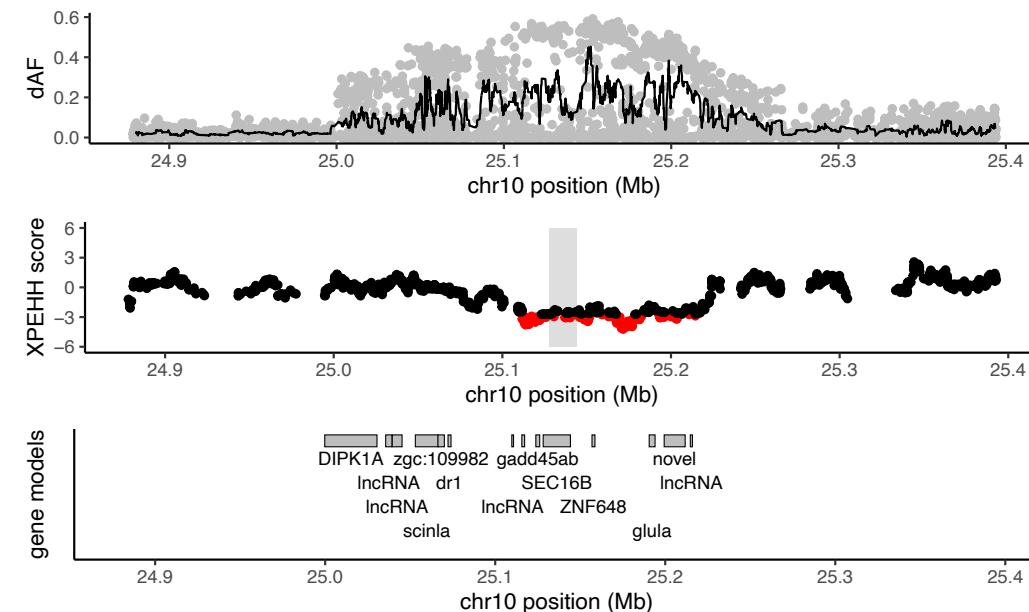
Captures signature of selective sweep

Excess of homozygote sites

EHH – Sabeti et al 2002 Nature

iHS – Voight et al 2006 Plos Biology

XP-EHH – Sabeti et al 2007 Nature



Signature of selection in Baltic
Spring spawning herring vs Autumn spawning

Software: hapbin

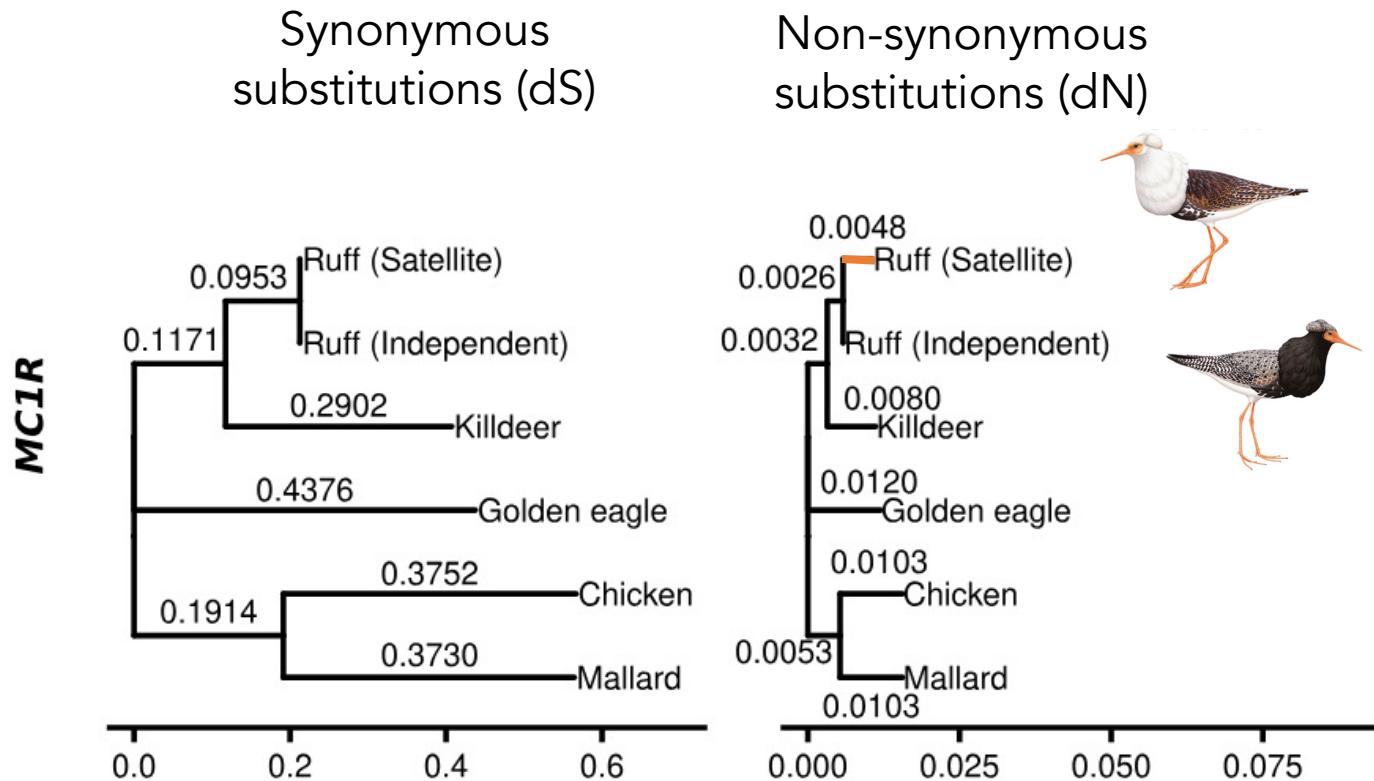
Population genomics / comparative genomics

Comparison to outgroup

- $\omega = dN/dS$ ratio
- McDonald Kreitman test
- Fay and Wu's H

Accumulation of non-synonymous subs.

Pigmentation gene

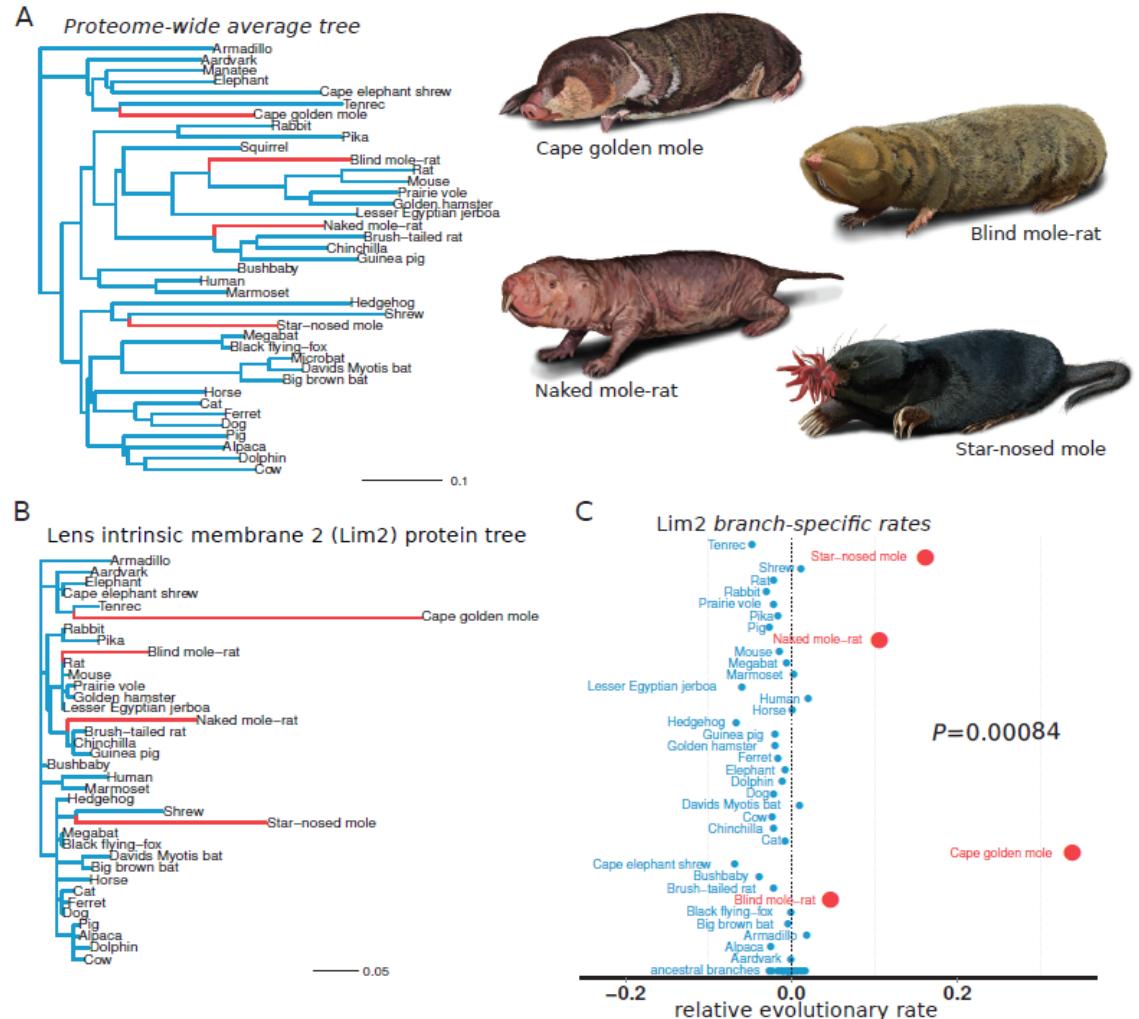


Population genomics / comparative genomics

Adaptive convergence across species

- Rapid evolution along branches of tree

Software: PAML; HyPhy



Trait based approaches

- Contrasting individuals/ populations with different phenotypes
- Explicitly test association of allele frequency differences with phenotypic variation

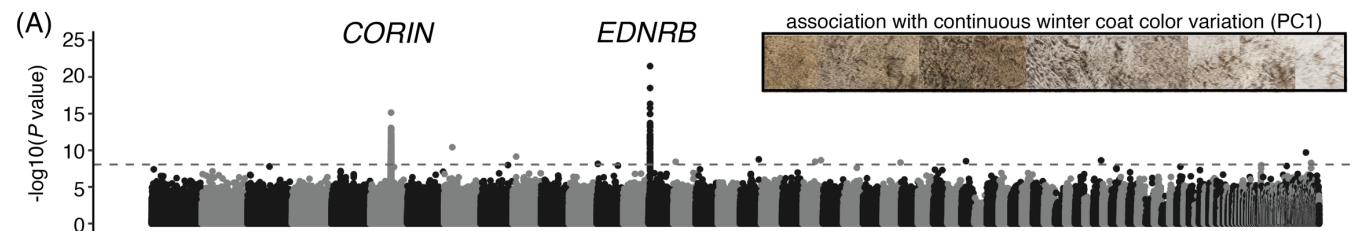
Trait based approaches

Genome wide association study (GWAS)

Winter coat color variation in white-tailed jackrabbits

- 61 individuals (more better!)
- Genome-wide data coverage ~2X
- GWAS with white vs brown & continuous color

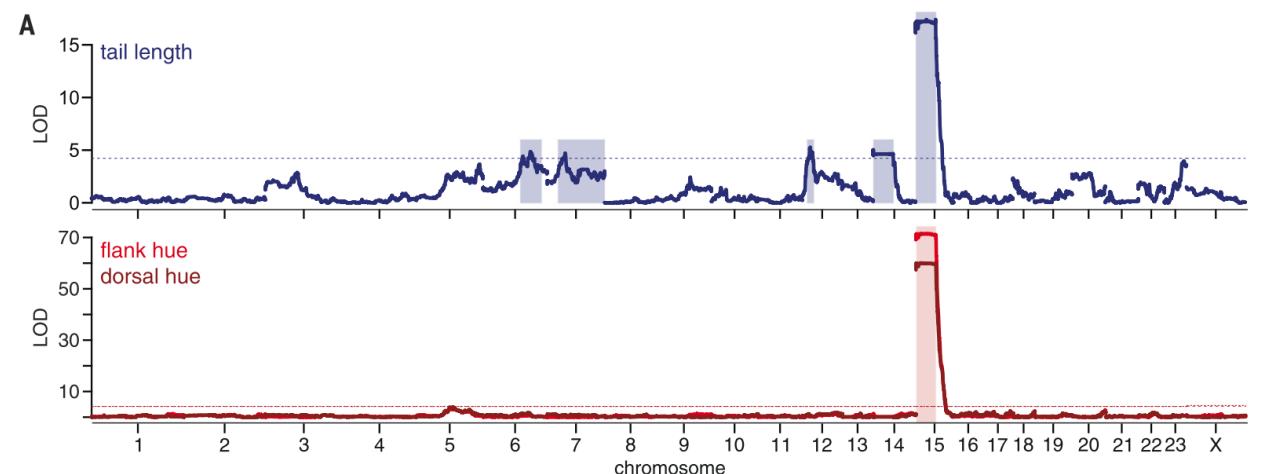
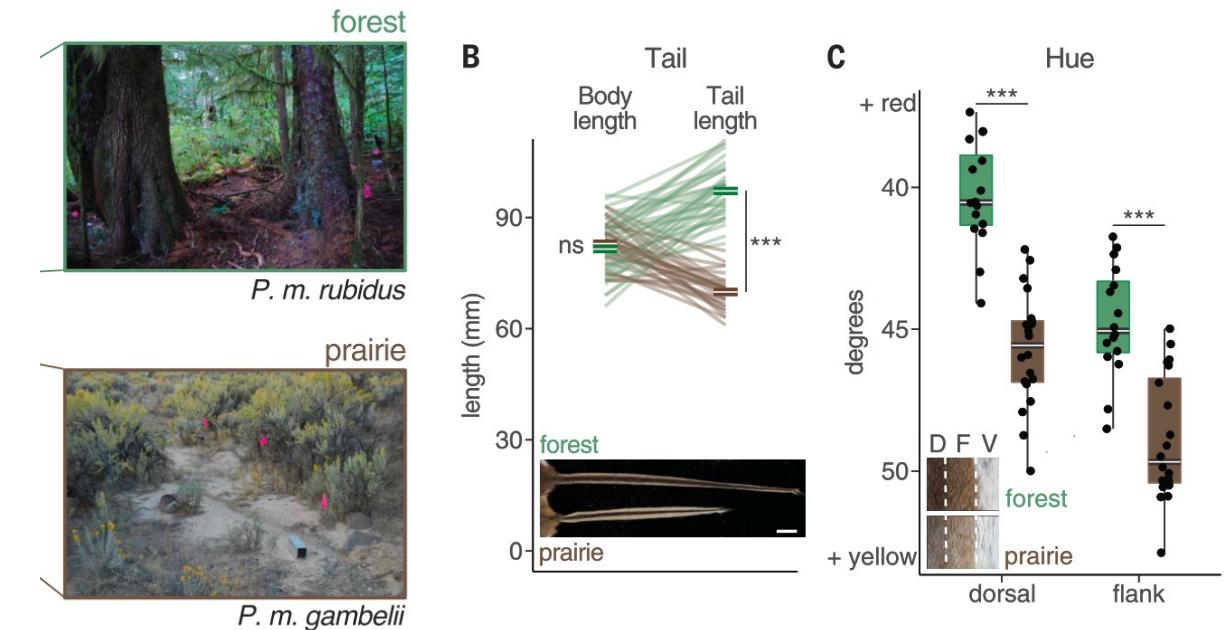
Spectrophotometry



Trait based approaches

- Quantitative trait loci (QTL)
 - Crosses between individuals with trait of interest
 - Linkage maps built with genetic markers (RADseq!)
 - Association tested in progeny

Hager et al 2022 Science

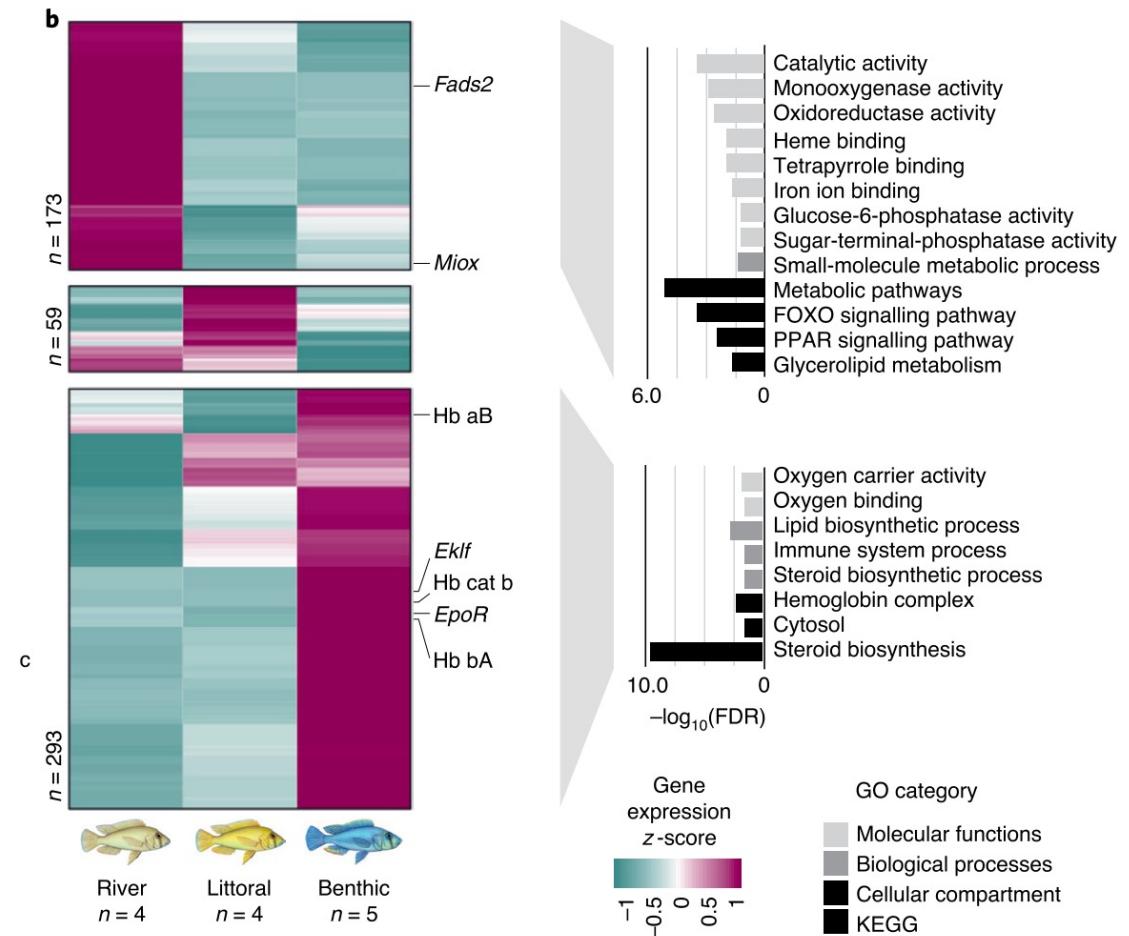


Example with RADseq : Huber et al 2015 Heredity

Transcriptomics

Quantify mRNA expression

- Whole tissue or single-cell
- Compare expression levels between groups
- Co-expression genes
- eQTL
- Allele specific expression



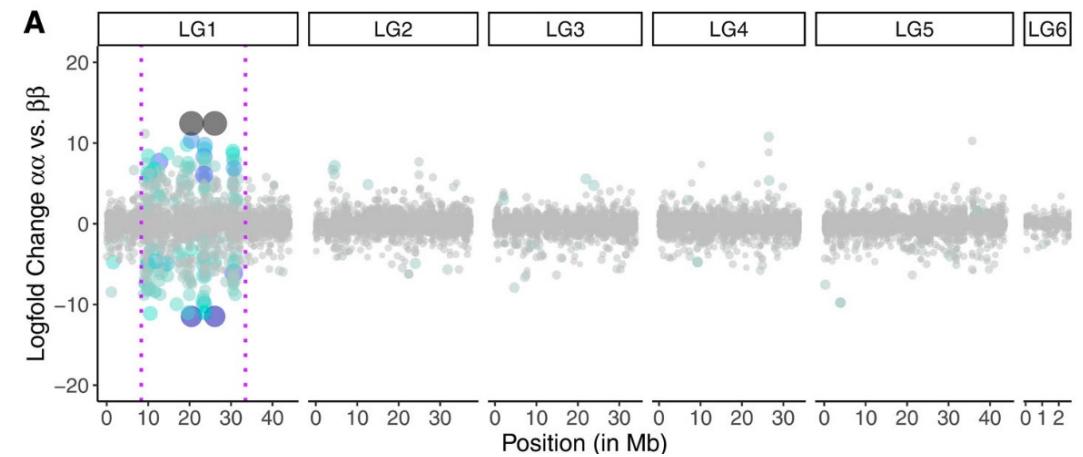
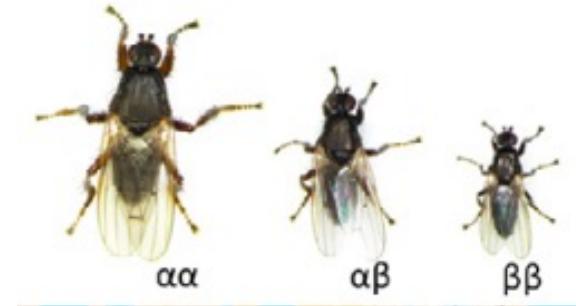
Gene expression level of genes associated with habitat in cichlid fish

Gene Ontology
Enrichment

Transcriptomics

Quantify mRNA expression

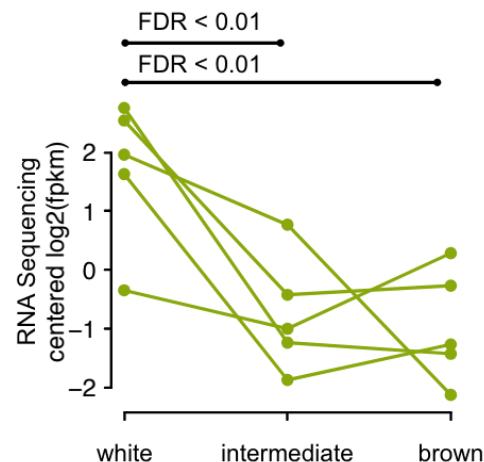
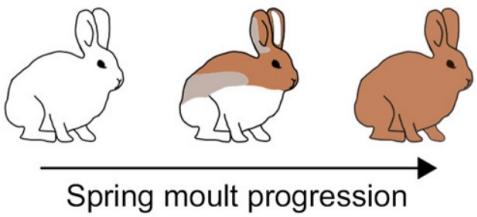
- Whole tissue or single-cell
- Compare expression levels between groups
- Co-expression genes
- eQTL
- Allele specific expression



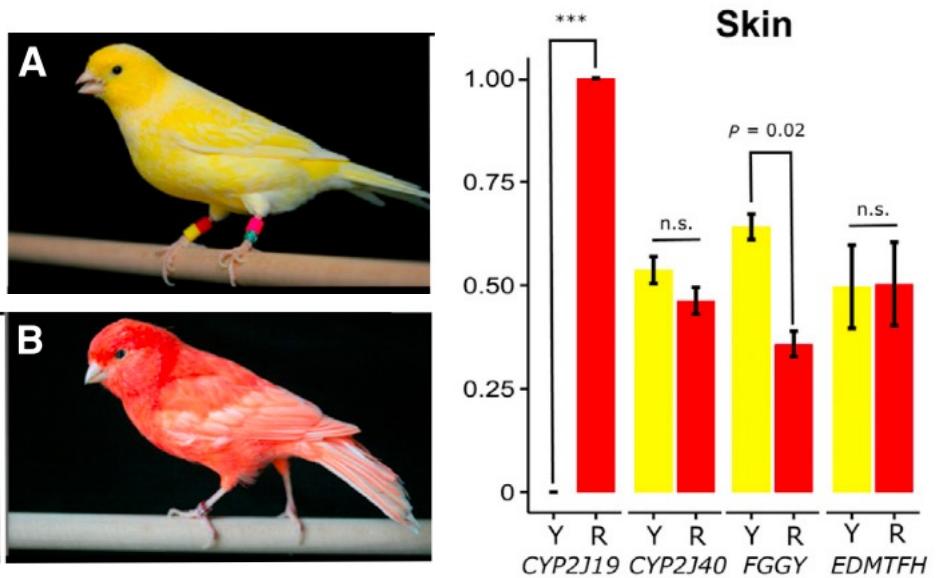
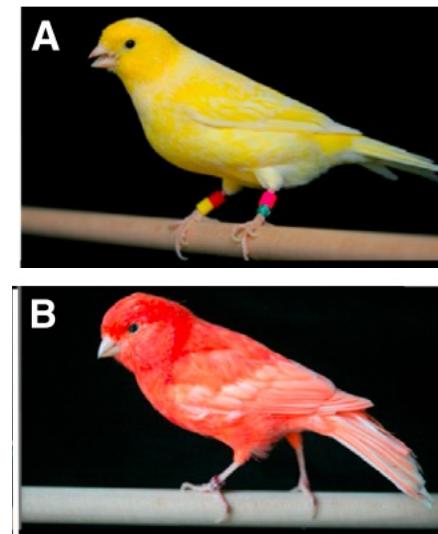
Gene expression differences within inversion

Transcriptomics

Expression of single genes:
Agouti expression during molt

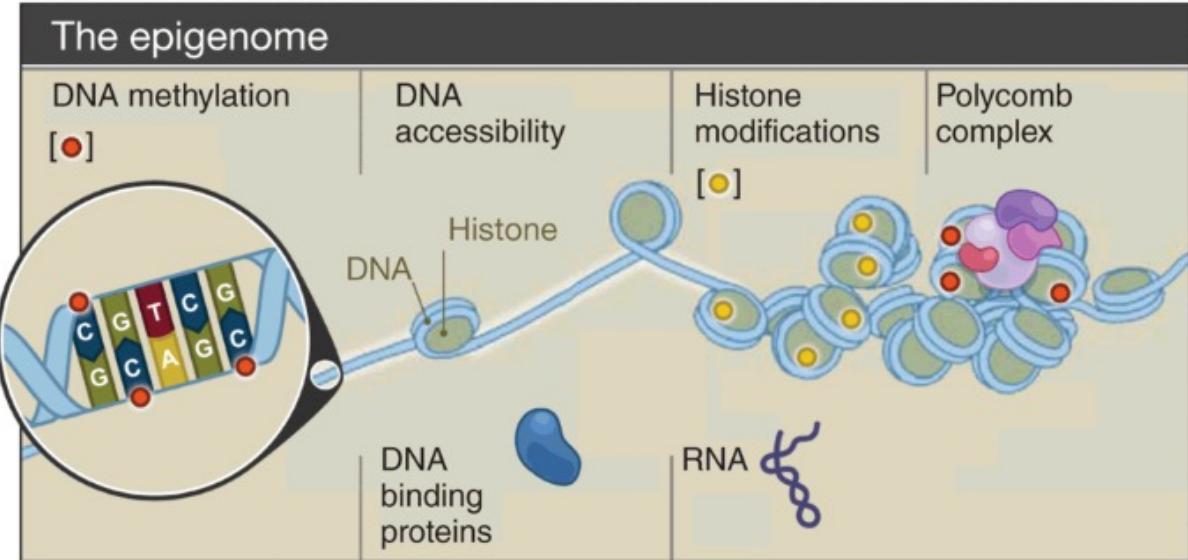


Allele specific expression:
Expression of Red and Yellow allele



Epigenomics

- DNA methylation
- DNA accessibility
- Histone modifications
- microRNA, longRNA



Good reviews:

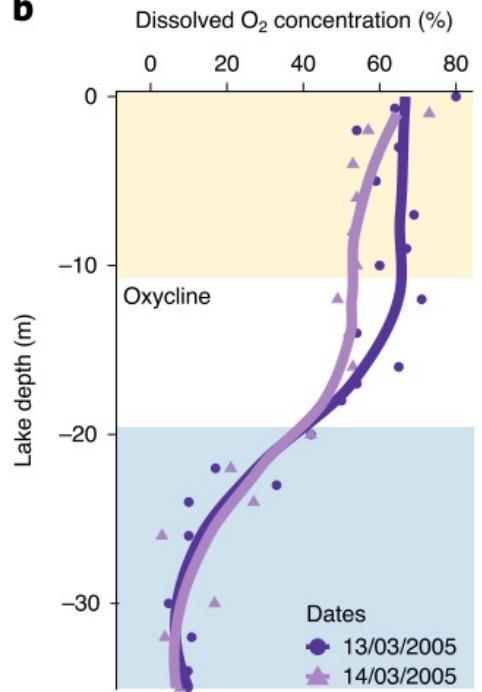
Ashe et al 2021, Philosophical Transactions B

Fishman et al 2023, Journal of Comparative Physiology

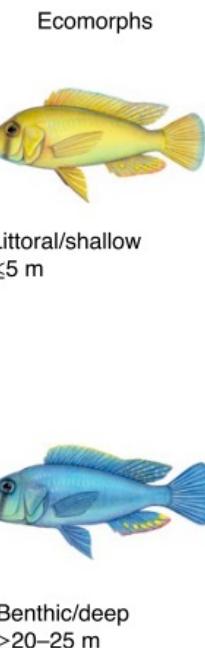
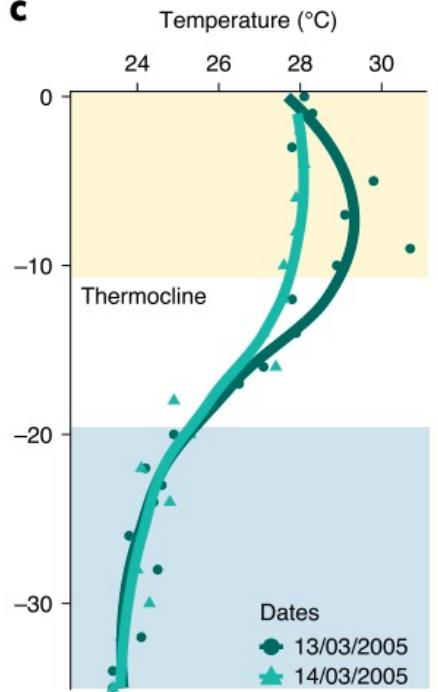
McCaw, Stevenson, Lancaster 2020 Integrative and Comparative Biology

Epigenomics

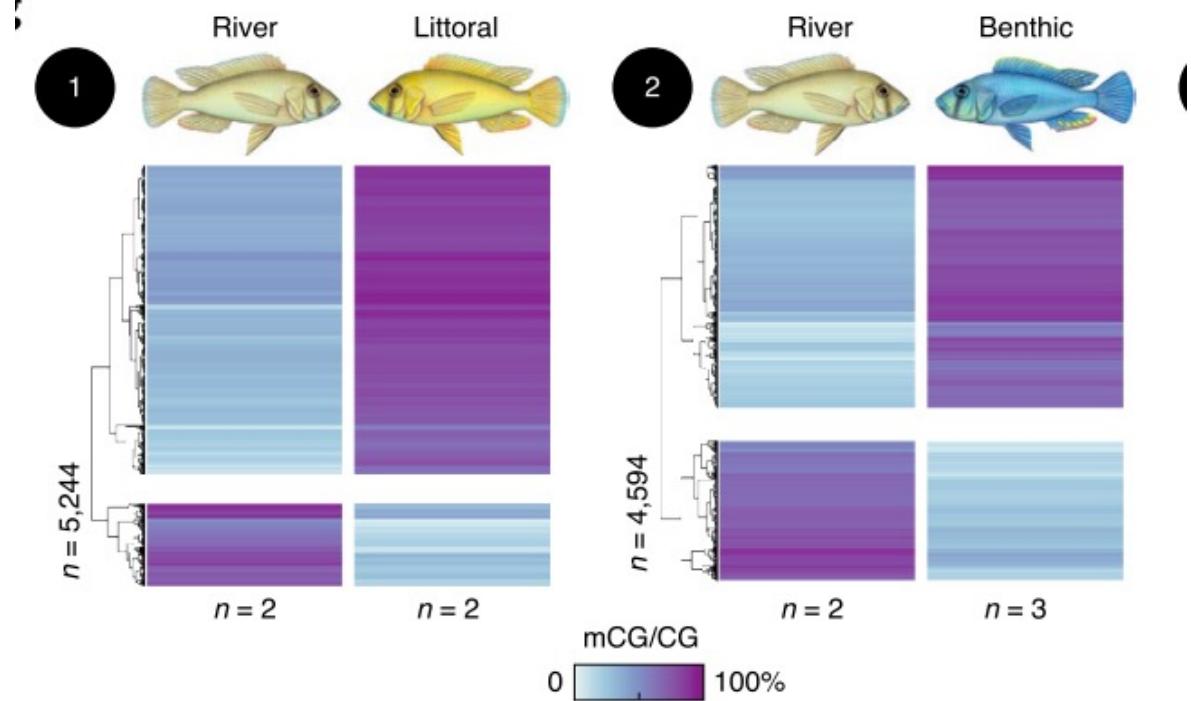
b



c



d

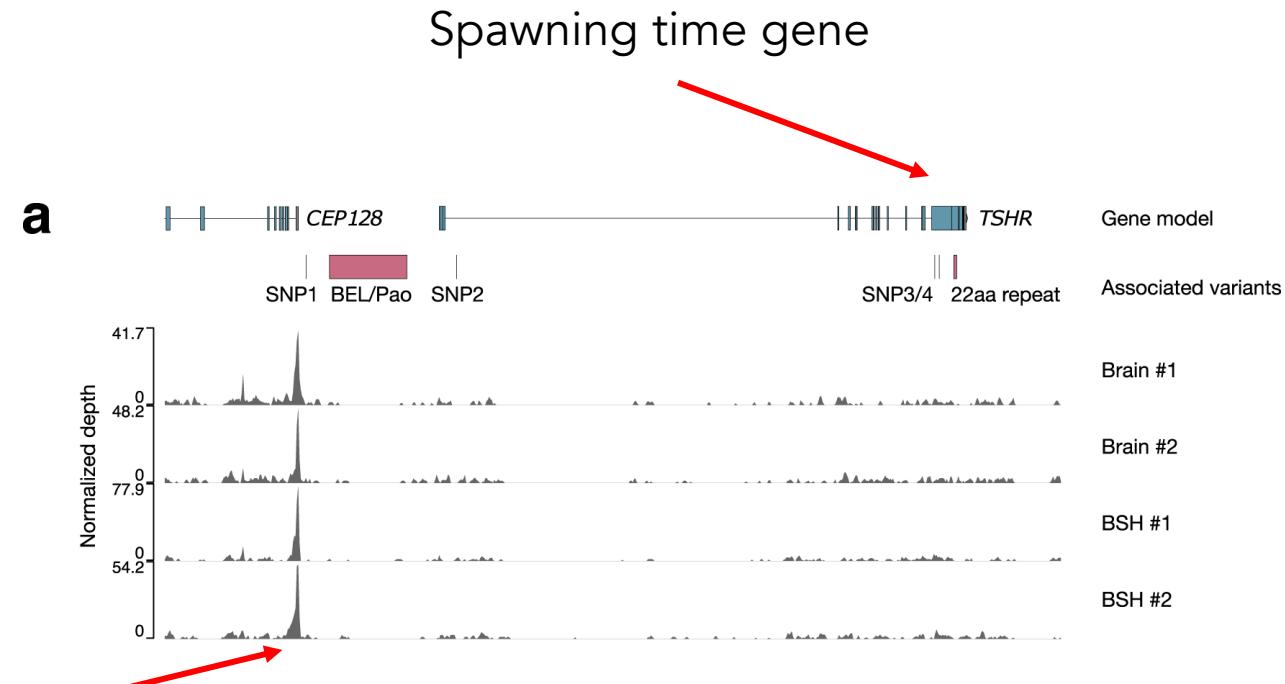


Vernaz et al 2022 Nature Ecology & Evolution

Techniques: WGBS, RRBS

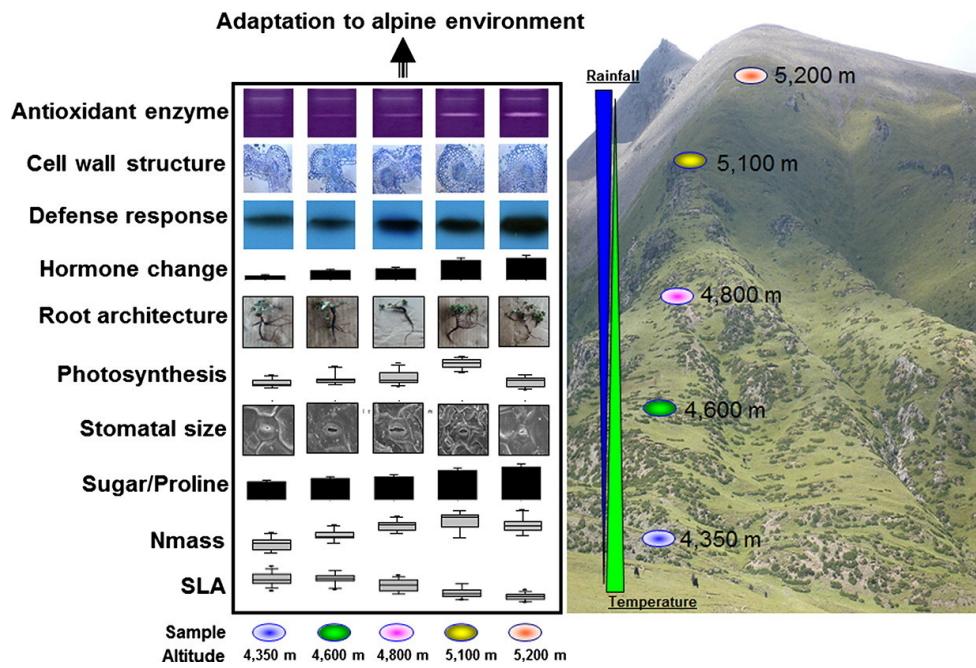
Epigenomics

- ATAC-seq
 - Transposase Accessible Chromating using sequencing
 - Actively regulated regions of the genome
- Regulated region in TSHR UTR

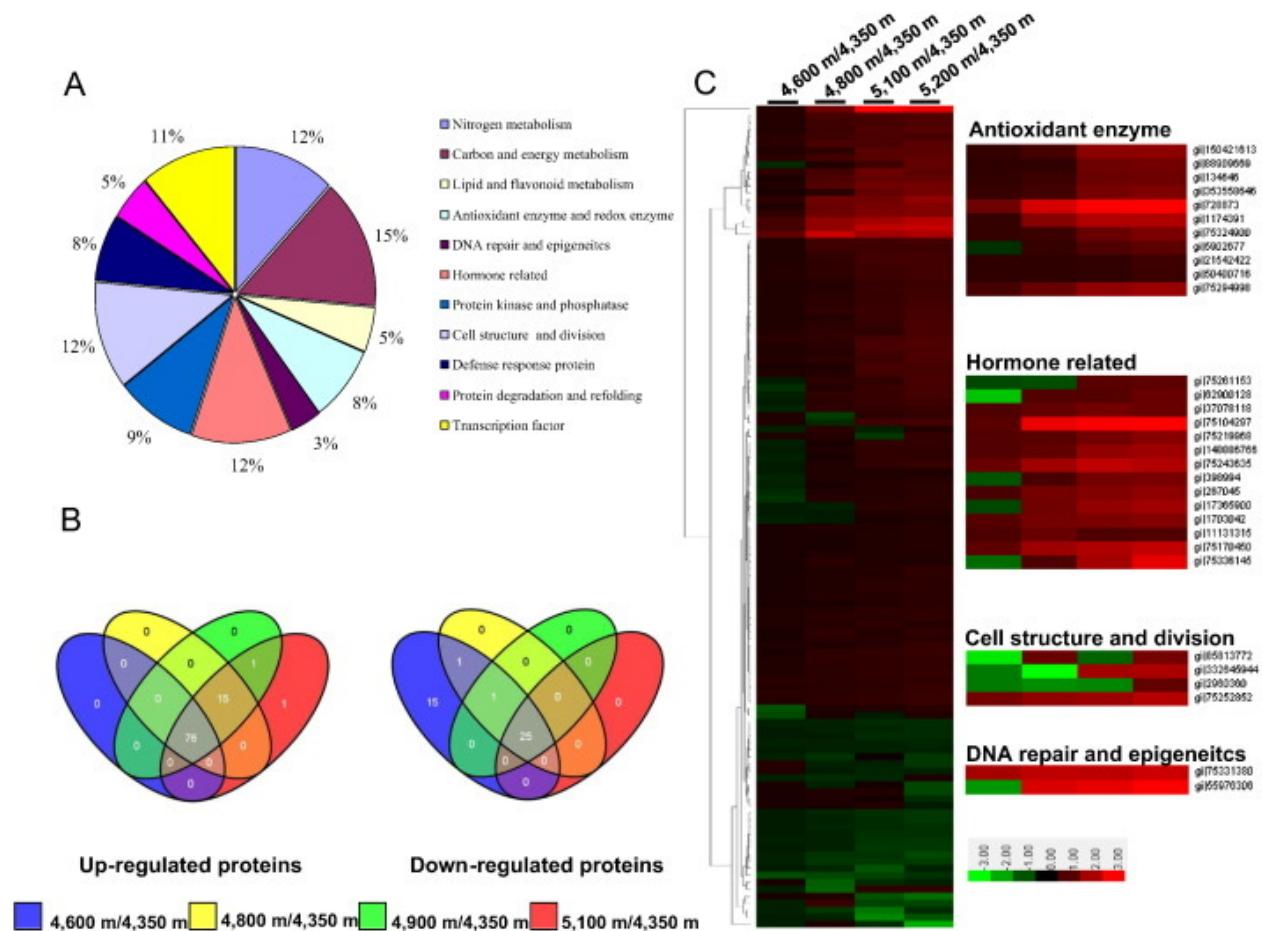


Proteomics

- Characterization of protein expression using mass spectrometry

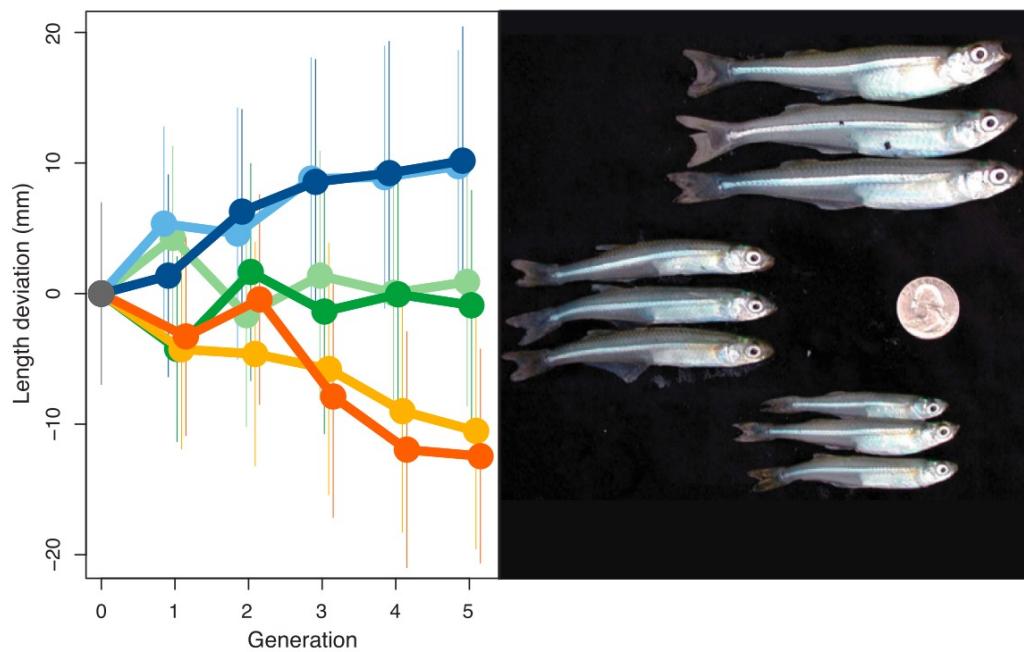


Proteomics of altitude adaptation



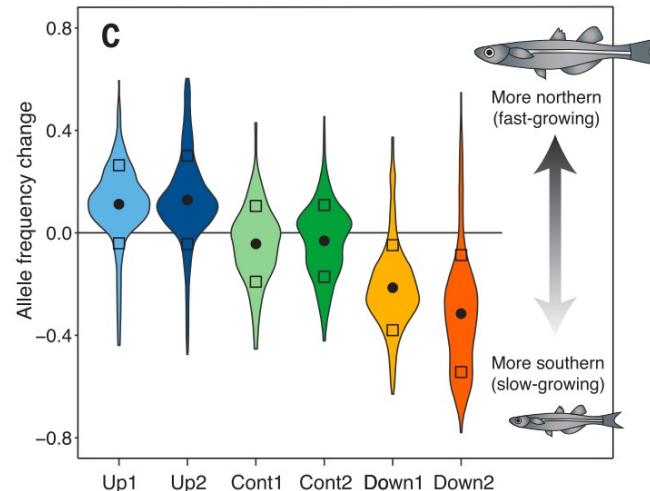
Experimental evolution

Body length change in response to harvest selection



Experimental selection under controlled conditions

Several generations



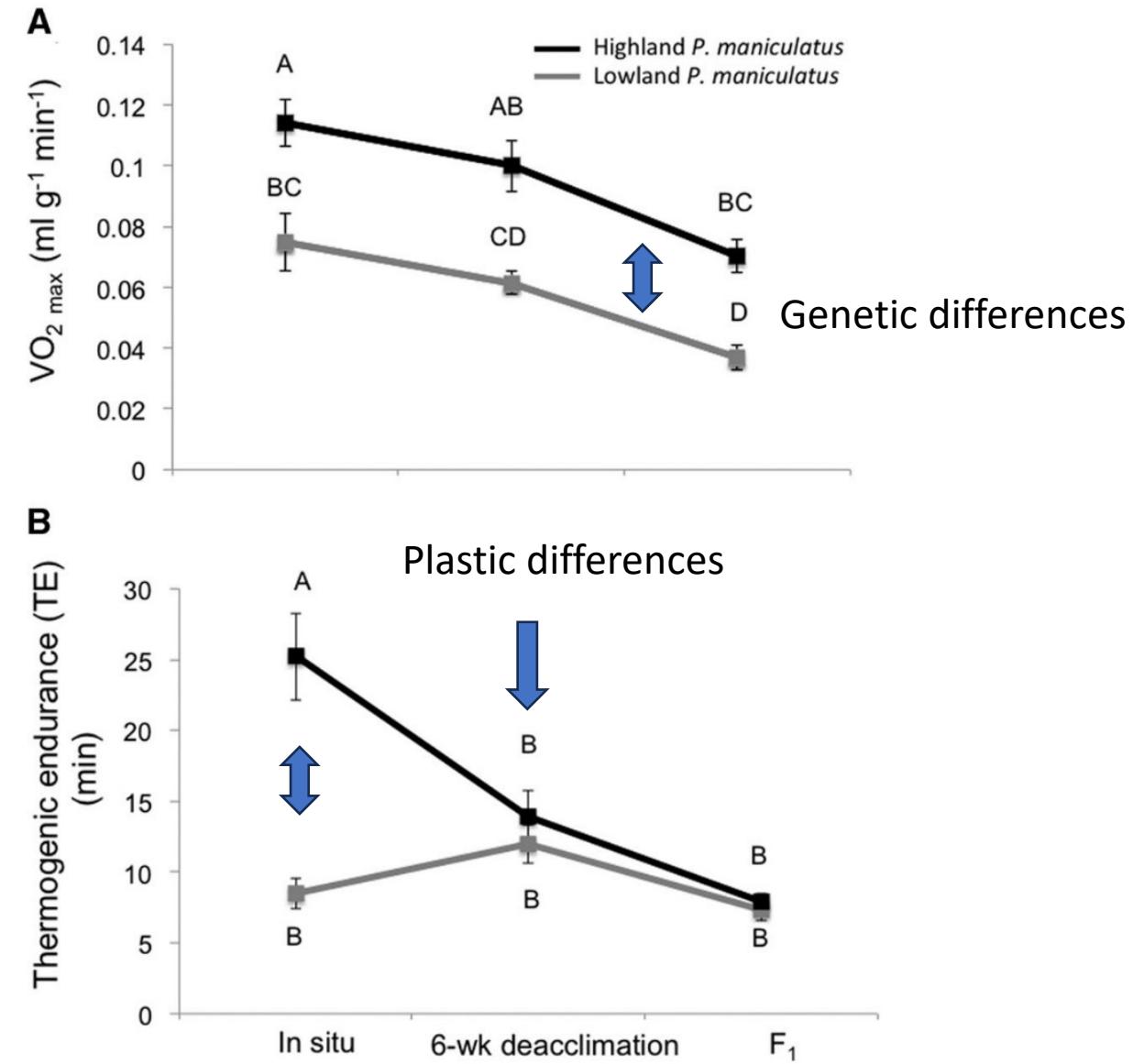
Allele frequency change of fast-growing alleles

Common garden

Bring locally adapted organisms to the same environment

Distinguish between plastic and genetic adaptation

Another good example: Exposito-Alonso 2019 Nature



Chevillon et al 2014 Evolution

Gene editing

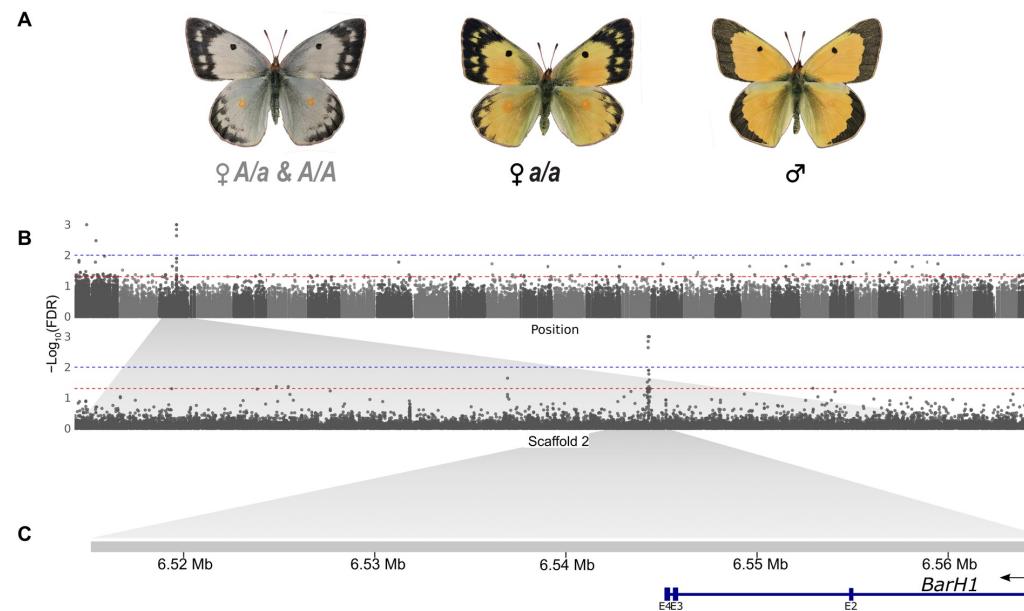
Confirm function of candidate gene

RNAi

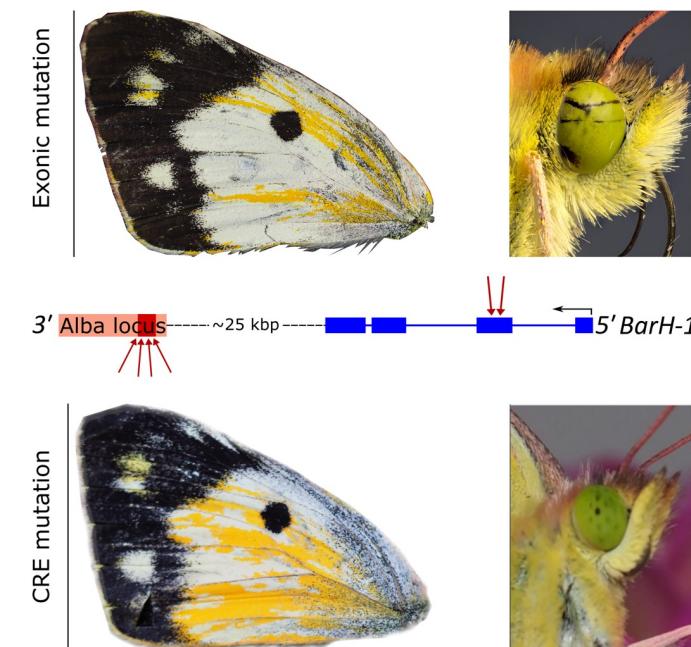
CRISPR-Cas9

Female limited life history strategy gene,
Alba, in *Colias*

Tunström et al 2023 Science Advances



Deletion of regulatory region in Alba females recovers pigmentation



Studying adaptation => integrative biology!

