



Modeling the genotype ~ environment relationship in a climate change context using redundancy analysis (RDA)

Thibaut Capblancq

Genotype-environment association (GEA): the basics



Pop	SNP1	SNP2	SNP3	...
1	0.78	1	0.20	...
2	0.75	1	0.22	...
3	0.80	0.95	0.64	...
4	0.60	0.94	0.65	...
5	0.50	0.70	0.70	...
...	

Genetic



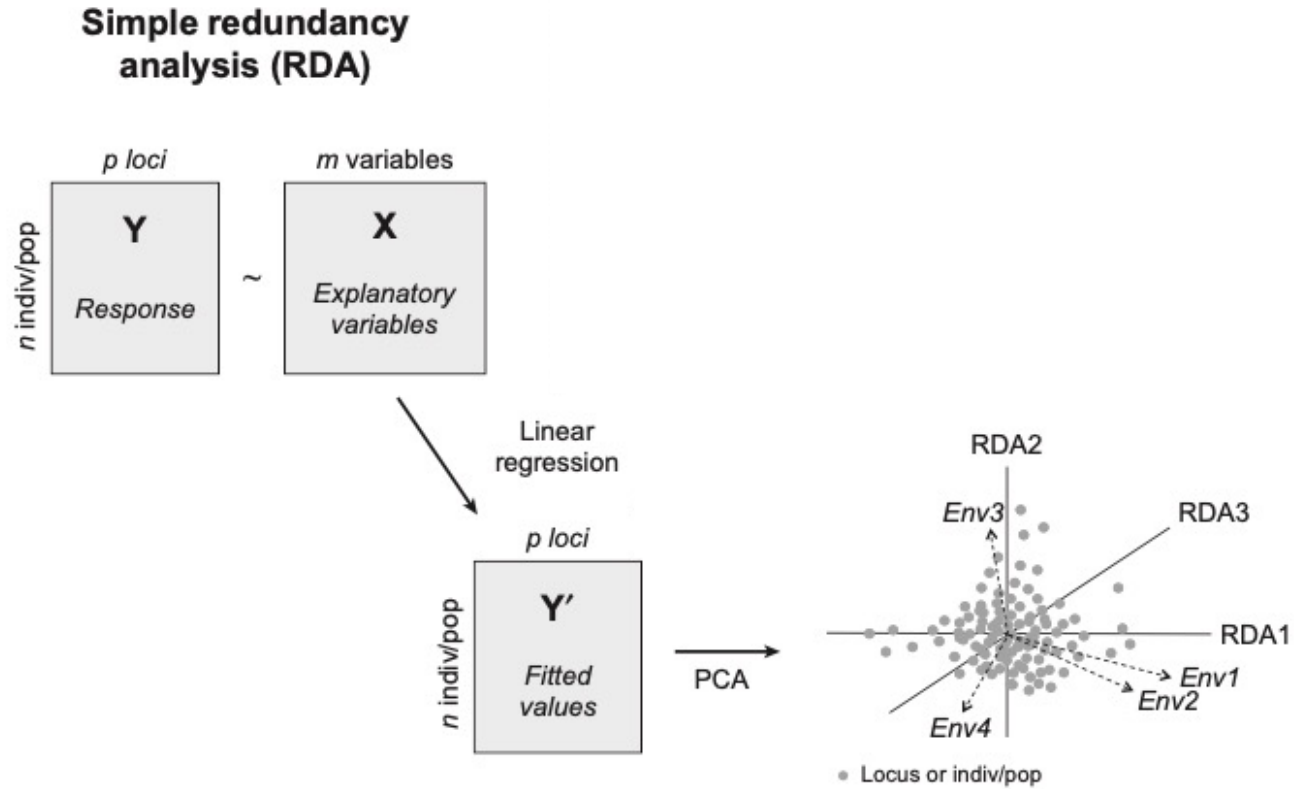
Ind	T°C	Prec	...
1	12	240	...
2	11	210	...
3	12.5	180	...
4	8	150	...
5	9.5	260	...
...	

Environment

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Redundancy analysis (RDA)



Genotype-environment association (GEA): confounding factors



Pop	SNP1	SNP2	SNP3	...
1	0.78	1	0.20	...
2	0.75	1	0.22	...
3	0.80	0.95	0.64	...
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Genetic



Ind	T°C	Prec	...
1	12	240	...
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Environment

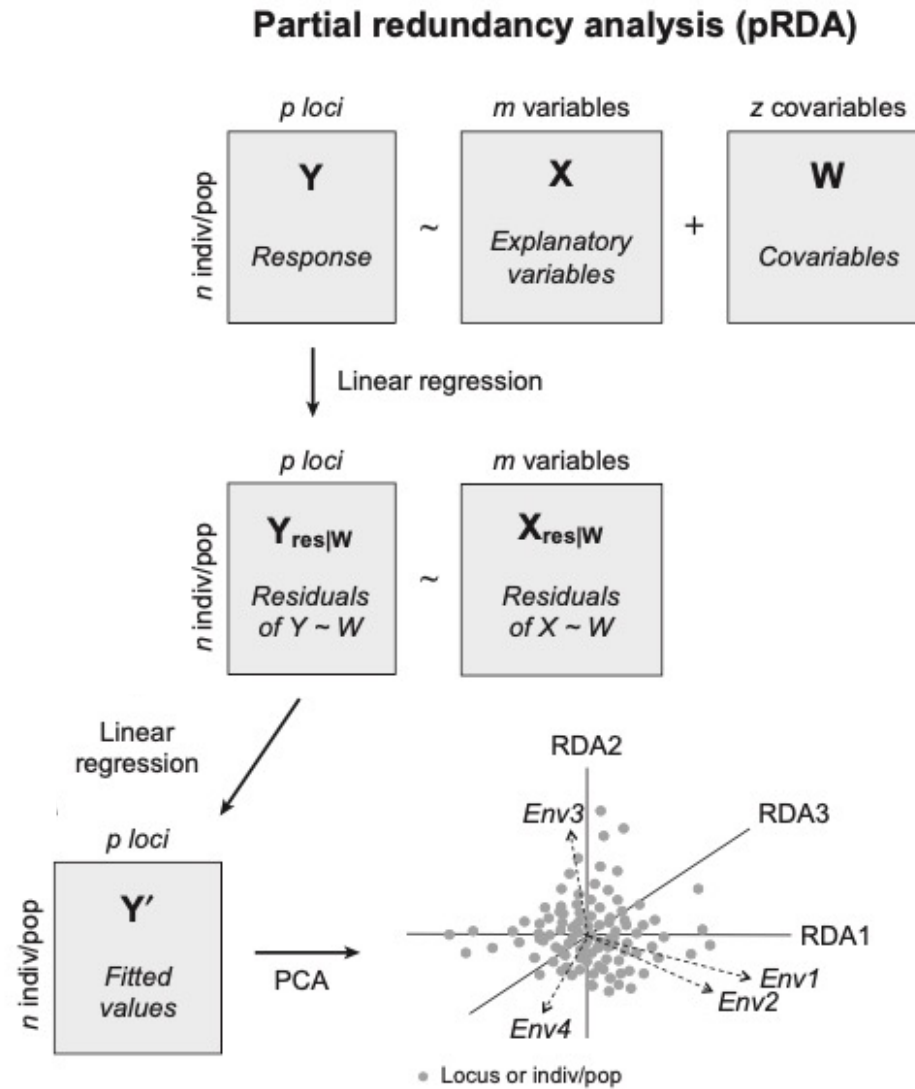


Ind	X	Y	...
1	6.3	45.12	...
2	6.4	46.3	...
3	5.8	45.2	...
4	6	47.8	...
5	5.7	44.6	...
...	

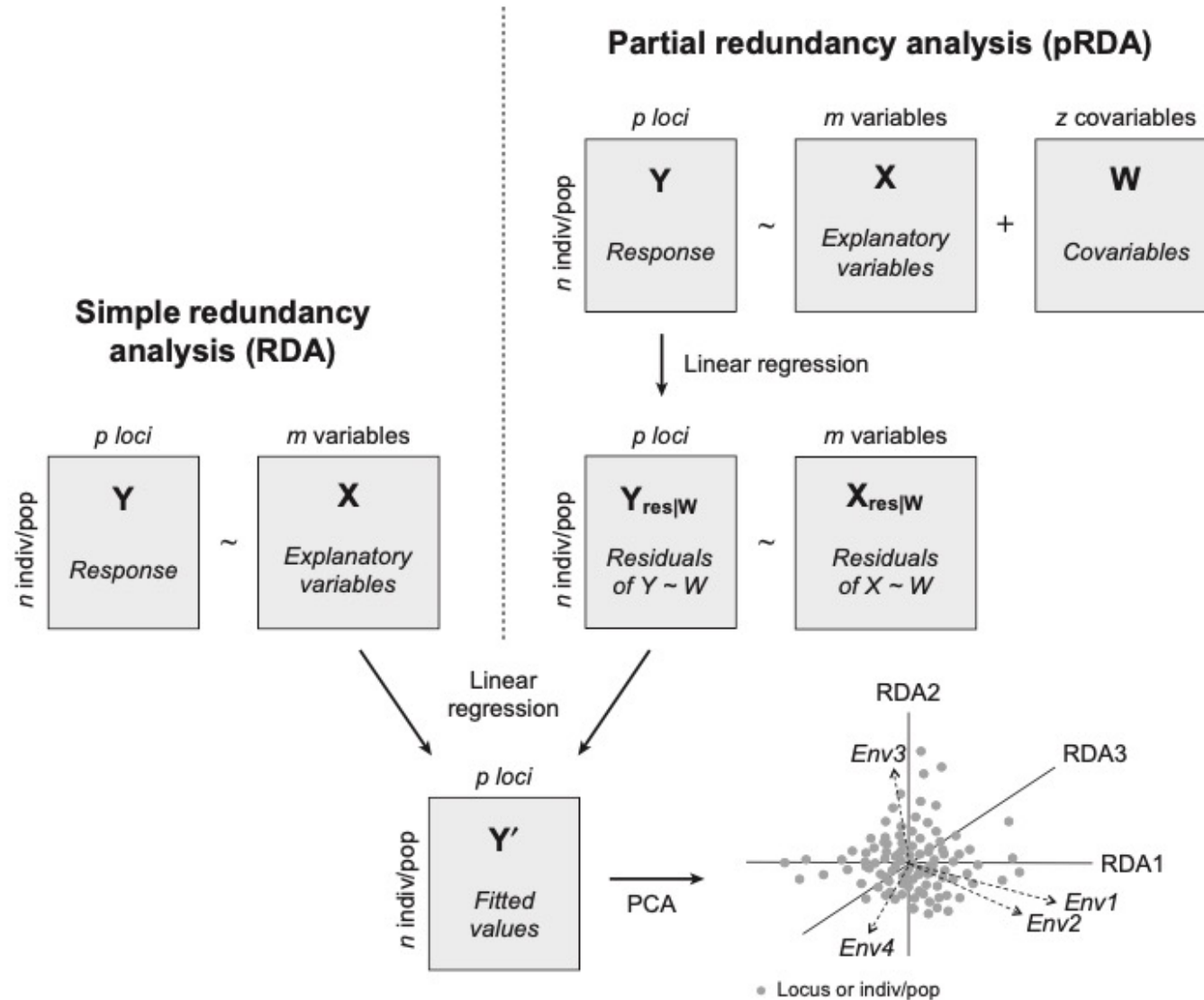
Confounding factors

(e.g., Geography, demography...)

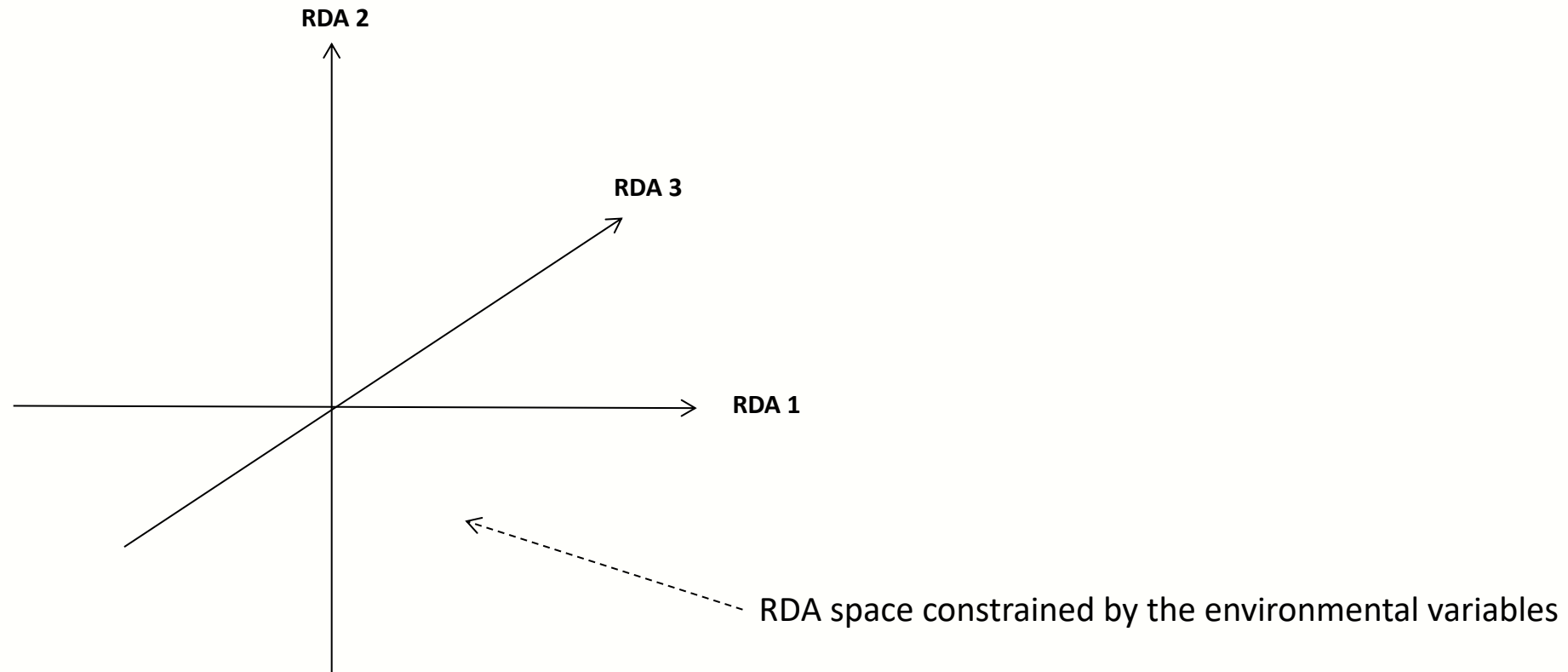
Partial redundancy analysis (pRDA)



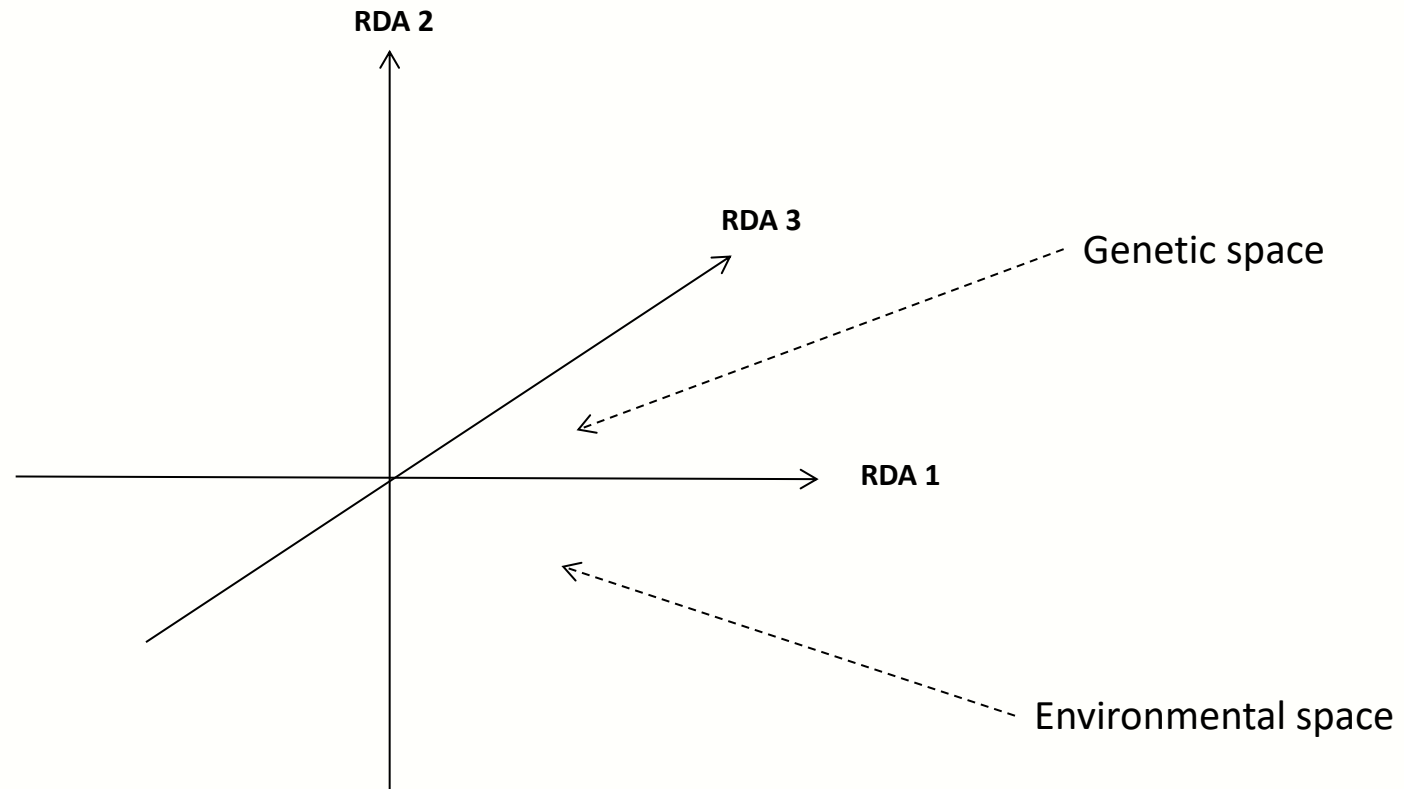
Two ways of conducting redundancy analysis (RDA)



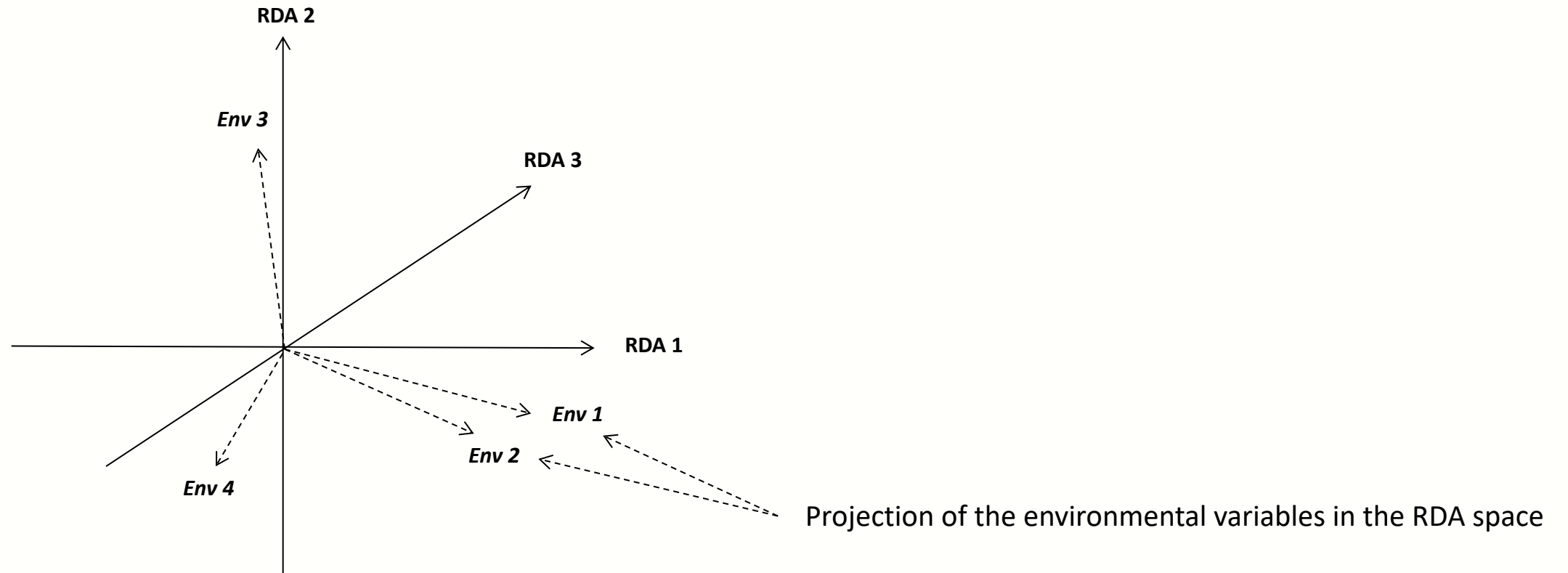
The outputs of redundancy analysis (RDA): a new space



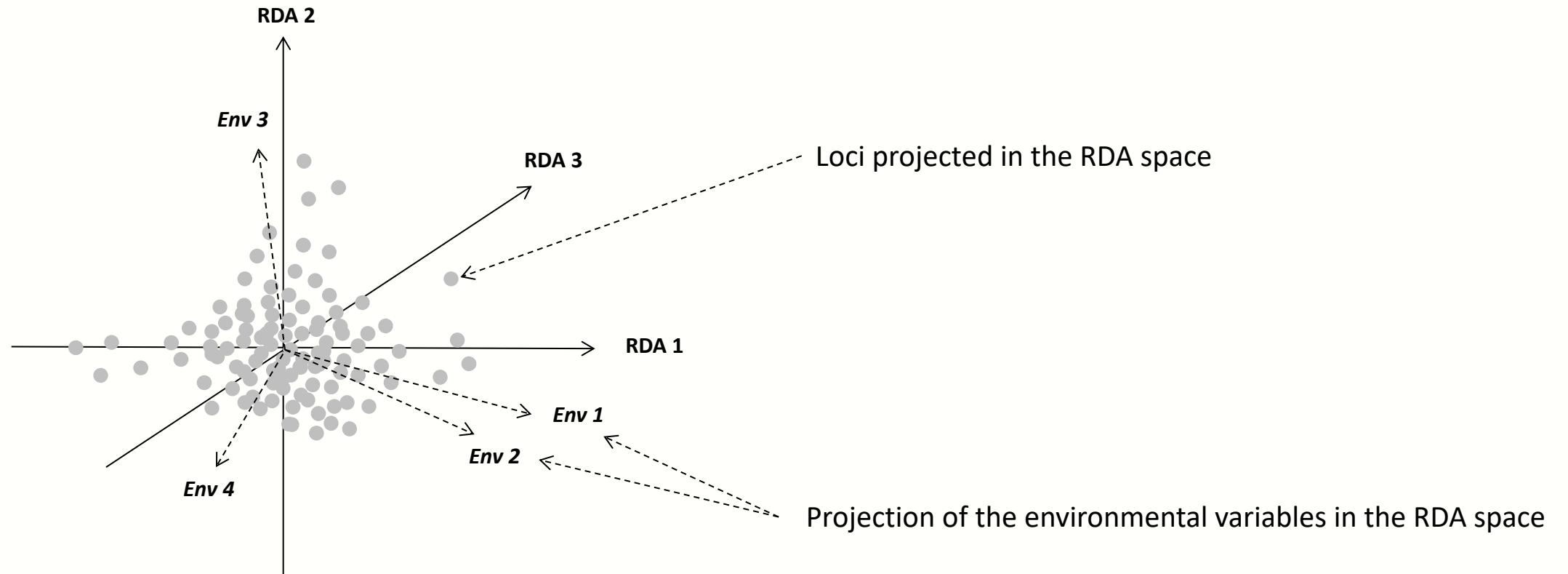
The outputs of redundancy analysis (RDA): a new space



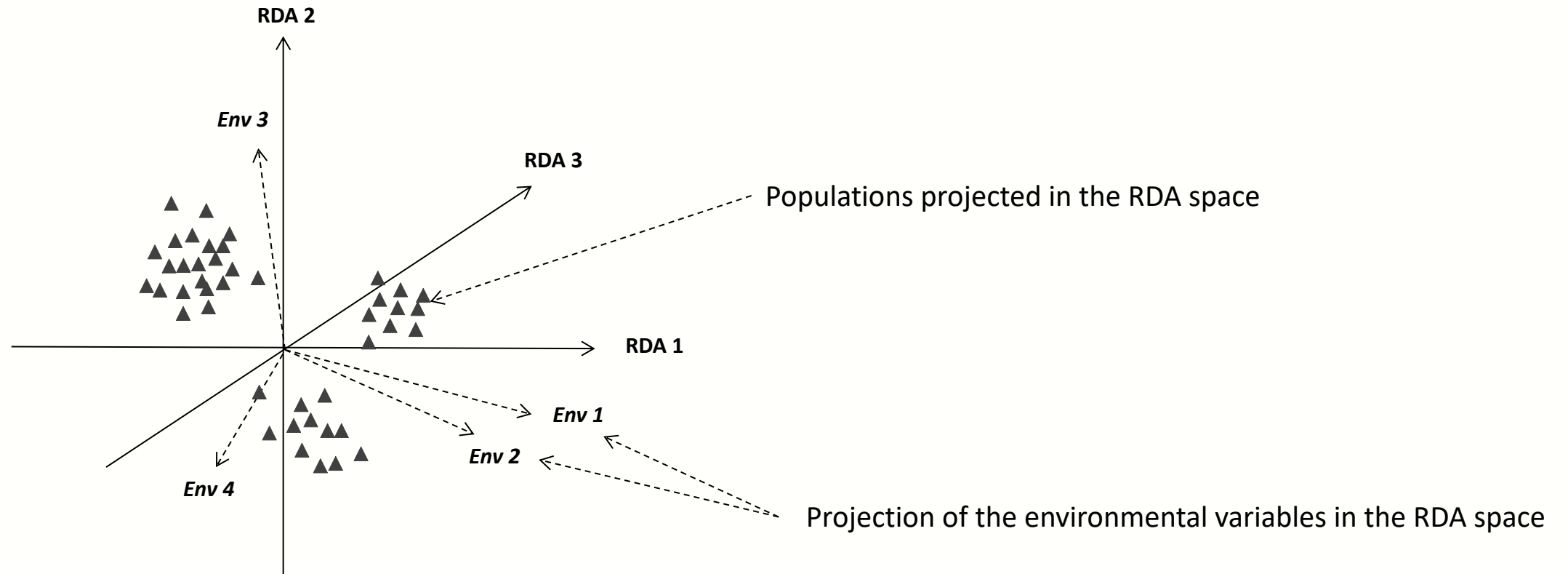
The outputs of redundancy analysis (RDA): predictors



The outputs of redundancy analysis (RDA): predictors



The outputs of redundancy analysis (RDA): sites/populations



Identifying the adaptive genetic
component

Identifying the adaptive genetic component

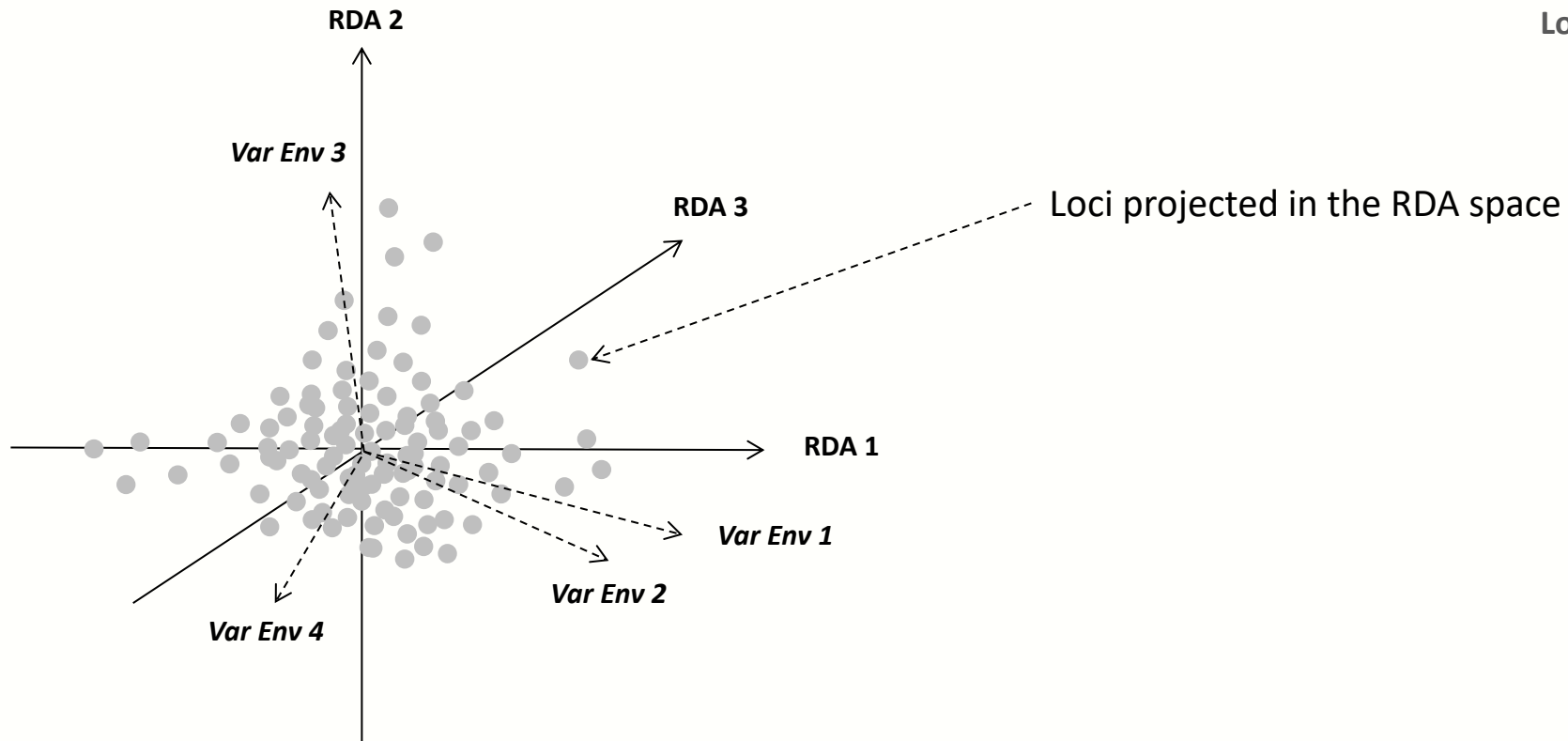


Lodgepole pine (*Pinus contorta*)

Identifying the adaptive genetic component



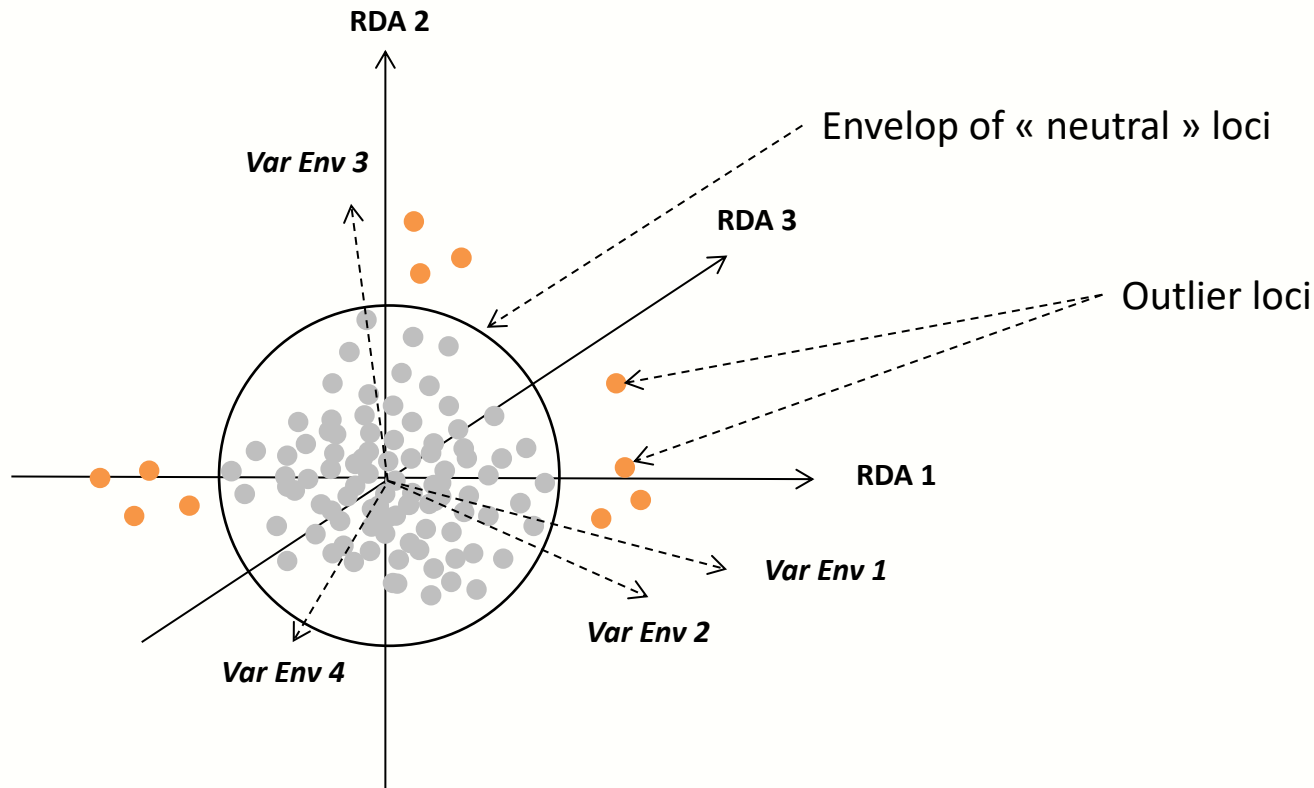
Lodgepole pine (*Pinus contorta*)



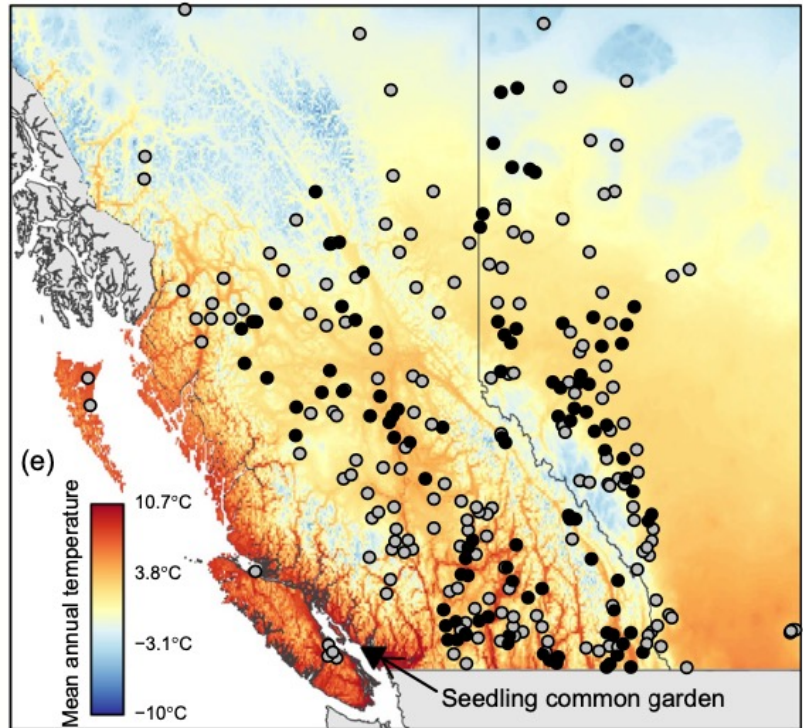
Identifying the adaptive genetic component



Lodgepole pine (*Pinus contorta*)



Estimating population (mal)adaptation to future climates

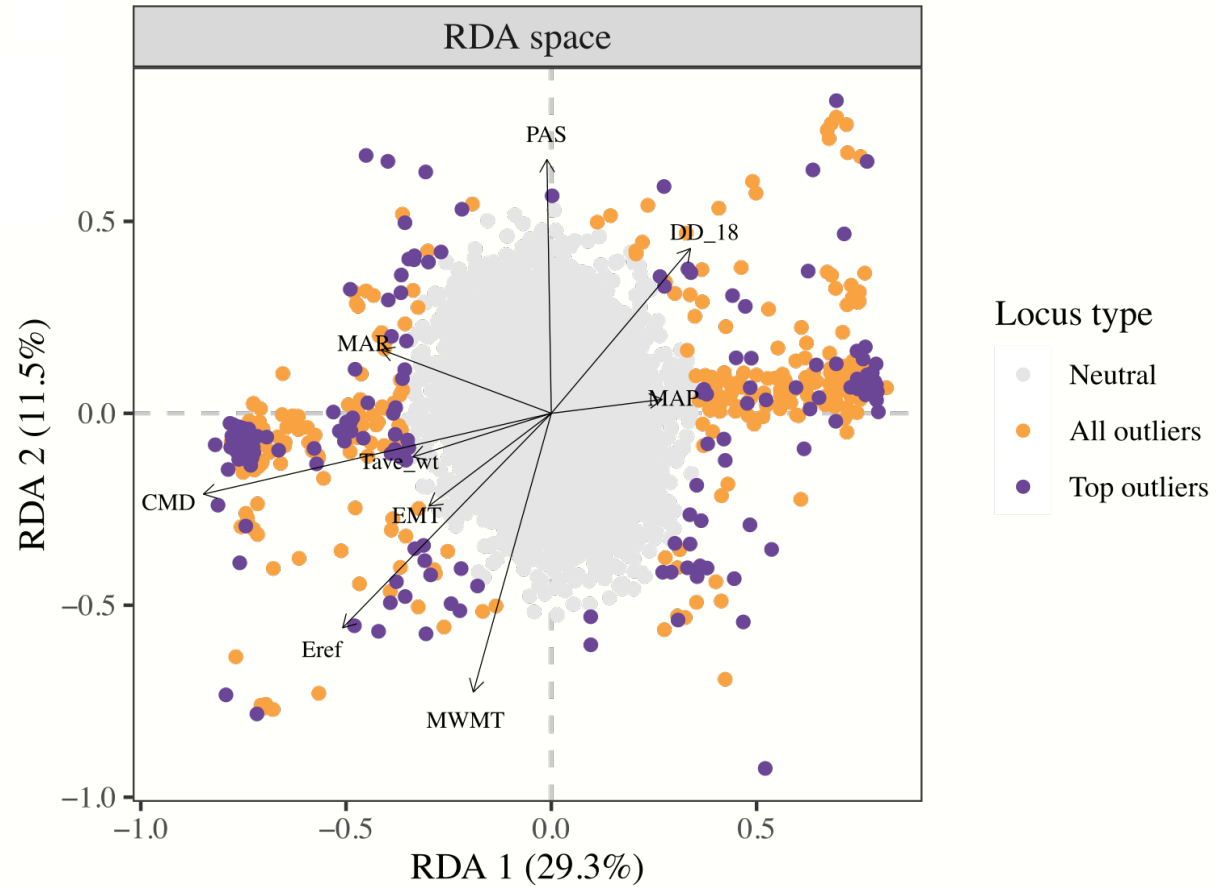


Mahony *et al.* (2020). Evaluating genomic data for management of local adaptation in a changing climate: A lodgepole pine case study. *Evolutionary Applications*



Brenna Forester - US fish and wildlife service

Identifying the adaptive genetic component

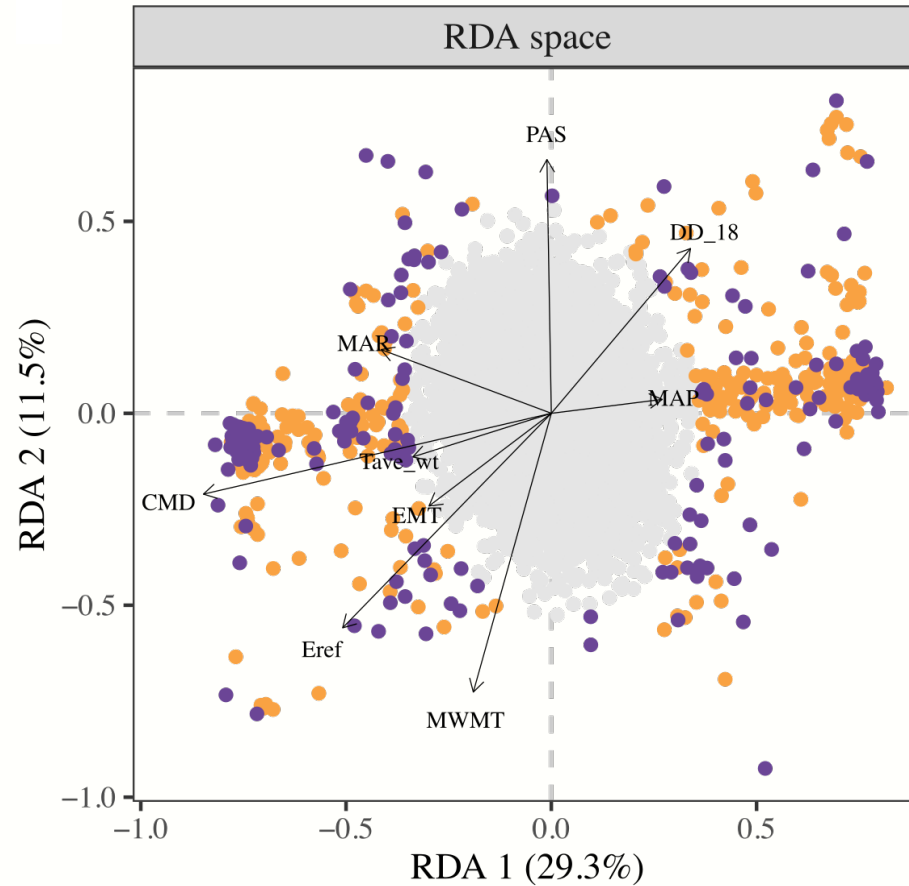


Lodgepole pine (*Pinus contorta*)

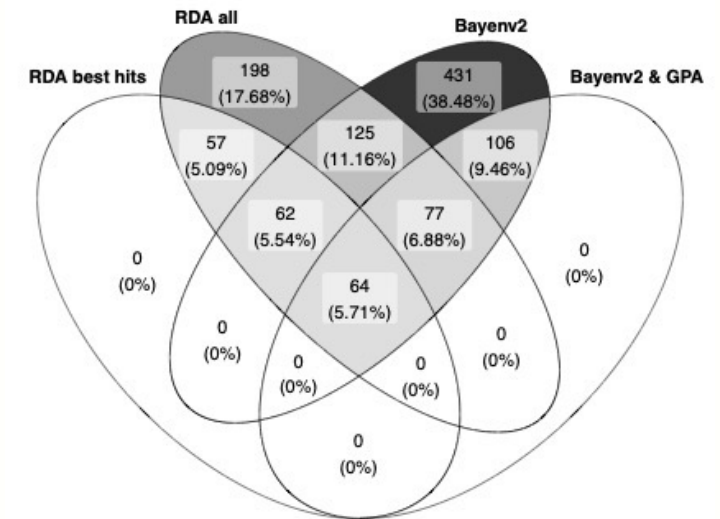
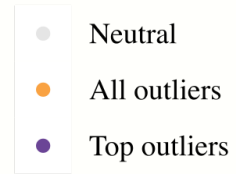
Identifying the adaptive genetic component



Lodgepole pine (*Pinus contorta*)



Locus type



Estimating population
(mal)adaptation to future climates

Genetic turnover across the species range

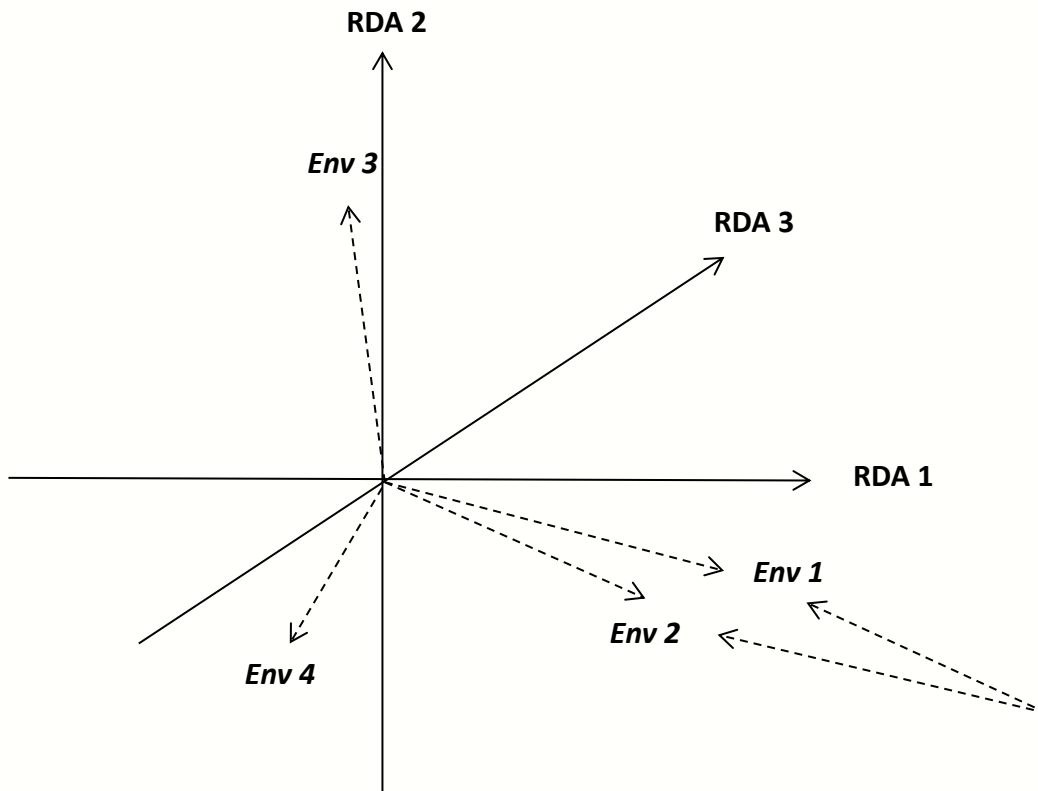


Lodgepole pine (*Pinus contorta*)

Genetic turnover across the species range



Lodgepole pine (*Pinus contorta*)

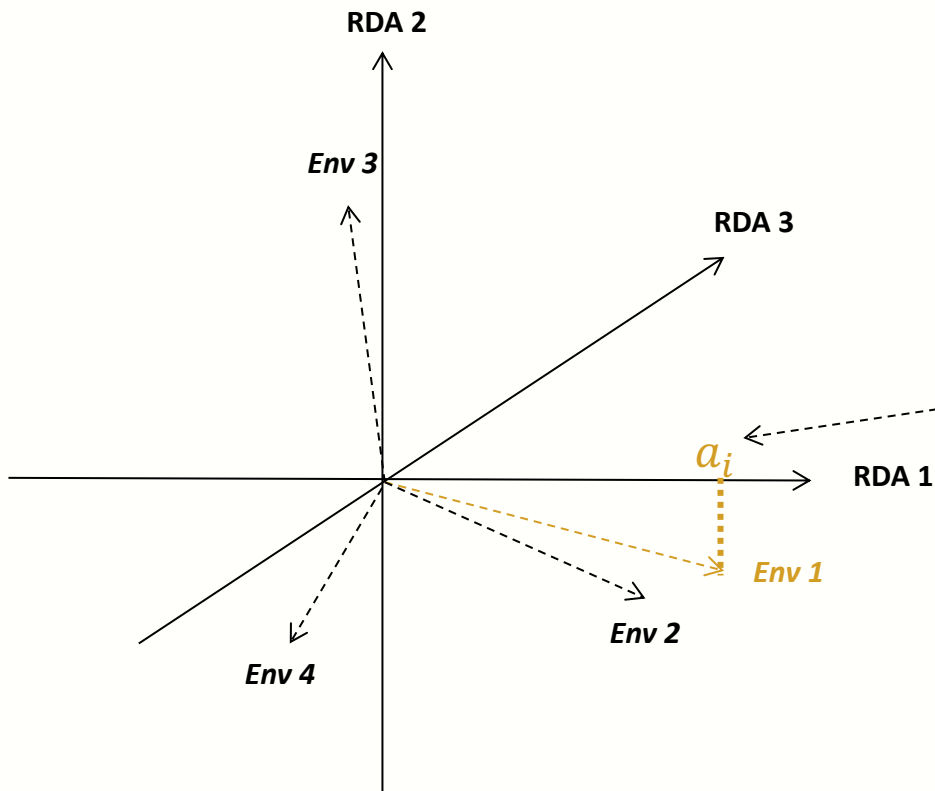


Projection of the environmental variables in the RDA space

Genetic turnover across the species range



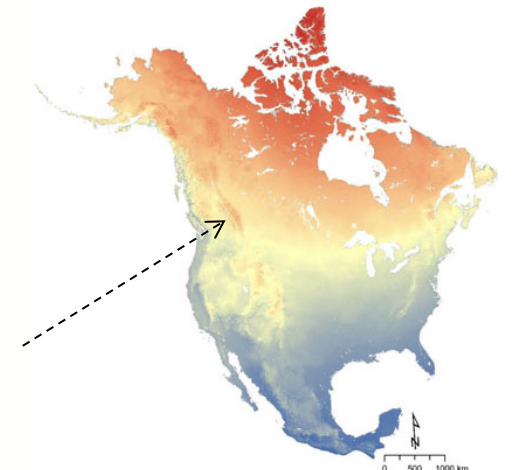
Lodgepole pine (*Pinus contorta*)



$$\text{Adaptive index} = \sum_{i=1}^n a_i b_i$$

a_i : score of climatic variable i along the RDA axis

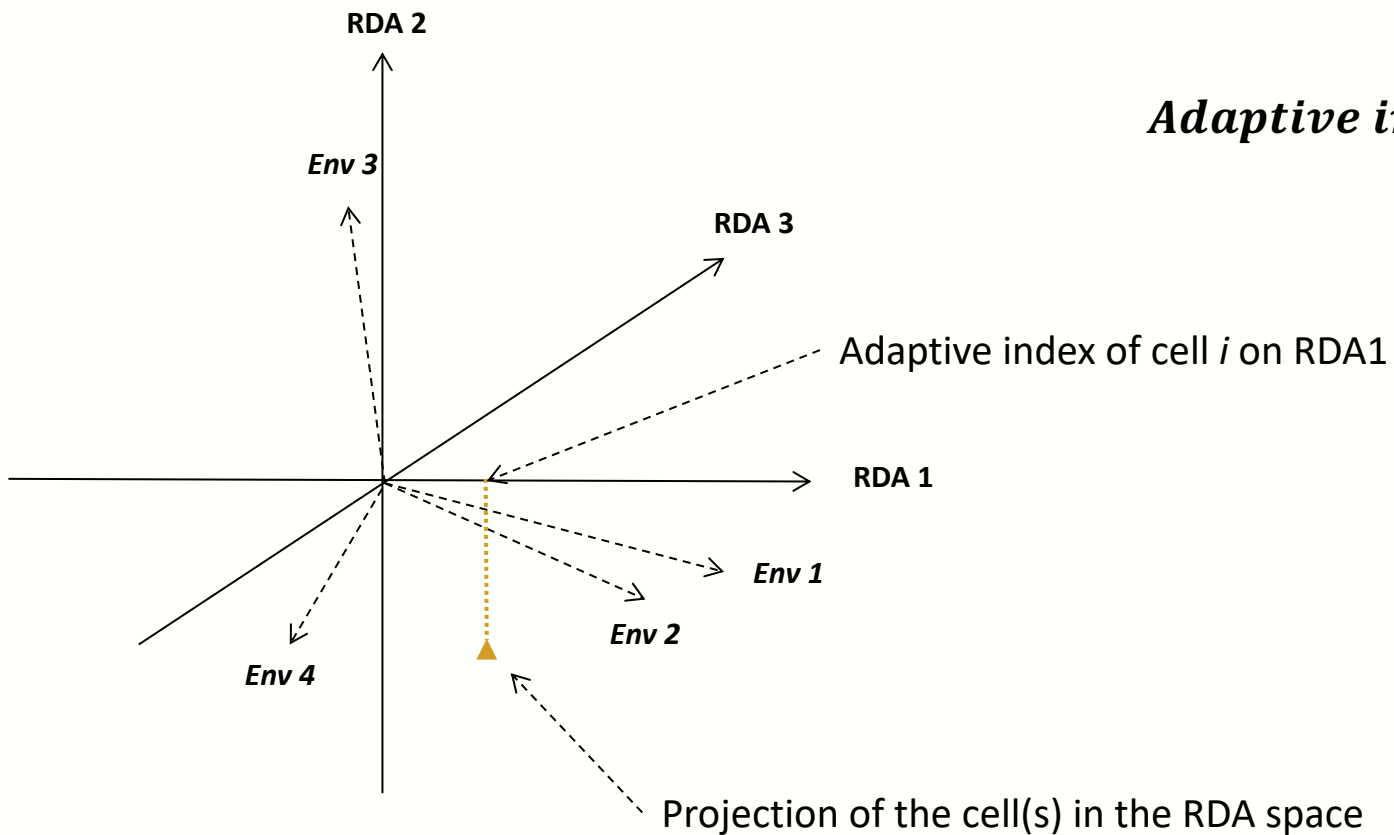
b_i : standardized value of climate variable i for a focal cell



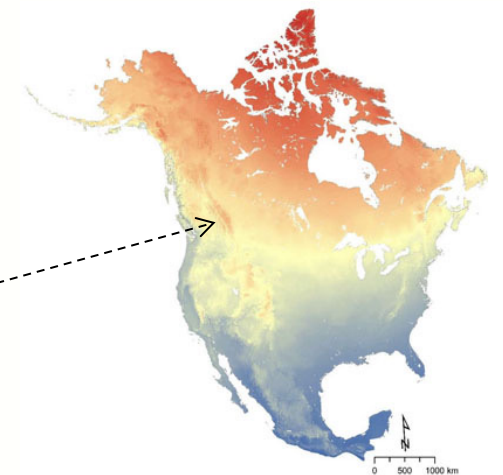
Genetic turnover across the species range



Lodgepole pine (*Pinus contorta*)



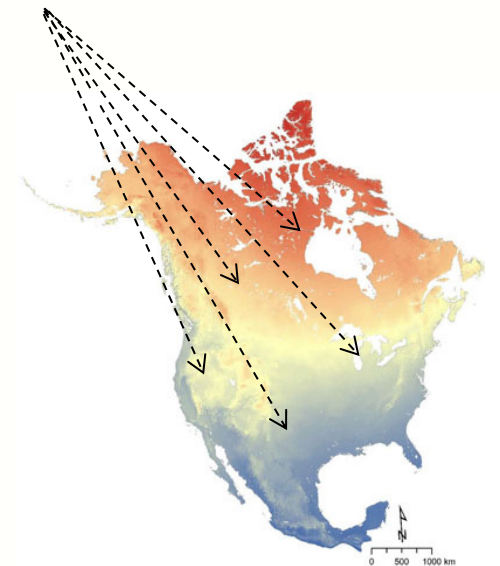
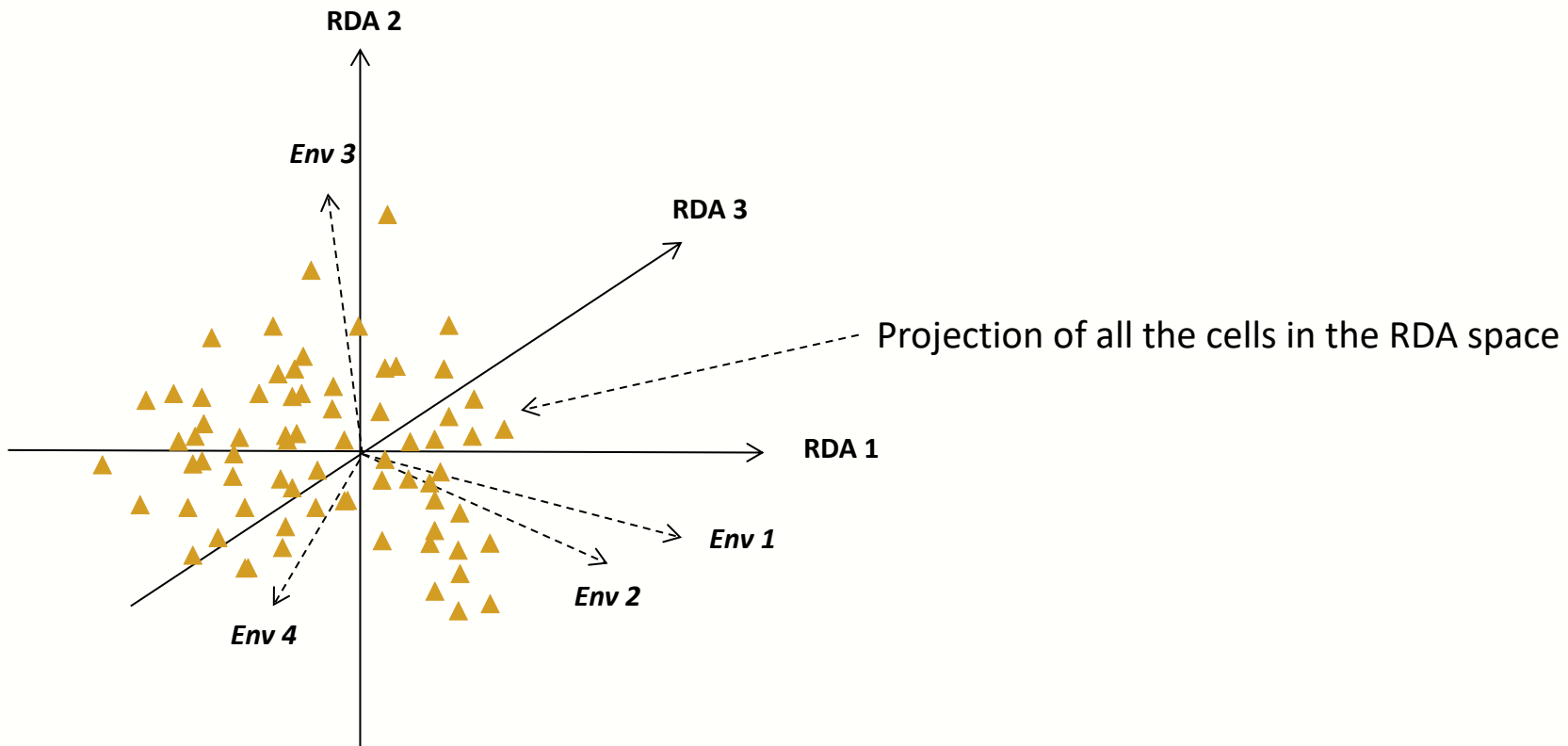
$$\text{Adaptive index} = \sum_{i=1}^n a_i b_i$$



Genetic turnover across the species range



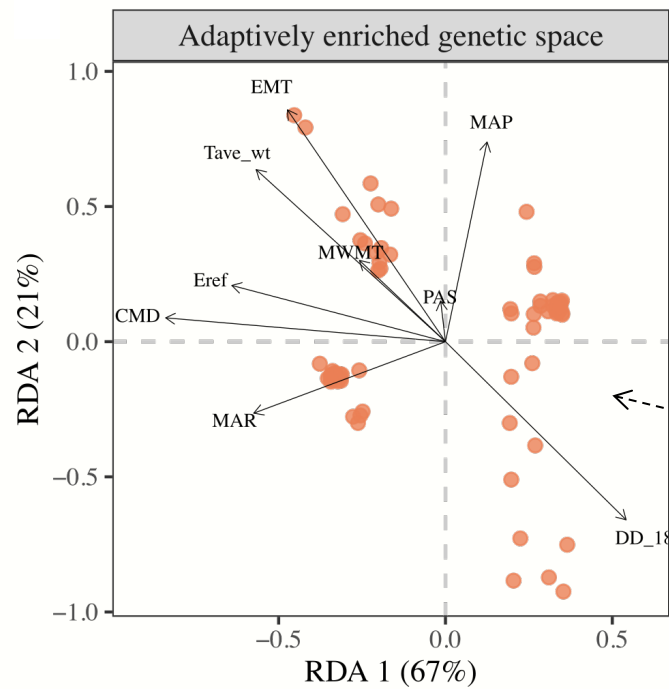
Lodgepole pine (*Pinus contorta*)



Genetic turnover across the species range



Lodgepole pine (*Pinus contorta*)



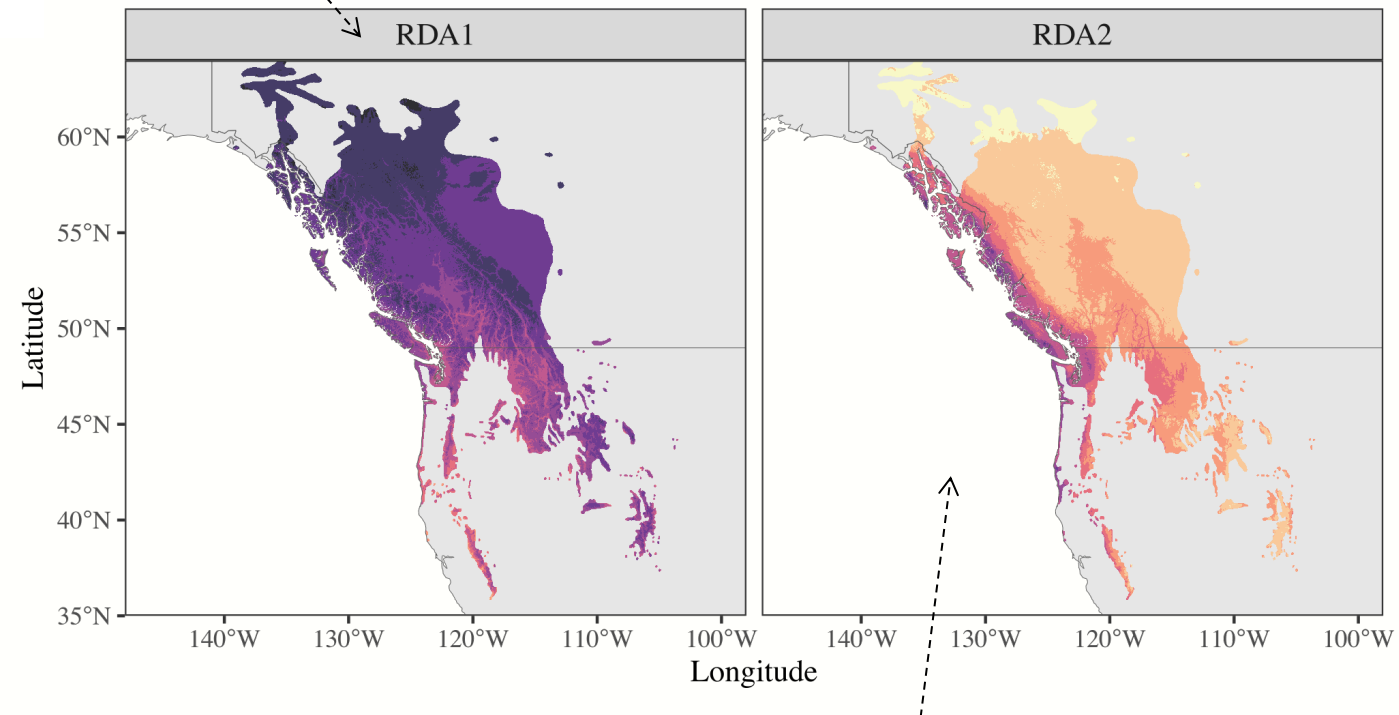
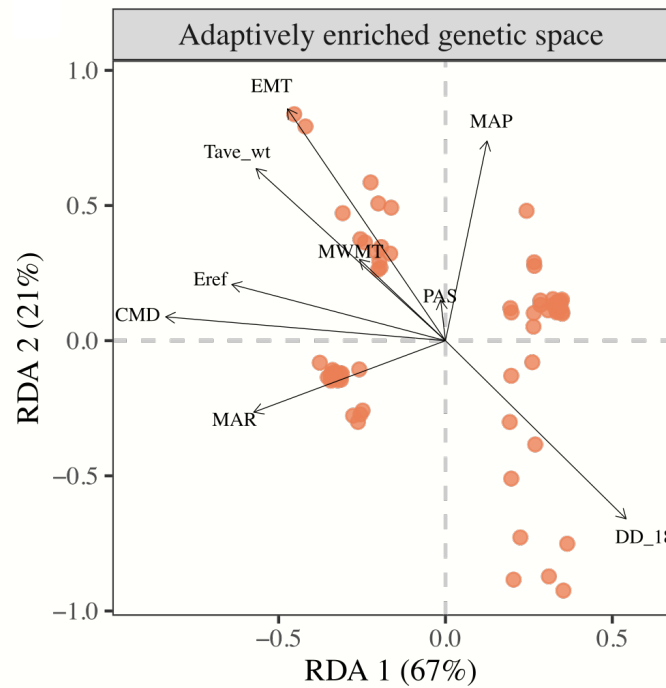
Adaptively enriched RDA space

Genetic turnover across the species range



Lodgepole pine (*Pinus contorta*)

Main adaptive gradient linked to temperature factors



Secondary adaptive gradient linked to precipitation regimes

Genetic mismatch associated with changing climates

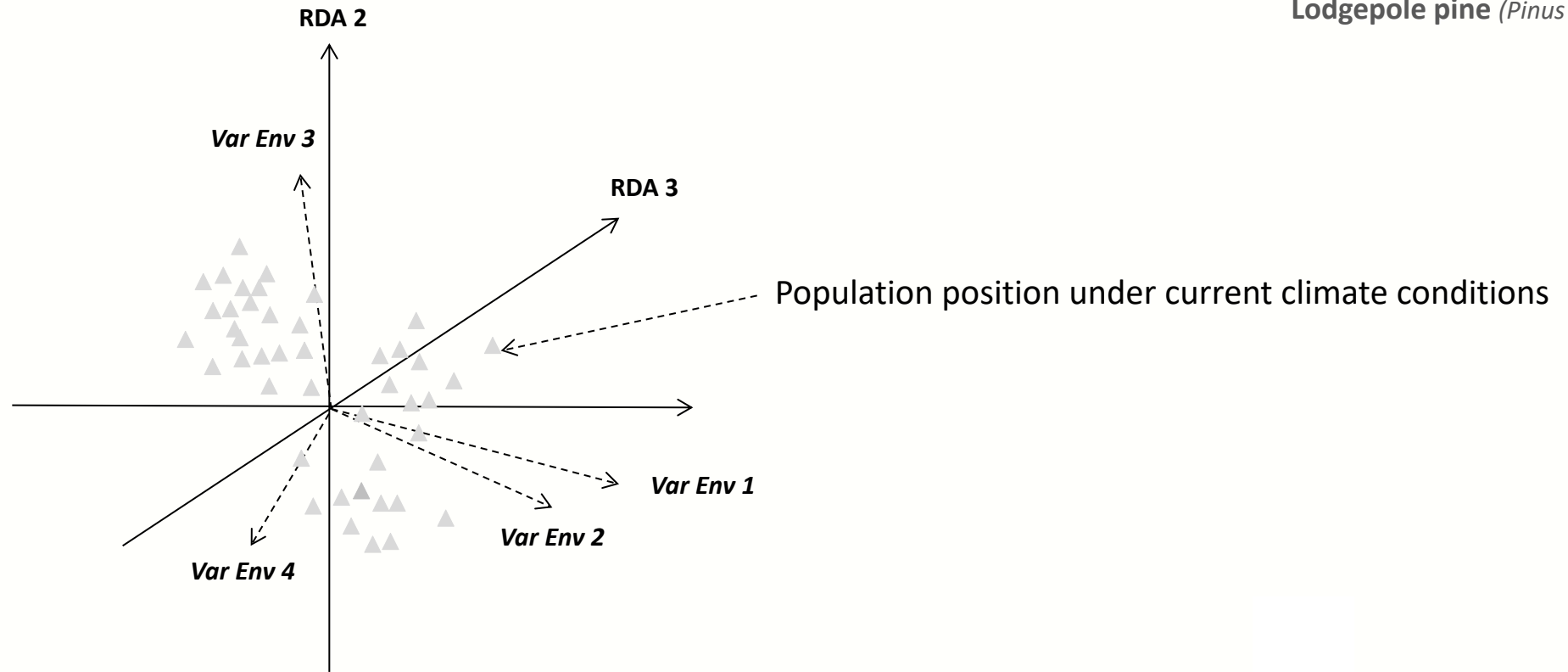


Lodgepole pine (*Pinus contorta*)

Genetic mismatch associated with changing climates



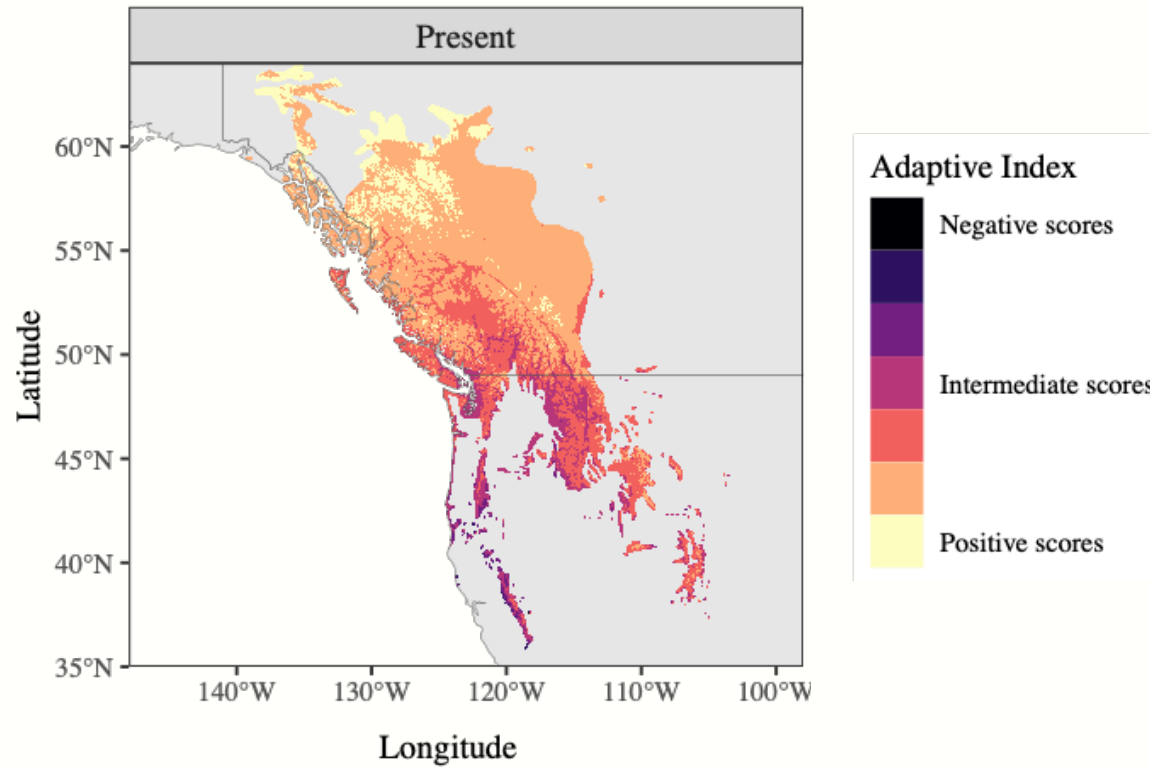
Lodgepole pine (*Pinus contorta*)



Genetic mismatch associated with changing climates



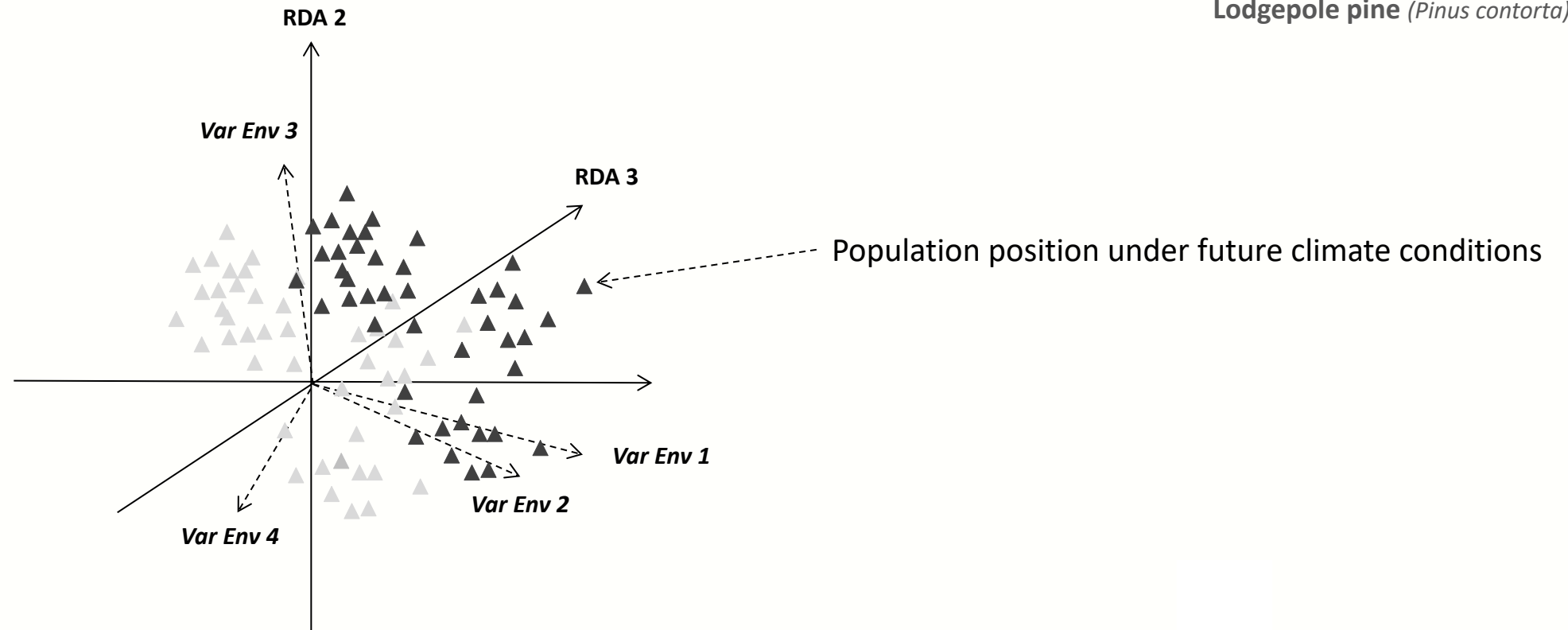
Lodgepole pine (*Pinus contorta*)



Genetic mismatch associated with changing climates



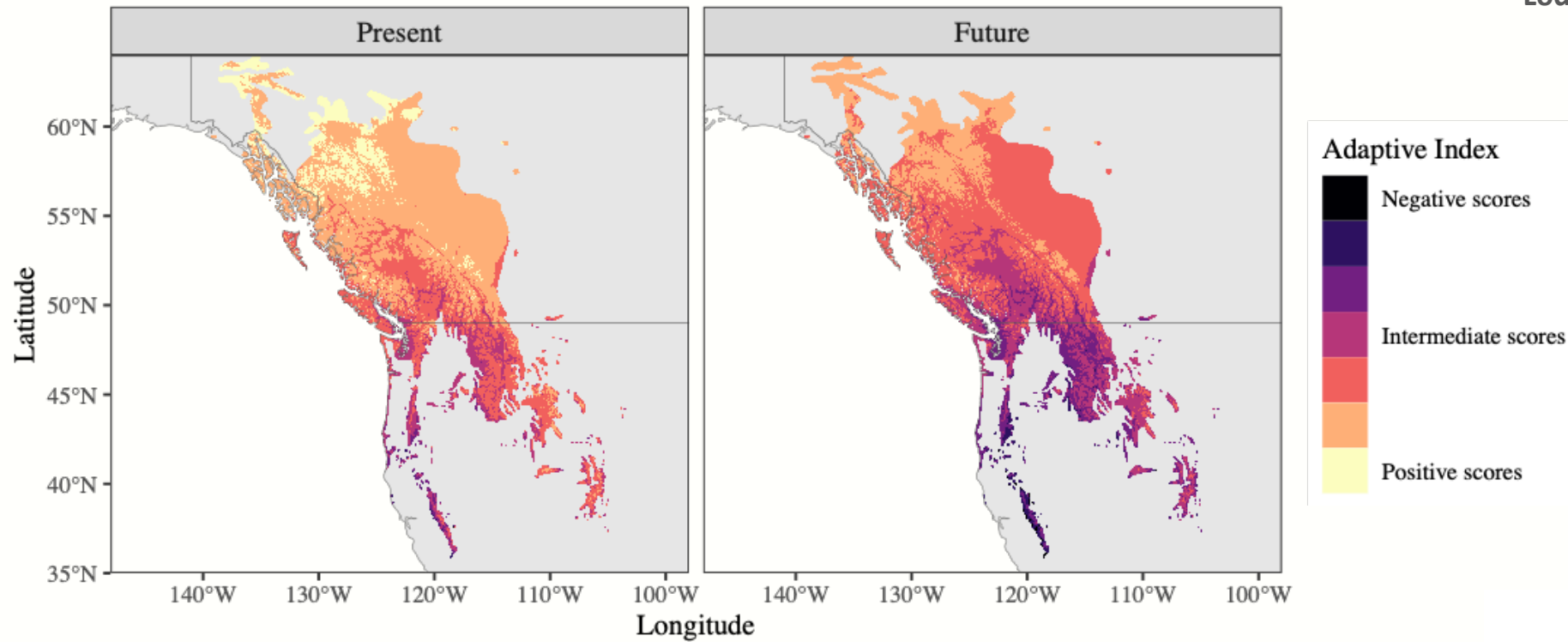
Lodgepole pine (*Pinus contorta*)



Genetic mismatch associated with changing climates



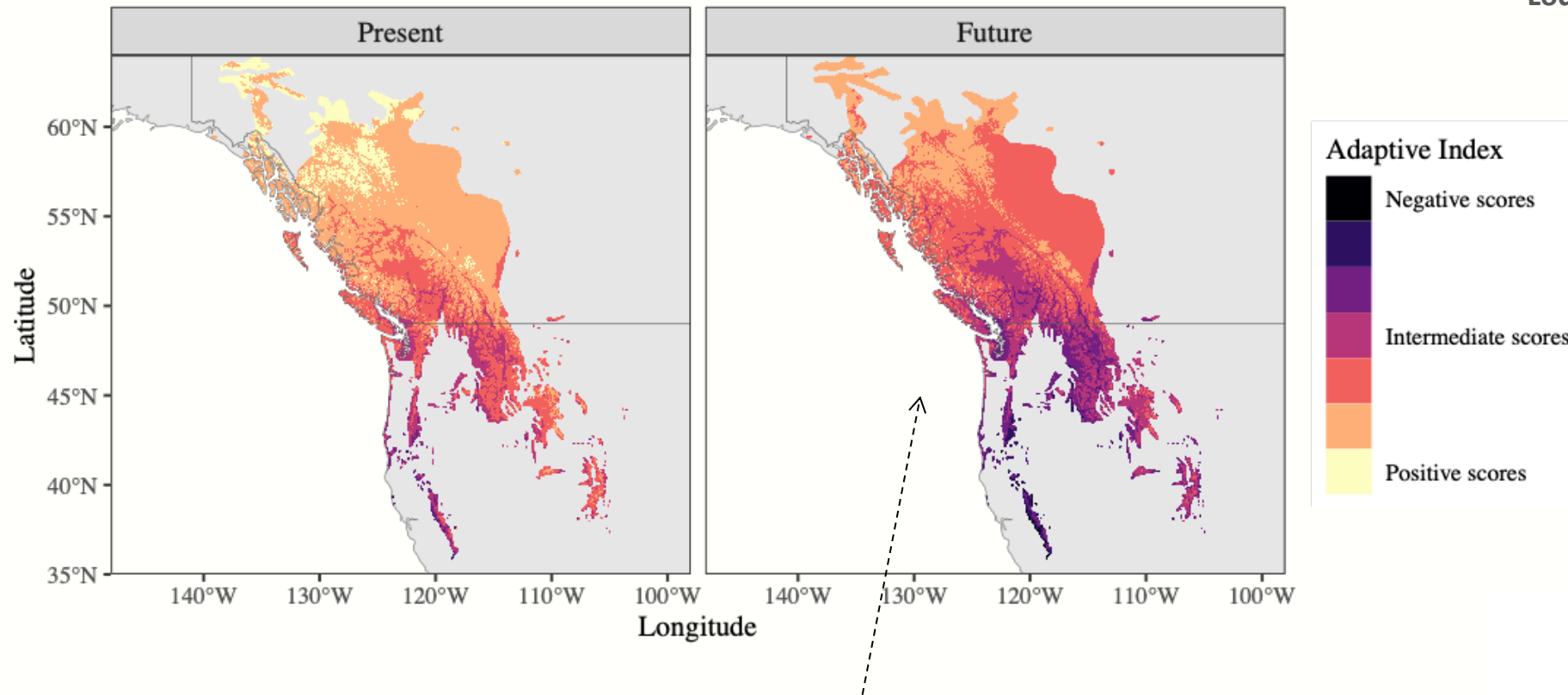
Lodgepole pine (*Pinus contorta*)



Genetic mismatch associated with changing climates



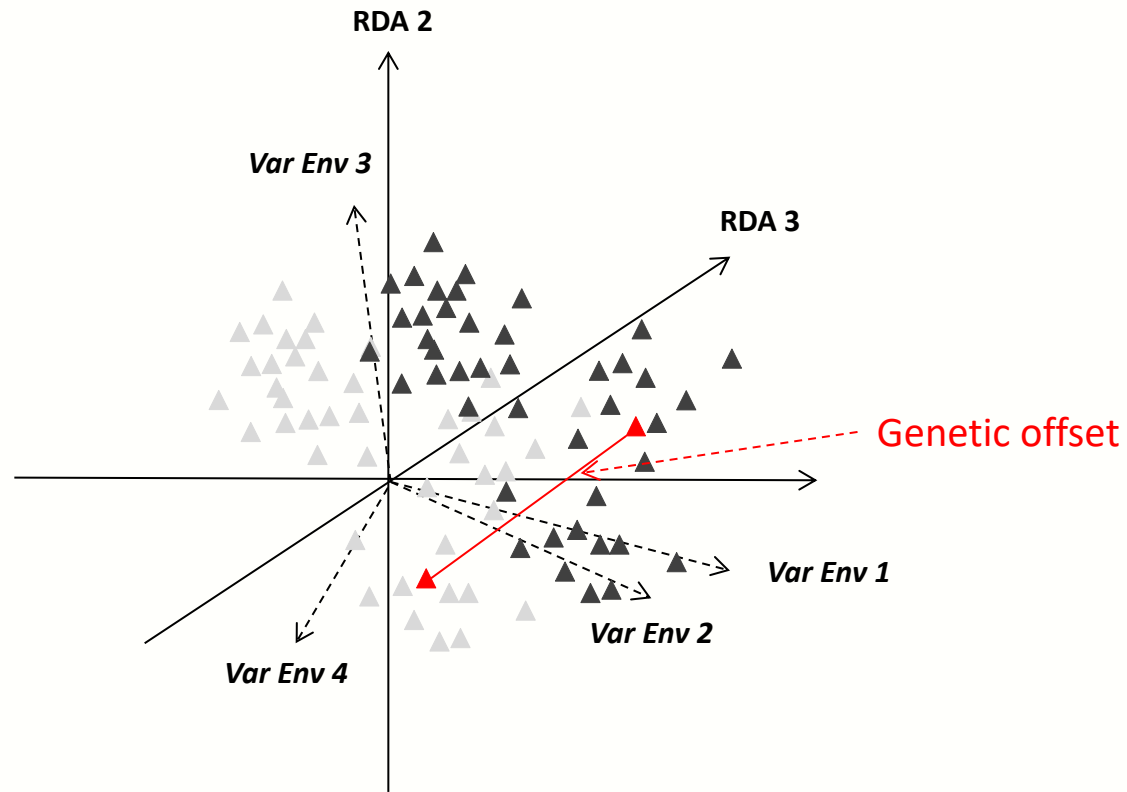
Lodgepole pine (*Pinus contorta*)



Genetic mismatch associated with changing climates



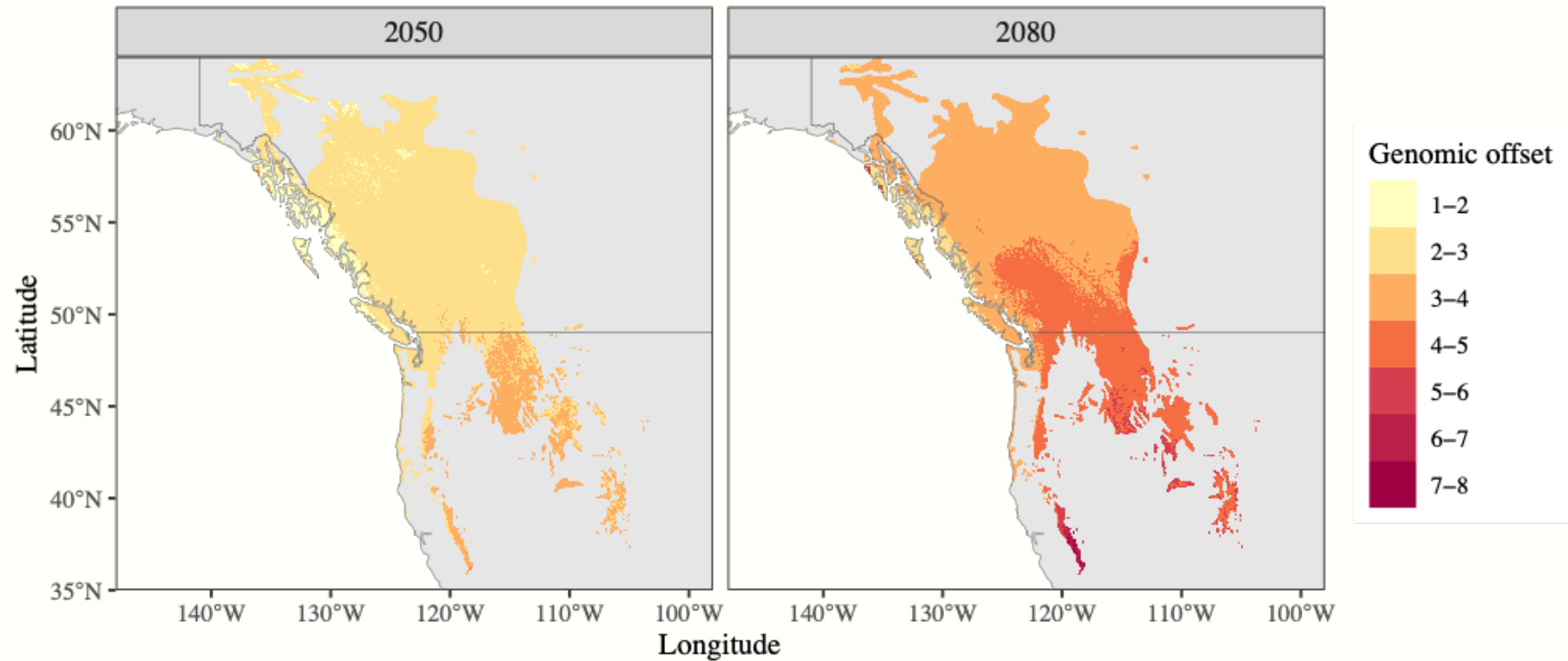
Lodgepole pine (*Pinus contorta*)



Genetic mismatch associated with changing climates



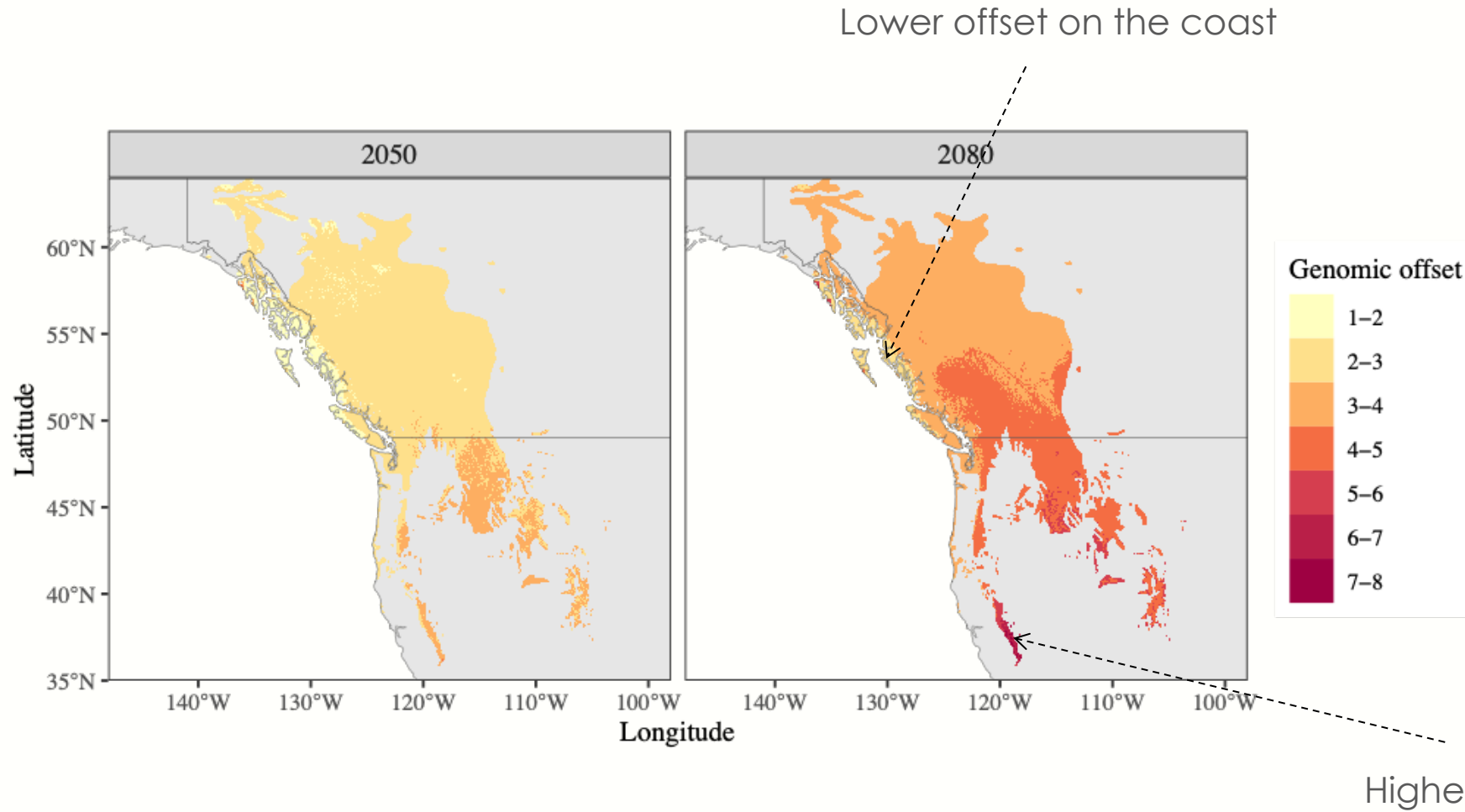
Lodgepole pine (*Pinus contorta*)



Genetic mismatch associated with changing climates



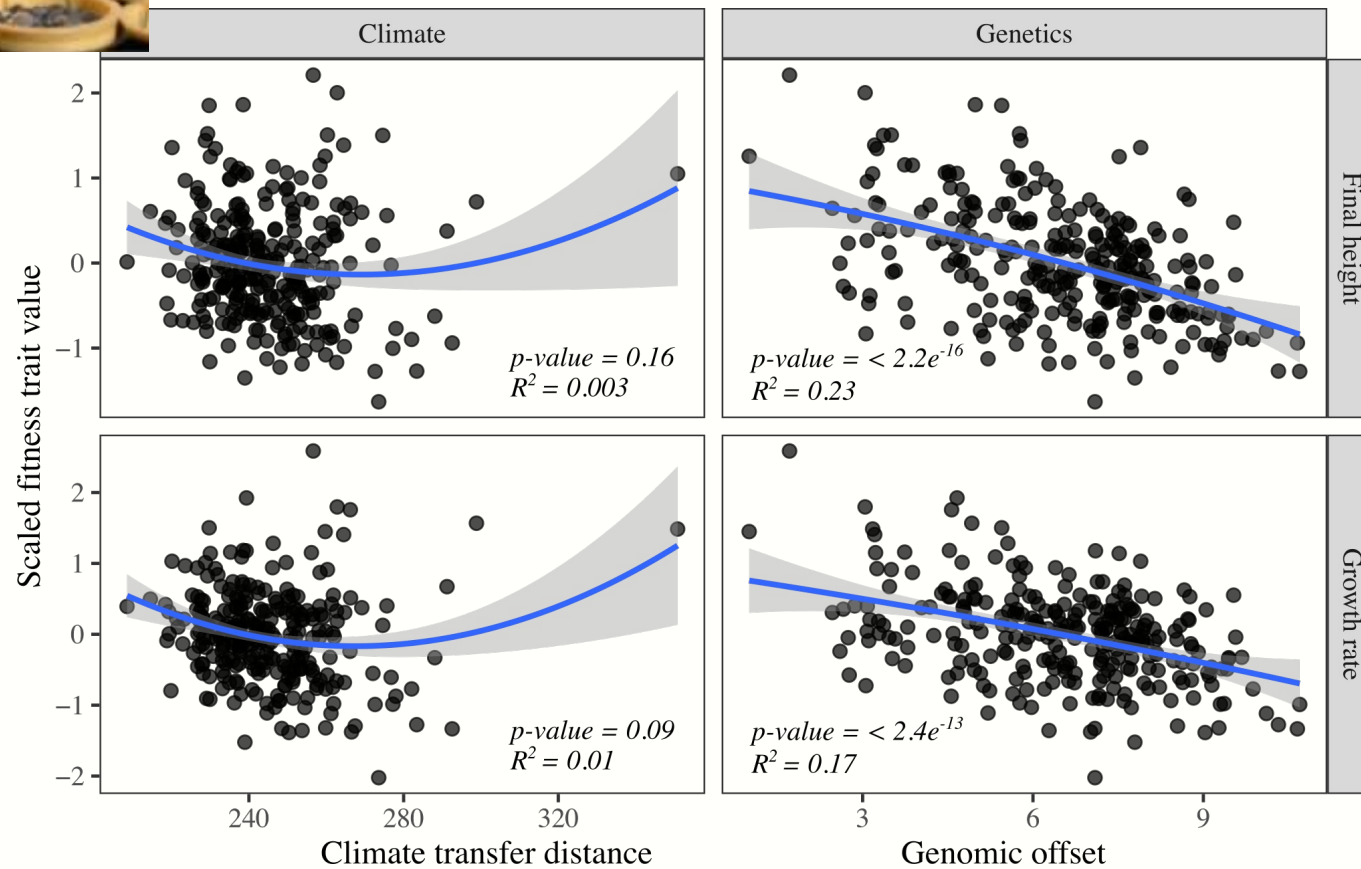
Lodgepole pine (*Pinus contorta*)



Genetic mismatch associated with changing climates



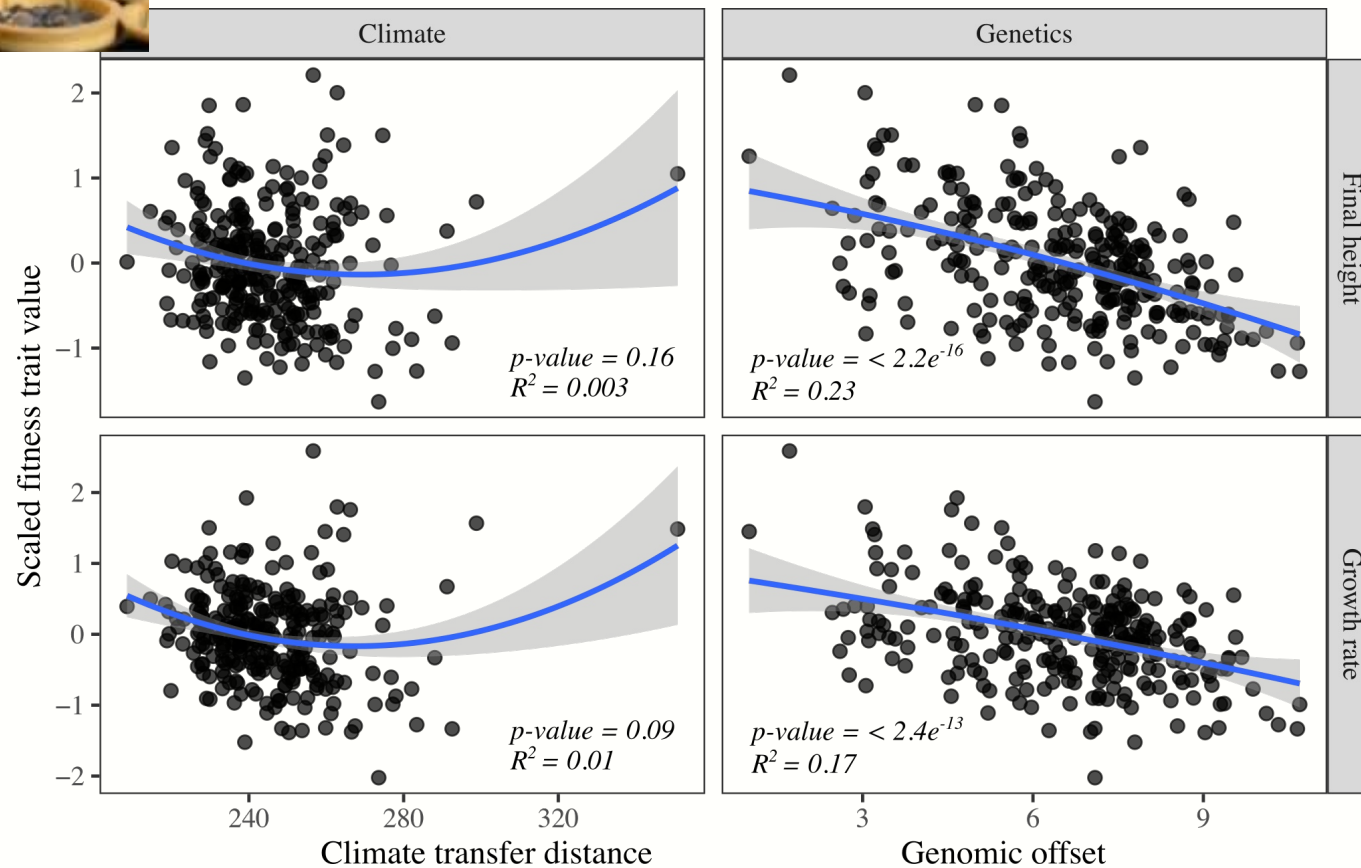
Lodgepole pine (*Pinus contorta*)



Genetic mismatch associated with changing climates



Lodgepole pine (*Pinus contorta*)



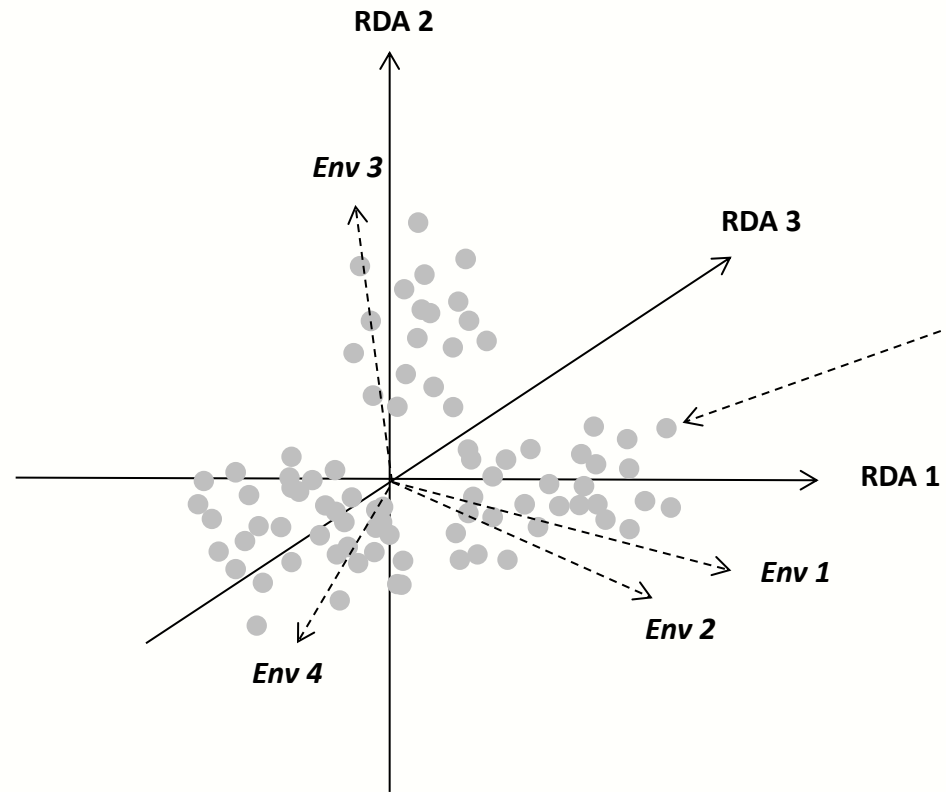
Genomic offset better **explains a decrease in fitness-related traits** than climate transfer distance alone

Identifying modules of covarying
adaptive loci

Modules of adaptive genes along environmental gradients



Red spruce (*Picea rubens*)

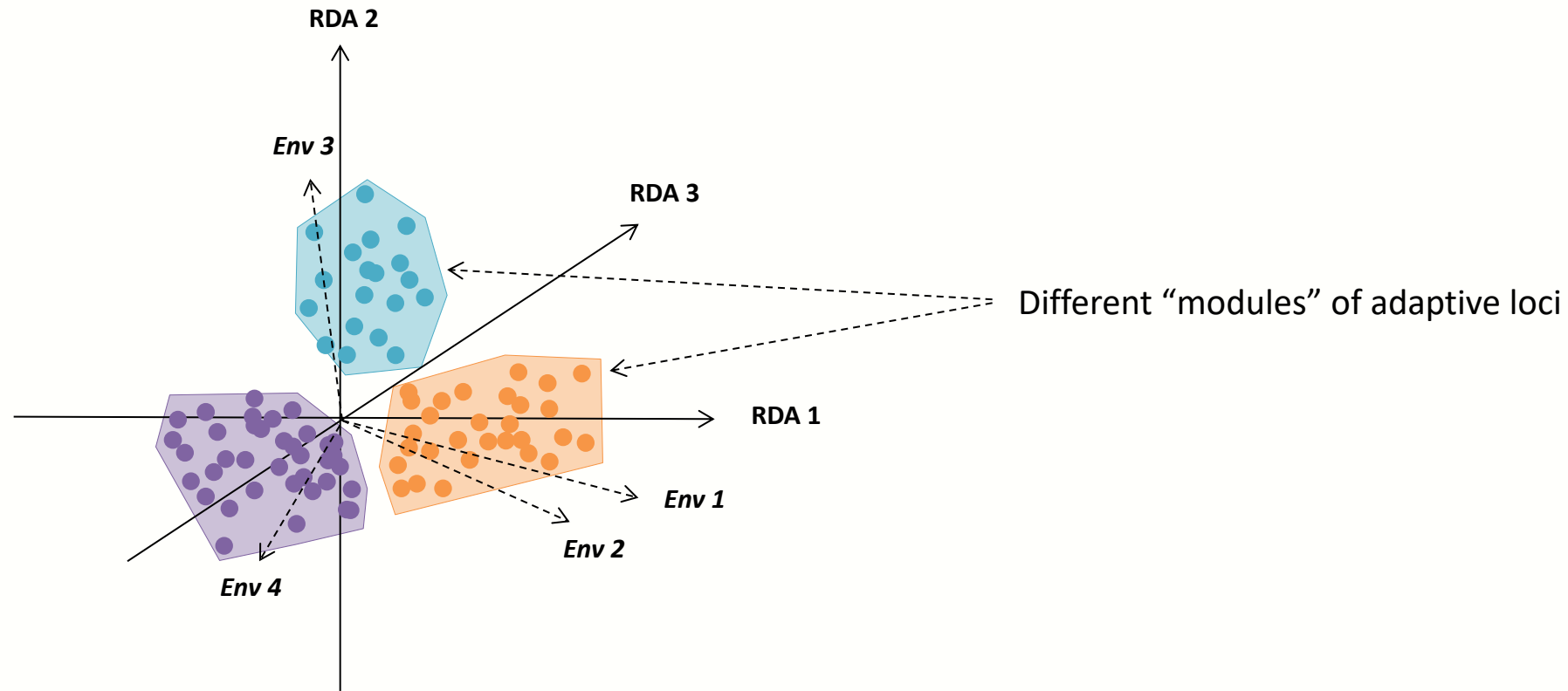


Adaptive loci projected in the RDA space

Modules of adaptive genes along environmental gradients



Red spruce (*Picea rubens*)



Modules of adaptive genes along environmental gradients



Red spruce (*Picea rubens*)



Stephen Keller - *University of Vermont*



Matt Fitzpatrick - *University of Maryland*

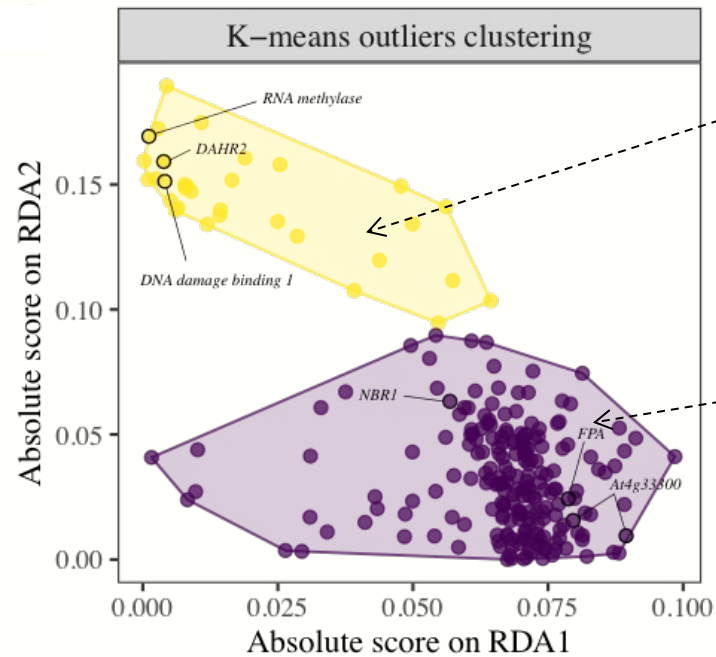


Susanne Lachmuth - *University of Maryland*

Modules of adaptive genes along environmental gradients



Red spruce (*Picea rubens*)



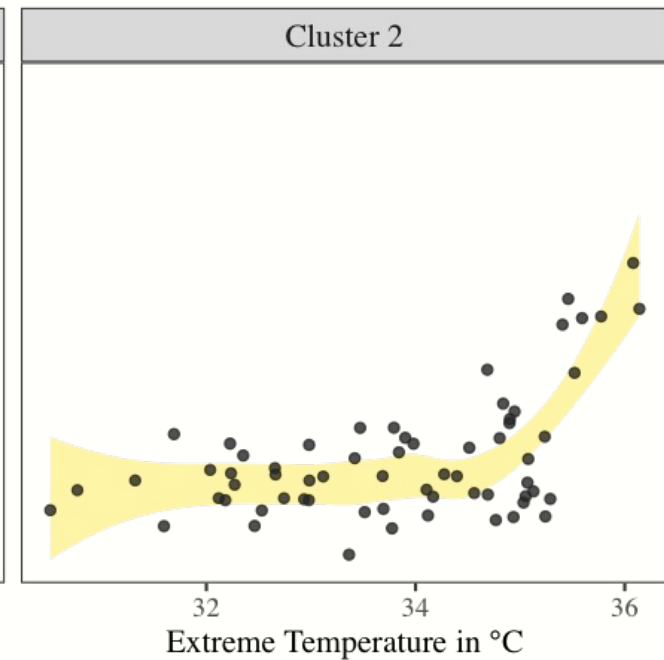
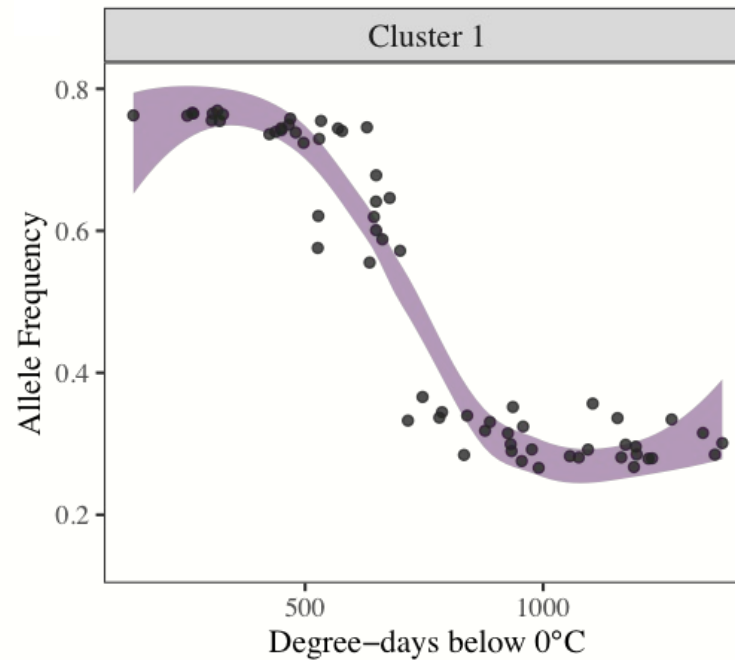
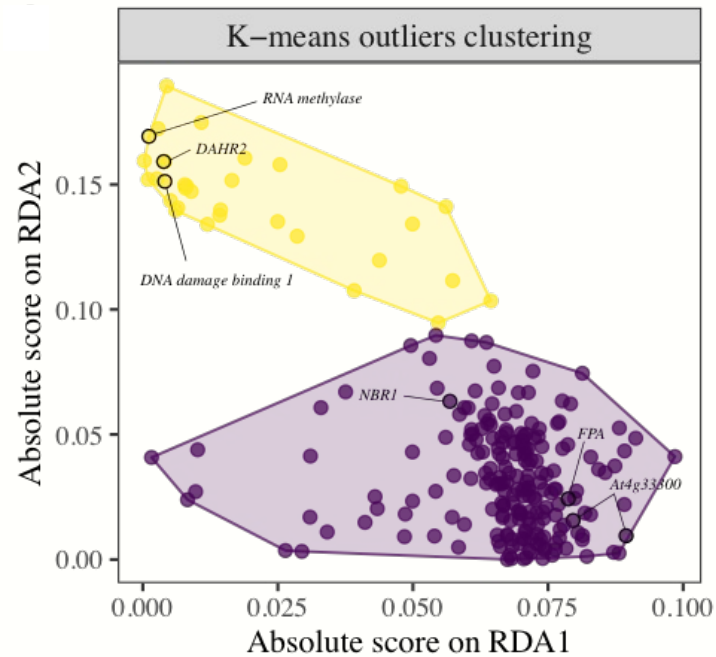
Genes associated with **acute stress response**

Genes associated with **drought, flowering time and pathogen resistance**

Modules of adaptive genes along environmental gradients



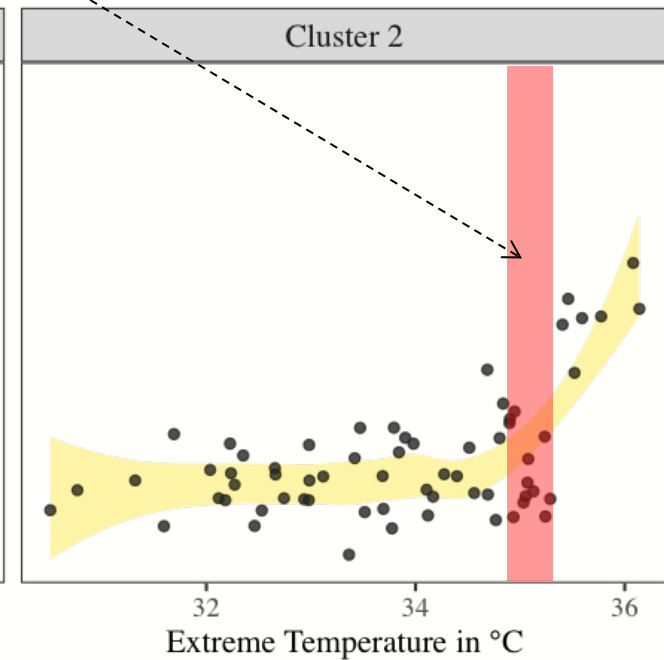
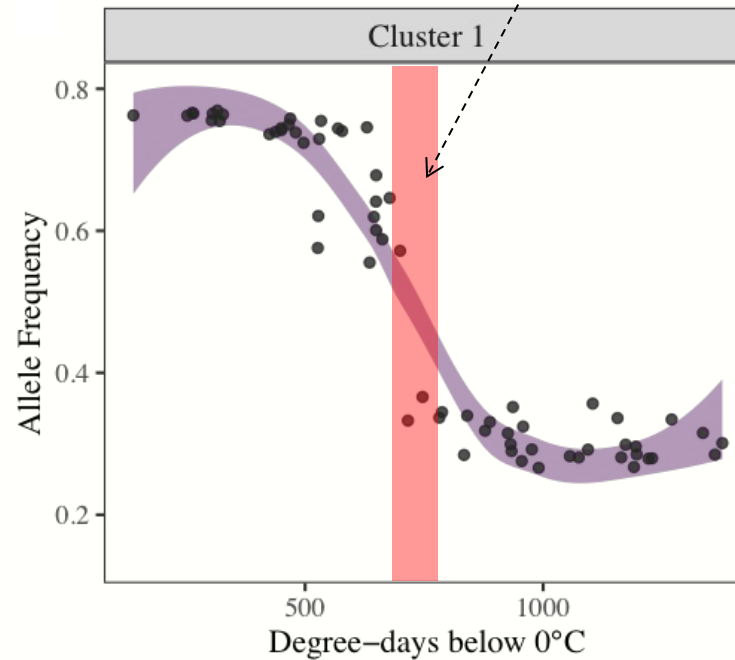
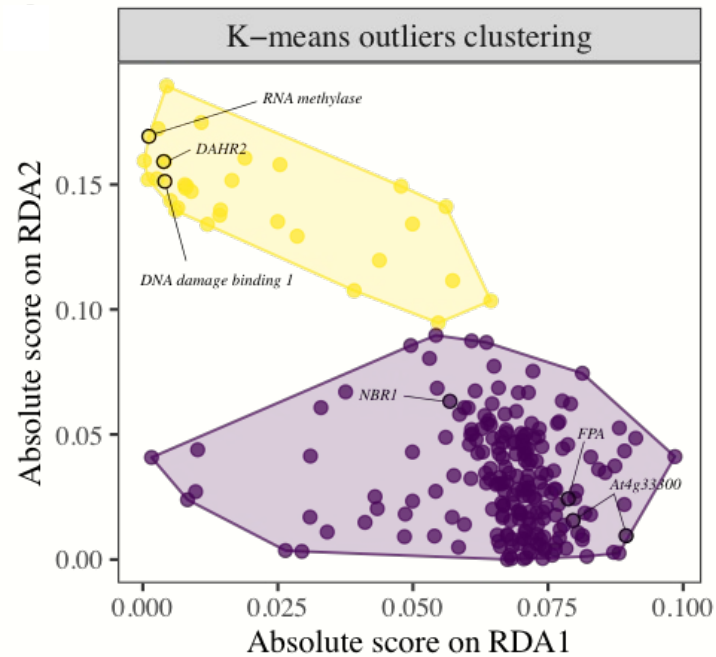
Red spruce (*Picea rubens*)



Modules of adaptive genes along environmental gradients



Red spruce (*Picea rubens*)



Important **climate thresholds**

Useful links

<https://landscape-genomics.github.io/rdadapt/>

<https://github.com/Capblancq/RDA-genome-scan>

<https://github.com/Capblancq/RDA-landscape-genomics>

https://popgen.nescent.org/2018-03-27_RDA_GEA.html