

Whole genomes reveal
continued northward movement
of a hybrid zone maintained by
strong postzygotic selection

Katherine Feldmann



Black-capped Chickadee (*Poecile atricapillus*)



Carolina Chickadee (*Poecile carolinensis*)



Hybridization and
Cognition



Hybridization and
Cognition

Study System



Hybridization and
Cognition

Study System

Geographic
Movement



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Introgression of
Chromosomes

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Genes and
Biological
Processes

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Cognition

Study System

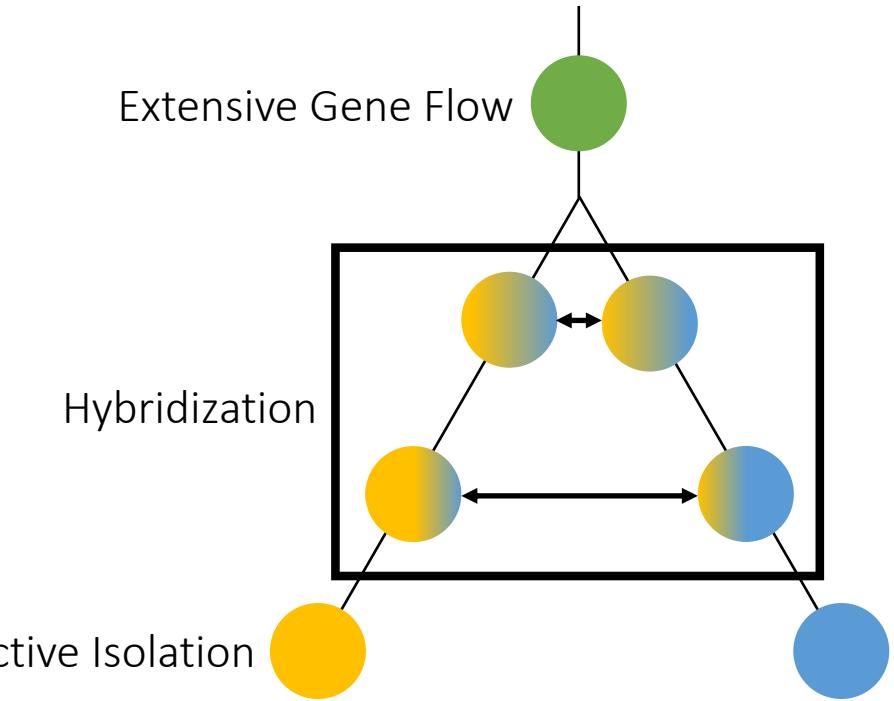
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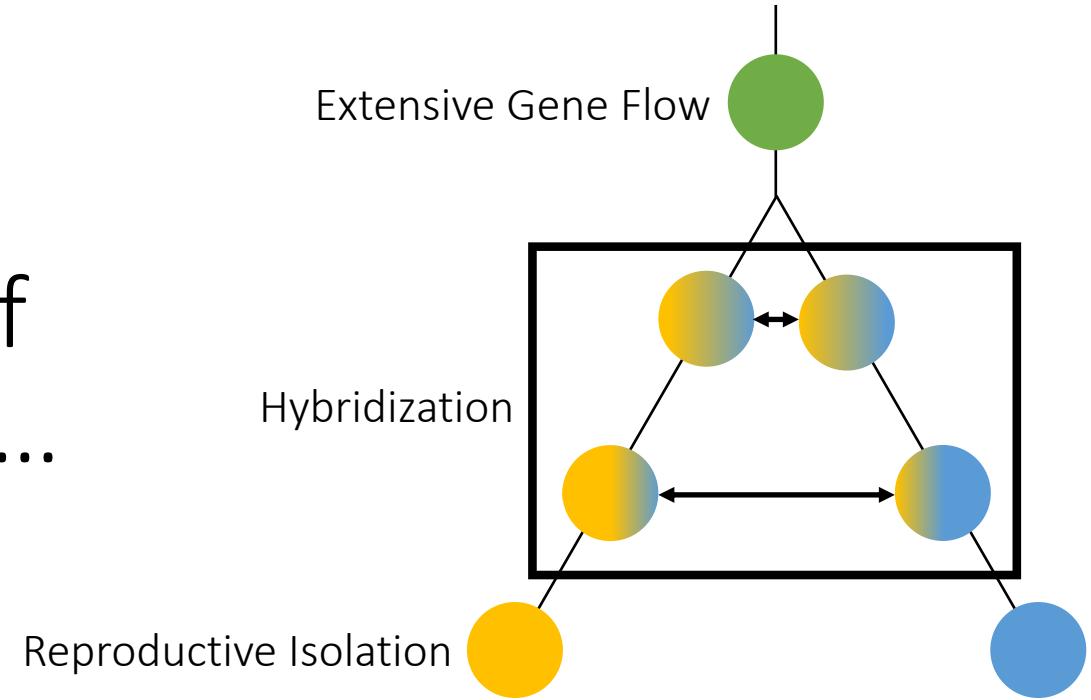
Genes and
Biological
Processes

Reproductive
Isolation

Hybridization can help us understand the evolutionary processes associated with speciation.

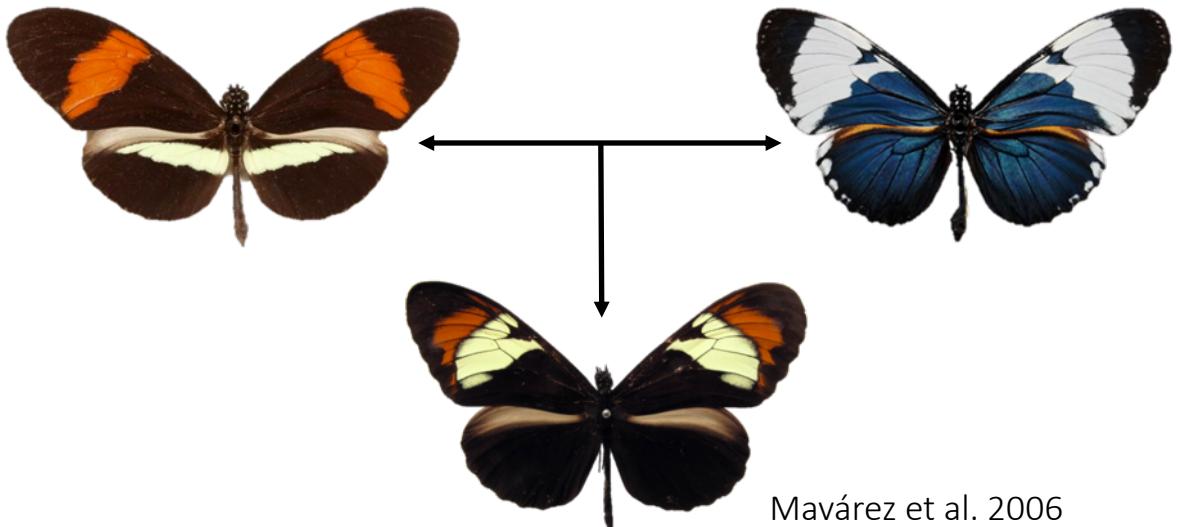
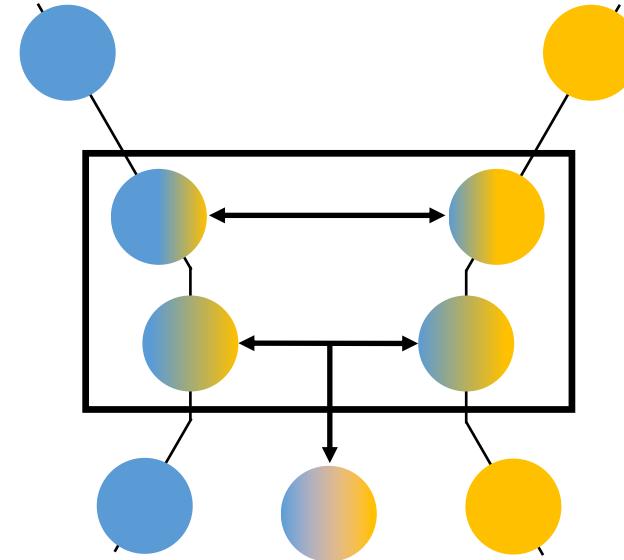


Specifically, the exchange of genetic material can lead to...



Hybrid Speciation

...reproductive isolation of the hybrid lineage from the parental species.



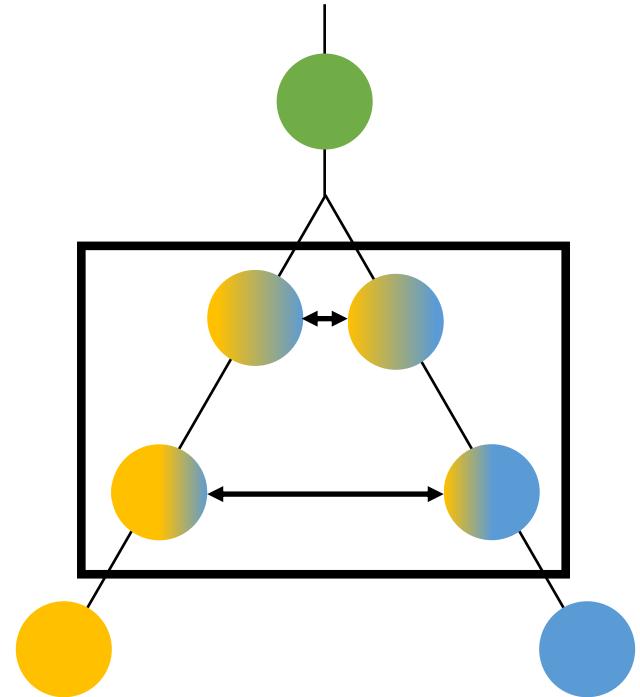
Abbott et al. 2013

Hybridization and
Cognition

Mavárez et al. 2006

Adaptive Divergence

...novel genetic variation that facilitates speciation of the hybridizing species.



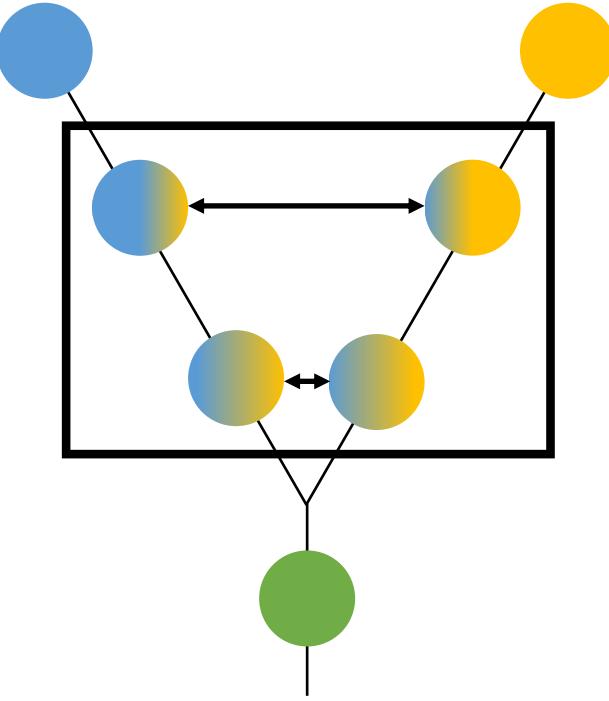
Abbott et al. 2013

Hybridization and
Cognition

vonHoldt et al. 2016

Lineage Fusion

...loss of genetic differentiation due to a breakdown in reproductive isolation.



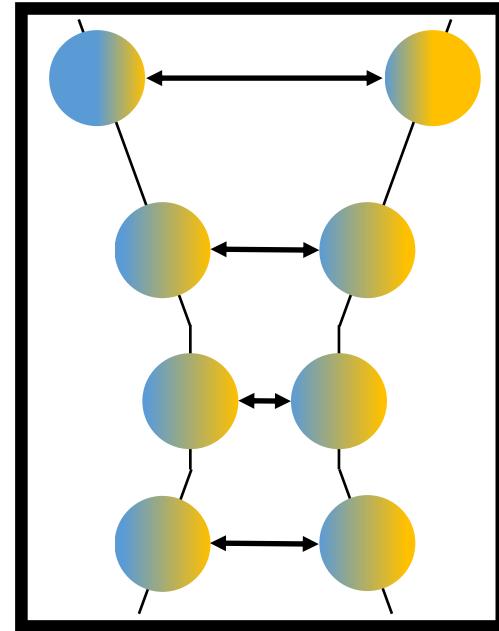
Budd and Pandolfi 2004



Hinojosa et al. 2019

Equilibrium

...the maintenance of reproductive isolation despite ongoing gene flow.



Abbott et al. 2013

Hybridization and
Cognition

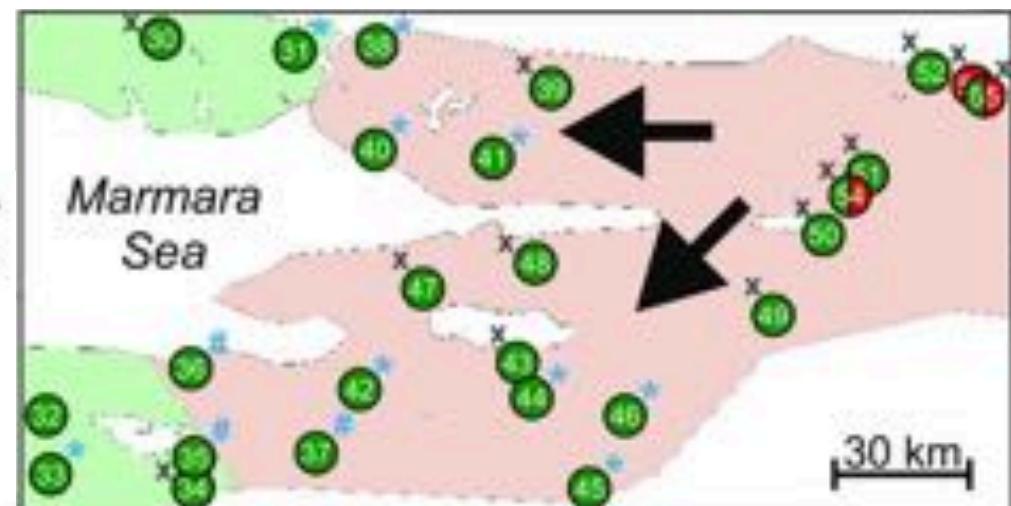
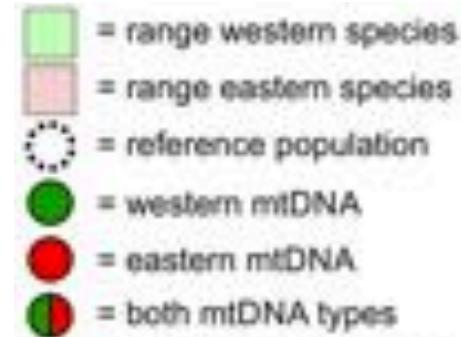
Saetre et al. 1997

While stable hybrid zones are maintained by reproductive isolation despite ongoing gene flow...

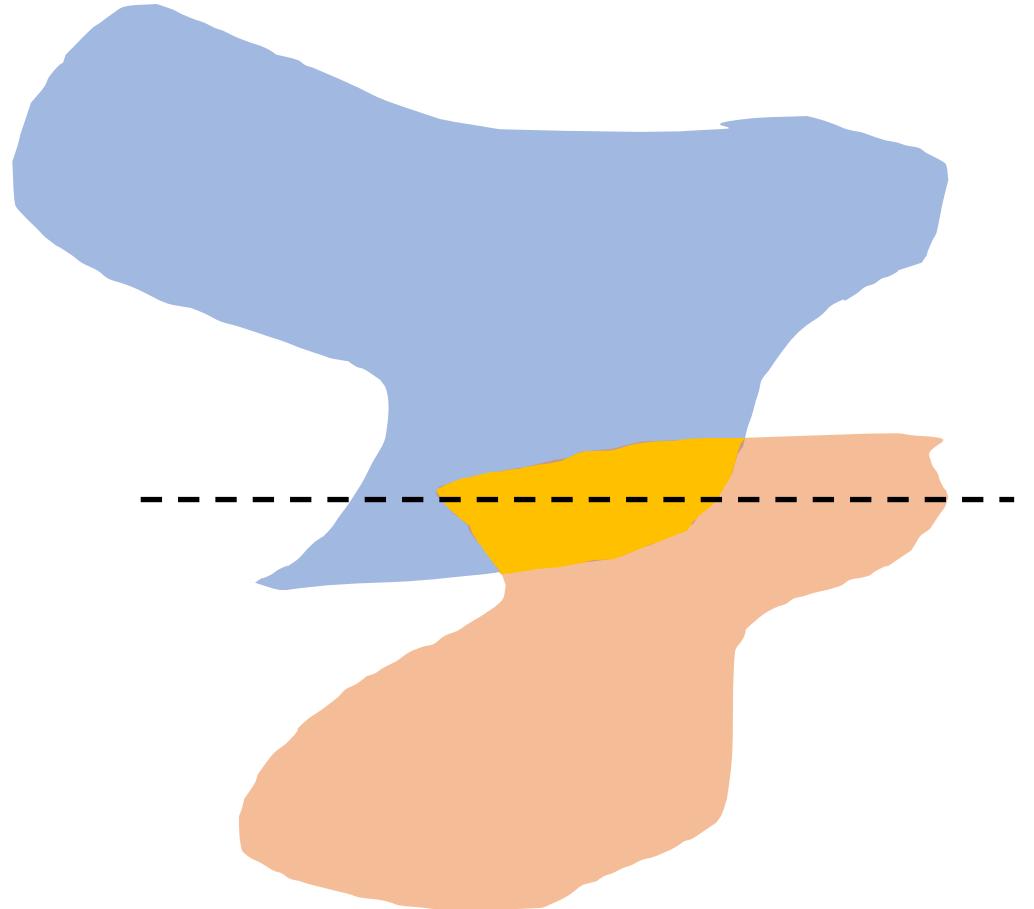


While stable hybrid zones are maintained by reproductive isolation despite ongoing gene flow...

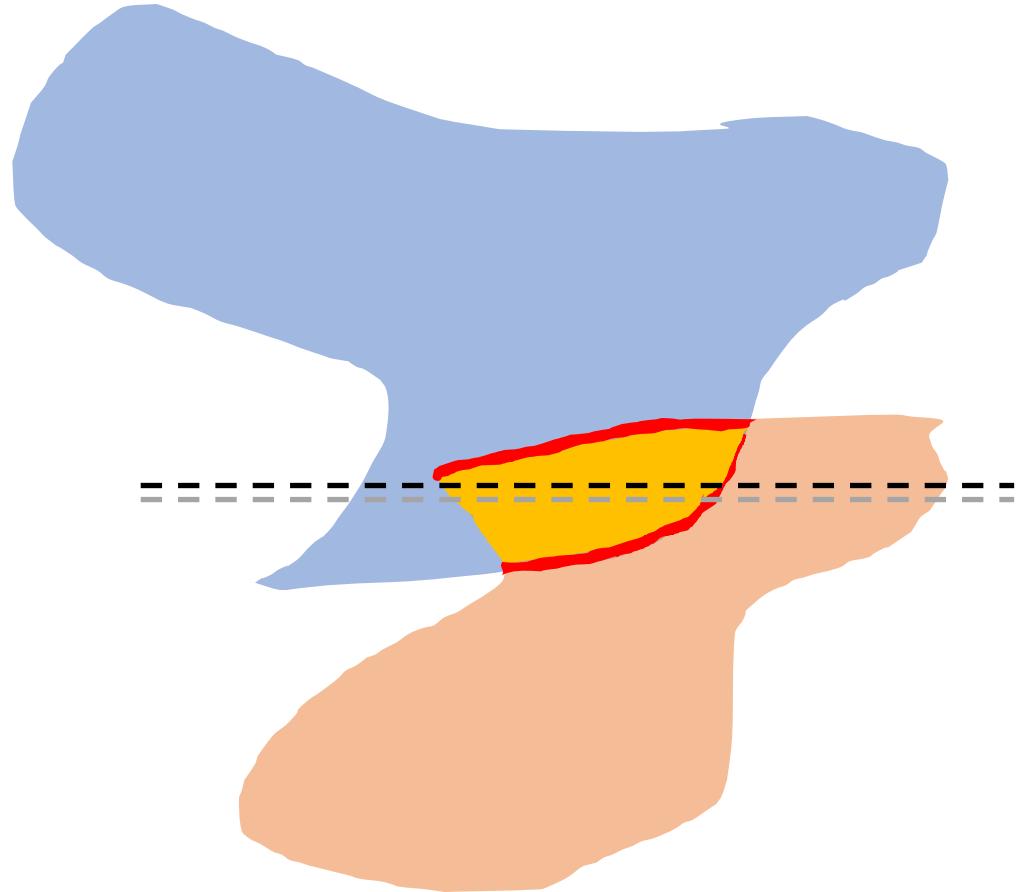
...these hybrid zones may move geographically.



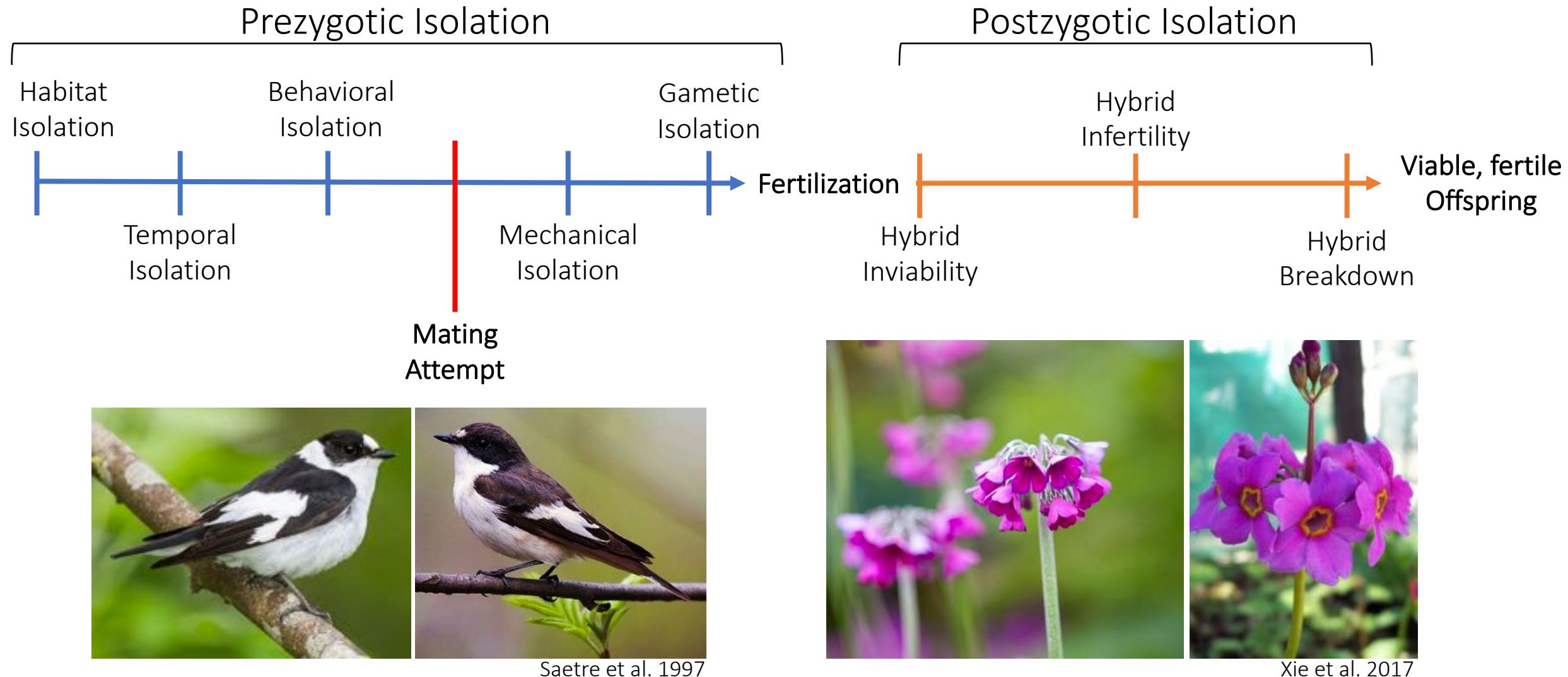
If the moving hybrid zone
does not expand in width,
then there is strong selection
against hybrids.



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does not expand in width,
then there is strong selection
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Selection against hybrids maintains reproductive isolation.



Cognition has received little attention as a [postzygotic](#), reproductive isolating barrier...



Mattucci et al. 2019

Cognition has received little attention as a postzygotic, reproductive isolating barrier...

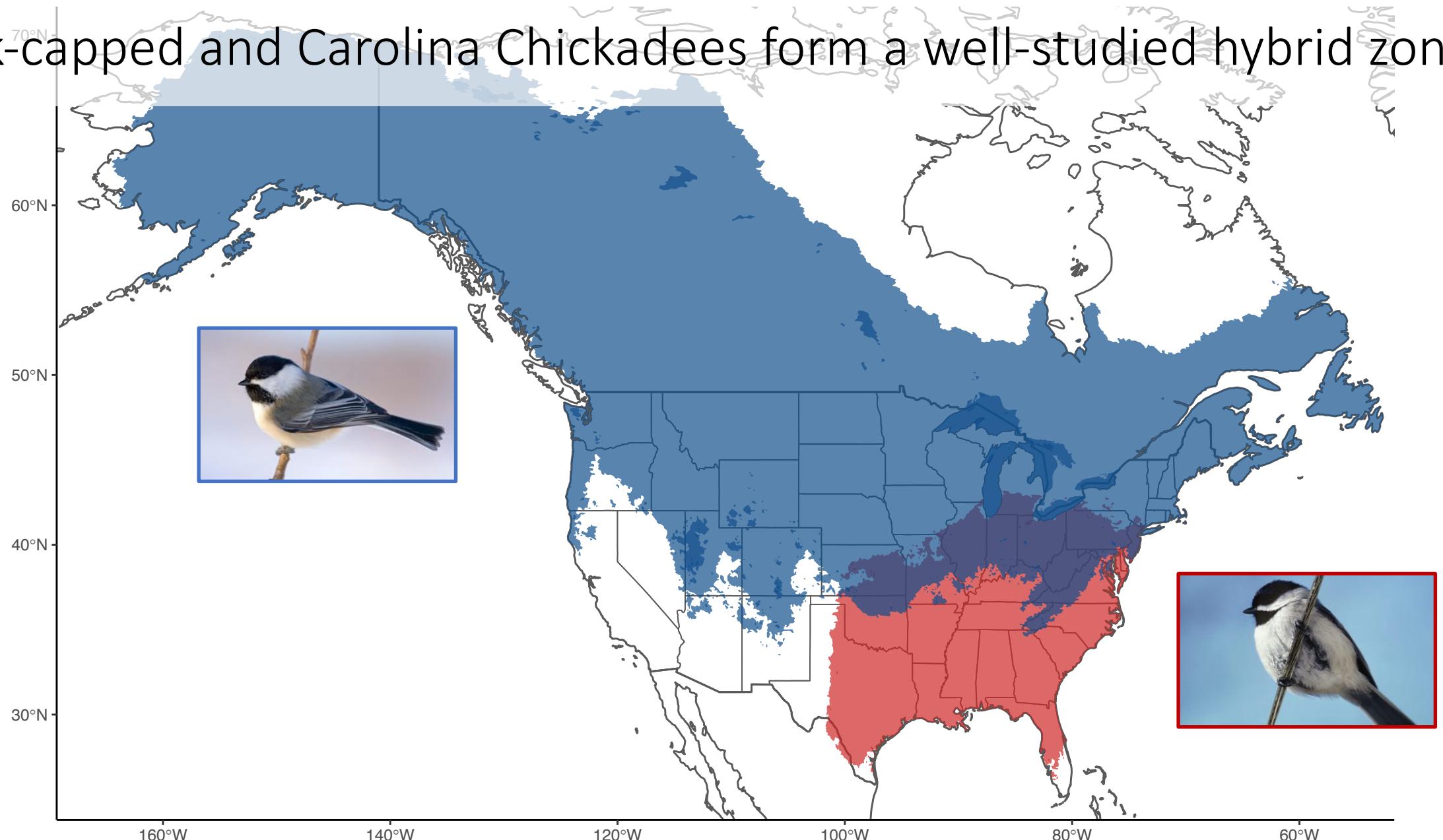
...despite learning and memory being **heritable** and evidence of selection on cognitive abilities.

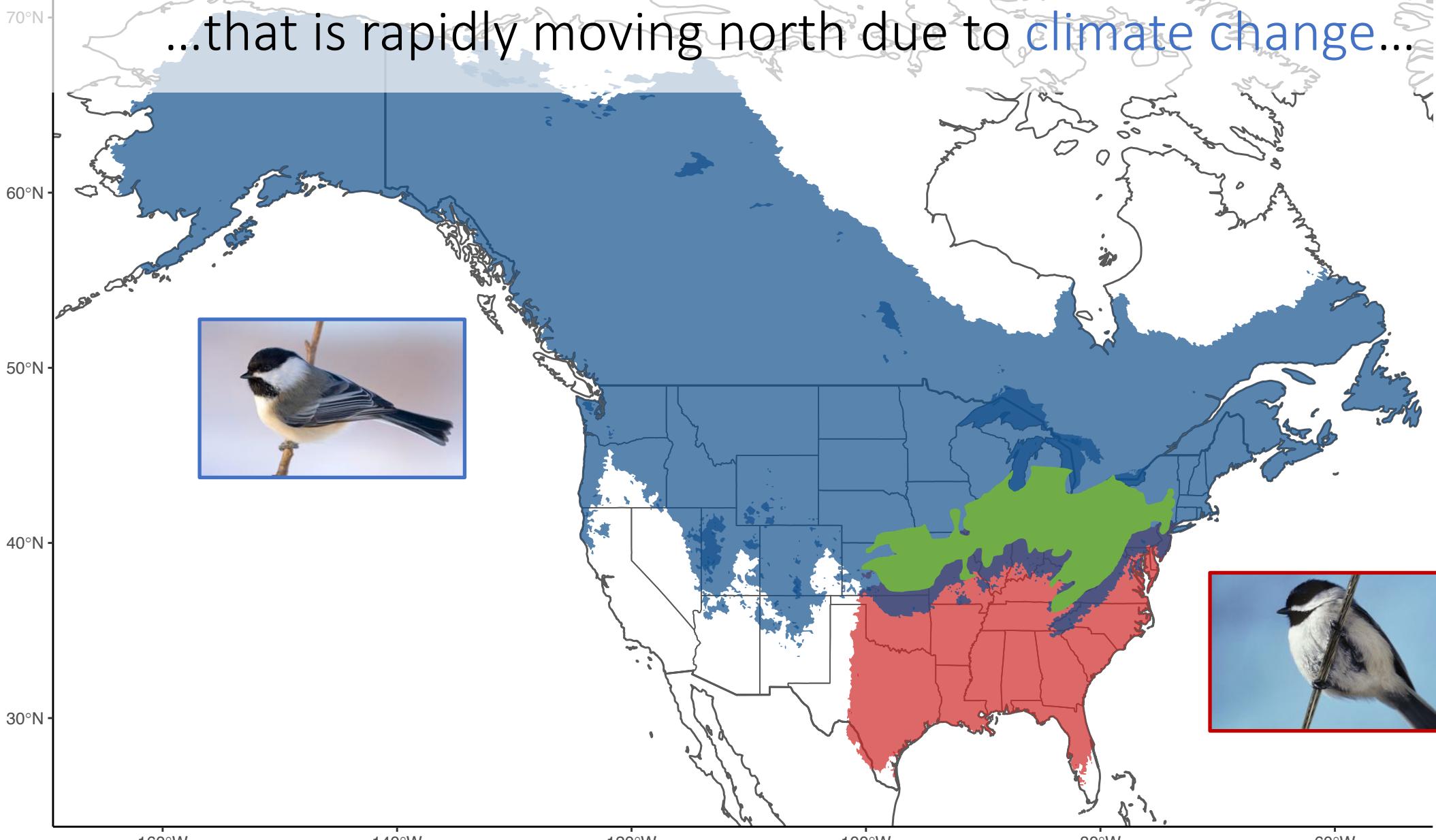


Mattucci et al. 2019

Does cognitive breakdown in hybrids act as a postzygotic, reproductive isolating barrier in a rapidly moving avian hybrid zone?

Black-capped and Carolina Chickadees form a well-studied hybrid zone...





...and cognition is important for [winter survival](#) in these non-migratory birds.



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Chickadees cache seeds for recovery in the winter when food resources are scarce.



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Chickadees cache seeds for recovery in the winter when food resources are scarce.

Successful retrieval of these caches is important for winter survival.



Sonnenberg et al. 2019

...and cognition is important for [winter survival](#) in these non-migratory birds.

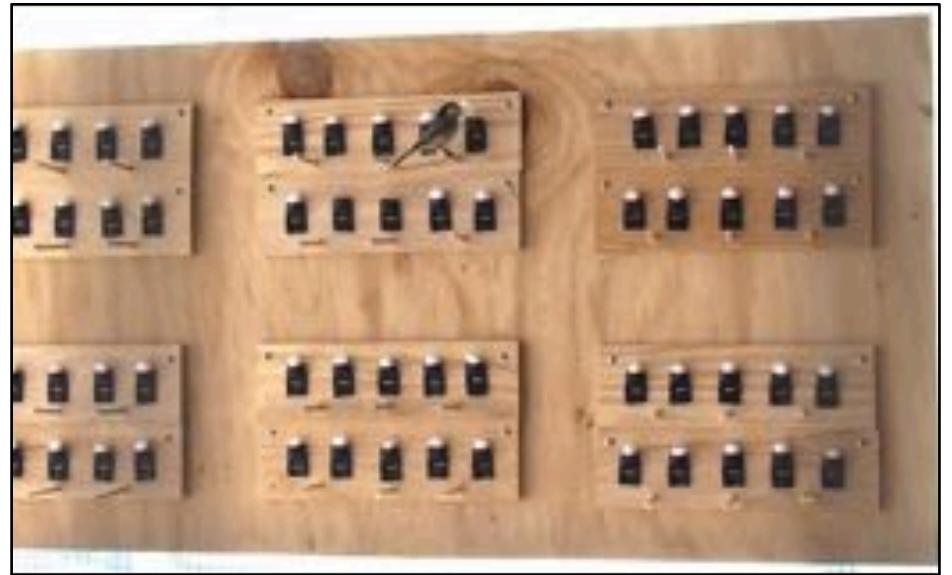
Chickadees cache seeds for recovery in the winter when food resources are scarce.

Successful retrieval of these caches is important for winter survival.

Successful retrieval of these caches is dependent on cognitive ability.



Yi et al. 2016



Hybrid chickadees have
deficient cognitive abilities.

novel problem solving



Does cognitive breakdown in hybrids act as a postzygotic, reproductive isolating barrier in a rapidly moving avian hybrid zone?

Does cognitive breakdown in hybrids act as a postzygotic, reproductive isolating barrier in a [rapidly moving avian hybrid zone](#)?

Geographic Movement

Has the hybrid zone continued to move north? Has the width changed?

Hybridization and Cognition

Study System

Does cognitive breakdown in hybrids act as a postzygotic, reproductive isolating barrier in a rapidly moving avian hybrid zone?

Geographic Movement

Has the hybrid zone continued to move north? Has the width changed?

Introgression of Chromosomes

How does the genome change across the hybrid zone?

Hybridization and Cognition

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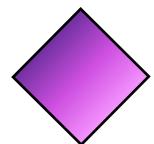
Genes and Biological Processes

Is there evidence that overrepresented biological processes are associated with cognition?

Hybridization and Cognition

Study System

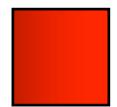
We sequenced 117 whole-genomes...



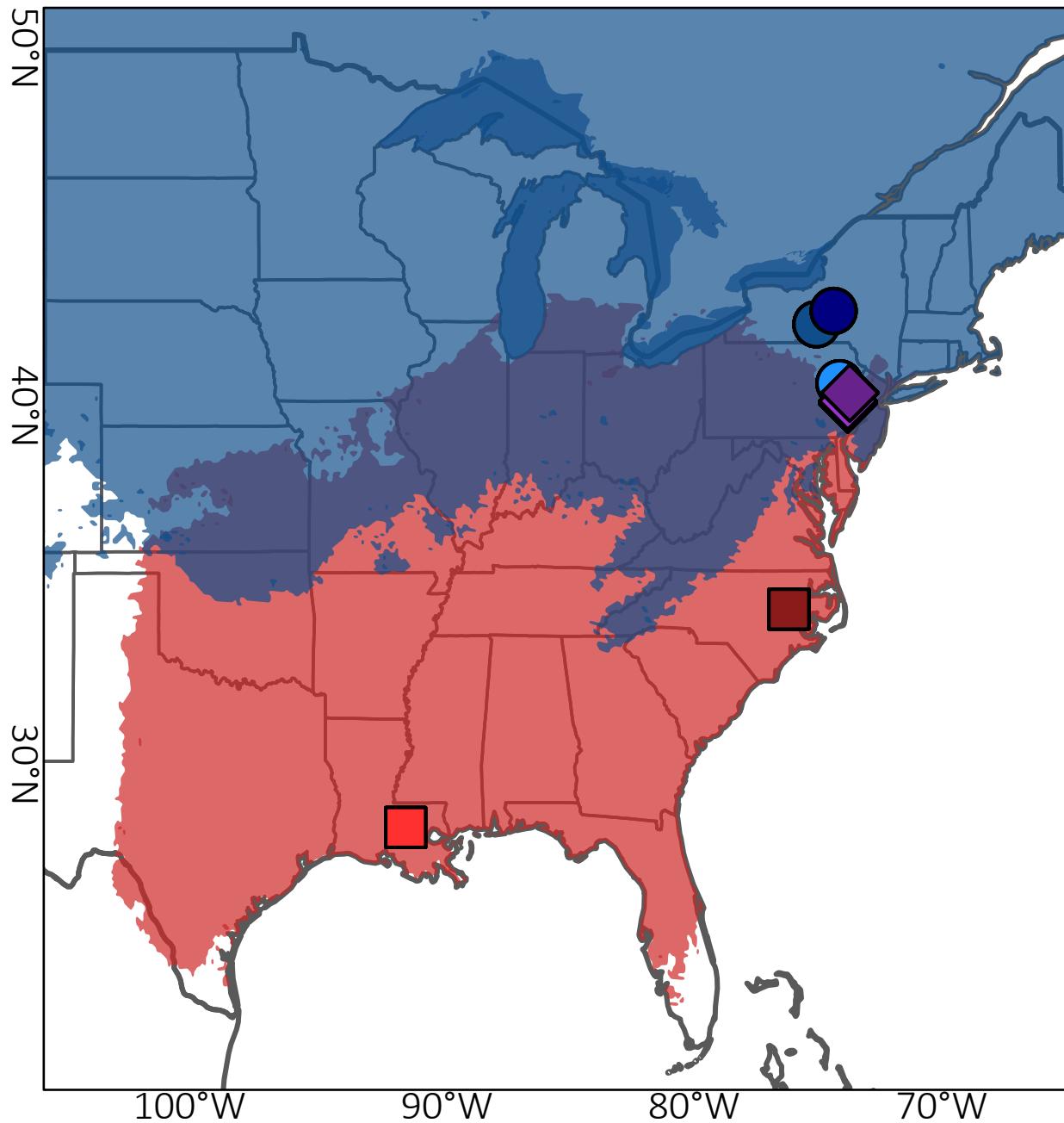
Across the hybrid zone



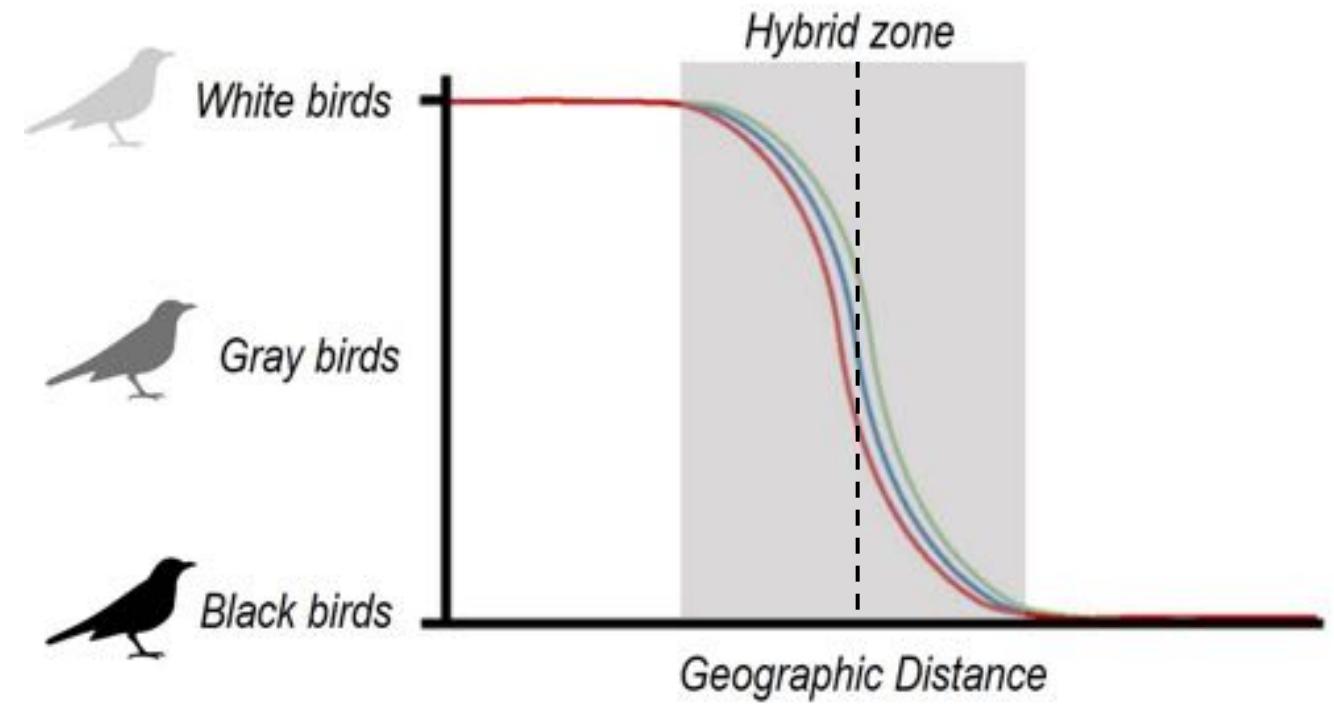
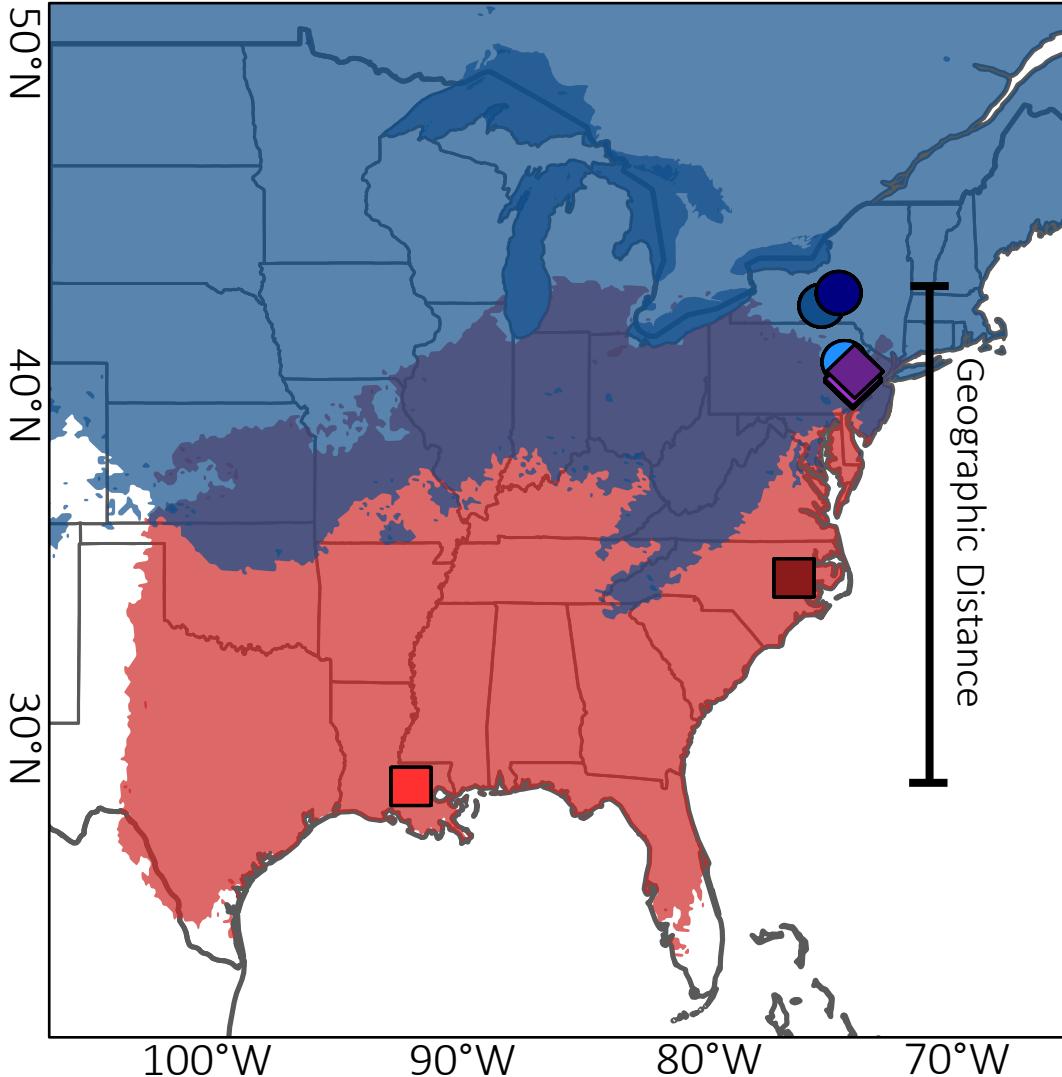
Black-capped Chickadees
outside the hybrid zone



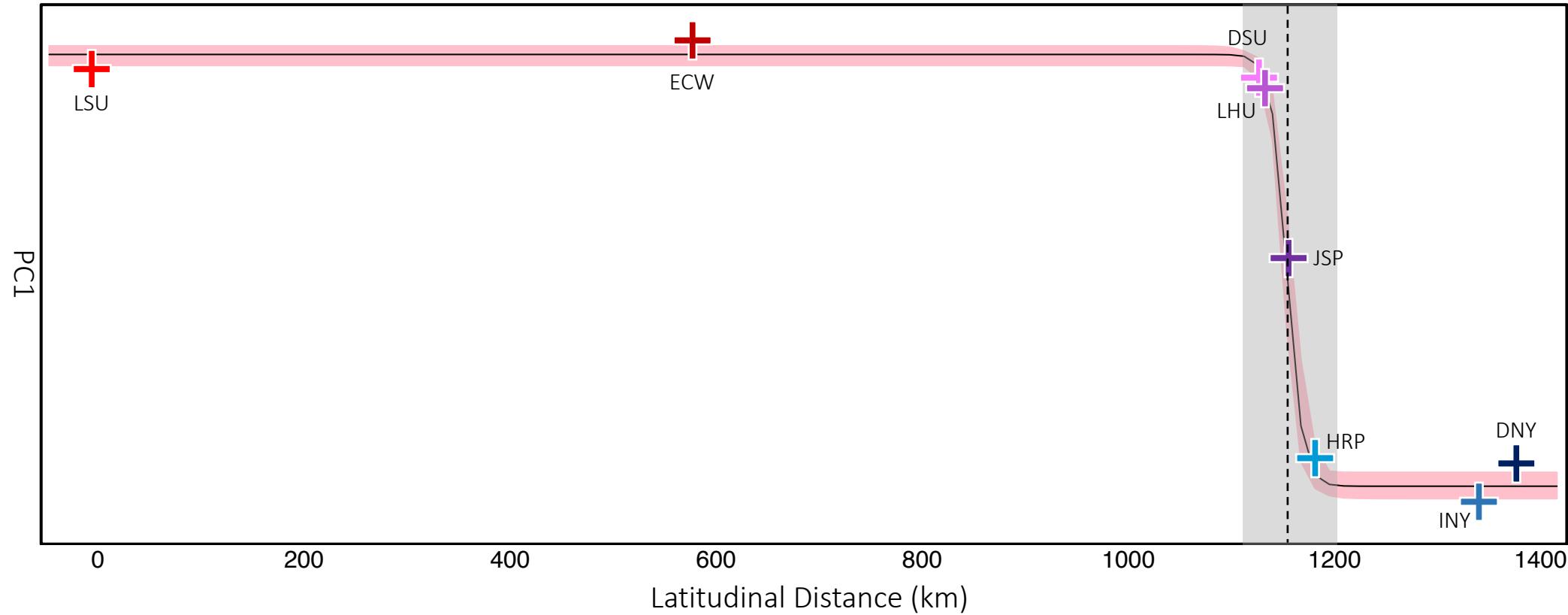
Carolina Chickadees outside
the hybrid zone



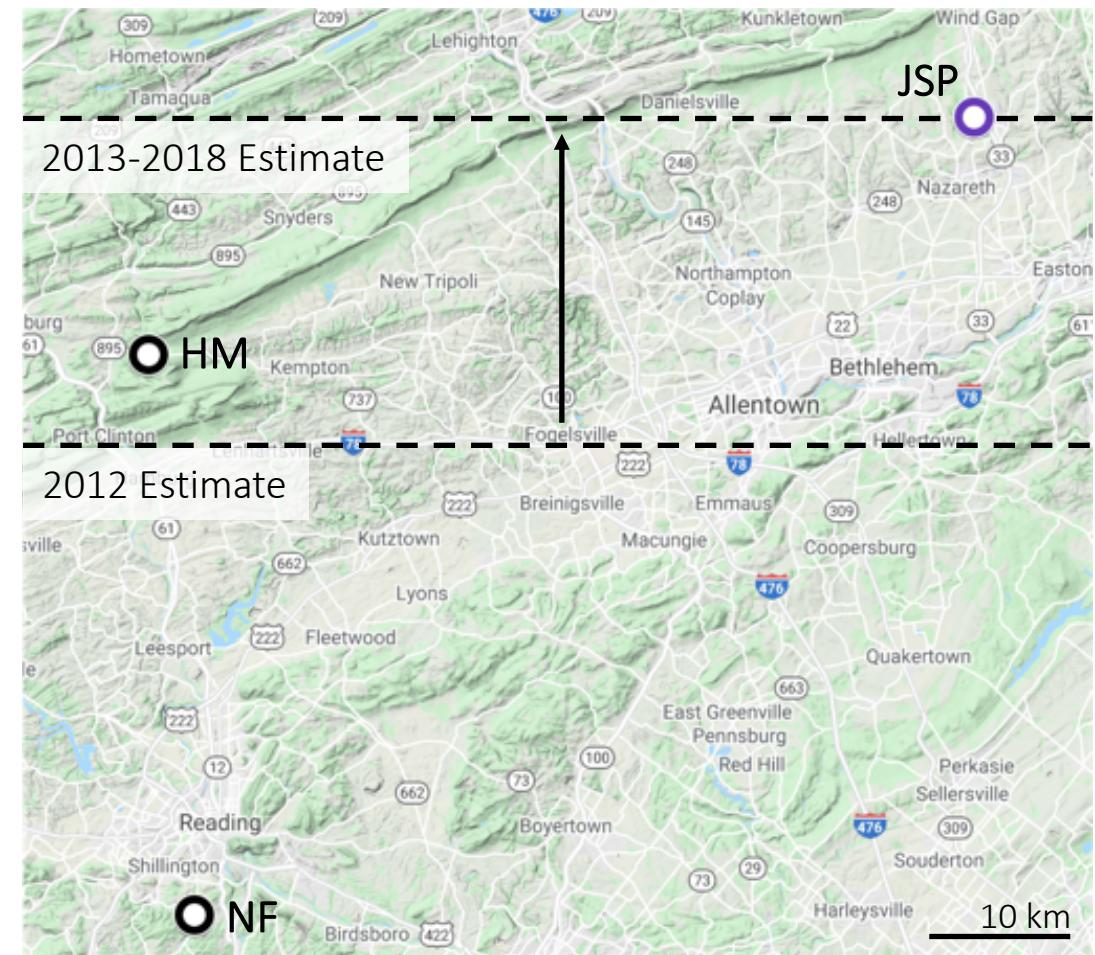
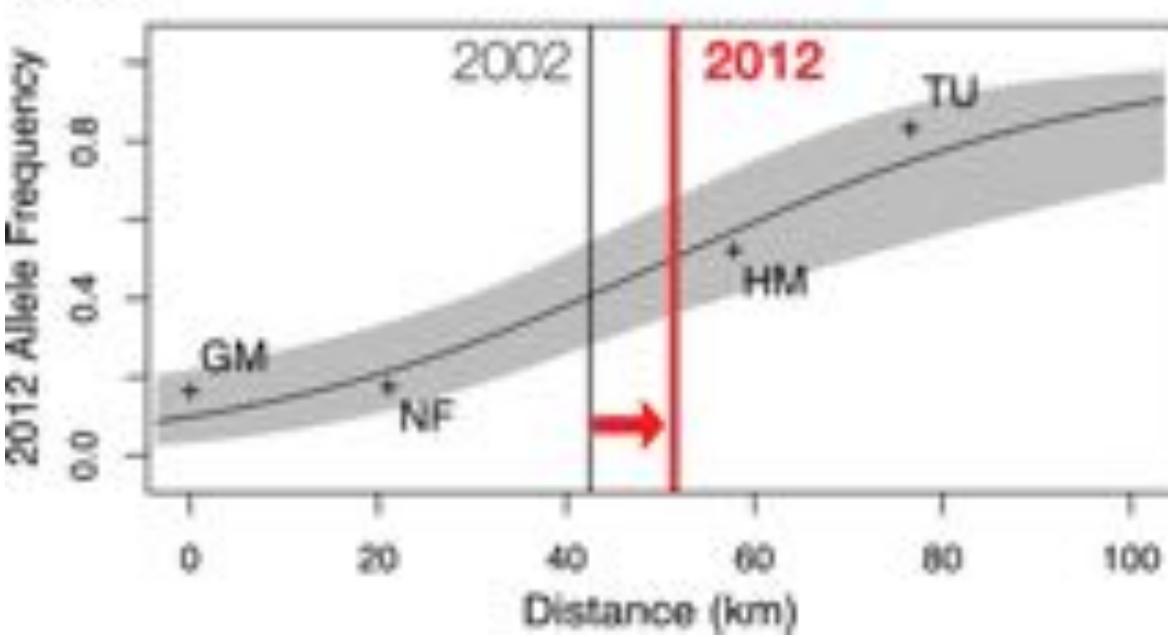
We used geographic clines to determine the [center](#) and [width](#) of the hybrid zone.



Geographic center of the hybrid zone is around Jacobsburg State Park, Pennsylvania and is roughly 30 km wide.



The hybrid zone has moved roughly 20 km north since 2012.



Where are the hybrids with intermediate ancestry?

Hybridization and
Cognition

Study System

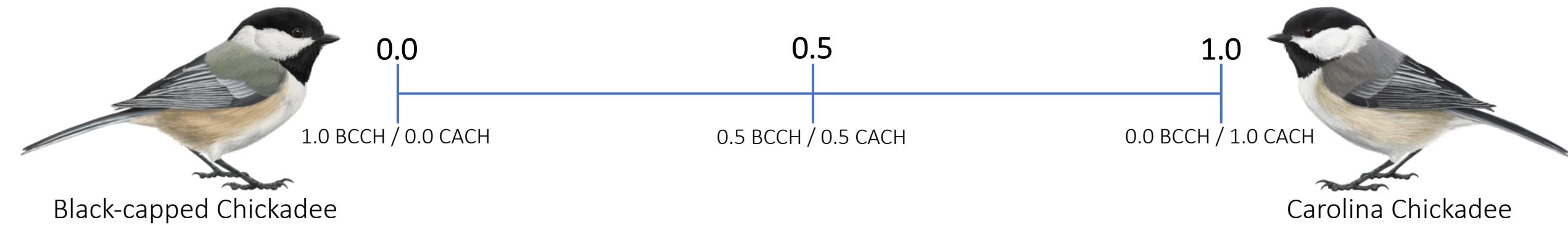
Geographic
Movement

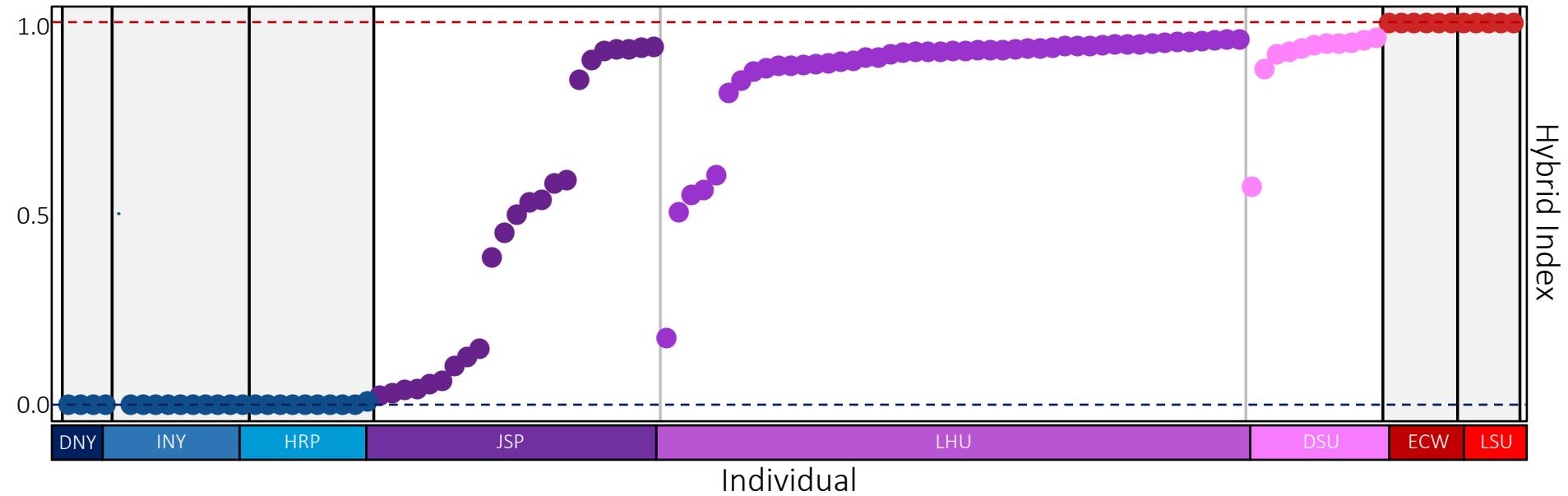
Where are the hybrids with intermediate ancestry?

Do the individuals in Jacobsburg State Park – the geographic center of the hybrid zone determined using a geographic cline analysis – have **equal proportions** of Black-capped and Carolina Chickadee ancestry?

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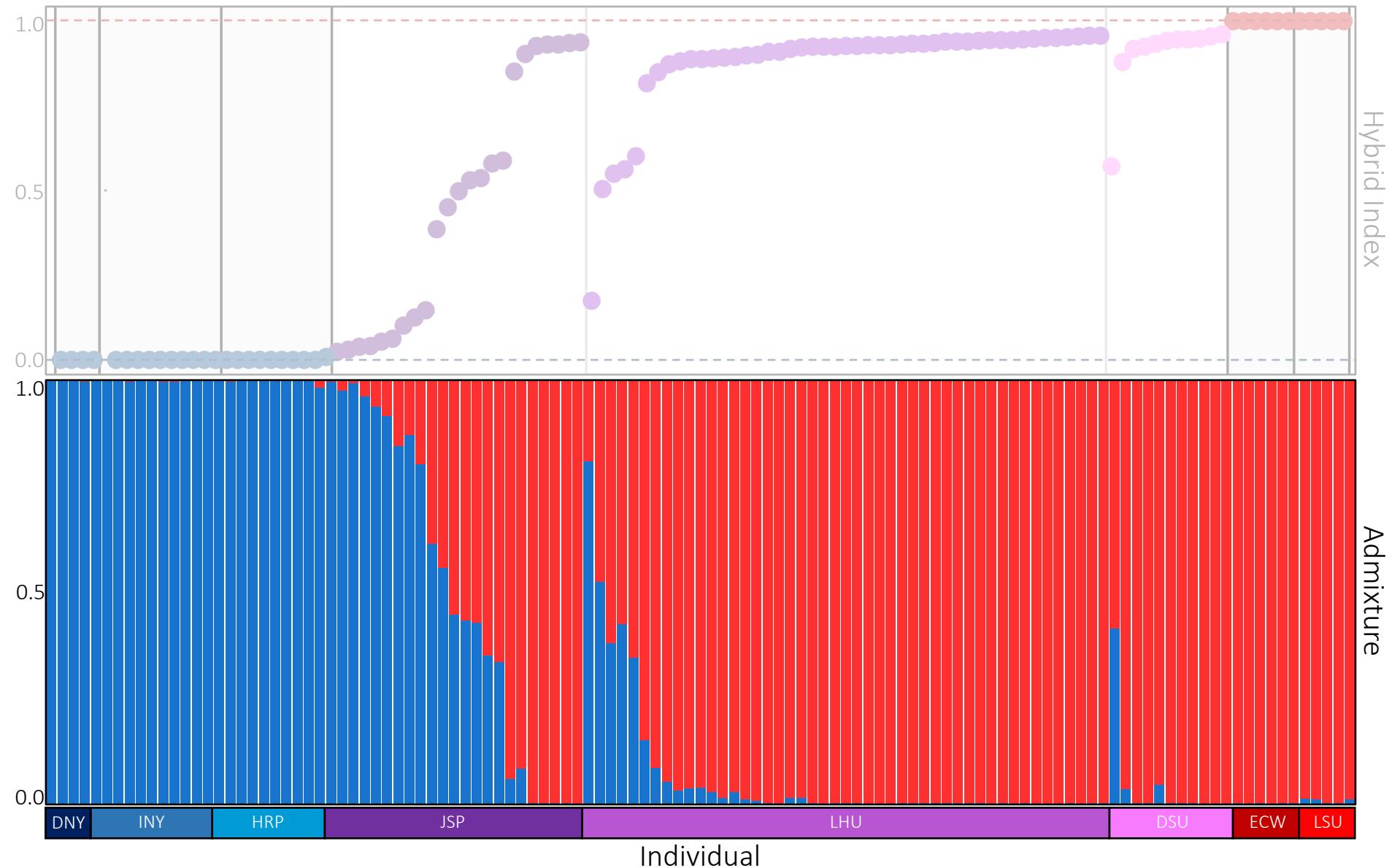




Hybridization and
Cognition

Study System

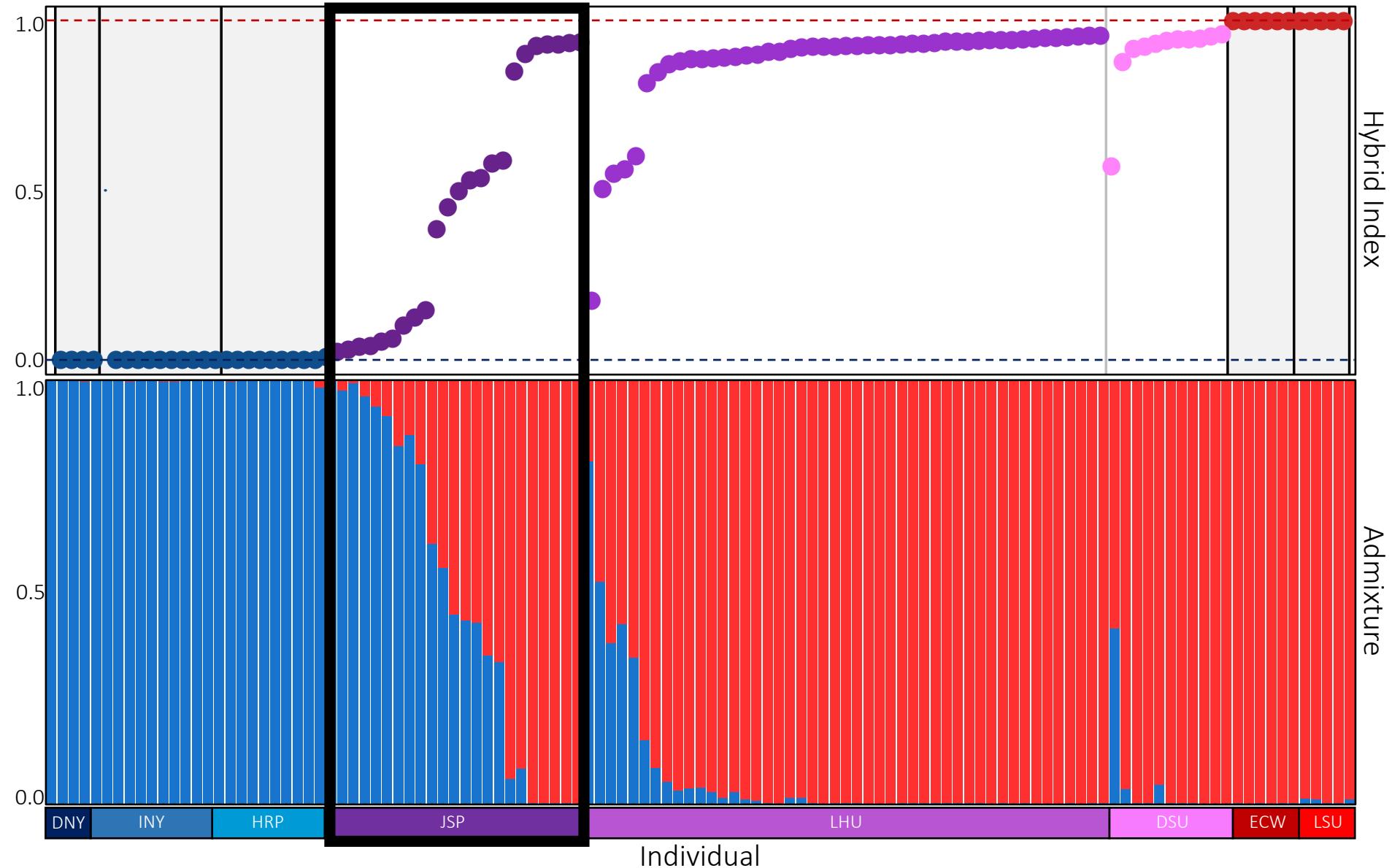
Geographic
Movement



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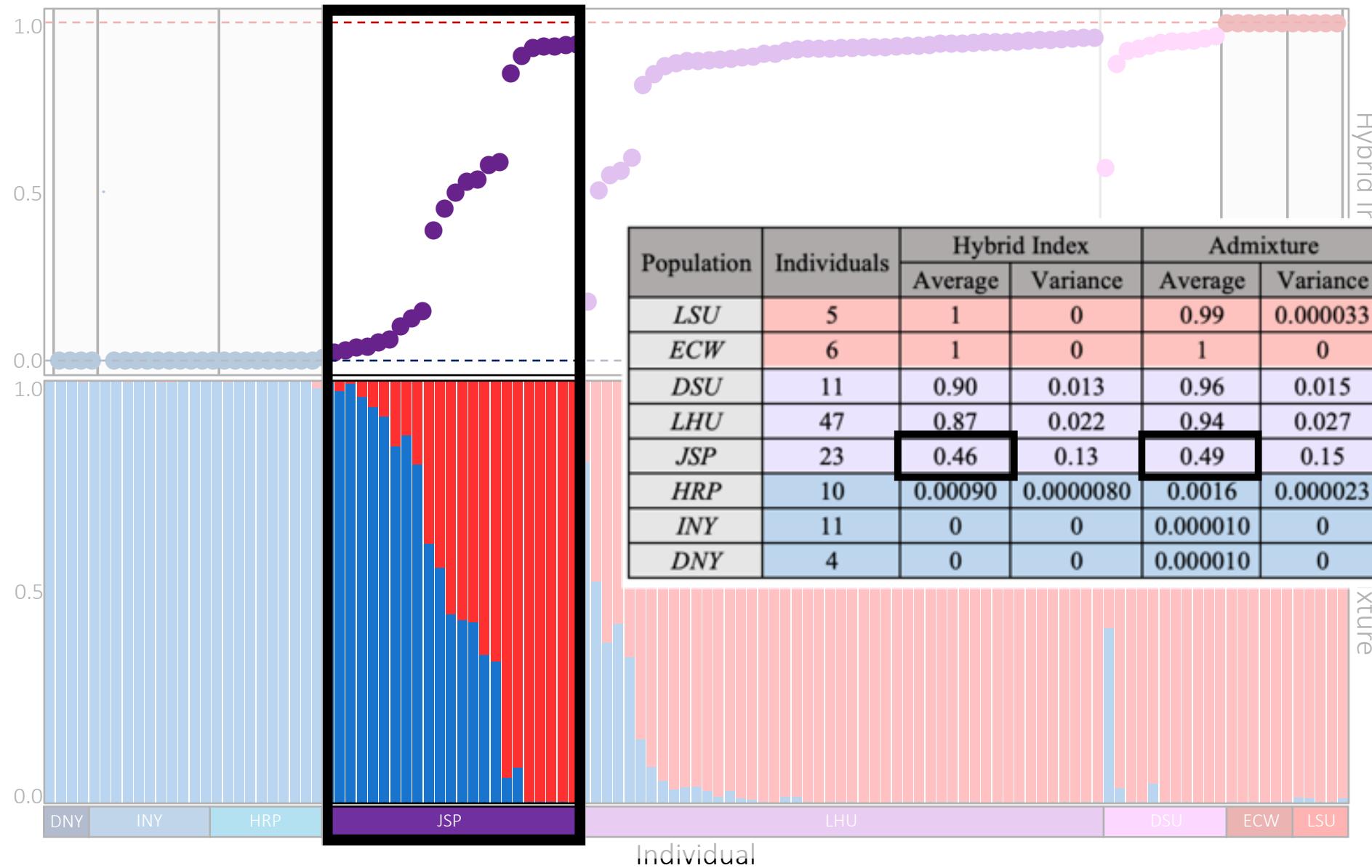
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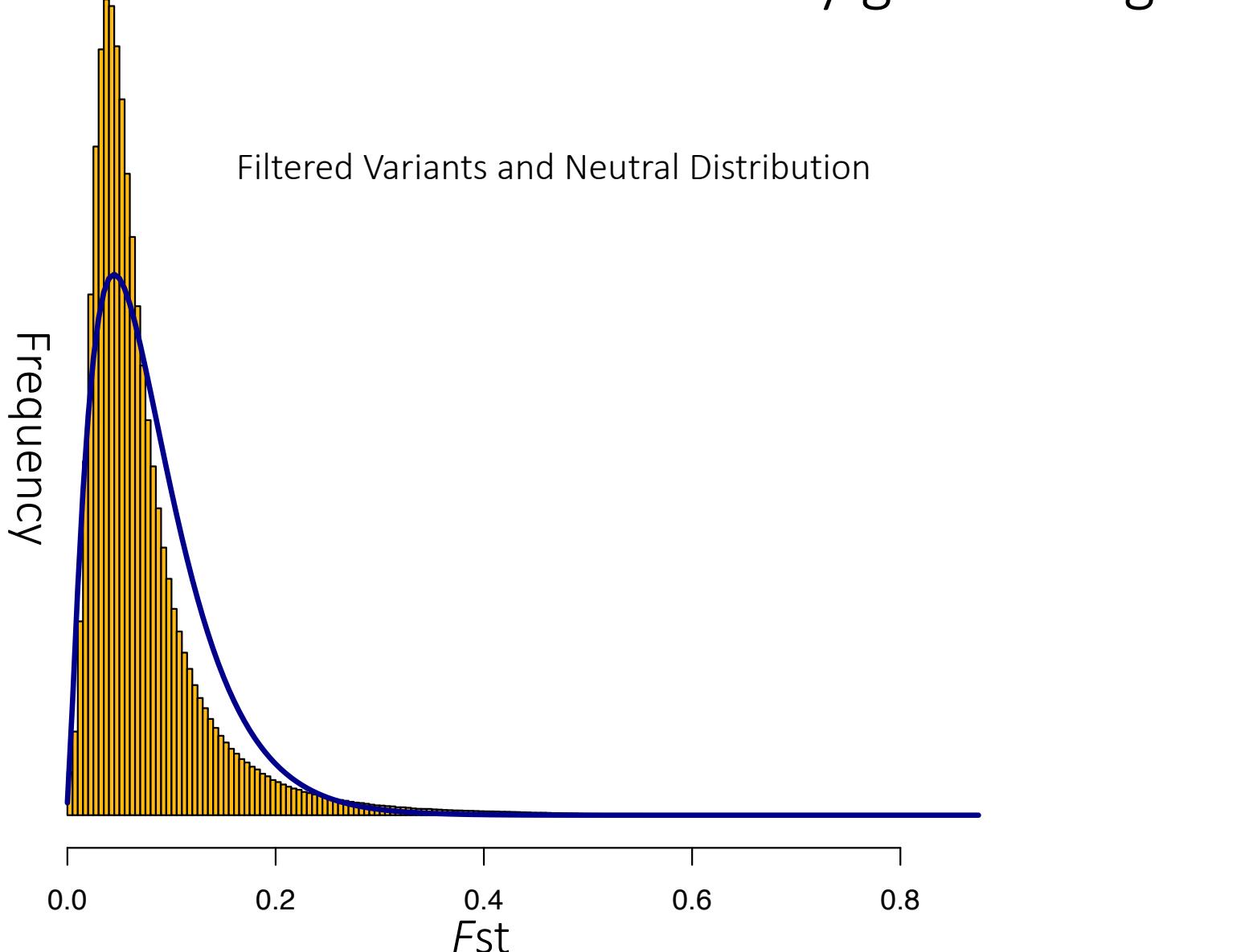


Hybrid Index

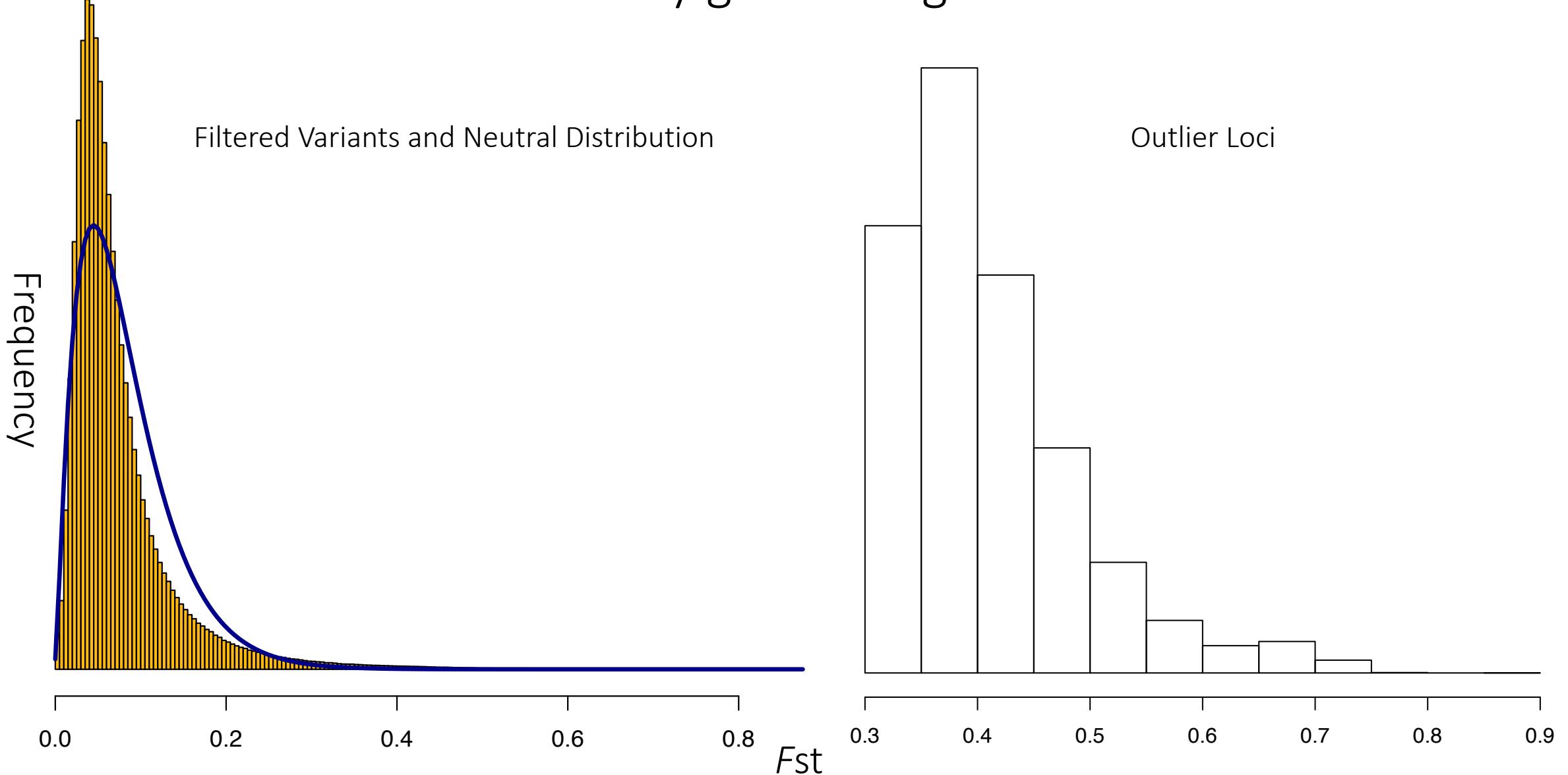
Admixture

Population

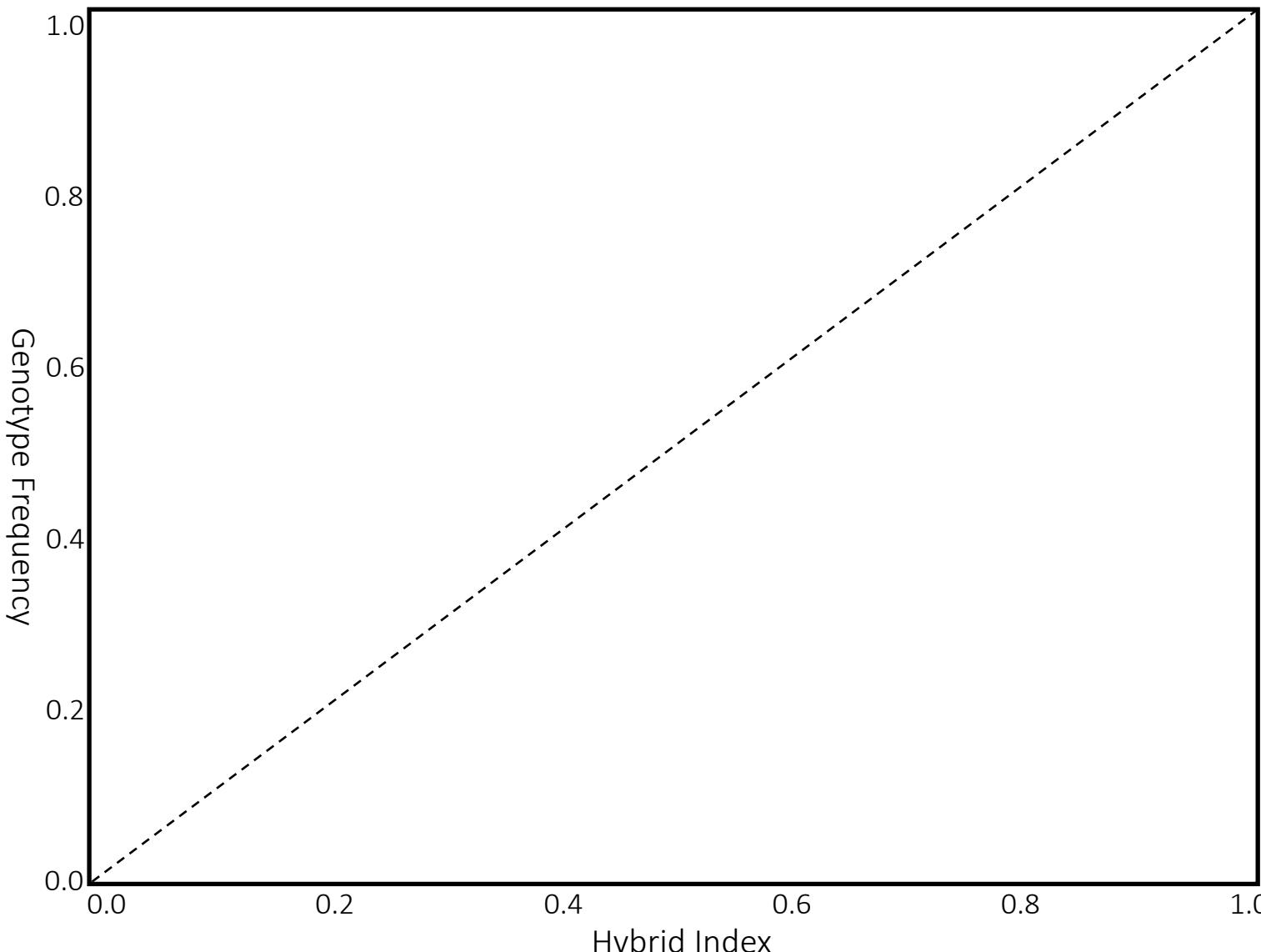
Identified F_{ST} outliers by generating a neutral distribution.



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We used genomic clines to determine [patterns of introgression](#) across the hybrid zone.



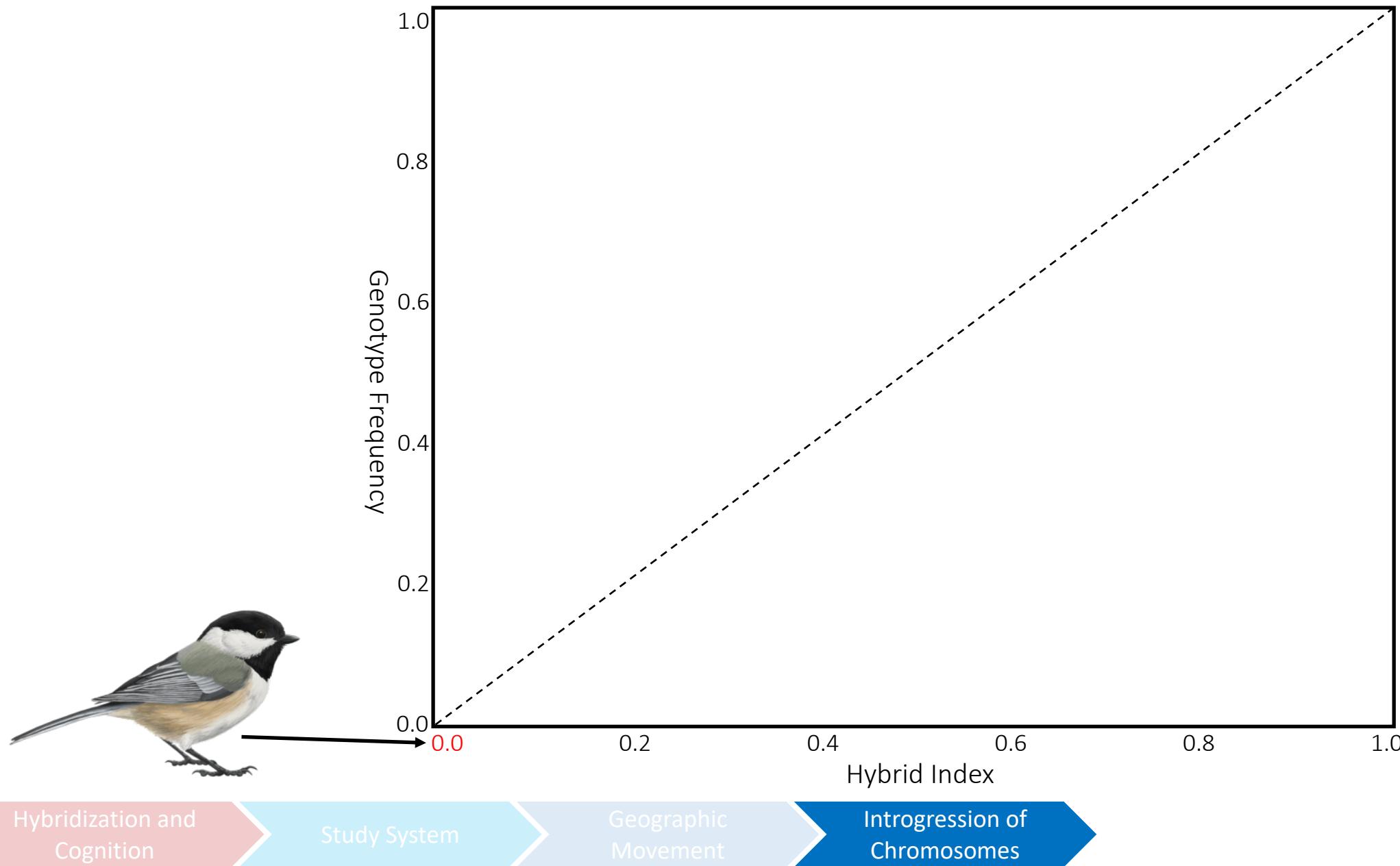
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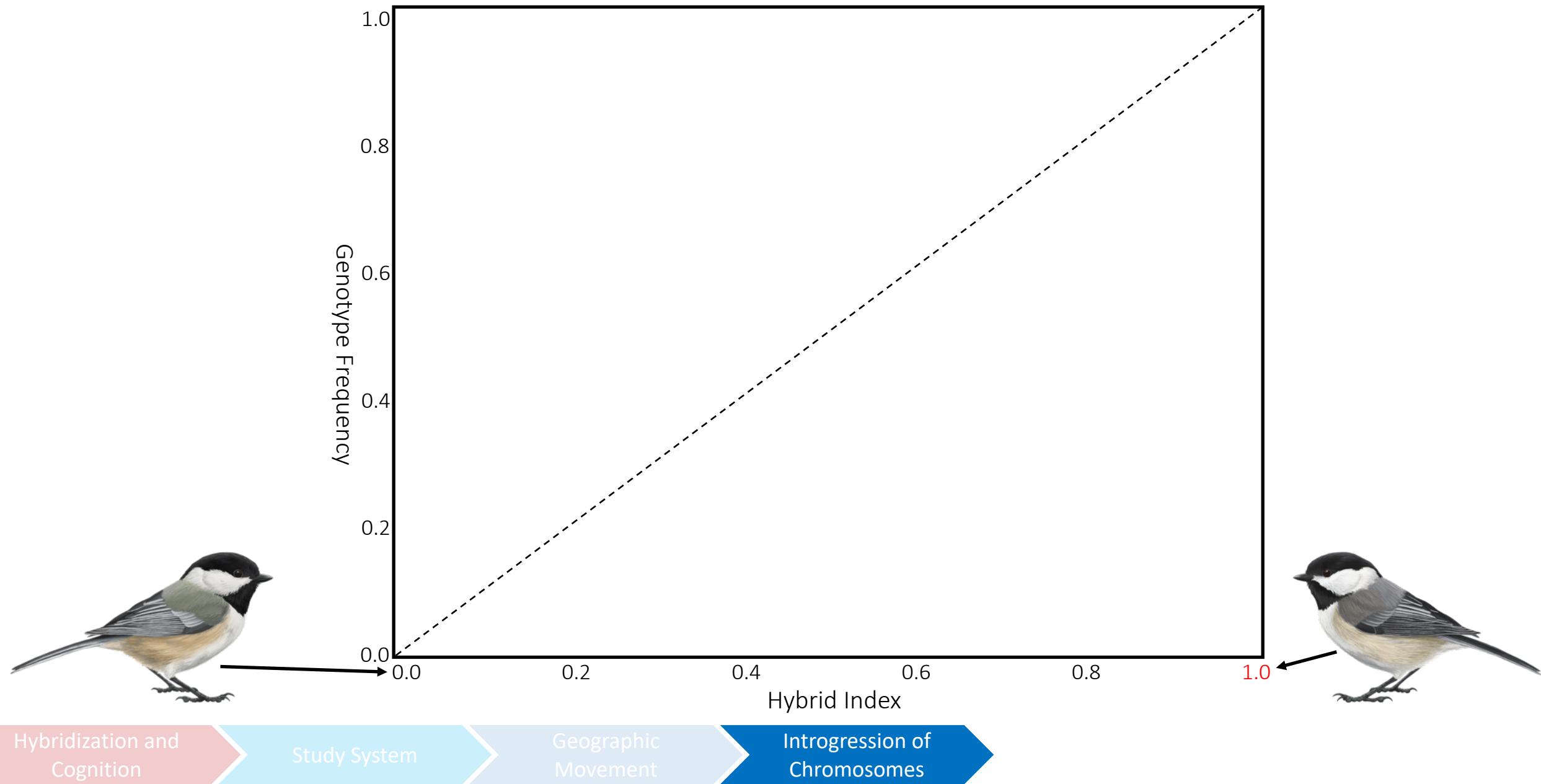
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Introgression of
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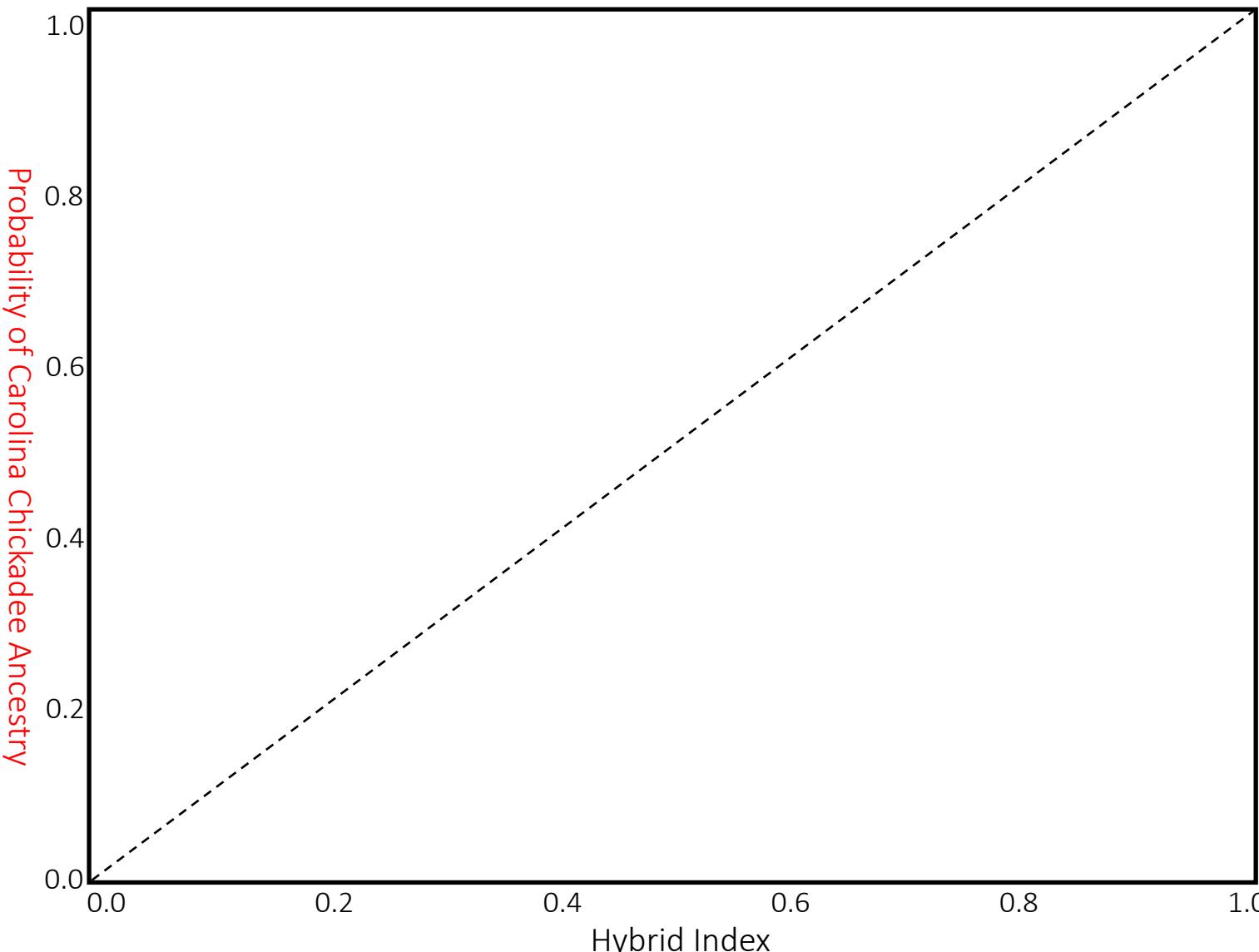
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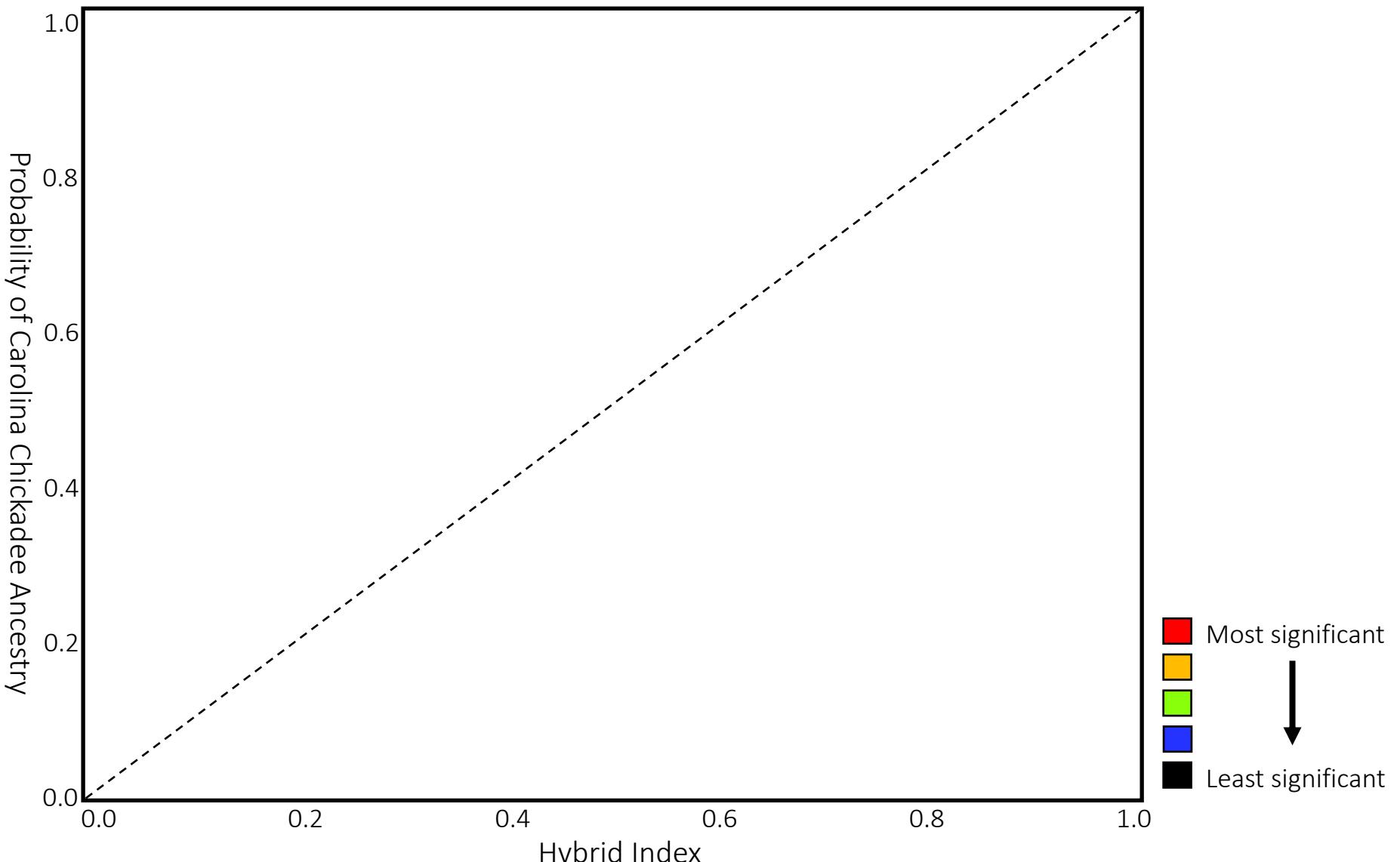
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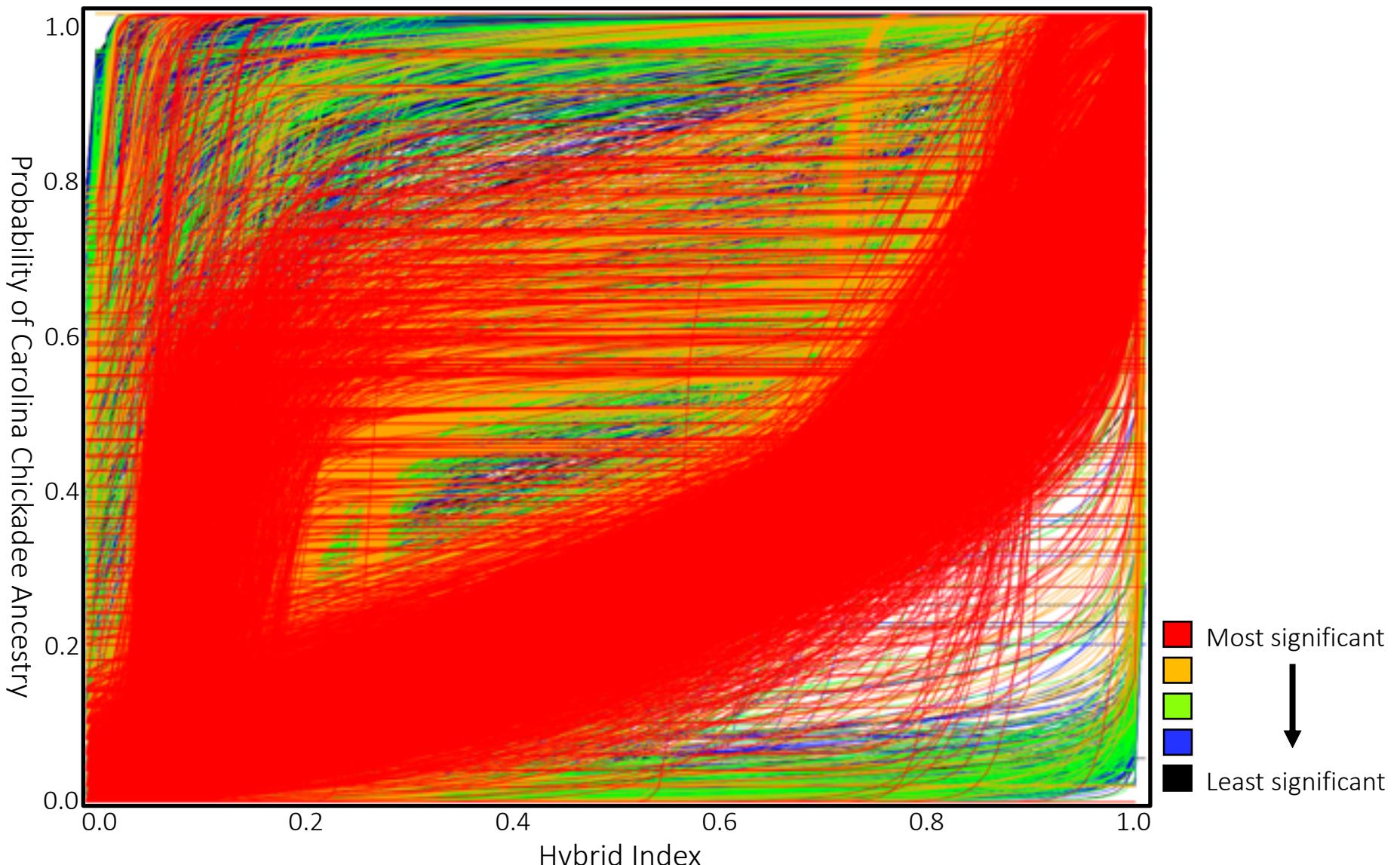
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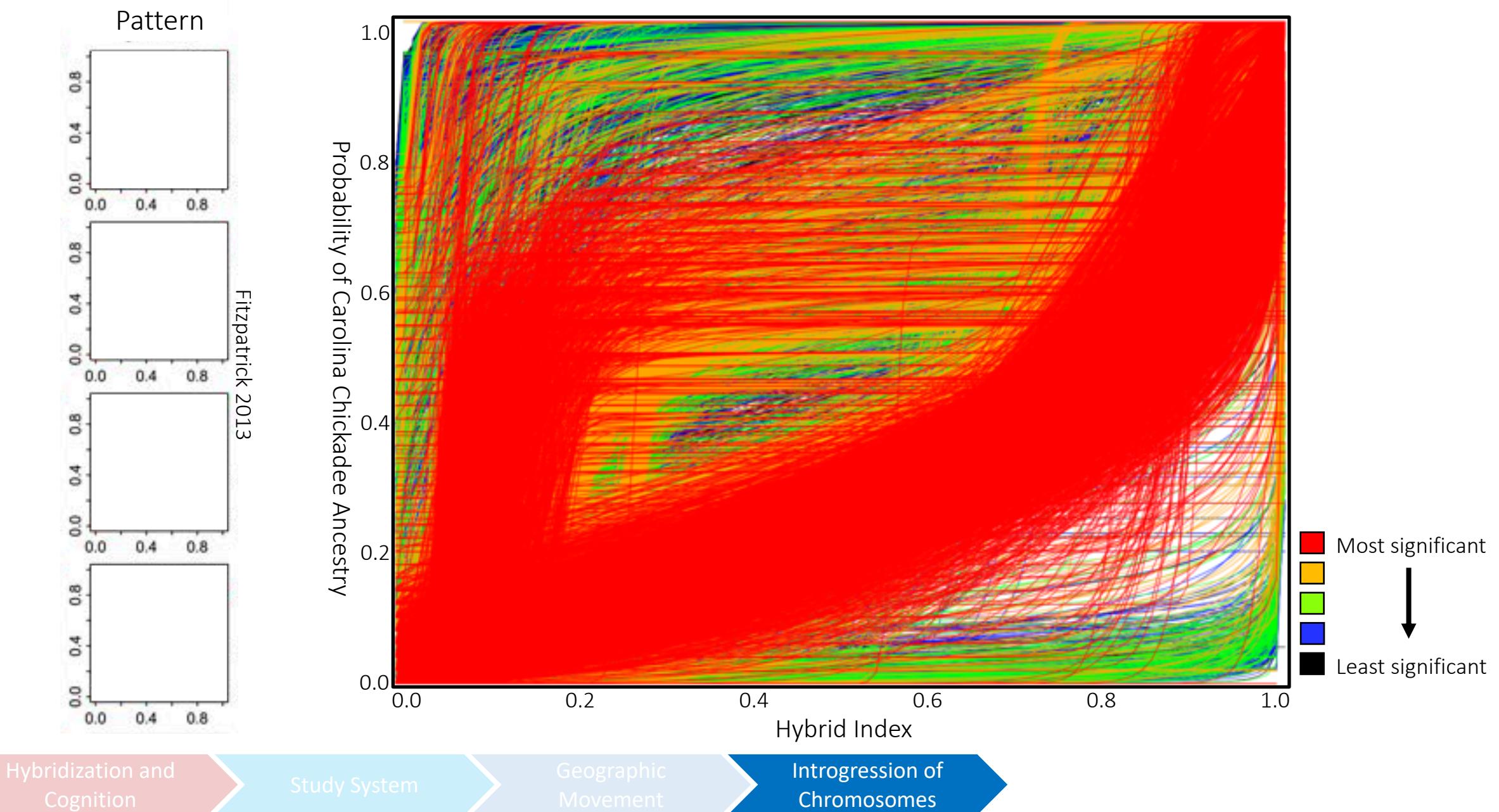
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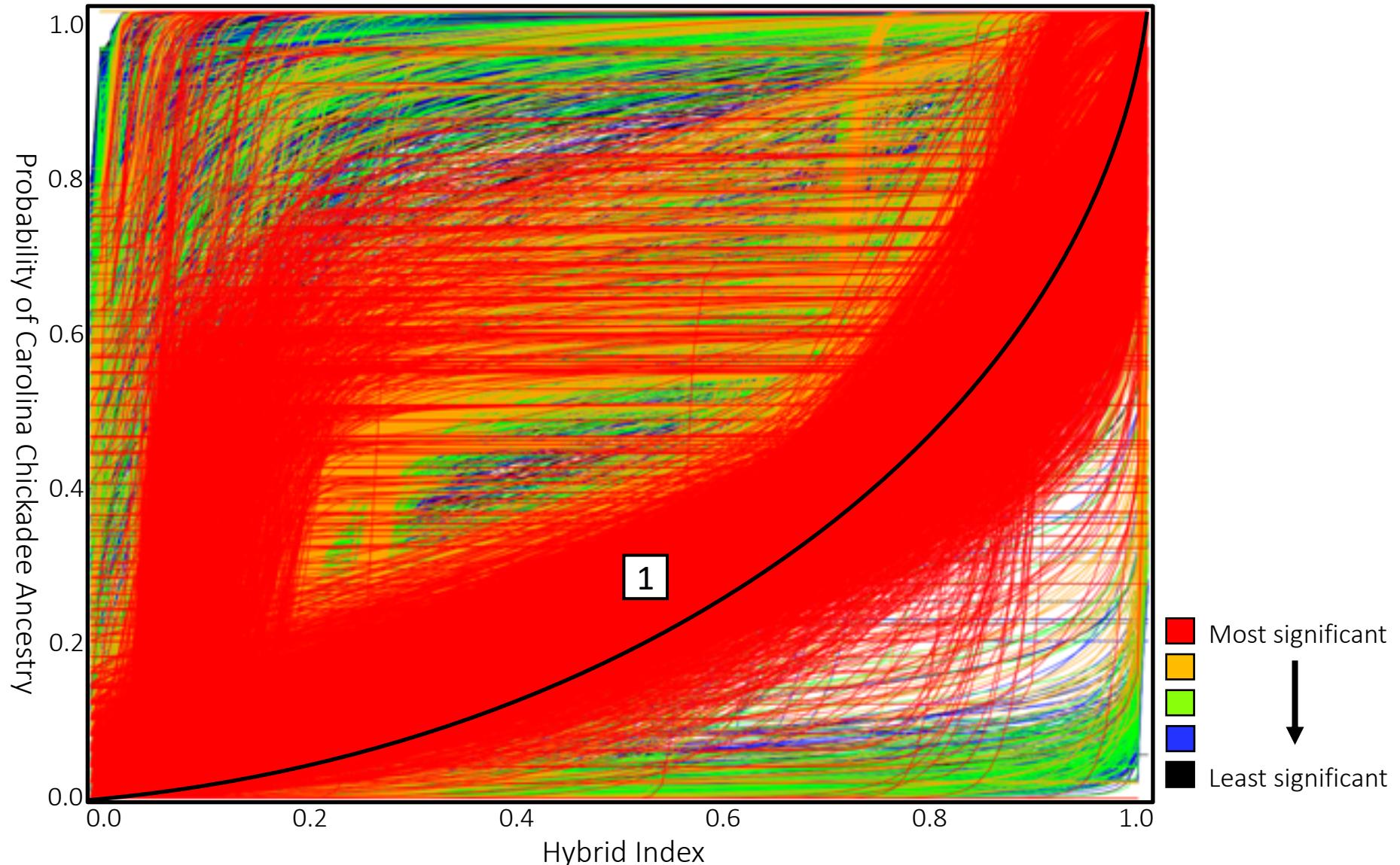
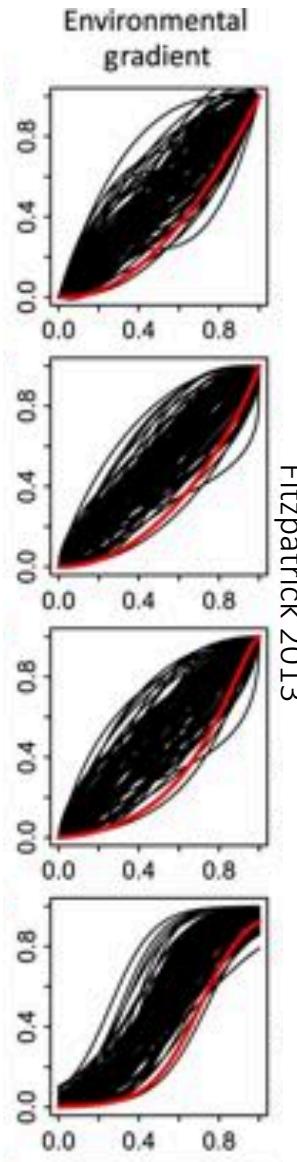
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Environmental selection favoring Black-capped Chickadee loci.



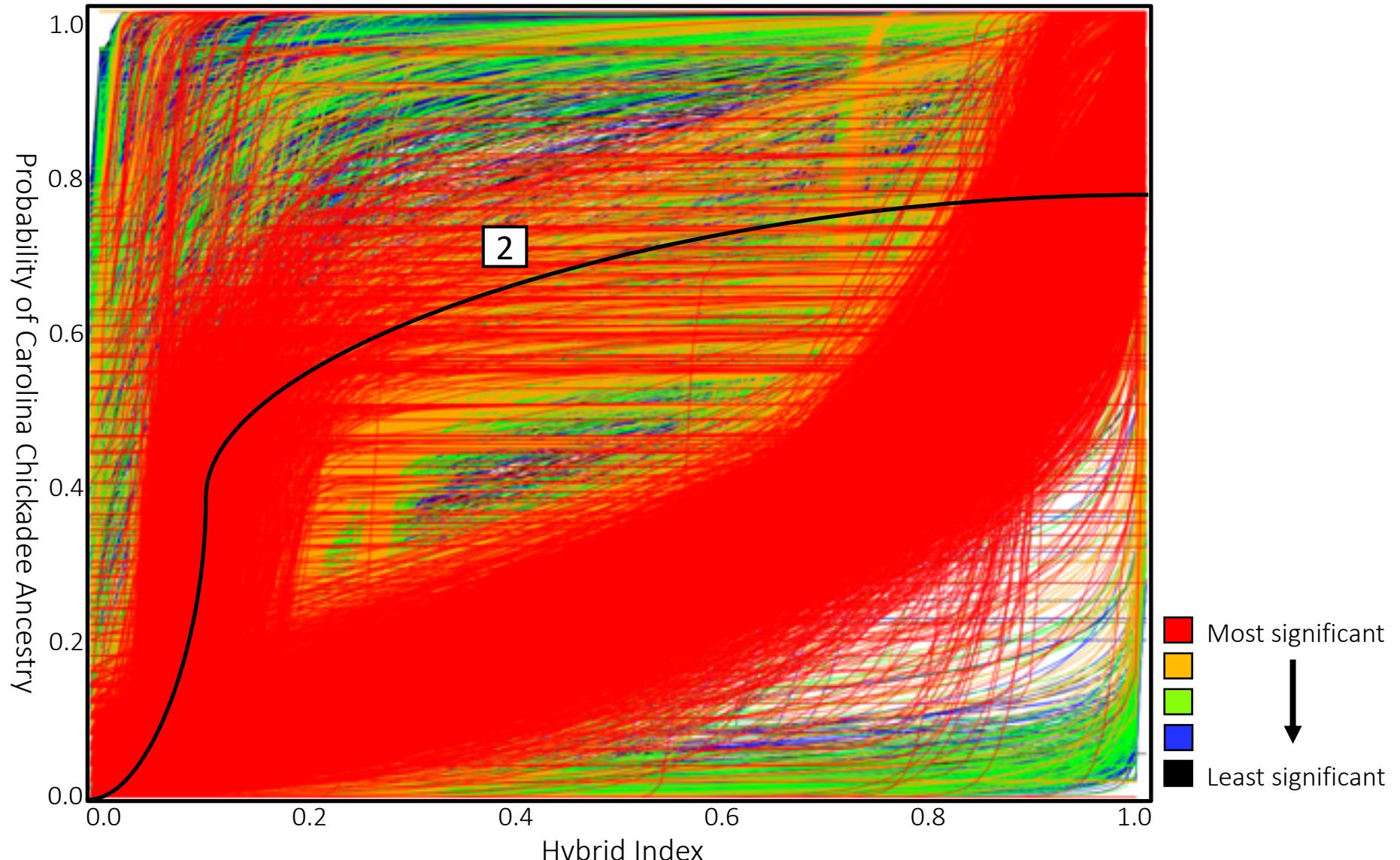
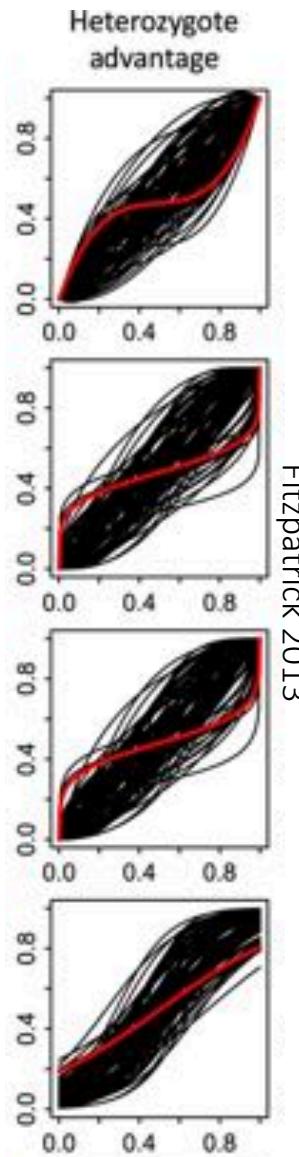
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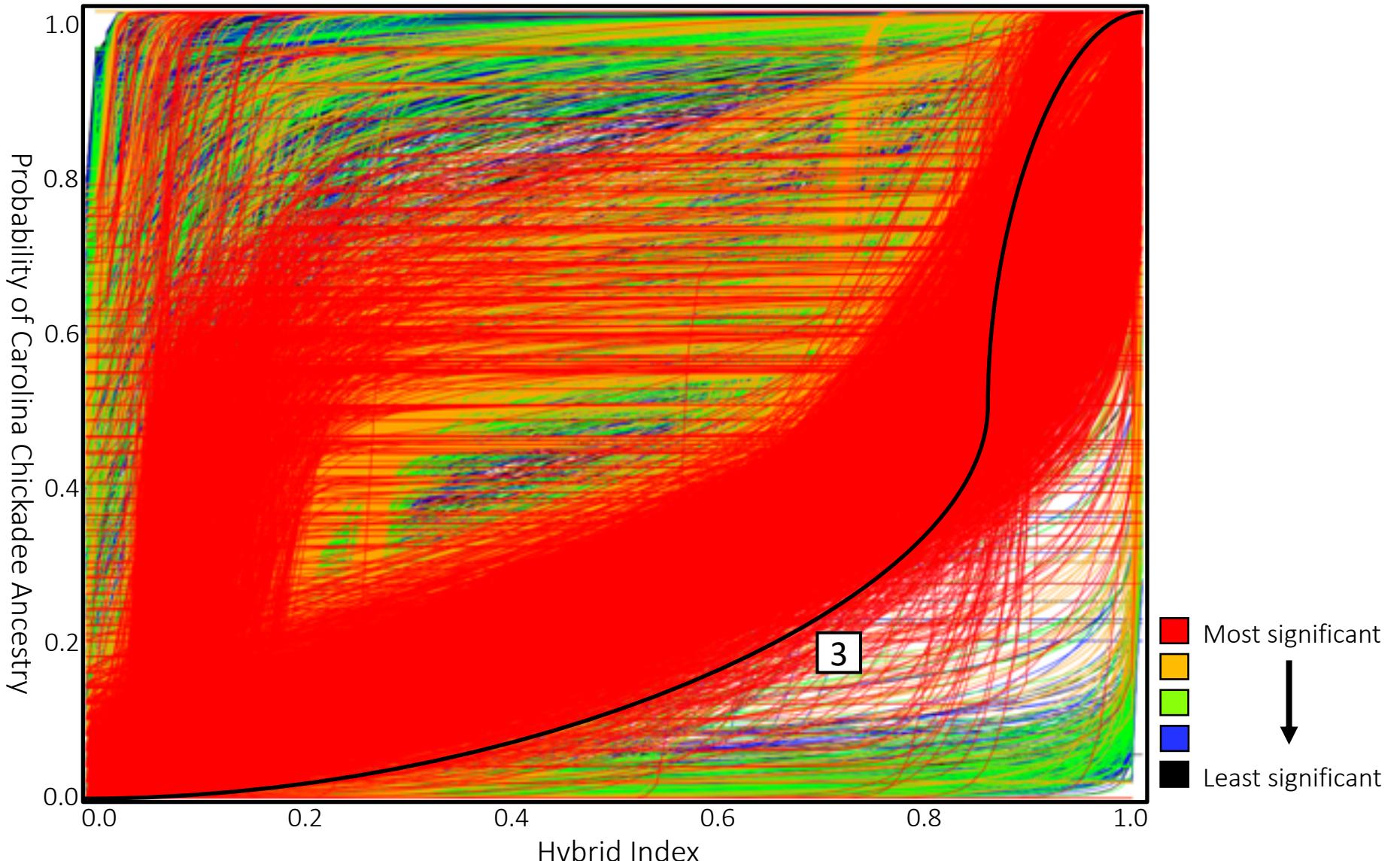
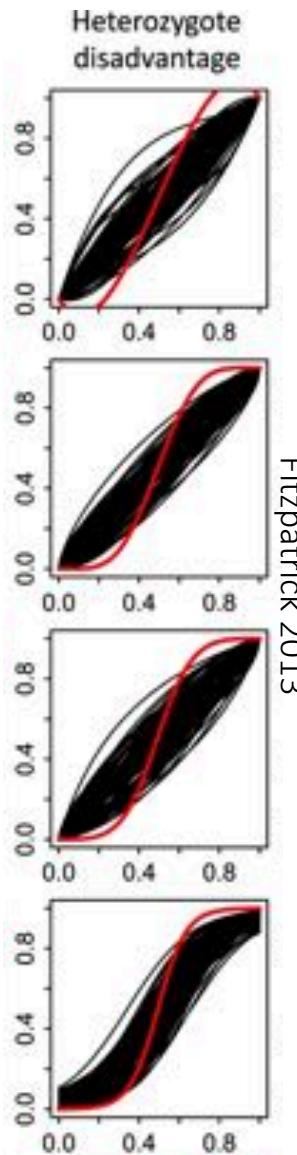
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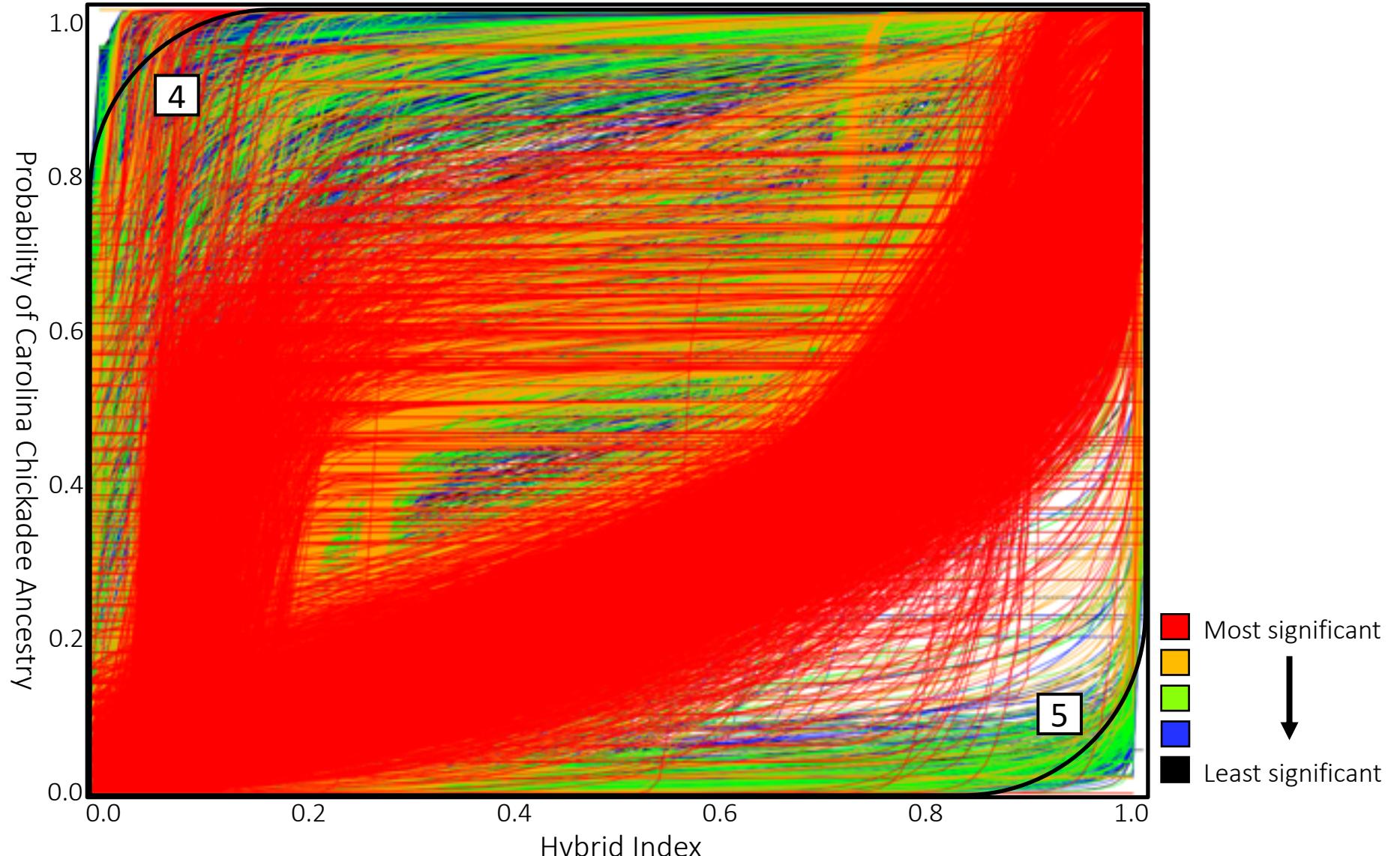
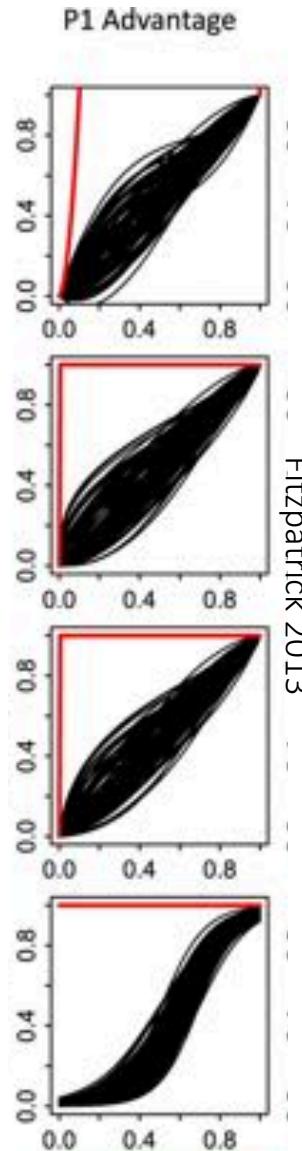
A roughly equal probability of ancestry indicates resistance to introgression.



Strong probability of either Black-capped or Carolina Chickadee ancestry.



Strong selection for either Black-capped or Carolina Chickadee loci.



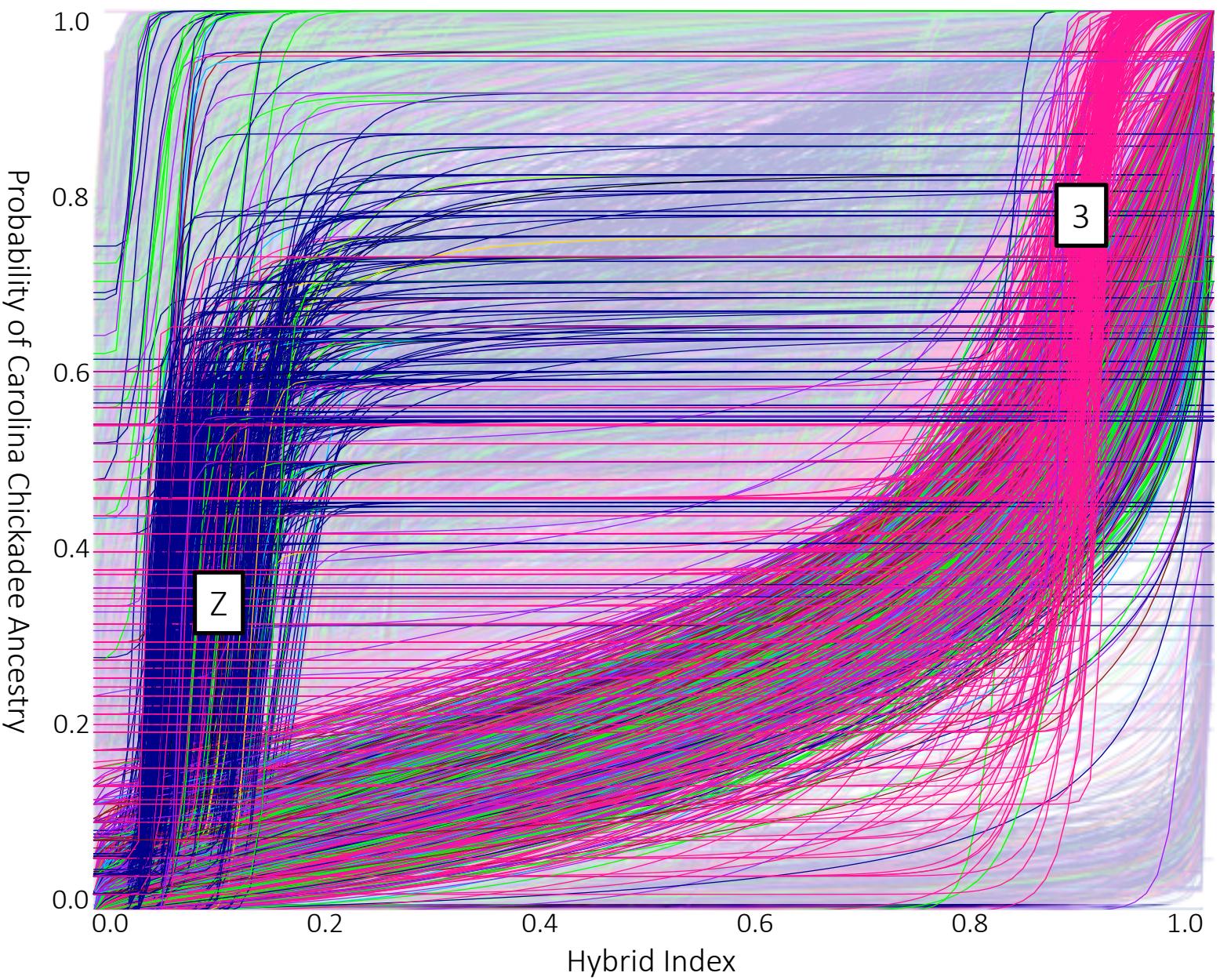
Hybridization and
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Geographic
Movement

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Chromosomal Patterns of Introgression



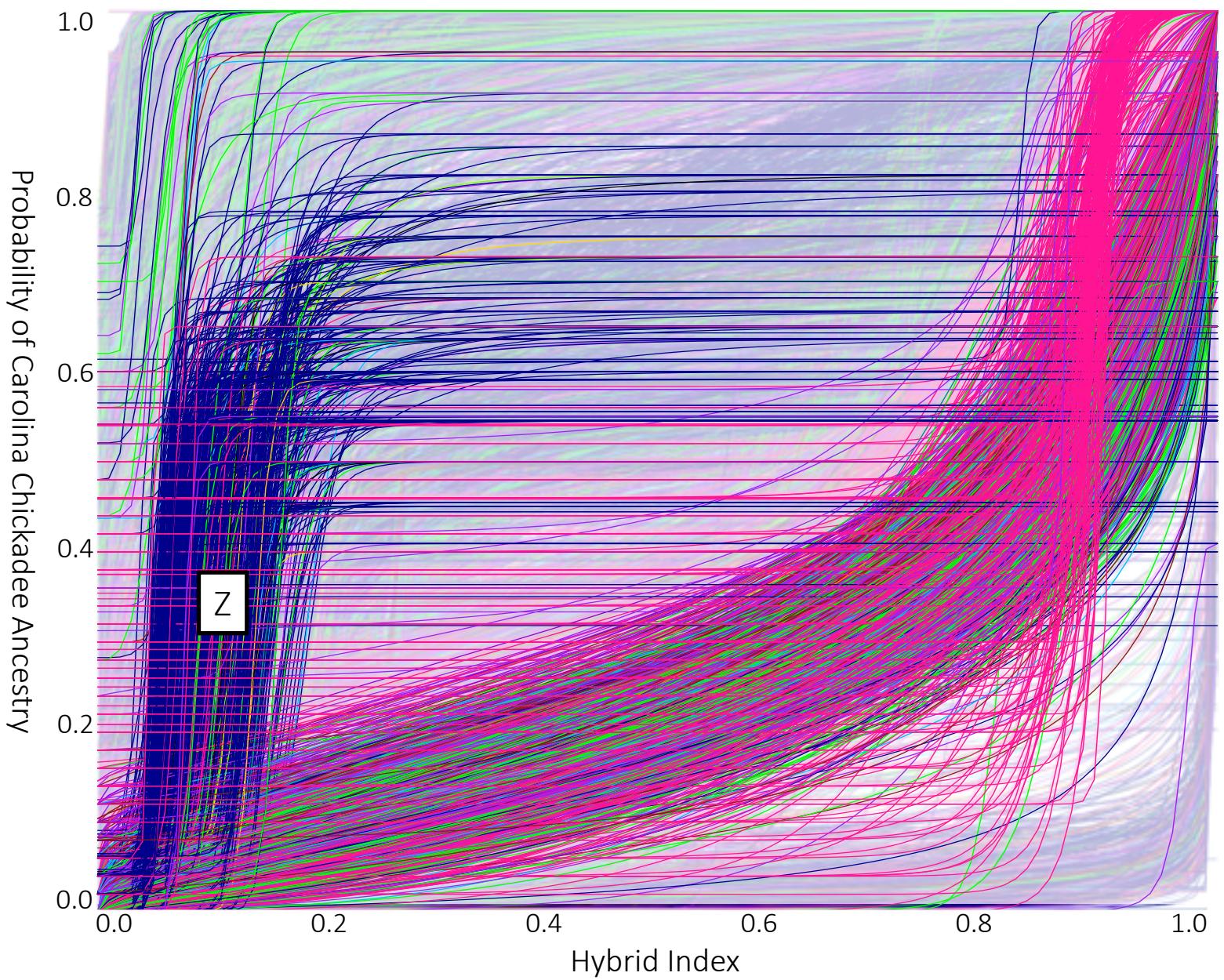
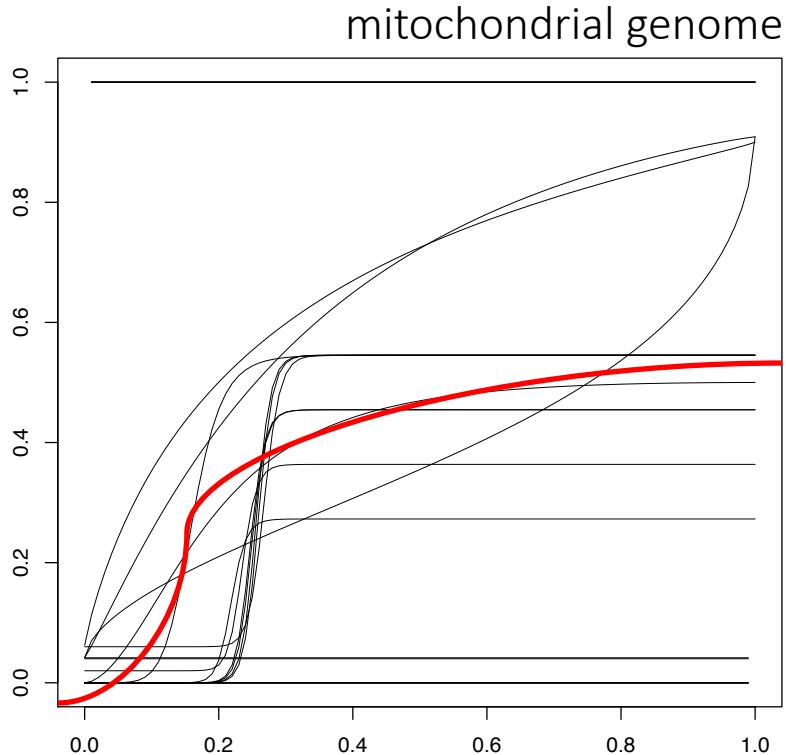
Hybridization and Cognition

Study System

Geographic Movement

Introgression of Chromosomes

Haldane's Rule



Hybridization and
Cognition

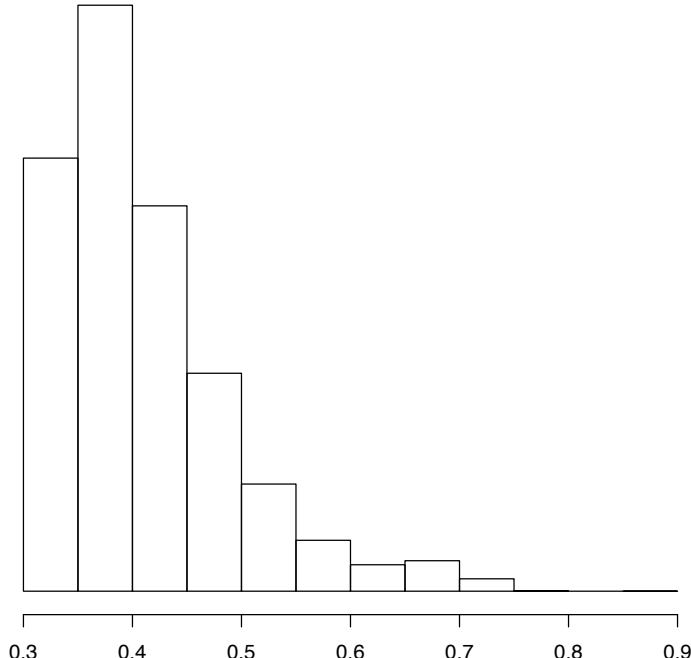
Study System

Geographic
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Genes associated with outliers and the biological processes they regulate.

Outlier Loci



Hybridization and
Cognition

Study System

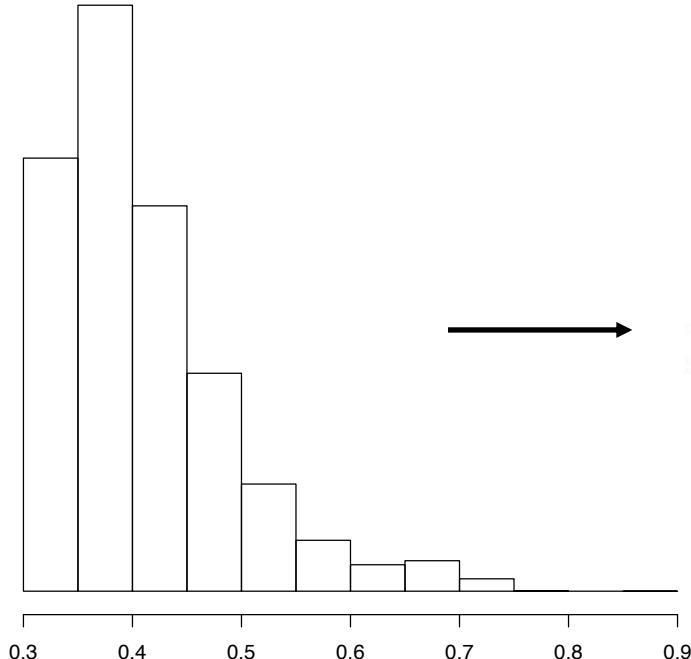
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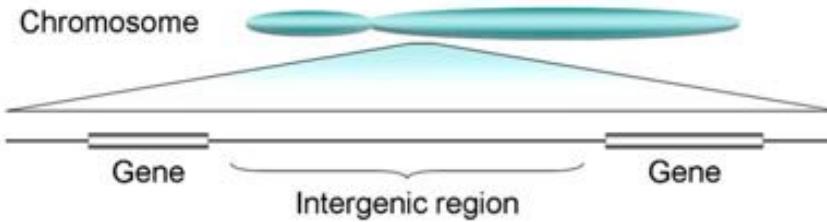
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Gene Associated with Loci



Hybridization and
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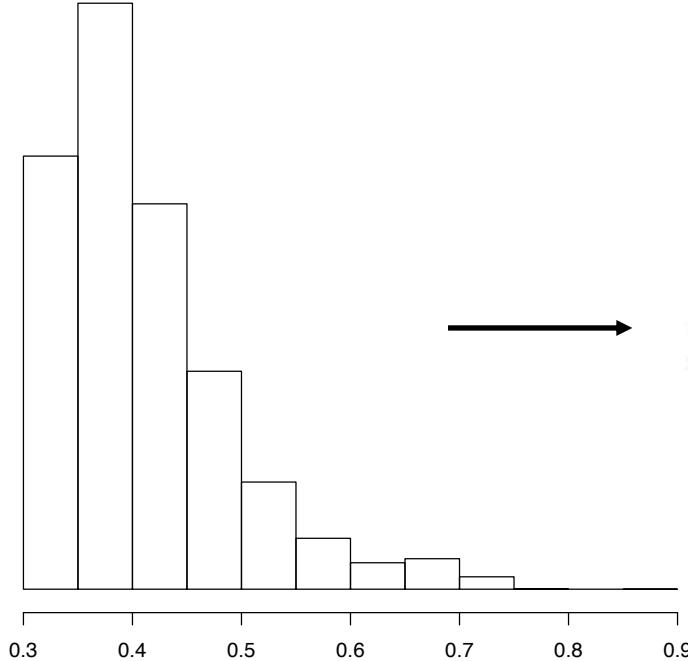
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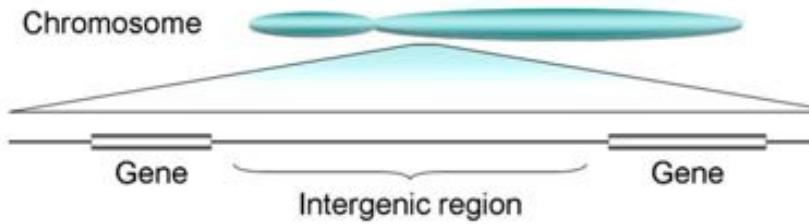
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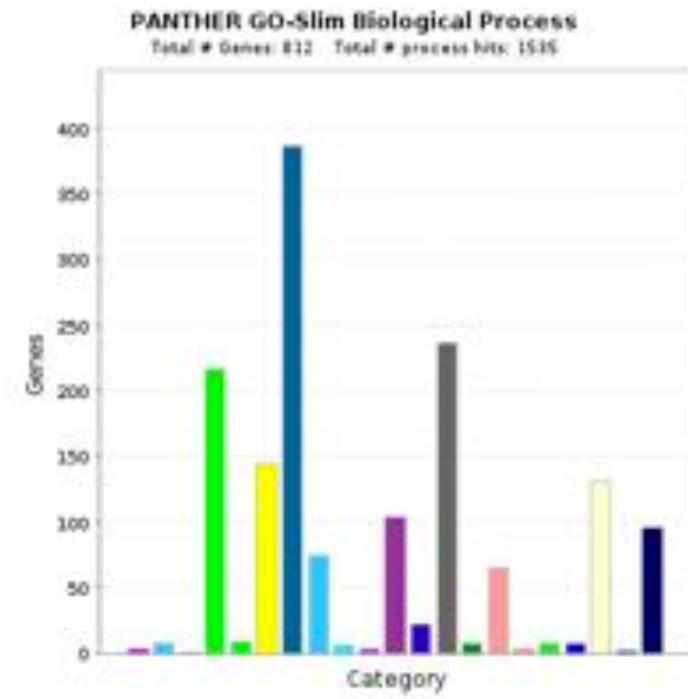
Outlier Loci



Gene Associated with Loci



Overrepresented Biological Processes



Hybridization and Cognition

Study System

Geographic Movement

Introgression of Chromosomes

Genes and Biological Processes

Enriched biological processes associated with transcripts.

BIOLOGICAL PROCESS
DNA Repair
Cell Differentiation
Cellular Localization
Negative Regulation of Cellular Processes
Organelle Organization

The epigenetic mechanisms that regulate cell differentiation also mediate *synaptic plasticity, learning and memory*.

Enriched biological processes associated with transcripts.

BIOLOGICAL PROCESS
DNA Repair
Cell Differentiation
Cellular Localization
Negative Regulation of Cellular Processes
Organelle Organization

In humans, a protein important for cellular localization regulates synaptic plasticity, cognition and neurotransmission.

Potential problems with gene ontology analysis?



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Due to file complications, we were forced to manually annotate the outlier loci, resulting in...



Potential problems with gene ontology analysis?

Due to file complications, we were forced to [manually annotate](#) the outlier loci, resulting in...

Imperfect gene annotations.

Hybridization and
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Limited number of outlier loci successfully annotated (33.60%).

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What next?

Address file complication to successfully annotate all outlier loci.

Does cognitive breakdown in hybrids act as a postzygotic, reproductive isolating barrier in a rapidly moving avian hybrid zone?

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Cognition

Study System

Geographic
Movement

Introgression of
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Reproductive
Isolation

Does cognitive breakdown in hybrids act as a postzygotic, reproductive isolating barrier in a [rapidly moving avian hybrid zone](#)?

Geographic Movement

Since 2012, the hybrid zone has continued to move north, possibly driven by climate change.

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Acknowledgements



Amber Rice



Sue McRae



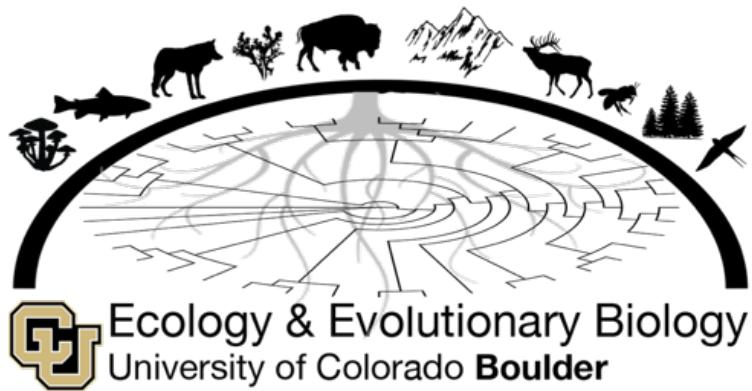
David Bonter

LSU Fred Sheldon and Vivien Chua

F&M Tim Roth



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Scott Taylor Kathryn Grabenstein
Nolan Kane Erik Funk
Stacey Smith Dom Wagner
Georgy Semenov

Nathan Clair
Patty Feit
John Feldmann

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