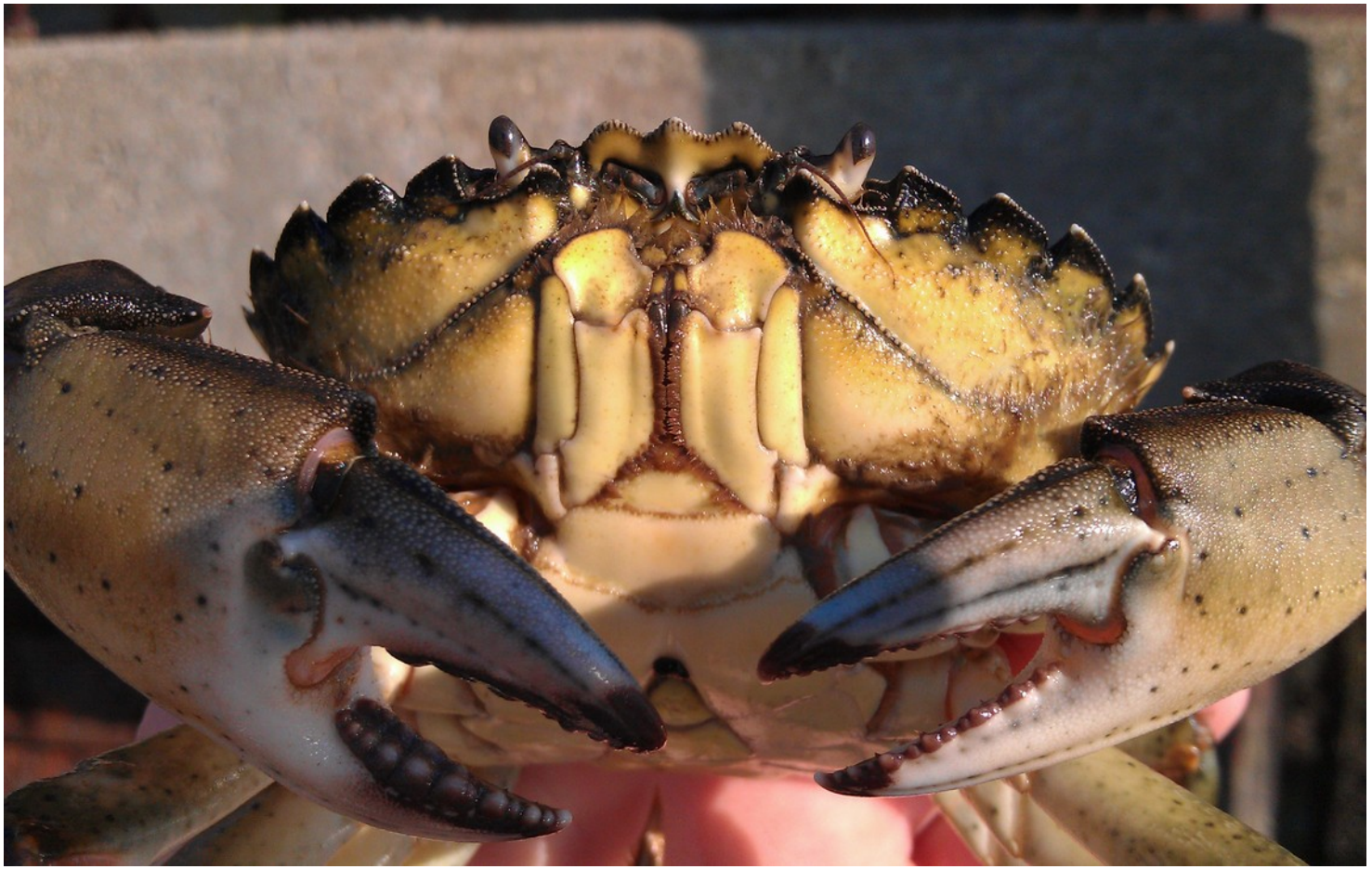
Next-generation marine invasion: using transcriptomics to explore adaptation in a global invader



Carolyn Tepolt
Smithsonian Institution, Washington, DC, USA
Environmental Research Center & Laboratory of Analytical Biology








From Pimentel *et al.* 2005

~50,000
invasive species
in US

From Pimentel *et al.* 2005

~50,000
invasive species
in US

$120 billion
annual cost

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annual cost

primary threat to
42%
of endangered
species

From Pimentel *et al.* 2005

Invasions as natural experiments in evolution

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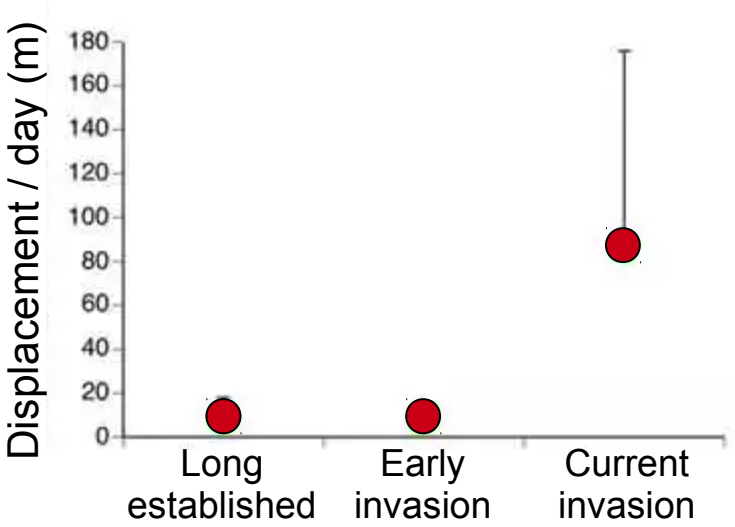
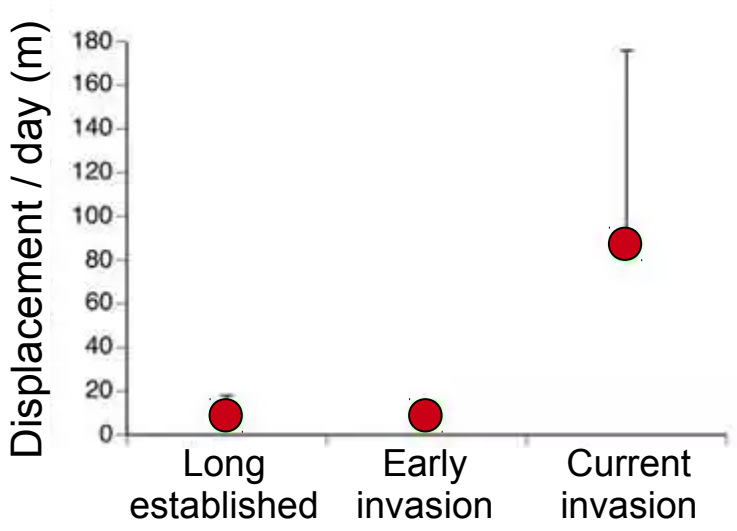
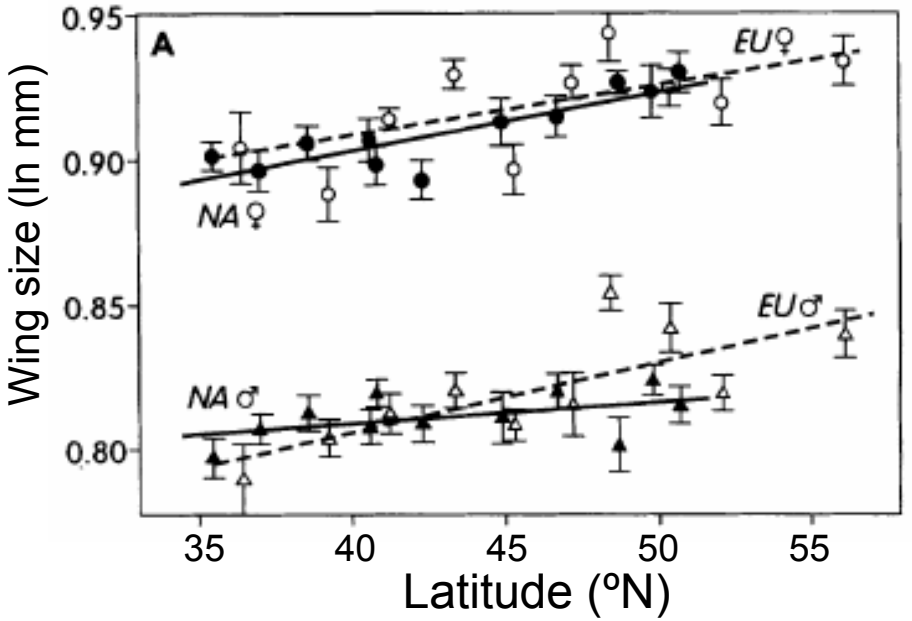


From R. Shine via CaneToadsinOz.com

Invasions as natural experiments in evolution



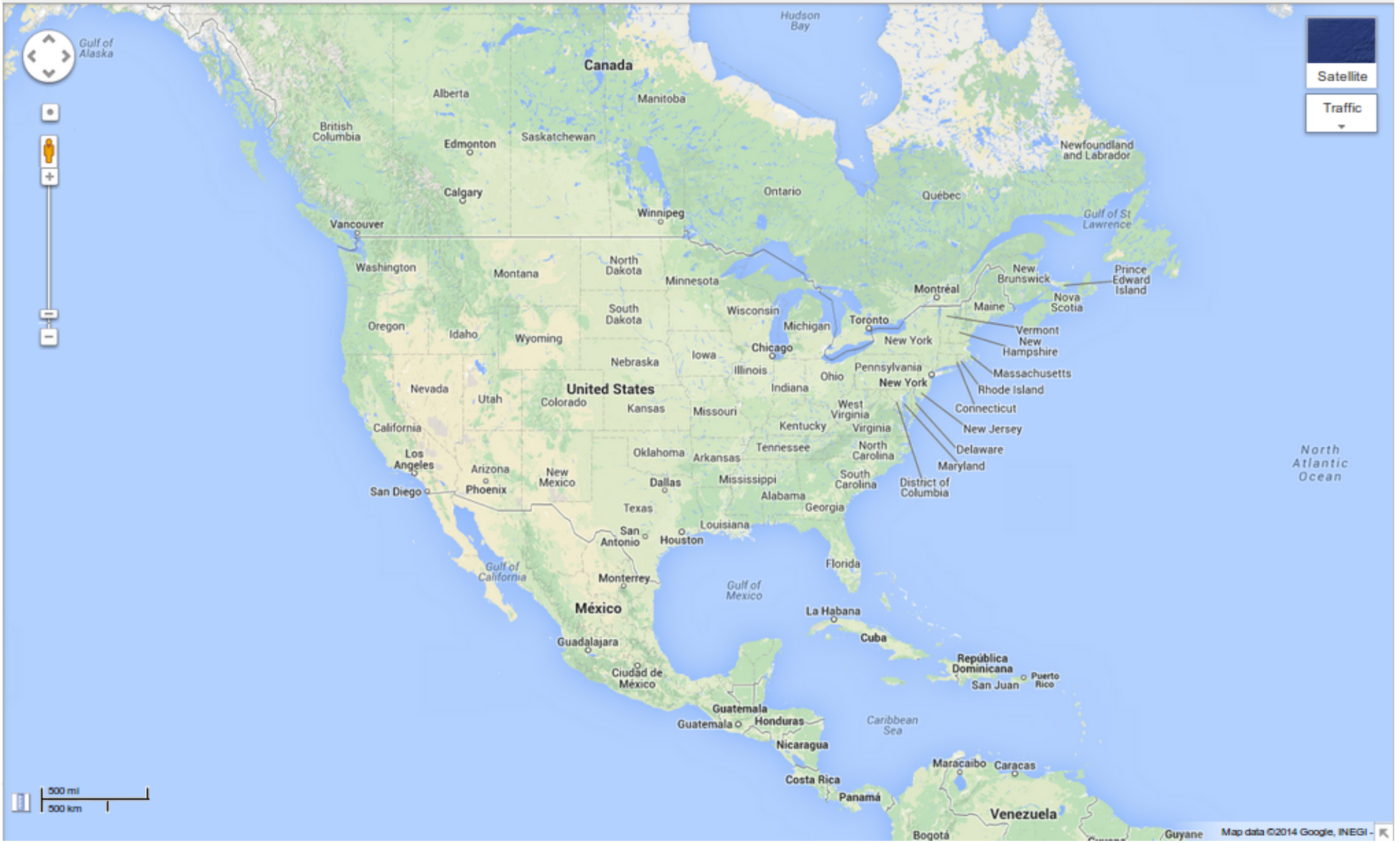


From R. Shine via CaneToadsinOz.com

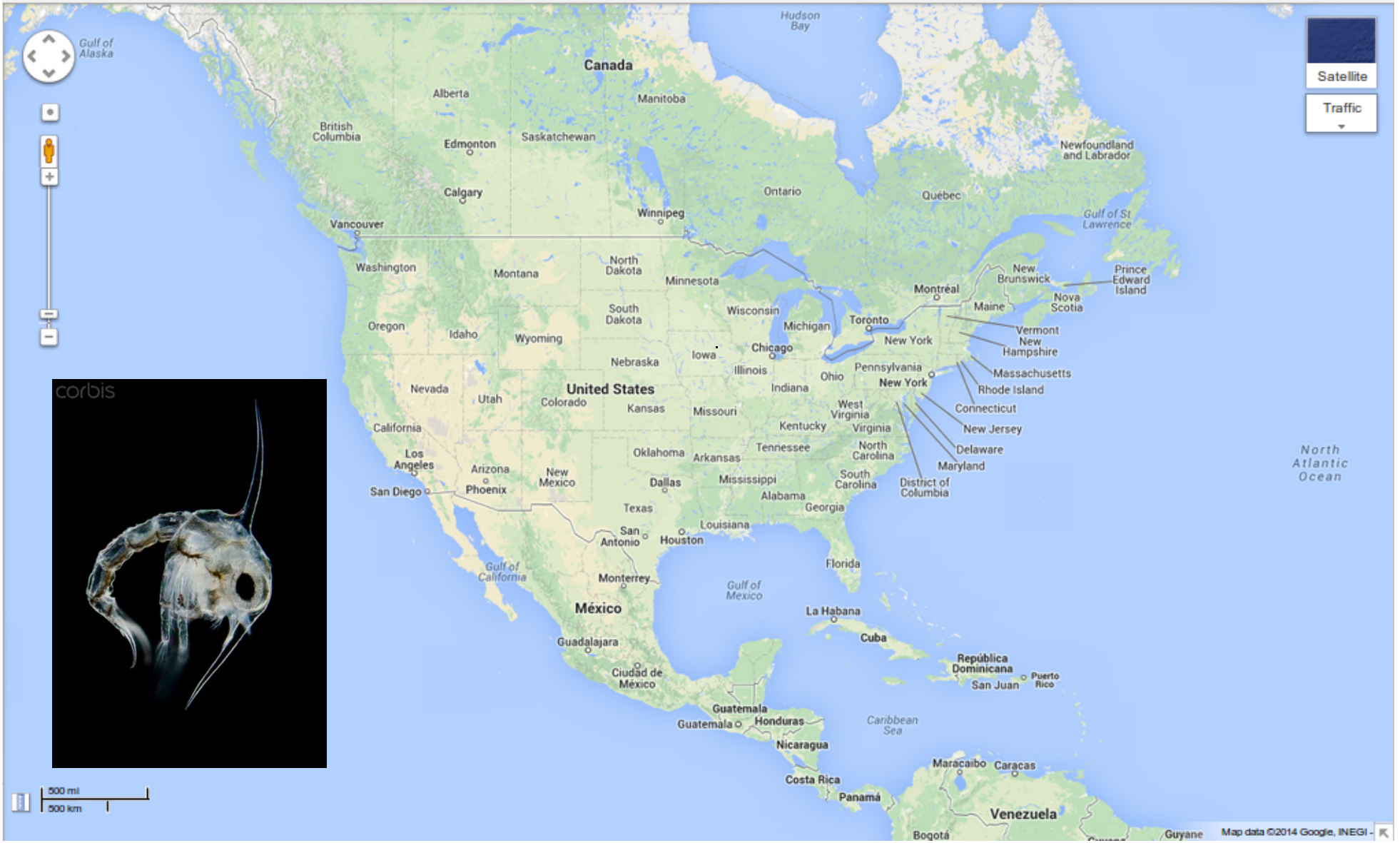
From Huey et al. 2000

What role does genetic adaptation play in the success of marine invasive species?

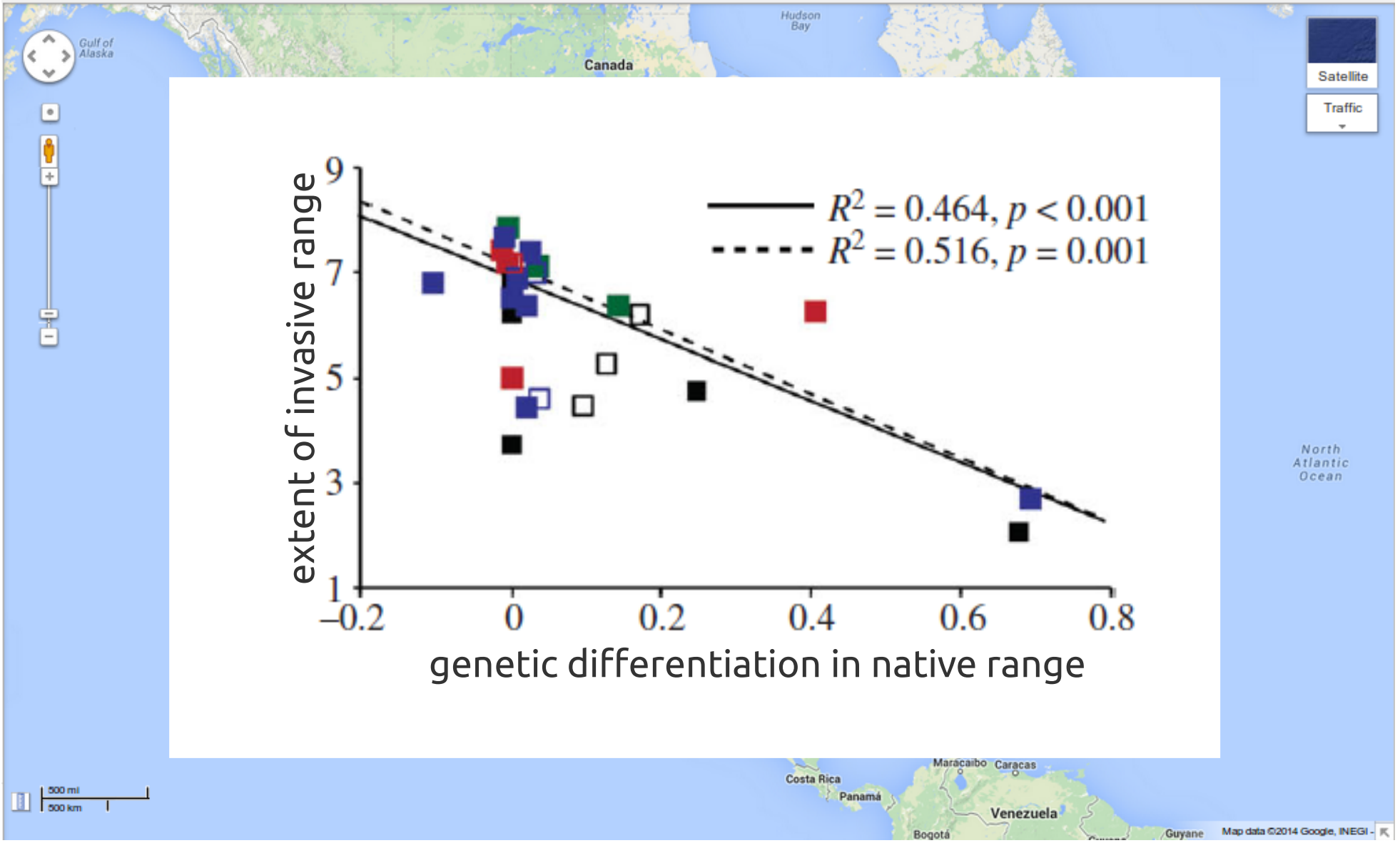
Traditional assumption: many marine systems are open



Traditional assumption: many marine systems are open



Traditional assumption: many marine systems are open



From Gaither et al. 2013

...but the ocean is complex.

Recent genomic work suggests local adaptation in many high-gene flow marine species

Atlantic herring

Lamichhaney et al. 2012

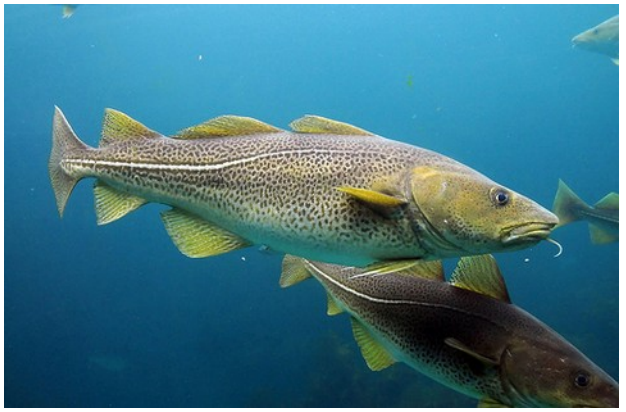
Purple sea urchin

Pespeni & Palumbi 2013

Red abalone

De Wit & Palumbi 2012

Atlantic cod

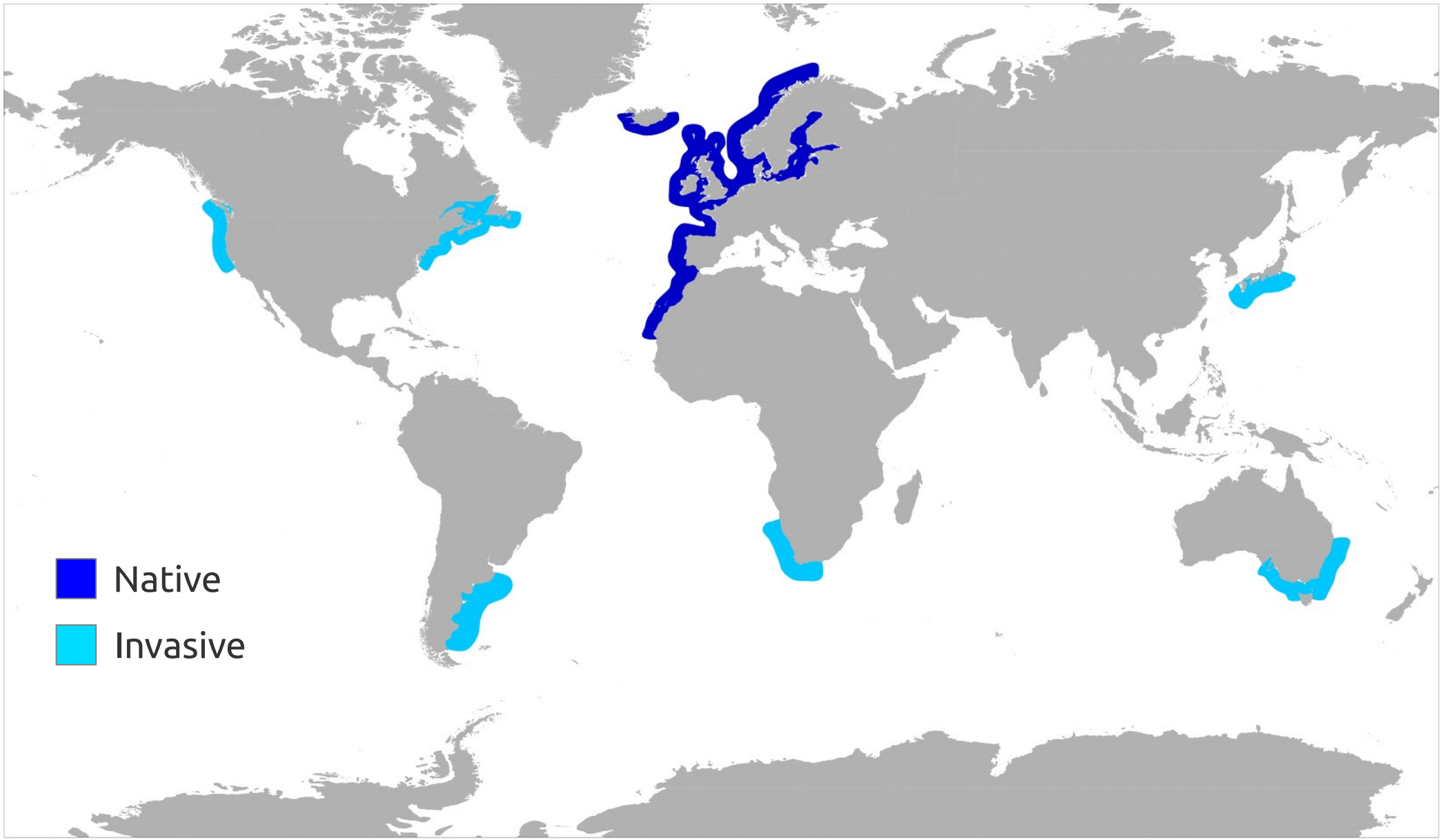


Nielsen et al. 2009

What can genomics tell us about adaptation in marine invasive species?

European green crab
Carcinus maenas

Global range of *C. maenas*



Range data from Carlton & Cohen 2003; Hidalgo *et al.* 2005; Best *et al.* 2009

What can genomics tell us about adaptation in *C. maenas*?

What can genomics tell us about adaptation in *C. maenas*?

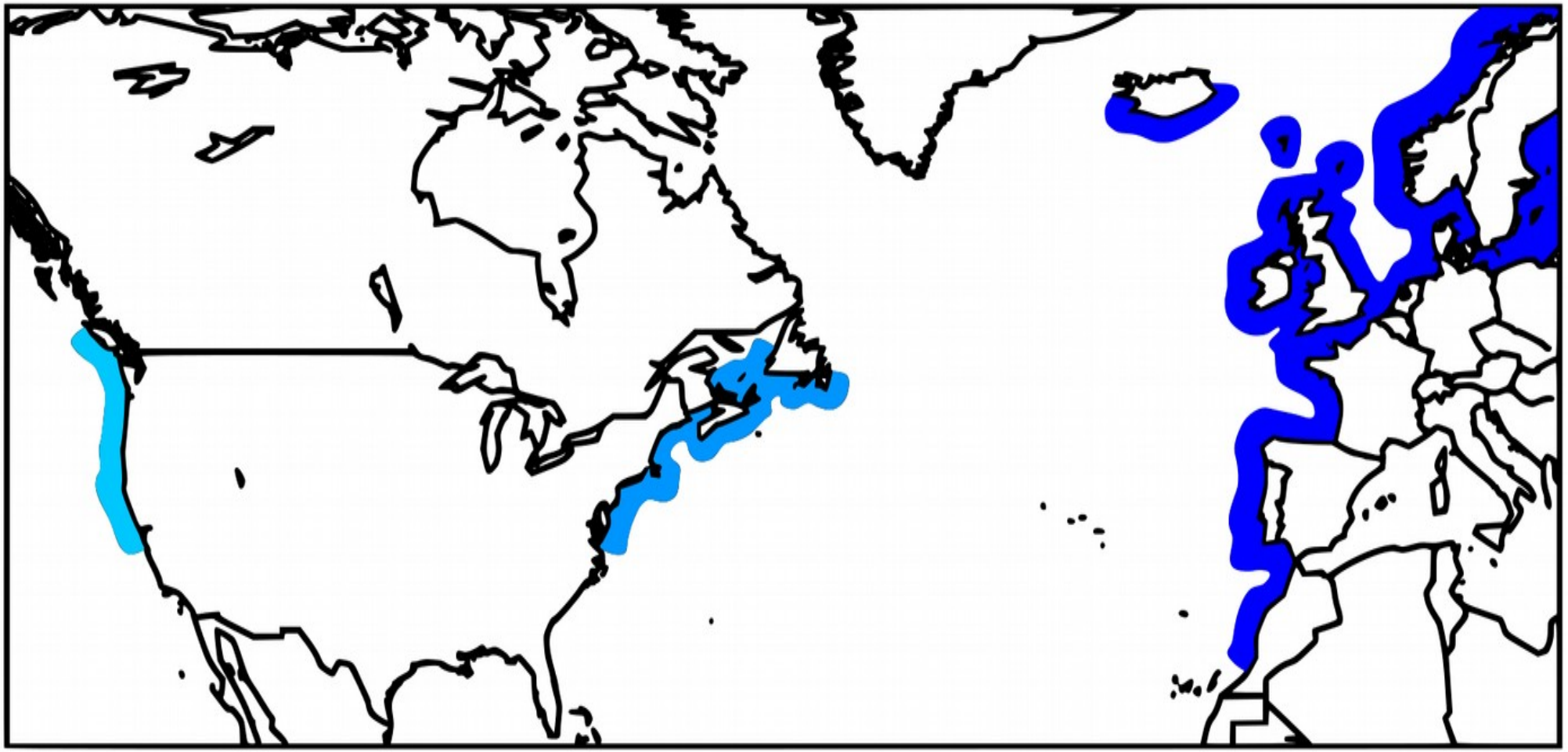
Are populations locally adapted?

What can genomics tell us about adaptation in *C. maenas*?

Are populations locally adapted?

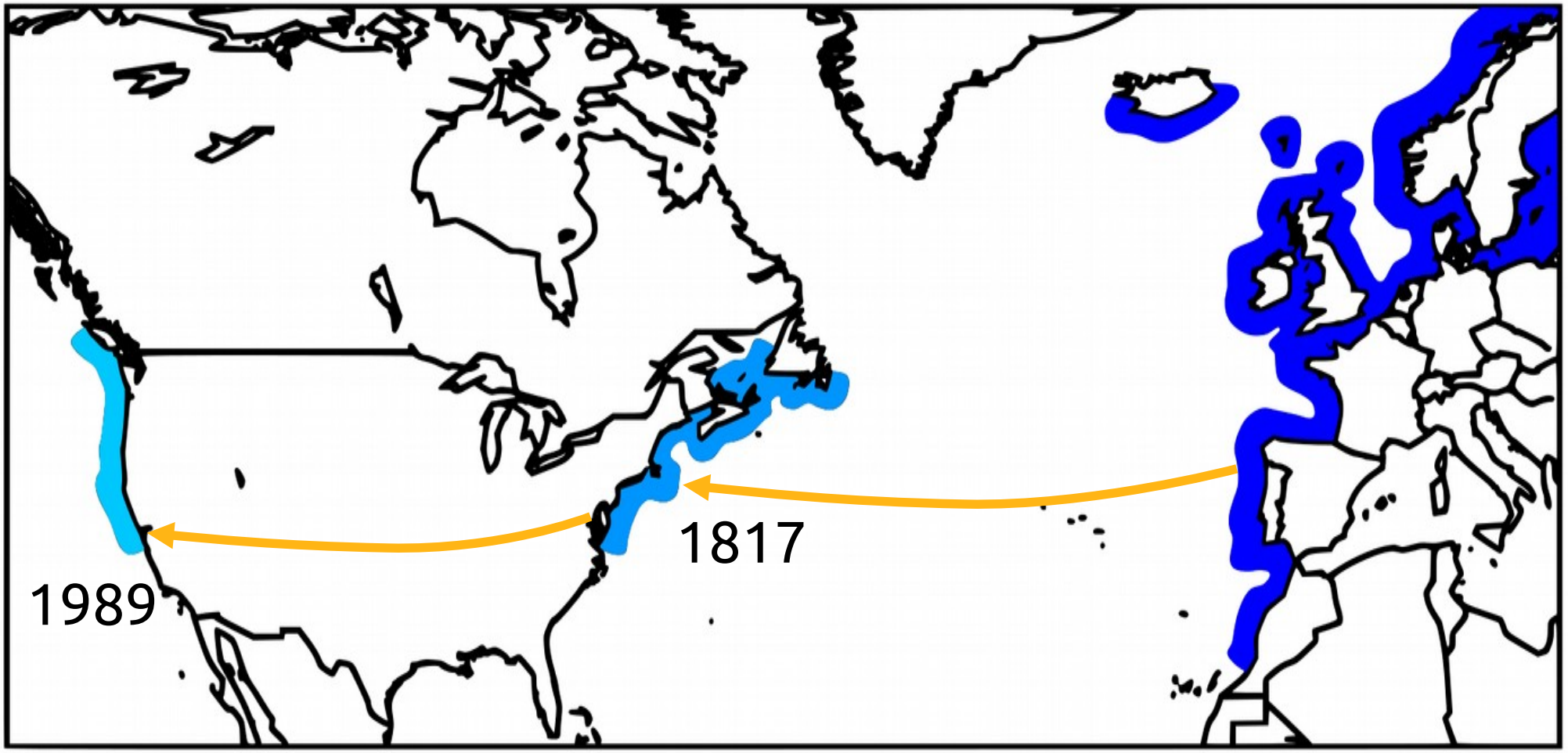
How quickly can genetic adaptation arise?

Study region



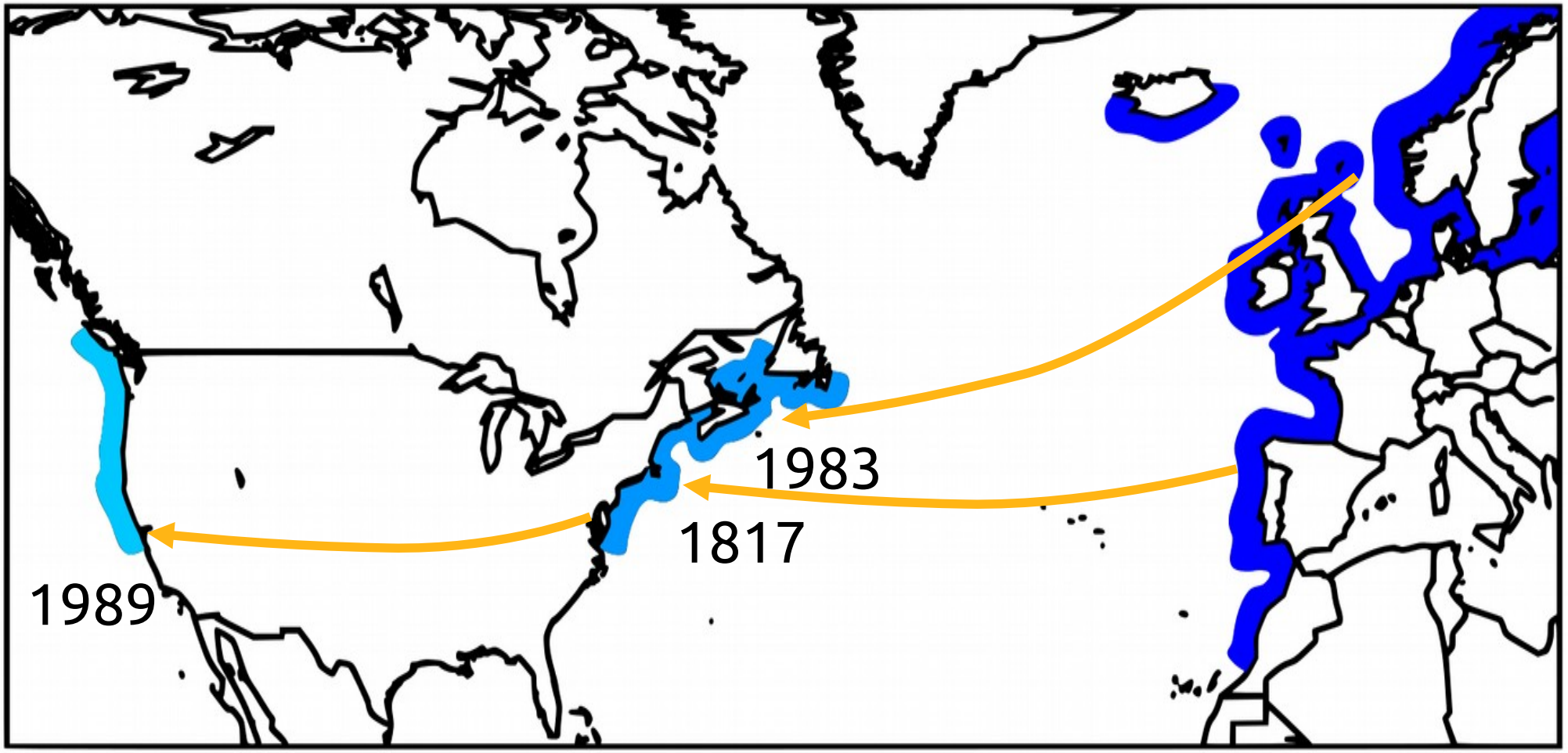
Range data from Carlton & Cohen 2003; Best *et al.* 2009

Invasion history



Range data from Carlton & Cohen 2003; Best *et al.* 2009

Invasion history



Range data from Carlton & Cohen 2003; Best *et al.* 2009

West coast:

British Columbia

California

East coast:

Newfoundland

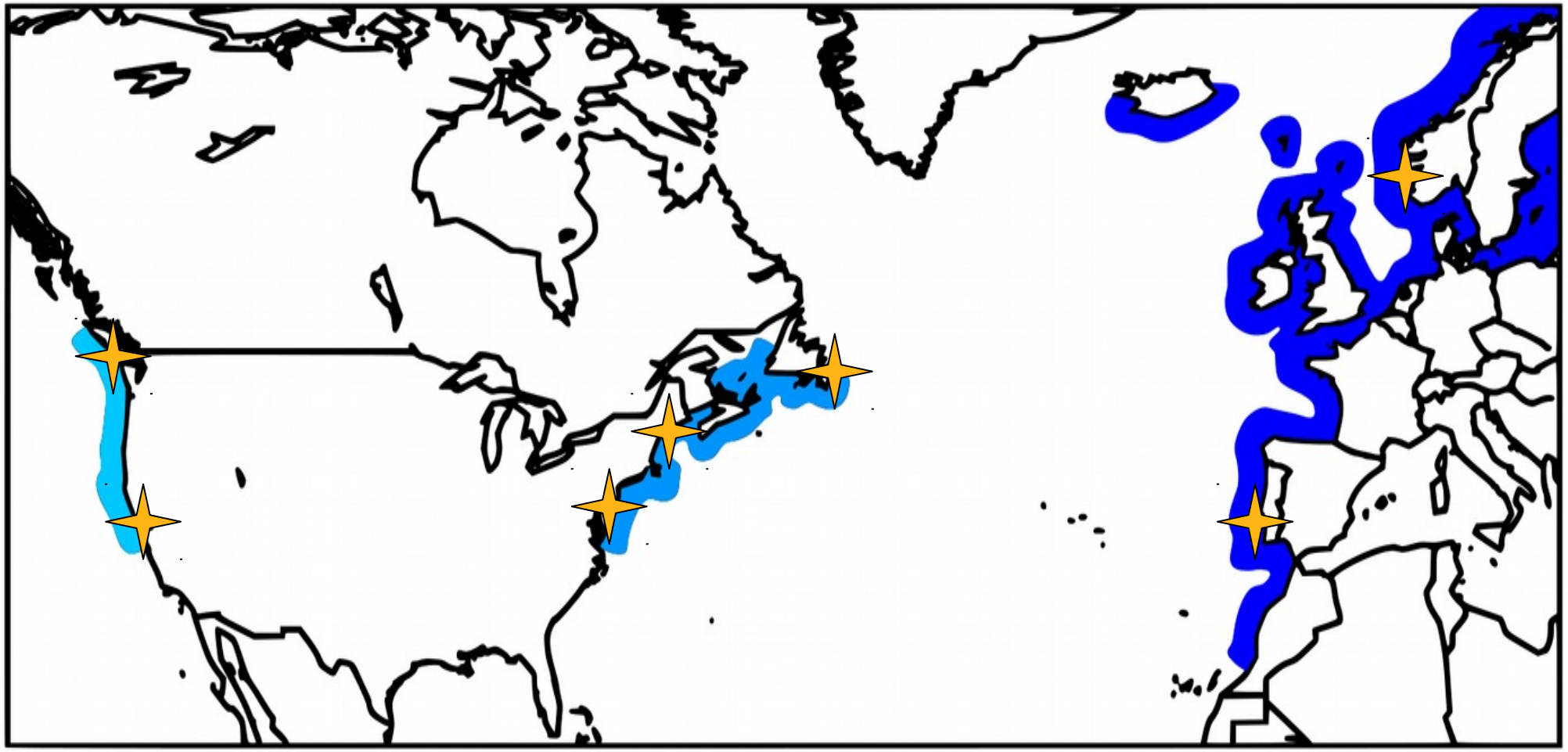
Maine

New Jersey

Europe:

Norway

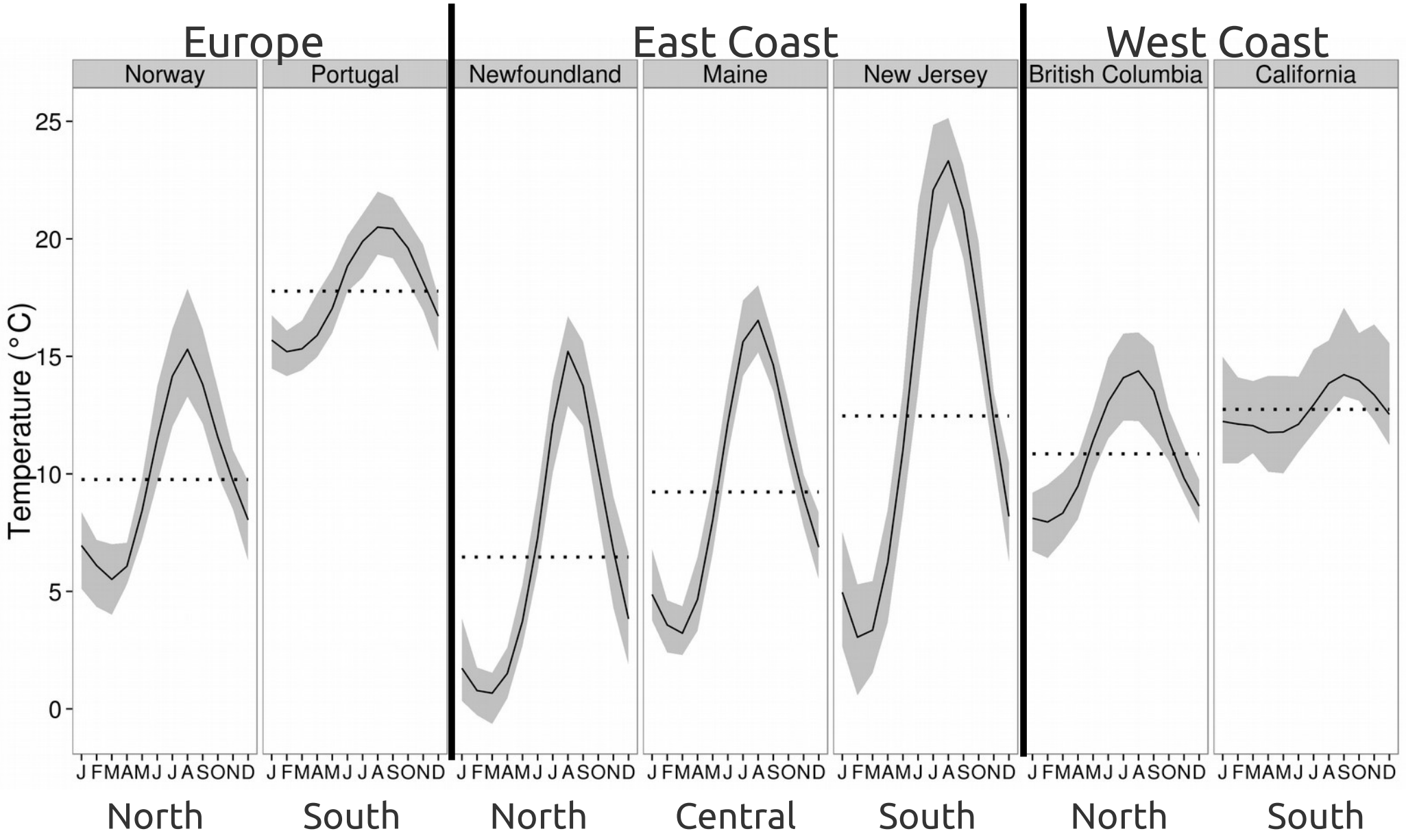
Portugal



Range data from Carlton & Cohen 2003; Best *et al.* 2009

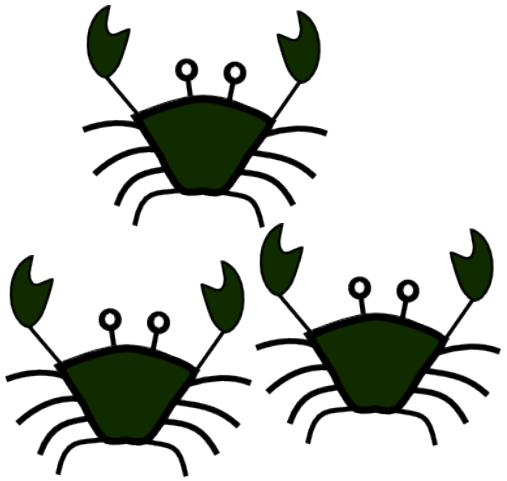
Long-term SST at study sites

(25-year average: 1987 - 2011)



Data from NOAA/NWS National Centers for Environmental Prediction (Reynolds *et al.* 2002)

Experimental setup



25°C

3 weeks

Heat tolerance
N = 12

Sequencing
N = 6

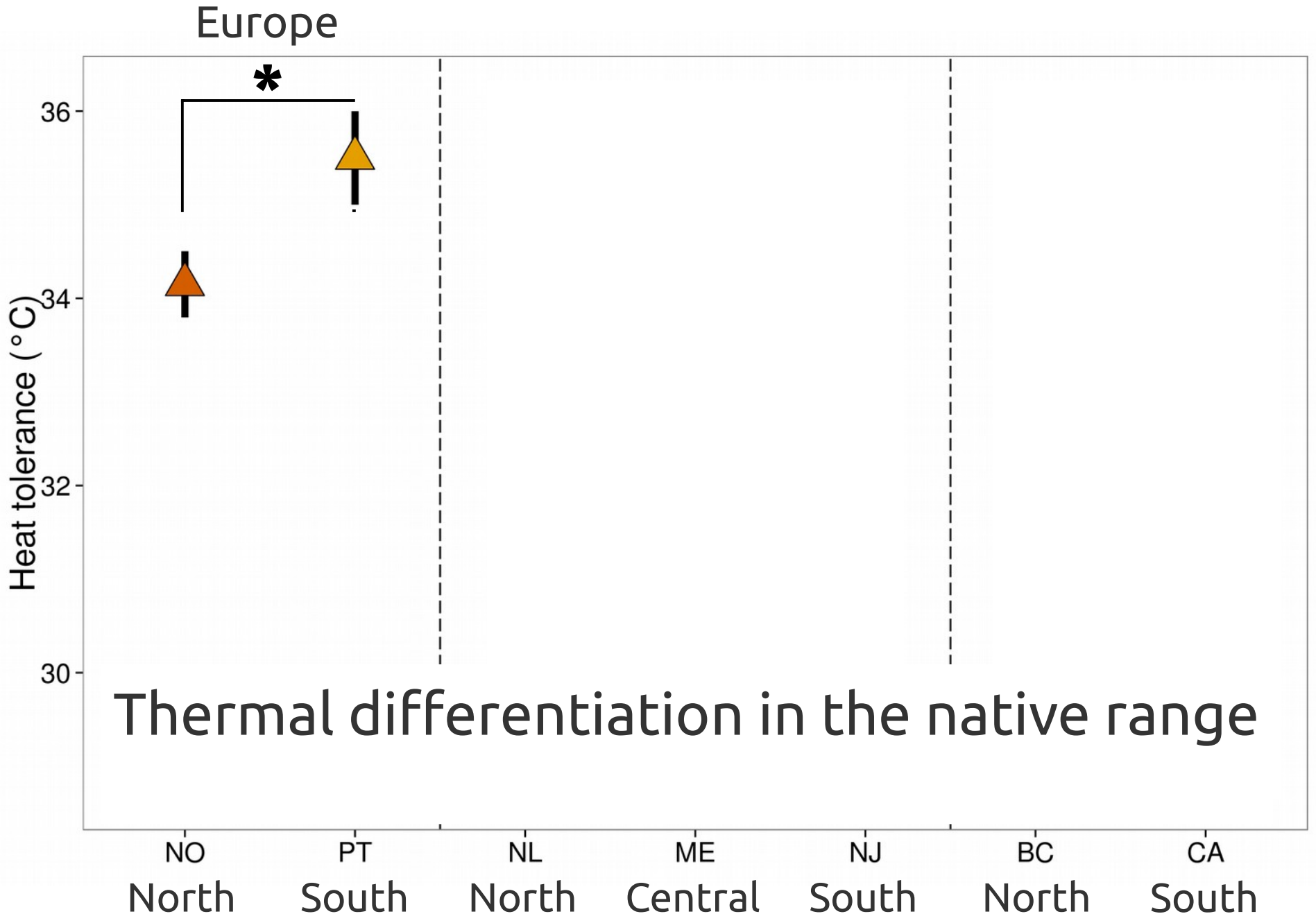
5°C

4 weeks

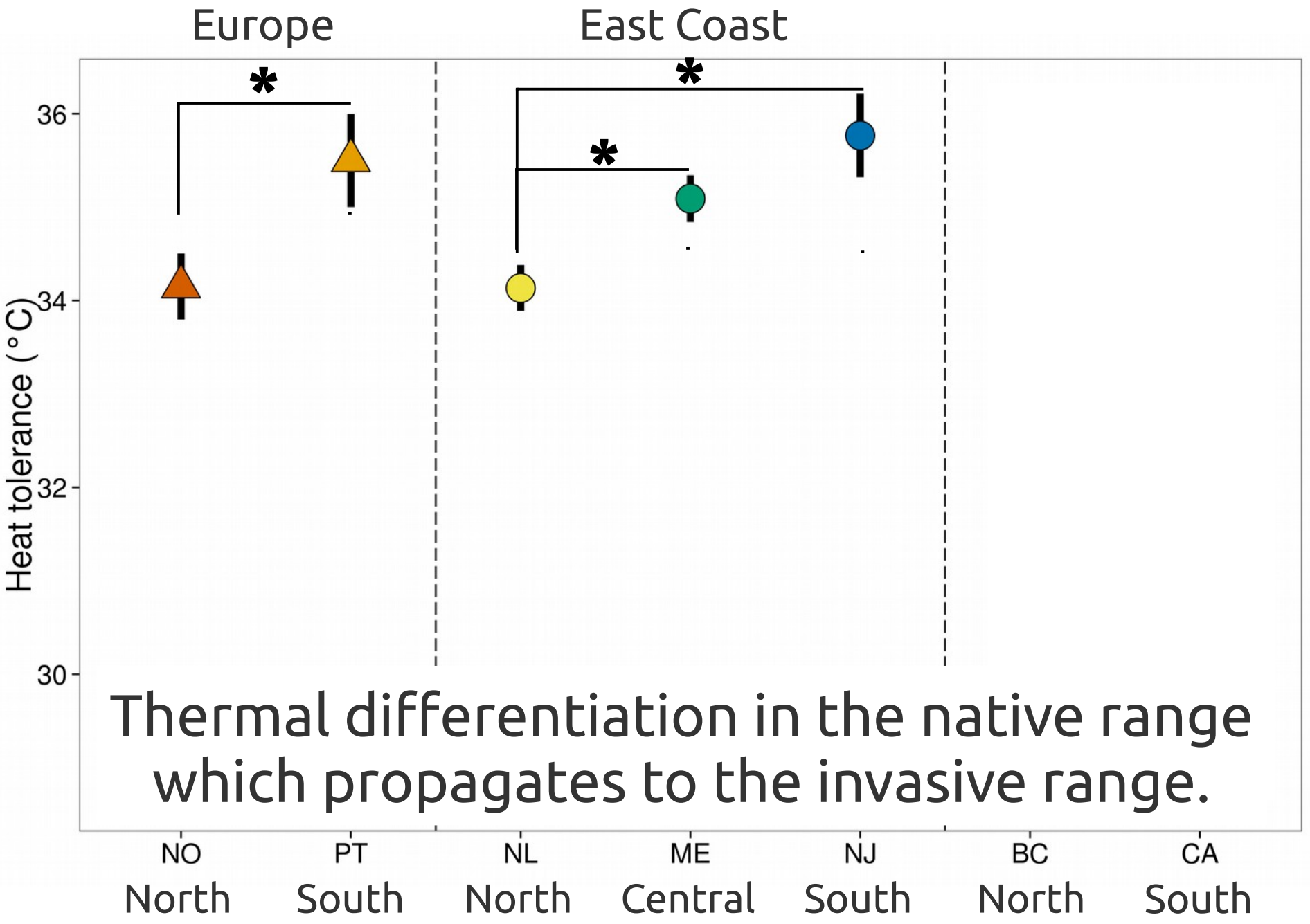
Heat tolerance
N = 12

Sequencing
N = 6

Are there physiological differences between populations that suggest local adaptation?

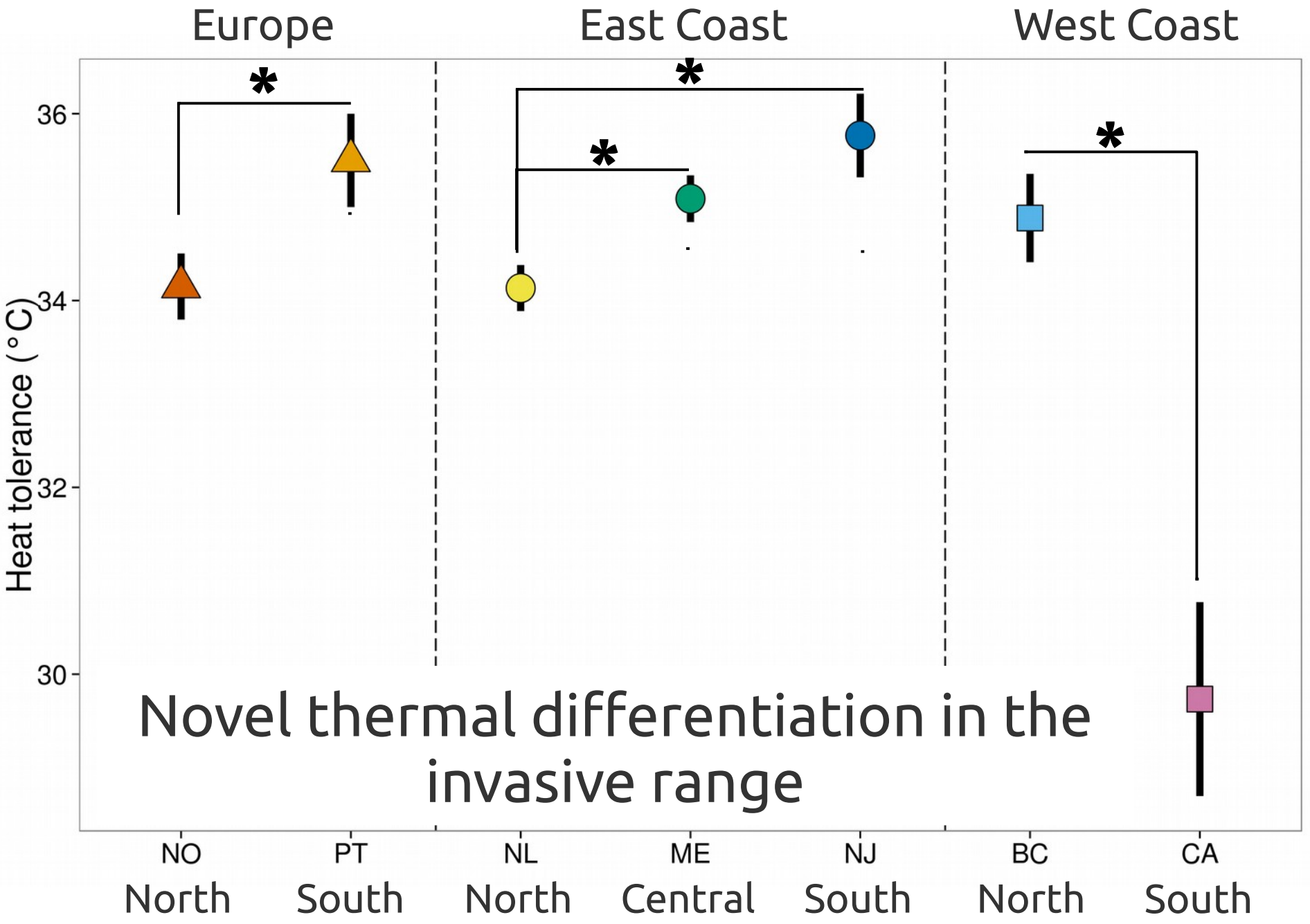


From Tepolt & Somero 2014



Thermal differentiation in the native range which propagates to the invasive range.

From Tepolt & Somero 2014



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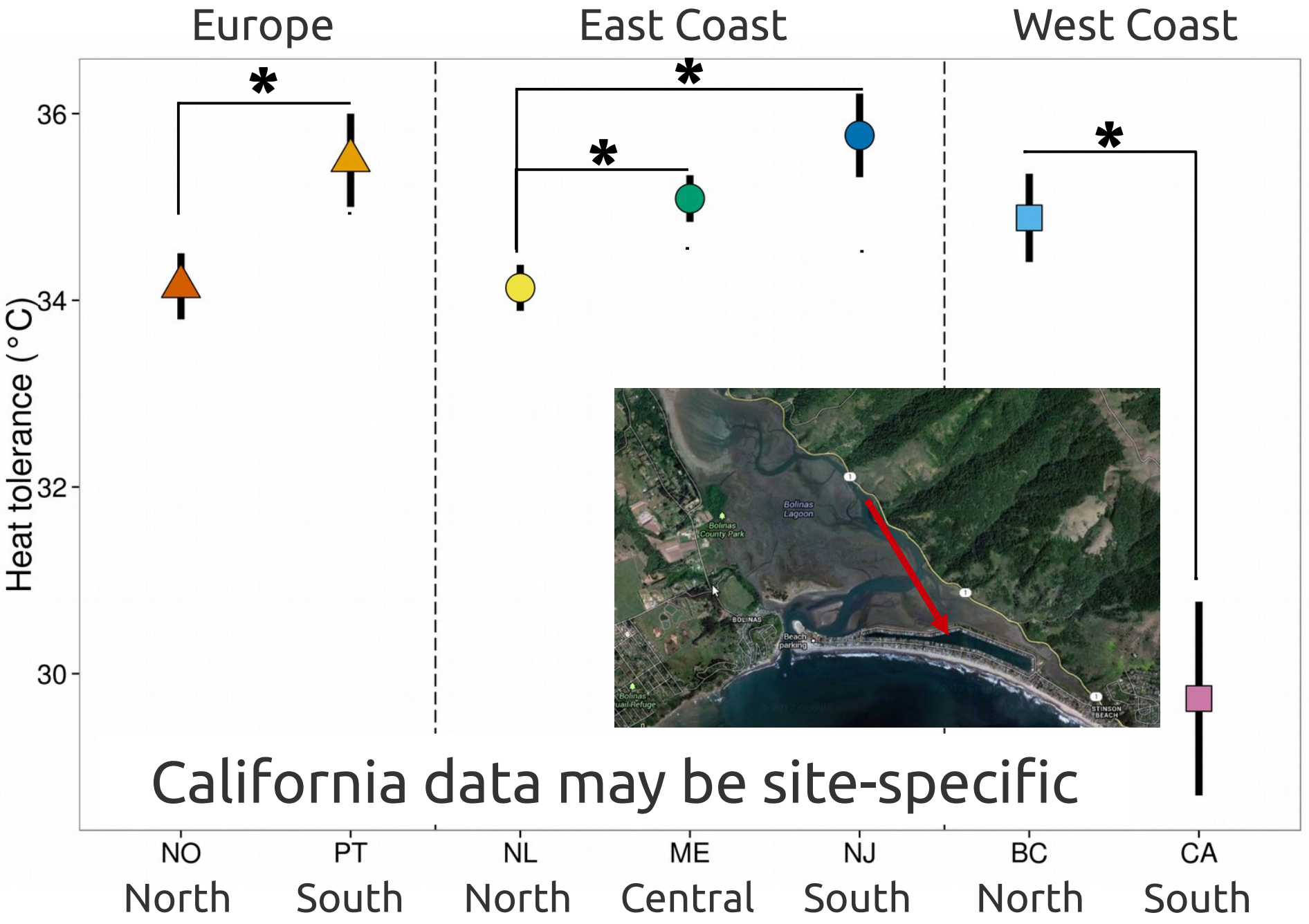
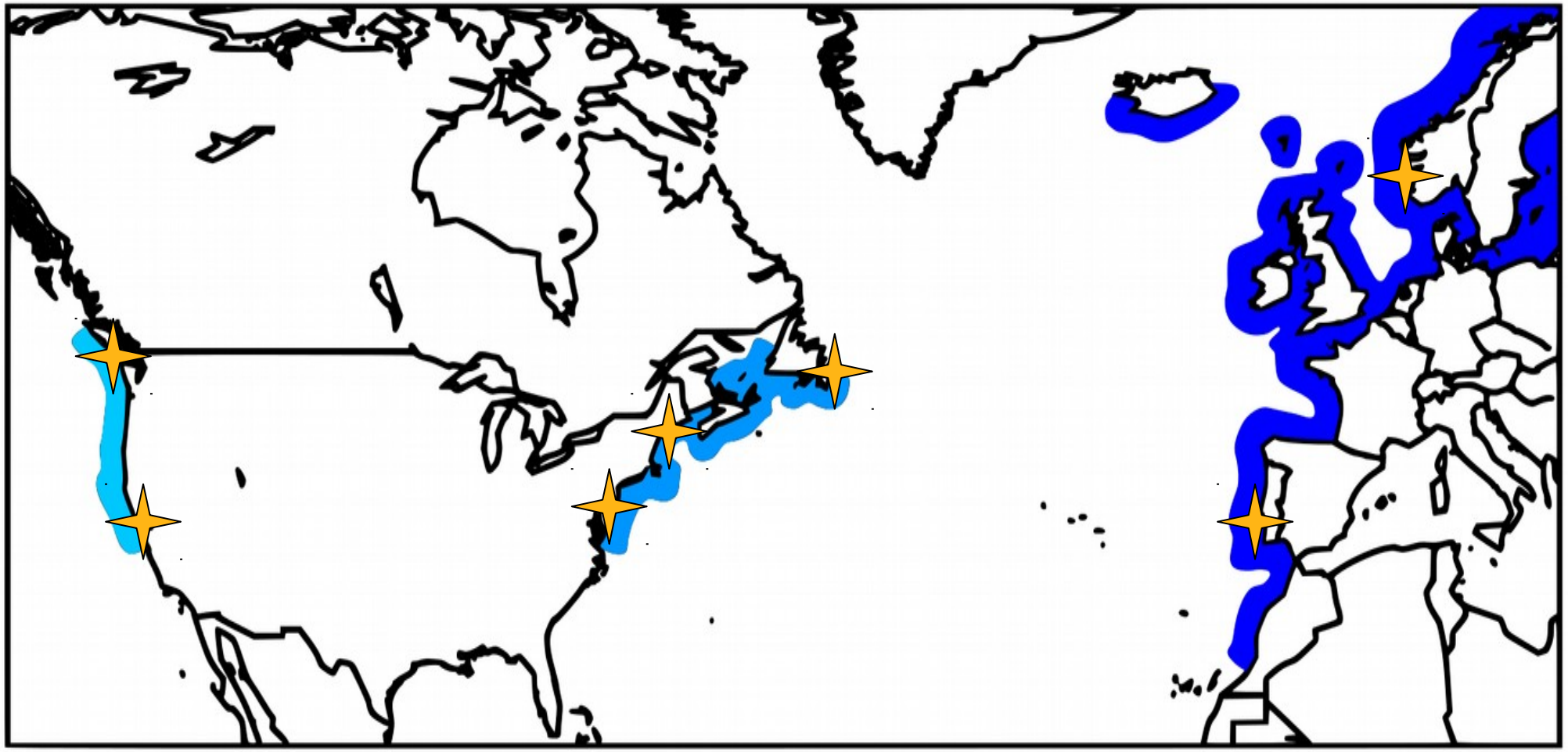


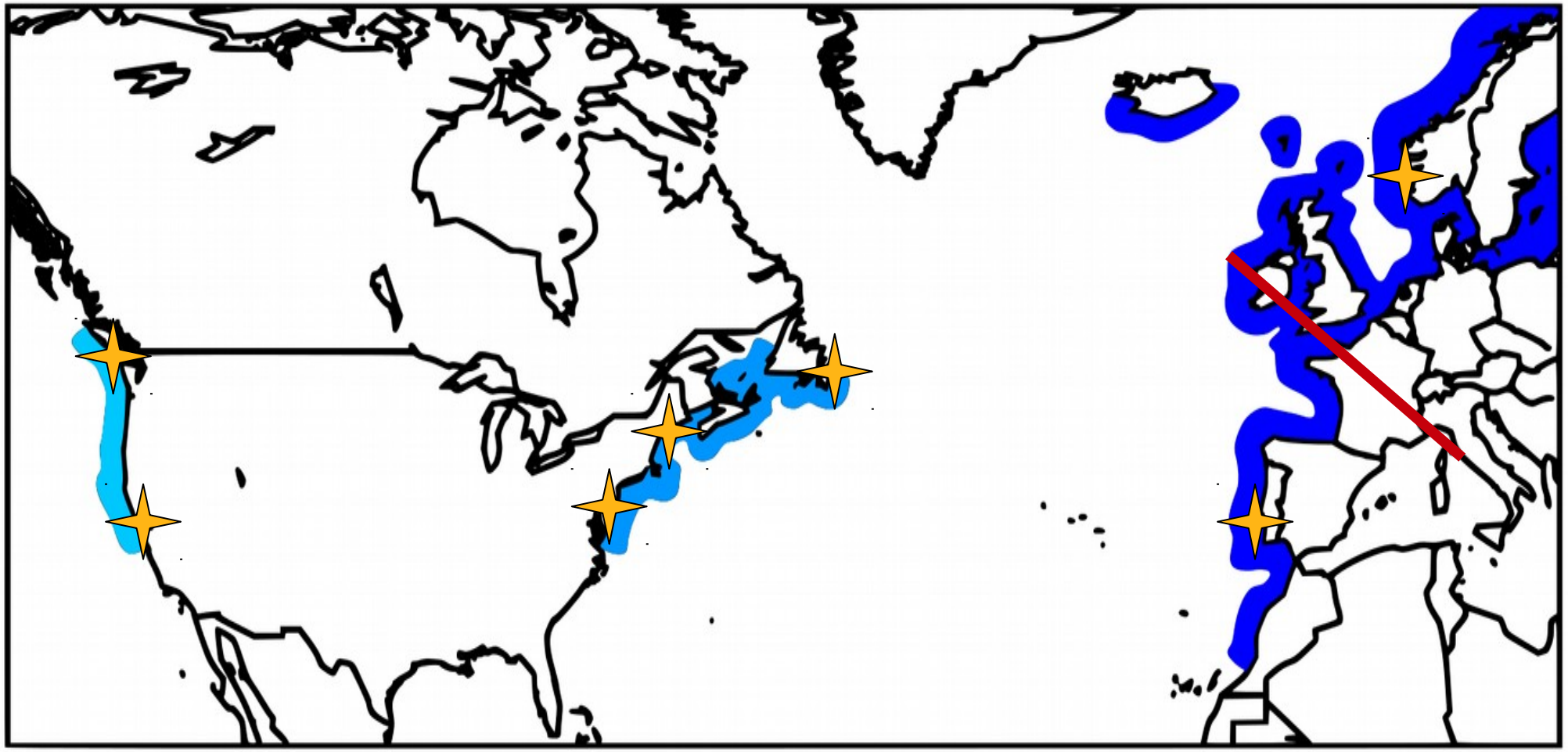
From Tepolt & Somero 2014

Heat tolerance differs between populations, suggesting local adaptation.



Range data from Carlton & Cohen 2003; Best *et al.* 2009

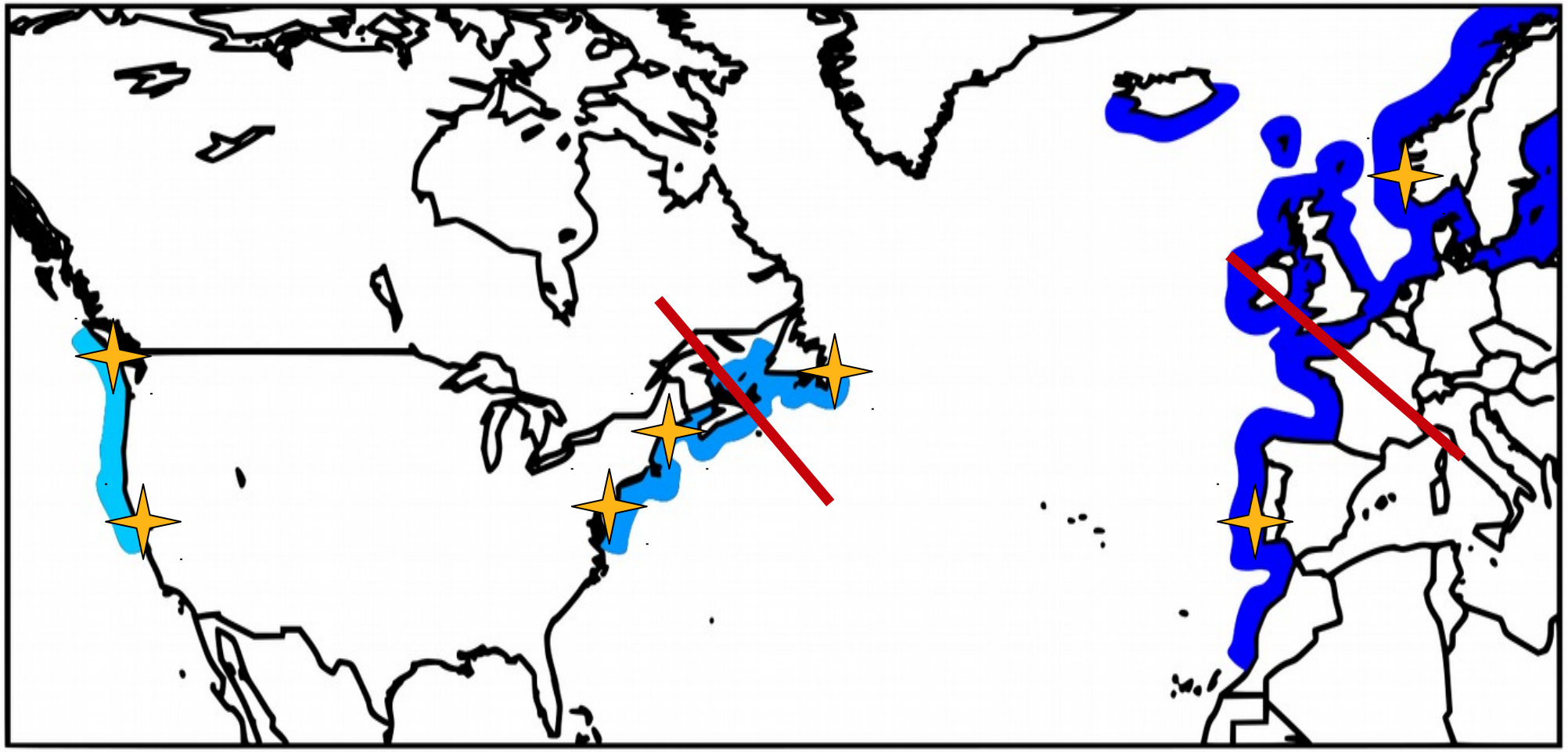
South is more heat-tolerant than north in the native range



Range data from Carlton & Cohen 2003; Best *et al.* 2009

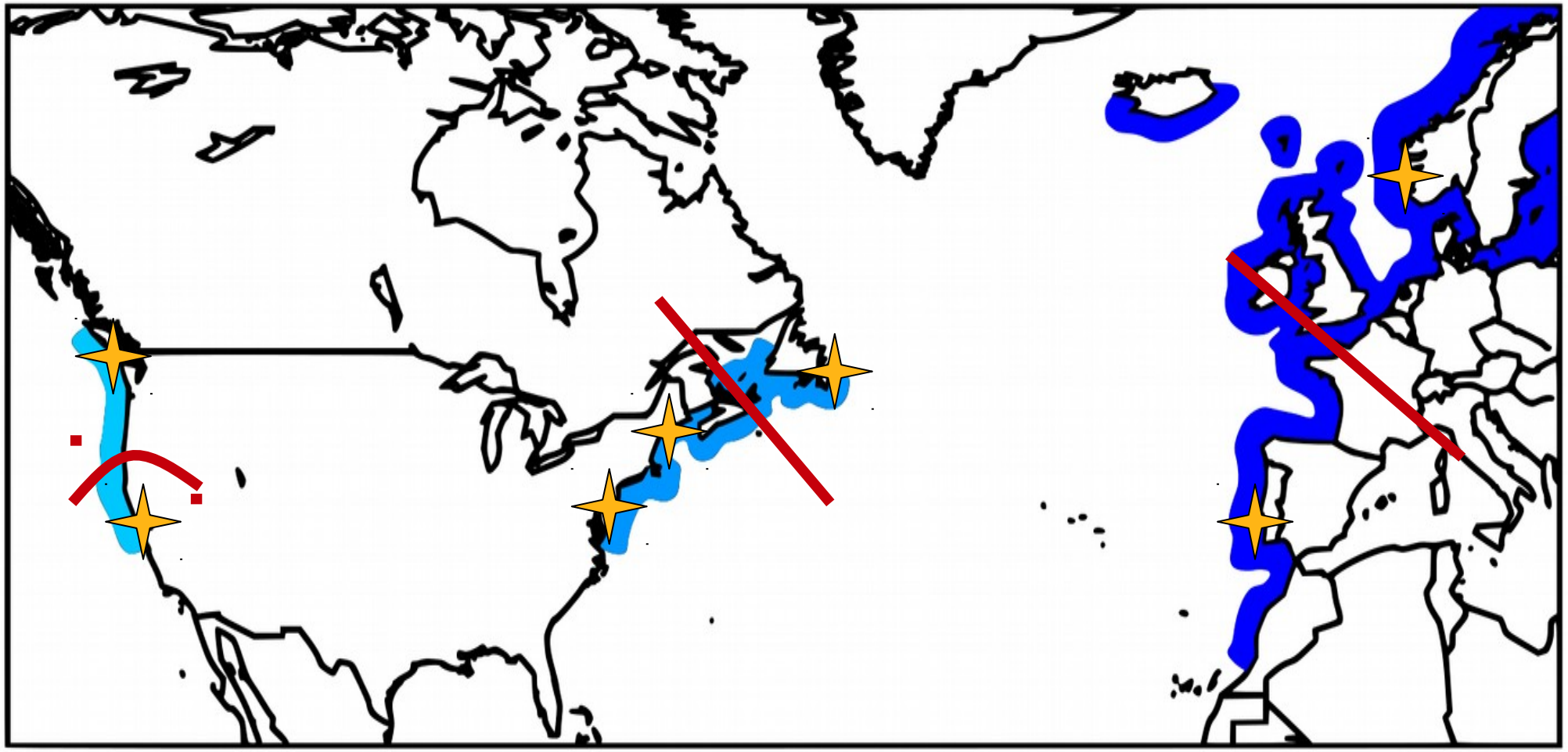
South is more heat-tolerant than north in the East Coast invasive range

Break between Maine and Newfoundland



Range data from Carlton & Cohen 2003; Best *et al.* 2009

California is idiosyncratic



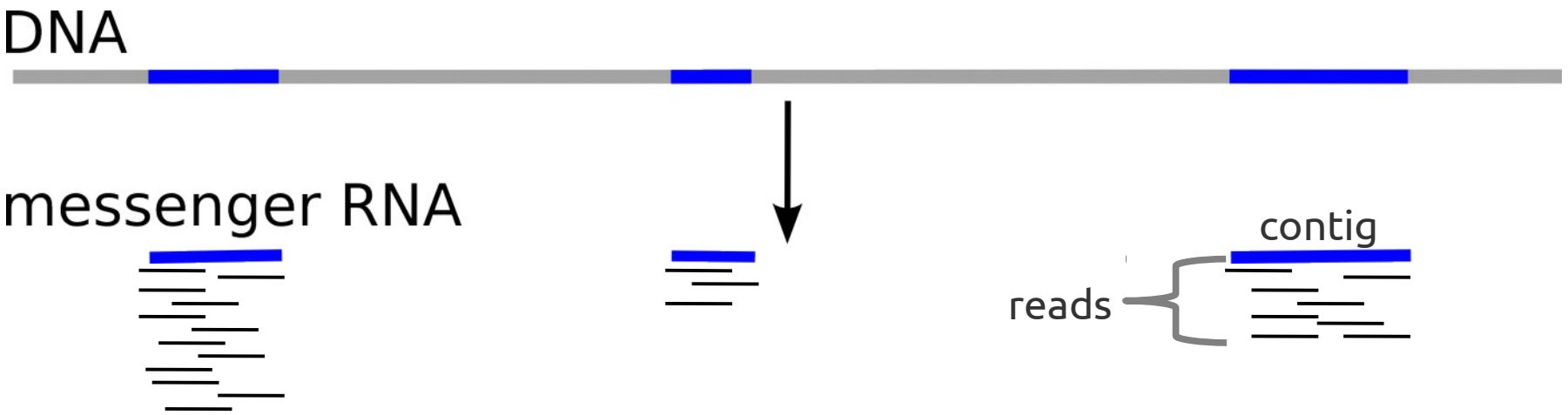
Range data from Carlton & Cohen 2003; Best *et al.* 2009

Heat tolerance differs between populations, suggesting local adaptation.

Heat tolerance differs between populations, suggesting local adaptation.

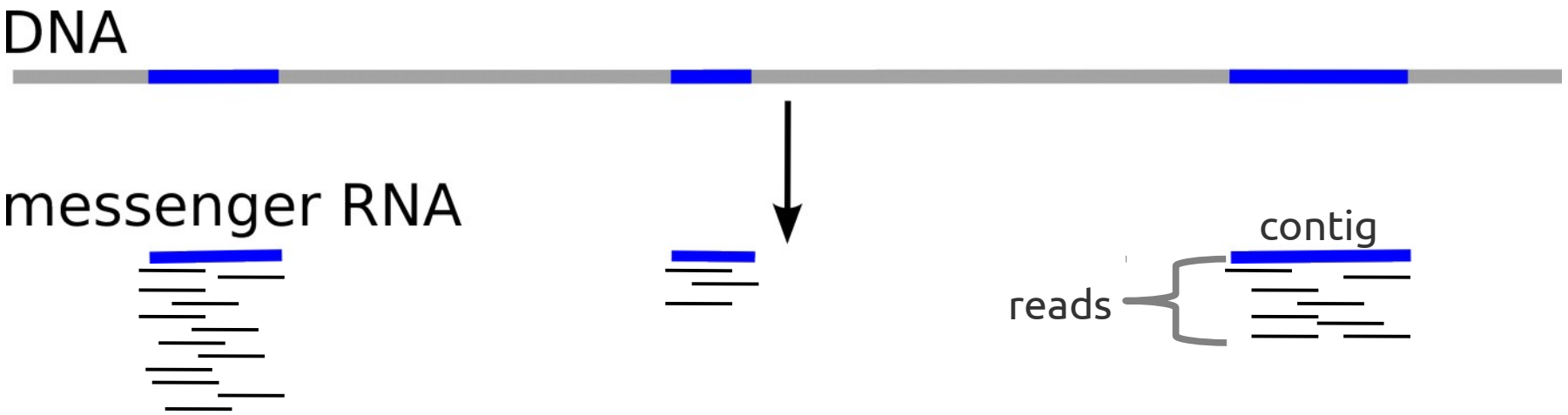
Do the genetic data support local adaptation?

Transcriptome sequencing
(Sequence just messenger RNA)



1,430,000,000 raw reads
(71,500,000,000 bp of data)

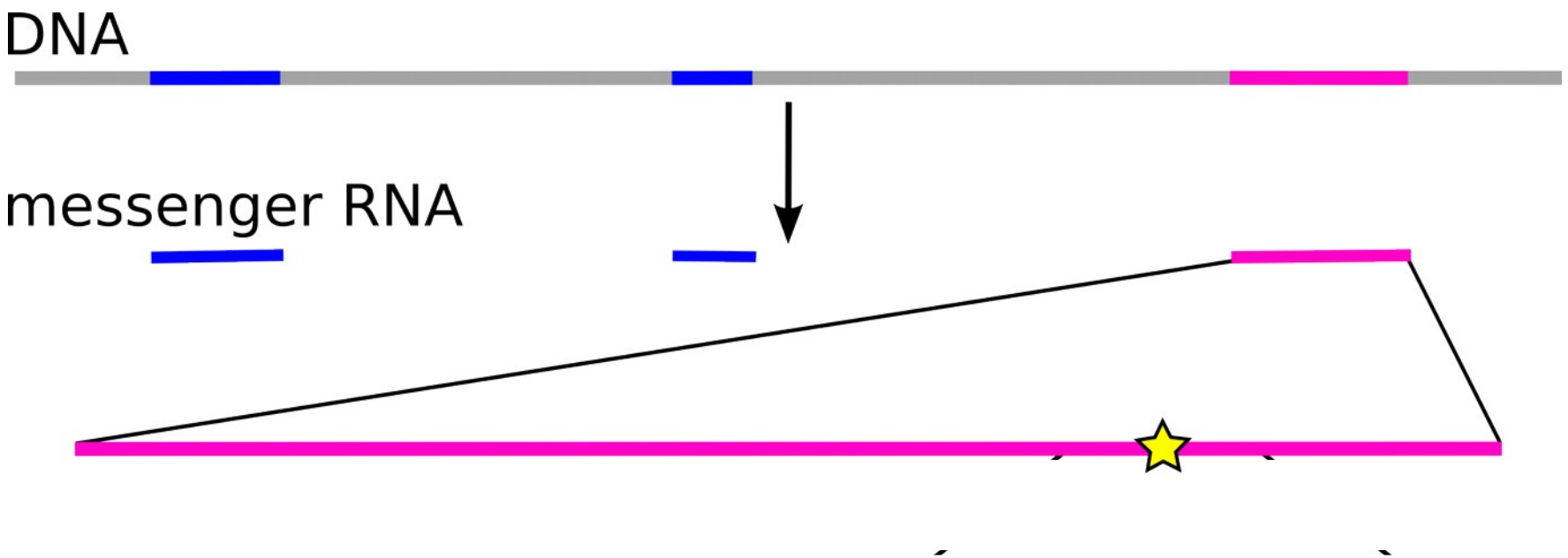
Transcriptome sequencing
(Sequence just messenger RNA)



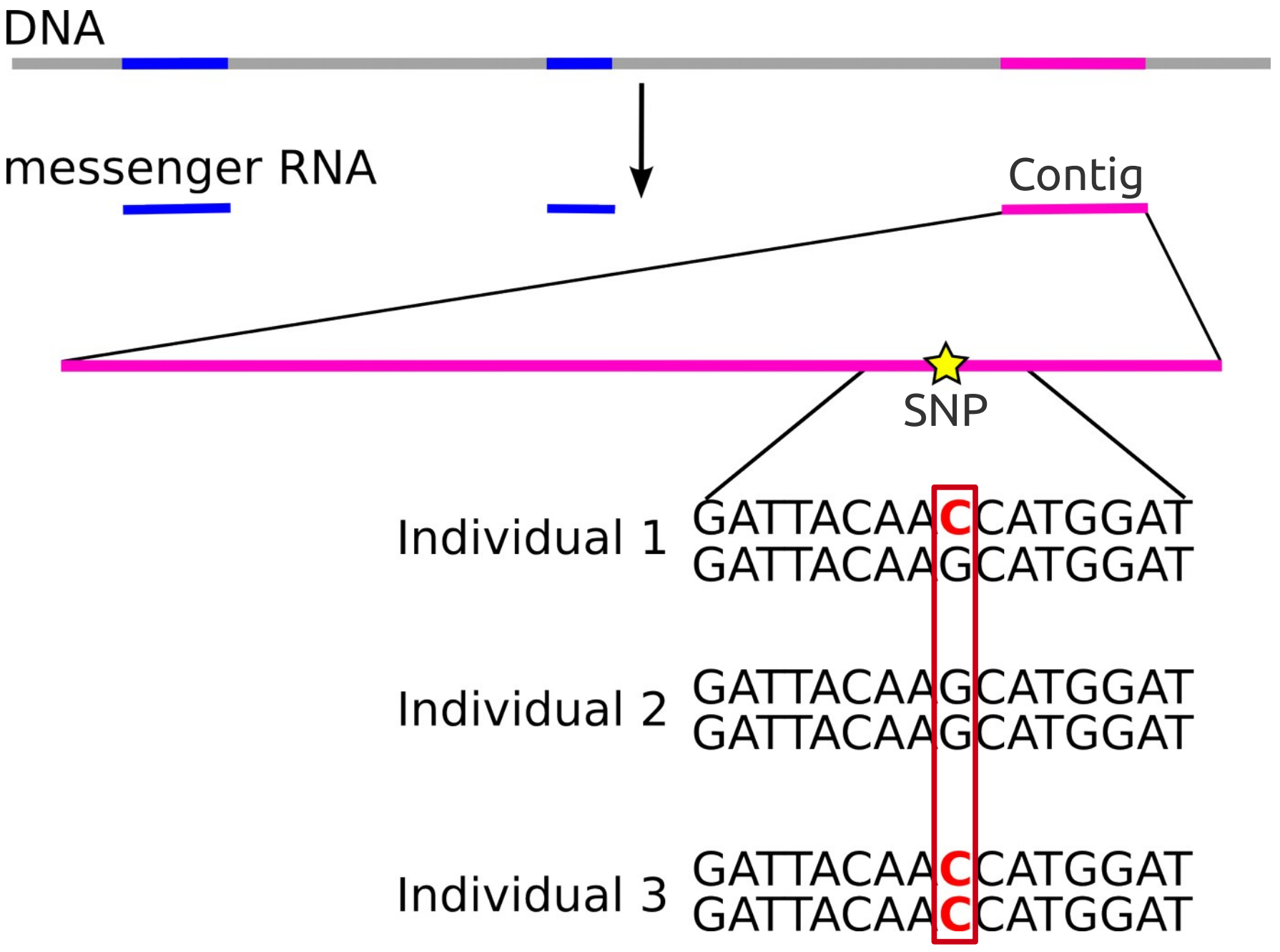
Assembled *de novo* transcriptome

116,241 contigs

Single-Nucleotide Polymorphisms (SNPs)



Single-Nucleotide Polymorphisms (SNPs)



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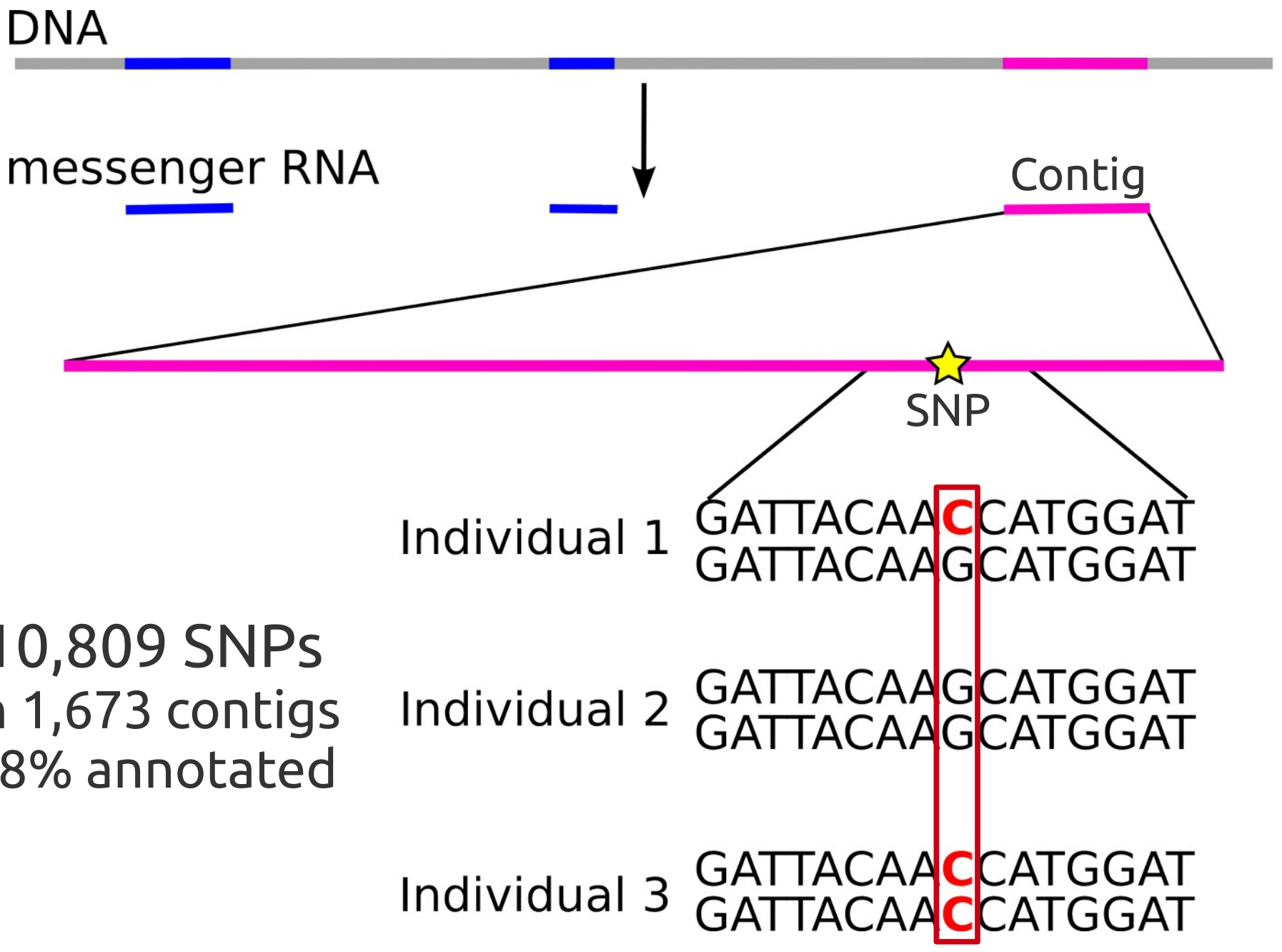
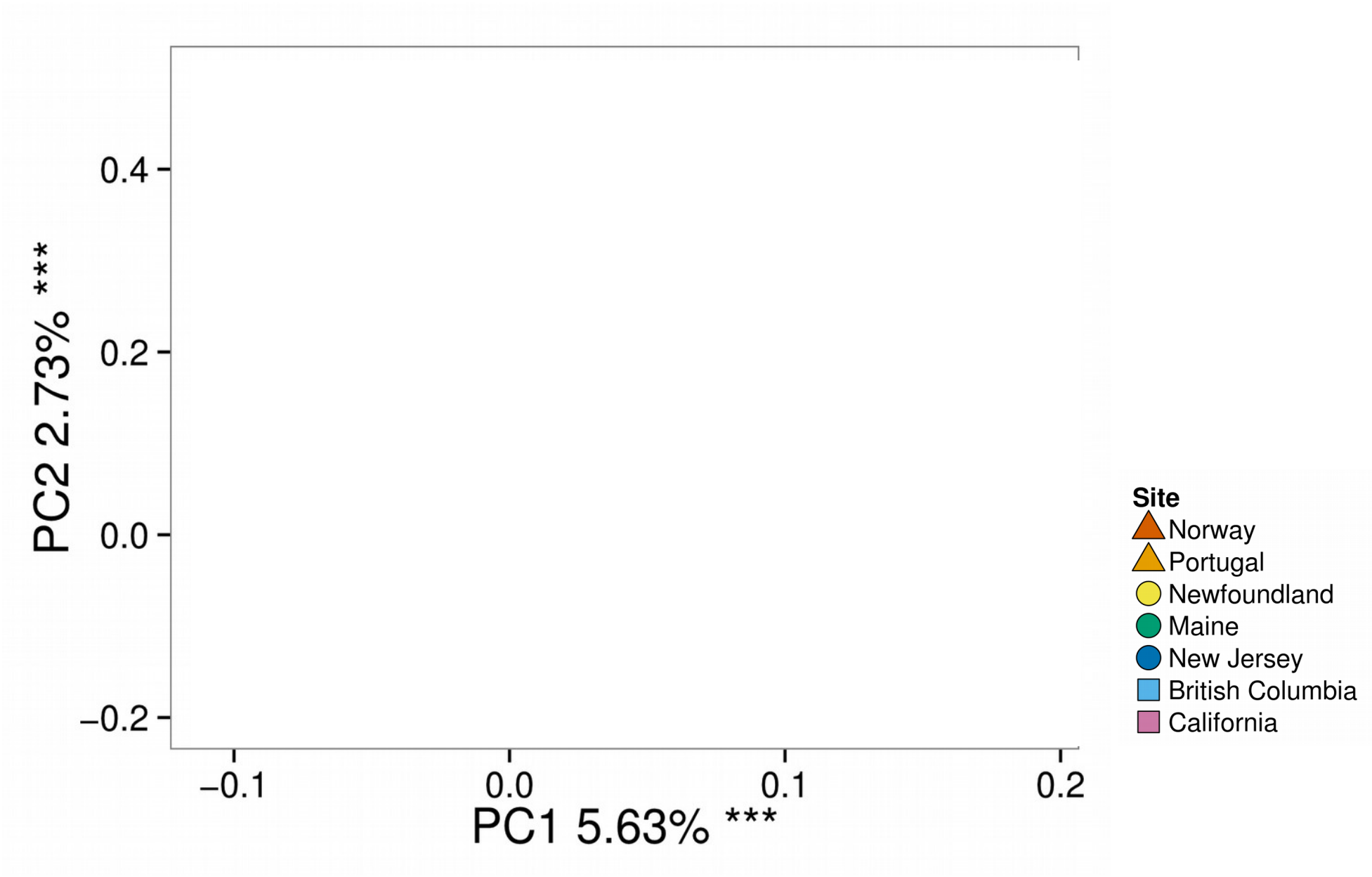
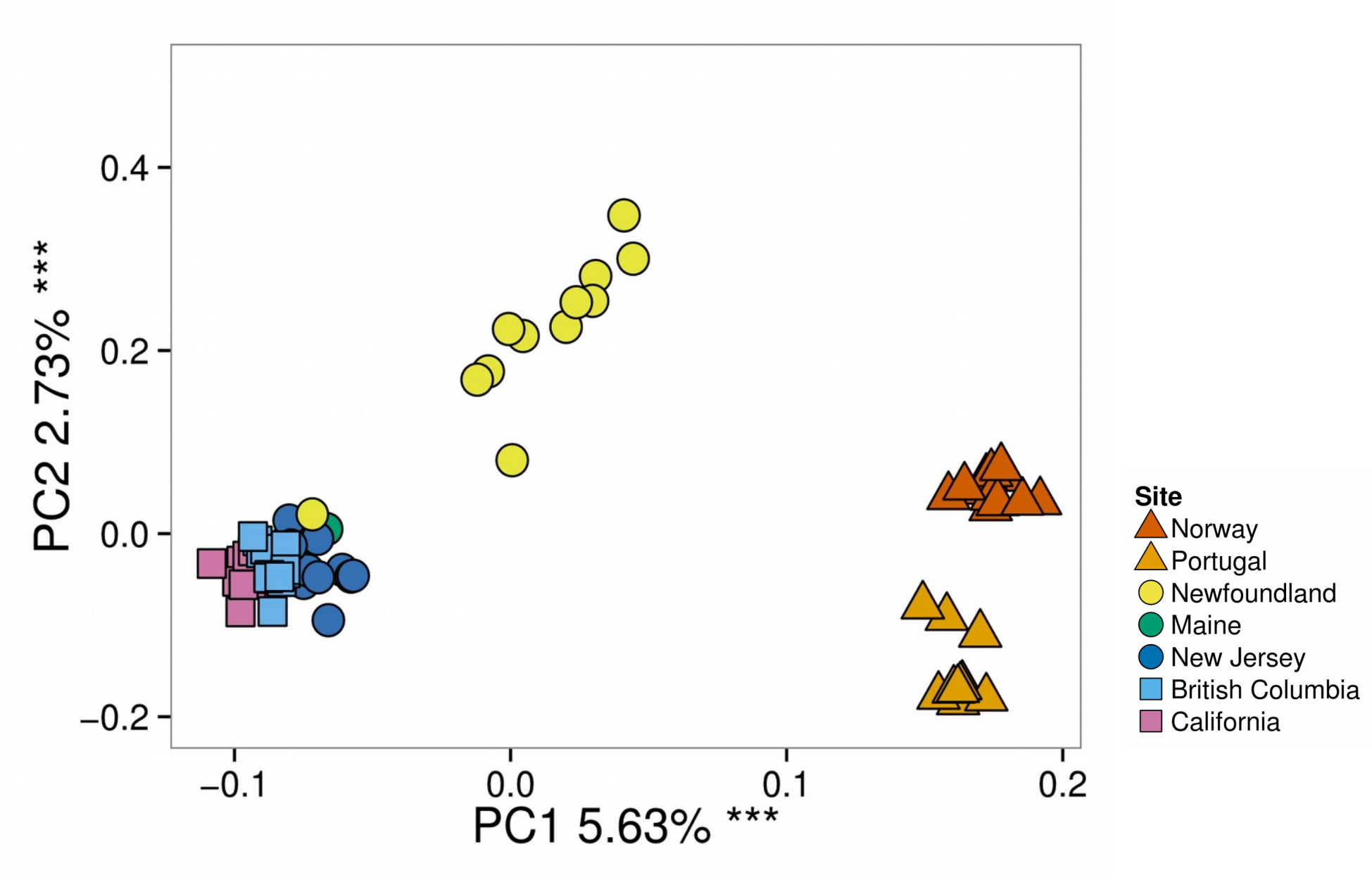


10,809 SNPs
in 1,673 contigs
78% annotated

Principal components analysis



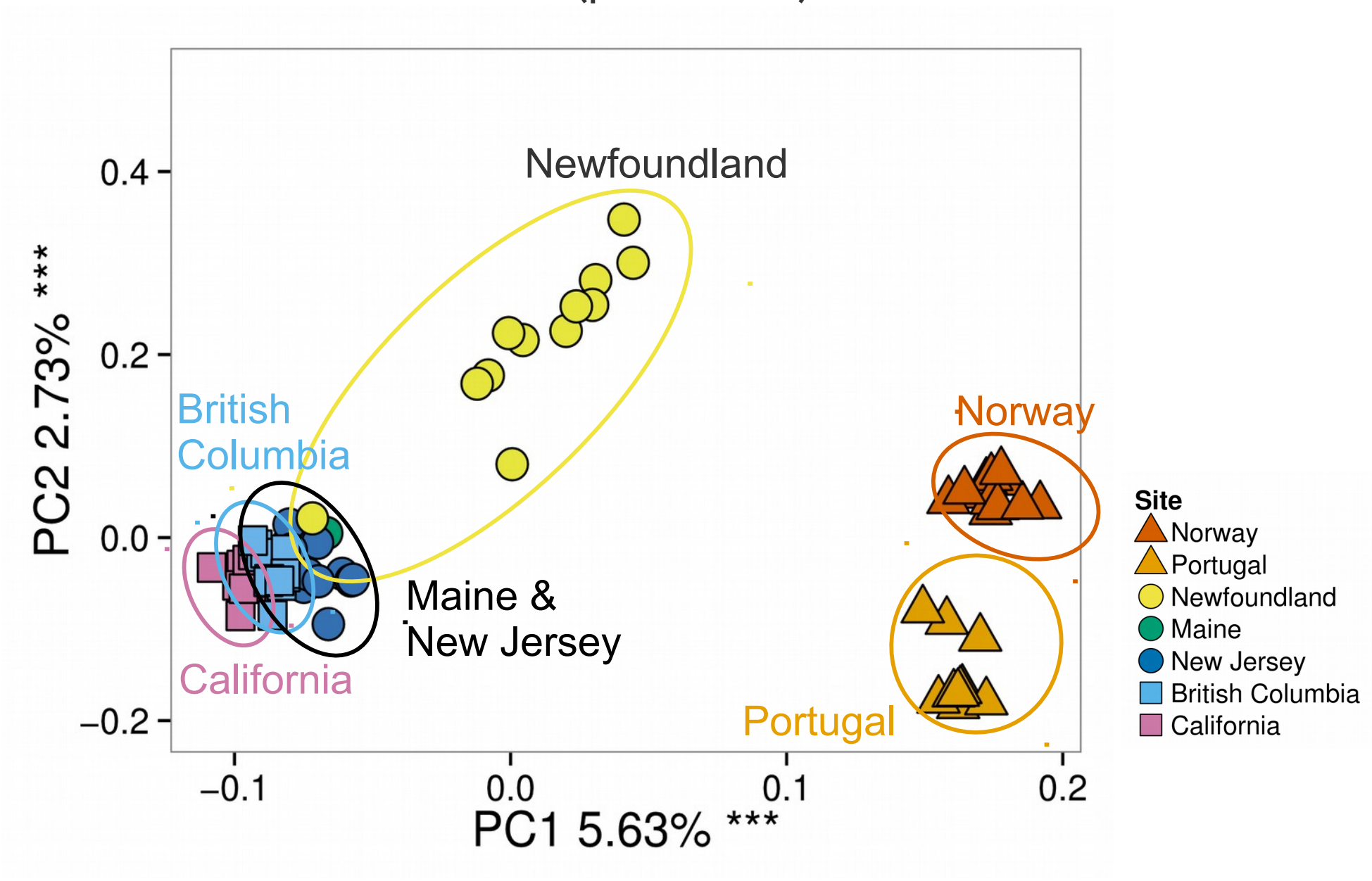
Genetic structure at 10,809 SNPs
in 1,673 contigs



From Tepolt & Palumbi, in press at *Molecular Ecology*

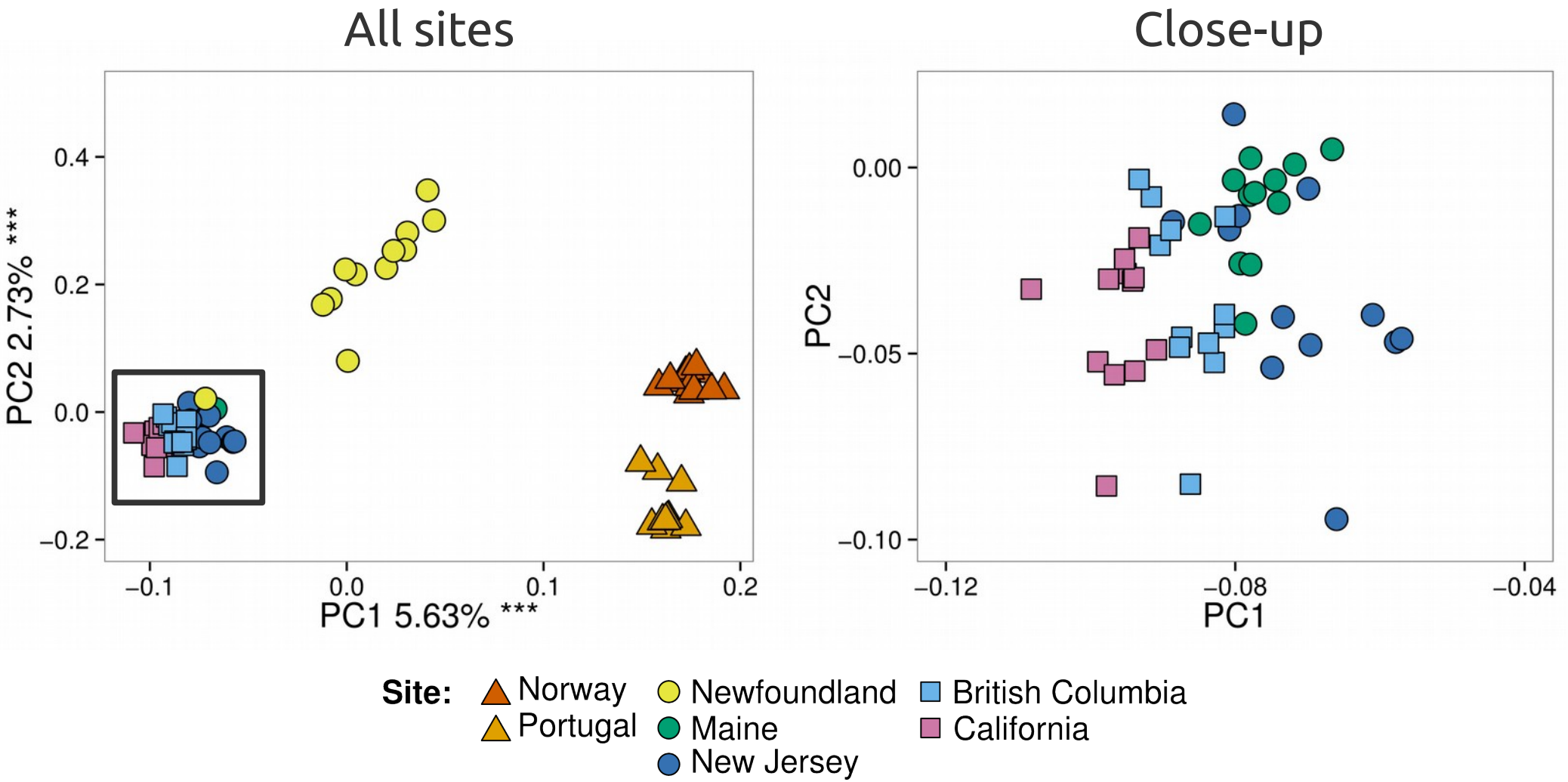
All clusters significantly differentiated

(p < 0.0001)



From Tepolt & Palumbi, in press at *Molecular Ecology*

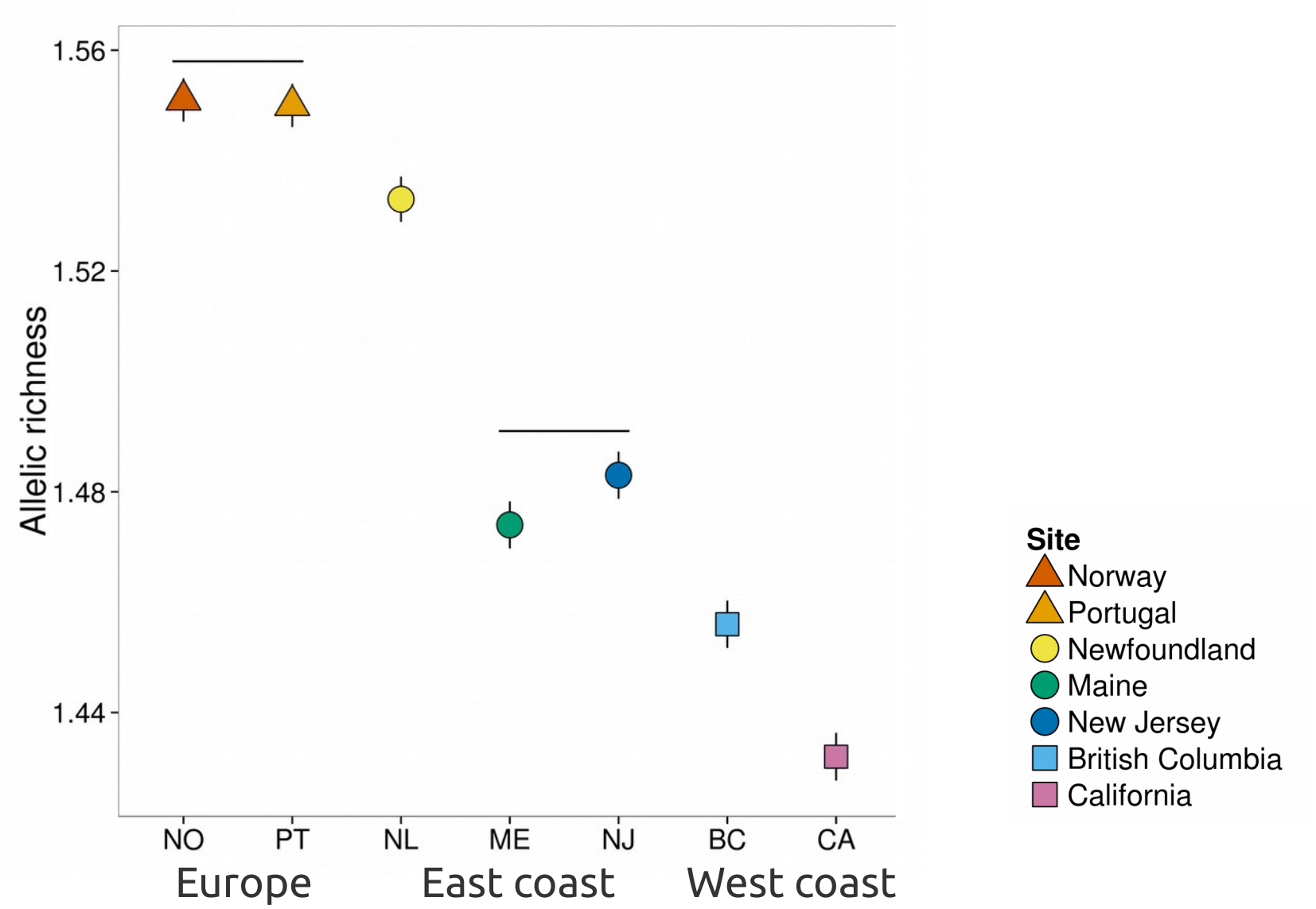
Genetic structure at all loci



From Tepolt & Palumbi, in press at *Molecular Ecology*

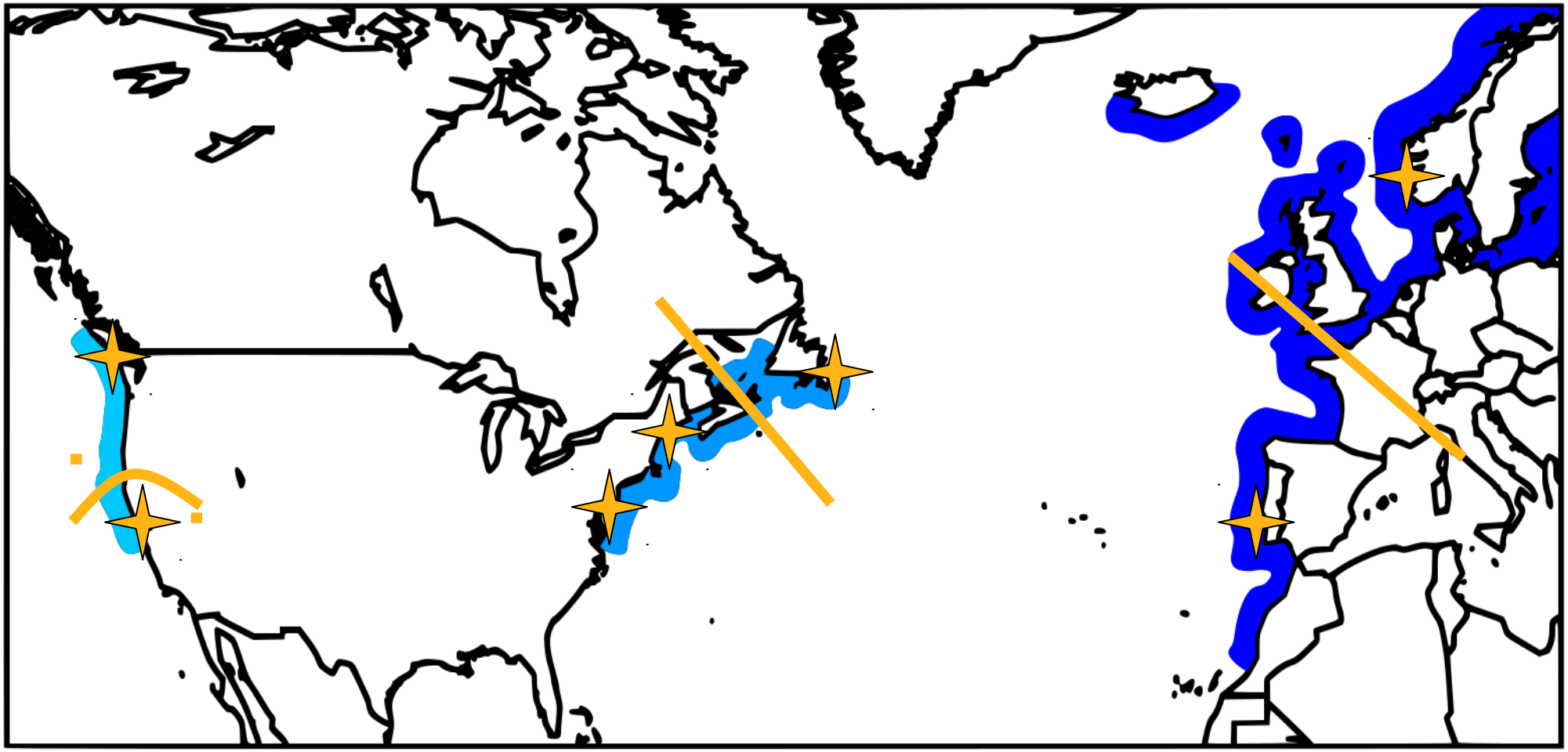
Genetic diversity shows serial bottlenecking

Loss of diversity with each introduction



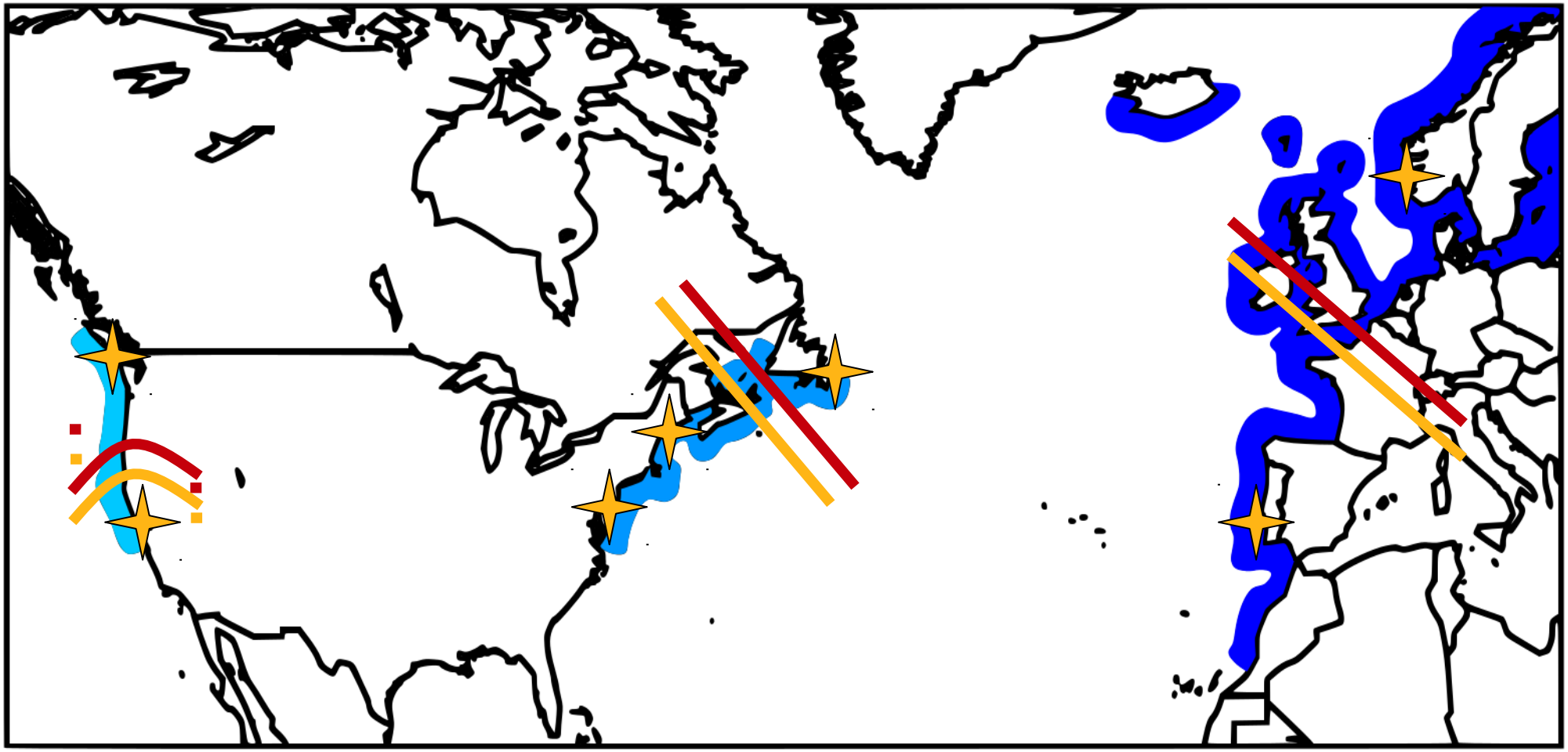
From Tepolt & Palumbi, in press at *Molecular Ecology*

Genetic differentiation between sites



Range data from Carlton & Cohen 2003; Best *et al.* 2009

Genetic differentiation between sites corresponding to differences in heat tolerance



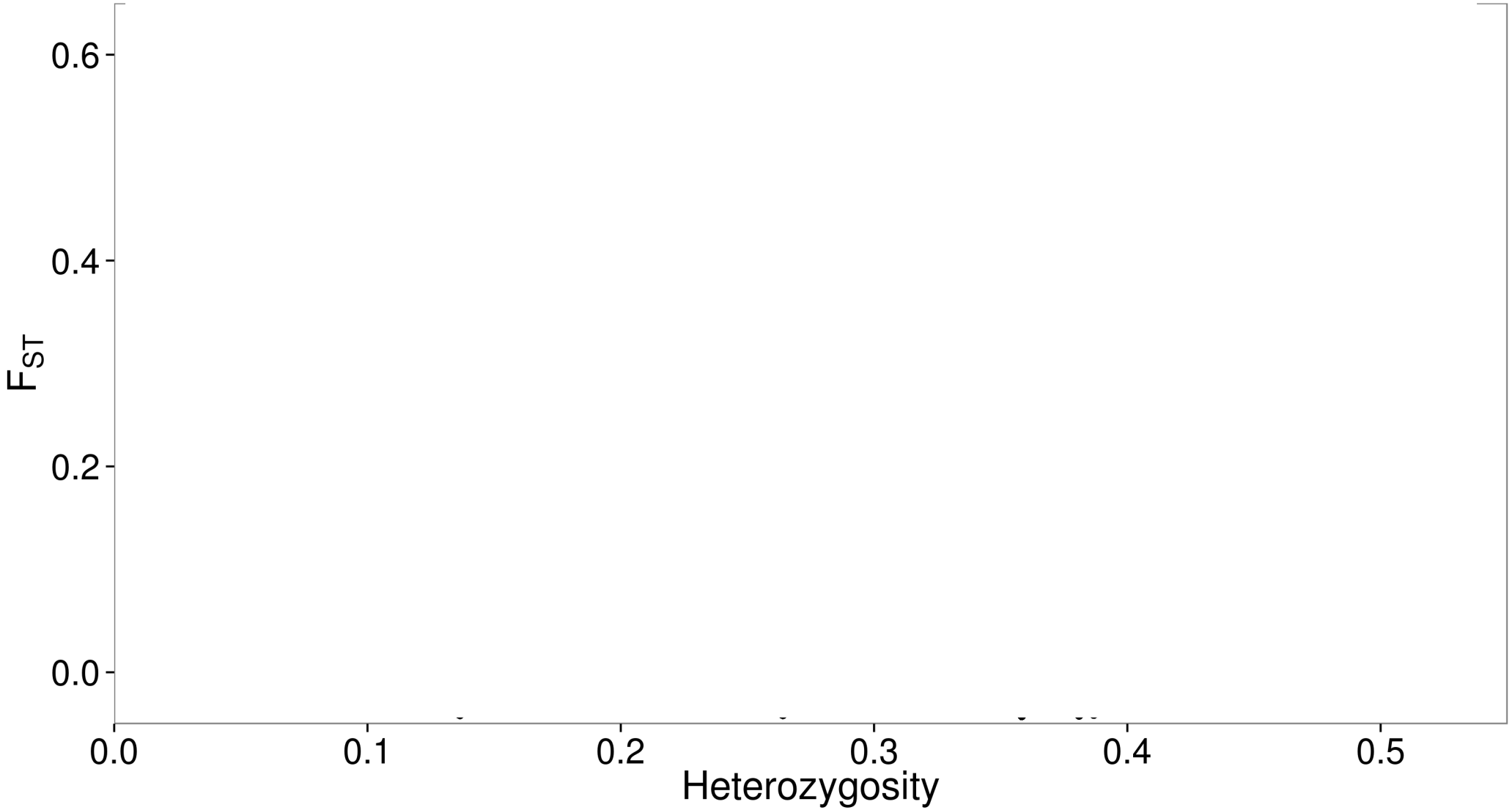
Range data from Carlton & Cohen 2003; Best *et al.* 2009

Field sites that differ in heat tolerance are also genetically different, supporting local adaptation.

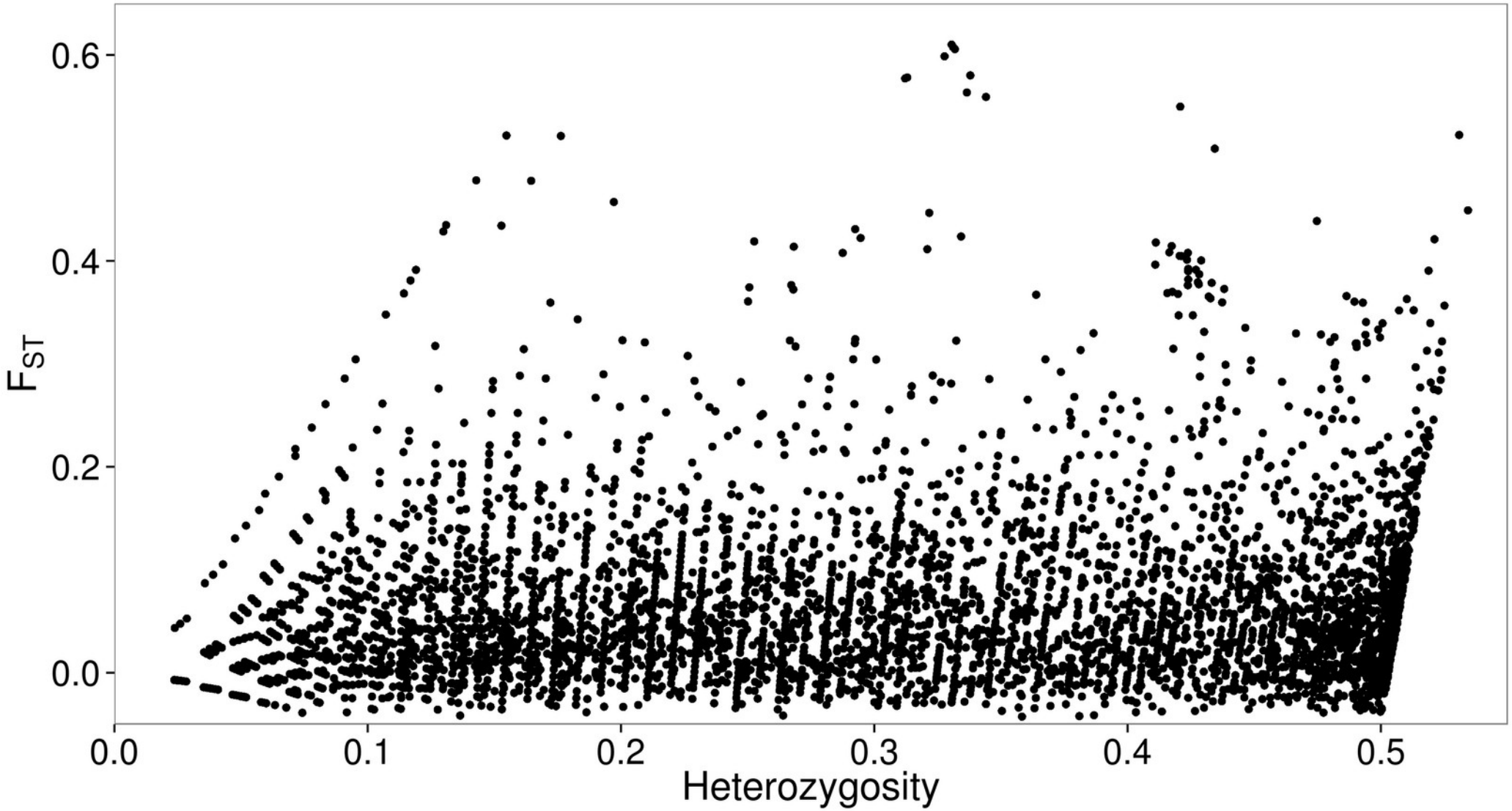
Field sites that differ in heat tolerance are also genetically different, supporting local adaptation.

Do differences between populations appear driven by selection?

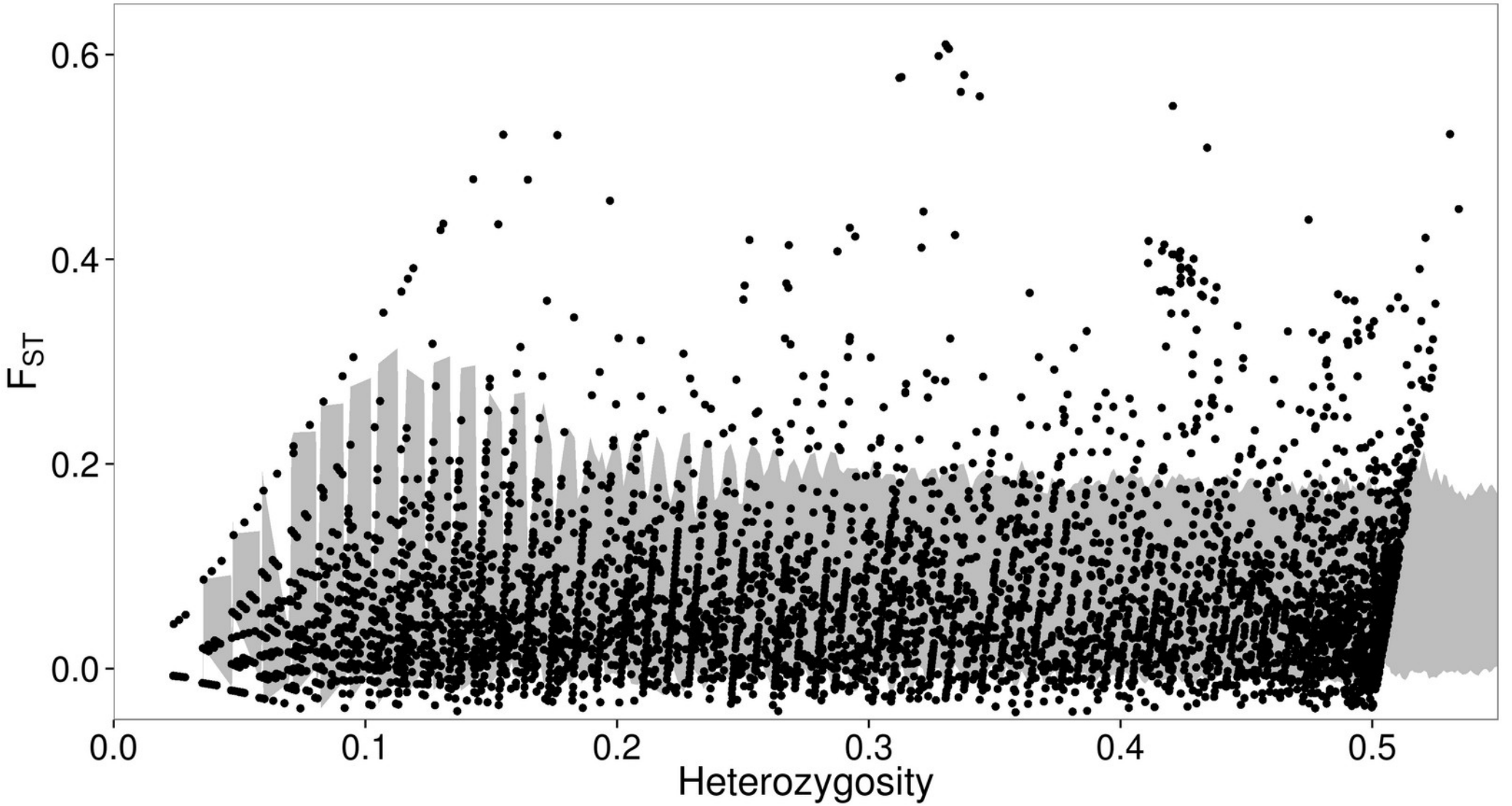
Outlier analysis to identify selected SNPs



Distribution of population differentiation at all 10,809 SNPs

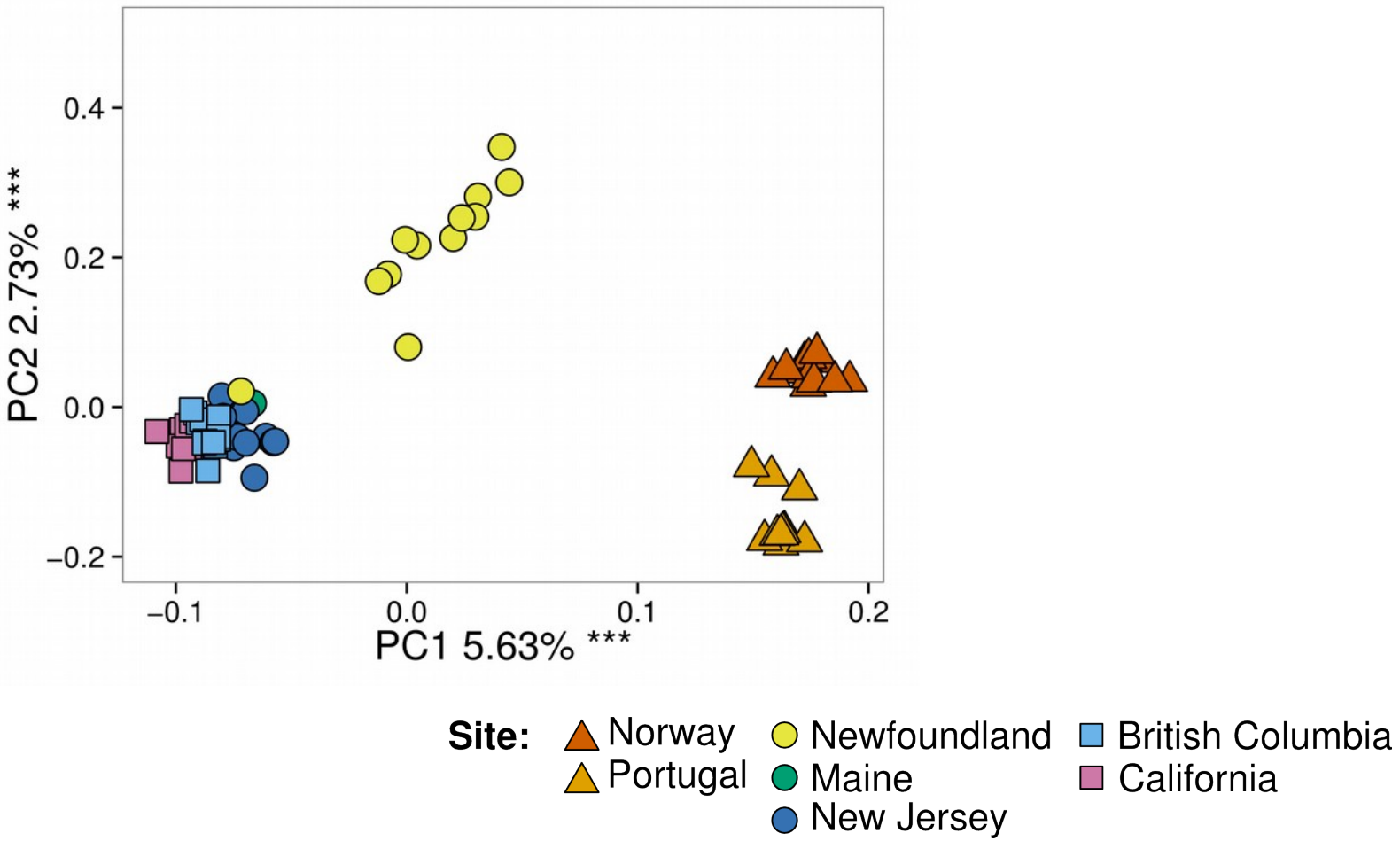


Identification of neutral SNPs



Genetic structure: all loci vs neutral loci

All loci



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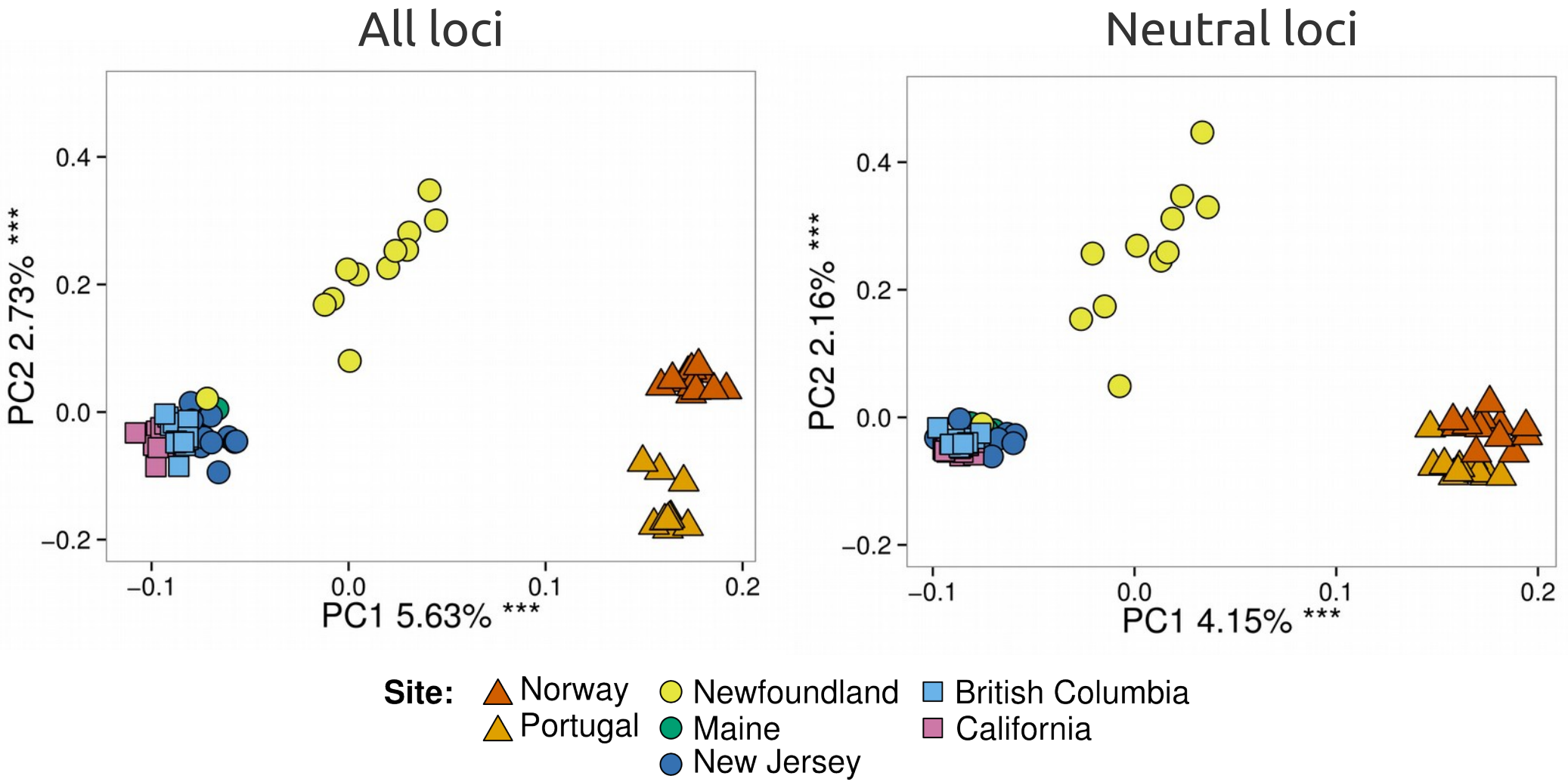
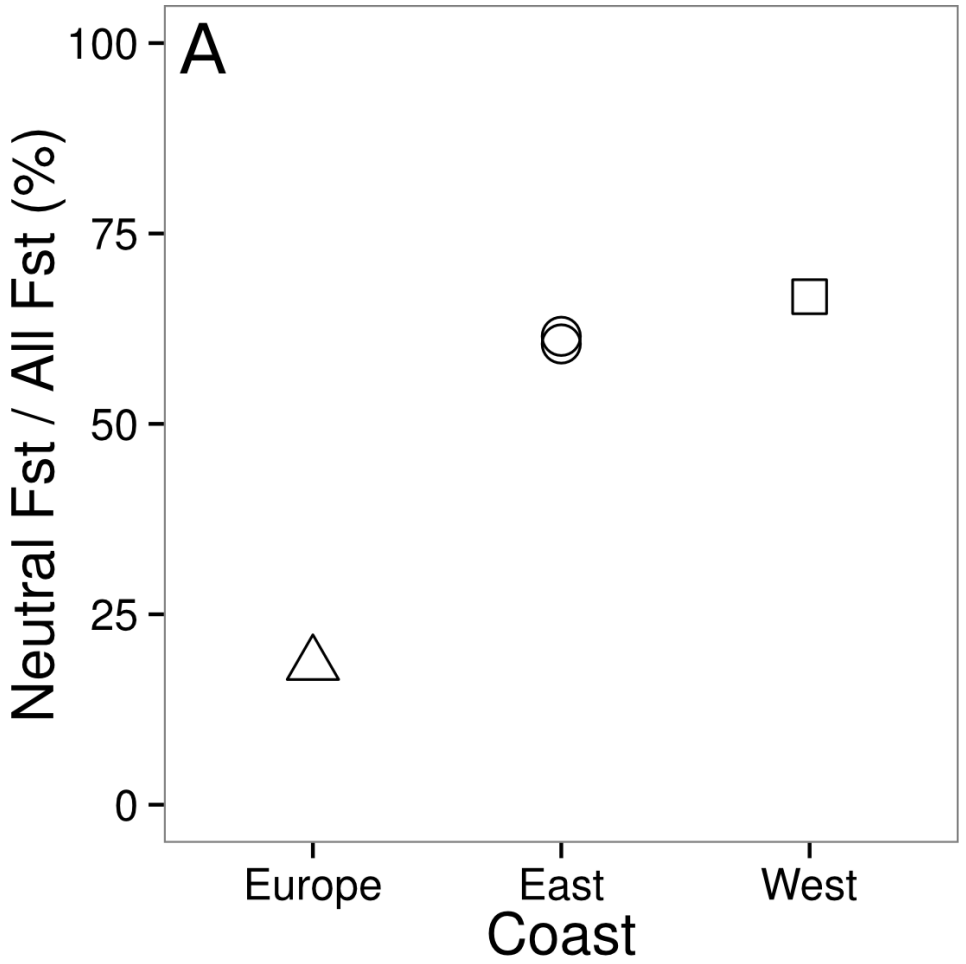
Genetic structure: all loci vs neutral loci



From Tepolt & Palumbi, in press at *Molecular Ecology*

Selection appears strongest in native range



From Tepolt & Palumbi, in press at *Molecular Ecology*

Differences between populations
are driven in part by selection,
which is strongest in the native range.

What can *C. maenas* tell us about adaptation in marine systems?

Are populations locally adapted?

Physiology and genetics both suggest local adaptation

What can *C. maenas* tell us about adaptation in marine systems?

Are populations locally adapted?

Physiology and genetics both suggest local adaptation

How quickly can genetic adaptation arise?

As little as 25 years, but much stronger in native range.

What role does genetic adaptation play in the success of marine invasive species?

Pre-adaptation in native range

What role does genetic adaptation play in the success of marine invasive species?

Pre-adaptation in native range

Capacity for rapid adaptation in invasive range

What role does genetic adaptation play in the success of marine invasive species?

Pre-adaptation in native range

Capacity for rapid adaptation in invasive range

Adaptation is important,
even in high-dispersal marine systems.

Acknowledgements

Committee: Steve Palumbi George Somero Liz Hadly Hunter Fraser

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Norway: Espeland Marinbiologisk Stasjon, Henrik Glenner, Agnes Aadneson

Portugal: Laboratório Marítimo da Guia, João Canning-Clode, Rui Rosa

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New Jersey: Rutgers Marine Field Station, Roland Hagan, Paul Jivoff

Maryland: Smithsonian Environmental Research Center, Greg Ruiz, April Blakeslee, Amy Fowler

British Columbia: Bamfield Marine Sciences Centre, Toquaht Marina & Campground, Dave Riddell

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SGF

Department of Defense

Stanford CEHG

PISCO

American Museum of Natural History

The Explorers Club

NSF

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Mille grazie!

The Gherardi family

Felicita Scapini & the selection committee