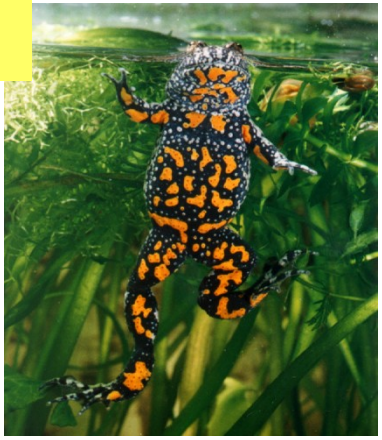
MODULARIZACE VÝUKY EVOLUČNÍ A EKOLOGICKÉ BIOLOGIE
CZ.1.07/2.2.00/15.0204

HYBRIDIZATION AND HYBRID ZONES



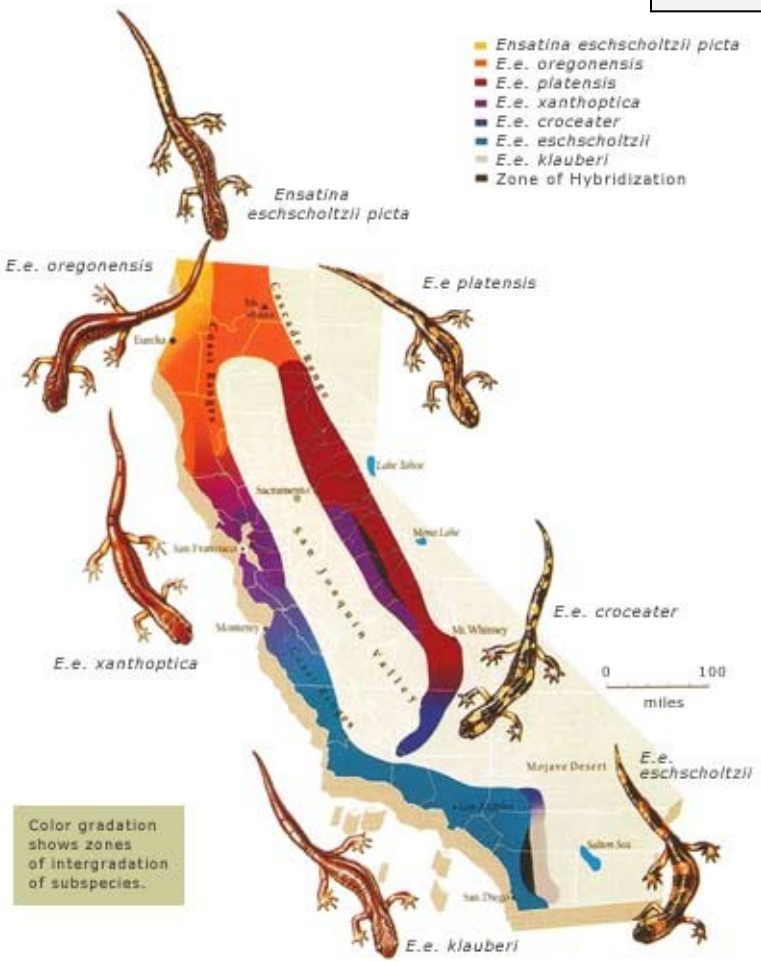





evropský sociální fond v ČR
EVROPSKÁ UNIE
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY
OP Vzdělávání pro konkurenceschopnost
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

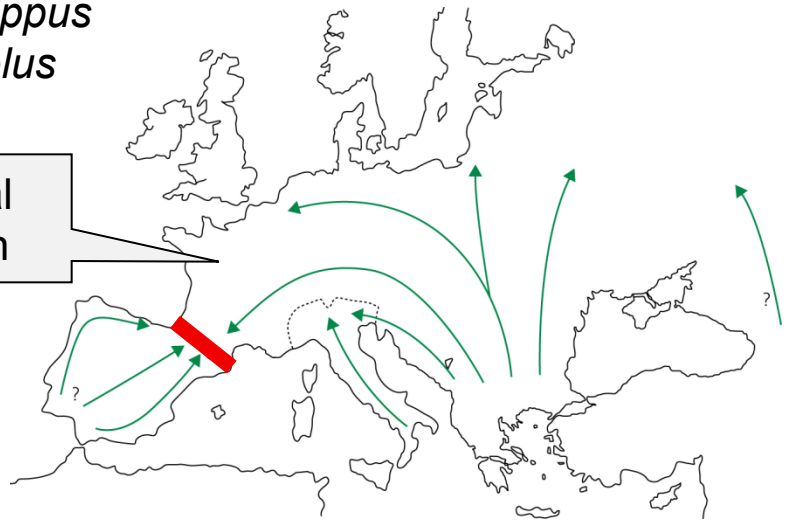
Secondary contact

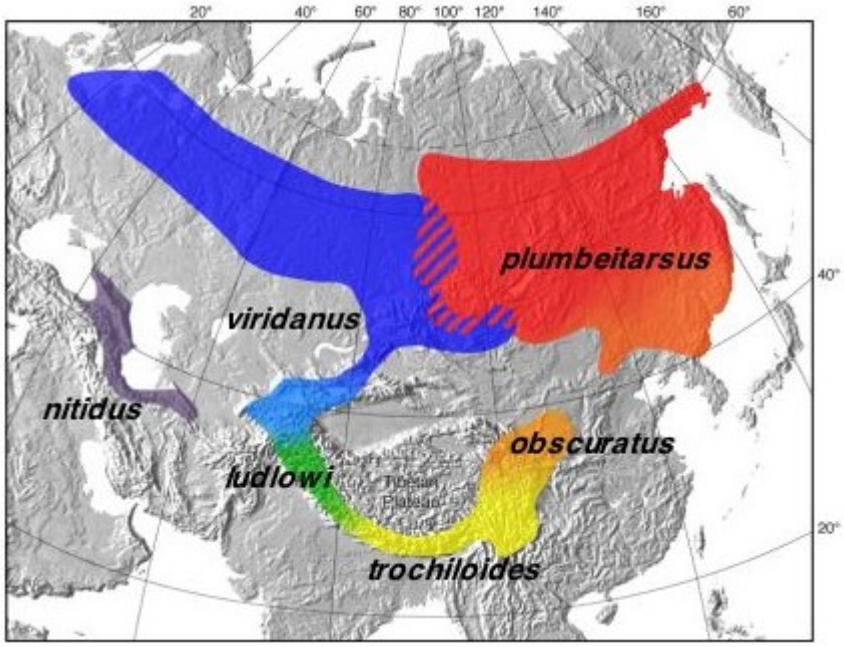
ring species:



Ensatina eschscholtzii - klauberi

Chorthippus parallelus





greenish warbler (*Philloscopus trochiloides*)

Hybridization:

25% species of vascular plants

10% species of animals

probably underestimation (only conspicuous species: ducks, birds of paradise, butterflies)

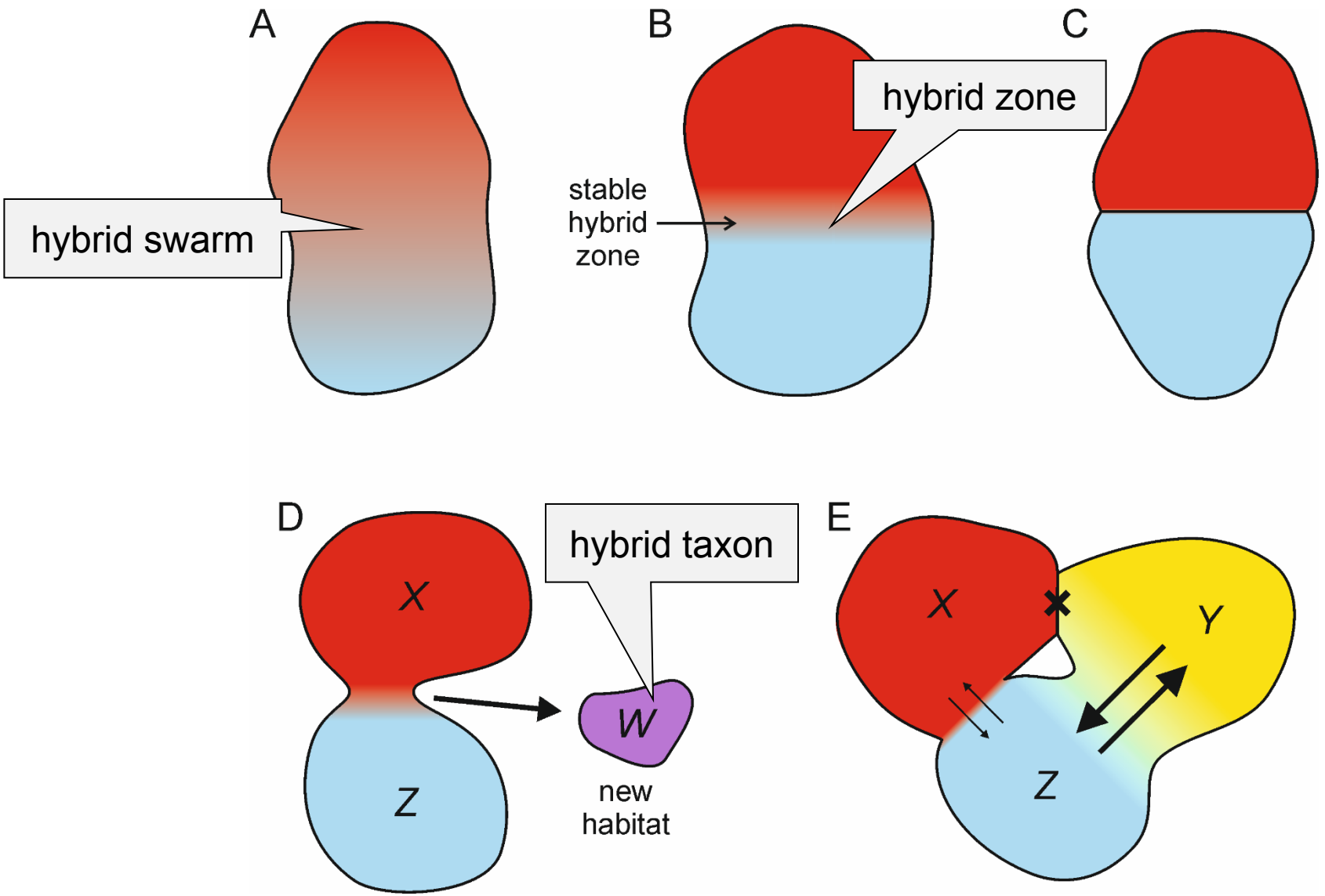
often result of environmental disturbance:
eg. „Darwin's finches" *Geospiza fuliginosa*, *G. fortis* and *G. scandens* after El Niño event

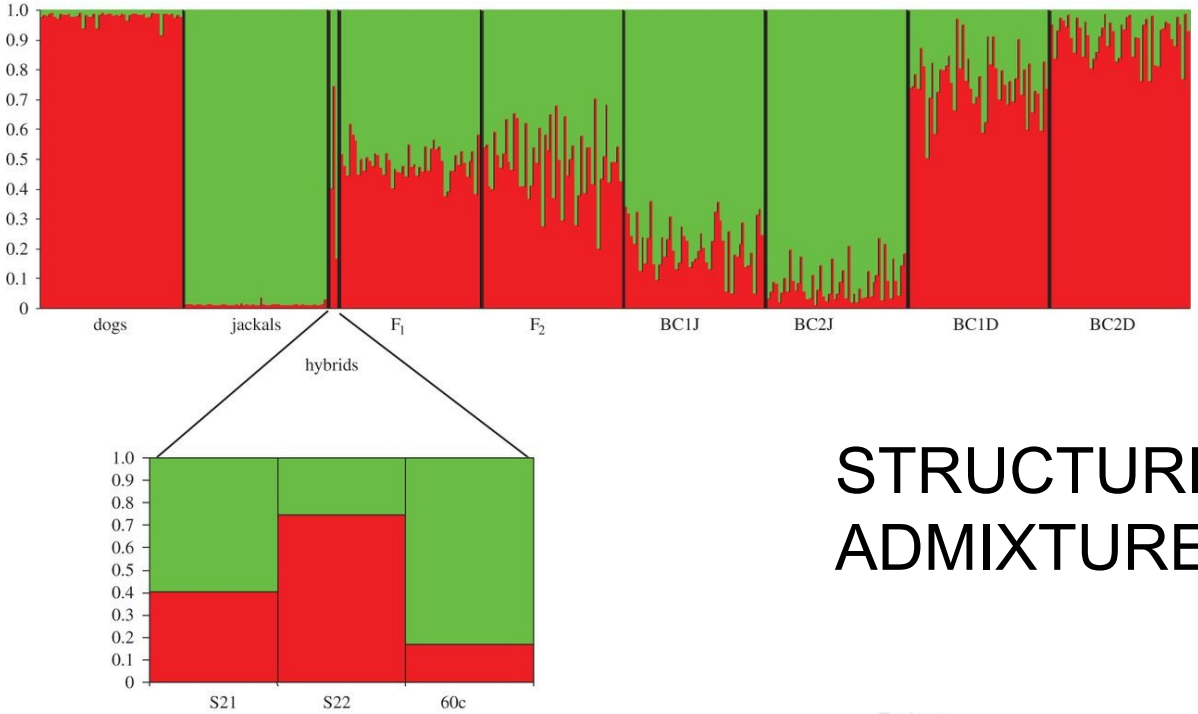
Geospiza fuliginosa


G. fortis

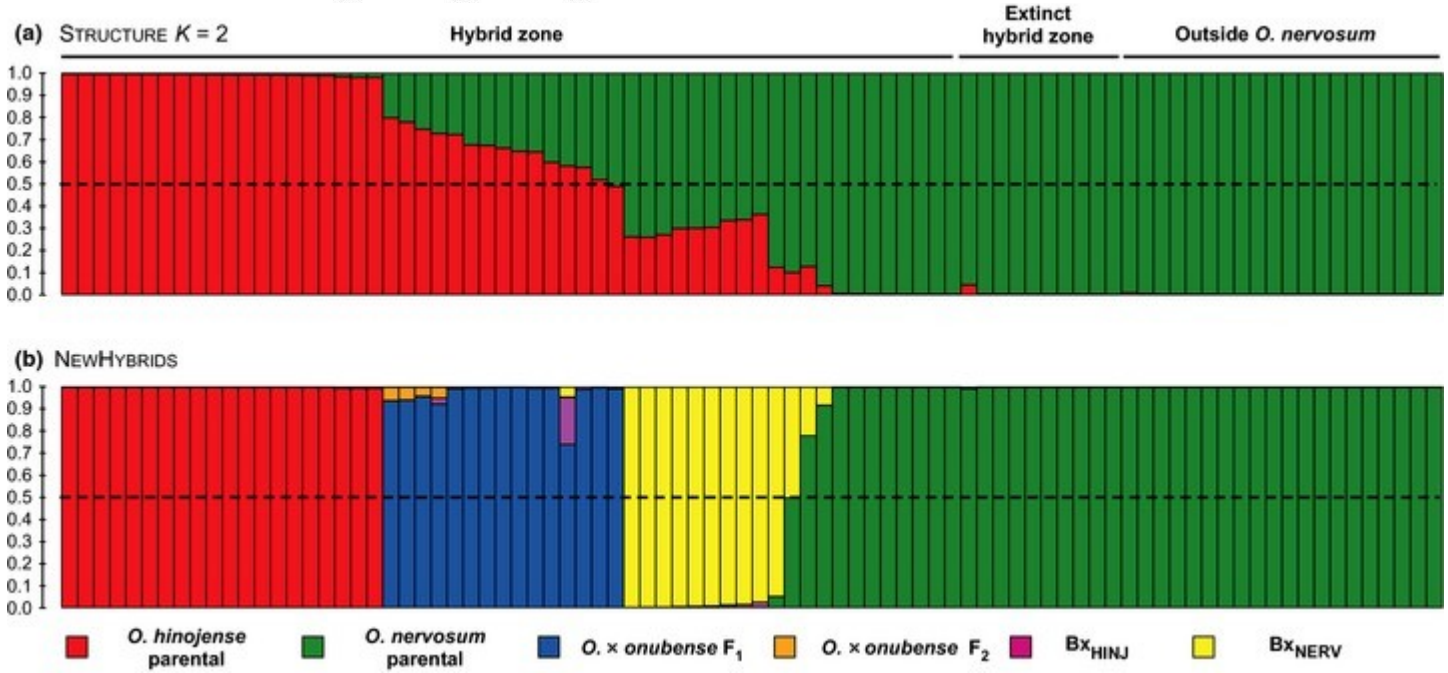

G. scandens

Possible outcomes of hybridization

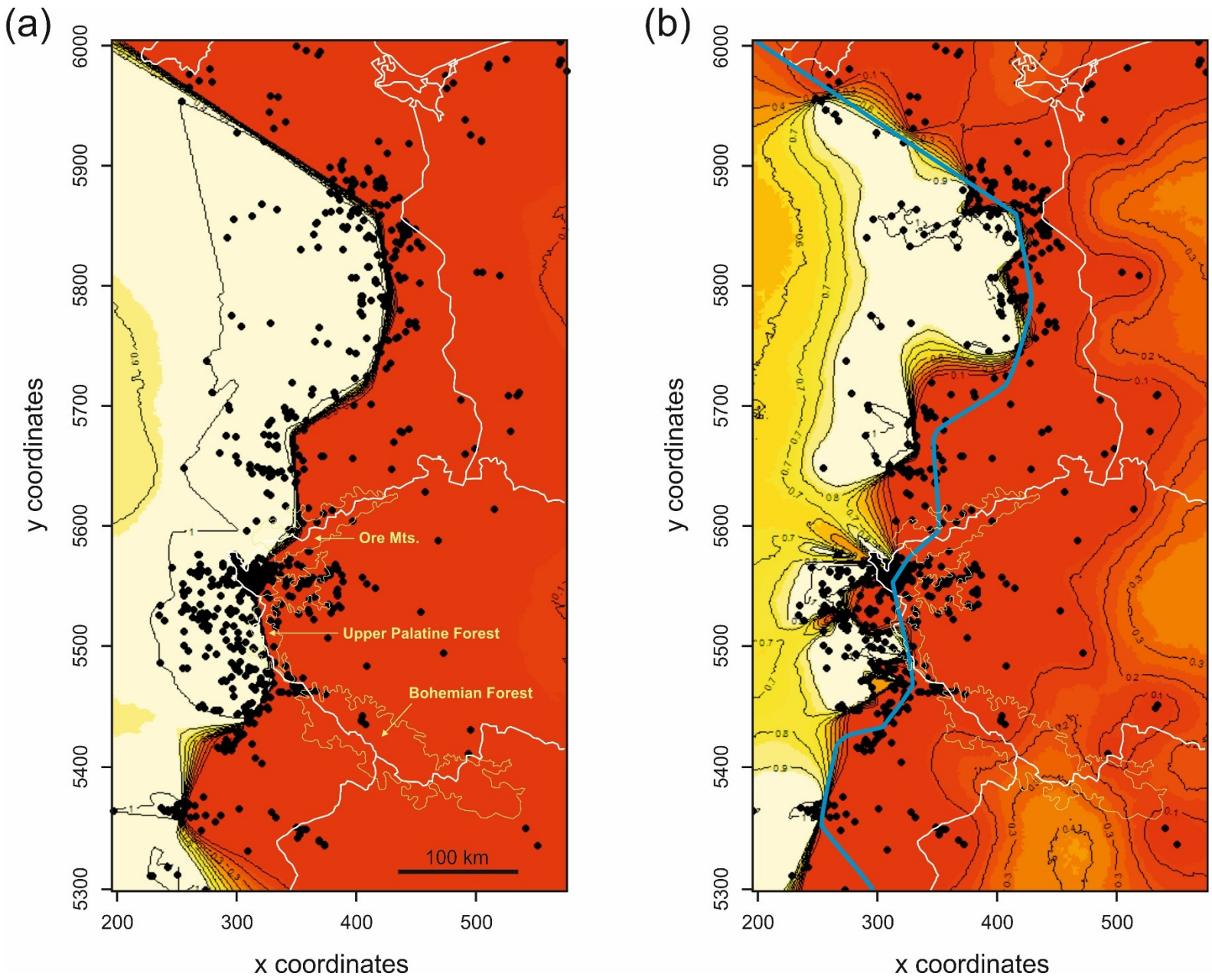




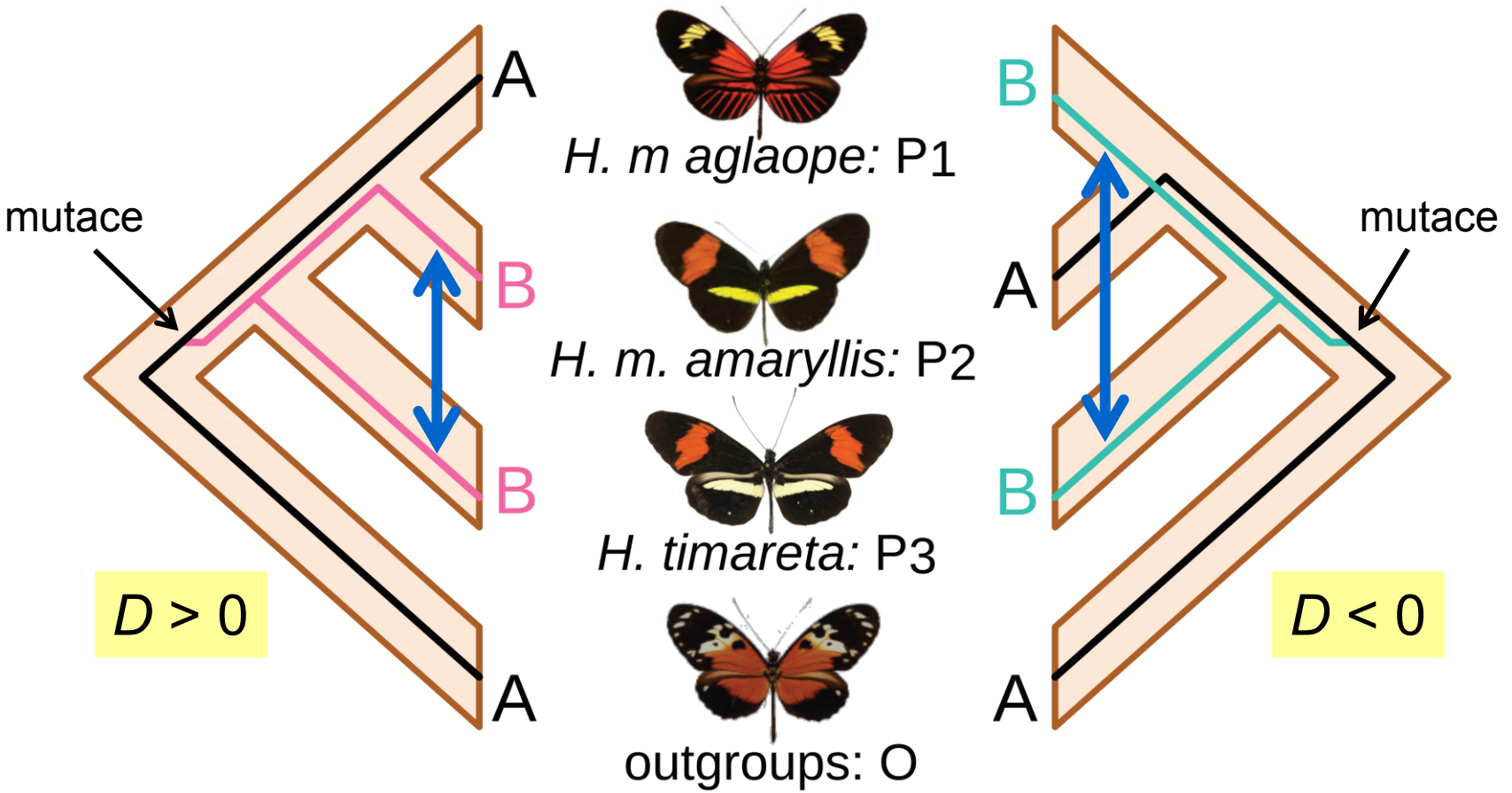
STRUCTURE
ADMIXTURE



Geneland


(a)
(b)
y coordinates
x coordinates
6000
5900
5800
5700
5600
5500
5400
5300
200
300
400
500
Ore Mts.
Upper Palatine Forest
Bohemian Forest
100 km

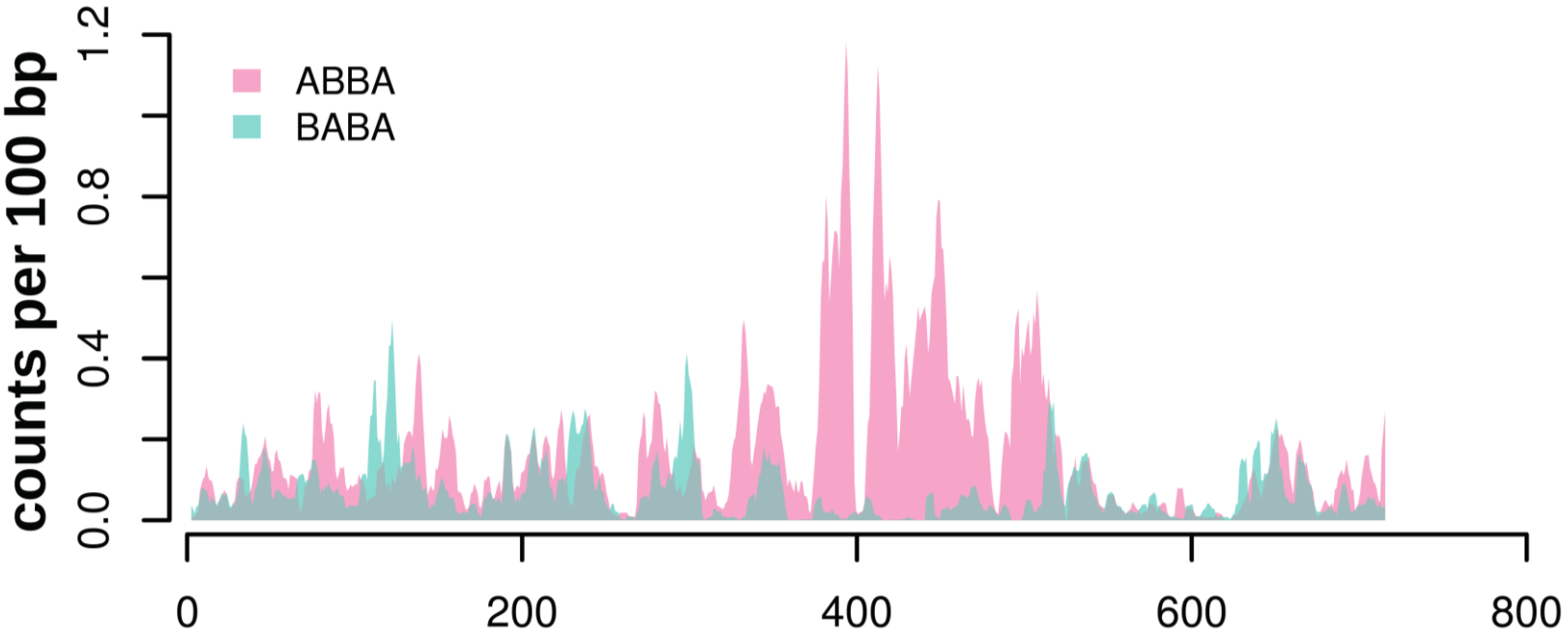
Nick Patterson: *D*-statistika (ABBA/BABA test):



Martin et al., bioRxiv

$$D\left(P_1,P_2,P_3,O\right)=\frac{\sum C_{ABBA}\left(i\right)-C_{BABA}\left(i\right)}{\sum C_{ABBA}\left(i\right)+C_{BABA}\left(i\right)}$$

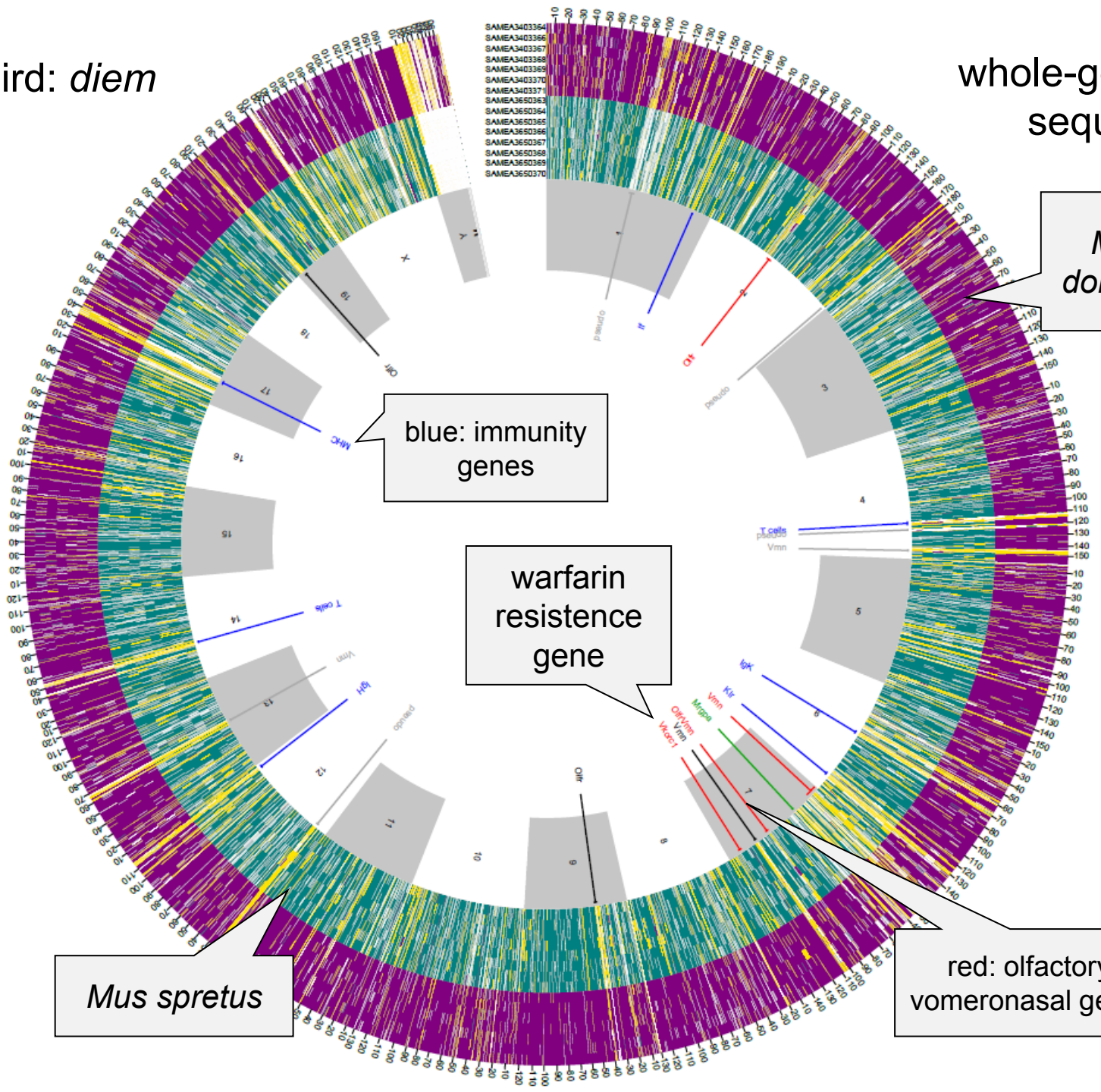
lokus *HmB*



Martin et al., bioRxiv

SJE Baird: *diem*

whole-genome sequences



Hybrid zone (Barton a Hewitt 1985)

= area, where genetically different populations meet, mate and give rise at least some hybrid offspring

Hybrid zones may be classified as:

primary

secondary

tension, mosaic, staggered, „mottled“ ...

extrinsic selection (external environment)

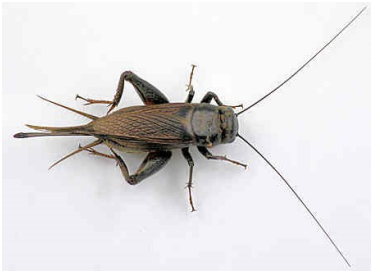
intrinsic selection (prezygotic or postzygotic barriers)

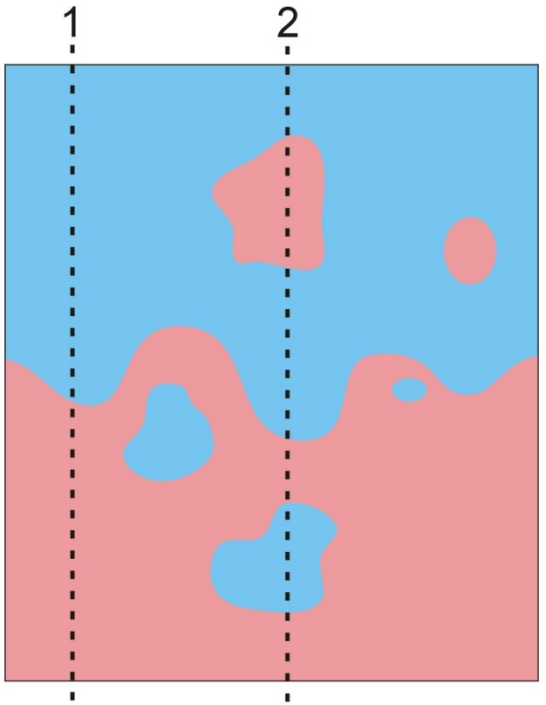
Mosaic hybrid zone:

influence of environment

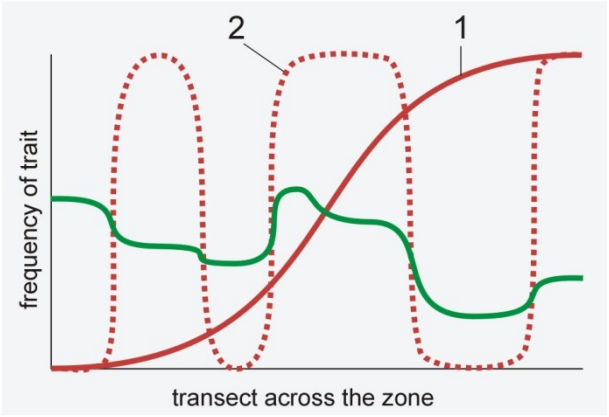
in fact a set of several hybrid zones

eg.: *Gryllus firmus* x *G. pennsylvanicus* (NE USA)
sandy x clayish soils

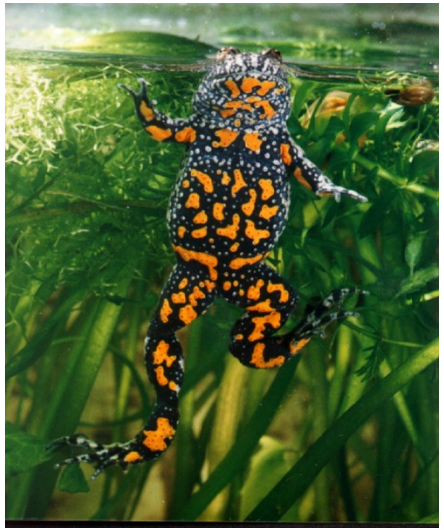




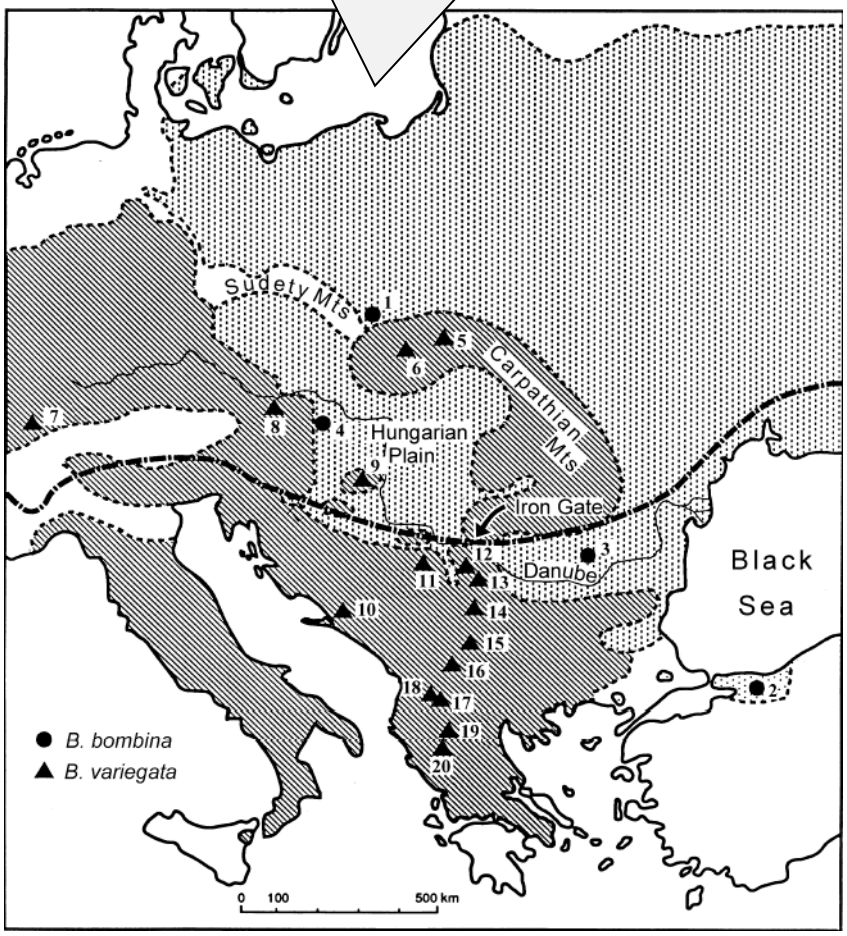
Iris fulva x *I. brevicaulis*:
I. fulva is limited to more forested sites



Bombina:



mosaic HZ in Croatia,
not in Poland



fire-bellied toad *B. bombina*:

lowlands
mostly in water
larger water surfaces
thiner skin
territorial
530 Hz
longer development

yellow-bellied toad *B. variegata*:

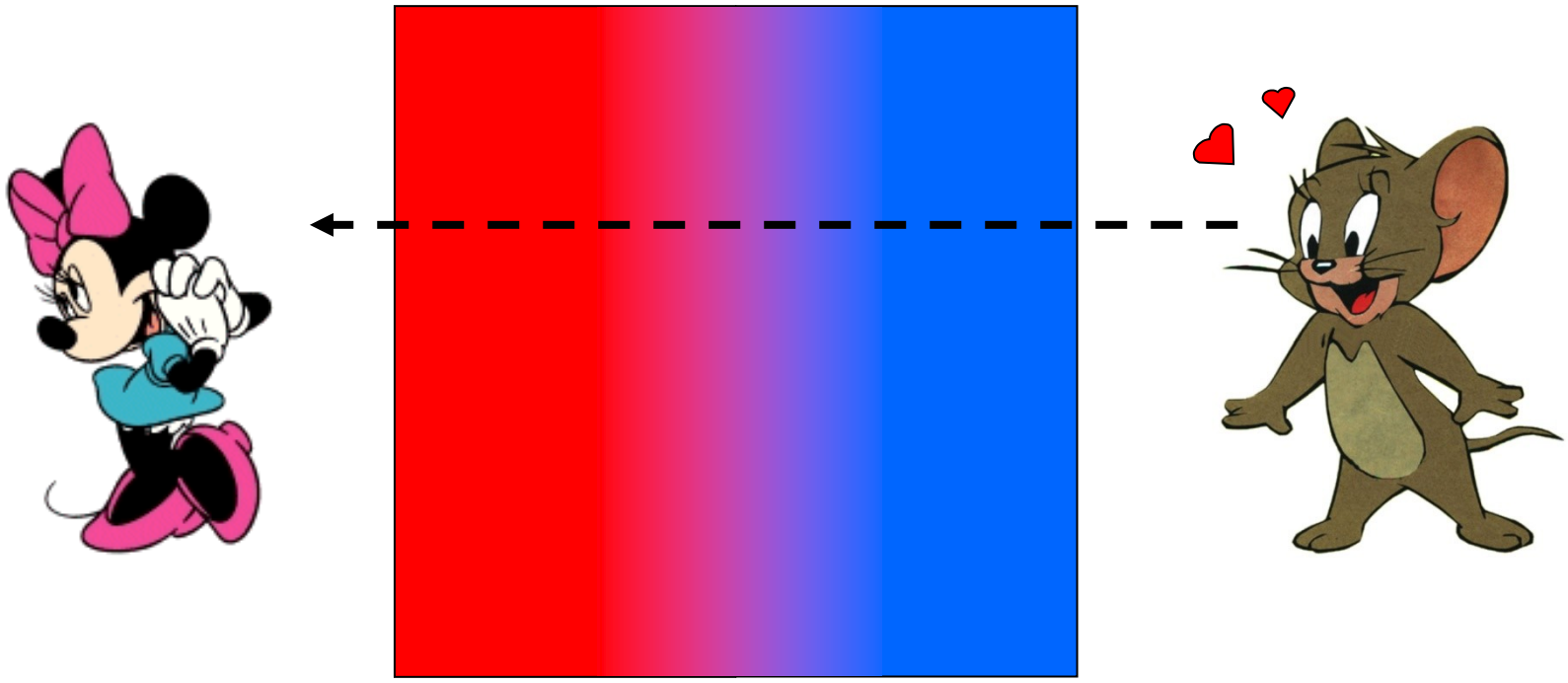
hills, highlands
terrestrial
mating in puddles
thick skin
nonterritorial
580 Hz
shorter development

Nick Barton

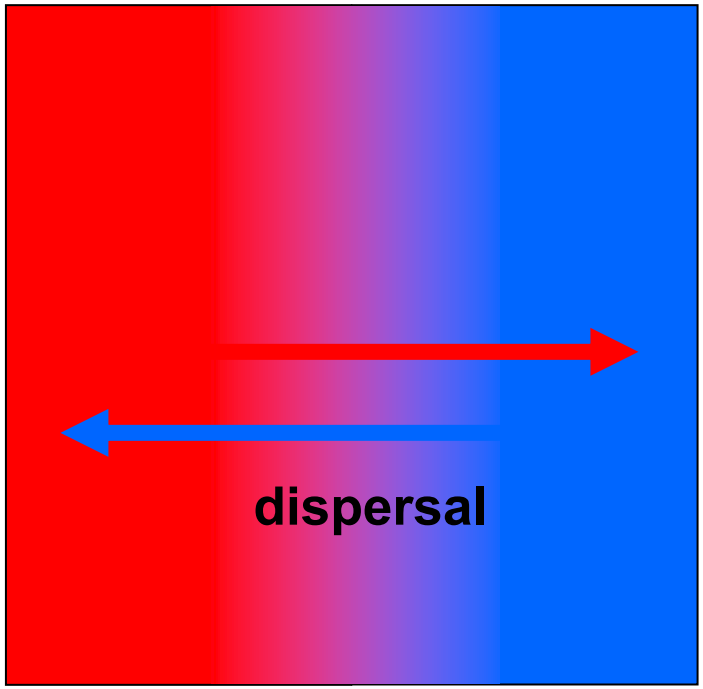
Most hybrid zones are tension zones.

... i.e., they are maintained by balance between dispersal and selection (Barton & Hewitt, 1985)

Tension zone is when…

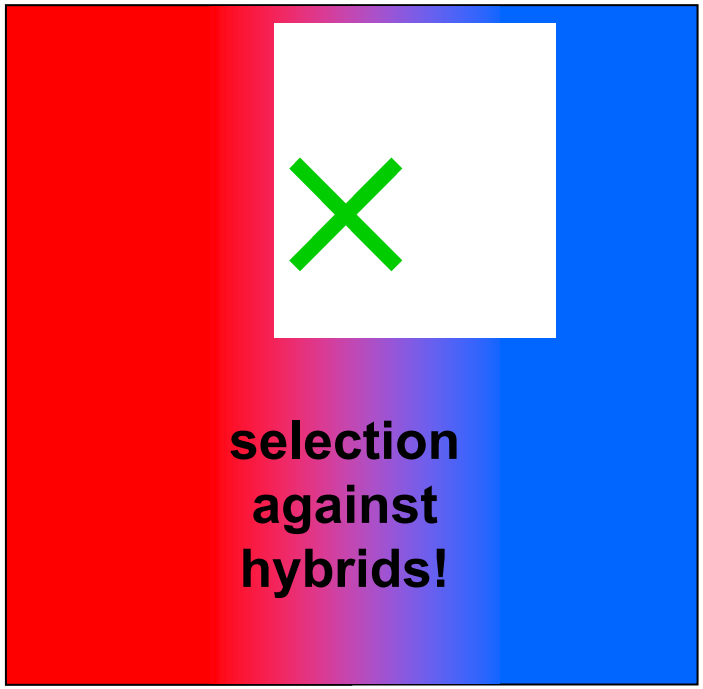


Tension zone is when…



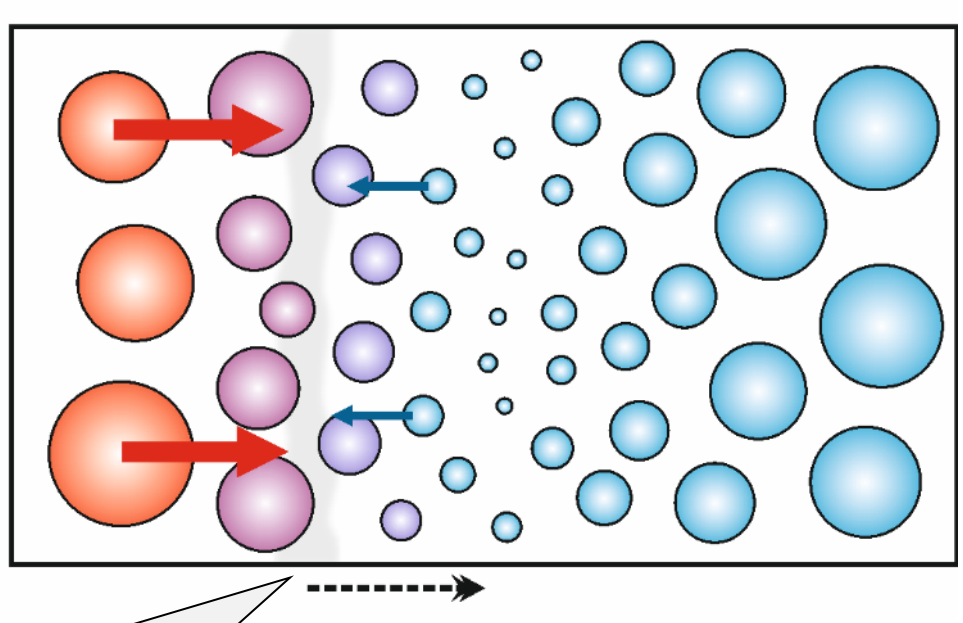
⇒ zone widening

Tension zone is when…



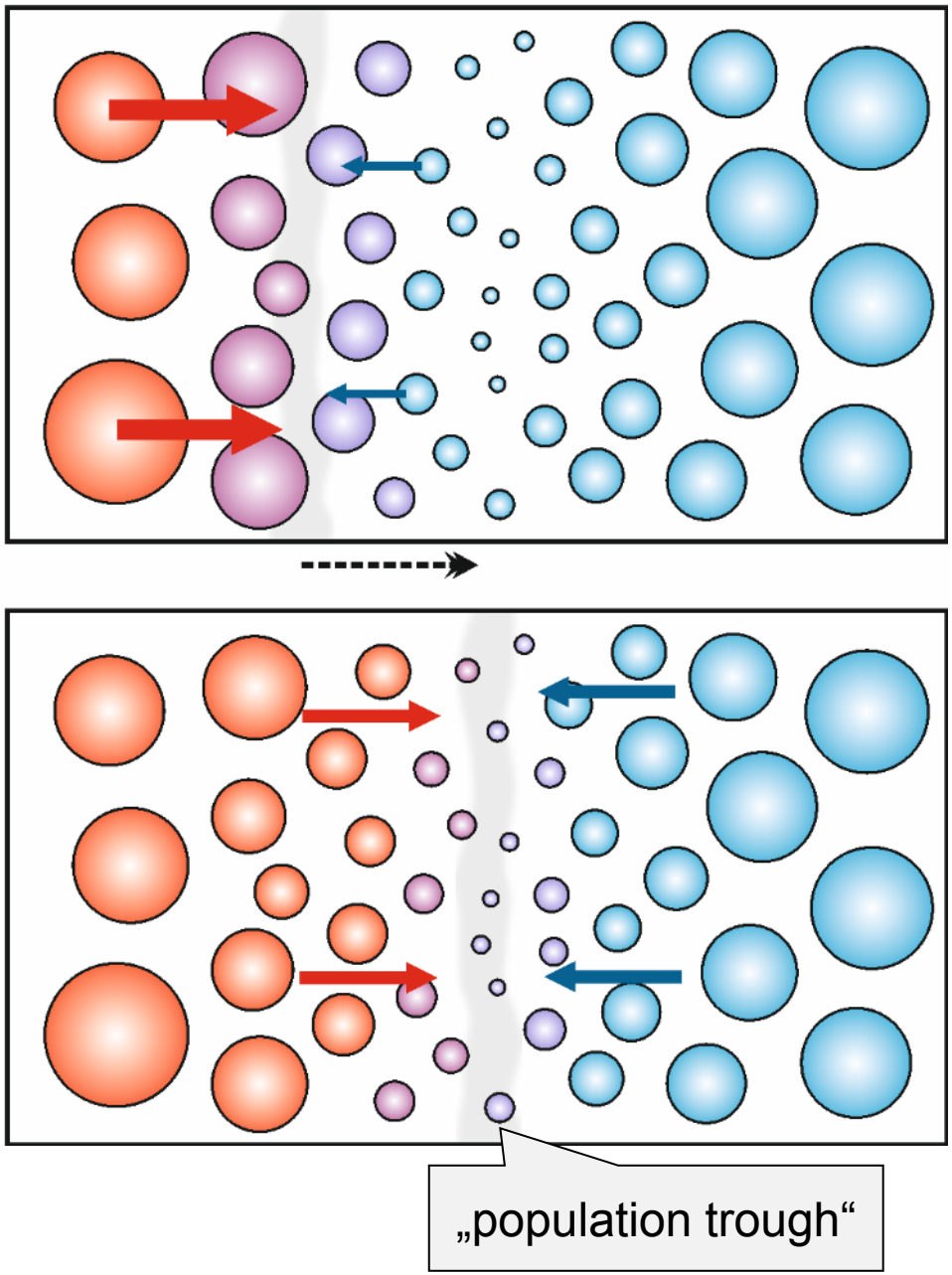
⇒ zone narrowing

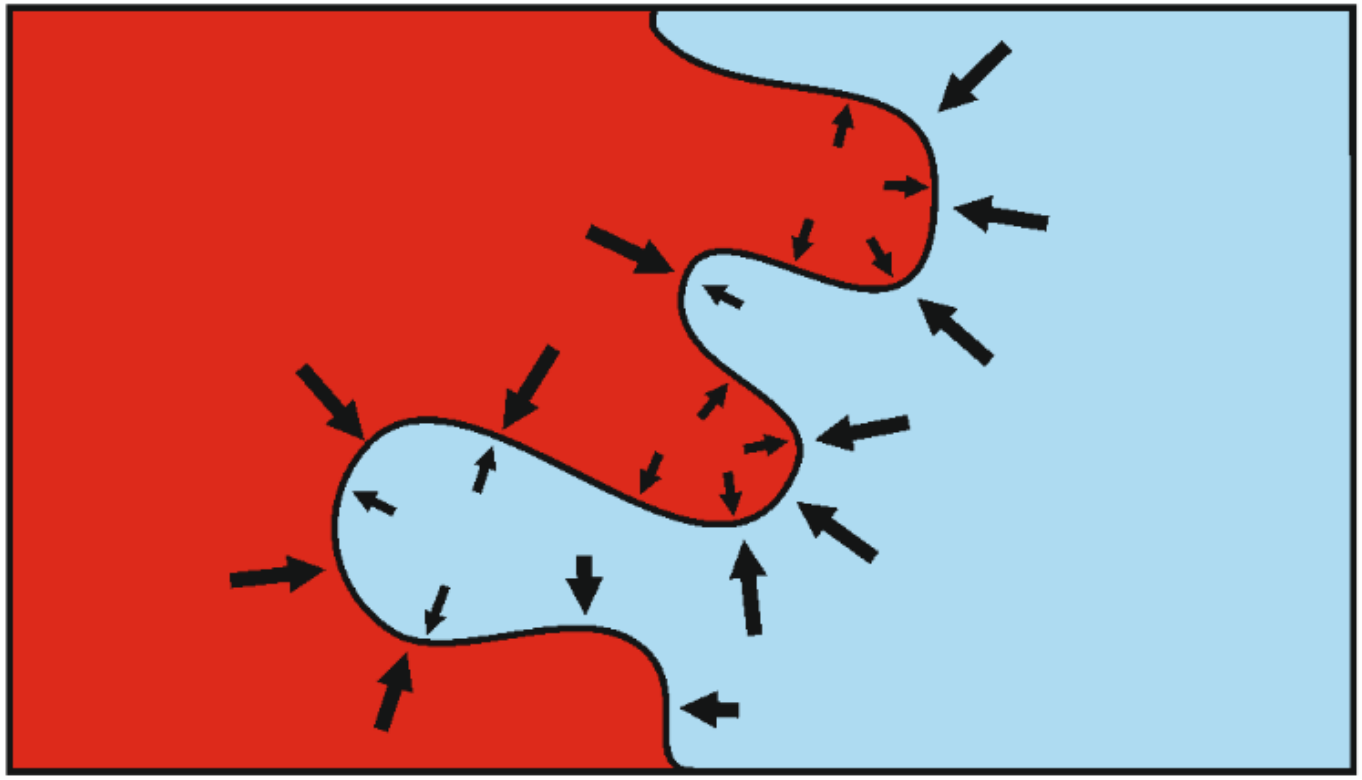
Tension zone is maintained by dynamic equilibrium between *dispersal* and *selection*



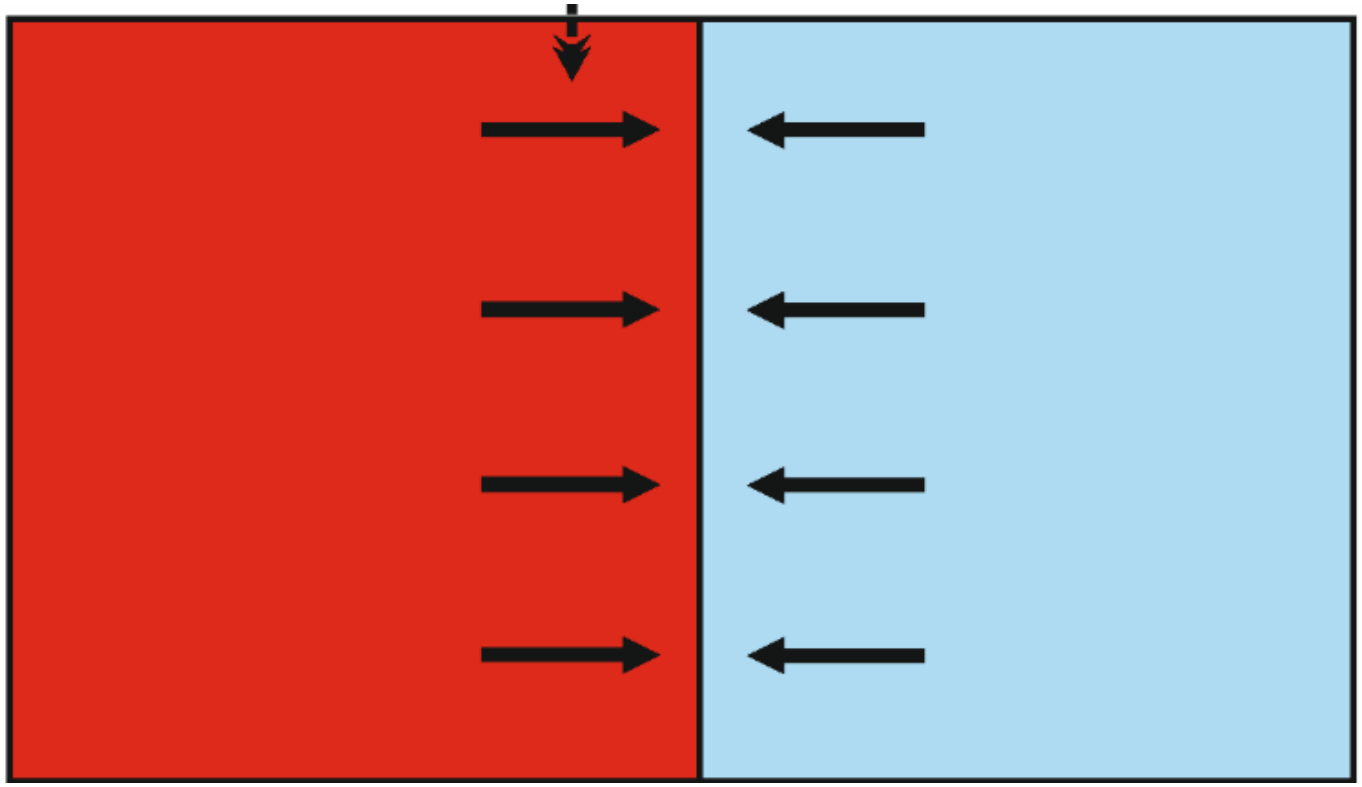
tension zone moves along the gradient of population density

Tension zone is independent of external conditions (*intrinsic selection*)
⇒ its movement ends at a geographical barrier or in the area of the lowest population density („*population/density trough*“)


„population trough“



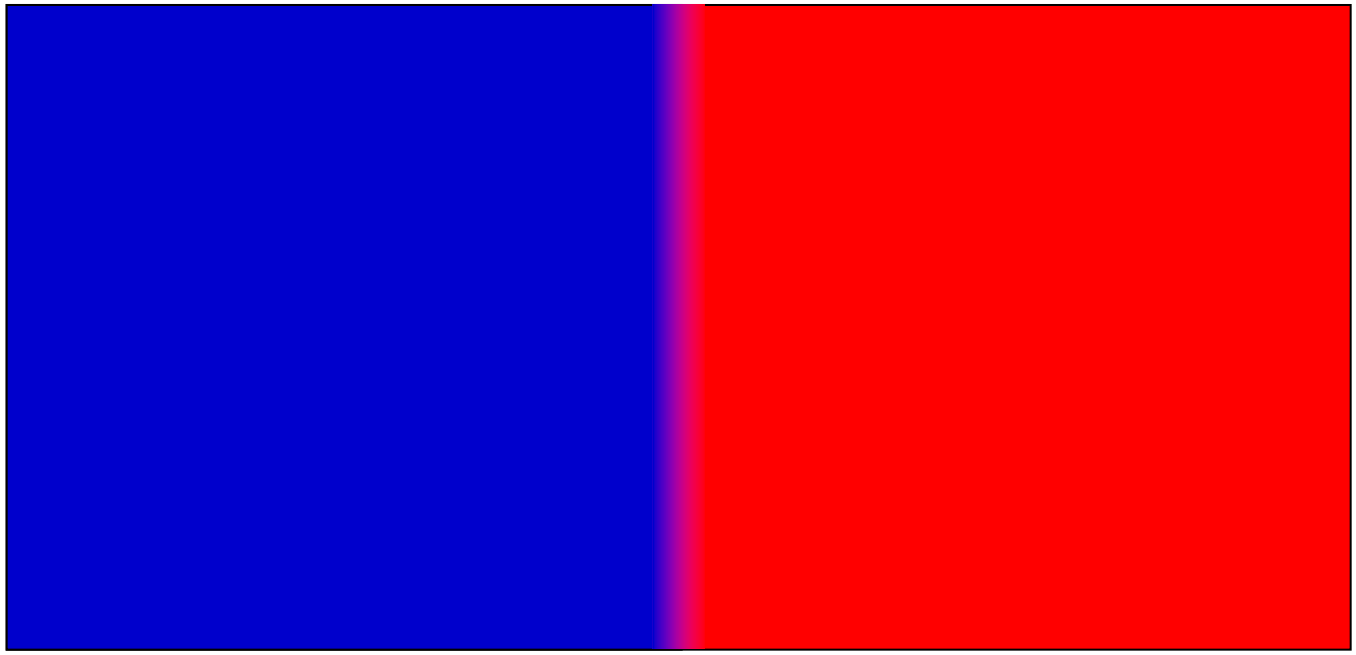
Tension zone moves along a population gradient ...



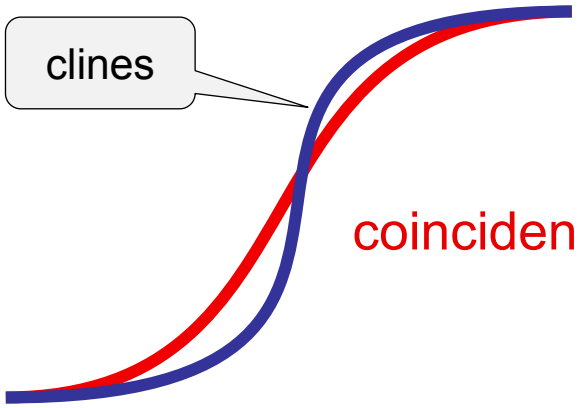
... ⇒ it tends to shorten its length.

Theory of cline:

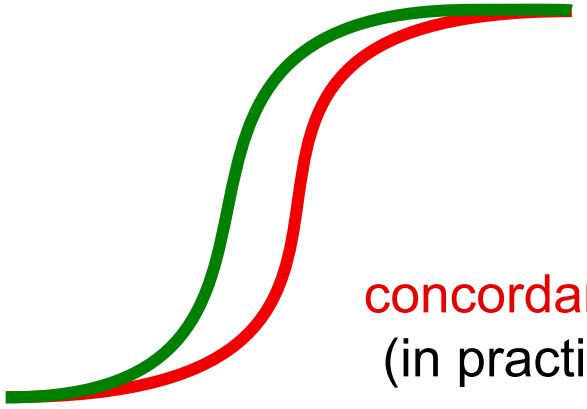
secondary contact: ⇨ coincident and concordant clines



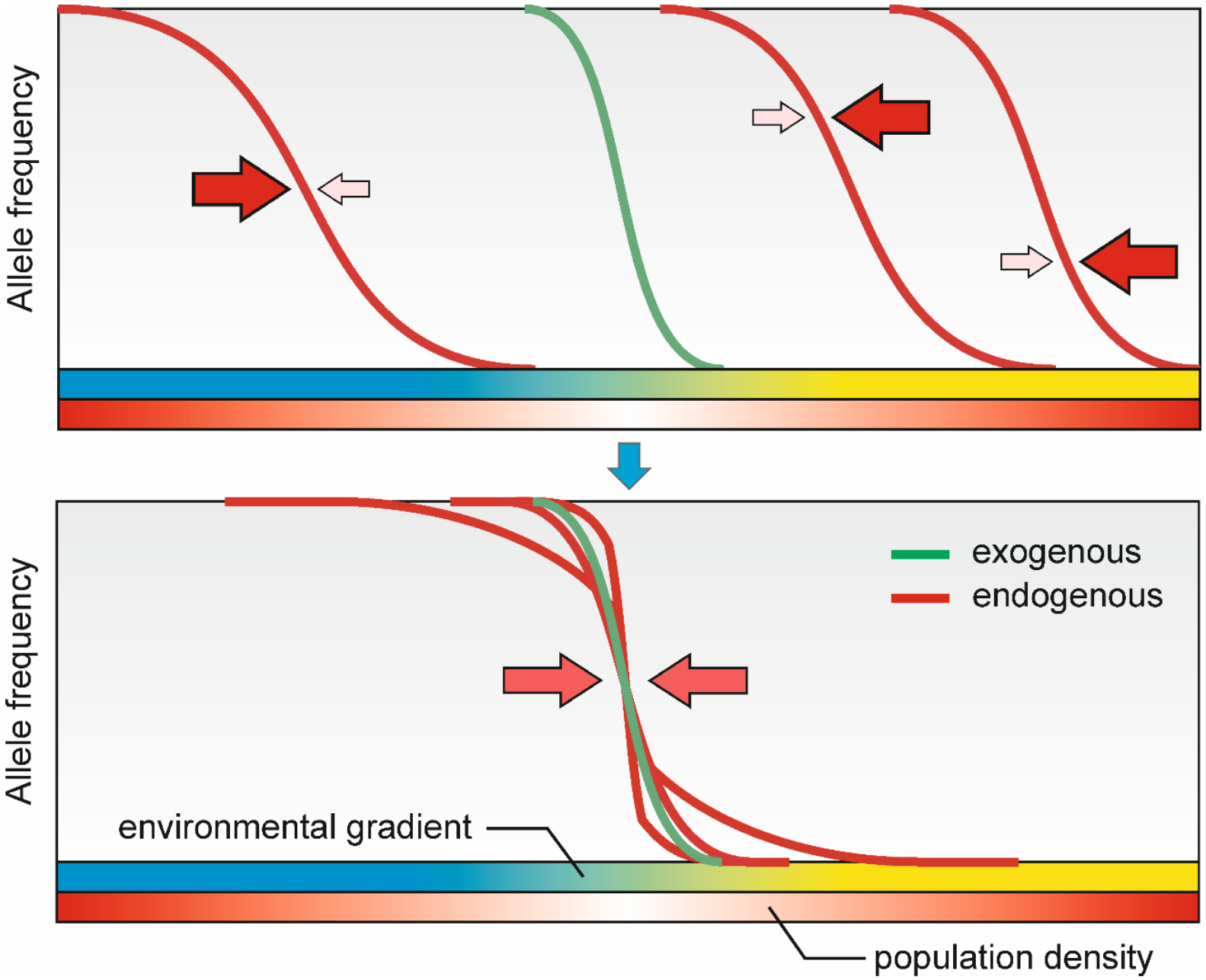
Cline = gradient of trait(s) (eg. allele frequency or mean of quantitative trait) across spatially continuous habitat



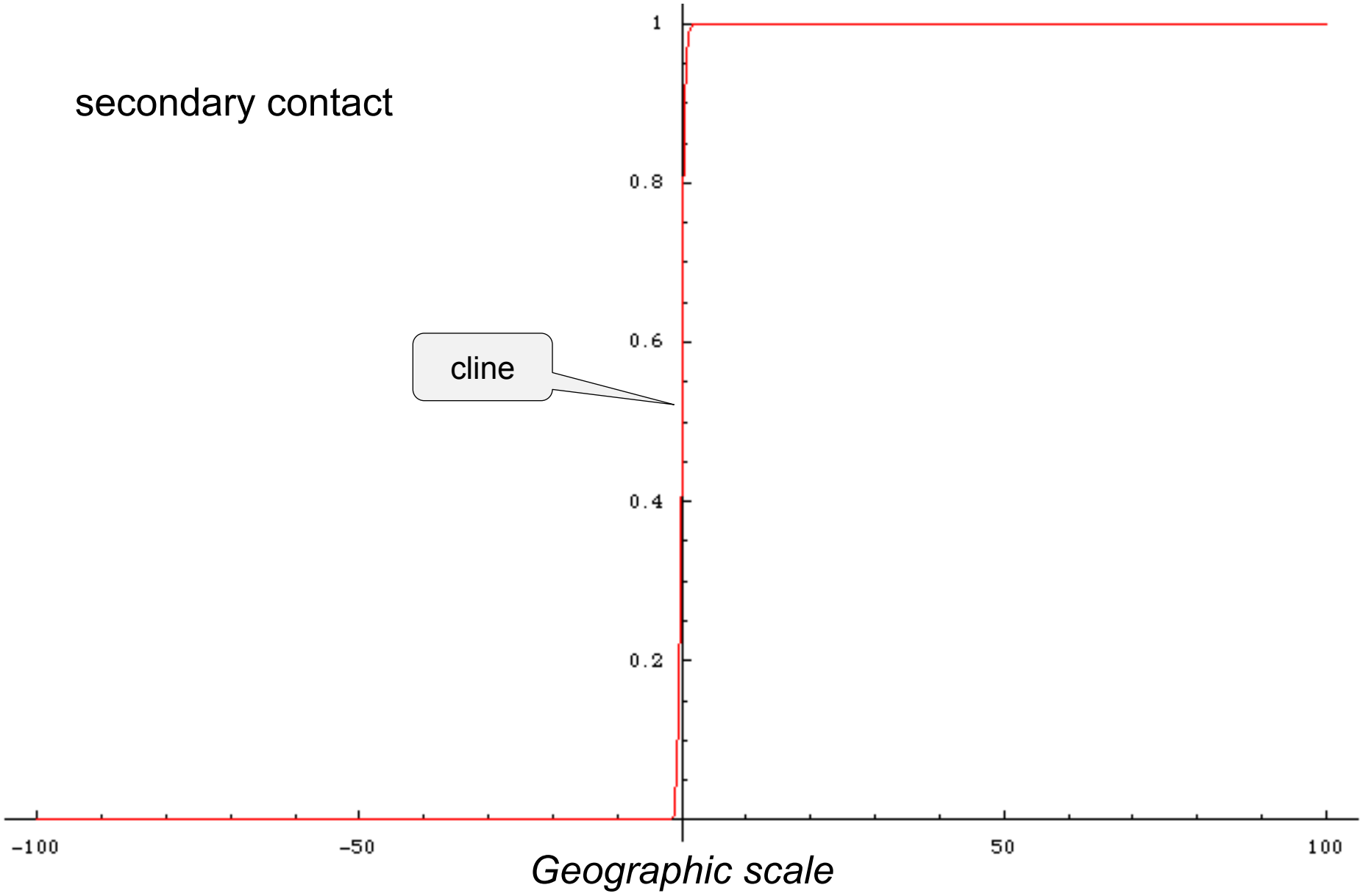
coincidence = same positions of zone centres



concordance = same cline shapes
(in practice usually same widths)


Allele frequency
Allele frequency
exogenous
endogenous
environmental gradient
population density

secondary contact

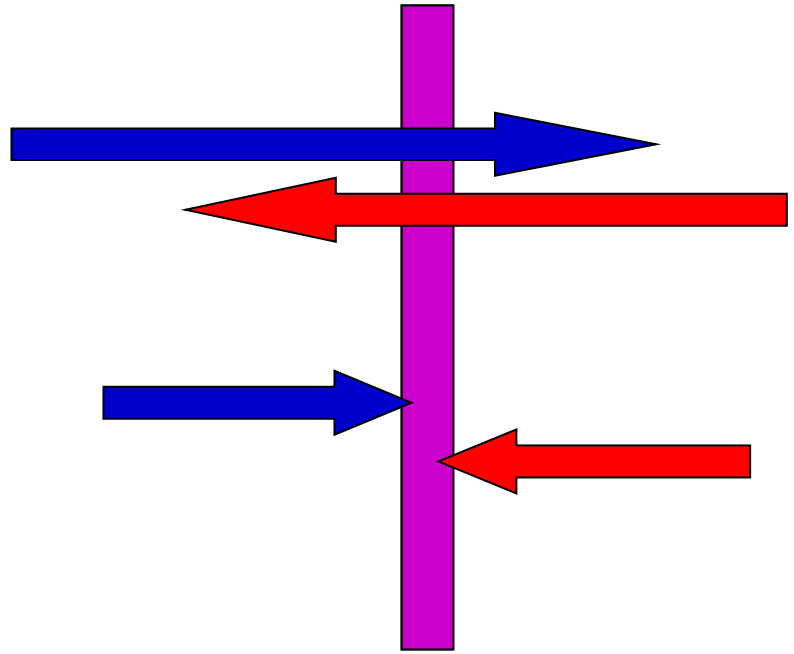


Theory of cline:

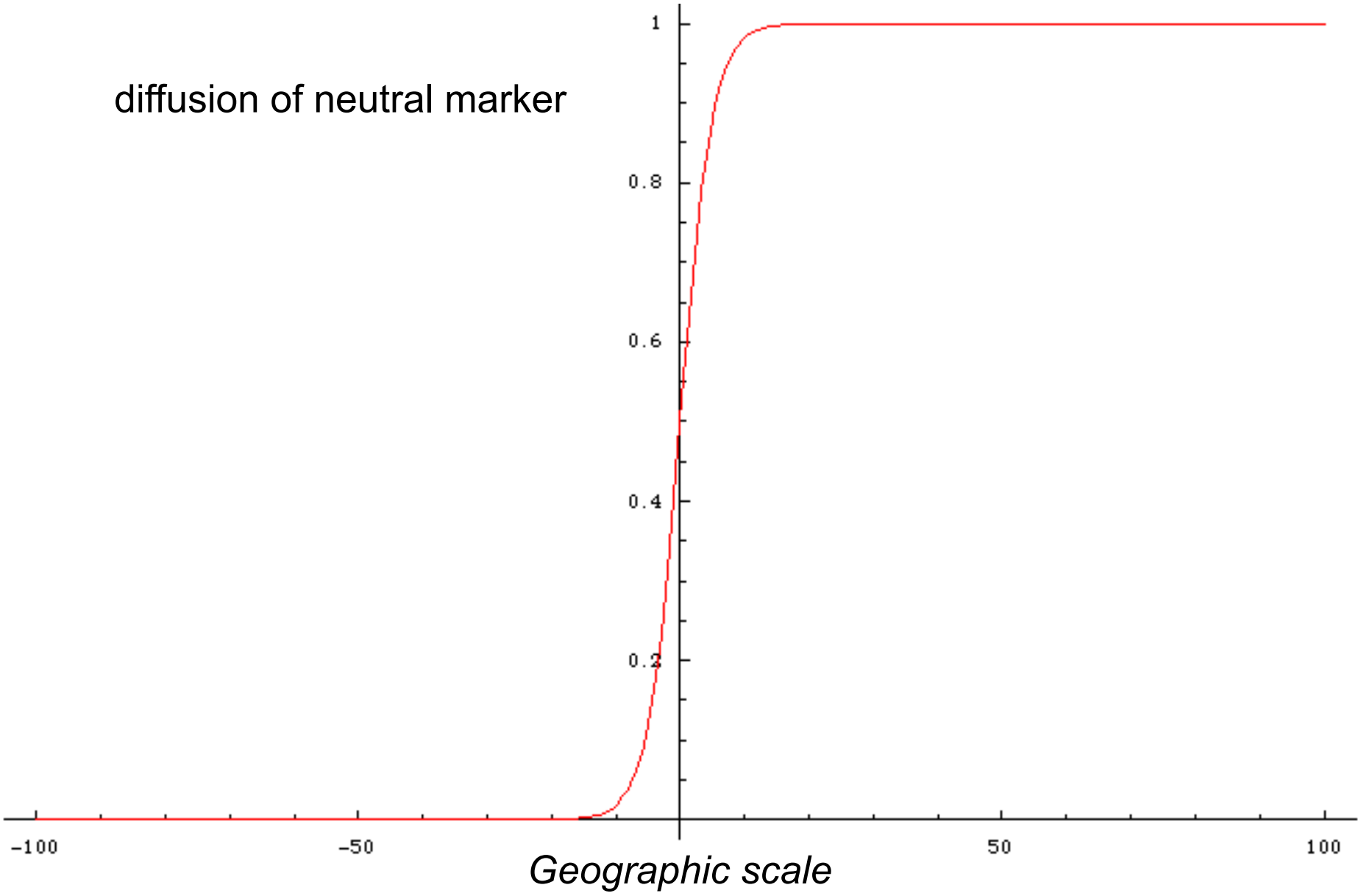
neutral vs. selected loci

neutral locus

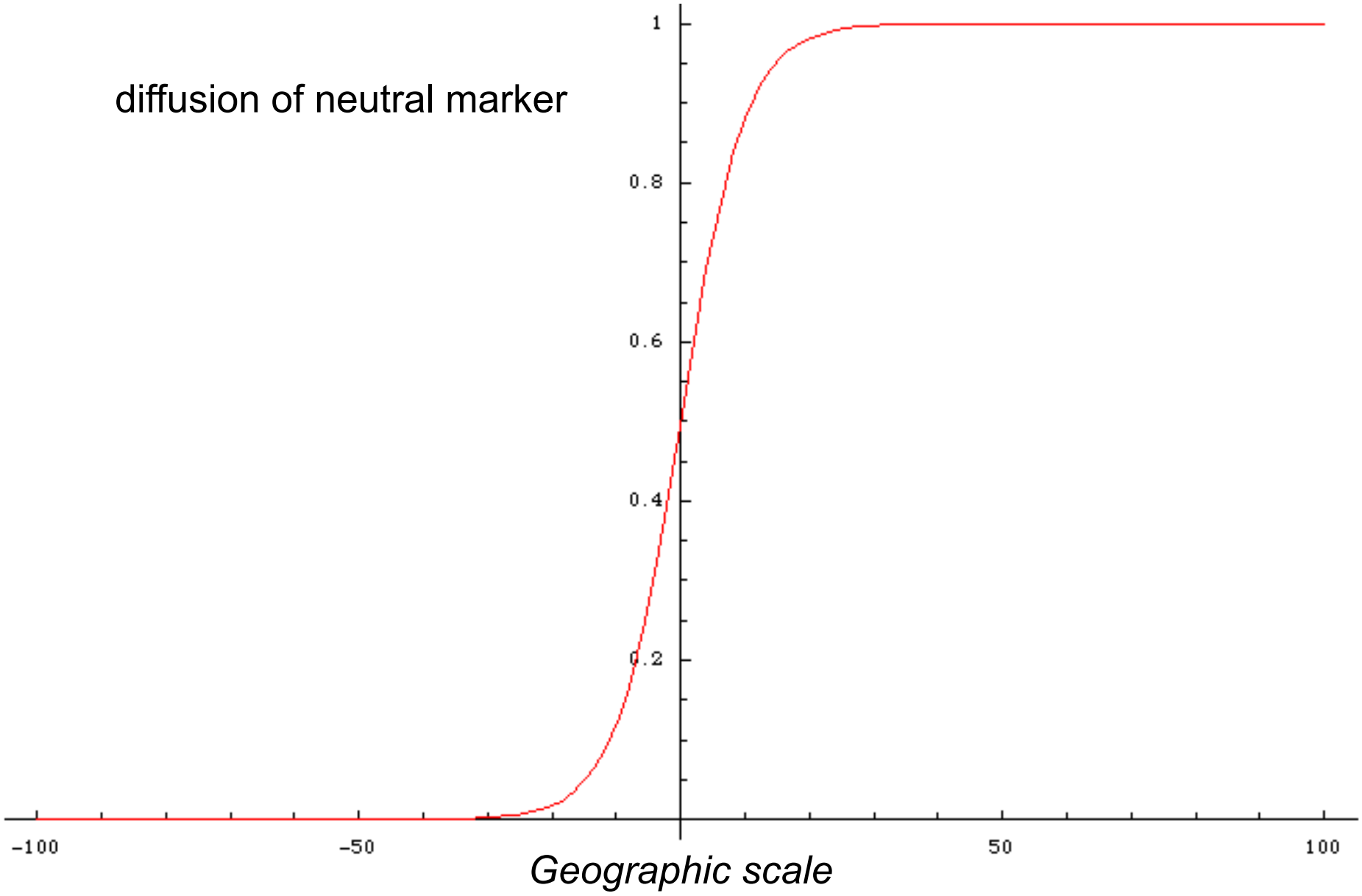
selection against hybrids



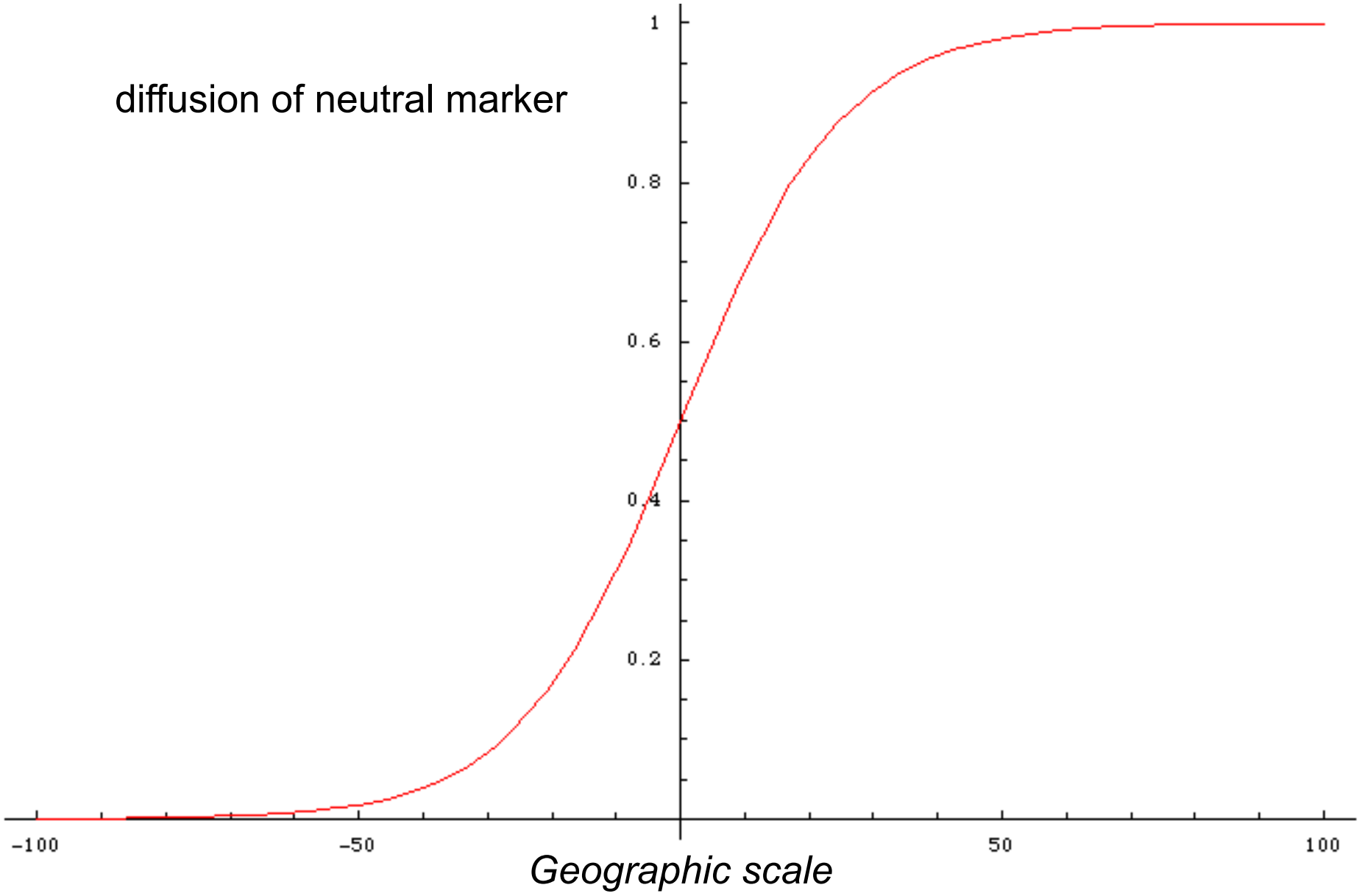
diffusion of neutral marker



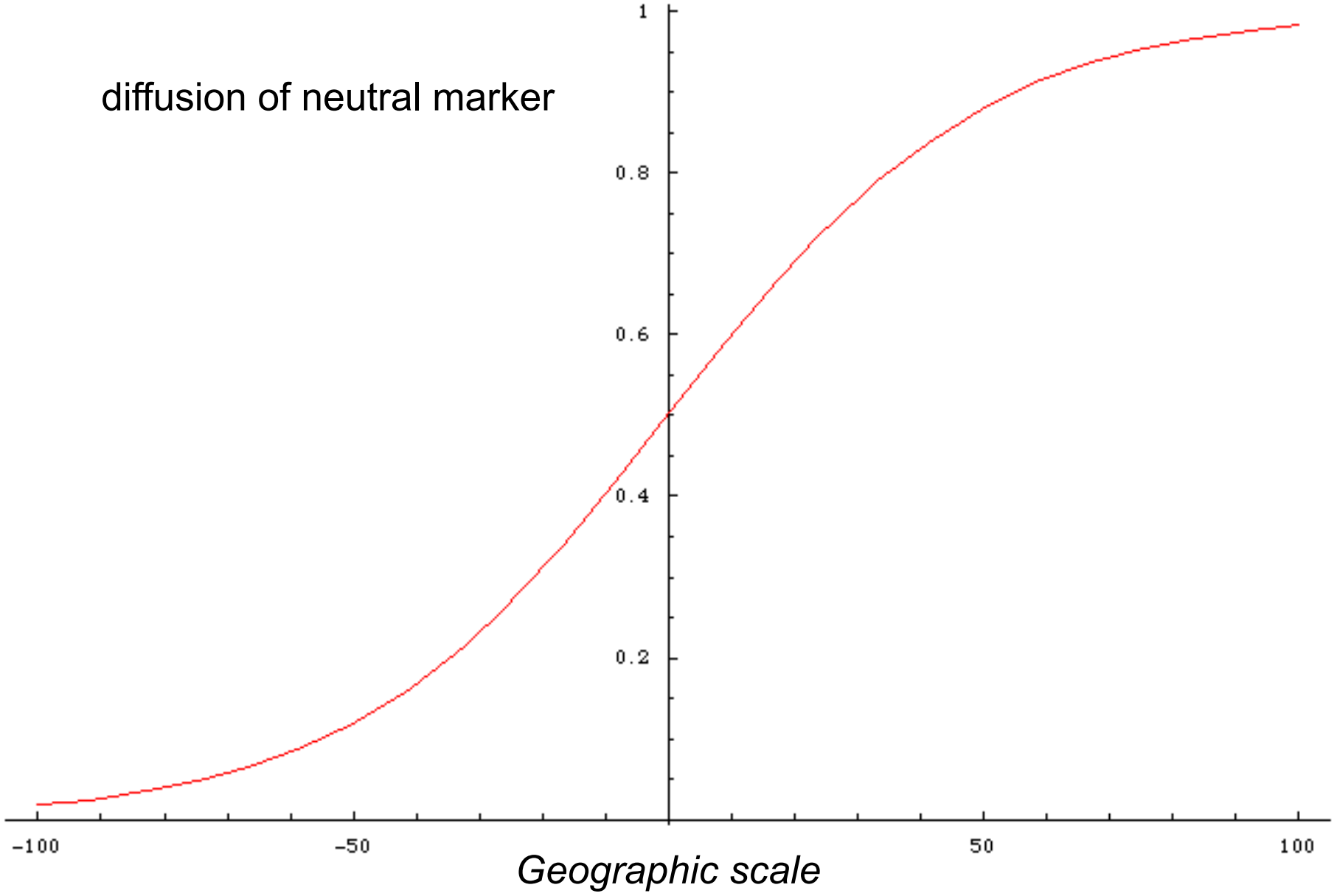
diffusion of neutral marker



diffusion of neutral marker

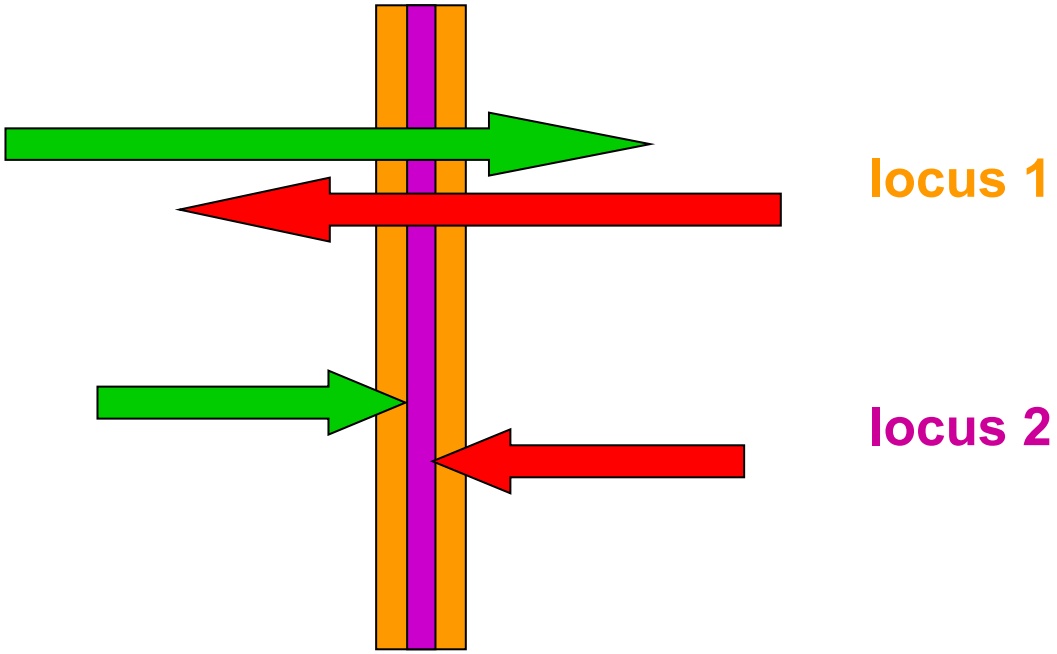


diffusion of neutral marker



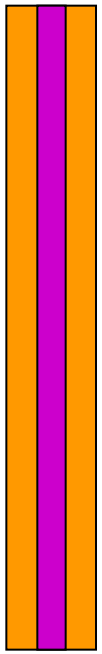
neutral vs. selected loci

with time, concordance is disappearing ...



... but (in tension zone) selection pushes clines for individual loci to each other
$\Rightarrow$ maintains coincidence

sometimes ...

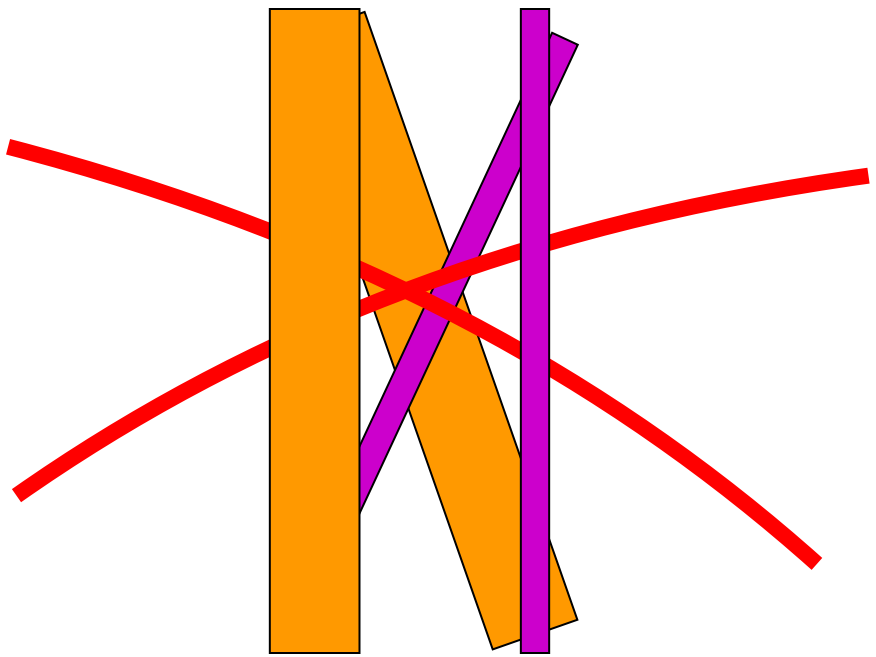


locus 1

locus 2

... but clines still parallel

cline models (diffusion approximation etc.), linkage disequilibrium, evolutionary parameters



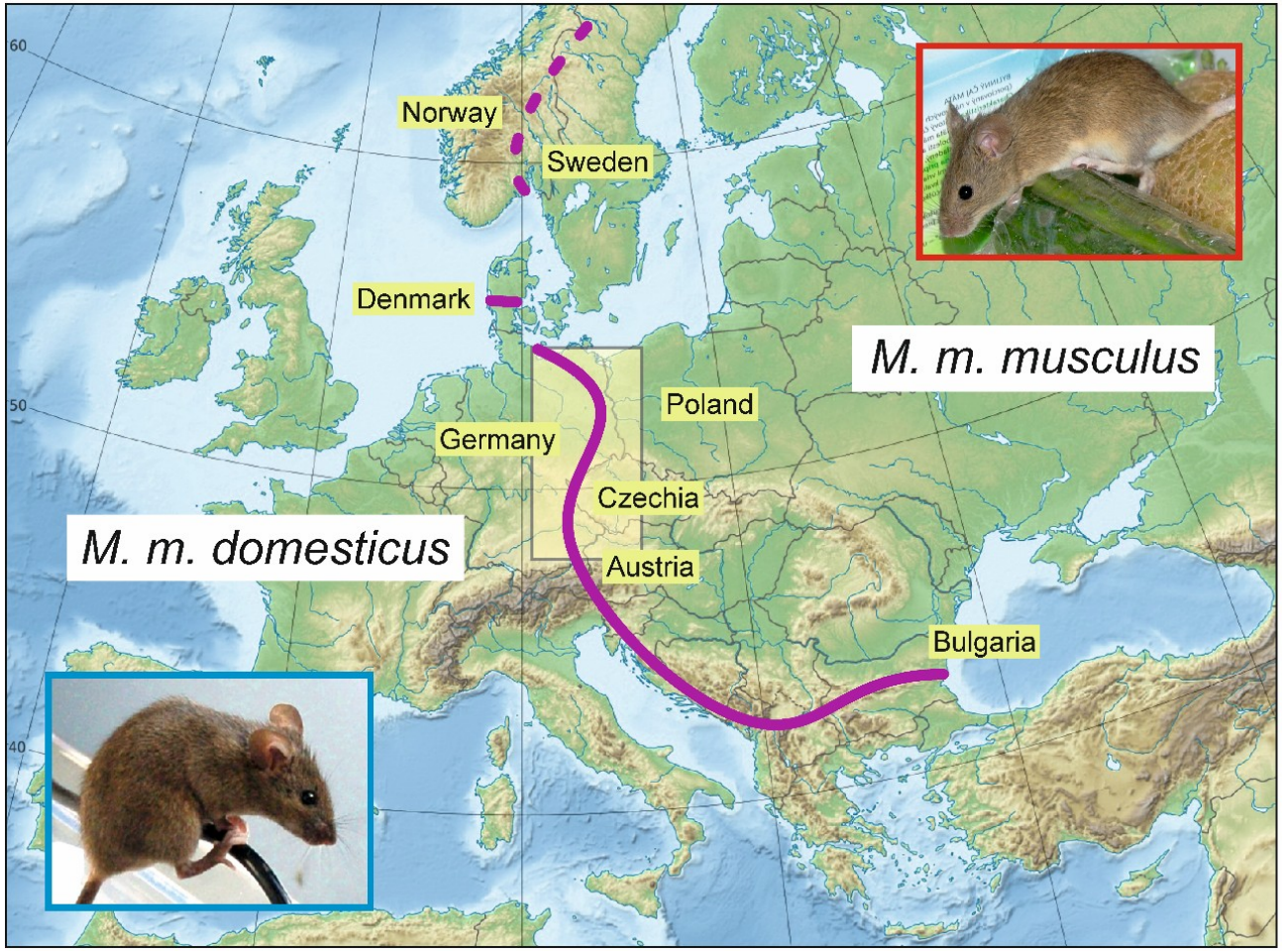
??

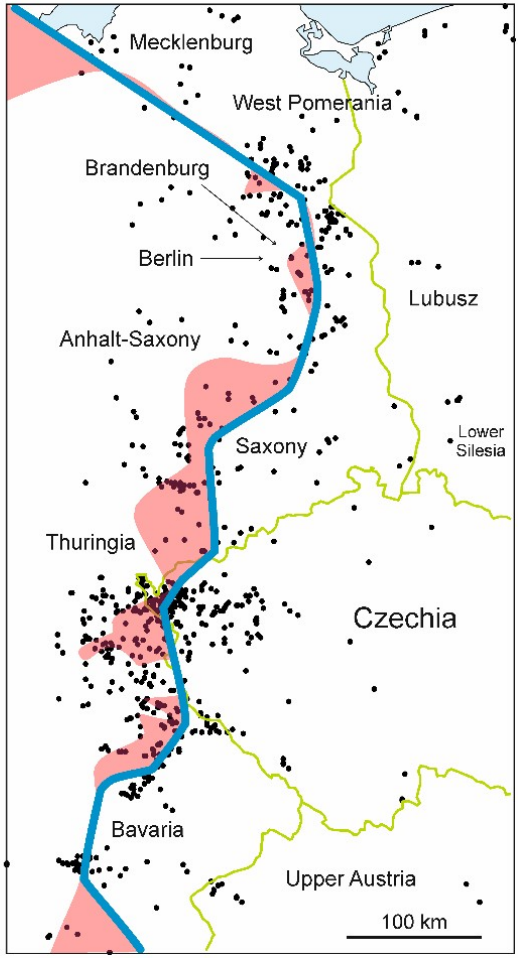
problem, how to analyse

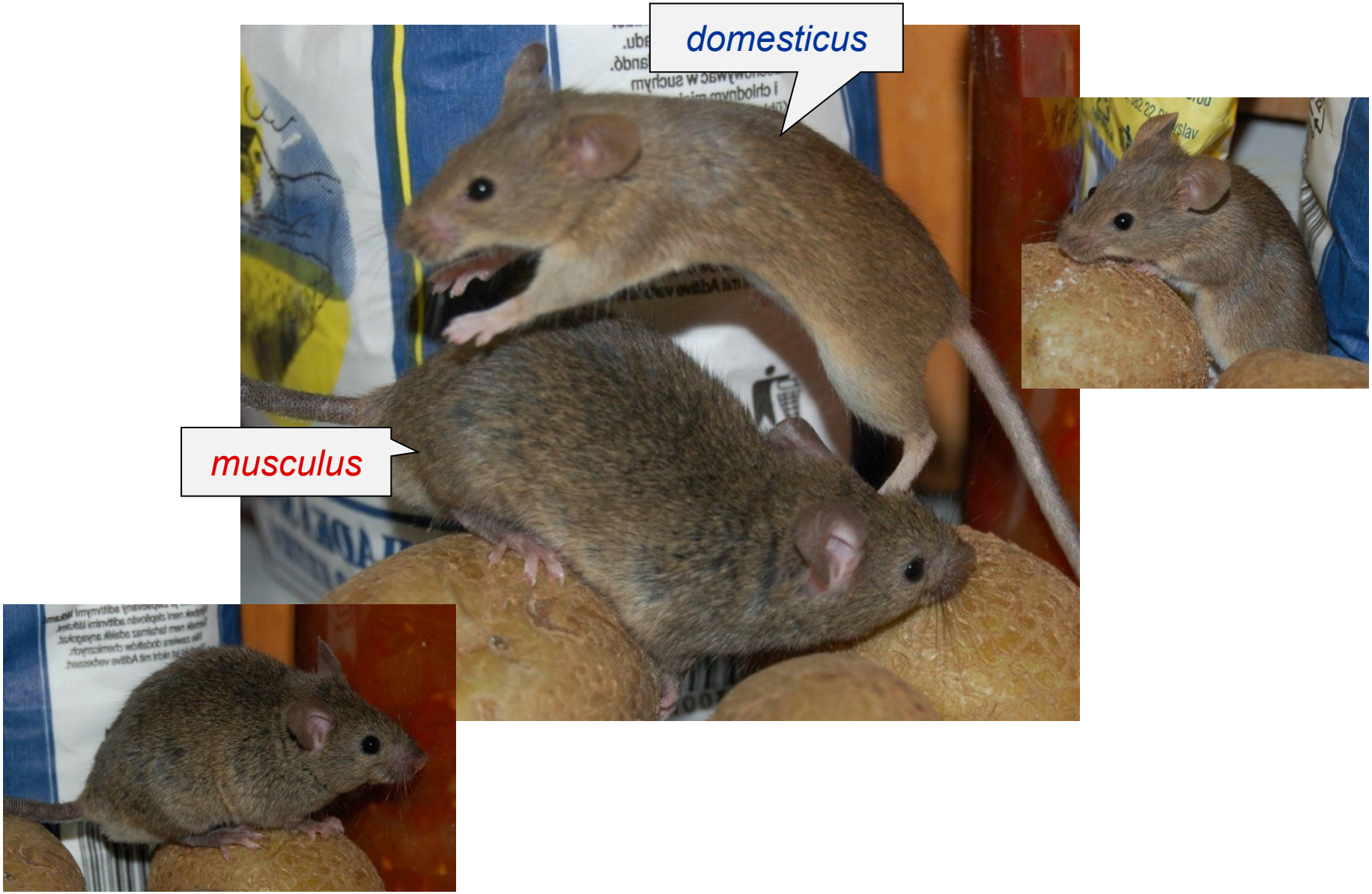
Hybrid zone study

1. Sampling along linear or 2D transect, geographic coordinates of localities
2. Genetic (morphological, behavioural etc.) analysis
   … problem of sample independence (F_{ST}, F_{IS} … effective No. alleles)
3. Geographic clines
4. Estimation of dispersal, selection, and other parametres
5. Alternative approaches:
   monotonic clines
   2D analysis
   genomic clines
   concordance analysis

Case study: house mouse hybrid zone






domesticus
musculus

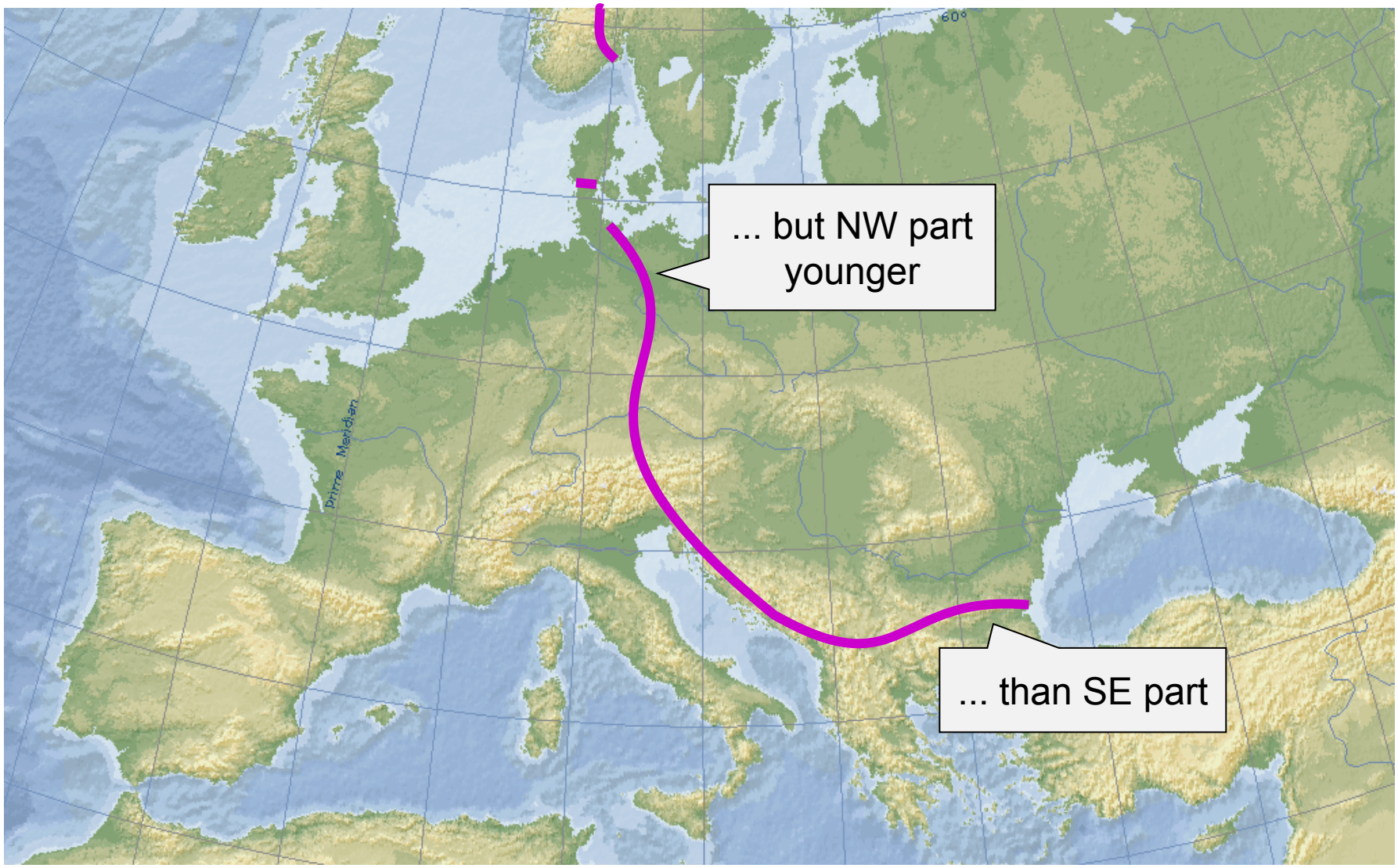
Hybrid zone in Europe

musculus

time of origin unknown…

domesticus

Hybrid zone in Europe



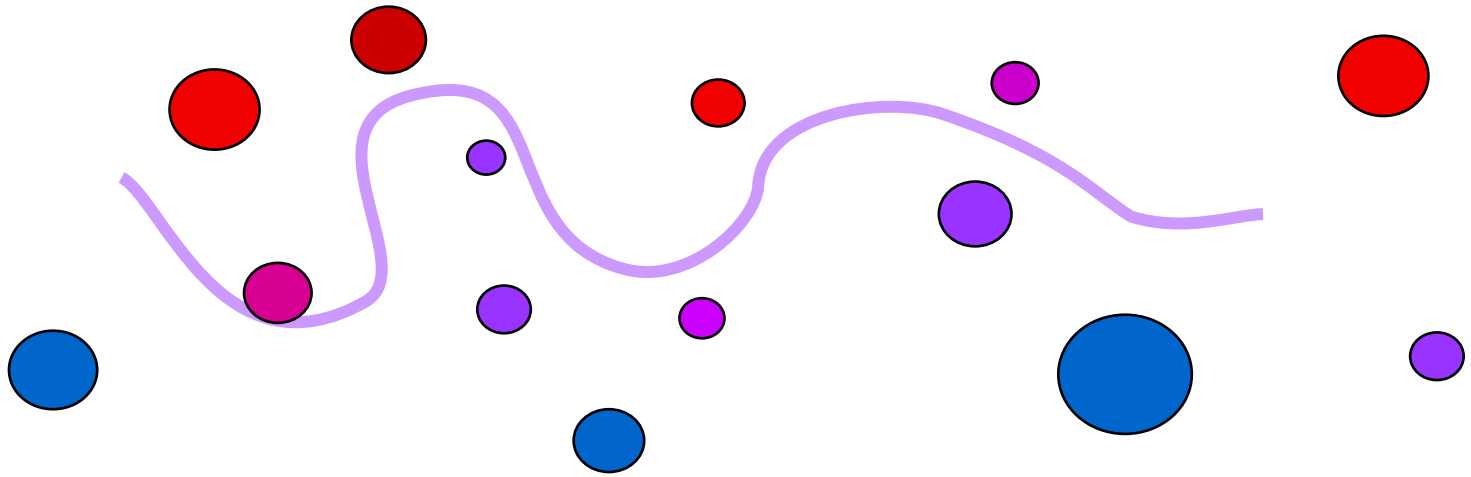

Europe
Arctic Circle
Norwegian Sea
Atlantic Ocean
0 350 Miles
0 350 Kilometers
Stockholm
Moscow
Baltic Sea
North Sea
Berlin
London
Paris
Bay of Biscay
Black Sea
ASIA
Rome
Madrid
Mediterranean Sea
AFRICA
oceanic climate
continental climate
Semiarid
Subtropical dry summer
Humid subtropical
Humid oceanic
Humid continental
Subarctic
Tundra
Highland

Hybrid zone in Europe

Most hybrid zones are
„tension zones“

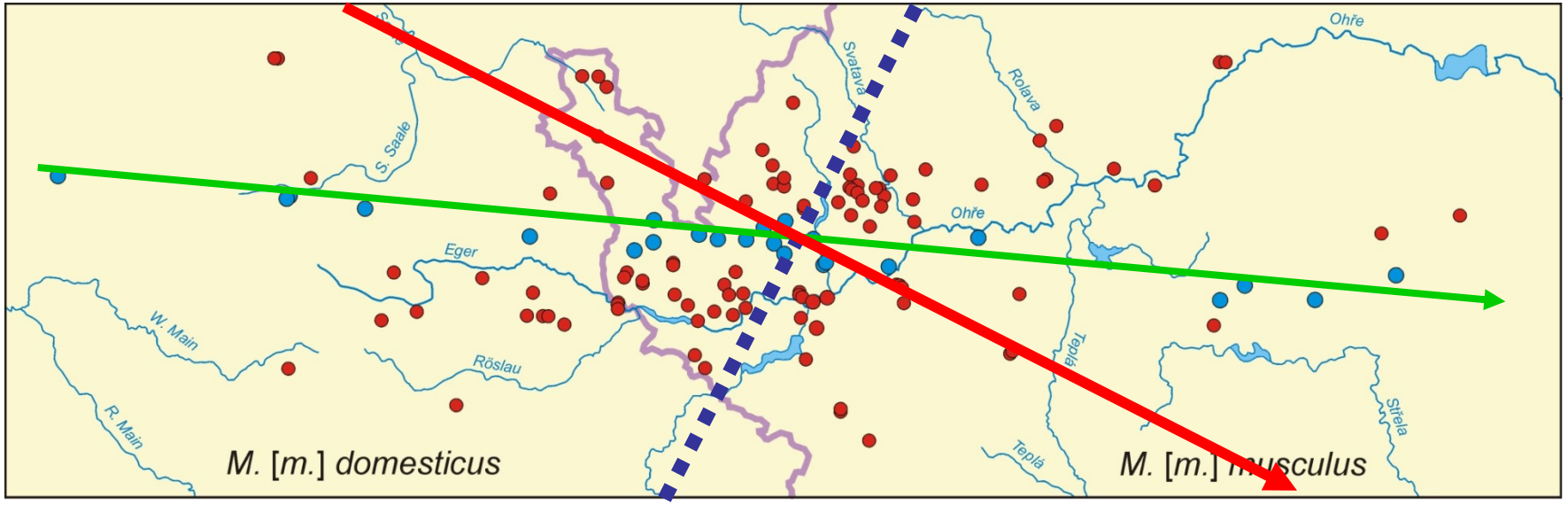
Nick Barton

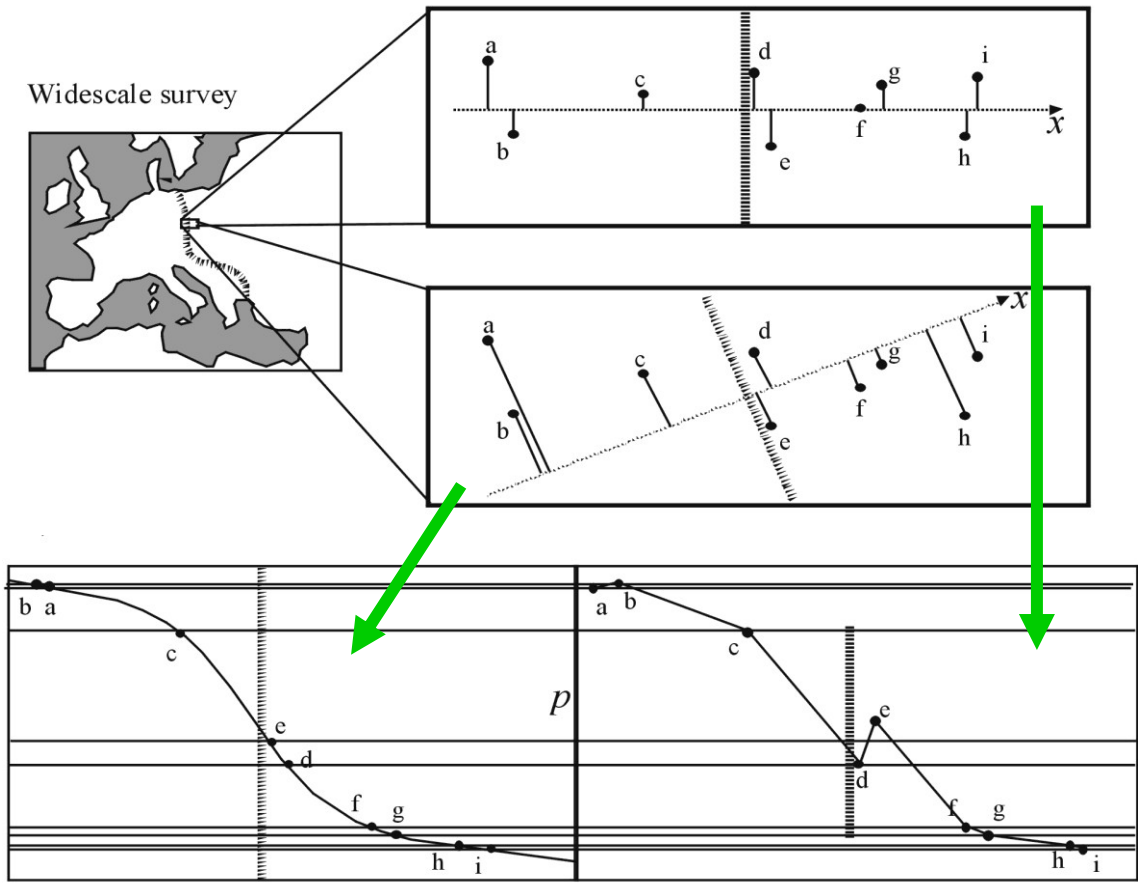
also the mouse hybrid zone?

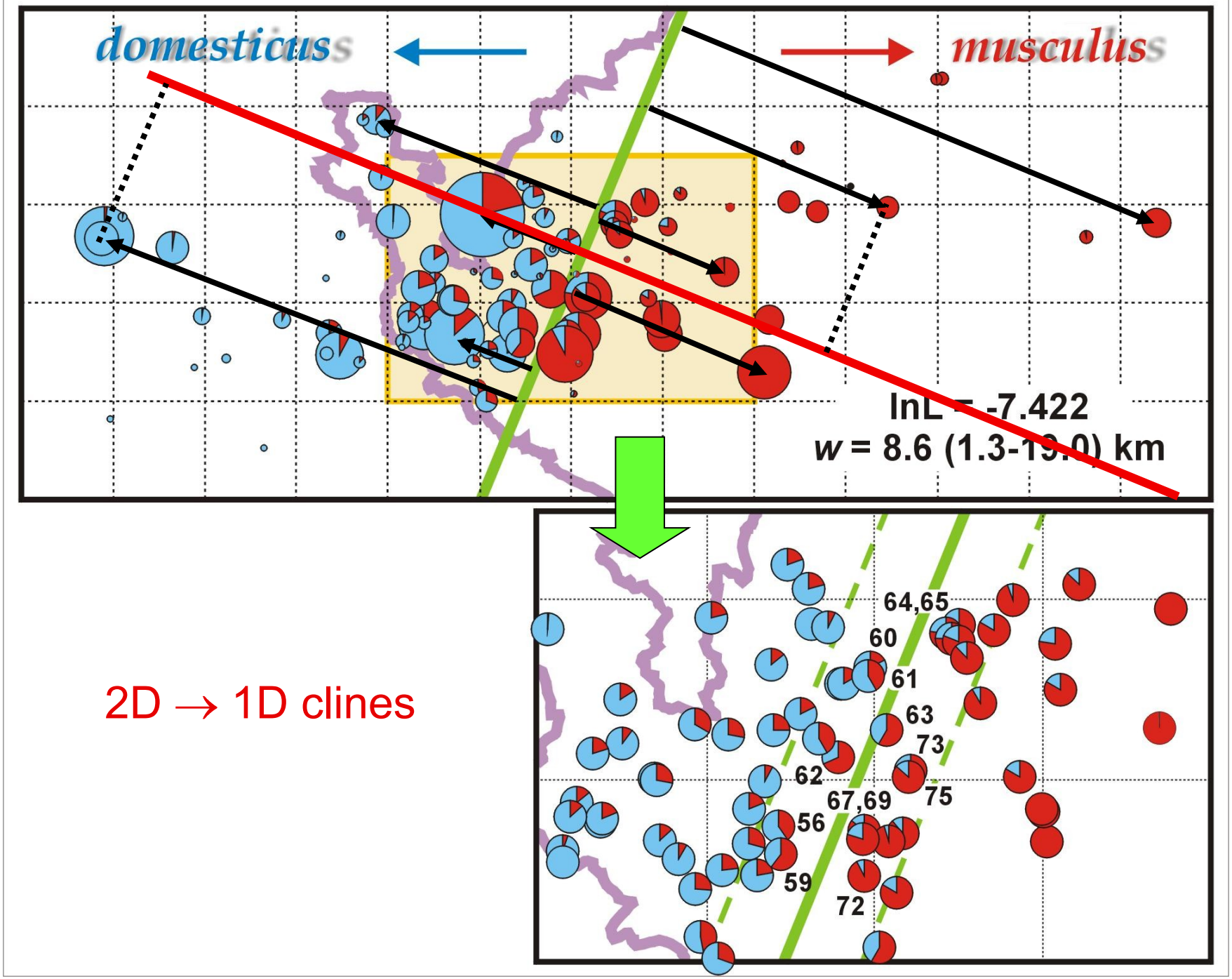


hybrid zone course may be complex....

... moreover, usually we don't know a priori, or we extrapolate from global direction

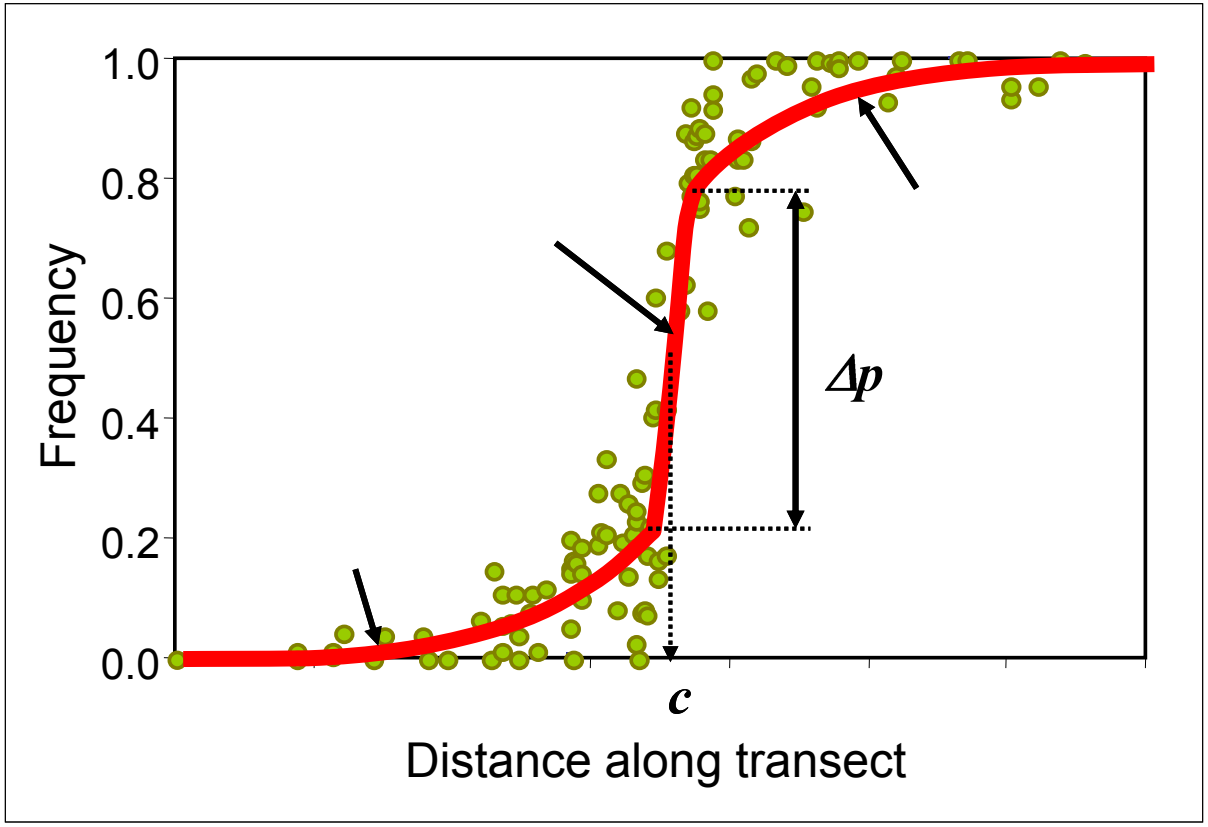



Widescale survey
a
b
c
d
e
f
g
h
i
x
p
Real local cline
Cline interpolated
from widescale survey


domesticus
musculus
lnL = -7.422
w = 8.6 (1.3-19.0) km
64,65
60
61
63
73
62
67,69
75
56
59
72

2D → 1D clines

Multiple genes:



„stepped“ model (symetrical, asymmetrical)

linkage disequilibrium resulting from influx of parental allele combinations ⇒ synergistic effect: strenghtening of selection in zone centre ⇒ central step

× introgression tails reflect selection at individual loci

We can estimate some other key evolutionary parametres from LD and cline parametres:

dispersal:

effective selection:

selection on marker loci:

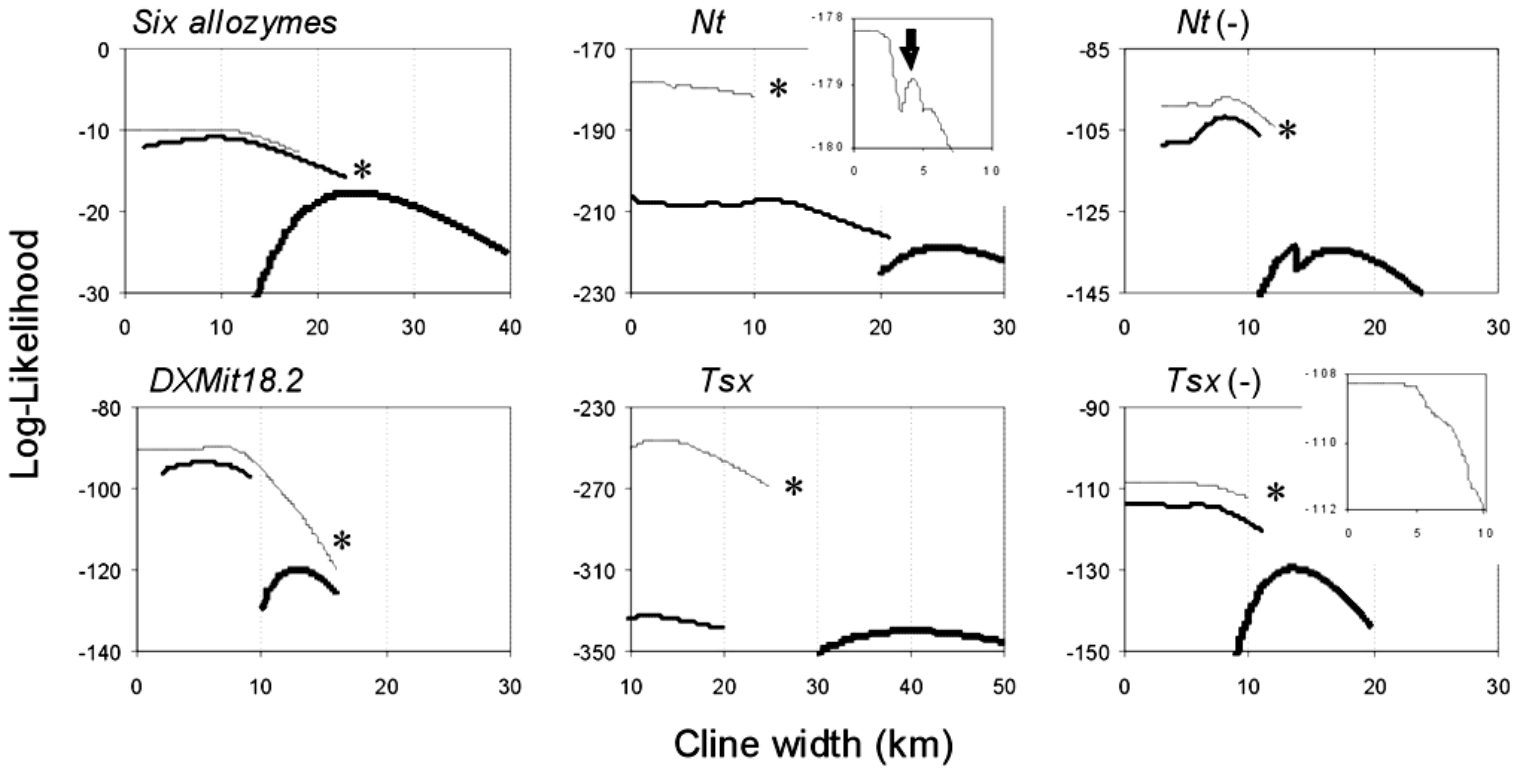
selection on selected loci:

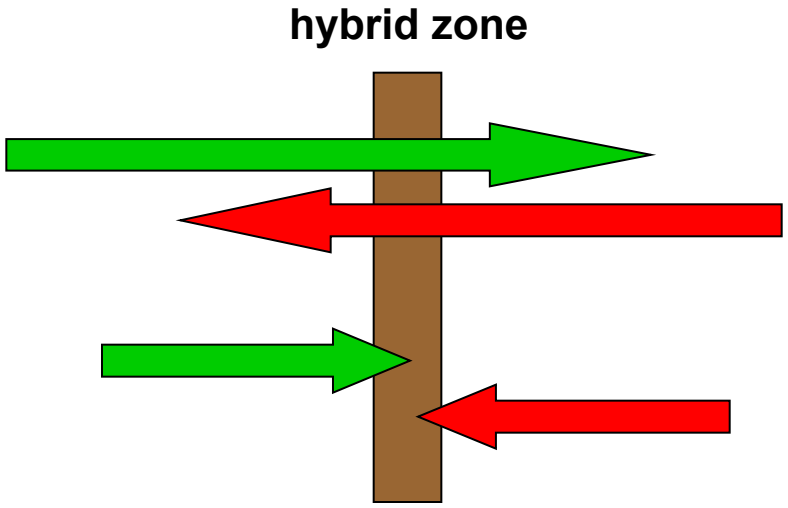
fitness of hybrids:

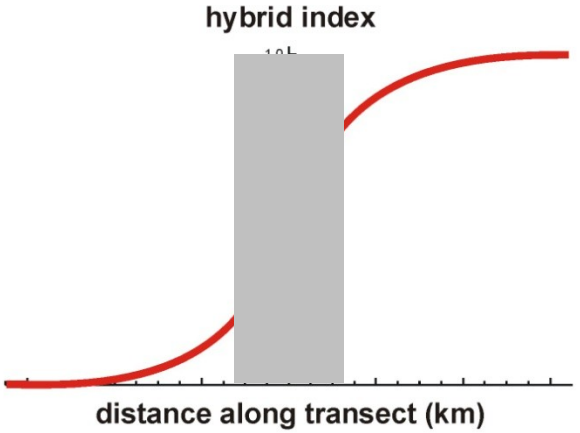
number of loci under selection:

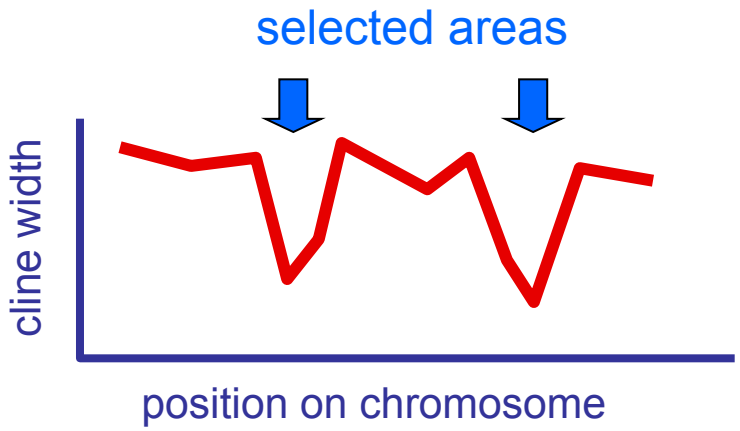
model comparison: LRT (they are nested); d.f. = difference in number of parametres

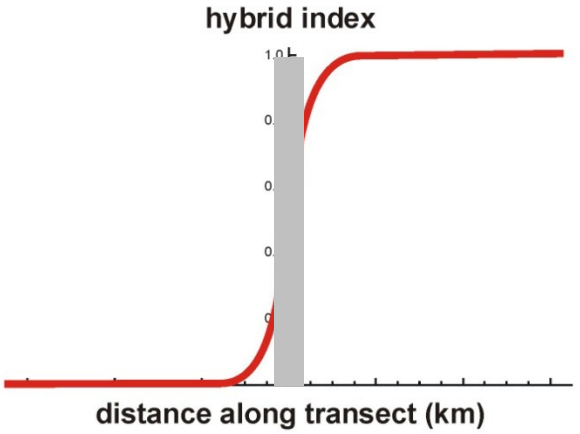
likelihood profiles:

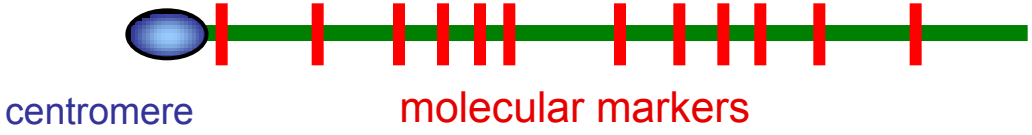



hybrid zone

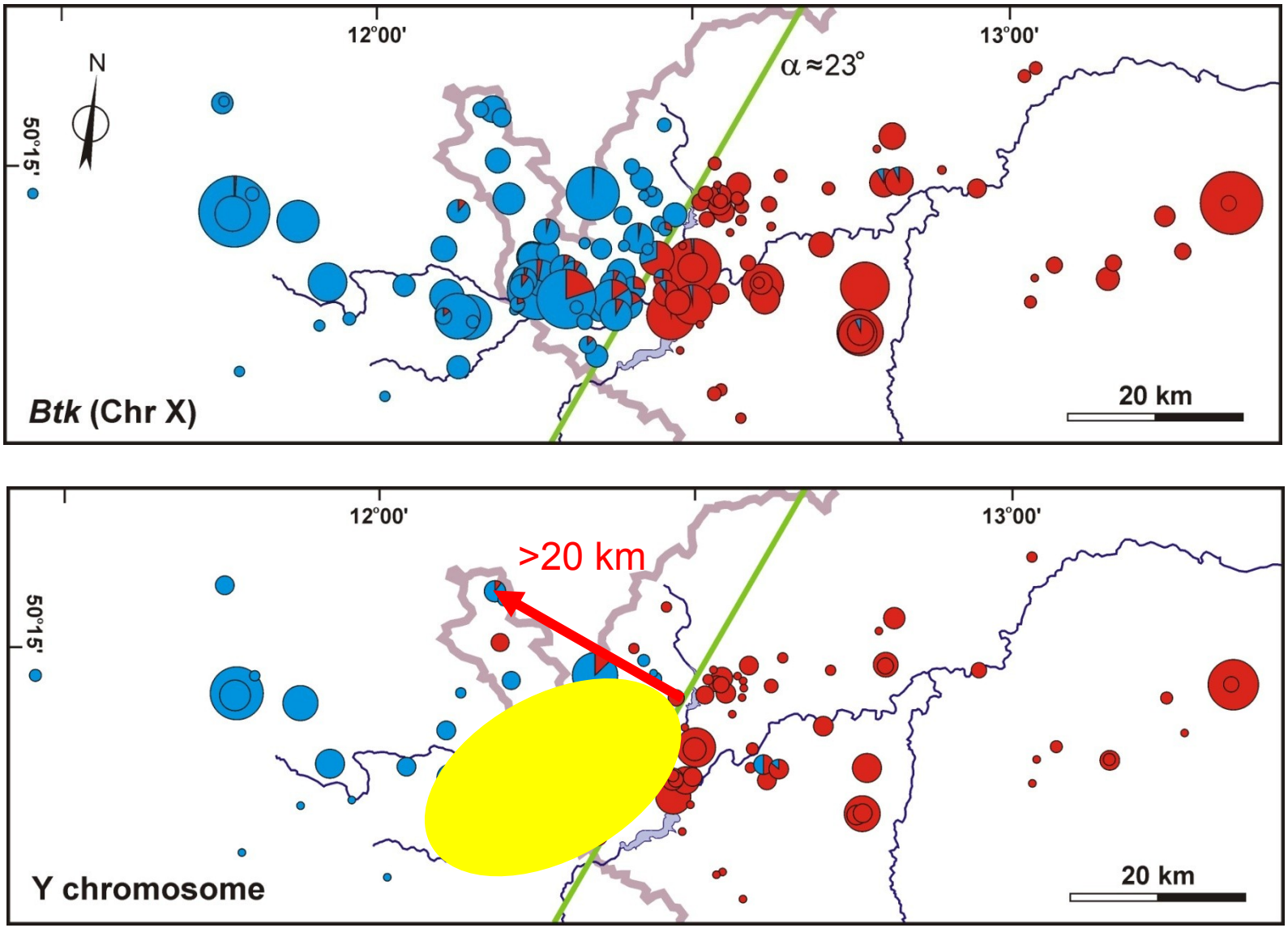

hybrid index
distance along transect (km)

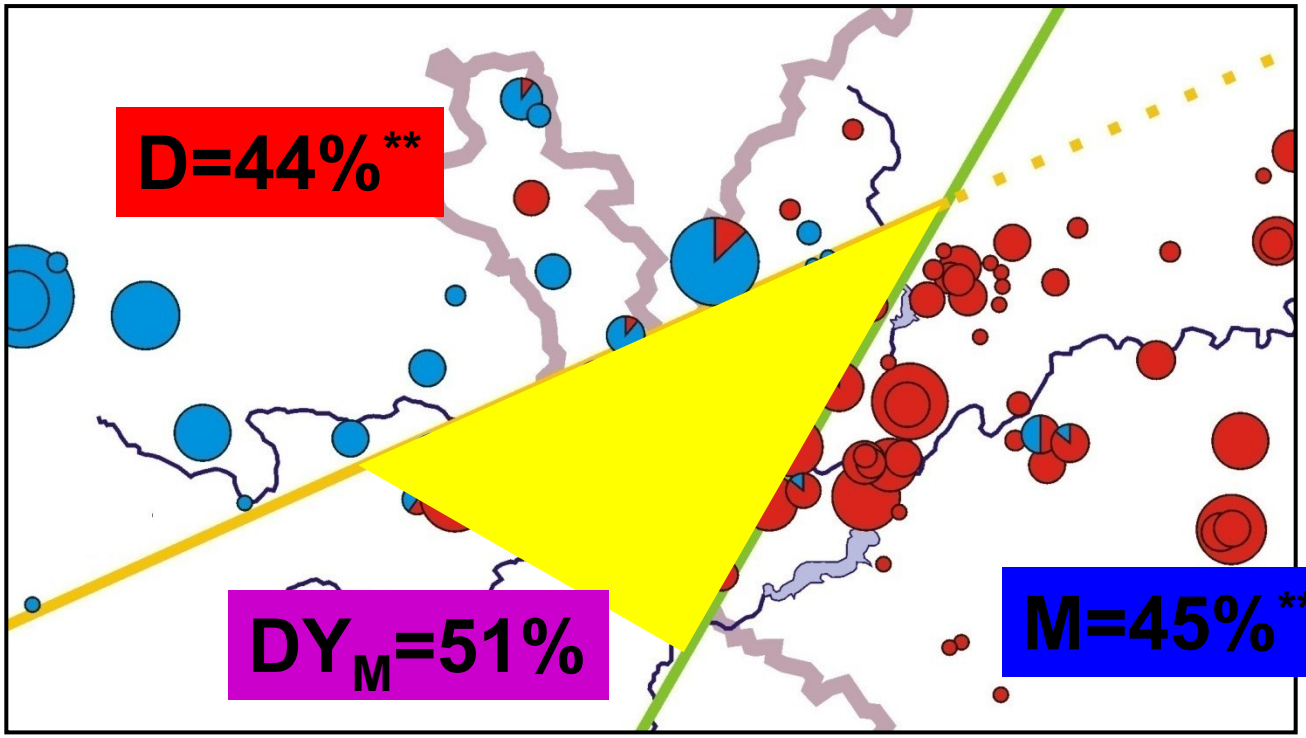

selected areas
cline width
position on chromosome


hybrid index
distance along transect (km)

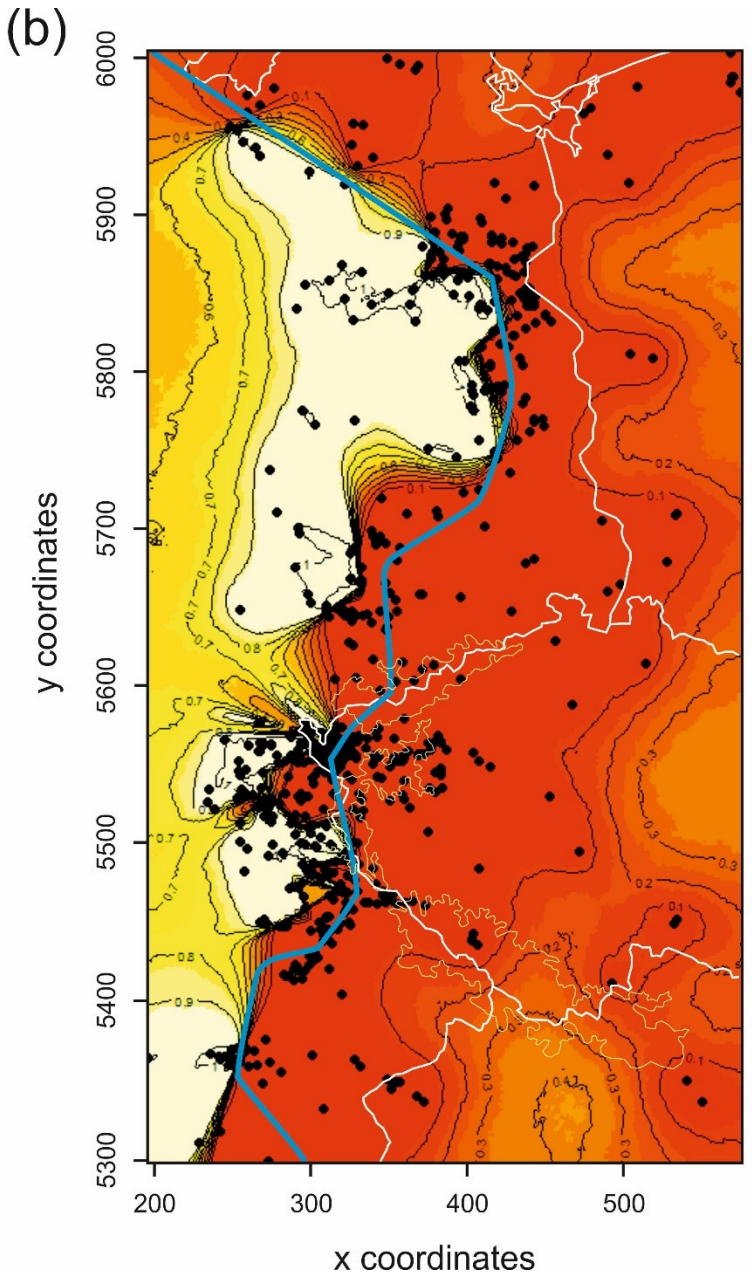

centromere
molecular markers

Problems – Y chromosome





salient/invagination ≈ 330 km²


(b)
y coordinates
x coordinates
6000
5900
5800
5700
5600
5500
5400
5300
200
300
400
500

Weird behaviour of the Y in the hybrid zone – summary:

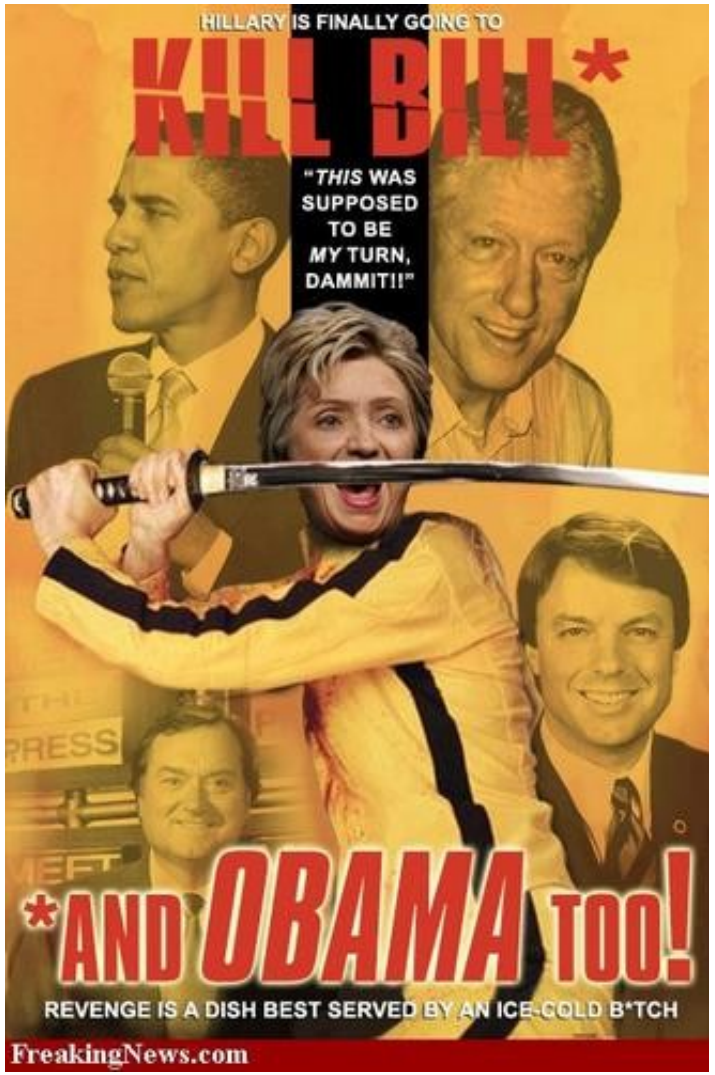
1. *musculus* Y more successful than *domesticus* Y on its own genetic background

2. higer proportion of males relative to other areas

Either coincidence, or ...

… or genetic conflict between X and Y

and probably some autosomal genes as well



segregation law

Gregor Mendel

Aa

A *a*

50% 50%

Intragenomic conflict results in higher proportion of a genomic element in the next generation

?!

Gregor Mendel

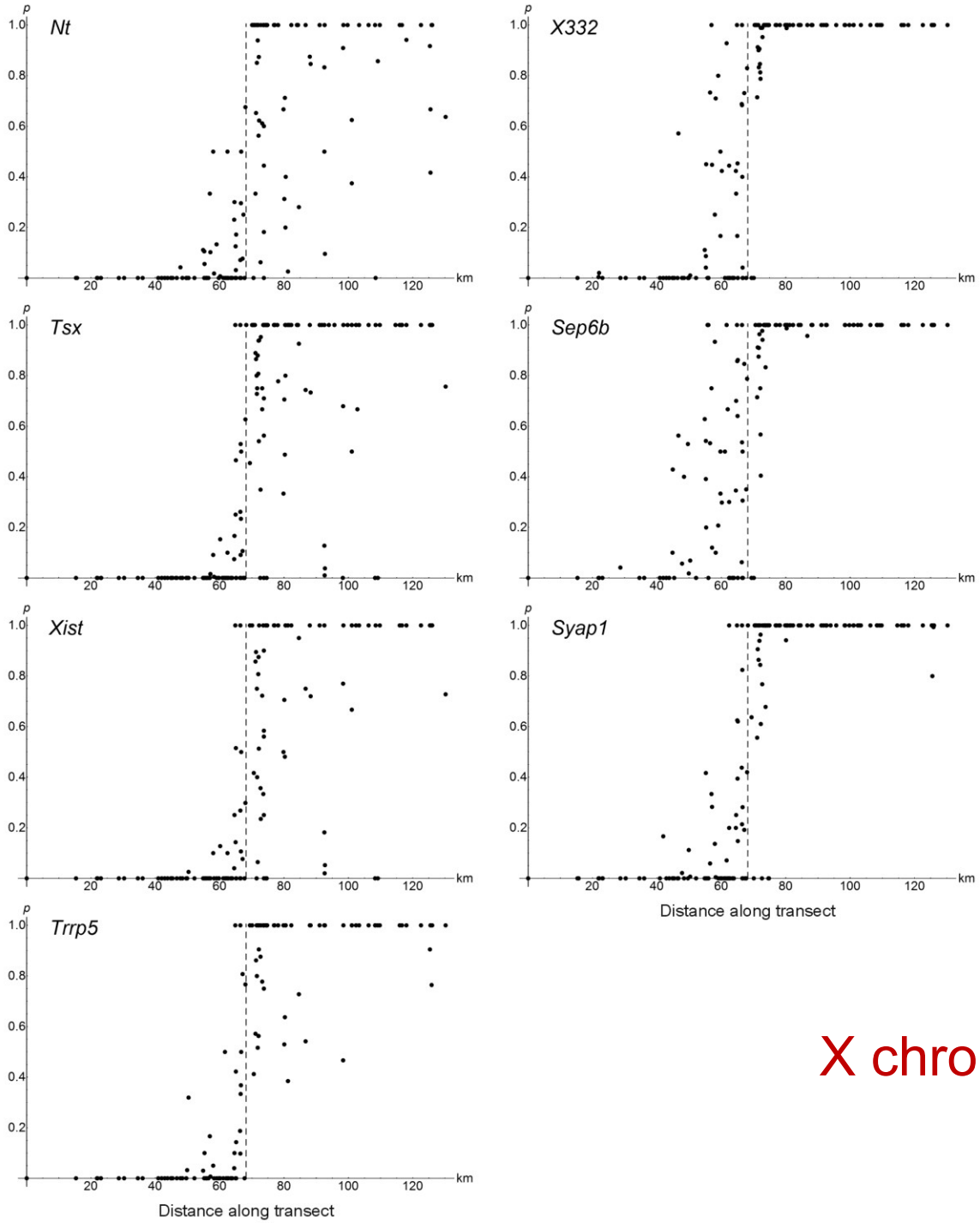
Aa

A *a*

„drive“

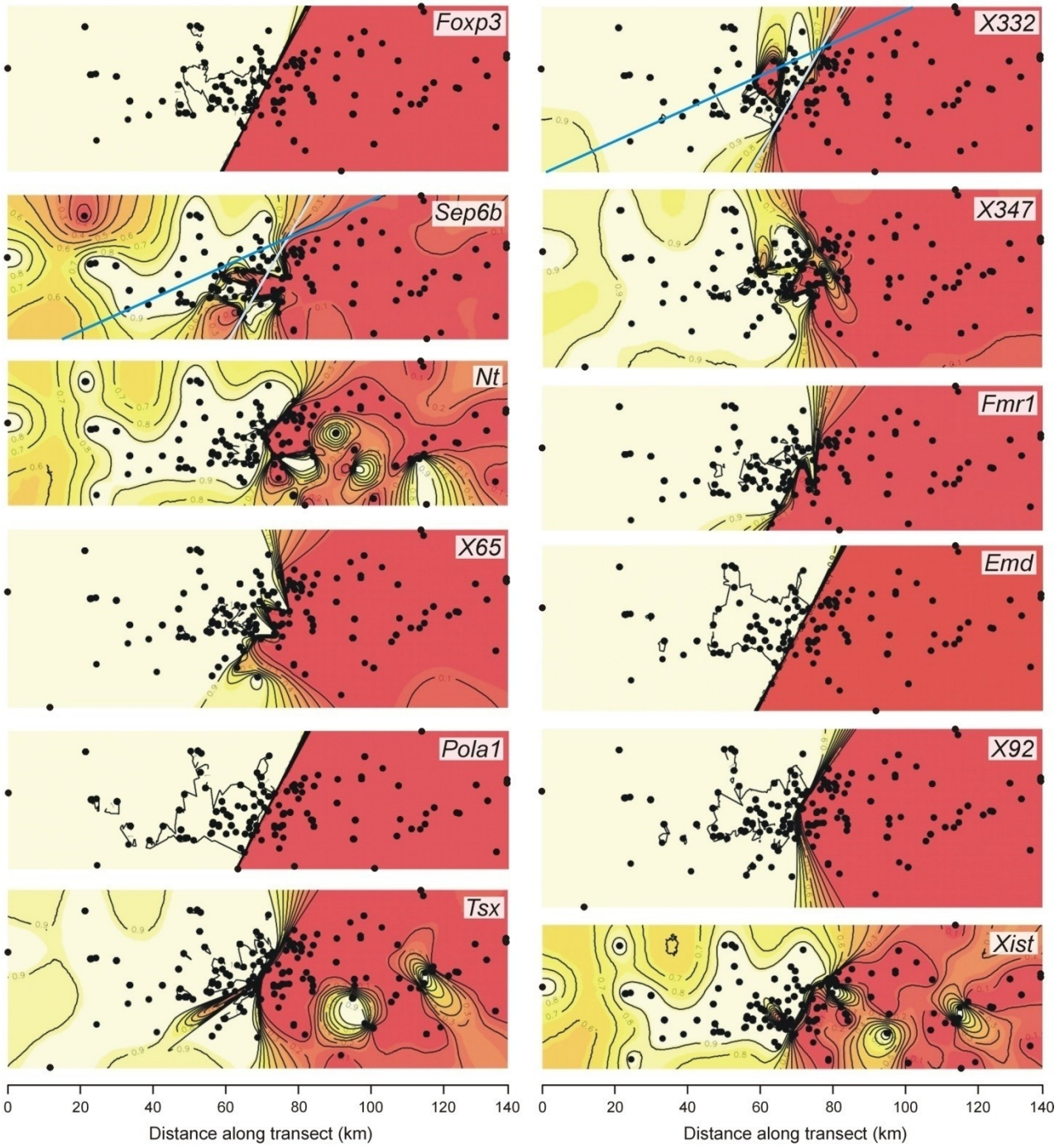
95% 5%

vychýlení segregačího (transmisního) poměru
= segregation distortion (SD)
= transmission ratio distortion (TRD)

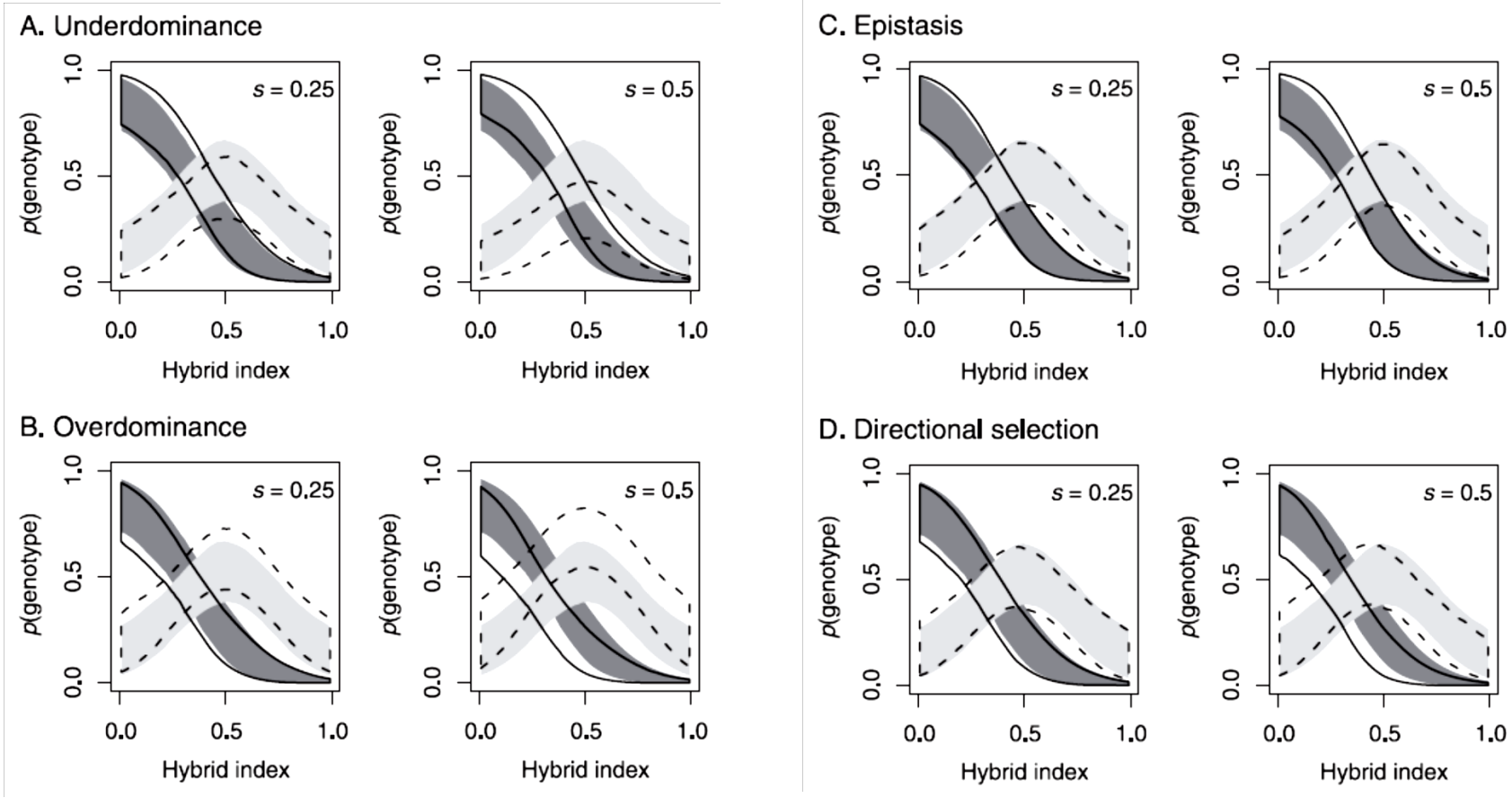


X chromosome

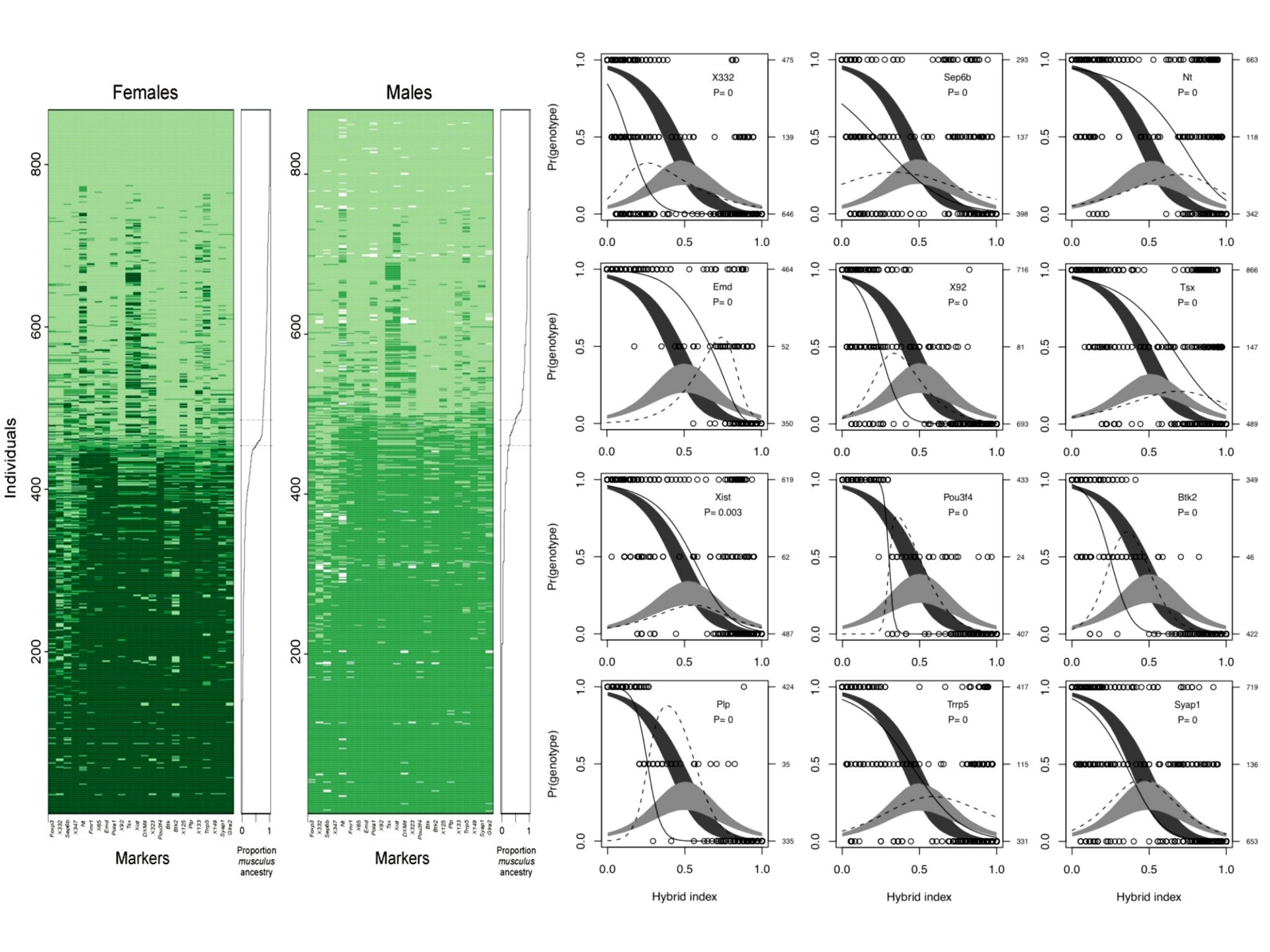
Chr. X - 2D analysis
Geneland



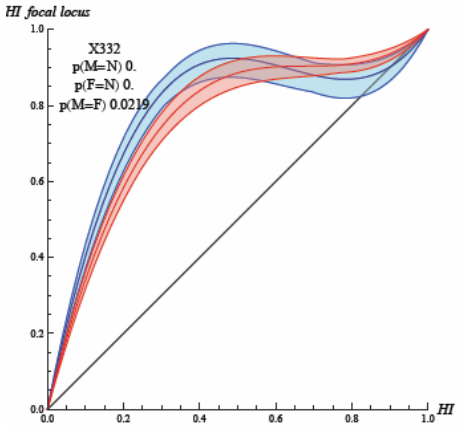
‘Genomic clines’

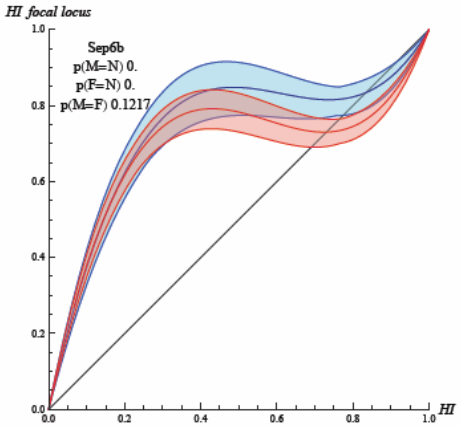


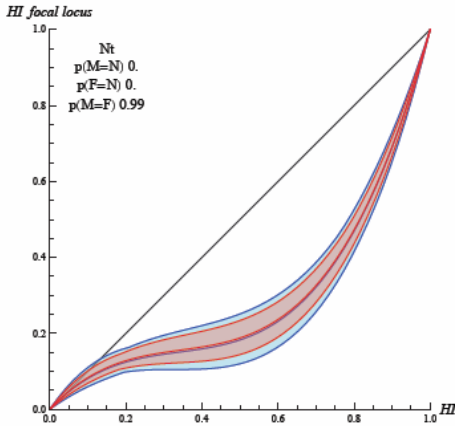
Z. Gompert & A. Buerkle

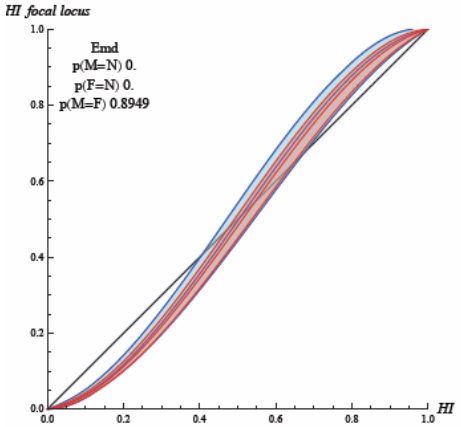

Females
Males
Individuals
800
600
400
200
Markers
Proportion musculus ancestry
0
1
Pr(genotype)
Hybrid index
X332
P= 0
Sep6b
P= 0
Nt
P= 0
Emd
P= 0
X92
P= 0
Tsx
P= 0
Xist
P= 0.003
Pou3f4
P= 0
Btk2
P= 0
Plp
P= 0
Trrp5
P= 0
Syap1
P= 0

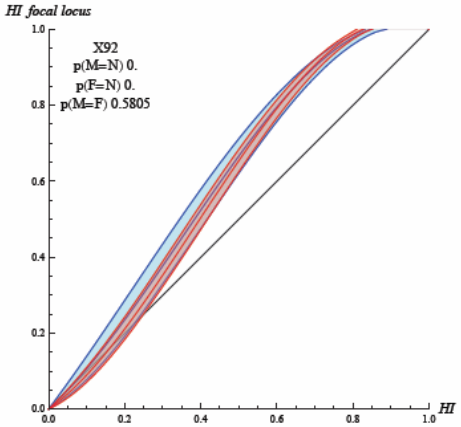
Concordance analysis:

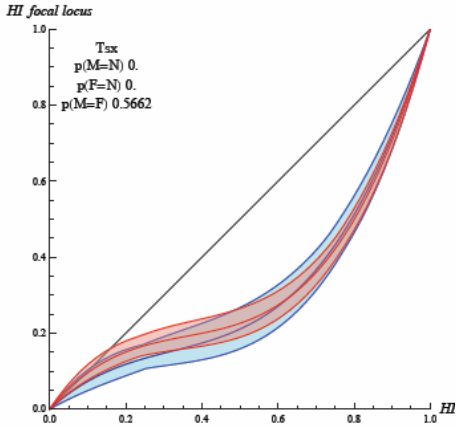


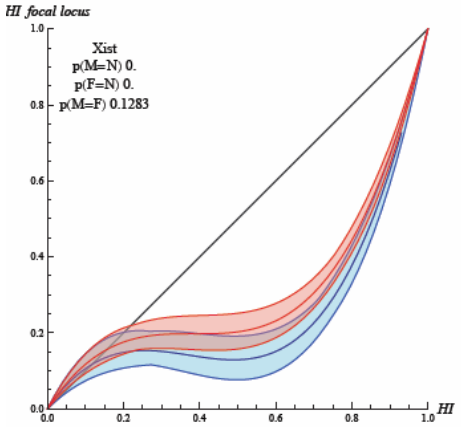


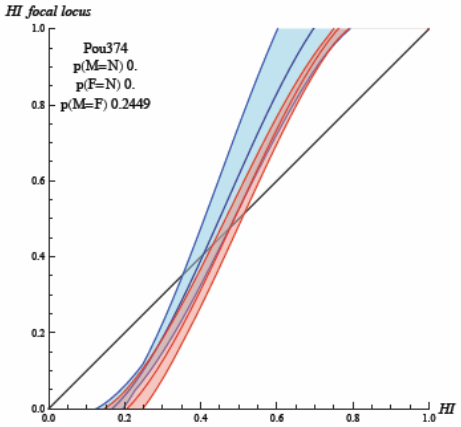


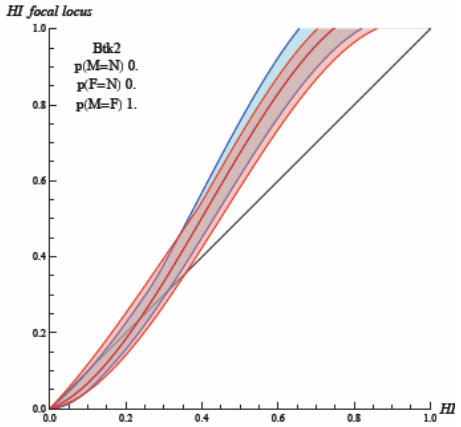












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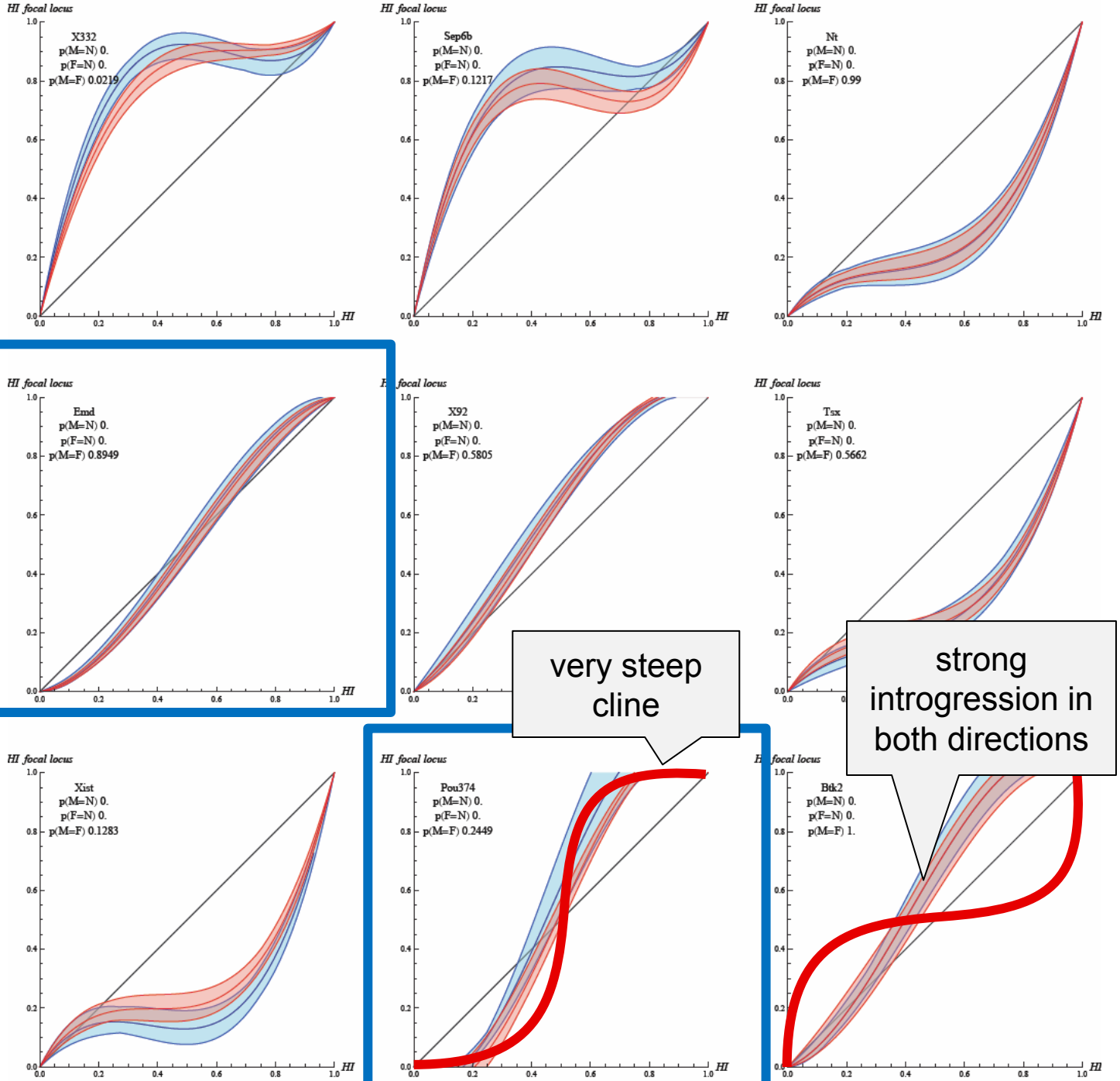
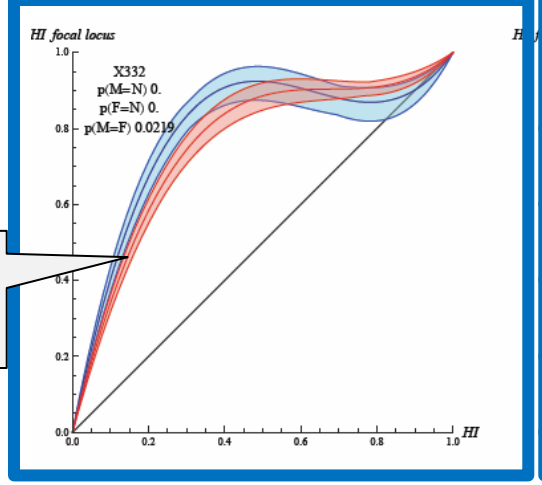
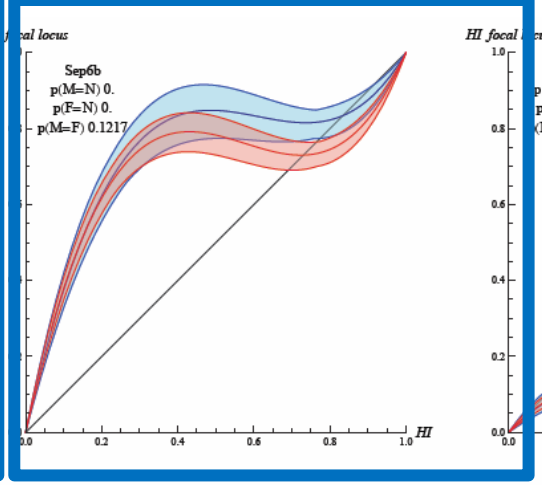

HI focal locus
X332
p(M=N) 0.
p(F=N) 0.
p(M=F) 0.0219
HI
HI focal locus
Sep6b
p(M=N) 0.
p(F=N) 0.
p(M=F) 0.1217
HI
HI focal locus
Nt
p(M=N) 0.
p(F=N) 0.
p(M=F) 0.99
HI
HI focal locus
Emd
p(M=N) 0.
p(F=N) 0.
p(M=F) 0.8949
HI
HI focal locus
X92
p(M=N) 0.
p(F=N) 0.
p(M=F) 0.5805
HI
HI focal locus
Tsx
p(M=N) 0.
p(F=N) 0.
p(M=F) 0.5662
HI
very steep cline
strong introgression in both directions
HI focal locus
Xist
p(M=N) 0.
p(F=N) 0.
p(M=F) 0.1283
HI
HI focal locus
Pou374
p(M=N) 0.
p(F=N) 0.
p(M=F) 0.2449
HI
HI focal locus
Btk2
p(M=N) 0.
p(F=N) 0.
p(M=F) 1.
HI

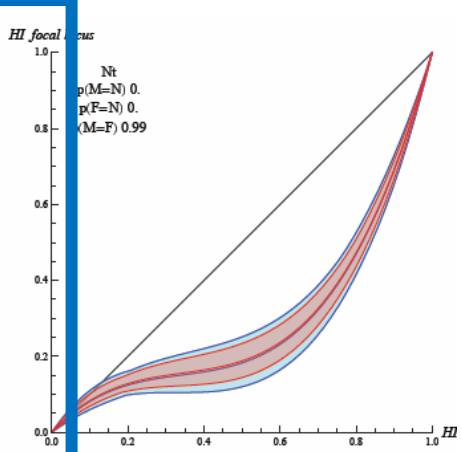
S.J.E. Baird

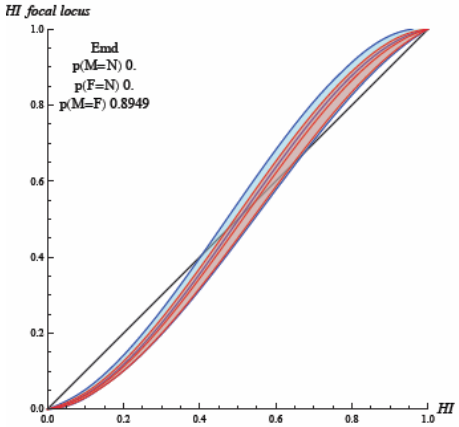
Concordance analysis:

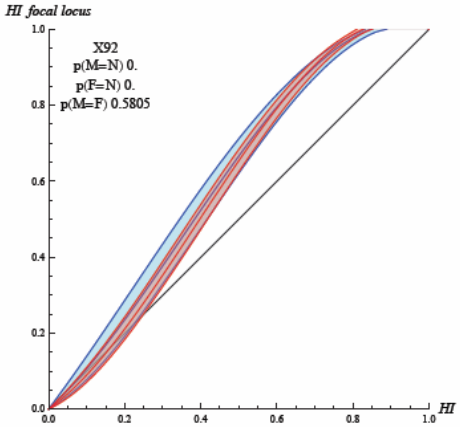
introgression to the left

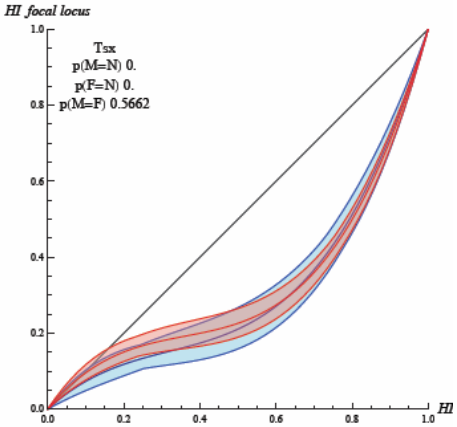


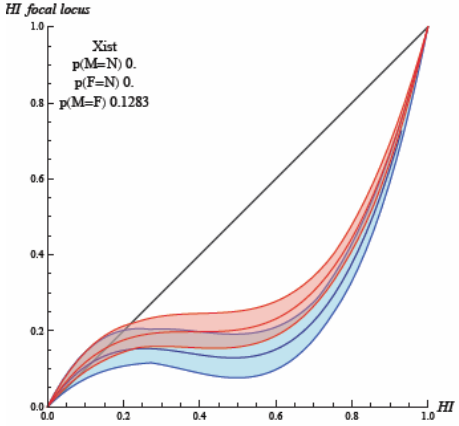


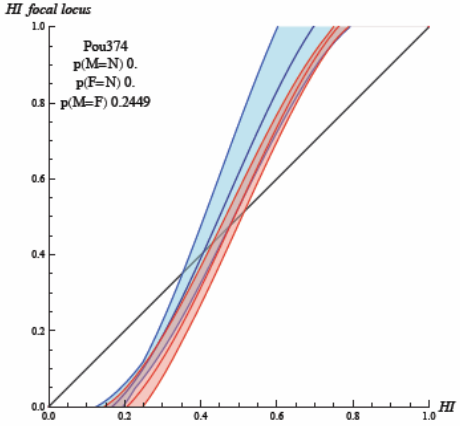


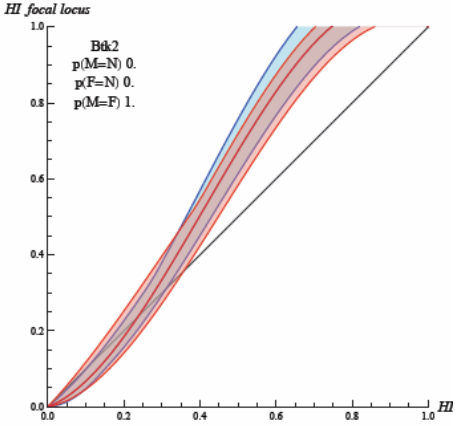












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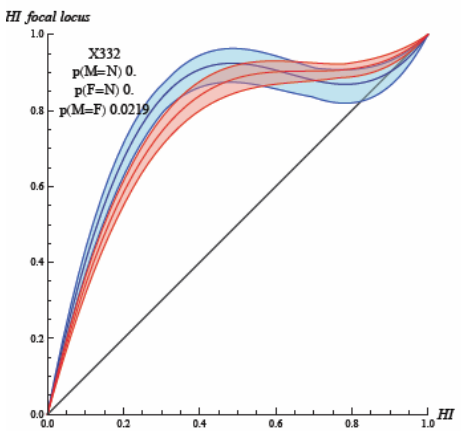
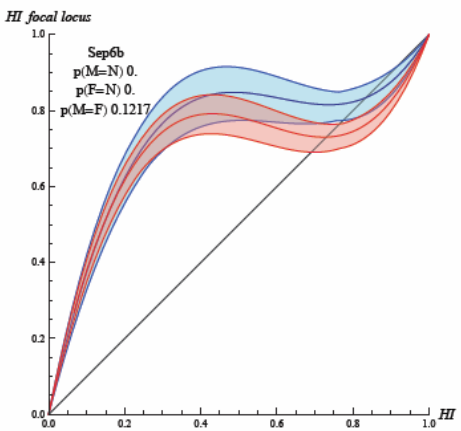
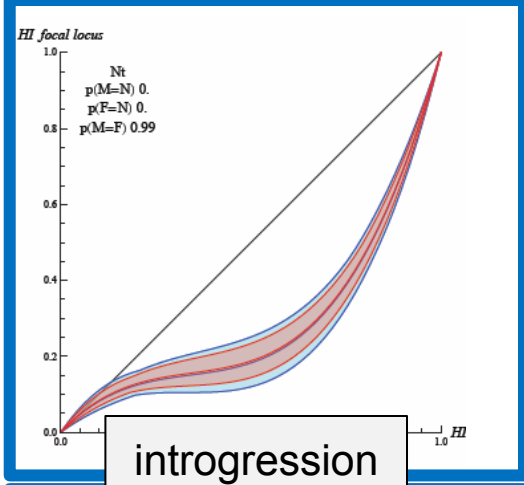
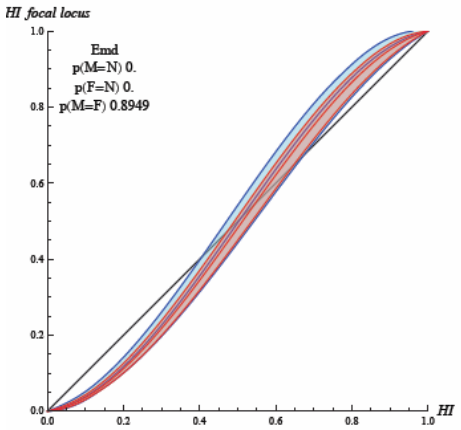
Concordance analysis:

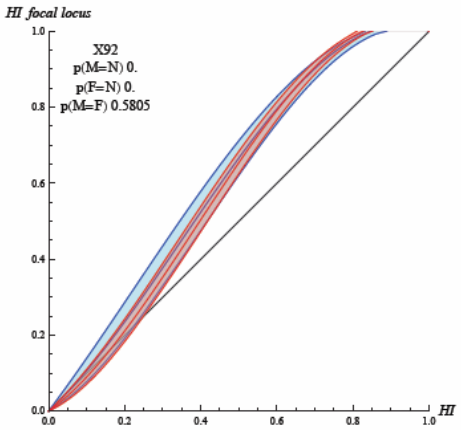


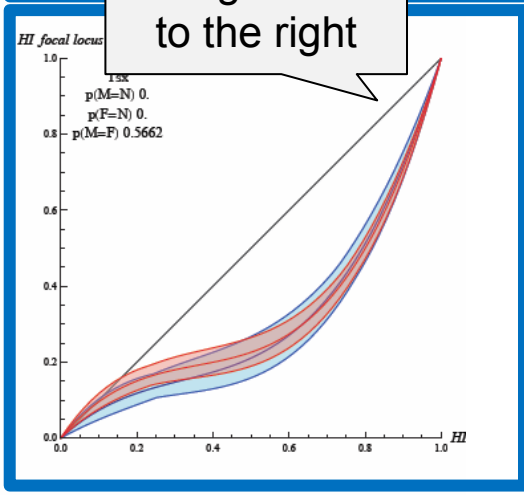


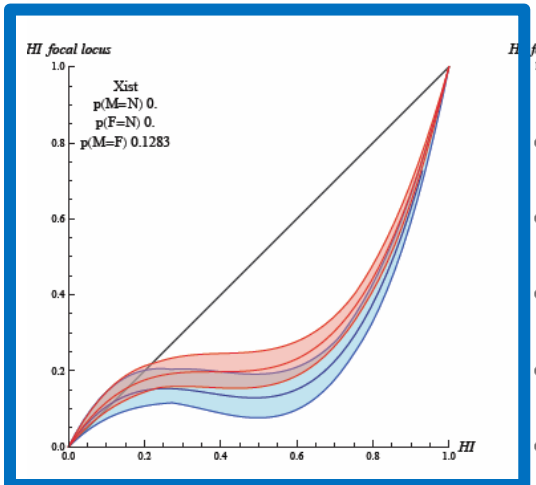


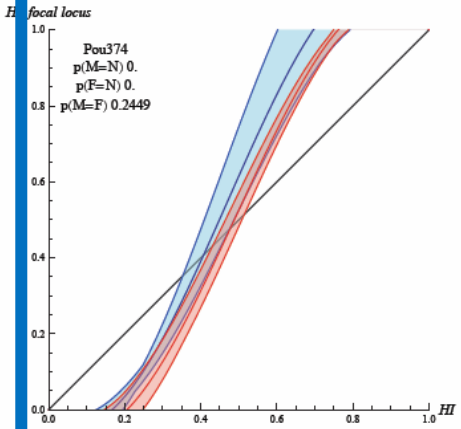
introgression to the right

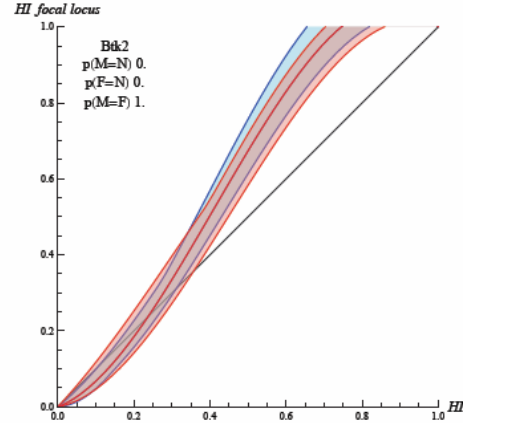












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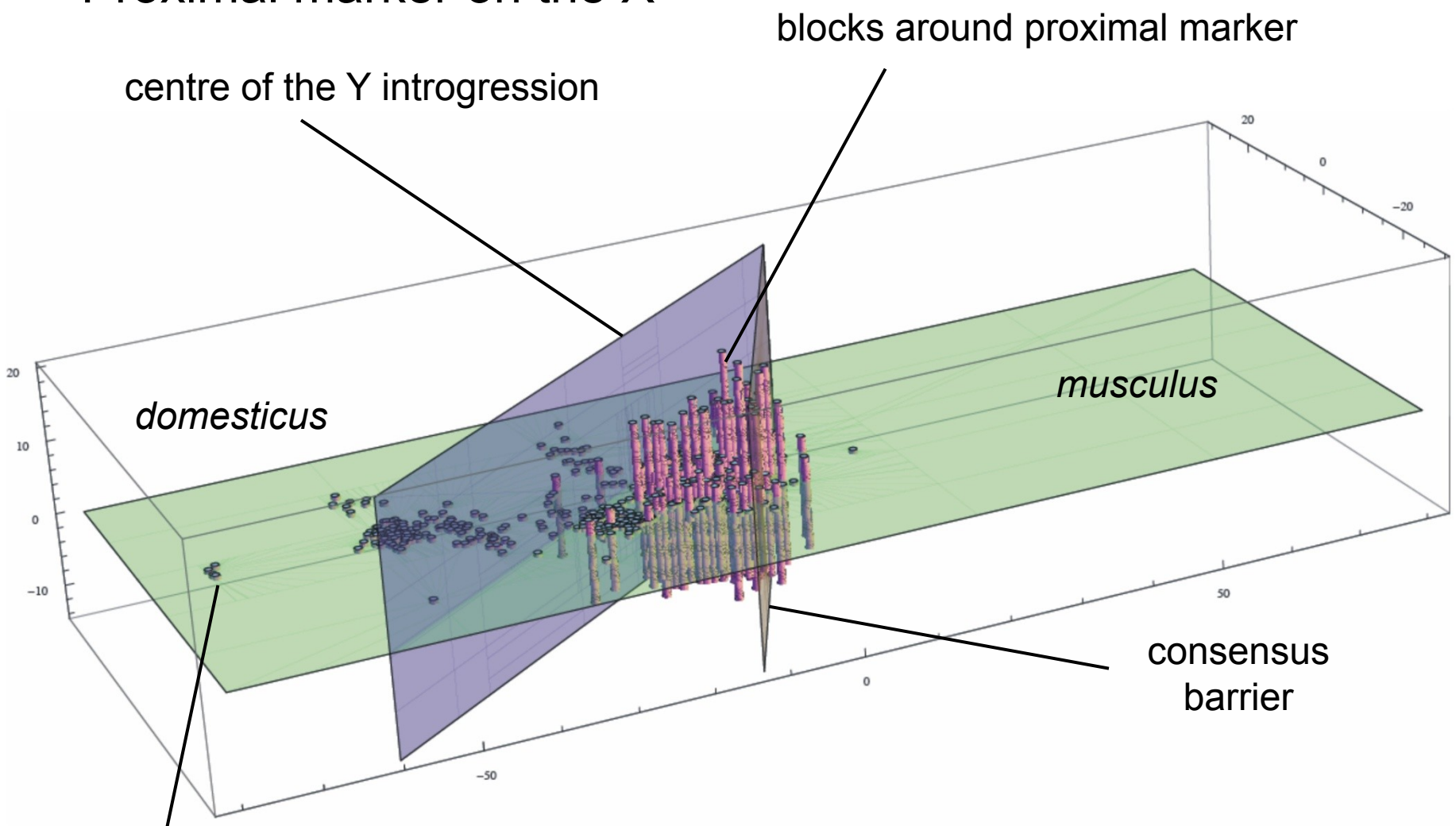
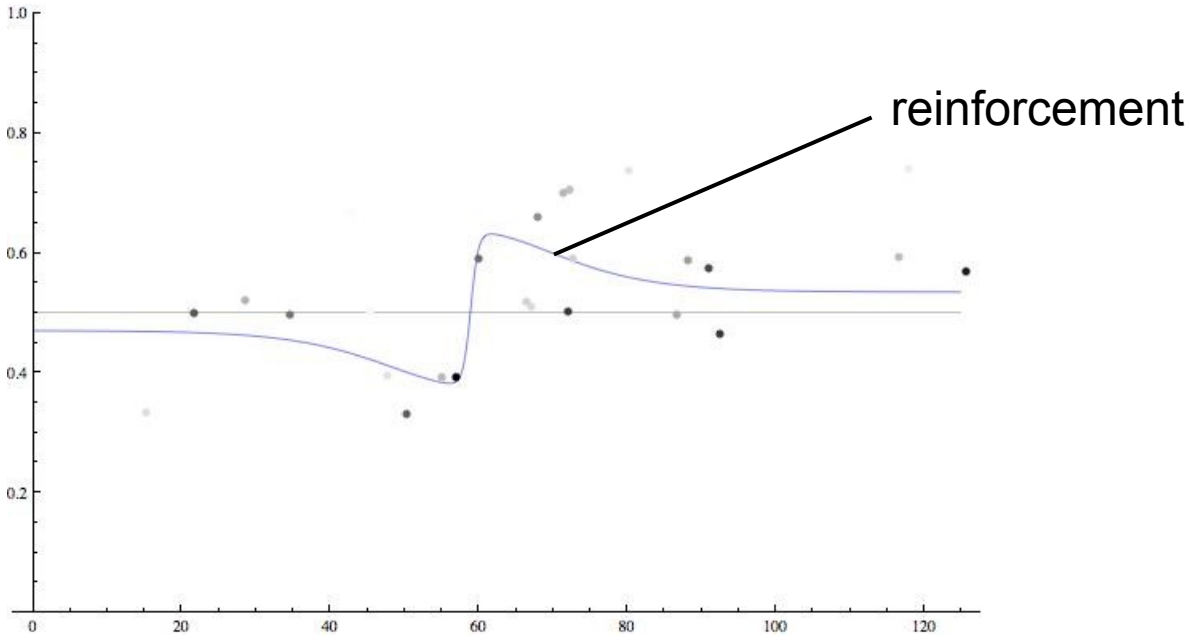
Proximal marker on the X

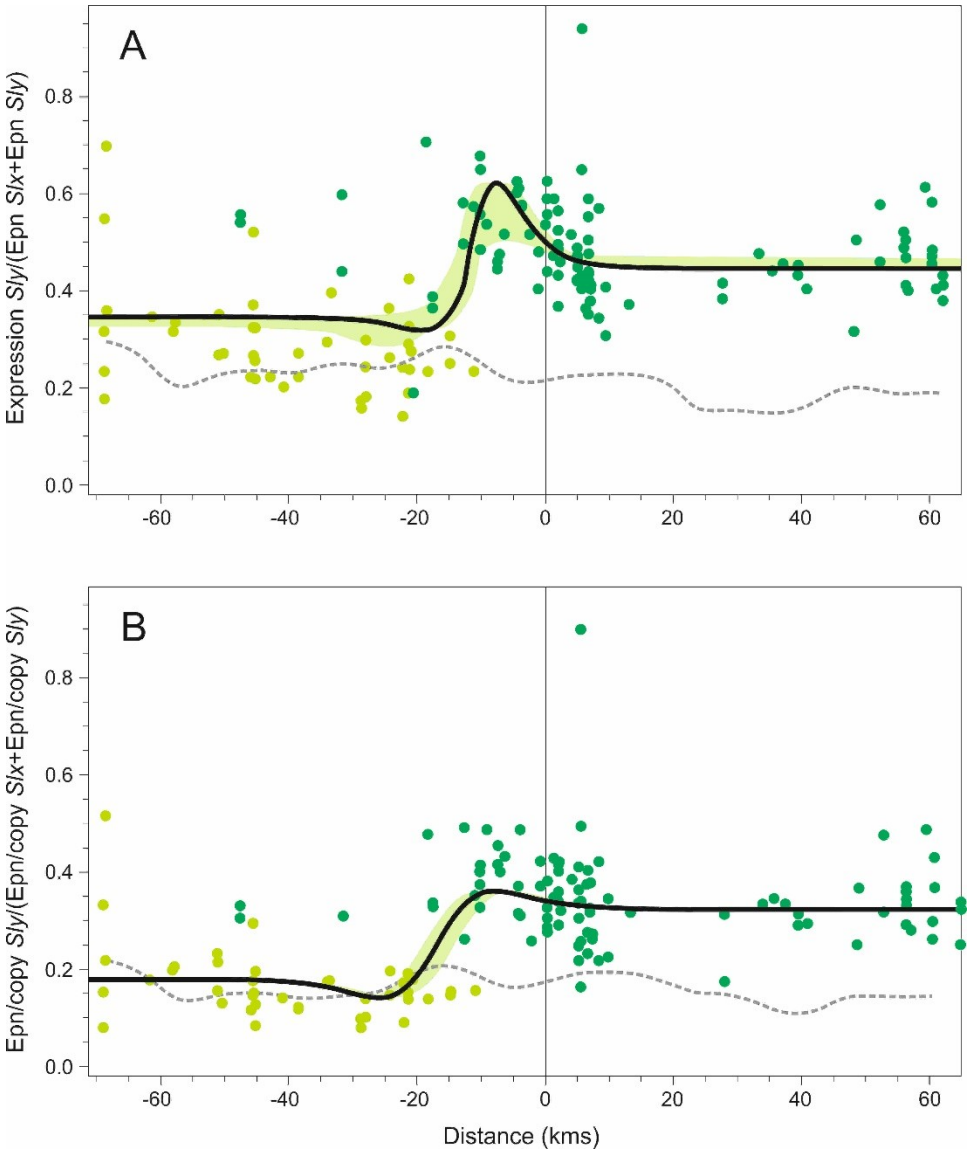


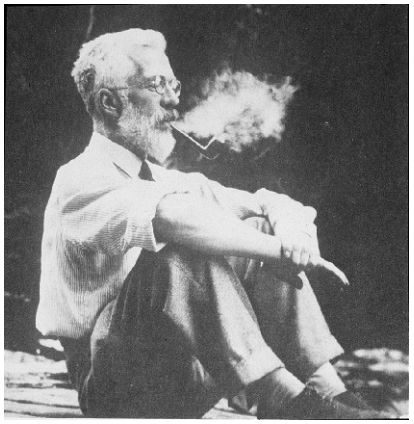
Recombination reduces size of introgressed block far of the zone centre

Using cline model for analysis of reinforcement – odour preference in the mouse hybrid zone



Using cline model for analysis of gene expression in the mouse hybrid zone – asymmetric model

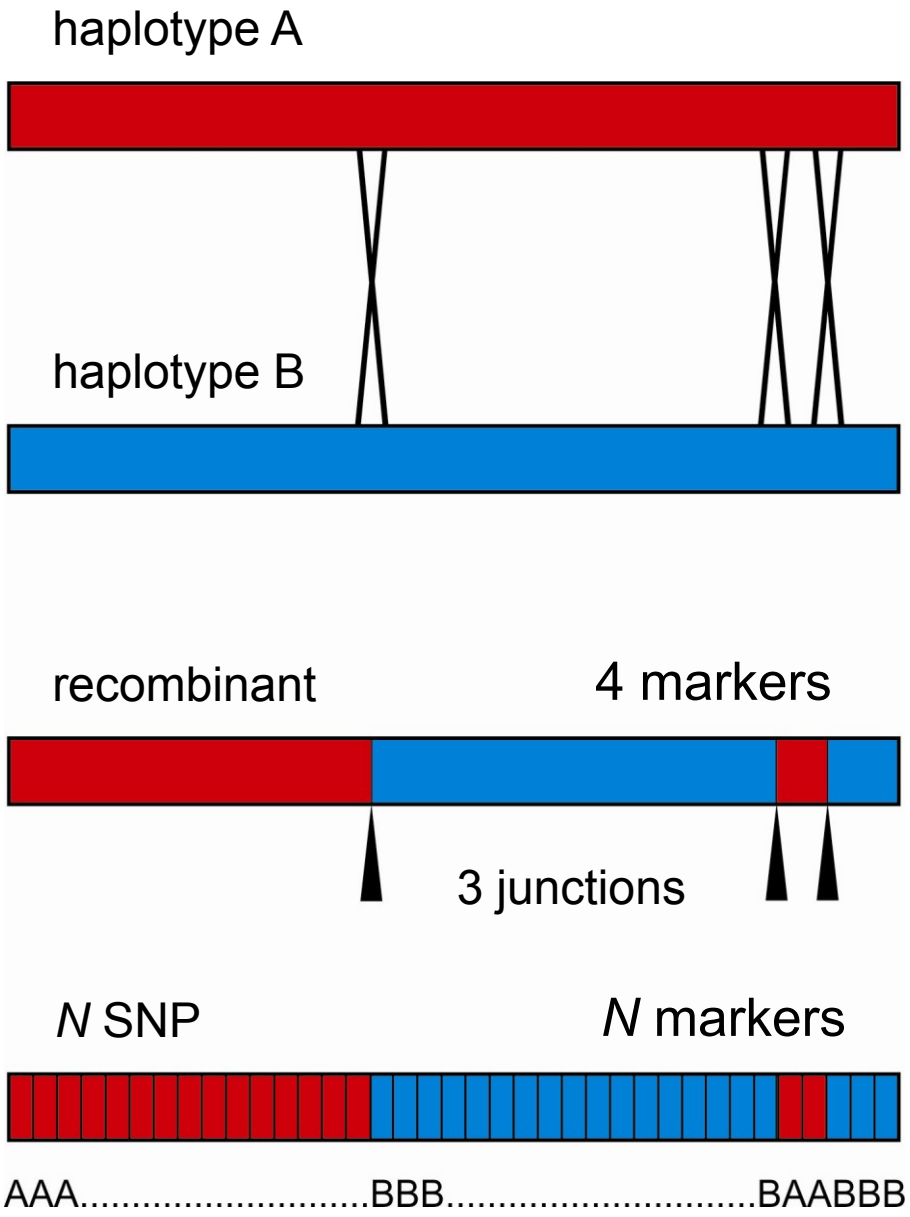




R. A. Fisher

Recombination brings together DNA of different origin and makes *junctions* (*breakpoints*)

they divide genome into *blocks* (*chunks*, *tracts*, *segments*)

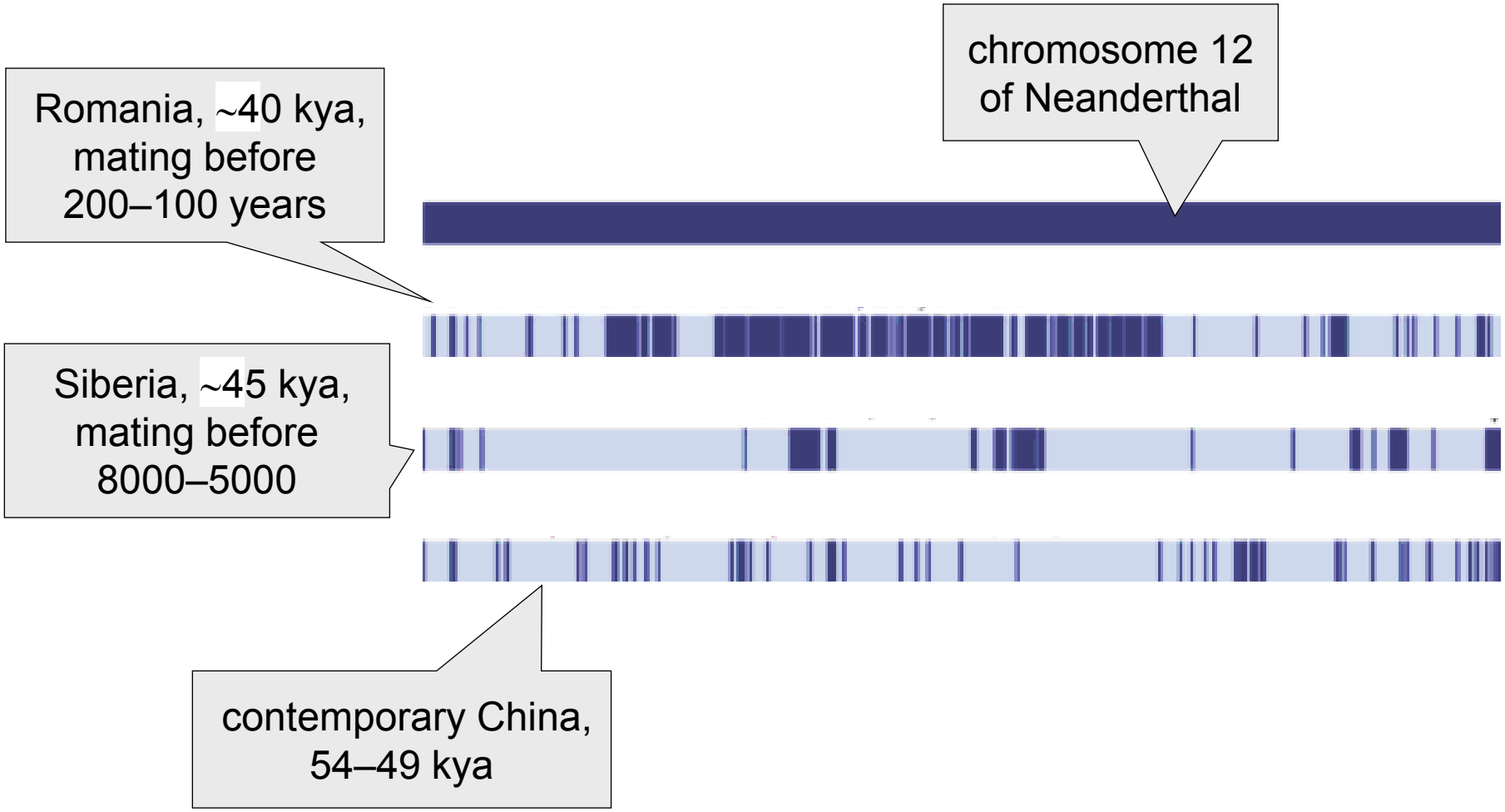


Neanderthal DNA specialist Svante Pääbo examines the
femur, found near Ust'-Ishim in western Siberia. Photogr

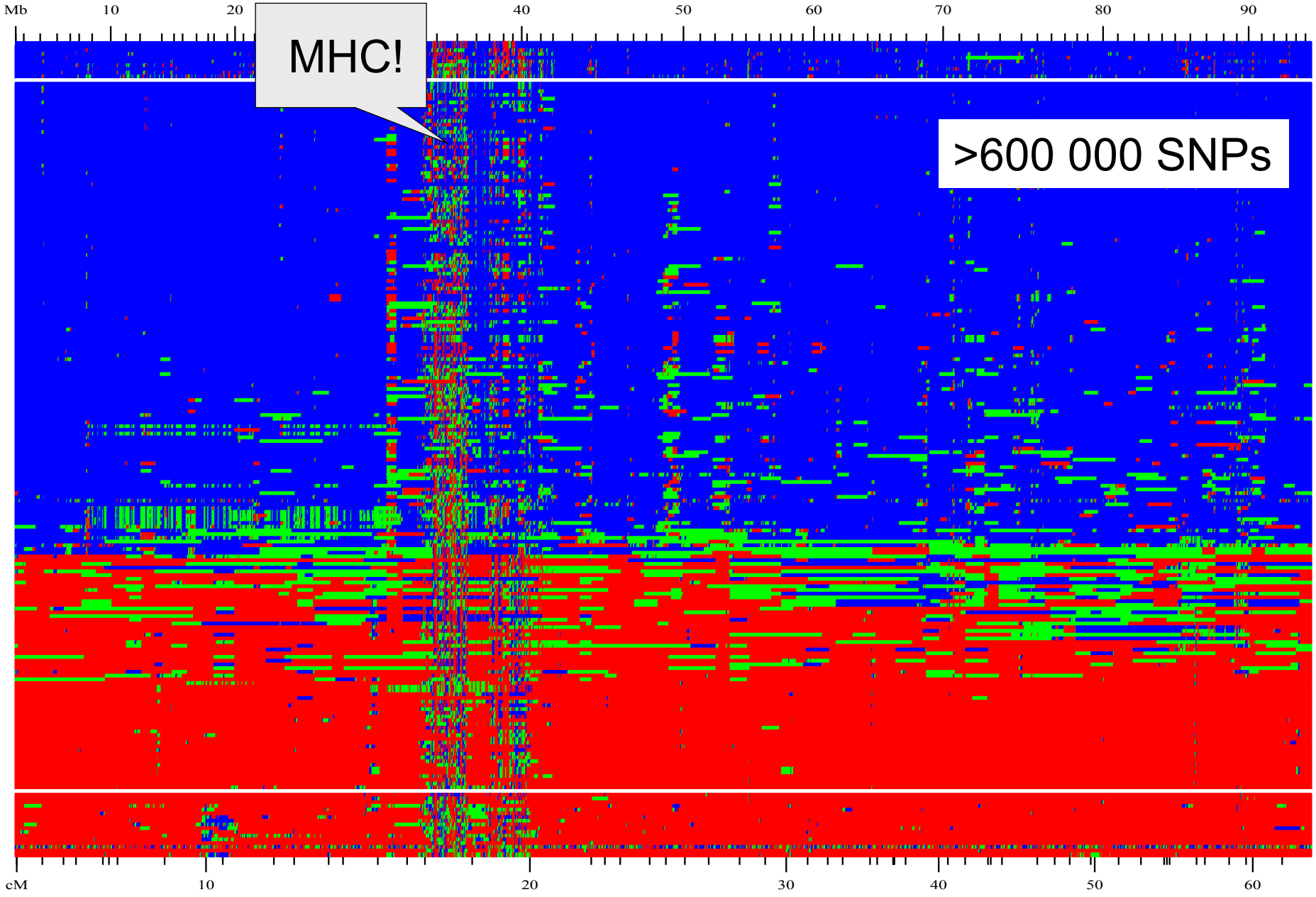
Blocks of Neanderthal DNA found in modern humans can act like a biological clock, because they are fragmented more and more with each generation since interbreeding happened. The **blocks** of Neanderthal DNA in the Siberian man were on average three times longer than those seen in people alive today. Working backwards, the scientists calculate that Neanderthals contributed to the man's genetic ancestry somewhere between 7,000 and 13,000 years before he lived.

The findings, published in the journal Nature, suggest that humans and Neanderthals had reproductive sex around 50,000 to 60,000 years ago…

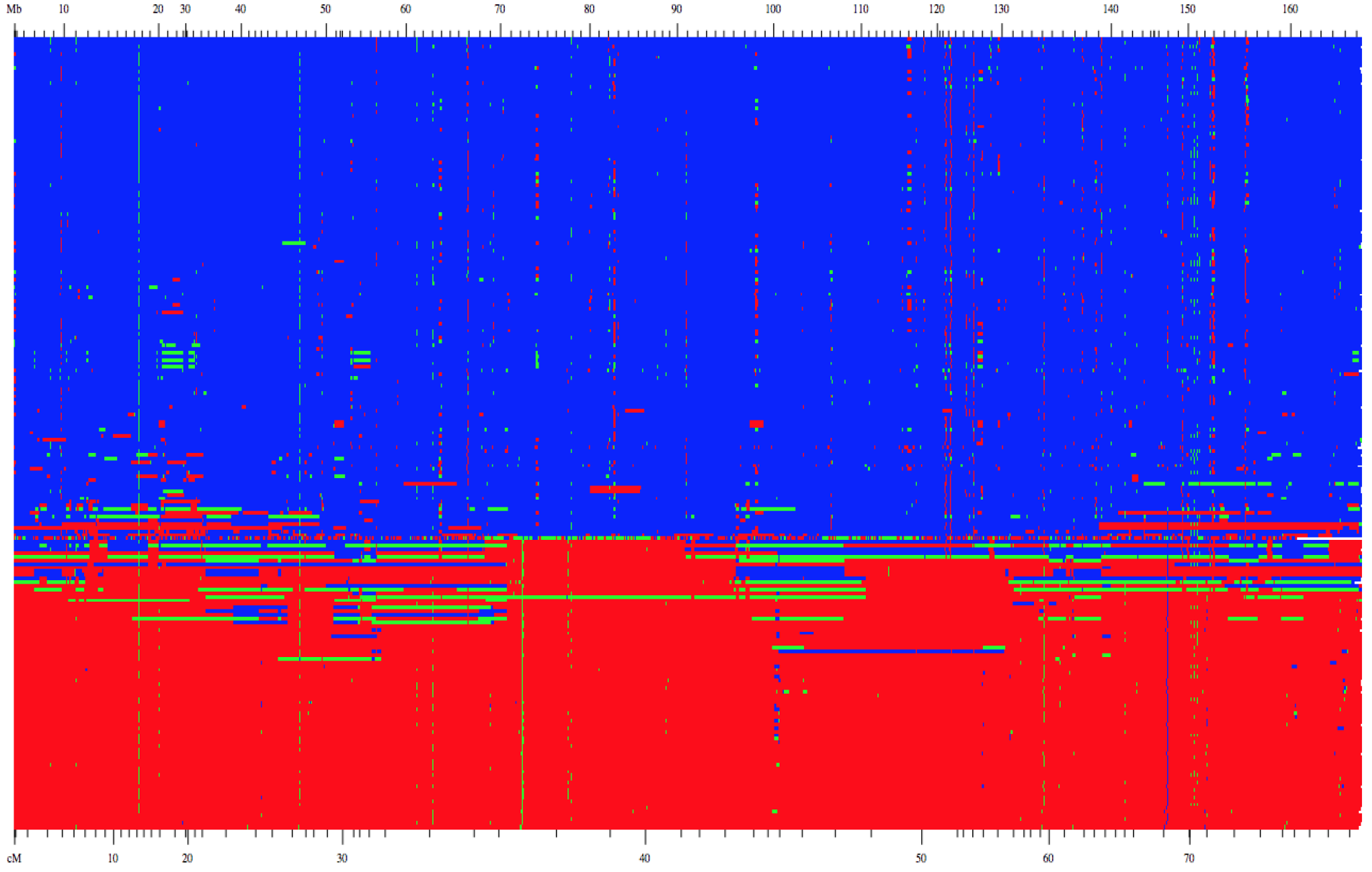
The Guardian Wednesday 22 October 2014


chromosome 12
of Neanderthal
Romania, ~40 kya,
mating before
200–100 years
Siberia, ~45 kya,
mating before
8000–5000
contemporary China,
54–49 kya

Chromosome 17

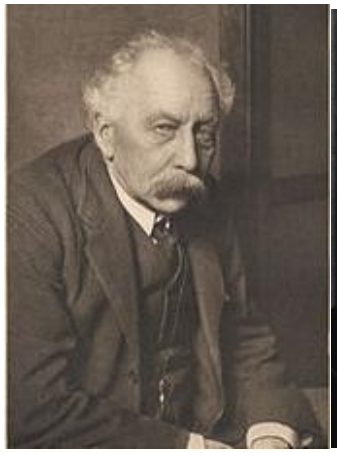


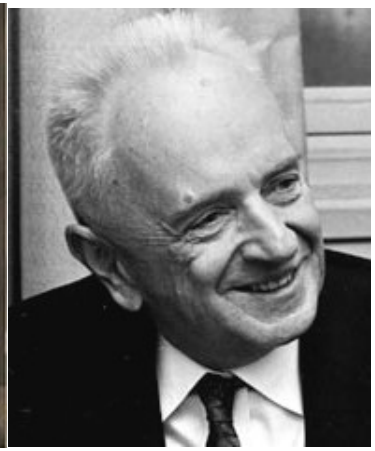
Chromozom X


Mb
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
cM
10
20
30
40
50
60
70

Why hybrid zones? Reproductive barriers and speciation!

Dobzhansky-Muller model





W. Bateson T. Dobzhansky H. Muller

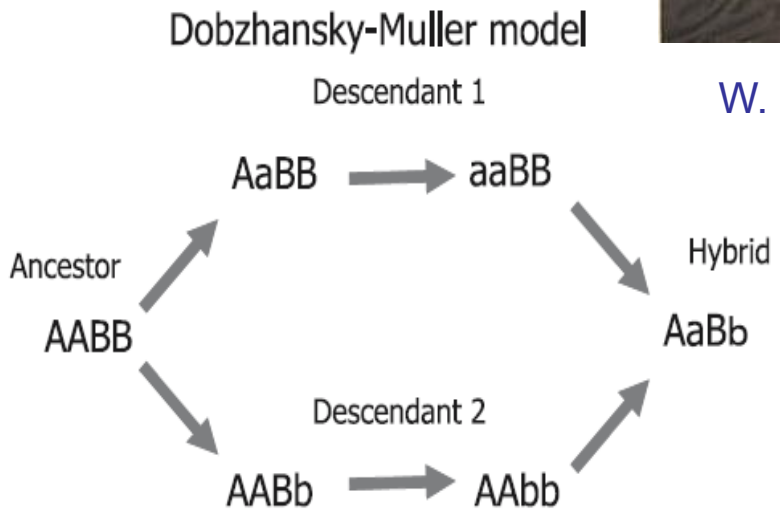
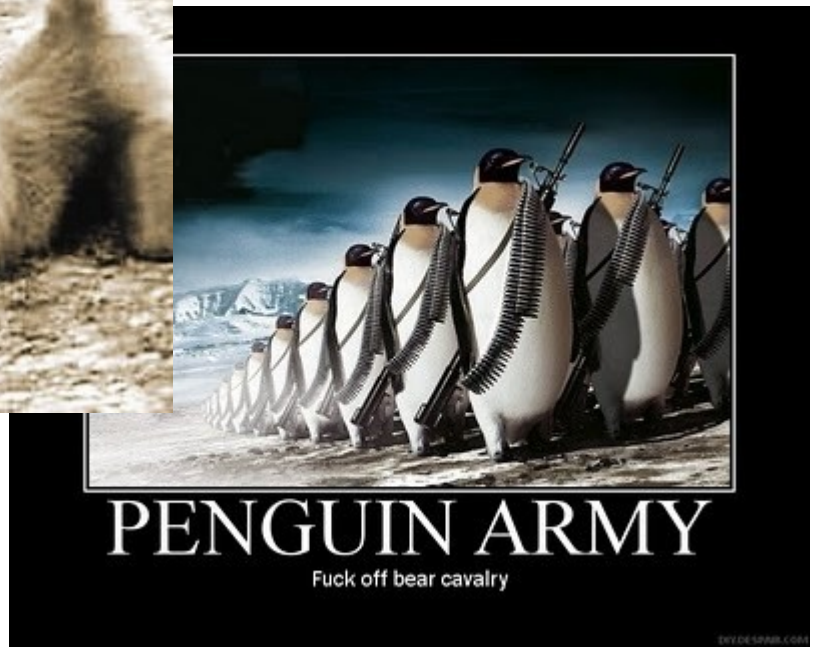


Fig. 1 The Dobzhansky–Muller model for postzygotic isolation

„Arms races“ and secondary contact



genetic conflict: “classical” scenario

arms race
in ancestral
population

subpop. 1

continuing
arms race

subpop. 2

incompatible!

secondary contact

MAD = *mutually assured destruction*

“speciation genes”

genetic conflict: alternative scenario

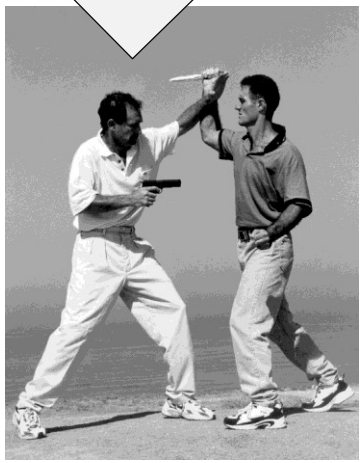
arms race
in ancestral
population

subpop. 1

continuing
arms race

subpop. 2

secondary contact

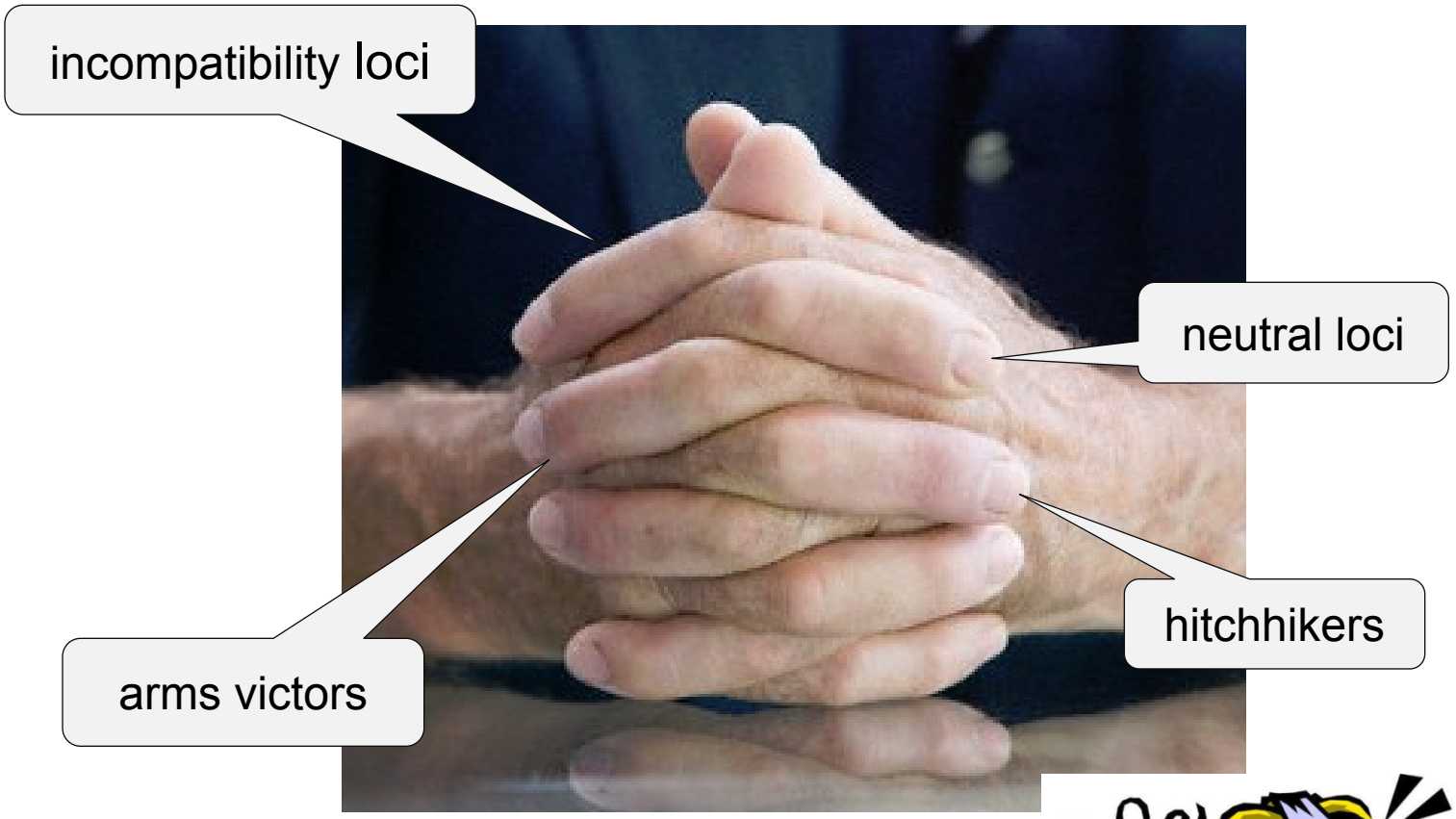


Never bring a knife to a gunfight!

the winner thrives on "naive" genetic background

"antispeciation genes"

Why we don’t see this more often?



Ticking time-bomb...

Cytonuclear disequilibria

- = non/random associations of nuclear and cytoplasmic (mitochondrial) alleles
- 3 × 2 table

	nuclear genotype:			
mtDNA:	*AA*	*Aa*	*aa*	**total**
M	u_1	v_1	w_1	***x***
m	u_2	v_2	w_2	***y***
total	***u***	***v***	***w***	**1**

No hybridization

mtDNA:	nuclear genotype: *AA*	*Aa*	*aa*
M	+++	0	0
m	0	0	+++

Random mating, hybrid swarm

mtDNA:	nuclear genotype: *AA*	*Aa*	*aa*
M	obs=exp	obs=exp	obs=exp
m	obs=exp	obs=exp	obs=exp

Hybridization without apparent introgression, crossing independent of sex

mtDNA:	nuclear genotype: AA	Aa	aa
M	++	obs=exp	0
m	0	obs=exp	++

Hybridization without apparent introgression, crossing depends on sex

mtDNA:	nuclear genotype: *AA*	*Aa*	*aa*
M	++	++	0
m	0	--	++

Hybrids mate more often with less discriminating species

mtDNA:	nuclear genotype: *AA*	*Aa*	*aa*
M	obs=exp	++	--
m	obs=exp	--	++

Symmetrical introgression

mtDNA:	nuclear genotype: *AA*	*Aa*	*aa*
M	++	obs=exp	--
m	--	obs=exp	++

Potential introgression, crossing dependent on sex

mtDNA:	nuclear genotype: AA	Aa	aa
M	++	++	--
m	0	0	++