



# Geonomics Simulation Lab

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*Lab created by: Drew Terasaki Hart, Natalie Graham, Monica Wilkinson  
and Keeley Takimoto*



# What is a simulation?

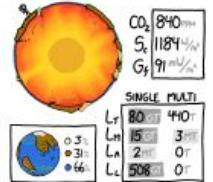
WHAT GAME IS THAT?

TECTONICS!

YOU STEER CHUNKS OF CRUST AROUND, RIFTING, SUBDUCTING AND BUILDING AND ERODING MOUNTAINS.



YOU TRY TO KEEP YOUR CLIMATE STABLE AND YOUR BIOSPHERE RICH. AVOID MAKING LARGE IGNEOUS PROVINCES! THEY'RE THE WORST.



COOL!  
I CAN I TRY?

SURE!

...HOW DO I UNPAUSE?  
IT'S NOT PAUSED.  
CONTINENTS CAN ONLY MOVE A FEW INCHES PER YEAR.

...

L<sub>f</sub> 80%, L<sub>m</sub> 440%, L<sub>a</sub> 0%, L<sub>n</sub> 3%, L<sub>d</sub> 0%, L<sub>e</sub> 0%, L<sub>g</sub> 91 m/s

IT'S REAL-TIME?

JUST 400 MILLENNIA TO GO UNTIL YOUR FIRST MOUNTAIN ACHIEVEMENT!



# Evolutionary Simulations in Geonomics

**Geonomics: Forward-Time, Spatially Explicit, and Arbitrarily Complex Landscape Genomic Simulations** 

Drew E Terasaki Hart , Anusha P Bishop, Ian J Wang

*Molecular Biology and Evolution*, Volume 38, Issue 10, October 2021, Pages 4634–4646,  
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*Simulation of local adaptation and speciation across realistic landscapes*



# Introduction to evolutionary simulations with Geonomics (Part 1)

The goal of this notebook is to get you to think critically about how evolution happens across space. This notebook will also introduce you to the usefulness of modeling and simulations for understanding evolutionary scenarios. We are using a Python package call "**Geonomics**" that was conceived and created by Dr. Drew Terasaki Hart a former graduate student at UC Berkeley in Ian Wang's lab in the College of Natural Resources, Environmental Science, Policy and Management Department.

- **Geographic variation:** As you've learned in lecture, there is often a geographic component to genetic divergence. Both genetic drift (founder effects in particular) and natural selection are facilitated by geographic isolation, while gene flow tends to be impeded by it (although this is not always the case). It makes sense to simulate evolution in a programmatic way that allows for explicit and different spatial landscape scenarios, just like in real life.

*Geonomics* allows the user to test hypotheses and run simulations about how the spatial arrangement and size of populations of organisms while incorporating any realistic or modeled geospatial **layers** of a landscape. The so-called forces of evolution can all be simulated: mutation, natural selection, founder effects, genetic drift, and gene-flow. The result is a very flexible platform to allow prediction of evolutionary outcomes during population divergence leading to speciation.

## Glossary

```
parameters:{  
    landscape: {  
        :  
    }  
  
    community: {  
        species: {  
            :  
  
            genomic_arch: {  
                :  
            }  
        }  
    }  
  
    model: {  
        :  
    }  
}
```

# What is all that code?

# Parameters = Recipe



## Brownie in a Mug

- 3 tablespoons sugar
- 3 tablespoons flour
- 1 ½ tablespoons cocoa powder
- 1 ½ tablespoons melted butter
- 3 tablespoons milk
- ¼ teaspoon vanilla extract

=

```
'mug_brownie': {  
    'sugar': 3  
    'flour': 3  
    'cocoa_powder': 1.5  
    'melted_butter': 1.5  
    'milk': 3,  
    'vanilla_extract': 0.25  
}
```

# Let's make a species!

Reproduction

Movement



```
'dragon': {  
    'mating' : {  
        <whatever you want to simulate!>  
    },  
    'mortality' : {  
        <whatever you want to simulate!>  
    },  
    'movement': {  
        <whatever you want to simulate!>  
    },  
},
```

Reproduction



Movement

# Let's make a landscape!



```
'landscape': {  
    'layers': {  
        <whatever you want to simulate!>  
    }  
},
```





```
'landscape': {  
    'layers': {  
        <whatever you want to simulate!>  
    }  
},
```



```
'landscape': {  
    'layers': {  
        <whatever you want to simulate!>  
    }  
},
```

# How does speciation occur?

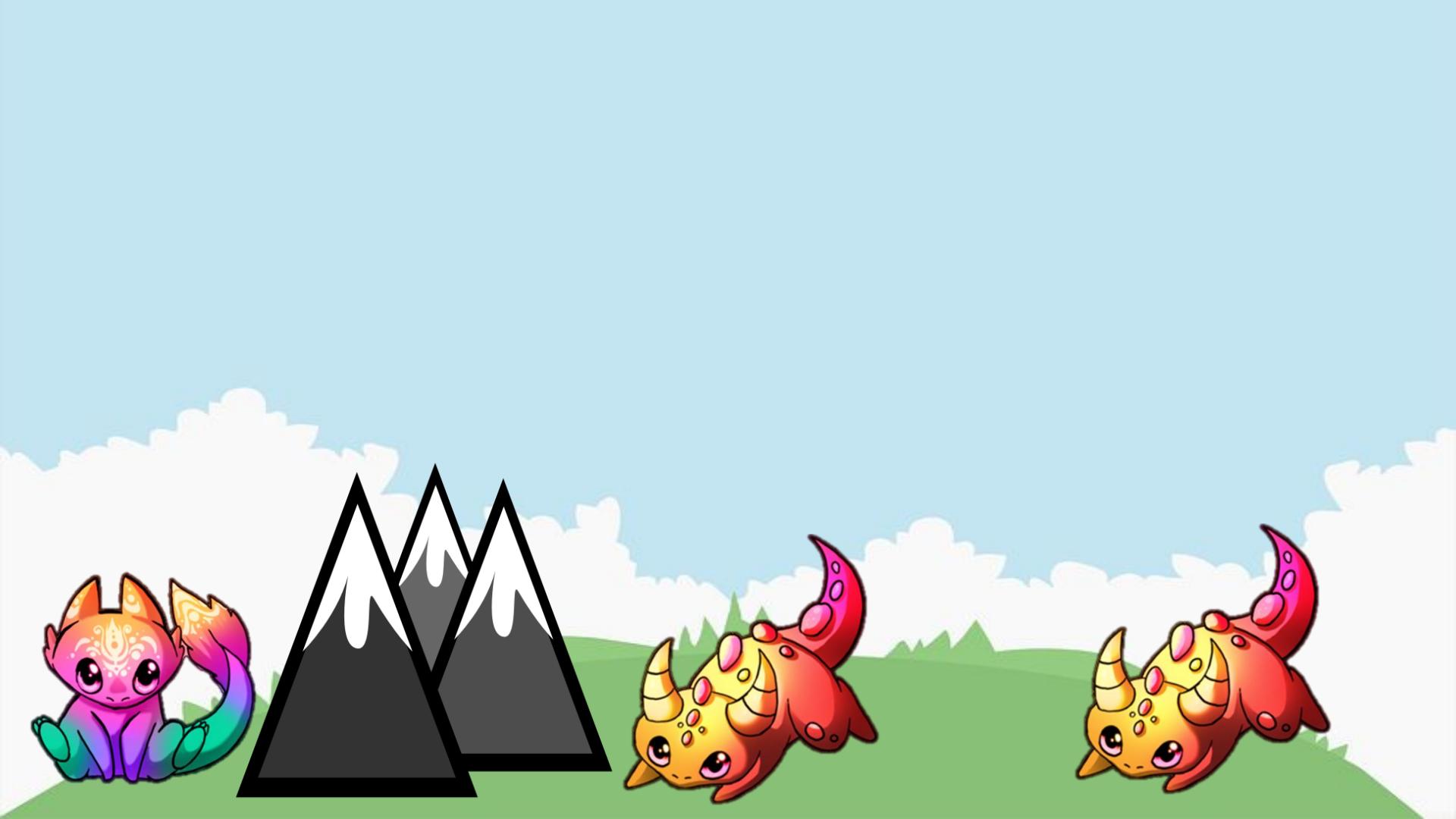


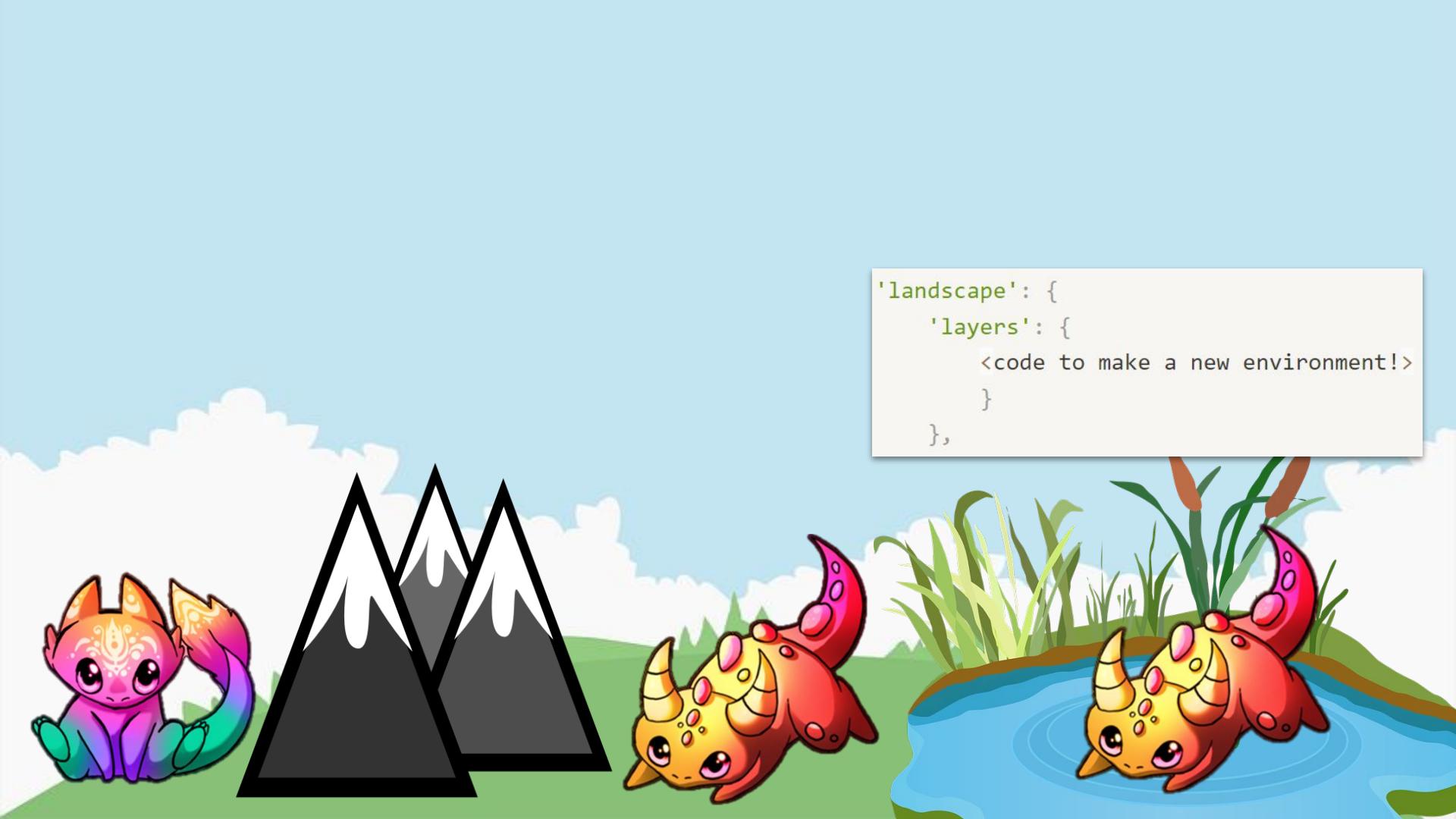
# How does speciation occur?



```
'landscape': {  
    'layers': {  
        <code to make a barrier!>  
    }  
},
```

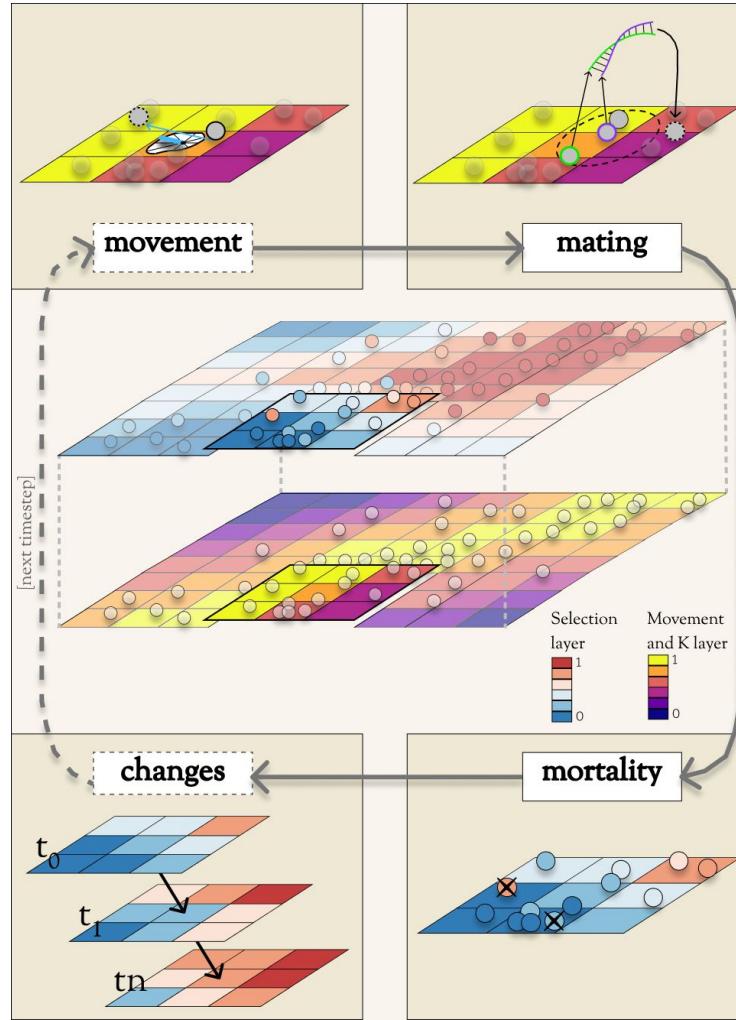






```
'landscape': {
    'layers': {
        <code to make a new environment!>
    }
},
```





### 1.) Create and edit a parameters file

*parameters file:*

```
parameters:{  
    landscape: {  
        .  
    }  
    community: {  
        species: {  
            .  
            genomic_arch: {  
                .  
            }  
        }  
    }  
    model: {  
        .  
    }  
}
```

*Optional: Include paths to raster files and/or directories of environmental-change rasters*

*raster file:*



*raster directory:*



*Optional: include path to a genomic architecture file (.csv)*

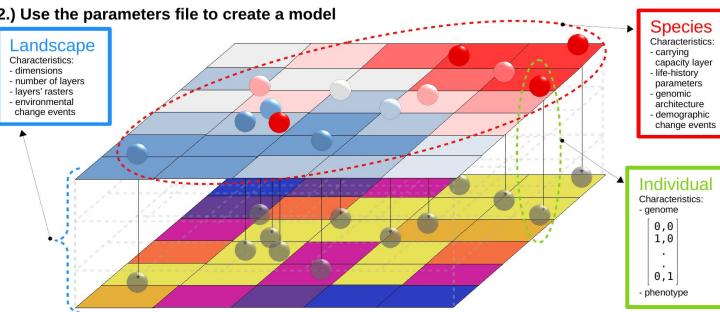
*genomic architecture file:*

loc,	p,	dom,	r,	trait,	alpha,	,
1,	0.5,	0,	0.5,	,	,	,
1,	0.5,	0,	0.5,	,	0.5,	,
1,	0.5,	0,	0.01,	0,	0.5,	,
1,	0.5,	0,	0.01,	1,	0.5,	,
1,	0.5,	0,	0.01,	2,	0.5,	,
1,	0.5,	0,	0.5,	,	,	,
1,	0.5,	0,	0.5,	,	,	,
.	.	.	.	.	.	.
.	.	.	.	.	.	.

### 2.) Use the parameters file to create a model

**Landscape**

Characteristics:  
- dimensions  
- number of layers  
- layers' rasters  
- environmental change events



**Species**

Characteristics:  
- carrying capacity layer  
- history parameters  
- genomic architecture  
- demographic change events

**Individual**

Characteristics:  
- genome:  

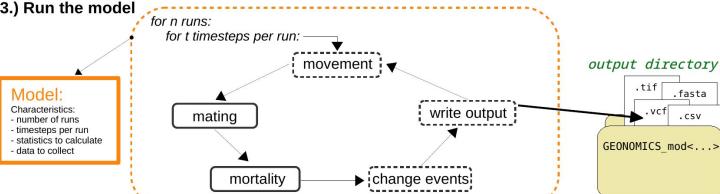
0,0
1,0
.
0,1

  
- phenotype

### 3.) Run the model

**Model:**

Characteristics:  
- number of runs  
- timesteps per run  
- statistics to calculate  
- data to collect

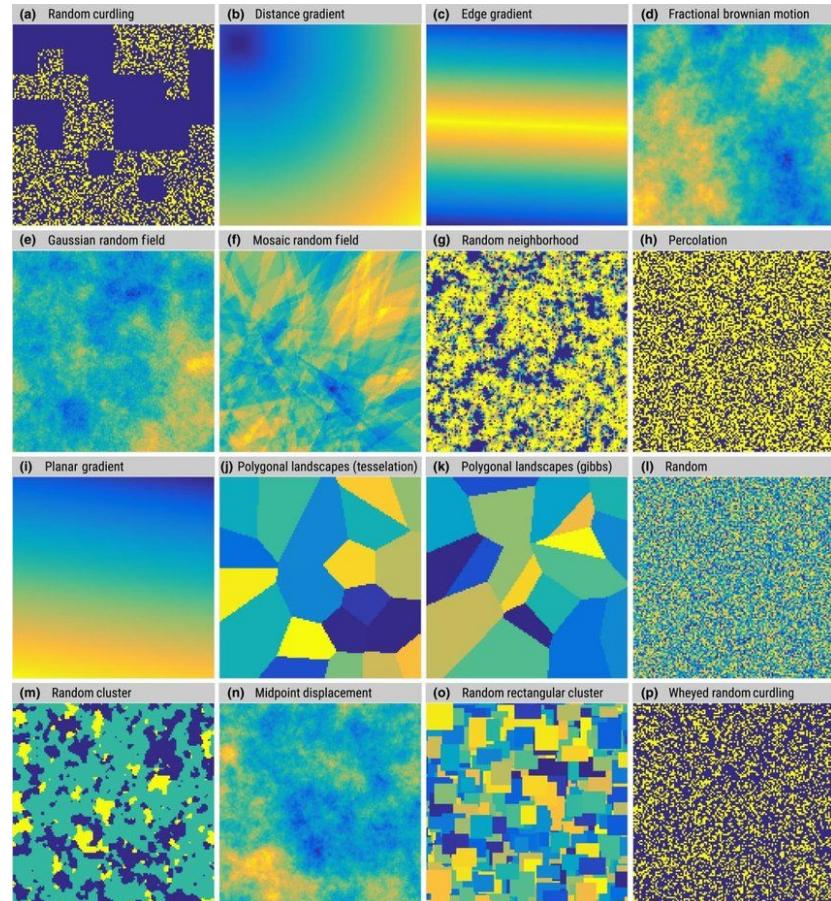




# Part 1: Neutral Evolution

# Neutral Landscape Models

Like a toy landscape!





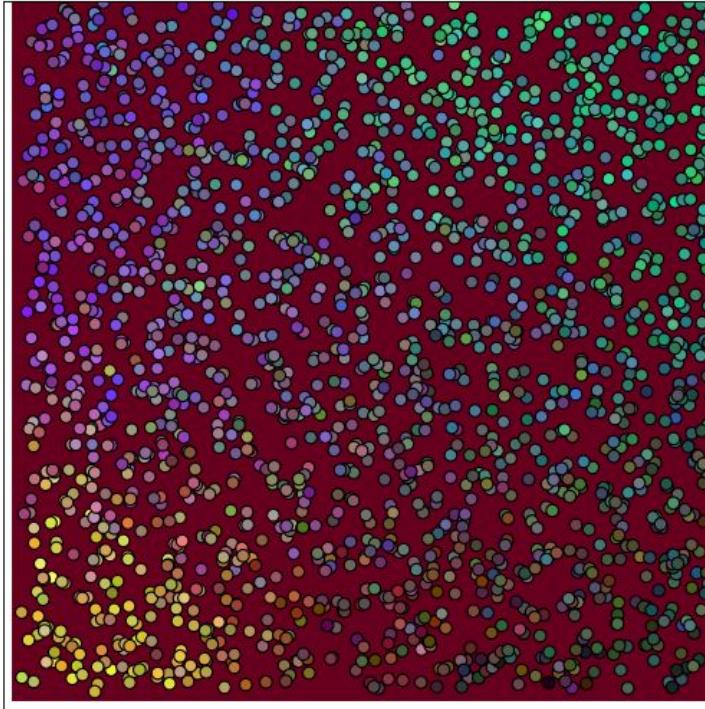
## **Part 2:** Environmental Change

# Hypothesis Testing:

## What is the impact of a new road on population fragmentation?

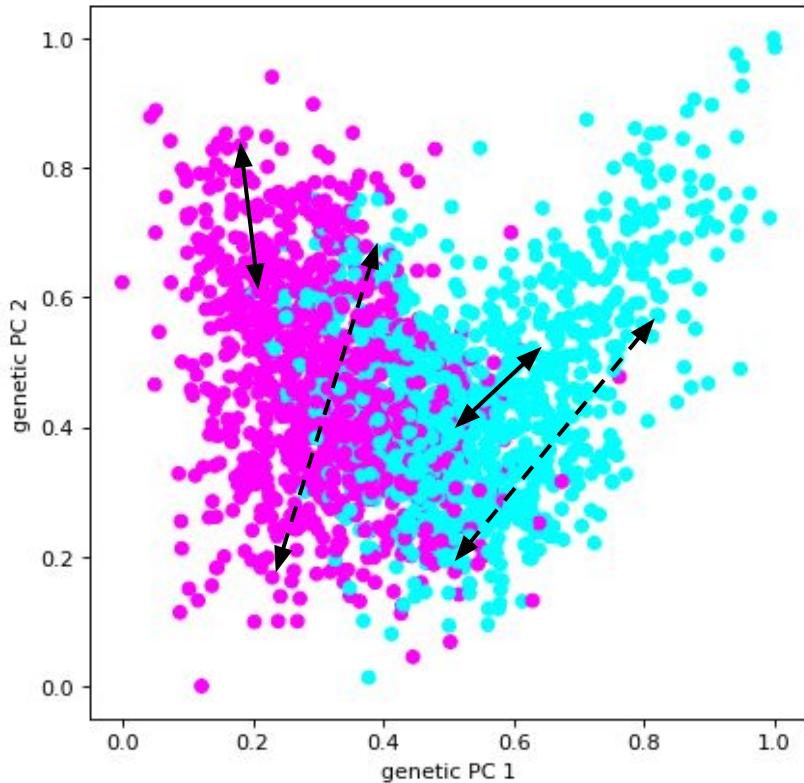


# PCA plots



**Individuals that have more similar colors are more similar**

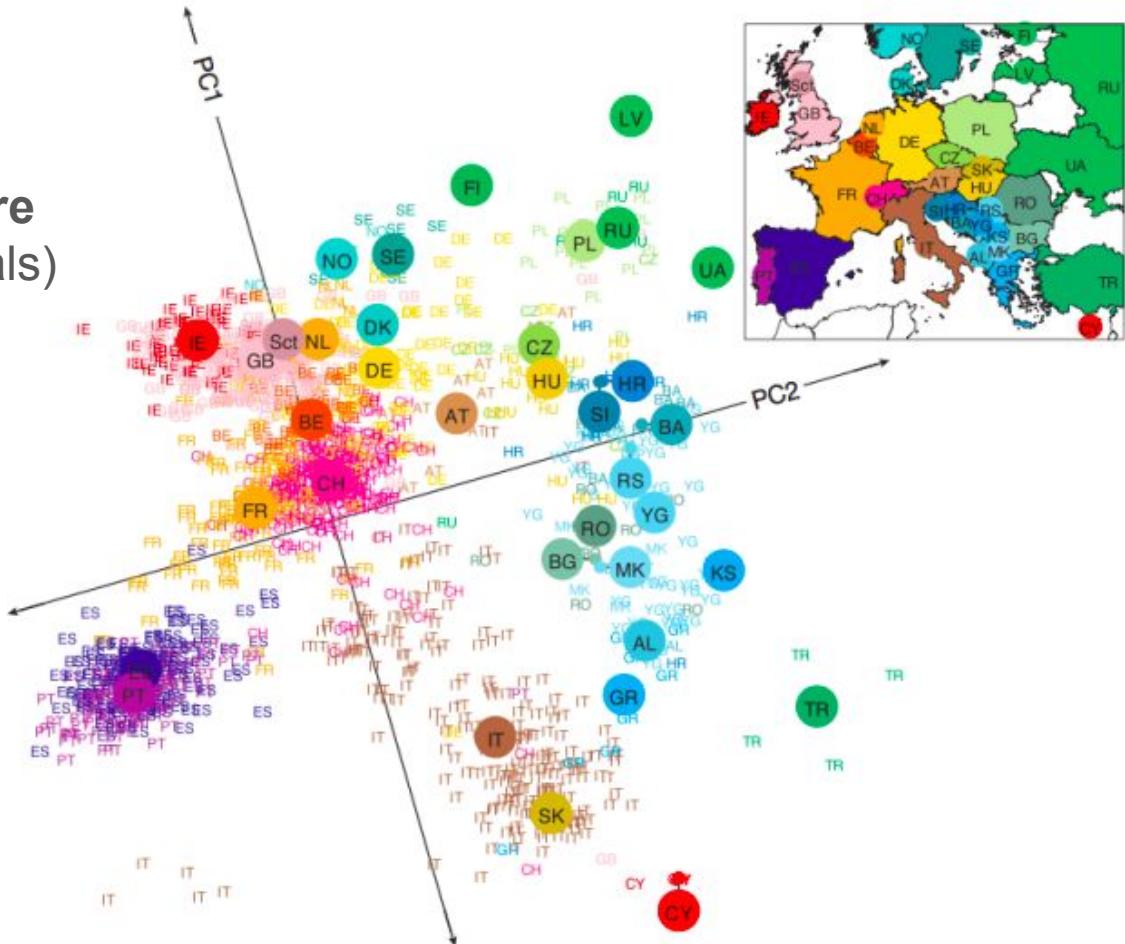
# PCA plots



**Individuals that are closer on the plot are more similar**

**Blue** = individuals on right side of road  
**Pink** = individuals on left side of road

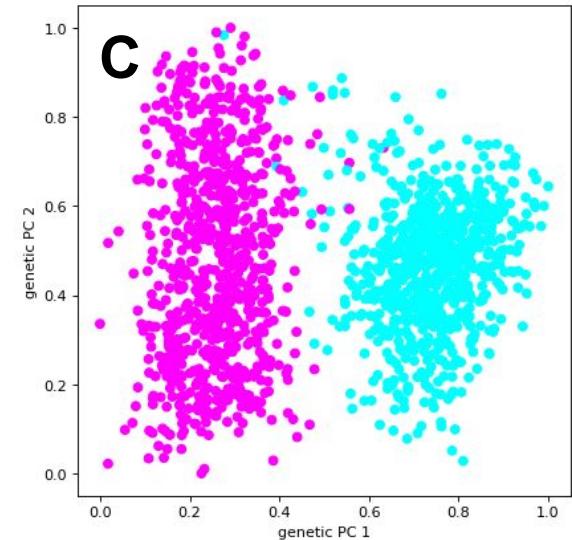
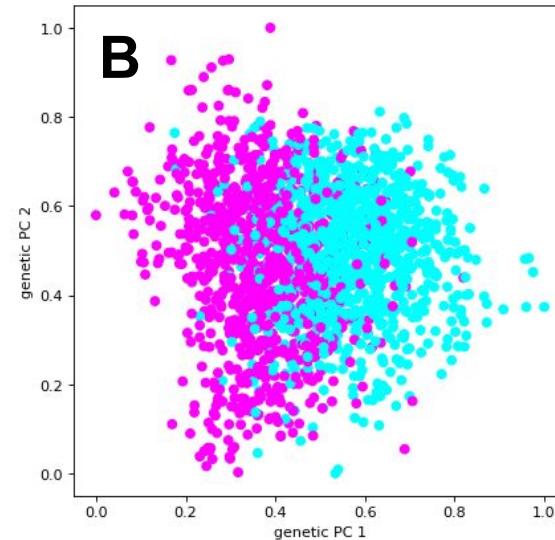
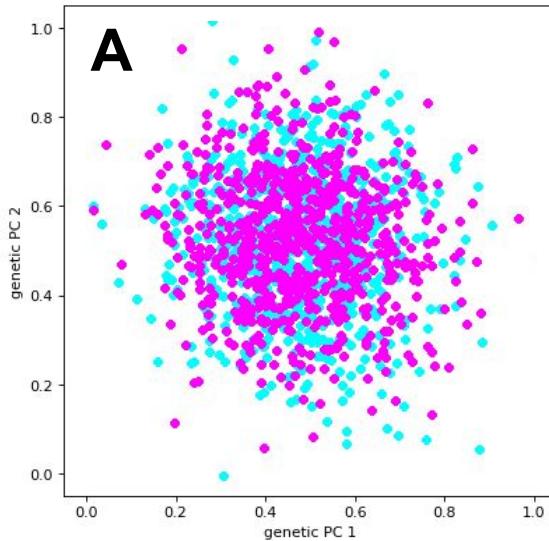
## European Population Structure (genomic data from 3k individuals)



ex: [Novembre et al., 2008](#)

# Null Hypothesis:

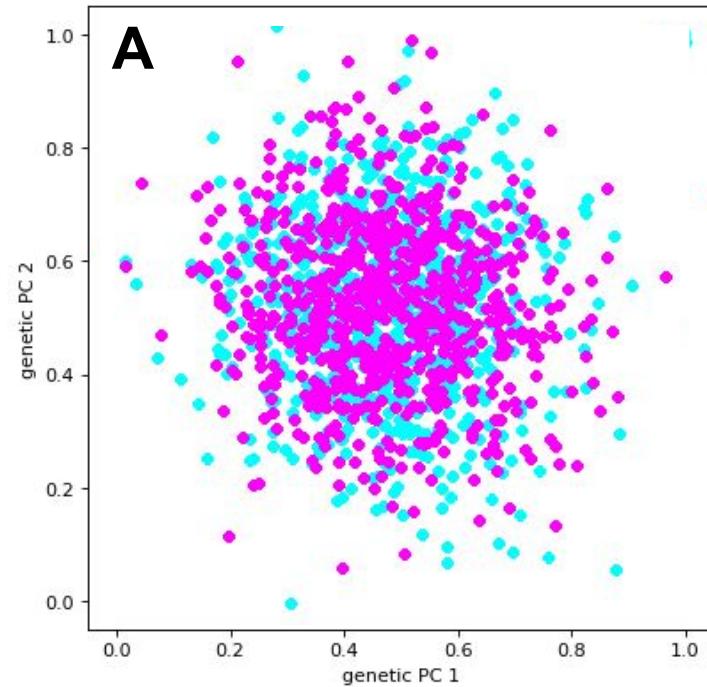
What would you expect if the road is not causing divergence?



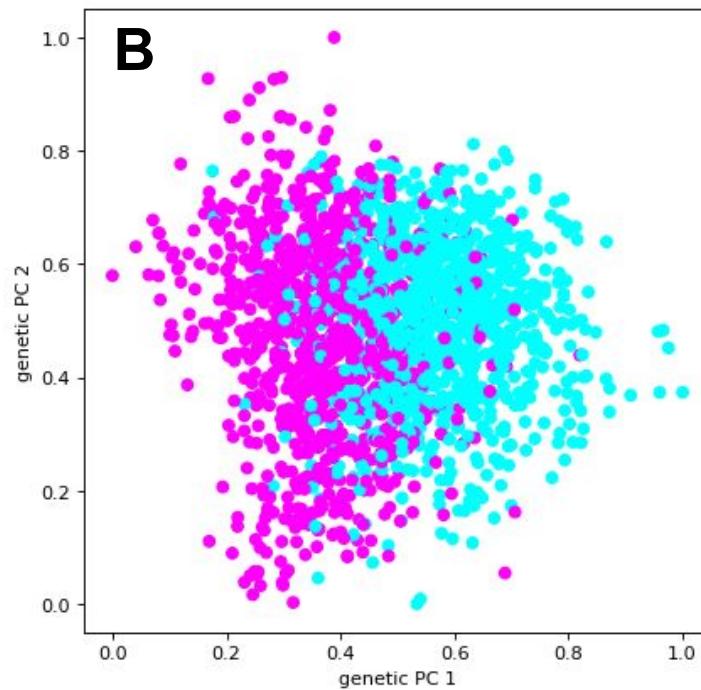
**Blue** = individuals on right side of road  
**Pink** = individuals on left side of road

Test it out!

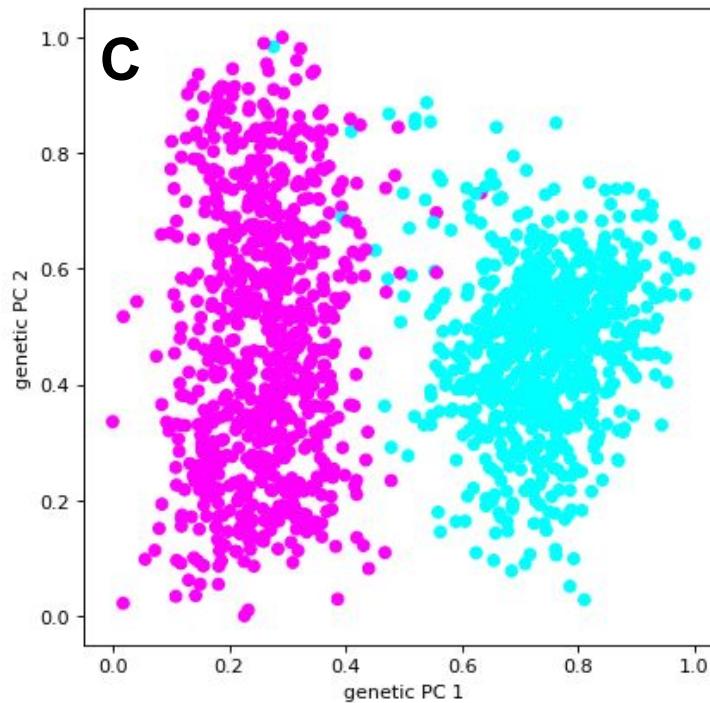
Intuitively, we might expect that if there is no divergence, the two sides of the road will be the same...



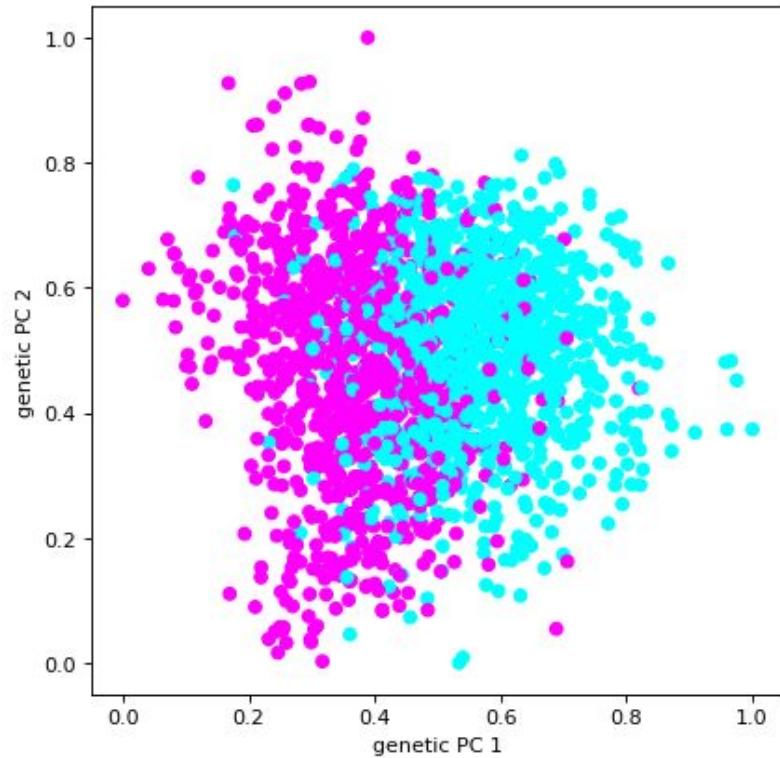
But, our simulations show that some clustering can occur even if there is no barrier...



Our simulations tell us that if the new barrier is causing divergence it should look more like this:



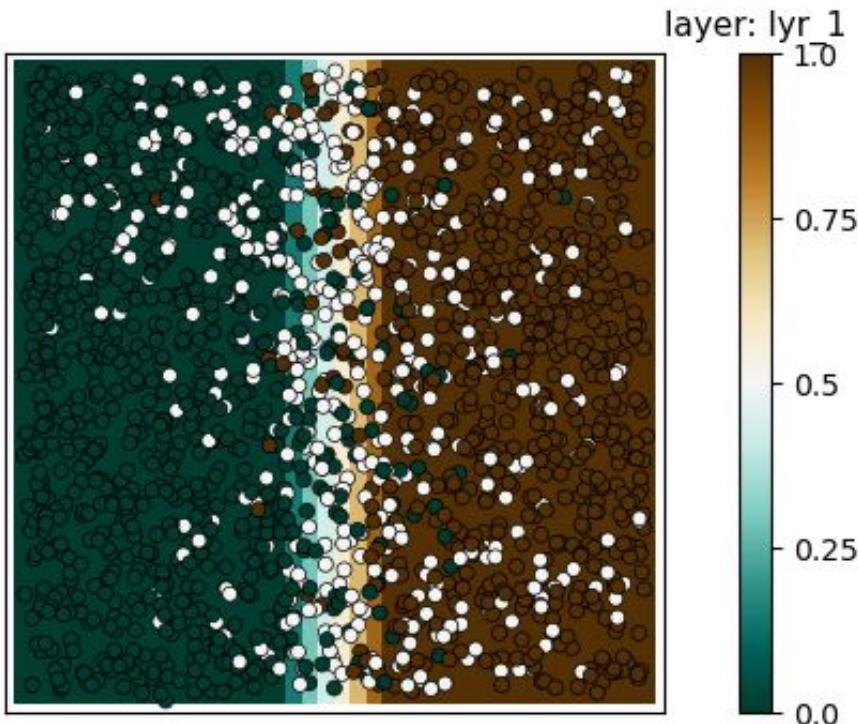
# What are some reasons you might be getting a null result?





## **Part 3:** Natural Selection

# Selection plots



Individual color = trait  
Landscape color = env

*Individual color matches the background color = local adaptation*



# Bonus: Hypothesis Testing

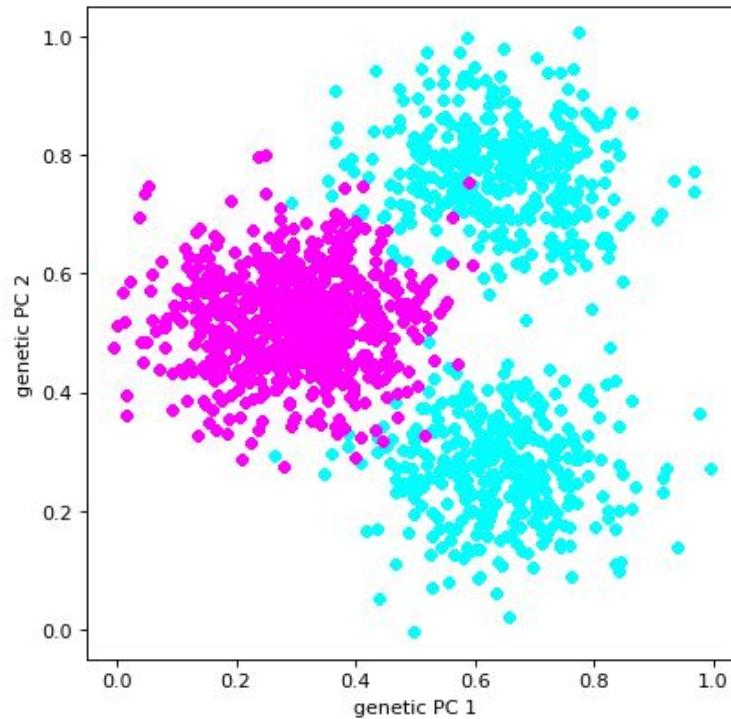
# Hypothesis Testing:

## What is the impact of a new road on population fragmentation?



Let's say you sample individuals, sequence their genotypes, and make a PCA plot, and it looks like this:

**Blue** = individuals on right side of road  
**Pink** = individuals on left side of road



Brainstorm some hypotheses as to why you might see that pattern

How could you test these hypotheses with simulations?



# Simulating climate change

*S. graciosus*



Yosemite National Park

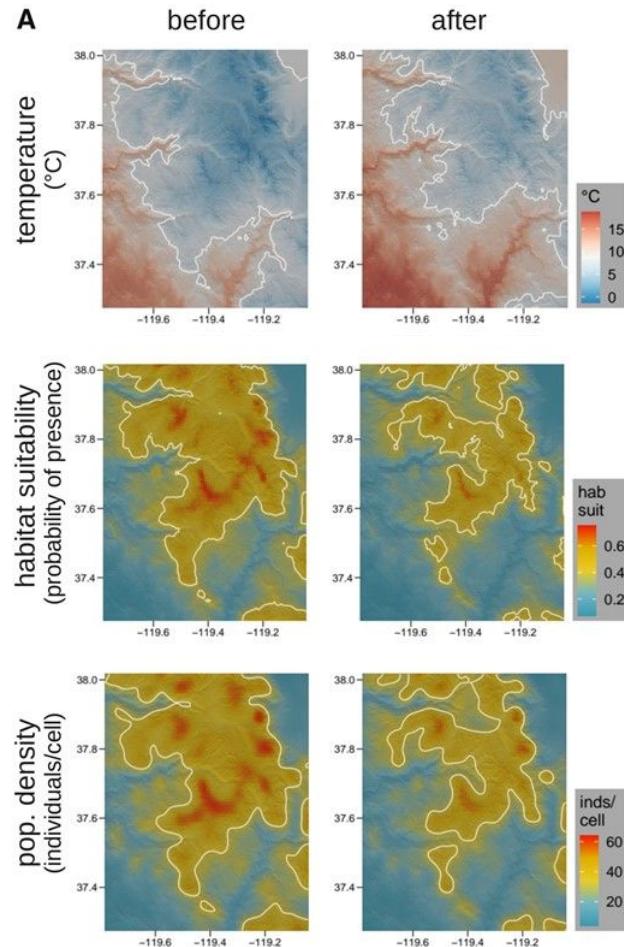


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# Developing and testing new methods



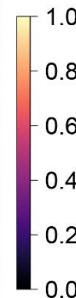
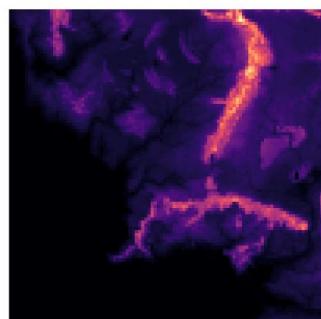
wingen

codecov 98% test-coverage passing license MIT

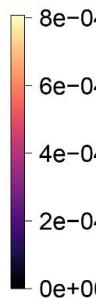
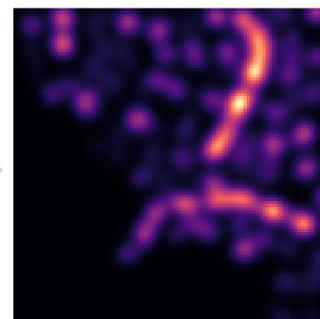
Generate continuous maps of genetic diversity using moving windows with options for rarefaction, kriging, and masking.



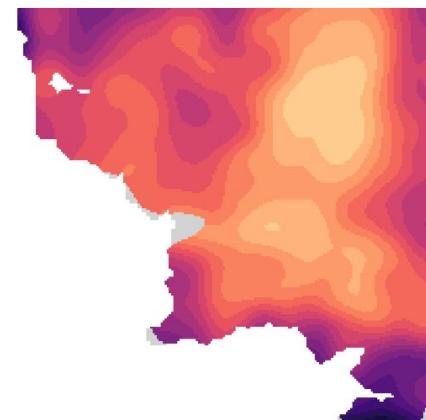
Carrying capacity/conductance



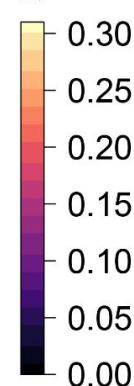
Population density



Map of Genetic Diversity



$\pi$



I HAVE A QUESTION.

WELL, LESS OF A QUESTION  
AND MORE OF A COMMENT.

I GUESS IT'S LESS OF A COMMENT  
AND MORE OF AN UTTERANCE

REALLY IT'S LESS AN UTTERANCE,  
MORE AN AIR PRESSURE WAVE.

IT'S LESS AN AIR PRESSURE WAVE  
AND MORE A FRIENDLY HAND WAVE.

I GUESS IT'S LESS A FRIENDLY  
WAVE THAN IT IS A FRIENDLY BUG.

I FOUND THIS BUG AND NOW WE'RE  
FRIENDS. DO YOU WANT TO MEET IT?



# Thanks! Questions?