

# **From Haircuts to Origin Models: A Guide to Emerging Tools to Study Animal Movement by Stable Isotope Analysis**

February 21, 2019

Workshop at joint meeting of the:

Southeastern Bat Diversity Network (SBDN) / Colloquium on the  
Conservation of Mammals in the Southeastern U.S.

# Overview

- Principles of stable isotope measurements
- Making probability-of origin maps
- Interpreting probability-of-origin maps

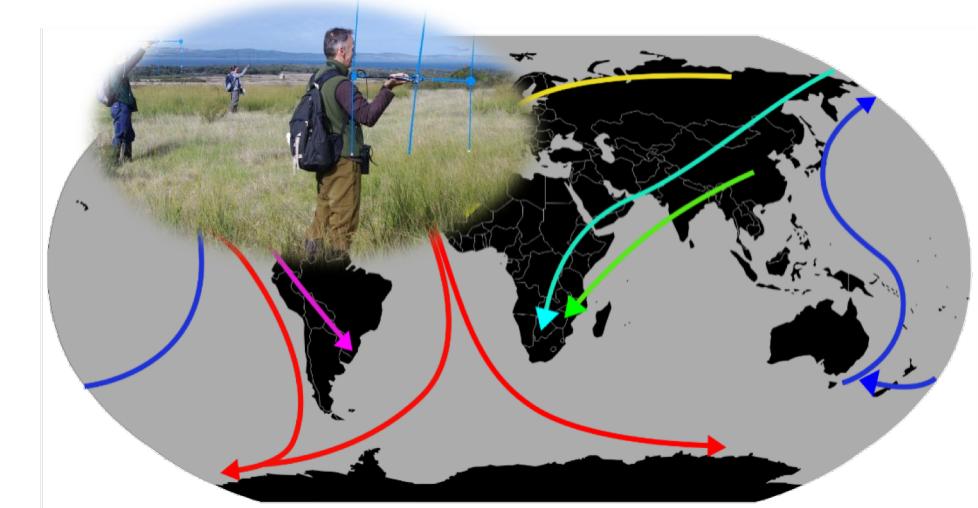
Follow along:

[github.com/cjcampbell/AnimalOrigins\\_SBDN/](https://github.com/cjcampbell/AnimalOrigins_SBDN/)

# Why use stable isotopes to study animal movement?

Difficult to study the movements of animals that are:

- Too small
- Too far-ranging
- Too stealthy
- Too dead



Monarch butterfly



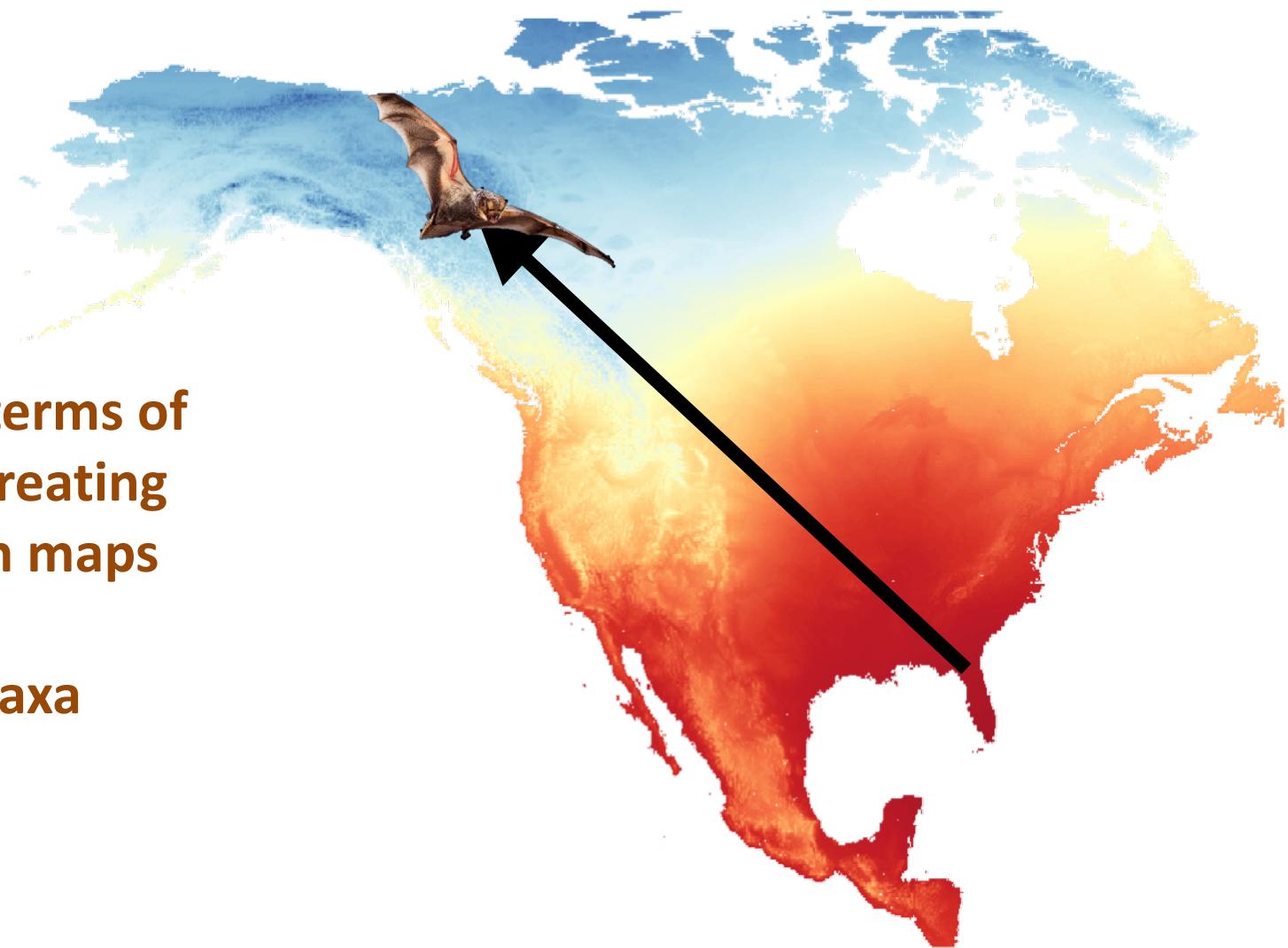
Sasquatch



Passenger Pigeon

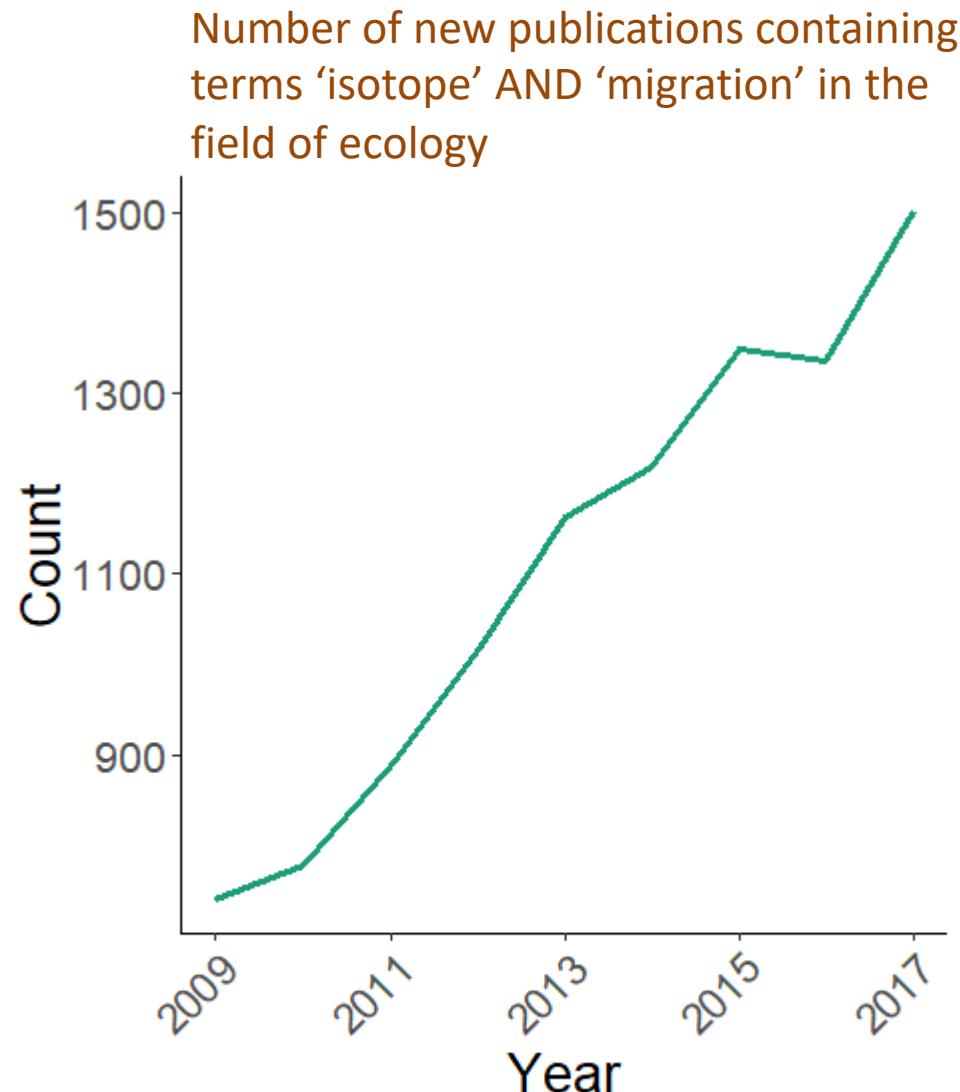


# Stable isotope analysis saves the day!



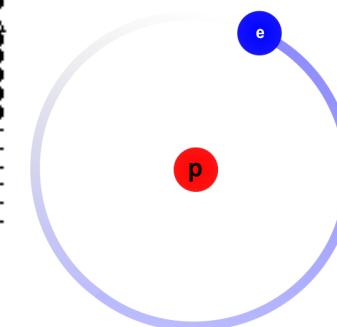
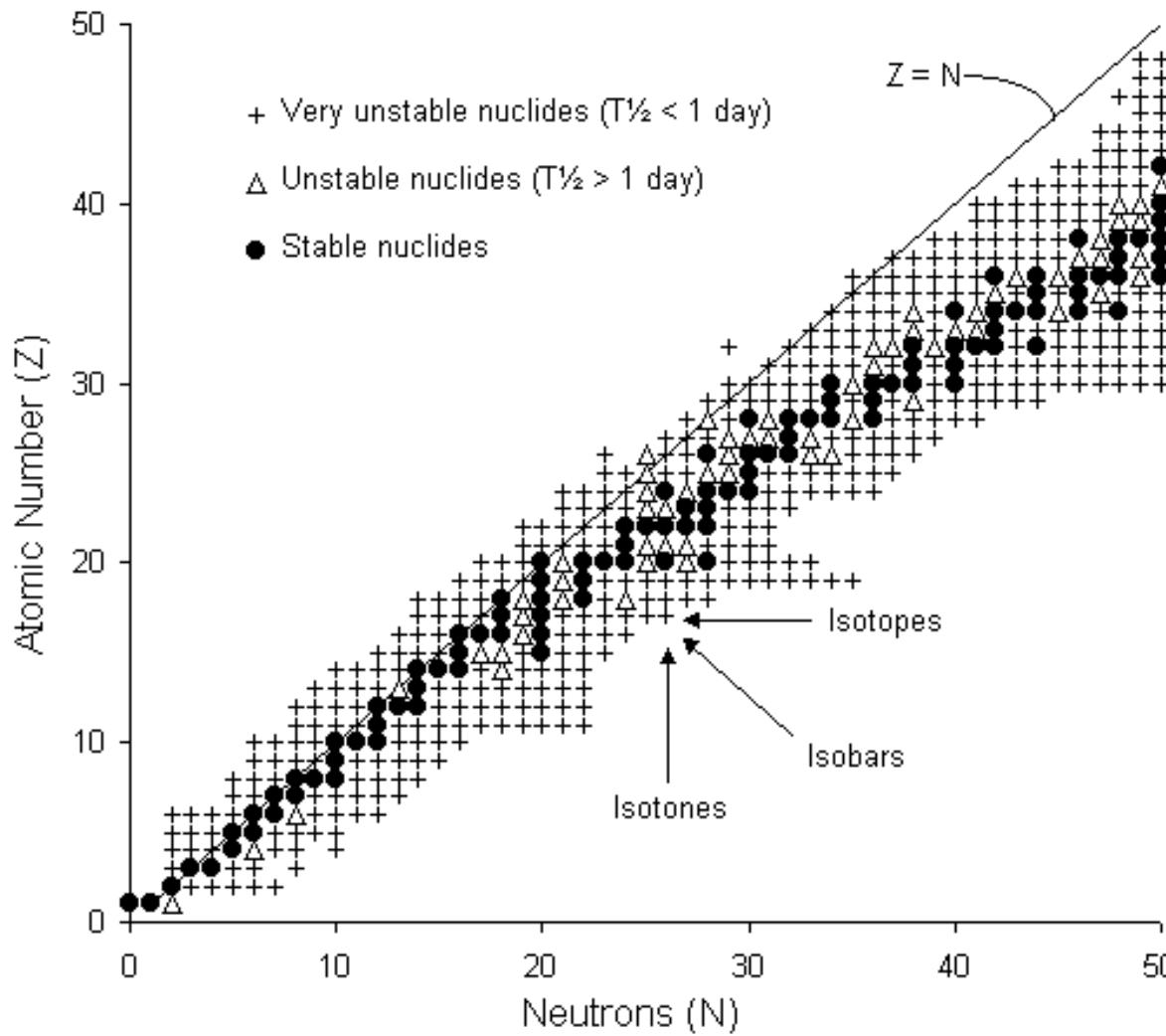
- Major advances in terms of inferring origin by creating probability-of-origin maps
- Applied to diverse taxa

# Why use stable isotopes to study animal movement?

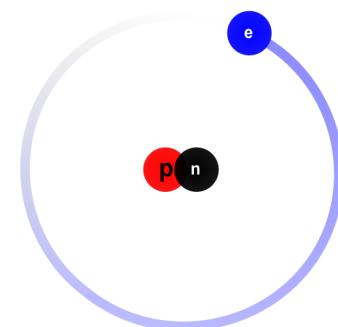


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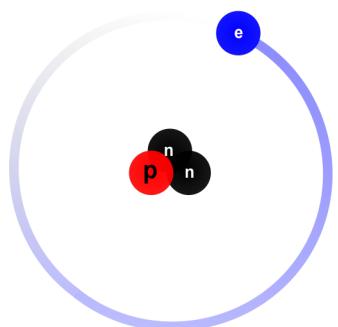
# What are stable isotopes?



${}^1_1 H$   
Protium



${}^2_1 H$   
Deuterium

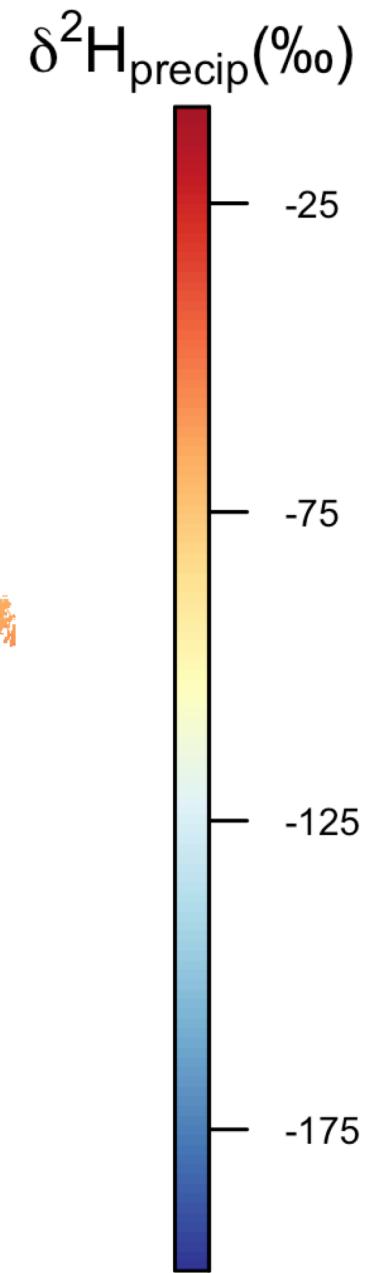
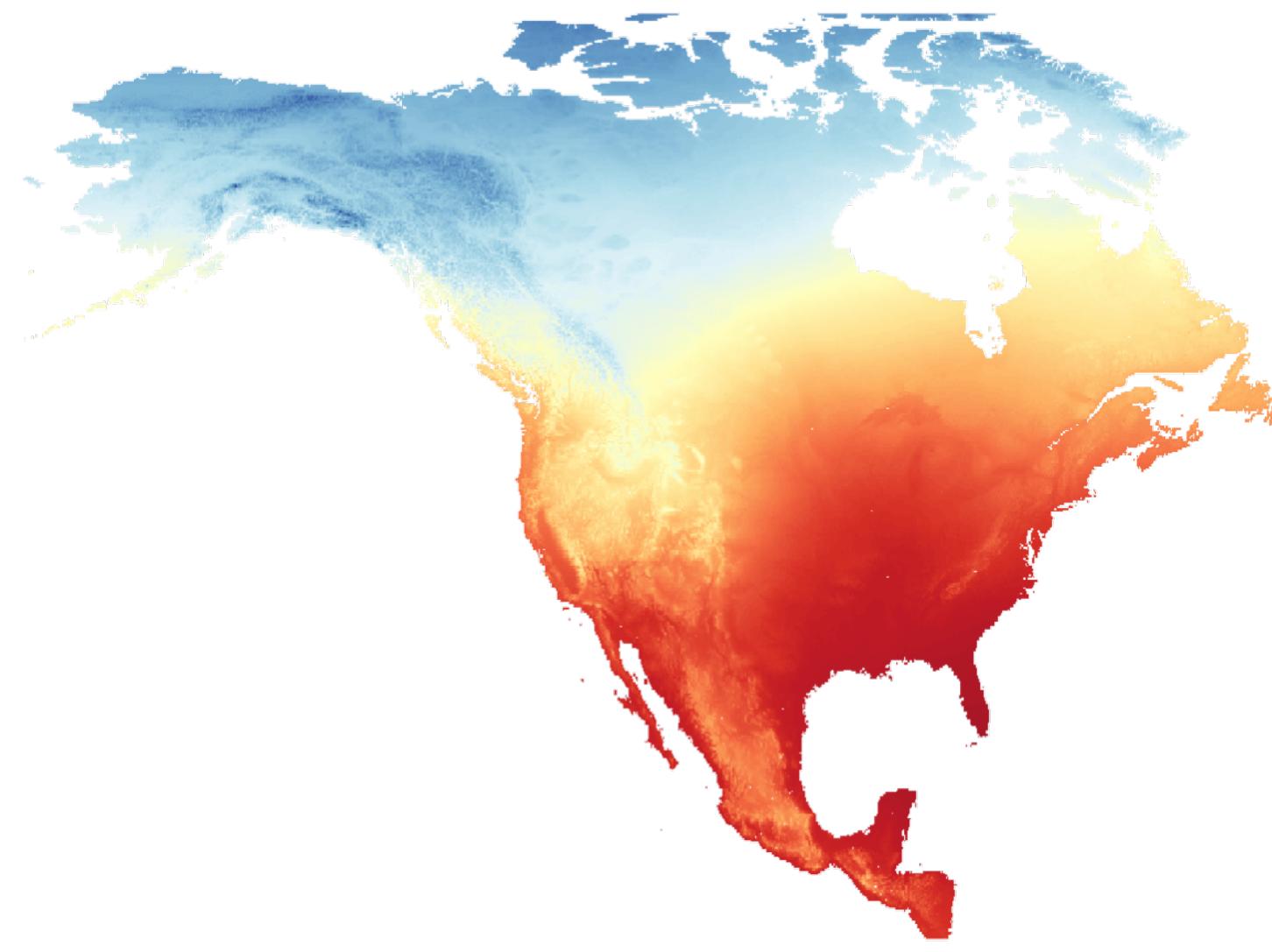


${}^3_1 H$   
Tritium

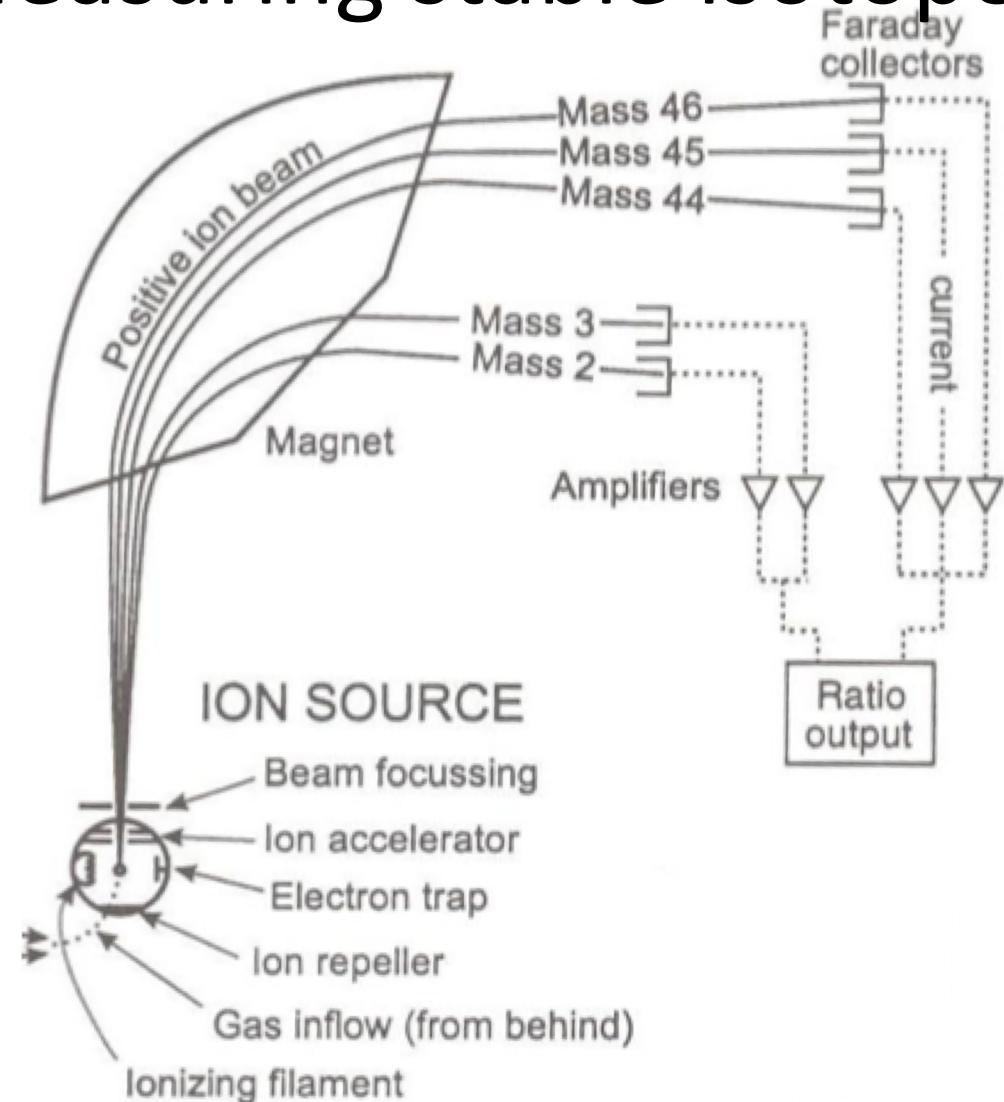
Image: UC Santa Cruz Stable Isotope Laboratory

# Stable isotopes that vary spatially

- H
- O
- N
- C
- Sr



# Measuring stable isotopes



# A note about notation

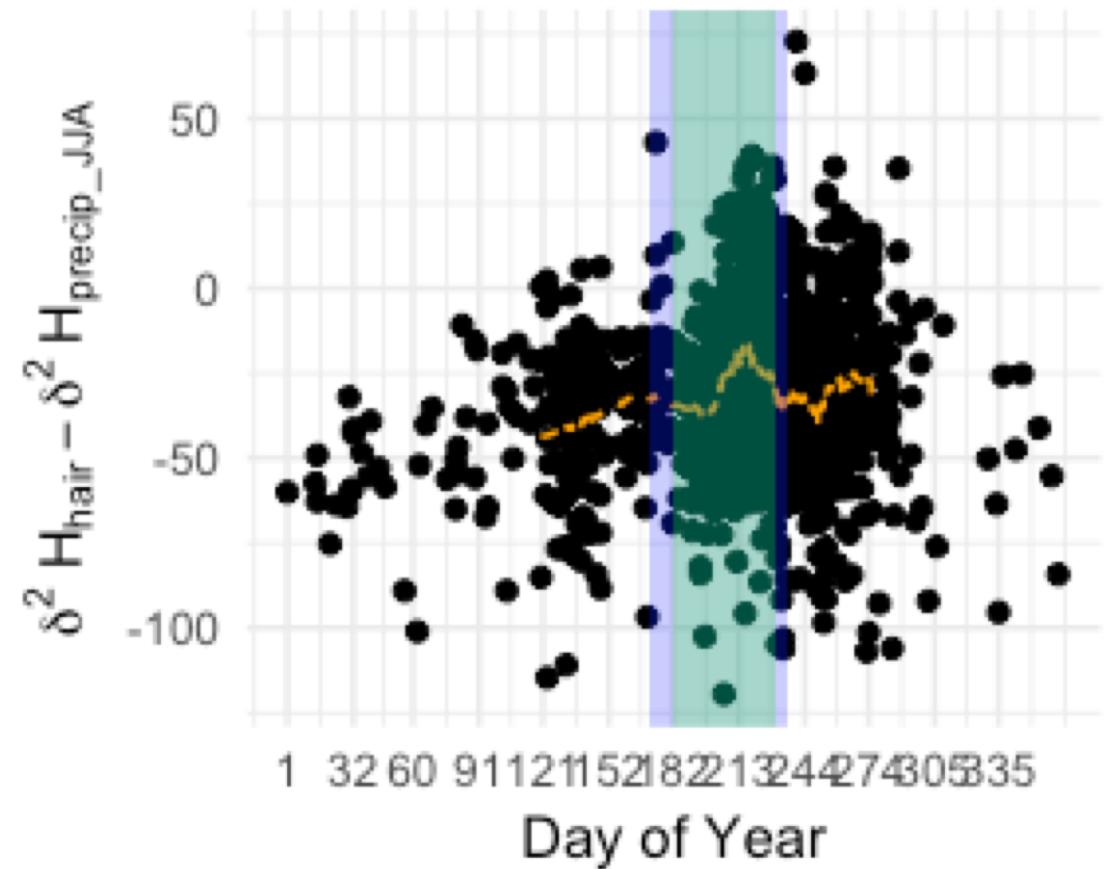
- R is the ratio of abundance of heavy:light isotopes (e.g.,  $^{13}\text{C}/^{12}\text{C}$ )
- Samples measured with respect to an international standard
  - e.g., VSMOW-SLAP scale maintained by International Atomic Energy Agency
  - (Often an extra step where lab standards related to international standards)
- $\delta = \frac{(R_{sample} - R_{standard})}{R_{standard}} \cdot 1000$

# What do we need to study animal origin with isotopic markers?

- Know about isotope ratios in the environment
- Know about animal tissue formation
- Measure isotope ratios within animal tissues
  - Ideally, known-origin tissues are available

# Tissue formation

- Different tissues turn over at different rates
  - Hair/organ/blood
- Defining period of tissue formation
  - Natural history
    - e.g., molt for inert hair/feathers; growth period for claws
  - Captive-feeding experiments
  - Isotopic signatures



# Measuring isotope ratios in tissues

## Example protocol for sampling bat hair

1. Clip hair from the back of the bat, between the wings (just as if you're attaching a transmitter)
2. Scoop hair into empty vial using scissors or gloved hand
3. Attach label w/ same code label as tissue sample (e.g., you should end w/ two vials with the same code, one with tissue and one with hair.)
4. Sterilize the scissors between bats w/ flame.



Ideal amount of hair sample (not a lot!)

# Measuring isotope ratios in tissues

- Cleaning
- Equilibration
- Analysis

# Measuring isotope ratios in tissues

- CASIF (Central Appalachians Stable Isotope Facility)
- NAU (Northern Arizona University)
- U of Utah
- UC Davis (Compound-specific)
- U Ottawa

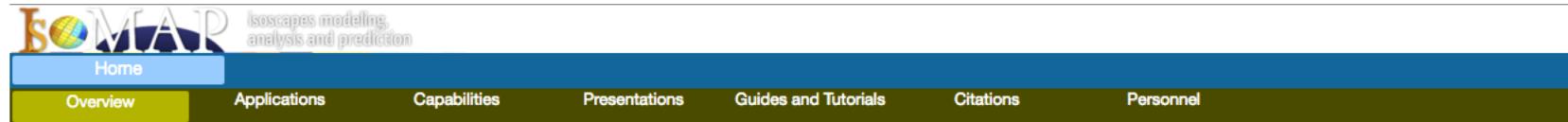
## Sample Preparation and Submission

ANALYSIS	ISOTOPES	ON-CAMPUS PRICE^	OFF-CAMPUS PRICE - STANDARD	OFF-CAMPUS PRICE - BULK	APPROXIMATE TURN AROUND TIME
TC/EA, solids	$\delta D$	\$14	\$16	\$15*	2-4 weeks
TC/EA, solids	$\delta^{18}O$	\$14	\$16	\$15*	2-4 weeks

# Environmental Isotope Values

- Can also use others' isoscapes
  - IsoMAP, WaterIsotopes.org (has common isoscapes)
- Temporal range is important!
  - Should match the isoscape used in transfer function
- Output: krigged isoscape, map of standard error
- Can make your own isoscape with known-origin tissue values
  - Best, but most difficult method

# Environmental Isotope Values: IsoMAP Walkthrough



The IsoMAP website features a top navigation bar with tabs: Home, Overview (highlighted in yellow), Applications, Capabilities, Presentations, Guides and Tutorials, Citations, and Personnel.

## IsoMAP Overview

IsoMAP is an online workspace for spatial analysis, modeling and prediction of stable isotope ratio variation in the natural environment ([isoscapes](#)). IsoMAP consists of a suite of web-based GIS and software tools allowing users to easily explore, develop, and implement models for isotope distributions.

- Data identification and processing are handled by ISOMAP and are transparent to the user.
- Hierarchically structured toolkits provide functionality for model assessment, prediction (map-making), and data analysis for a variety of model and substrate types.
- Users can conduct end-to-end data exploration and modeling within an online workspace, with automatic data and metadata curation and cross-toolkit integration.
- Products are accessible for download and can be published to a shared workspace, enabling access by other users.

IsoMAP provides sophisticated tools for research and analysis but is designed with accessibility in mind. Our user community includes not only researchers with experience in isotope chemistry but also educators and individuals from outside of academia who could benefit from the educational and applied scientific uses of isoscapes.

### Quick Guide for new IsoMAP users

### Getting Started Video Tutorial

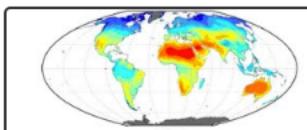
### Learn more about Isoscapes:

"Isoscapes: Spatial pattern in isotopic biogeochemistry" (Bowen, 2010, Annual Review of Earth and Planetary Sciences)

[IsoMAP: Understanding environmental patterns and processes at Earth through Isoscapes](#)



A screenshot of a Twitter post from the IsoMAP account (@Isoscapes). The tweet reads: "Welcome to all the #Isoecol18 delegates using #IsoMAP in today's workshop!" It includes a photo of a workshop audience seated at desks. Below the photo are standard Twitter interaction icons (like, retweet, reply) and the date "Jul 29, 2018".



A small world map showing global isoscapes patterns, with color-coded regions indicating different isotopic values across the globe.

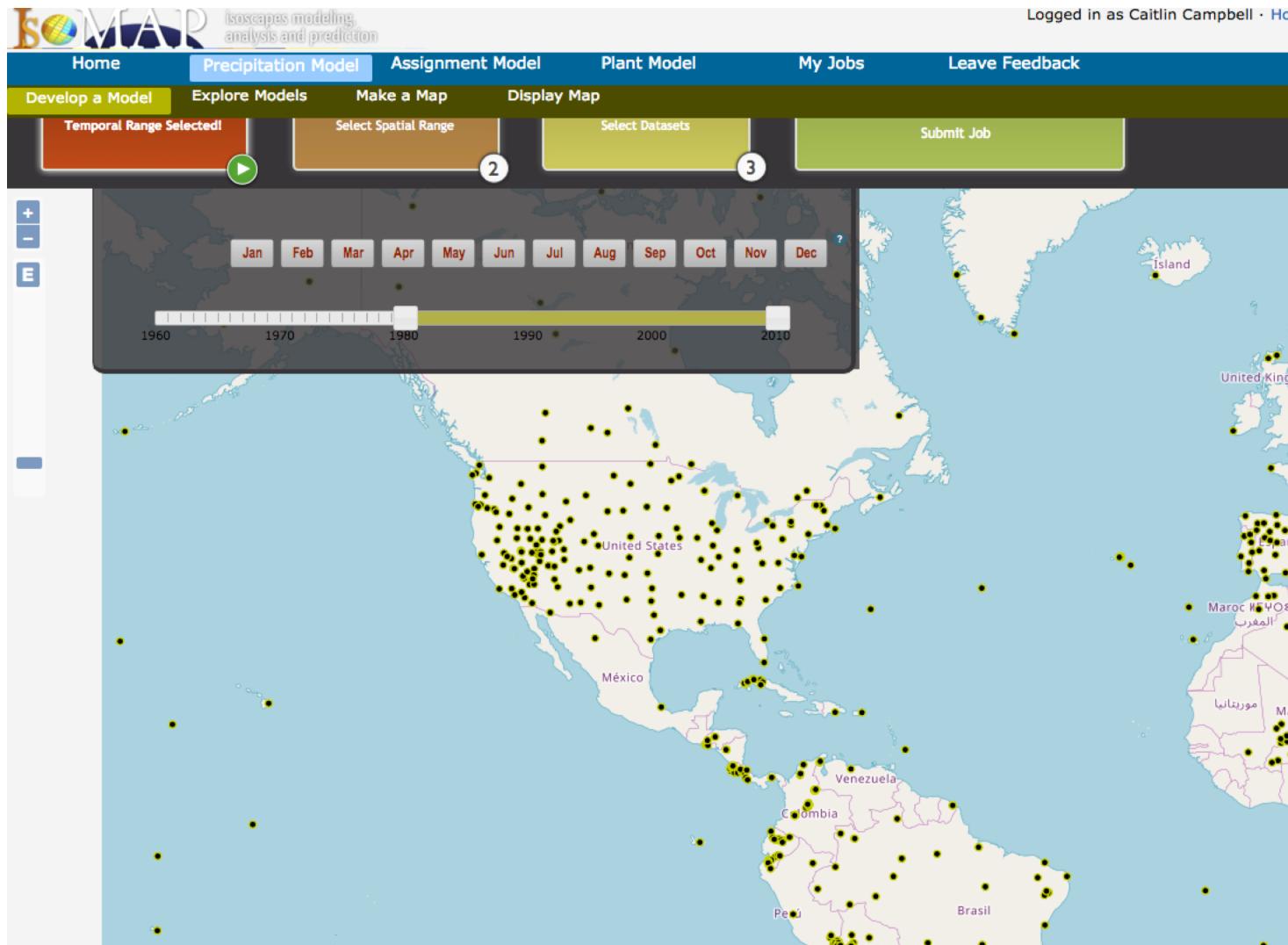
### Login

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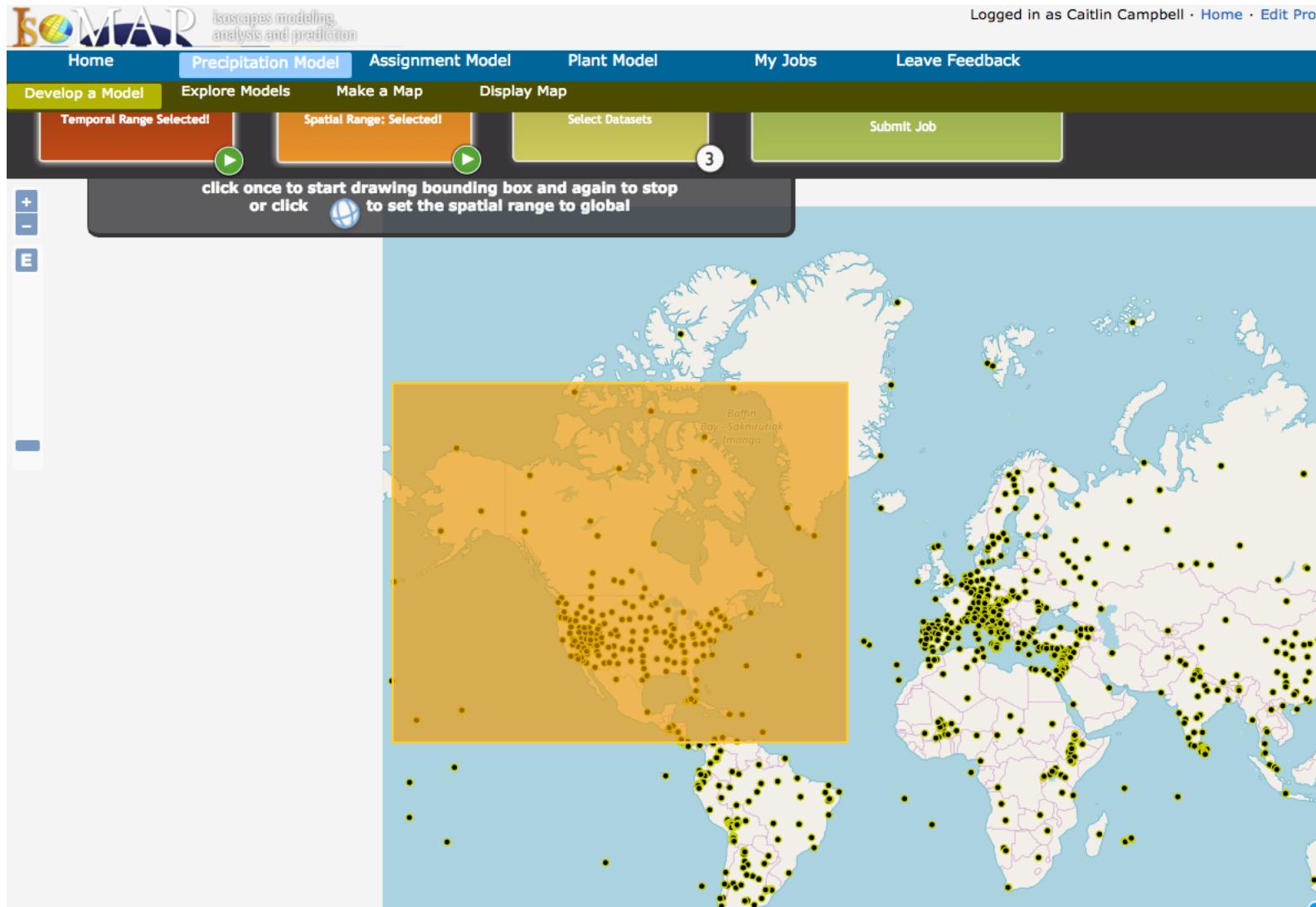
Password:

[Forgot your password?](#)

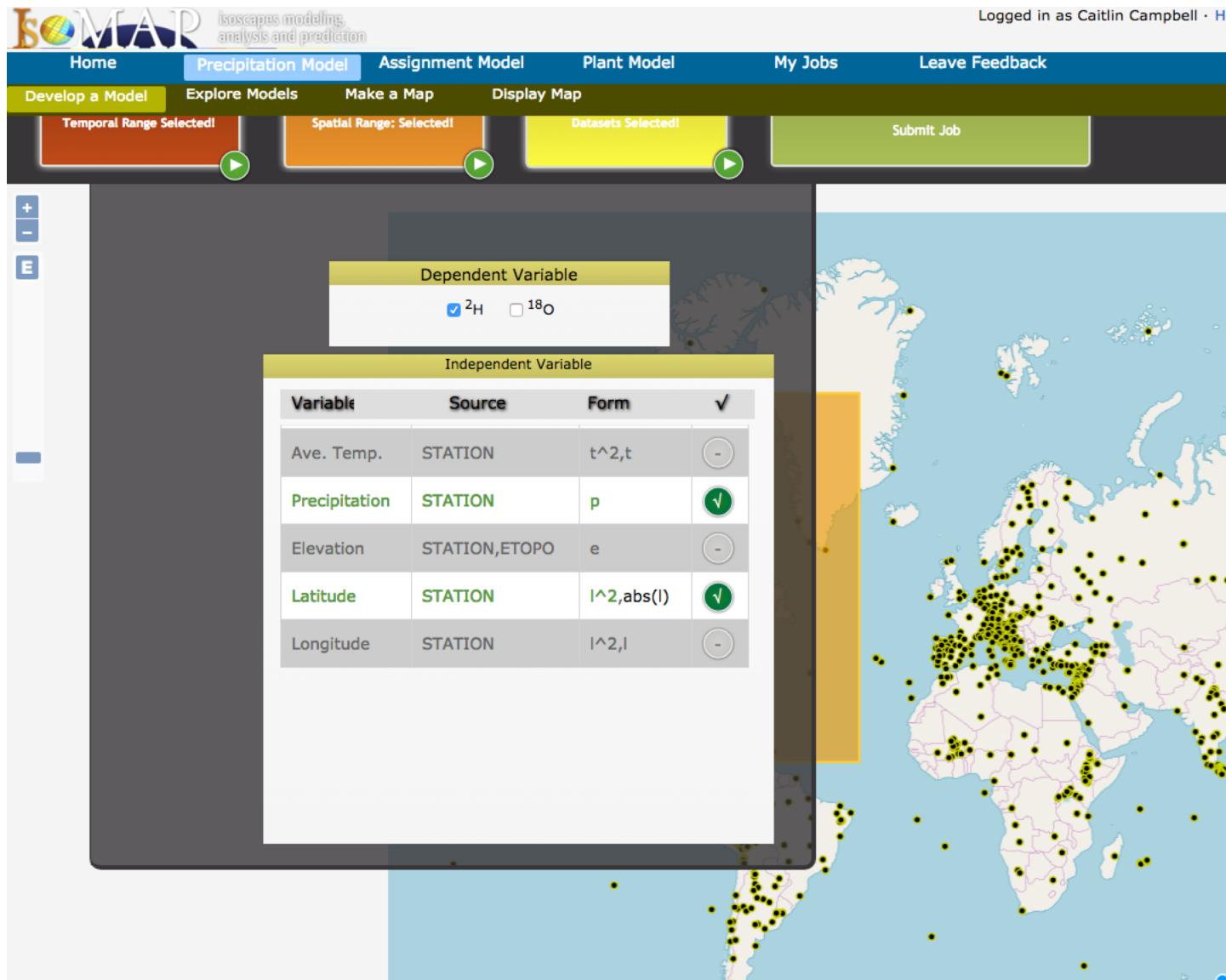
# Environmental Isotope Values: IsoMAP Walkthrough



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# Environmental Isotope Values: IsoMAP Walkthrough

IsoMAP Isotopes modeling, analysis and prediction

Home Precipitation Model Assignment Model Plant Model My Jobs Leave Feedback

Select All

Publish Jobs Unpublish Jobs Delete Jobs

Select	Key	Case Name	Model Run type	Application type	Job Status	Start Time	Time Taken	Download	Action
<input type="checkbox"/>	73128	exampleRun	Model Fitting	Precipitation	PENDING			<a href="#">Metadata</a>   <a href="#">Results</a>	<a href="#">» Publish</a> <a href="#">» Delete</a>
<input type="checkbox"/>	66100	Annual_NoAm_Map_H_1980_2010	Prediction	Precipitation	DONE	2018-01-24 17:45.35	0 m 52 s	<a href="#">Metadata</a>   <a href="#">Results</a>	<a href="#">» Unpublish</a>
<input type="checkbox"/>	66098	JJA_NoAm_Map_1980_2009	Prediction	Precipitation	DONE	2018-01-24 17:42.47	0 m 52 s	<a href="#">Metadata</a>   <a href="#">Results</a>	<a href="#">» Unpublish</a>
<input type="checkbox"/>	66087	JJA_NoAm_H_1980_2010	Model Fitting	Precipitation	DONE	2018-01-24 17:09.34	0 m 41 s	<a href="#">Metadata</a>   <a href="#">Results</a>	<a href="#">» Publish</a> <a href="#">» Delete</a>
<input type="checkbox"/>	66085	Annual_NoAm_H_1980_2010	Model Fitting	Precipitation	DONE	2018-01-24 17:05.09	0 m 52 s	<a href="#">Metadata</a>   <a href="#">Results</a>	<a href="#">» Publish</a> <a href="#">» Delete</a>

# Environmental Isotope Values: IsoMAP Walkthrough

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IsoMAP isoscapes modeling, analysis and prediction

Home Precipitation Model Assignment Model Plant Model My Jobs Leave Feedback

Assignment Batch Assignment Display Assign

Search Select Spatial Range or click me to use world default Enter Parameters Submit Job

1 2 3

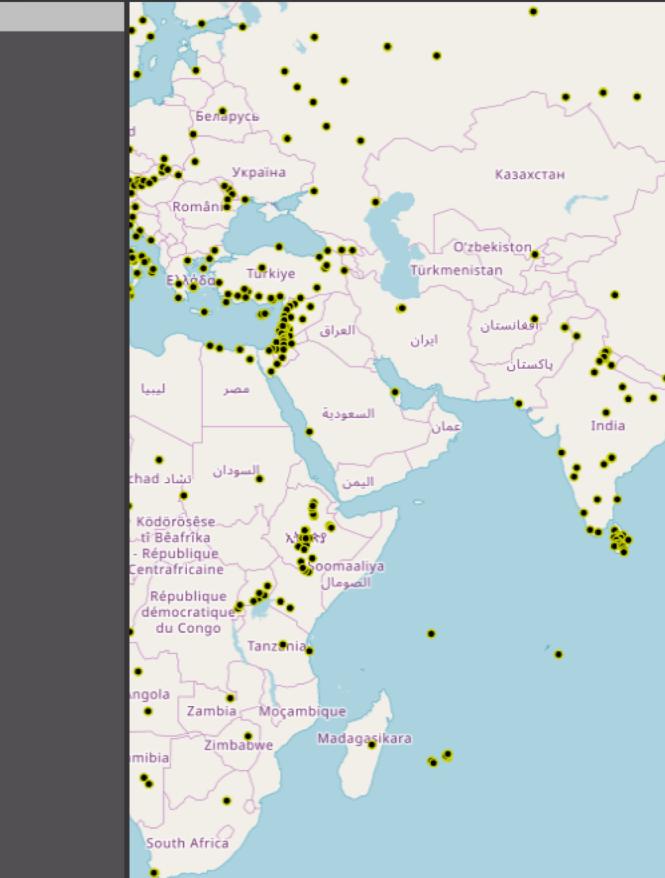
Job Key Job Description Case Name

AND AND

List All Search

Job Key Owner Case Name Start Time

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71738	lkr270	2018_01	2018-12-06 07:17:41
71389	Stef	eumap	2018-11-23 09:06:07
70643	eflaher@purdue.edu	Owl1026_amap	2018-10-26 09:08:23
70448	VDaux	WEurope_d18O_map3	2018-10-12 13:11:22
70103	michael.bird@jcu.edu	9099_JJA_map	2018-09-18 21:01:07
70101	michael.bird@jcu.edu	7098_map	2018-09-18 20:59:59
70085	michael.bird@jcu.edu	tropics_wetSmap	2018-09-18 18:18:02
70082	michael.bird@jcu.edu	tropics_wetS	2018-09-18 18:12:36
69264	trhermes	NED_map1_1	2018-08-06 03:18:22
68672	gbowen	isoecol18_afmap_3	2018-07-26 11:02:28
68670	gbowen	isoecol18_afmap_2	2018-07-26 11:01:56
68663	gbowen	isoecol18_samap_2	2018-07-26 10:52:55
68661	gbowen	isoecol18_samap_1	2018-07-26 10:52:17
67902	brian.hayden@unb.ca	BH_worldH	2018-06-25 12:54:08
66100	caitcampbell	Annual_NoAm_Map_H_1980_20	2018-01-24 12:43:08
66098	caitcampbell	JJA_NoAm_Map_1980_2009	2018-01-24 12:42:15
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63026	lisamarrack	Oprecip_2017_B	2017-07-01 18:35:05
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61594	laurenannez	I_a_Rinia	2017-03-30 11:28:17



# Environmental Isotope Values: IsoMAP Walkthrough

IsoMAP Isoscapes modeling, analysis and prediction

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Home Precipitation Model Assignment Model Plant Model My Jobs Leave Feedback

Develop a Model Explore Models Make a Map Display Map

Search 1 Select Temporal Range 2 Select Spatial Range 3 Select Datasets 4 Submit Job

Job Key e.g., 3000 or >3000  
AND Job Description  
AND Case Name  
List All Search

Job Key	Owner	Case Name	Start Time
73128	caitjcampbell	exampleRun	2019-02-20 11:15:38
72858	neumannl	TestOwls	2019-02-07 11:04:13
72157	Adjan	Argentinatest	2019-01-11 02:56:01
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71401	Stef	eumap_1	2018-11-23 09:47:11
71385	Stef	europe	2018-11-23 09:04:20
71338	Stef	eu	2018-11-23 07:21:55
71015	drakej	JDTTest	2018-11-08 09:54:34
70994	maxpm	testjob	2018-11-08 07:12:33
70686	emniespolo	EN_SubSahAf_Ppt18O	2018-10-28 13:11:57
70066	michael.bird@jcu.edu.au	jan_mar	2018-09-18 02:37:26
69407	brian.hayden@unb.ca	Global_O	2018-08-29 13:05:41
69258	trhermes	NED_model1	2018-08-06 02:41:28
68667	gjbowen	isoecol18_afmodel_3	2018-07-26 10:58:17
68665	gjbowen	isoecol18_afmodel_2	2018-07-26 10:55:01

Map showing environmental isotope values across the Middle East and North Africa region. Numerous yellow dots represent data points, primarily concentrated in the Mediterranean basin, the Persian Gulf, and parts of Central Asia like Kazakhstan and Turkmenistan.

# Environmental Isotope Values: IsoMAP Walkthrough

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IsoMAP isoscapes modeling, analysis and prediction

Home Precipitation Model Assignment Model Plant Model My Jobs Leave Feedback

Develop a Model Explore Models Make a Map Display Map

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Job Key e.g., 3000 or >3000  
AND Job Description  
AND Case Name  
List All Search

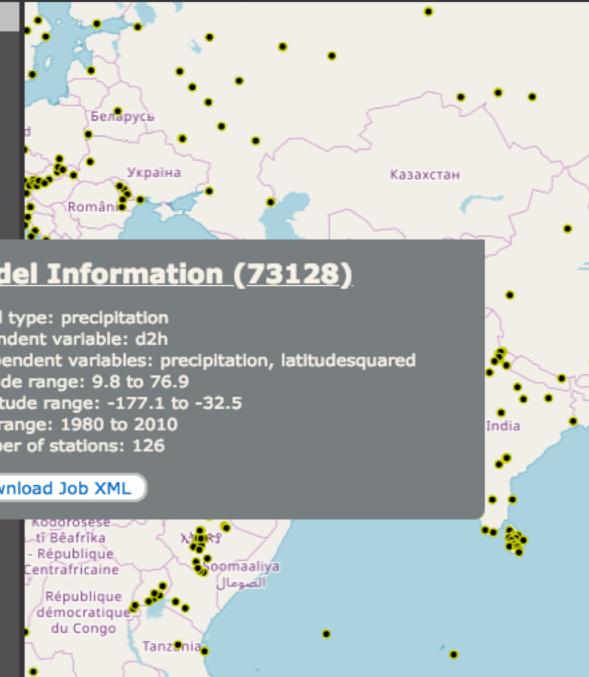
Job Key Owner Case Name Start Time

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71401	Stef	eumap_1	2018-11-23 09:47:11
71385	Stef	europe	2018-11-23 09:04:20
71338	Stef	eu	2018-11-23 07:21:55
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70994	maxpma	testjob	2018-11-08 07:12:33
70686	emniespolo	EN_SubSahAf_Ppt180	2018-10-28 13:11:57
70066	michael.bird@jcu.edu.au	jan_mar	2018-09-18 02:37:26
69407	brian.hayden@unbc.ca	Global_O	2018-08-29 13:05:41
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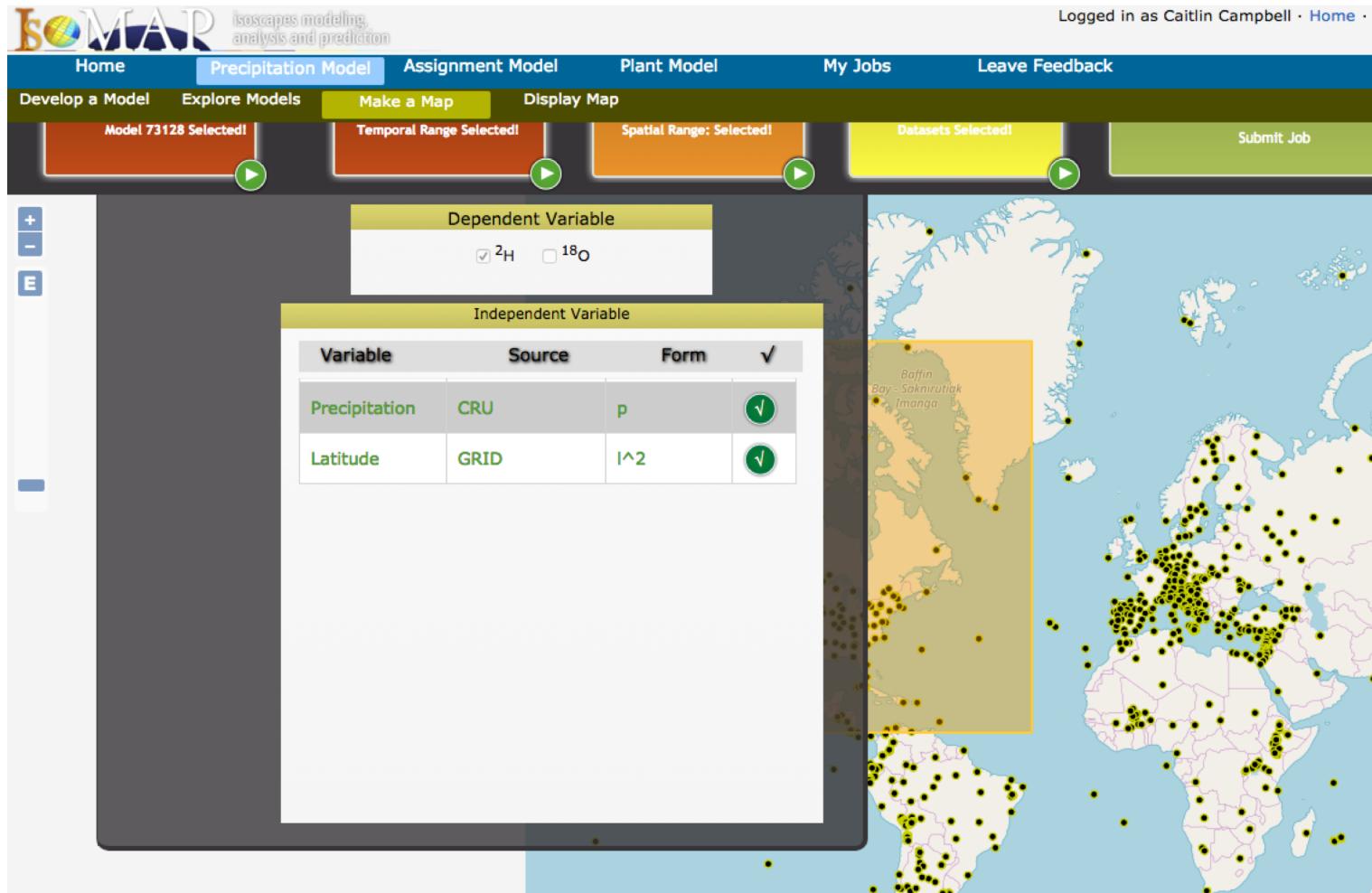
**Model Information (73128)**

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Dependent variable: d2h  
Independent variables: precipitation, latitudesquared  
Latitude range: 9.8 to 76.9  
Longitude range: -177.1 to -32.5  
Year range: 1980 to 2010  
Number of stations: 126

[Download Job XML](#)

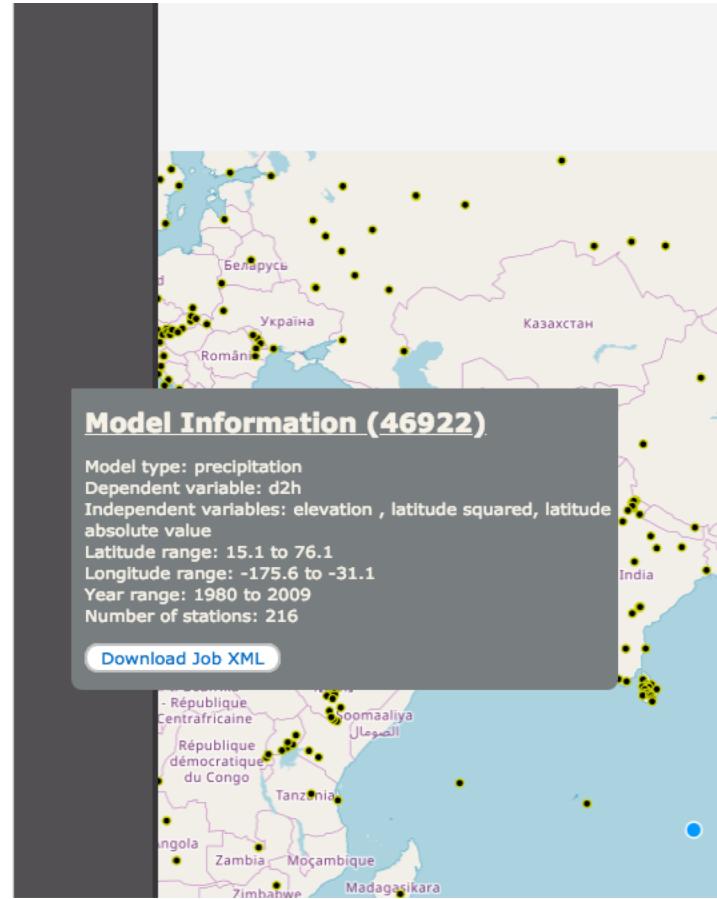


# Environmental Isotope Values: IsoMAP Walkthrough



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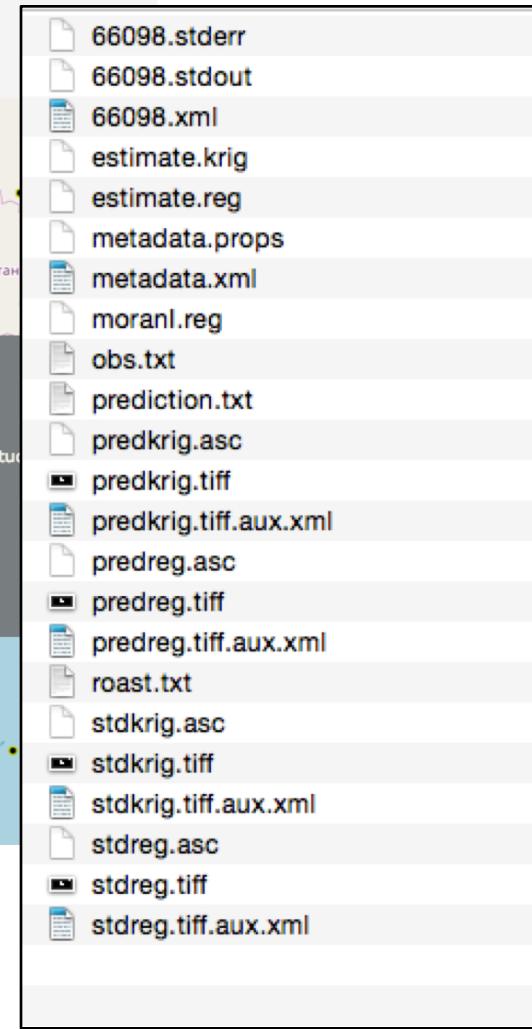
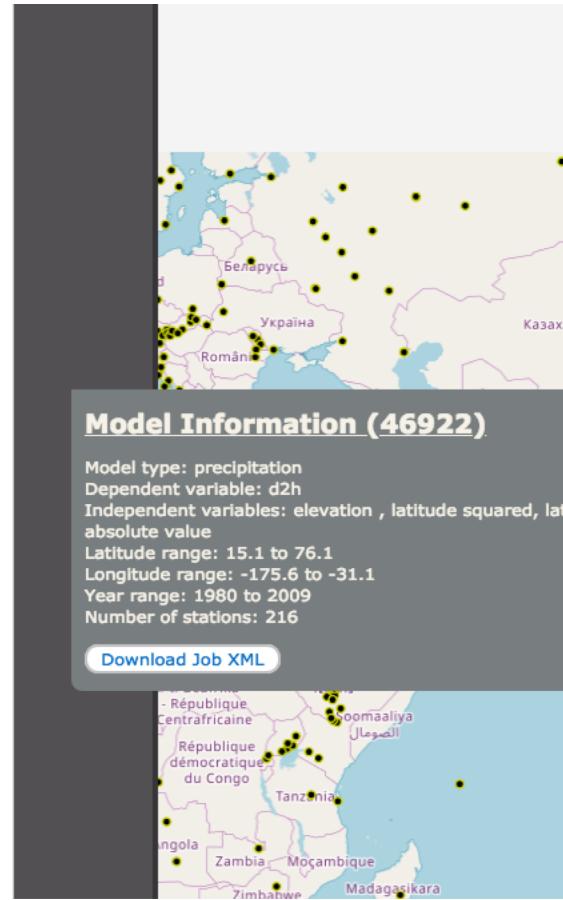
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50333	lisamarrack	Hprecip_ellatlong	2015-09-09 12:17:00
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46827	yassow	TestTwo	2015-05-03 16:44:12
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42554	trhermes	Kazakhstan_map	2014-11-11 11:04:42
42498	somerwillad	d18OprecipMap	2014-11-09 04:42:15
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35100	msc1	chrisDMAP	2014-03-17 20:03:46
34563	lpoolman	OMedMidEast	2014-02-23 12:54:28
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30132	Casey	WINTER4MAP	2013-09-30 16:24:56
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# Environmental Isotope Values: IsoMAP Walkthrough

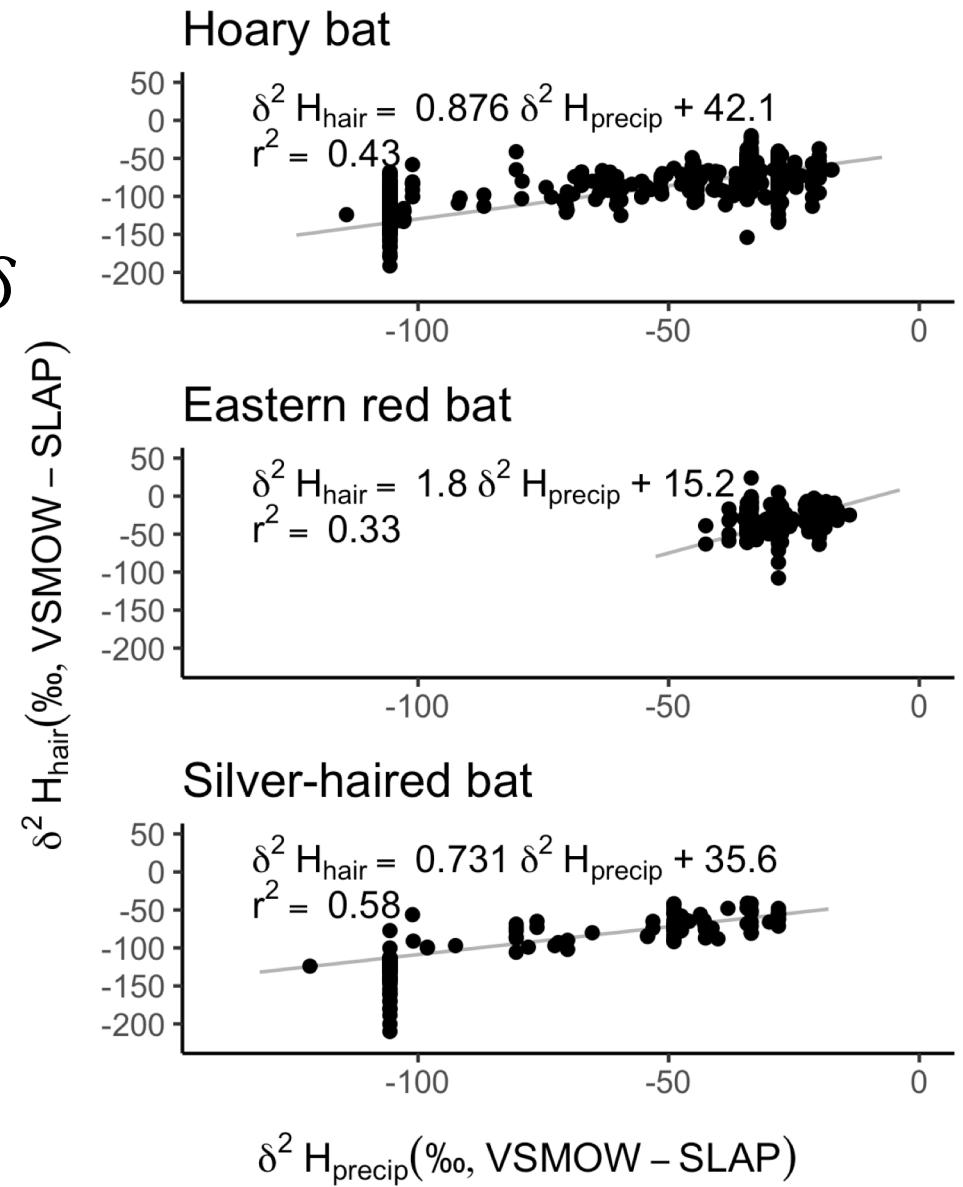


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50948	cgerlein	test_Map2	2015-10-12 14:49:19
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50333	lisamarrack	Hprecip_ellatlong	2015-09-09 12:17:00
48851	nitzsche	SSC15plwtJAS1961_1900	2015-06-25 15:43:39
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48624	nitzsche	SSC15plwtJAS1960_2006	2015-06-24 17:34:02
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46827	yassow	TestTwo	2015-05-03 16:44:12
42921	rtw63	rtw63_1	2014-11-17 09:18:15
42554	trhermes	Kazakhstan_map	2014-11-11 11:04:42
42498	somervillead	d18OprecipMap	2014-11-09 04:42:15
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41507	vwlgs	map	2014-10-20 13:23:38
40745	EBDCurro	ebd2	2014-10-09 10:08:06
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35100	msc1	chrisDMAP	2014-03-17 20:03:46
34563	lpoolman	OMedMidEast	2014-02-23 12:54:28
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30132	Casey	WINTER4MAP	2013-09-30 16:24:56
30123	Casey	winter2map	2013-09-30 16:10:42
30066	Casey	winter_hmap	2013-09-30 13:29:22



# Transfer functions

- Relate environmental  $\delta$  values to tissue  $\delta$  values for *known-origin* individuals
- Predictable linear relationship during incorporation due to *fractionation*
- Make sure you are using an appropriate regression for your goals (many in literature are one-way)
- Many available in the literature
  - Species- and taxon-specific



# Transfer functions

- Finite time and money
- Prioritizing unknown-origin individuals makes sense if transfer functions already exist
- Known-origin individuals very important!
  - Especially if your species of interest is/are understudied with your isotope of interest
  - Necessary sample size debatable

# Transfer functions: a note on Databanking

- In coming years, keep an eye out for IsoBank
  - Should improve transfer functions, sample sizes available
- Whenever possible, share data and detailed methods!

# Probability-of-origin maps

- Bayesian framework estimating probability of an individual occurring at any given location based on:
  - Tissue isotope value\*
  - Tissue isotope error
  - Isoscape value at location \*\*
  - Isoscape estimation error at location

\*(transformed with transfer function)

\*\*(alternatively, transformed with transfer function)

# Probability-of-origin maps

- IsoMAP
  - Online workspace
  - User-friendly
  - Very time-consuming to apply to multiple individuals
  - Results publicly accessible
  - Not easy to reproduce or modify
- ISOorigin
  - Currently available
  - R package
  - Currently on github, forthcoming on CRAN
- Isocat
  - Currently available
  - R package
  - Currently on github, forthcoming on CRAN

# Use R to make a probability-of-origin map: isocat: Isotope Clustering and Assignment Tools

To install:

```
library(devtools)  
install_github("cjcampbell/isocat")
```

# Use R to make a probability-of-origin map: isocat: Isotope Clustering and Assignment Tools

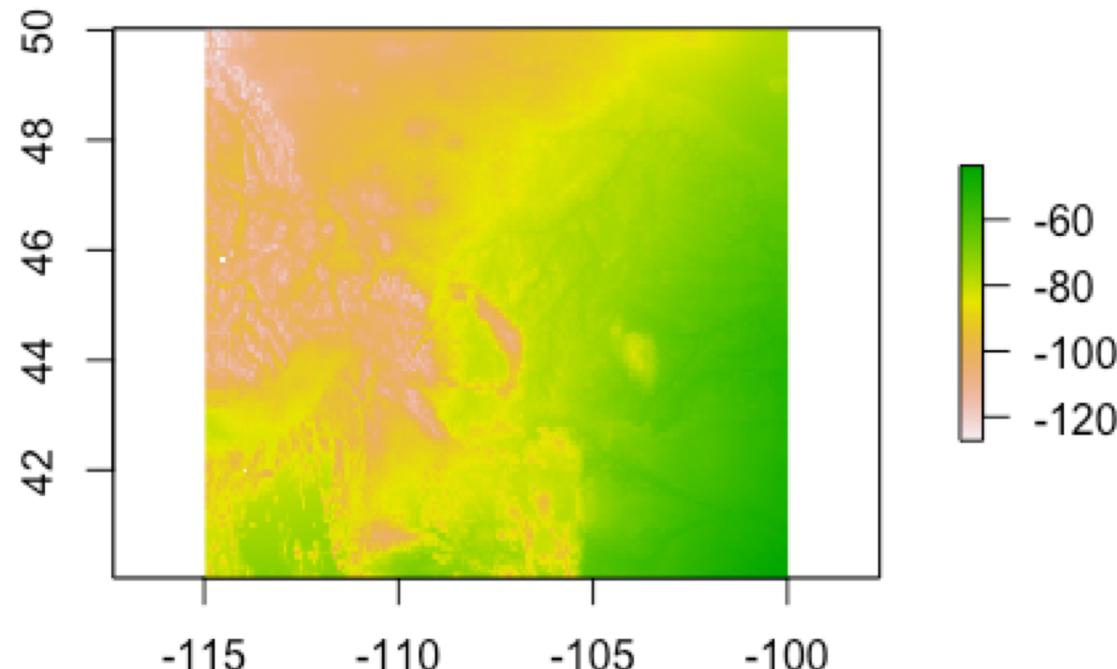
To use:

```
library(isocat)  
library(raster)
```

# Use R to make a probability-of-origin map: isocat: Isotope Clustering and Assignment Tools

Reproducible example:

```
data(isoscape) # Load example data  
myiso <- rasterFromXYZ(isoscape) # Load isocat's example isoscape  
myiso_sd <- rasterFromXYZ(isoscape_sd) # Load example isoscape error  
raster::plot(myiso)
```



# Use R to make a probability-of-origin map: **isocat**: Isotope Clustering and Assignment Tools

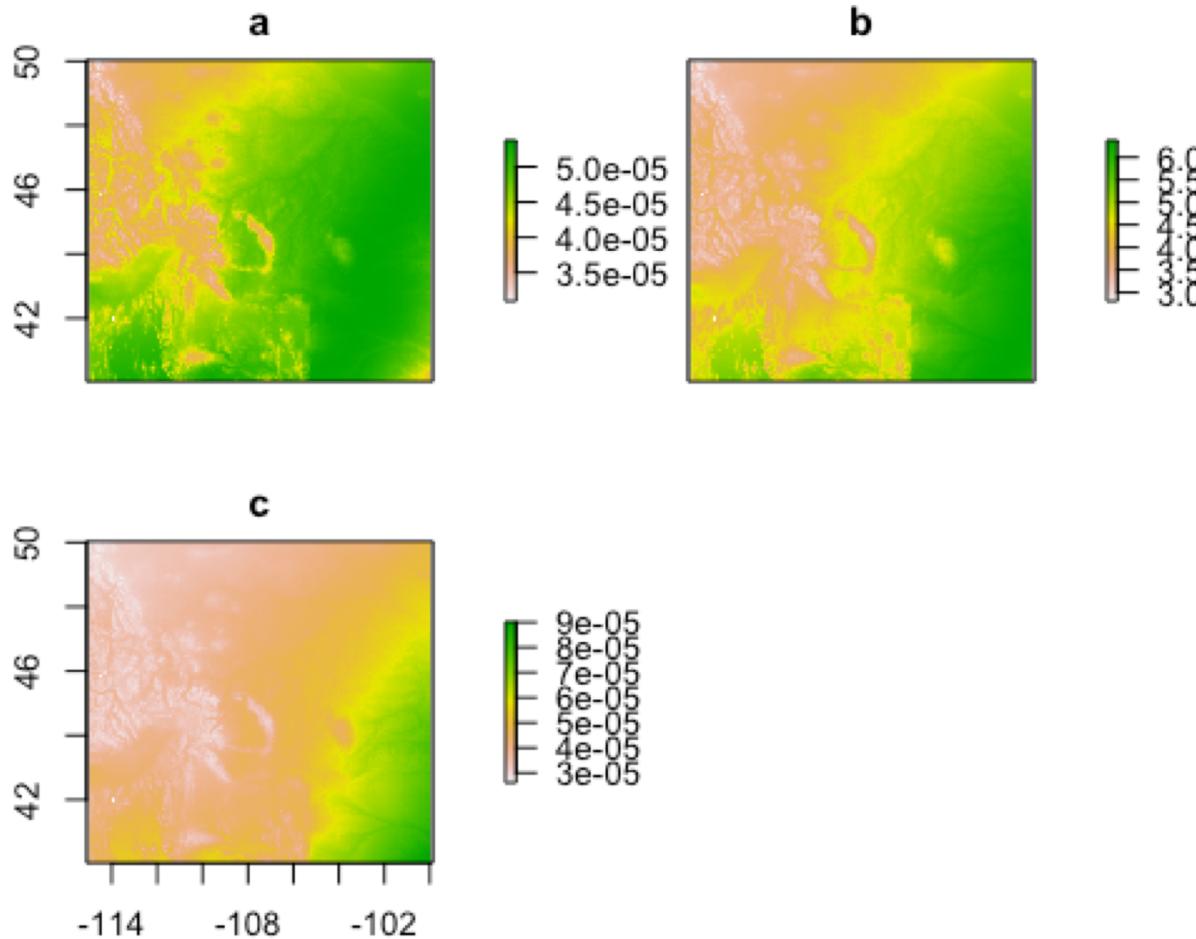
Reproducible example (continued):

```
df <- data.frame(  
  # example individual IDs:  
  ID = letters[1:3],  
  # environment-transformed hydrogen isotope values:  
  dD = c(-100, -80, -50),  
  # standard dev from isotope analysis:  
  SD_indv = rep(5, 3)  
)  
  
df  
##   ID   dD SD_indv  
## 1  a -100      5  
## 2  b   -80      5  
## 3  c    -50      5
```

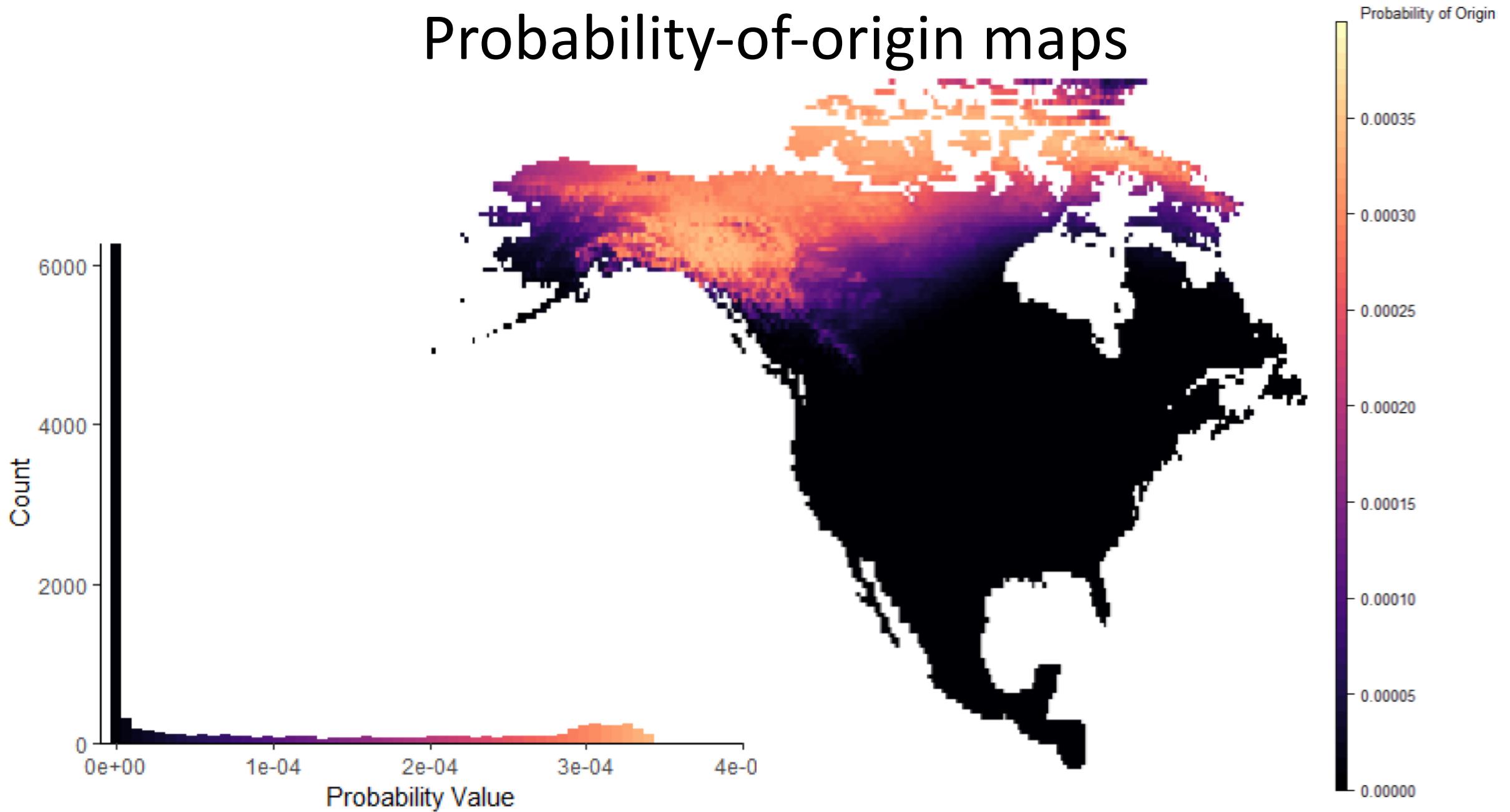
Use R to make a probability-of-origin map:  
isocat: Isotope Clustering and Assignment Tools  
Reproducible example (continued):

```
assignmentModels <- isotopeAssignmentModel(  
  ID = df$ID,  
  dD = df$dD,  
  SD_indv = df$SD_indv,  
  precip_raster = myiso,  
  precip_SD_raster = myiso_sd,  
  nClusters = FALSE  
)
```

Use R to make a probability-of-origin map:  
isocat: Isotope Clustering and Assignment Tools  
Reproducible example (continued):  
`raster::plot(assignmentModels)`



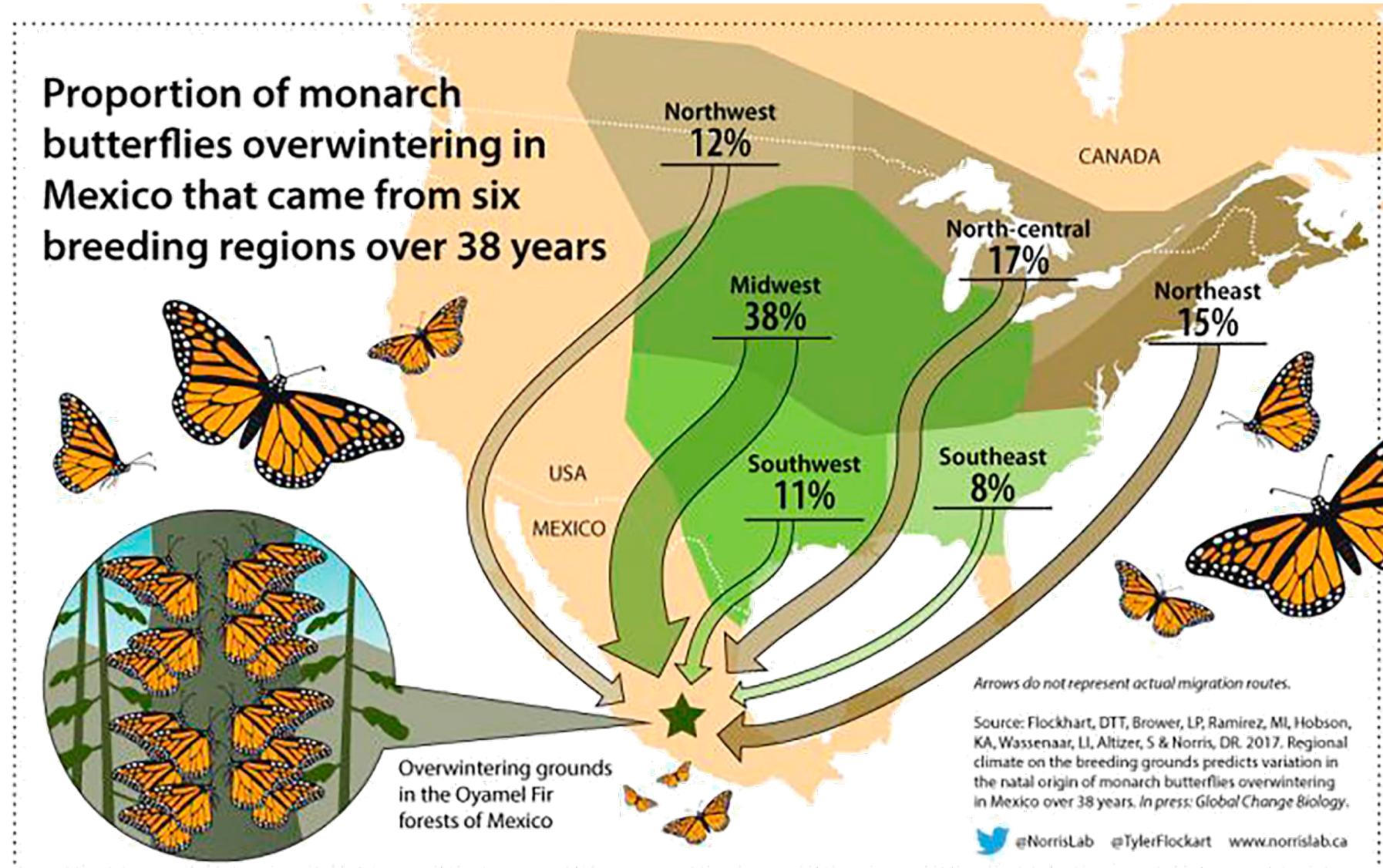
# Probability-of-origin maps



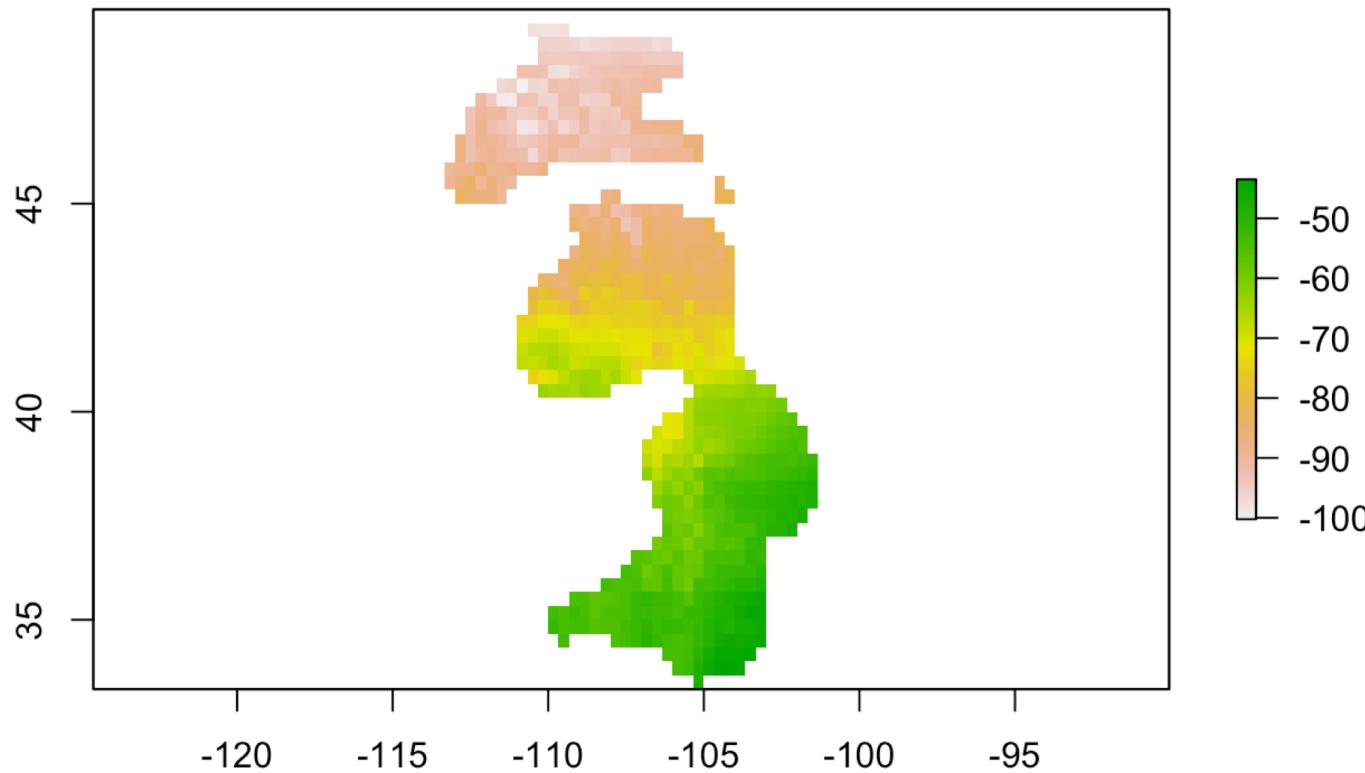
# Interpreting maps

- Assignment to discrete regions
- Summary maps
- Grouping by common origins
- Local Status
- Distance and direction of travel

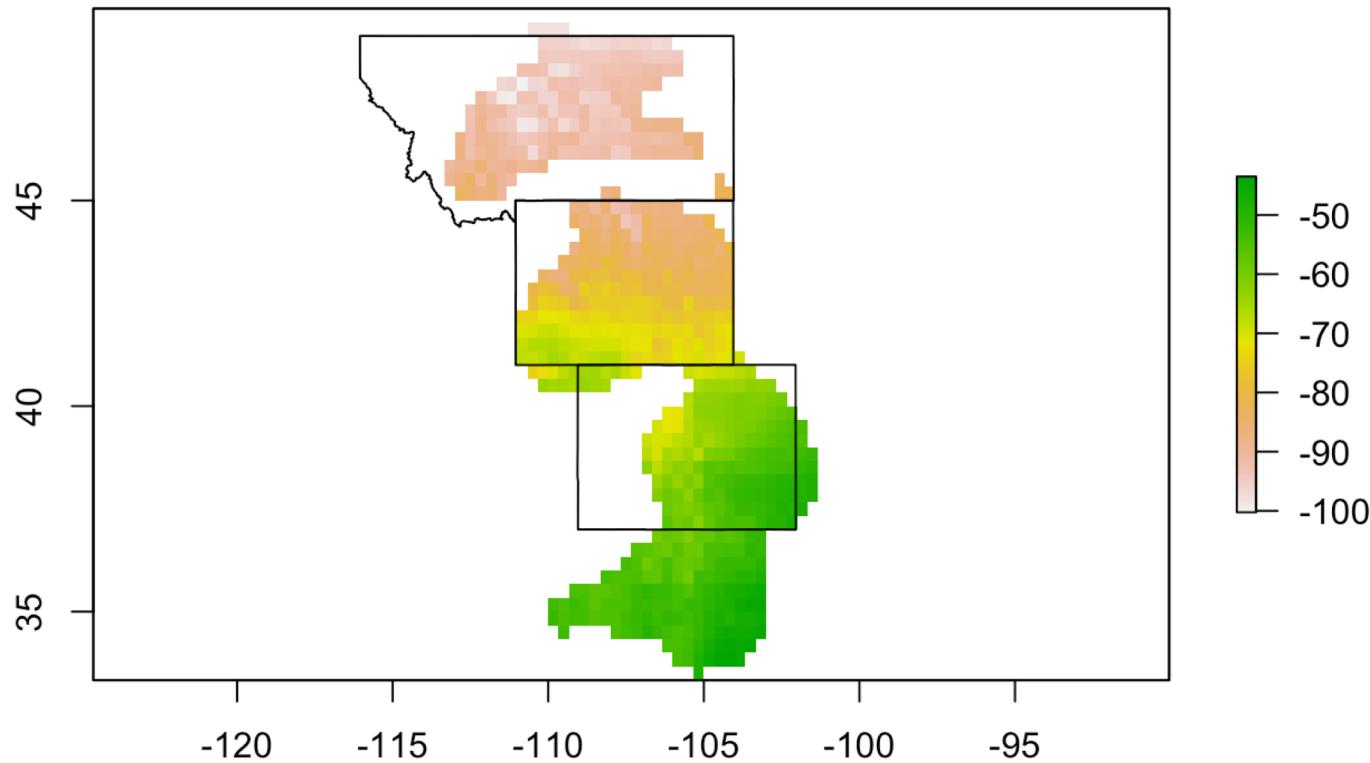
# Assignment to discrete regions



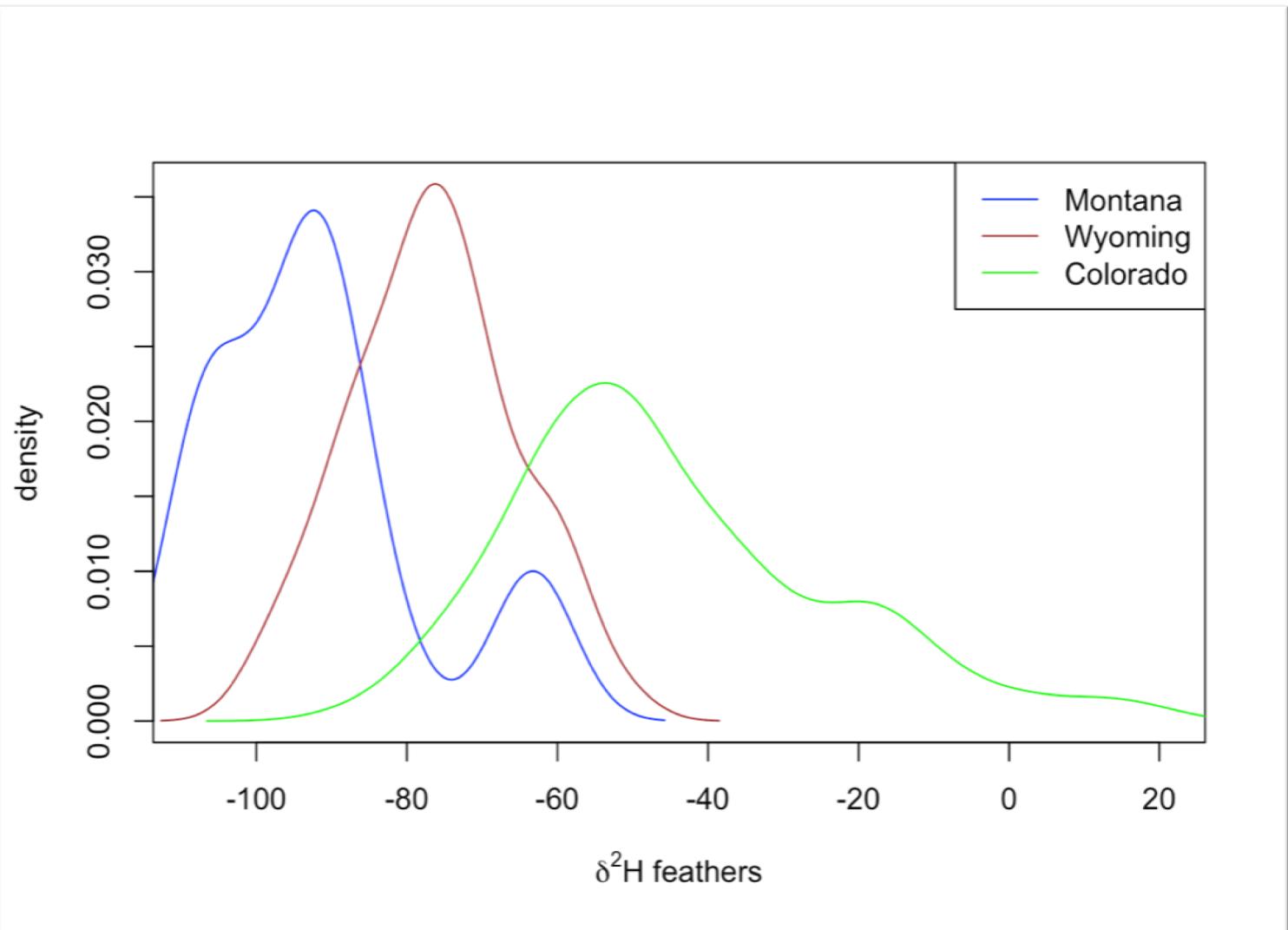
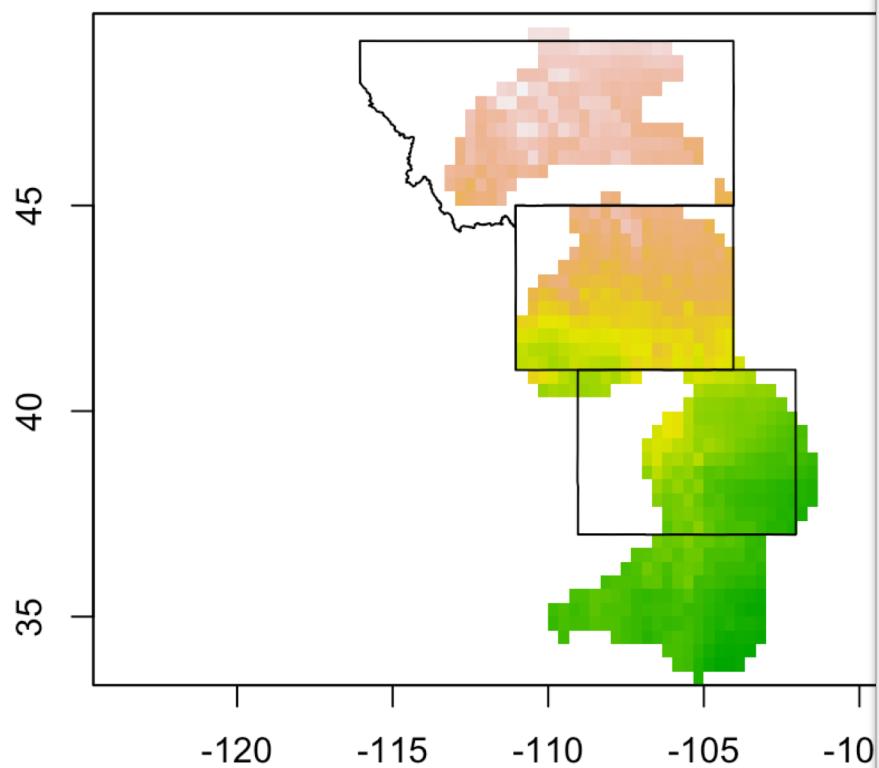
# Assignment to discrete regions



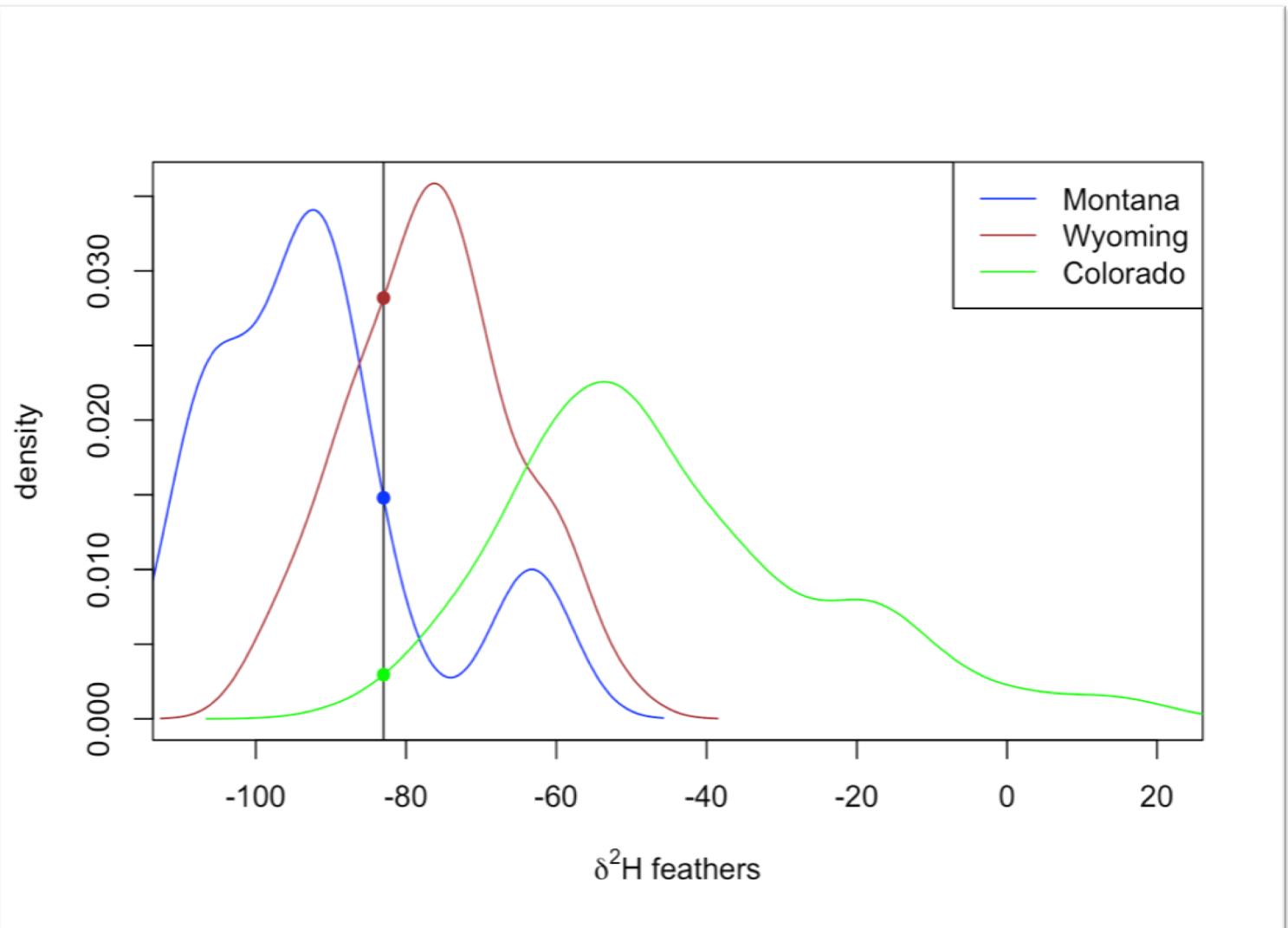
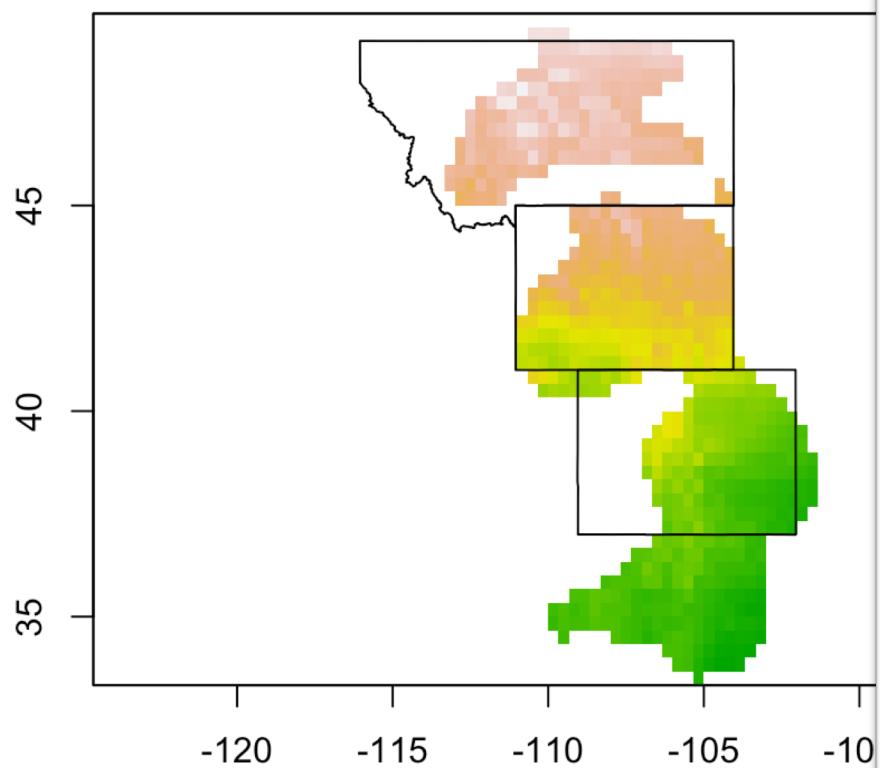
# Assignment to discrete regions



# Assignment to discrete regions

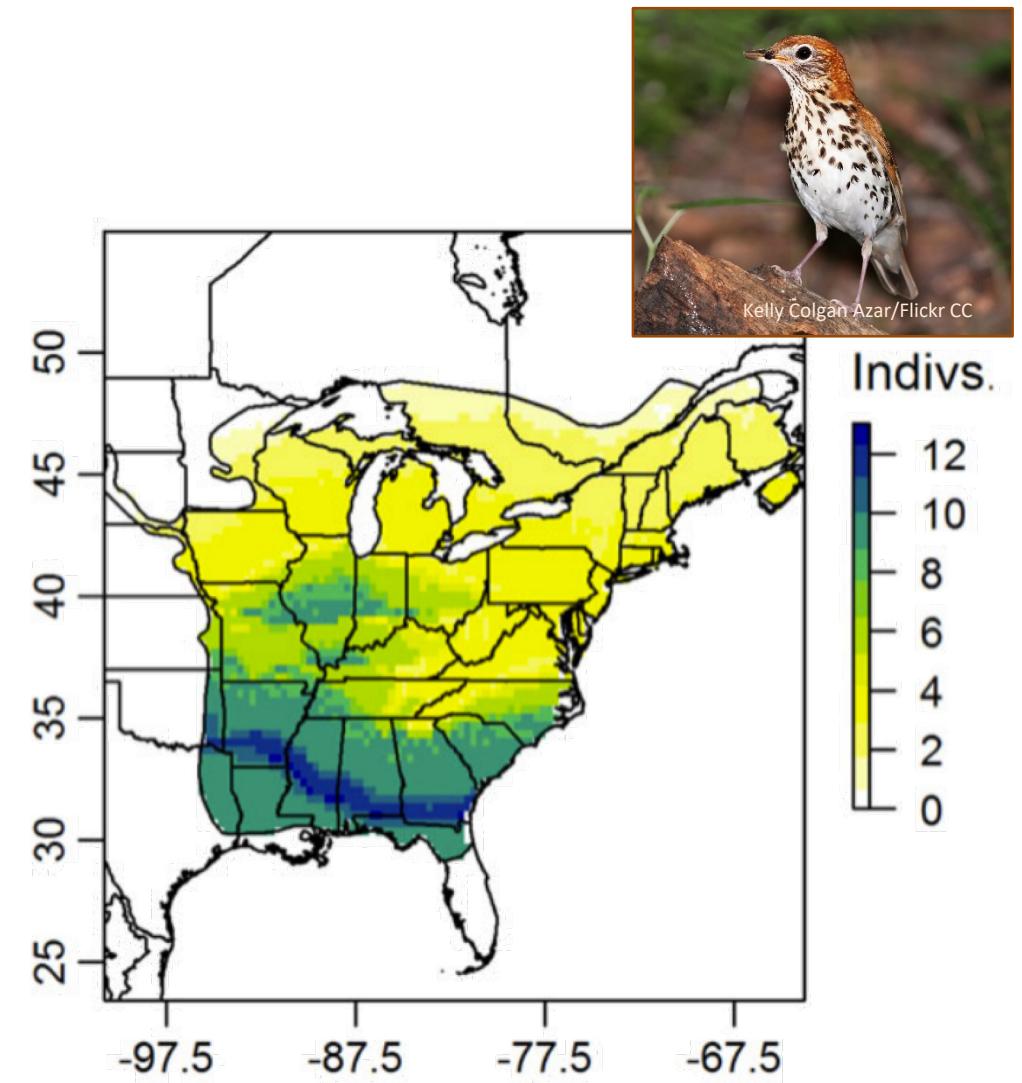
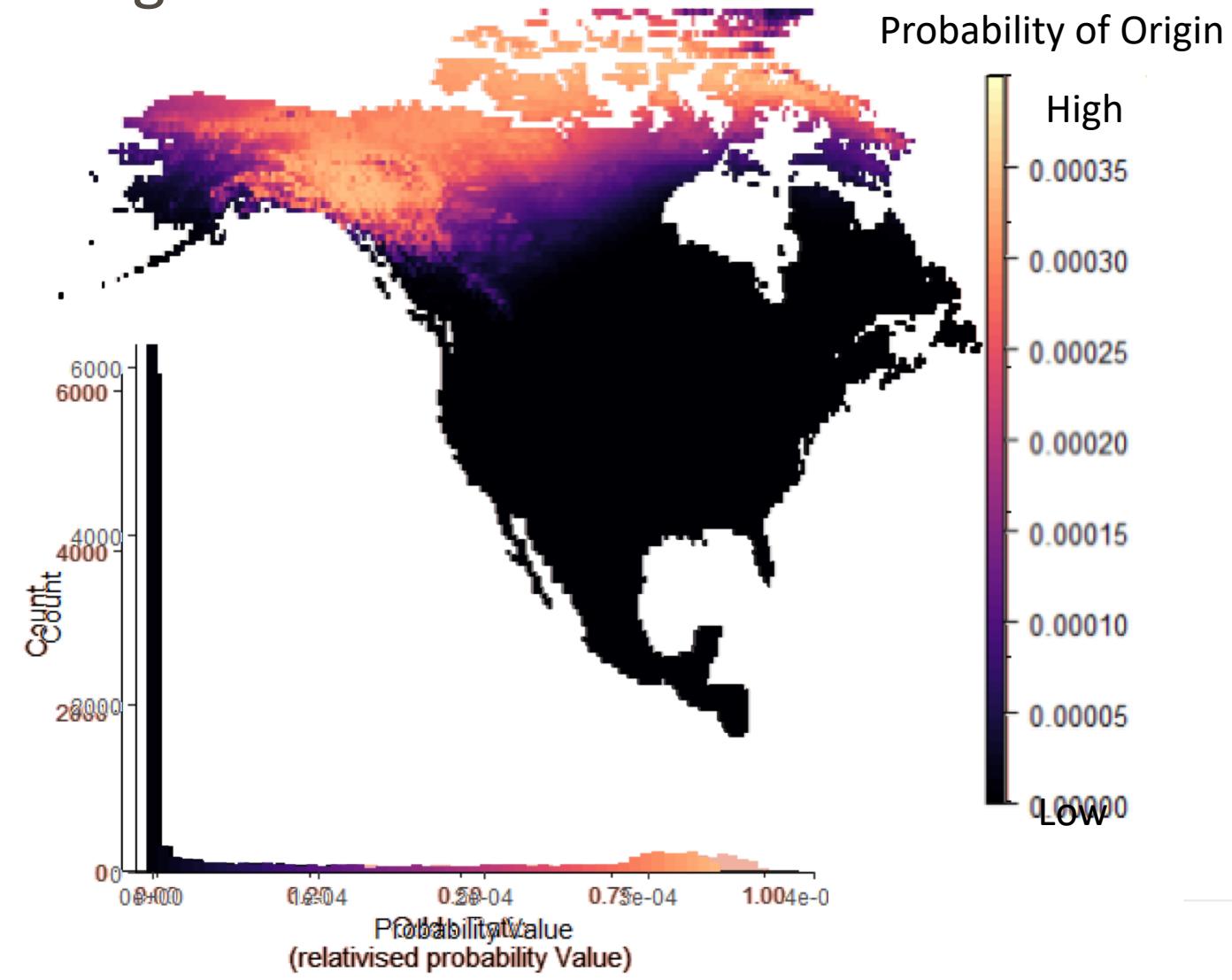


# Assignment to discrete regions



# Summary maps

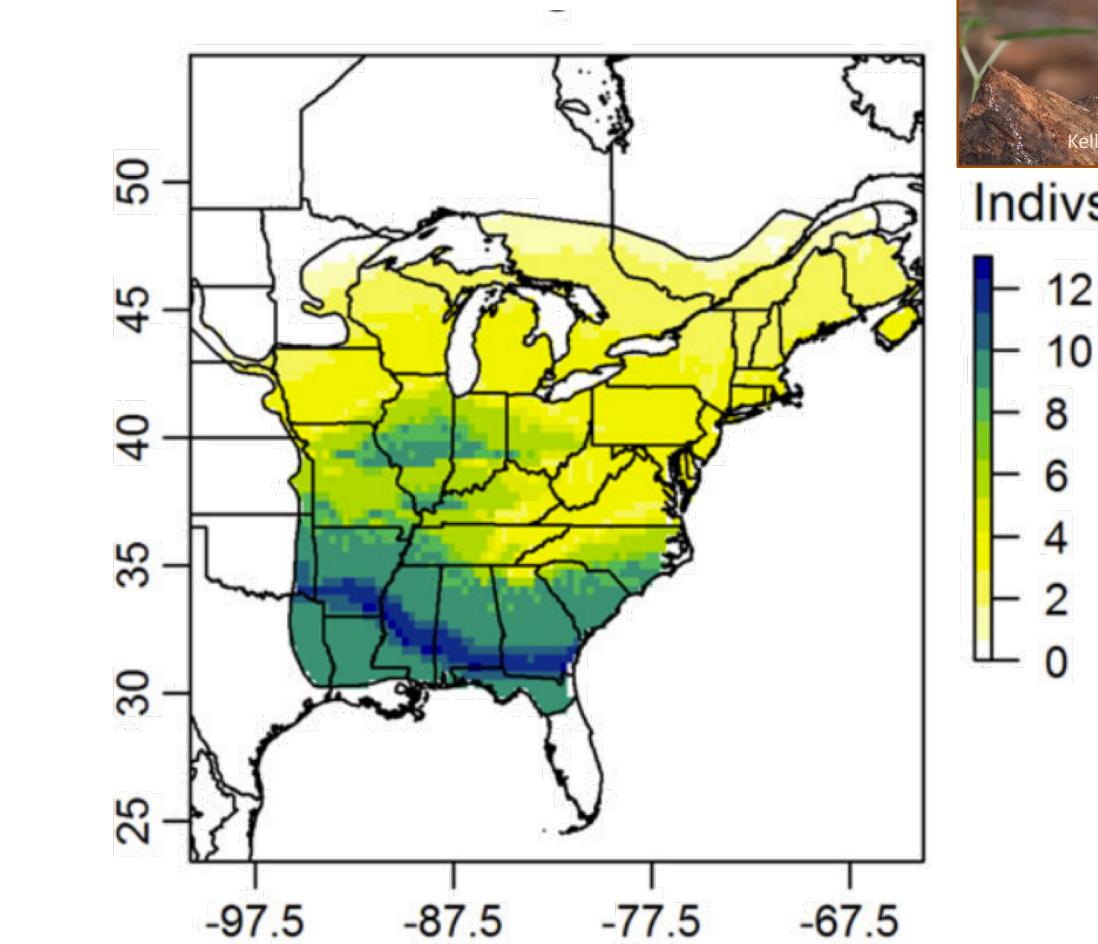
Popular methods for summarizing origins without using predefined regions have limitations.



Hobson et al., 2014

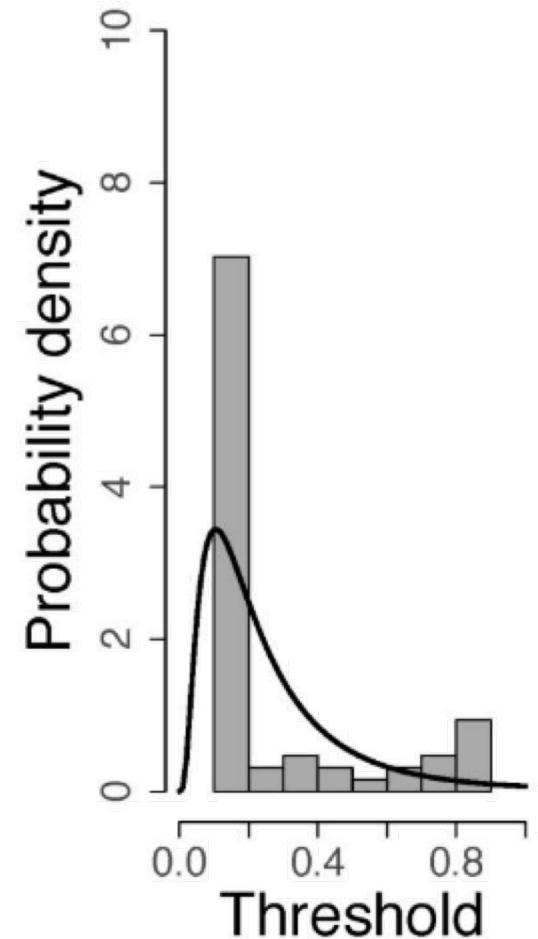
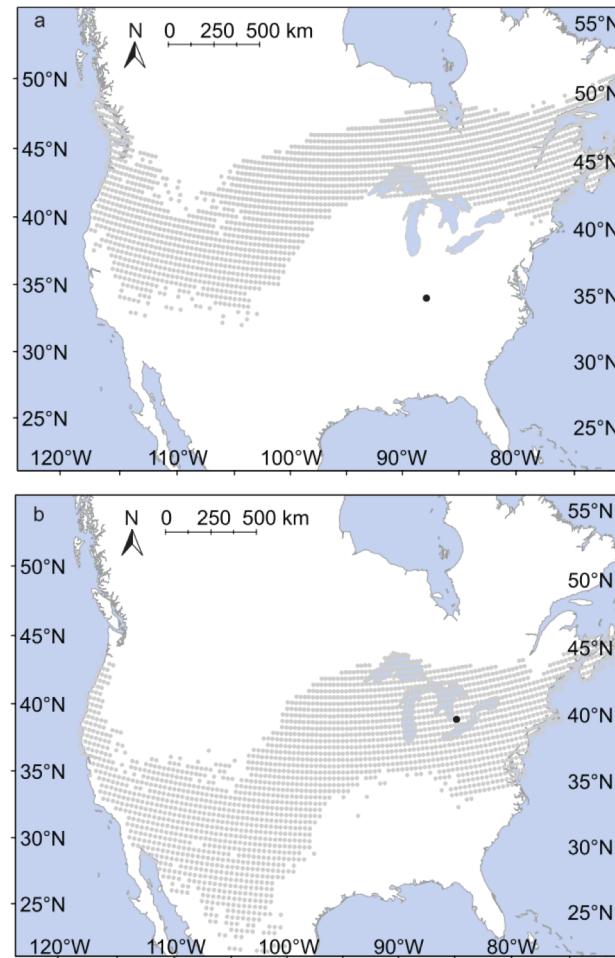
# Summary maps

- Look great, have drawbacks:
  - Hard to interpret with large sample sizes
  - Origin patterns easily obscured
  - Delineation for “high probability” region often arbitrary

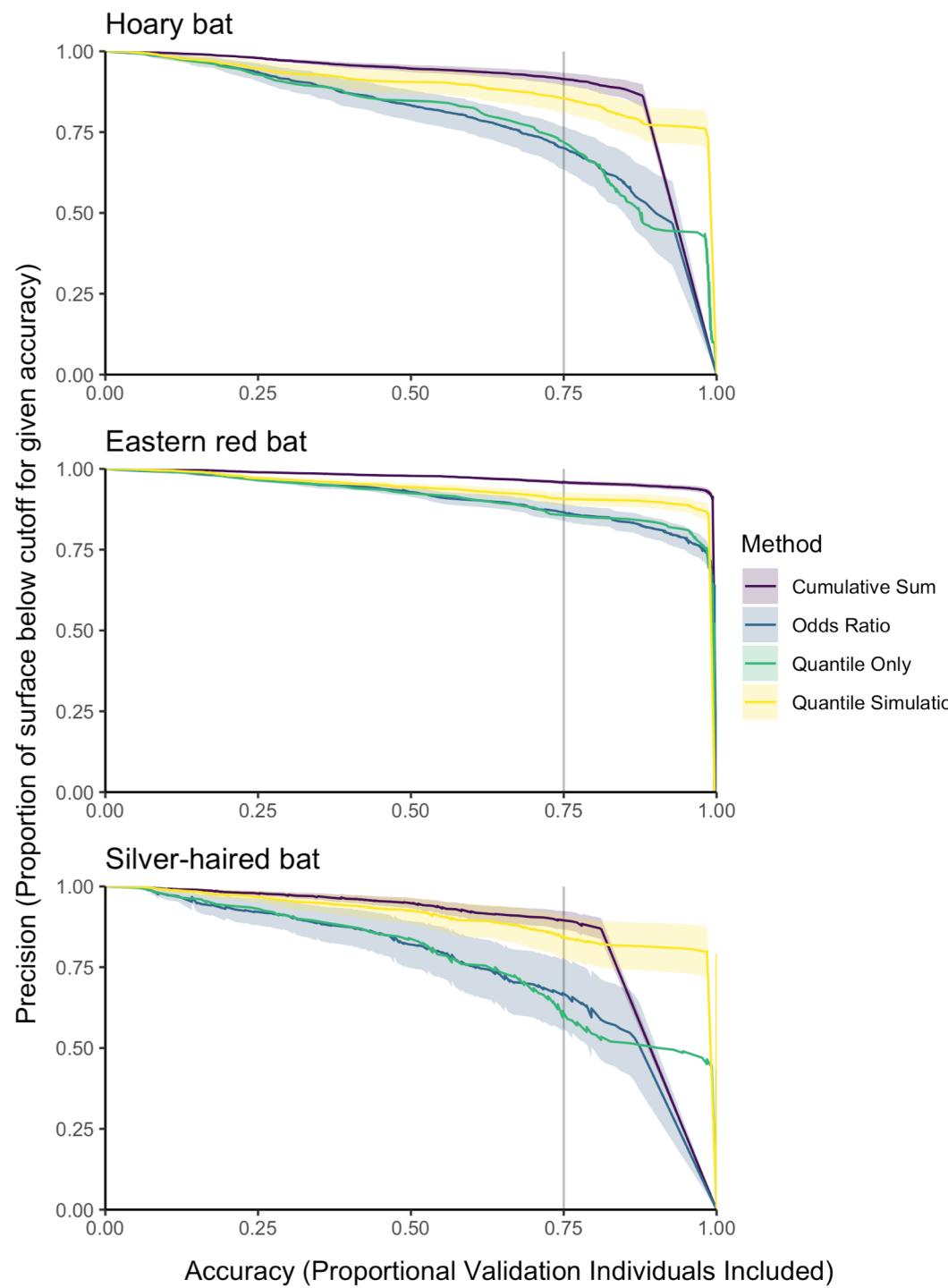


# Other summary statistics

- Common statistics
  - Local status
  - Distance Traveled
  - Direction Traveled
- Most methods require defining “high probability” regions, which had previously not been validated for accuracy.



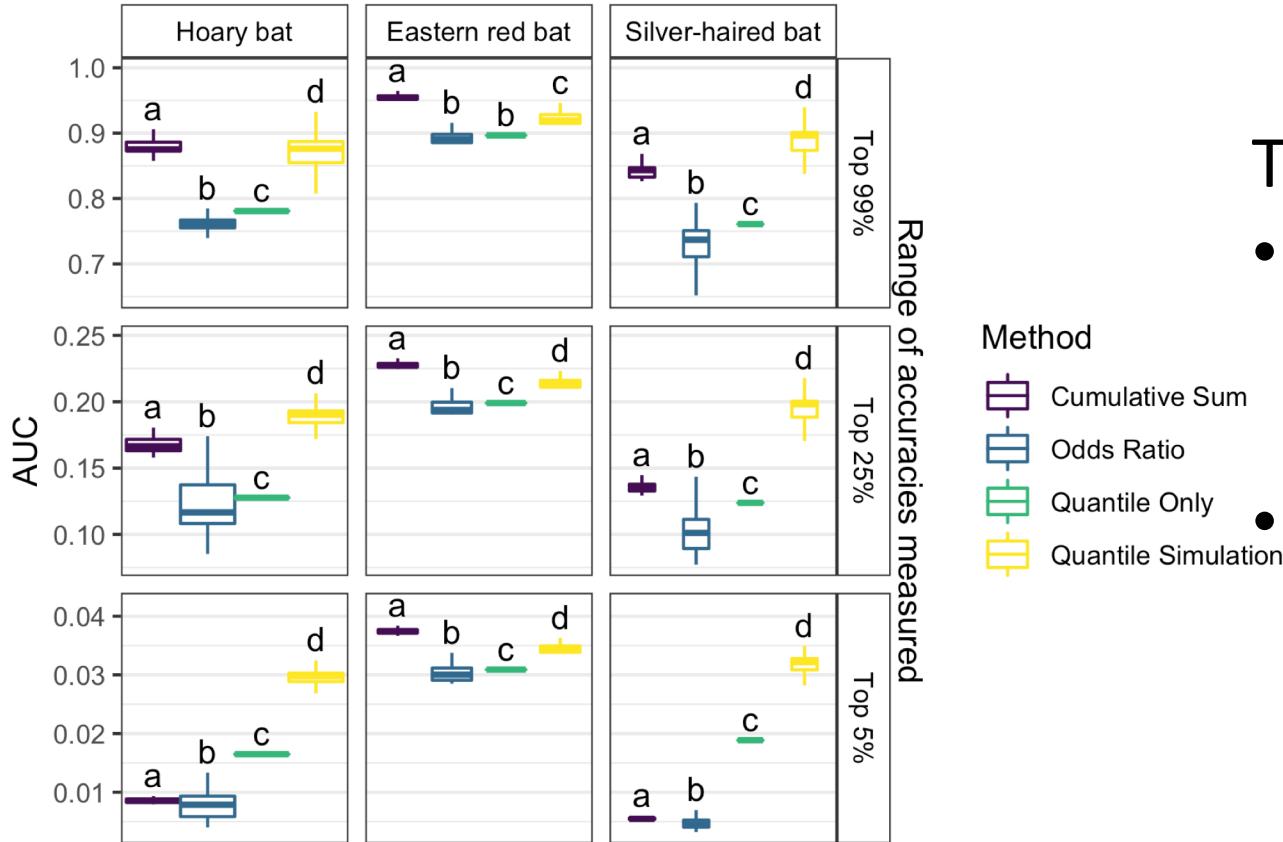
# Local Status



- Forthcoming paper sampled known-origin individuals
- Four methods evaluated:
  - Cumulative sum
  - Odds Ratio
  - Quantile Only
  - Quantile-Simulation
- Determined accuracy at local status at given thresholds
- Determined precision of models at given accuracy levels

Campbell, Vander Zanden, Fitzpatrick, and Nelson; *in prep*

# Local Status



Campbell, Vander Zanden, Fitzpatrick, and Nelson; *in prep*

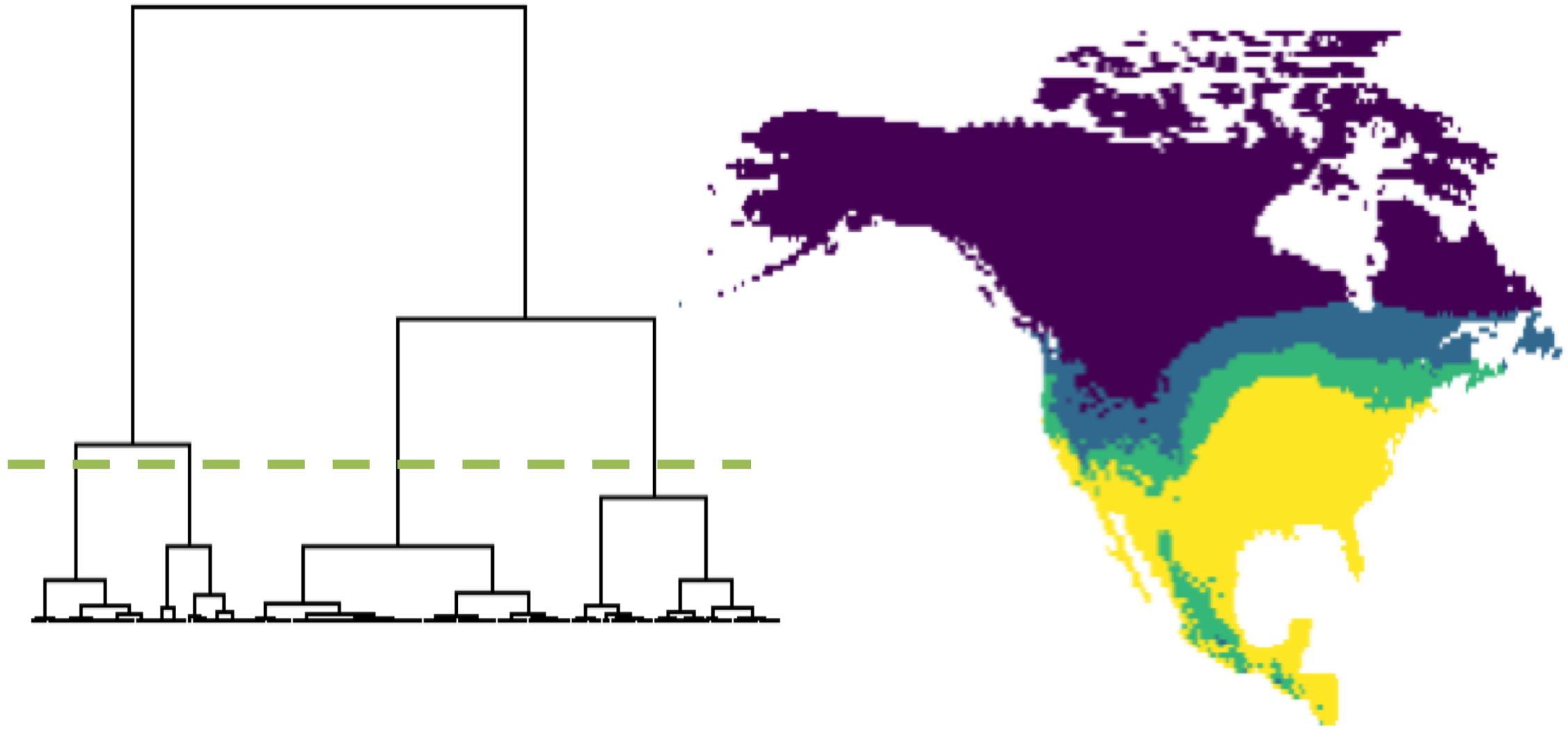
## Takeaways:

- Quantile-simulation probably best (accuracy + precision), but requires known-origin individuals
  - If you don't have known-origin individuals, use 'Cumulative Sum'
    - If you can't validate, know that the cutoff for "local" or "high probability of origin" might be arbitrary and vary in accuracy across species.

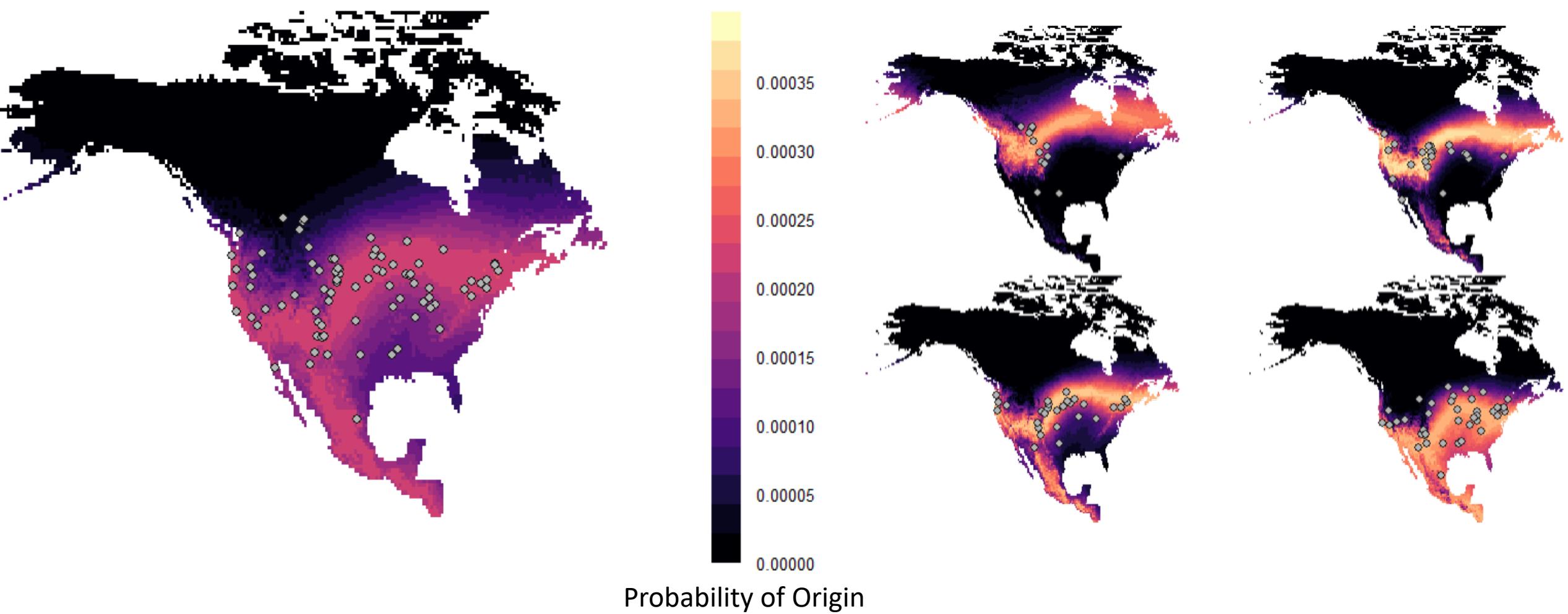
# Local Status

- Functions for all methods explored are available in ‘isocat’

# Grouping by common origins

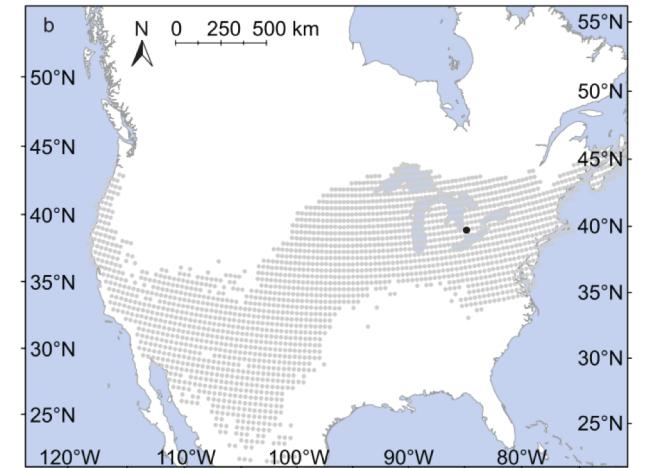
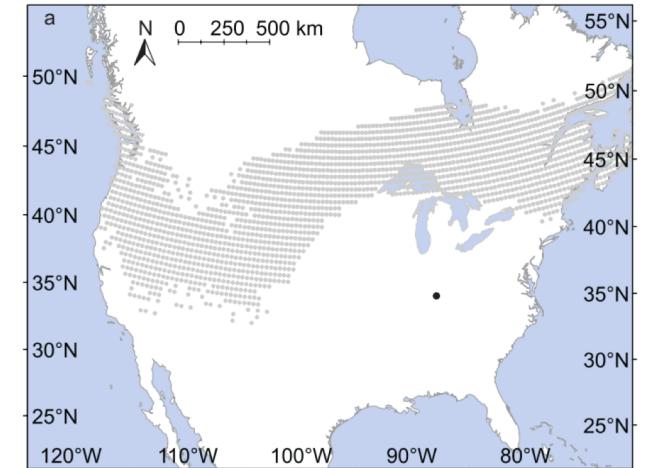


# Grouping by common origin



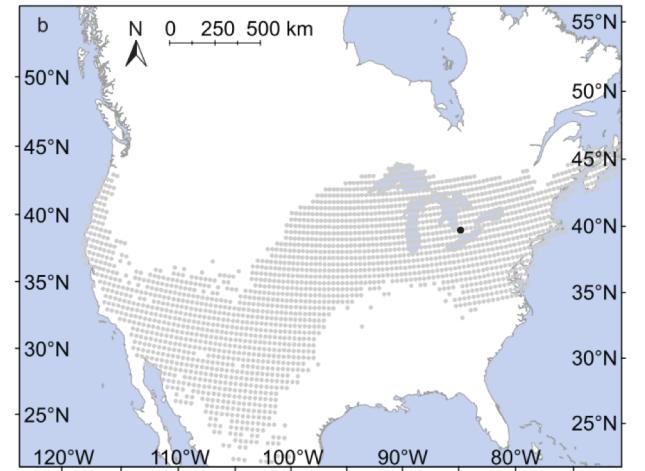
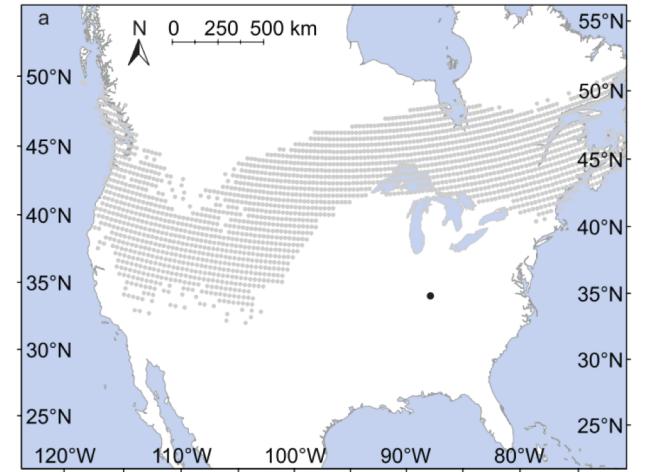
# Distance and direction of travel

- Can measure from nearest area of "high probability"



# Distance and direction of travel

- Can measure from nearest area of "high probability"
- Emerging tools to consider all probabilities in continuous surface



# Contact Information

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- Github: [github.com/cjcampbell](https://github.com/cjcampbell)

# Resources

- Slides, links to additional resources available:

[github.com/cjcampbell/AnimalOrigins\\_SBDN/](https://github.com/cjcampbell/AnimalOrigins_SBDN/)