



Local and Global Biodiversity Monitoring with the Internet of Animals

Roland Kays

North Carolina Museum of Natural Sciences

North Carolina State University



SARASOTA, FLORIDA

GREAT
RANDMASTERS
WORLD CHAMPIONSHIPS

NOVEMBER 6-7, 2021

Sarasota

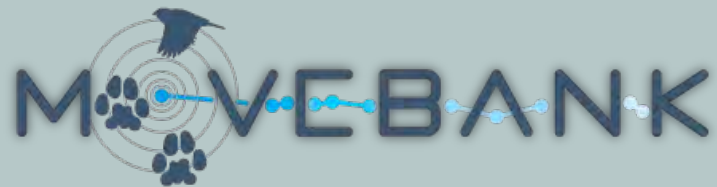








Acknowledgements - representing big team efforts



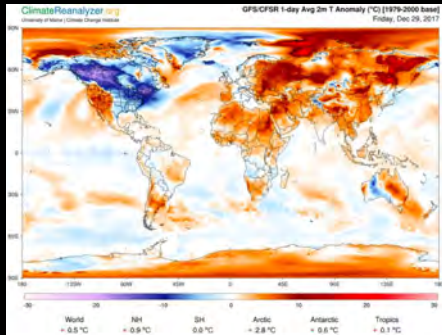
ANIMAL TRACKING



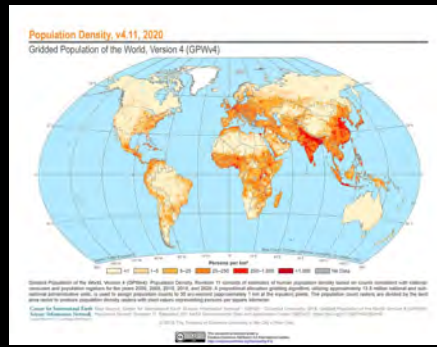
CAMERA TRAPS







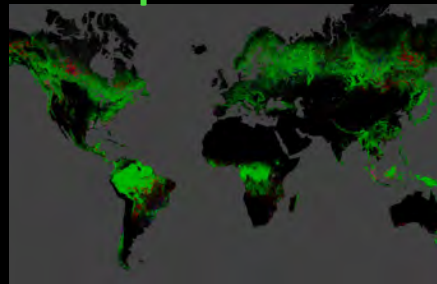
Temperature



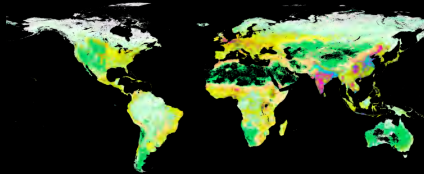
Human
Population



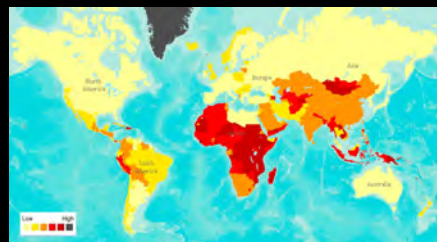
Fires



Deforestation



Habitat



Fresh Water

The Physical World is Changing Fast

What About the Animals?

- We need new data every year
- We need timely analyses
- Variety of species, locations, scales

Some Species Thriving

Common Raccoon





Some Species Not Thriving
Sumatran Rhino

18 17:46

Trends, 2012-2022

Breeding season 7 Jun – 9 Aug

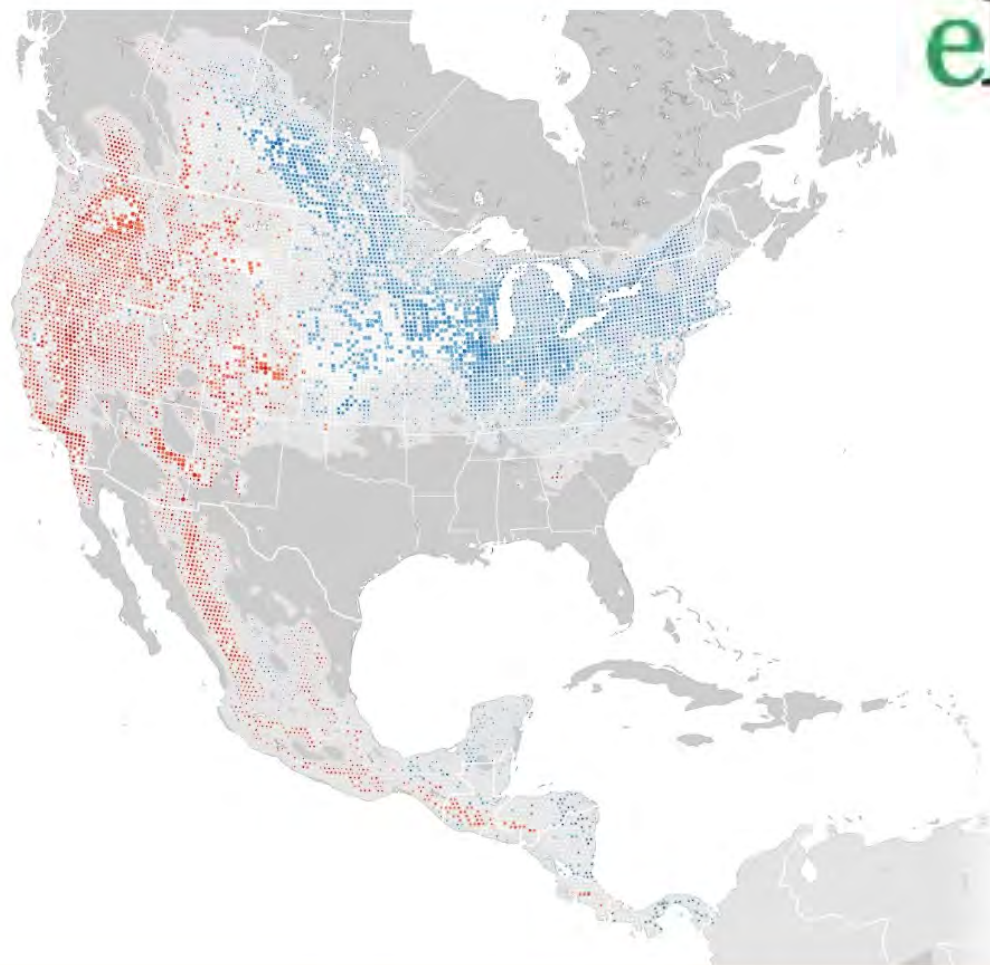
Range-wide trend

↑ 3%

Abundance trend



Abundance

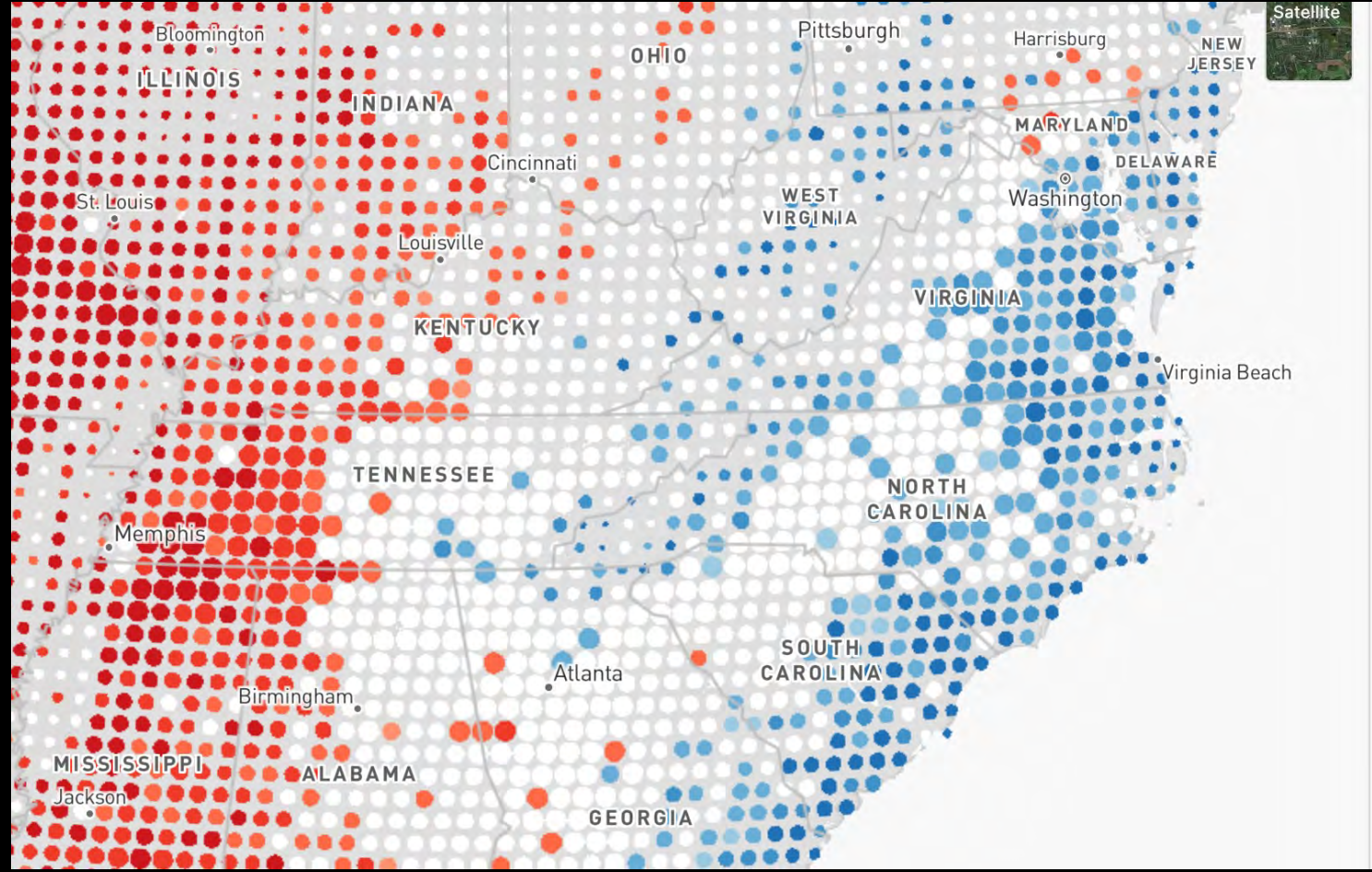
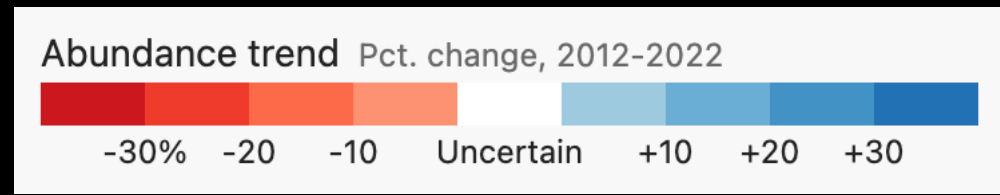


House Wren *Troglodytes aedon*

Data provided by eBird

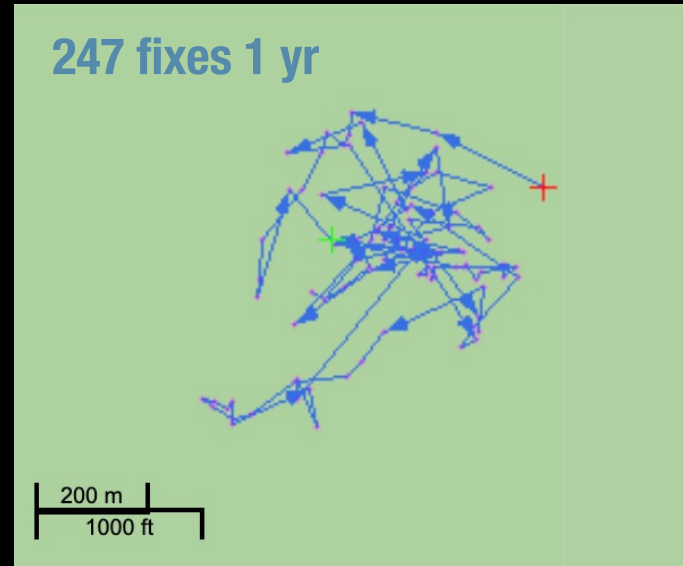


Eastern Bluebird Population Trends



Fink, D., et al 2023. eBird Status and Trends, Data Version: 2022; Released: 2023. Cornell Lab of Ornithology

NOT THAT SURPRISING – GETTING THESE DATA IS HARD WORK



Kinkajou

Animal Tracking 1996



MY FIRST CAMERA TRAP PICTURE, ALBANY PINE BUSH, 2000

29 5:59

A lot has changed in the last 25 years!

Big Data for Conservation





Wildlife Insights

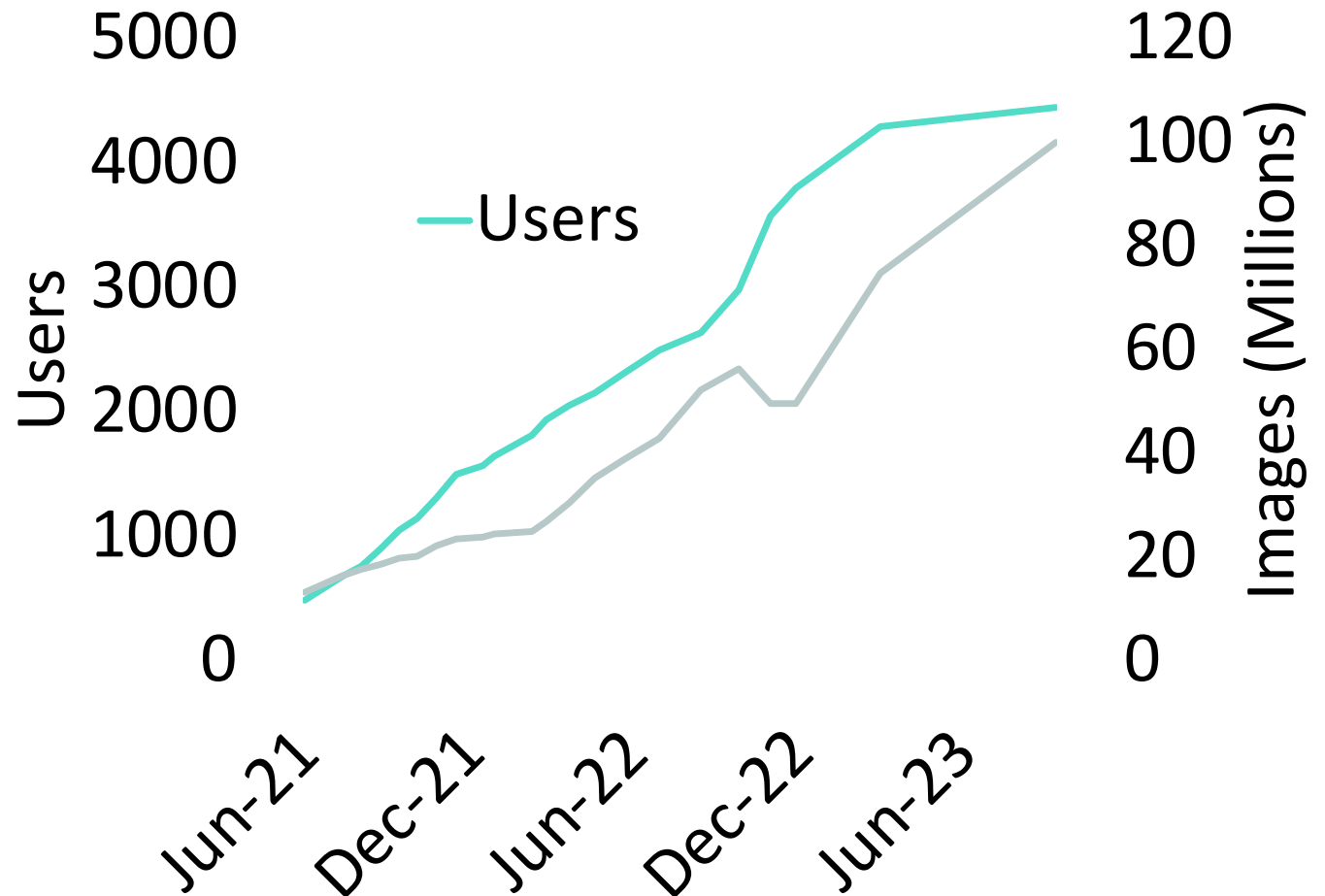
A new platform to maximize the use of camera trap and passive sensor wildlife data for conservation

©Will Burrard-Lucas / www.burrard-lucas.com

Camera Trap Data

- Community database using AI to help process images

5000 Users
1600 Projects
98 Countries
117 Million Images







ANIMAL TRACKING DATA

Search Studies

Search

Advanced Search

All Sensor Types

Only studies where I can see data

Search

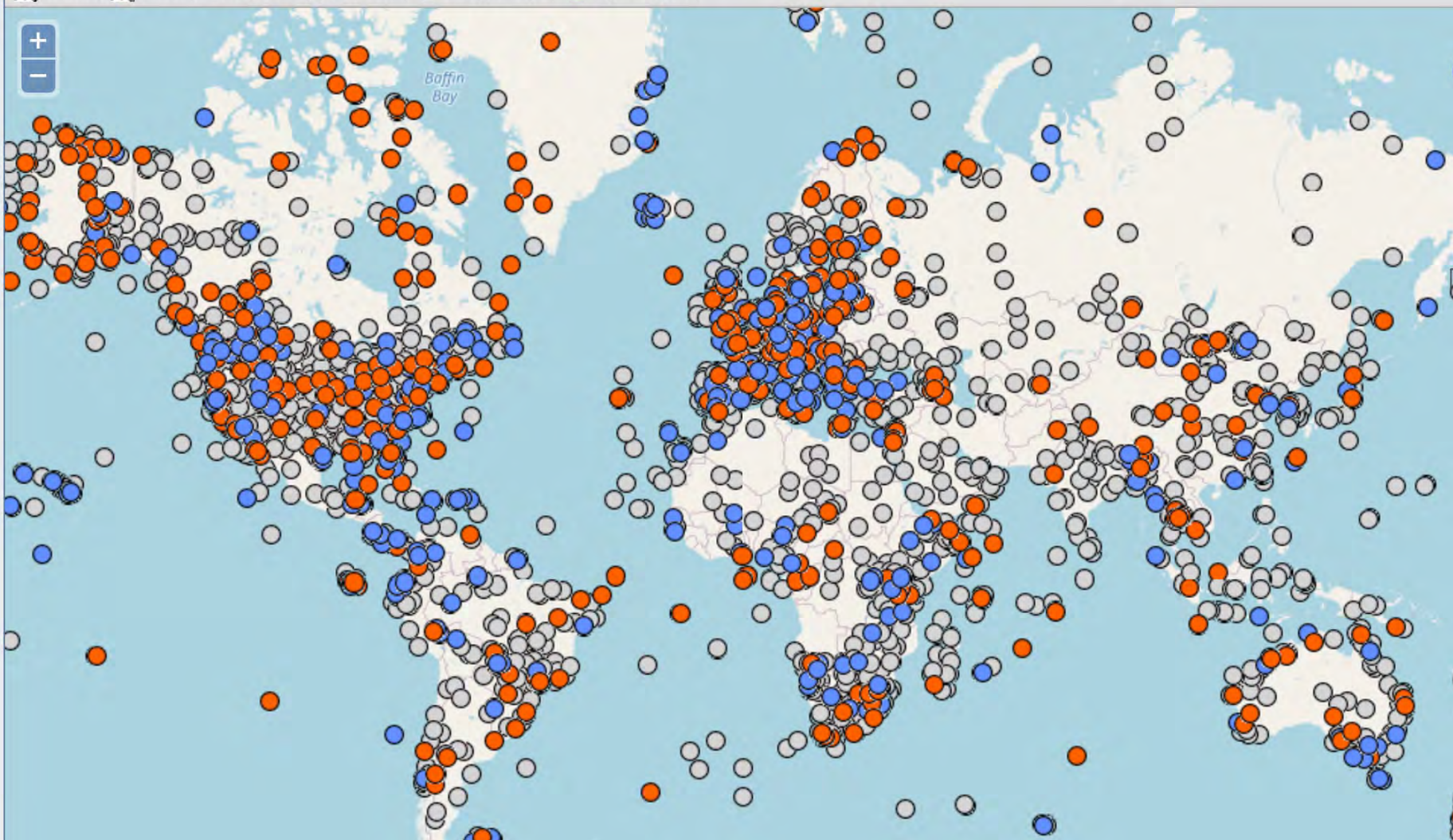
Search result

Sort by Animal Identifier

<input type="checkbox"/>	Bornean Orangutan, 2012 GPS Split by Month, Tuana	<input type="button" value="i"/>	<input type="button" value="Q"/>
<input type="checkbox"/>	Feral Pig Sus scrofa Kimberley Region, Western Austr	<input type="button" value="i"/>	<input type="button" value="Q"/>
<input checked="" type="checkbox"/>	Chelonia mydas_bijagos_females_2018	<input type="button" value="i"/>	<input type="button" value="Q"/>
<input type="checkbox"/>	Conservation	<input type="button" value="i"/>	<input type="button" value="Q"/>
<input type="checkbox"/>	migratory bird migration strategy	<input type="button" value="i"/>	<input type="button" value="Q"/>
<input checked="" type="checkbox"/>	White Stork Denmark	<input type="button" value="i"/>	<input type="button" value="Q"/>
<input type="checkbox"/>	"AEQUILIBRIUM+ Project": Diet of the mediterranean	<input type="button" value="i"/>	<input type="button" value="Q"/>
<input type="checkbox"/>	"Oceanodroma castro" "Neves" "Azores"	<input type="button" value="i"/>	<input type="button" value="Q"/>
<input checked="" type="checkbox"/>	"Proyecto Eremita" Geronticus eremita Reintroduction	<input type="button" value="i"/>	<input type="button" value="Q"/>
<input type="checkbox"/>	"Proyecto Pennatus" Booted Eagle (Hieraetus penna	<input type="button" value="i"/>	<input type="button" value="Q"/>
<input type="checkbox"/>	"Realizando el valor socioecológico de una especie er	<input type="button" value="i"/>	<input type="button" value="Q"/>
<input type="checkbox"/>	'ATLAS [harod] [Pigeon] [2021]'	<input type="button" value="i"/>	<input type="button" value="Q"/>
<input type="checkbox"/>	(Bearded Vulture (Gypaetus barbatus), Pyrenees and	<input type="button" value="i"/>	<input type="button" value="Q"/>
<input type="checkbox"/>	(Circus pygargus) tracking	<input type="button" value="i"/>	<input type="button" value="Q"/>
<input type="checkbox"/>	(EBD) Anodorhynchus leari (Lear's Macaw)	<input type="button" value="i"/>	<input type="button" value="Q"/>

Search

Select Zoom Options Link Google Maps Open Layers



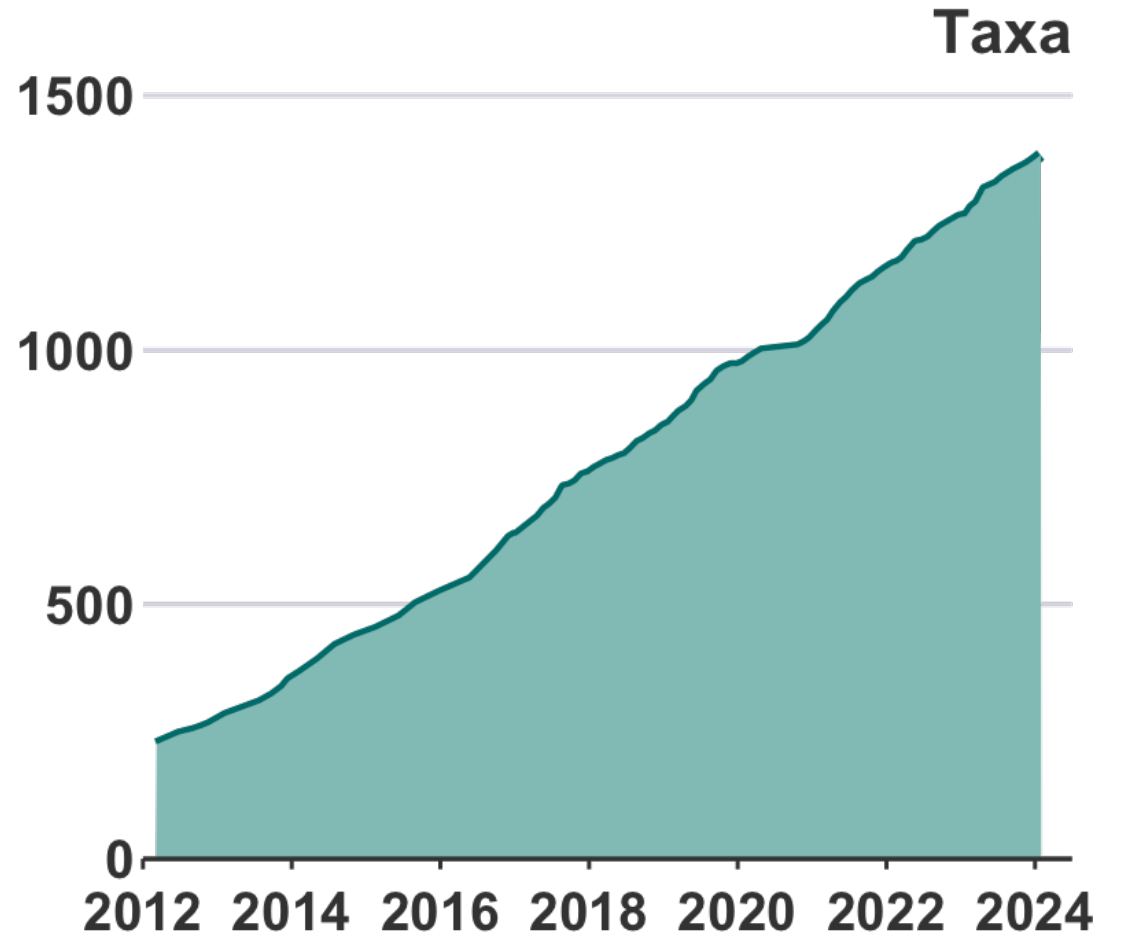
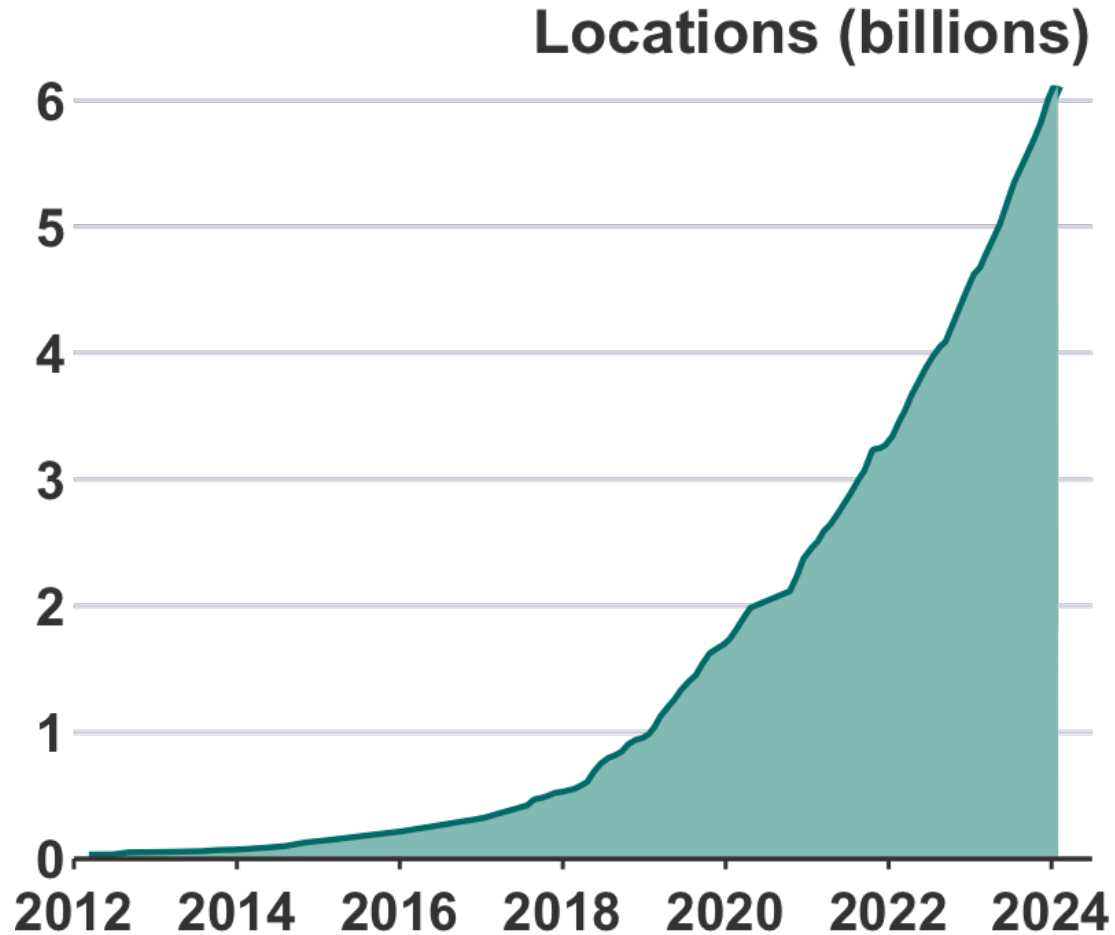


You don't have to share data, but
if you want to, we make it easy



MOVEBANK GROWTH

growing +11M/day





Analyse without Code

MoveApps is a no-code analysis platform for animal tracking data hosted by the Max Planck Institute of Animal Behavior. The aim is to make sophisticated analytical tools accessible to a larger audience.

Automated Workflow Analysis of Animal Tracking Data

- Apps: small analysis tools with customizable settings, built with R or Python
- Workflows: combinations of multiple apps

Segment Data by Speed

Threshold movement speed for segmentation
Insert speed (in m/s)

4

Direction of positions selected

Select if you want to select locations with speed above or below the threshold

- select above the threshold
- select below the threshold

 HISTORY

CANCEL

SAVE CONFIGURATION

golden eagle migration

> START WORKFLOW

OUTPUT



Animal Databases



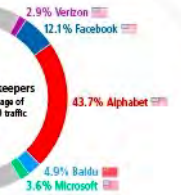
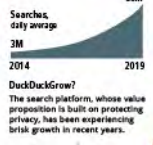
20M

TOP 100 WEBSITES

Global, June 2019

URL Monthly Visits in billions

google.com	60.49
youtube.com	24.31
facebook.com	19.98
bbc.com	9.77
wikipedia.org	4.69
twitter.com	3.92
yahoo.com	3.74
pornhub.com	3.26
instagram.com	2.21
webos.com	3.19
yandex.ru	3.06
anpproject.org	2.76
msn.com	2.47
amazon.com	2.41
live.com	2.25
vk.com	2.16
netflix.com	1.81
rt.com	1.76
whatsapp.com	1.75
mail.ru	1.64
reddit.com	1.55
yahoo.co.jp	1.50
google.com.br	1.38
twimg.com	1.32
ok.ru	1.08
shutterstock.com	1.06
giphy.com	1.00
ebay.com	0.95
bitly.com	0.95
twinkl.co.uk	0.91
linkedin.com	0.91
samsung.com	0.89
sm.cn	0.81
msn.com	0.80
office.com	0.79
globo.com	0.74
taobao.com	0.74
pinterest.com	0.74
google.de	0.73
microsoft.com	0.72
accuweather.com	0.71
naver.com	0.64
aliexpress.com	0.64
fandom.com	0.61
goya.com	0.58
gizmodo.com	0.57
india.com	0.57
uol.com.br	0.56
doom.me.jp	0.56
paypal.com	0.55
bbc.co.uk	0.55
microsoftonline.com	0.55
paypal.com	0.53
google.fr	0.53
yidianshi.com	0.51
wordpress.com	0.51
news.google.com	0.51
sohu.com	0.51
dundu.de	0.51
google.uk	0.51
10086.cn	0.50
iqiyi.com	0.50
booking.com	0.50
amazon.co.jp	0.49
cnbuz.com	0.49
taboola.com	0.48
amazon.de	0.48
cn.com	0.47
jd.com	0.47
apple.com	0.47
google.it	0.45
bitlii.com	0.44
google.co.jp	0.44
livejasmin.com	0.44
tmall.com	0.44
news.yahoo.co.jp	0.44
youku.be	0.44
tribune.com	0.43
amazon.co.uk	0.43
chaturbate.com	0.43
google.in	0.41
crisjst.org	0.41
imgur.com	0.41
bbc.com	0.41
rt.com	0.39
tyndata.com	0.39
weblio.com	0.38
tumblr.com	0.37
fournews.com	0.36
raikuten.co.jp	0.36
google.es	0.35
outbrain.com	0.35
discofdapp.com	0.35
amazon.in	0.35
crpigate.com	0.34
weather.com	0.34
tooth.com	0.34
youku.com	0.34
adobe.com	0.34
news.yandex.ru	0.33



You may not know these companies by name, but you've definitely seen their content recommendations at the end of articles and blog posts.

Rakuten is the biggest e-commerce website in Japan.

Accelerated Mobile Pages (AMP) Project is a Google-backed, open source initiative to standardize and simplify mobile pages.

Cricket became one of the busiest websites on the planet.

WGC2 HAWK'S two biggest porn sites get more monthly traffic than Wikipedia.

In 2009, Google launched the YouTube domain name to shorten video URLs.

This isn't the real BitTorrent. It's a phishing scam operating at a large scale.

Of the top 100 websites, YouTube has by far the longest visit duration.

Odnoklassniki and VKontakte are Russia's home-grown social networks.

Tencent is currently the world's most valuable unicorn and a top news aggregator in China. The company is owned by ByteDance, which also runs TikTok - a short-form video app gaining traction in the global market.

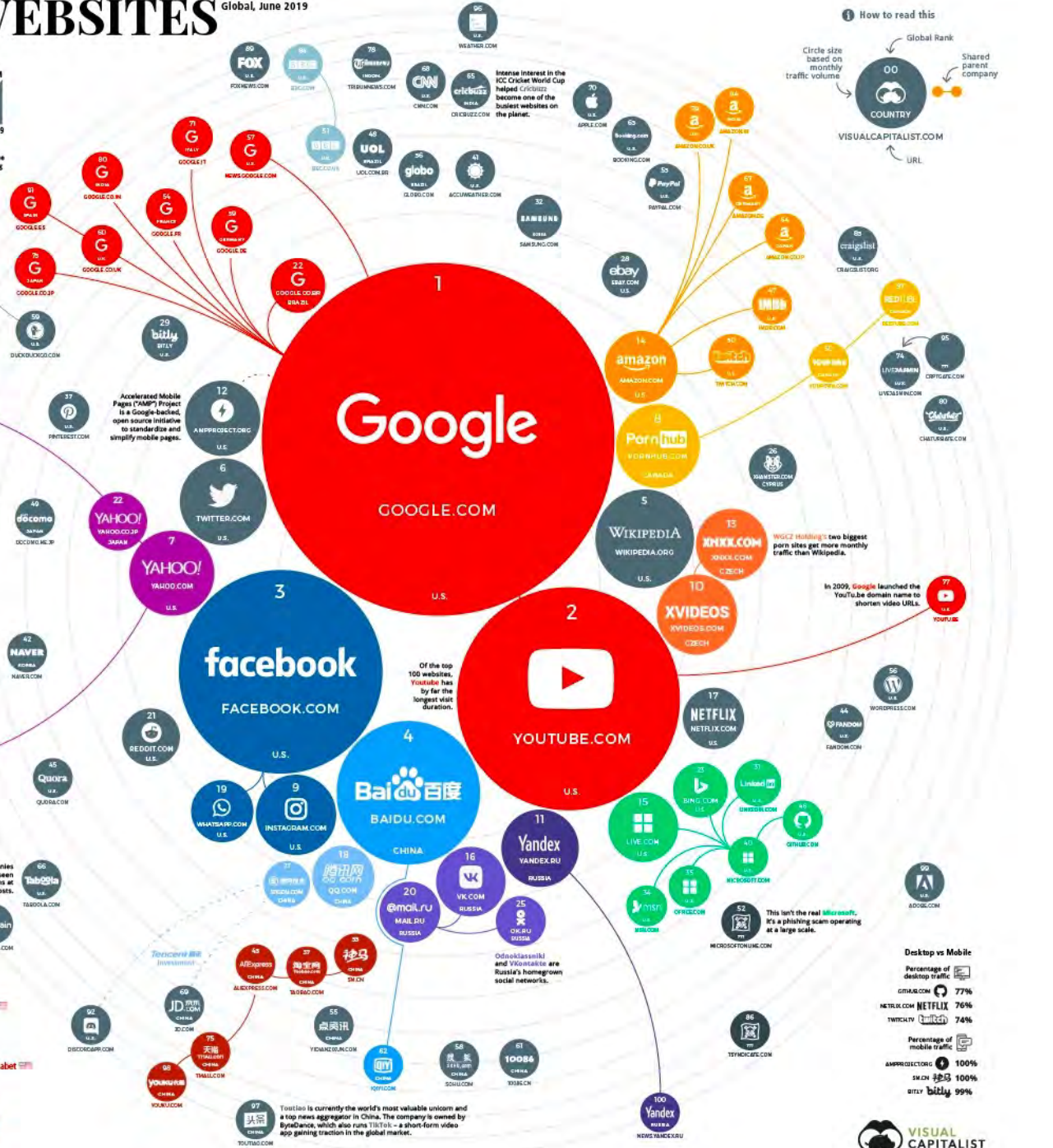
Desktop vs Mobile Percentage of desktop traffic

- 77% GMAIL.COM
- 76% NETFLIX.COM
- 74% TWITCH.TV
- 100% ANPPROJECT.ORG
- 100% SM.CN
- 99% RTV.BITLY

Percentage of mobile traffic

- 100% SM.CN
- 100% RTV.BITLY
- 99% RTV.BITLY

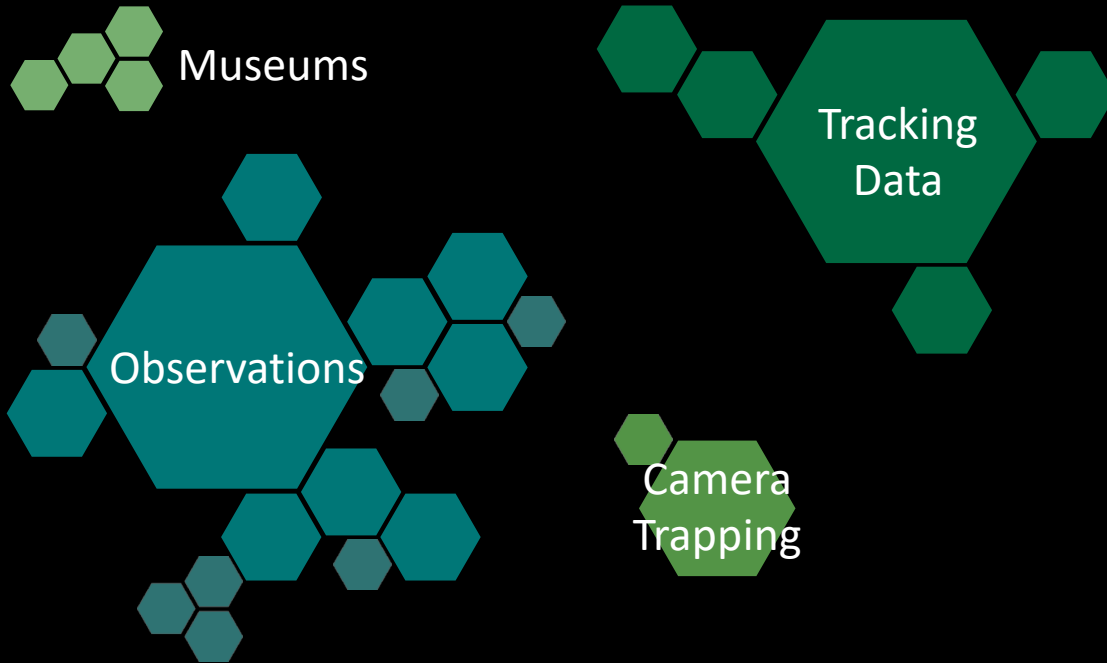
Source: SimilarWeb



The Internet

Internet of Animals Top 50 Databases

Types of Spatial Data



Smithsonian
2M verts

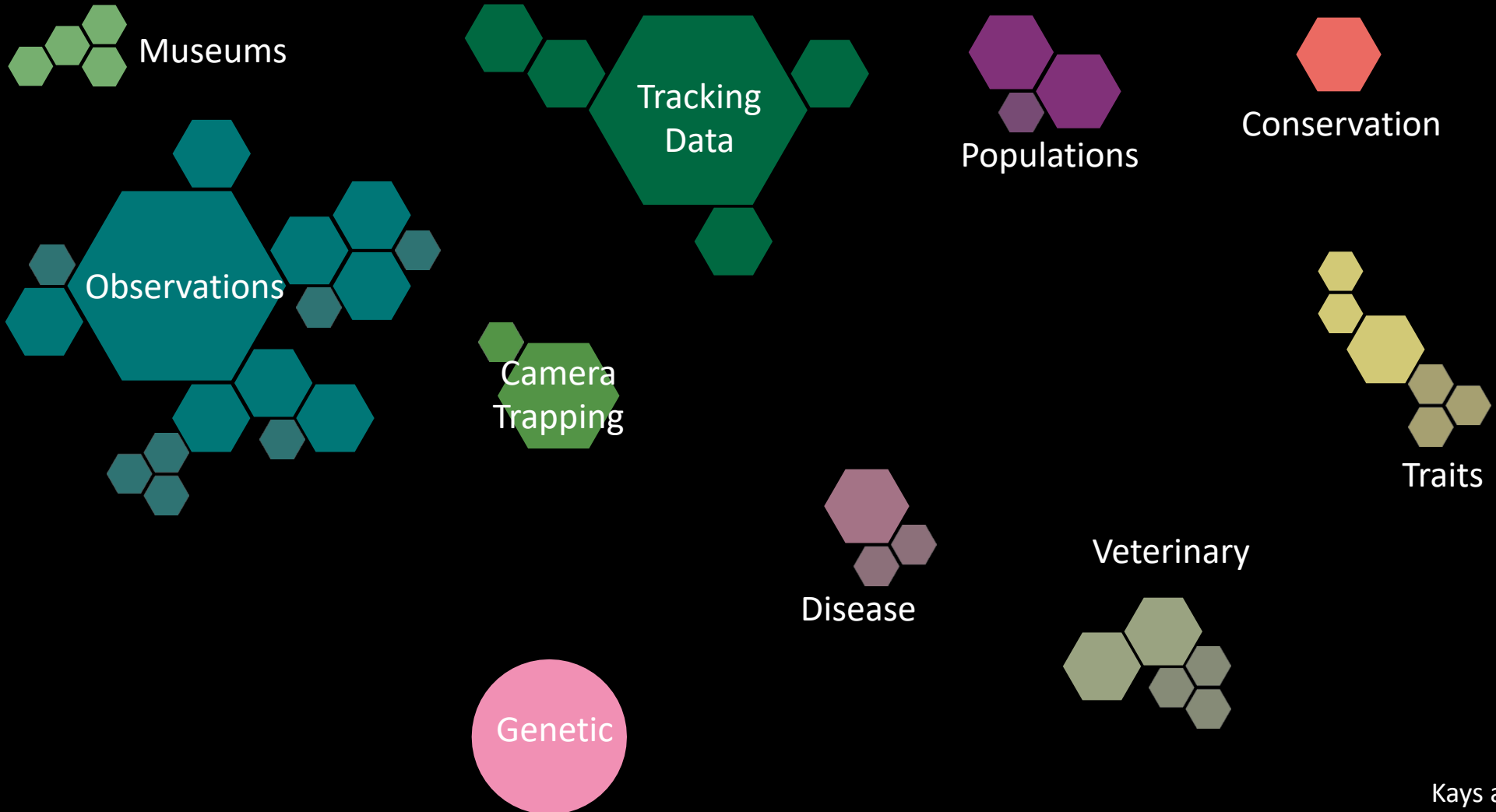


16M

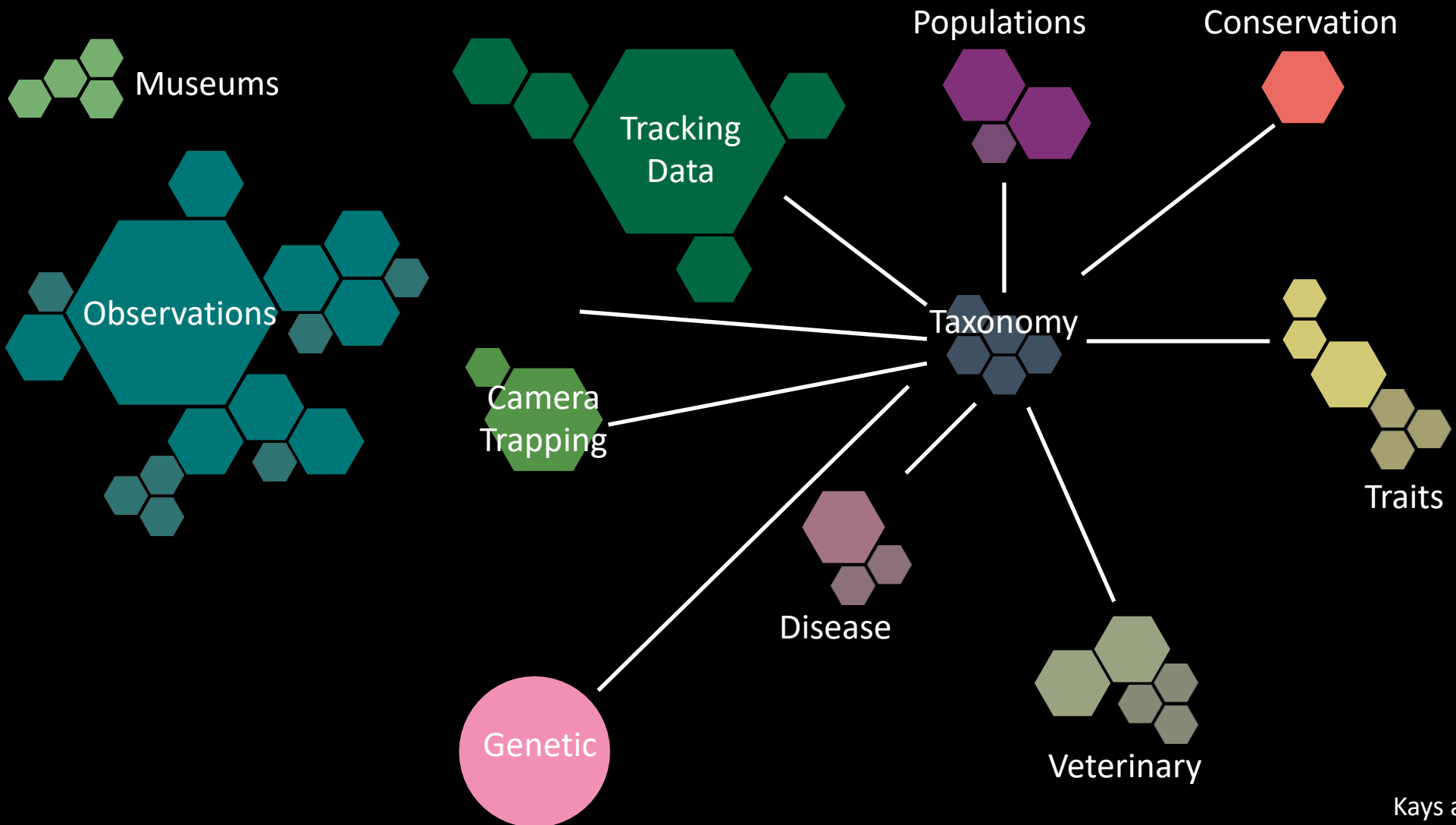


1.3B

Internet of Animals Top 50 Databases



Internet of Animals Top 50 Databases



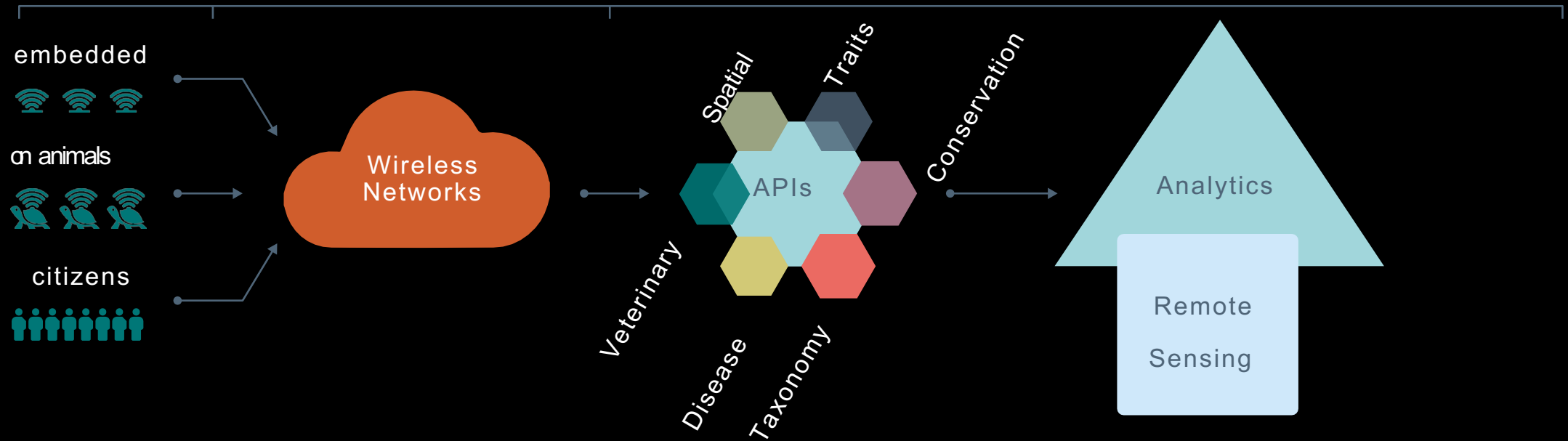
The Internet of Animals

1. Sensing

2. Live data

3. Linked data

4. Automated Analytics



What can we do with the Internet of Animals?

The Vision

To Inform Conservation Decision Making

- Abundance: Animal Population Sizes and Trends
- Movement: Connectivity Between Populations

The Vision

To Inform Conservation Decision Making

- Abundance: Animal Population Sizes and Trends
- Movement: Connectivity Between Populations



The Vision

We're not going to achieve this
today

But

We can start to plot a course to get
us there



Part #1. Abundance & Trend Maps



Hardware

- Motion Sensitive
- Digital
- Video
- Inexpensive
- Many cameras

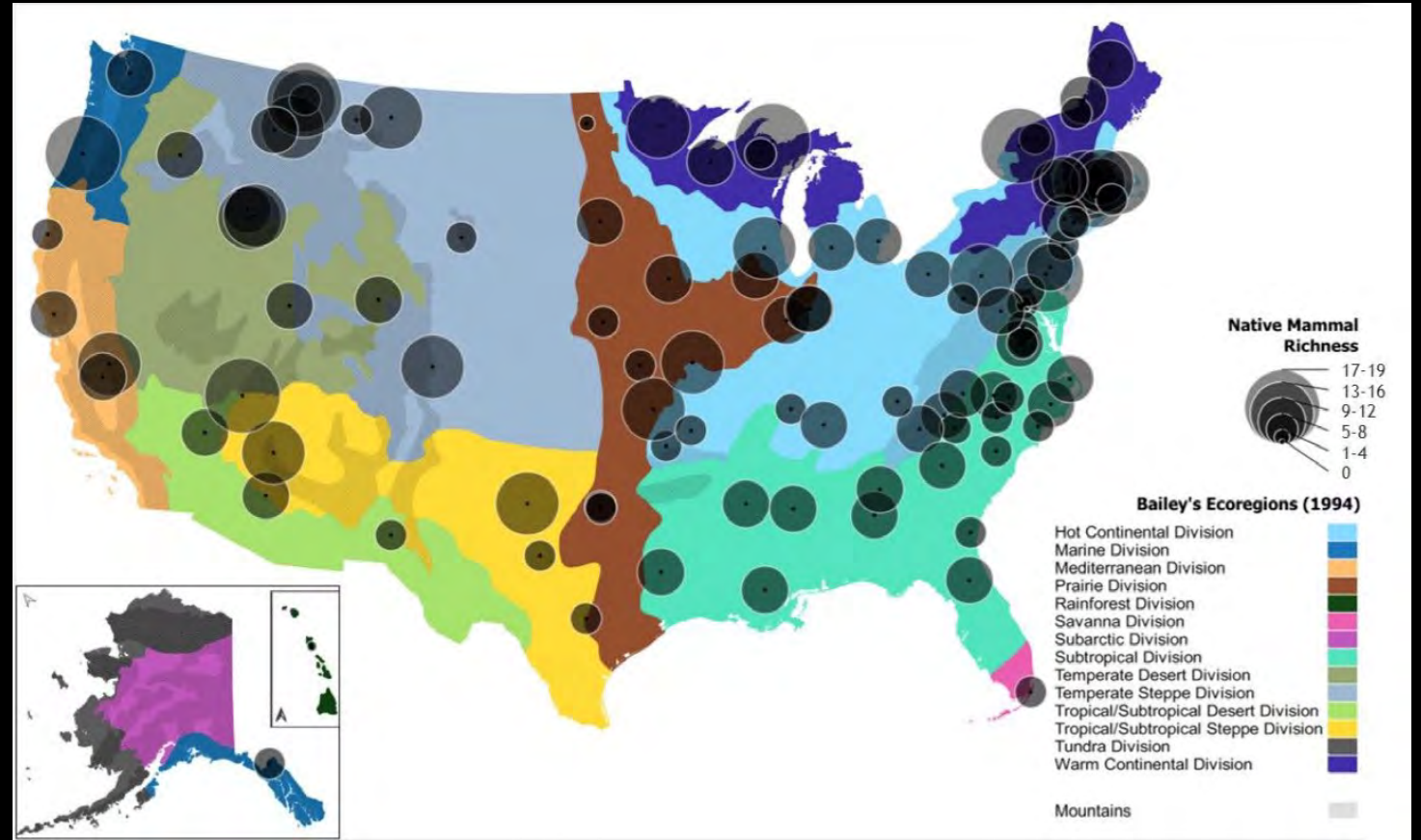


Collecting Data at Scale

- Large-scale scientific collaboration (not citizen science)
- Every Fall since 2019
- Data published, everyone co-author



Brainchild of
Bill McShea
Smithsonian



Snapshot USA

Snapshot USA 2019

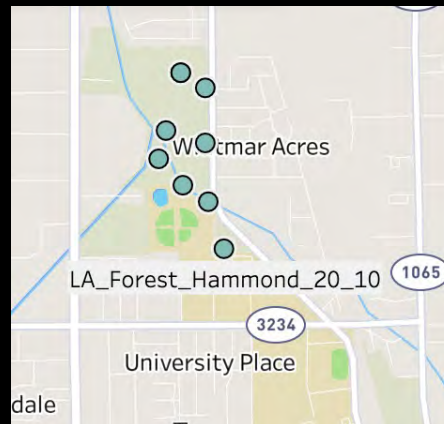
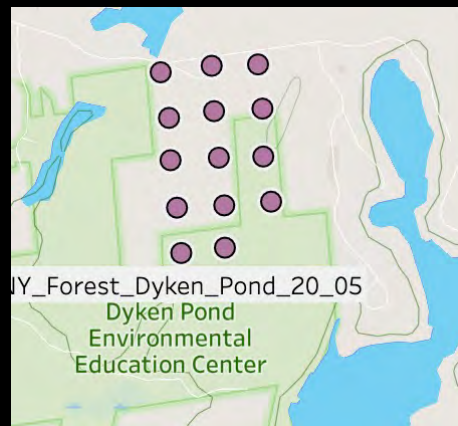
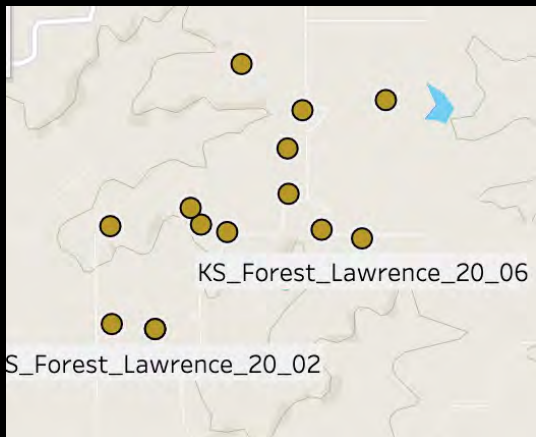
127 Participants

All 50 States



Snapshot USA

2019: 1503 cameras in 109 arrays
2020: 1400 cameras in 103 arrays
2021: 1400 cameras in 106 arrays
2022: 2170 cameras in 131 arrays
2023: 2173 cameras in 146 arrays

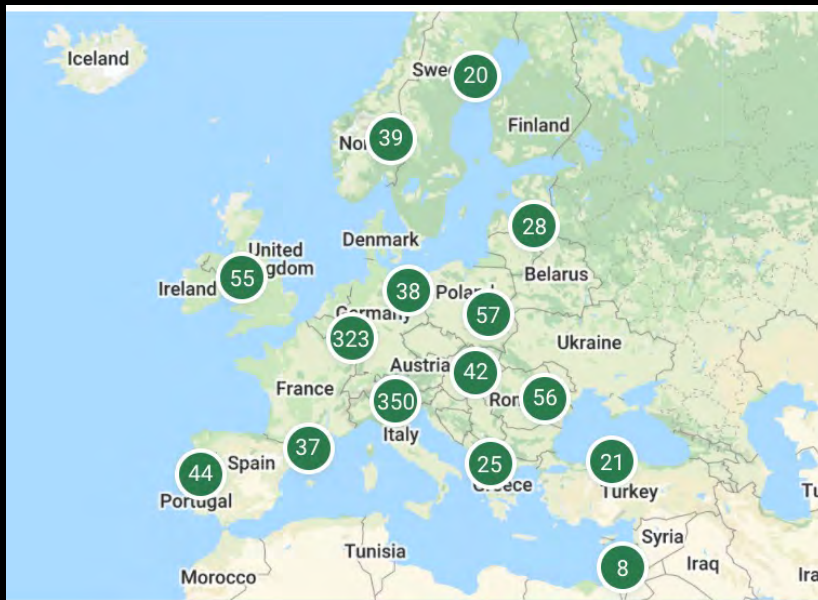


Snapshot EURO

2021: 1100 cams in 57 arrays

2022: 941 cams in 69 arrays

23 Countries

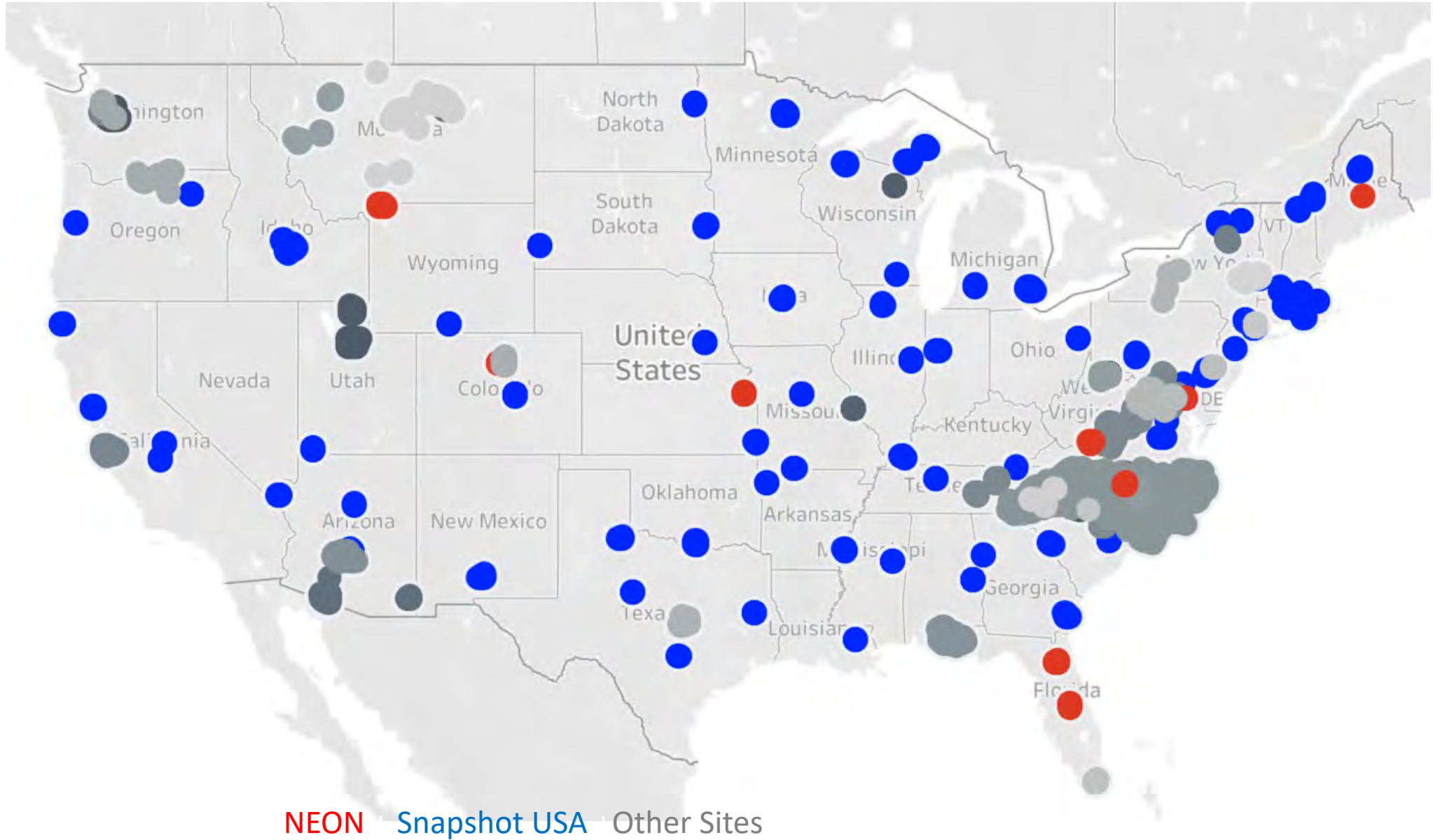


Snapshot Japan

2023 – 90 Locations



Camera trap data collection so far






iNaturalist as opportunistic wildlife sightings, photo verified


- Upload a picture of anything
- Community helps identify

iNaturalist Search [x] Explore Your Observations Community Identify More Upload 0 23

Eastern Red Bat (*Lasiurus borealis*) Research Grade Follow



Observation Details:
Observed: Mar 3, 2024 - 4:57 PM EST
Submitted: Mar 3, 2024 - 6:01 PM EST




Activity

- davidgeorge** suggested an ID Improving 2d
- Eastern Red Bat**
Lasiurus borealis Compare Agree
- caitjcampbell** suggested an ID 21h
- Eastern Red Bat**
Lasiurus borealis

Community Taxon What's this?

Eastern Red Bat (*Lasiurus borealis*)
Cumulative IDs: 4 of 4



Agree Compare About

Annotations



iNaturalist as opportunistic wildlife sightings, photo verified

- Example From Chapel Hill
- >3000 iNat mammal observations
- 256 in in the last month

Observations



Mammals

Chapel Hill-Carrboro School

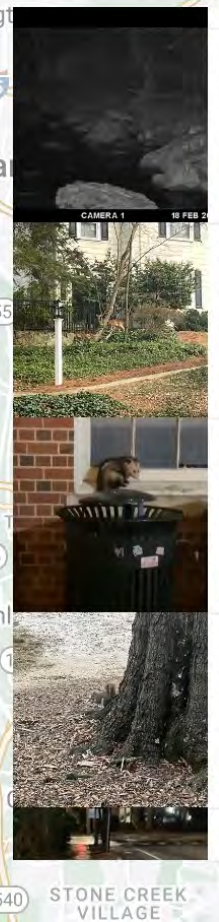
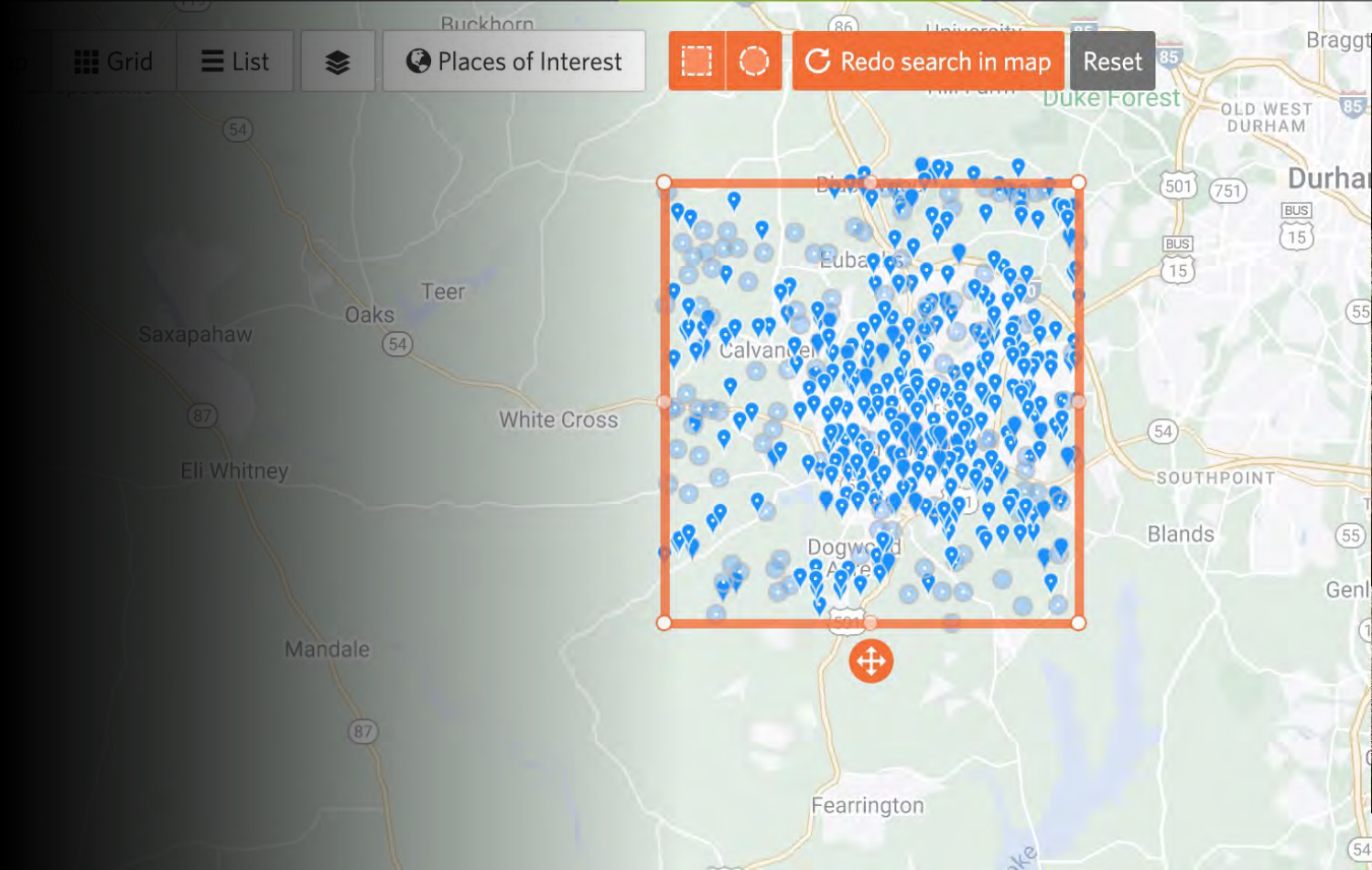
Boundary

3,150 OBSERVATIONS

37 SPECIES

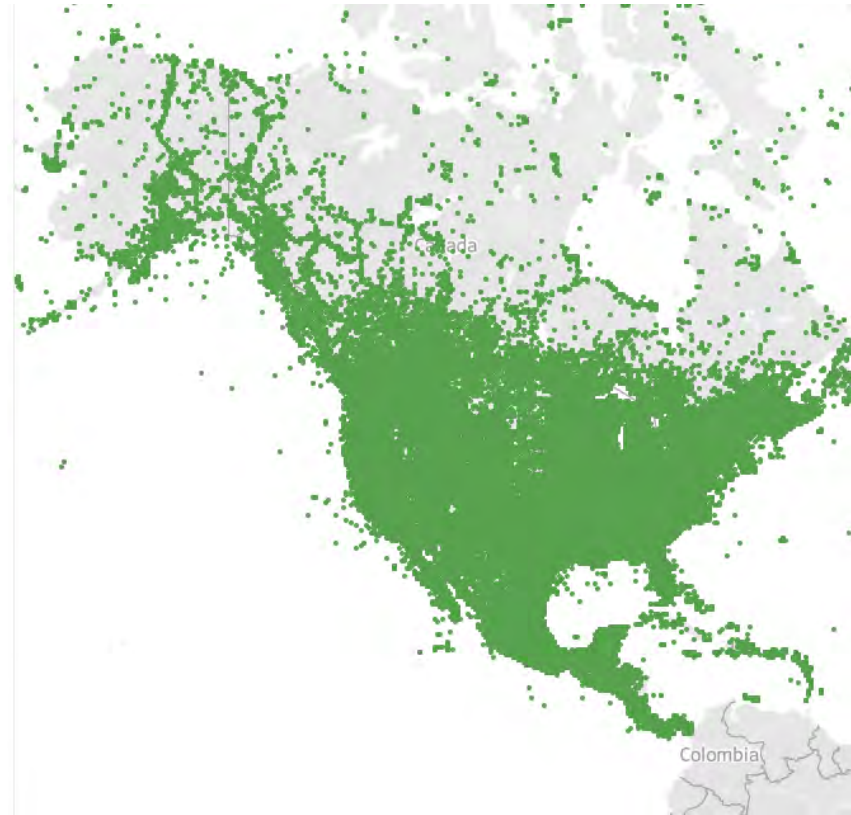
665 IDENTIFIERS

Grid List Places of Interest Redo search in map Reset





iNaturalist



1.5M North American Mammal Records

Data Integration: new project underway



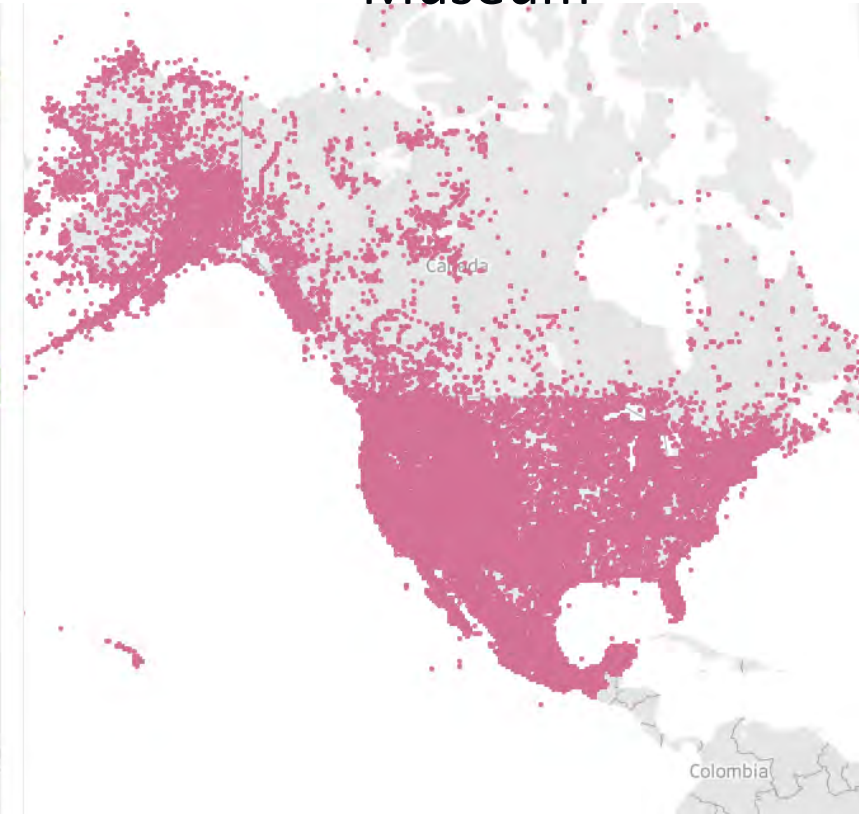
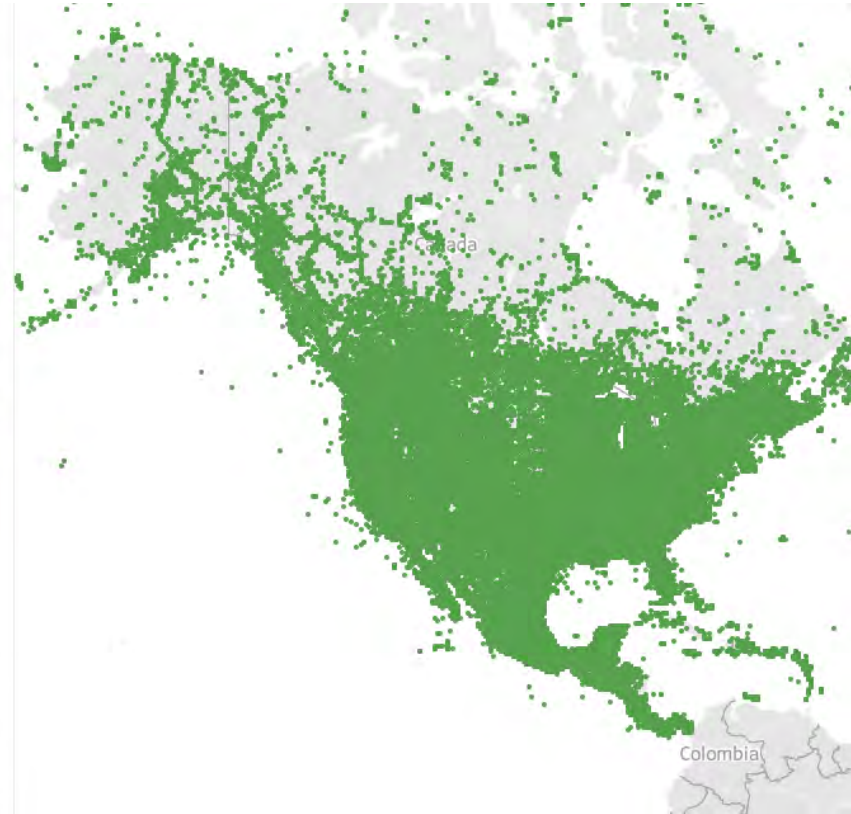
Camera Trap



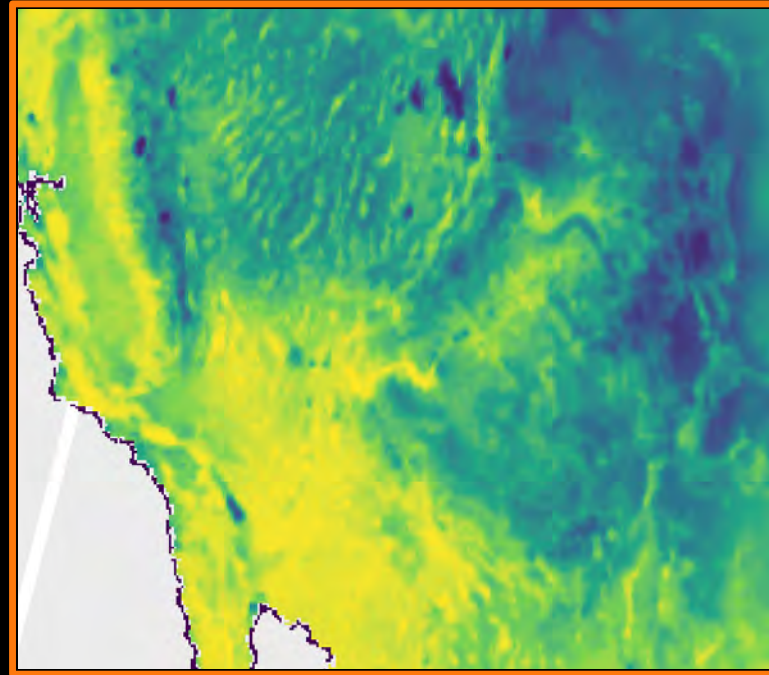
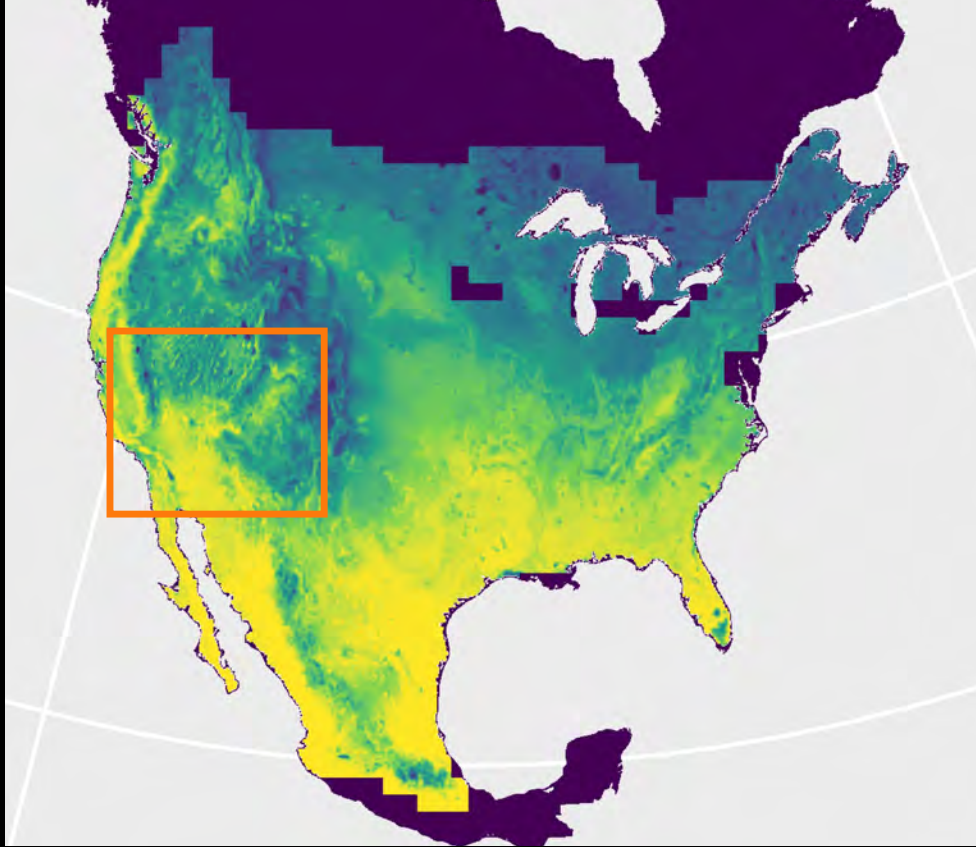
iNat



Museum

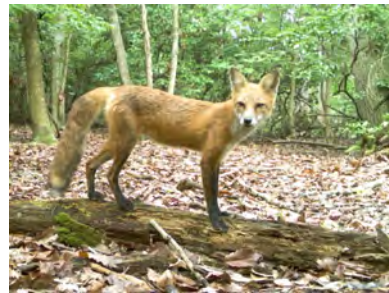
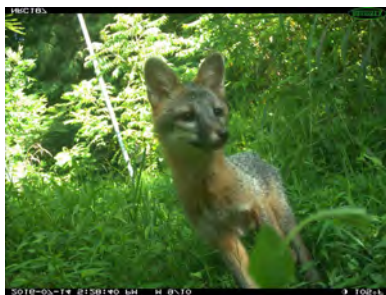
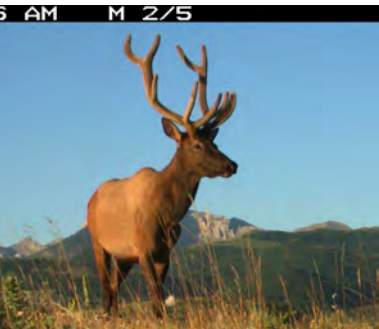
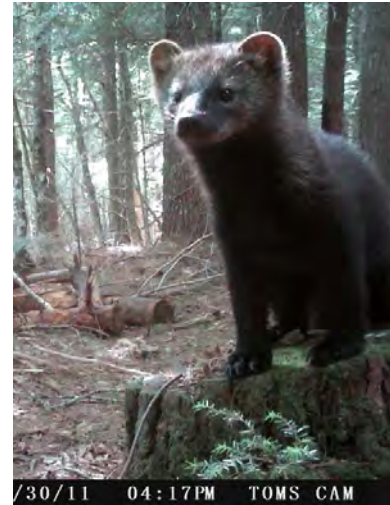
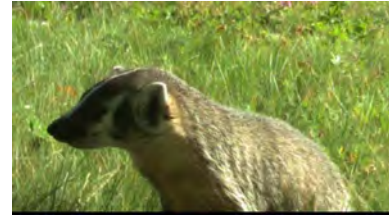
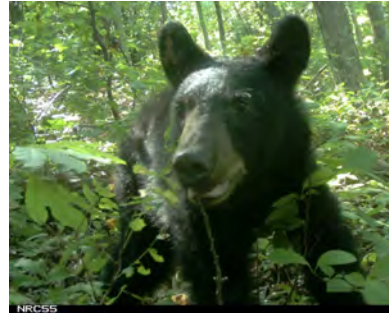


North American Mammal Records



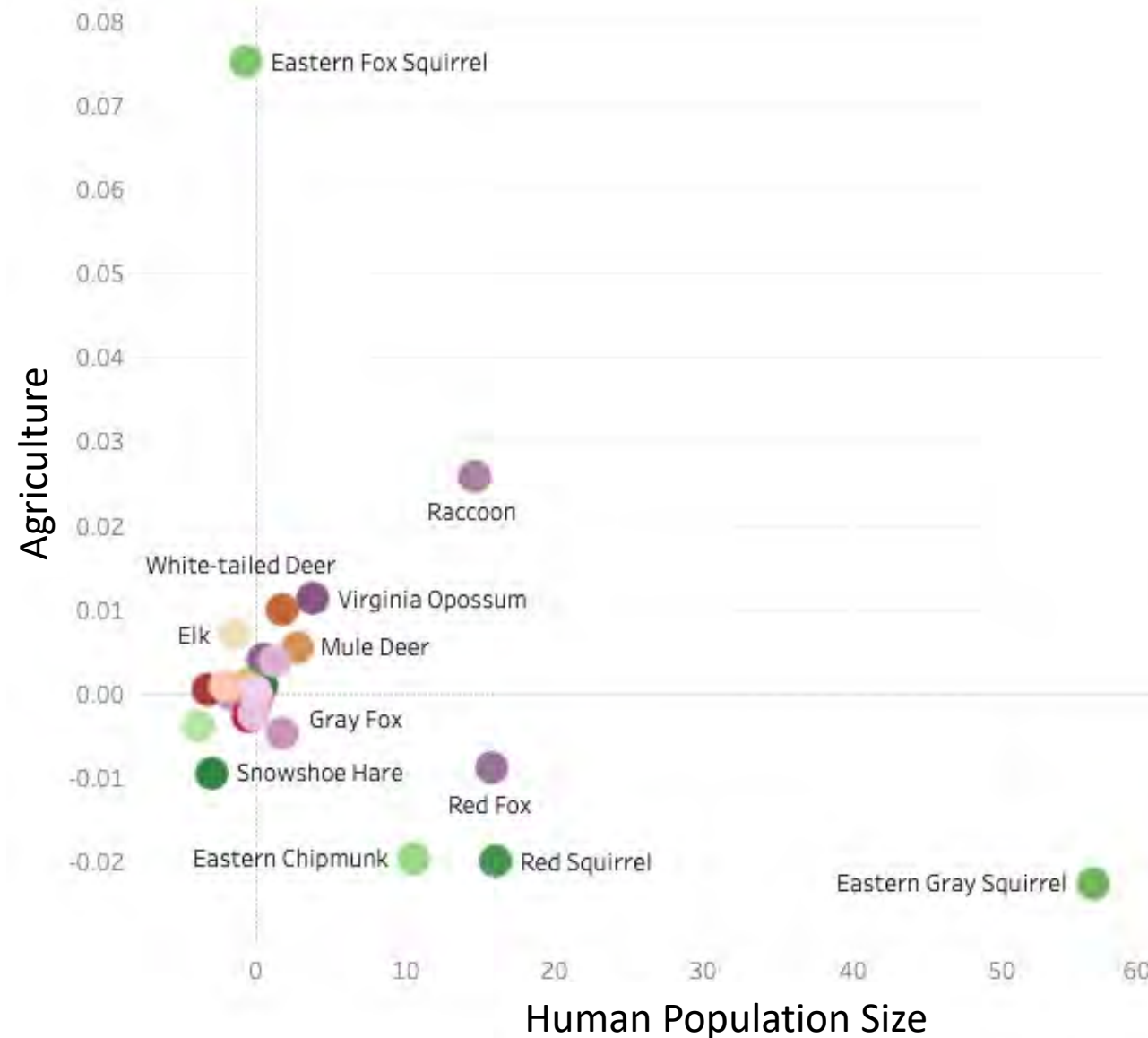
Bobcat occupancy combining cameras + iNat [in prep]

Repeating for more species



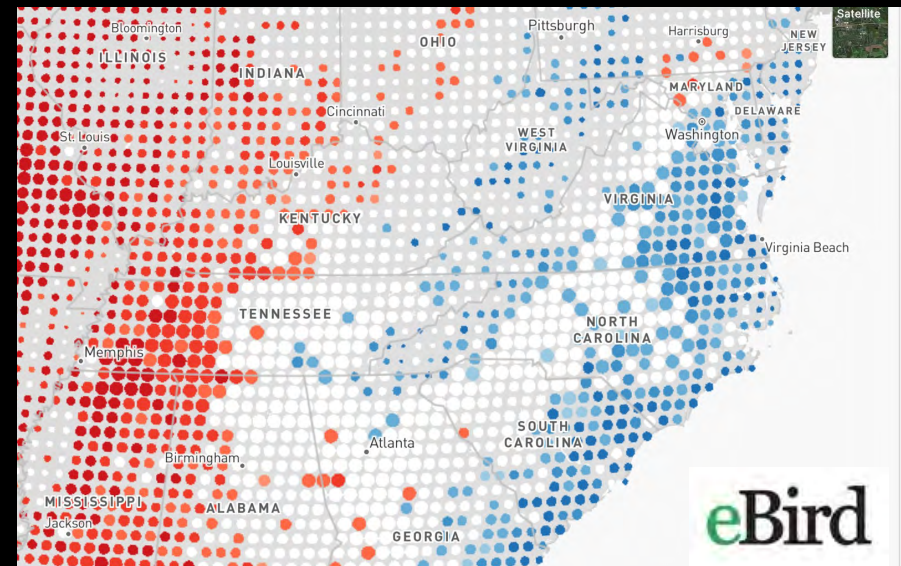
We also learn about the ecological drivers

Example: 2 human factors



The next challenge

How can we extract trend info from mammal data?



Back to The Vision

To Inform Conservation Decision Making

- Abundance: Animal Population Sizes and Trends
- **Movement: Connectivity Between Populations**

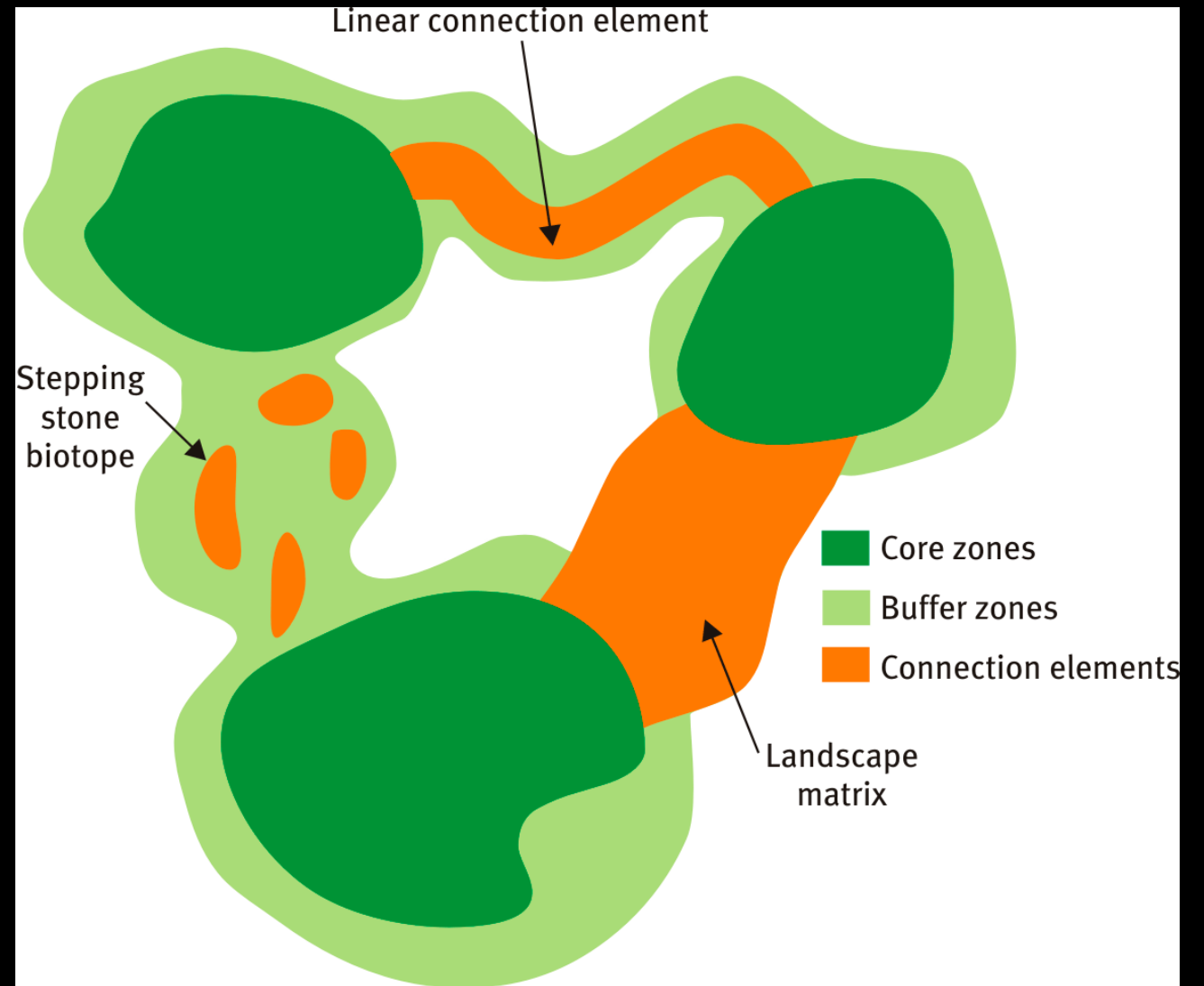


Part #2. Animal
Movement &
Habitat
Connectivity



Habitat Connectivity is Critical to allow animals to:

1. Maintain geneflow between populations
2. Recolonize areas where they have gone extinct
3. Find newly suitable habitat due to climate change



GOLDEN AGE OF ANIMAL TRACKING



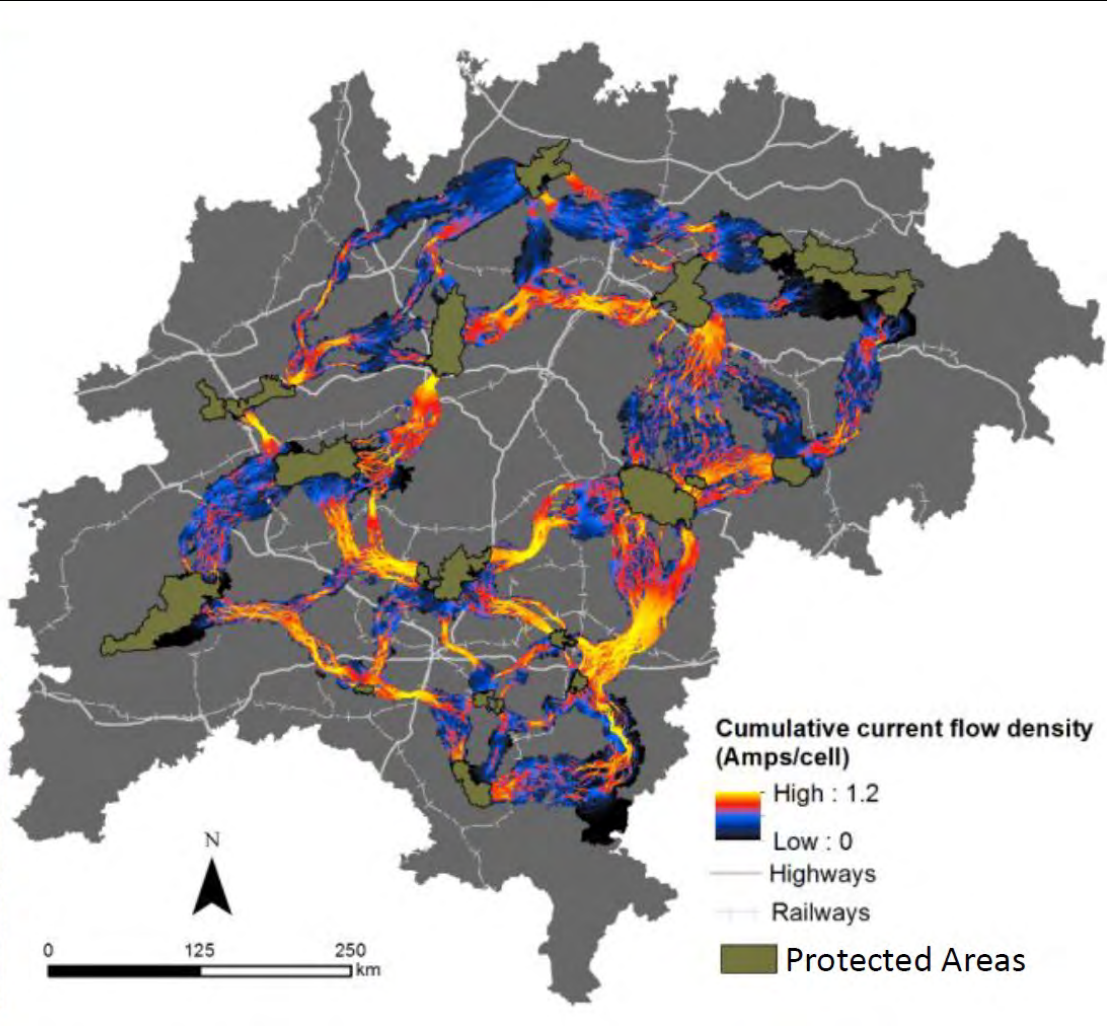
Photo by @UntamedScience

A map of North Carolina showing major cities and green connectivity corridors. The corridors are represented by thick green lines that connect various parts of the state, including the Piedmont and Coastal Plain regions. Major cities labeled include Greensboro, Durham, Raleigh, Rocky Mount, Greenville, Fayetteville, Jacksonville, and Wilmington. National Forests like Croatan and Lumber Sound are also marked. The map is overlaid with a semi-transparent green tint.

Connectivity models are can be improved

If we have so much animal tracking data, why are we still treating animals like electrons?

Habitat Connectivity Modeling



Old way = Circuitscape
Animals = electrons

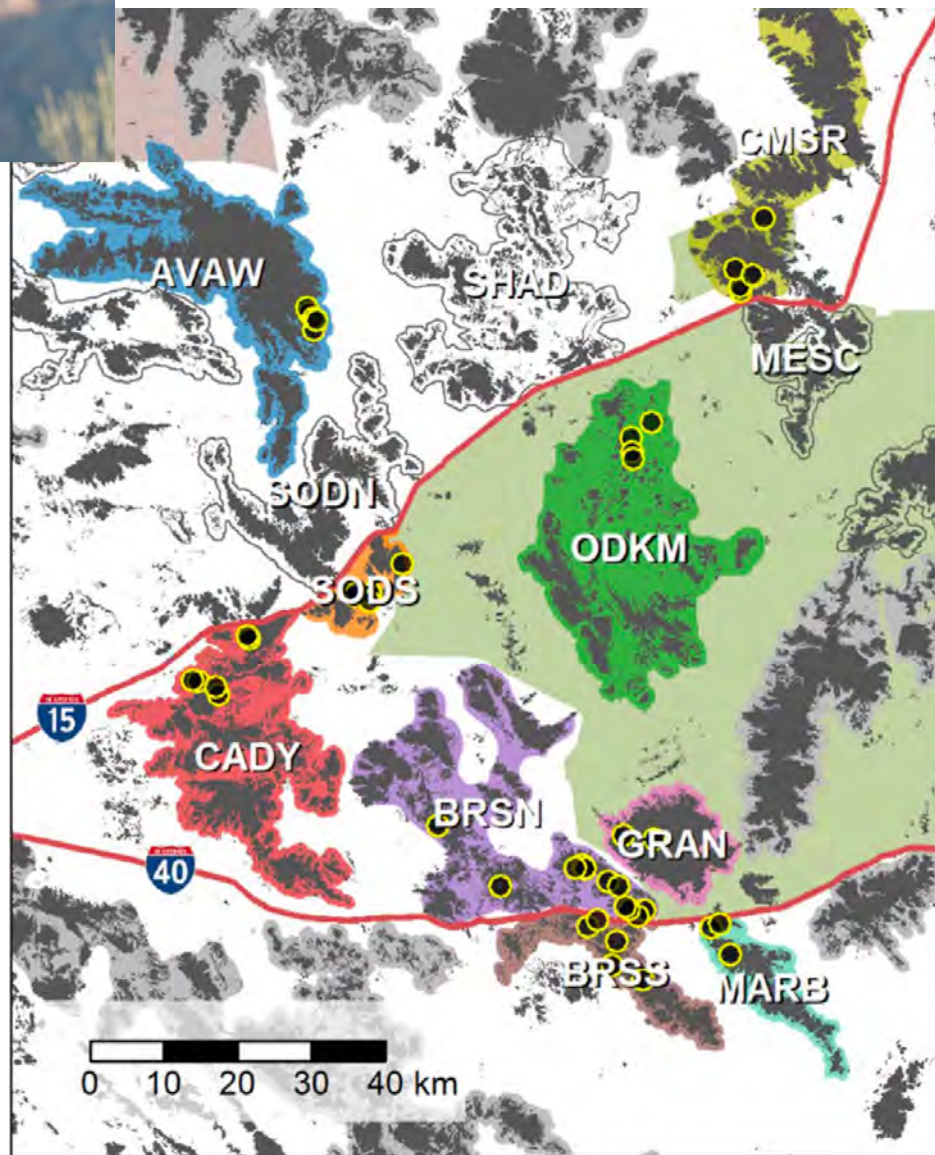
New Way

= Animal Movement
Models

Animals = Animals



Agent Based Models



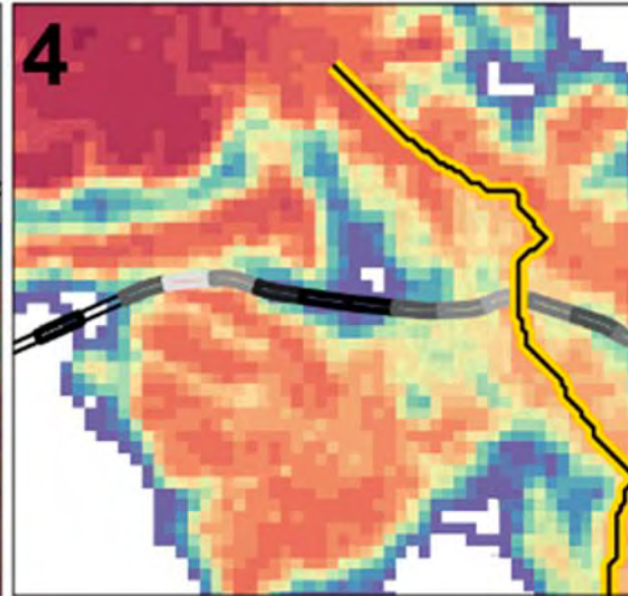
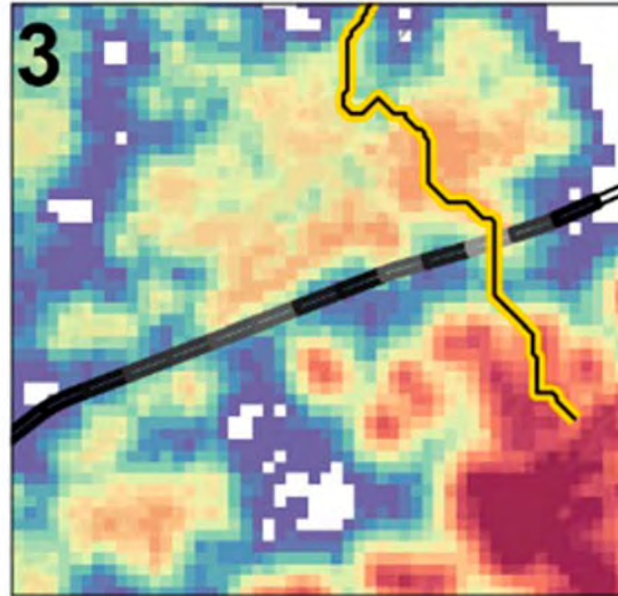
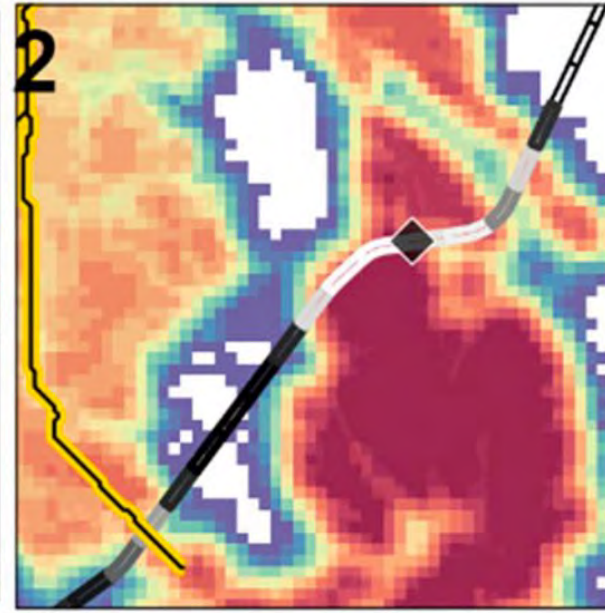
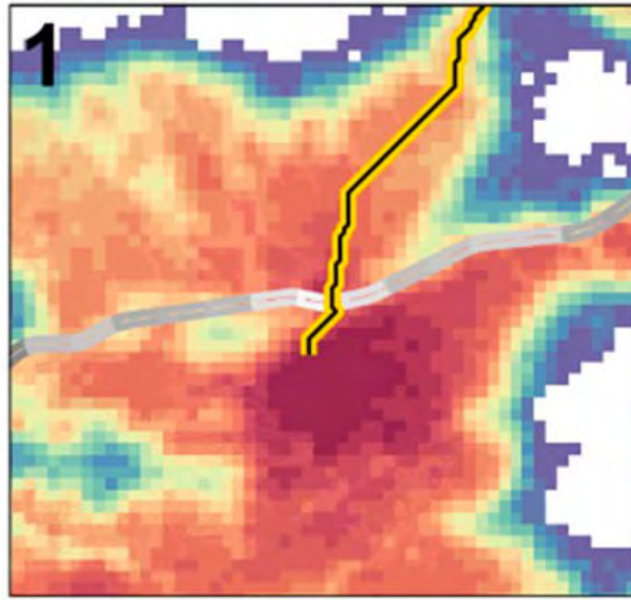
Recent Example Study

Movement models and simulation reveal highway impacts and mitigation opportunities for a metapopulation-distributed species

Christina M. Aiello · Nathan L. Galloway ·
Paige R. Prentice · Neal W. Darby ·
Debra Hughson · Clinton W. Epps

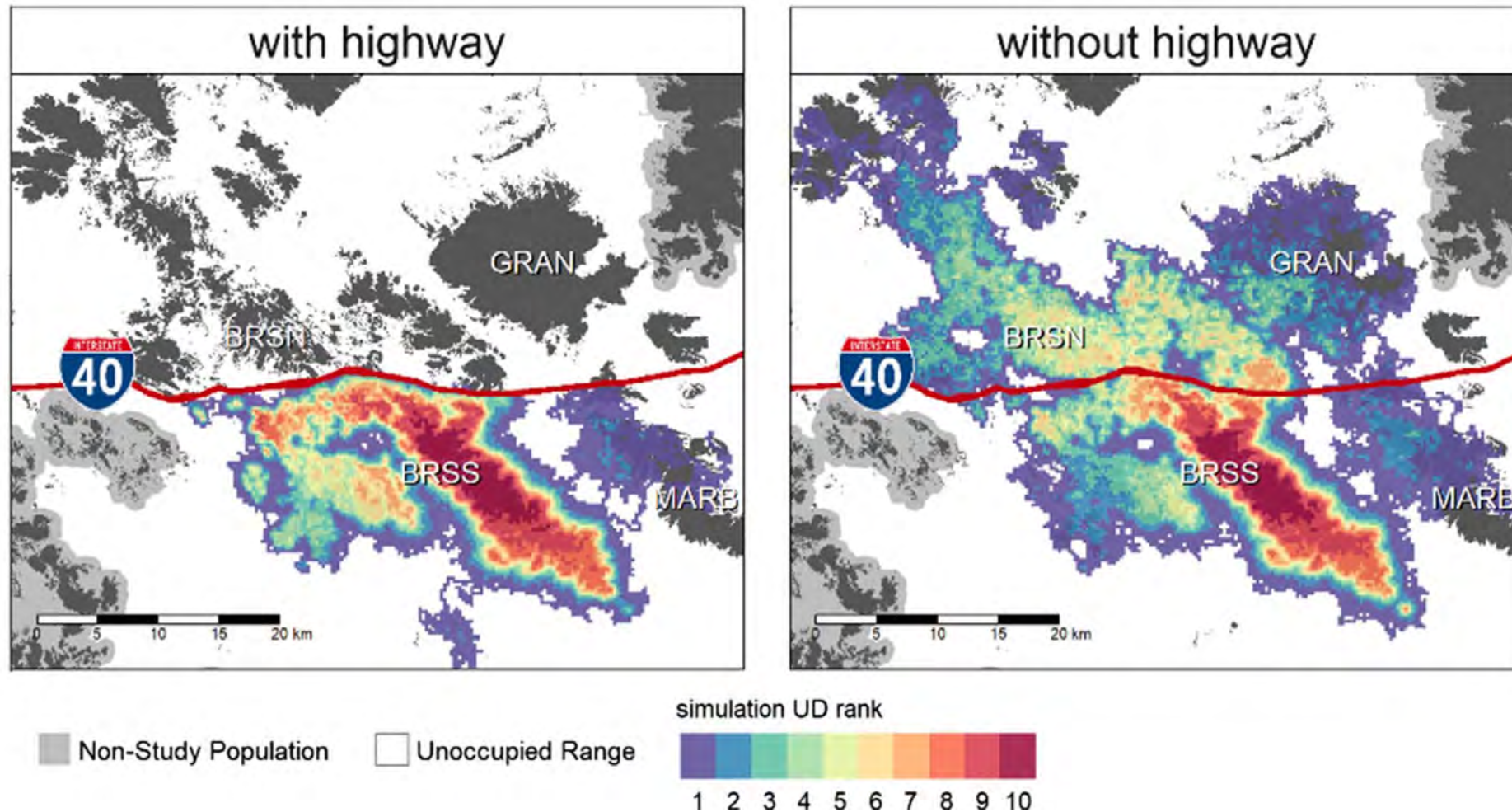
1. Derive animal movement decision rules from real tracking data
2. Simulate animals moving through 'experimental' landscapes to figure out best road crossing places

Simulation
Result:
optimized
crossing
locations



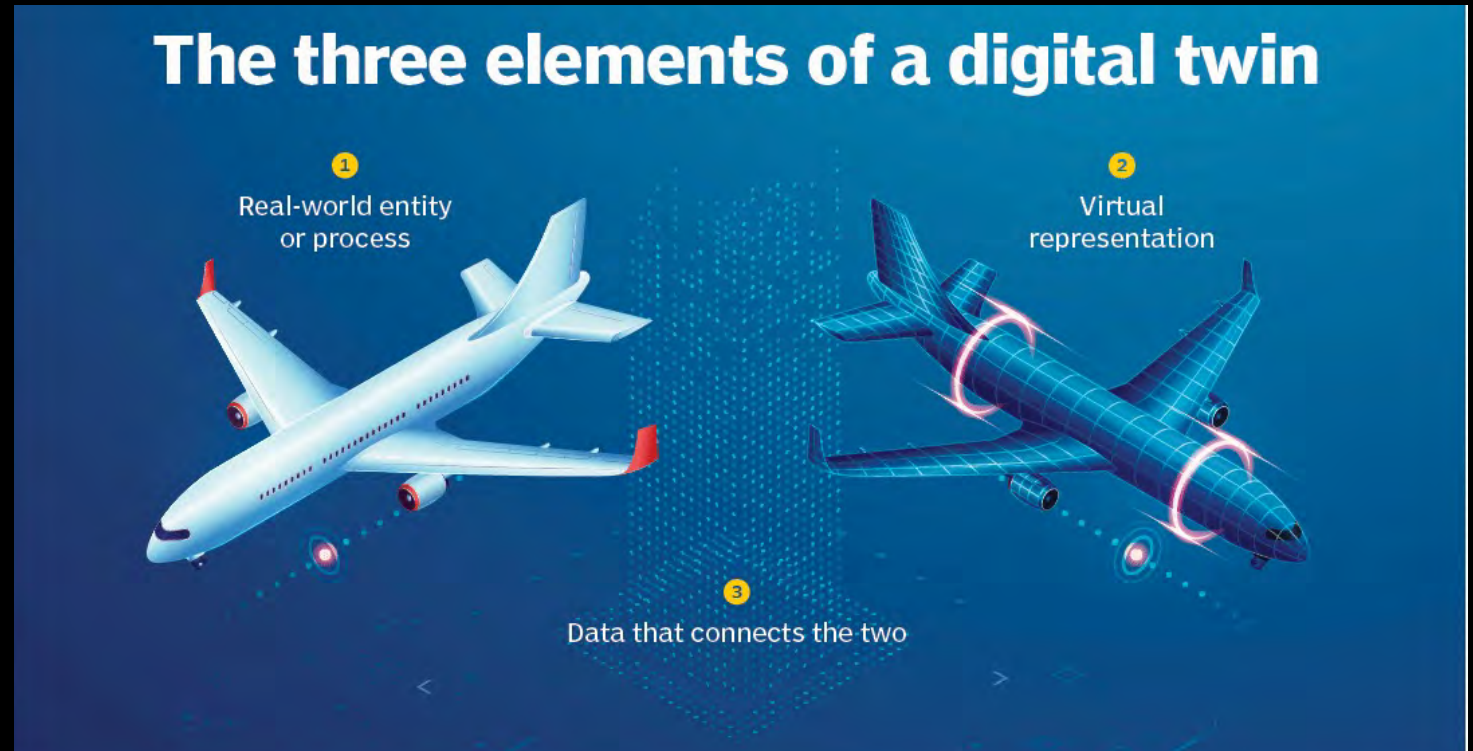
Simulation Result:

Sheep habitat with and without connectivity across the road



This is a type of digital twin

- Allow accurate, precise, and real-time monitoring and simulation of processes that are hard to observe in the real world
- dynamic model always updating with new data.
- users can interactively explore system dynamics and scenarios.



EU Effort

#DestinE

“Develop a highly accurate digital model of the Earth on a global scale”

Digital Twin

Destination Earth

Flagship initiative of the European Commission



#DigitalEU #DestinE

Climate Model
Underway



Forest Model
Underway



Animal Model
Needs Development





New bobcat movement around agriculture and solar facilities
North Carolina
Michael Levin

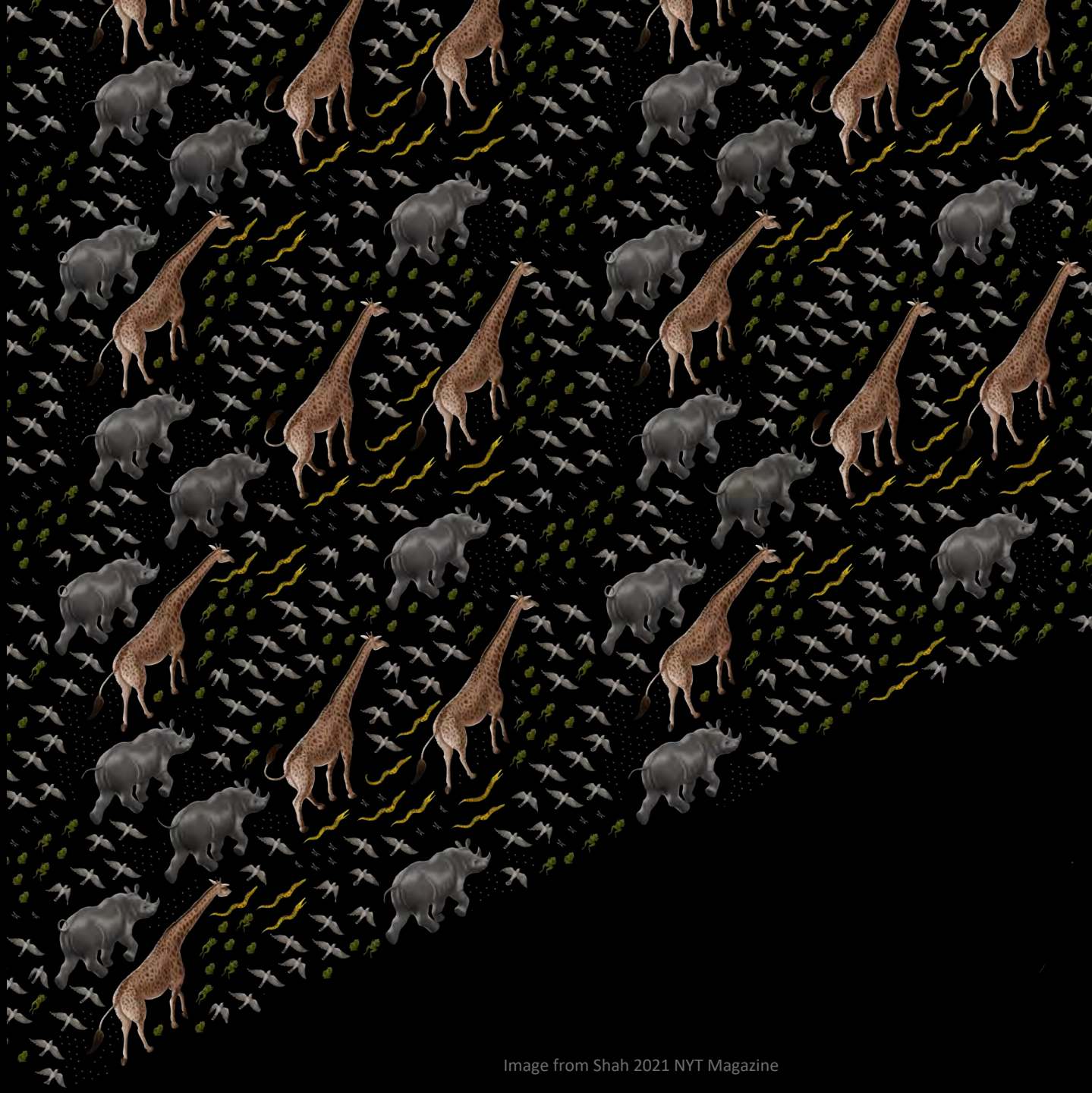
New bobcat movement
around agriculture and solar
facilities
North Carolina
Michael Levin



Internet of Animals

Conclusion

1. Live Data
2. Linked Data
3. Automated Analytics



Internet of Animals

Looking Forward - What could it be?

Population Monitoring

Possible Now



Counting animals camera traps

Futuristic



Counting animals with doorbell cameras, car sensors, and edge computing

Internet of Animals

Looking Forward - What could it be?

Population Monitoring

Futuristic



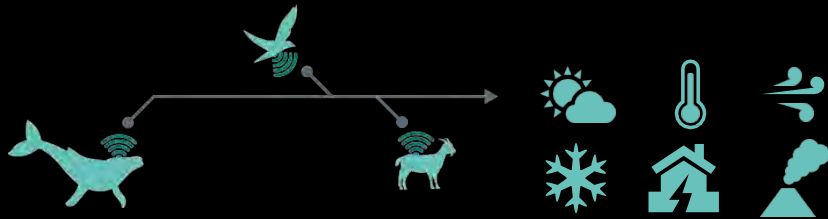
Counting insects with lidar on cars

Internet of Animals

Looking Forward - What could it be?

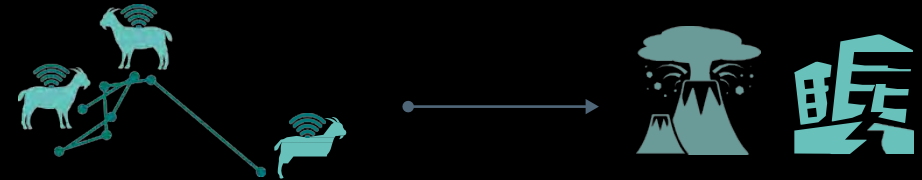
Environmental Monitoring

Possible Now



Animals as environmental sensors (i.e. buoys)

Futuristic



Early earthquake and volcano detection

Internet of Animals

Looking Forward - What could it be?

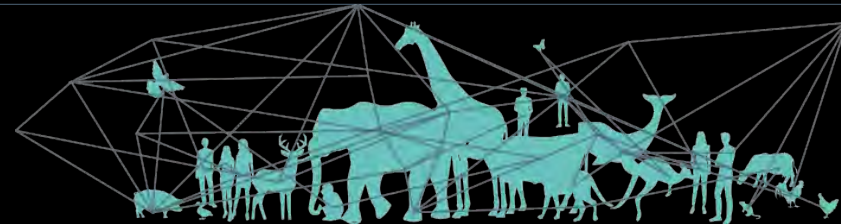
Disease Monitoring

Possible Now



Coordinated disease monitoring

Futuristic



One Health:
combine wild, domestic, human

Summary

To Inform Conservation Decision Making

- Abundance: Animal Population Sizes and Trends
- Movement: Connectivity Between Populations



A black bear is shown from the back, standing in a dense forest of tall, thin trees with vibrant green foliage. The bear's head is turned upwards and to the right, as if it is looking at something in the canopy. The lighting is bright, suggesting a sunny day. The overall scene is a natural, serene depiction of wildlife in its habitat.

The End