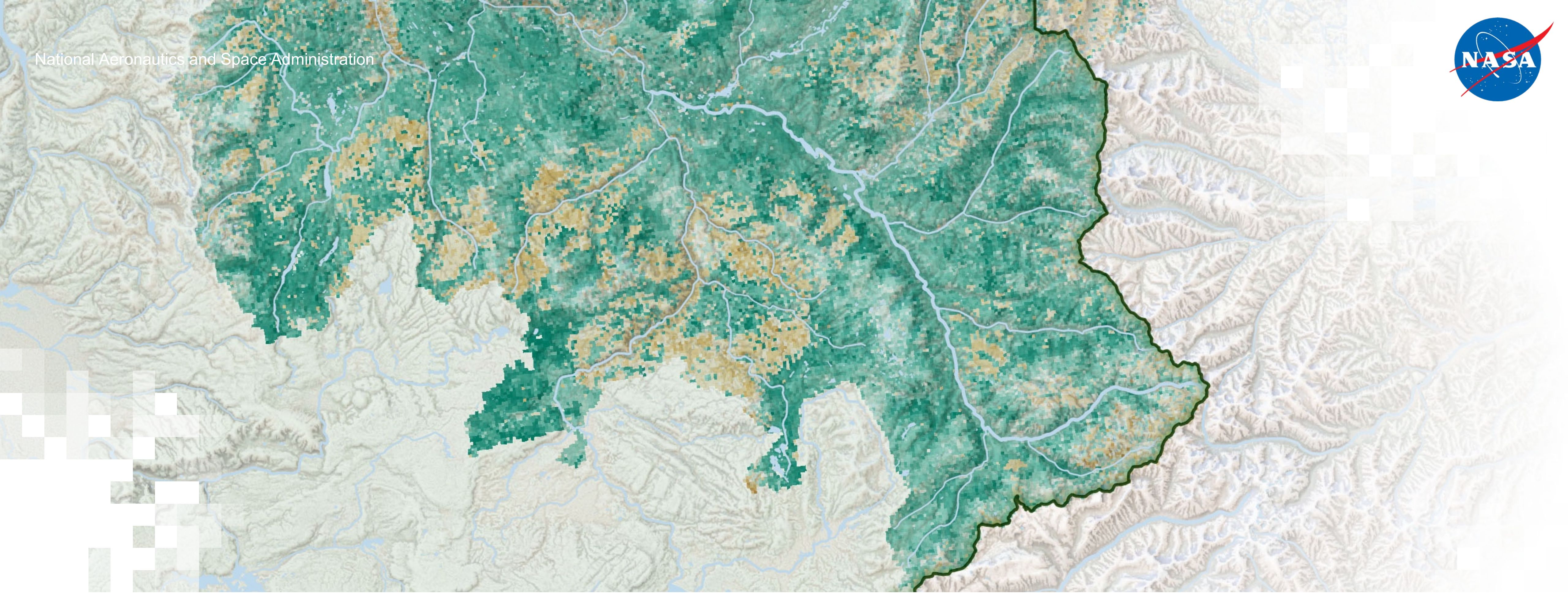


National Aeronautics and Space Administration

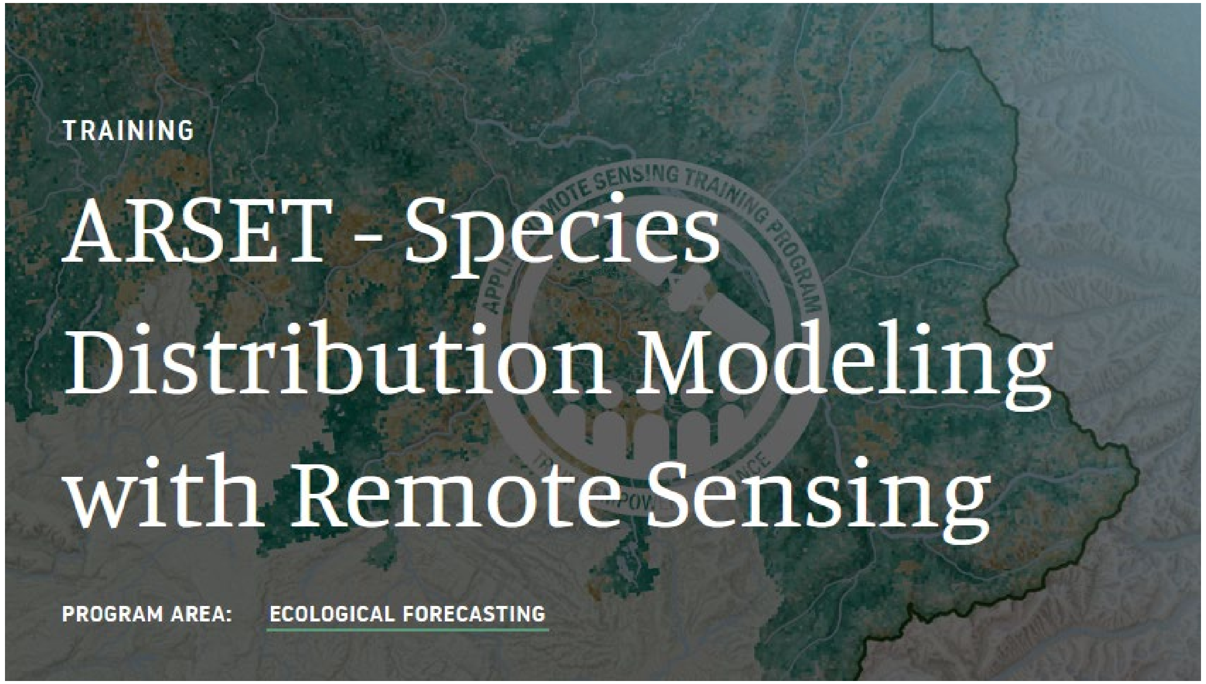
Species Distribution Modeling with Remote Sensing

Amber McCullum, Juan Torres-Perez, Zach Bengtsson

Aug 19, 2021

Course Structure and Materials

- Three 1.5-hour sessions on August 12, 17, & 19
- Sessions will be presented once in English 12:00-13:30 EDT
- Webinar recordings, PowerPoint presentations, and the homework assignment can be found after each session at:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-species-distribution-modeling-remote-sensing
- Q&A following each lecture and/or by email at:
  - amberjean.mccullum@nasa.gov
  - juan.l.torresperez@nasa.gov
  - bengtsson@baeri.org




Amber McCullum


Juan Torres-Pérez


Zach Bengtsson

Webinar Agenda

Part 1: Overview of Species Distribution Models (SDMs)

Part 2: Using Wallace to Model Species Niches and Distributions

Part 3: Additional SDM Tools and Techniques, ASP Projects, and Summary

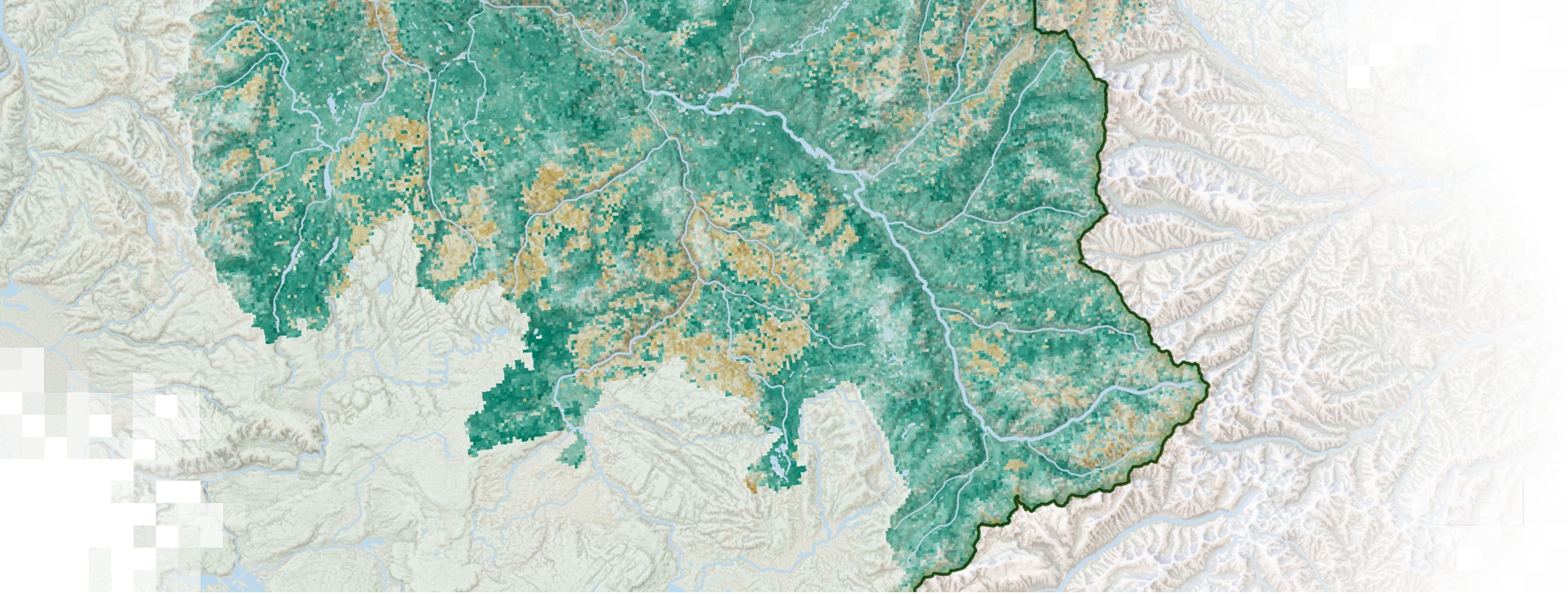
Part 3 Overview

- Mapping Application for Penguin Populations and Projected Dynamics (MAPPD)
- Wildlife Insights
- Map of Life (MOL)
- Circuitscape and Omniscape
- Fisheries and Climate Toolkit (FaCeT)
- Training Summary
- Q&A


Image Credit: eBird


Image Credit: ecori.org


Image Credit: GVI Costa Rica



Mapping Application for Penguin Populations and Projected Dynamics (MAPPD)

Mapping Application for Penguin Populations and Projected Dynamics

http://www.penguinmap.com/

Heather J. Lynch[1], Mathew Schwaller[2]
Chris Che-Castaldo[1], Grant Humphries[1], Michael Schrimpf[1]
[1]Stony Brook University Ecology & Evolution
[2]NASA Goddard

MAPPPD Overview

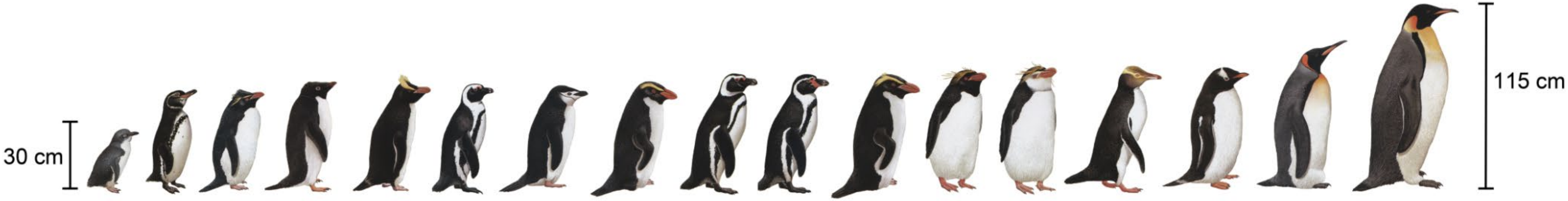
- Web-based, open-access, decision support tool
- Designed to assist scientists, non-governmental organizations, and policy-makers working to meet the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) objectives
- Penguin population models
- Abundance estimates


Image Credit: Maureen Lynch via MAPPPD


Image Credit: MAPPPD

MAPPD Primary Objectives

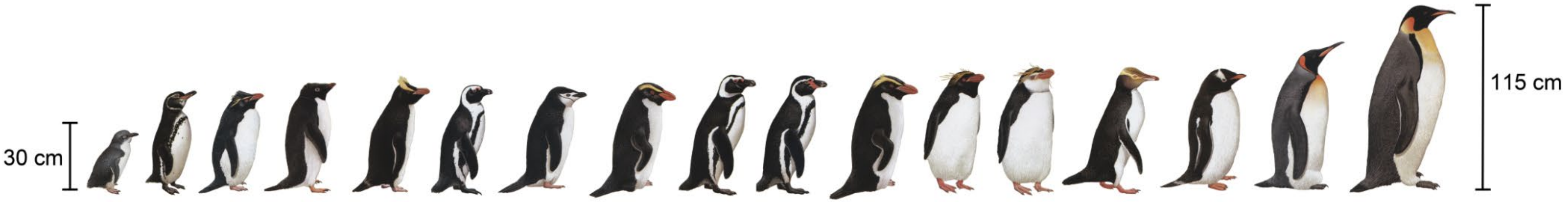
1. A repository for submitting, vetting, and storing data on the distribution and abundance of penguin species data
2. A tool for searching the existing state of knowledge on Antarctic penguin abundance and distribution
3. A mechanism for creating and delivering checklists of all bird species at sites along the Antarctic Peninsula that are likely to be visited by humans



Drawings from del Hoyo et al. 1992

MAPPD Big Questions

1. Can we detect penguins?
2. Can we differentiate different species of penguins?
3. Can we estimate abundance?
4. Can we assess changes in abundance?
5. Can we start doing global/regional censuses?
6. Can we learn something new about penguin biology?
7. **Can we improve the decision-making process for conserving Antarctic marine living resources?**

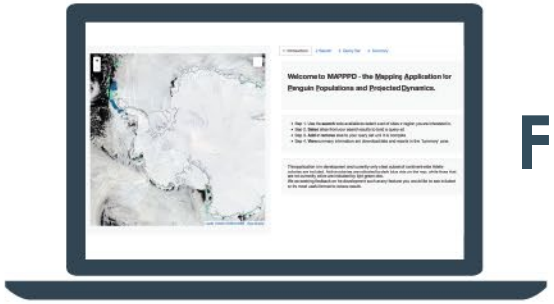


Drawings from del Hoyo et al. 1992

MAPPPD Schematic

Satellite imagery & Field counts

Map-based search engine for current abundance and predicted dynamics



Front End

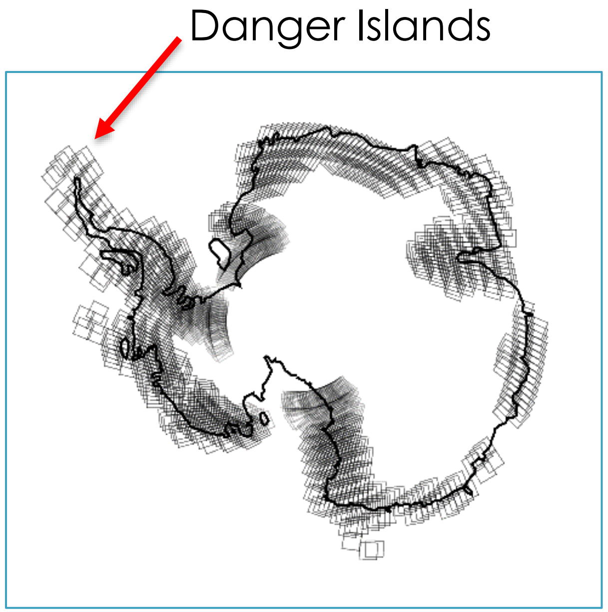
Back End

Dynamic Naive Bayesian Network Modelling

MAPPD Project Highlights

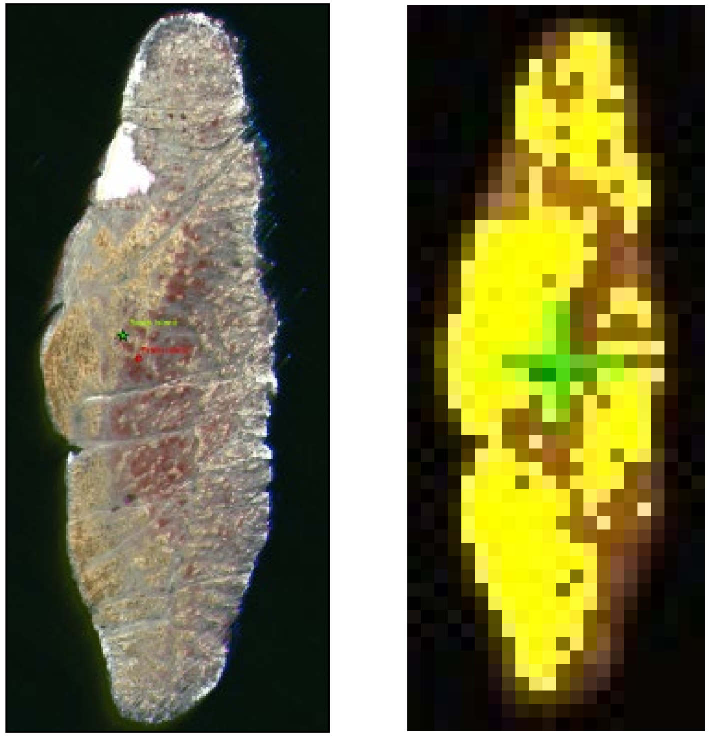
1 – Algorithm Development & Improvement

Develop algorithms to identify penguins and seabirds over the entire continent of Antarctica



2 – Discovery

Discovered several penguin and petrel “mega-colonies” from Landsat



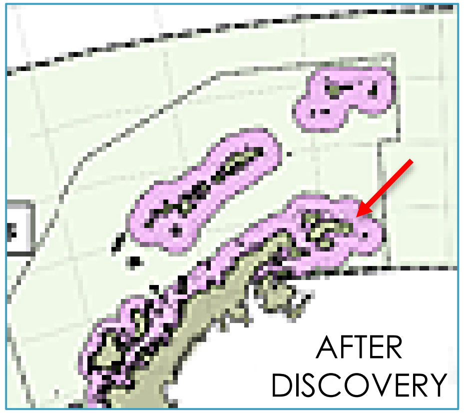
Brash Island (Danger Islands)

[> 1 million penguins discovered by Landsat]

MAPPD Project Highlights

3 – Influencing Management

Danger Islands colonies were not considered high priority (blue shading) for conservation, but the Marine Protected Area (MPA) has been expanded (pink polygons) by ~ 2 million ha.



Maps taken from actual policy document being prepared by Argentina for the Antarctic Treaty Consultative Meeting.

4 – Ground Validation

Landsat-enabled exploration of previously unsurveyed territory.


Credit: Thomas Sayre-McCord (WHOI)

MAPPD Research: Adélie Penguin Abundance

- Indicator species for ocean health
- Abundance and breeding data collected at fixed sites
- What are the mechanisms that underlie Adélie population dynamics?
  - Bayesian Population Dynamics Model
    - Includes process and observation error to all known Adélie penguin abundance data in Antarctic

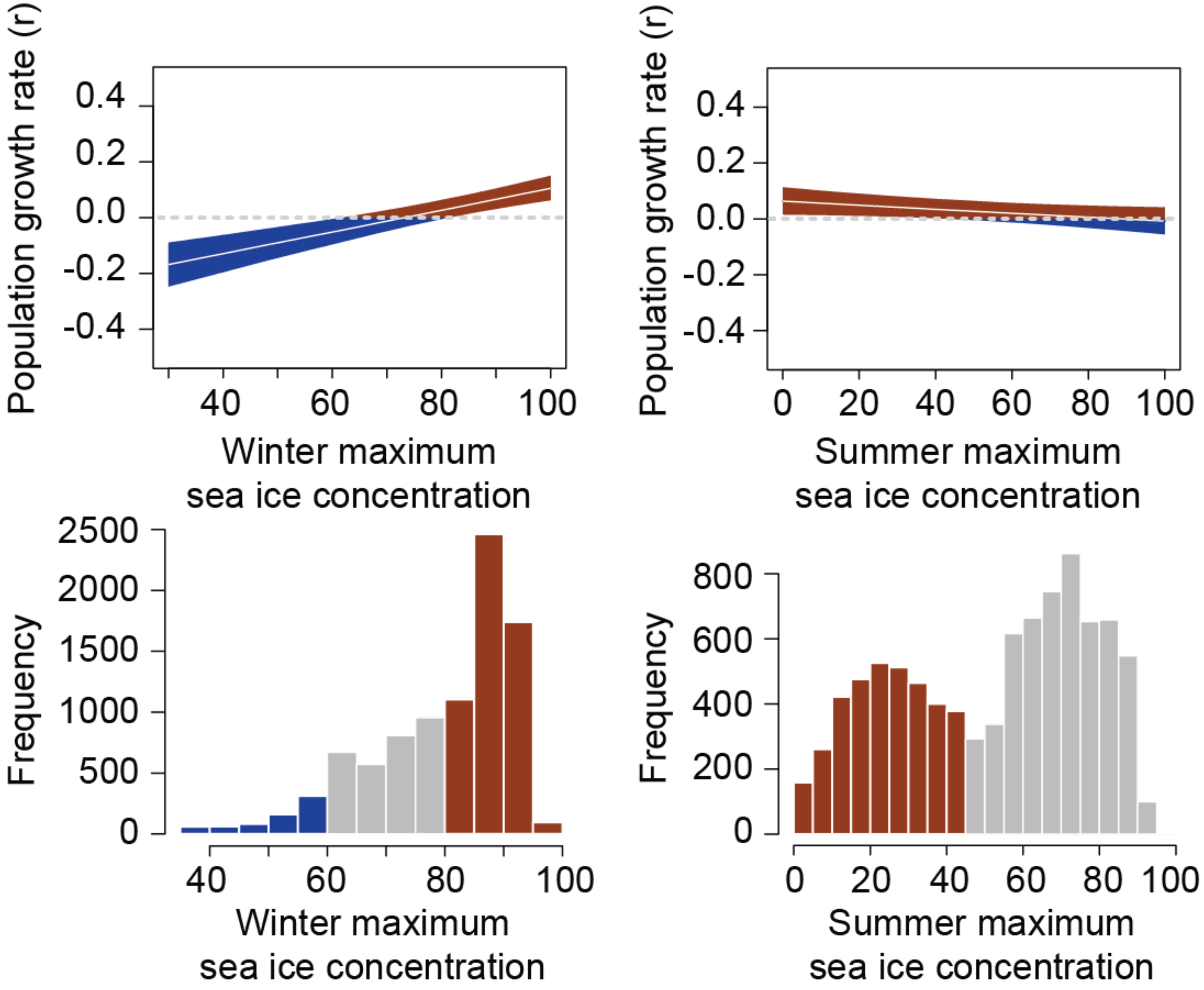

Image Credit: Audubon Society


Image Credit: National Geographic

MAPPD Research: Adélie Penguin Abundance

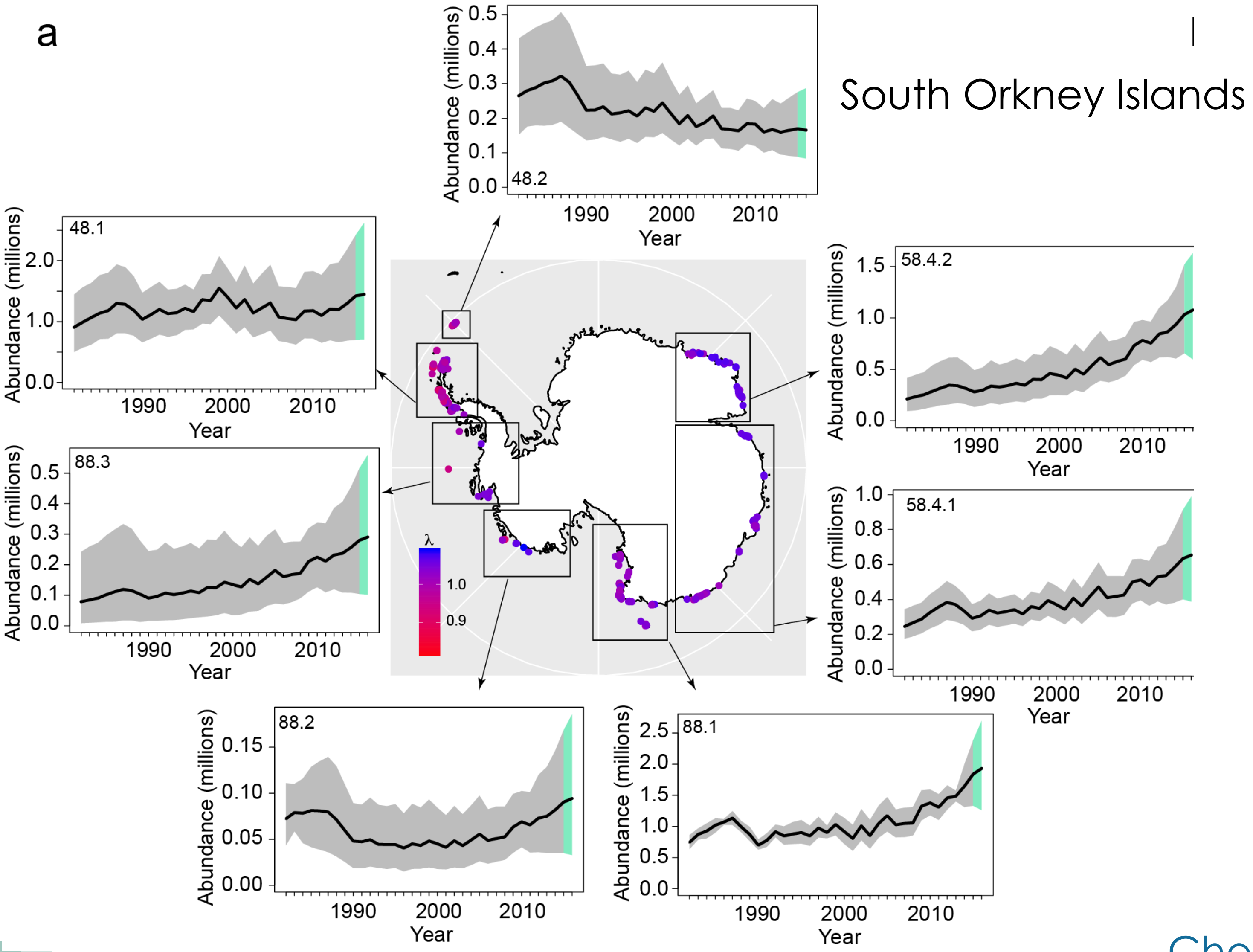
What did we find?

1) Interannual growth rates positively associated with maximum winter sea ice in year t and negatively associated with maximum summer sea ice in $t-4$.
2) Almost all of the interannual variability in growth rates remains unexplained.



Che-Castaldo et al, 2017

MAPPD Research: Adélie Penguin Abundance



- Average population growth rate multiplier: highly variable
- Periods of increased and decreased abundance
- Abundance declines in South Orkney Islands
- Steady increase in all other regions of Antarctic

[Che-Castaldo et al, 2017]

MAPPD Citizen Science and Community Engagement

Random Walk of the Penguins

HOSTED BY DRIVENDATA

5
WEEKS LEFT

HOME PROBLEM DESCRIPTION ABOUT

Photo by Casey Youngflesh

$16,000.00

LEADERBOARD

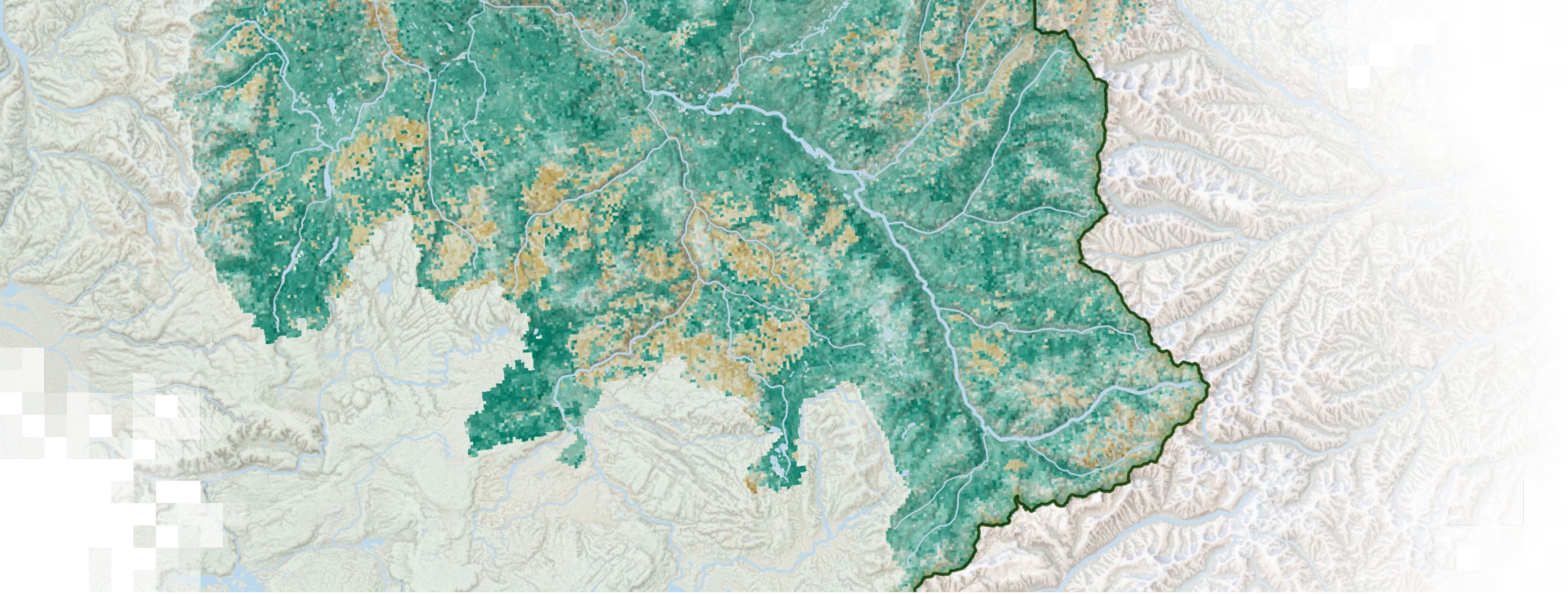
You're not part of this competition. Yet...

Join the competition!

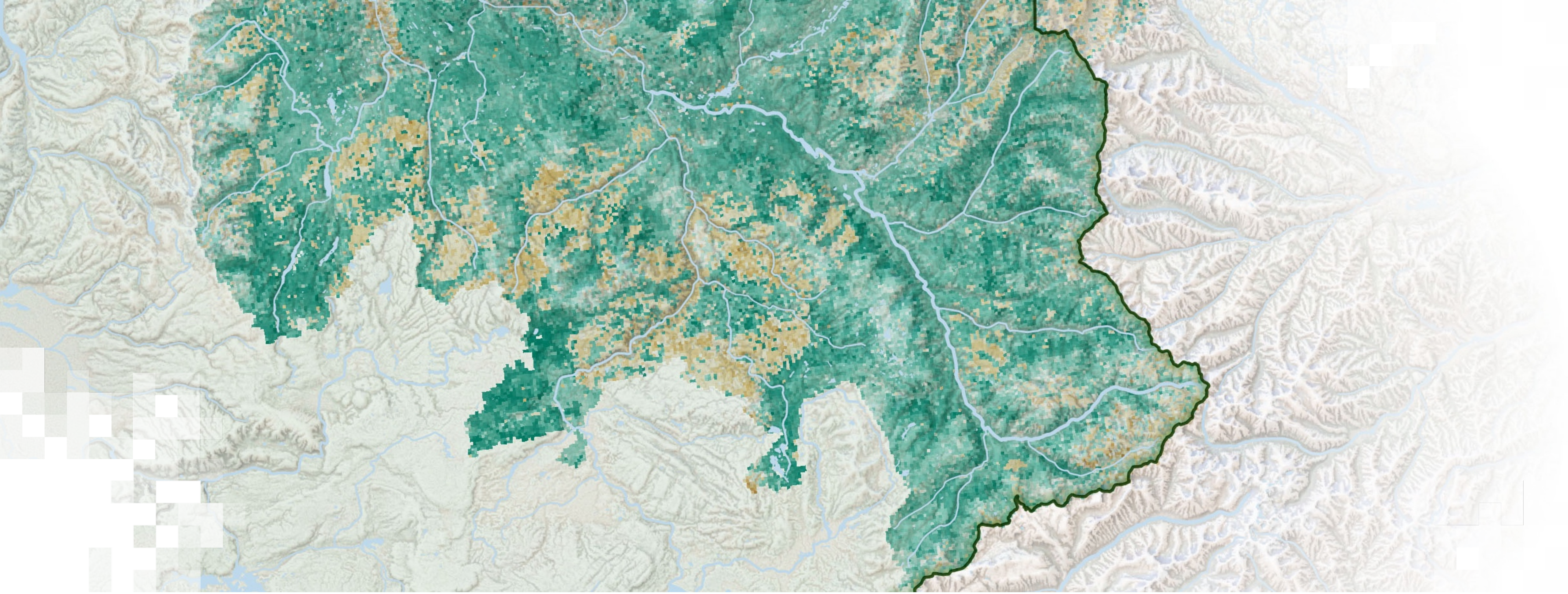
Penguins are among the most charismatic animals in the world and have captured the imaginations of news-makers, scientists, film producers, and the general public. Beyond their general intrinsic value, they are considered important ecosystem indicators. In other words, monitoring these beautiful species can tell us a lot about the general health of the Antarctic because penguins are important krill and fish predators, and changes (natural or anthropogenic) that influence prey abundance and environmental conditions will ultimately be detected through changes in distribution or population size.

MAPPD Outcomes and Lessons Learned

- High-resolution remote sensing is answering questions we were not even asking 5-10 years ago (and not just for penguins!), and MAPPPD is a key component of sharing this new data stream with policymakers.
- MAPPD and additional software can provide Antarctic stakeholders quasi-real time information on abundance and distribution at any user-defined spatial scale.
- MAPPD continues to be a work-in-progress.
  - "Once you get fancy, fancy gets broken." – Morgan Spurlock
- Scientists and non-scientists have different needs, so be flexible and open to alternative workflows/software.



MAPPD Demo

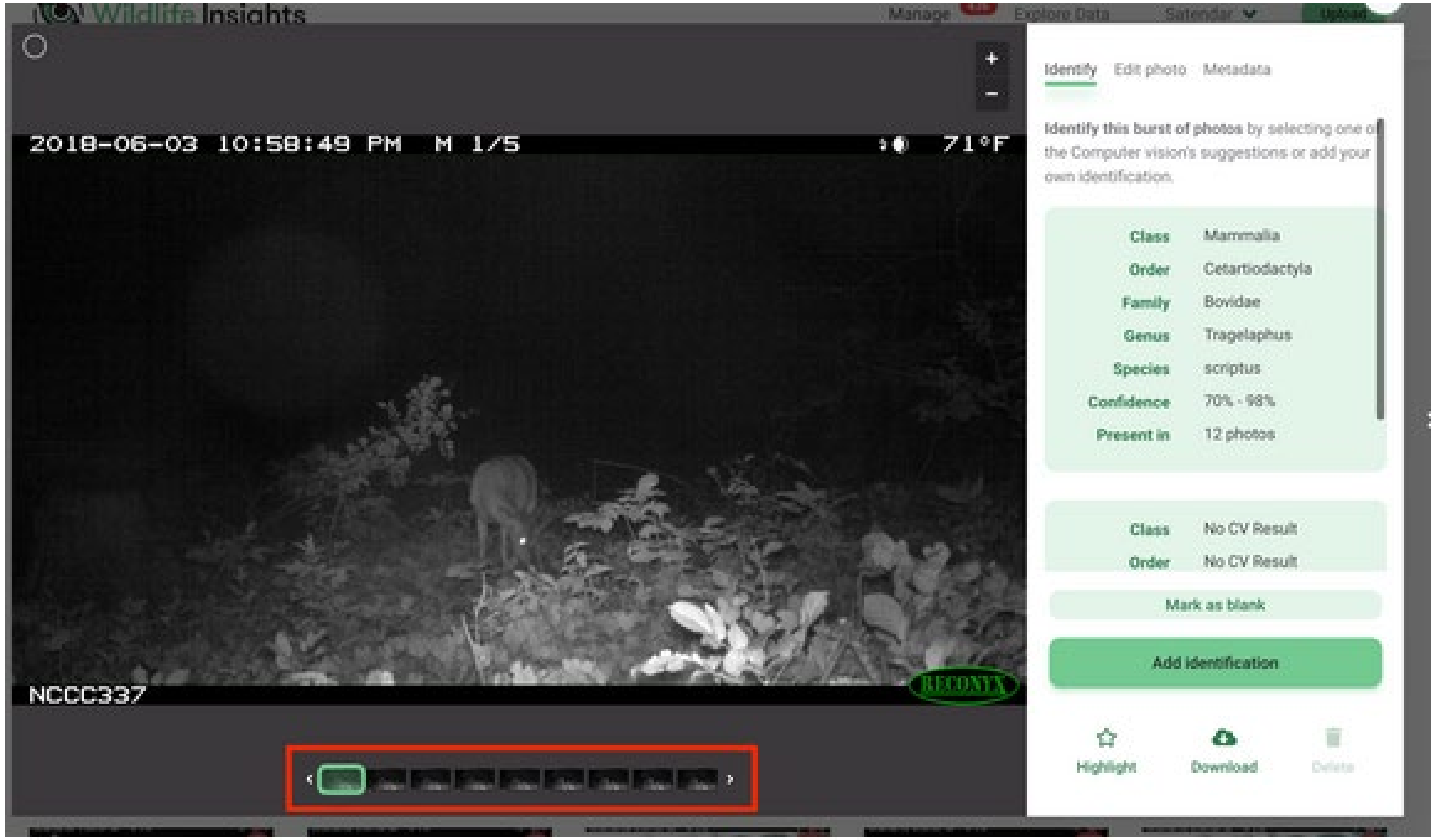


Wildlife Insights

Wildlife Insights

https://www.wildlifeinsights.org

- Collection, dissemination, and analysis of camera trap data globally
- Combines field and sensor expertise, cutting edge technology, and advanced analytics to enable people everywhere to share wildlife data and better manage wildlife populations
- Upload images to website for species identification with artificial intelligence



Wildlife Insights: Model

- Artificial Intelligence Model within Google Cloud
  - Blank Image Filtering
  - Species Classification
    - Training data from multiple locations
    - Includes 837 classes with 732 species from around the world
    - Deep convolutional neural nets for classification using TensorFlow framework

Wildlife Insights: Model Performance

- Accuracy Assessment
  - View per-class performance for each species
  - https://www.wildlifeinsights.org/about-wildlife-insights-ai

Wildlife Insights

Search

peccary

Per-Class Performance

Family	Genus	Species	Common Name	# of images	% of Dataset	Precision	Recall
tayassuidae	pecari	tajacu	collared peccary	199123	0.01707	90.47	65.44
tayassuidae	tayassu	pecari	white-lipped peccary	105481	0.00904	78.54	76

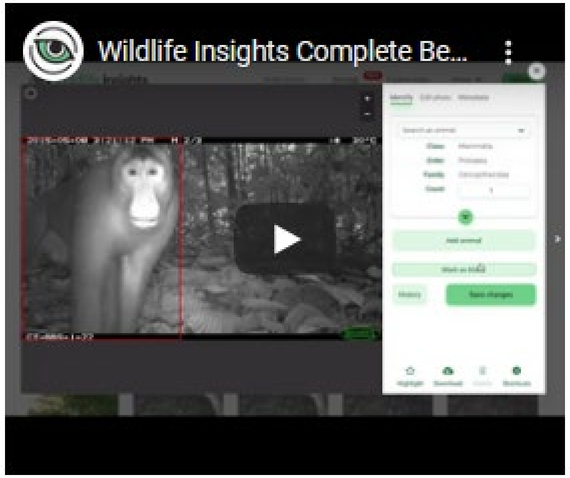
Start 1 to 2 of 2 entries (filtered from 841 total • entries)

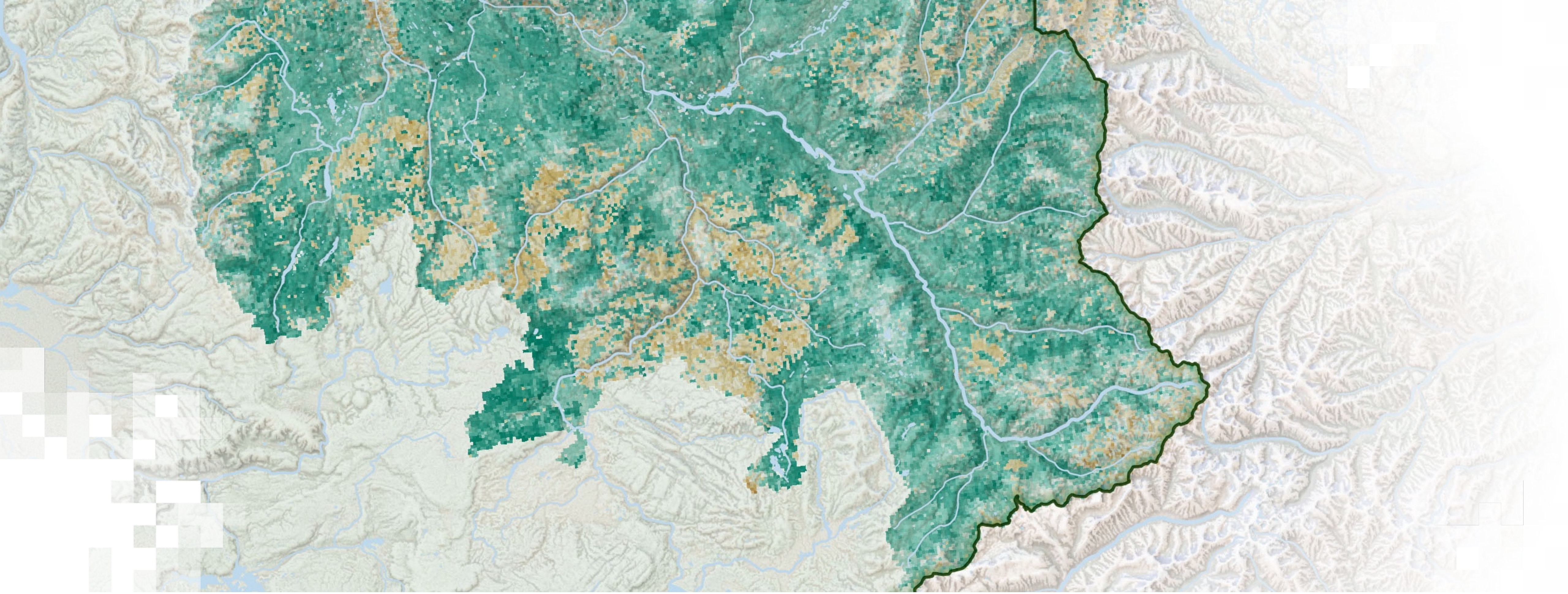
Previous Next

Wildlife Insights: Get Involved

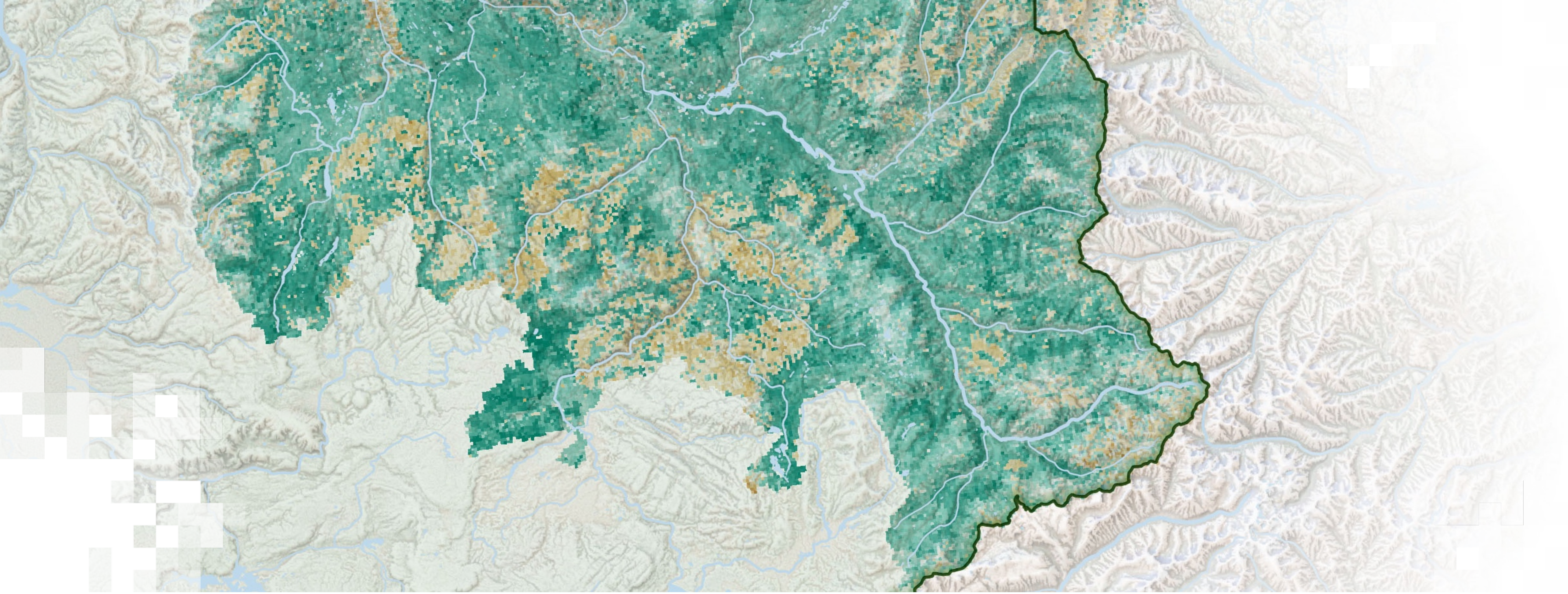
- Public Account:
  - https://app.wildlifeinsights.org/join
- Contributing and Managing Data Account:
  - https://www.wildlifeinsights.org/account-approval
- Join the Community Forum:
  - https://groups.google.com/u/0/g/wildlifeinsights?pli=1
- Check Out All the Video Tutorials:
  - https://www.wildlifeinsights.org/get-started/video-tutorials

Complete Beginners Tutorial





Wildlife Insights Video Introduction



Map of Life (MOL)

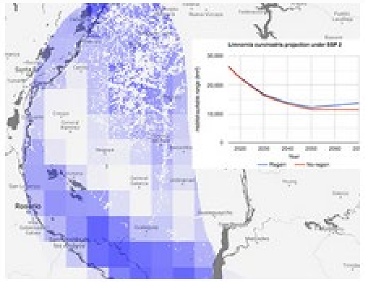
Map of Life (MOL)

https://mol.org

- Provides species range information and species lists for any geographic area
- Multiple tools for exploring species habitat and trends in biodiversity
- Mobile app for discovering, identifying, and recording biodiversity

Map species

View species range map, inventory, and occurrence data



Project species

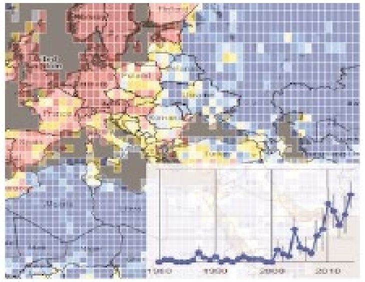
Explore species habitat loss projected for a range of plausible futures

Species by location

Select a location, filter by distance or group, and view a list of species along with source data

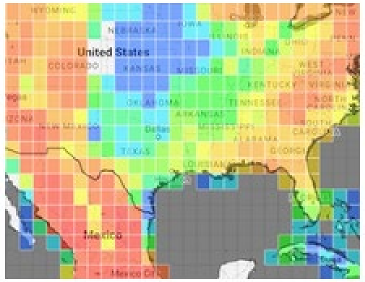
Explore Places

Dashboard for biodiversity data coverage and conservation information



Indicators

Explore trends in biodiversity knowledge, distribution, and conservation



Patterns

Explore richness patterns and biodiversity facets

Datasets

Explore datasets used across MOL

Mobile App

Discover, identify, and record biodiversity worldwide

MOL Framework

- Data Integration Goal: Derive the best-possible probabilistic estimate of the occurrence of each species at the finest possible scale over a given temporal range, using the maximum amount of available information
- Assembles and integrates different sources of data describing species distributions worldwide
  - Species Range Maps
  - Species Occurrence Points
  - Ecoregions
  - Protected Areas
- Uses the power of Google Cloud to store and process data

MOL Team

Faculty

Walter Jetz
Lead PI
Yale University

Robert Guralnick
Associate Professor
University of Florida

Staff

Ajay Ranipeta
Lead Engineer
Yale University

Anna Schuerkmann
Program Manager
Yale University

Megan Blake
Senior Administrative Assistant
Yale University

Yanina Sica
Research Associate
Yale University

John Wilshire
Software Engineer
Yale University

Kate Ingenloff
Research Associate
Yale University

Isabel Del Toro Mijares
Research Assistant
Yale University

Jessica Vigneron
Post Grad Associate
Yale University

Rob Anderson
Post Grad Associate
Yale University

Krish Maypole
Research Assistant
Yale University

….And MANY MORE! https://mol.org/team

Funding for Map of Life

NASA

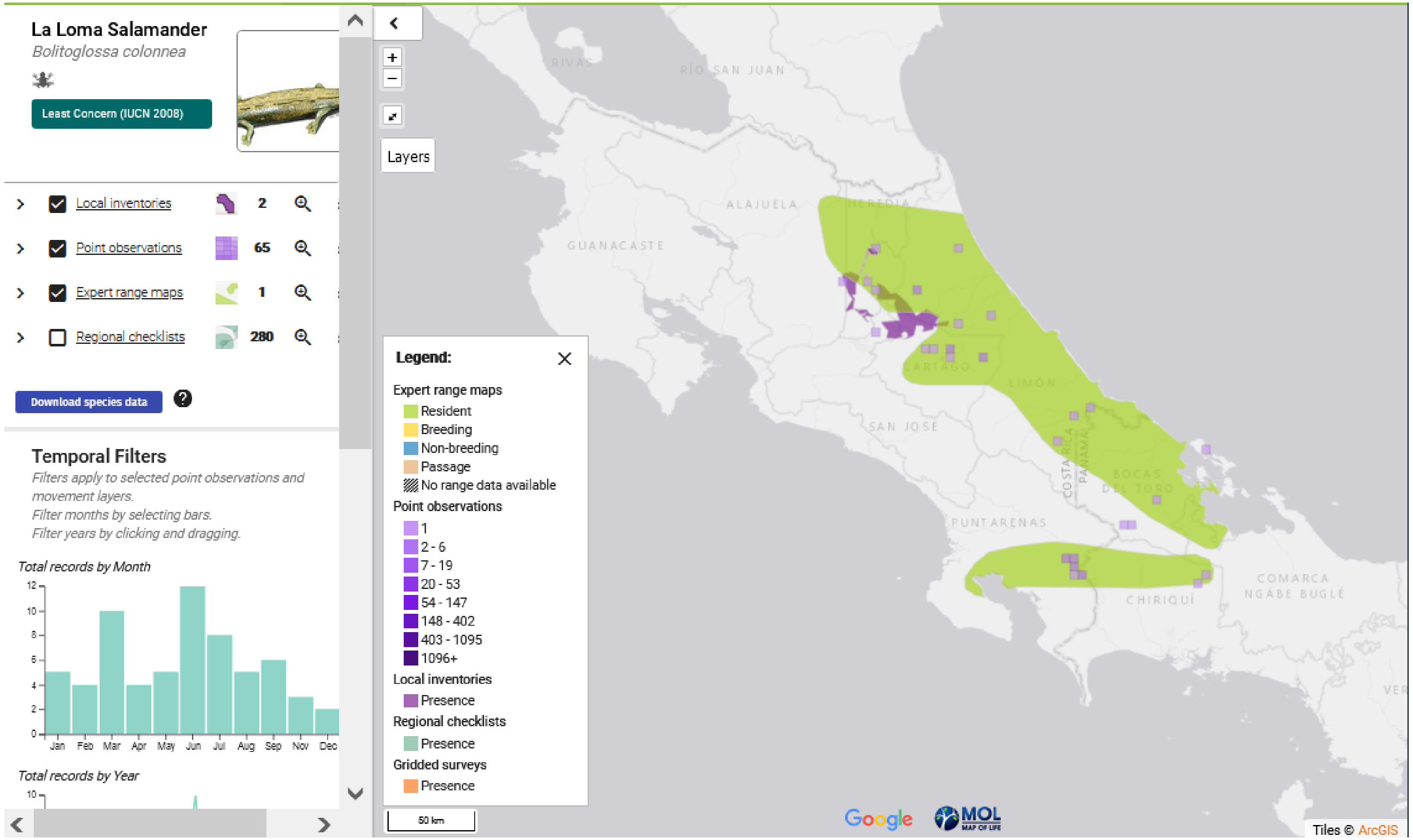
National Science Foundation (NSF)

MacArthur Foundation

….And MANY MORE! https://mol.org/partnerships

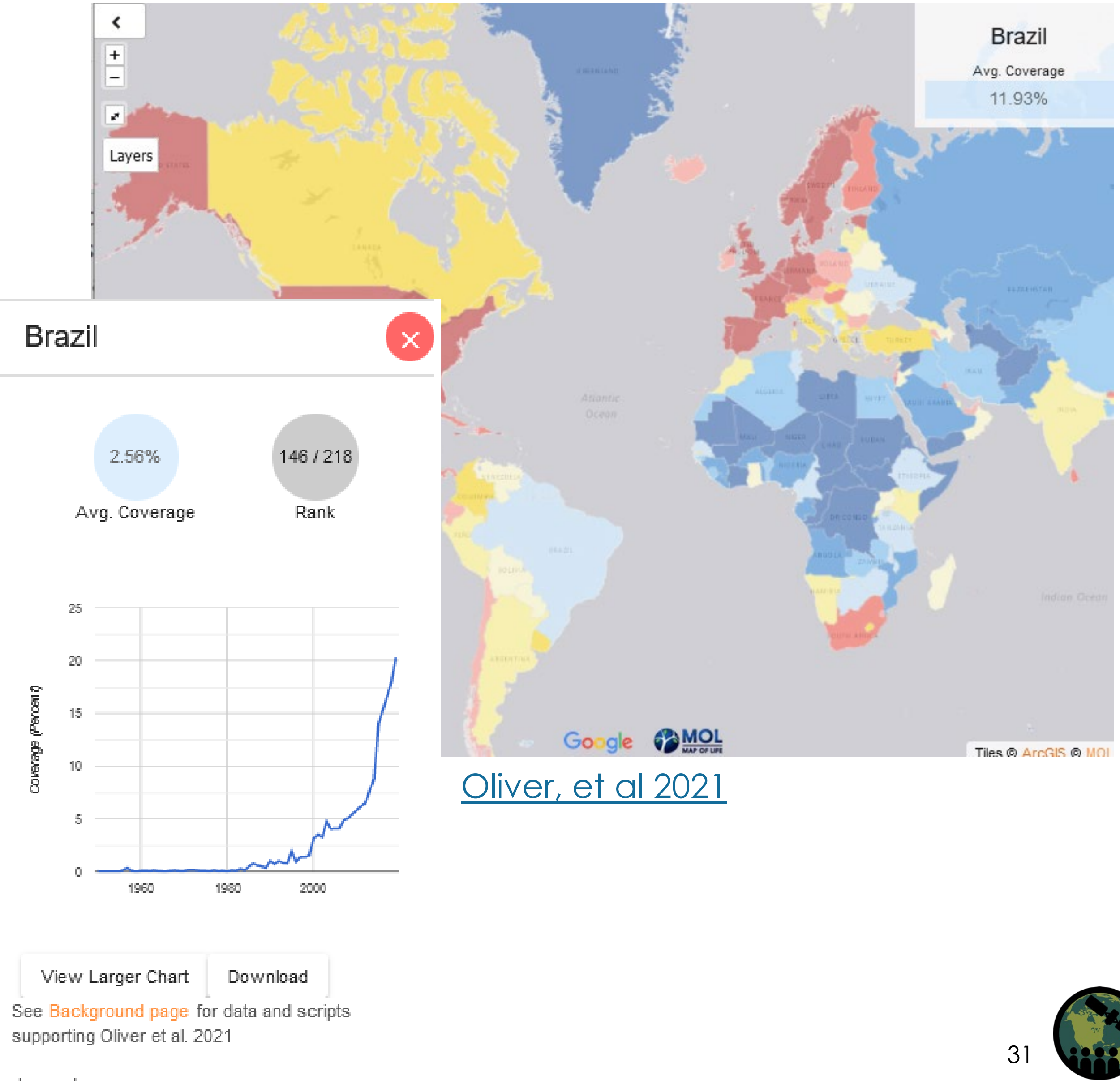
Map Species

- Summary Maps
  - By species or location
- Detailed Maps
- Habitat Distribution
- Reserve Coverage
- Habitat Trends
- Projections



Species Status Information Index (SSII)

- Species occurrence data is important for understanding the distribution of biodiversity in space and time.
- For some regions and species biodiversity is poorly understood/reflected.
  - Small number of records
  - Disproportionate data collection in time and/or space
- SSII captures how well existing data covers the species' expected range.



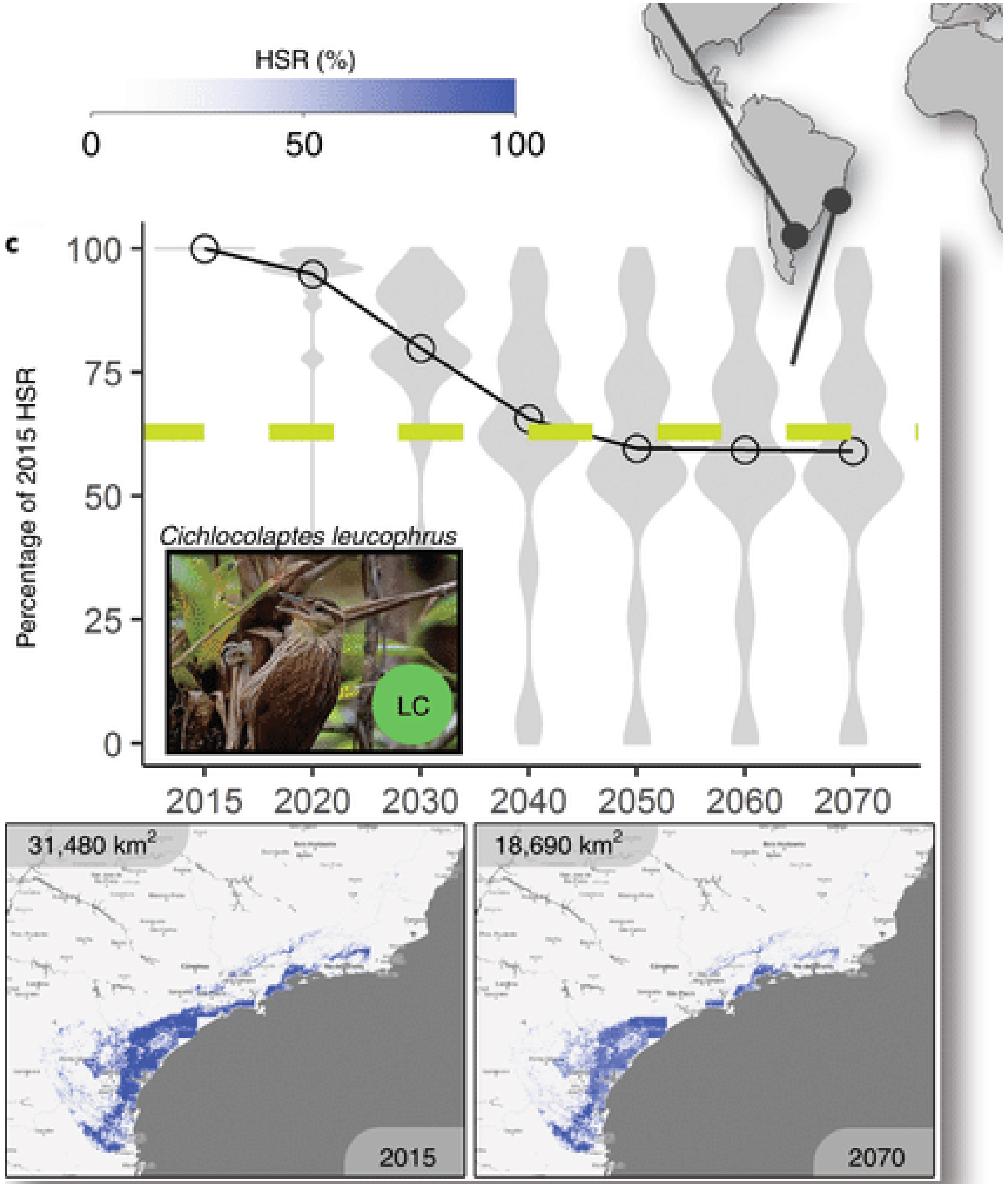
[Oliver, et al 2021](#)

Half Earth Map

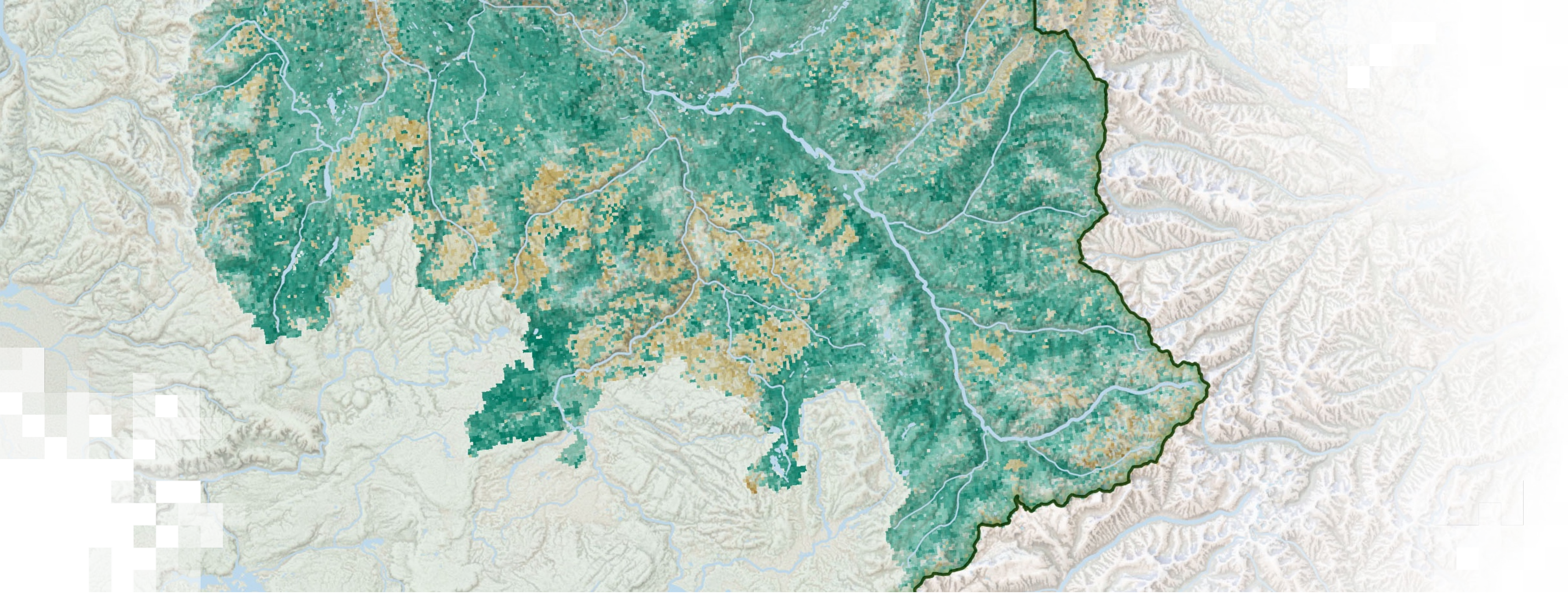
https://map.half-earthproject.org

MOL Example: Global Habitat Loss

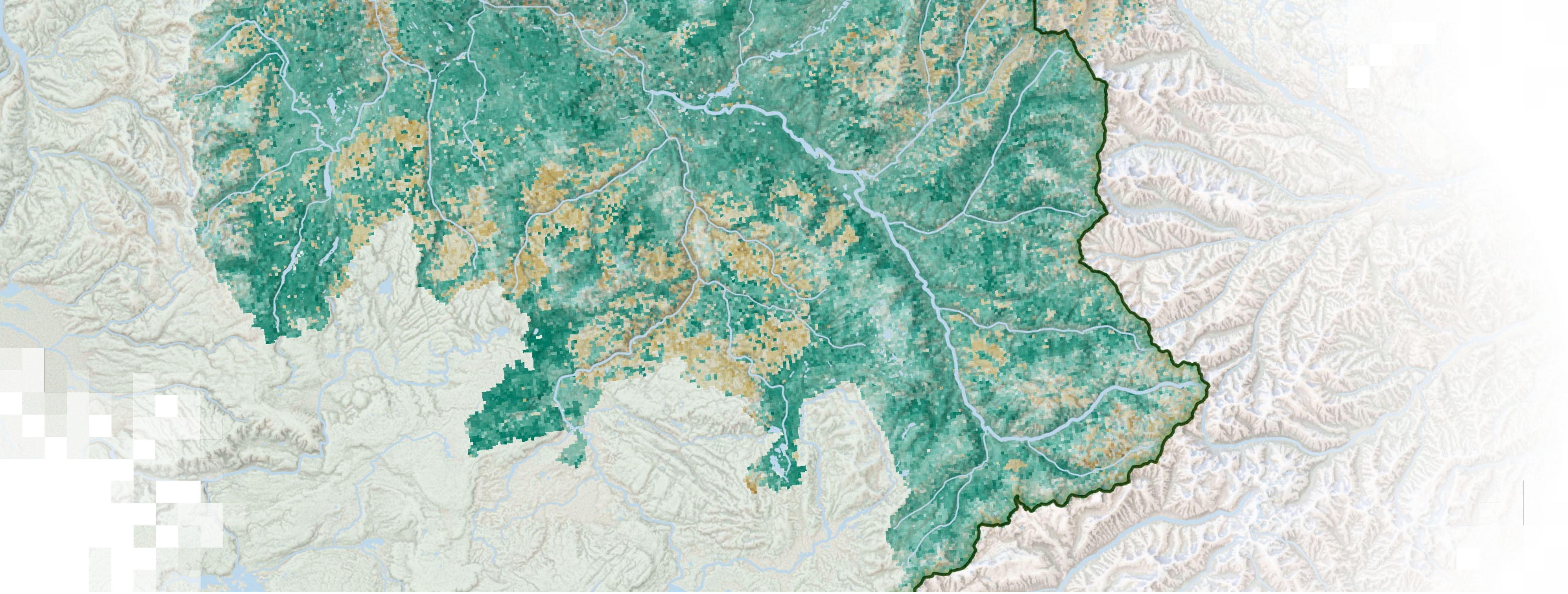
- Focus on terrestrial vertebrates
- Future land use change scenarios and impacts to biodiversity
- Substantial declines in suitable habitat for about 1,700 species of amphibians, birds, and mammals
- Identified regions and species in need of conservation planning activities



[Powers and Jetz, 2019](#)



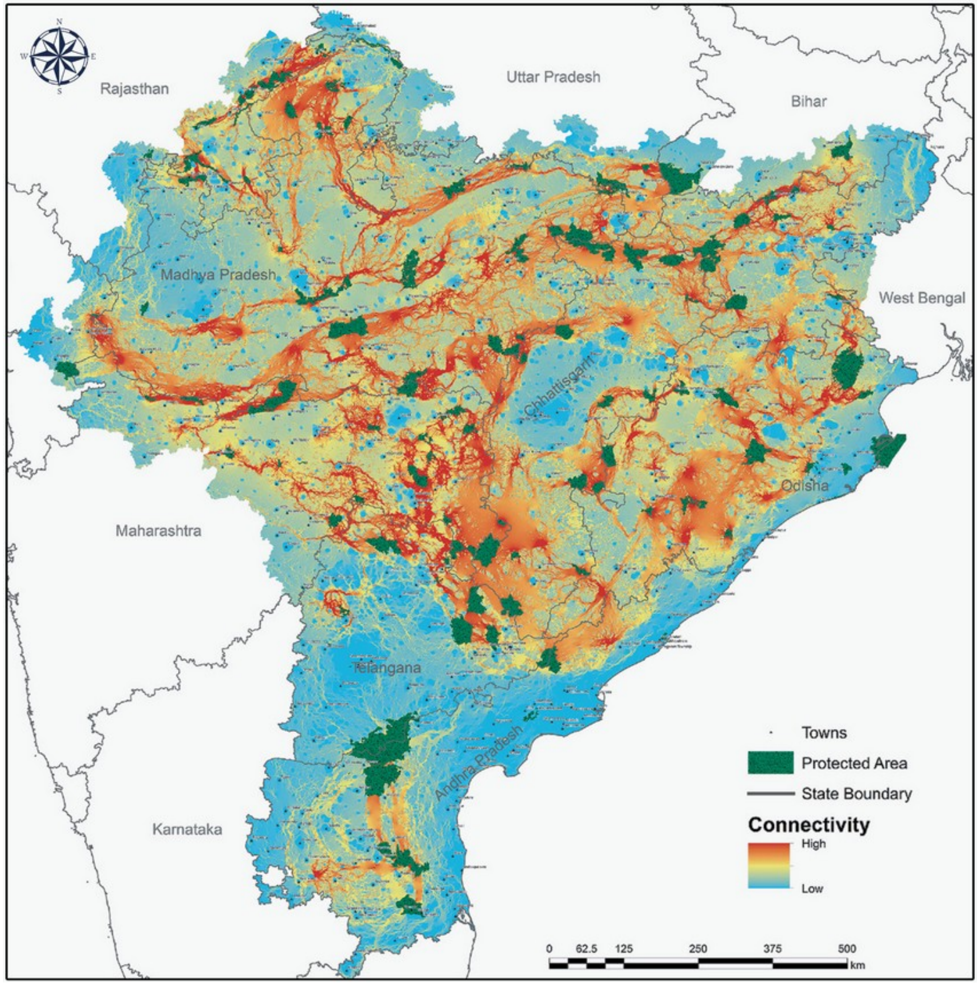
Map of Life (MOL) Demo



Circuitscape and Omniscape

Landscape Connectivity

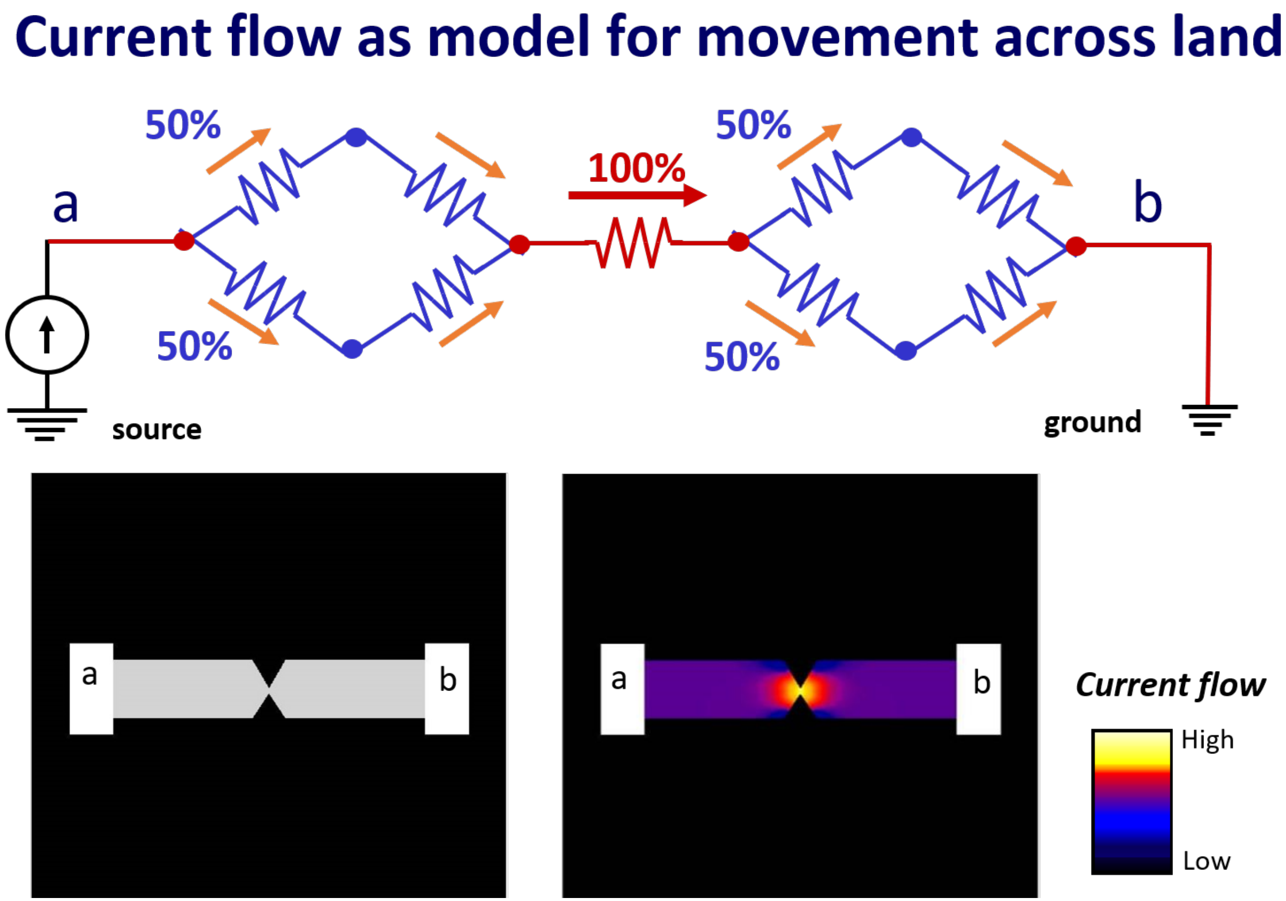
- The extent to which a landscape facilitates the movements of organisms and their genes
  - **Structural:**
    - Physical characteristics of a landscape
    - Topography, hydrology, vegetative cover, human and land use patterns, etc.
  - **Functional:**
    - Ecological preferences of an organism (including movement)
    - Habitat preference, dispersal ability, etc.



Areas best suited for movement of tigers and possible pinch points along them. The red and orange regions in the map show areas with least resistance to tiger movement. Image Credit: [Wildlife Conservation Trust]

Connectivity and Circuit Theory

- <u>Circuit Theory</u>: A process driven approach to modeling gene flow and the dispersal or movement routines of organisms.



Current flow responds to number of pathways available & presence of barriers

Image Credit: Circuitscape Team via Kim Hall

Resistance Grid

- A grid in which each cell value reflects the landscape permeability (structural connectivity) or the energetic cost, movement difficulty, mortality risk, and/or avoidance behavior associated with species movement through that cell (functional connectivity).

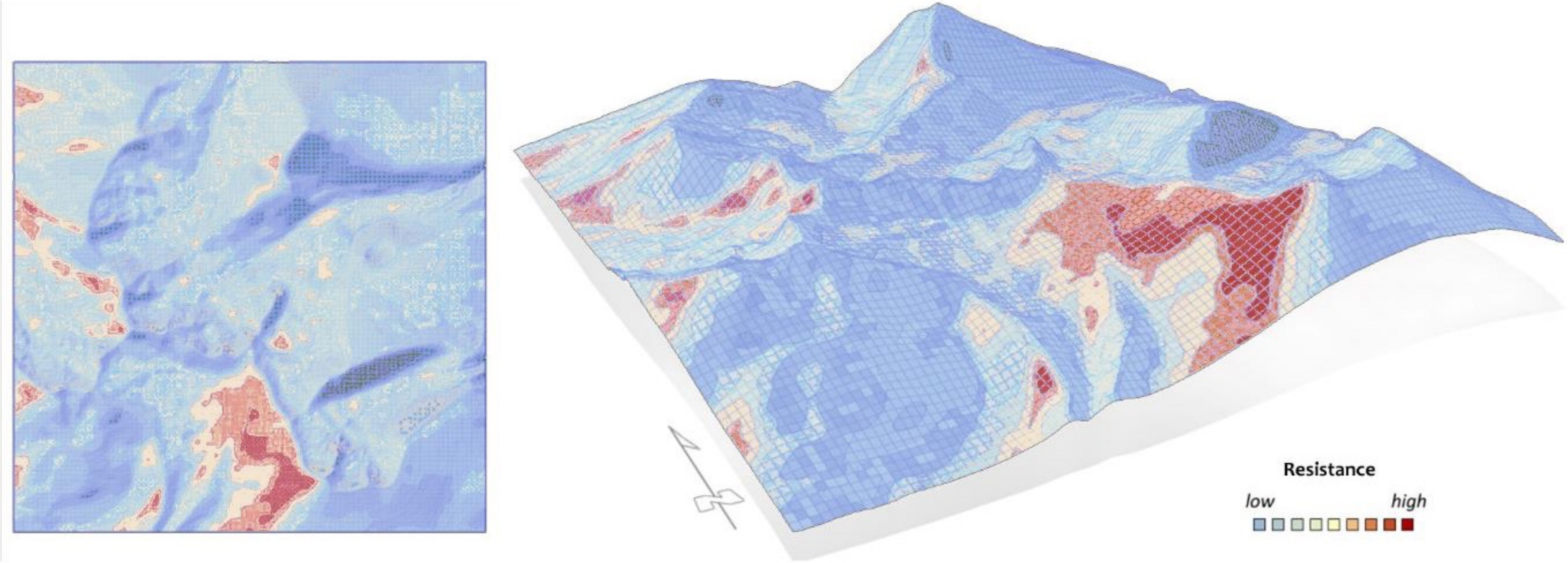


Image Credit: Circuitscape Team via Kim Hall

Why Circuit Theory?

- **Connectivity is not just about corridors.**
  - We need to think about it more diffusely, particularly in working or dynamic landscapes. *The matrix matters.*
  - Connectivity is a dynamic process.
  - Redundancy is key - *especially under changing land cover or climate*.

- **Circuit theory helps to:**
  - Quantify gene flow and redundancy over complex landscapes
  - Prioritize pinch-points where connectivity might be lost sooner
  - Identify restoration opportunities and explore change scenarios
  - Provide theoretical justification for our work protecting and reconnecting landscapes

From Dickson et al. 2019

The Circuitscape Team

The Nature Conservancy

Kim Hall – NASA Lead (after Brad McRae)
Melissa Clark – Wall-to-Wall Circuitscape
Jim Platt – Coding/GIS/ArcGIS Plug-In
Mark Anderson – Co-PI and Applications
Carrie Schloss – Omniscape
Aaron Jones – Omniscape/Linkage Mapper

MIT & Julia Computing

Ranjan Anantharaman – Lead on Update
Viral Shah – Co-PI
Alan Edelman – Collaborator

Conservation Science Partners

Brett Dickson - Circuitscape
Dave Theobald – Resistance Grids
Vincent Landau – Circuitscape, Omniscape

Brad McRae (1966-2017)

What is Circuitscape?

https://circuitscape.org/

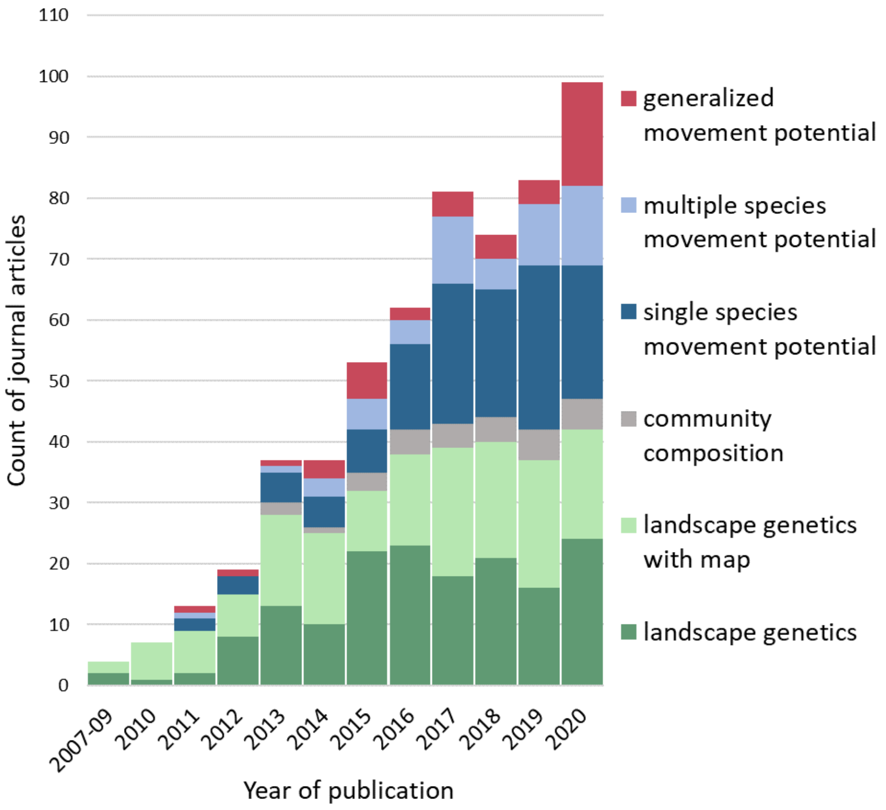
- Open-source connectivity analysis software package, currently in the Julia programming language
- Applies electrical circuit theory to questions of how genes, animals, or processes flow across a heterogenous landscape
  - Tracks where "current" flows across the resistance surface
  - Quantifies spatial patterns of current accumulation along higher or lower resistance areas
- Inputs:
  - Habitat suitability, topography, climatic factors
- Output:
  - Animal movement flow maps (current or future)

Developed by Brad McRae and Viral Shah

Accessing and Using Circuitscape

- The new Circuitscape is built entirely in the Julia language, a new programming language for technical computing.
- Available on GitHub: https://github.com/Circuitscape/Circuitscape.jl/blob/master/README.md#Installation
  - Anantharaman et al, 2020
- Over 500 papers in the natural sciences published in English from 2007–2020 where Circuitscape analyses used

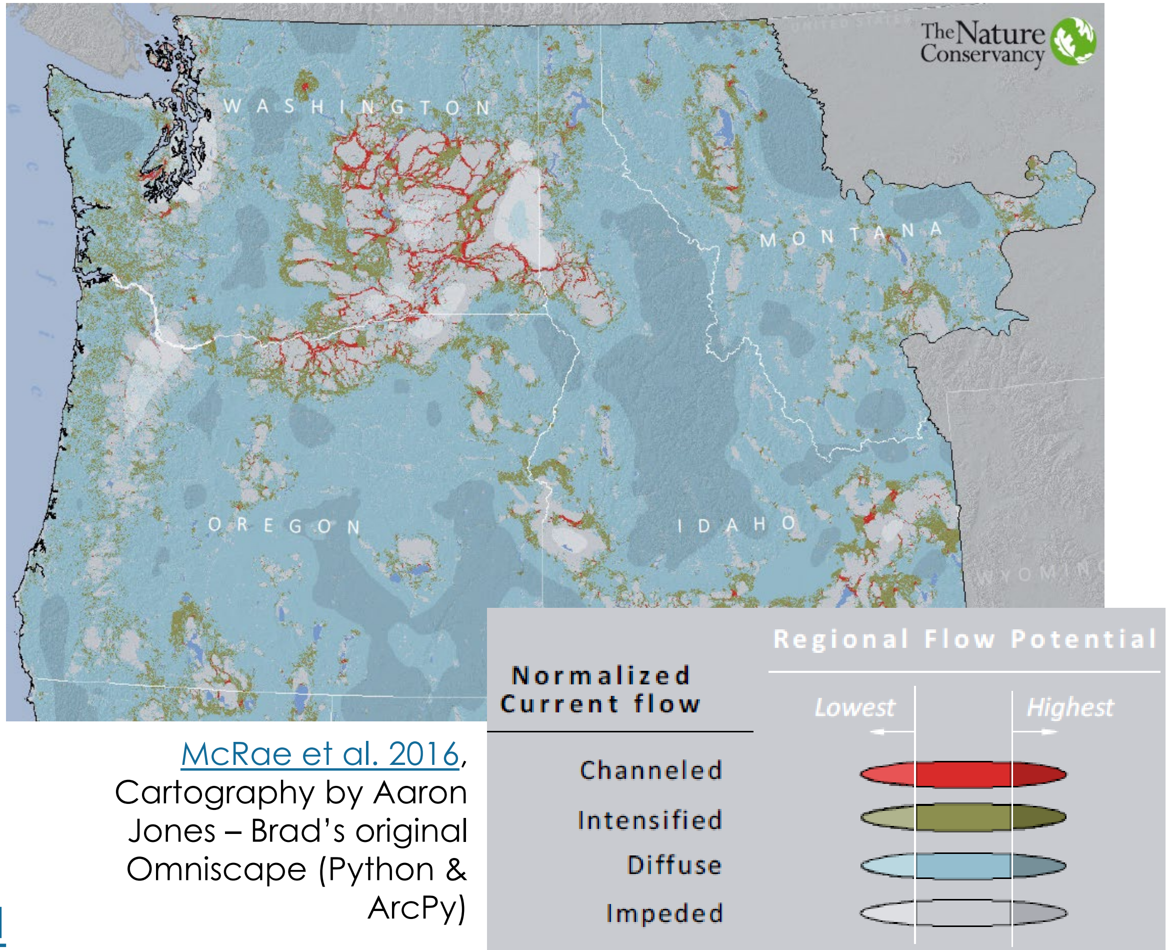
Circuitscape is widely used, with diverse applications.



Hall et al. 2020

Omniscape

- Runs Circuitscape in a circular moving window
- Used to produce omni-directional habitat connectivity
  - Allows sources, destinations, and intensity of animal movement to be informed by continuous spatial data
- Outputs:
  - Cumulative Current Flow
  - Flow Potential
  - Normalized Current Flow
- Available on GitHub: https://github.com/Circuitscape/Omniscape.jl#installation

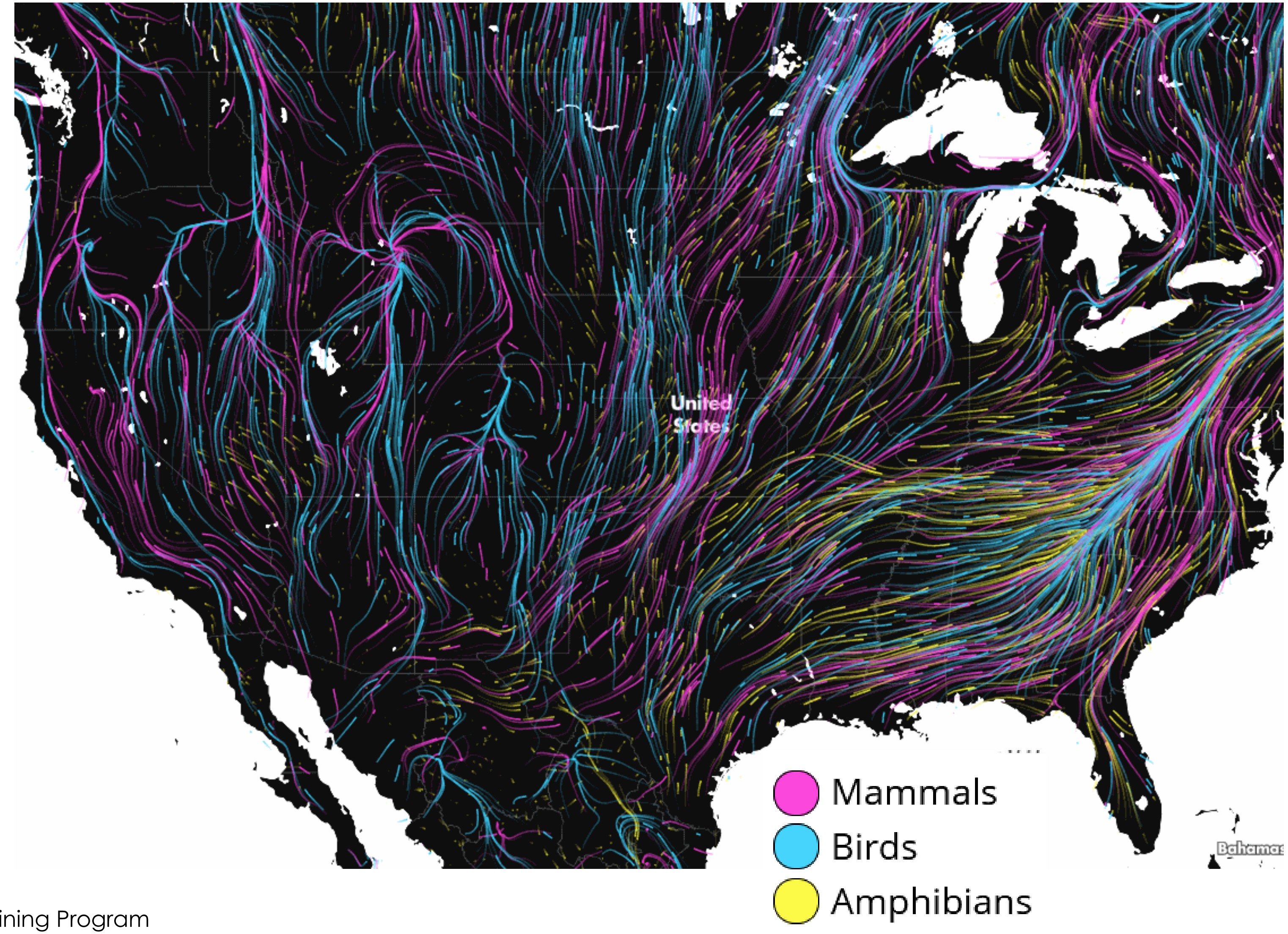


McRae et al. 2016, Cartography by Aaron Jones – Brad's original Omniscape (Python & ArcPy)

Migrations in Motion

https://maps.tnc.org/migrations-in-motion/#4/38.82/-103.93

- The average direction mammals, birds, and amphibians need to move to track hospitable climates as they shift across the landscape.



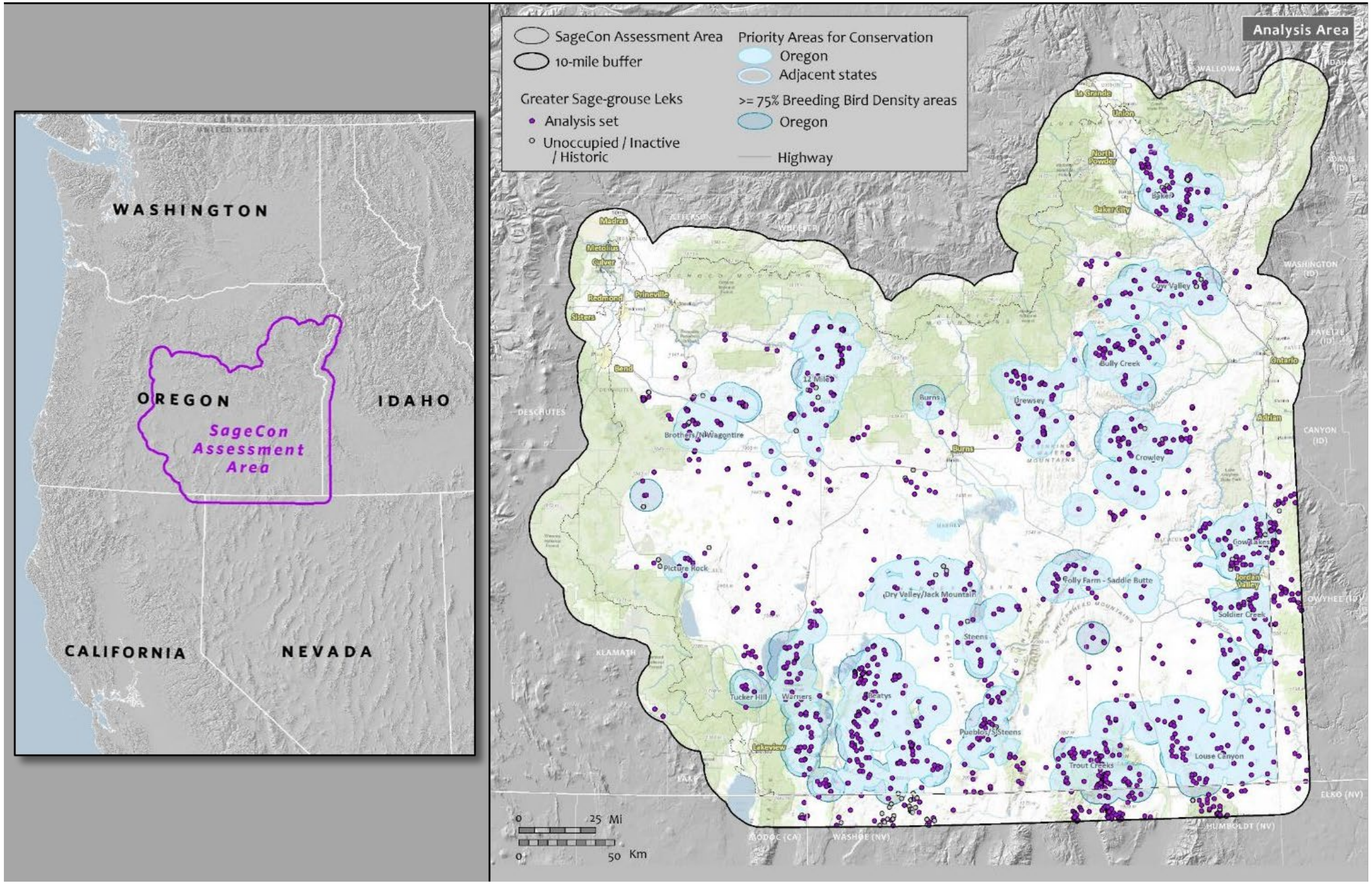
Circuitscape Example: Sage-Grouse Conservation

- Assisted in the development of a Sage-Grouse Conservation Partnership in Southern Oregon
- Goals:
  - Model relative accessibility of localized areas
  - Identify linkage zones of easiest movement based on landscape
  - Describe areas where movement may be constrained or fragmented


Image Credit: eBrid


Image Credit: Sage Grouse Initiative

Sage-Grouse Conservation: Study Area



[Jones, 2015](#)

Sage-Grouse Conservation: Data Inputs

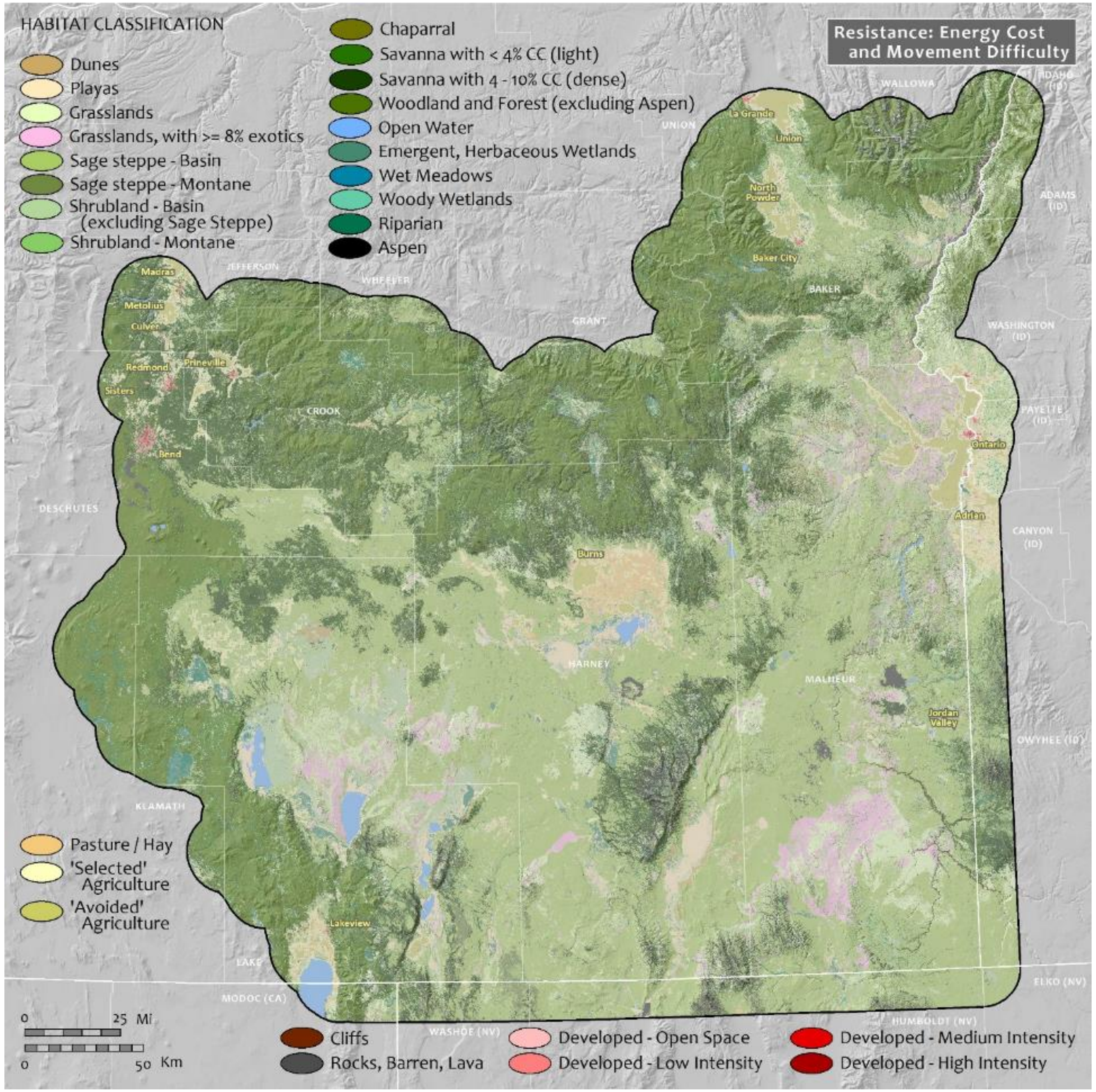
- MANY spatial datasets, including Landsat-derived landcover map from the National Land Cover Database
- Resistance Data Types:
  - Energy Cost/Movement Difficulty: *Includes base habitat layers*
  - Mortality Risk: *Physical footprints of anthropogenic landscape features*
  - Avoidance: *Densities/inverse Euclidean distances of anthropogenic features*

Sage-Grouse Conservation: Habitat Classification

Energy Cost/Movement Difficulty

Habitat Classification

- These classes were included in the modeling of resistance due to energy cost and movement difficulty.



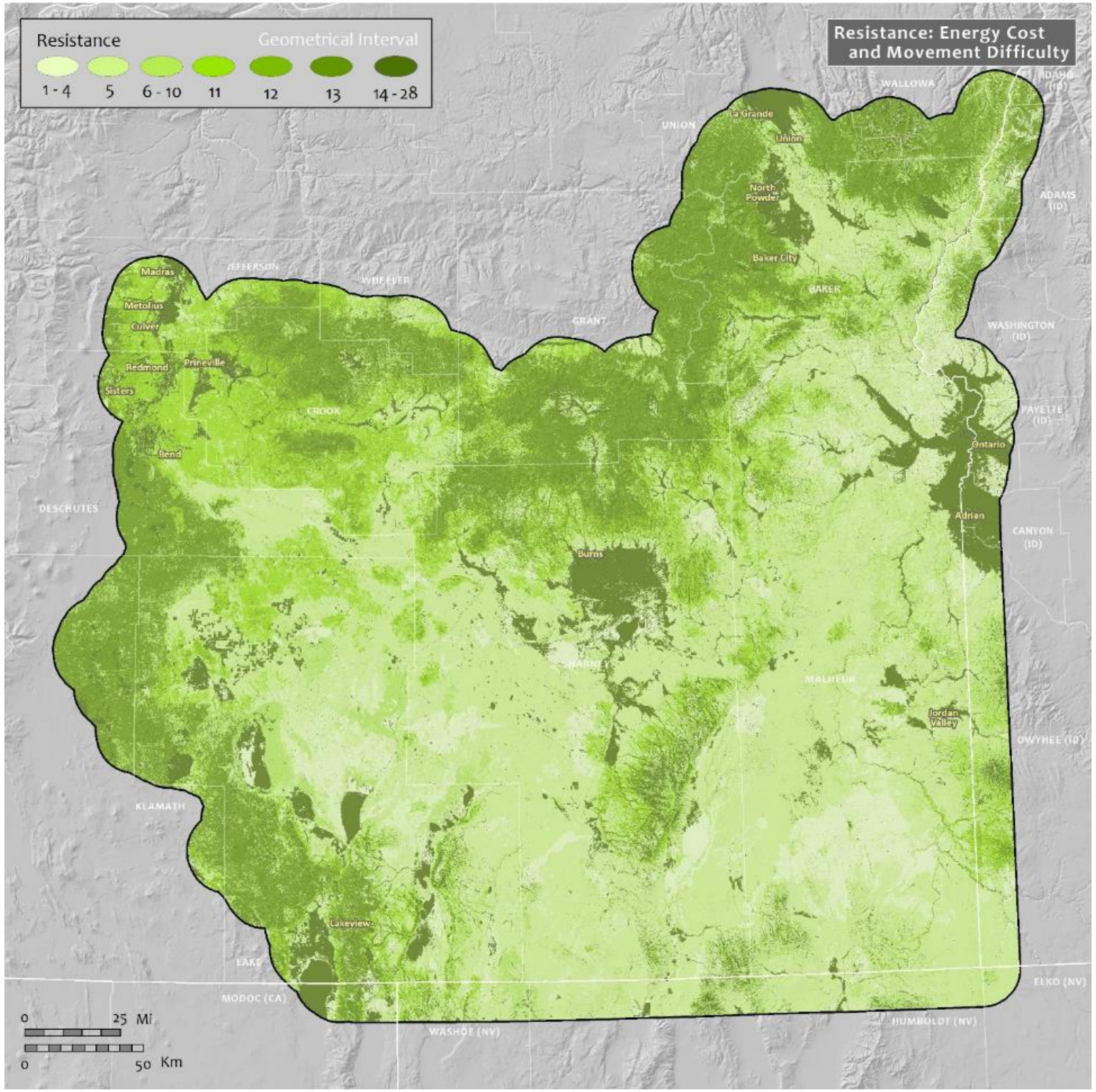
Jones, 2015

Sage-Grouse Conservation: Resistance

Energy Cost/Movement Difficulty

Resistance

- Higher resistance values indicate greater cost and difficulty for sage-grouse movement.



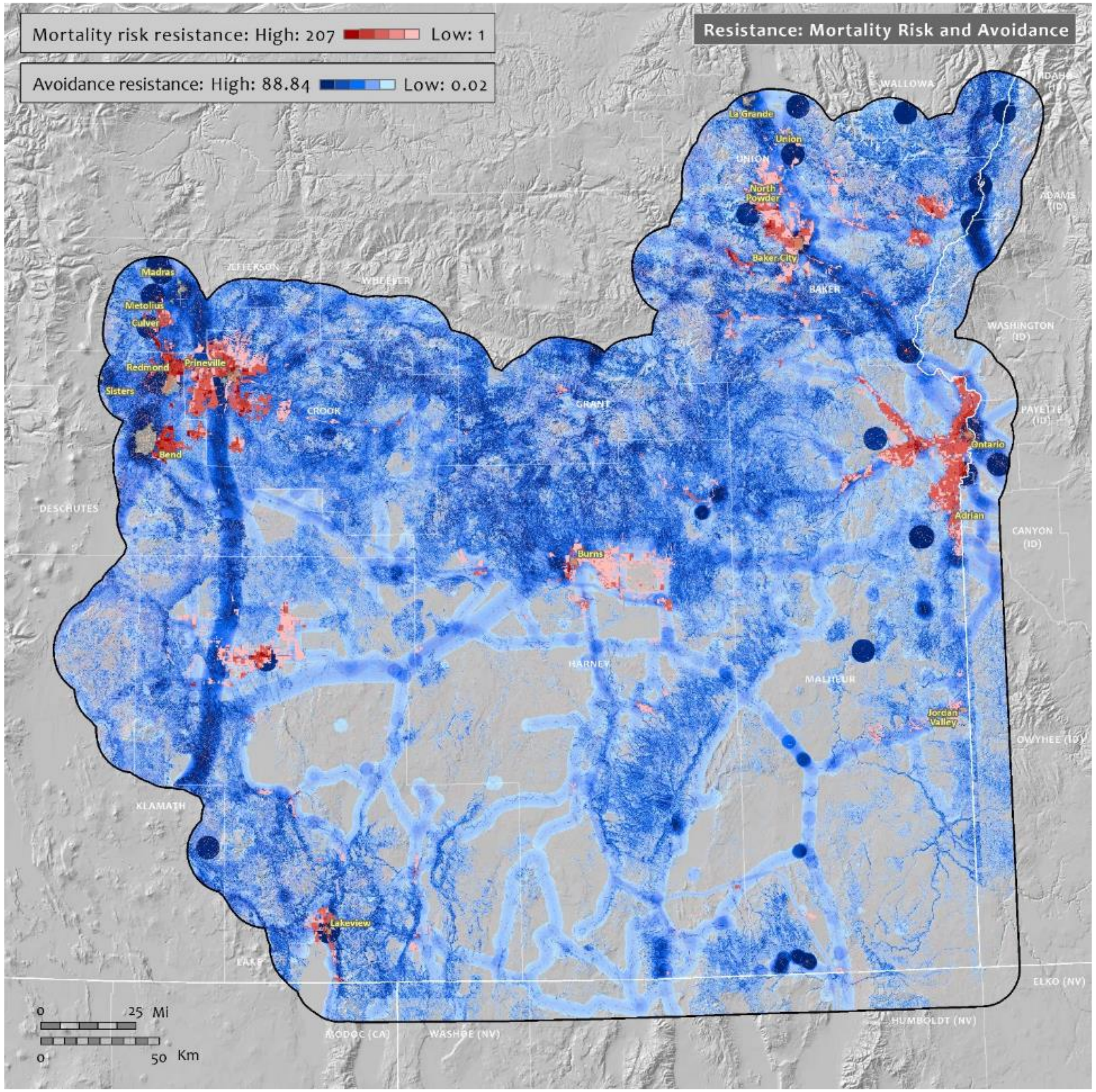
Jones, 2015

Sage-Grouse Conservation: Resistance

Mortality Risk or Avoidance

Resistance

- Higher resistance/mortality: high housing densities
- Higher resistance/avoidance: powerplants and high-voltage transmission lines



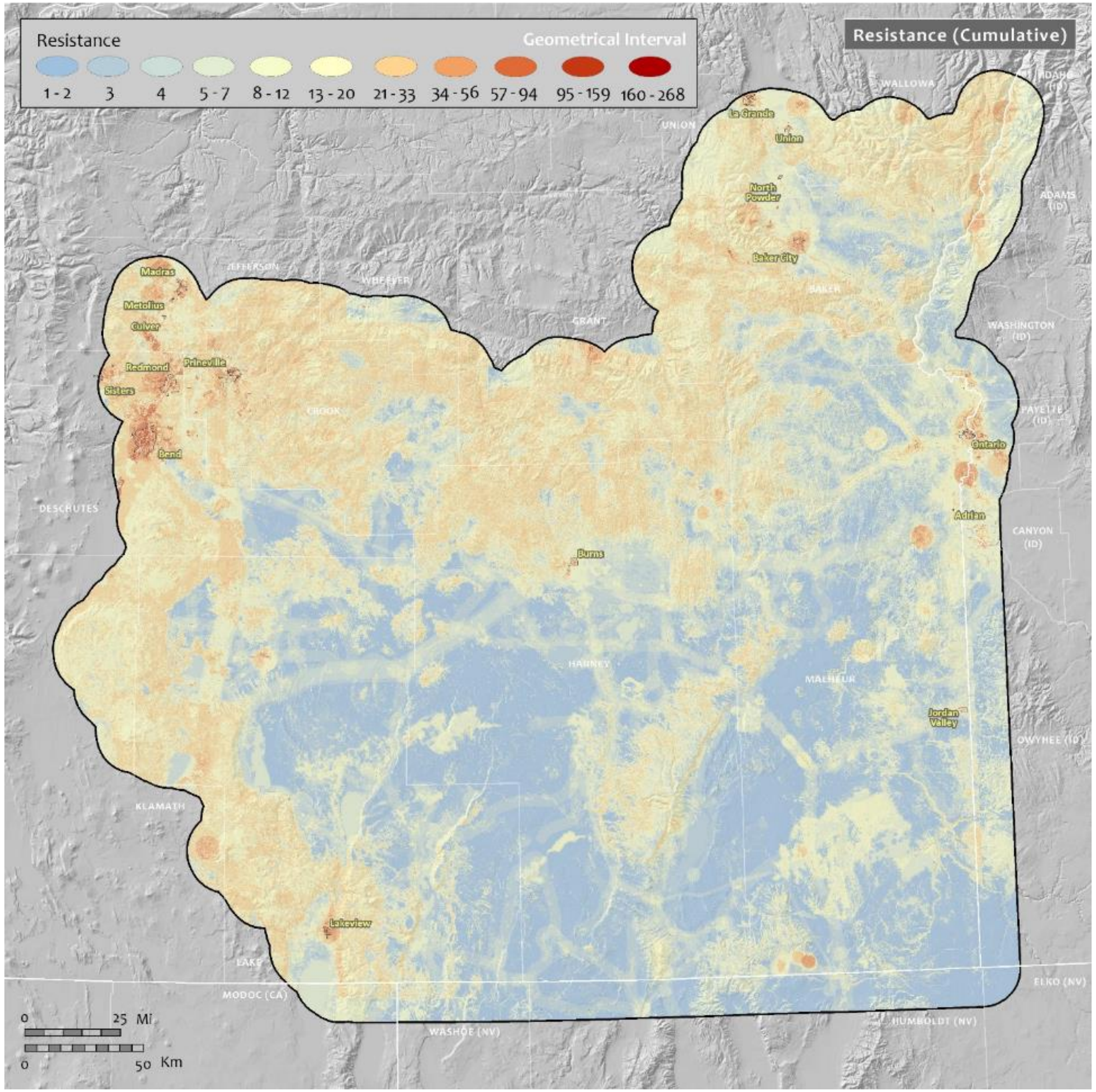
Jones, 2015

Sage-Grouse Conservation: Cumulative Resistance

Combined Resistance Surface

- Higher resistance values indicate greater cost and difficulty for sage-grouse movement, greater mortality risk, and/or greater avoidance behavior.

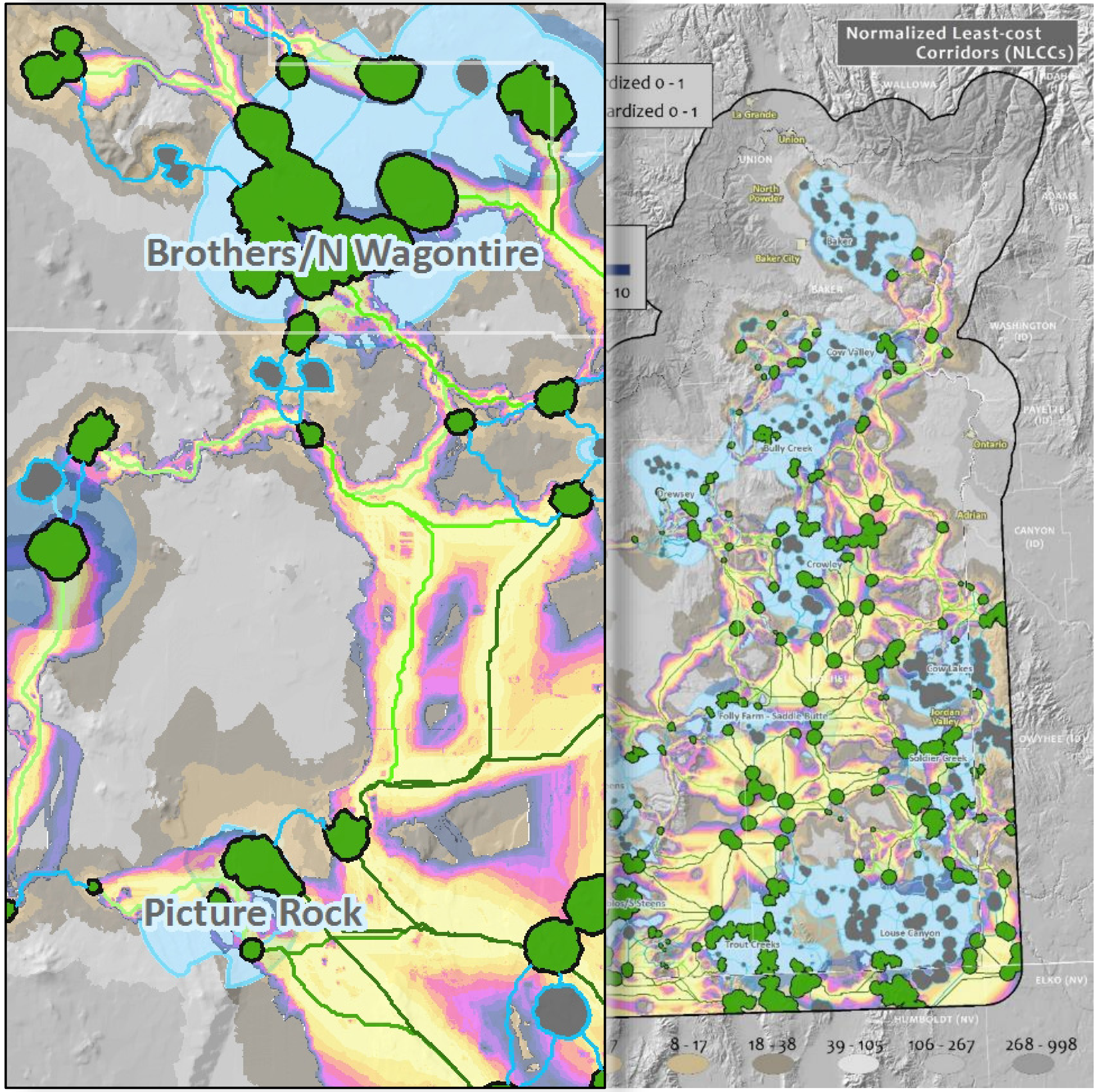
Warmer Colors =
Higher Resistance



[Jones, 2015](#)

Sage-Grouse Conservation: Normalized Least-Cost Corridors (NLCCs)

- **NLCCs (Corridors):** Each defined by cumulative movement costs relative to its respective LCP.
- **'Linkage Zone':** Broad belts of land with relatively greater habitat continuity. (Here, NLCCs = Linkage Zones.)
- Framework for Circuitscape runs

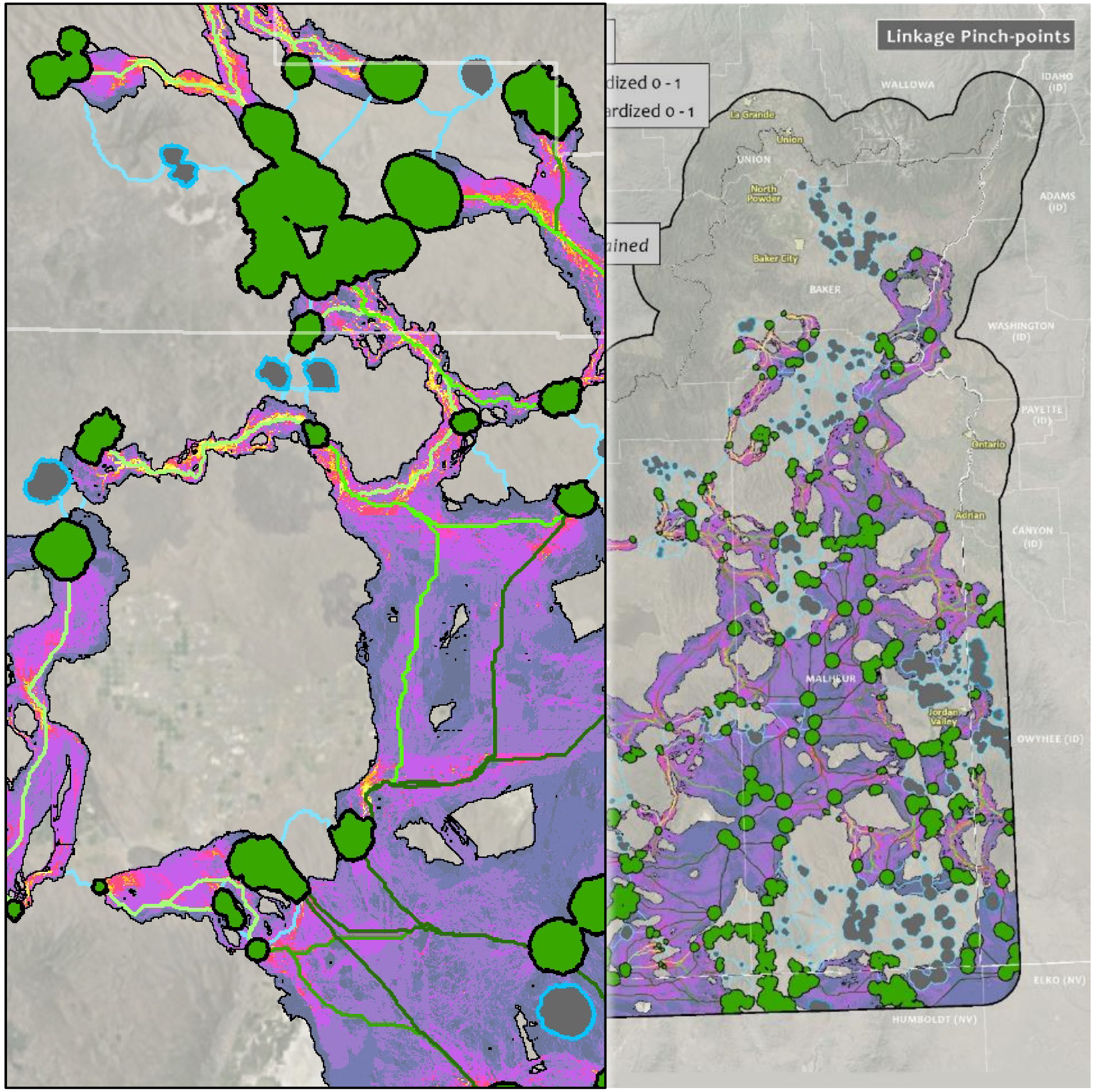


Jones, 2015

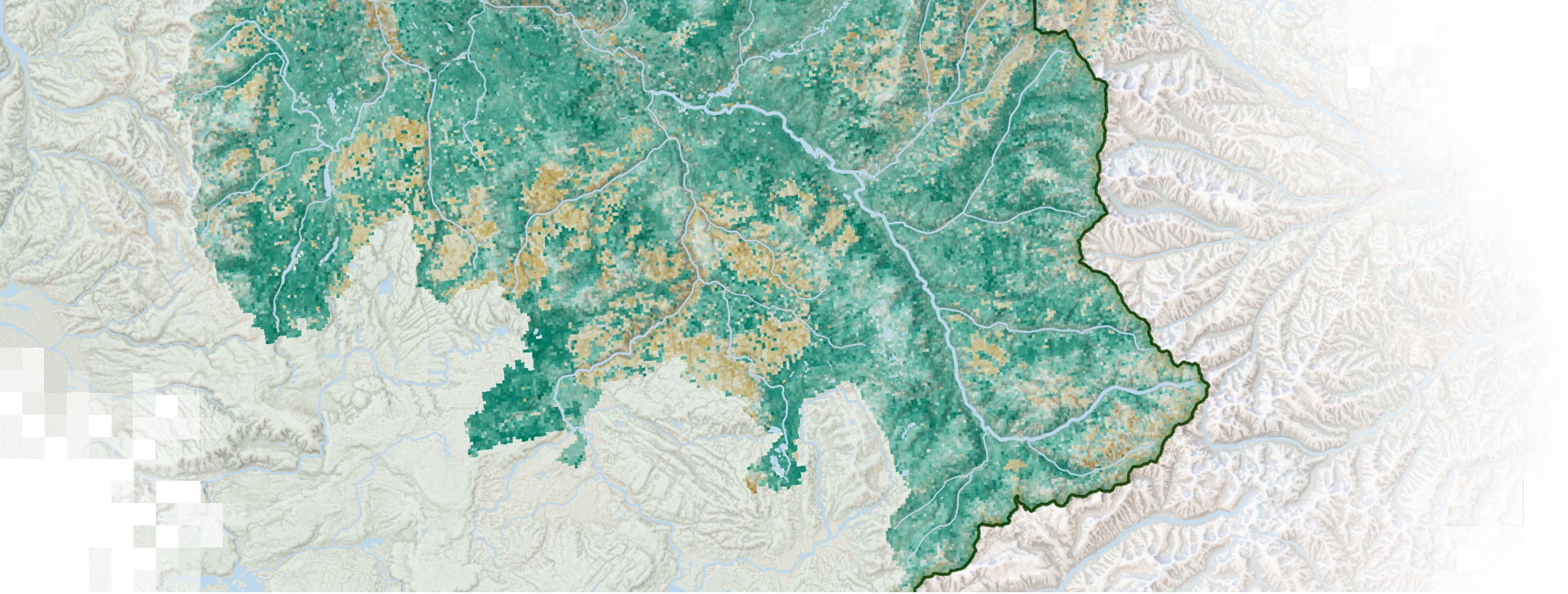
Sage-Grouse Conservation: Linkage Pinch-Points

Pinch-Points:

- Locations of highly constricted (and thus strong) current flow
- Network severance possible with loss of small amount of movement habitat
- Potential areas for protection from habitat loss or degradation



Jones, 2015



Fisheries and Climate Toolkit (FaCeT)

Dynamic Ocean Management

- Improved understanding of the nature of aquatic species, users, and oceanographic features to guide commercial activities
  - Balance economically viable industries with ecological sustainability
- Climate change shifting species distributions and therefore fishing fleets
  - Adaptation of management and conservation strategies
- Need to address Sustainable Development Goal 14 and related targets 14.2 and 14.4


Image Credit: NOAA


Image Credit: FaCeT

Fisheries and Climate Toolkit (FaCeT)

https://fisheriesclimatetoolkit.sdsu.edu/

Camrin Braun[1,2], Nima Farchadi[3], Kathy Mills[4], Dylan Pugh[4], Alex Kerney[4], Riley Young Morse[4], Stephanie Brodie[5], Heather Welch[5], Andrew Allyn[4], Nerea Lezama Ochoa[5], Steven Bograd[5,6], Elliott Hazen[5,6], Rebecca Lewison[3]

[1]University of Washington, [2]Woods Hole Oceanographic Institution, [3]San Diego State University, [3]Gulf of Maine Research Institute, [4]NOAA SWFSC, Environmental Research Division, [5]University of California Santa Cruz

Fisheries Needs and Applications of FaCeT

- Providing Forecasting/Predictions
- Tracking Magnitude/Velocity of Change
- Harnessing Big Data and Data Pipelines
- Climate Change Uncertainty in a Fisheries Context

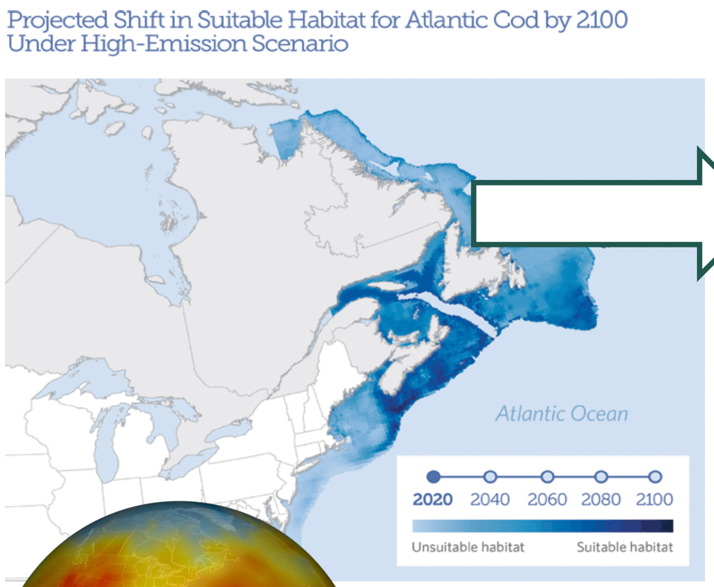
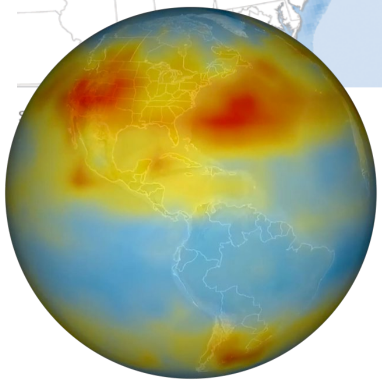


Image Credit: FaCeT



Climate-Driven Anomalies

Ecological Consequences

Economic Impacts

FaCeT Goals

Develop online products that enable:

- Tracking dynamic species & vessel distributions
- Project fishery interactions and “hotspots”
- Integrate climate projections to:
    - Identify fishery-relevant climate anomalies
    - Inform climate-resilient fisheries management

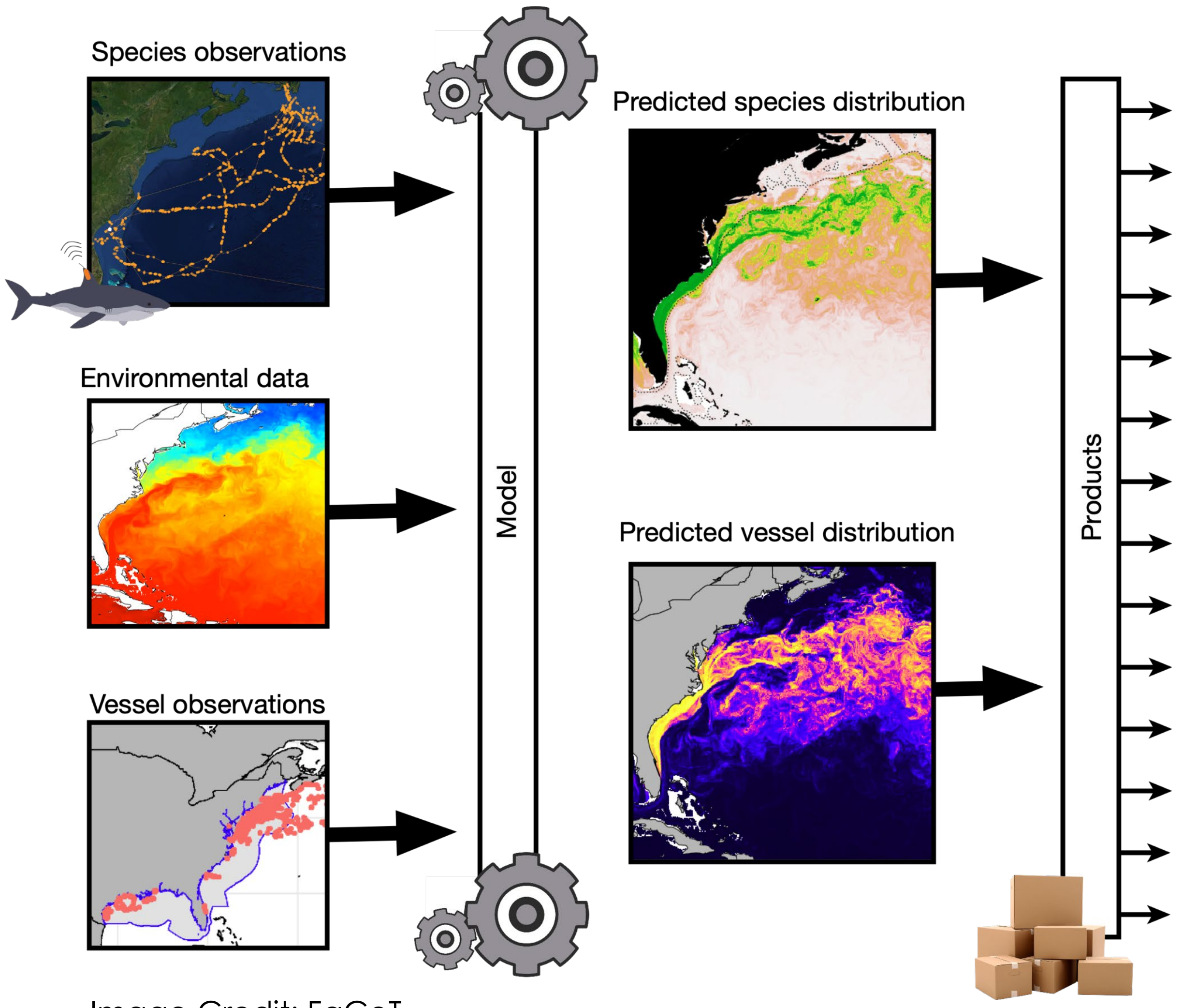


Image Credit: FaCeT

FaCeT Example: Shortfin Mako Shark

- Shortfin mako sharks subject to overfishing
- Slow growth rates, reproduce after many years
- Found along the East Coast of the US
- Highly migratory
- Managed through NOAA's Consolidated Atlantic Highly Migratory Species Fishery Management Plan
- Often caught incidentally in longline fisheries targeting swordfish and tuna
- Current regulations exist

Image Credit: FaCeT

Shortfin Mako Shark Locations

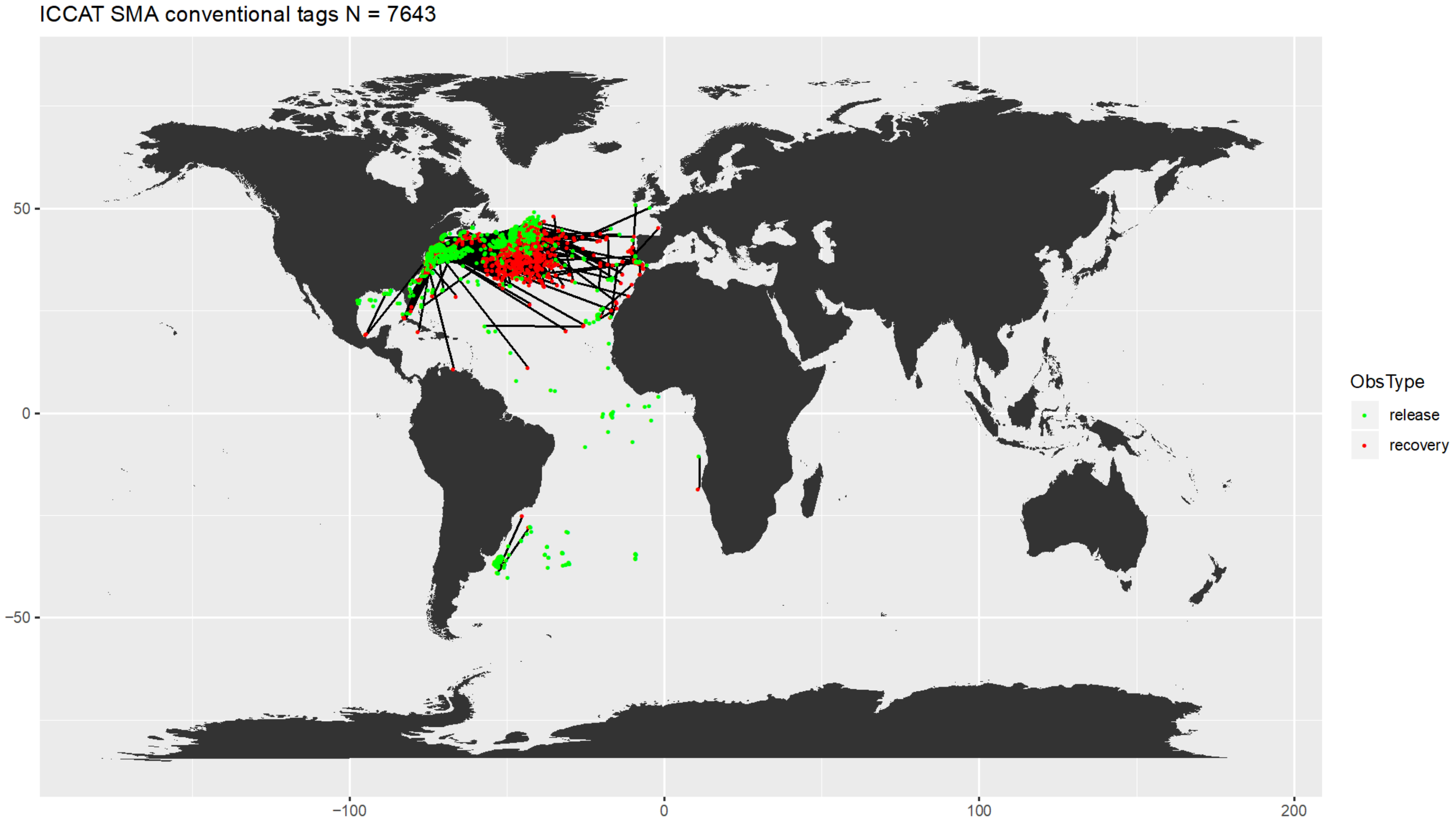


Image Credit: FaCeT

Shortfin Mako Shark Suitable Habitat

Habitat Suitability

Image Credit: FaCeT

FaCeT Example: Dynamic Vessel Distribution Models (dVDMs)

- Shipboard AIS >70,000 fishing vessels globally
- Potential climate-driven shifts in fisher distribution

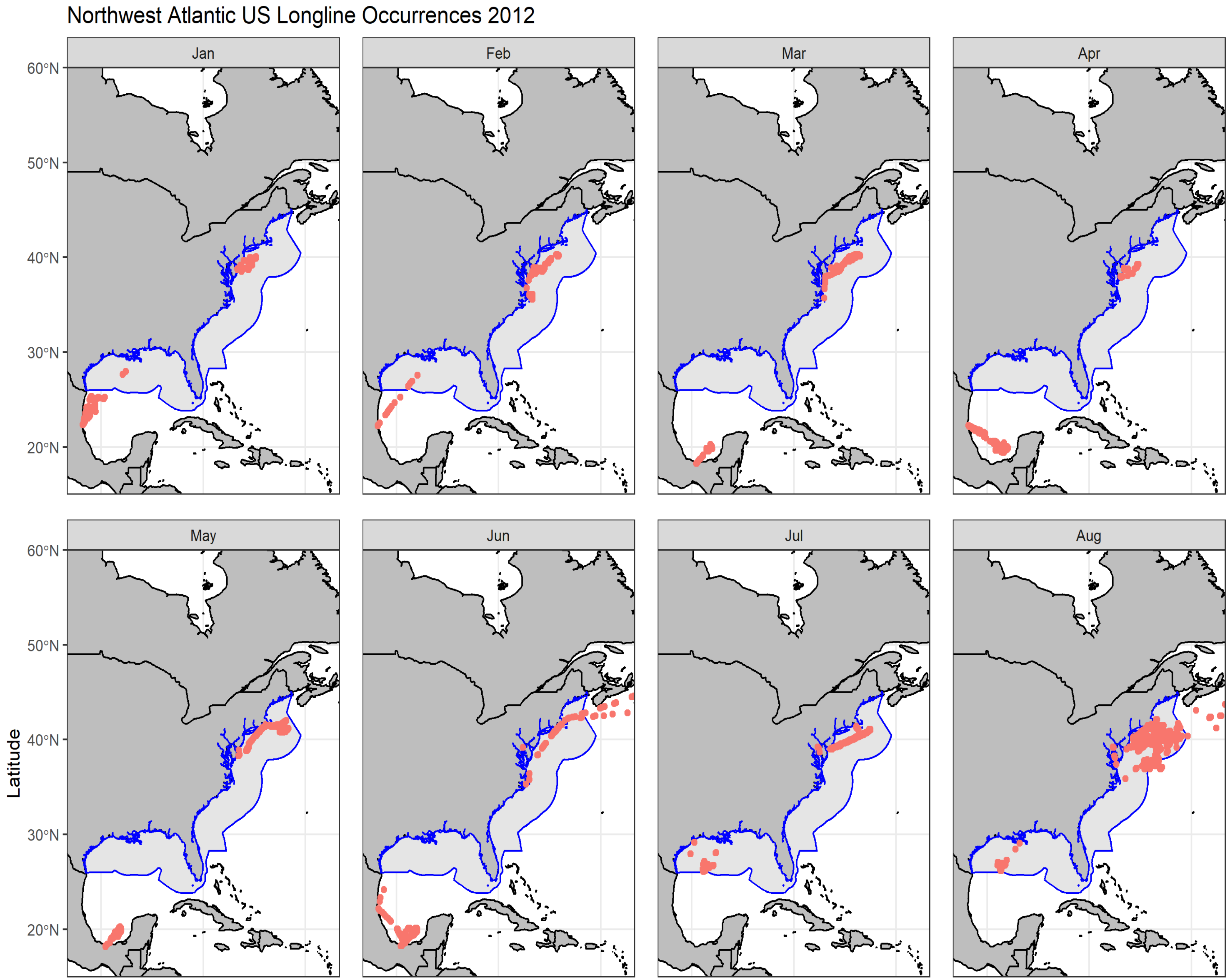


Image Credit: FaCeT

FaCeT Example: Dynamic Vessel Distribution Models (dVDMs)

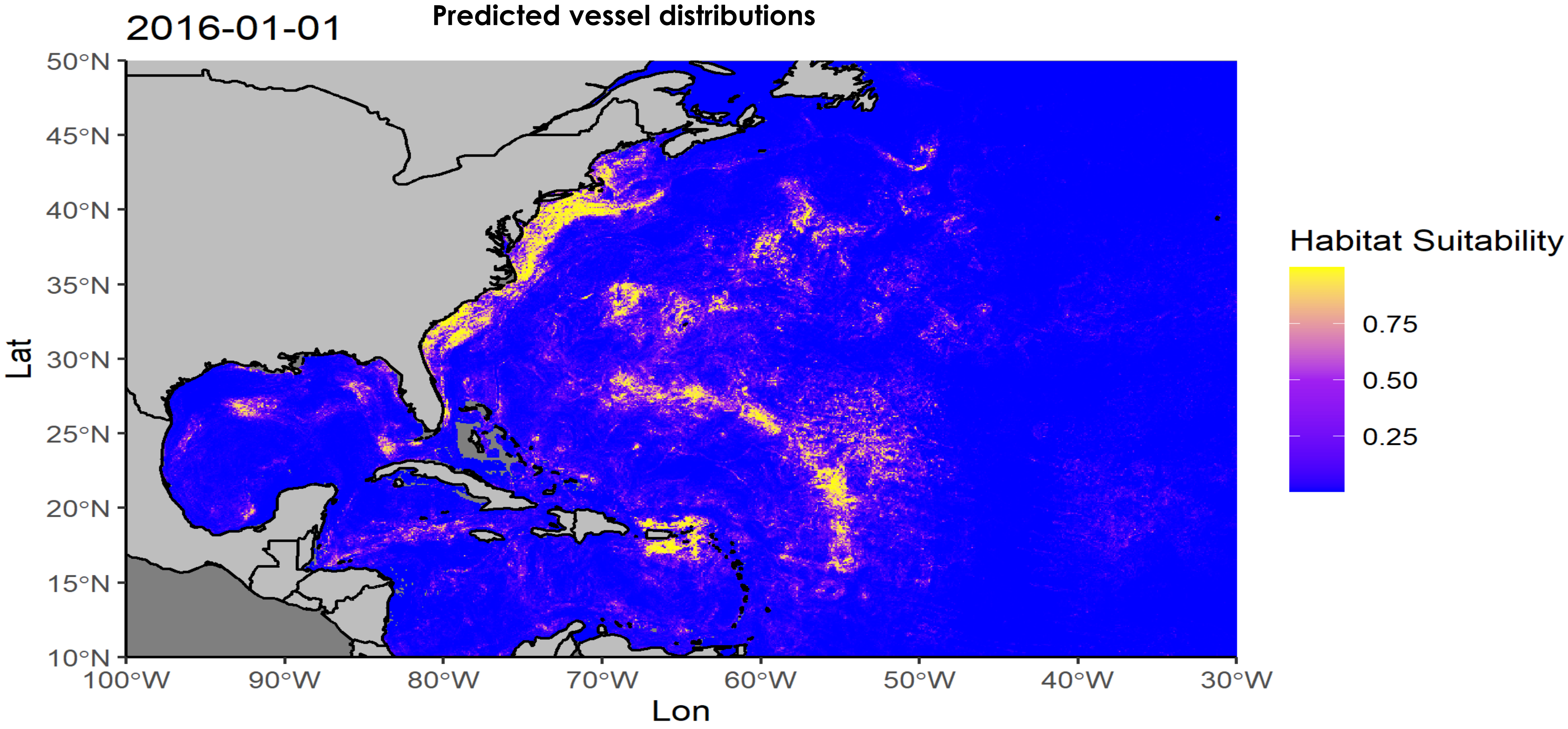


Image Credit: FaCeT

FaCeT Example: Dynamic Vessel Distribution Models (dVDMs)

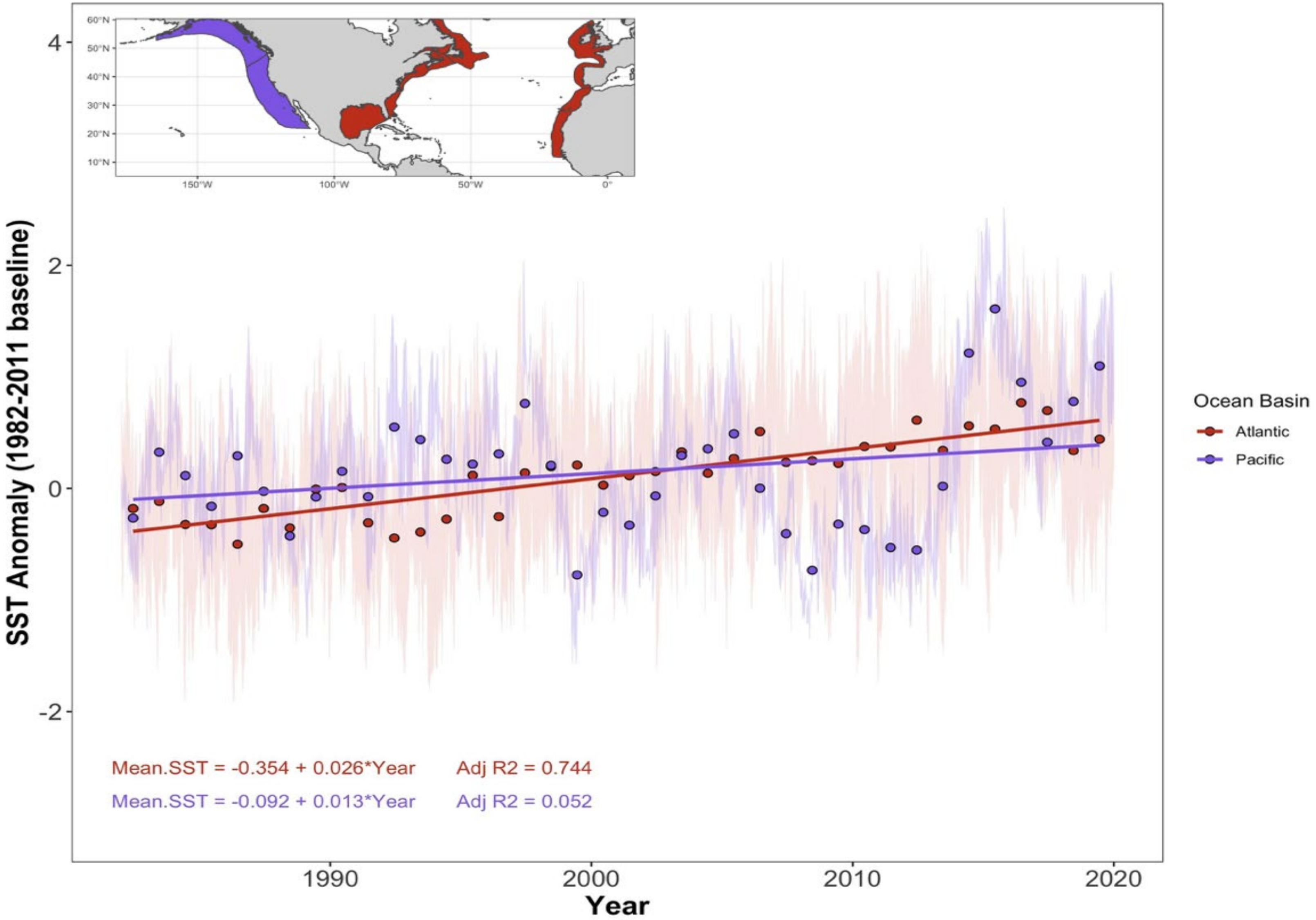


Image Credit: FaCeT

Summary

- Species Distribution Models (SDMs) allow us to assess the suitability of a habitat for a species.
  - SDMs primarily use environmental data and occurrence data to build a model for predictions of habitat suitability.
- `Wallace` is a user-friendly application for SDM that provides guidance towards following best-practices at each step.
- Additional projects and tools for SDM include:
  - Mapping Application for Penguin Populations and Projected Dynamics (MAPPD)
  - Wildlife Insights
  - Map of Life (MOL)
  - Circuitscape and Omniscape
  - Fisheries and Climate Toolkit (FaCeT)

Homework and Certificate

- One homework assignment:
  - Answers must be submitted via Google Form, accessed from the ARSET website.
  - Due date for homework: **September 2, 2021**
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline
  - You will receive a certificate approximately two months after the completion of the course from marines.martins@ssaihq.com.

Contacts

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- Training Webpage:
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  - https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

Thank You!