Harnessing Machine Learning for Long-Term Monitoring of Beaver Dams in Satellite Imagery

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Why do beaver dam locations matter?

1. Ecological impact

Image credit: Montana Fish and Wildlife

2. Easily identifiable sign of beaver presence*

Image credit: Montana Fish and Wildlife

*Presence:

- Current occupancy, or
- Occupancy in the recent past

Documenting dams at large scales is difficult

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Boots on the ground

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Boots on the ground

Remote sensing

Image credit: ESA Sentinel-2

Boots on the ground

Remote sensing

Challenging over long periods of time, and at large spatial scales

Image credit: ESA Sentinel-2

Where might dam location data be helpful?

West Yellowstone, USA

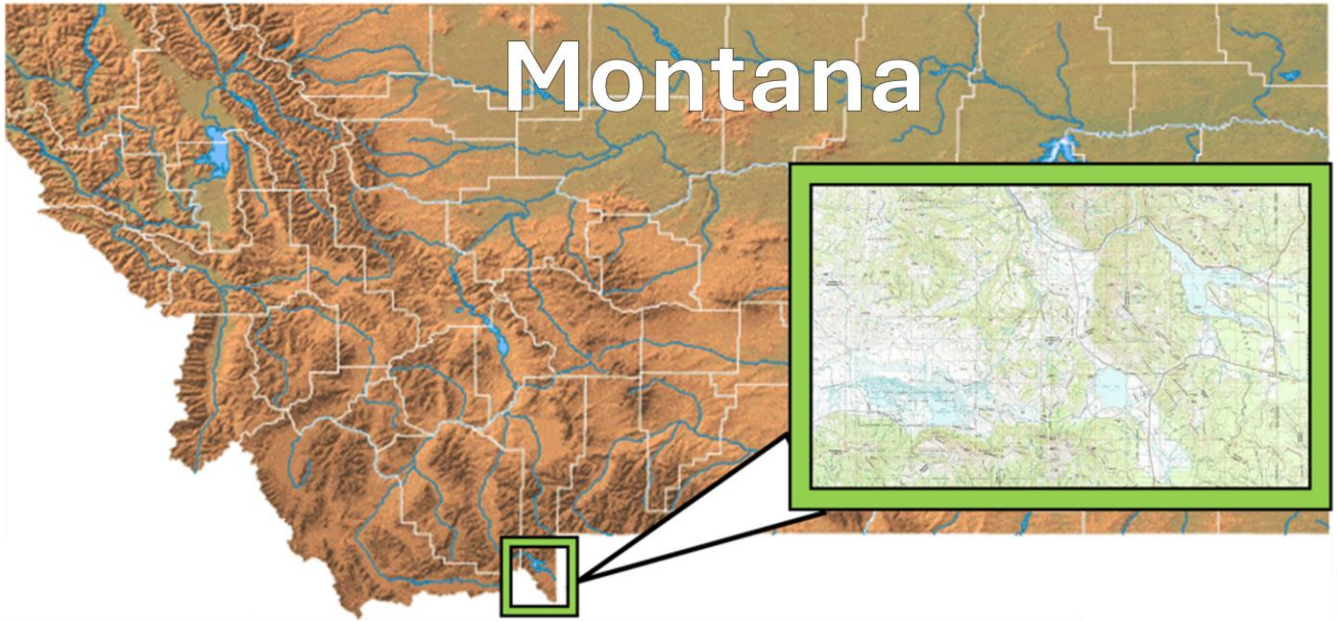
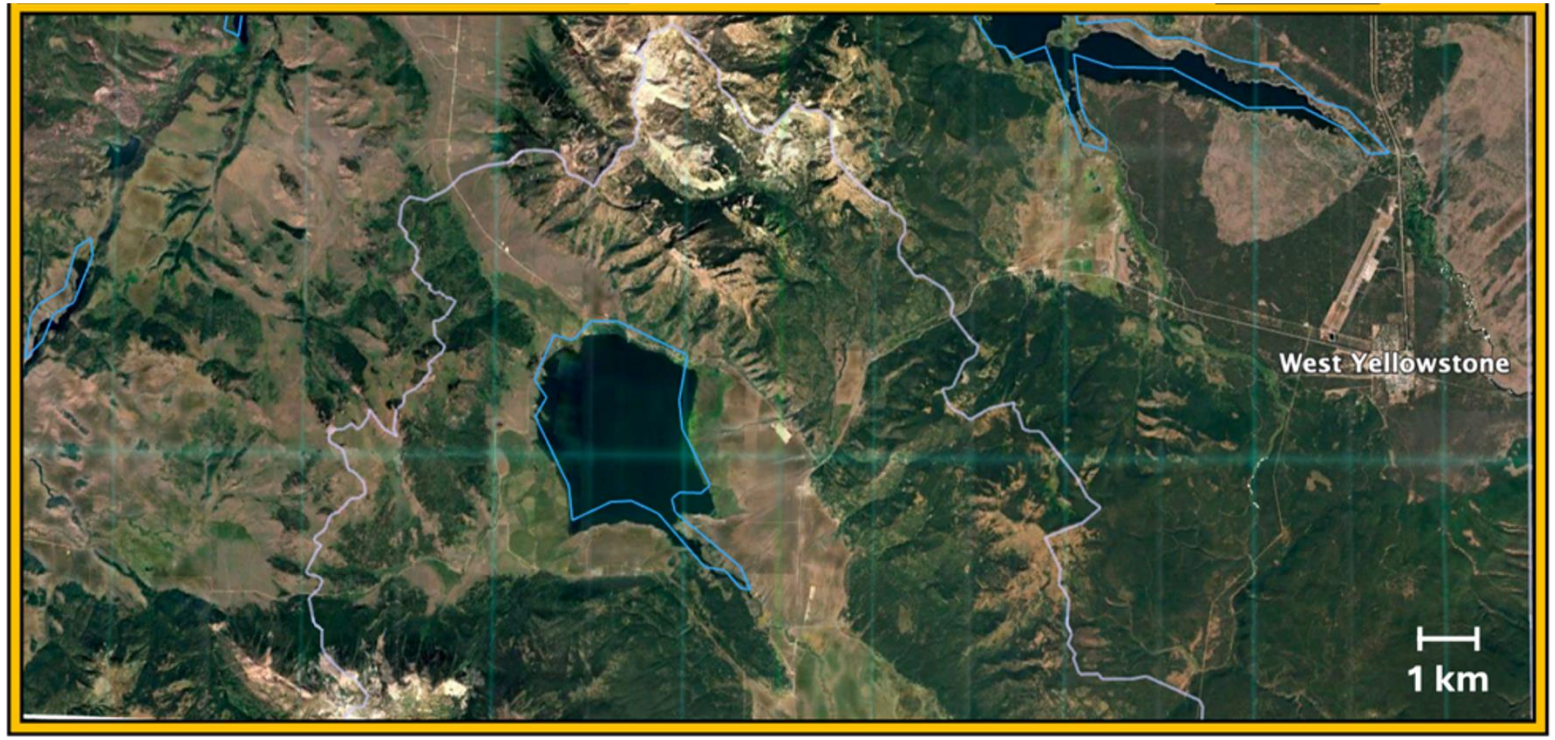


Image credit: USGS

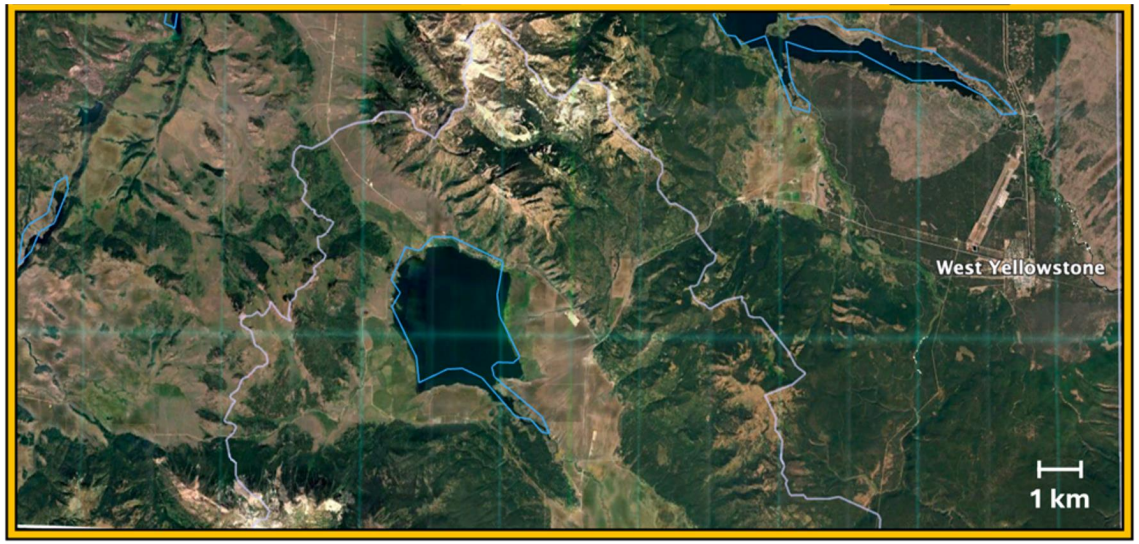
West Yellowstone, USA



Survey area: 100,000 hectares of the Custer-Gallatin National Forest

Image credit: ESA Sentinel-2

West Yellowstone, USA



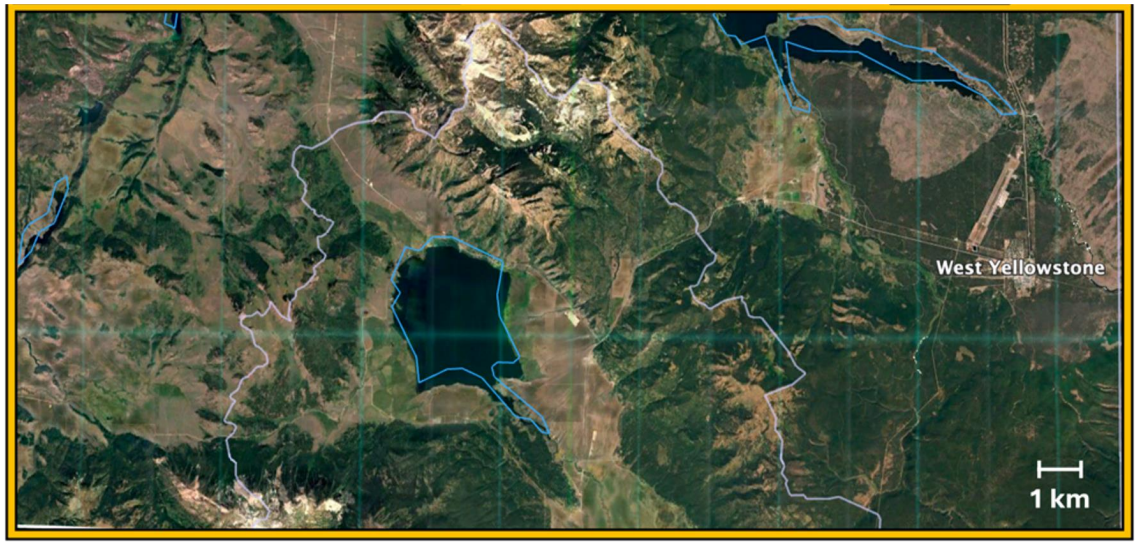
Survey area: Custer-Gallatin National Forest

Ecology:

- High-energy freestone waters
- Large rivers and small tributaries
- Riparian, forests, grassland
- Largest concentration of mammals in continental USA

Image credit: ESA Sentinel-2

West Yellowstone, USA



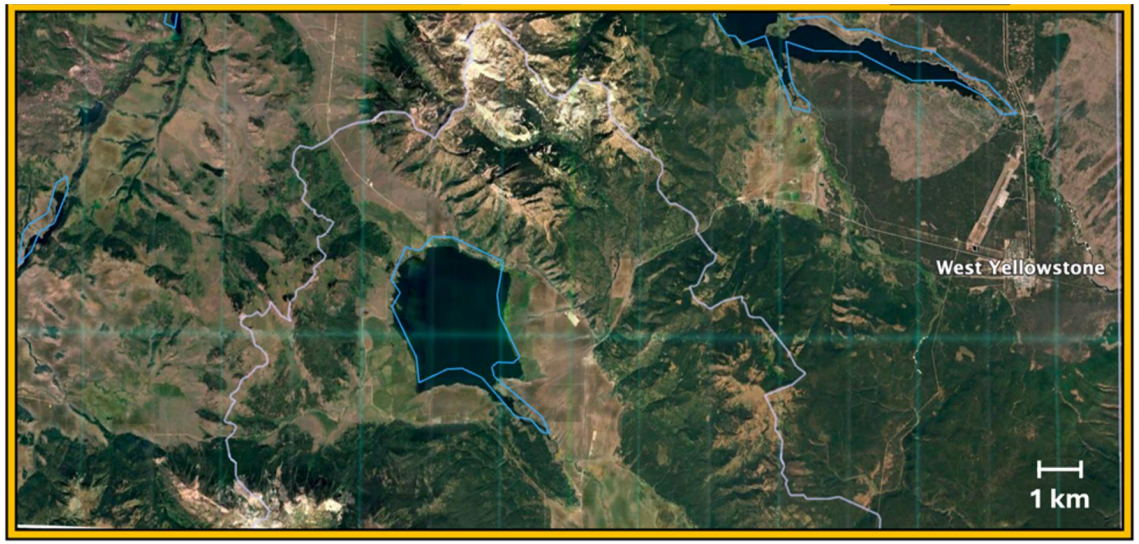
Survey area: Custer-Gallatin National Forest

Historic beaver presence:

- High density of beavers pre-fur trade
- Overtrapping led to near-extirpation
- Montana Fish and Wildlife restricted trapping from 1980's-present

Image credit: ESA Sentinel-2

West Yellowstone, USA



Survey area: Custer-Gallatin National Forest

Why is dam documentation useful here?

- Region is still in active recovery
- Offers insights into:
  - Patterns of recolonization
  - Beavers' site selection in low-competition environment

Image credit: ESA Sentinel-2

My research interest:

Quantify long-term patterns of beaver population spread.

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The question:

Can machine learning help to effectively assess yearly variation in beaver settlement at large scales?

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The test:

Capture 10 years of dam location data using a machine learning model.

Where machine learning (ML) comes in:

ML is a process of training a computer program to identify patterns through trial and error.

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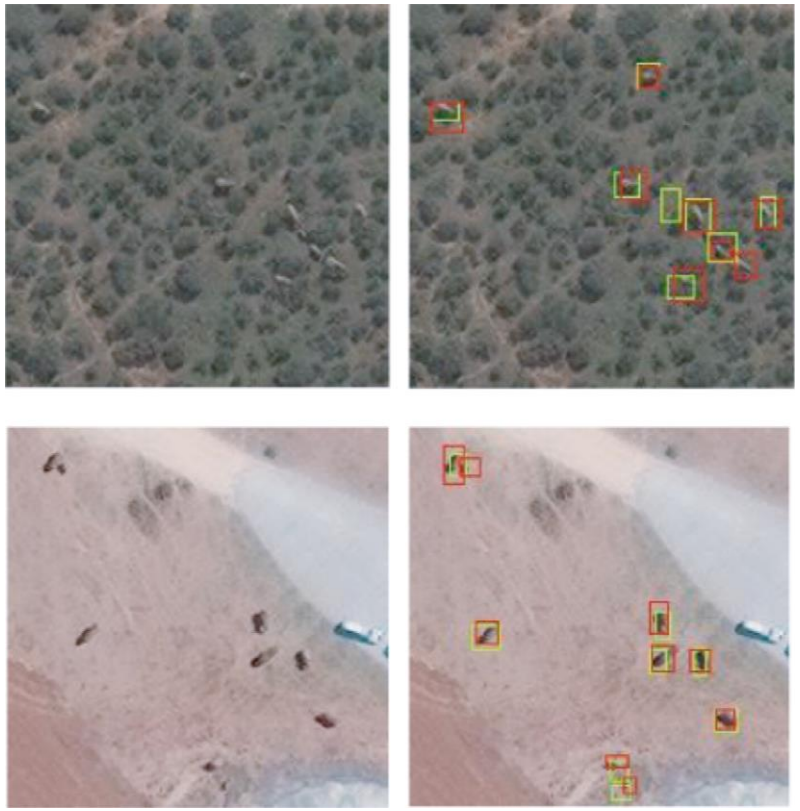
Examples:

Monitoring elephant movement



(Duporge et al., 2020)

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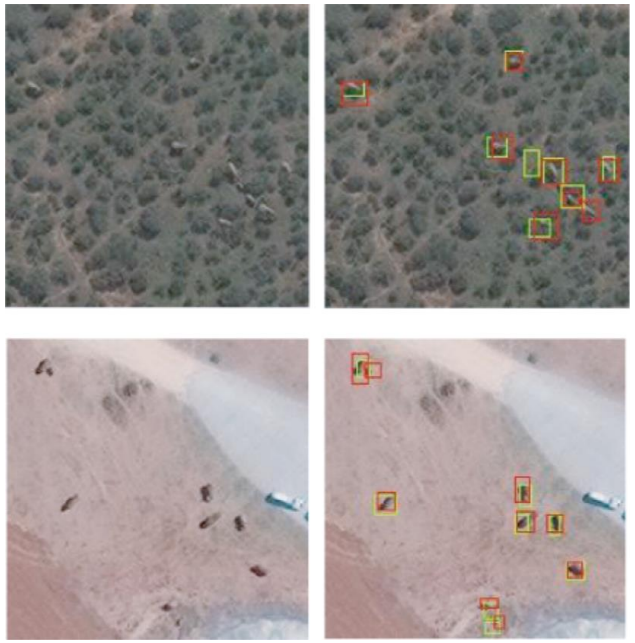
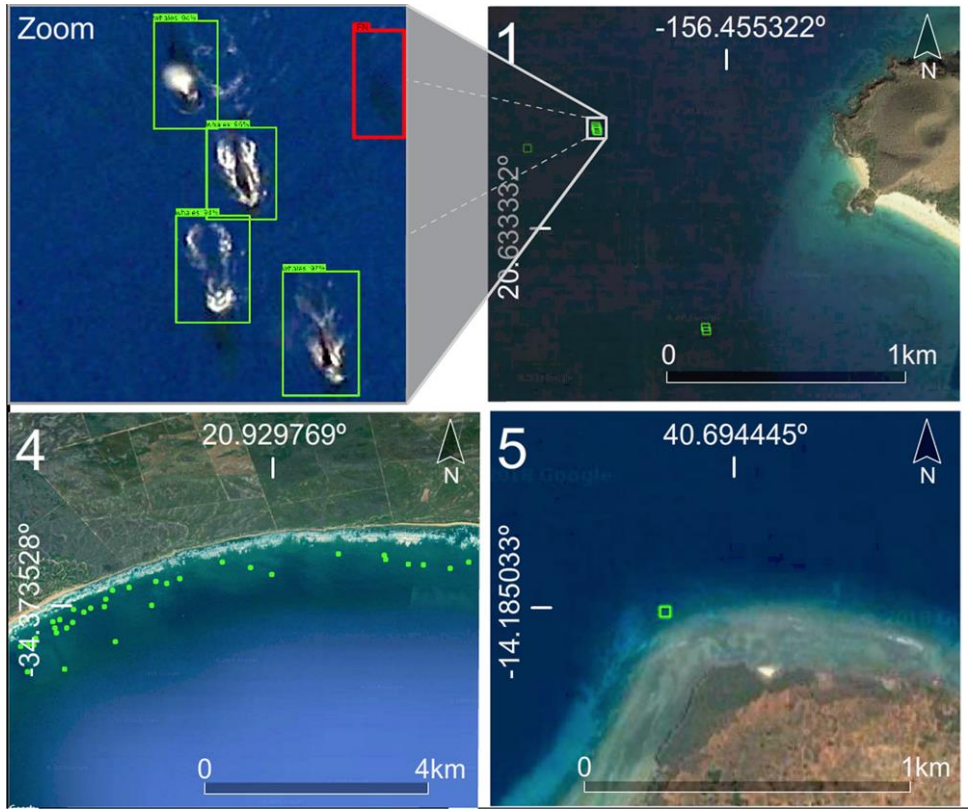


(Duporge et al., 2020)

Counting whales



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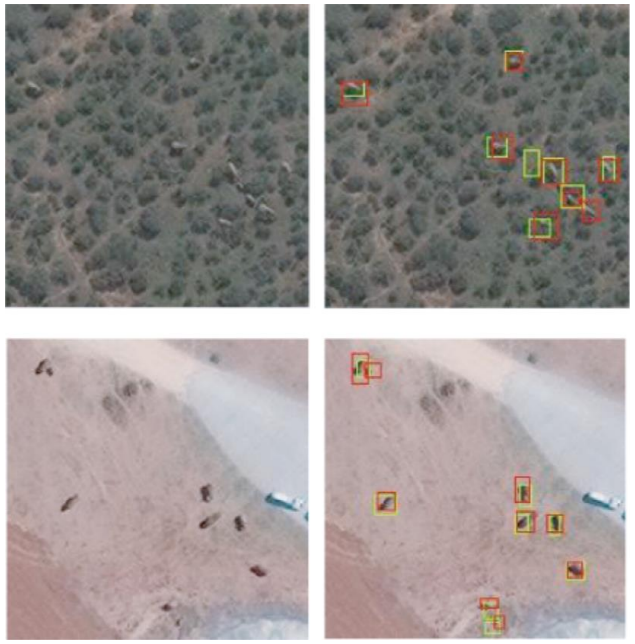
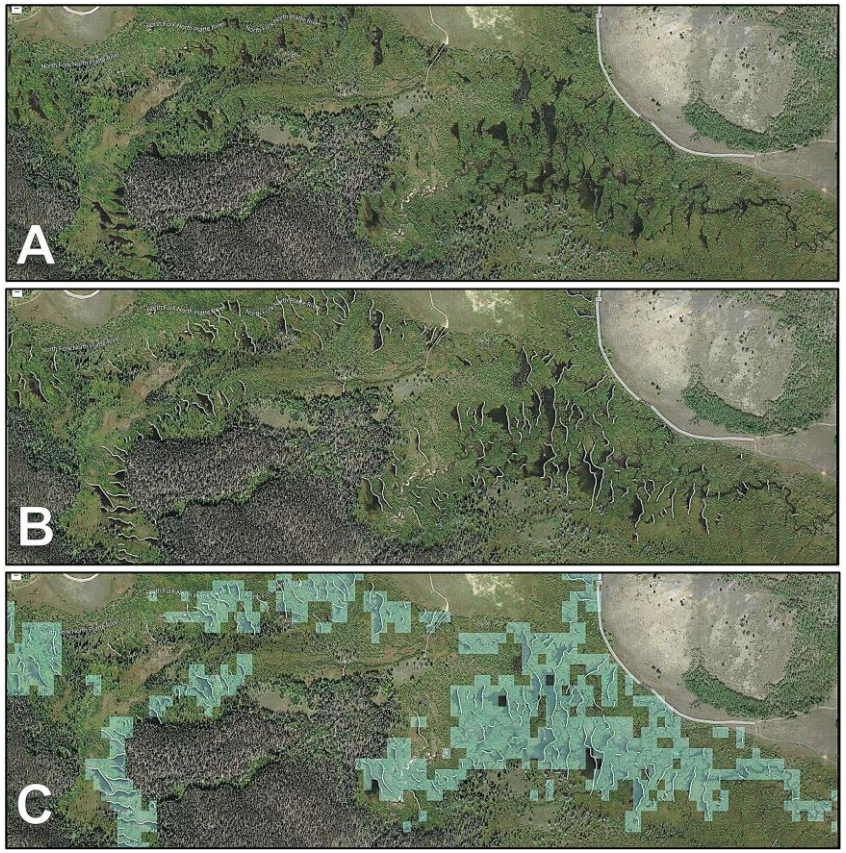


(Duporge et al., 2020)

Identifying beaver dams



(Fairfax et al., 2023)

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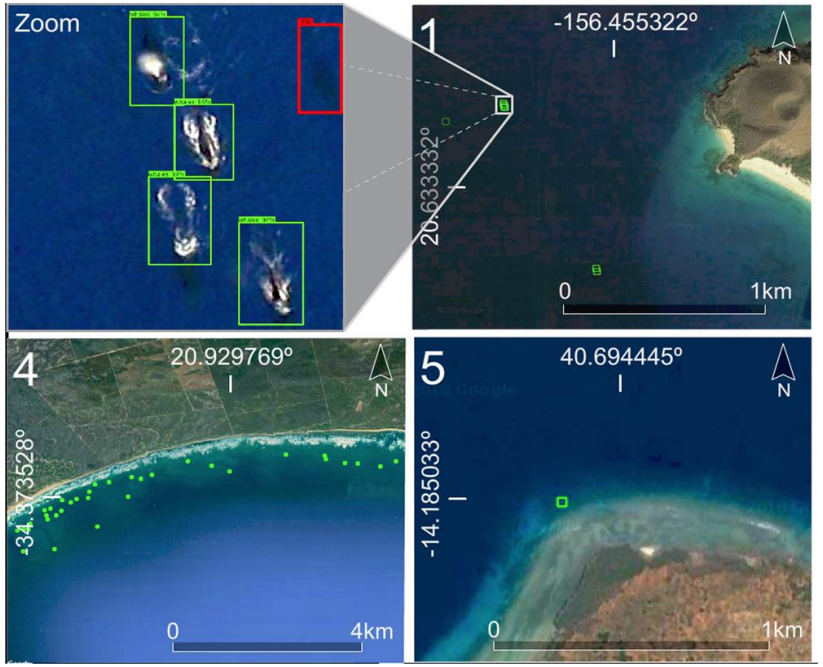

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Evaluating model performance:

Identify dams as effectively as a (trained) human looking at the same image

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Model performance threshold:

>70% accuracy

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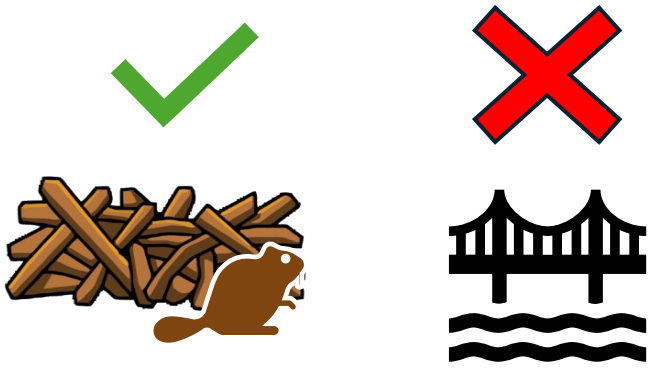
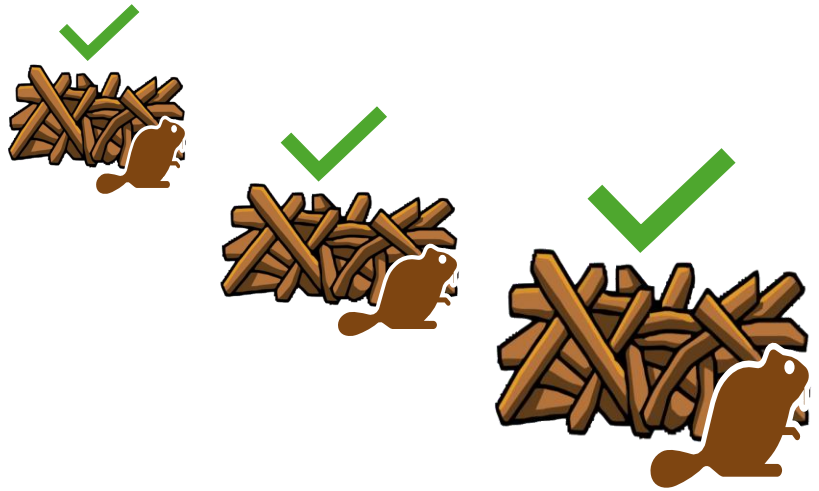
Precision



v.

Recall



Step 1: *Build a large training dataset of dams*

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98% accuracy for our high-confidence dam IDs

Step 2: *Use those data to teach the model what a beaver dam looks like*

Image credit: ESA Sentinel-2

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Beaver dam

Potentially misleading sandbar

Image credit: ESA Sentinel-2

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Image details:

- Compiled 30 images/year, after the runoff season
- Combination of ESA Sentinel-2 (10 m/px), Airbus SPOT (6 m/px), and Dove CubeSat (3.7 m/px) satellite images
- Used R,G,B, and infrared satellite imaging bands
- 168,500 hectares of ground

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Step 3: *Train and retrain model, until it can accurately identify dams on the landscape*

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Model performance:

76.38% accuracy 

Restating the question:

Can machine learning effectively assess yearly variation in beaver settlement?

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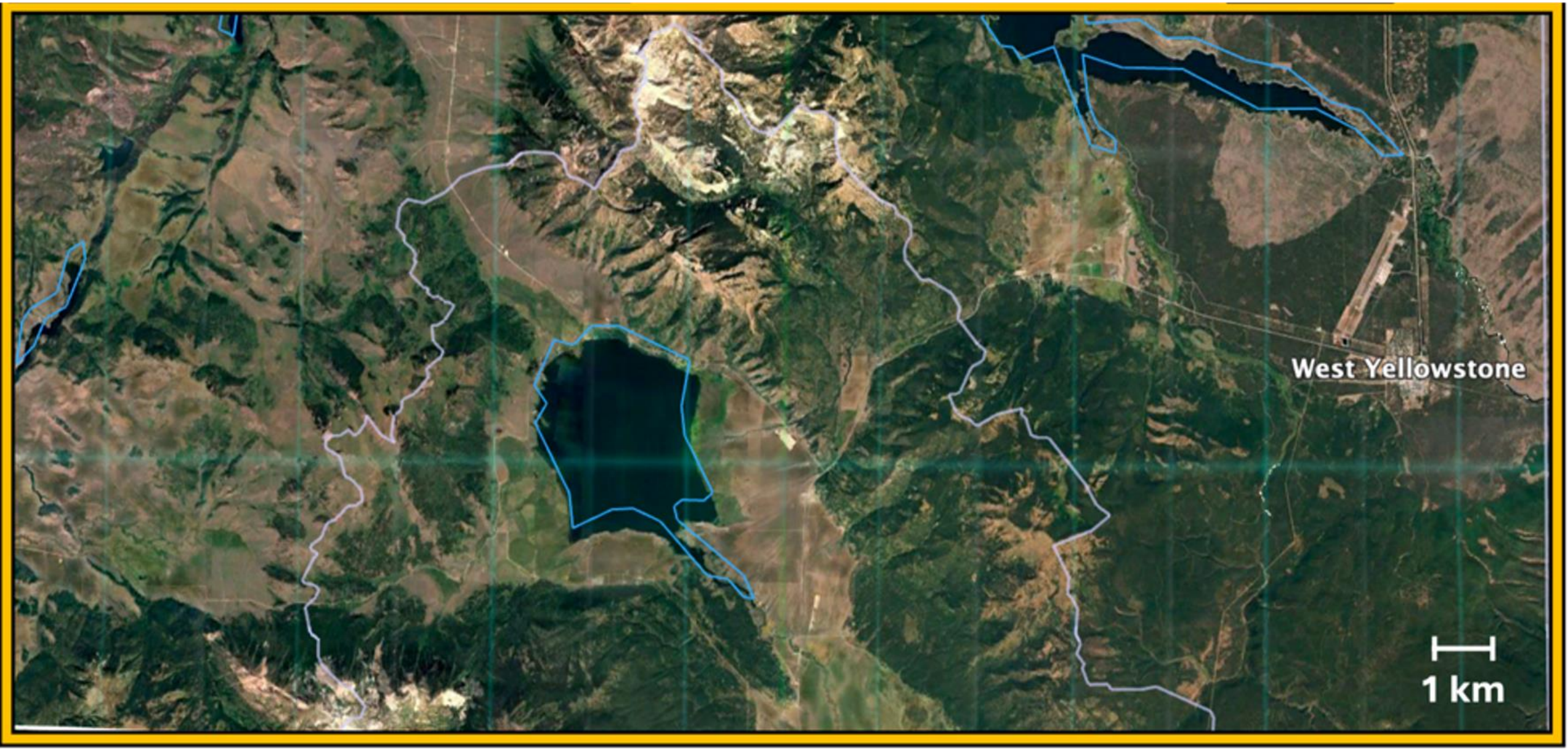
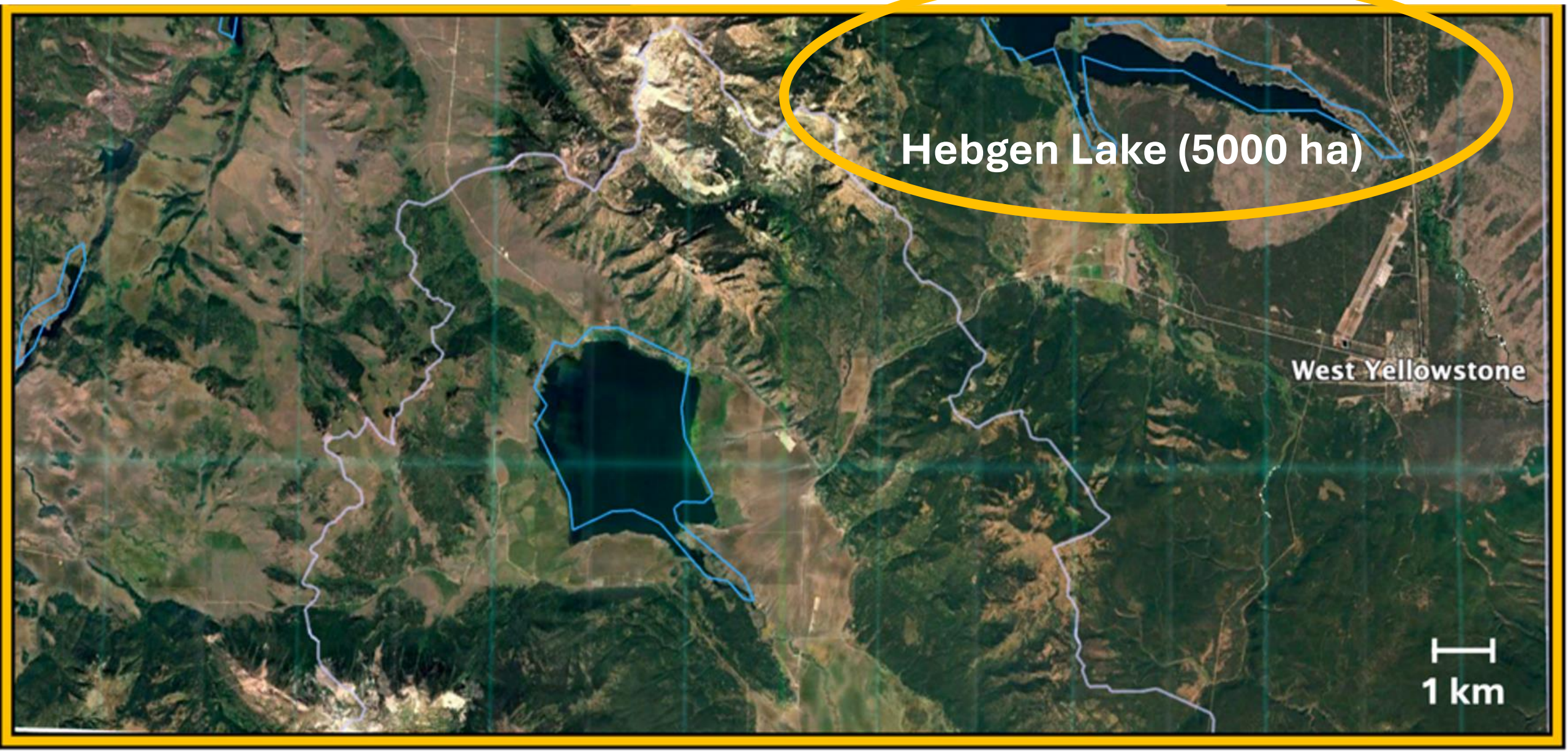
Yes



100,000 hectares/1,000 km^2



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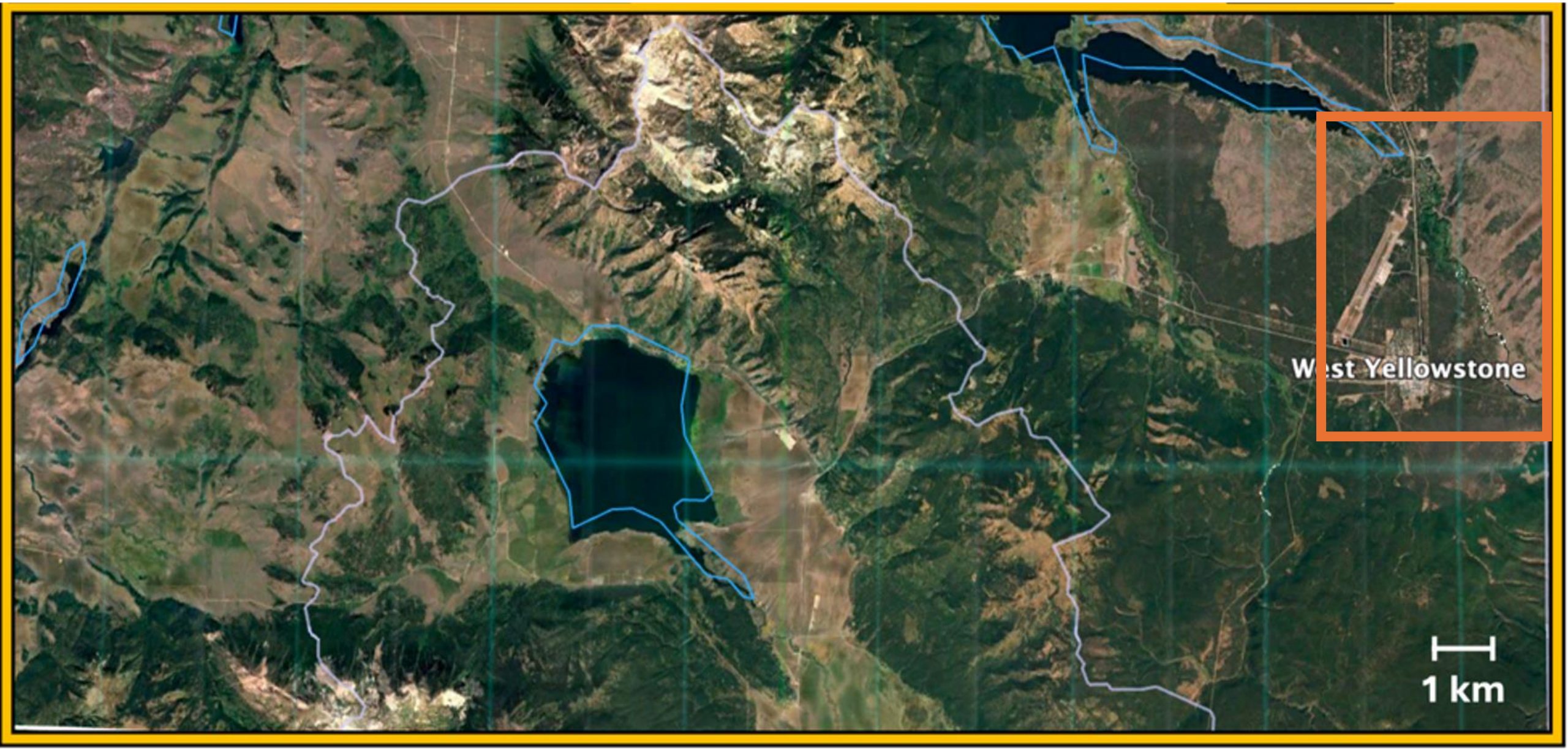
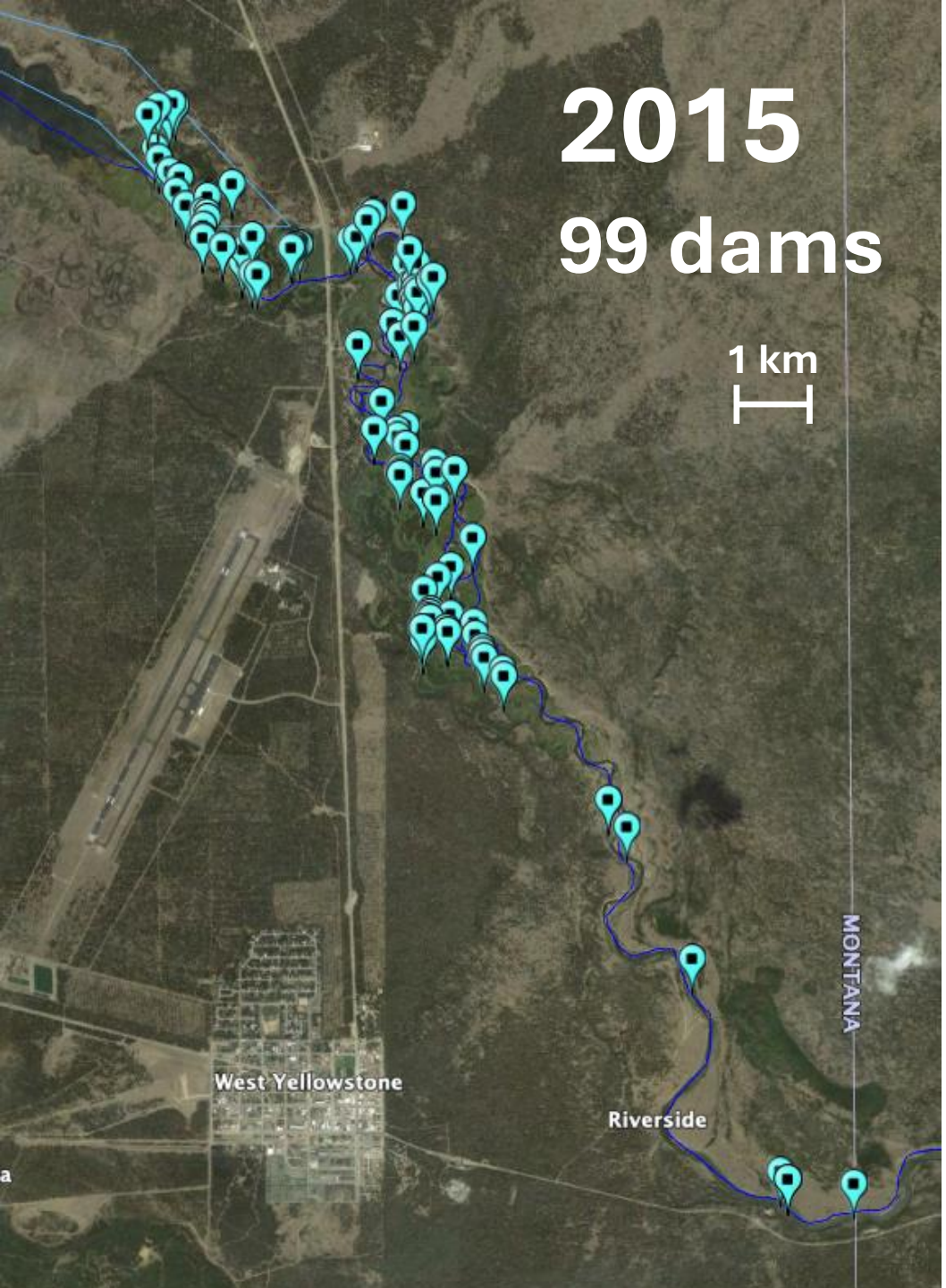


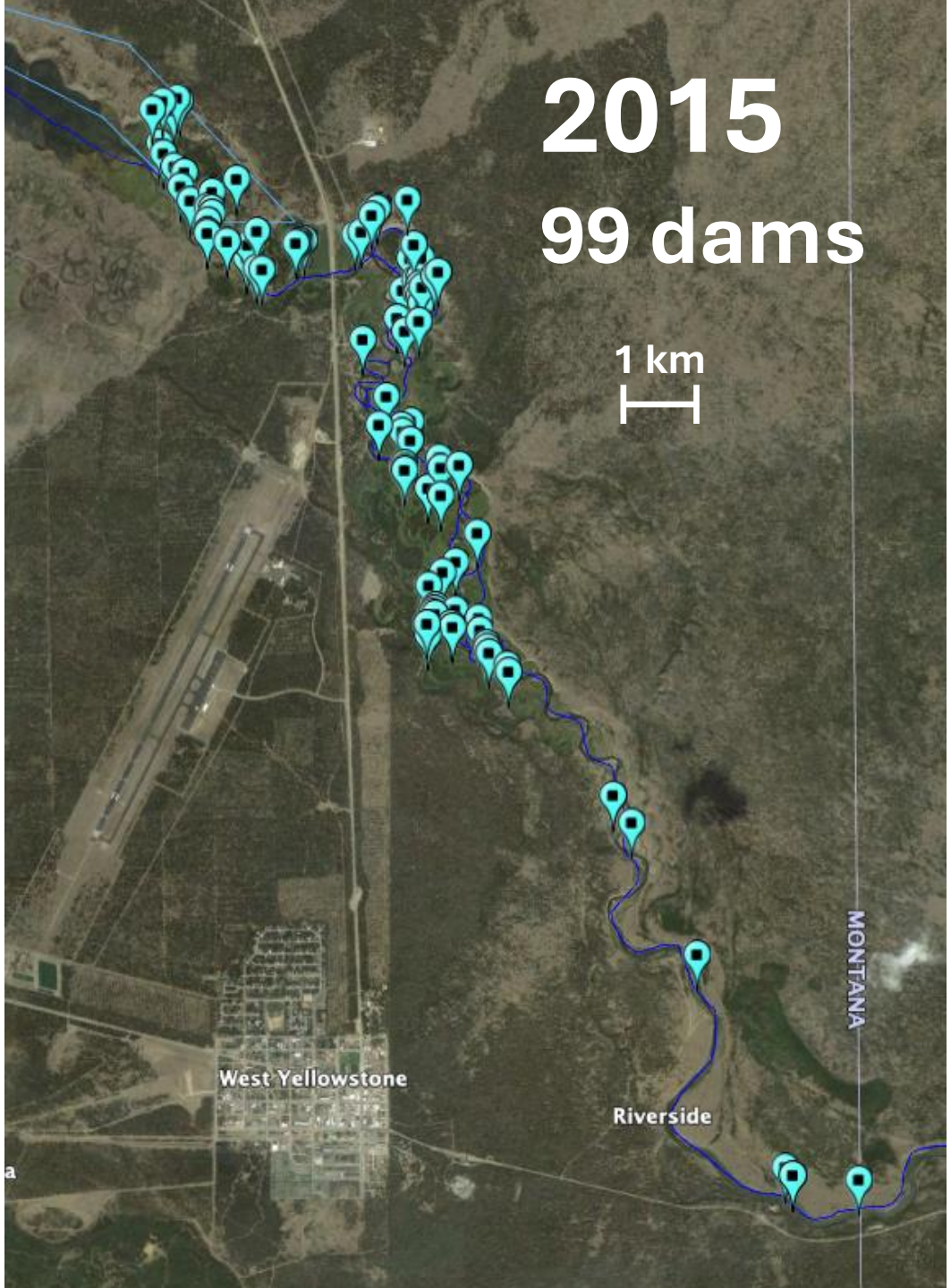
111 km^2

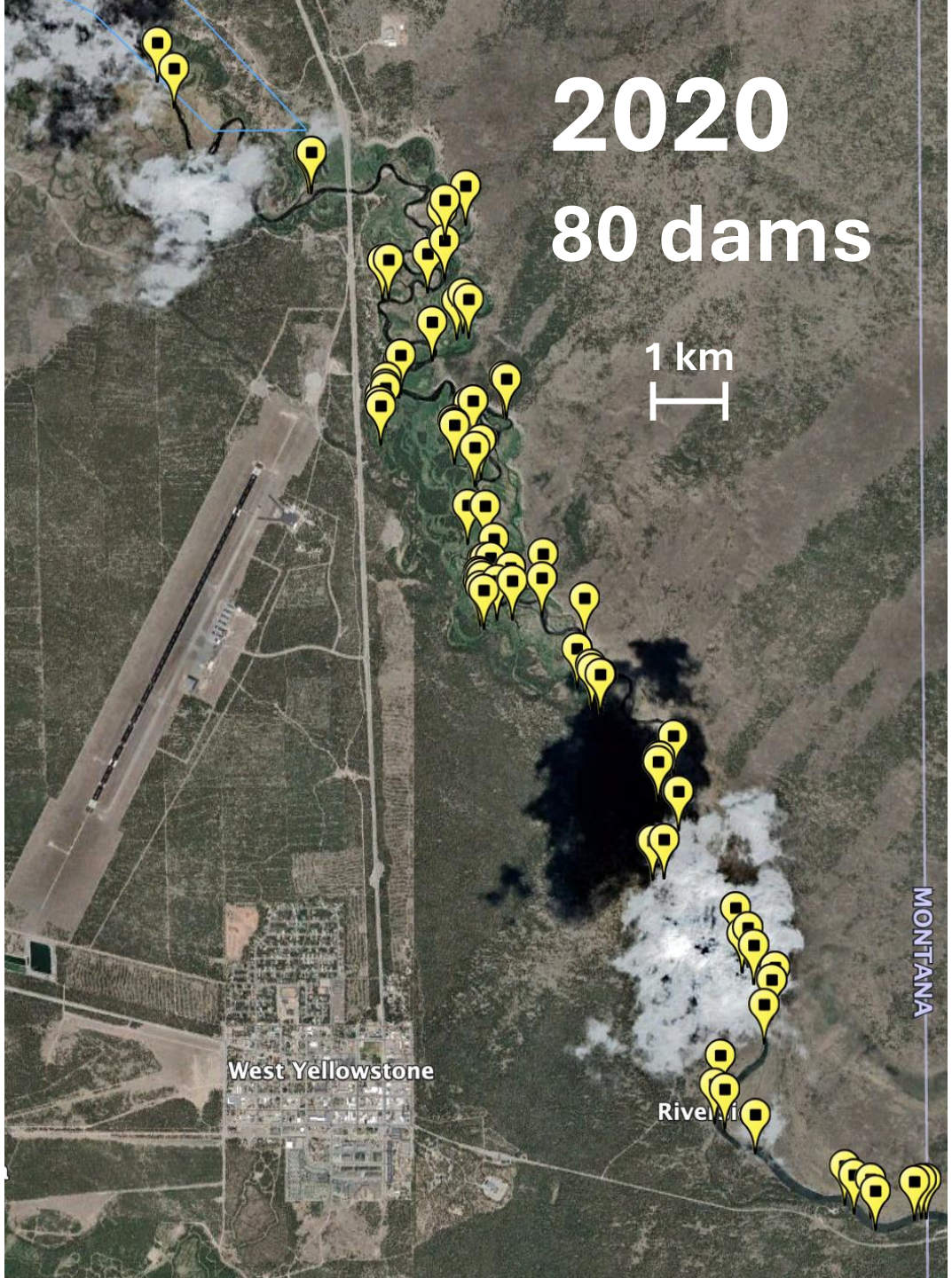


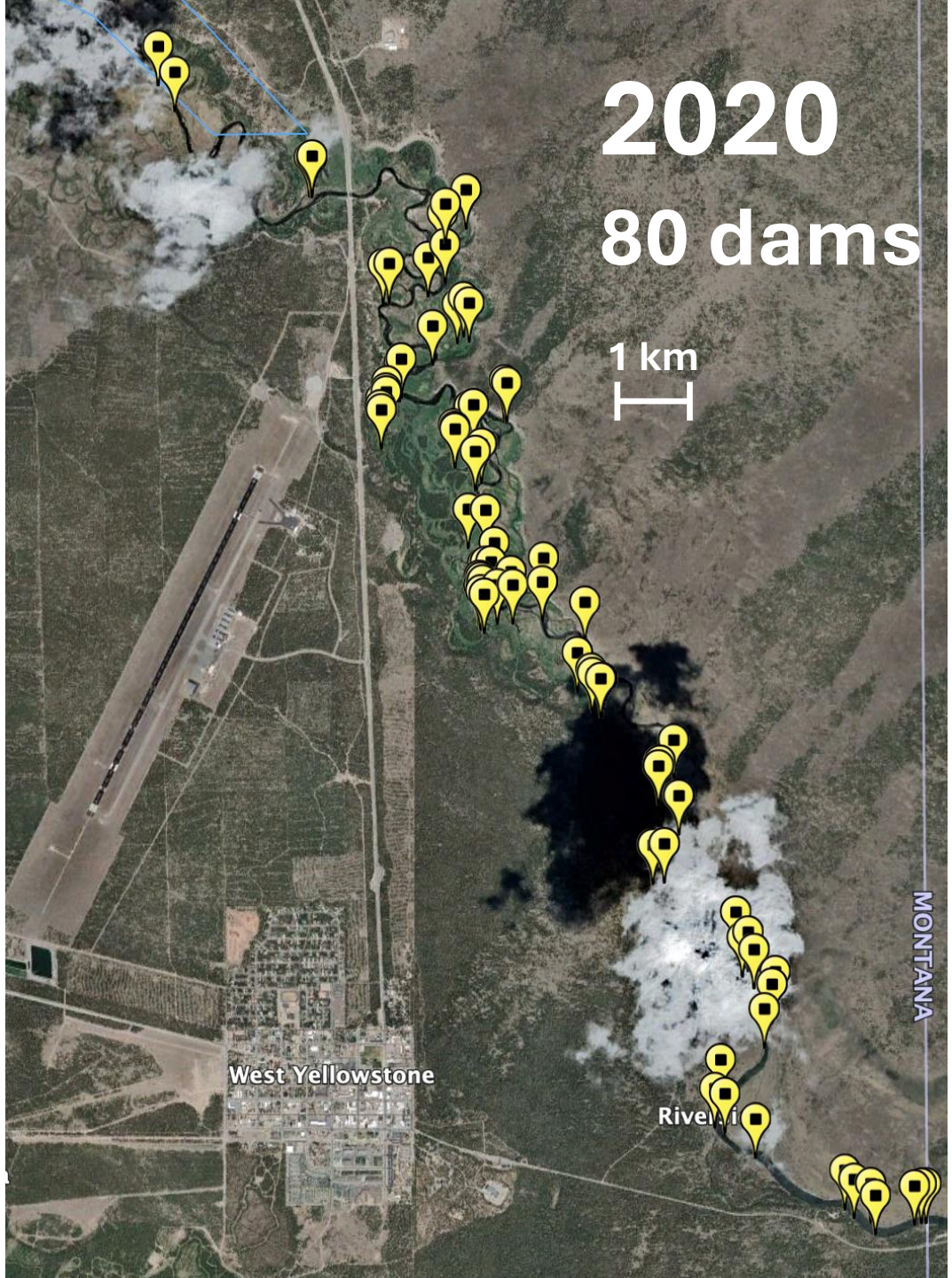
Some initial results: 2015

Seen here:

- East Madison River
- ~10% of full survey area


2015
99 dams
1 km
West Yellowstone
Riverside
MONTANA


2020
80 dams
1 km
West Yellowstone
MONTANA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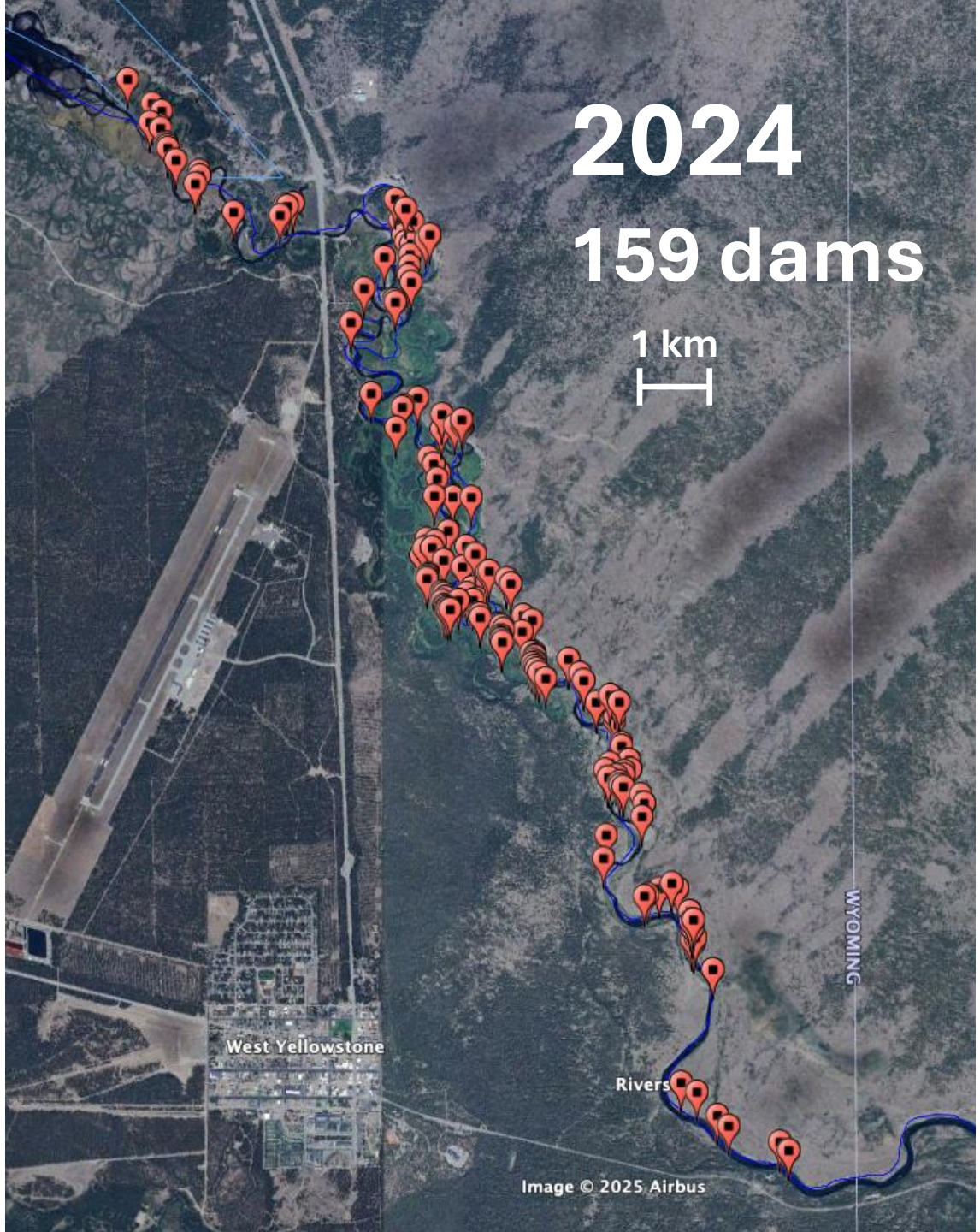
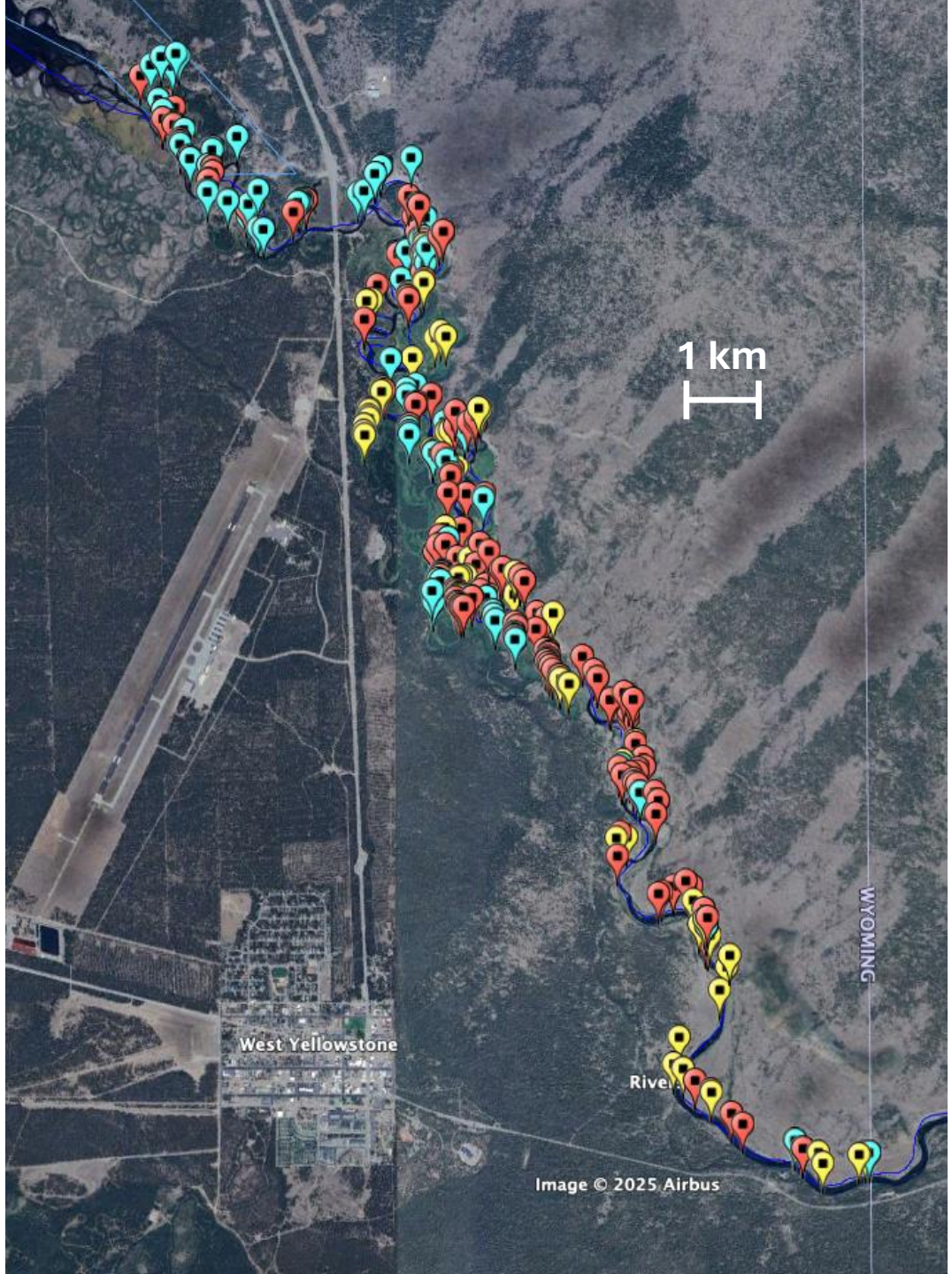
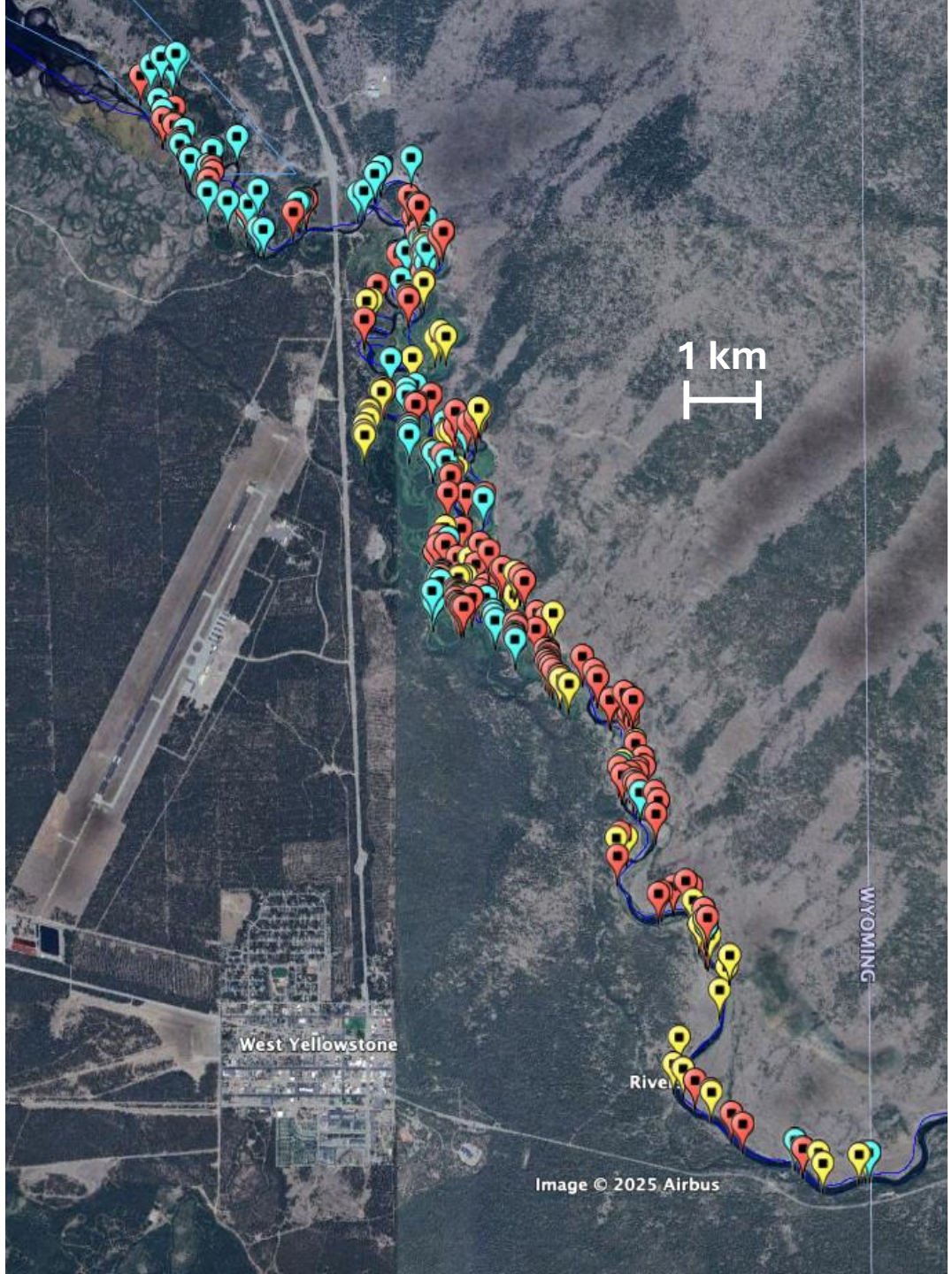

2024
159 dams
1 km
West Yellowstone
WYOMING
Image © 2025 Airbus



Of 4.7 km^2 of <u>waterway</u>:

- 2015 avg. density is 21 dams/ km^2
- 2020 avg. density is 17 dams/ km^2
- 2024 avg. density is 33.8 dams/ km^2



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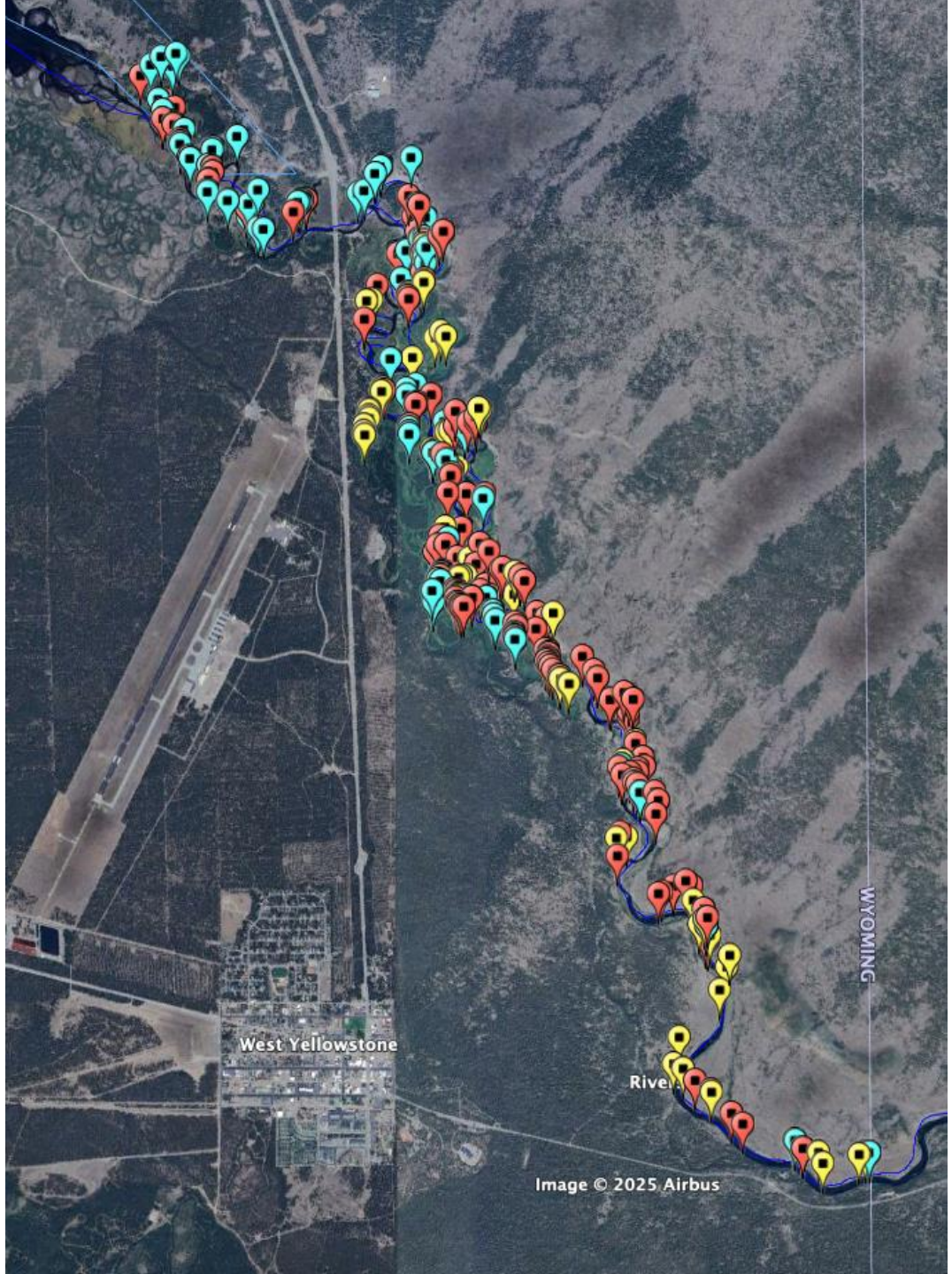
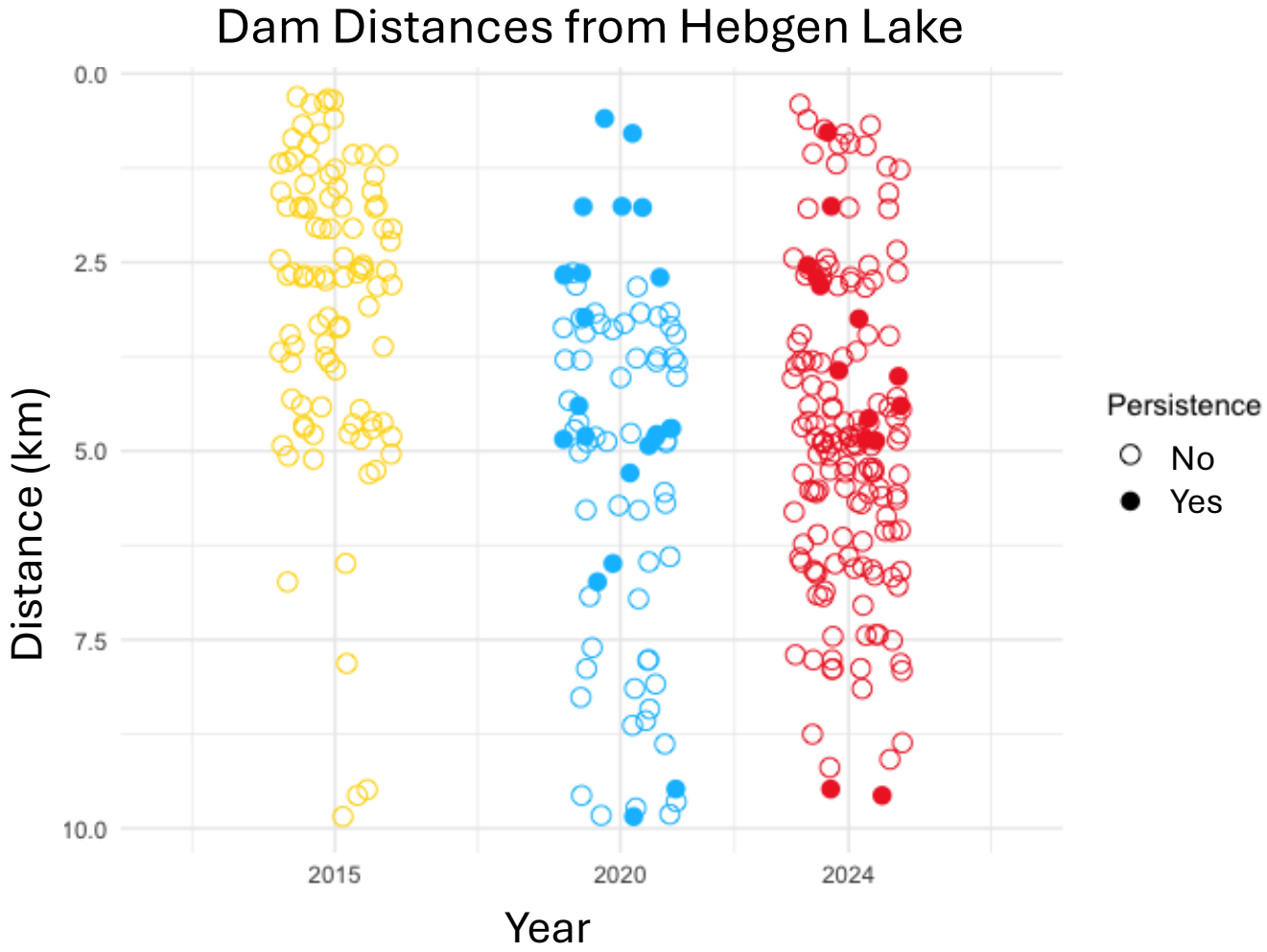
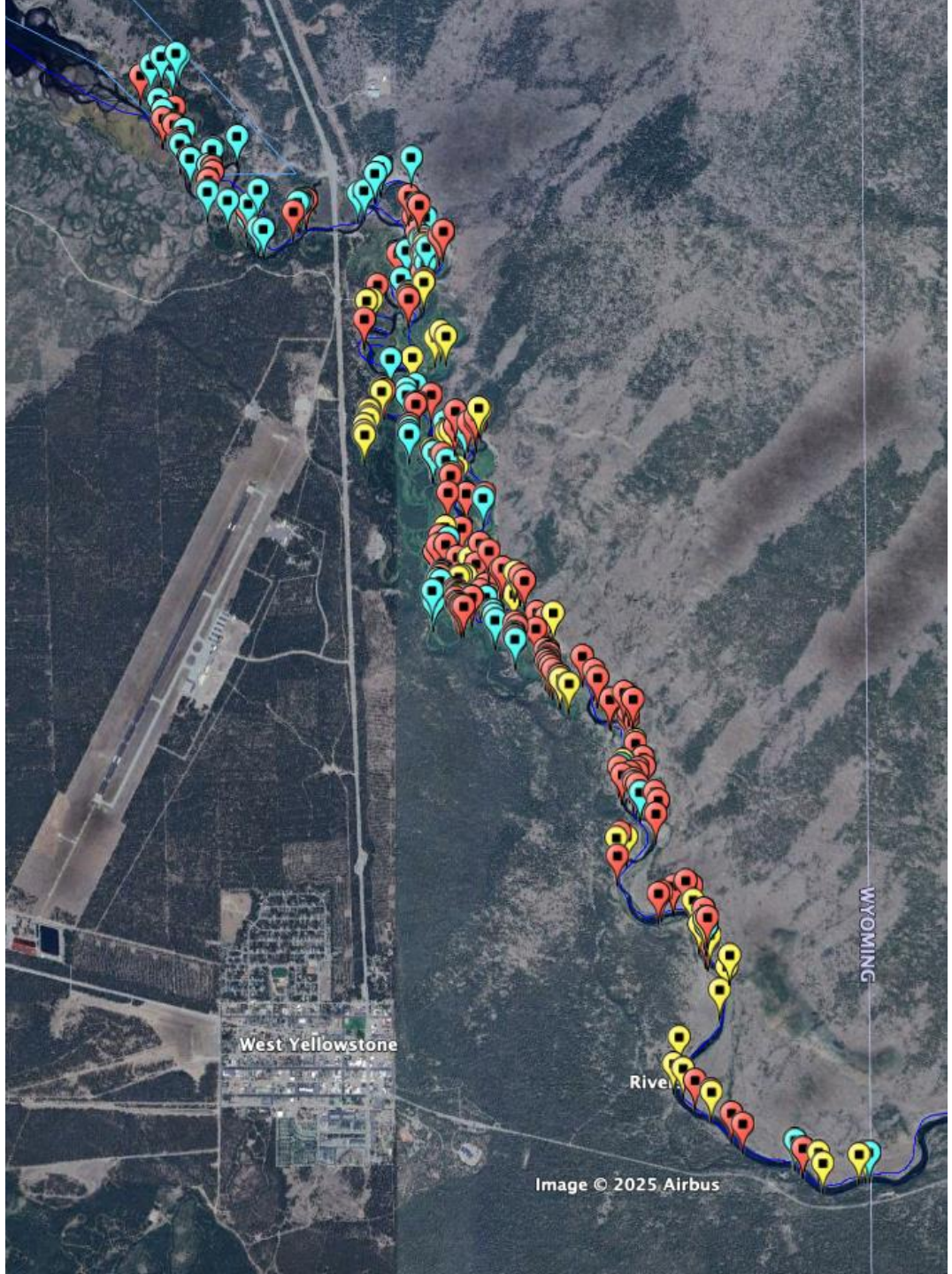
2015 colony density of Madison drainage estimated at 0.42/ km^2 (Ritter et al.)

- 46% of structures active


West Yellowstone
WYOMING
Image © 2025 Airbus


Dam Distances from Hebgen Lake
Distance (km)
0.0
2.5
5.0
7.5
10.0
2015
2020
2024
Year
Persistence
No
Yes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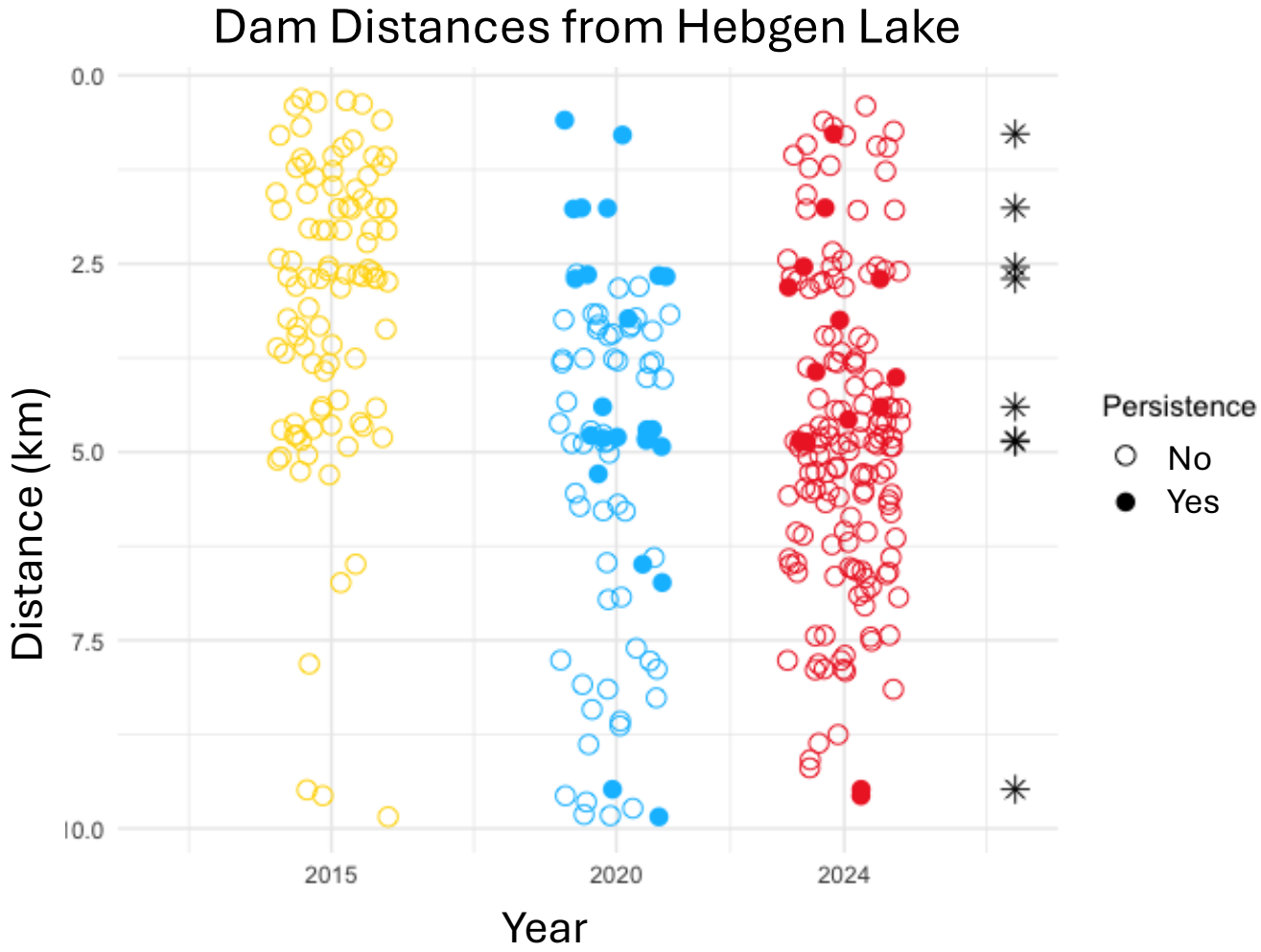
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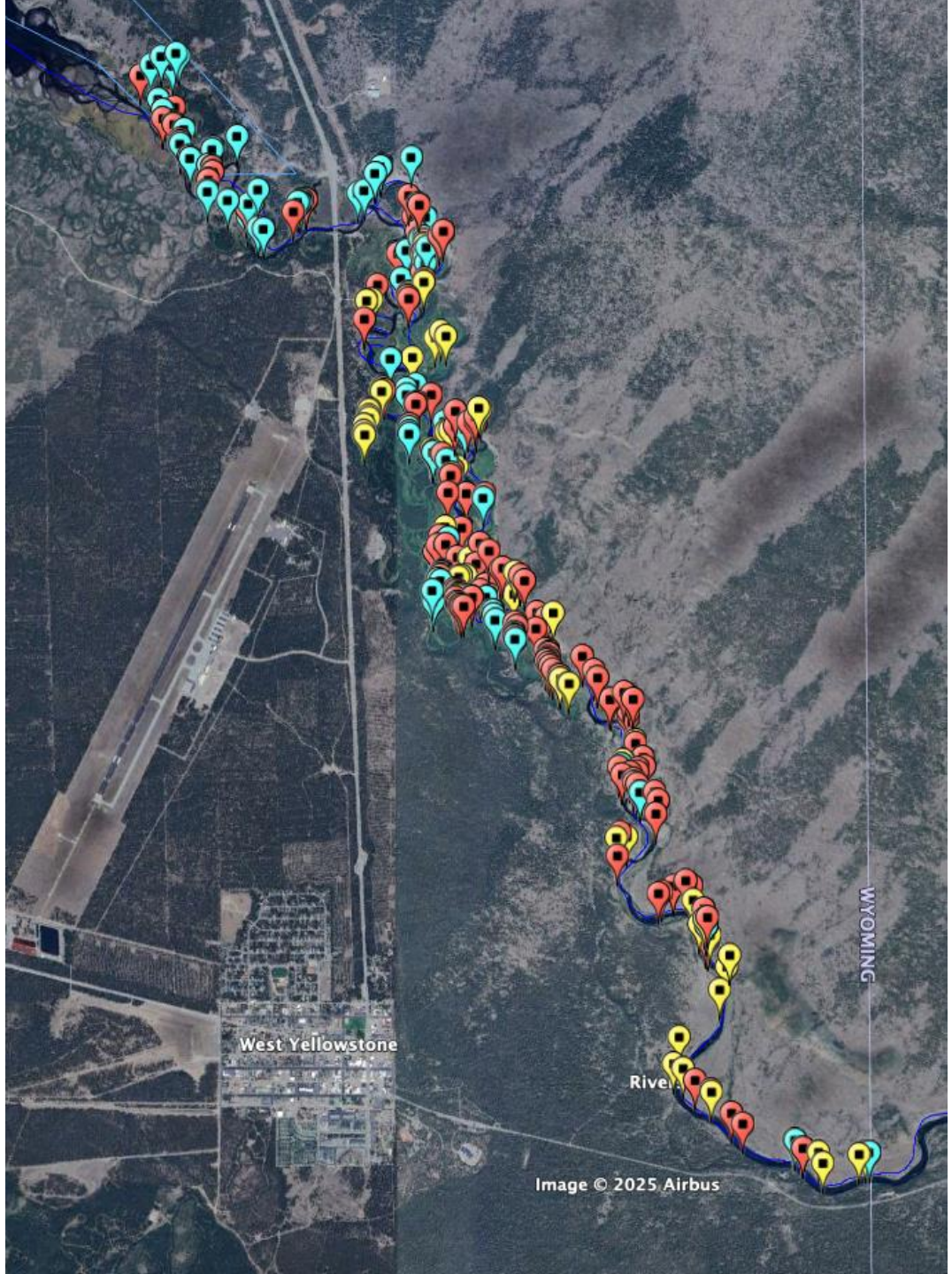
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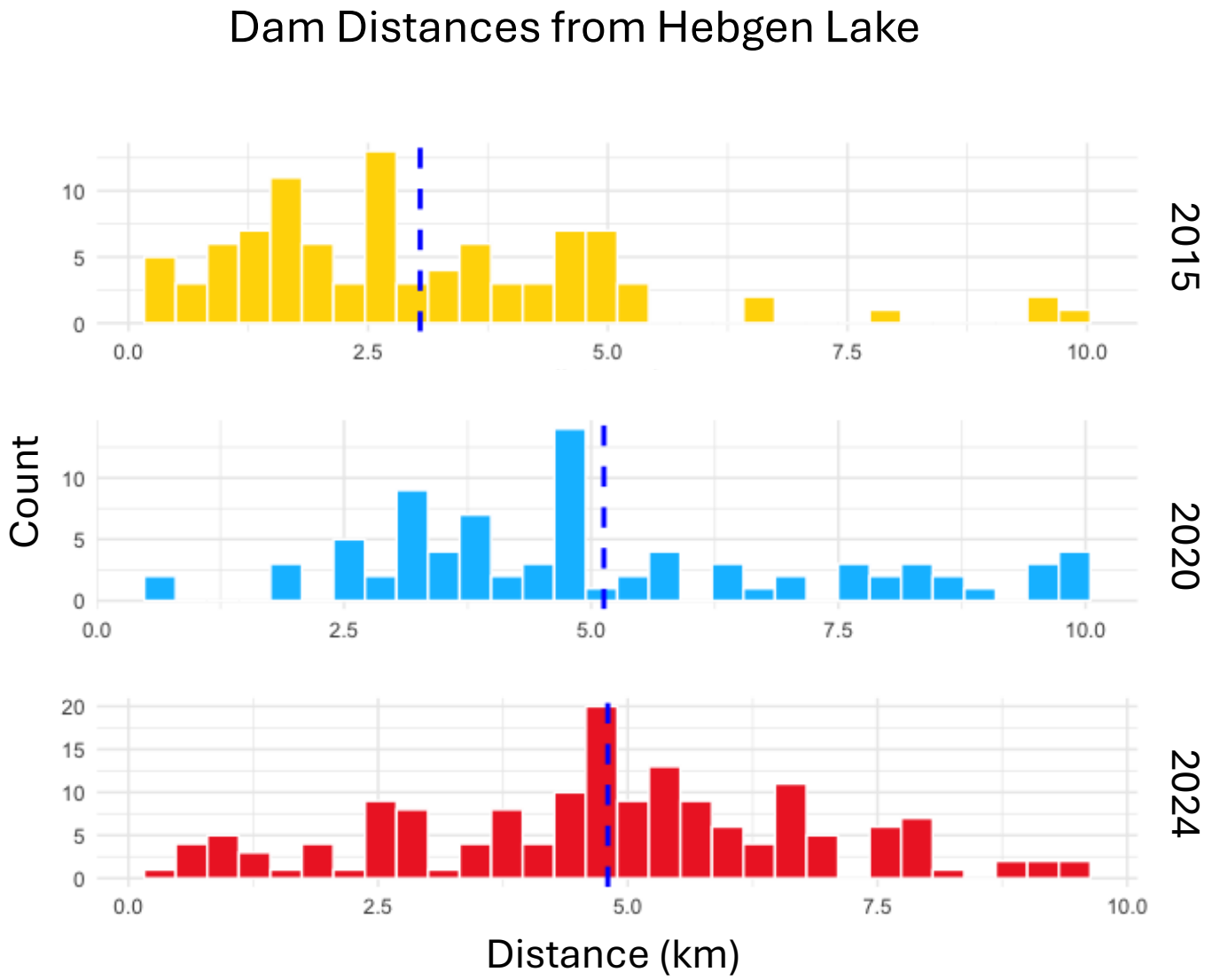
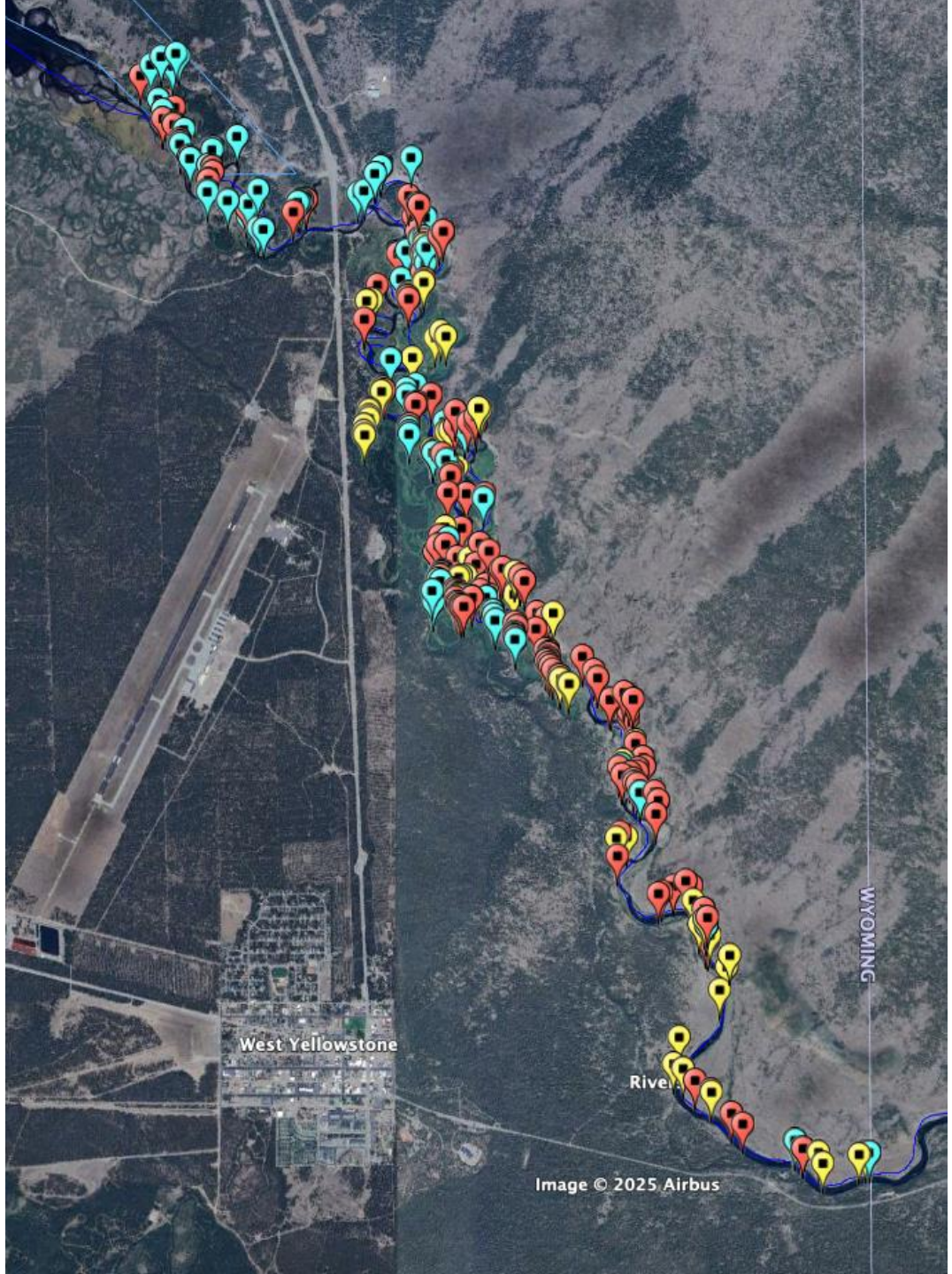
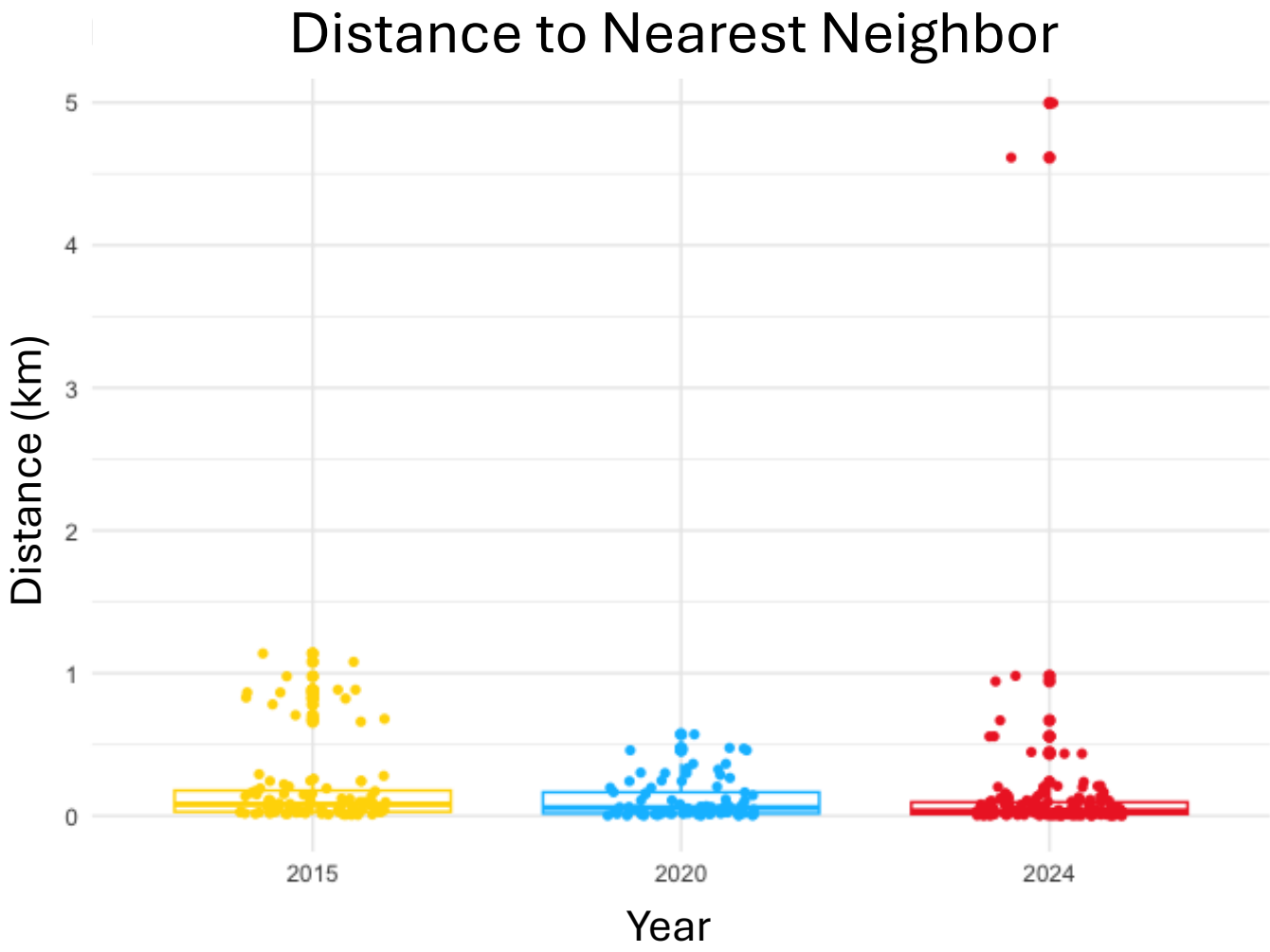
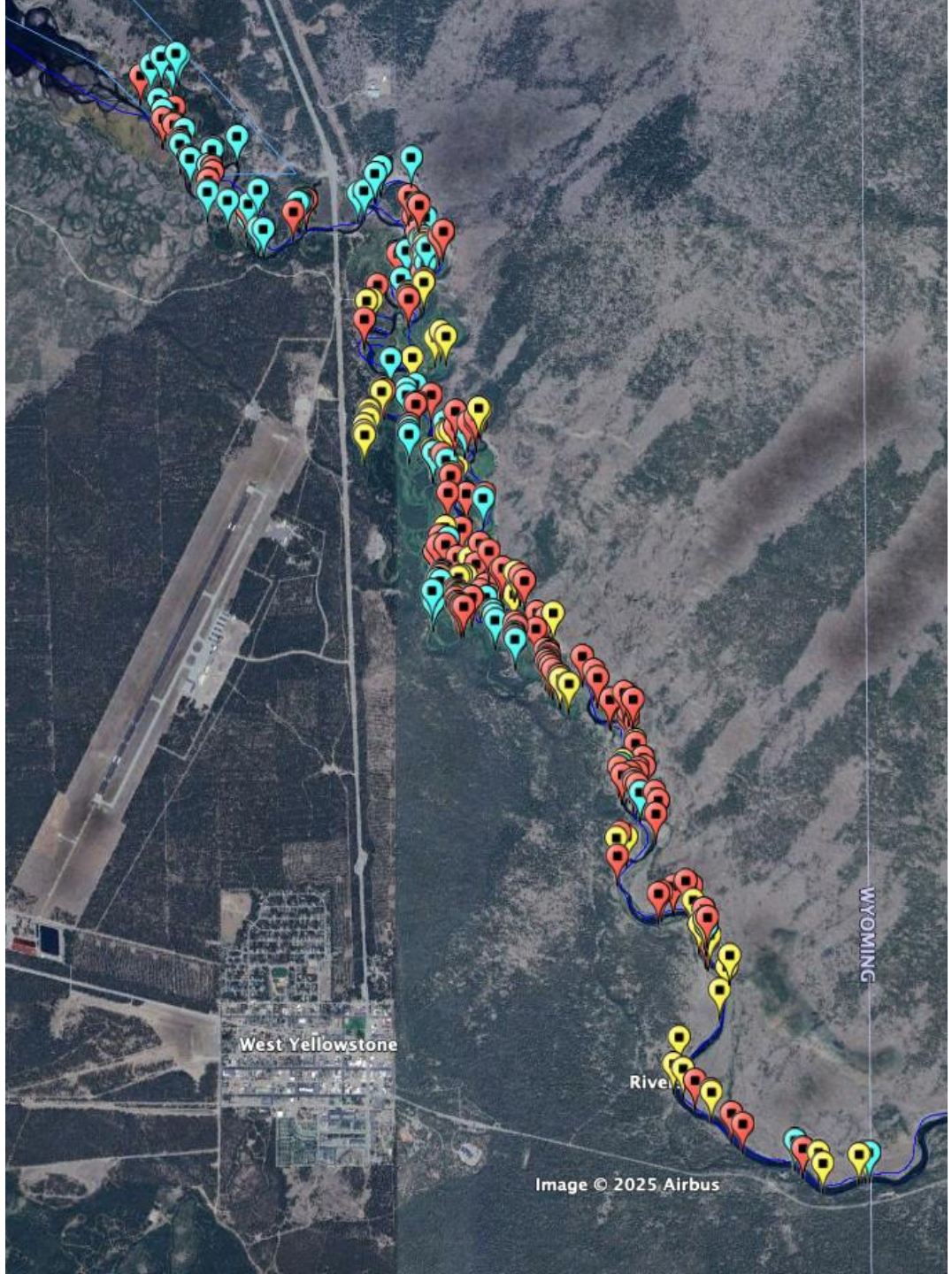

Dam Distances from Hebgen Lake
Count
Distance (km)
2015
2020
2024
0.0
2.5
5.0
7.5
10.0
0
5
10
15
20


West Yellowstone
Image © 2025 Airbus
WYOMING


Distance to Nearest Neighbor
Distance (km)
0
1
2
3
4
5
2015
2020
2024
Year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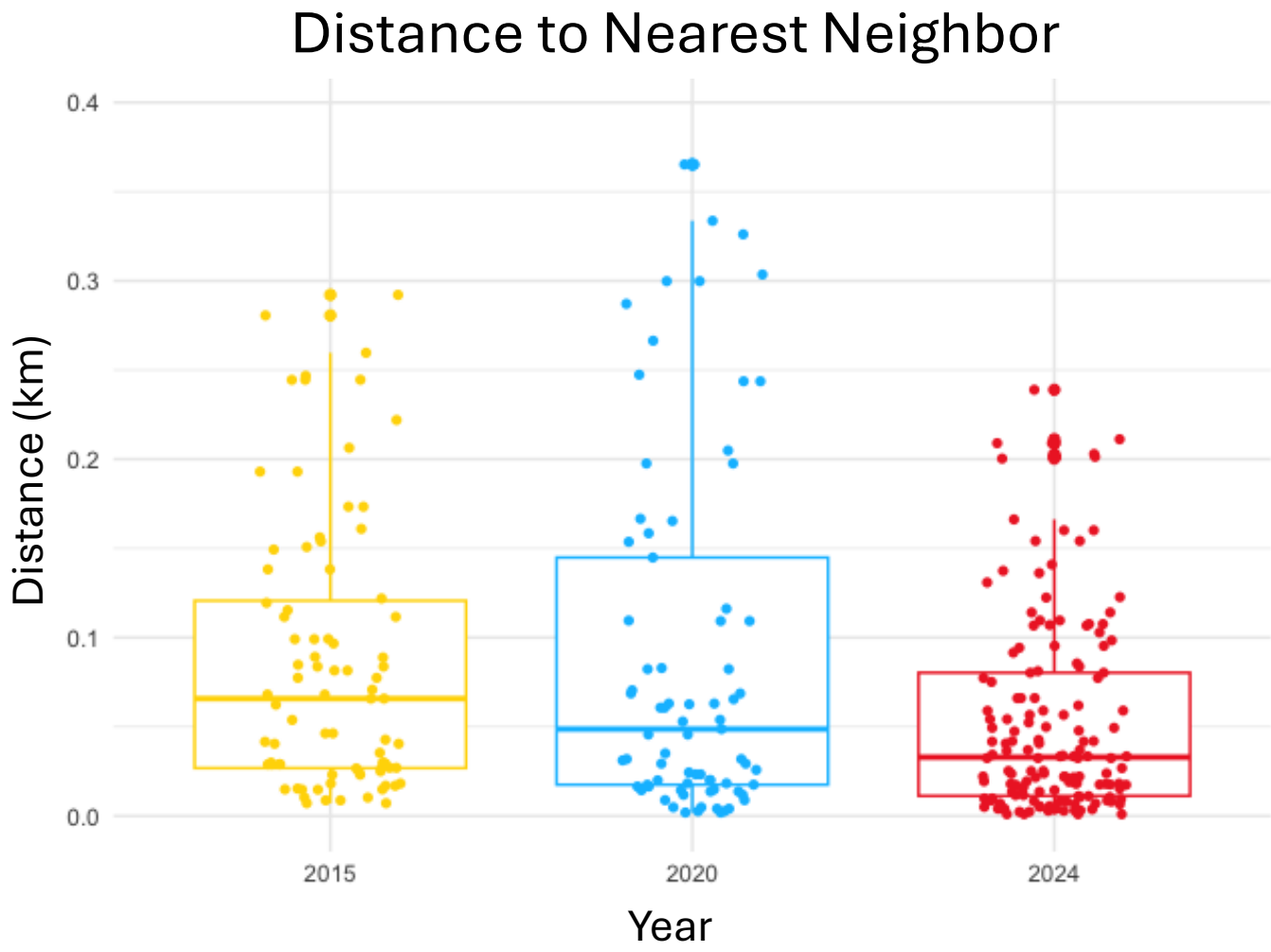
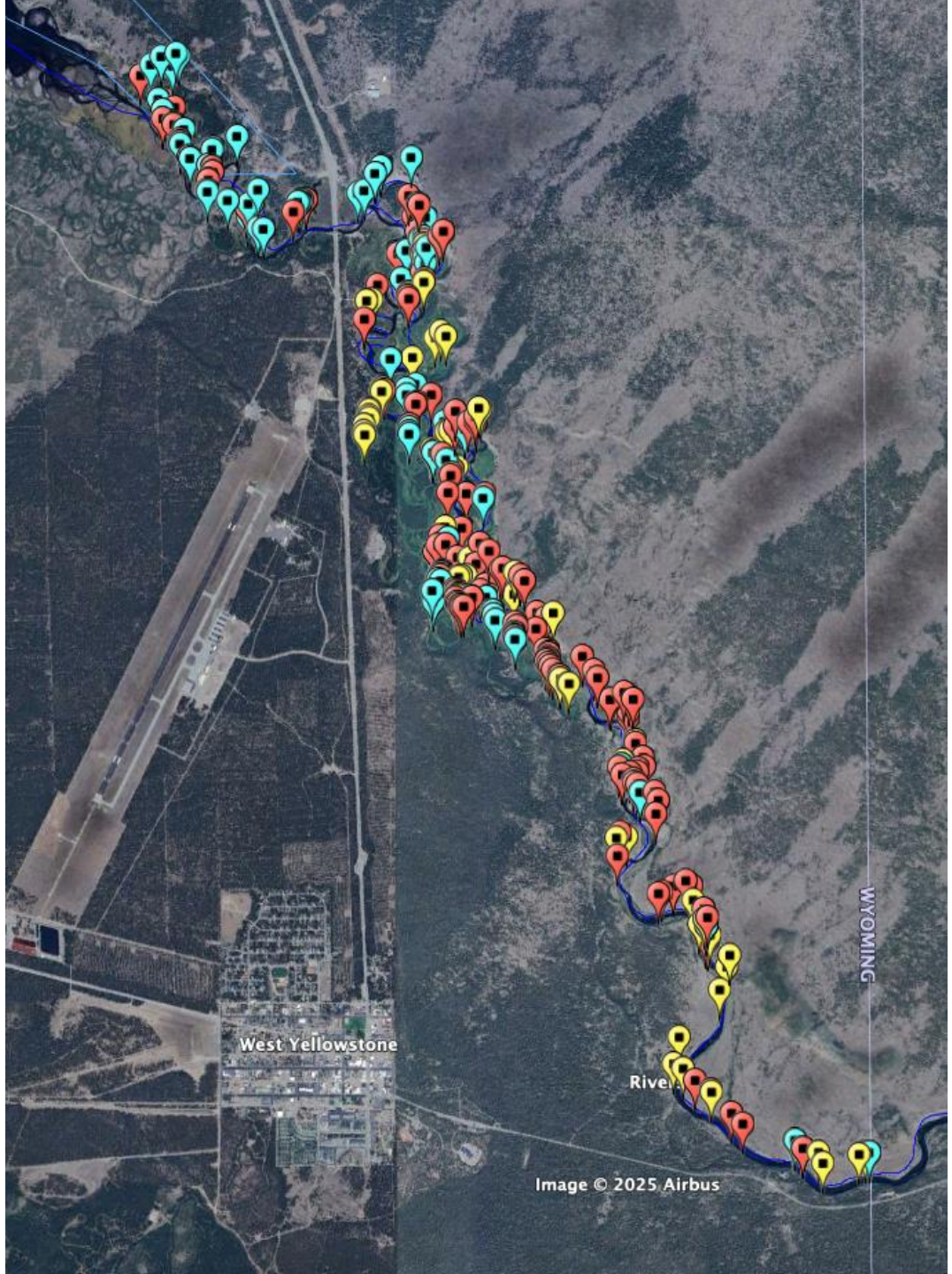

Distance to Nearest Neighbor
Distance (km)
0.4
0.3
0.2
0.1
0.0
2015
2020
2024
Year



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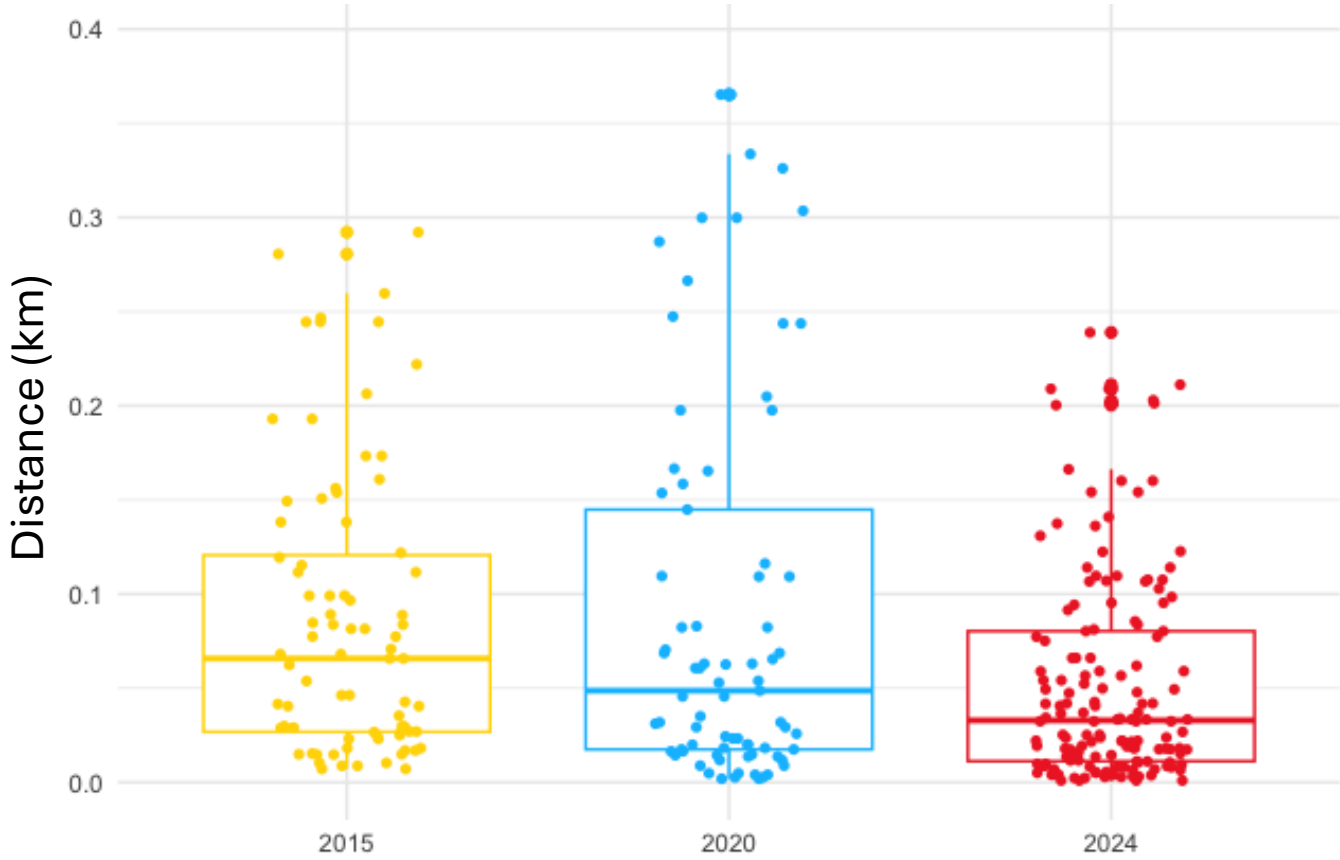

99 dams

80 dams

159 dams

p = 9.43 e-6

Next steps:

- Fill in years from 2015-present
- Measure rate/patterns of spread year over year
- Compare habitat suitability vs. observed occupancy

Future work:

- Long-term survey of BDA presence and nearby beaver settlement

Thanks

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Lab
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Remy Deplanche

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