Building like beavers

Stigmeric robotics for landscape design

10th International Beaver Symposium
Wednesday 17th, 2025

HARVARD UNIVERSITY GRADUATE SCHOOL OF DESIGN

The Beaver INSTITUTE™

OKI

Jordan Kennedy (Blackfeet Nation)

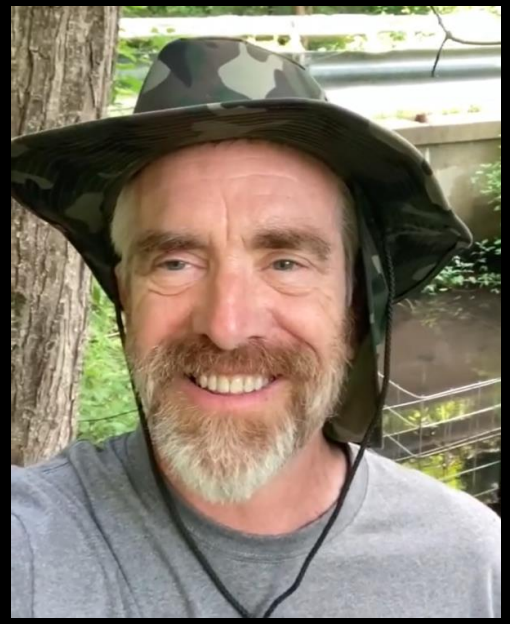
INDIGENOUS FUTURISMS

1. Post-doctoral Research Fellow – Harvard University Graduate School of Design, Landscape Architecture
    1. Mechanical engineer
    2. Beaver behavior
    3. Multi-agent robotic systems
    4. Landscape Design
    5. Technologist
2. Tribal Partnerships Liaison and Beaver Behaviorist – Beaver Institute
    1. Descendant of the Blackfeet Tribe
    2. Kin-empathy frameworks (research and relationship building)
    3. Beaver Futurism
3. Co-PI on NSF RCN:
    1. Emily Fairfax, Jonah Piovia-Scott, Sandra Clinton
    2. Integrating Traditional Ecological Knowledge from Tribal Narratives through cultural media and storytelling
    3. The Great Plains

BEAVER INSTITUTE

Adam Burnett

Executive Director
Beaver Institute



Mike Callahan

Founder Board President
Beaver Institute

Loren Taylor

Policy and Science Director
Beaver Institute

Aaron Hall

BeaverCorps Program Director
Beaver Institute

BEAVER BOT TEAM

Karen Lee Bar-Sinai

Assistant Professor of Landscape Architecture
Harvard University Graduate School of Design
Landscape Robotics

Amir Degani

Faculty of Civil and Environmental Engineering
Technion – Israel Institute of Technology
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Federico Olivia

Postdoctoral Researcher
Multi-agent robotic systems
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William Boles

Theatre and Nature
Master of Landscape Architecture at Harvard University Graduate School of Design

BEAVER BOT TEAM

Justin Werfel

Senior Research Fellow
Harvard University

Nathan Melenbrick

Fabrication Lab Supervisor/Lecturer
Harvard University

Tolu Ademola

Mechanical Engineering Concentrator
Excavation Robotics
Harvard College

Ben Witzel

Computer Science Concentrator
Convolution Neural Network – Training AI on Beaver habitat
Harvard College

BEAVER BOT (Not a single robot)

Reimaging landscapes through the engineering lens of beavers

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Reimaging landscapes through the engineering lens of beavers

Chen et al, 2022

I **love** this →
BUT not this kind of Beaver Bot we are talking about

BEAVER BOT (Not a single robot)

Reimaging landscapes through the engineering lens of beavers

SUITE OF ROBOTIC TOOLS

1) Habitat mapping (Digital twins)
2) Multi-agent simulation: Speaking/thinking like a beaver
3) Excavator robot (canals, ponds)
4) Harvester robot (vegetation clearing)
5) Deposition bot (build derms that are dam-like (BDAs))

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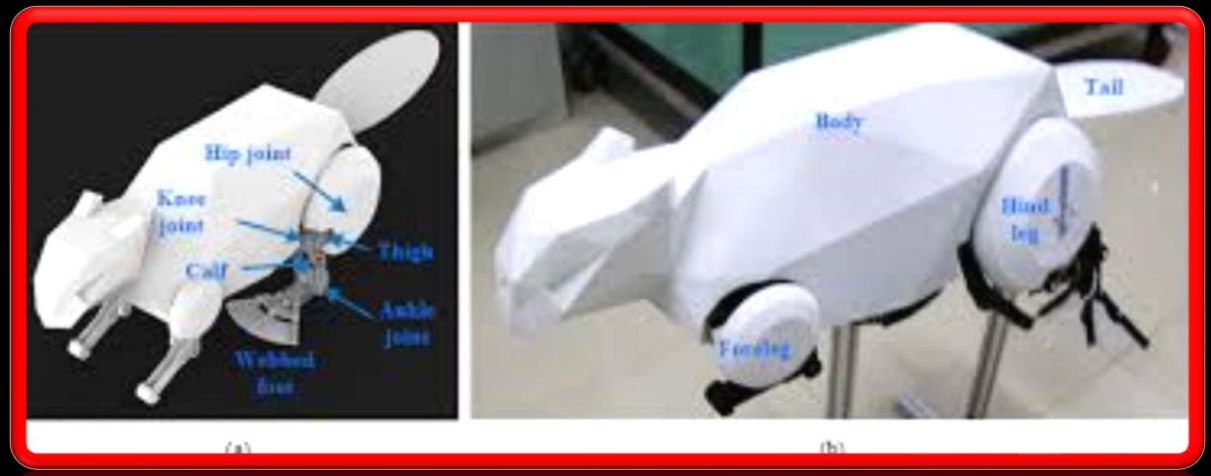
Chen et al, 2022



BEAVER BOT (Not a single robot)

Reimaging landscapes through the engineering lens of beavers

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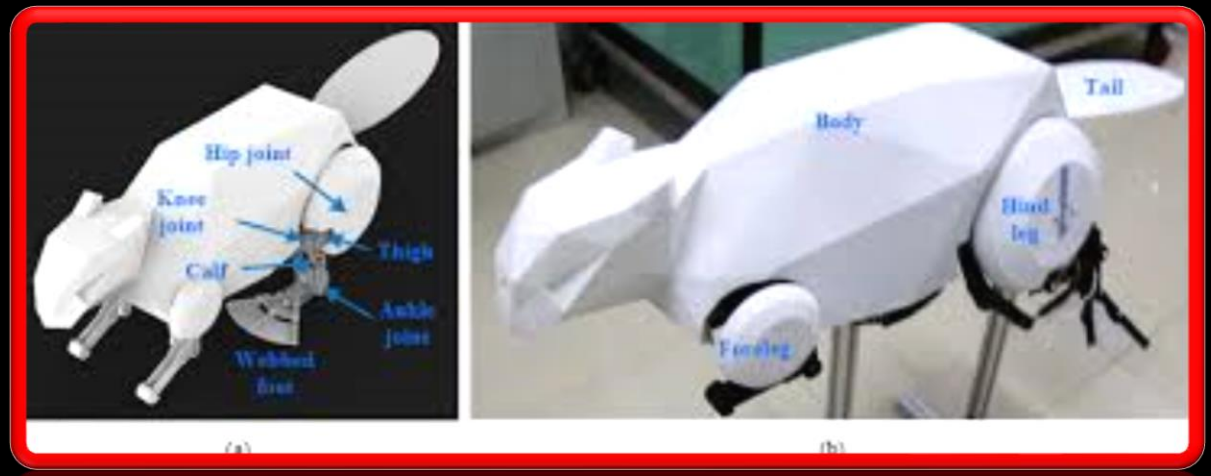

BEAVER CONSTRUCTS

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Multi-generational

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Multi-generational

Lifetime/Seasonal

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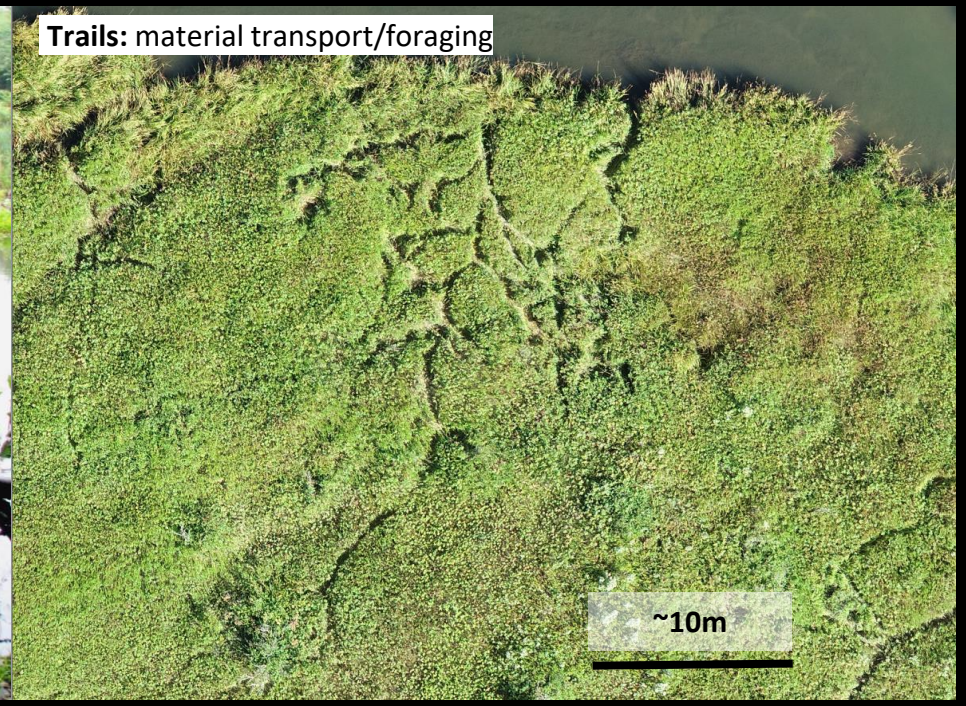
Multi-generational

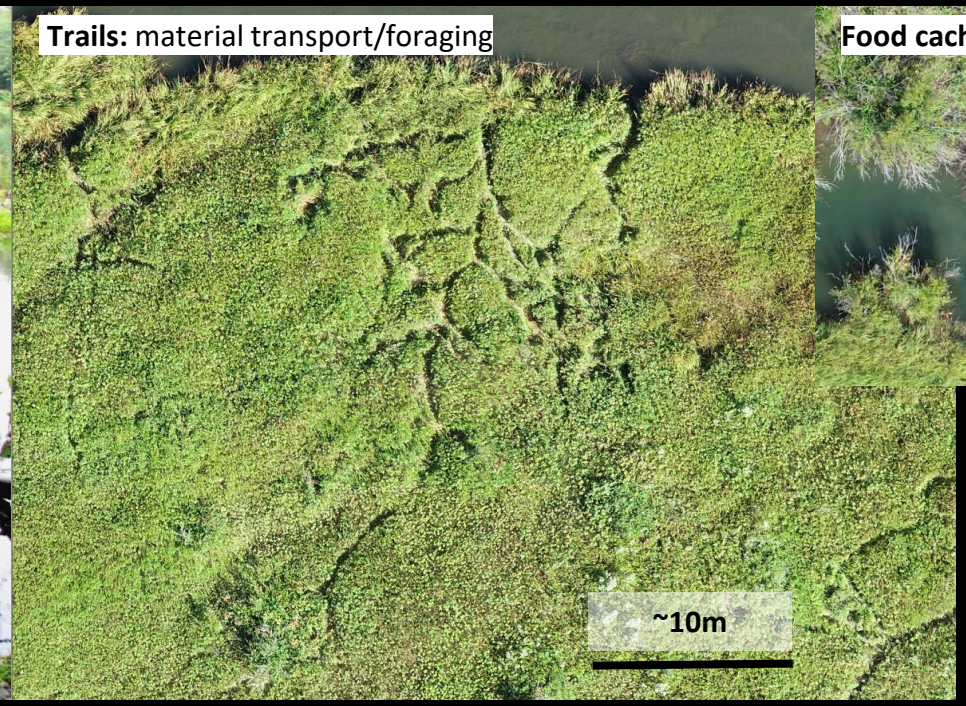
Lifetime/Seasonal

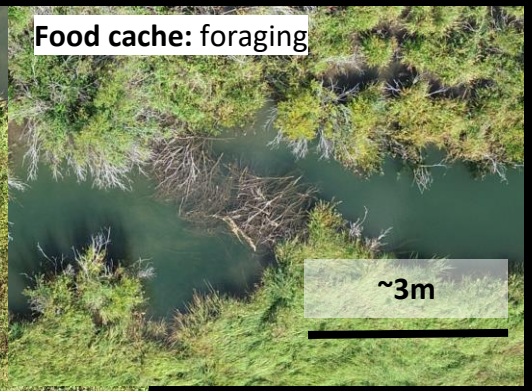


BEAVER CONSTRUCTS

Multi-generational

Lifetime/Seasonal

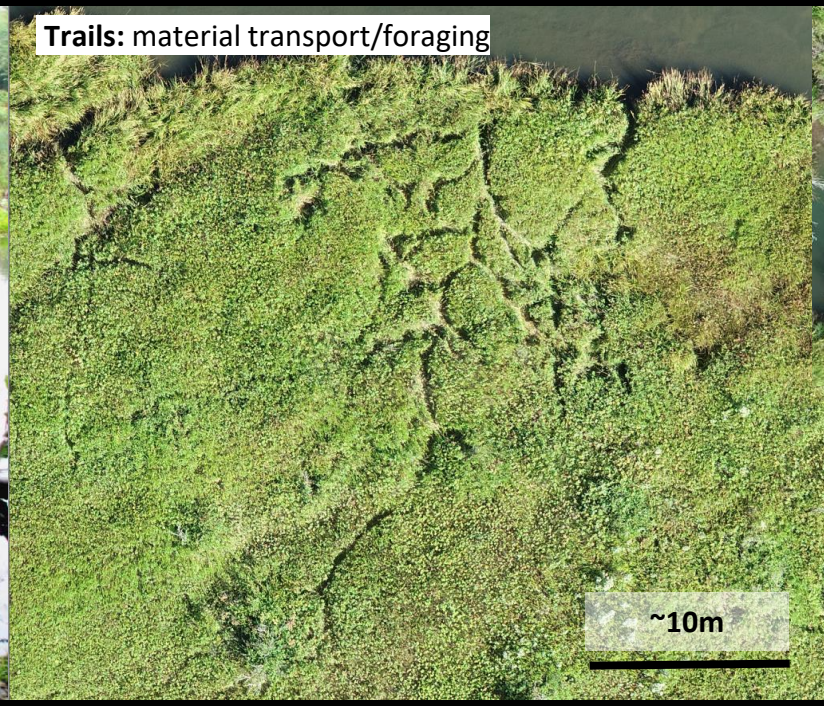




BEAVER CONSTRUCTS

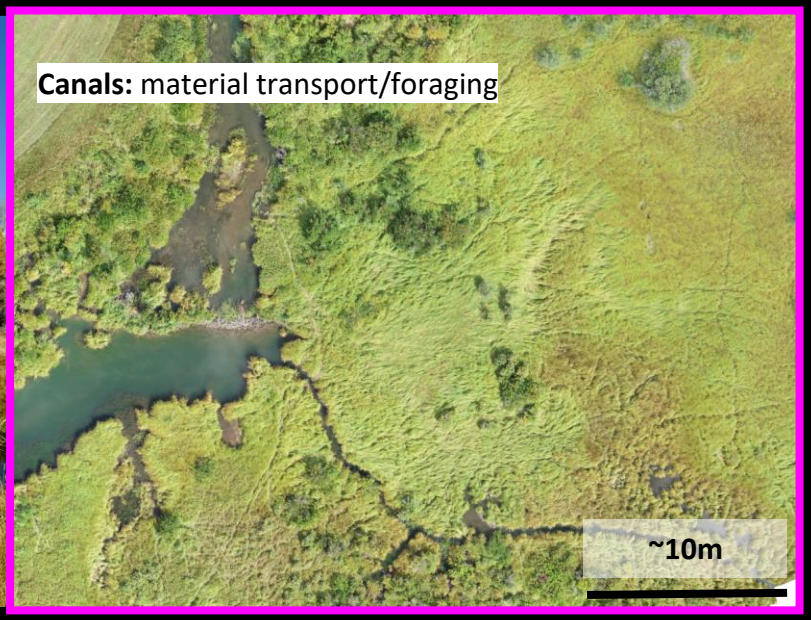
Multi-generational

Lifetime/Seasonal

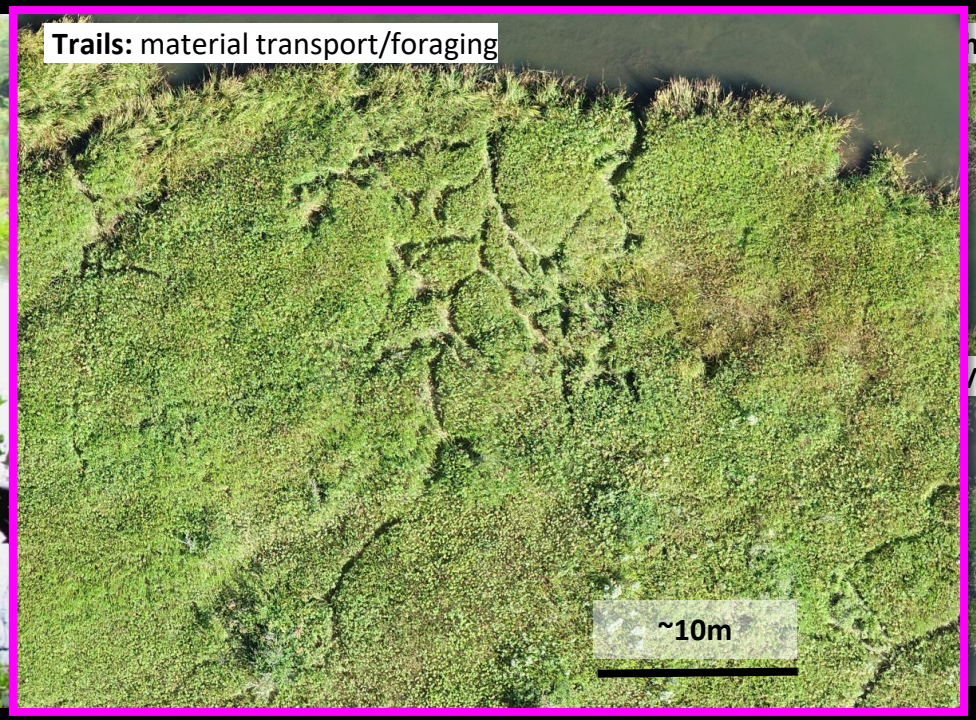


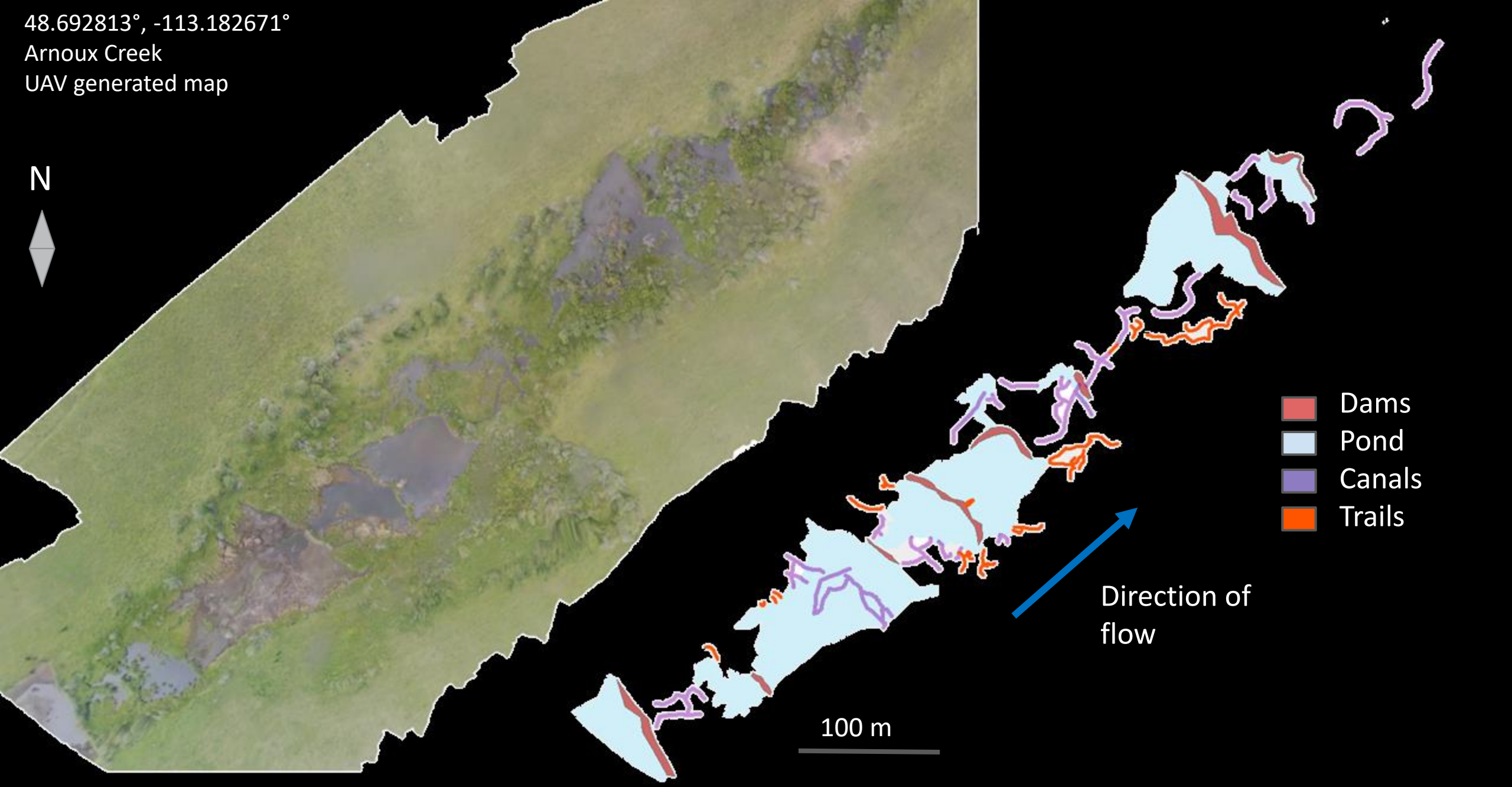
BEAVER CONSTRUCTS

Multi-generational



Lifetime/Seasonal

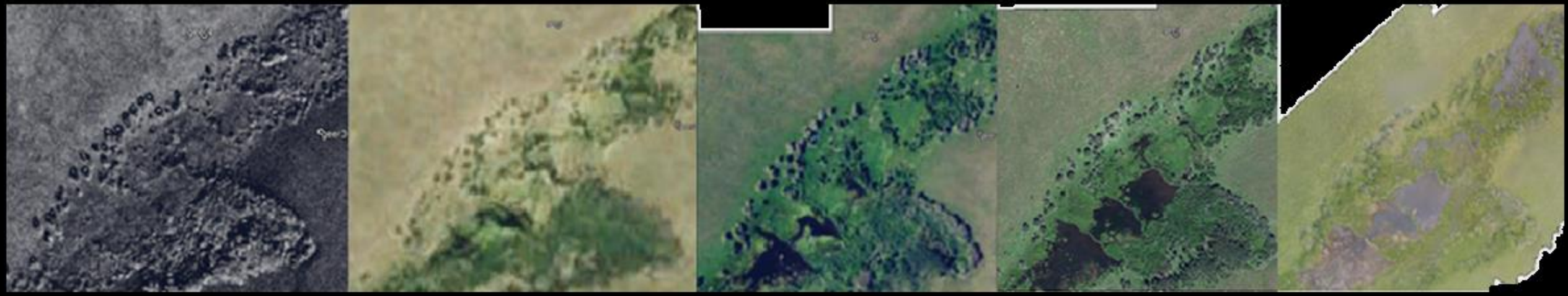




A BEAVER DAMMING COMPLEX

A BEAVER DAMMING COMPLEX MULTI-GENERATIONAL GROWTH

48.692813°, -113.182671°



N

200 m.

2003*

2006*

2009*

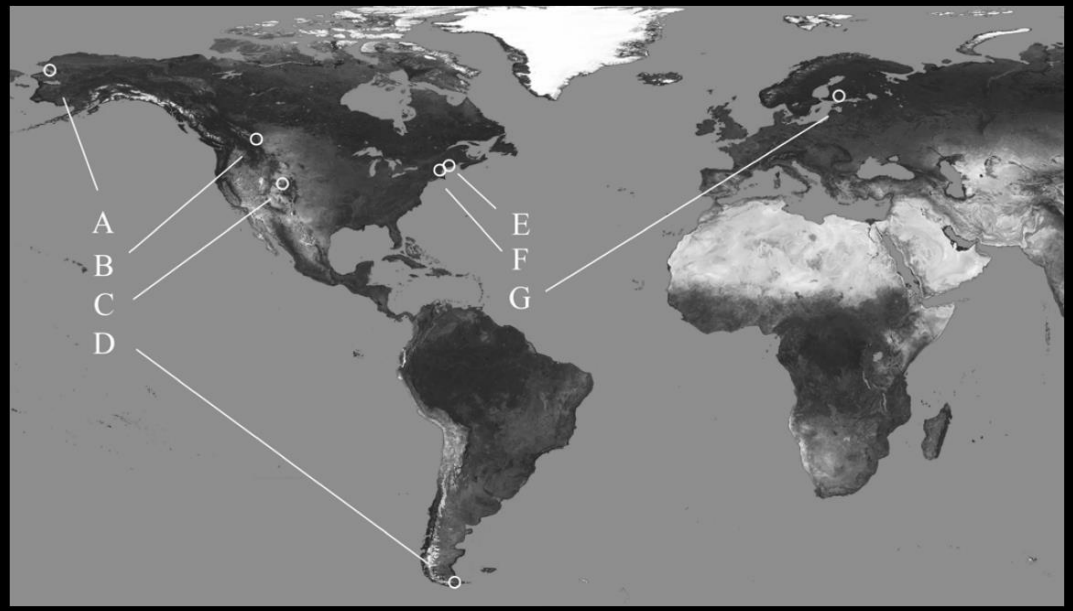
2014*

2017

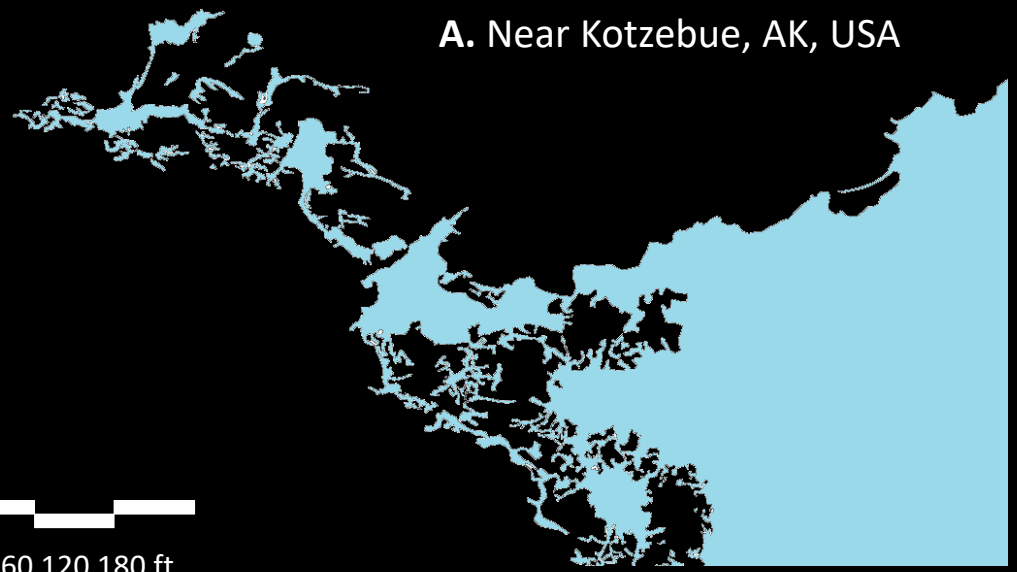
Exposed water

* Satellite images

BESPOKE TO LANDSCAPE



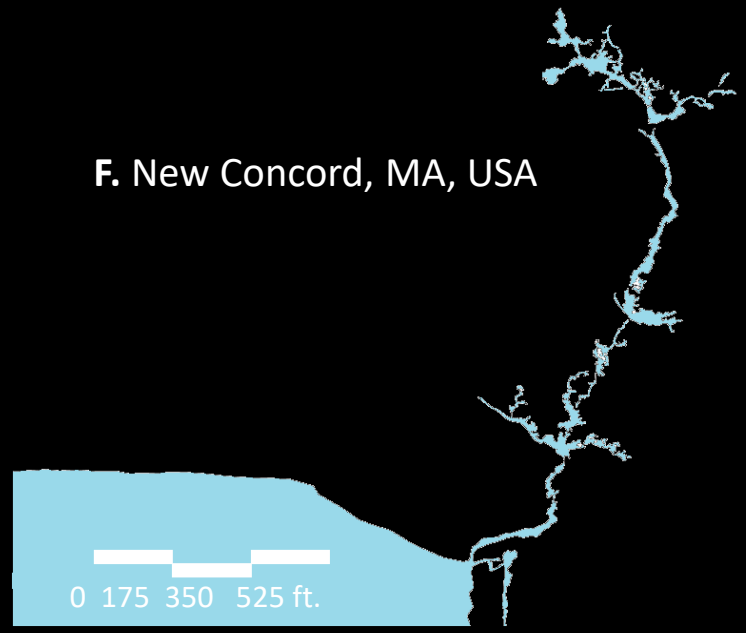
A. Near Kotzebue, AK, USA



D. Valle Carabajal, Tierra del Fuego, Argentina

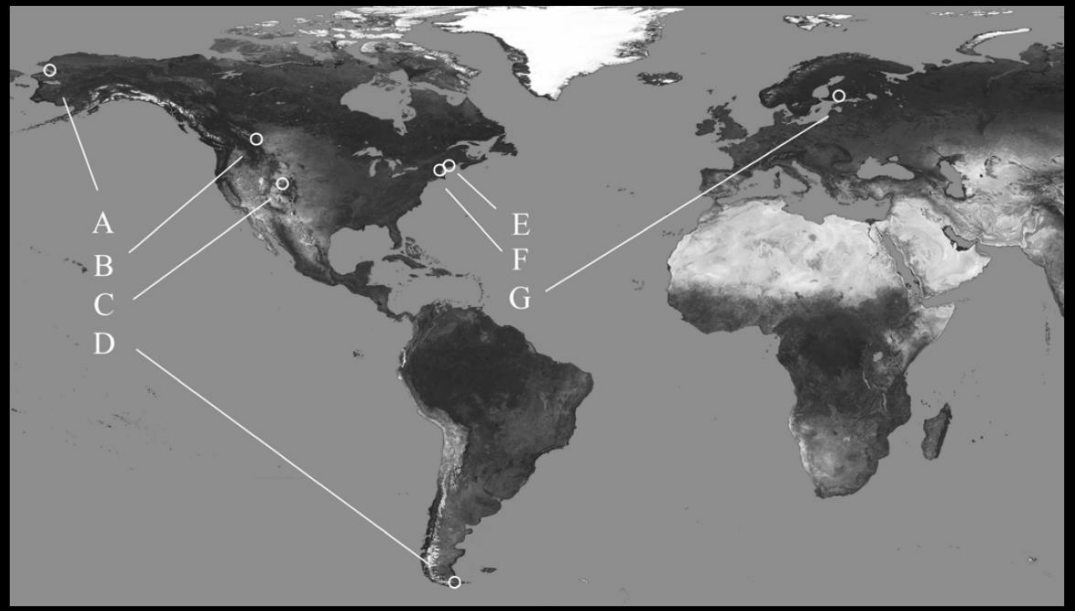
Gabriel Garon
Landscape Architecture
Harvard GSD

F. New Concord, MA, USA

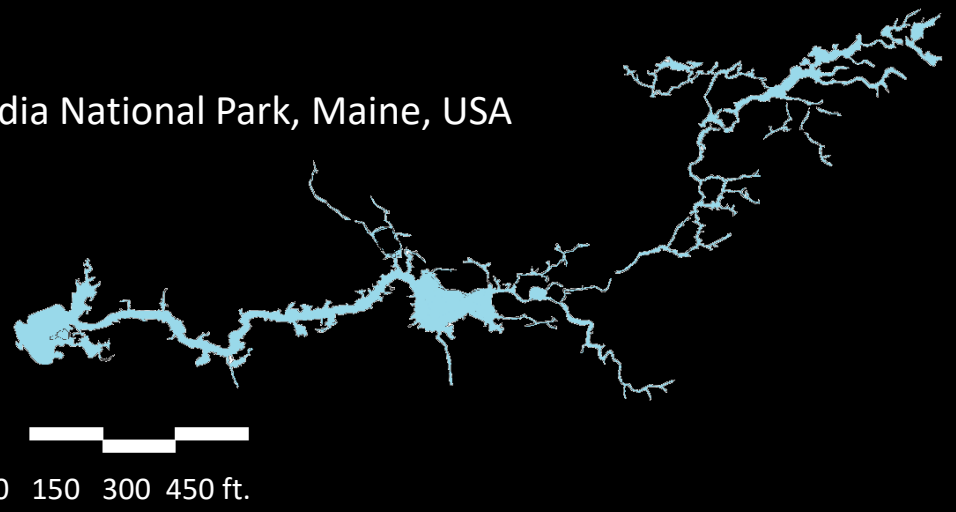


Exposed water

BESPOKE TO LANDSCAPE

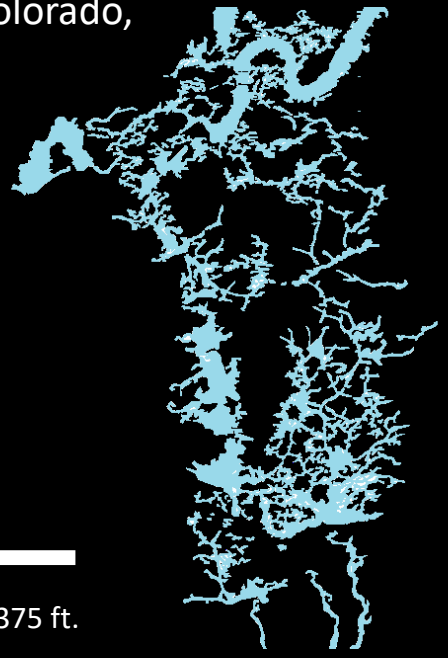


E. Acadia National Park, Maine, USA

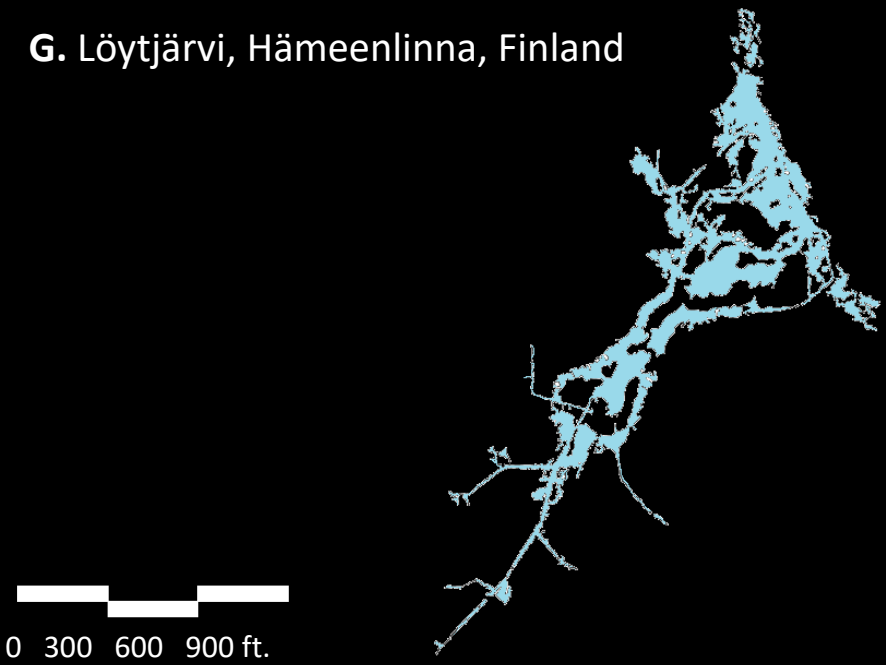


C. Buford, Colorado, USA

Gabriel Garon
Landscape Architecture
Harvard GSD



G. Löytjärvi, Hämeenlinna, Finland

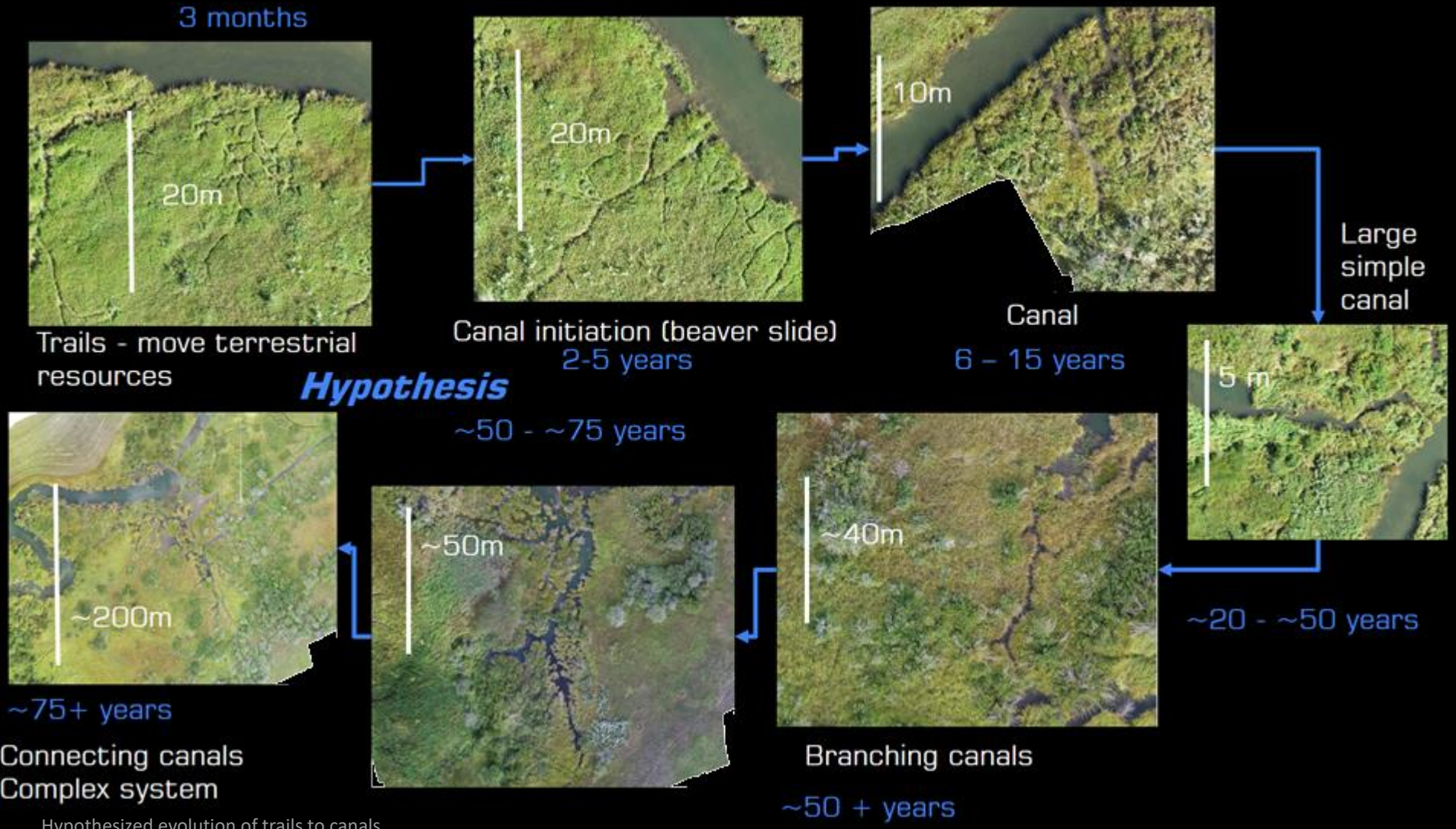


DYNAMIC ARCHITECTURE

- Acadia National Park, Maine, USA
- Lat. 44.362418, Long. -68.271618
- Years accessed: 1991, 1996, 2011, 2016, 2019, 2023

Exposed water

HYPOTHESIS – TRAILS & CANALS ARE DECENTRALIZED COORDINATION MECHANISMS



Hypothesized evolution of trails to canals

IF a beaver trail system is productive (i.e., it connects to high quality vegetation or other aquatic resources), it slowly becomes reinforced into a canal over time.

CONSTANT CONVERSATION:
DIALOGUE BETWEEN BEAVERS AND LANDSCAPE

CONSTANT CONVERSATION:
DIALOGUE BETWEEN BEAVERS AND LANDSCAPE

Beaver to beaver conversation across time:

CONSTANT CONVERSATION: DIALOGUE BETWEEN BEAVERS AND LANDSCAPE

Beaver to beaver conversation across time:
Trails: Short-term conversation between colony members

CONSTANT CONVERSATION: DIALOGUE BETWEEN BEAVERS AND LANDSCAPE

Beaver to beaver conversation across time:
Trails: Short-term conversation between colony members
Canals: Long-term conversation across generations and colonies

CONSTANT CONVERSATION:
DIALOGUE BETWEEN BEAVERS AND LANDSCAPE

Beaver to beaver conversation across time:
Trails: Short-term conversation between colony members
Canals: Long-term conversation across generations and colonies

Beaver to Environment conversation across time:

CONSTANT CONVERSATION: DIALOGUE BETWEEN BEAVERS AND LANDSCAPE

Beaver to beaver conversation across time:
Trails: Short-term conversation between colony members
Canals: Long-term conversation across generations and colonies

Beaver to Environment conversation across time:
Primary inputs

1. Flow (When to build)
2. Vegetation (Habitat quality)
3. Water quality

CONSTANT CONVERSATION: DIALOGUE BETWEEN BEAVERS AND LANDSCAPE

Beaver to beaver conversation across time:
Trails: Short-term conversation between colony members
Canals: Long-term conversation across generations and colonies

Beaver to Environment conversation across time:
Primary inputs
1. Flow (When to build)
2. Vegetation (Habitat quality)
3. Water quality

Secondary inputs
1. Predators

ARCHITECTURE AS LANGUAGE

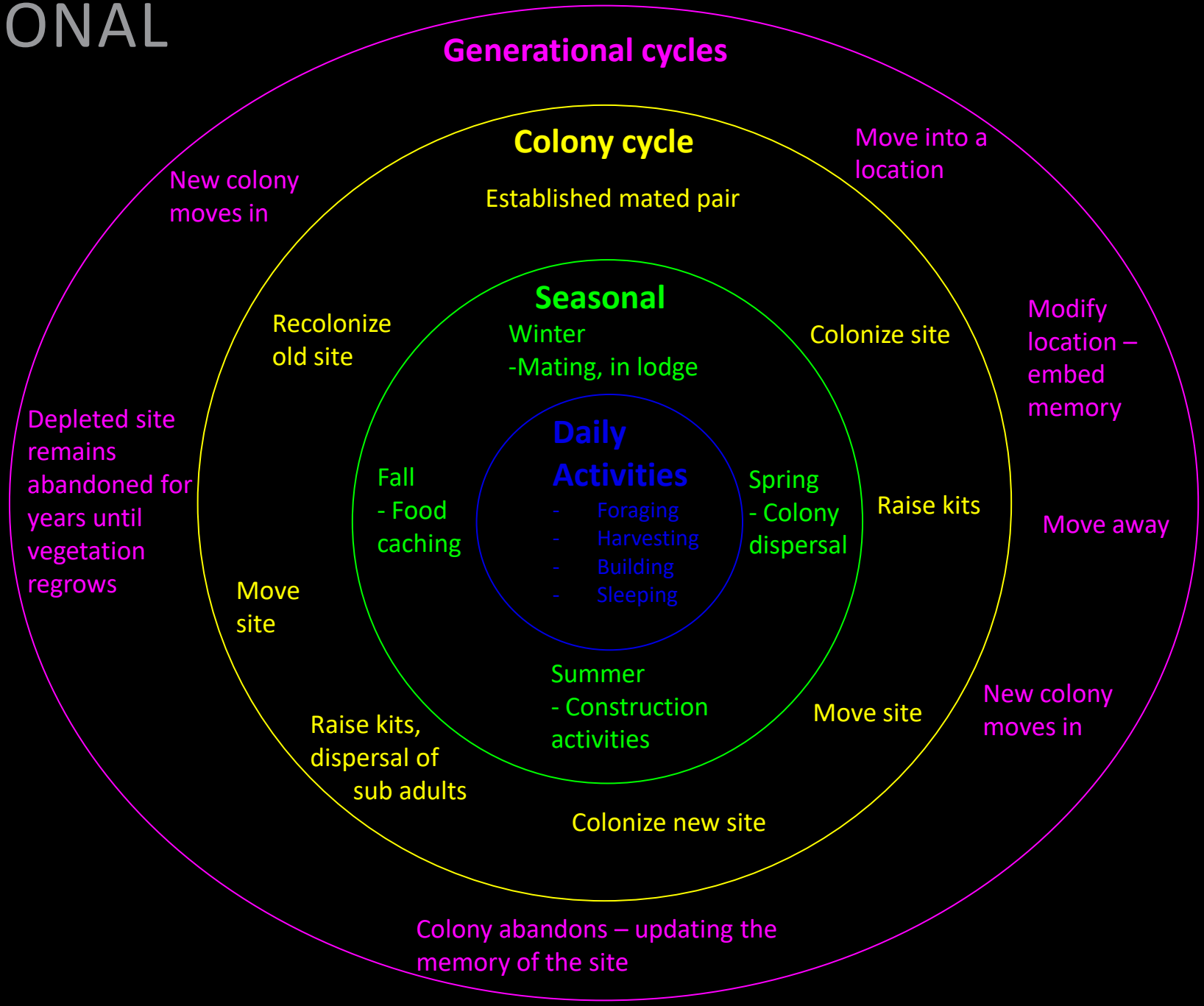
IF we can learn from beavers on how to speak with landscapes, perhaps we can, too.

Can we learn the language of architecture?

MULTI-GENERATIONAL BUILDERS

INDIVIDUAL ACTIONS OF BEAVERS, OVER TIME, GIVE RISE TO SPATIAL AND TEMPORAL COMPLEXITY UPON THE LANDSCAPE

LANDSCAPE MODIFICATIONS INFORM FUTURE BEAVERS OF POTENTAL HABITAT FITNESS OF A SITE



MULTI-AGENT SIMULATION

RULES OF BUILDING

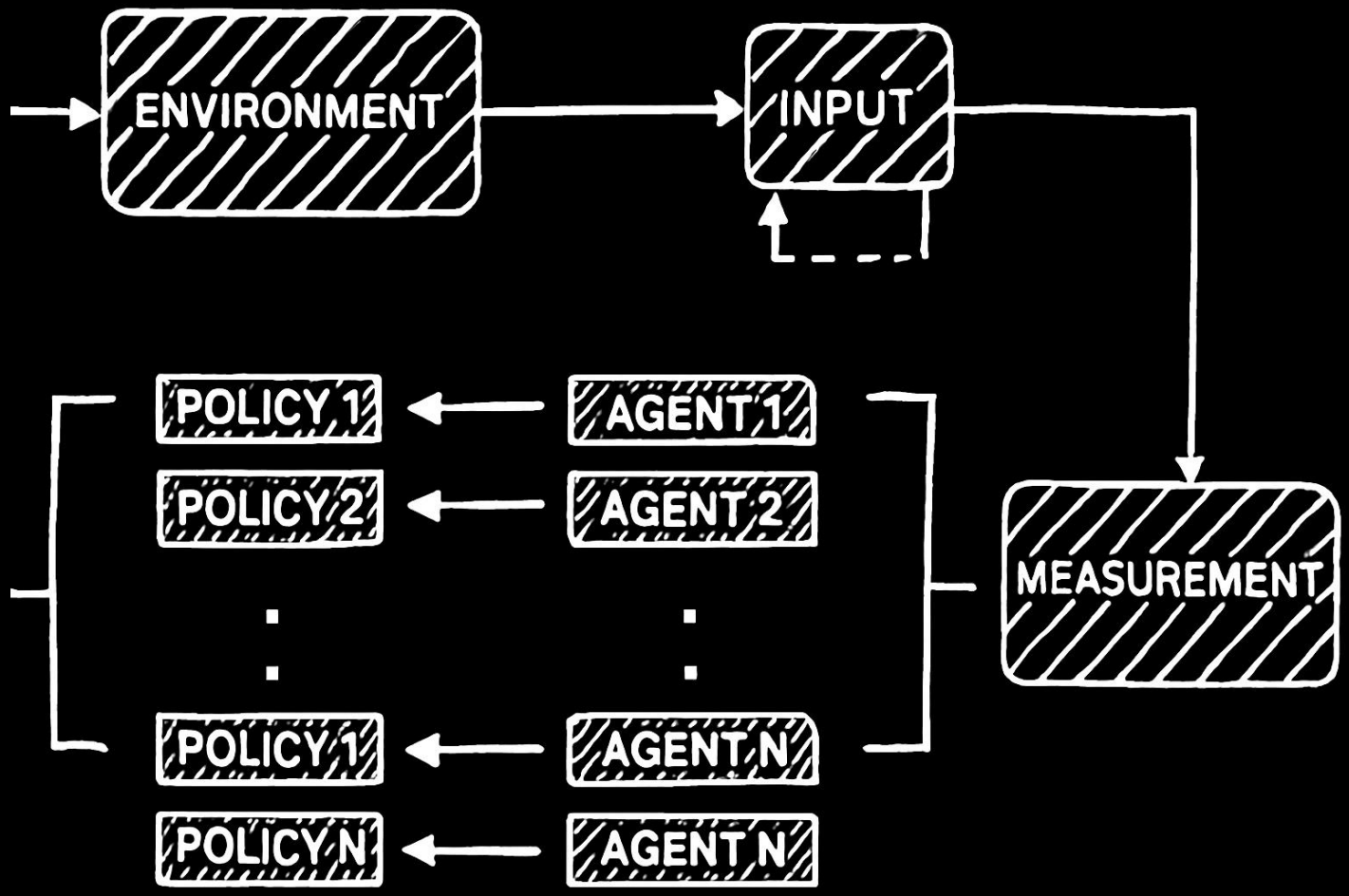
- Vegetation gradients
- Flow conditions
- Follow trails, follow canals
- Physical limitations of real landscapes
  - Gravity, slope, obstacles

DYNAMICS OF LANDSCAPES

- Low flow
- High flow
- Fire/Disaster
- Seasonality
- Variation in materials
- Variation in flow

Seasonality of landscapes

PROGRAMMING BEAVER BEHAVIOR



Federico Olivia

Postdoctoral Researcher
Multi-agent robotic systems
Civil, Environmental, and Agricultural Robotics Lab

SIMULATOR OVERVIEW – HYPOTHESIS TESTING

BEAVERS - GOAL

BEAVERS MIMICKING

- Realistic simulator
  - Branching
  - Harvesting
  - Storing
- Behavioral logic
  - Predators
  - Ponds/dams

TODO

- Metrics
- Test scenarios
- Evaluate

CONSTRUCTION GOAL

- Realistic simulator
  - Branching
  - Harvesting
  - Storing
  - Fluid Dynamics
- Behavioral logic
  - Ponds/dams

BEAVERS - TRAIL BUILDING

COMMENTS
- branching during exploration

BEAVERS - GOAL

SPOILER

COMMENTS
- trails reinforced when source found
- eating around the source

BEAVERS - SENSING

MEASURE

UPDATE MAP

DECIDE TASK

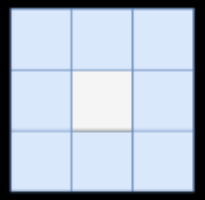
DO TASK

UPDATE ENERGY

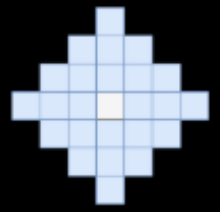
UPDATE MAP

D4

D8

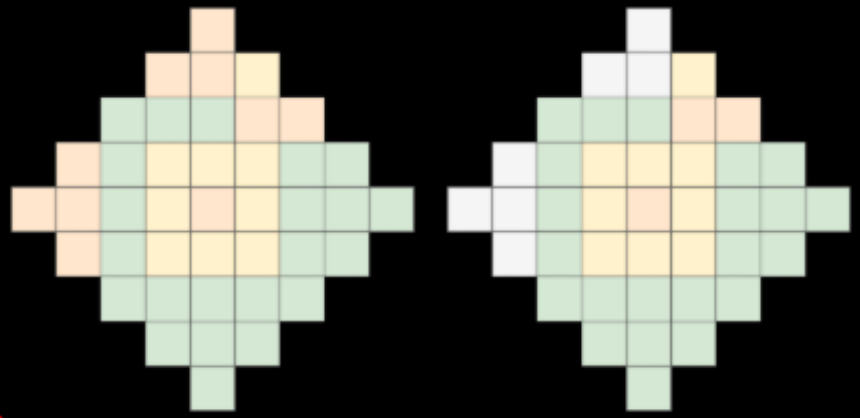


D24



D40

gradient_D##



full_map

BEAVERS - SENSING

MEASURE

UPDATE MAP

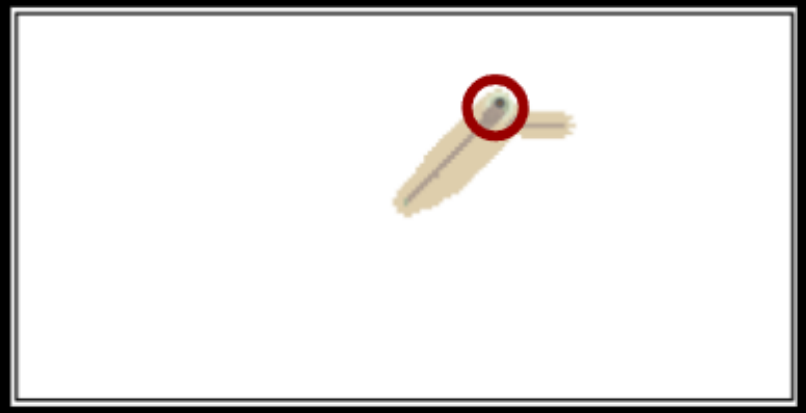
DECIDE TASK

DO TASK

UPDATE ENERGY

UPDATE MAP

local_map



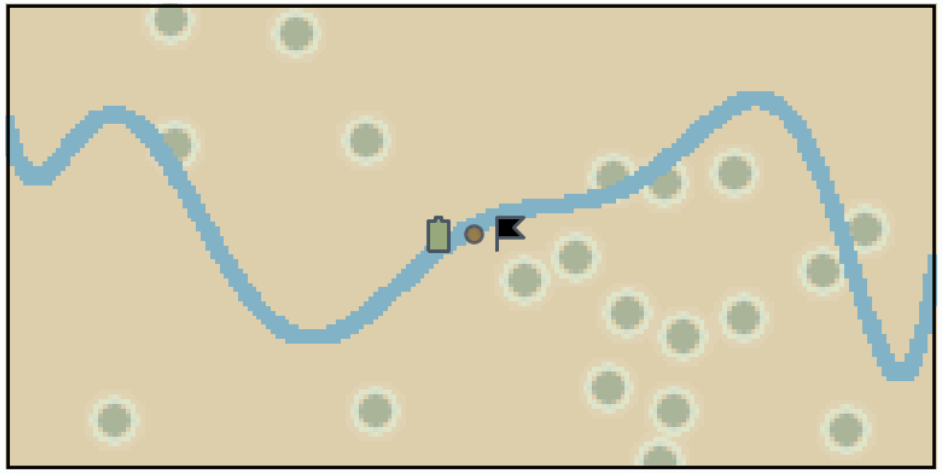
environment

BEAVERS - SCENARIO B.1

COMMENTS

- eating around the source is good (too much?)
- exploring
- trail reinforcement consequence of exploration
- exploiting the river
- less carried by the river
  - cluttered (local info)

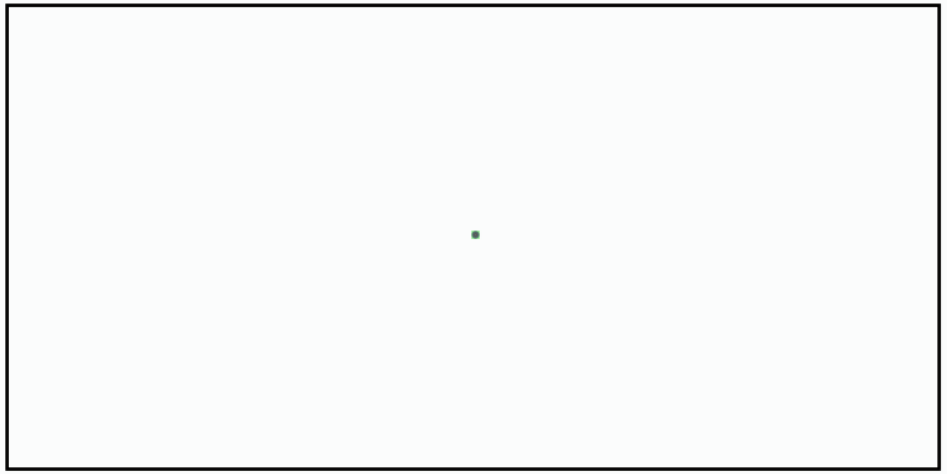
Trail and Canal Heatmap



```
ENGINE:
   t: 0
   dt: 1.0
   N agents: 1

ENVIRONMENT:
   day: 0 hour: 0 light: day
   dimensions: 200 x 100
   vegetation clusters: 20
```

Agent 0: local map



```
AGENT 0:

   TIME: 0 ENERGY: 100.0
   VEGETATION: nan LOAD: 0.0
   POS: [100  50] DST: None CTRL: IDLE
   TASK: None STATUS: IDLE
   ROBOT STATUS: IDLE ACTION: None
```

HYPOTHESIS TESTING IN REALITY

SANDBOX LANDSCAPES → DIGITAL REPRESENTATIONS OF REAL LANDSCAPES

Data source: Kennedy, 2023

DIGITAL TWINS

Representing real landscapes virtually

4 cm. vertical resolution

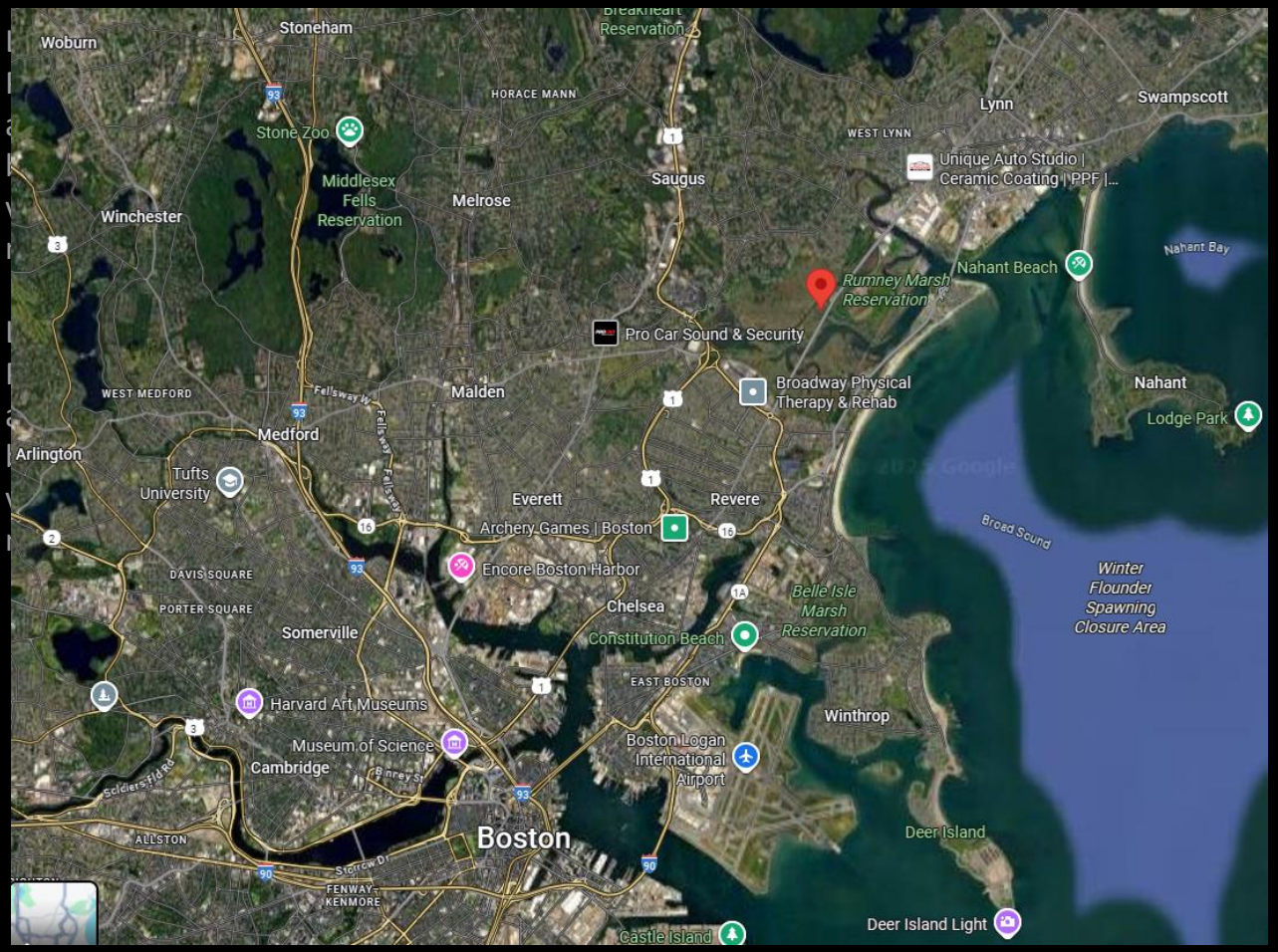
Data inputs

- Drone/UAV Imagery
- LIDAR IMAGERY
- Fabricated environments (Video games)
- Real environments digitally modified
- Satellite imagery *

* 2D Imagery is limited, 3D is preferred

CASE STUDY – RUMNEY MARSH

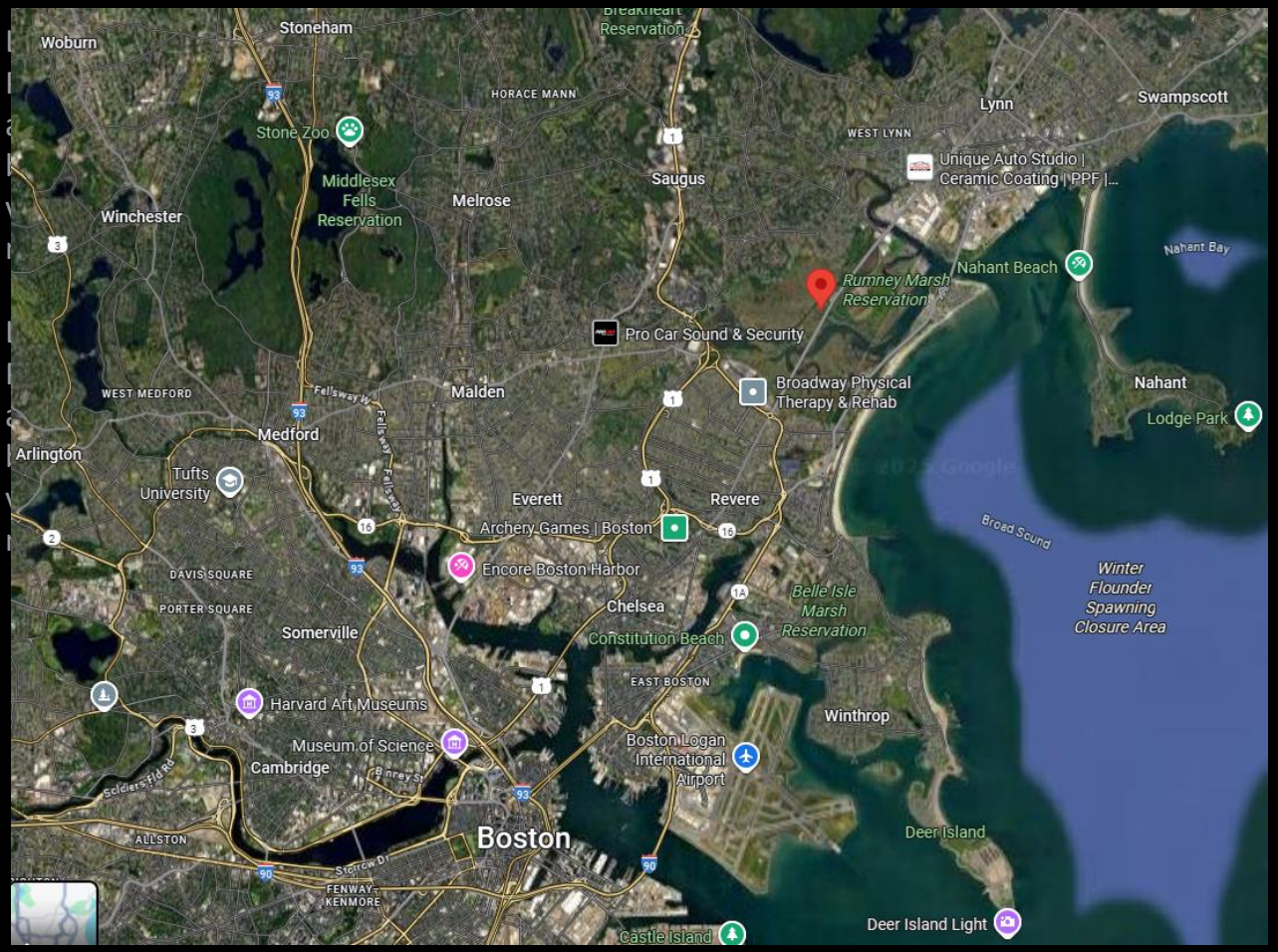
DEGRADED INTERTIDAL ZONE



William Boles – Theatre and Landscapes

CASE STUDY – RUMNEY MARSH

DEGRADED INTERTIDAL ZONE



William Boles – Theatre and Landscapes

Multi-bodied partnerships

1. Human Interventions
2. Landscape Robotics
    1. Beaver bot
3. Beavers

HUMAN INTERVENTIONS

HUMAN DESIGN TOOLS

1) Planting trees
2) Excavating canals – Tapping into the mechanism of communicat
   beavers
3) Phytoremediation
4) BDAs (with filtration material built in)
5) Community engagement/ enabling community access

BEAVER BOT: Process driven design

Reimaging landscapes through the engineering lens of beavers

SUITE OF ROBOTIC TOOLS

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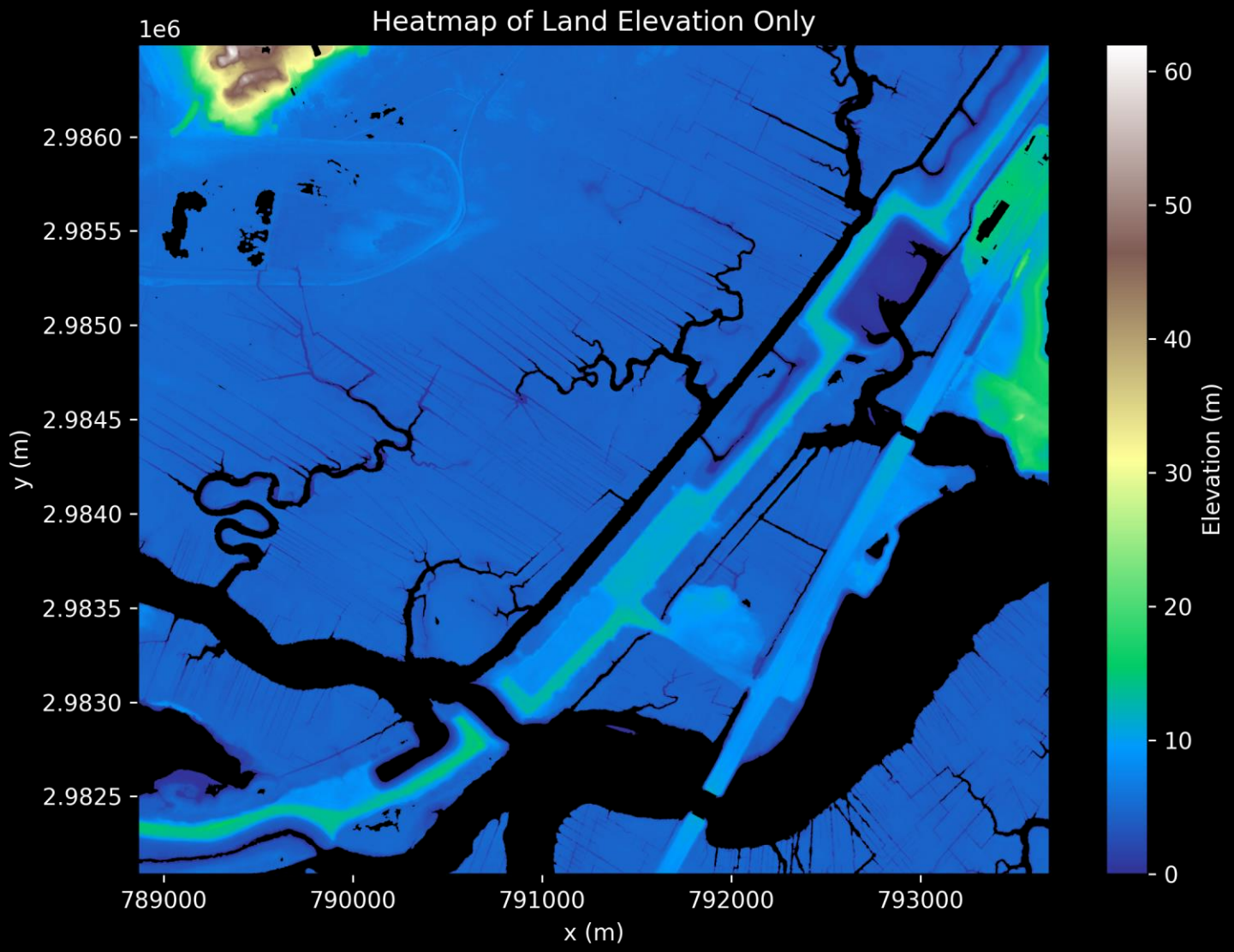
BEAVERS

LET BEAVERS BEAVER

If we can restore these landscapes, can we invite beavers back in and let them do what they do best?

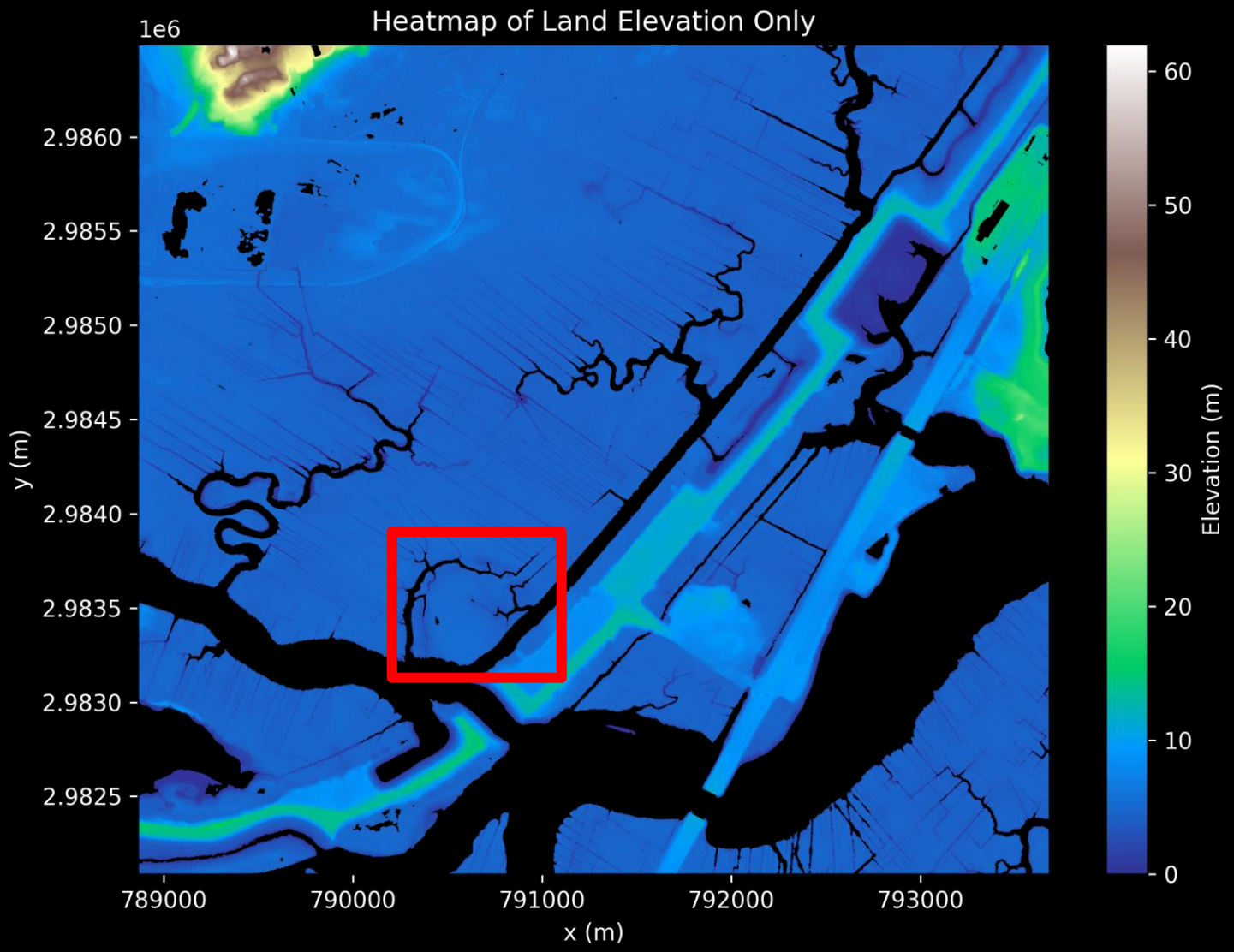
Photo credit: Timothy G. Lumley

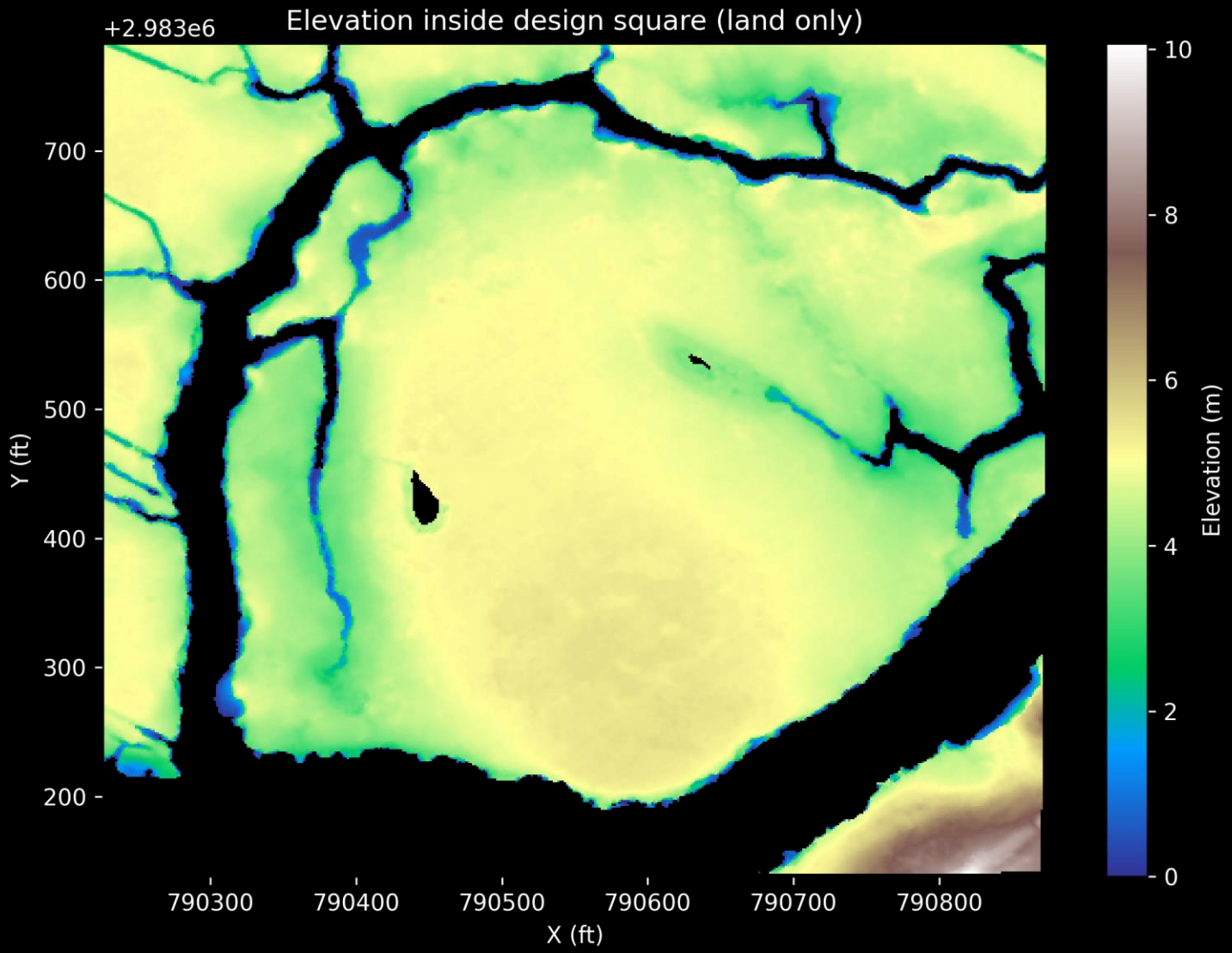
RUMNEY MARSH

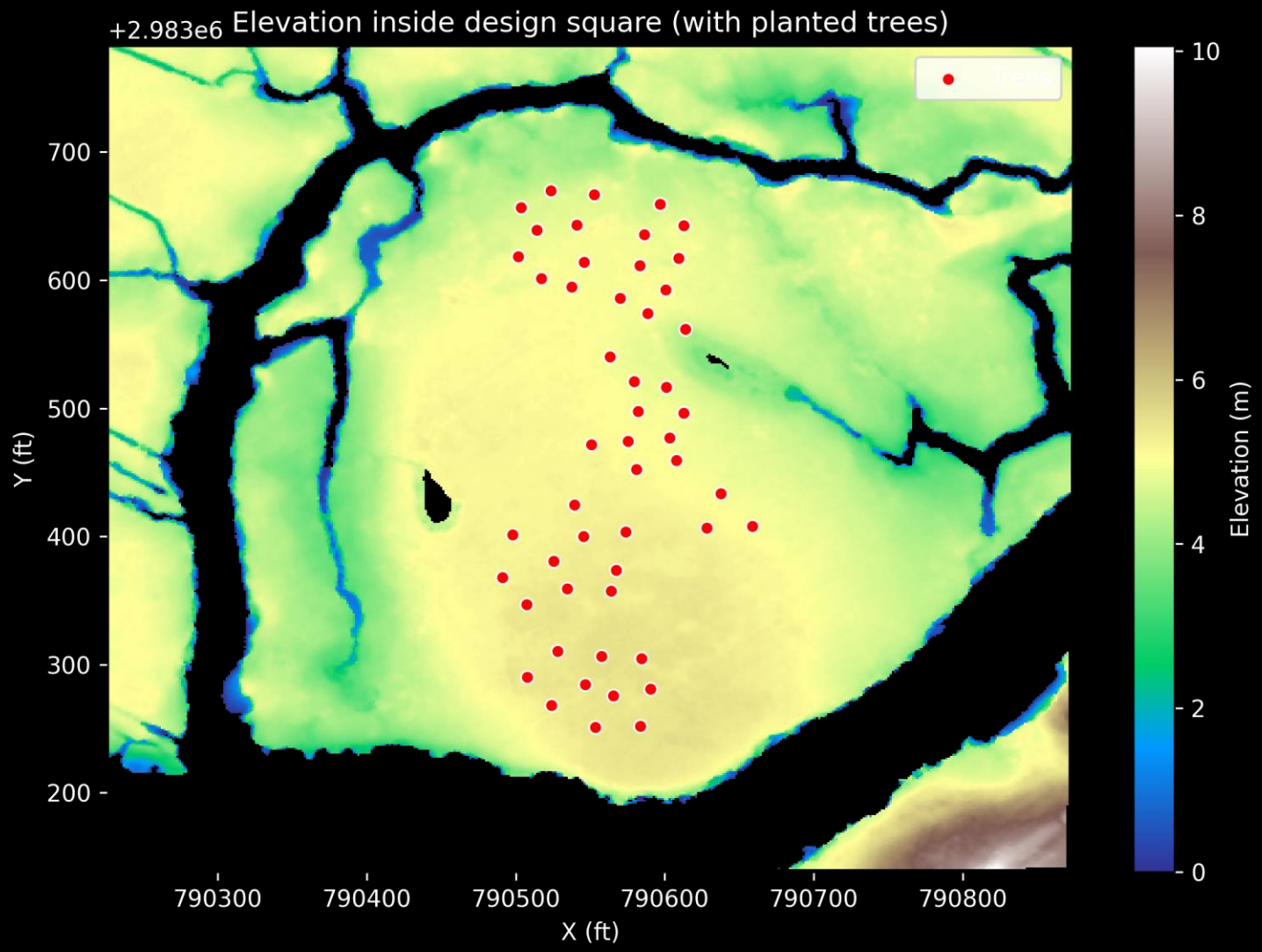


Data source: NOAA

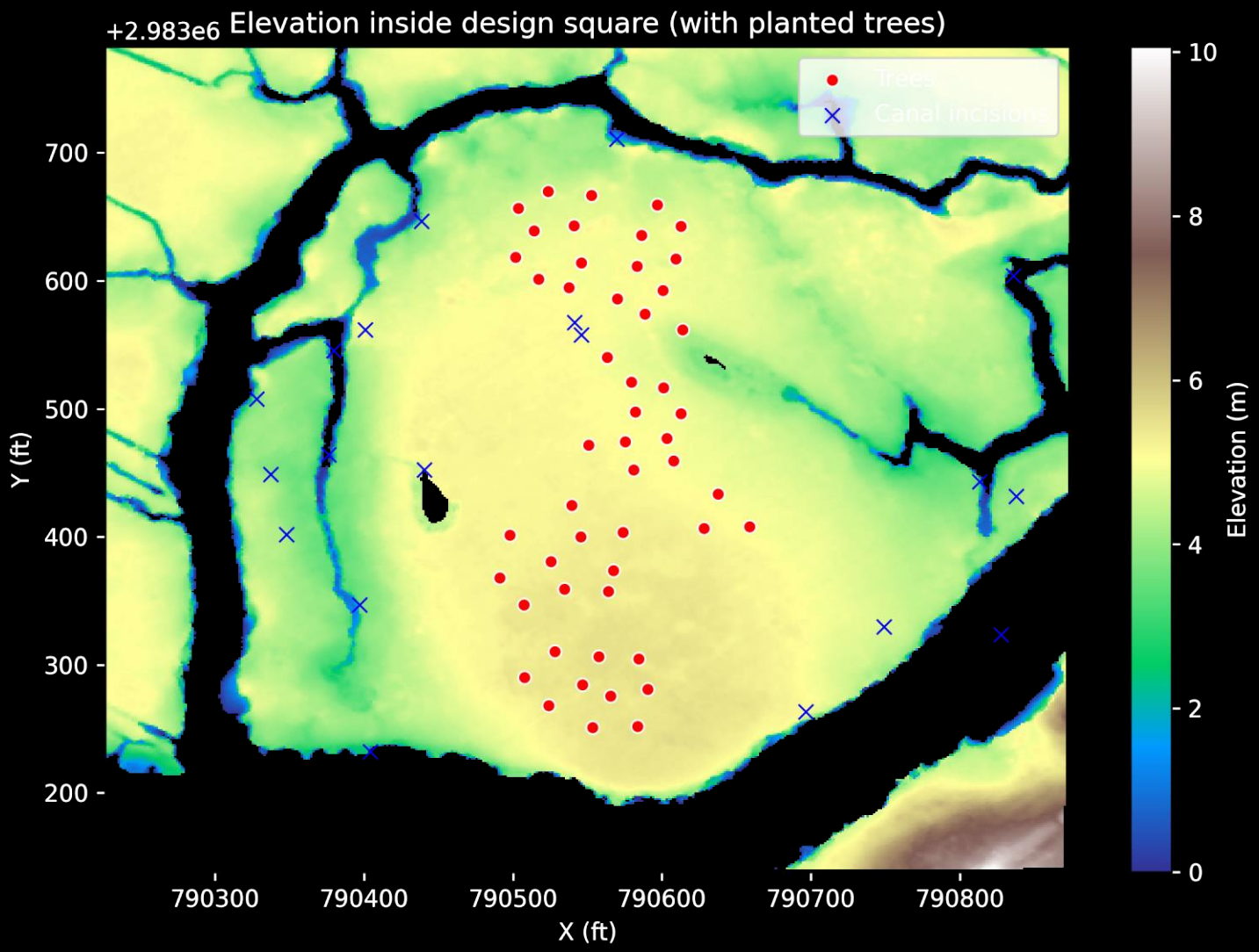
RUMNEY MARSH




Elevation inside design square (land only)
+2.983e6
700
600
500
400
300
200
Y (ft)
790300
790400
790500
790600
790700
790800
X (ft)
10
8
6
4
2
0
Elevation (m)



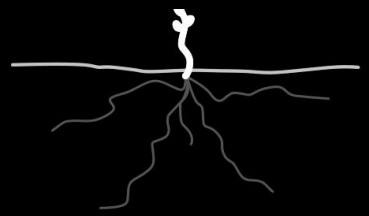
Tree design intervention

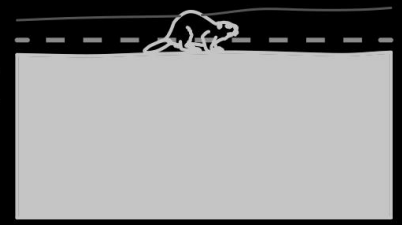


Tree design intervention

Canal incisions

DESIGN ACTIONS





1. Exisiting Site
   A degragaded marsh located in Saugua, MA with urban edges.

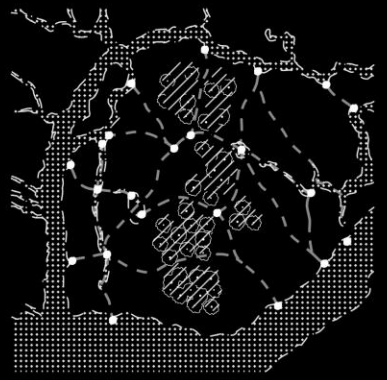
2. Planting vegatation
   Willow's and Cottonwoods are planted to provide future food and material for beavers.

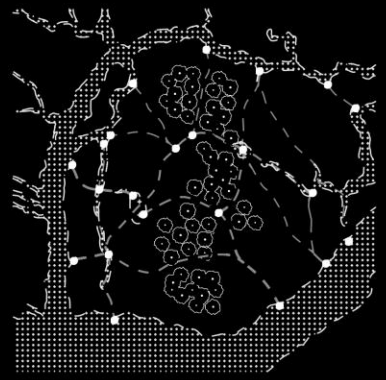
3. Environmental Robotics Incisions
   -Particular areas along the edges and interior of the marsh are noted as beginning points.

4. Creation of trails
   -Environmental robotics go back and forth between points to create indentions into the marsh. This will be read as exisiting 'trails' by the beavers.

5. Incorporation of beavers
   -As beavers inhabit the land they will futher dig canals and create dams that will route water into new ways, changing the hydrology of the site, fosting more biodiversity.

CONCEPT SEQUENCE

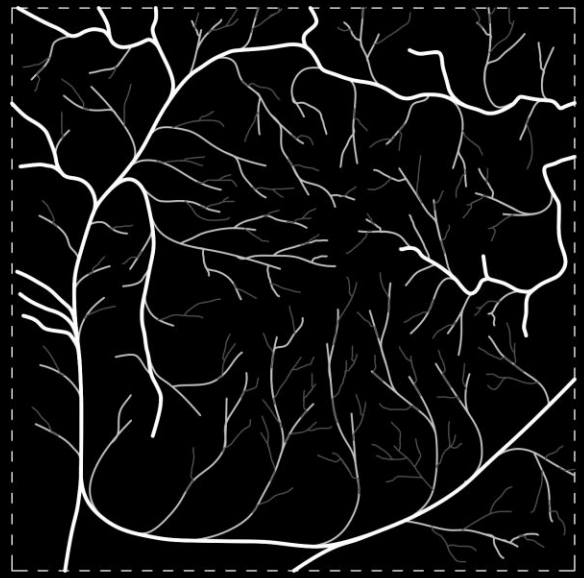




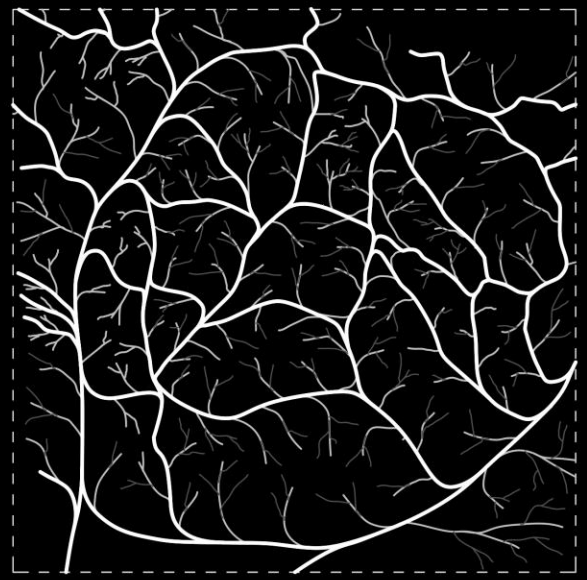
HYDRO MODELS

Rumney Marsh
Saugus, MA

0' 550' 1100'



700'



UNOCCUPIED BY BEAVER ACTIVITY

42°26'02"N 71°00'03"W

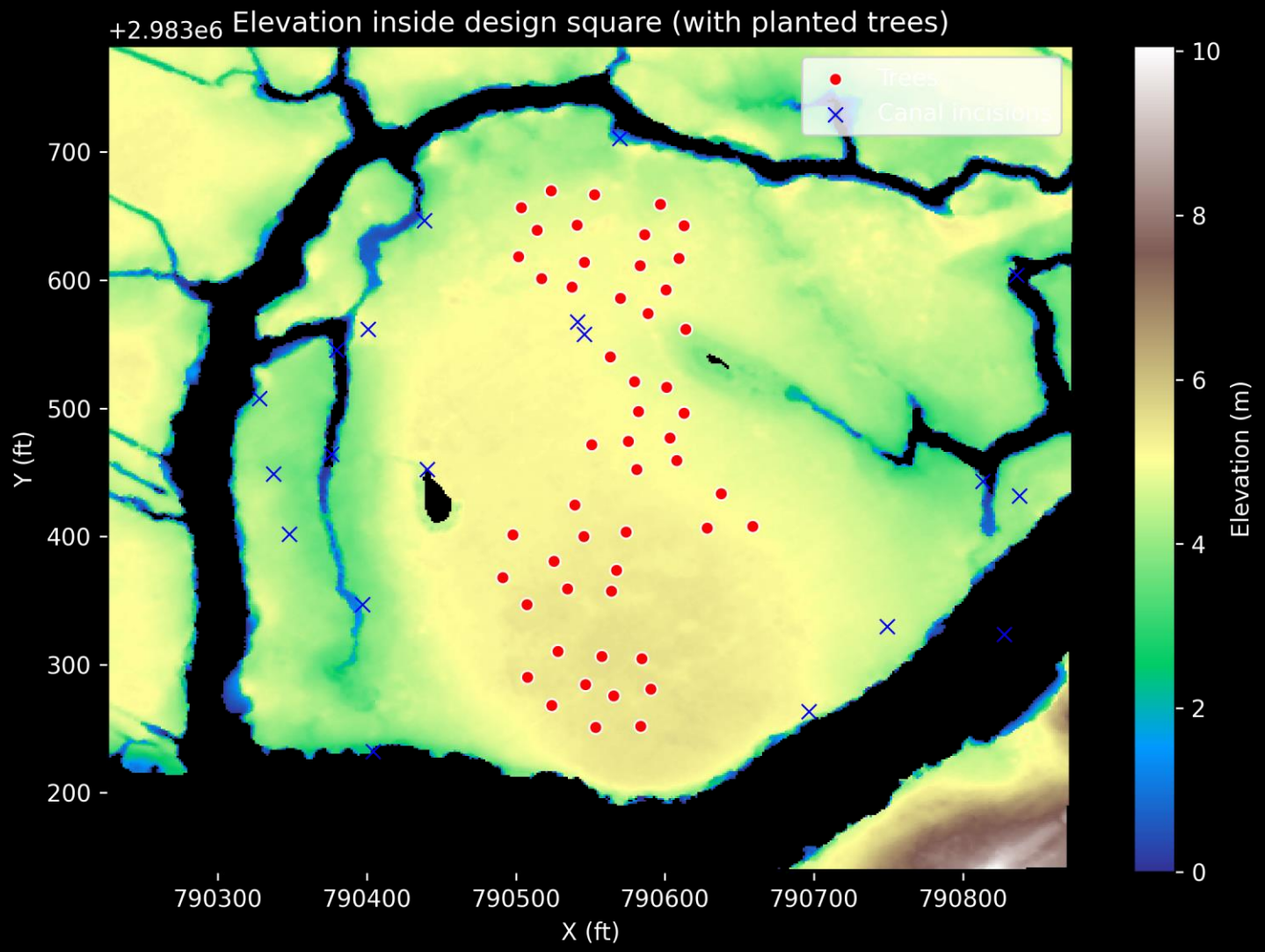
OCCUPIED BY BEAVER ACTIVITY (SPECUALTION)

42°26'02"N 71°00'03"W

Water volume enhanced
by 26,613 cubic feet,
Approximately 199,094 gallons.

stream canals shortcut trails drainage

0' 175' 350'



NEXT: Introduce digital beavers!!

ONGOING WORK

DEPLOY DIGITAL AGENTS IN 3D ENVIRONMENT

Currently, the multi-agent system works in 2D; we are building it for 3D landscapes.

Test on multiple landscape types and compare how Beaver Bot perform compared to real ecosystems.

TEST INITIAL DESIGN CONDITIONS TO INFORM BEST LONG-TERM GOALS

Work with design interventions to reimagine landscapes across time to make better informed design decisions.

MECHANICAL ROBOTS

Designing excavator mechanisms for a robotic tool

THANK YOU

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