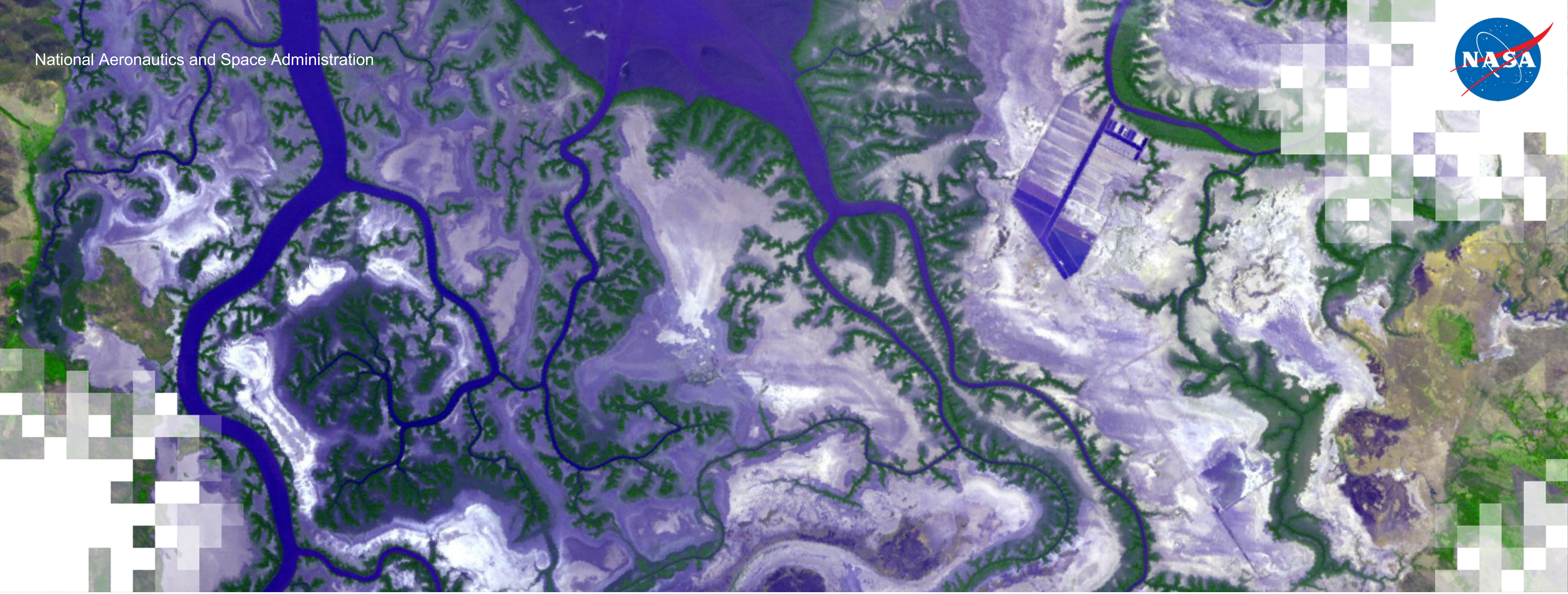


Evaluating Ecosystem Services with Remote Sensing

Amber McCullum, Juan L. Torres-Pérez, Guest Speaker: Mehdi Heris (Hunter College City University of New York)

Aug. 30, 2022

Course Structure and Materials

- Three, 1.5 -hour sessions on August 23, 25, & 30 at 11:00-12:30 EDT (UTC-4) (English)
- Webinar recordings, PowerPoint presentations, and the homework assignment can be found after each session at:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-evaluating-ecosystem-services-remote-sensing
  - Q&A following each lecture and/or by email at:
    - amberjean.mccullum@nasa.gov or juan.l.torresperez@nasa.gov

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Answers must be submitted via Google Forms
  - **HW Deadline: Tuesday, September 13th**

- **Certificate of Completion:**
  - Attend all three live webinars
  - Complete the homework assignment by the deadline (access from ARSET website)
  - You will receive certificates approximately two months after the completion of the course from: marines.martins@ssaihq.com

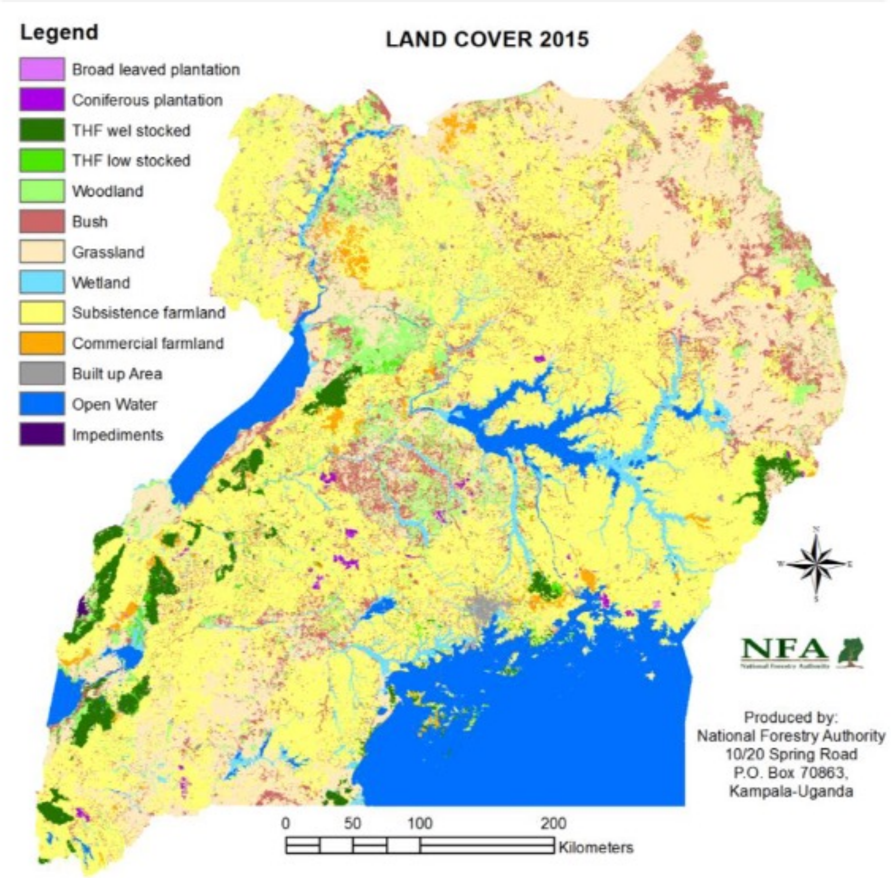
Prerequisites

- Prerequisites:
  - Please complete Sessions 1 & 2A of Fundamentals of Remote Sensing or have equivalent experience.
- Course Materials:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-evaluating-ecosystem-services-remote-sensing

Learning Objectives

By the end of this session, you will become familiarized with multiple projects for ecosystem assessments, including :

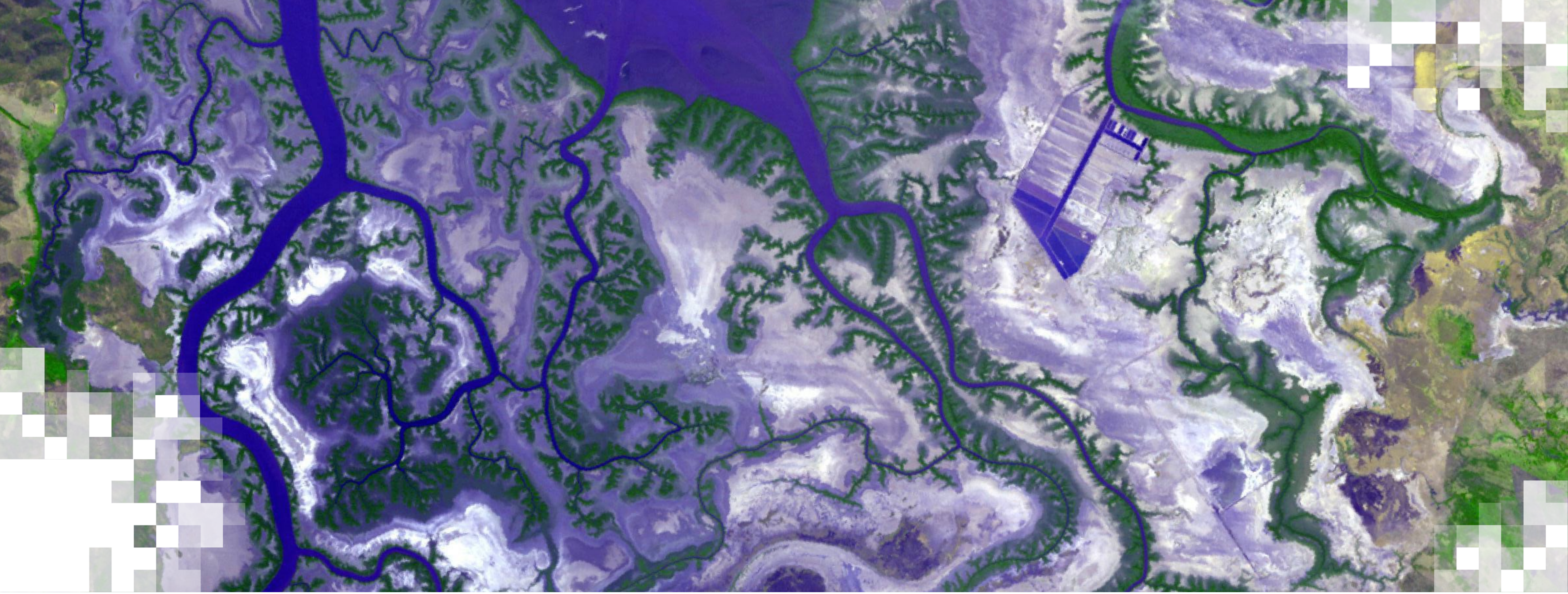
- Ecosystem Accounting in Liberia
- Experimental Ecosystem Accounts for Uganda
- Indonesian Assessment of Land Cover
- Valuing the Role of U.S. Coral Reefs in Coastal Hazard Risk Reduction
- Piloting Urban Ecosystem Accounting for the United States



Credit: UNEP-WCMC & IDEEA (2017) Experimental Ecosystem Accounts for Uganda. Cambridge, UK.

Session 2 Review

- Remote sensing can be used to assess a variety of questions related to the valuation of ecosystems services.
- There are many types of models and methods for assessing the value of ecosystem services.
- The ARIES technology highlights interoperability:
  - To allow models and data to be contributed by independent researchers, hosted on a network, and automatically assembled into model workflows
- The Natural Capital Project aims to improve the well-being of people and our planet by motivating targeted investments in nature.
  - Science, technology, partnerships



Gaborone Declaration for Sustainability in Africa (GDSA): Liberia

Gaborone Declaration for Sustainability in Africa (GDSA)

- A commitment to a new model of development that, for the first time, takes into account the role of natural capital in development by bringing the value of natural resources from the periphery to the center of all economic decision-making.

Image Credit: [Conservation International]

Image Credit: Rod Mast

Image Credit: Will Turner

Image Credit: CI/John Martin

Conservation International (CI) and NASA Partnership

- Long-Term Goal: Develop decision-making tools and practices based on satellite observations of Earth that can be used worldwide
  - Multiple projects underway
- Support the GDSA countries by providing tools and approaches to advance earth observation applications for NCA
- Develop a low-cost, replicable approach and tools that countries can use for ecosystem extent mapping

CONSERVATION INTERNATIONAL

NASA

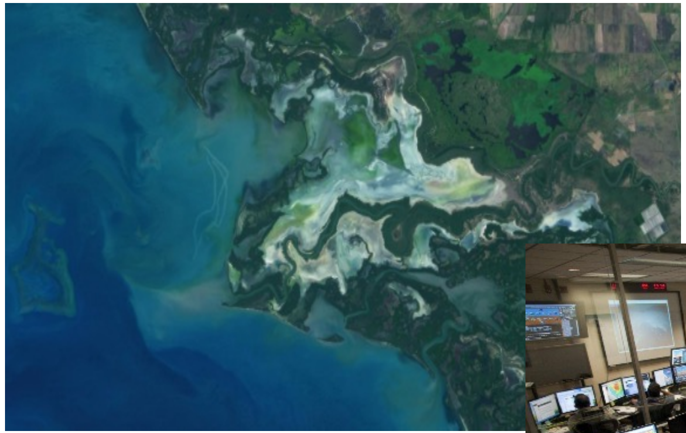


Image and Information Credit: Daniel juhn, Max wright
eo4ea.org, secretariat@eo4ea.org

GDSA Example: Ecosystem Accounting in Liberia

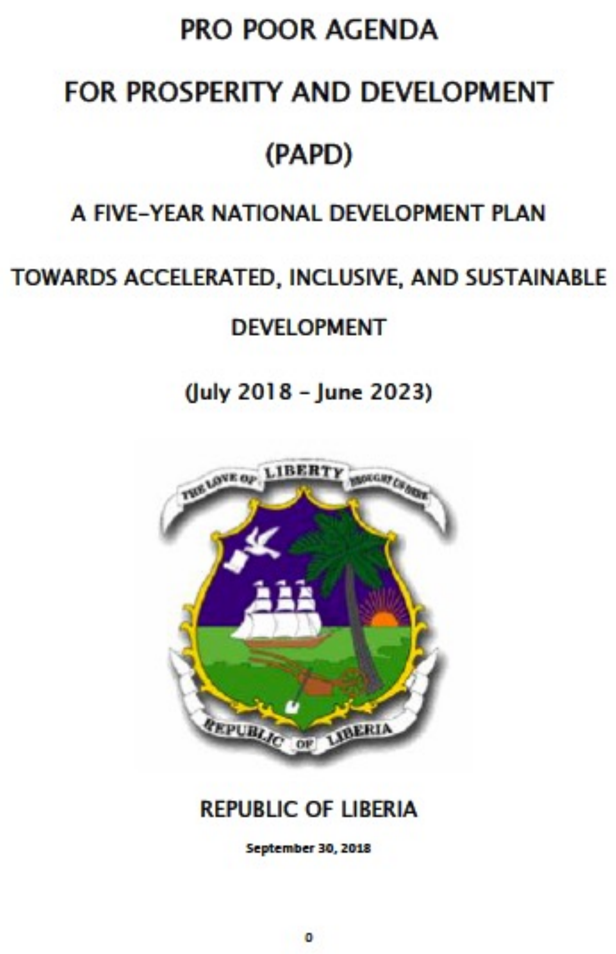
- Liberia holds some of West Africa's last intact forests
  - Fisheries and mangroves also important
- 63% of Liberians live under the poverty line, 70% dependent on forests for food and livelihoods
- Sustainable management of these ecosystems while meeting needs of people

Image Credit: Conservation International

Slides for this case study example were adapted from Africa Natural Capital Accounting Community of Practice Webinar, May 2021. Credits: Mr. Z. Elijah Whapoe, Liberia Environmental Protection Agency; Celio de Sousa, PhD, NASA Goddard Space Flight Center, Earth Sciences Division

The Pro Poor Agenda for Prosperity and Development (PAPD)

- PADP: Promote sustainable, transparent, and well-managed use of Liberia's natural resources
- Indicators on existing national accounts do not measure progress towards achieving sustainability objectives of the PADP.
- Natural capital accounting in Liberia will reveal the impacts and dependencies of economic activity on the environment and support better economic decisions in the long term.


PRO POOR AGENDA

FOR PROSPERITY AND DEVELOPMENT

(PAPD)

A FIVE-YEAR NATIONAL DEVELOPMENT PLAN

TOWARDS ACCELERATED, INCLUSIVE, AND SUSTAINABLE DEVELOPMENT

(July 2018 – June 2023)

REPUBLIC OF LIBERIA

September 30, 2018

0

Initial Mapping Efforts

- Mapping Liberia is globally significant for biodiversity, sources of freshwater, wild sources of food, and natural places that are important for cultural identity.
- Key Findings: Most essential natural capital is still intact but mostly unprotected and a management strategy is needed for more sustainable development.
- Need for more systematic, rigorous, and replicable approach to measure nature's contribution to the economy.

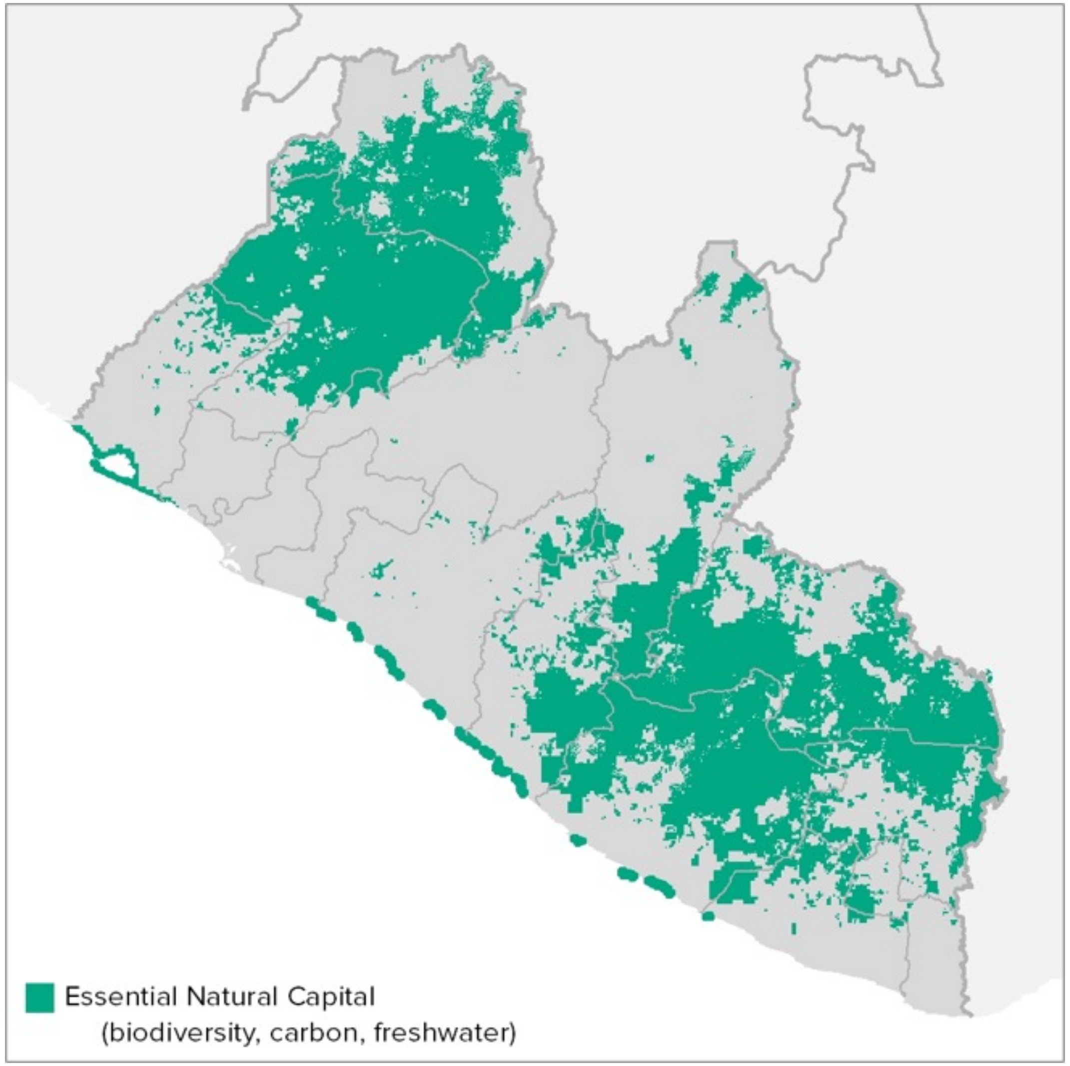


Image Credit: Conservation International

Mapping Ecosystem Classes and their Distribution

- Needs: Ecosystem classification and up-to-date maps of ecosystem distribution at the national scale
- Partnership with NASA and CI for ecosystem extent mapping
- Products: Use and ecosystem distribution maps, as well as officially endorsed land and extent accounts from 2000–2018

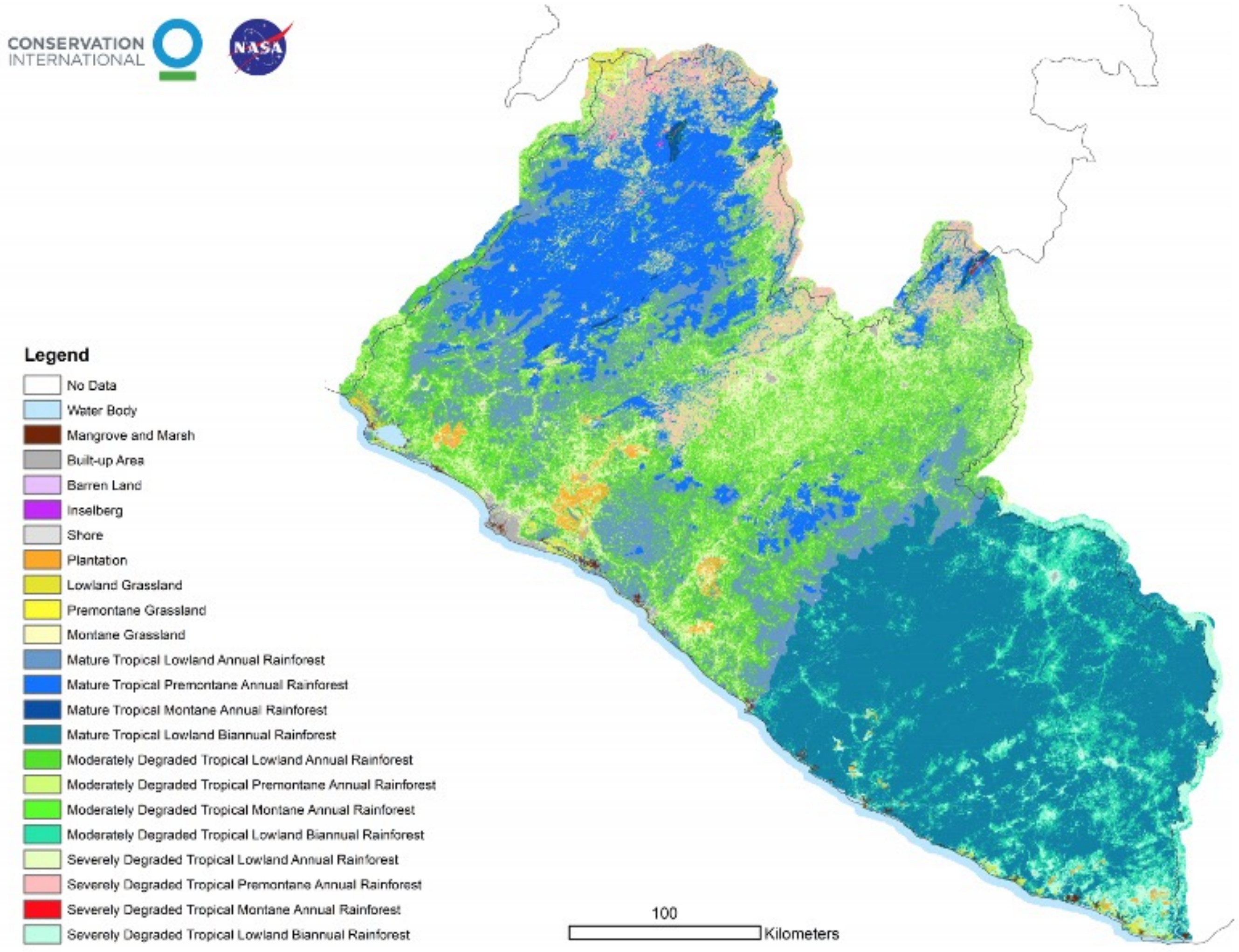


Image Credit: Conservation International

Processes for Ecosystem Mapping

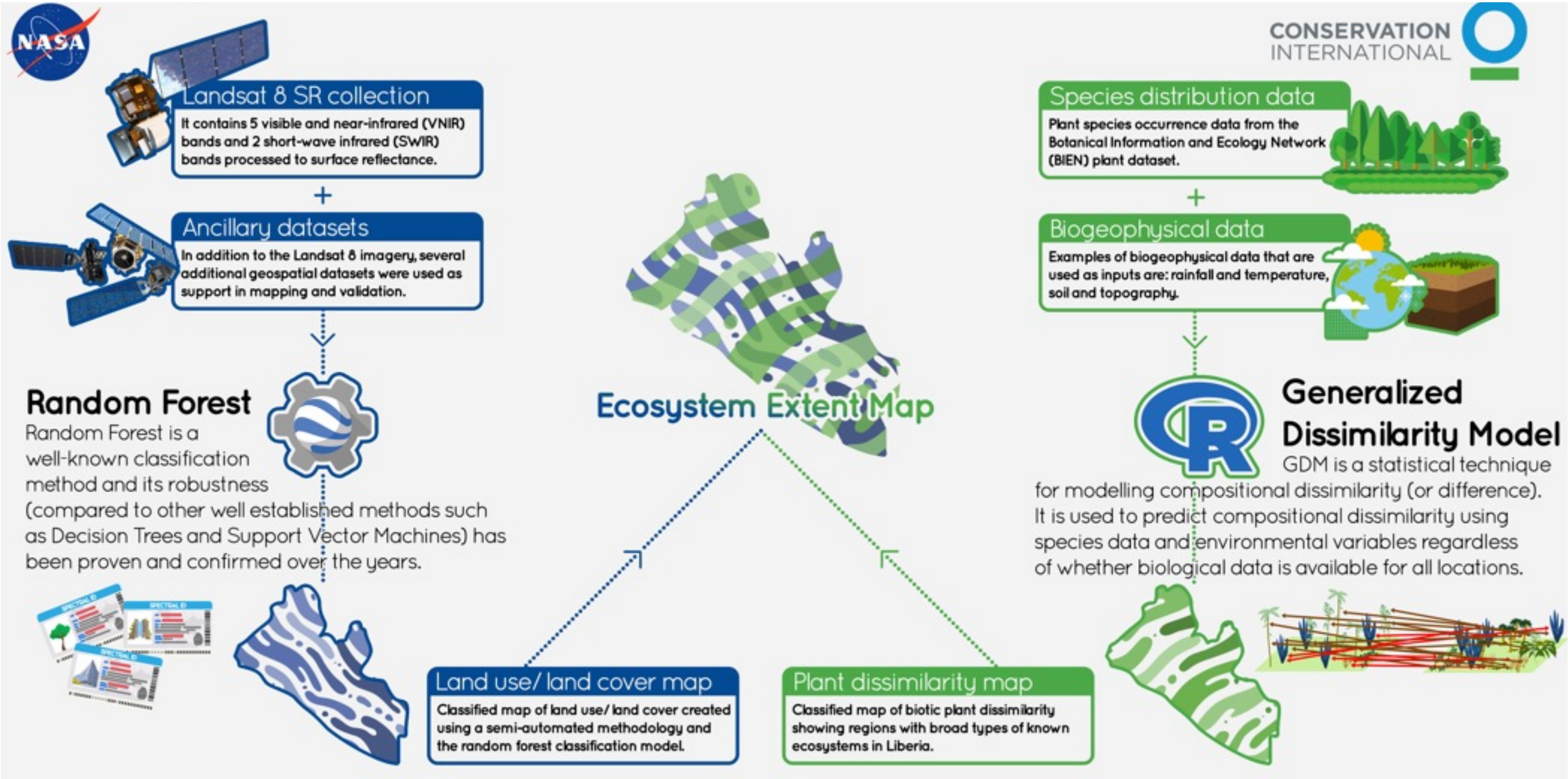
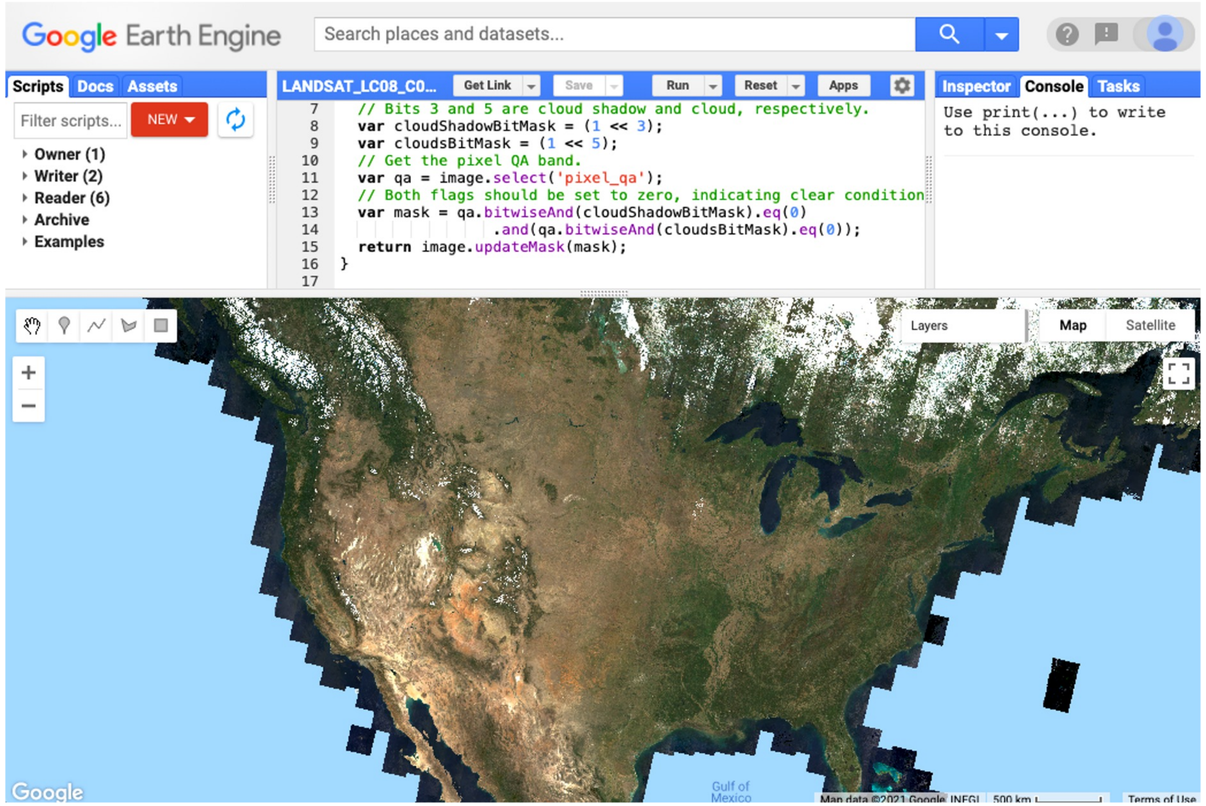


Image Credit: NASA and Conservation International

Open-Source Software and Cloud Computing

- Use of Google Earth Engine for imagery processing and analysis and R for statistical computing and graphics
- Low Cost
  - Open-source, freely available software
- Reproducible
  - Streamlined methodology
  - Facilitates replicability and transferability
- Accurate
  - Algorithms and classifiers ensure accurate maps



Google Earth Engine code editor interface using the JavaScript API, displaying Landsat 8 surface reflectance true color imagery for the U.S.
Credit: [Google Earth Engine Developers]

Land Use/Land Cover Map

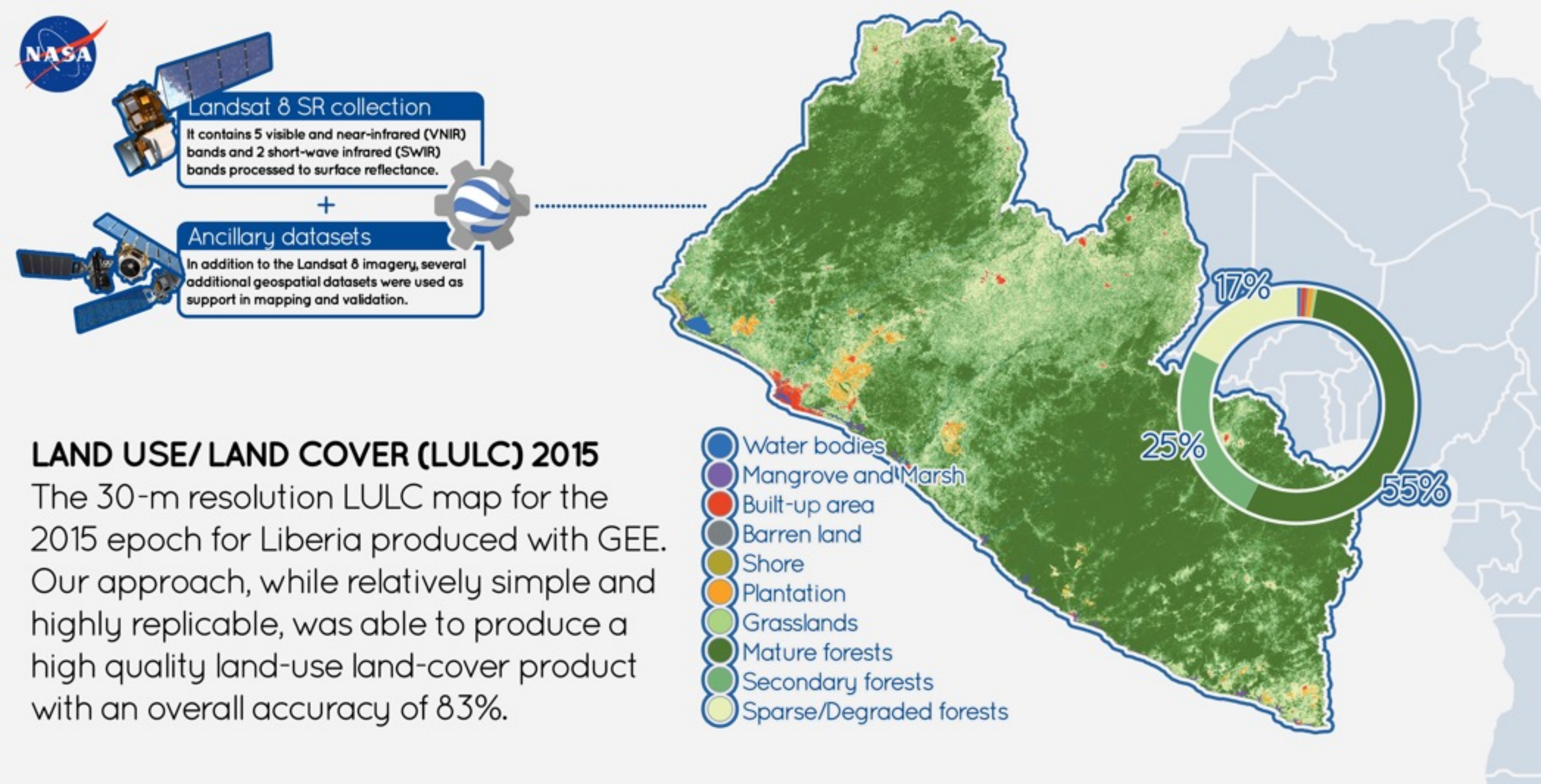


Image Credit: NASA and Conservation International

Biotic Plant Dissimilarity/Ecosystem Distribution

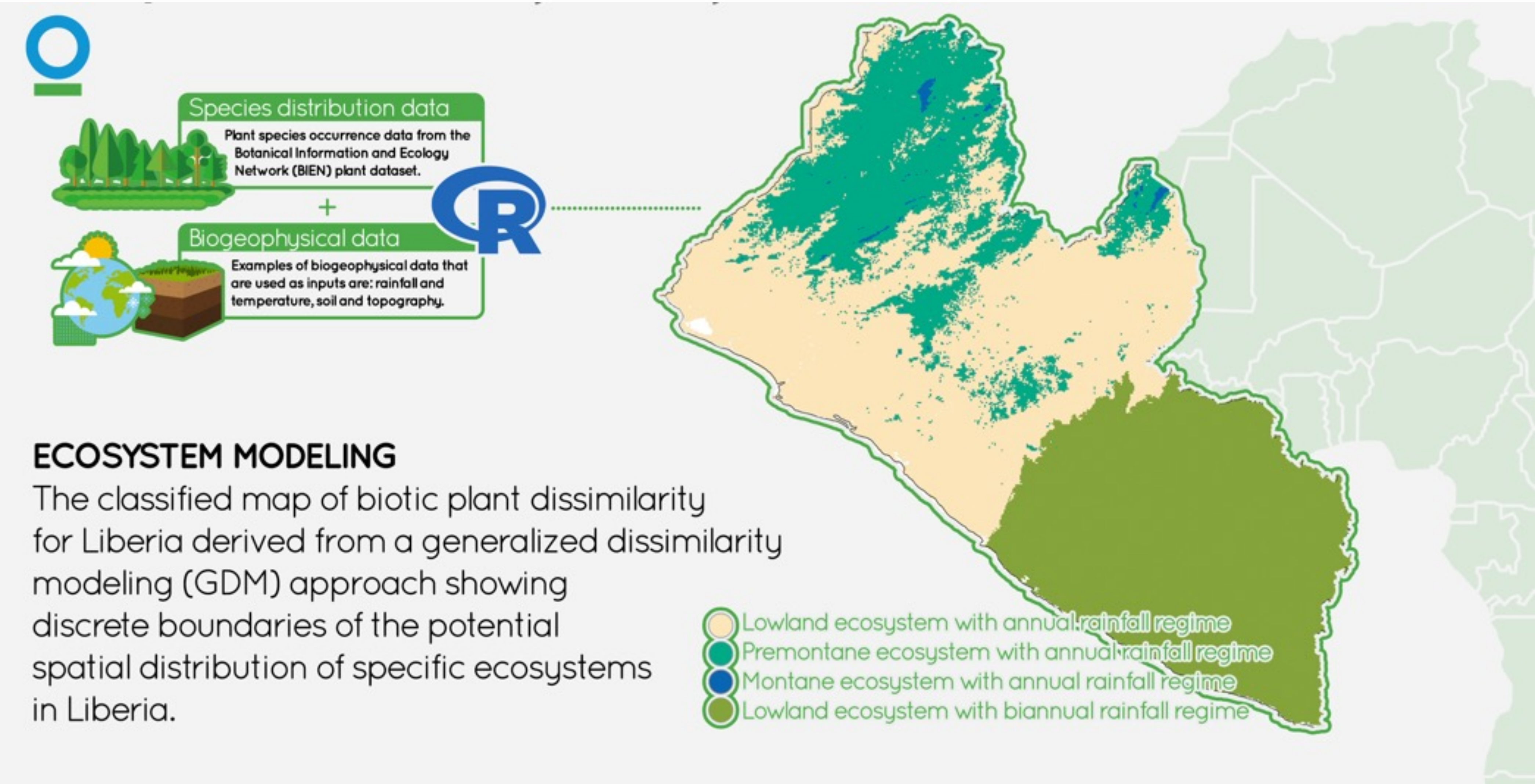


Image Credit: NASA and Conservation International

Ecosystem Extent

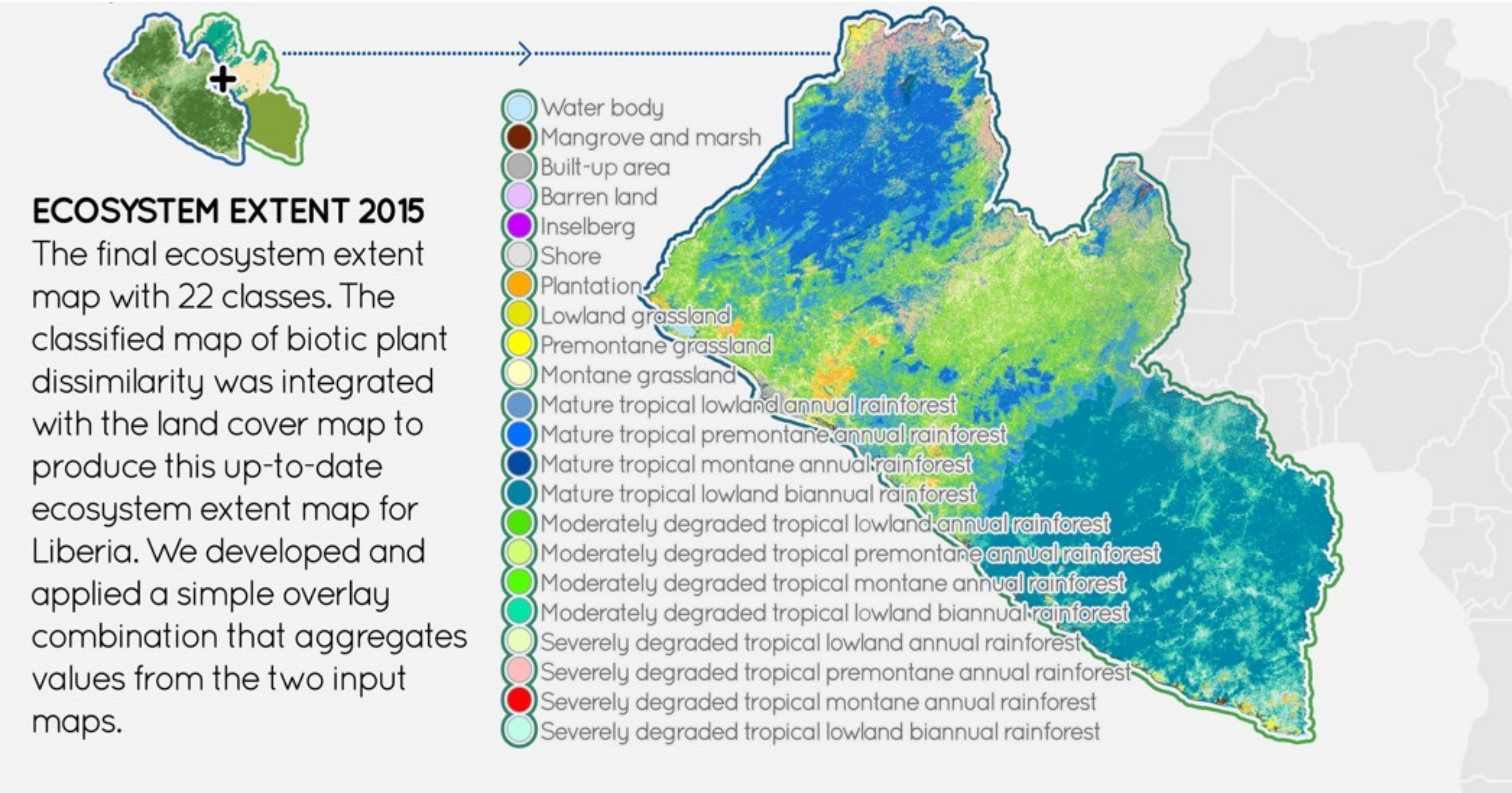


Image Credit: NASA and Conservation International

Future Training and Capacity Building

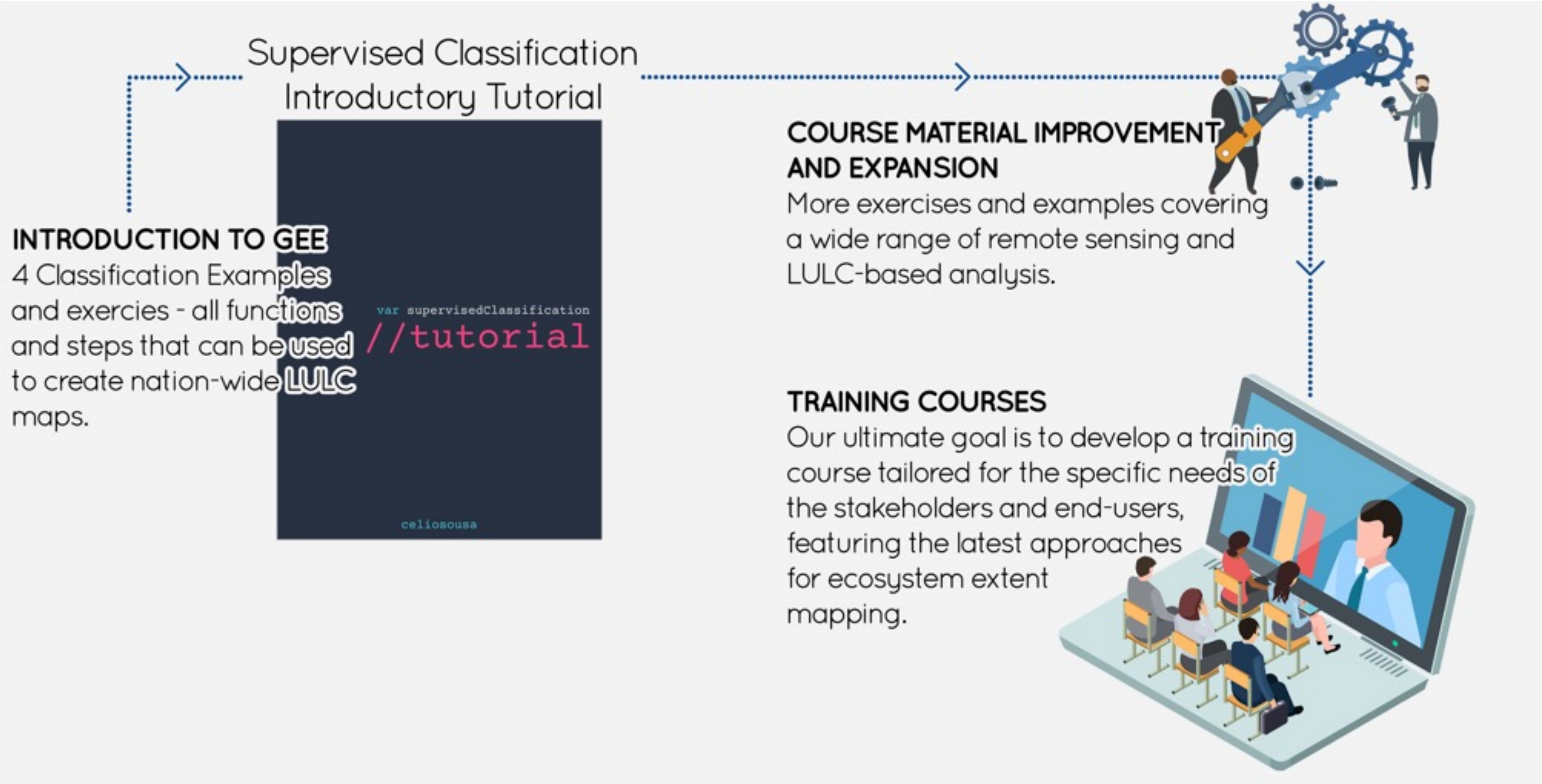
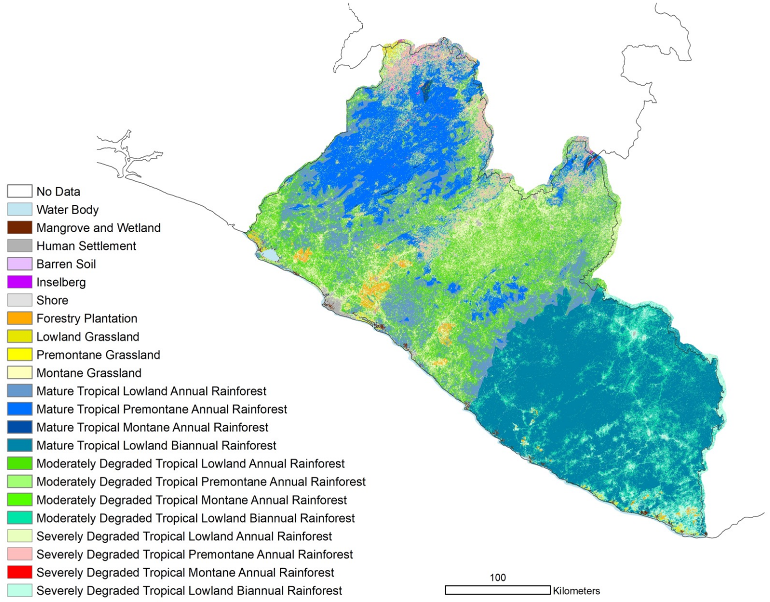
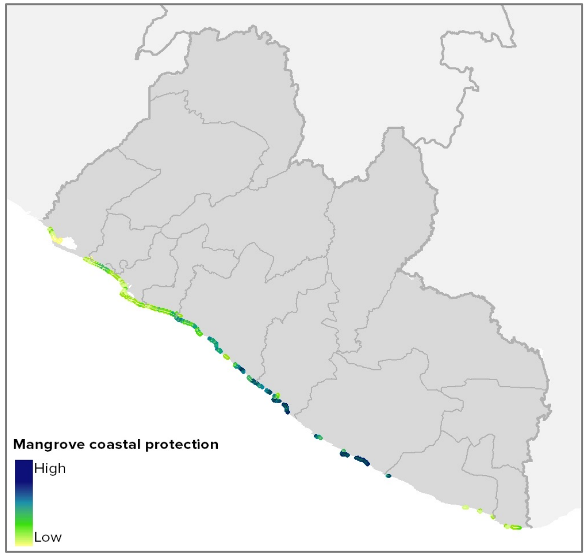


Image Credit: NASA and Conservation International

Next Steps for Natural Capital Accounting Projects

- GEF-Funded Project: 'Conservation and sustainable use of Liberia's coastal natural capital'



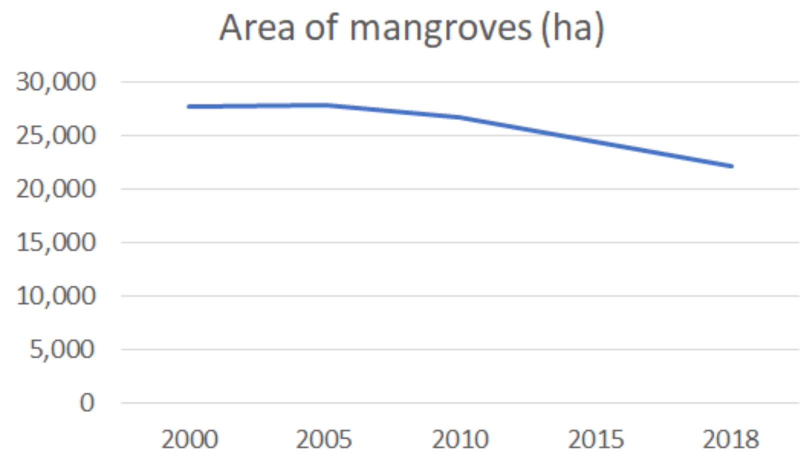


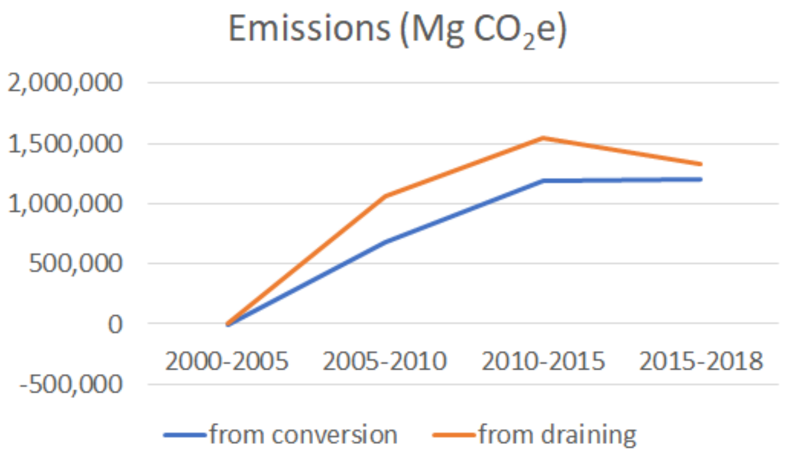
Land Account → Ecosystem Extent Account → Ecosystem Services Account (GEF-NCA Mangroves)

Image Credit: Conservation International

Policy Applications

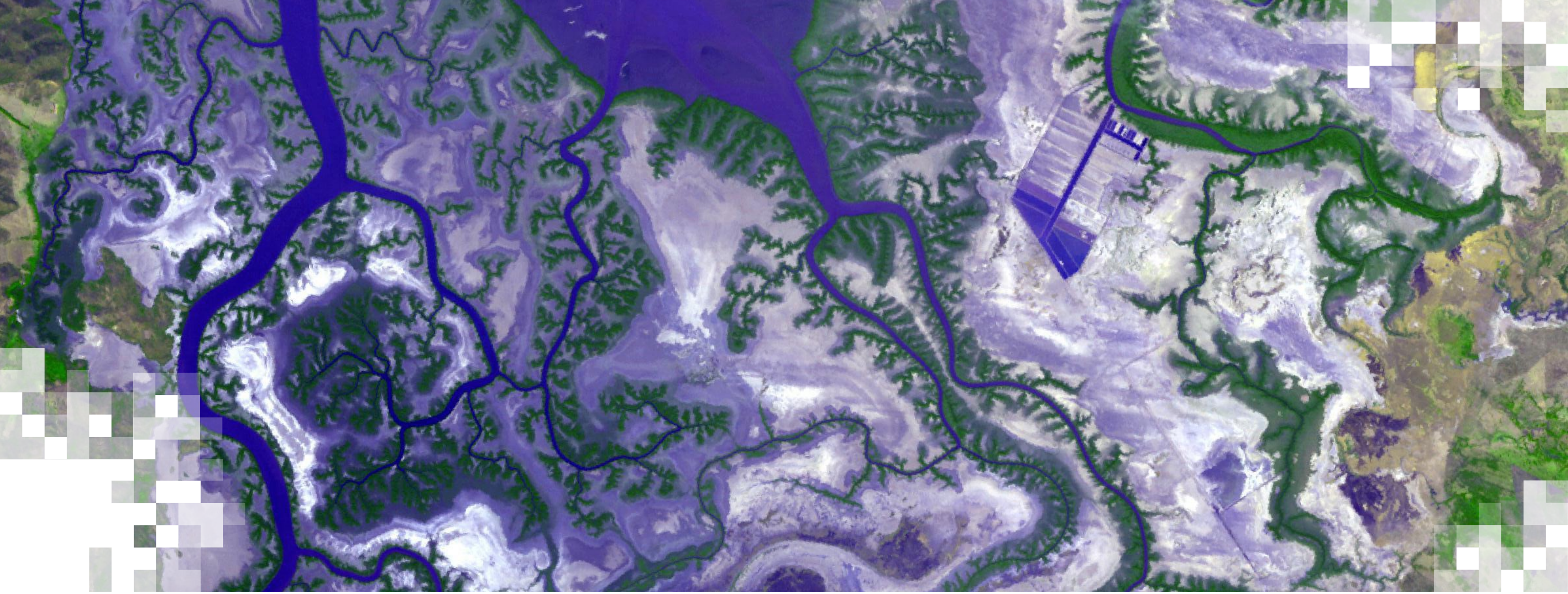
- Supporting the goal of protecting 30% of its territory
- Cross-Sectoral Planning and Decision-Making
- Impact assessment, siting of interventions, climate change adaptation/mitigation, spatial planning, etc.
- Supporting Multilateral Environmental Agreements
- Sustainable Development Goals
- Post 2020 Global Biodiversity Framework
- Climate Mitigation (NDCs)
  - Informing revisions
  - Measuring sectoral contributions of CO_2 emissions and sequestration
  - Supporting design, planning, and monitoring of NDC targets, activities, and indicators
  - Measuring co-benefits and human well-being





Continued Connections and Coordination

- The maps, land, and extent accounts generated through this partnership are an important step forward for informing policy and decision-making in Liberia.
- Environmental Protection Agency: Commitment to foster development of information, data, and knowledge-sharing for monitoring and reporting
- Multi-agency coordination with LISGIS, Forestry Development Authority (FDA), Land Authority, Maritime Authority, etc., ensuring alignment with national policies and laws, best practices, and new initiatives.



Earth Observations for Ecosystem Accounting (EO4EA): Uganda

Experimental Ecosystem Accounts for Uganda

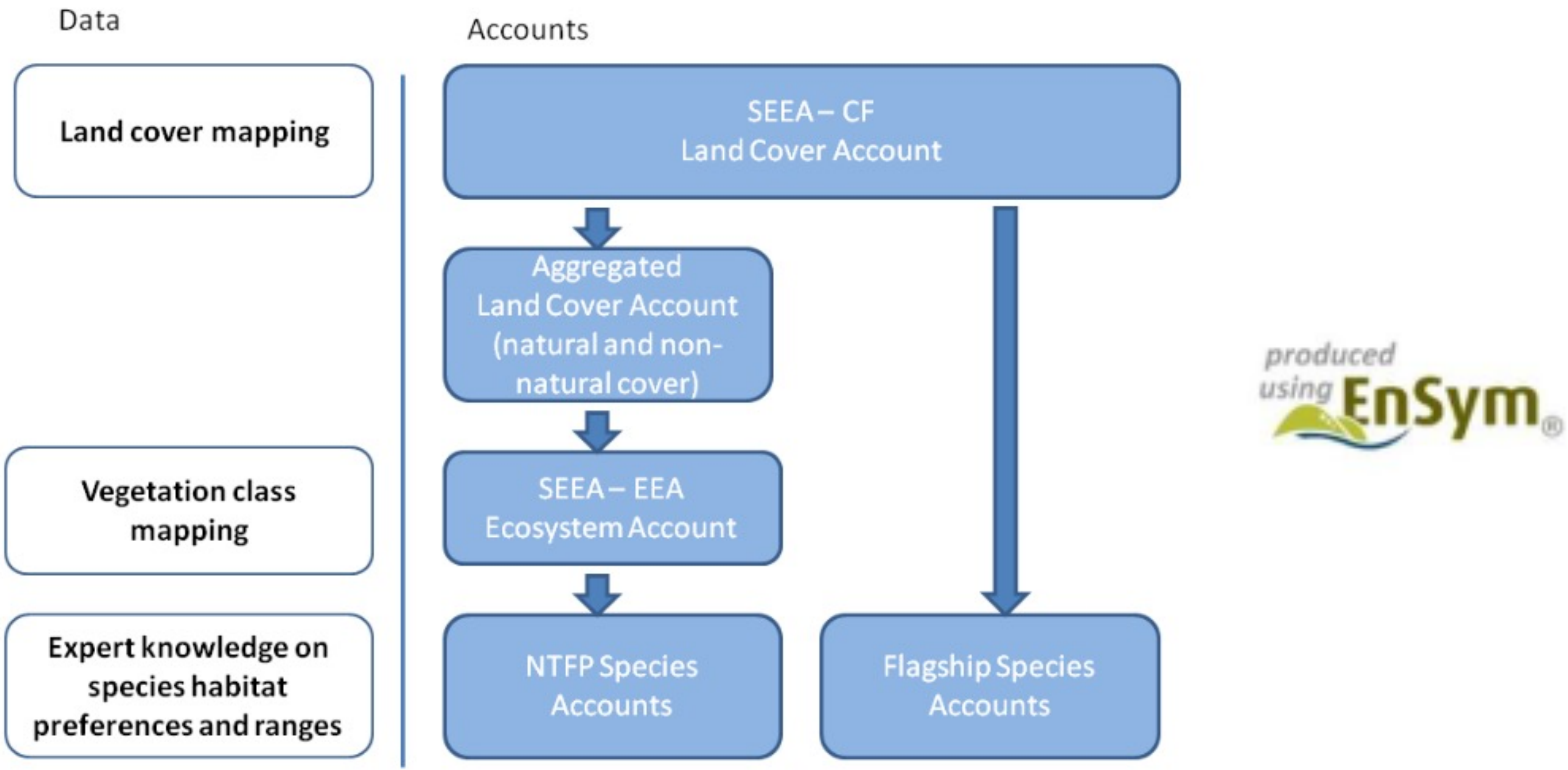
- Project to rapidly develop the required underlying spatial-data infrastructure and the compilation of key ecosystem and biodiversity-related accounts using the SEEA-EA framework
- Accounts:
  - Land cover
  - Ecosystem extent
  - Three non-timber forests
  - Two flagship mammals (Chimpanzees and Elephants)
- Project Report

UNEP-WCMC and IDEEA Group in collaboration with the Wildlife Conservation Society (WCS), National Planning Authority (NPA) of Uganda, National Environmental Management Authority (NEMA) of Uganda, and National Biodiversity Databank of Makerere University. The project was funded by the Swedish International Development Cooperation Agency (SIDA)

Policy Applications

1. To inform the ongoing debates surrounding the gazettement and de-gazettement of protected areas.
2. To make the case for increased budget allocation and investment in biodiversity-rich sectors for conservation and management (e.g., forestry as it maintains relatively high levels of biodiversity).
3. To establish the extent of ecosystem degradation and where declining biodiversity threatens the delivery of ecosystem services and implications on economic growth and human well-being.
4. To increase awareness and appreciation of biodiversity as a natural capital asset amongst decision makers and the public.
5. To assess national progress towards the objectives of Uganda's National Biodiversity Strategy Plan (NBSAP II) and National Development Plan (NDP II) and associated international commitments (i.e., the Aichi targets and SDGs).

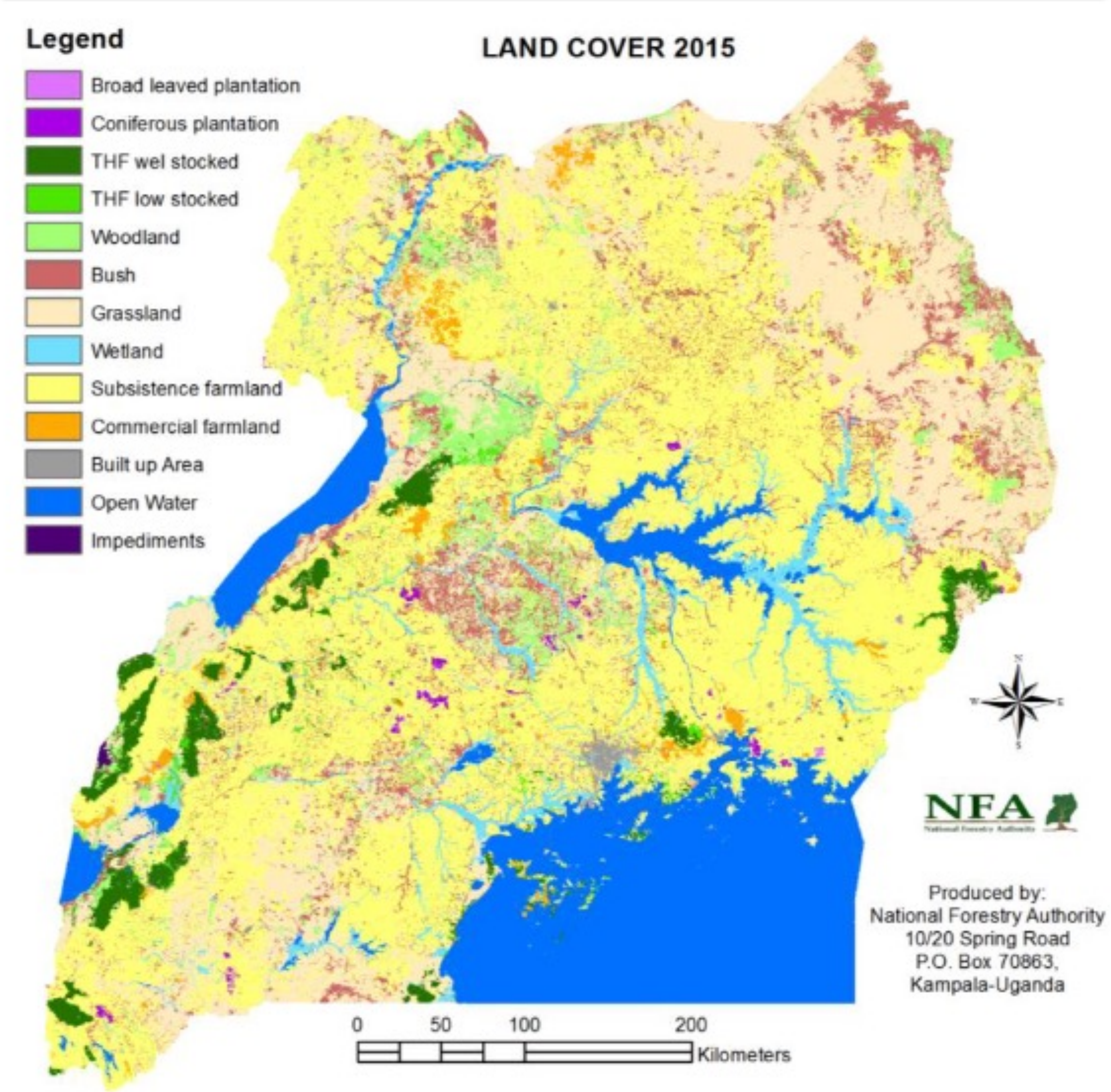
Approach



Credit: UNEP-WCMC & IDEEA (2017) Experimental Ecosystem Accounts for Uganda. Cambridge, UK.

Land Cover Mapping

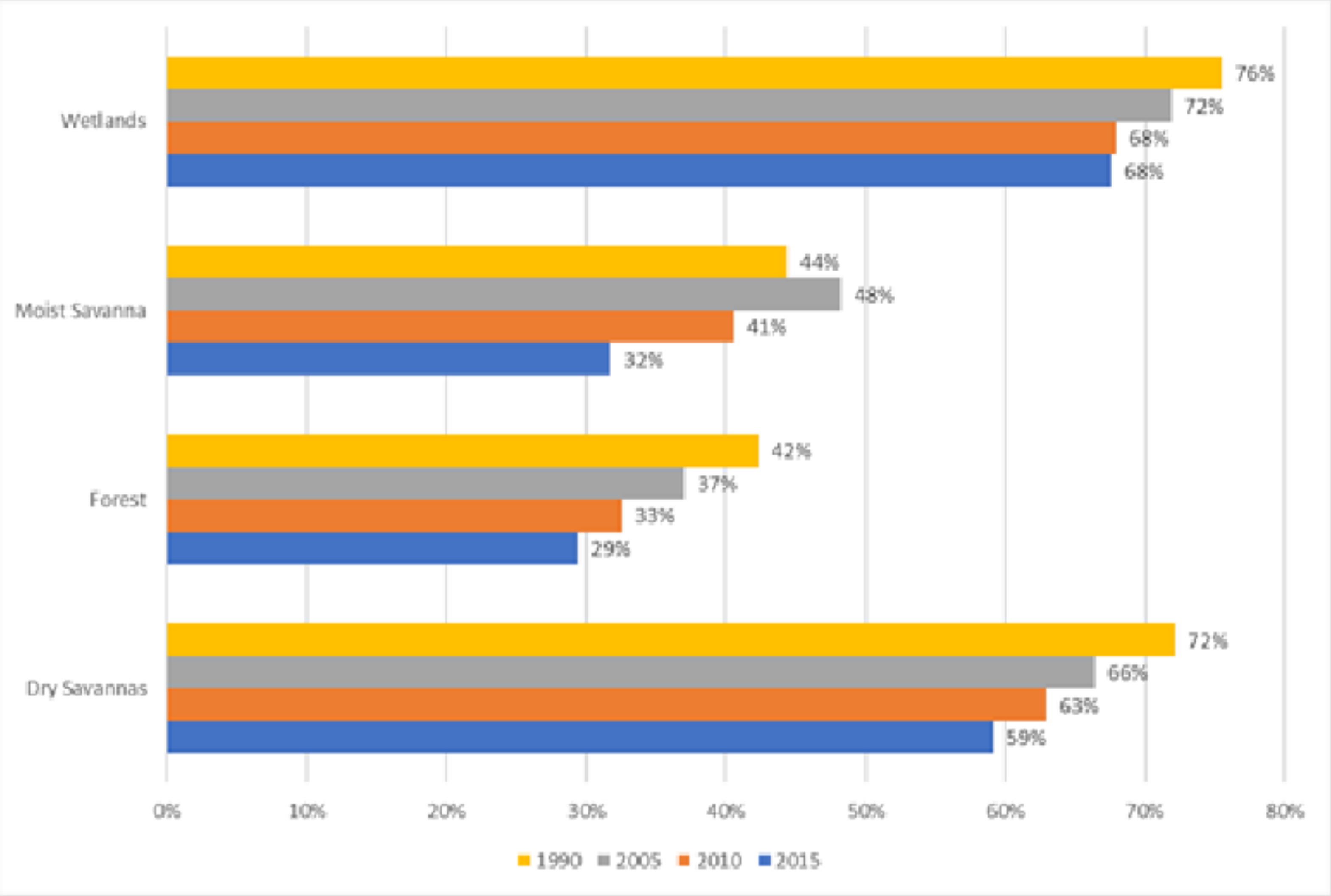
- National Biomass Study (NBS) produced maps from 1989–2005
- 2005-Onward: FAO Land Cover Classification System (LCCS) produced maps



Credit: [UNEP-WCMC & IDEEA (2017) Experimental Ecosystem Accounts for Uganda. Cambridge, UK].

Key Ecosystem Changes

- Changes to Key Ecosystems (1990-2015)
  - Substantial reductions in forests (29% of original extent remaining) and savanna (32% remaining)



Credit: [UNEP-WCMC & IDEEA (2017) Experimental Ecosystem Accounts for Uganda. Cambridge, UK]().

Protected Areas

- The protected areas estate has performed well by preventing the loss of natural ecosystems and the benefits they confer to Uganda. The protected areas prevented the loss of natural ecosystems and the benefits they confer to Uganda.
- Wildlife-watching tourism opportunities, a large majority of remaining fully-suitable chimpanzee habitat is protected in the Southwestern (96%), Western (84%), and West Nile (74%) sub-regions.
- However, substantial habitat still exists outside of protected areas in the Western sub-region (51,000ha) providing opportunities to target areas for future protection and tourism development.

Suitable Habitat for Key Species

- For elephants, a large majority of fully-suitable habitat is protected in the Karamoja (94%), Southwestern (97%), and Western (94%) sub-regions.
- For Prunus Africana (African Cherry), the protected area estate has been effective in covering the remaining highest quality range of this species.
- There are potentially significant species conservation benefits from conserving natural areas in Acholi, Karamoja, and West Nile (high bird and large mammal species richness).

Credit: infonet-biovistion.org

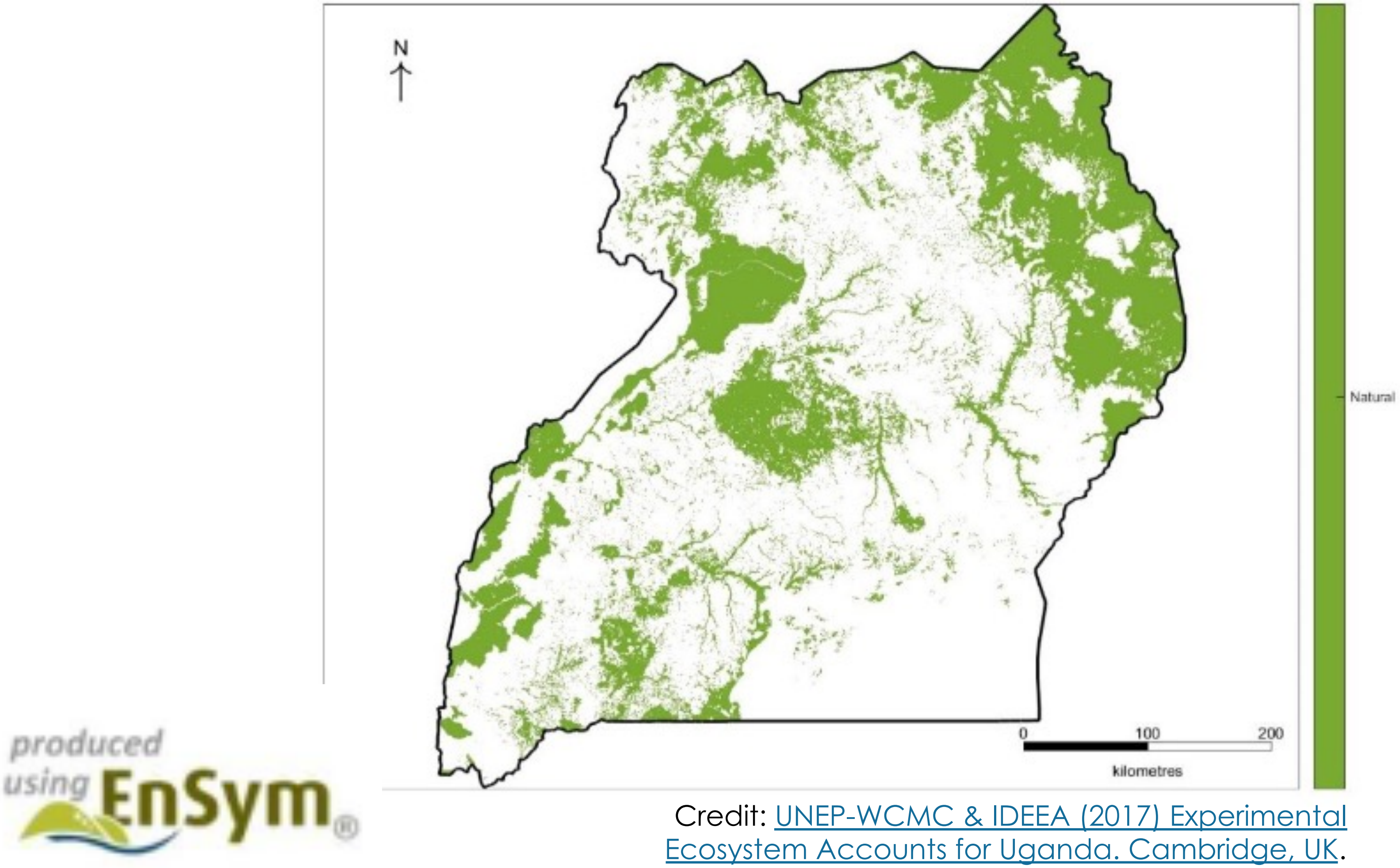
Credit: Janegoodall.ca

Credit: NRCD

Natural Vegetation and Non-Timber Forest Products (NTFPs)

- Large areas of potentially suitable natural vegetation for harvesting non-timber forest products (NTFPs)

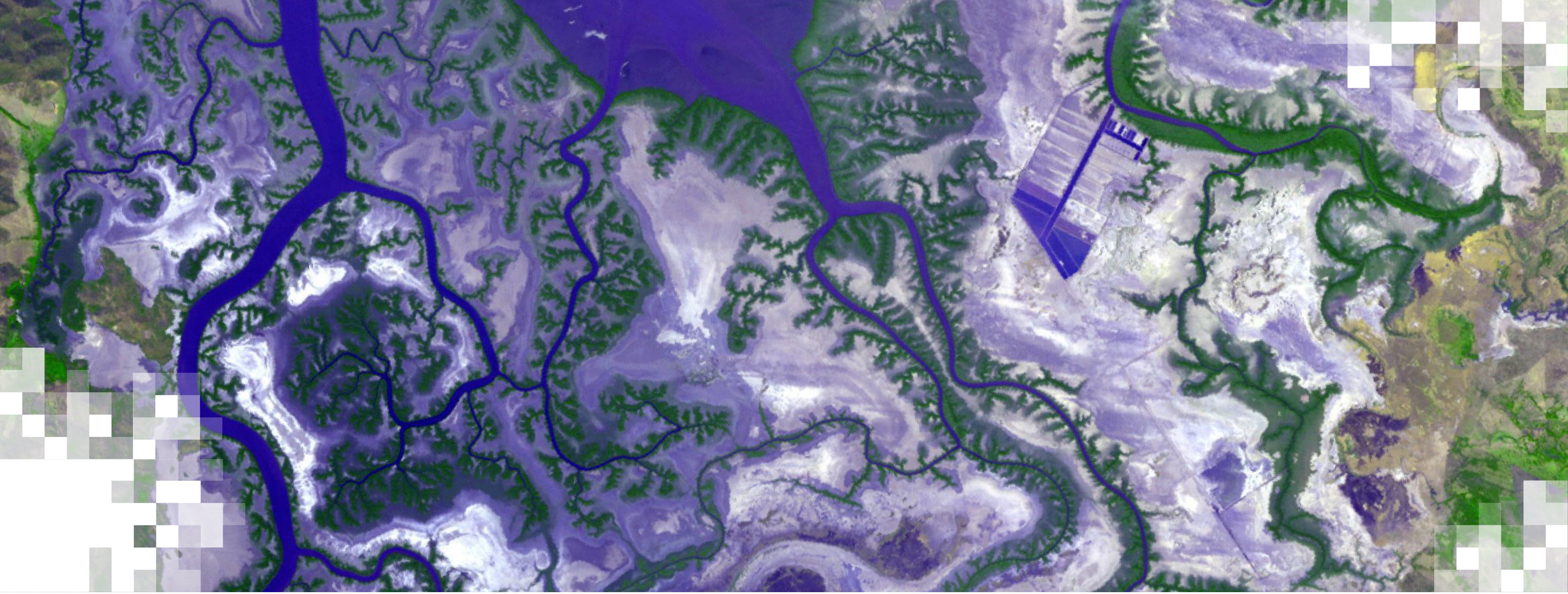
Extent of Permanently Natural Land Cover (1990-2015)



Credit: UNEP-WCMC & IDEEA (2017) Experimental Ecosystem Accounts for Uganda. Cambridge, UK.

Pathways Forward and Policy Implications

- Regular updates can be assessed in a timely manner for trends and extent of natural ecosystems and implications for key species
- Methodology will assist reporting on a range of policy commitments, including:
  - National strategic objectives for biodiversity specified in Uganda's NBSAP (II)
  - Aichi Targets (e.g., 4, 5, 11, 12, 13, and 15)
  - National development plan (II) objectives for Environmental and Natural Resources (ENR) and associated SDGs (e.g., 1, 12, and 15)
- Opportunities for:
  - Improving accounts in the future
  - Establishment of institutional arrangements and program connections



Wealth Accounting and the Valuation of Ecosystem Services (WAVES) in Indonesia

WAVES Overview

https://www.wavespartnership.org/en

- A World Bank-led global partnership that aims to promote sustainable development by ensuring that natural resources are mainstreamed in development planning and national economic accounts
- Part of the Global Program for Sustainability (GPS)
  - Aim to integrate environmental and other sustainability considerations into public and private decisions, by providing metrics and tools

Tsefaye Kidane, a 40-year-old coffee farmer from the Kafa Biosphere Reserve in southwest Ethiopia. Photo Credit: Kaia Rose, Connect4Climate – World Bank Group

GPS Global Program on Sustainability

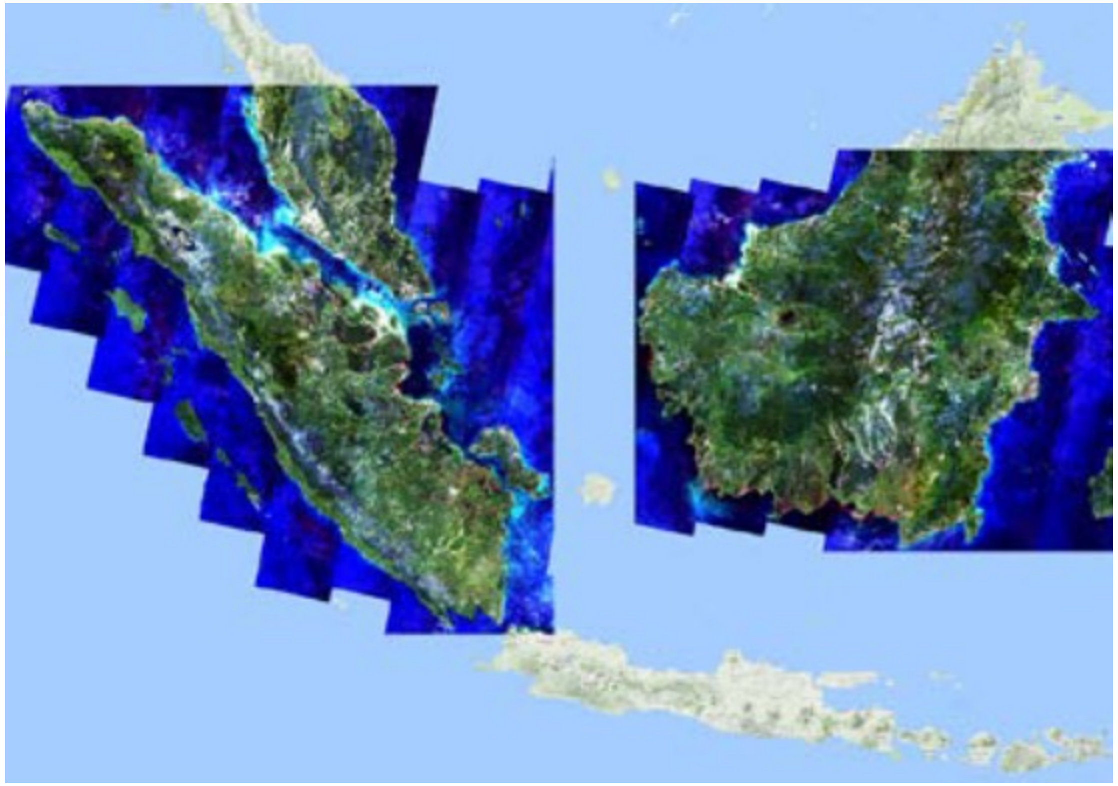
WAVES

Indonesian Assessment of Land Cover

- Agriculture, forestry, and fishing contribute to 11.4% of Indonesia's Gross Domestic Product (GDP).
  - Economic development is dependent on natural resources and the country wants to ensure that growth is conducted within the framework of the Sustainable Develop Goals (SDGs).
- Low Carbon Development Initiative for Indonesia (LCDI):
  - Incorporate greenhouse gas emissions targets into planning
  - Ensure growth while minimizing exploitation of natural resources and keep emissions low
- WAVES provided SEEA compliant data for modeling
  - Land cover and extent
  - Peatlands

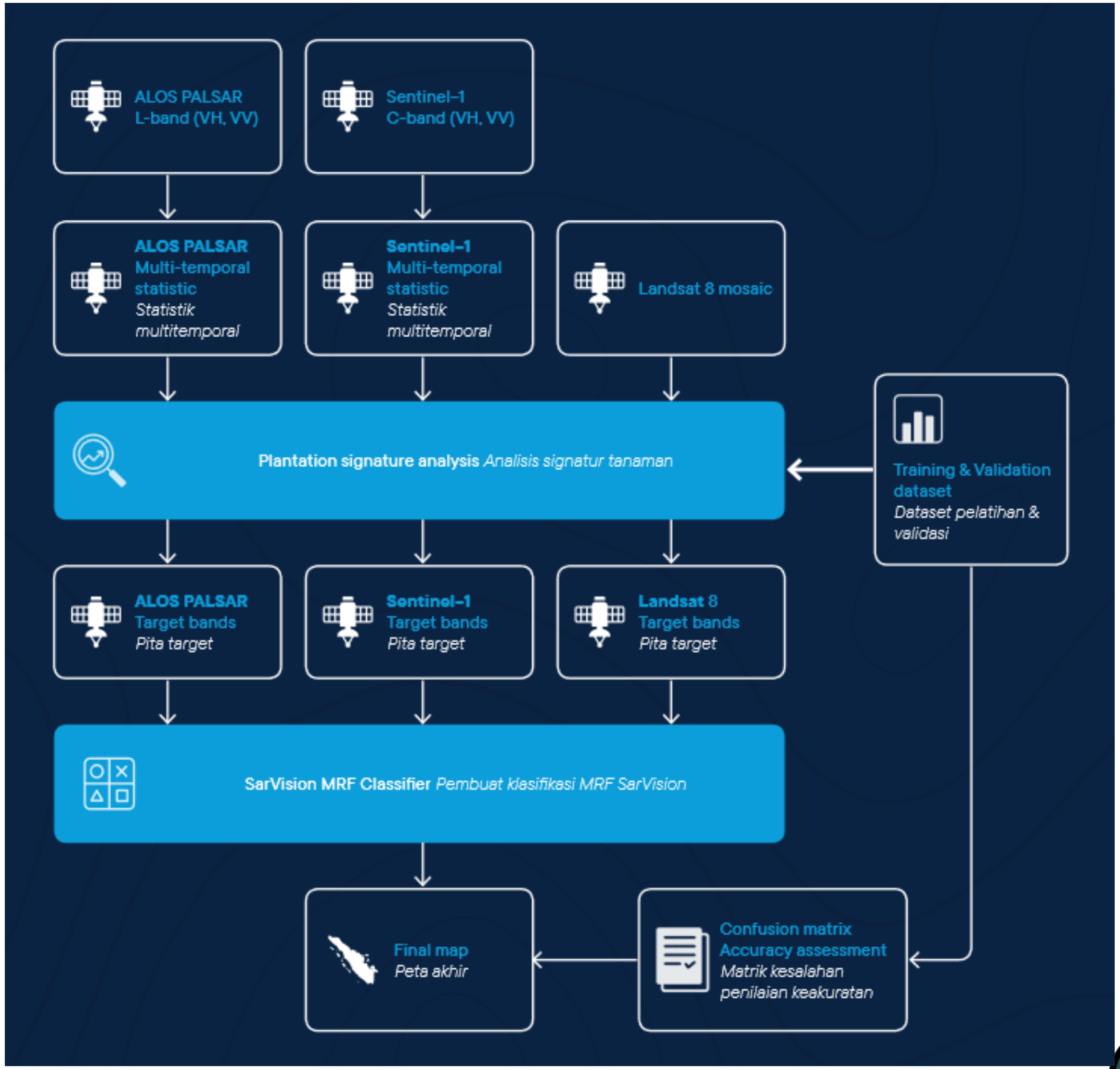
Indonesia Land Cover Mapping

- 22 classes of land cover
- 1990–2014
- Many remotely-sensed datasets



Real-color composite of the generated mosaics for Sumatera and Kalimantan in 2017, Image Credit: World Bank 2019

Image Classification Workflow: Image Credit World Bank 2019



Land Cover

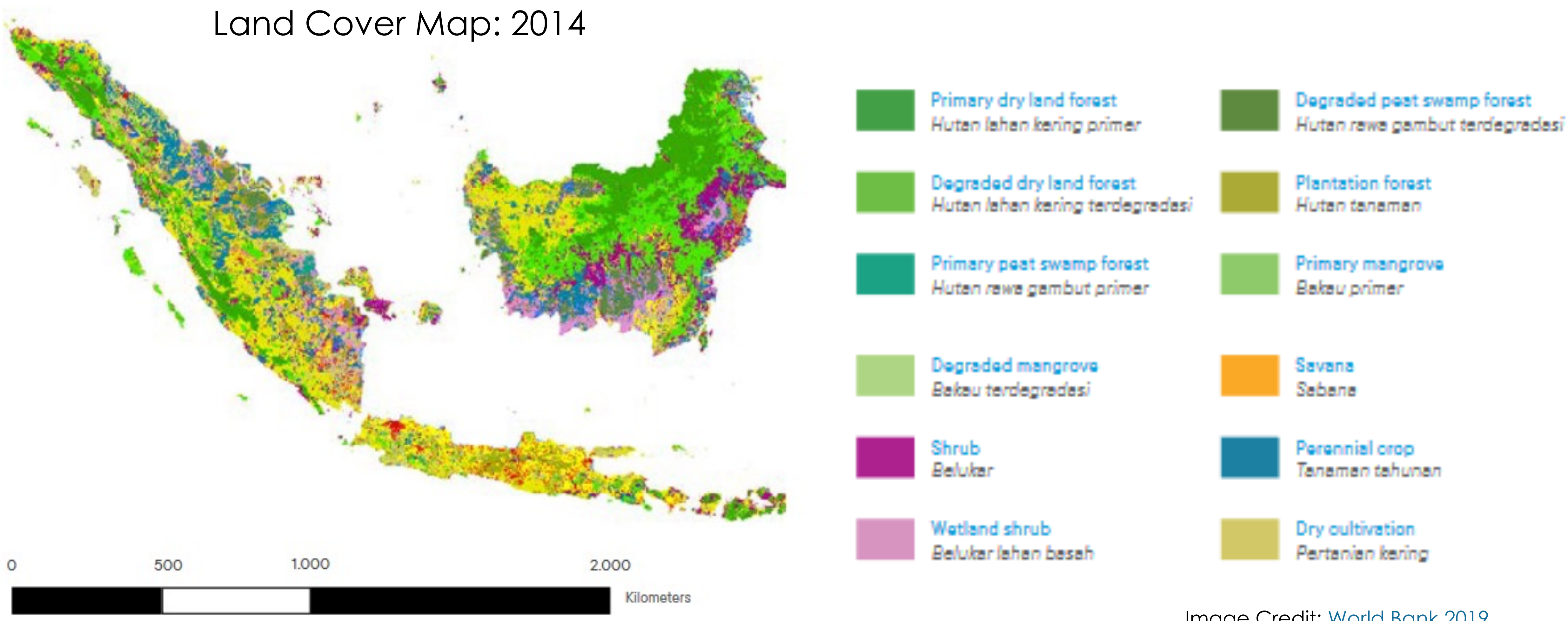


Image Credit: [World Bank 2019]

Land Account Key Takeaways

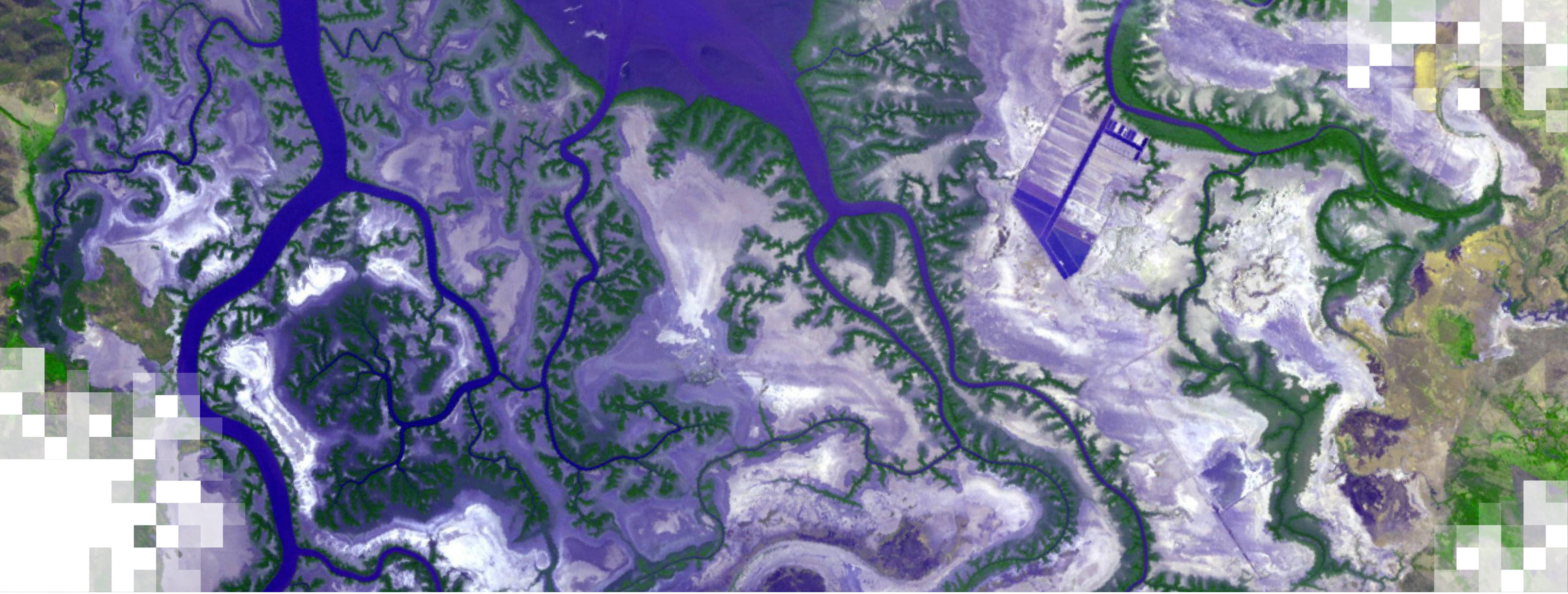
- The land account displays the changes in land cover over time.
- The major type of land conversion has been from forest to plantations.
- Perennial crops and plantation forestry may be significantly underestimated in official statistics.
- Indonesia lost about 33 million ha of its natural forests (about 17% of Indonesian land area) from 1990 to 2014.
- Perennial crops, which are currently dominated by oil palm plantation, were rapidly expanding from 1990 to 2014.
- Land cover change clearly varies in different island groups.

Adi Lumaksono, Principal Secretary of BPS hands over two technical reports of the I-WAVES program to Dr. Ir. Arifin Rudiyanto, Deputy Minister of Maritime and Natural Resources of Bappenas. Image Credit: World Bank

Extent Account Key Takeaways

- Policy implications similar to land account
- Remote sensing data key:
  - Use of Sentinel -1, Landsat, ALOS Palsar
  - WorldView and Planet data used in support
- Need to differentiate classes of perennial and plantation forests into crop and tree species
  - Difficult for some plantations
- Oil palm is the dominant perennial crop in both islands, acacia is the main plantation forestry species.

Palm Oil. Image Credit: joakimbkk



Ecosystem Services of Coral Reefs

Ecosystem Services of Coral Reefs

- Coral reefs are among the most biodiverse and biologically complex ecosystems of the world.
- Provide habitat to >25% of all known marine species including plants, algae, invertebrates, and vertebrates.
- Provide a food source for millions of people through fisheries.
- Major source of recreation and income to local communities through tourism activities.

Photo Credit: Juan L. Torres-Pérez

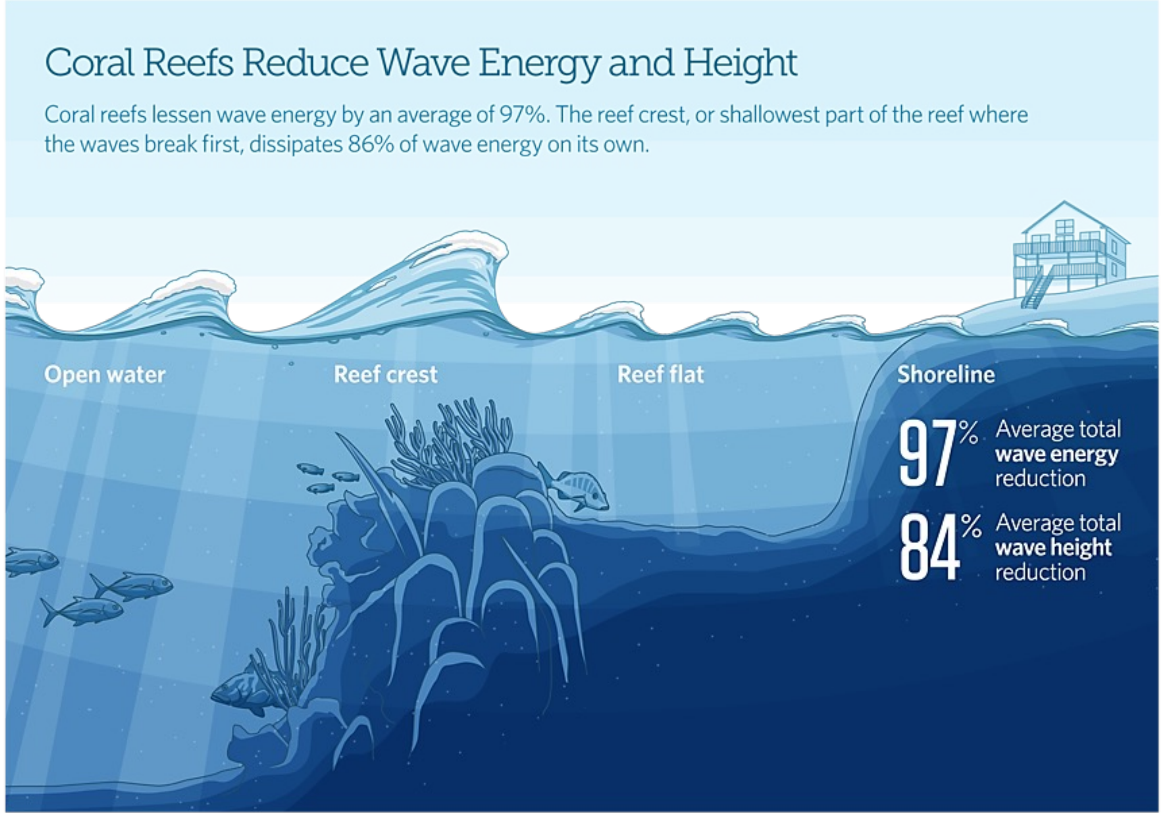
Ecosystem Services of Coral Reefs

- Spalding et al (2017) estimated the total global value of coral reefs for tourism at $36 billion per year.
- In the US, the touristic value of coral reefs alone is estimated to be ~$1.2 billion per year.
- For example, in Florida, it is estimated that ~70,400 jobs depend on coral reefs.
- Overall, the annual economic value of the world's coral reefs (including tourism, fishing, local jobs, and shoreline protection) is estimated between $375 billion and $9.9 trillion! (Costanza et al 2014)

Photo Credit: Juan L. Torres-Pérez

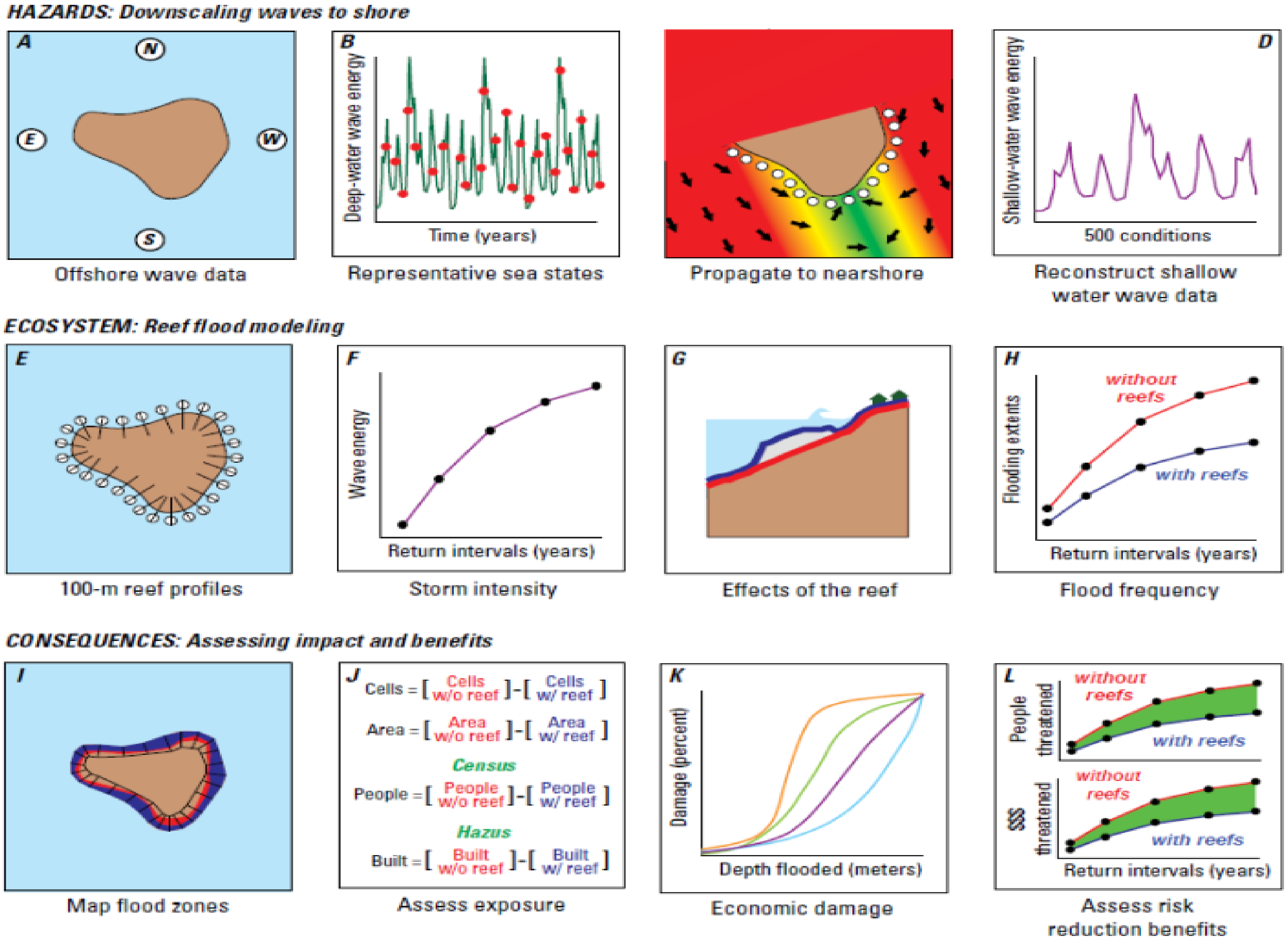
Ecosystem Services of Coral Reefs

- Reefs can dissipate ~97% of the wave energy resulting in decreased coastal flooding (Ferrario et al (2014).
- Storlazzi et al (2019; 2021) estimated the value of coral reefs for flood protection to be ~$1.8 billion for the US alone.
- Benefits of reef restoration were estimated at ~$232 million for Florida and ~$40 million for Puerto Rico annually (Storlazzi et al 2021).
- The present value of large-scale reef restoration for Fl and PR (when reefs are considered as natural infrastructure) exceeds $3.75 billion per year.



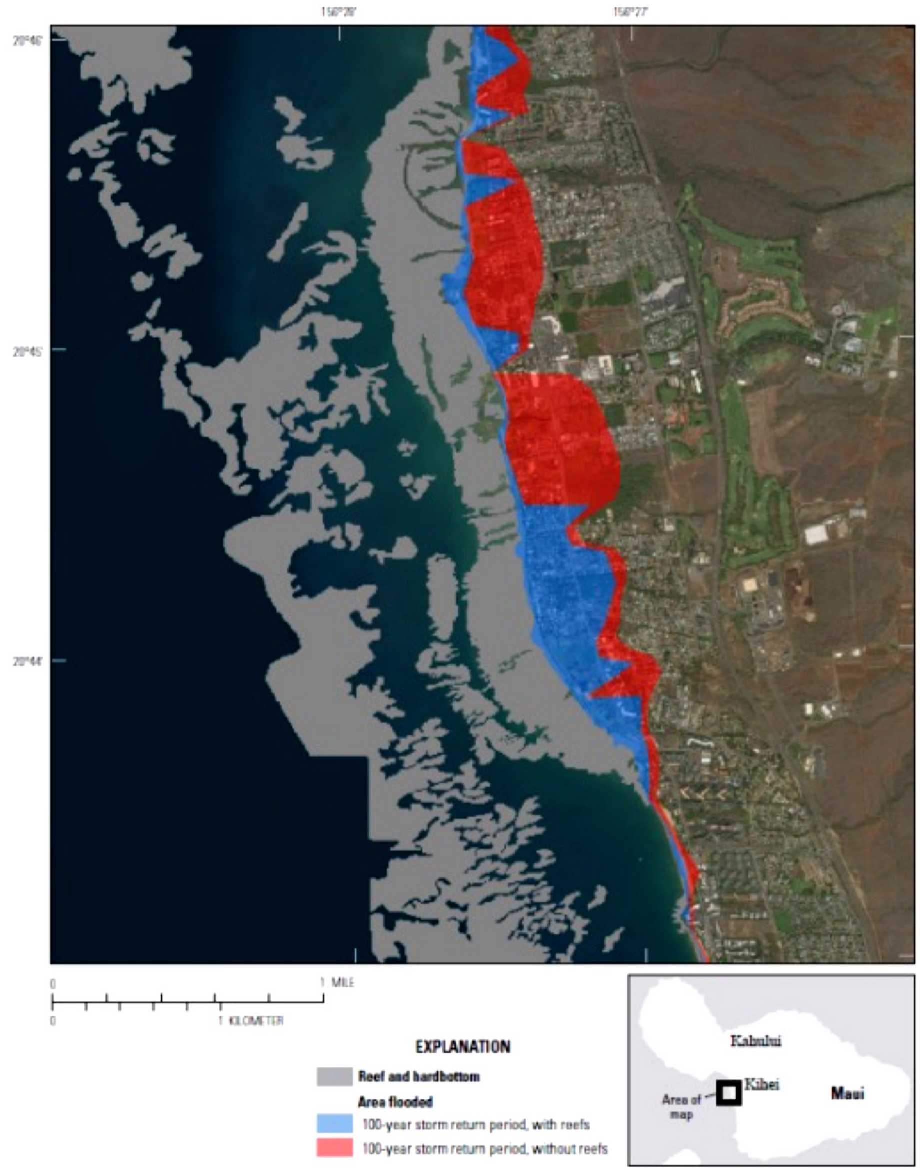
Credit: Ferrario et al (2014)

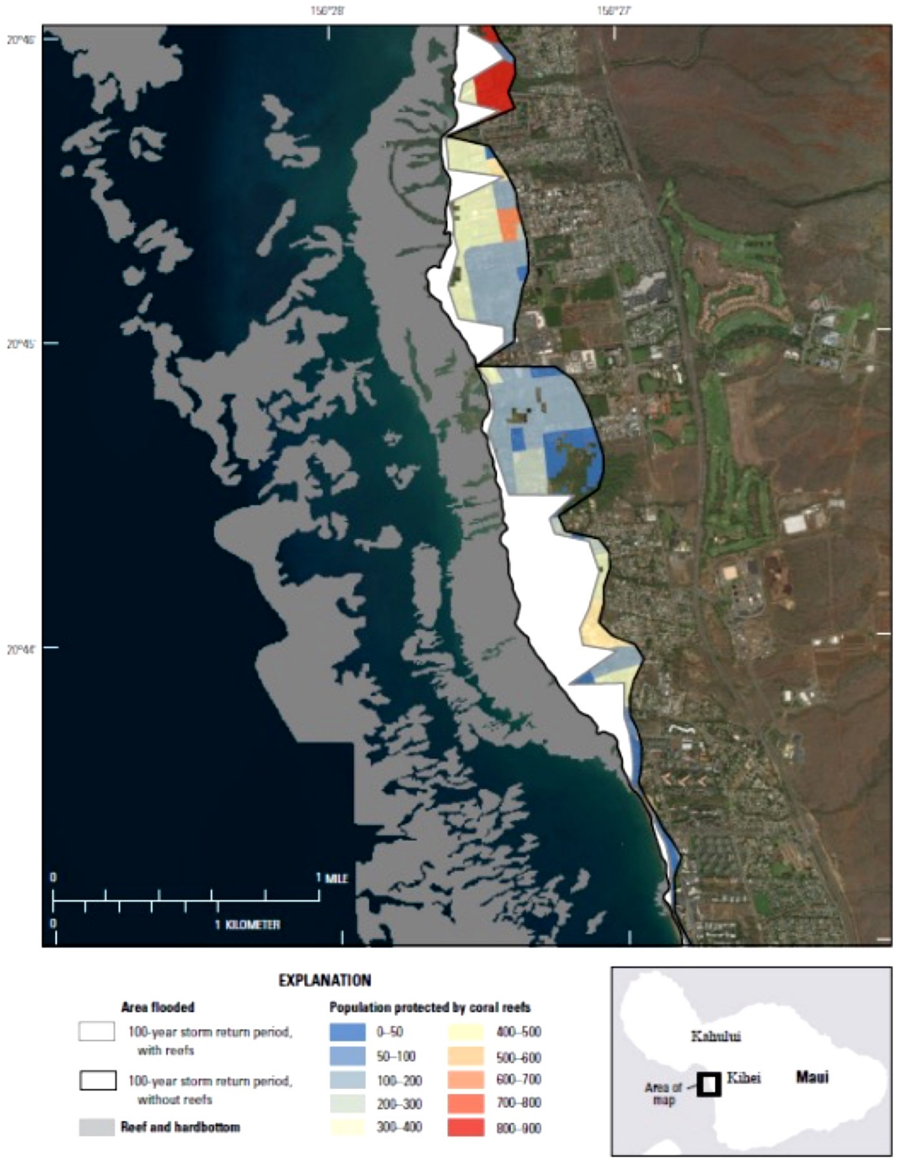
Evaluating the Role of Coral Reefs on Coastal Risk Reduction



Credit: Storlazzi et al (2019, 2021)

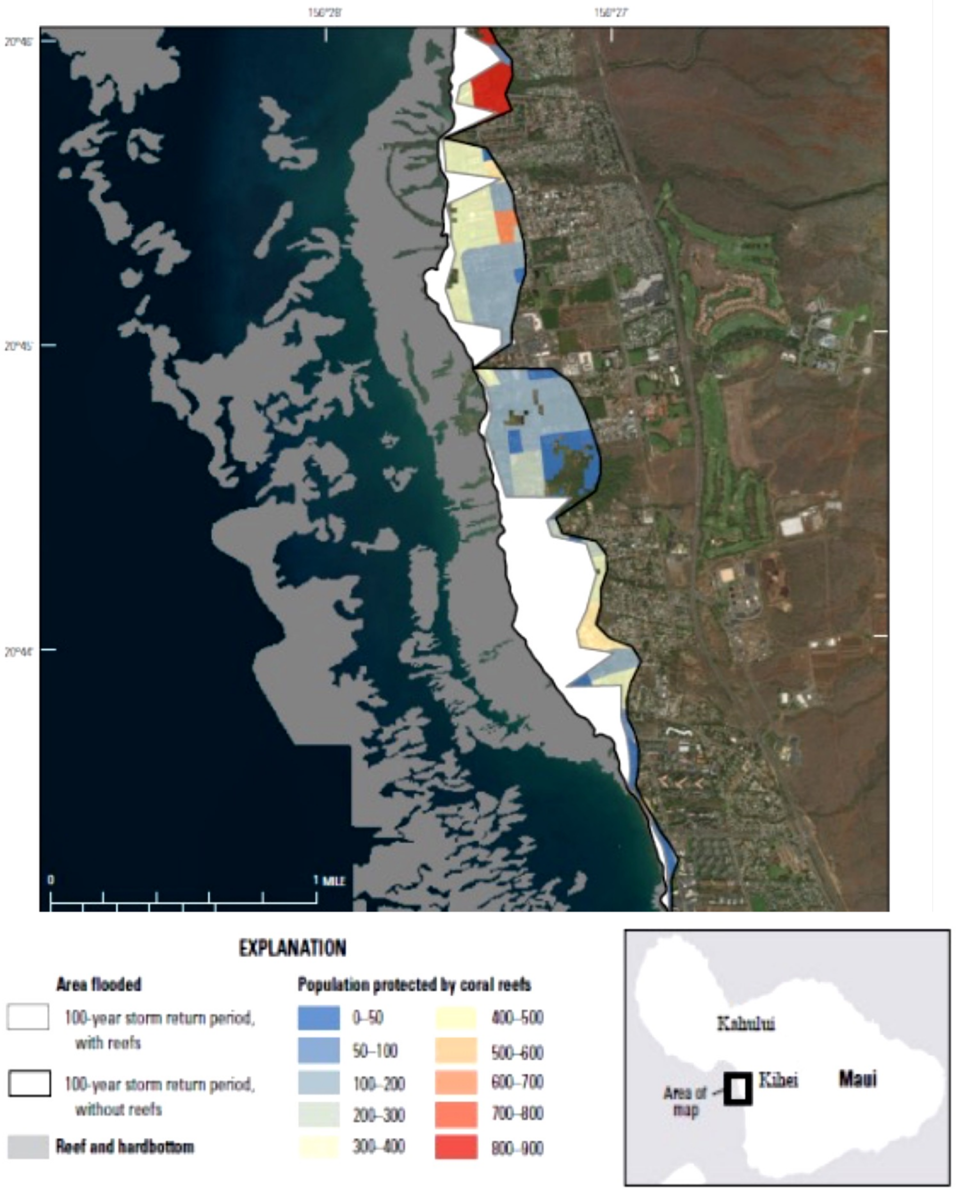
Coastal Protection by Coral Reefs – Maui, HI

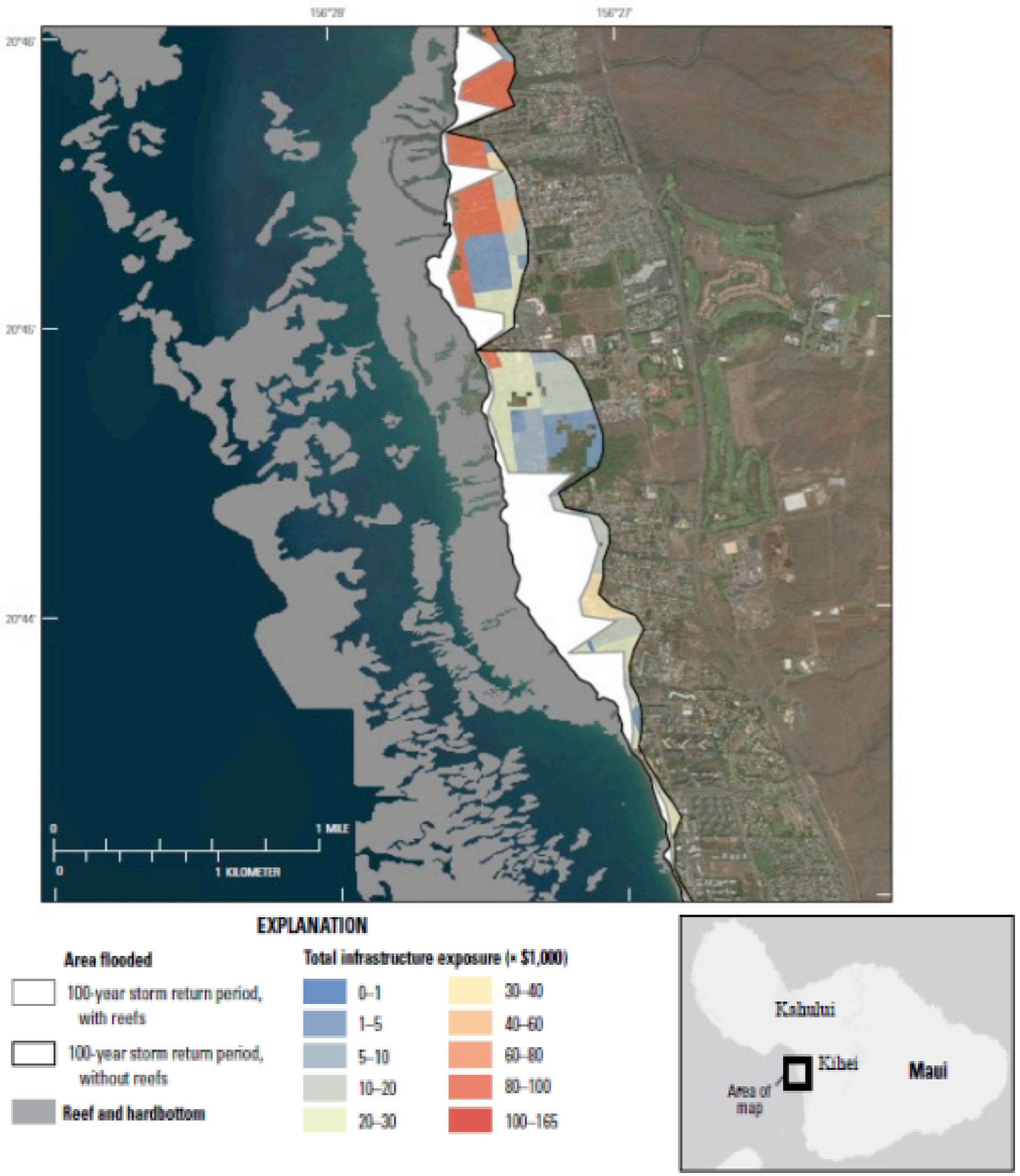




Credit: Storlazzi et al (2019)

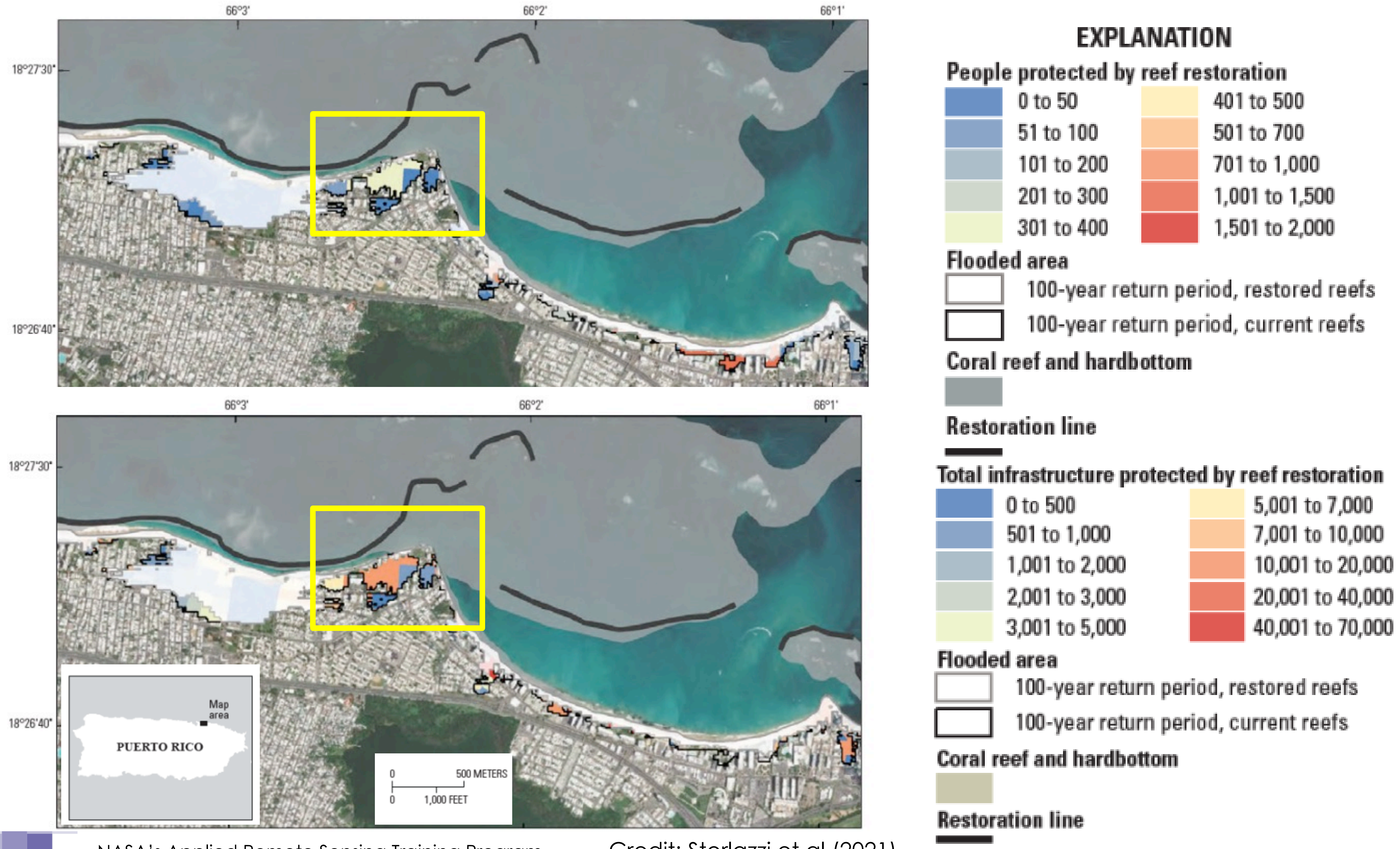
Coastal Protection by Coral Reefs – Maui, HI



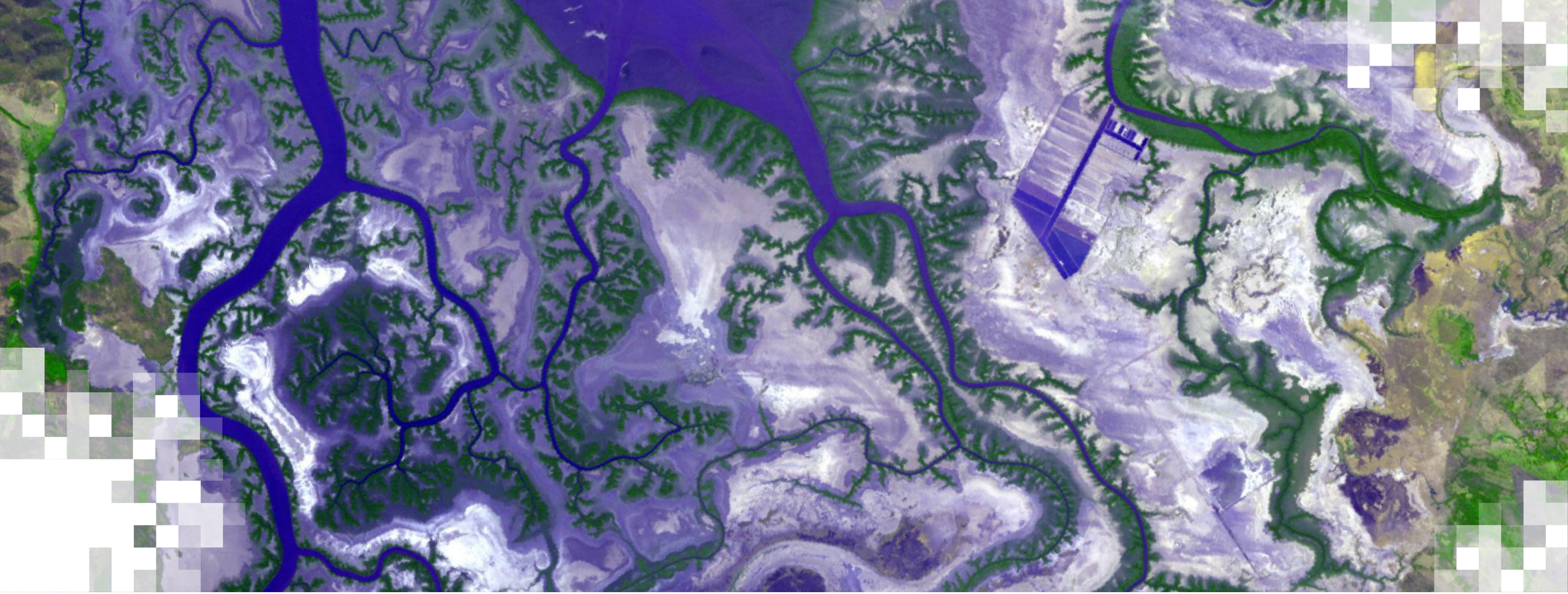


Credit: Storlazzi et al (2019)

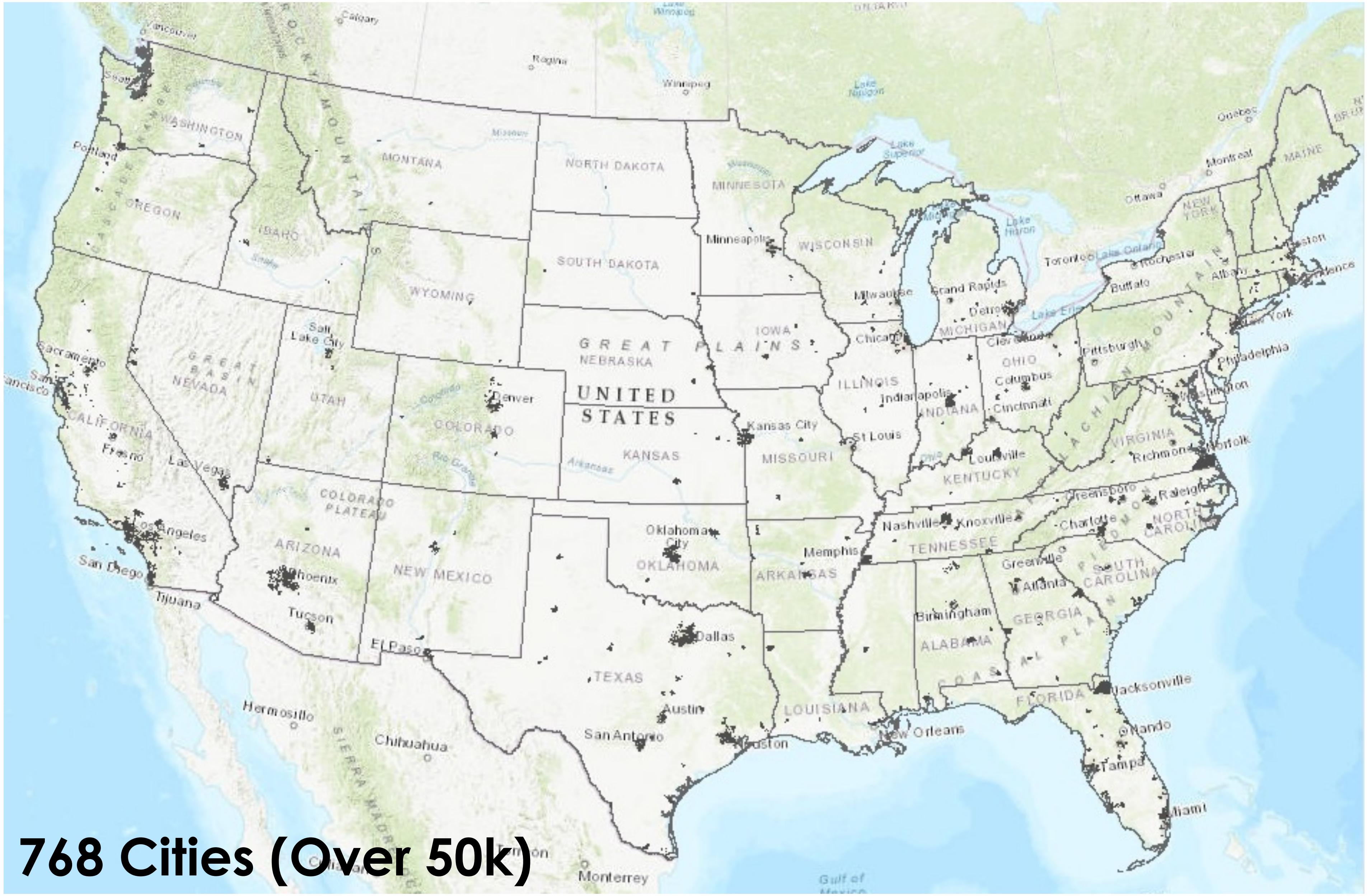
Coastal Protection by Coral Reefs – Puerto Rico and FL



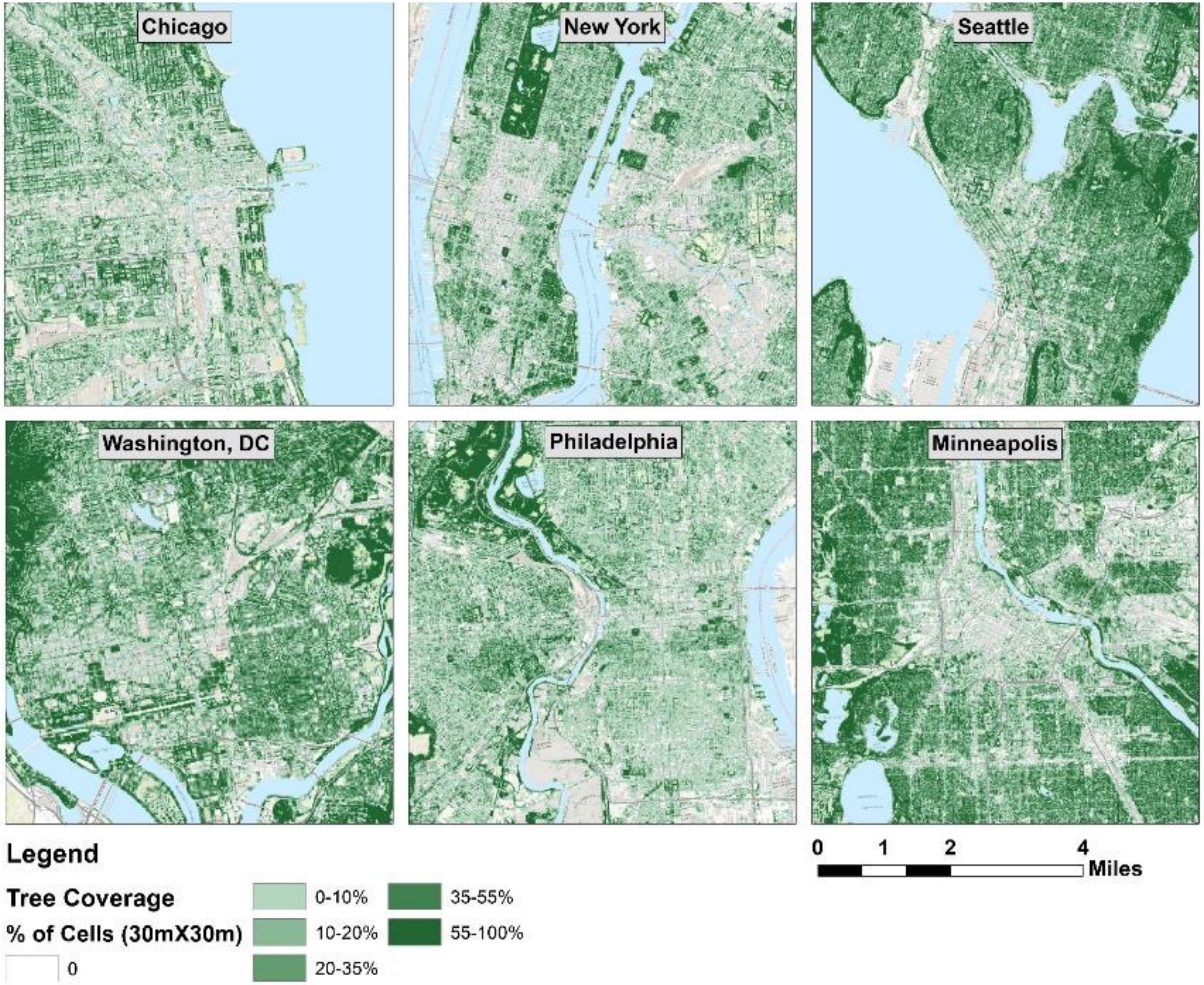
Credit: Storlazzi et al (2021)



Guest Speaker: Mehdi Heris (Hunter College City University of New York)



768 Cities (Over 50k)



Chicago
New York
Seattle
Washington, DC
Philadelphia
Minneapolis
Legend
Tree Coverage
% of Cells (30mX30m)
0
0-10%
10-20%
20-35%
35-55%
55-100%
0 1 2 4
Miles

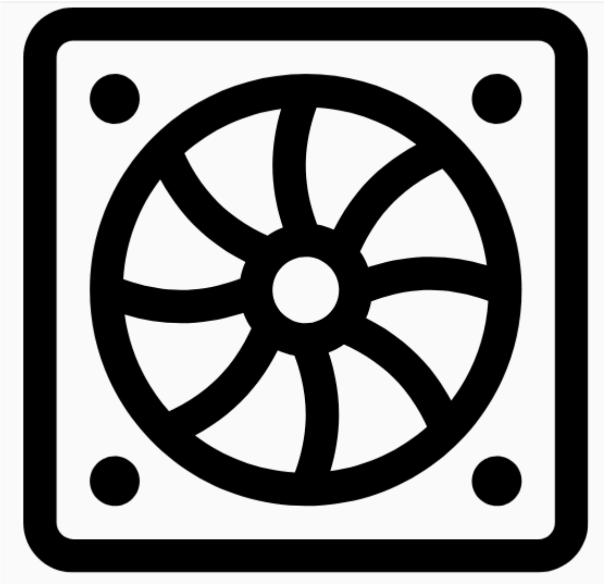
Ecosystem Services of Urban Trees

- We will discuss valuation of:
  - Urban heat mitigation
  - Storm water reduction through rainfall interception

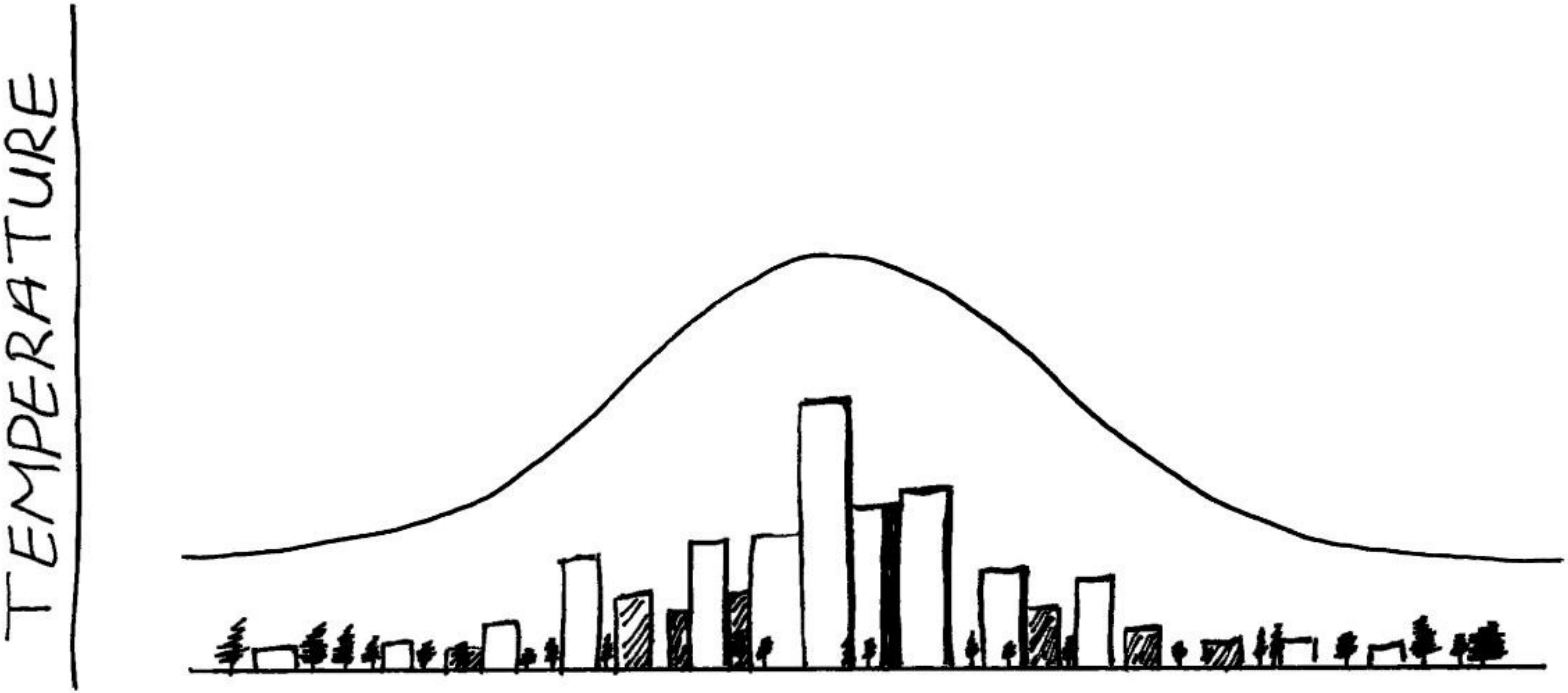
- Other Services:
  - Air quality regulation
  - Biodiversity
  - Habitat
  - Aesthetic value translated to land value
  - Positive impact of the environment on mental health

Heat Mitigation

Cooling Energy Savings



What is Urban Heat (Island)?

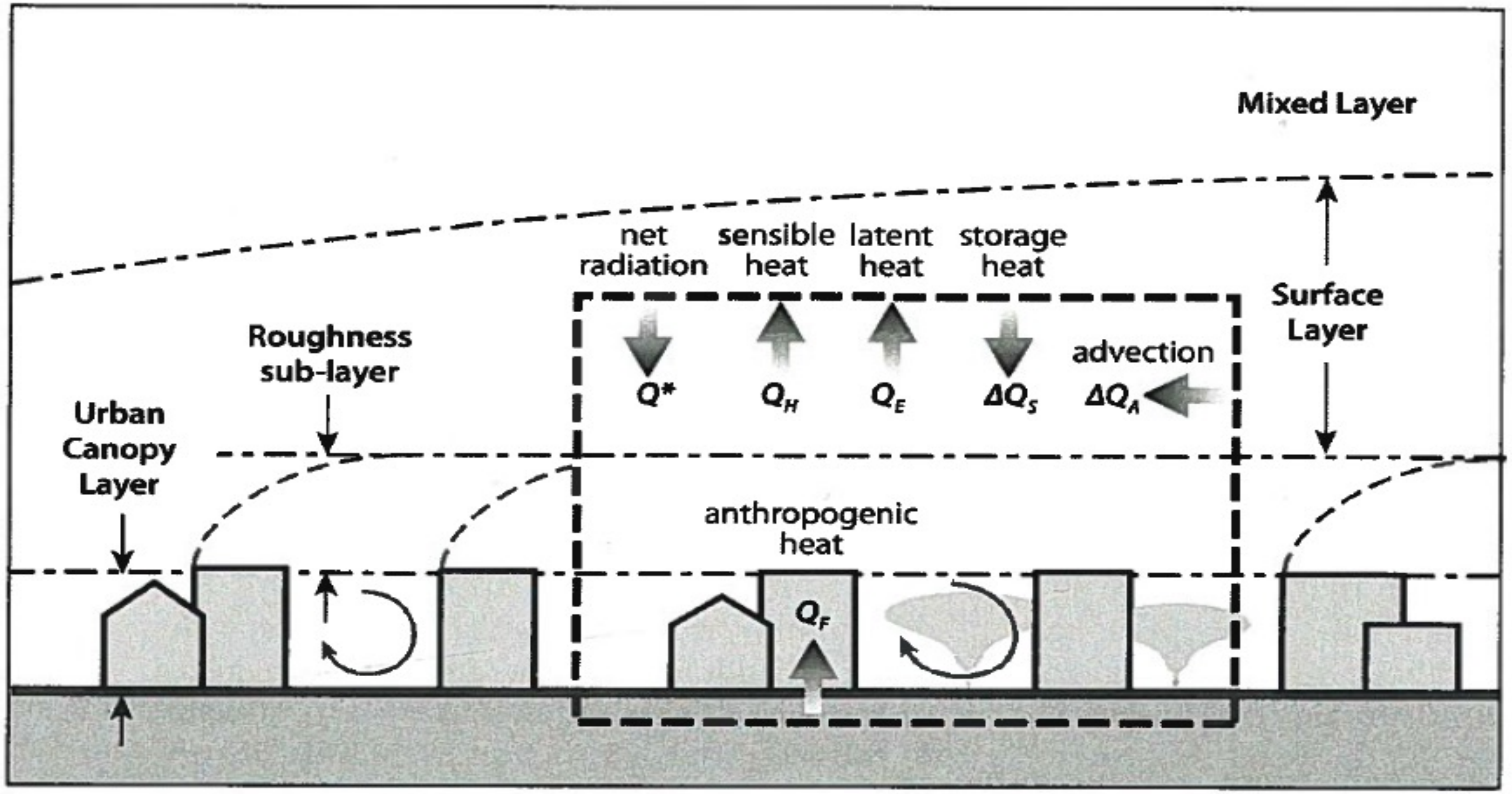


Heat Mitigation Data Infrastructure

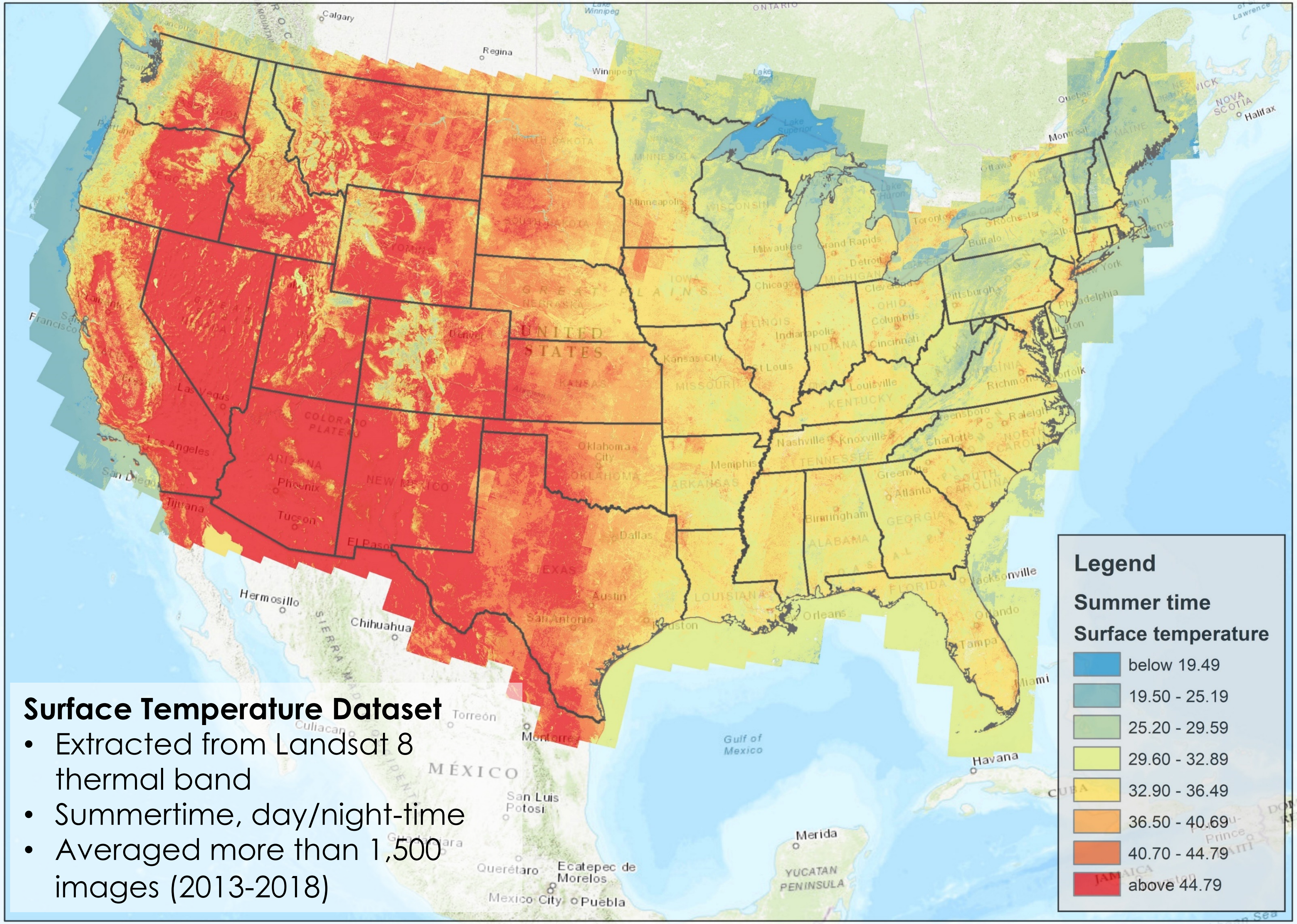
1. Surface Temperature
2. NLCD Tree Canopy
3. NLCD Land Cover
4. Weather Station Data
5. Building Footprint Data
6. Building Energy Use Data

Urban Energy Balance

$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S + \Delta Q_A$$

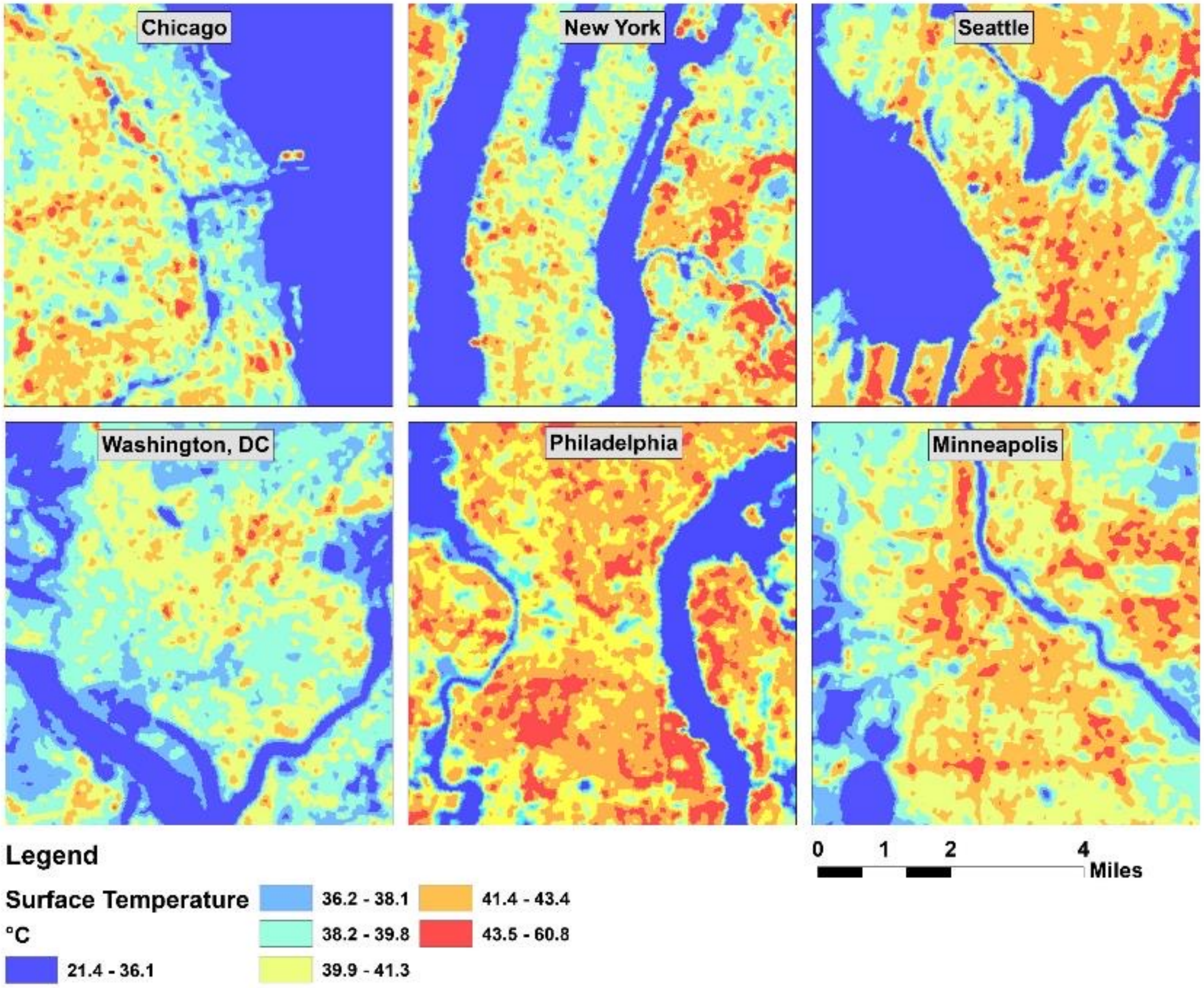


Erell, E., Pearlmutter, D., & Williamson, T. (2012). *Urban microclimate: designing the spaces between buildings*. Routledge.



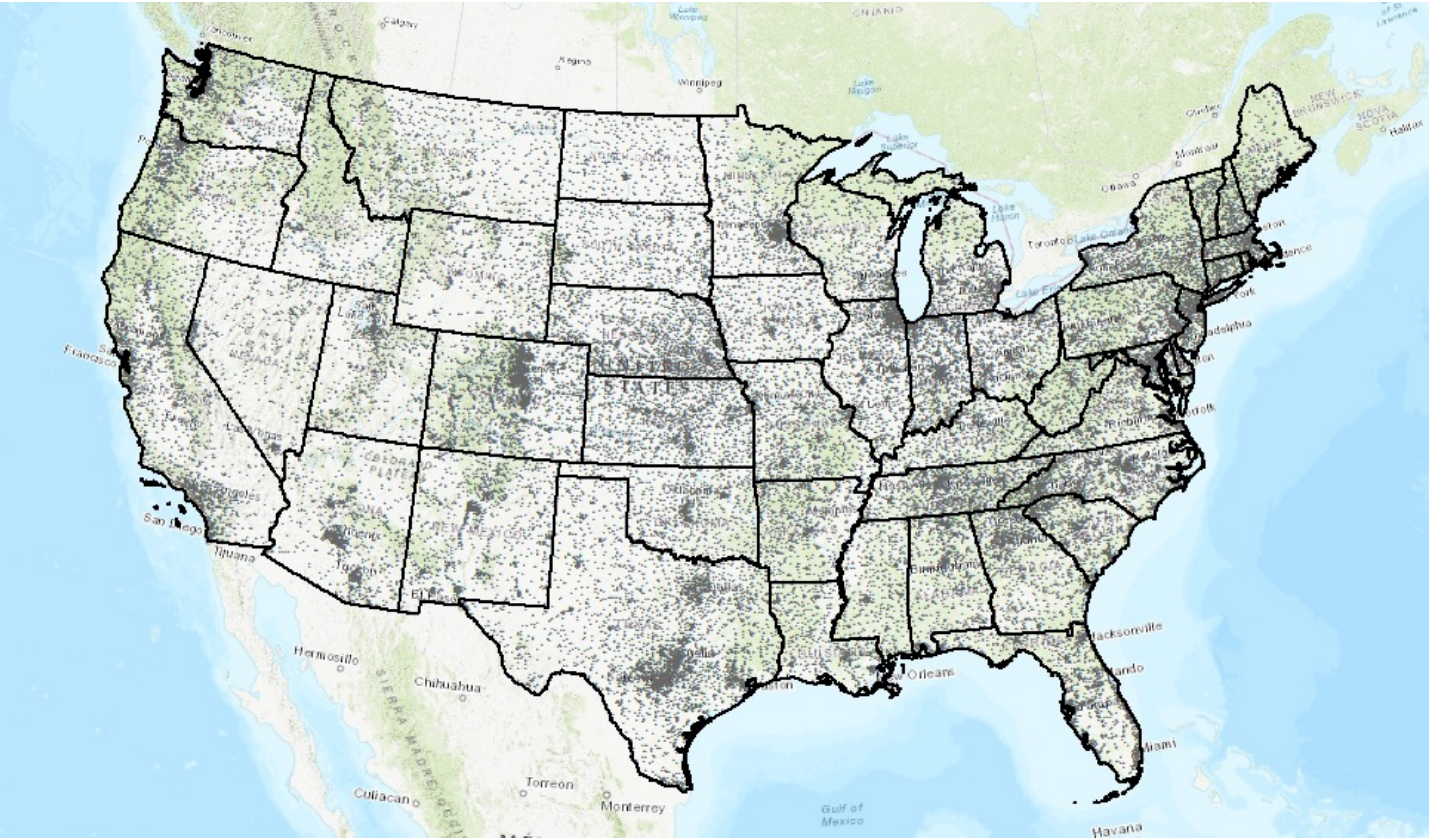
Surface Temperature Dataset

- Extracted from Landsat 8 thermal band
- Summertime, day/night-time
- Averaged more than 1,500 images (2013-2018)

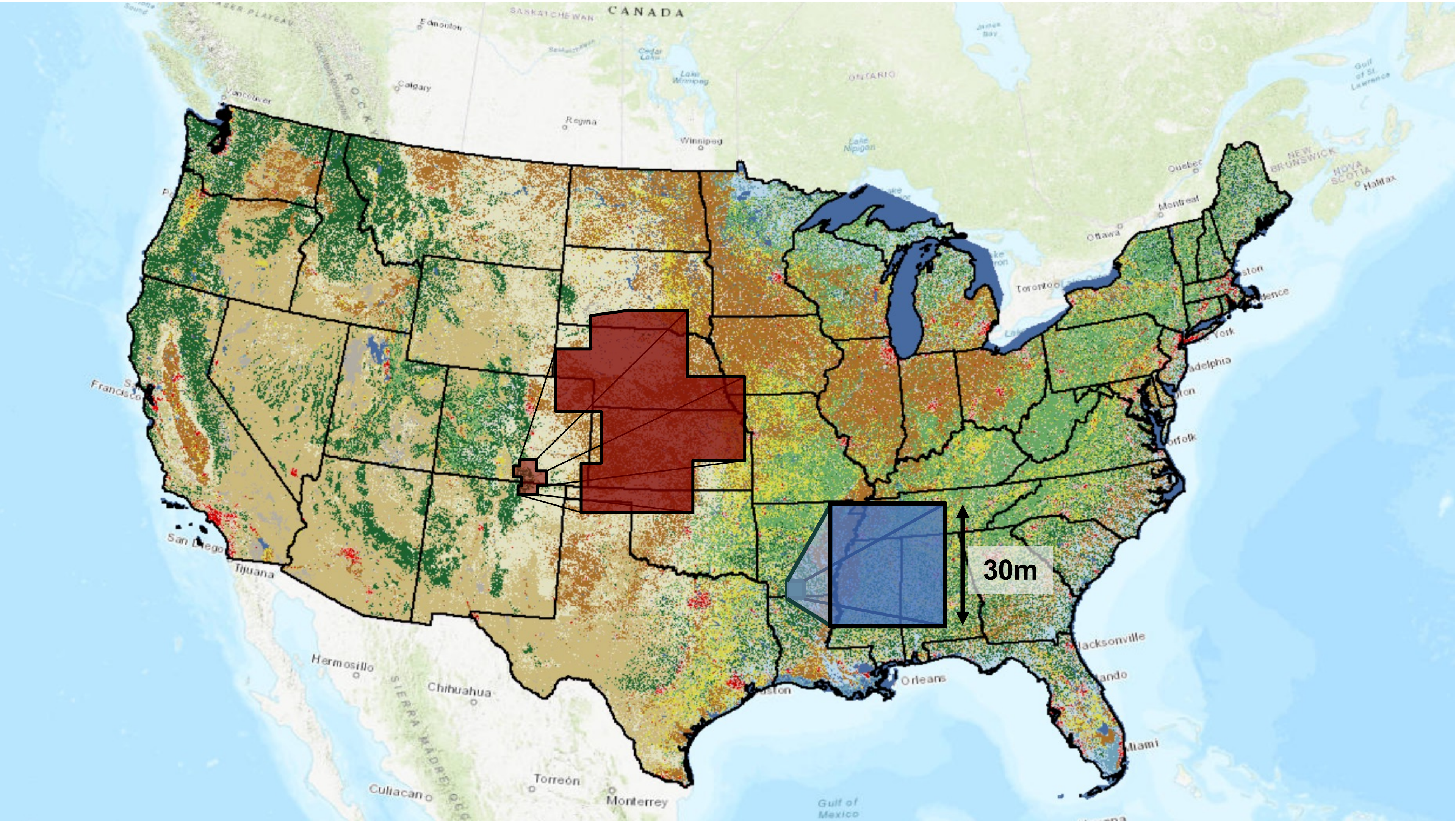


Chicago
New York
Seattle
Washington, DC
Philadelphia
Minneapolis
Legend
Surface Temperature
°C
21.4 - 36.1
36.2 - 38.1
38.2 - 39.8
39.9 - 41.3
41.4 - 43.4
43.5 - 60.8
0
1
2
4
Miles

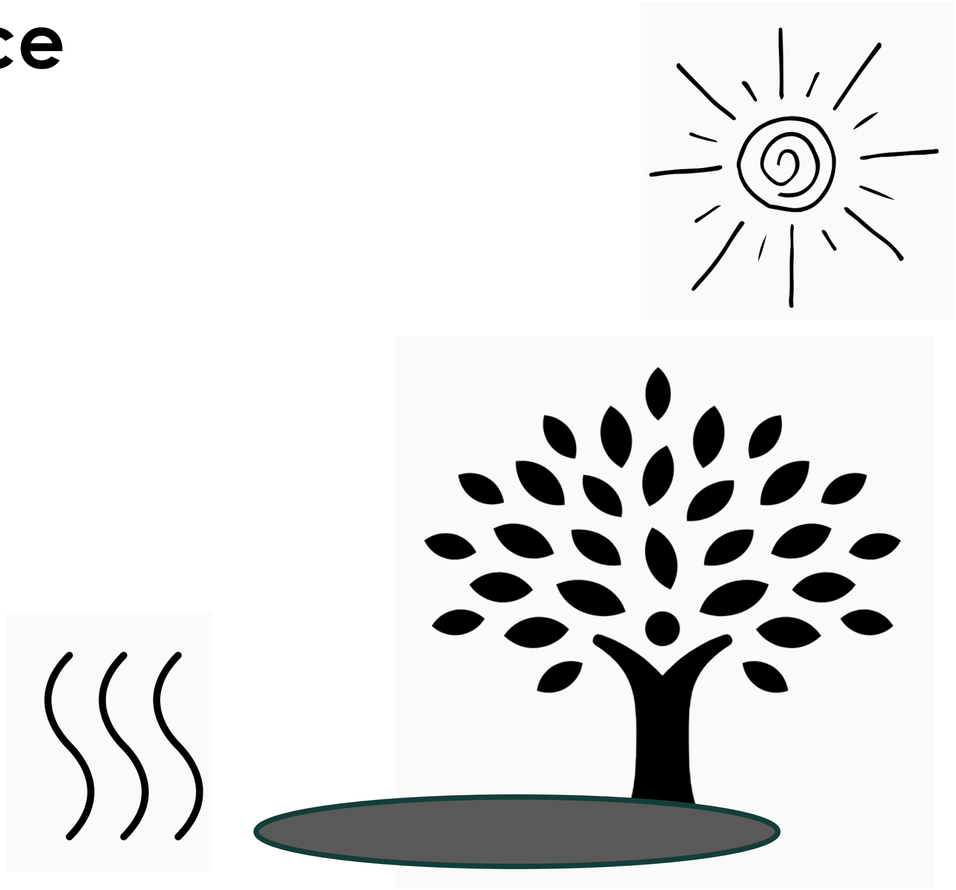
56k Weather Stations



Spatial Data Unit vs. Ecosystem Accounting Area

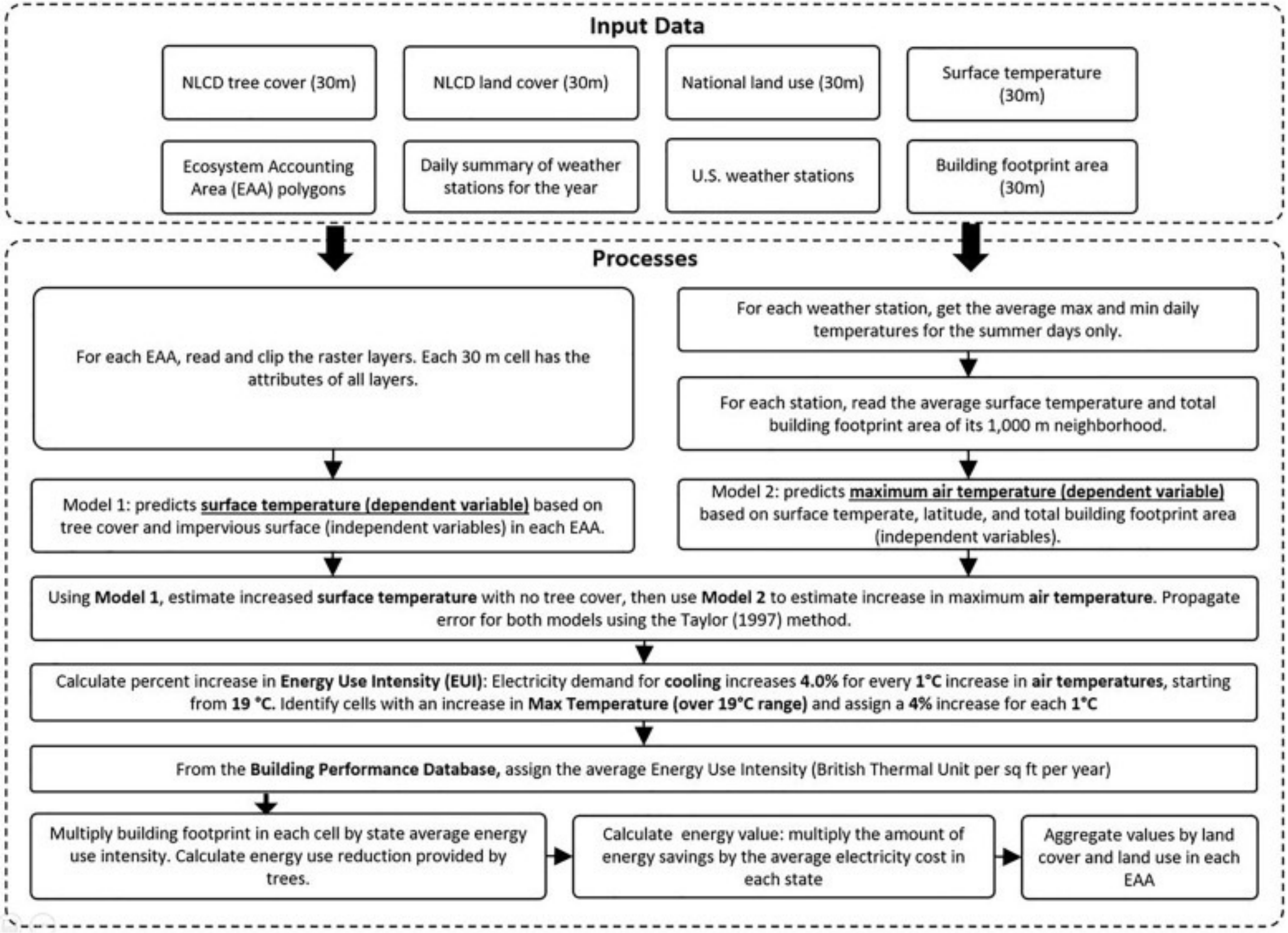


Conceptualizing the Role of Trees in the Energy Balance

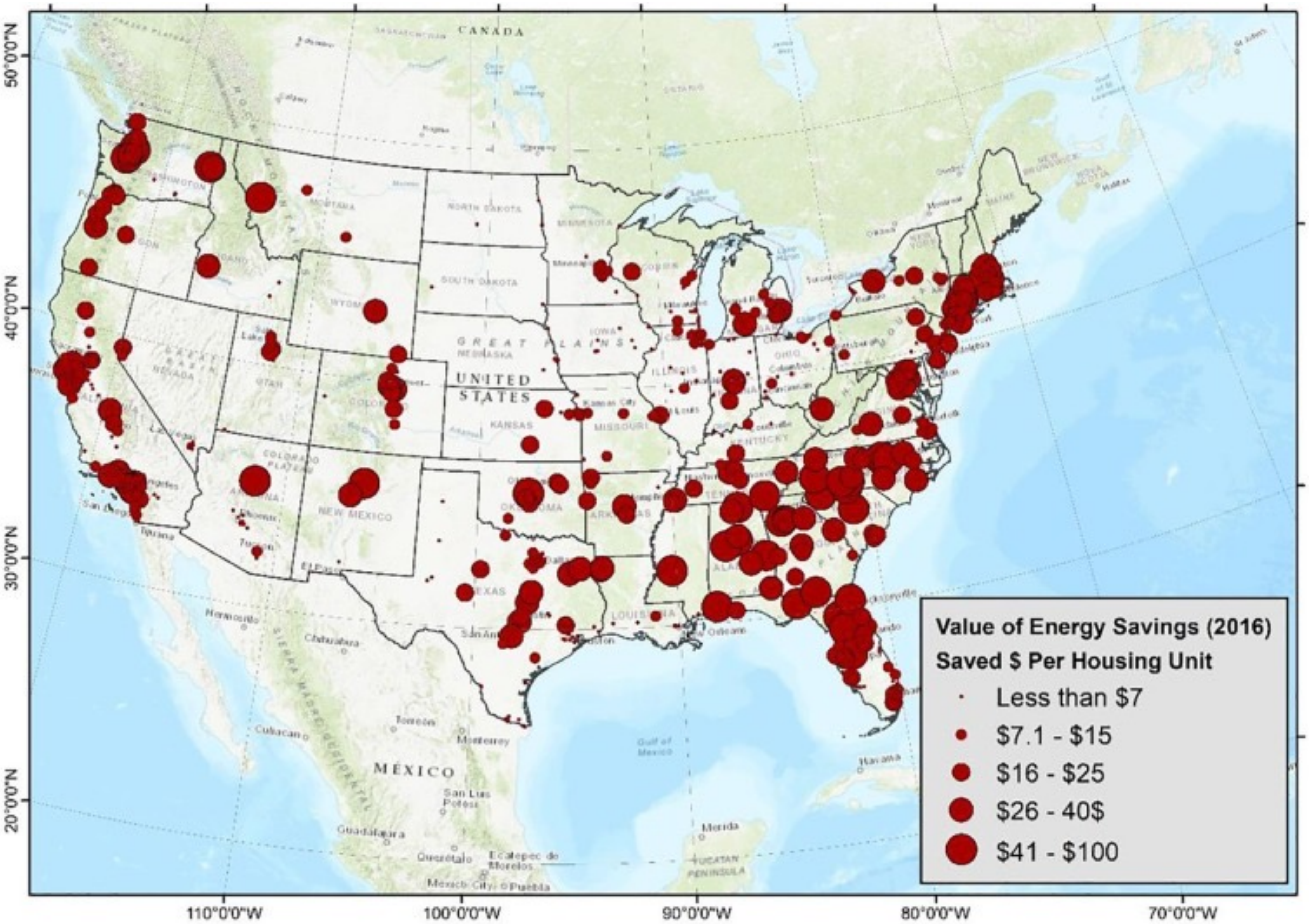


Trees → Surface Temperature → Ambient Temperature

The Heat Mitigation Model



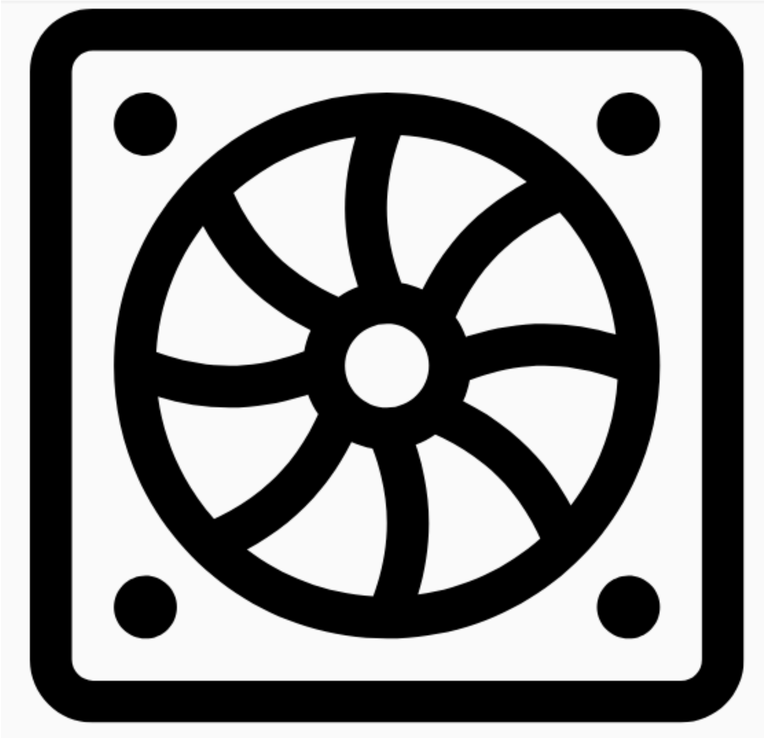
Results


Value of Energy Savings (2016)
Saved $ Per Housing Unit
Less than $7
$7.1 - $15
$16 - $25
$26 - 40$
$41 - $100
50°0'0"N
40°0'0"N
30°0'0"N
20°0'0"N
110°0'0"W
100°0'0"W
90°0'0"W
80°0'0"W
70°0'0"W
CANADA
UNITED STATES
MEXICO

Results

In 2011:
4,098 and, valued at
<u>$523 million</u>

In 2016:
4,229 GWh valued at
<u>$539 million</u>



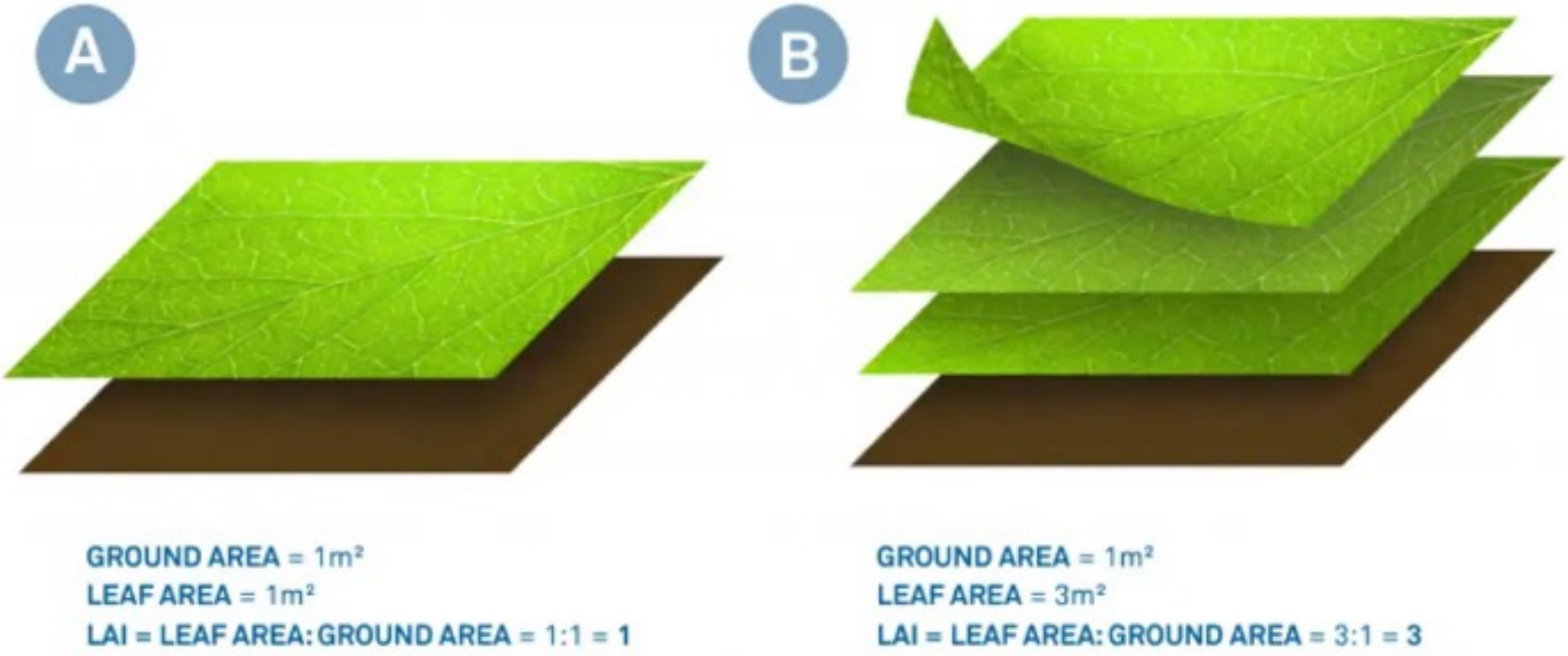

Modeling Rainfall
Interception

Rainfall Interception Data Infrastructure

1. NLCD Tree Canopy
2. NLCD Land Cover
3. Weather Station
4. MODIS Seasonality

What is leaf area index (LAI)?

Leaf area index (LAI) quantifies the amount of leaf material in a canopy. By definition, it is the ratio of one-sided leaf area per unit ground area. LAI is unitless because it is a ratio of areas. For example, a canopy with an LAI of 1 has a 1:1 ratio of leaf area to ground area (Figure 1a). A canopy with an leaf area index of 3 would have a 3:1 ratio of leaf area to ground area (Figure 1b).



Introducing the Model Components

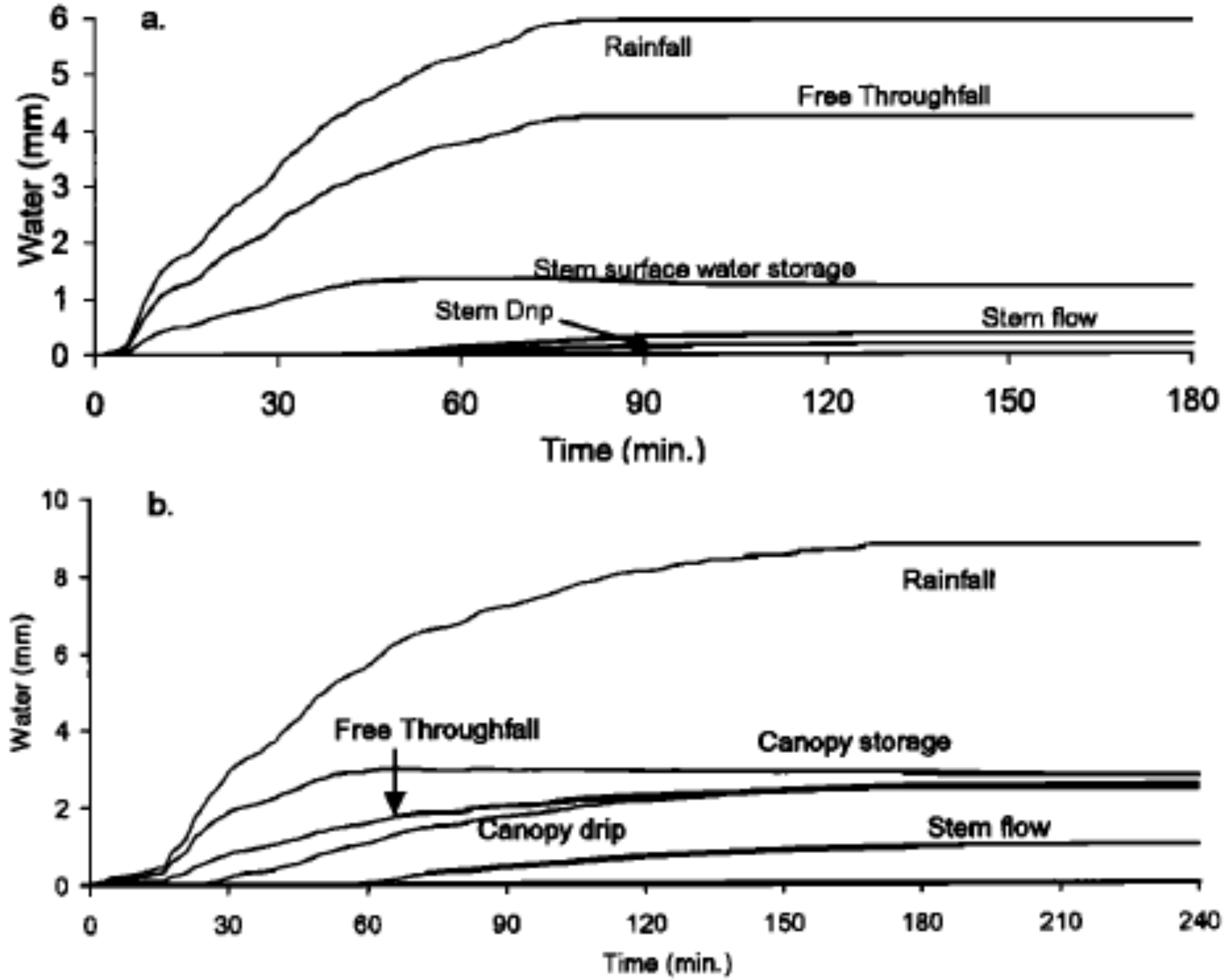
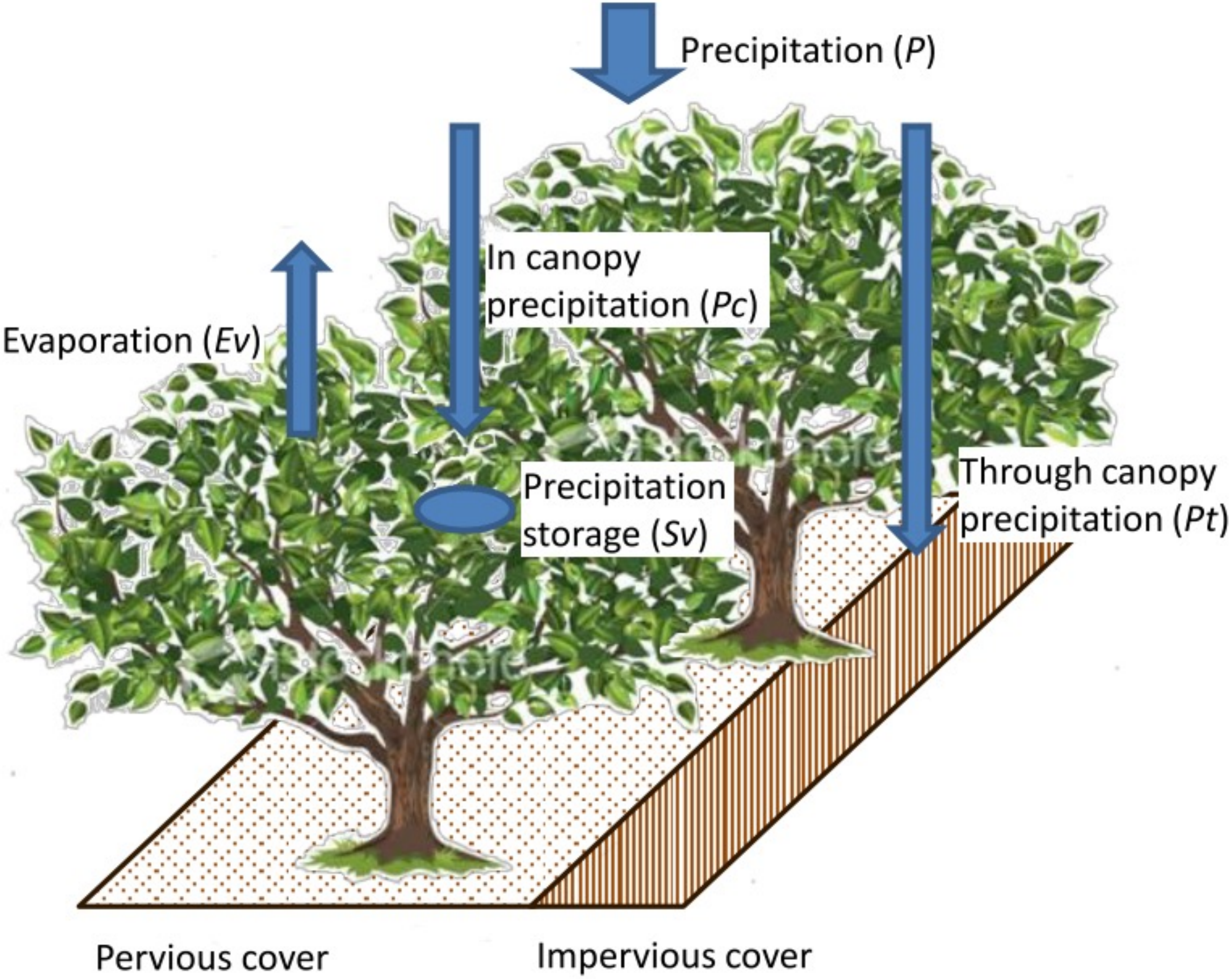


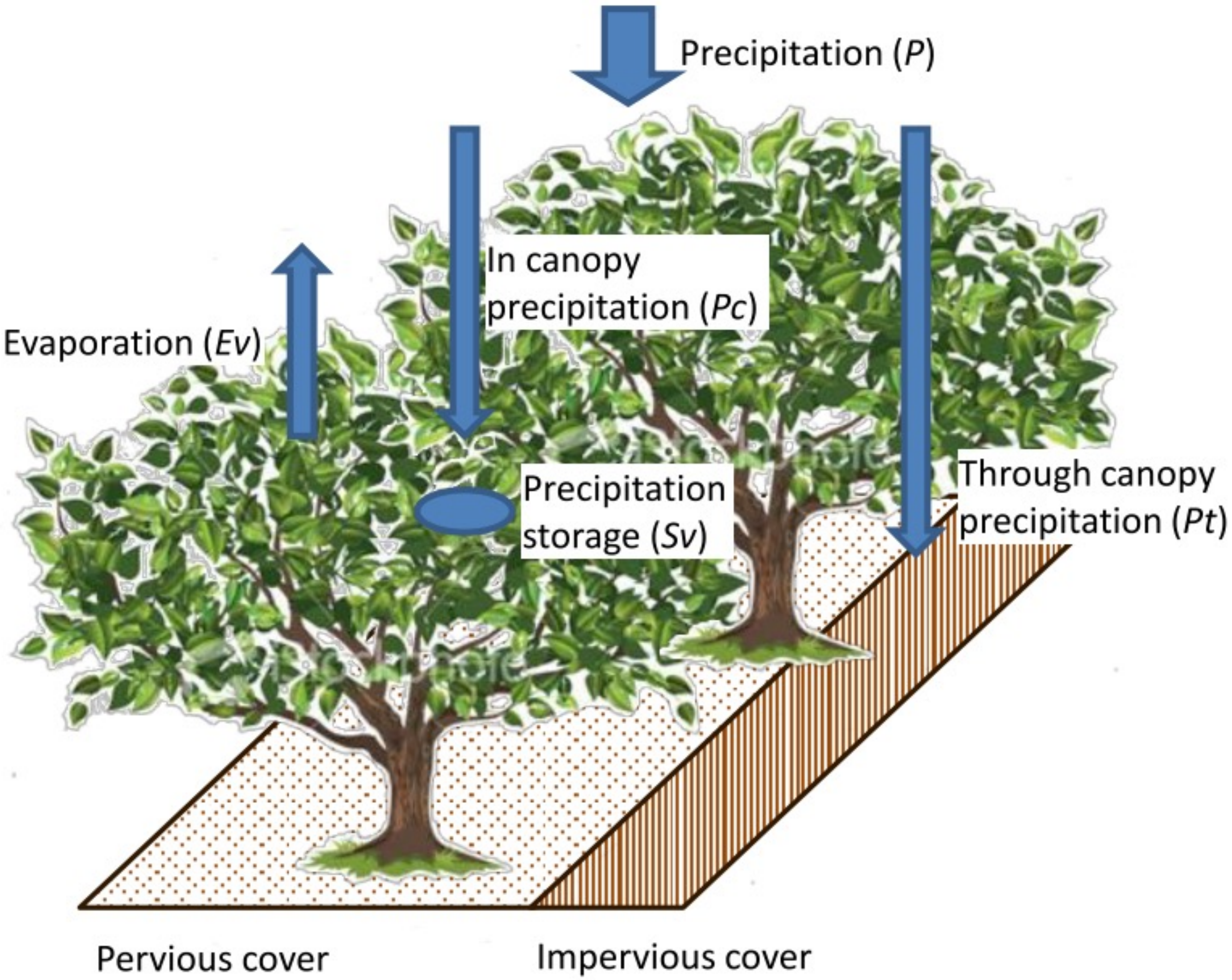
Figure 8. Rainfall interception processes. (a) Rainfall interception on the pear tree started at 0000:00, January 4, 1998, and it lasted about 3 hours. (b) Rainfall interception on the oak tree started at 0052:00, February 4, 1997, and it lasted about 80 min.

Xiao, Q., McPherson, E. G., Ustin, S. L., & Grismer, M. E. (2000). A new approach to modeling tree rainfall interception. *Journal of Geophysical Research: Atmospheres*, *105*(D23), 29173-29188.

Key Terms



Hirabayashi, S. (2013). *i-Tree Eco Precipitation Interception Model Descriptions*. 21. Retrieved from https://www.itreetools.org/eco/resources/iTree_Eco_Precipitation_Interception_Model_Descriptions.pdf



$$Sv_{max} = S_L LAI$$

SL is specific leaf storage of water (=0.0002 m).

Pc = P - Pt

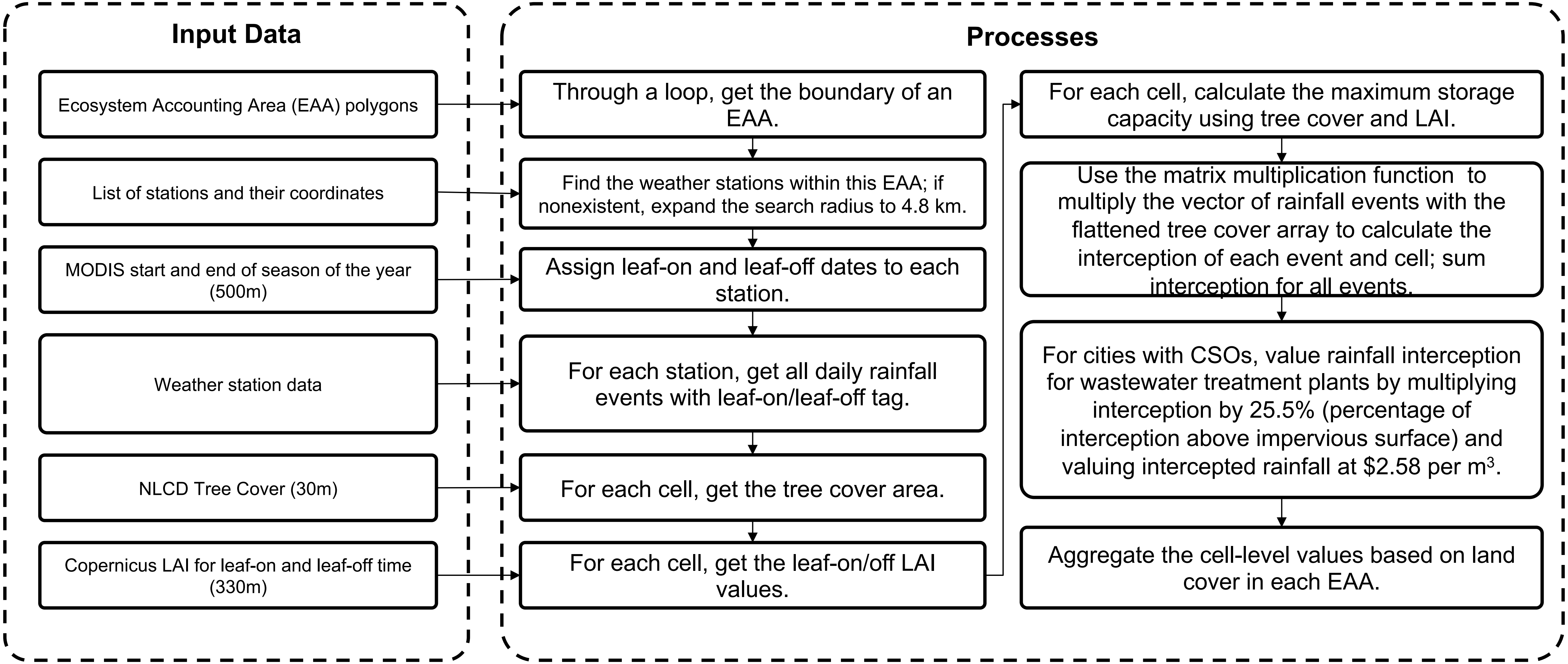
Pt = P * (1 - c)

C = 1 – e ^ (-k * LAI)

k is an extinction coefficient (=0.7 for trees and 0.3 for shrubs)

Hirabayashi, S. (2013). *i-Tree Eco Precipitation Interception Model Descriptions*. 21. Retrieved from https://www.itreetools.org/eco/resources/iTree_Eco_Precipitation_Interception_Model_Descriptions.pdf

Rainfall Interception Model

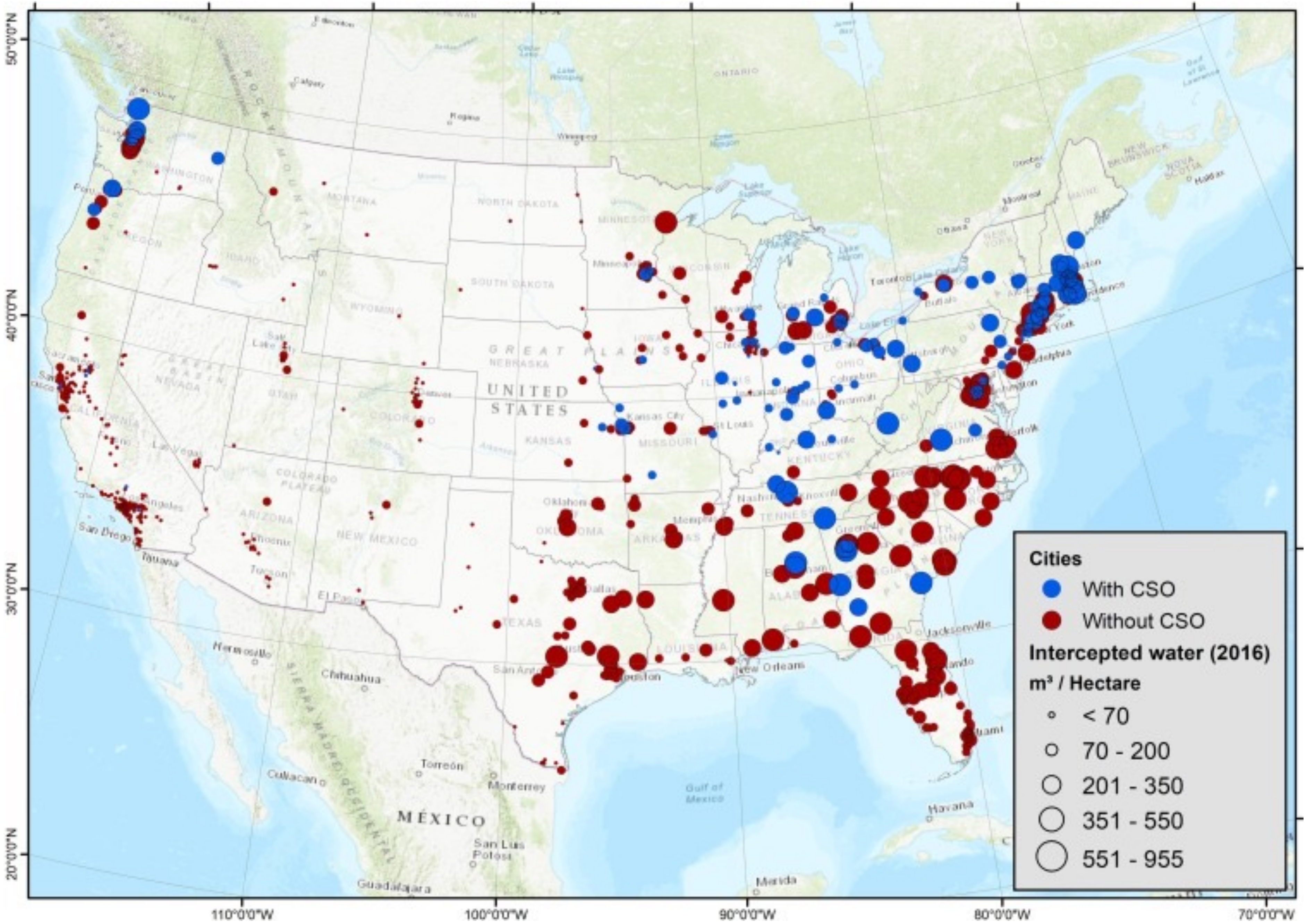


Results

In 2011:
2,422 million m^3, valued at **<u>$434 million</u>**

In 2016:
2,627 million m^3 valued at **<u>$425 million</u>**

Results


Cities
With CSO
Without CSO
Intercepted water (2016)
m³ / Hectare
< 70
70 - 200
201 - 350
351 - 550
551 - 955
UNITED STATES
MÉXICO
110°0'0"W
100°0'0"W
90°0'0"W
80°0'0"W
70°0'0"W
50°0'0"N
40°0'0"N
30°0'0"N
20°0'0"N

City	Population	Average Cooling Energy Use (KBTU)	Electricity Cost ($/ KWh)	Energy Savings (million $)						Rainfall Interception ($m^3 * 10^6$)							
				2011			2016			2011				2016			
				Lower CI (95%)	Mean	Upper CI (95%)	Lower CI (95%)	Mean	Upper CI (95%)	Copernicus LAI	i-Tree LAI Average	i-Tree +10%	Total Canopy Rain	Copernicus LAI	i-Tree LAI Average	i-Tree +10%	Total Canopy Rain
New York, NY*	8,175,133	17	0.18	1.1	1.1	1.2	1.3	1.4	1.5	5.0	11.0	12.0	268.5	5.2	11.4	12.4	179.0
Los Angeles, CA	3,792,621	14	0.20	14.4	16.5	18.6	14.5	16.6	18.7	1.4	4.8	5.2	79.4	1.0	3.5	3.8	65.4
Chicago, IL*	2,695,598	15	0.13	2.3	2.4	2.5	2.3	2.4	2.5	1.3	4.3	4.6	68.2	1.2	3.9	4.3	63.3
Houston, TX	2,099,451	21	0.12	1.7	2.0	2.4	1.5	1.9	2.2	13.2	30.8	33.6	754.1	18.6	42.1	46.1	1,673.7
Philadelphia, PA*	1,526,006	27	0.14	1.0	1.0	1.1	1.0	1.1	1.1	3.5	6.3	6.9	150.5	3.0	5.8	6.3	94.7
Phoenix, AZ	1,445,632	30	0.12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
San Antonio, TX	1,327,407	21	0.12	5.3	5.9	6.6	5.4	6.0	6.7	7.2	20.5	22.3	415.5	13.4	39.1	42.7	1,258.7
San Diego, CA	1,307,402	14	0.20	4.4	5.1	5.7	4.5	5.2	5.9	0.6	2.3	2.5	27.9	0.5	2.1	2.2	26.3
Dallas, TX	1,197,816	21	0.12	3.9	4.2	4.6	3.9	4.3	4.7	5.3	19.1	20.8	468.8	9.0	30.5	33.4	825.9
San Jose, CA	945,942	14	0.20	1.8	2.0	2.3	1.8	2.1	2.3	0.6	1.9	2.0	22.0	0.5	1.6	1.7	27.8
Jacksonville, FL	821,784	22	0.12	12.3	14.0	15.8	13.1	15.1	17.1	127.4	199.9	218.4	5,429.6	132.3	204.7	223.8	5,668.9
Indianapolis, IN*	820,445	23	0.12	5.7	6.2	6.6	5.8	6.2	6.7	13.8	25.8	28.1	468.3	12.0	21.3	23.2	431.6
San Francisco, CA*	805,235	14	0.20	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.4	0.4	5.3	0.2	0.4	0.4	8.1
Austin, TX	790,390	21	0.12	9.1	10.5	11.9	9.2	10.6	12.0	10.1	29.0	31.4	425.6	18.3	54.8	59.7	1,549.9
Columbus, OH*	787,033	20	0.12	2.1	2.3	2.5	2.1	2.3	2.4	6.3	13.2	14.4	233.0	5.2	10.7	11.7	152.3
Fort Worth, TX	741,206	21	0.12	2.0	2.3	2.5	2.1	2.3	2.5	2.6	9.8	10.7	217.7	3.3	12.5	13.6	309.8
Charlotte, NC	731,424	31	0.12	12.9	14.6	16.3	13.6	15.5	17.4	21.2	50.1	54.8	1,060.8	20.5	47.0	51.3	965.1
Detroit, MI*	713,777	14	0.15	0.8	0.8	0.9	0.8	0.8	0.9	1.7	4.6	5.0	71.9	1.6	4.2	4.5	51.1
Memphis, TN	646,889	33	0.11	4.9	5.3	5.7	5.0	5.4	5.9	19.7	39.4	43.1	1,025.8	20.2	38.9	42.6	980.8
Baltimore, MD*	620,961	20	0.13	1.1	1.3	1.4	1.2	1.3	1.4	2.4	4.8	5.3	101.8	1.8	3.9	4.2	59.6
Boston, MA*	617,594	16	0.23	1.5	1.6	1.8	1.6	1.8	2.0	1.4	3.1	3.4	51.4	1.2	2.9	3.2	35.8
Seattle, WA*	608,660	30	0.09	1.8	2.0	2.3	2.3	2.7	3.1	2.4	6.9	7.5	64.0	2.2	6.5	7.1	78.5
Washington, DC*	601,723	9	0.13	0.5	0.5	0.6	0.5	0.5	0.6	1.8	3.8	4.1	59.8	1.7	3.6	3.9	47.2
Nashville, TN*	601,222	33	0.11	6.4	7.3	8.1	6.4	7.4	8.3	79.8	118.8	129.5	2,832.2	80.3	114.0	124.5	2,632.5
Denver, CO	600,158	16	0.12	3.5	5.1	6.6	3.5	5.0	6.5	0.4	1.4	1.6	14.6	0.4	1.3	1.4	13.4
Louisville, KY*	597,337	28	0.10	2.7	3.0	3.2	2.8	3.0	3.3	31.1	47.9	52.4	1,148.3	29.6	44.5	48.6	864.4
Milwaukee, WI*	594,833	14	0.14	1.4	1.5	1.6	1.5	1.6	1.6	1.4	4.4	4.8	55.8	1.7	5.1	5.6	64.8
Portland, OR*	583,776	19	0.11	4.0	5.3	6.6	4.1	5.4	6.8	8.9	16.8	18.3	182.3	8.8	17.1	18.7	262.0
Las Vegas, NV	583,756	25	0.12	0.5	0.7	0.9	0.5	0.7	0.9	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
Oklahoma City, OK	579,999	34	0.10	4.7	5.2	5.8	4.8	5.3	5.8	15.3	36.2	39.4	820.3	19.4	45.0	49.1	899.9
Albuquerque, NM	545,852	17	0.13	4.0	8.2	12.5	4.0	8.2	12.5	0.1	0.8	0.8	6.4	0.2	1.1	1.1	8.9

Building the Supply Table

Ecosystem Accounting Area	Service Type	year	Ecosystem types (Land cover)															
			Open Water	Developed - Open	Developed - Low	Developed - Medium	Developed - High	Barren	Deciduous Forest	Evergreen Forest	Mixed Forest	Scrub/Shrub	Grassland/Herbaceous	Pasture/Hay	Cultivated Crops	Woody Wetlands	Emergent Herbaceous Wetlands	Total
All U.S. cities (population>=50,000)	Intercepted water by urban trees (1000m3)	2001	7,647.7	320,911.4	209,883.4	54,797.1	3,327.4	1,199.0	422,914.2	260,253.1	69,532.0	37,858.4	22,132.8	18,067.9	10,728.6	300,915.5	15,339.8	1,755,508.2
		2011	5.5	404,770.9	266,974.4	70,641.5	7,073.8	1,872.6	433,311.9	184,358.4	59,537.3	49,801.8	35,074.9	25,727.2	14,510.1	303,279.8	16,909.7	1,873,849.7
	Energy Savings by urban trees mWh	2001	0.0	686,907.8	1,195,035.5	436,080.9	39,102.9	716.8	193,749.1	134,299.6	36,265.7	25,264.6	14,026.5	12,641.4	16,846.8	32,990.7	1,291.7	2,825,220.1
		2011		967,225.9	1,799,185.3	733,586.3	87,435.7	622.4	117,722.0	70,589.8	19,465.6	20,085.0	14,030.8	8,470.0	2,902.2	13,480.5	1,210.8	3,856,012.2
Colorado	Intercepted water by urban trees (1000m3)	2001	12.3	626.6	1,684.2	258.3	6.7	0.1	134.8	579.8	0.4	184.0	36.1	6.3	12.2	216.9	16.7	3,775.3
		2011	0.0	770.6	2,317.4	665.4	59.2	1.1	131.7	522.5	0.6	350.7	80.2	11.7	22.0	235.6	23.1	5,191.8
	Energy Savings by urban trees mWh	2001		11,578.5	51,036.4	8,749.4	315.5	0.3	442.0	571.3	0.9	532.6	140.0	24.4	83.5	814.1	65.2	74,354.1
		2011		16,970.1	93,034.7	30,284.4	3,441.3	6.4	486.9	628.3	5.0	876.0	216.9	30.0	32.5	720.0	62.6	146,795.0
Denver	Intercepted water by urban trees (1000m3)	2001	2.5	151.7	410.8	53.0	1.9	0.0	0.7	0.5	0.0	0.6	1.8	0.2	1.0	23.7	1.0	649.4
		2011	0.0	174.0	515.8	142.8	19.6	0.1	0.8	0.4	0.1	0.7	3.0	0.1	4.8	23.8	0.8	886.8
	Energy Savings by urban trees mWh	2001	0.0	4,206.0	16,498.0	2,267.8	109.2	0.0	16.4	0.3	0.8	6.2	5.2	0.0	2.3	49.1	2.0	23,163.4
		2011	0.0	6,974.7	30,416.9	8,983.4	1,445.6	0.0	22.6	0.5	4.5	2.9	15.8	0.0	1.2	65.7	3.1	47,936.7
Sensitivity analysis on Denver	Intercepted water by urban trees (1000m3)	2011	32.1	3,156.6	10,063.7	3,172.1	432.4	2.0	7.0	3.8	0.7	3.9	36.9	2.9	37.1	222.5	4.8	17,178.4
	Energy Savings by urban trees mWh	2011	0.0	6,585.6	38,124.8	12,476.1	1,880.9	0.4	14.4	0.3	2.0	3.8	5.7	0.0	3.1	40.9	1.6	59,139.7

Building the Use Table

Ecosystem Accounting Area	Service Type	Year	Economic units												
			NAICS 11 Livestock	Wastewater treatment 221320	NAICS 31-33 Manufacturing	NAICS 44-45 Retail	NAICS 48-49 Transport warehousing	NAICS 51-56 Offices	NAICS 61 Educational services	NAICS 62 Health care & social assistance	NAICS 71 Entertainment	NAICS 92 Government	Households (No NAICS Code)	No NAICS equivalent	Total
All U.S. cities (population>=50,000)	Intercepted water by urban trees (1000m3)	2001	0.0	1,755,508.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1,755,508.2
		2011	0.0	1,873,849.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1,873,849.7
	Energy Savings by urban trees MegaWh	2001	325.6	0.0	16,047.8	28,927.2	10,951.7	28,933.7	26,132.7	9,097.3	840.5	8,615.9	2,624,267.5	71,080.1	2,825,220.1
		2011	302.3	0.0	17,722.2	25,660.4	13,799.7	31,539.6	33,475.0	9,472.4	1,421.8	6,816.4	3,639,349.7	76,452.6	3,856,012.2
Colorado	Intercepted water by urban trees (1000m3)	2001	0.0	3,775.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3,775.3
		2011	0.0	5,191.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5,191.8
	Energy Savings by urban trees MegaWh	2001	0.5	0.0	76.5	248.1	98.4	311.0	561.1	166.3	11.8	177.5	71,386.3	1,316.6	74,354.1
		2011	2.7	0.0	411.0	1,218.9	330.1	1,428.8	1,621.2	513.6	77.4	611.2	137,884.7	2,695.4	146,795.0
Denver	Intercepted water by urban trees (1000m3)	2001	0.0	649.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	649.4
		2011	0.0	886.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	886.8
	Energy Savings by urban trees MegaWh	2001	0.0	0.0	15.9	38.6	34.3	76.8	297.2	64.7	9.9	114.2	22,199.4	312.5	23,163.4
		2011	0.8	0.0	167.1	340.1	169.4	465.5	772.3	198.1	70.5	408.2	44,609.0	735.9	47,936.7
Sensitivity analysis on Denver	Intercepted water by urban trees (1000m3)	2011	0.0	17,178.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17,178.4
	Energy Savings by urban trees MegaWh	2011	2.1	0.0	257.0	305.3	280.3	742.2	951.5	20.7	37.6	520.7	56,004.4	17.2	59,139.7

Summary

- For modeling the ecosystem services of trees, we can use the physical models.
- Simplifying assumptions is an inevitable step in such estimations.
- Confidence intervals and error propagation is an essential component.
- Preparing accounting tables requires a model that is designed for such outputs.

Session 3 Summary

- Multiple projects were highlighted that present clear methods and policy applications for valuing ecosystems services in multiple countries and for ecosystem service types.
- Remote sensing is a major component in the valuation of ecosystem services.
- There is a need for continued use of these data, alongside other forms of data, for continued benefits of ecosystems to people and protection of these ecosystems for the sustainable health of the planet.

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