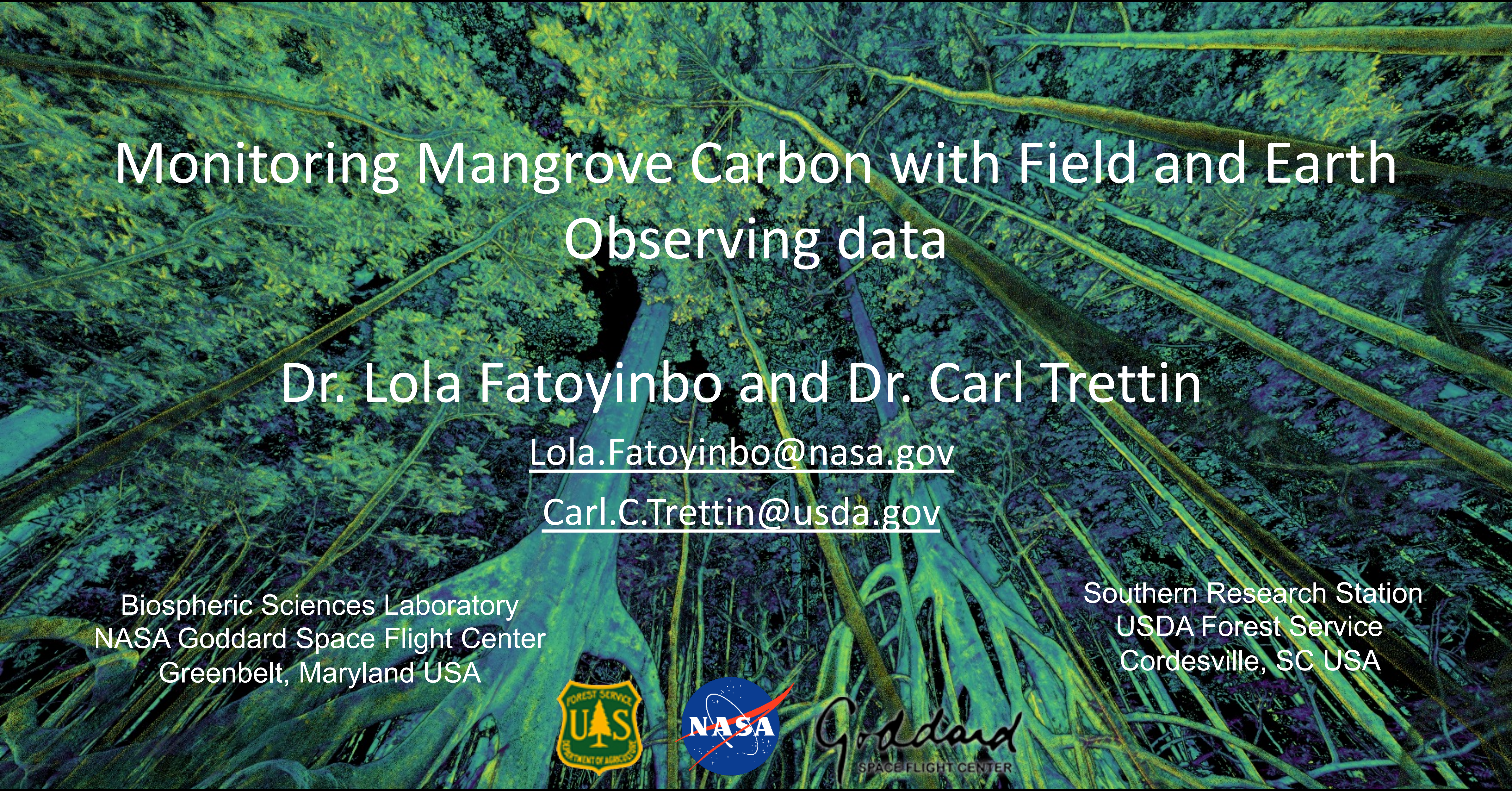

Monitoring Mangrove Carbon with Field and Earth Observing data

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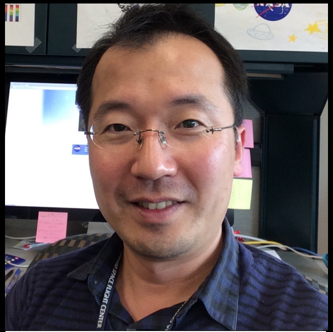
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Selena Chavez


Priscilla Baltezar


Richard Lucas


Pete Bunting


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Jet Propulsion Laboratory

University of Dar es Salaam
Institute of Marine Sciences

SWAMP Sustainable Wetlands Adaptation and Mitigation Program

PRIFYSGOL ABERYSTWYTH UNIVERSITY

Goals – Improved Mapping and Monitoring of Coastal and Blue Carbon Ecosystem Carbon Stocks

- When protected or restored, blue carbon ecosystems sequester and store carbon.
- When degraded or destroyed, these ecosystems emit the carbon they have stored for centuries into the atmosphere and oceans and become sources of greenhouse gases.
- 1.02 billion tons of carbon dioxide are being released annually from degraded coastal ecosystems
  - equivalent to 19% of emissions from tropical deforestation globally*.
- To better manage them, we need better estimates of their distribution, Carbon stocks and emissions

Outline

- Earth Observations and Remote Sensing of Mangrove Forest Canopy Height
- Field inventory design and Field Data collection
- Biomass and Carbon stock estimation
- Mangrove Extent mapping, and Global Drivers of Change mapping
- Data Availability and Applications

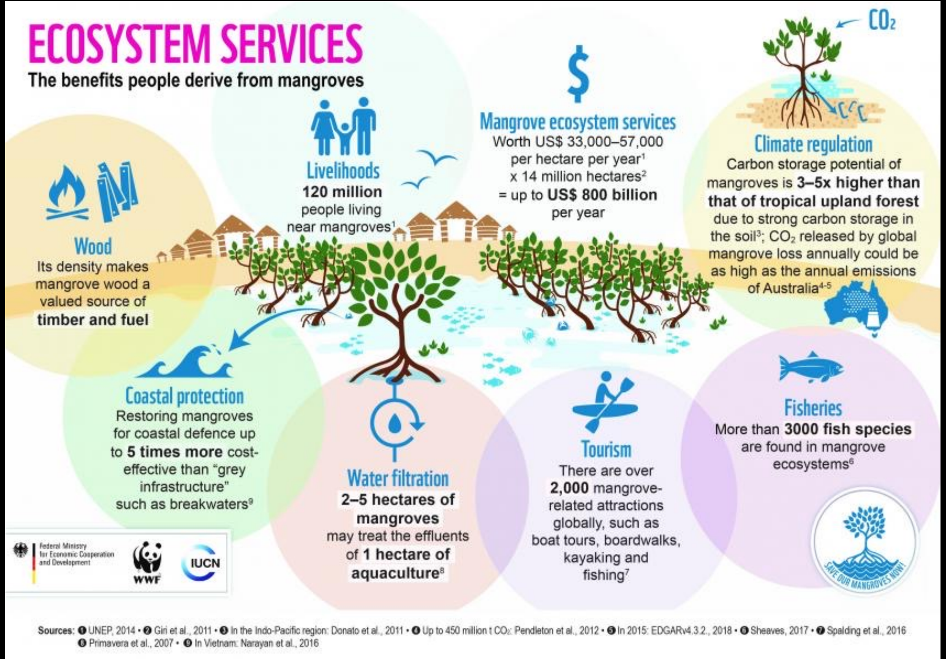
MANGROVES

These forests, found where the ocean meets land and sea water meets fresh water, provide a wealth of benefits for people but are losing their rightful place in nature.

© Ami Vitale

Why Mangroves?

- Numerous Ecosystem Services
  - Nutrient Cycling
  - Fishery Support
  - Biodiversity
  - Flood Control
  - Water Quality
  - Coastline Stabilization
  - Carbon Sequestration



ECOSYSTEM SERVICES

The benefits people derive from mangroves

Wood
Its density makes mangrove wood a valued source of **timber and fuel**

Livelihoods
120 million people living near mangroves[1]

Mangrove ecosystem services
Worth US$ 33,000–57,000 per hectare per year[1] x 14 million hectares[2] = up to **US$ 800 billion** per year

Climate regulation
Carbon storage potential of mangroves is **3–5x higher than that of tropical upland forest** due to strong carbon storage in the soil[3]; CO_2 released by global mangrove loss annually could be as high as the annual emissions of Australia[4-5]

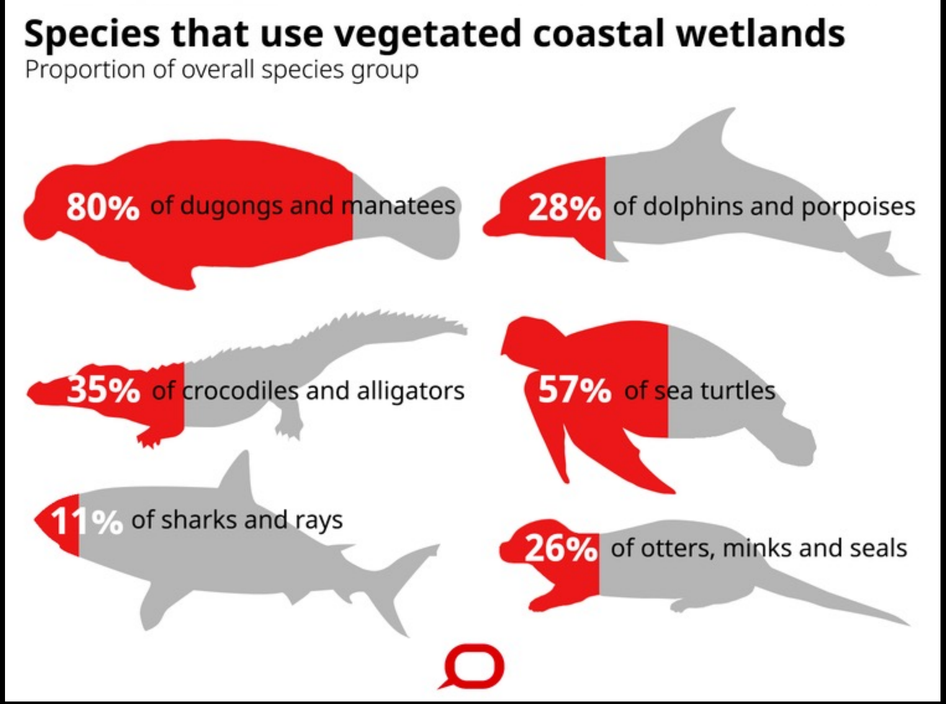
Coastal protection
Restoring mangroves for coastal defence up to **5 times more** cost-effective than "grey infrastructure" such as breakwaters[9]

Water filtration
2–5 hectares of mangroves may treat the effluents of **1 hectare of aquaculture**[8]

Tourism
There are over **2,000** mangrove-related attractions globally, such as boat tours, boardwalks, kayaking and fishing[7]

Fisheries
More than **3000 fish species** are found in mangrove ecosystems[6]

Sources: ❶ UNEP, 2014 • ❷ Giri et al., 2011 • ❸ In the Indo-Pacific region: Donato et al., 2011 • ❹ Up to 450 million t CO_2: Pendleton et al., 2012 • ❺ In 2015: EDGARv4.3.2., 2018 • ❻ Sheaves, 2017 • ❼ Spalding et al., 2016 • ❽ Primavera et al., 2007 • ❾ In Vietnam: Narayan et al., 2016

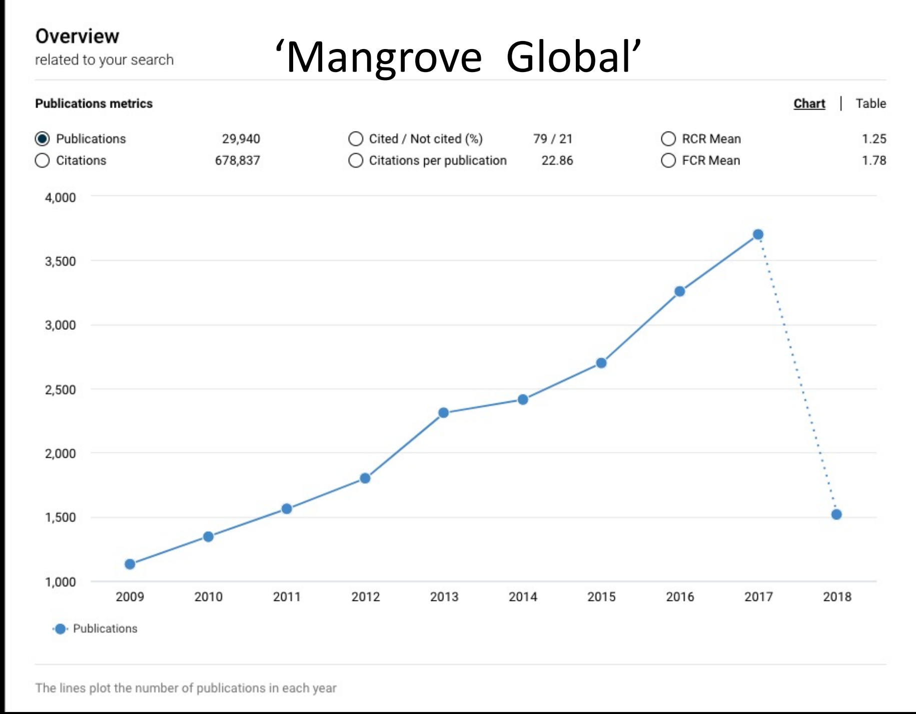


Species that use vegetated coastal wetlands

Proportion of overall species group

Thompson et al, 2019. Beyond ecosystem services: Using charismatic megafauna as flagship species for mangrove forest conservation

‘Mangrove Global’

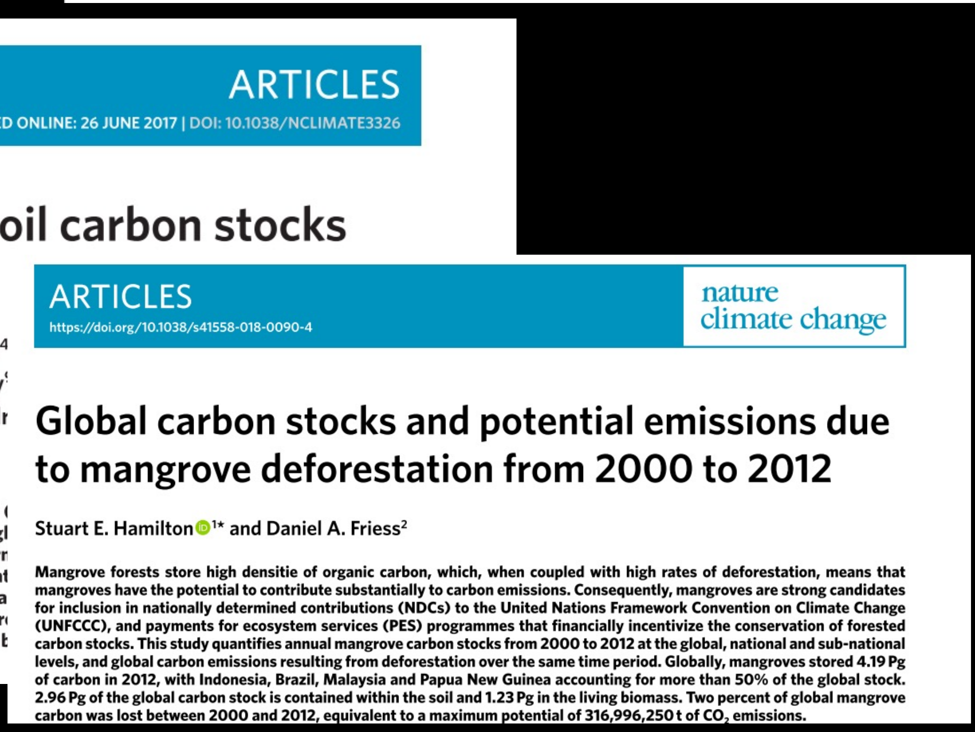


Overview
related to your search

Publications metrics

● Publications	29,940	○ Cited / Not cited (%)	79 / 21	○ RCR Mean	1.25
○ Citations	678,837	○ Citations per publication	22.86	○ FCR Mean	1.78

The lines plot the number of publications in each year



LETTERS

Predicting global patterns in mangrove forest biomass

James Hutchison[1], Andrea Manica[1], Ruth Swetnam[2], Andrew Balmford[1], & Mark Spalding[3]

[1] Department
[2] School of Sc
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Keywords
Mangrove; bi
carbon; ecos
global model

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doi: 10.1111/

Global Ecology and Biogeography, (Global Ecol. Biogeogr.) (2015)

A Journal of Macroecology
Biogeography

RESEARCH PAPER

Scaling mangrove aboveground biomass from site-level to continental-scale

A. S. Rovai[1]*, P. Riul[2], R. R. Twilley[3], E. Castañeda-Moya[3],

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nature climate change
LETTERS
PUBLISHED ONLINE: 27 JULY 2015 | DOI: 10.1038/NCLIMATE2734

The potential of Indonesian mangrove forests for global climate change mitigation

Daniel Murdiyarso[1,2]*, Joko Purbopus
Sigit D. Sasmito[1], Daniel C. Donato[6], S
and Sofyan Kurnianto[1,4]

Mangroves provide a wide range of ecosys
including nutrient cycling, soil formation, woo
fish spawning grounds, ecotourism and carbon
High rates of tree and plant growth, coupled w
water-logged soils that slow decomposition, r
long-term C storage. Given their global signific
sinks of C, preventing mangrove loss would b
climate change adaptation and mitigation strate
reported that C stocks in the Indo-Pacific regi
average 1,023 MgC ha^{-1} (ref. 2). Here, we est
donesian mangrove C stocks are 1,083 ± 378 Mg
up to the country-level mangrove extent of 2.9
Indonesia's mangroves contained on average 3.1
decades Indonesia has lost 40% of its mangrove
result of aquaculture development[5]. This has res
emissions of 0.07–0.21 Pg CO_2e. Annual mangr
tion in Indonesia is only 6% of its total forest l
if this were halted, total emissions would be r
amount equal to 10–31% of estimated annual e
land-use sectors at present. Conservation of car
groves in the Indonesian archipelago should be
component of strategies to mitigate climate cha

Globally, deforestation and conversion of mang

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nature climate change
ARTICLES
PUBLISHED ONLINE: 26 JUNE 2017 | DOI: 10.1038/NCLIMATE3326

Global patterns in mangrove soil carbon stocks and losses

Trisha B. Atwood[1,2]*, Rod M. Connolly[3], Hanan Almahasheer[4
Carolyn J. Ewers Lewis[5], Xabier Irigoien[7,8], Jeffrey J. Kelleway[
Oscar Serrano[10,12], Christian J. Sanders[13], Isaac Santos[13], Andr
and Catherine E. Lovelock[1,15]

Mangrove soils represent a large sink for otherwise rapidly recycled carbon (
the preservation of this important C stock. It is therefore imperative that gl
susceptibility to remineralization are understood. Here, we present pattern
latitudes, countries and mangrove community compositions, and estimat
where mangroves occur. Global potential CO_2 emissions from soils as a
~7.0 Tg CO_2e yr^{-1}. Countries with the highest potential CO_2 emissions fr
Malaysia (1,288 Gg CO_2e yr^{-1}). The patterns described serve as a baseline f
C stocks and potential emissions from mangrove deforestation.

ARTICLES
https://doi.org/10.1038/s41558-018-0090-4
nature climate change

Global carbon stocks and potential emissions due to mangrove deforestation from 2000 to 2012

Stuart E. Hamilton[1]* and Daniel A. Friess[2]

Mangrove forests store high densitie of organic carbon, which, when coupled with high rates of deforestation, means that mangroves have the potential to contribute substantially to carbon emissions. Consequently, mangroves are strong candidates for inclusion in nationally determined contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC), and payments for ecosystem services (PES) programmes that financially incentivize the conservation of forested carbon stocks. This study quantifies annual mangrove carbon stocks from 2000 to 2012 at the global, national and sub-national levels, and global carbon emissions resulting from deforestation over the same time period. Globally, mangroves stored 4.19 Pg of carbon in 2012, with Indonesia, Brazil, Malaysia and Papua New Guinea accounting for more than 50% of the global stock. 2.96 Pg of the global carbon stock is contained within the soil and 1.23 Pg in the living biomass. Two percent of global mangrove carbon was lost between 2000 and 2012, equivalent to a maximum potential of 316,996,250 t of CO_2 emissions.

3-D Structure

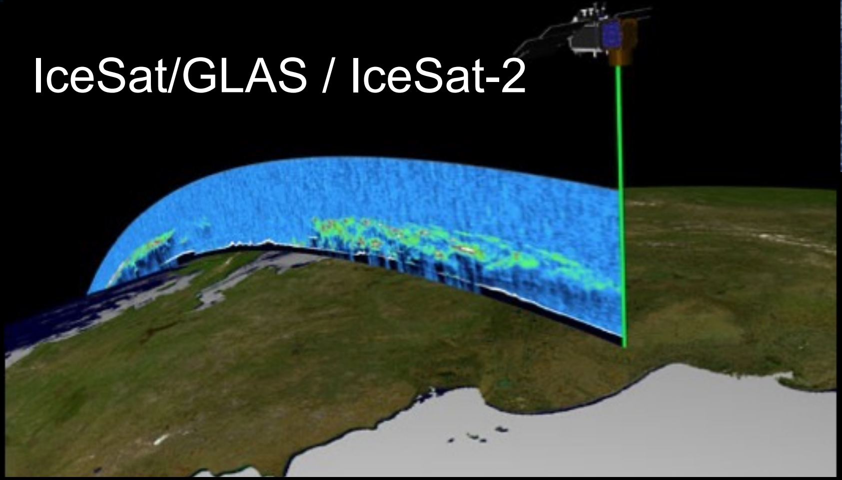
Why do we care about mangrove structure?

- Height, Biomass and Carbon Stocks
- Ecosystem Condition (intact vs degraded)
- Ecosystem services
- Environmental drivers
- Management and restoration

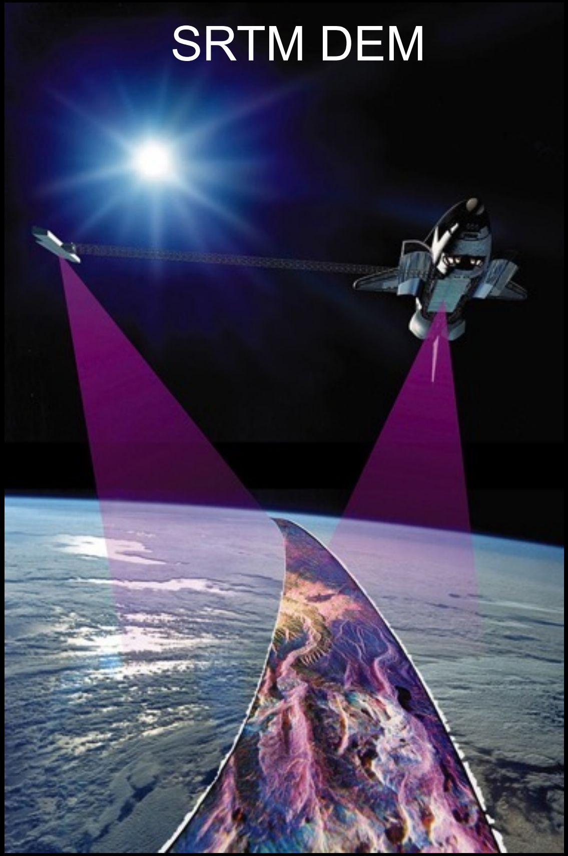
Remote Sensing Techniques: Mangrove 3D structure from Radar and Lidar

TanDEM-X Digital Elevation Modal

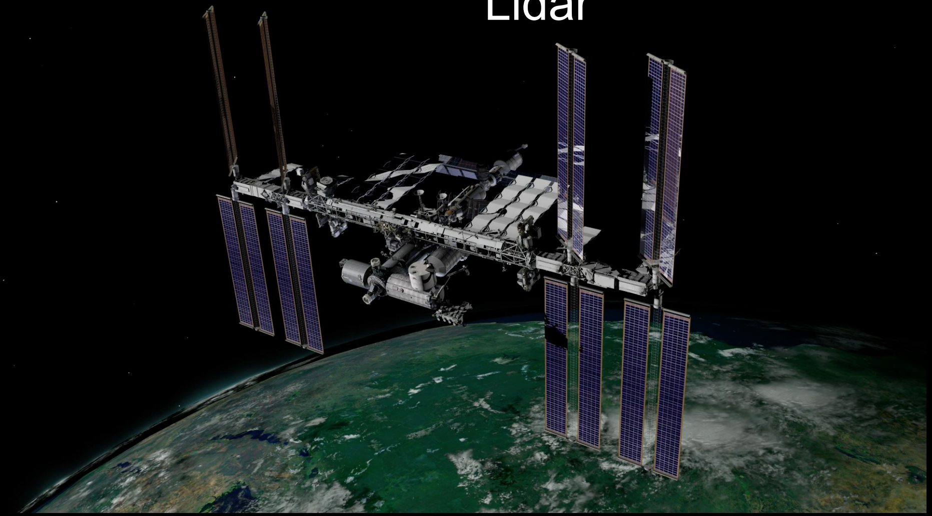
IceSat/GLAS / IceSat-2



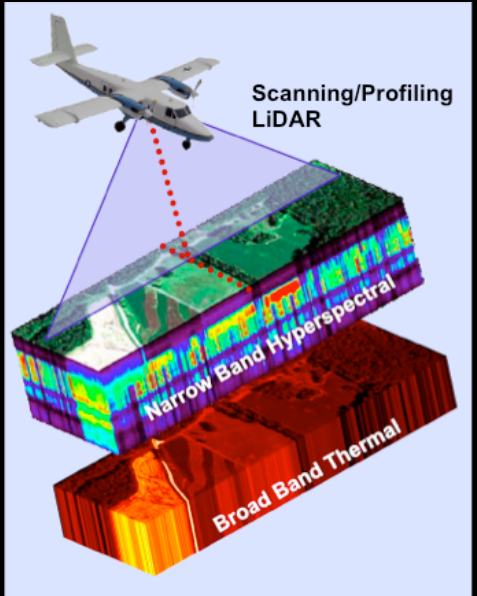
SRTM DEM



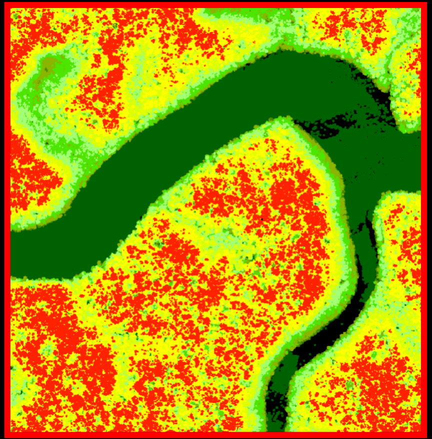
Global Ecosystem Dynamics Investigation (GEDI) Lidar

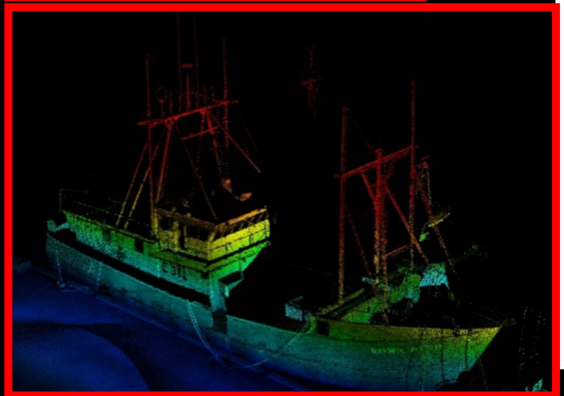


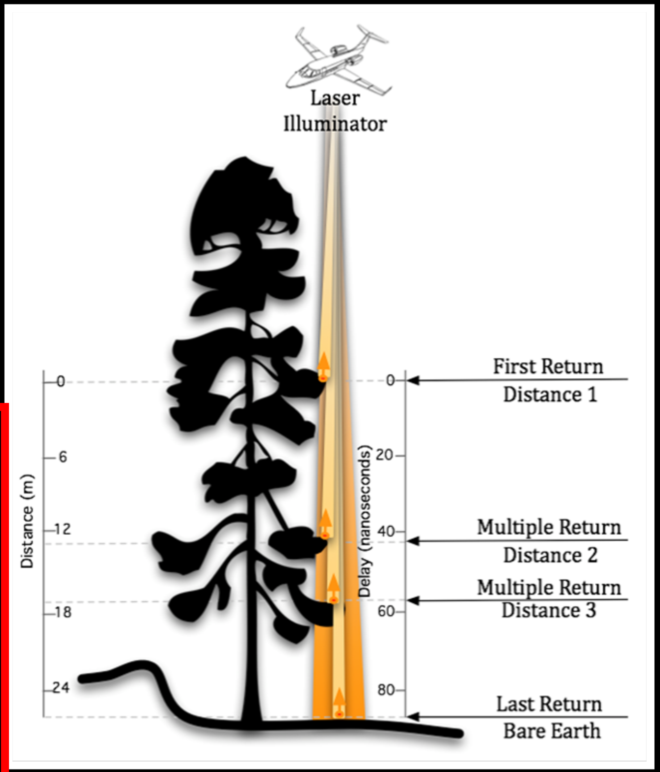
Airborne Lidar



How do we measure 3D structure? Lidar







University of California

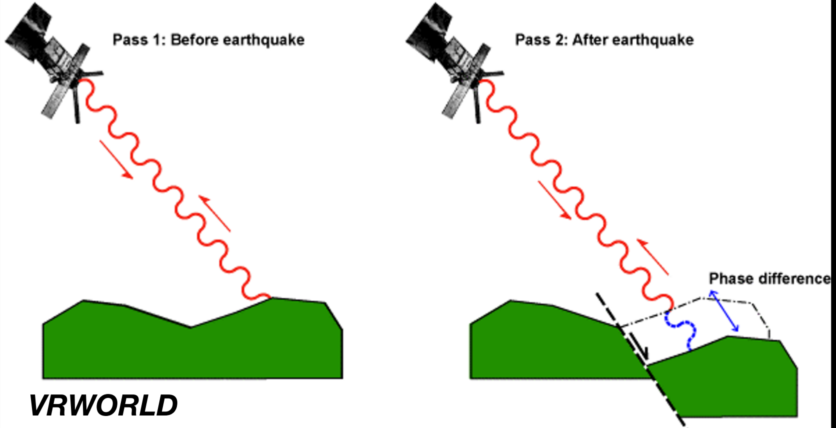
Light Detection and Ranging (LiDAR)

- Ground-based, airborne or spaceborne.
- High resolution active remote sensing technology that measures the distance of reflected laser light.
- 3D point cloud, waveform or photons with x, y and z coordinates
- Canopy height = First returns minus last returns
- Canopy height is proportional to AGB
- ALS uncertainty for canopy height measurements is < 1 m
- Samples/footprints or small area wall to wall coverage

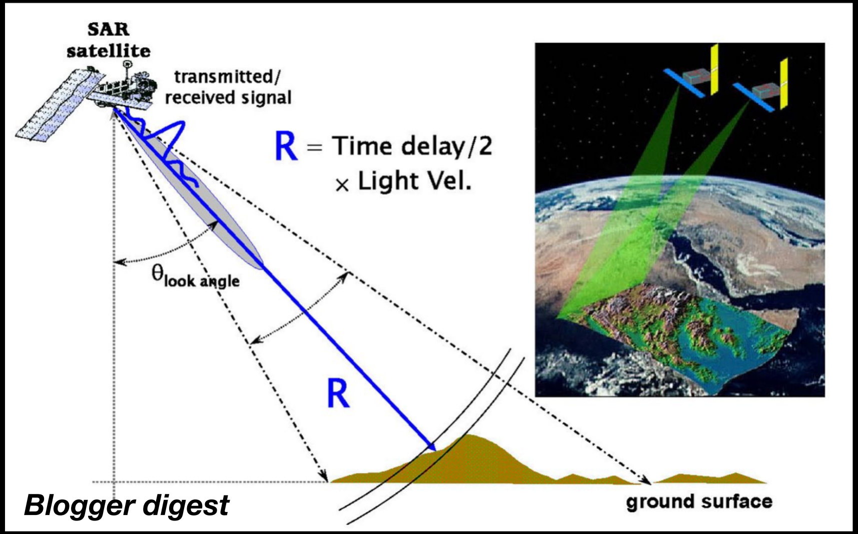
Synthetic Aperture Radar Interferometry

Radio Detection and Ranging (RaDAR)

(Active RS)



VRWORLD

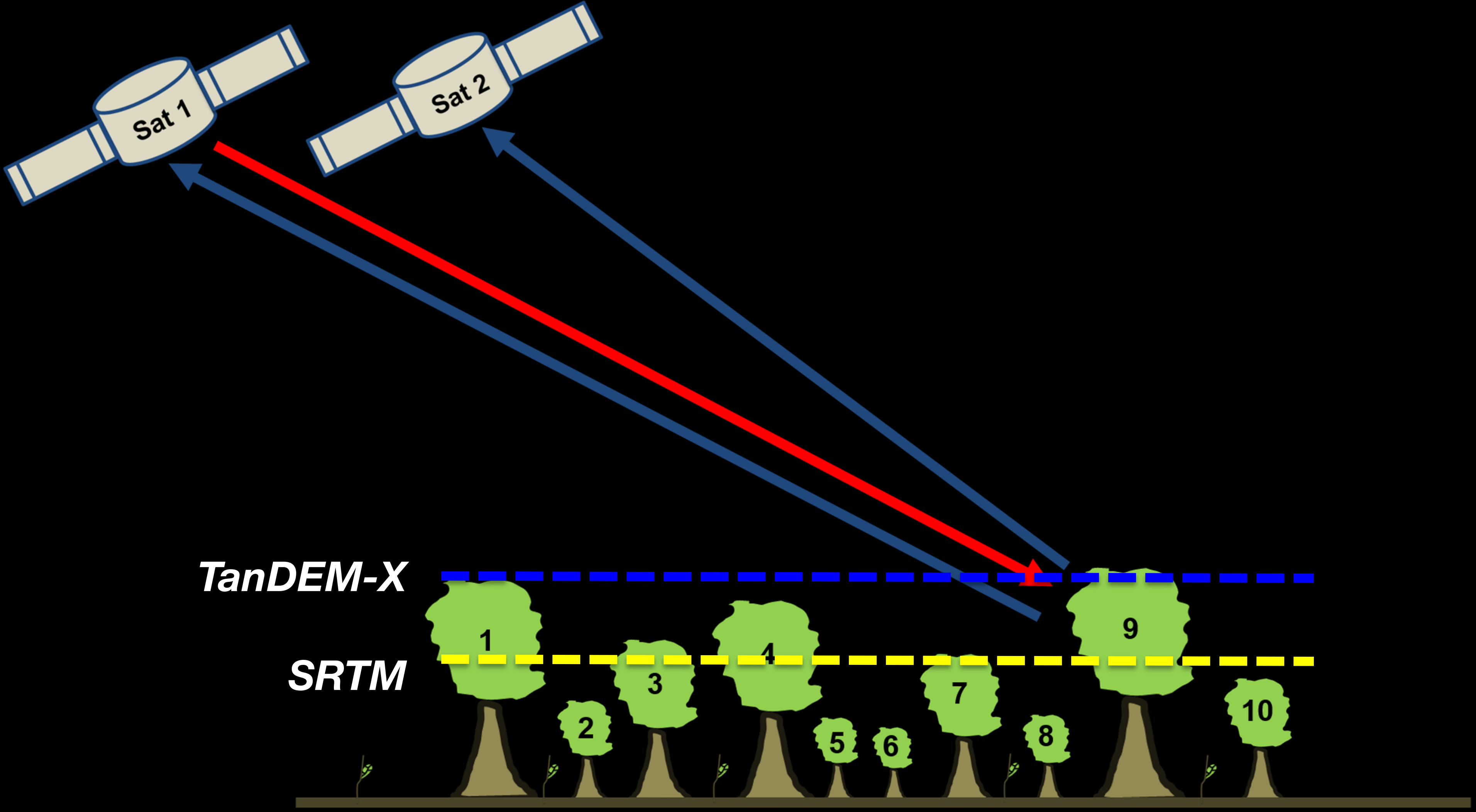


Blogger digest

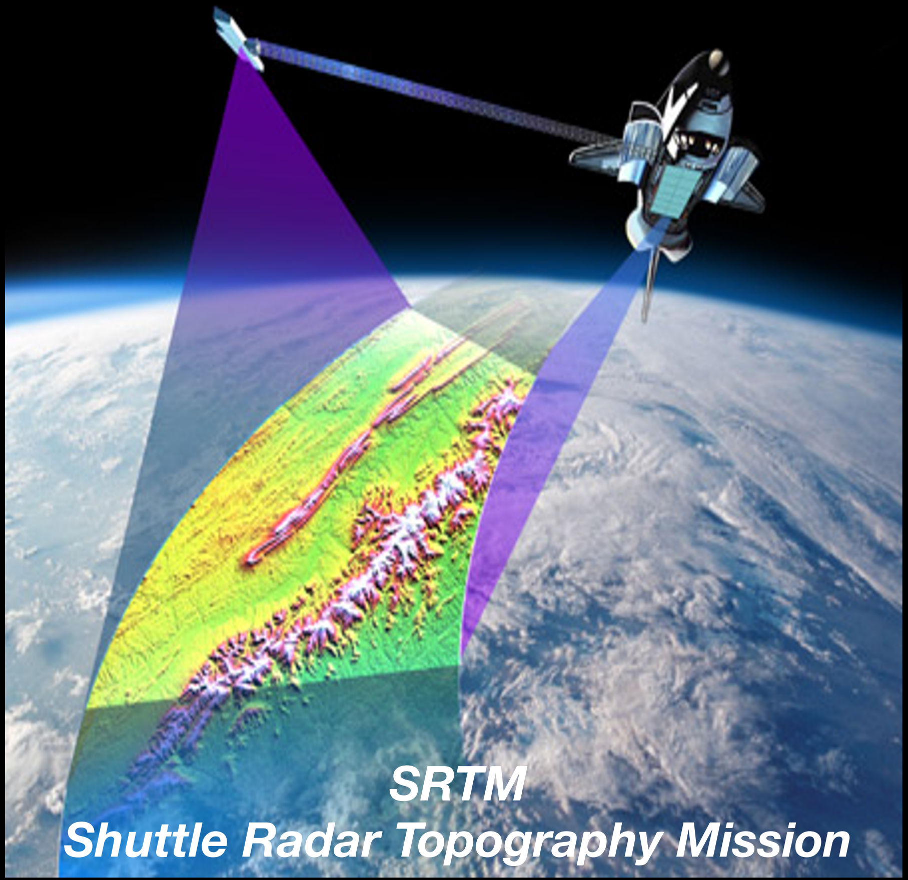
- **Synthetic Aperture Radar (SAR)**
  - Radar - active illumination system
  - Reflected signal or echo, is backscattered from the surface and received a fraction of a second later at the same antenna
  - Can penetrate through clouds
  - Covers larger ground area

- **Interferometric SAR (InSAR)**
  - InSAR – measure phase changes between two acquisitions
  - Commonly used to quantify changes and deformation in the Earth
  - Single – pass InSAR: TanDEM-X (2010 –present) and SRTM (2000)

SAR Interferometry

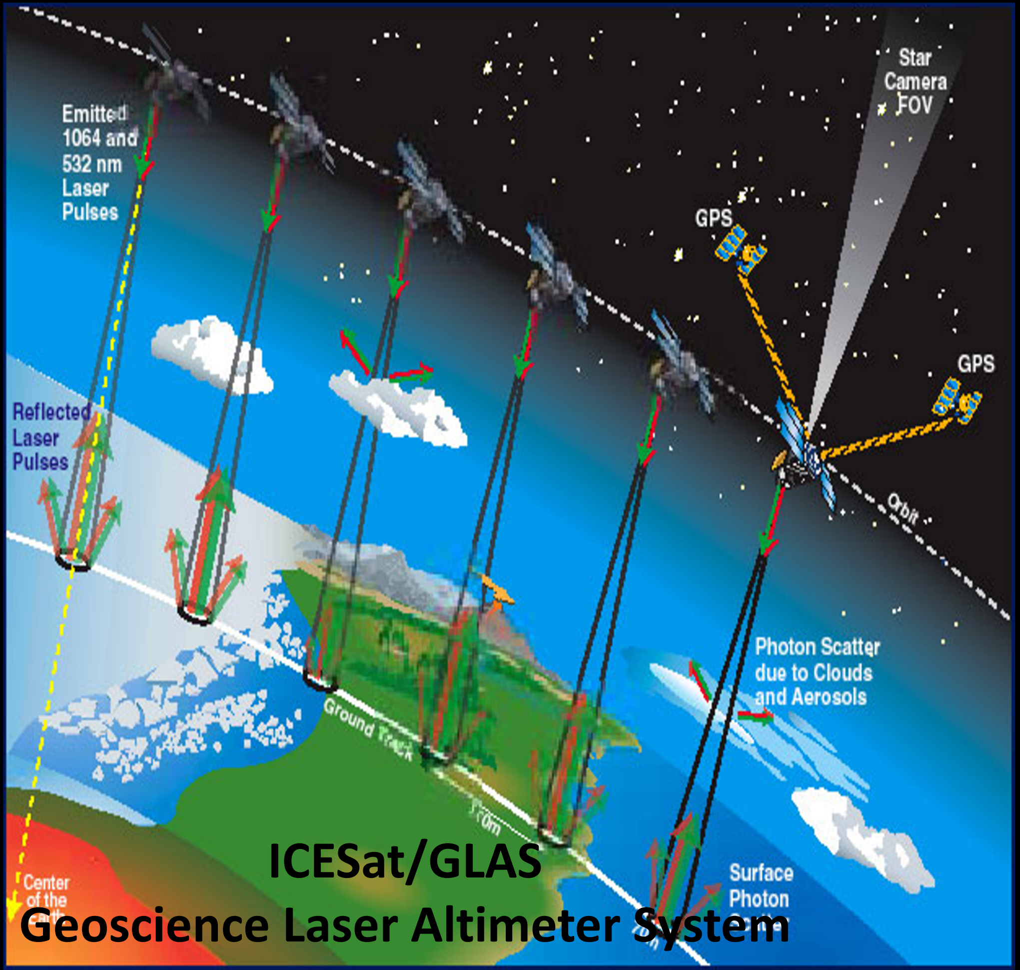


Global Mangrove Height and Biomass



SRTM

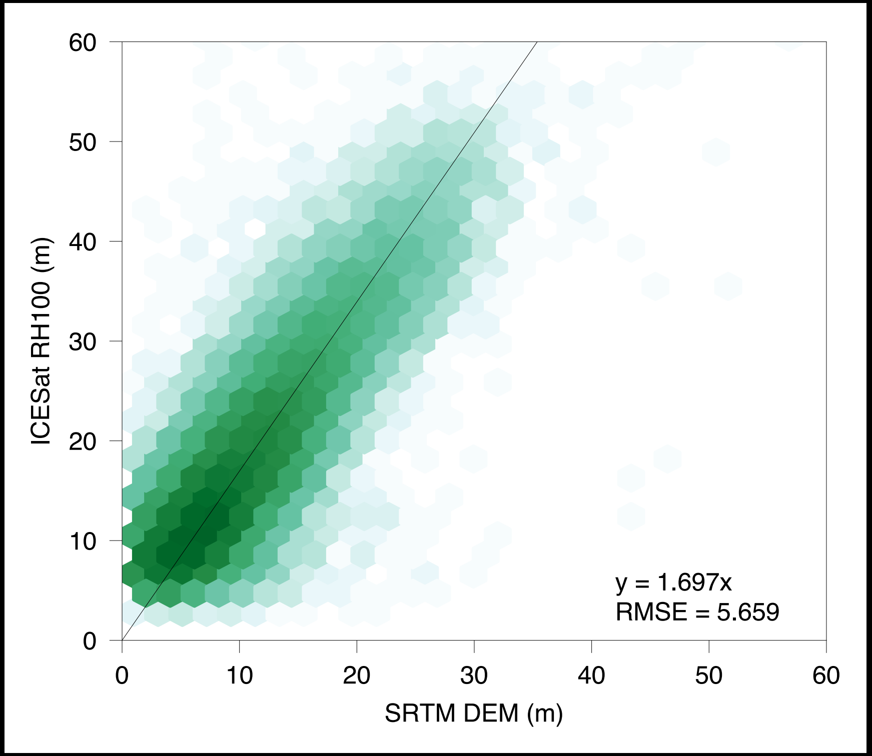
Shuttle Radar Topography Mission

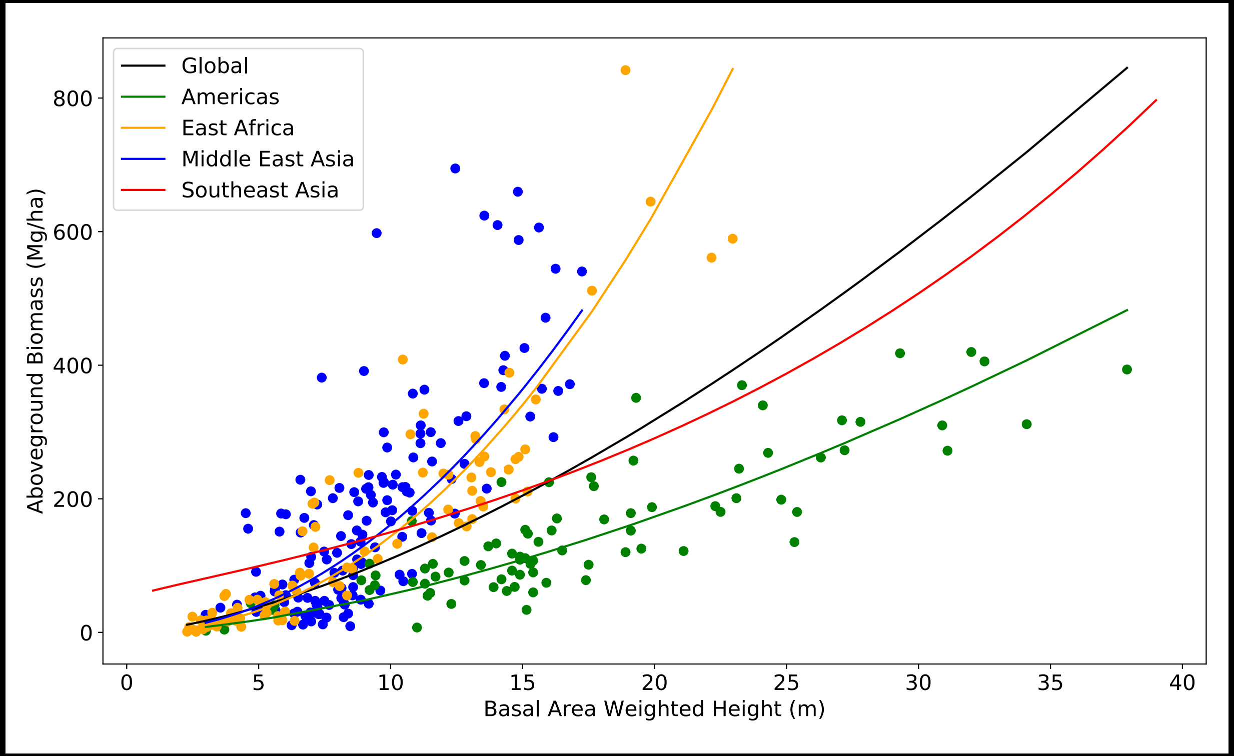


ICESat/GLAS

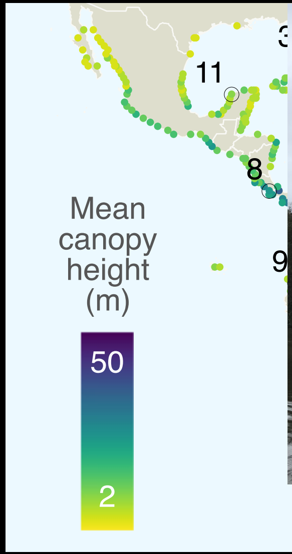
Geoscience Laser Altimeter System

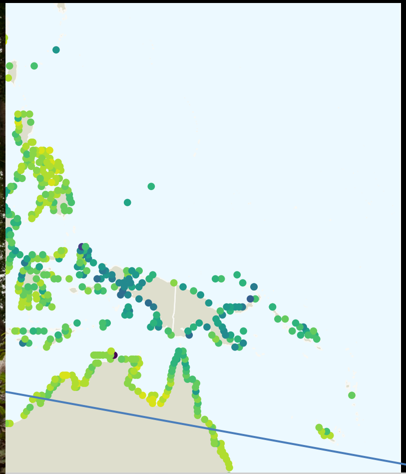
Global Canopy Height and Biomass Calibration

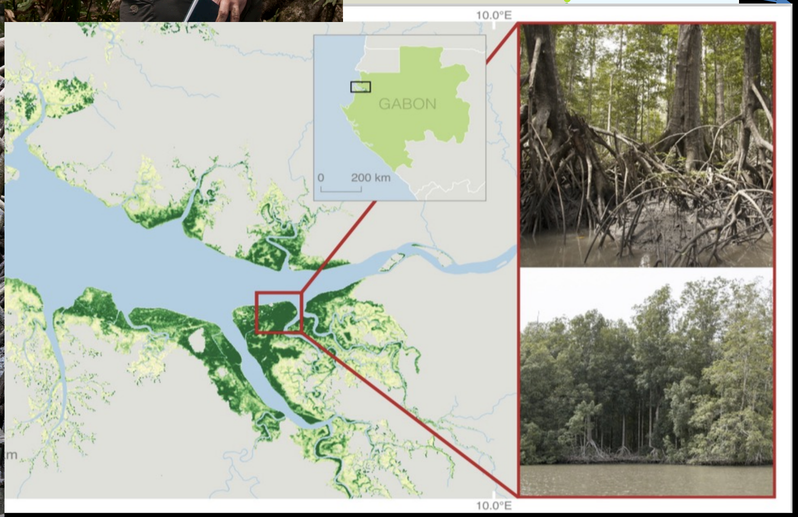




The world’s tallest Mangroves!





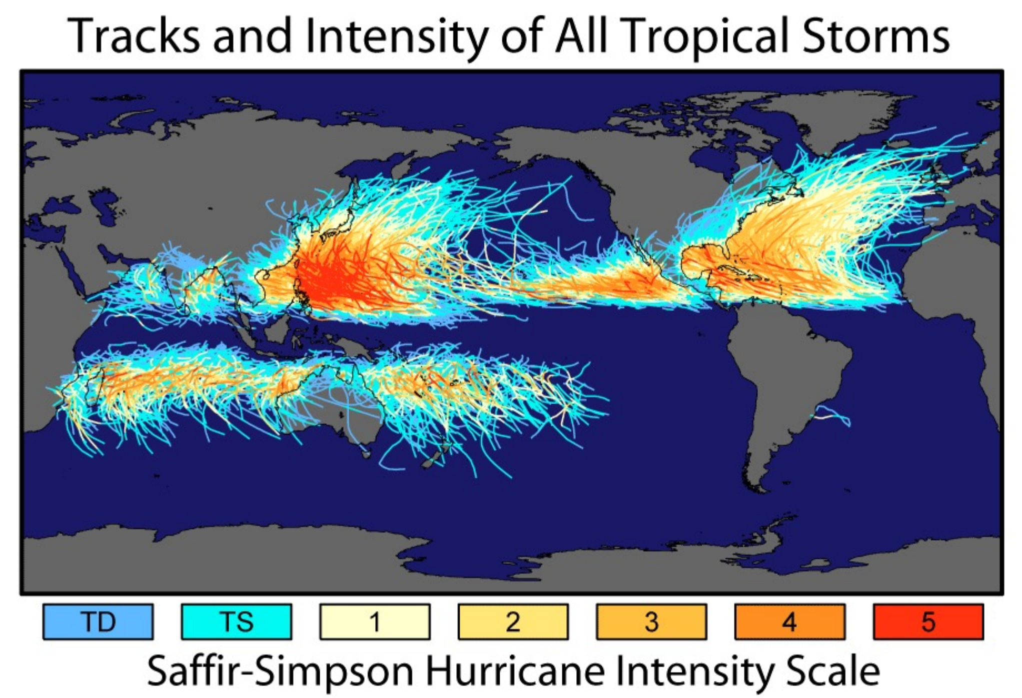


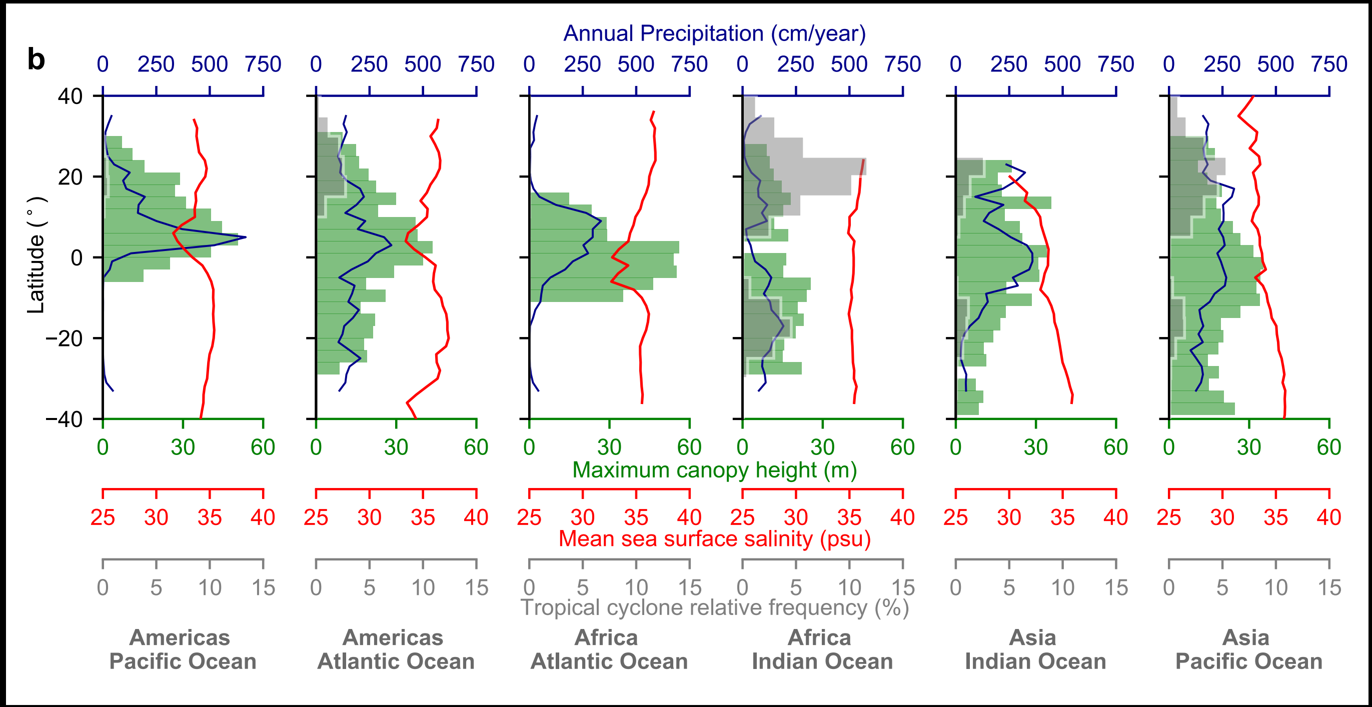
Highlights
- Maximum canopy heigh
- Tallest forests were four
- Tallest tree measured in
- Mean canopy height (30
- 5% of mangrove canopi

Simard, M., **Fatoyinbo, L.**, Smetanka, C., Rivera-Monroy, V.H., Castañeda-Moya, E., Thomas, N. and Van der Stocken, T., 2019. Mangrove canopy height globally related to precipitation, temperature and cyclone frequency. Nature Geoscience, 12(1), p.40.

Maximum Height Controls

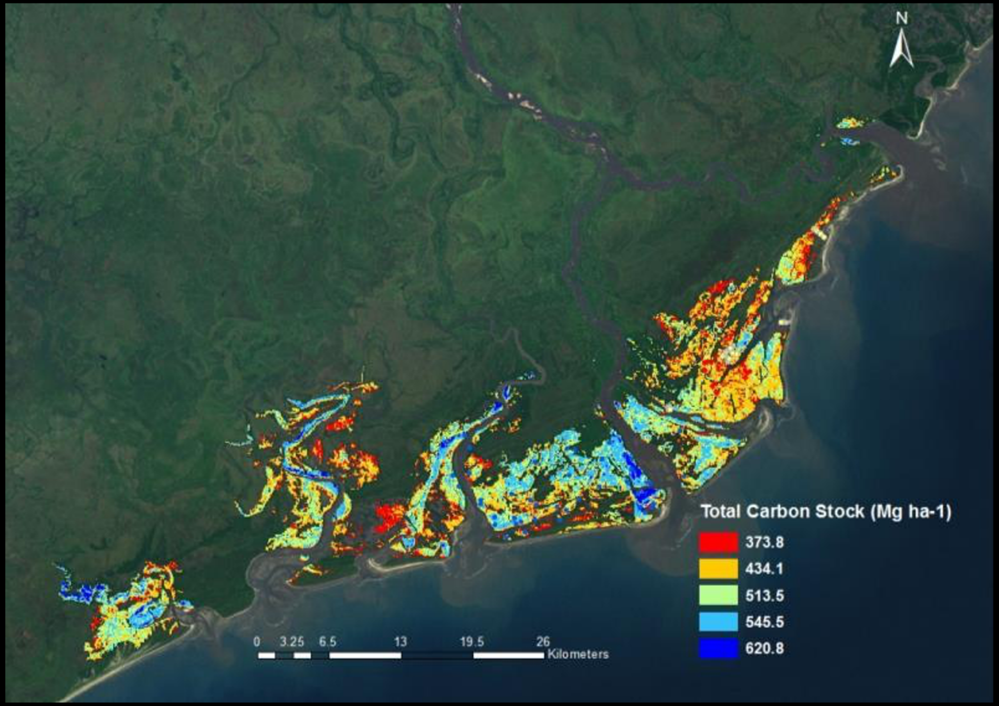
- Main predictors of Canopy height are total annual precipitation, mean annual temperature and tropical cyclone landfall frequency.



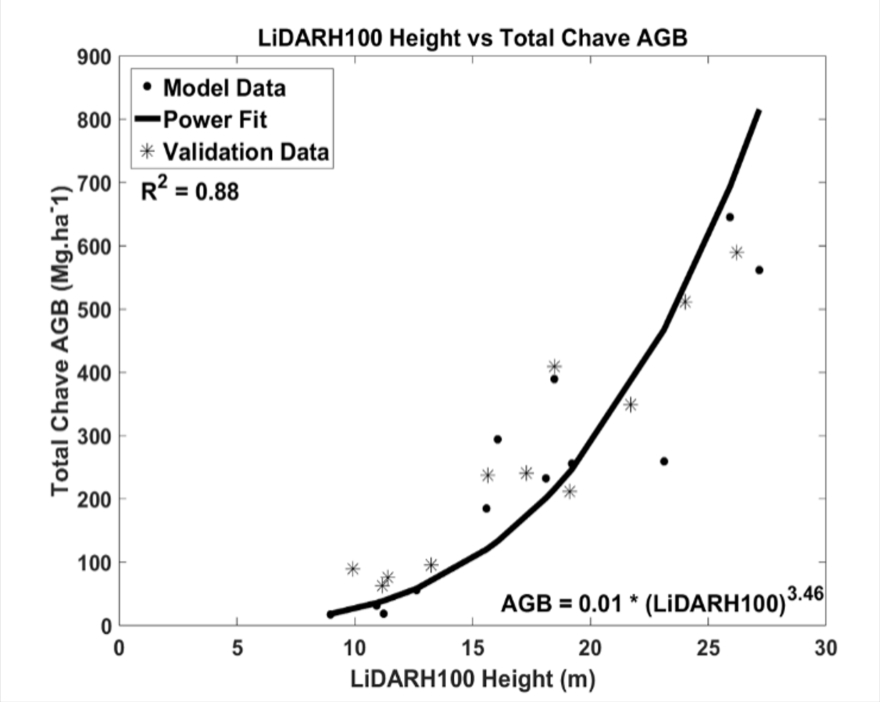


Biomass Estimation Approaches

- Paint-by-number



- Allometric Models

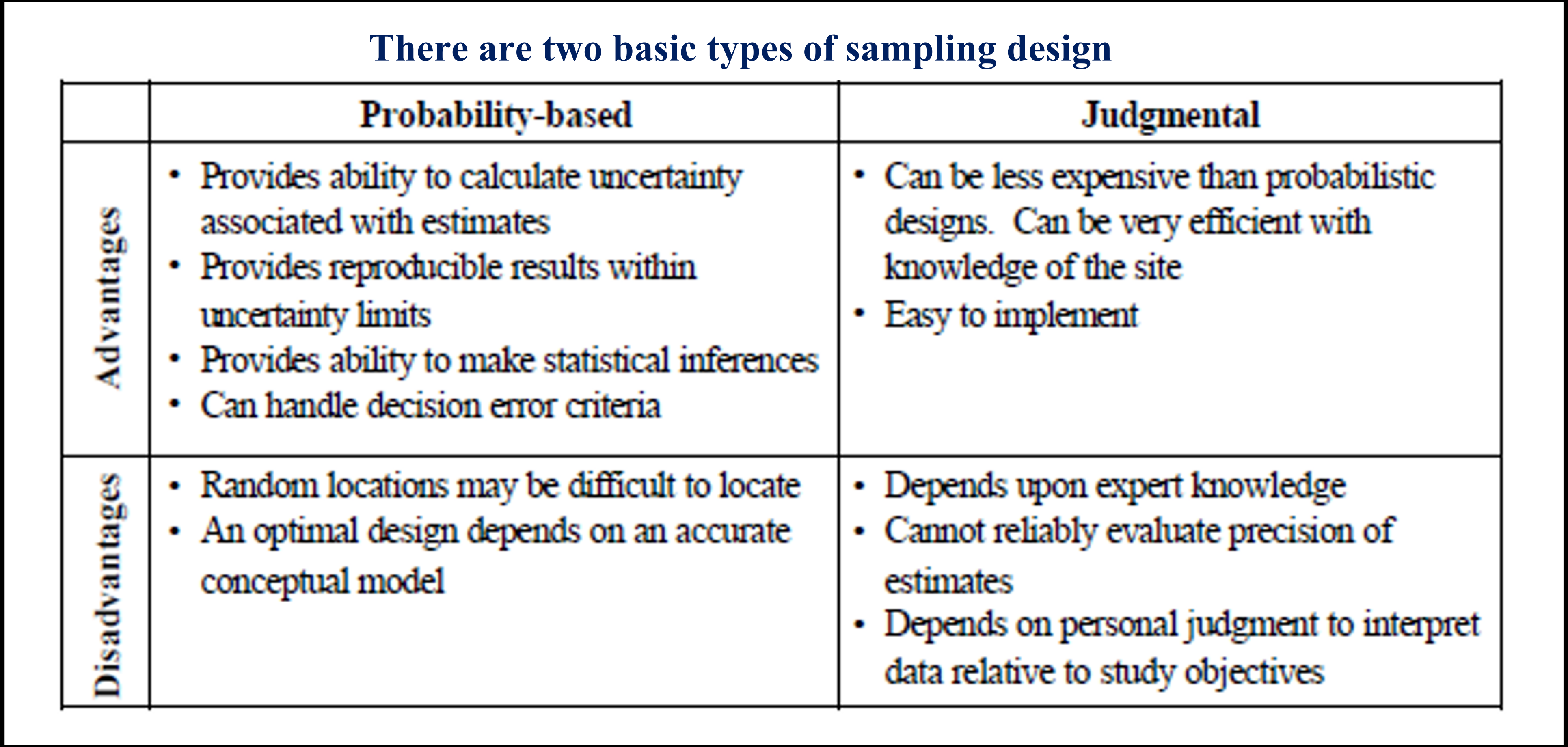


Mangrove Field Inventory

A Carbon Inventory of Mangroves in the Zambezi River Delta, Mozambique

- Characterize ecosystem carbon stock of mangroves on the Zambezi River Delta;
- Provide a <u>baseline inventory</u> and framework for monitoring forest growth and change;
- Build capacity within Mozambique to <u>implement inventory and monitoring protocols to support REDD+</u> and other mitigation and adaptation strategies.

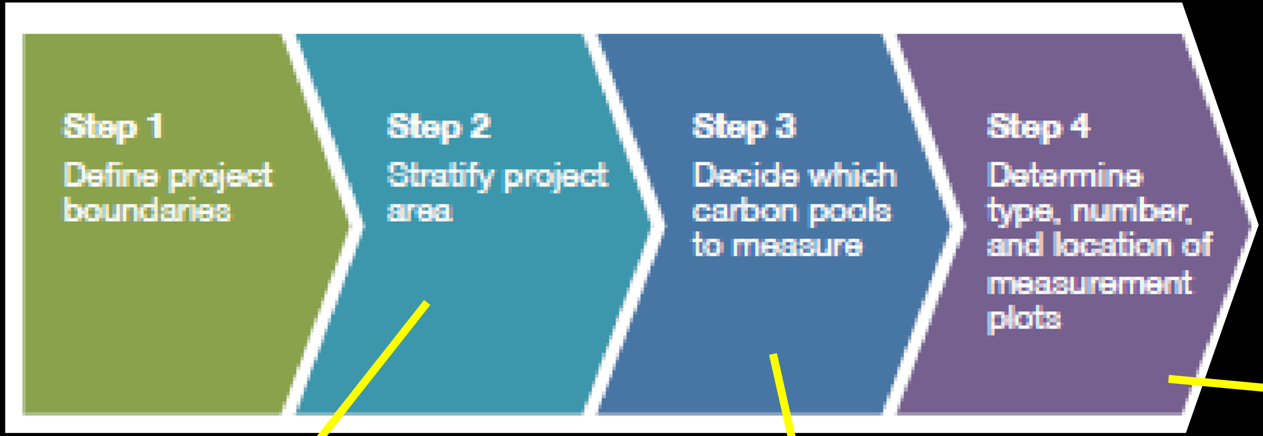
Inventory Design – Objective



There are two basic types of sampling design

	Probability-based	Judgmental
Advantages	• Provides ability to calculate uncertainty associated with estimates • Provides reproducible results within uncertainty limits • Provides ability to make statistical inferences • Can handle decision error criteria	• Can be less expensive than probabilistic designs. Can be very efficient with knowledge of the site • Easy to implement
Disadvantages	• Random locations may be difficult to locate • An optimal design depends on an accurate conceptual model	• Depends upon expert knowledge • Cannot reliably evaluate precision of estimates • Depends on personal judgment to interpret data relative to study objectives

Inventory Design – Steps



Step 1
Define project boundaries

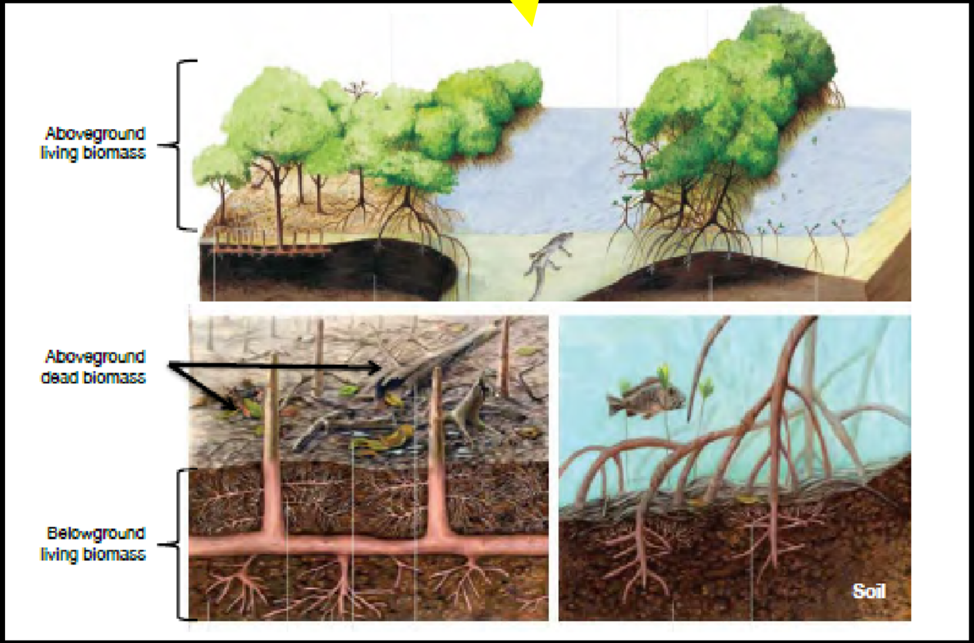
Step 2
Stratify project area

Step 3
Decide which carbon pools to measure

Step 4
Determine type, number, and location of measurement plots

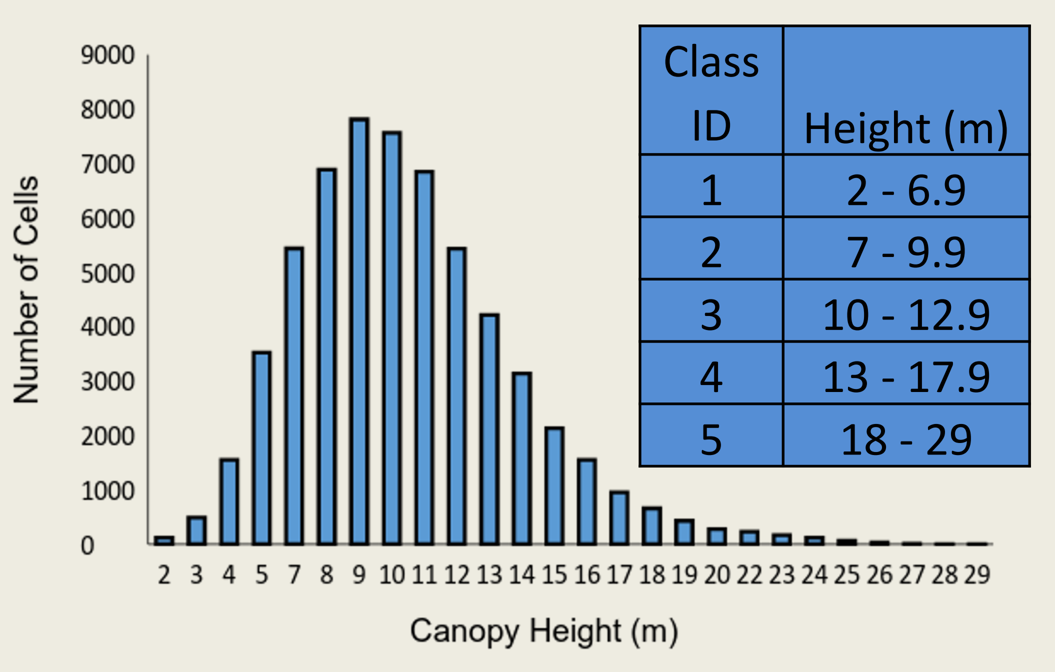
- Literature
- Pilot study

Basis of Stratification
- Forest structure (e.g., canopy height)
- Geomorphic setting
- Zonation
- Etc.



A Spatial Decision Support System is a way to integrate these steps and maintain an objective inventory

Inventory Approach :
Stratified Random Sampling Design

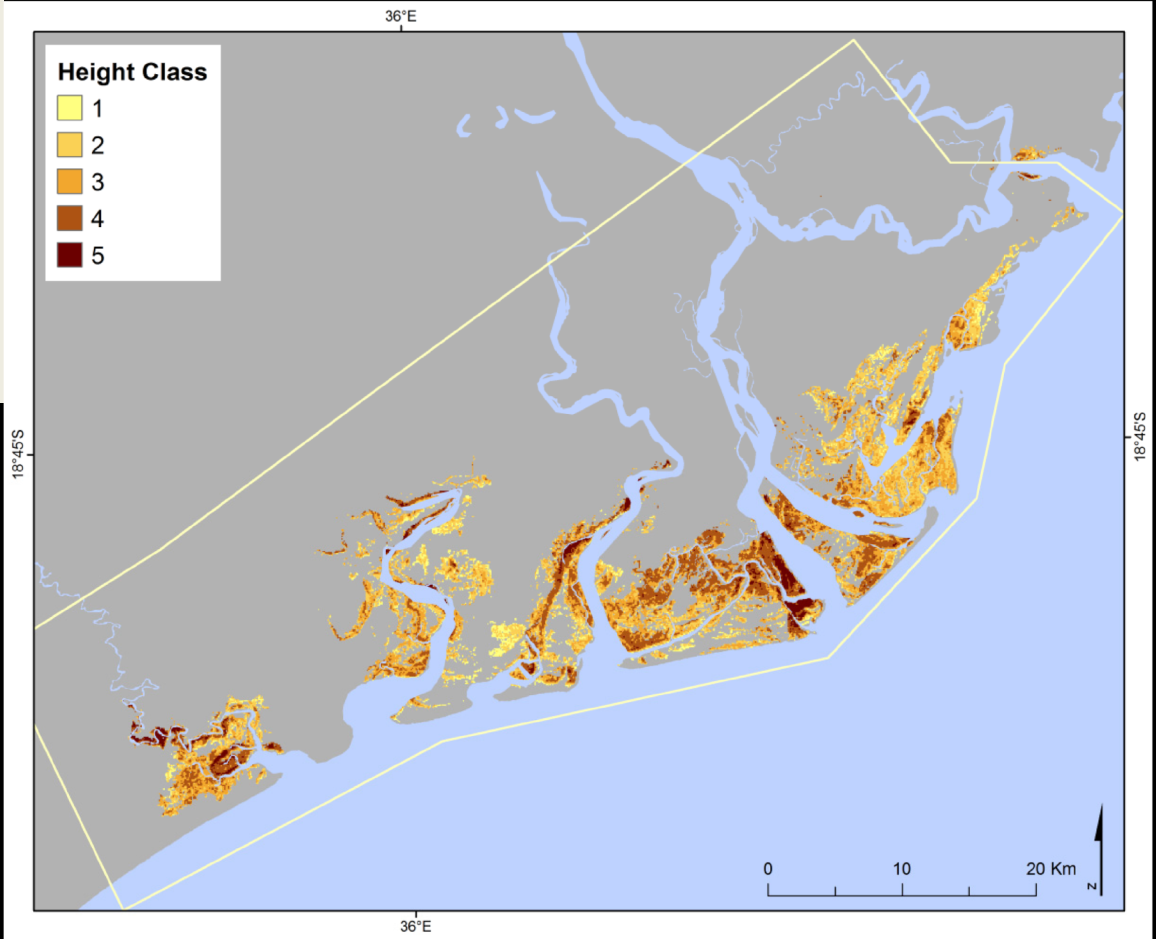


Class ID	Height (m)
1	2 - 6.9
2	7 - 9.9
3	10 - 12.9
4	13 - 17.9
5	18 - 29

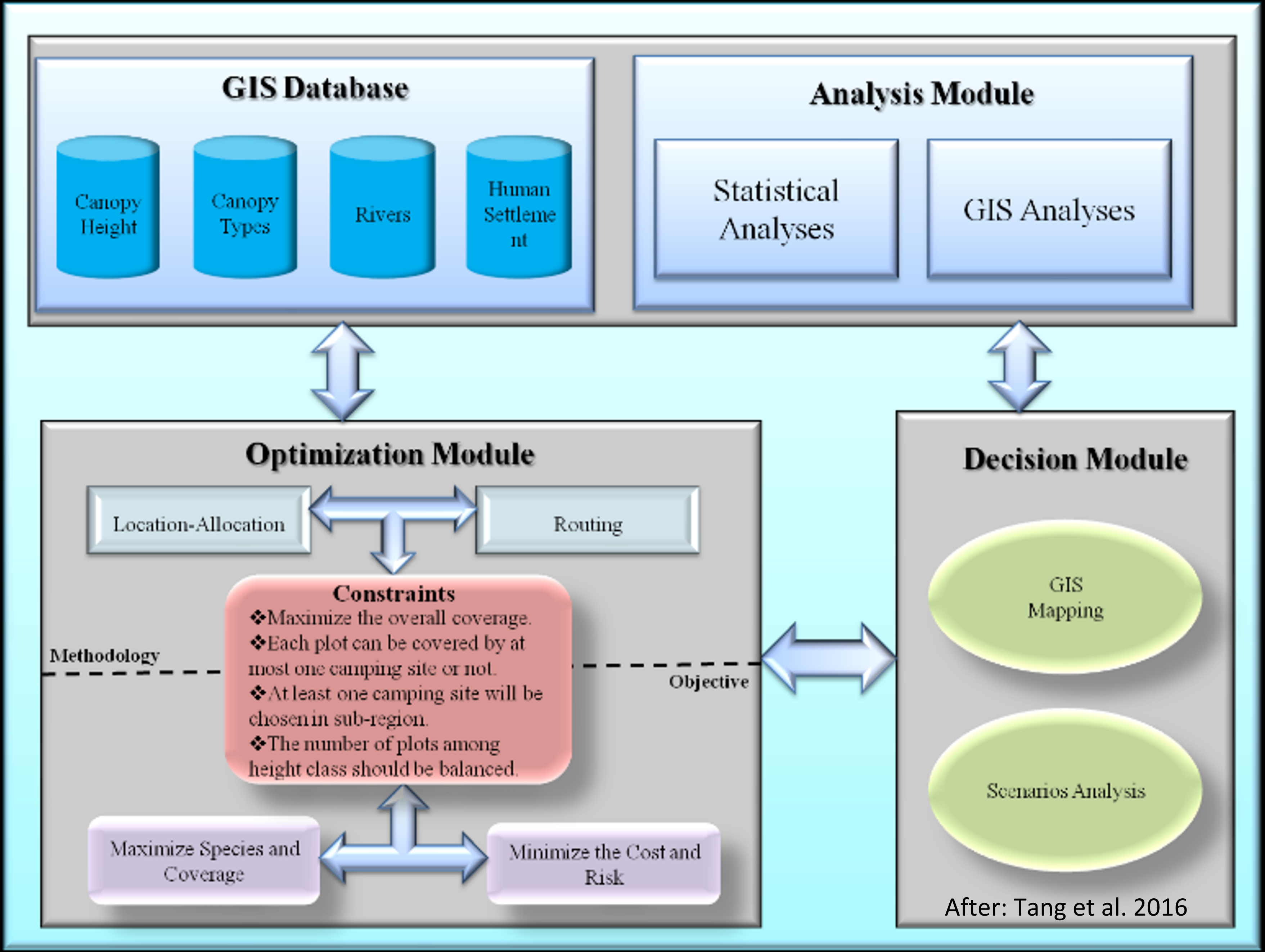
Data from Fatoyinbo and Simard, 2013

Stratification: Forest Canopy Height

Because canopy height is functionally related to biomass, it's a sound basis for stratification



Spatial Decision Support System



GIS Database

Canopy Height

Canopy Types

Rivers

Human Settlement

Analysis Module

Statistical Analyses

GIS Analyses

Optimization Module

Location-Allocation

Routing

Constraints

- ❖Maximize the overall coverage.
- ❖Each plot can be covered by at most one camping site or not.
- ❖At least one camping site will be chosen in sub-region.
- ❖The number of plots among height class should be balanced.

Methodology

Objective

Maximize Species and Coverage

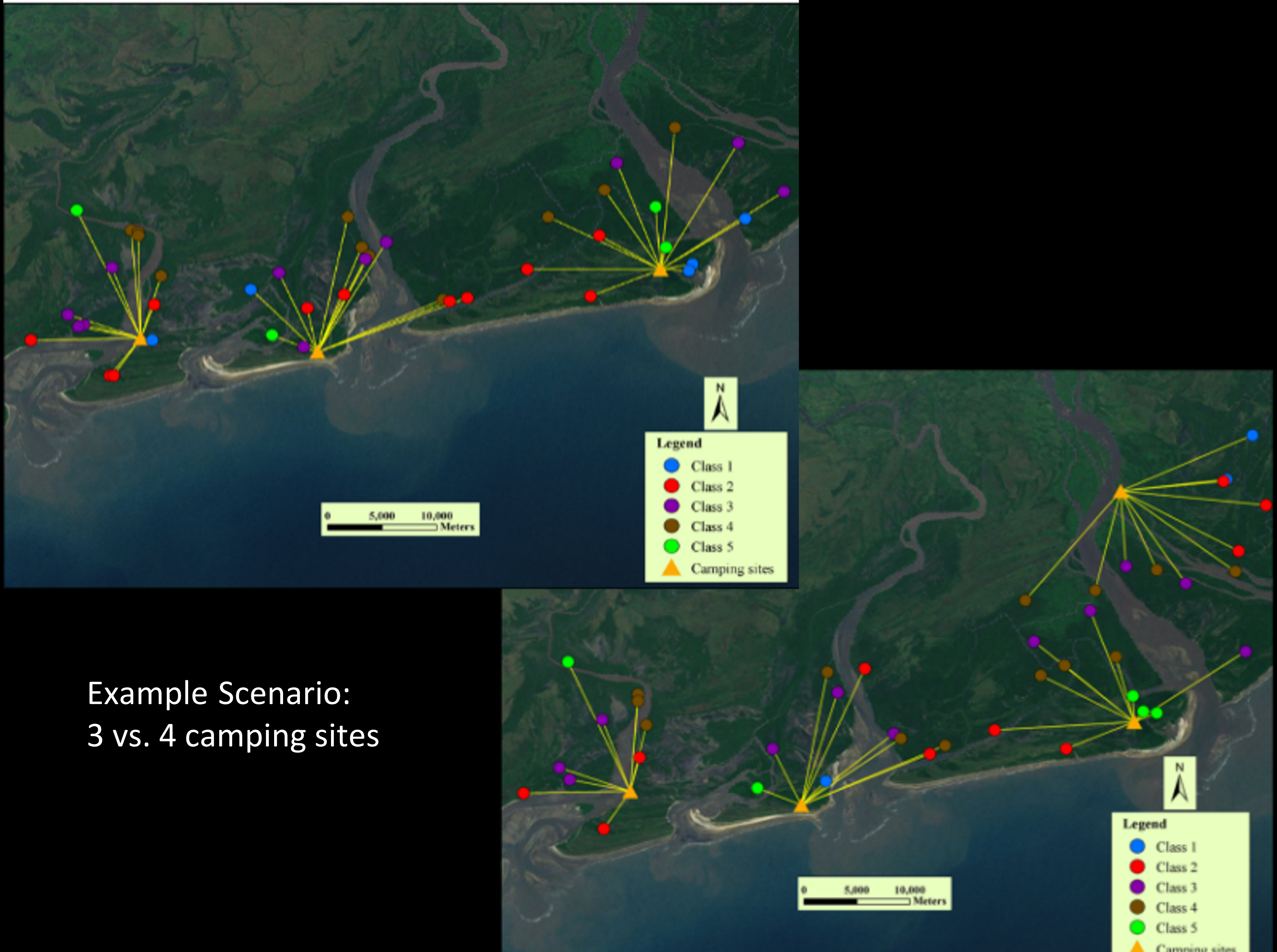
Minimize the Cost and Risk

Decision Module

GIS Mapping

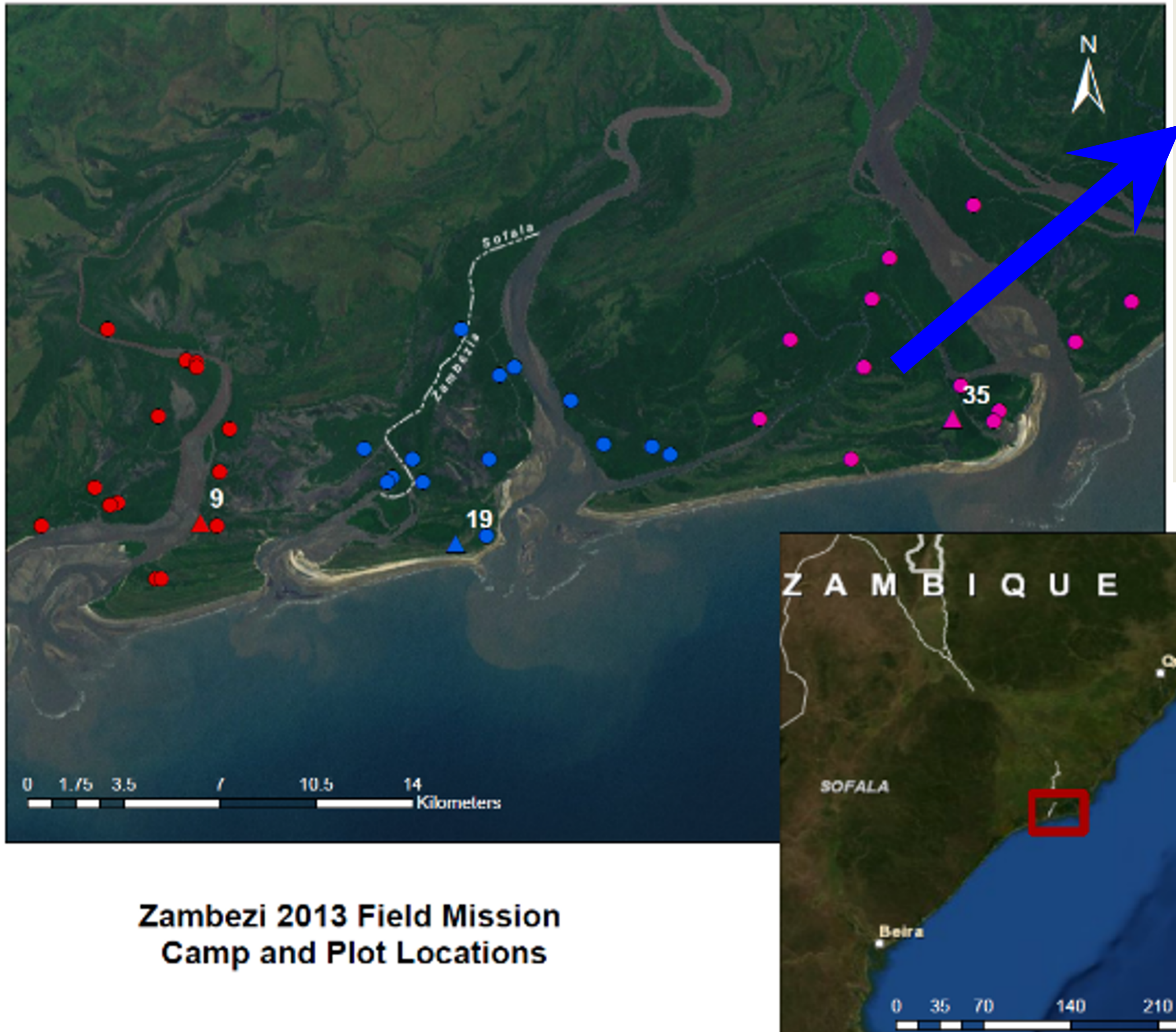
Scenarios Analysis

After: Tang et al. 2016

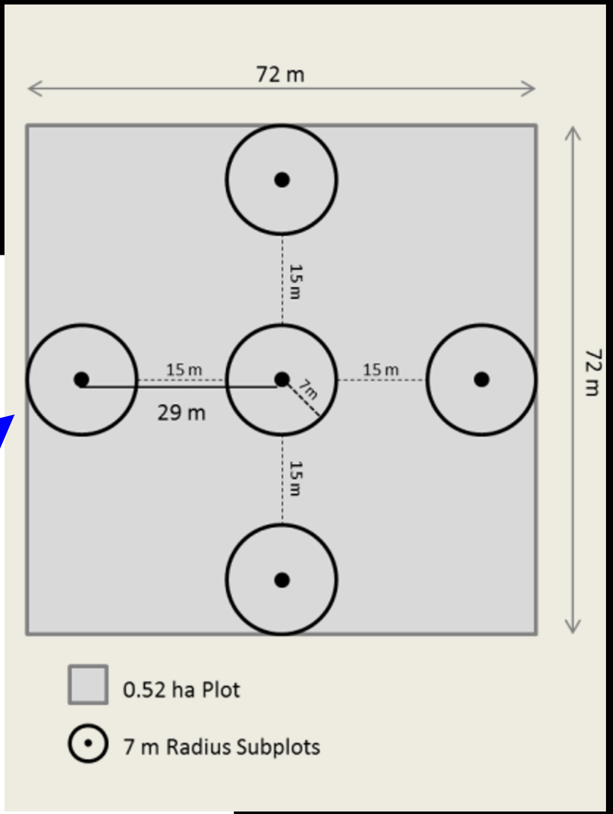


Example Scenario:
3 vs. 4 camping sites

Field Sampling Plan
Plots randomly located within strata



Zambezi 2013 Field Mission
Camp and Plot Locations



Measurements to Estimate Ecosystem C Pools

Above-ground pools - live

- Tree biomass
  - > 50 cm DBH
  - >5 & < 50 cm DBH
  - < 5 cm DBH
- Shrub layer + seedlings

Above-ground pools- dead

- Tree biomass
  - > 50 cm DBH
  - >5 & < 50 cm DBH
  - < 5 cm DBH
- Litter
- Coarse wood - down
  - 5 categories

Below-ground pools

- Tree biomass (live & dead)
  - > 50 cm DBH
  - >5 & < 50 cm DBH
  - < 5 cm DBH

Soils

- to 200 cm depth

Africa Sites

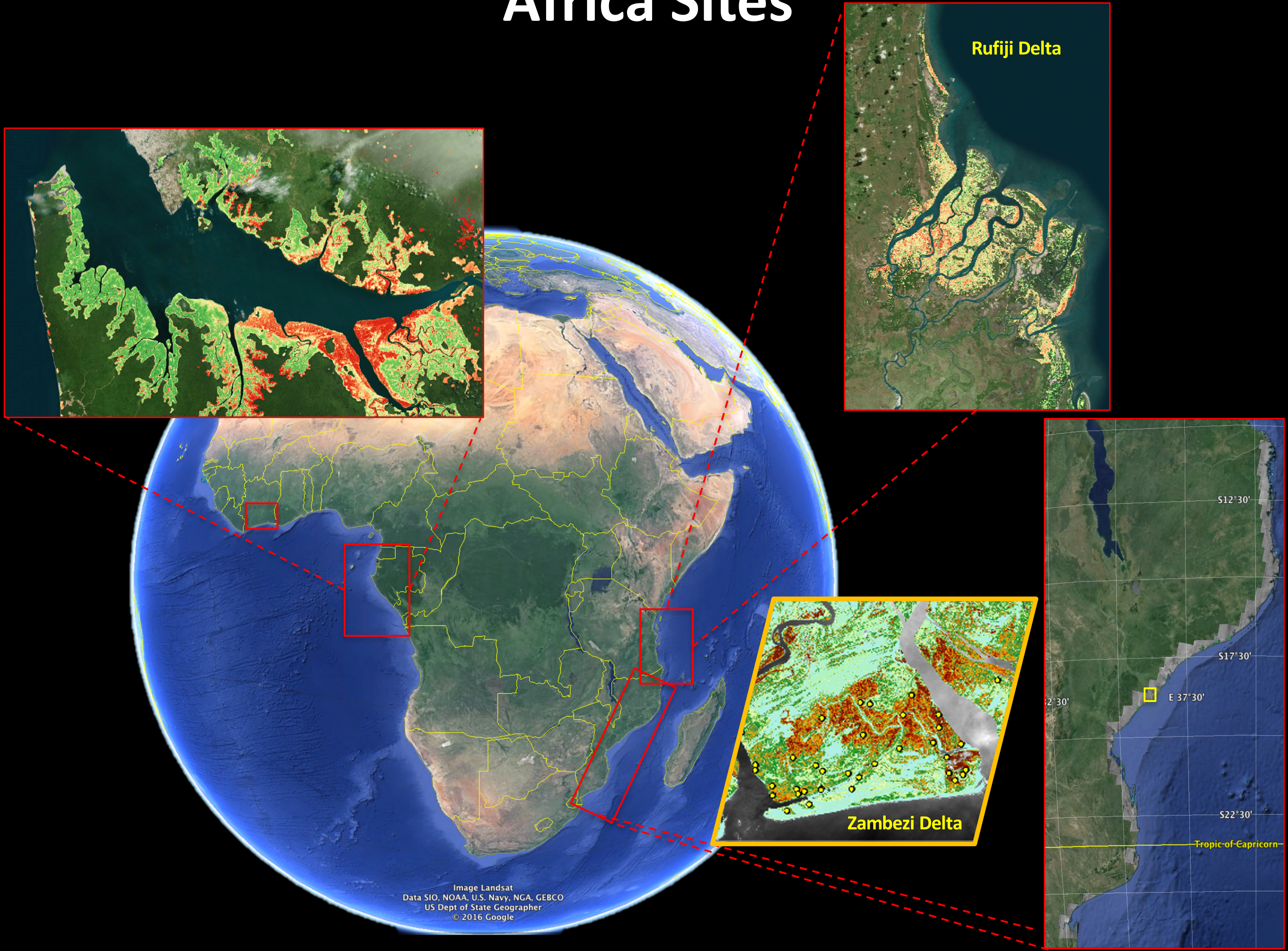
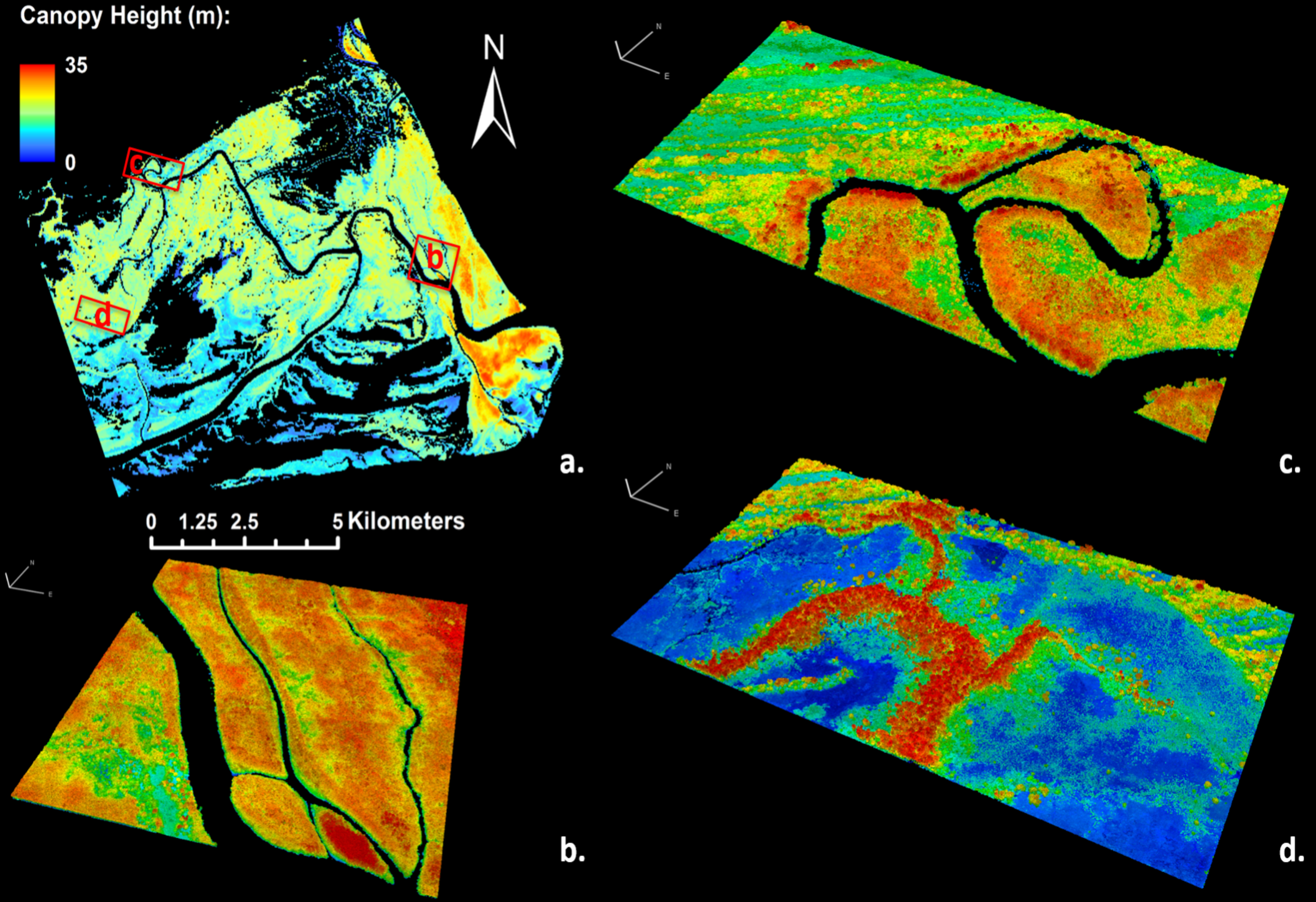
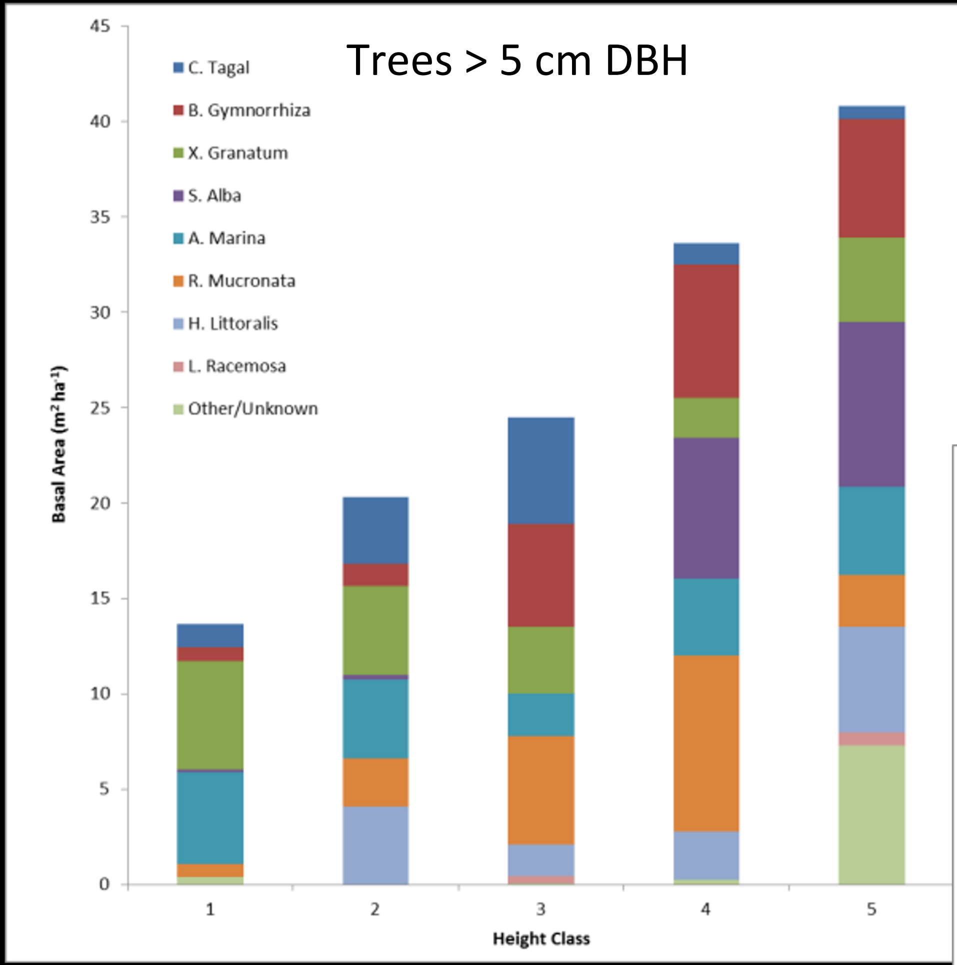


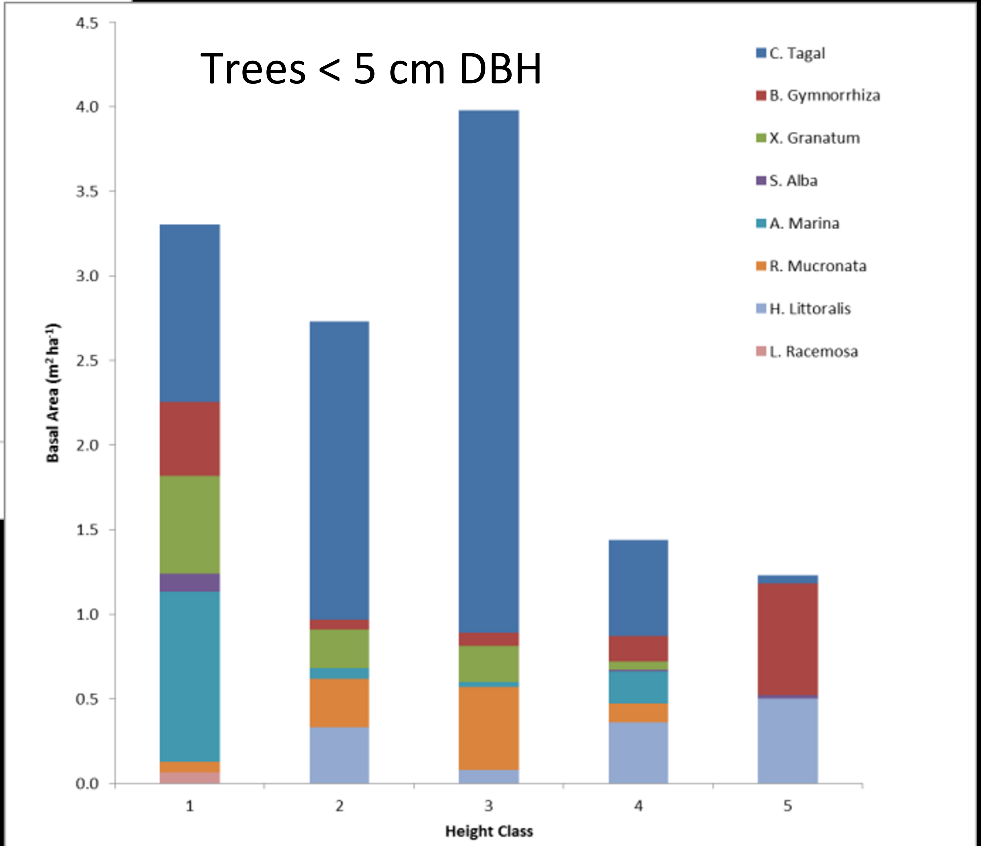
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
US Dept of State Geographer
© 2016 Google

Airborne Lidar: Zambezi Delta



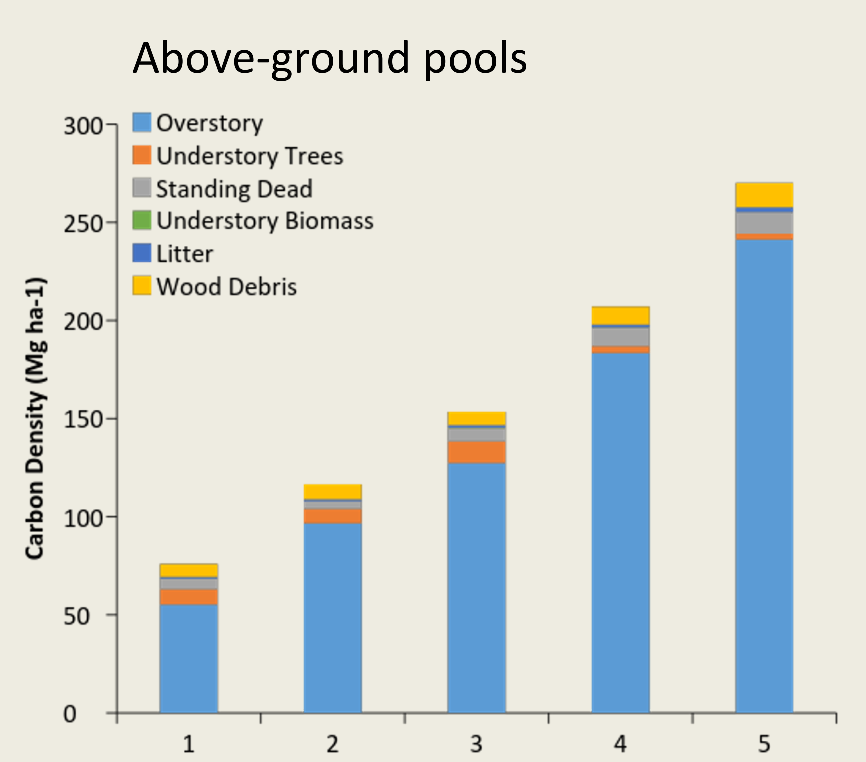
Mangrove Composition

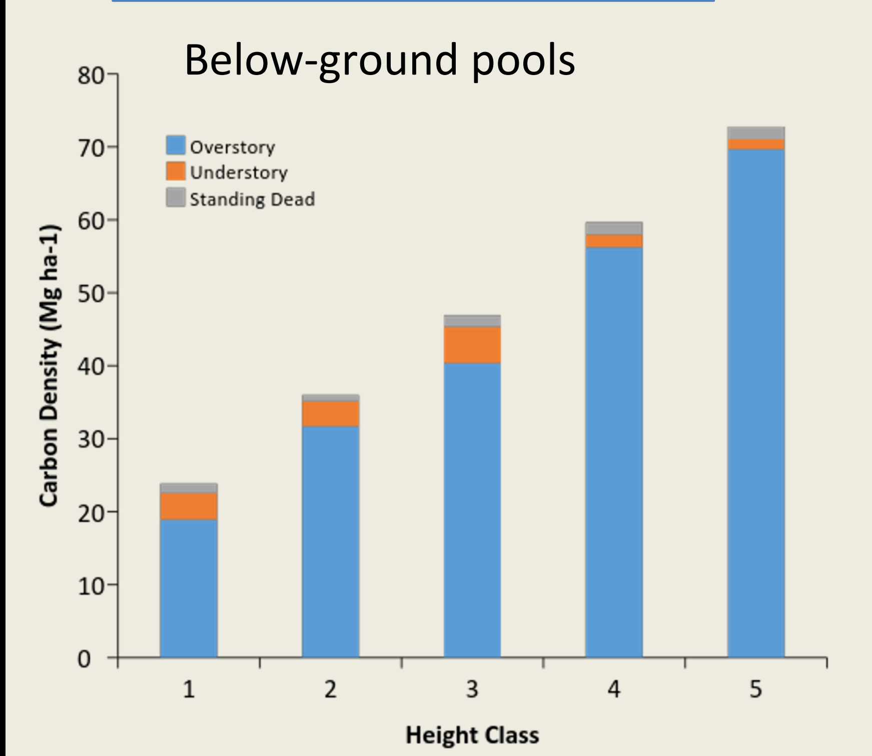




Trettin, C.C., Stringer, C.E. and Zarnoch, S.J., 2016. Composition, biomass and structure of mangroves within the Zambezi River Delta. *Wetlands ecology and management*, *24*(2), pp.173-186.

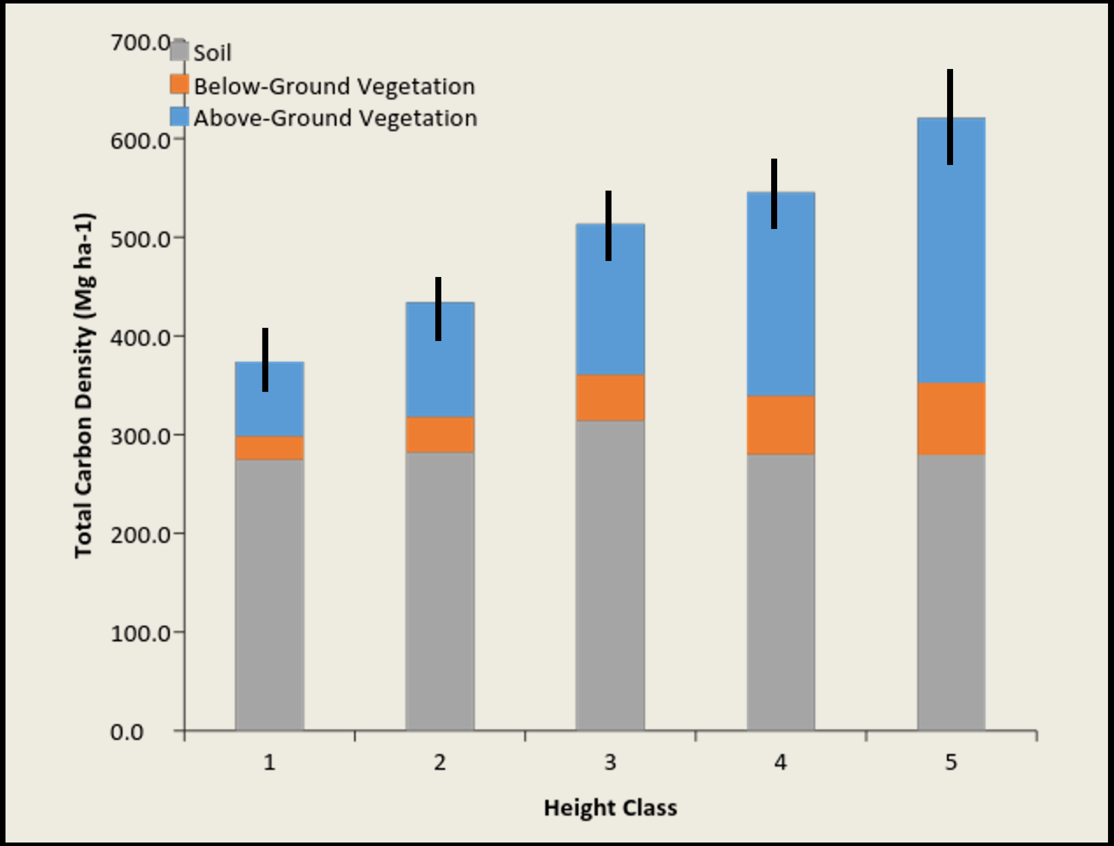
Carbon Distribution in Above- and Below-ground Biomass Pools – Zambezi Delta





Stringer, C.E., Trettin, C.C., Zarnoch, S.J. and Tang, W., 2015. Carbon stocks of mangroves within the Zambezi River Delta, Mozambique. *Forest Ecology and Management*, *354*, pp.139-148.

Ecosystem Carbon Stocks – Zambezi Delta

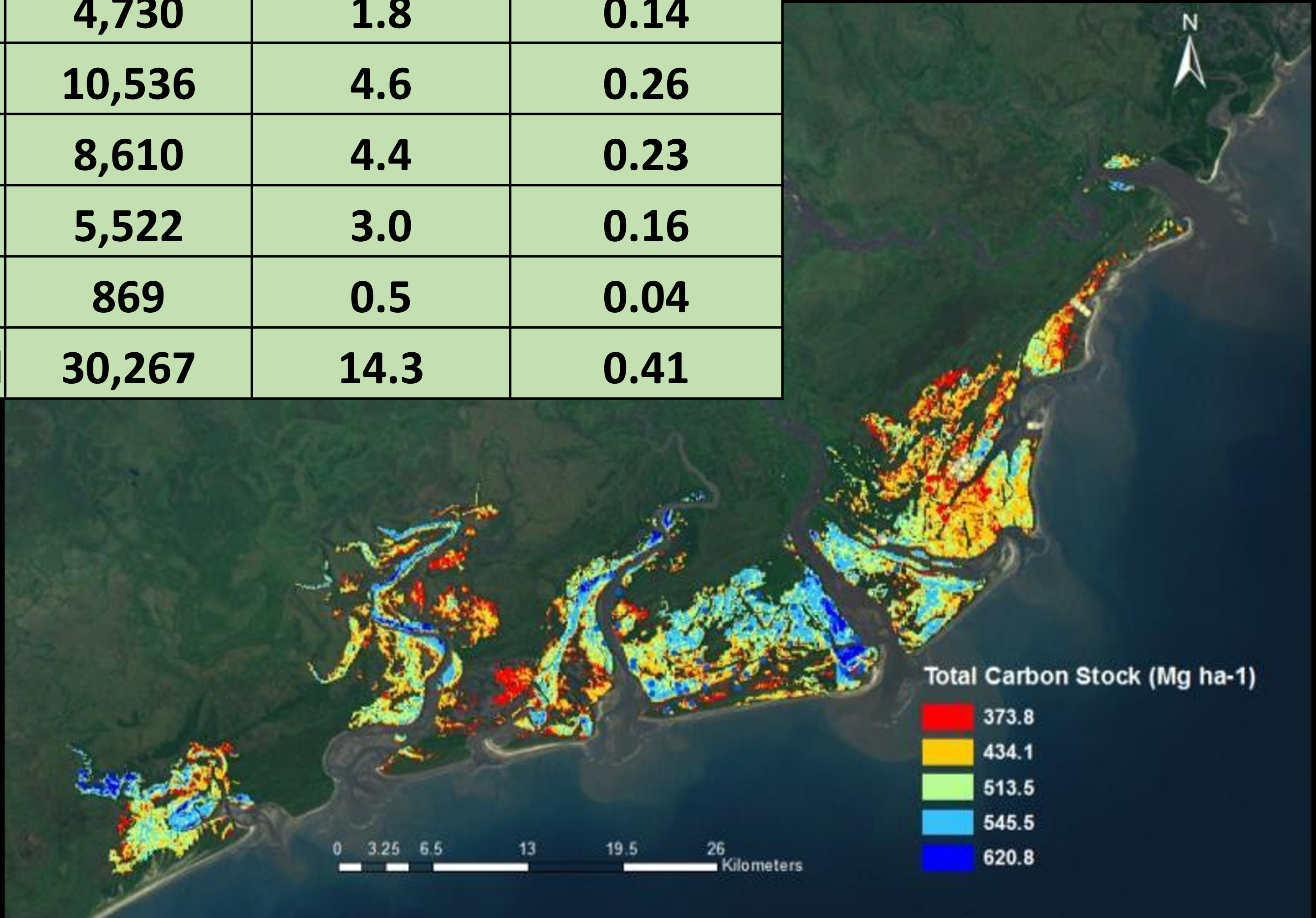


After: Stringer et al. 2015

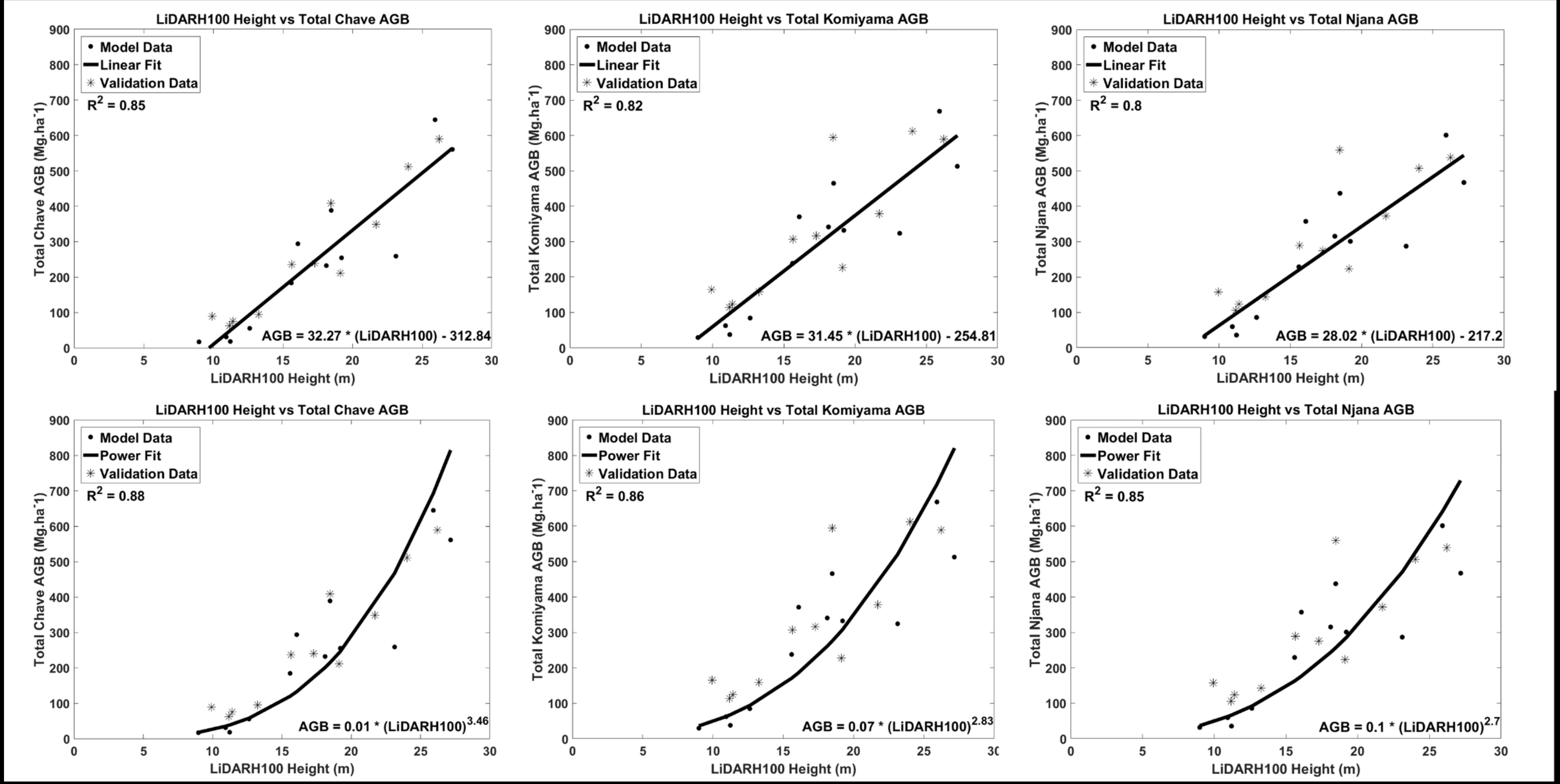
Mangrove Carbon Stock & Spatial Distribution

Height Class	Total Carbon Stock (Mg C ha^{-1})	Area (ha)	Total Carbon (Gg)	Std. Err. (Gg)
1	373.84	4,730	1.8	0.14
2	434.05	10,536	4.6	0.26
3	513.51	8,610	4.4	0.23
4	545.51	5,522	3.0	0.16
5	620.82	869	0.5	0.04
Total		30,267	14.3	0.41

After: Stringer et al. 2015

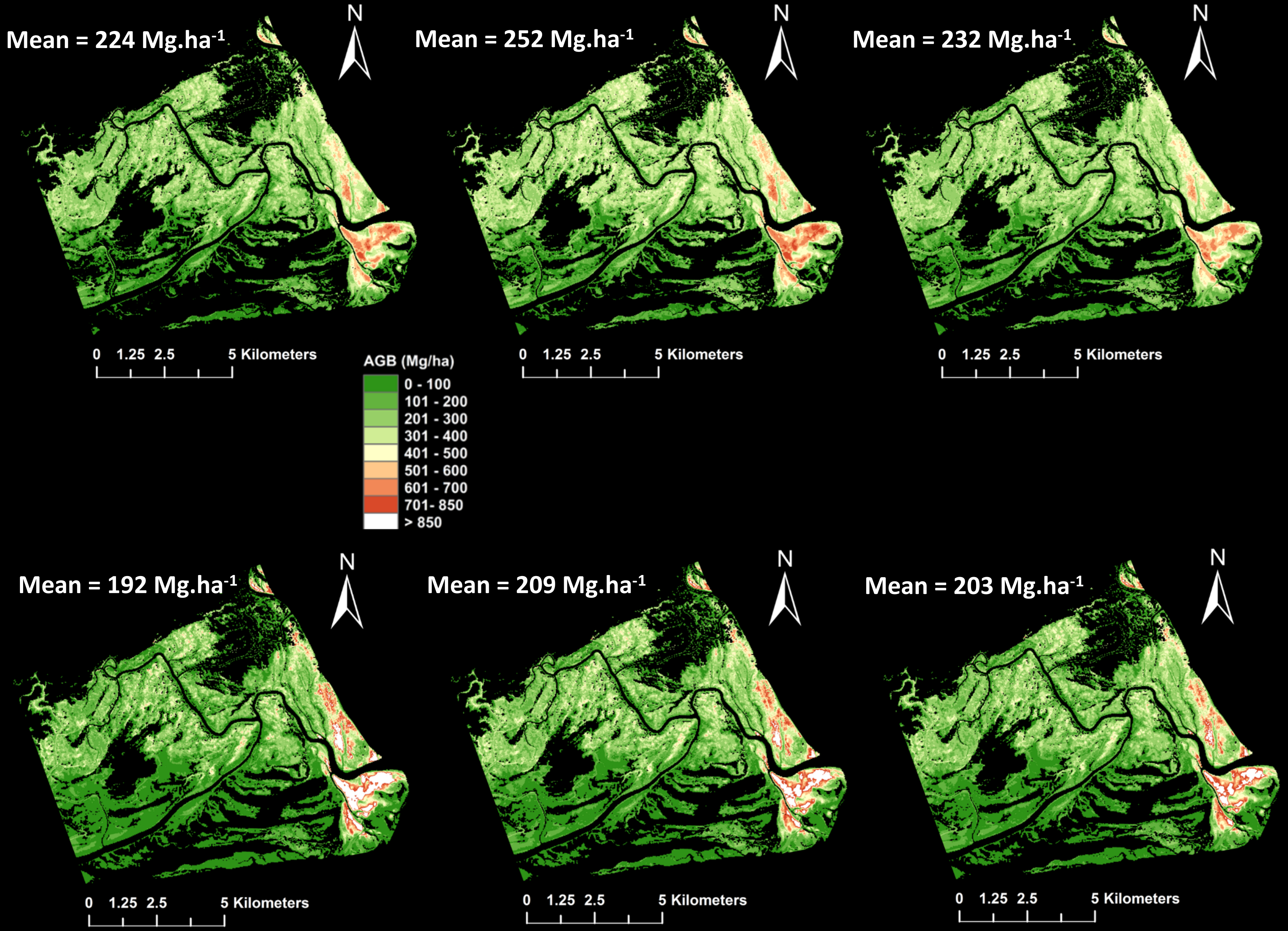


Zambezi Delta AGB LiDAR-based Regressions



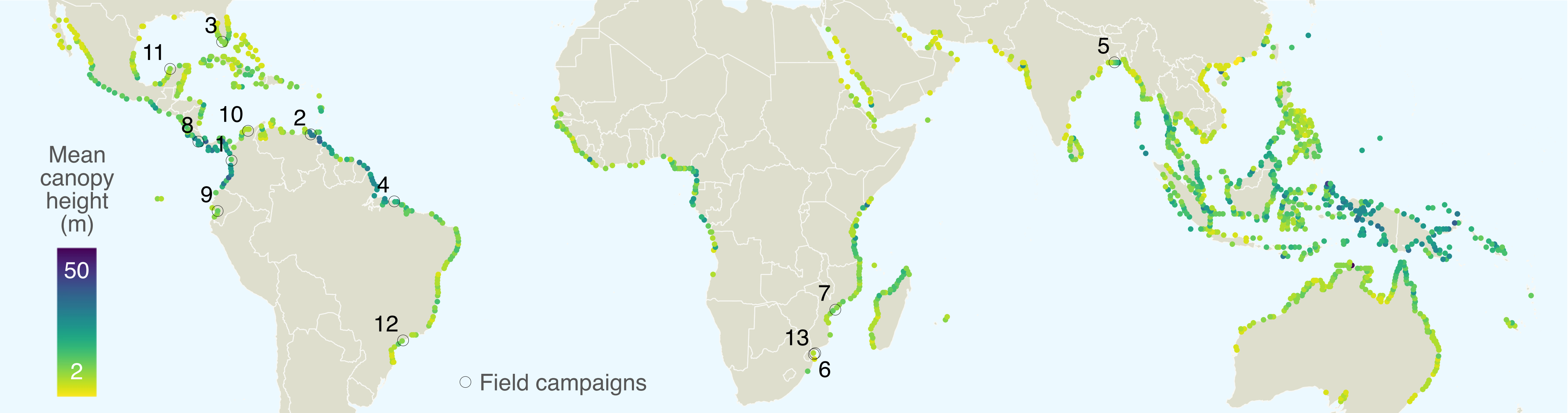
Fatoyinbo, T., Feliciano, E. A., Lagomasino, D., Lee, S. K., & Trettin, C. (2018). Estimating mangrove aboveground biomass from airborne LiDAR data: a case study from the Zambezi River delta. *Environmental Research Letters*.

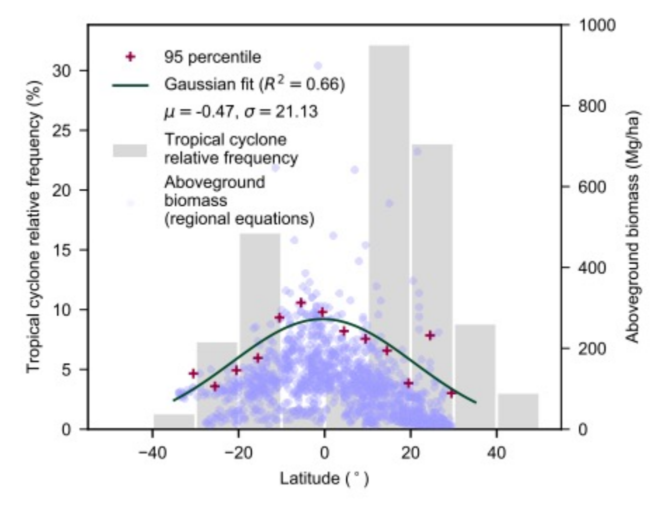
Zambezi Delta AGB Maps



Fatoyinbo, T., Feliciano, E. A., Lagomasino, D., Lee, S. K., & Trettin, C. (2018). Estimating mangrove aboveground biomass from airborne LiDAR data: a case study from the Zambezi River delta. *Environmental Research Letters*.

Global Mangrove Biomass

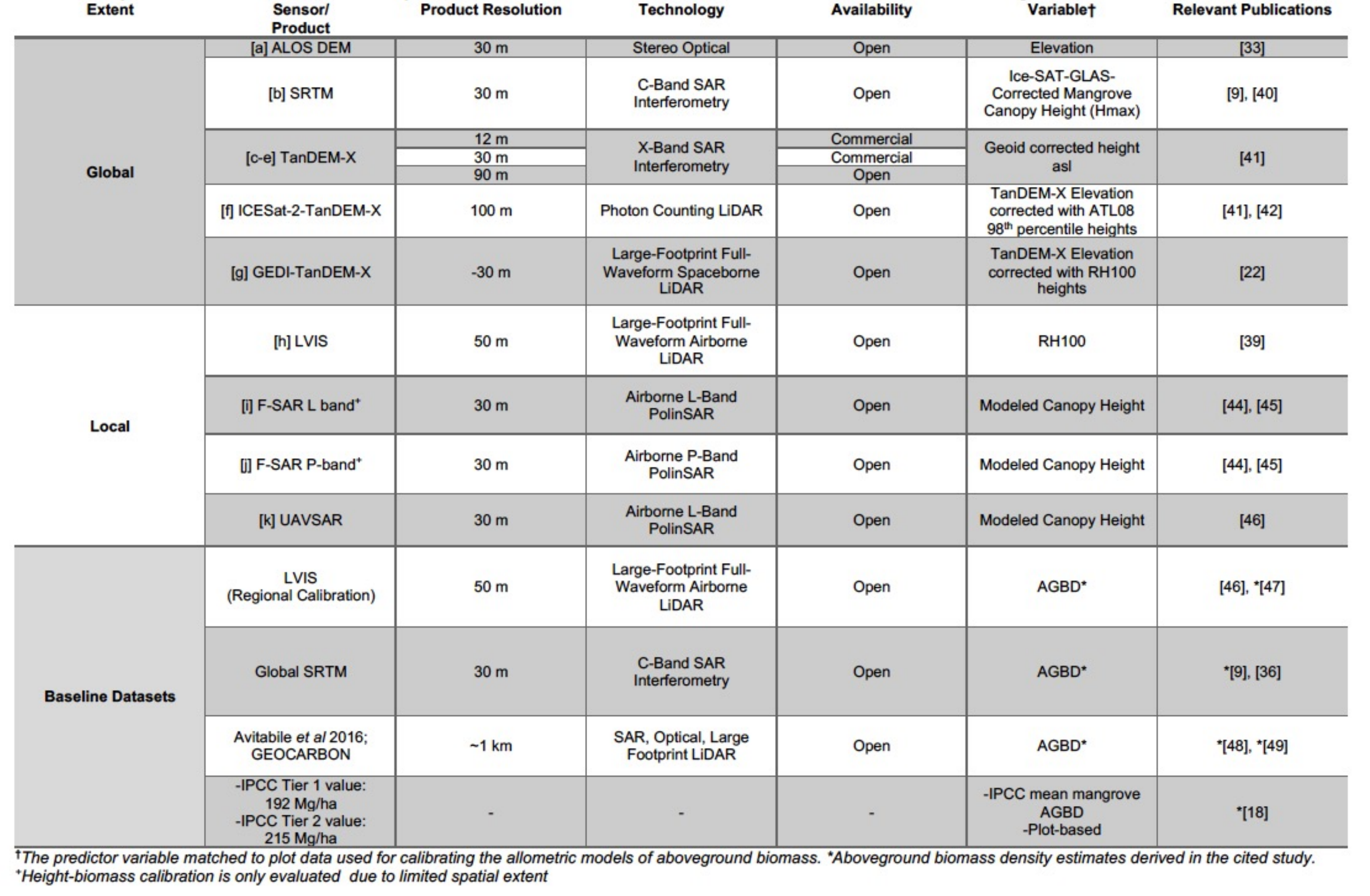




	Country	Maximum Height (m)	Mean height (m)	Max AG Biomass ($Mg.ha^{-1}$)	Mean AG Biomass ($Mg.ha^{-1}$)	Total AG Biomass (Mg)	Total Carbon (Mg)	Percent Global Total Carbon
1	Indonesia	47.5	24.7	456.4	218.5	578,630,876	1,138,076,289	24.0
2	Brazil	40.7	20.3	260.5	94.6	97,367,688	354,985,555	7.5
3	Australia	28.8	12.2	241.8	121.7	111,643,417	333,910,624	7.0
4	Nigeria	33.9	13.9	355.3	99.6	68,016,334	238,906,942	5.0
5	Malaysia	35.6	20.4	308.3	176.5	92,120,954	209,655,257	4.4
6	Papua New Guinea	45.8	28.6	432.5	248.1	114,089,528	206,806,176	4.4
7	Mexico	39.0	11.7	243.3	41.2	26,958,637	202,515,476	4.3
8	Bangladesh	25.5	15.5	421.2	173.0	73,916,017	170,612,893	3.6
9	Cuba	22.1	10.1	97.5	31.1	12,790,694	124,960,442	2.6
10	Mozambique	20.4	10.8	247.3	75.0	23,666,210	104,950,554	2.2
	Total top 10 Carbon					1,199,200,354	3,085,380,208	65.0

Simard, Fatoyinbo et al, 2019

We compare 17 different products for mapping mangrove biomass

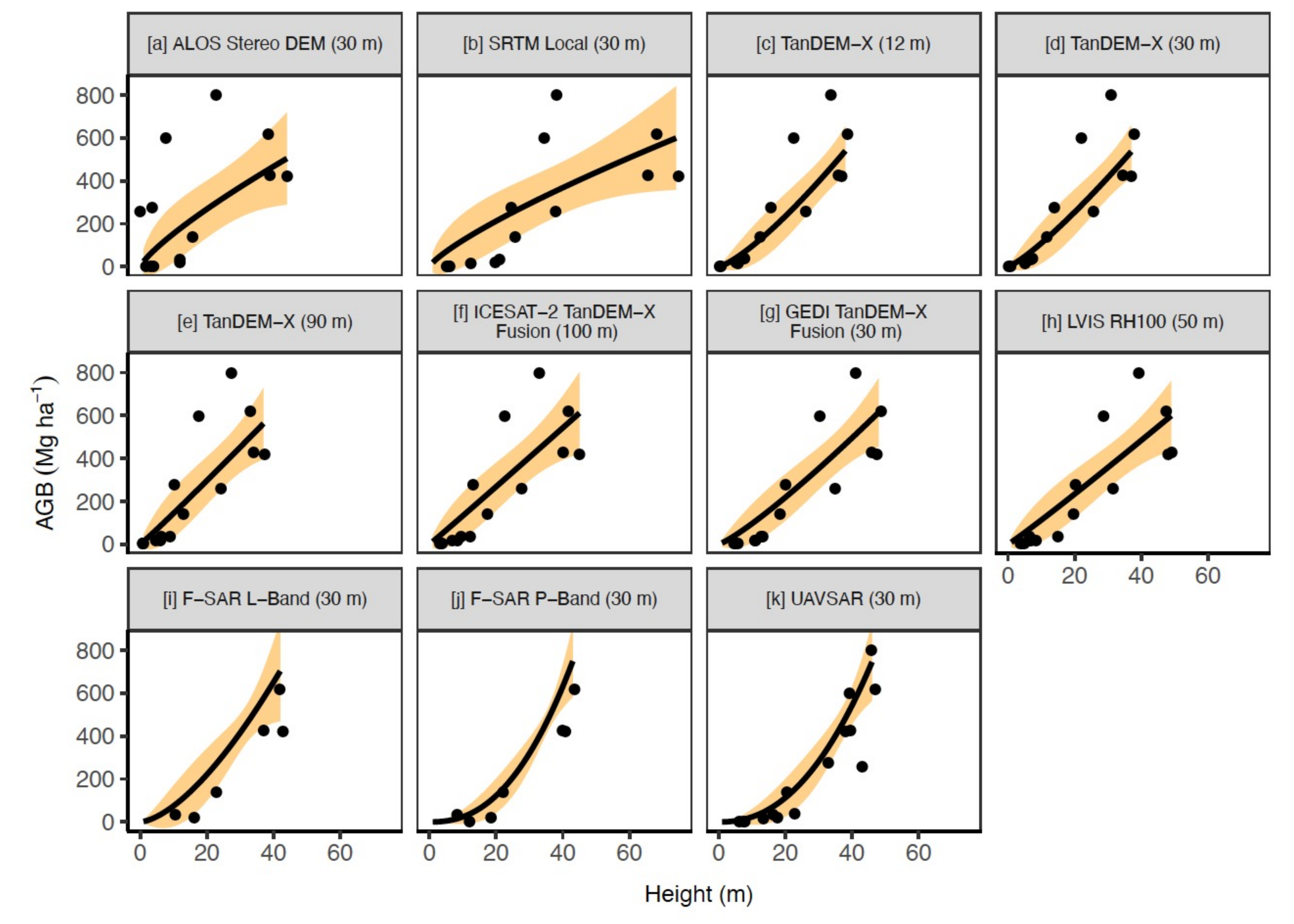


Extent	Sensor/ Product	Product Resolution	Technology	Availability	Variable†	Relevant Publications
Global	[a] ALOS DEM	30 m	Stereo Optical	Open	Elevation	[33]
	[b] SRTM	30 m	C-Band SAR Interferometry	Open	Ice-SAT-GLAS-Corrected Mangrove Canopy Height (Hmax)	[9], [40]
	[c-e] TanDEM-X	12 m	X-Band SAR Interferometry	Commercial	Geoid corrected height asl	[41]
		30 m		Commercial		
		90 m		Open		
	[f] ICESat-2-TanDEM-X	100 m	Photon Counting LiDAR	Open	TanDEM-X Elevation corrected with ATL08 98th percentile heights	[41], [42]
	[g] GEDI-TanDEM-X	-30 m	Large-Footprint Full-Waveform Spaceborne LiDAR	Open	TanDEM-X Elevation corrected with RH100 heights	[22]
Local	[h] LVIS	50 m	Large-Footprint Full-Waveform Airborne LiDAR	Open	RH100	[39]
	[i] F-SAR L band^{+}	30 m	Airborne L-Band PolinSAR	Open	Modeled Canopy Height	[44], [45]
	[j] F-SAR P-band^{+}	30 m	Airborne P-Band PolinSAR	Open	Modeled Canopy Height	[44], [45]
	[k] UAVSAR	30 m	Airborne L-Band PolinSAR	Open	Modeled Canopy Height	[46]
Baseline Datasets	LVIS (Regional Calibration)	50 m	Large-Footprint Full-Waveform Airborne LiDAR	Open	AGBD*	[46], *[47]
	Global SRTM	30 m	C-Band SAR Interferometry	Open	AGBD*	*[9], [36]
	Avitabile *et al* 2016; GEOCARBON	~1 km	SAR, Optical, Large Footprint LiDAR	Open	AGBD*	*[48], *[49]
	-IPCC Tier 1 value: 192 Mg/ha -IPCC Tier 2 value: 215 Mg/ha	-	-	-	-IPCC mean mangrove AGBD -Plot-based	*[18]

*†The predictor variable matched to plot data used for calibrating the allometric models of aboveground biomass. *Aboveground biomass density estimates derived in the cited study.*

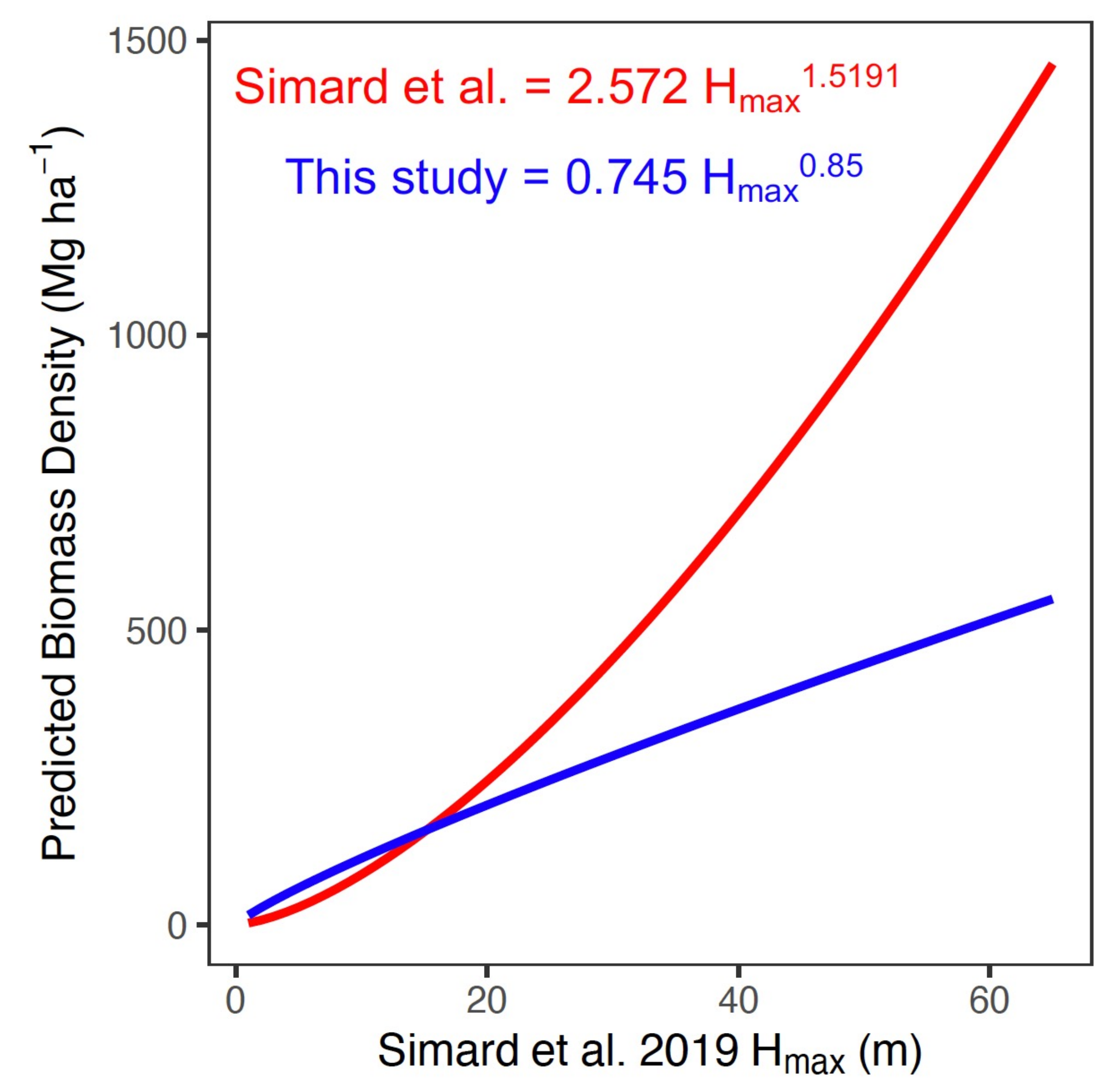
$^{+}$Height-biomass calibration is only evaluated due to limited spatial extent

How does height-AGB allometry compare?



Why is the global mangrove model estimating high?

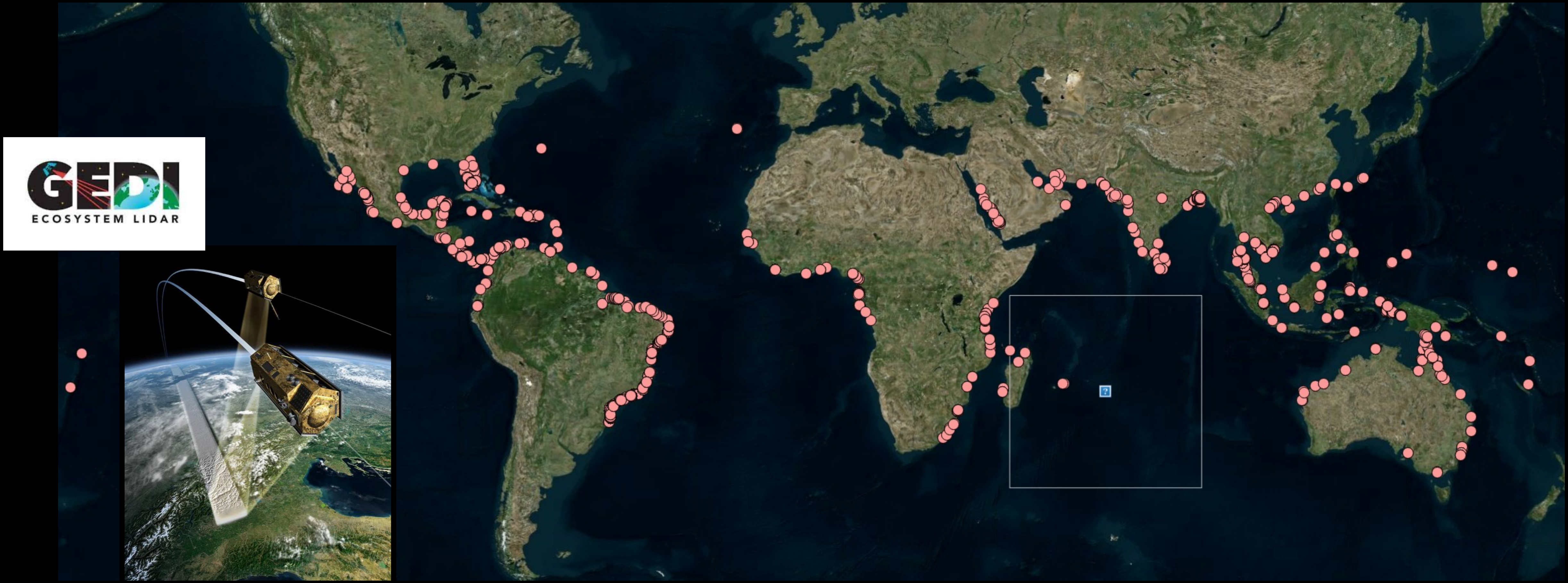
- All comes down to calibration
- Need tall mangroves in calibration to predict AGB in tall mangroves.
- Solution is all in local calibration and better plot data



Stovall, A.E., Fatoyinbo, T., Thomas, N.M., Armston, J., Ebanega, M.O., Simard, M., Trettin, C., Zogo, R.V.O., Aken, I.A., Debina, M. and Kemoe, A.M.M., 2021. Comprehensive comparison of airborne and spaceborne SAR and LiDAR estimates of forest structure in the tallest mangrove forest on earth. *Science of Remote Sensing*, *4*, p.100034.

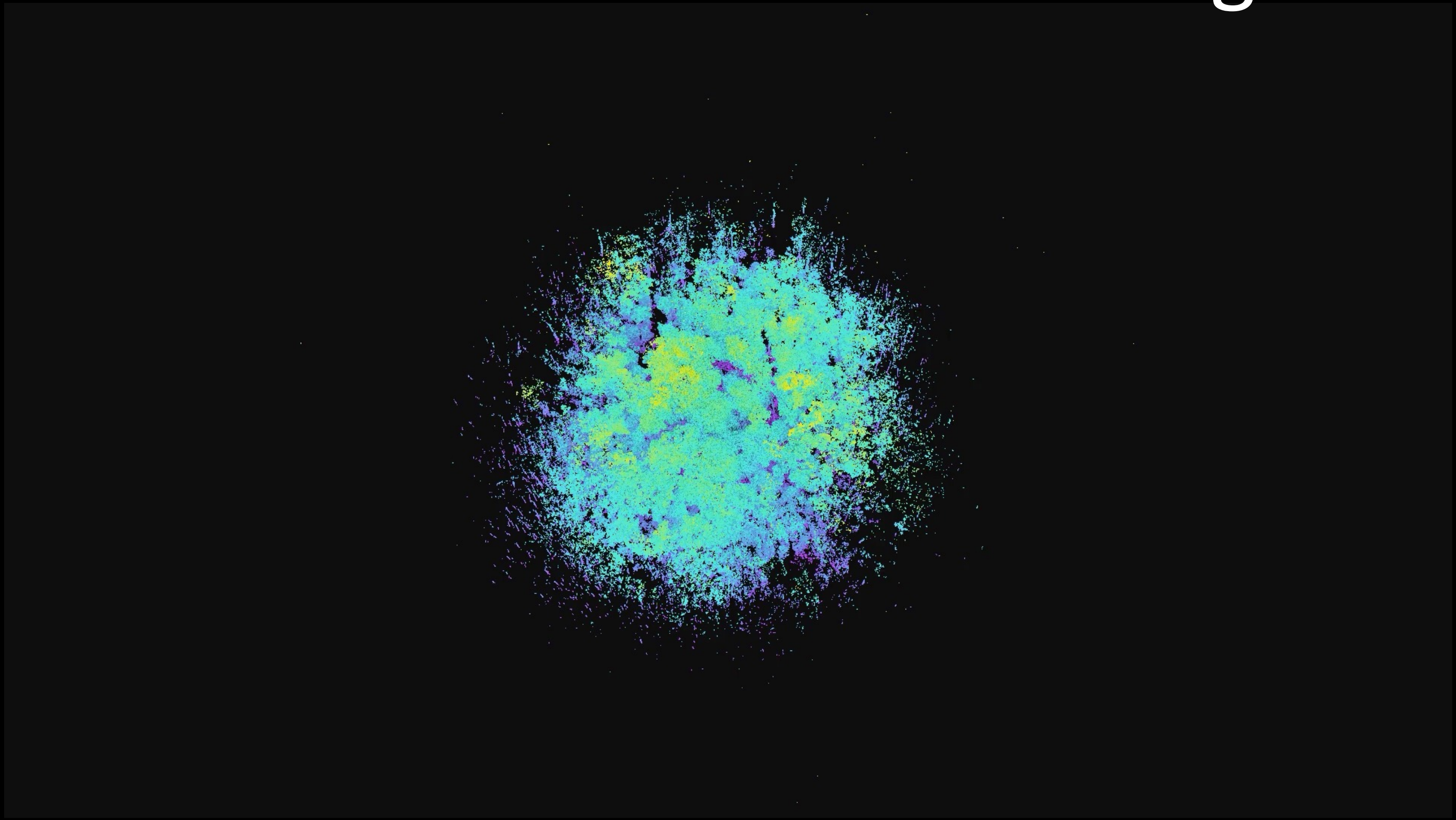
Next step:

Create a better global mangrove height and AGB model.



From Rovai 2019 et al and SWAMP

Terrestrial Laser Scanning



Terrestrial Laser Scanning

Allometric Equation Development

Figure 4: A sample of the 90 TLS-based tree models used to develop non-destructive allometric equations in Pongara National Park, Gabon. Approximately 1200 tree objects were segmented and will be modeled.

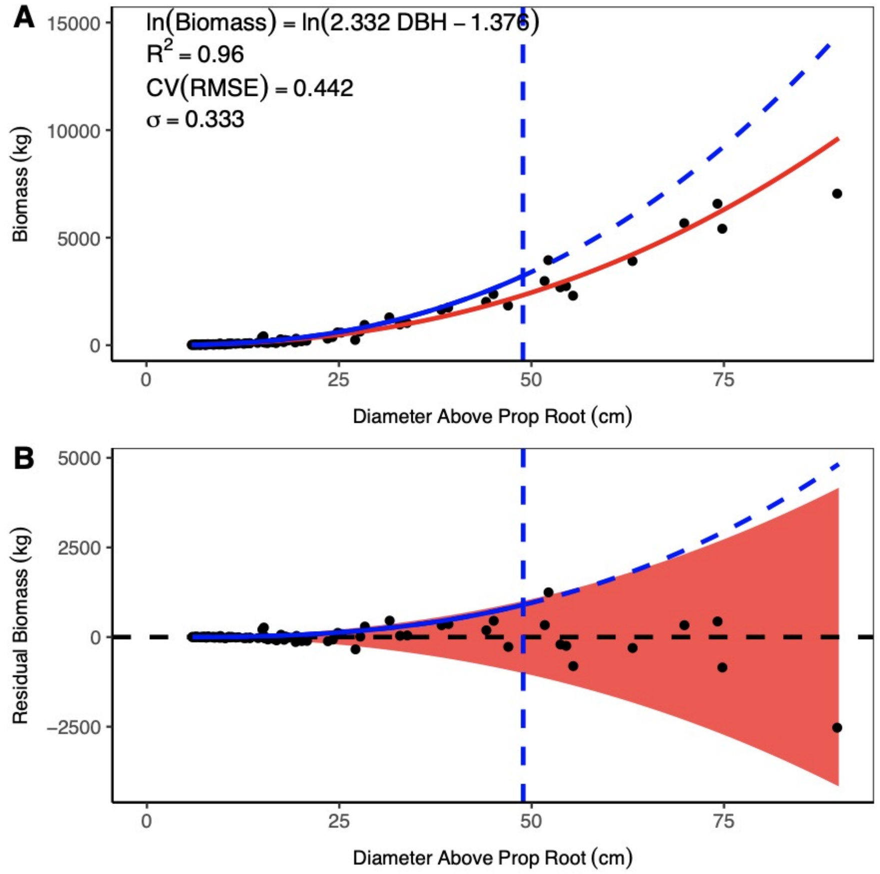
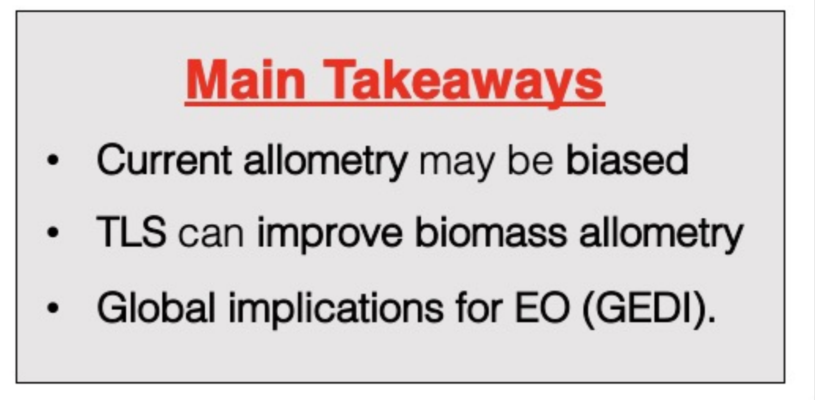


Figure 5: (A) TLS-based *Rizophora* allometry (red) developed from 90 individual trees compared to commonly used Komiyama et al. (2005) mangrove allometry (blue). Dashed line indicates the limit of observations in the current mangrove allometry, above which predictions are highly-uncertain. (A) Residual variation in the diameter-based model with ~40% RMSE (red) across the observed diameter range.

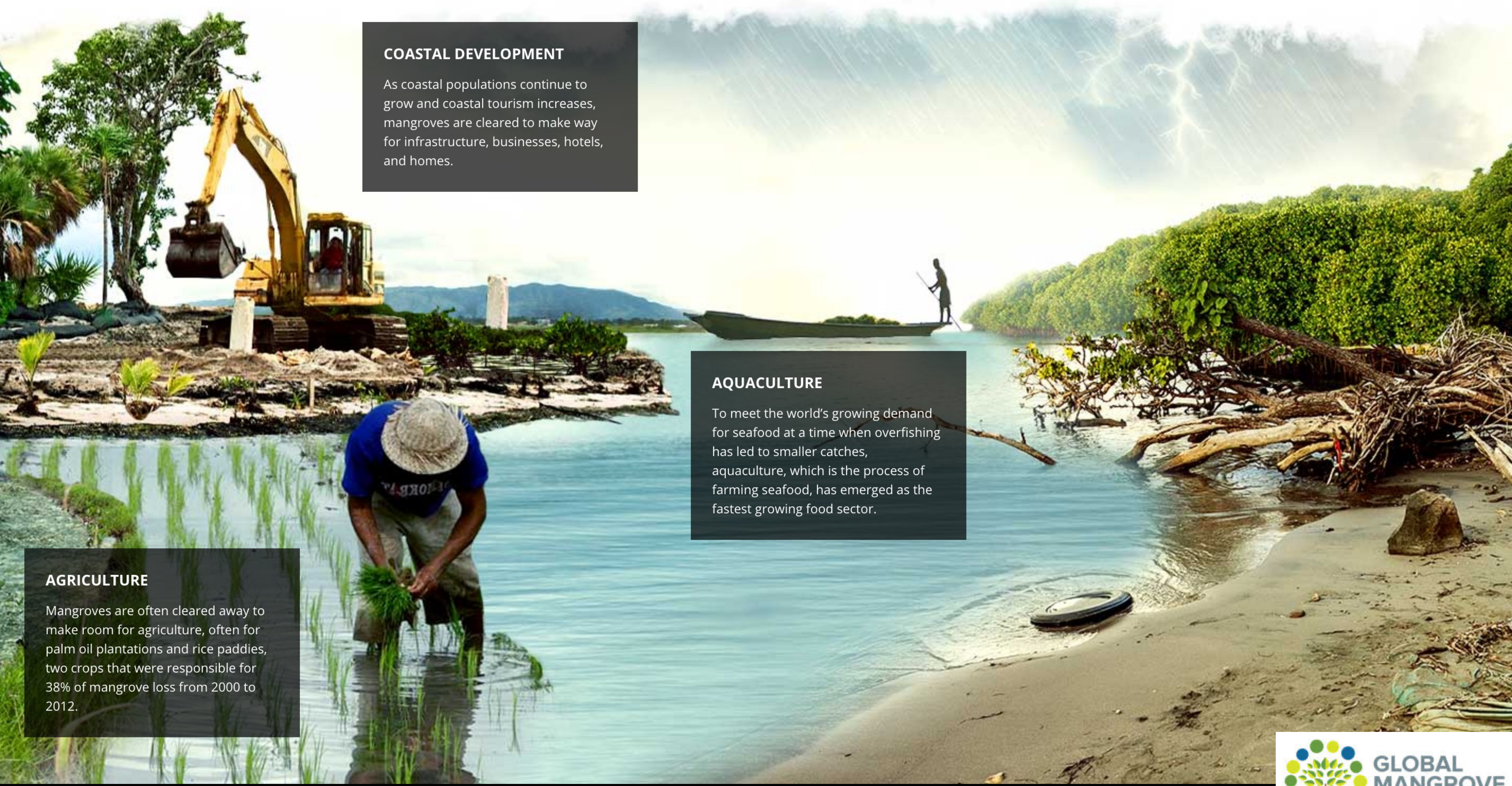


Main Takeaways

- **Current allometry** may be **biased**
- **TLS** can **improve biomass allometry**
- **Global implications for EO (GEDI).**

Stovall et al in prep

Drivers of Loss and Carbon emissions



COASTAL DEVELOPMENT

As coastal populations continue to grow and coastal tourism increases, mangroves are cleared to make way for infrastructure, businesses, hotels, and homes.

AQUACULTURE

To meet the world's growing demand for seafood at a time when overfishing has led to smaller catches, aquaculture, which is the process of farming seafood, has emerged as the fastest growing food sector.

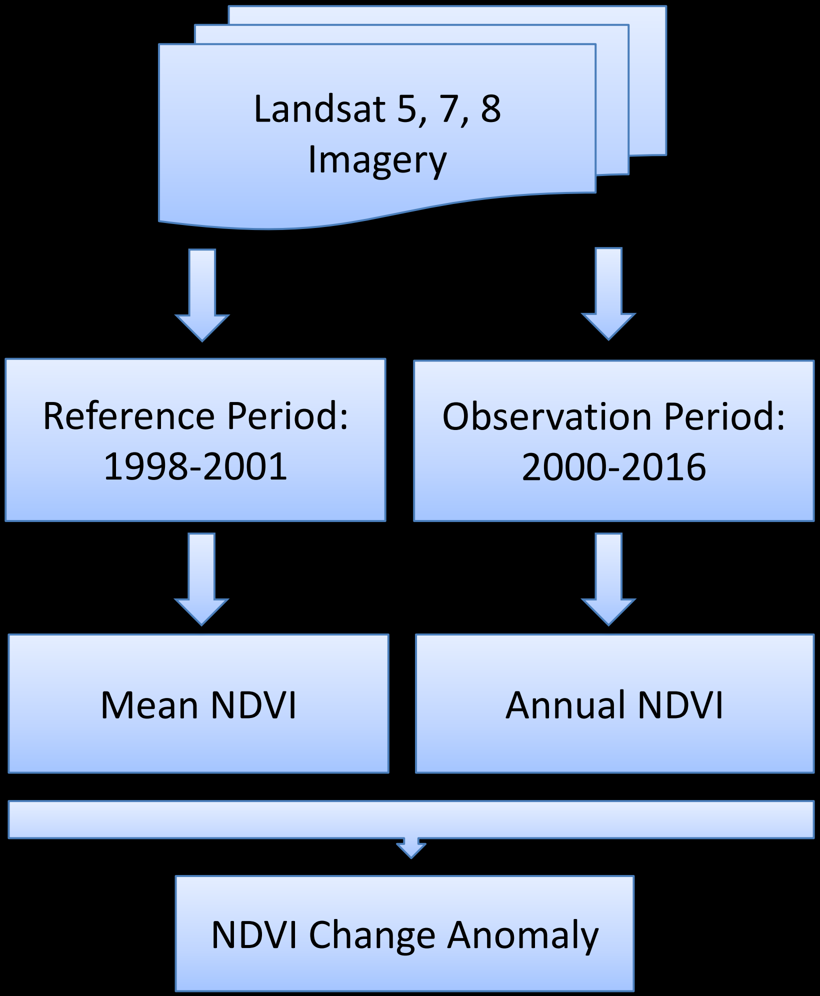
AGRICULTURE

Mangroves are often cleared away to make room for agriculture, often for palm oil plantations and rice paddies, two crops that were responsible for 38% of mangrove loss from 2000 to 2012.

GLOBAL MANGROVE ALLIANCE

Gulf of Carpentaria, Australia

Global Loss Extent Mapping



Landsat 5, 7, 8 Imagery

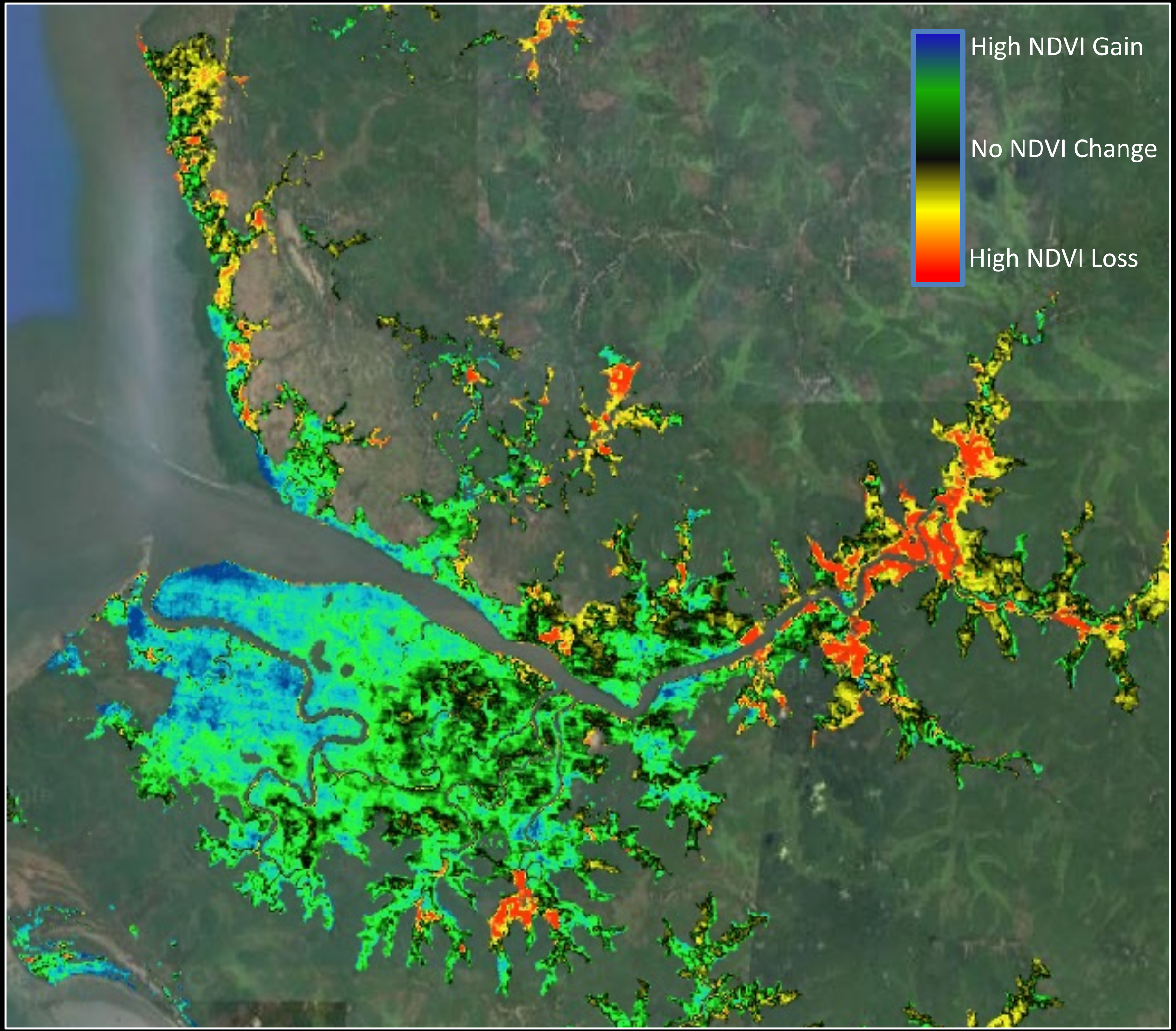
Reference Period: 1998-2001

Observation Period: 2000-2016

Mean NDVI

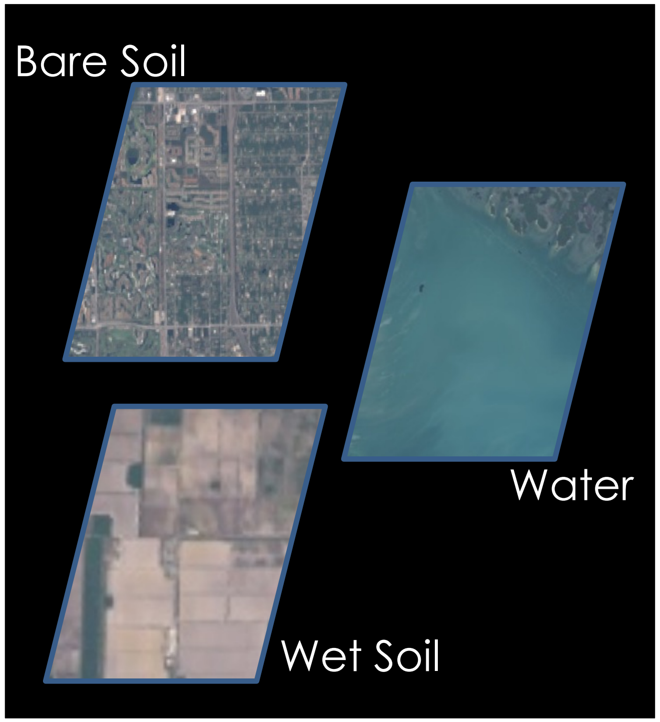
Annual NDVI

NDVI Change Anomaly

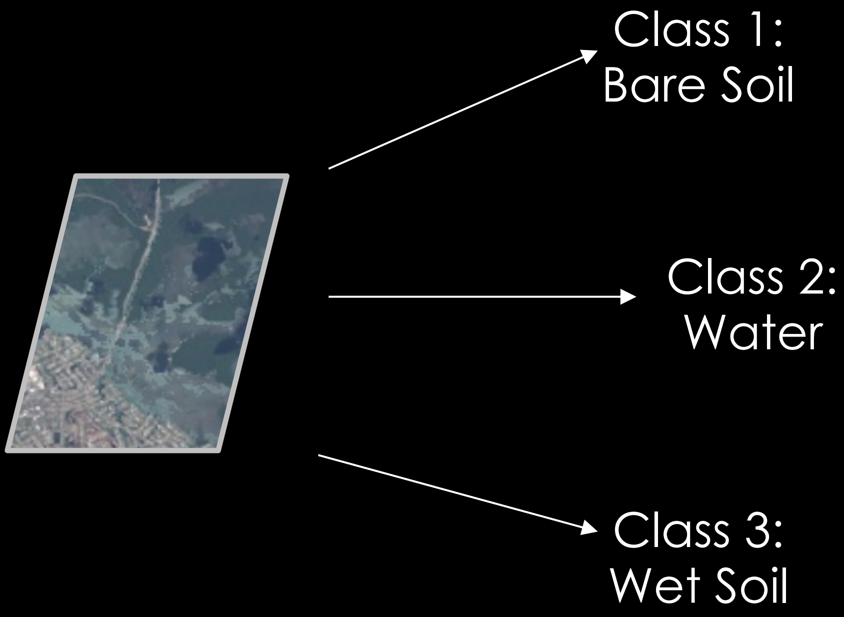


Yawri Bay, Sierra Leonne

Random Forest Land Cover Change Classification



Training Data:
Landsat 7,8 imagery in classified regions

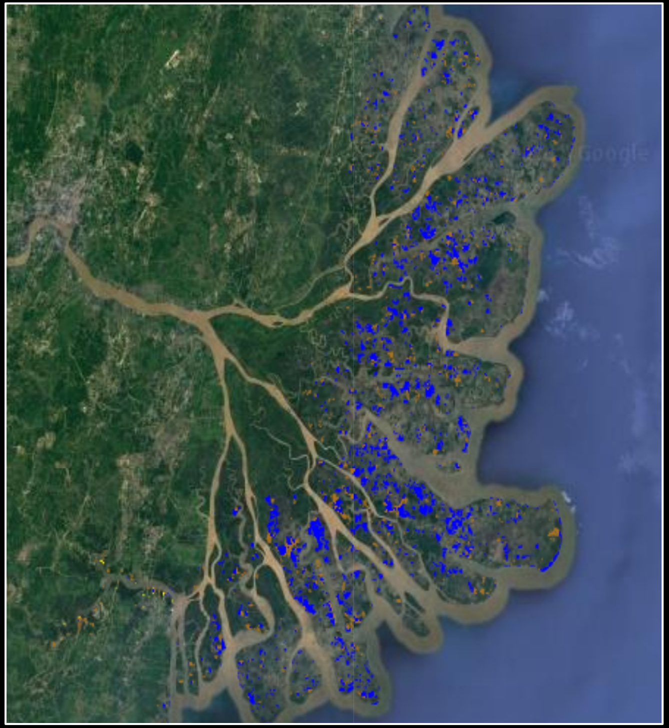


Class 1:
Bare Soil

Class 2:
Water

Class 3:
Wet Soil

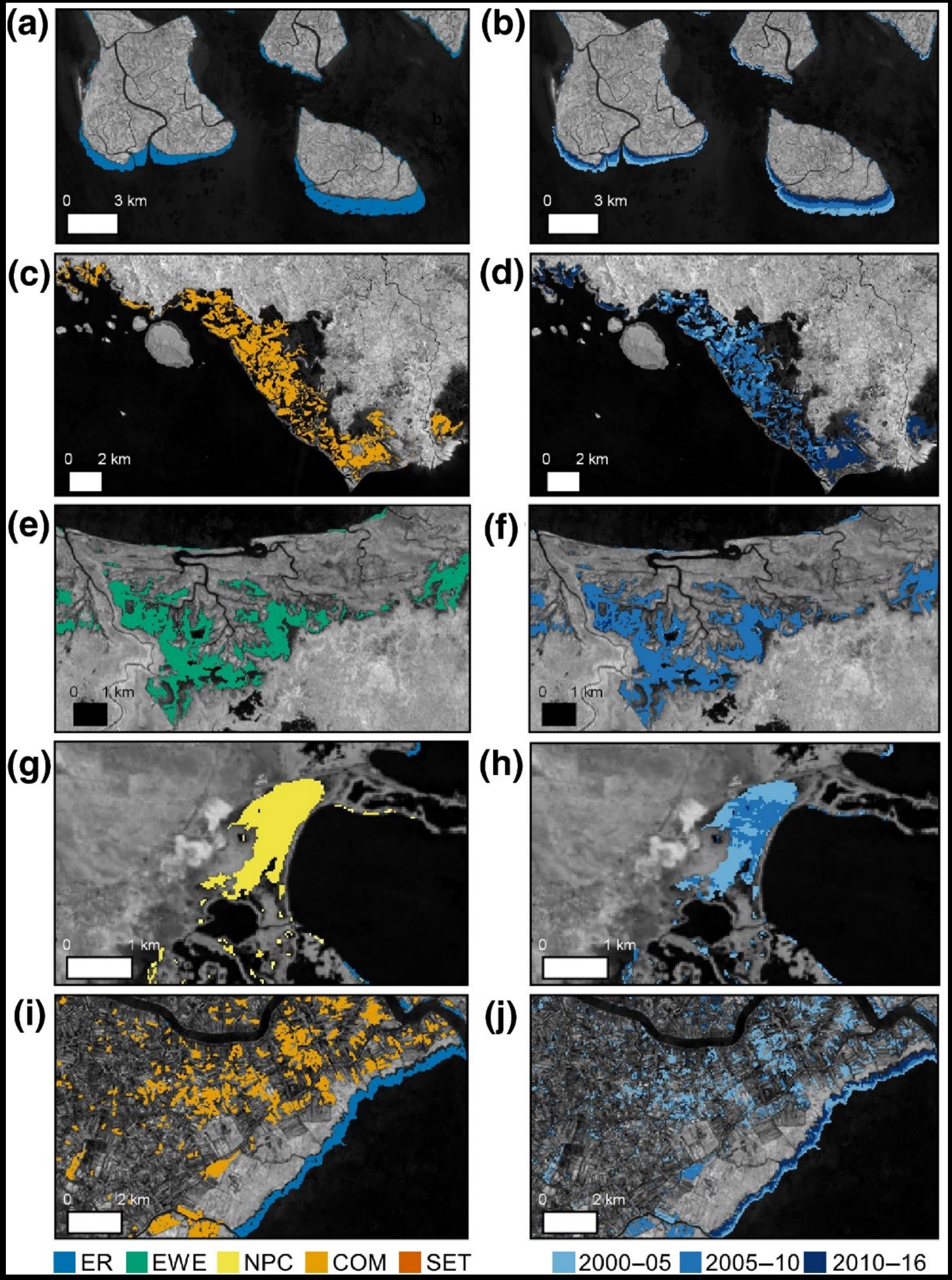
RF Classification:
Landsat 7,8 imagery in all mangrove loss regions



Land Cover Change Classification

Image Credit: Liza Goldberg

Erosion
Sundarbans, Bangladesh
🟥 2000-2005
🟧 2005-2010
🟨 2010-2015
N
5 km



Shoreline
Erosion

Commodities

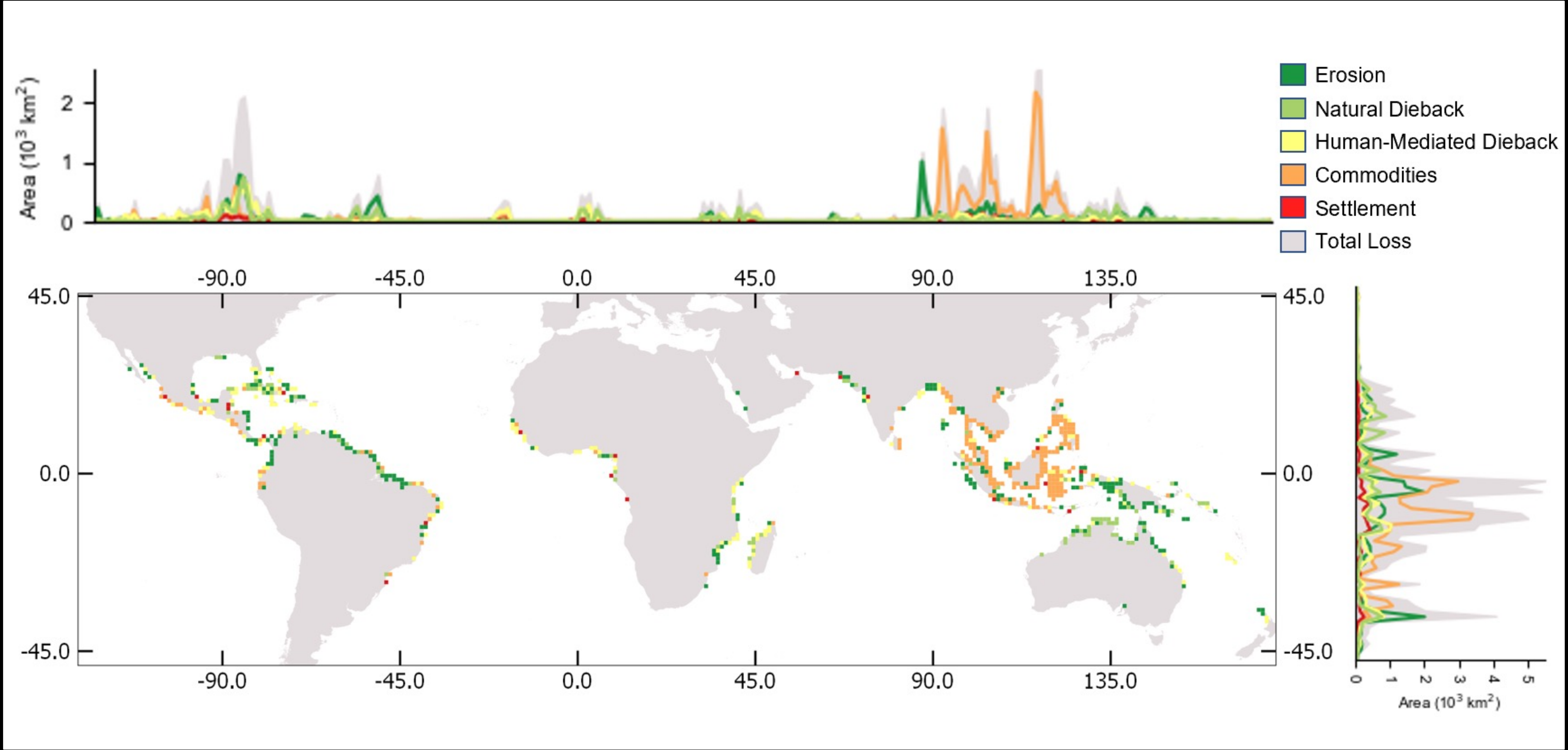
Extreme
Weather
Events

Non-
Productive
Conversion

Coastal
Squeeze

A variety of natural, human, and combined human factors play a role in mangrove loss

Goldberg, L., Lagomasino, D., Thomas, N., & Fatoyinbo, T. (2020). Global declines in human-driven mangrove loss. Global Change Biology.

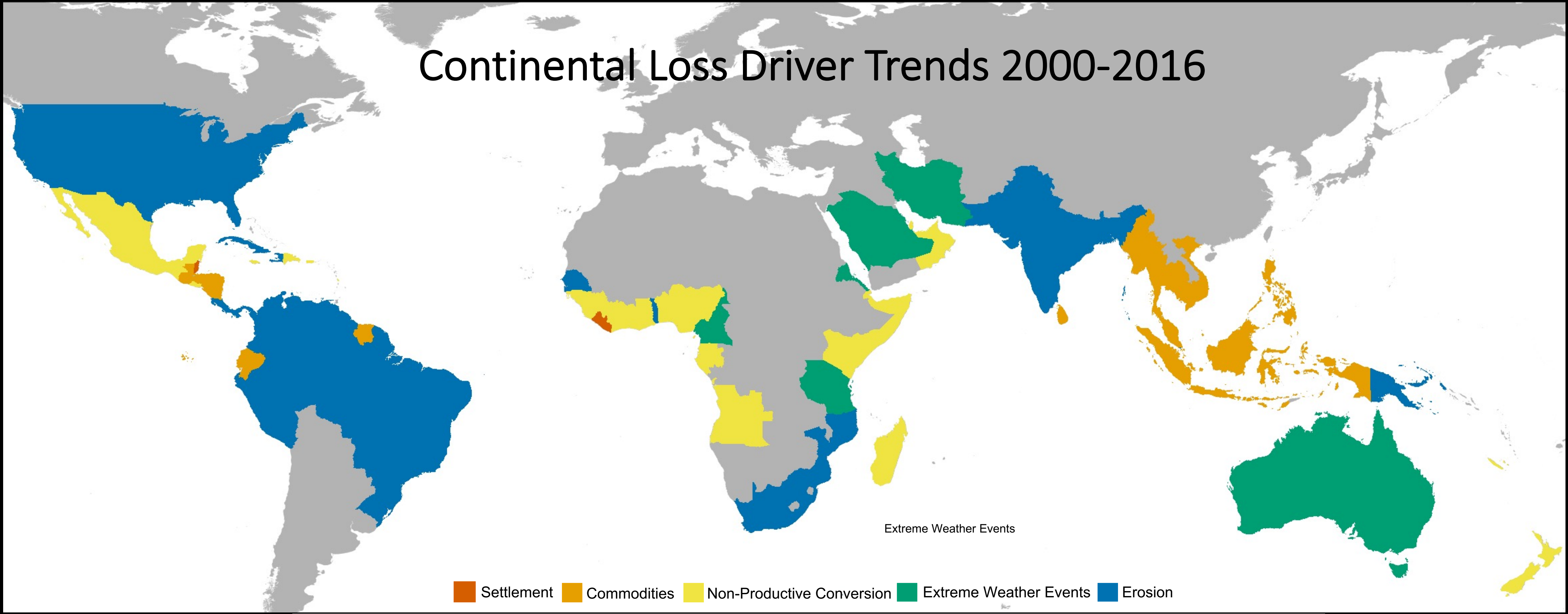


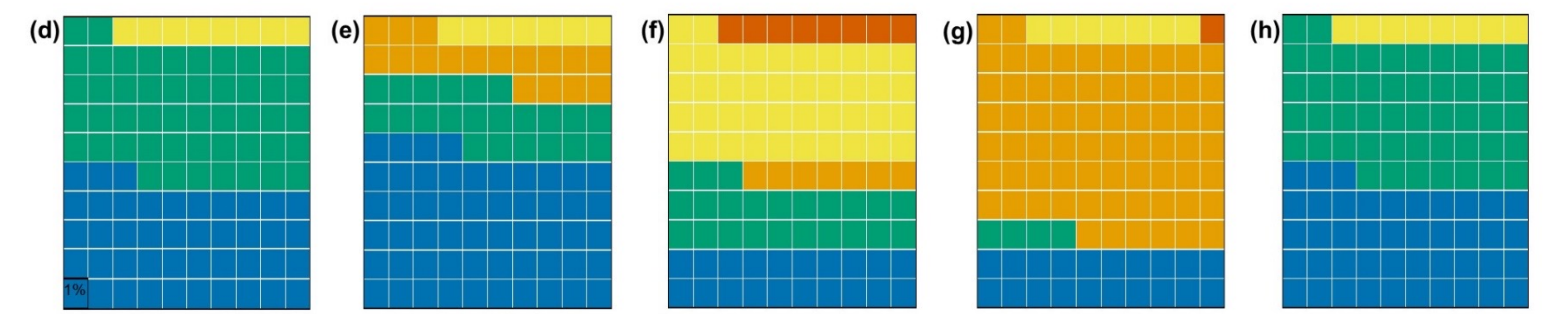
*More than half of the global losses have an anthropogenic origin, most of which are concentrated in Asia

*Nearly all land reclamation to commodities (agriculture & aquaculture) occurred within 8 countries

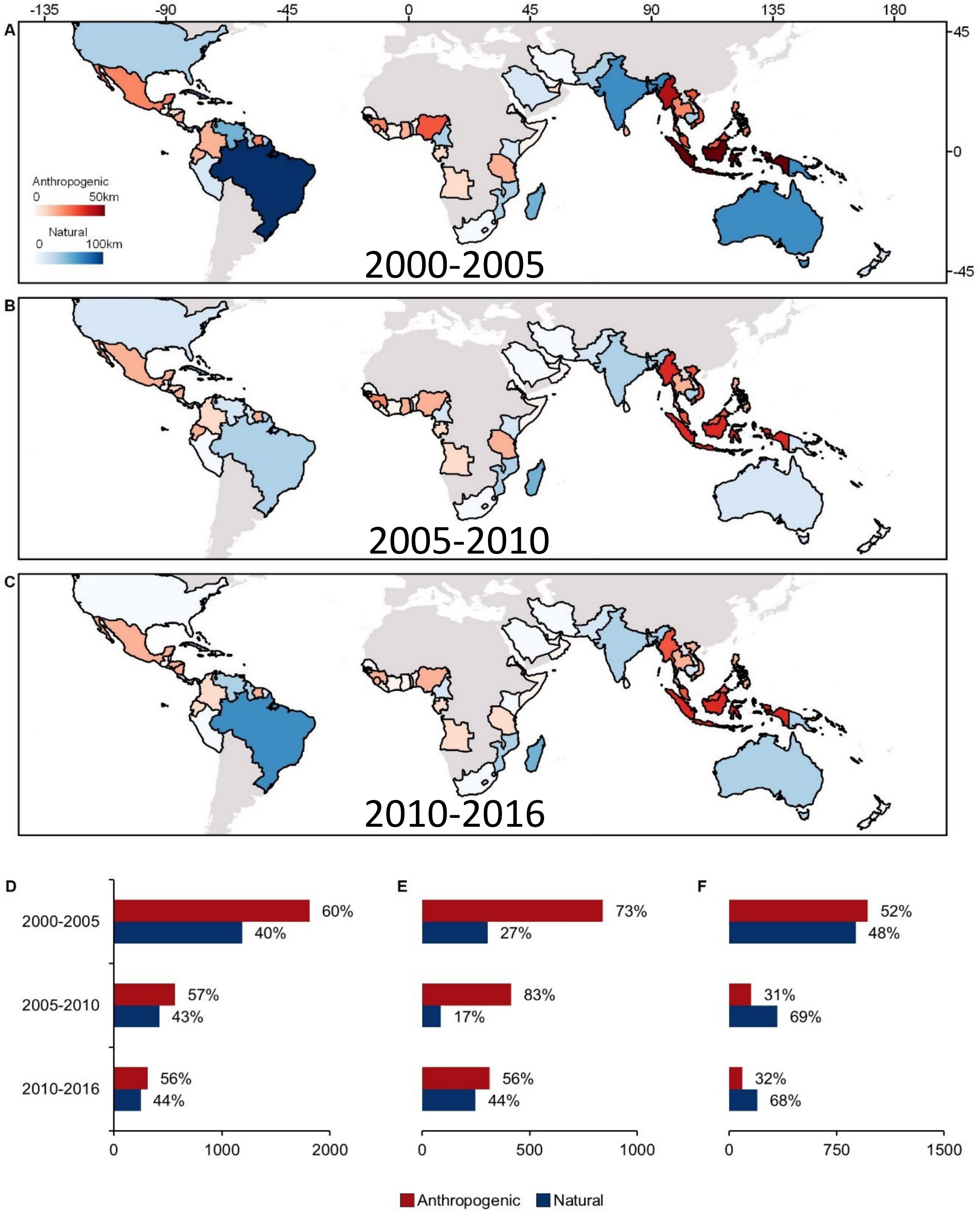
Goldberg et al, 2020

Continental Loss Driver Trends 2000-2016





(d) North America, **(e)** South America, **(f)** Africa, **(g)** Asia, **(h)** Australia together with Oceania



Key Findings:

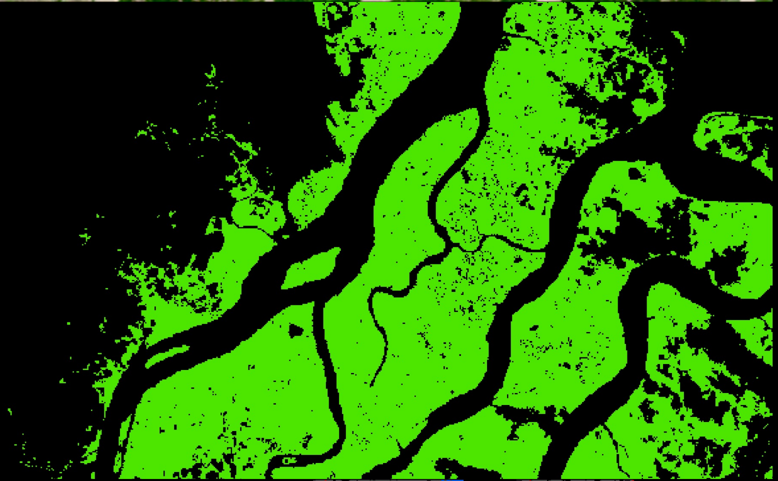
- Direct human-driven mangrove loss declined by 73% from 2000 to 2016.
- 62% of global losses from 2000-2016 resulted from land-use change.
- 80% of these human-driven losses occurred within six Southeast Asian nations (Myanmar, Malaysia, the Philippines, Thailand, and Vietnam)

- https://www.mangrovelossdrivers.app/

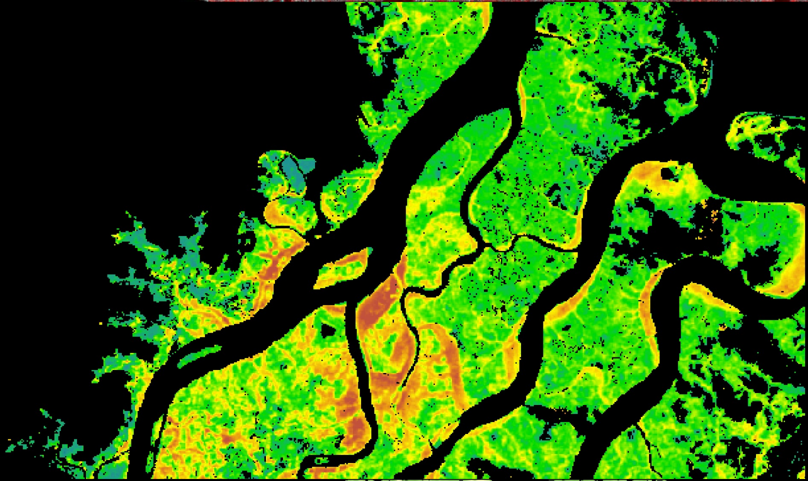
Goldberg, L., Lagomasino, D., Thomas, N. and Fatoyinbo, T. (2020), Global declines in human-driven mangrove loss. Glob Change Biol. doi:10.1111/gcb.15275

Landsat 8
Natural Color Composite

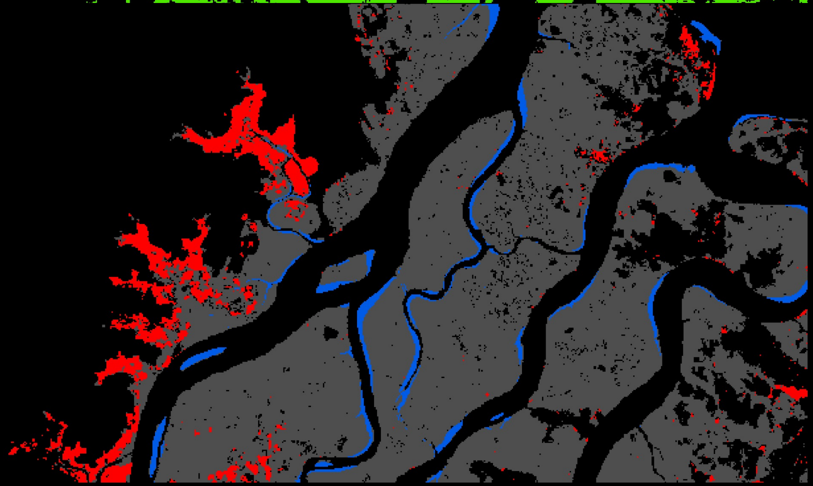
TanDEM-X
False-Color Composite



Mangrove Extent 2016

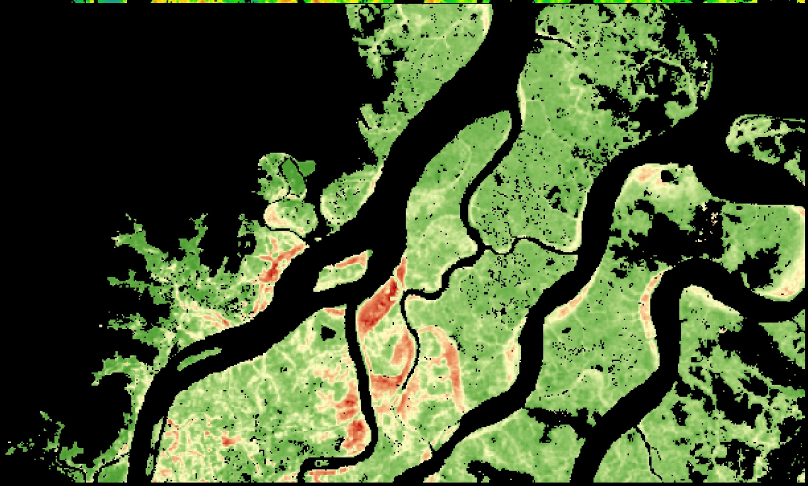


Canopy Height



Change 2000-2016

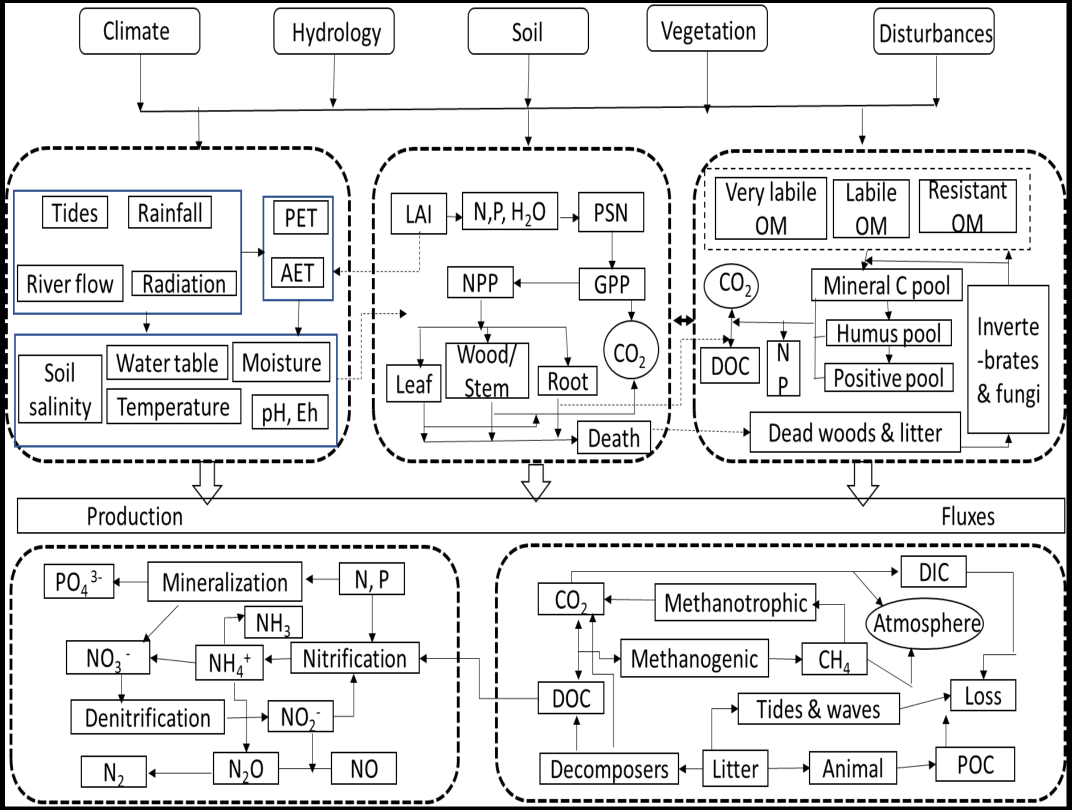
🟦 Gain
🟥 Loss



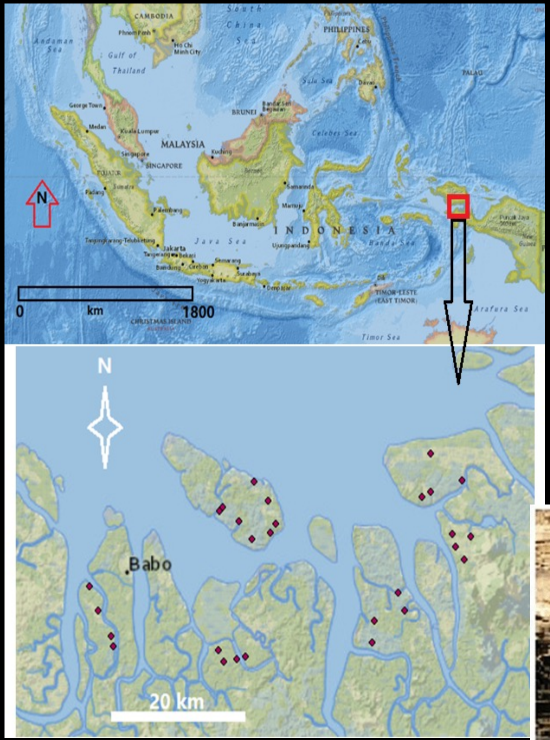
Aboveground Biomass

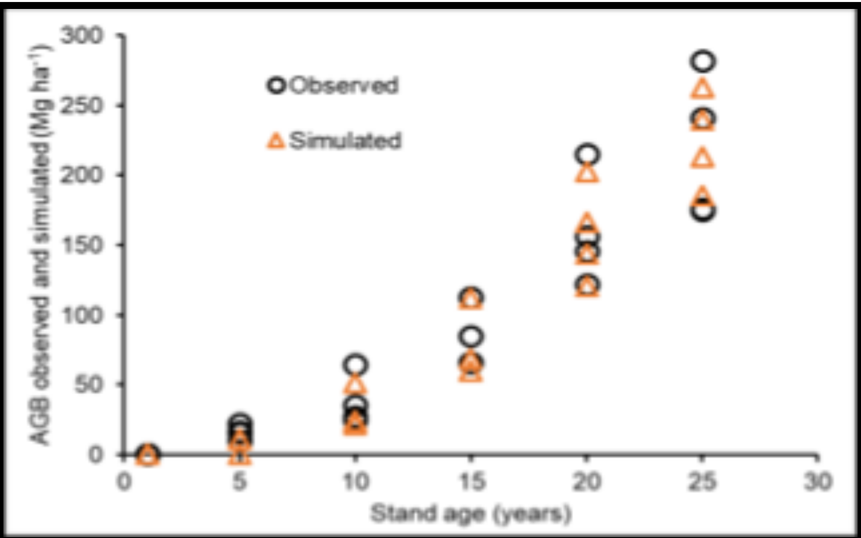
Mangrove Carbon Assessment Tool (MCAT)

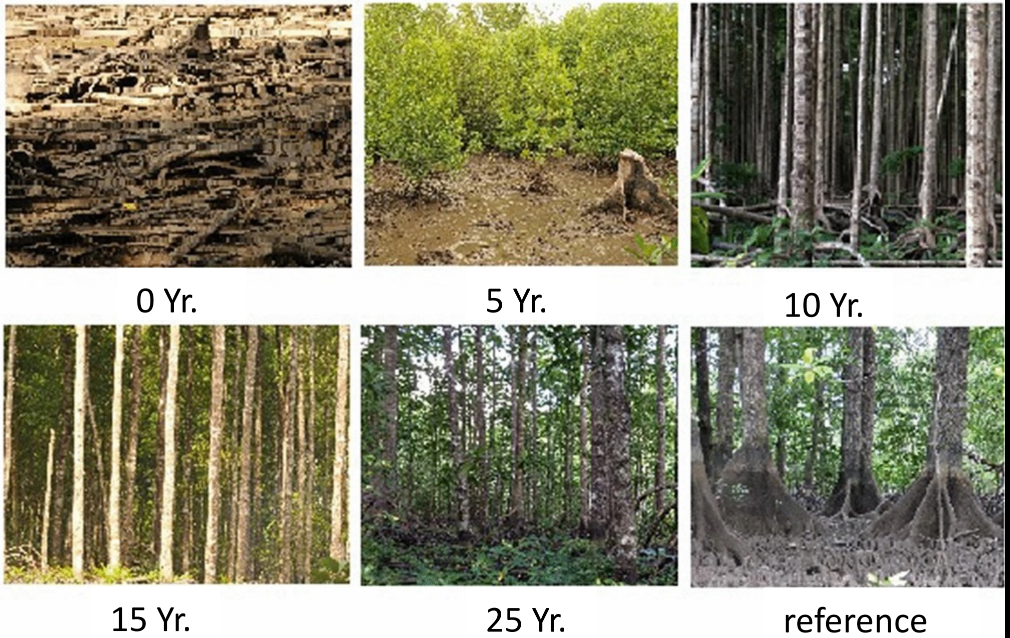
- Process-based biogeochemical model to simulate carbon sequestration, turnover and fluxes (atmosphere and water) in mangroves.
- Sensitive to climate, soil chemical and physical properties, tide and salinity.
- Tool provides capabilities for predicting C dynamics:
  - Monitoring
  - Restoration
  - Response to stressors



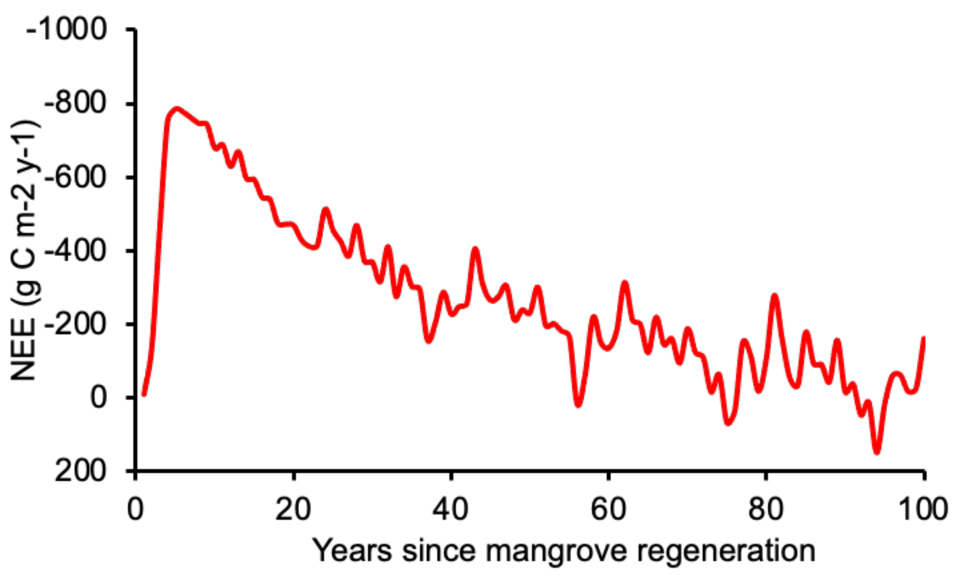
Application of MCAT – Managed Mangroves, Indonesia





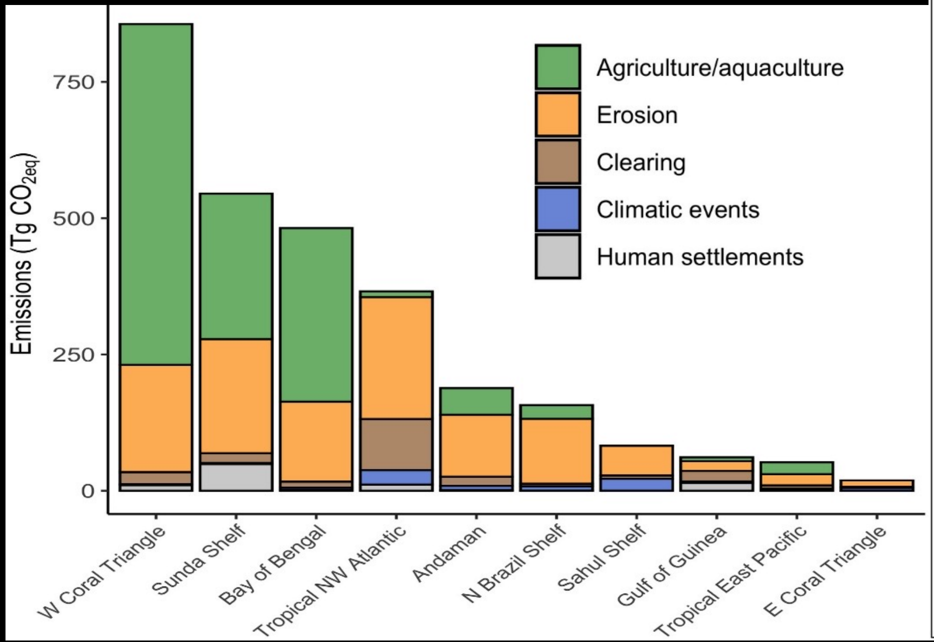

0 Yr.
5 Yr.
10 Yr.
15 Yr.
25 Yr.
reference

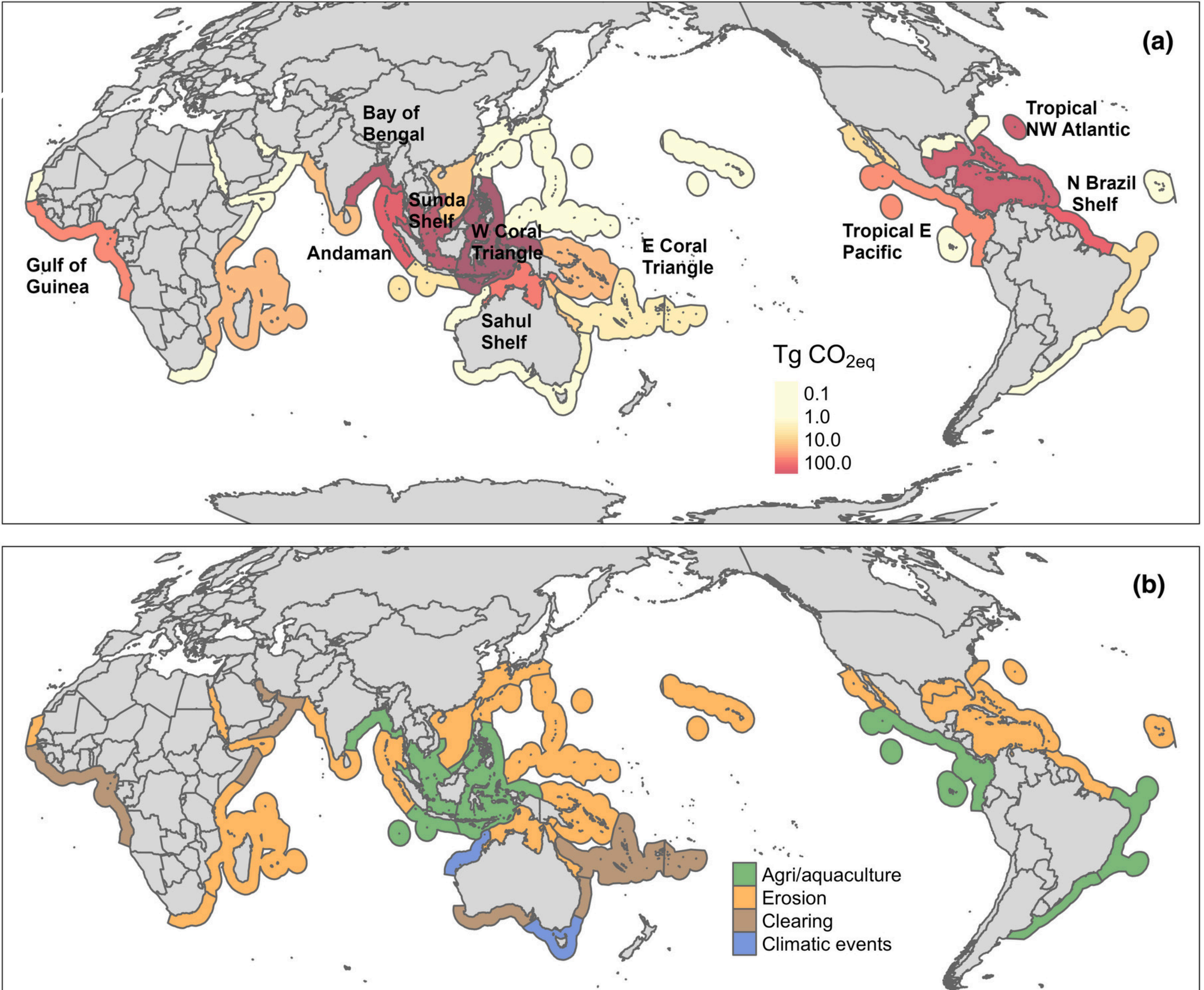
(photos: Mudiyarso et al. 2021)



Future carbon emissions from global mangrove forest loss

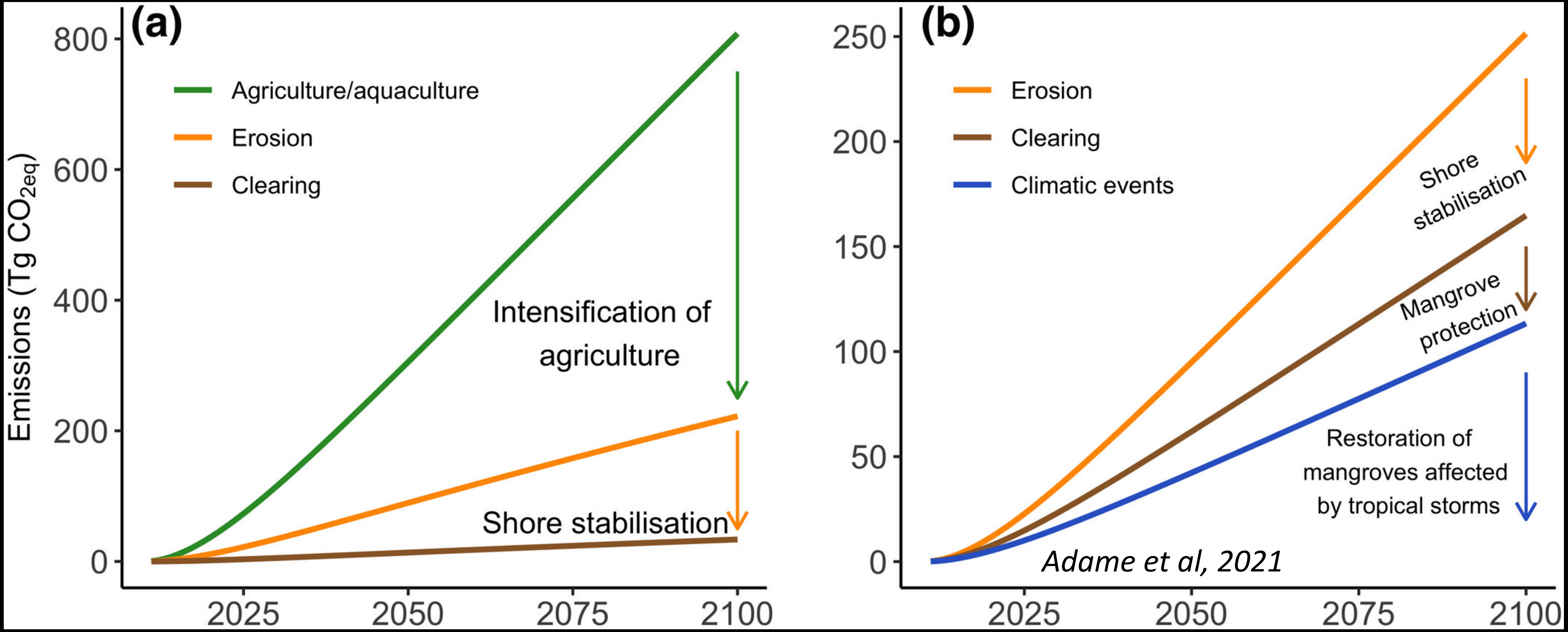
- Six regions accounted for 90% of the total potential $CO_{2\ eq}$ future emissions



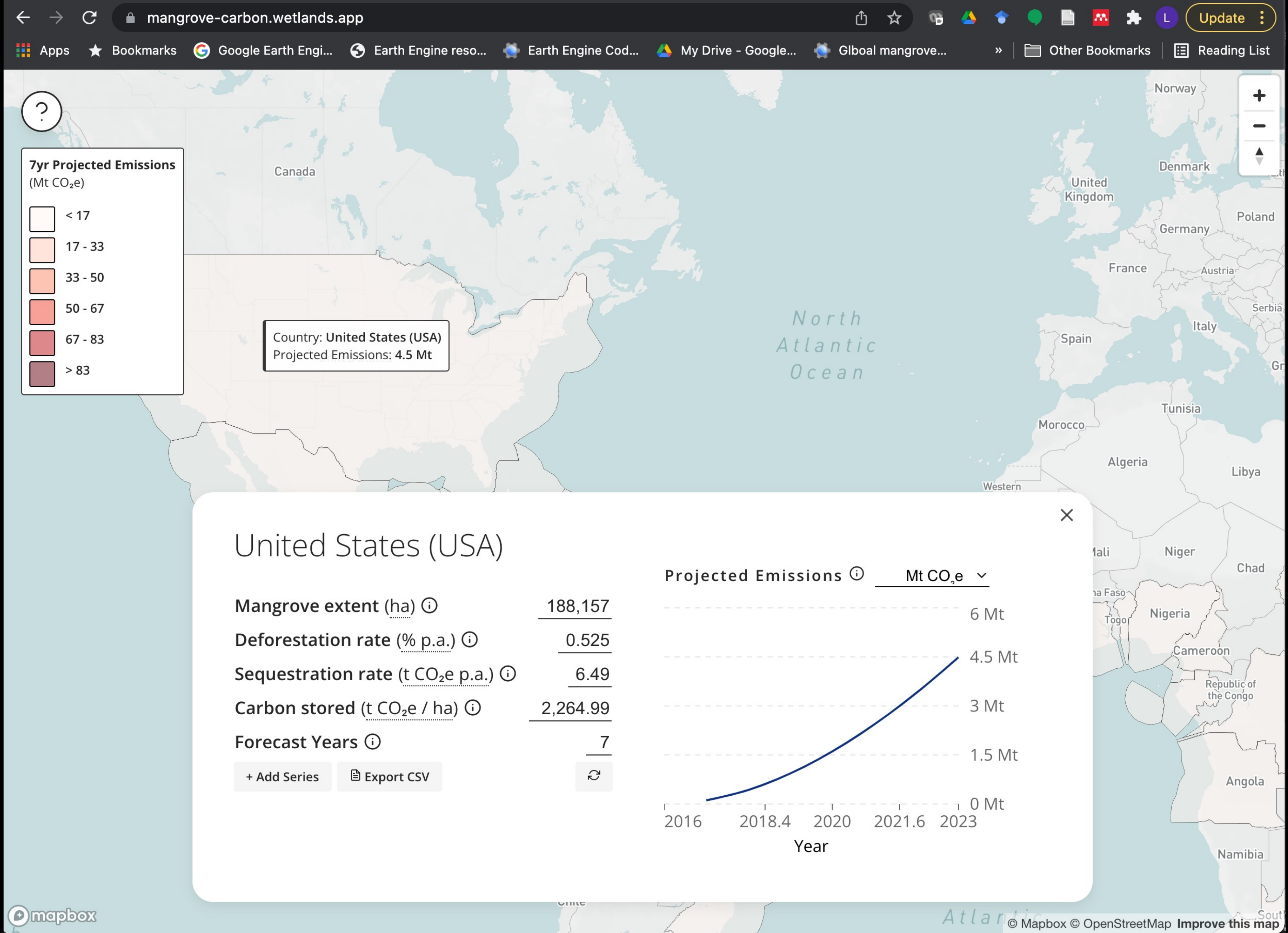


Adame, M.F., Connolly, R.M., Turschwell, M.P., Lovelock, C.E., Fatoyinbo, T., Lagomasino, D., Goldberg, L.A., Holdorf, J., Friess, D.A., Sasmito, S.D., Sanderman, J., Sievers, M., Buelow, C., Kauffman, J.B., Bryan-Brown, D. and Brown, C.J. (2021), Future carbon emissions from global mangrove forest loss. Glob Change Biol. https://doi.org/10.1111/gcb.15571

Activities that improve agricultural practices to reduce further expansion into mangrove areas and efforts to stabilize coastlines and restore former mangrove areas should be prioritized to decrease emissions from mangrove loss by the end of the century



Adame et al, 2021



7yr Projected Emissions
(Mt CO₂e)

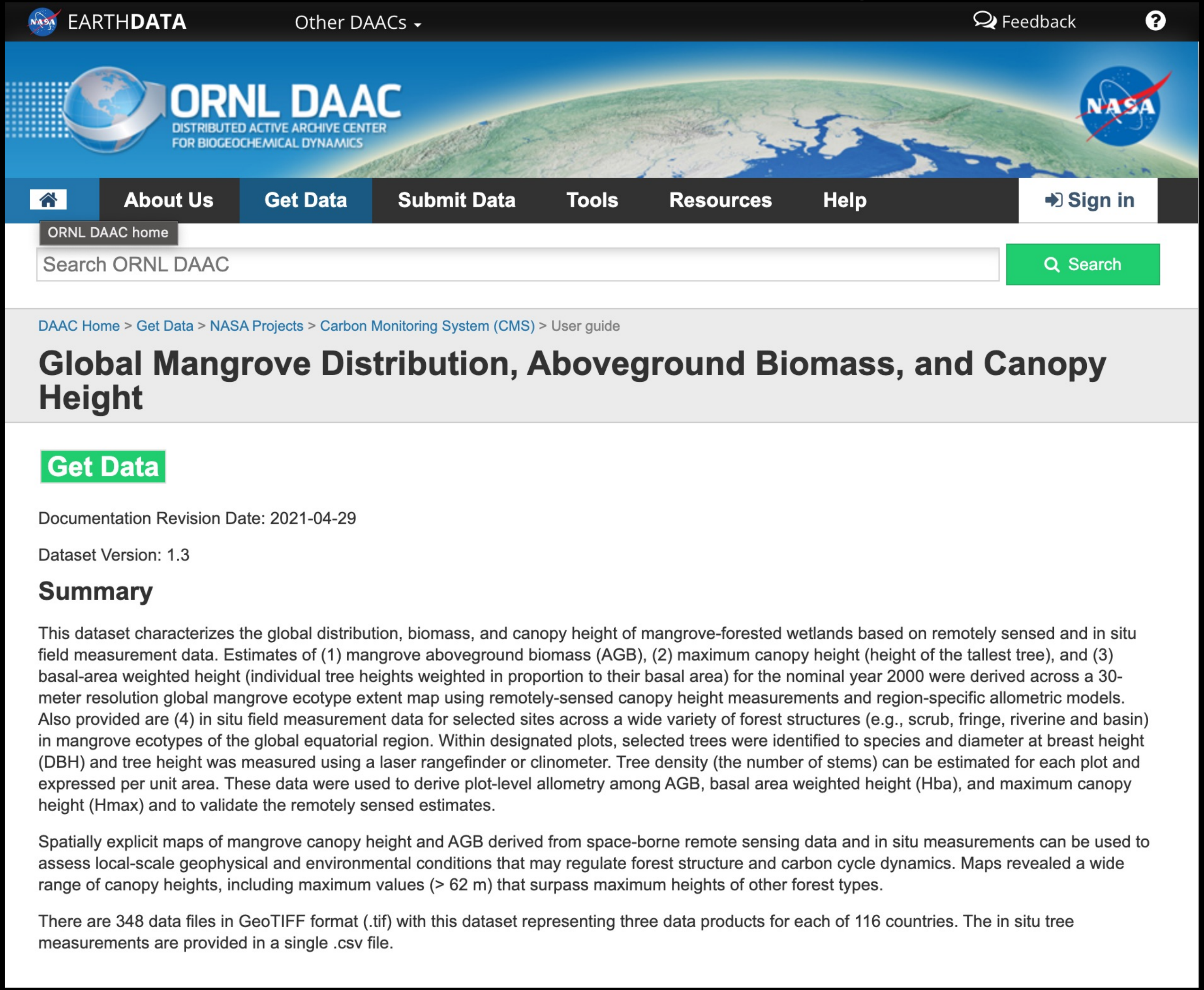
☐	< 17
☐	17 - 33
☐	33 - 50
☐	50 - 67
☐	67 - 83
☐	> 83

Country: **United States (USA)**
Projected Emissions: **4.5 Mt**

United States (USA)

Mangrove extent (ha) ⓘ	188,157
Deforestation rate (% p.a.) ⓘ	0.525
Sequestration rate (t CO₂e p.a.) ⓘ	6.49
Carbon stored (t CO₂e / ha) ⓘ	2,264.99
Forecast Years ⓘ	7

Data Availability



DAAC Home > Get Data > NASA Projects > Carbon Monitoring System (CMS) > User guide

Global Mangrove Distribution, Aboveground Biomass, and Canopy Height

Documentation Revision Date: 2021-04-29

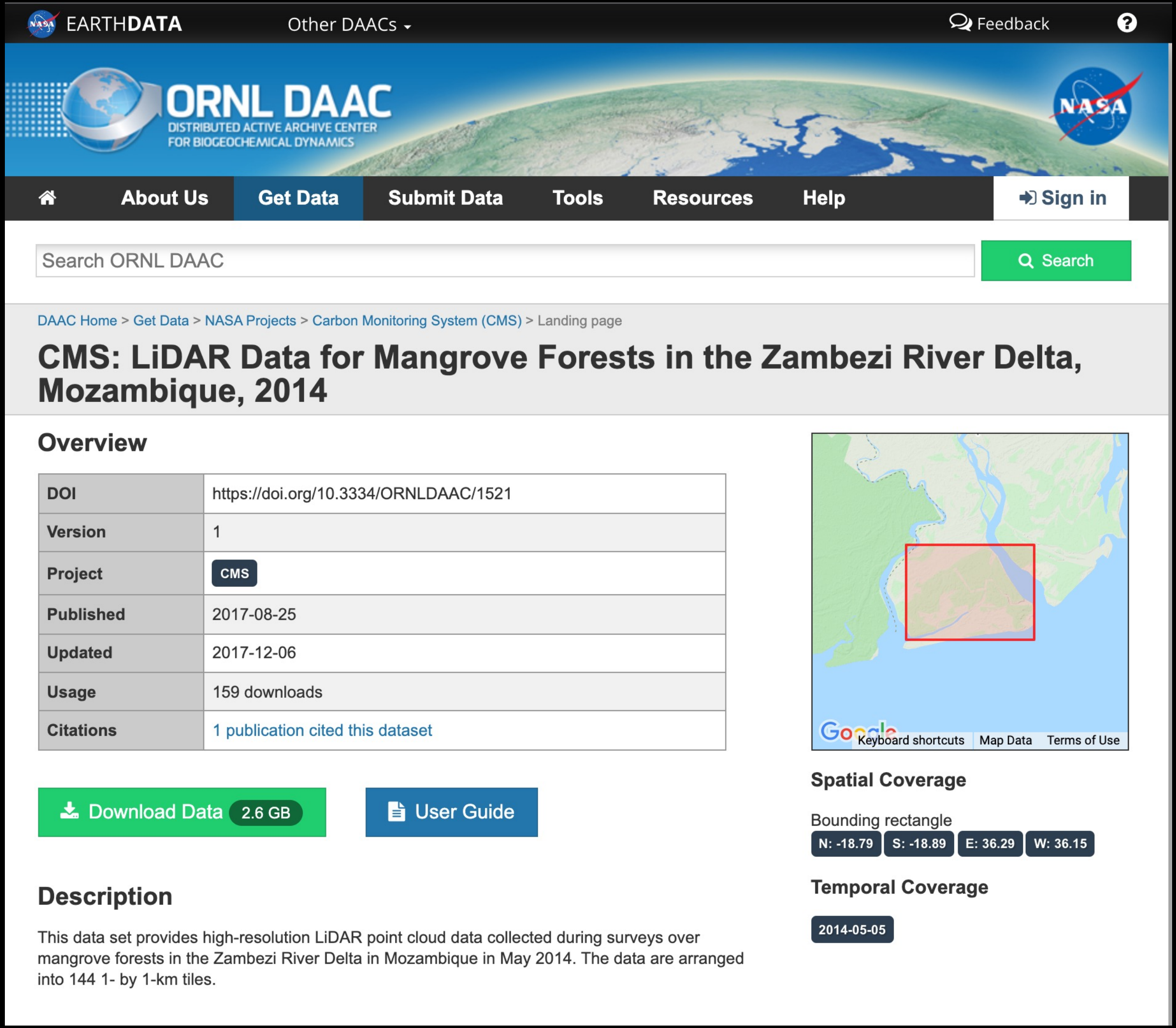
Dataset Version: 1.3

Summary

This dataset characterizes the global distribution, biomass, and canopy height of mangrove-forested wetlands based on remotely sensed and in situ field measurement data. Estimates of (1) mangrove aboveground biomass (AGB), (2) maximum canopy height (height of the tallest tree), and (3) basal-area weighted height (individual tree heights weighted in proportion to their basal area) for the nominal year 2000 were derived across a 30-meter resolution global mangrove ecotype extent map using remotely-sensed canopy height measurements and region-specific allometric models. Also provided are (4) in situ field measurement data for selected sites across a wide variety of forest structures (e.g., scrub, fringe, riverine and basin) in mangrove ecotypes of the global equatorial region. Within designated plots, selected trees were identified to species and diameter at breast height (DBH) and tree height was measured using a laser rangefinder or clinometer. Tree density (the number of stems) can be estimated for each plot and expressed per unit area. These data were used to derive plot-level allometry among AGB, basal area weighted height (Hba), and maximum canopy height (Hmax) and to validate the remotely sensed estimates.

Spatially explicit maps of mangrove canopy height and AGB derived from space-borne remote sensing data and in situ measurements can be used to assess local-scale geophysical and environmental conditions that may regulate forest structure and carbon cycle dynamics. Maps revealed a wide range of canopy heights, including maximum values (> 62 m) that surpass maximum heights of other forest types.

There are 348 data files in GeoTIFF format (.tif) with this dataset representing three data products for each of 116 countries. The in situ tree measurements are provided in a single .csv file.



DAAC Home > Get Data > NASA Projects > Carbon Monitoring System (CMS) > Landing page

CMS: LiDAR Data for Mangrove Forests in the Zambezi River Delta, Mozambique, 2014

Overview

DOI	https://doi.org/10.3334/ORNLDAAC/1521
Version	1
Project	CMS
Published	2017-08-25
Updated	2017-12-06
Usage	159 downloads
Citations	1 publication cited this dataset

Spatial Coverage

Bounding rectangle

N: -18.79 S: -18.89 E: 36.29 W: 36.15

Temporal Coverage

2014-05-05

Description

This data set provides high-resolution LiDAR point cloud data collected during surveys over mangrove forests in the Zambezi River Delta in Mozambique in May 2014. The data are arranged into 144 1- by 1-km tiles.

- https://daac.ornl.gov/CMS/guides/CMS_Global_Map_Mangrove_Canopy.html

Publication Details

Title: Carbon stock inventory of mangroves, Pongara National Park, Gabon

Author(s): Trettin, Carl C.; Dai, Zhaohua; Tang, Wenwu; Lagomasino, David; Thomas, Nathan; Lee, Seung-Kuk; Ebanega, Médard Obiang; Simard, Marc; Fatoyinbo, Temilola E.;

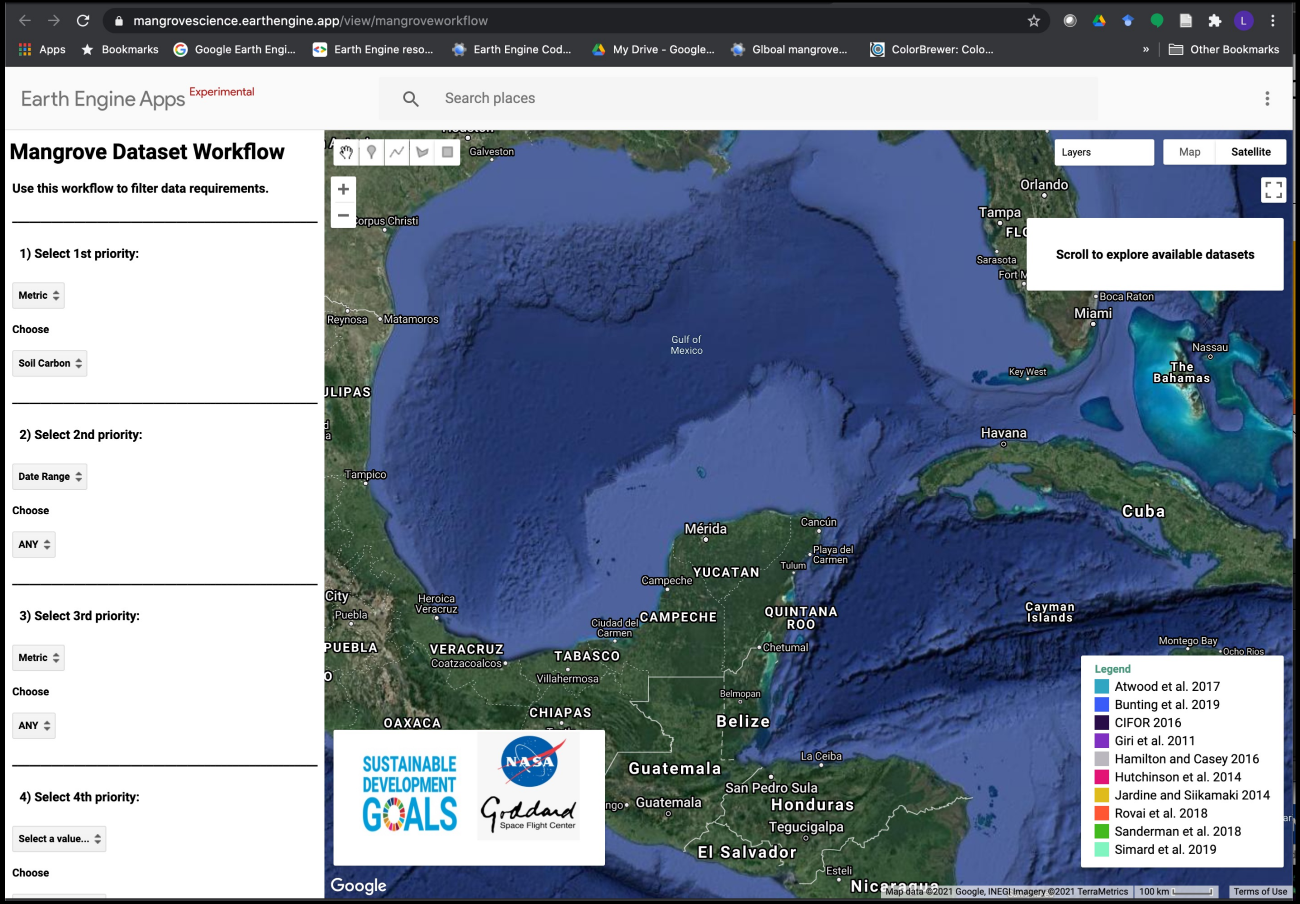
Publication Year: 2020

How to Cite: These data were collected using funding from the U.S. Government and can be used without additional permissions or fees. If you use these data in a publication, presentation, or other research product please use the following citation:

> Trettin, Carl C.; Dai, Zhaohua; Tang, Wenwu; Lagomasino, David; Thomas, Nathan; Lee, Seung-Kuk; Ebanega, Médard Obiang; Simard, Marc; Fatoyinbo, Temilola E. 2020. Carbon stock inventory of mangroves, Pongara National Park, Gabon. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2020-0040

Data Availability NASA ORNL and Forest Service DAAC

- Lagomasino, D., T. Fatoyinbo, S. Lee, E. Feliciano, M. Simard, and C. Trettin. 2016. CMS: Mangrove Canopy Height Estimates from Remote Imagery, Zambezi Delta, Mozambique. ORNL DAAC, Oak Ridge, Tennessee, USA. http://dx.doi.org/10.3334/ORNLDAAC/1357
- Fatoyinbo, T., and C. Trettin. 2017. CMS: LiDAR Data for Mangrove Forests in the Zambezi River Delta, Mozambique, 2014. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1521
- Lagomasino, D., T. Fatoyinbo, S. Lee, E. Feliciano, C. Trettin, A. Shapiro, and M. Mwita. 2019. CMS: Mangrove Forest Cover Extent and Change across Major River Deltas, 2000-2016. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1670
- Fatoyinbo, T., E. Feliciano, D. Lagomasino, S. Lee, and C. Trettin. 2017. CMS: Aboveground Biomass for Mangrove Forest, Zambezi River Delta, Mozambique. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1522
- Simard, M., T. Fatoyinbo, C. Smetanka, V.H. Rivera-monroy, E. Castaneda, N. Thomas, and T. Van der stocken. 2019. Global Mangrove Distribution, Aboveground Biomass, and Canopy Height. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1665
- Lagomasino, D., T. Fatoyinbo, S. Lee, E. Feliciano, C. Trettin, A. Shapiro, and M. Mwita. 2019. CMS: Mangrove Forest Cover Extent and Change across Major River Deltas, 2000-2016. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1670
- Lagomasino, D., T. Fatoyinbo, S. Lee, E. Feliciano, C. Trettin, and M.C. Hansen. 2017. CMS: Mangrove Canopy Characteristics and Land Cover Change, Tanzania, 1990-2014. ORNL DAAC, Oak Ridge, Tennessee, USA. http://dx.doi.org/10.3334/ORNLDAAC/1377
- Trettin, Carl C.; Dai, Zhaohua; Tang, Wenwu; Lagomasino, David; Thomas, Nathan; Lee, Seung-Kuk; Ebanega, Médard Obiang; Simard, Marc; Fatoyinbo, Temilola E.. (2022). Carbon stock inventory of mangroves, Pongara National Park, Gabon. USDA Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2020-0040.



Mangrove Dataset Workflow

Use this workflow to filter data requirements.

1) Select 1st priority:

Metric

Choose

Soil Carbon

2) Select 2nd priority:

Date Range

Choose

ANY

3) Select 3rd priority:

Metric

Choose

ANY

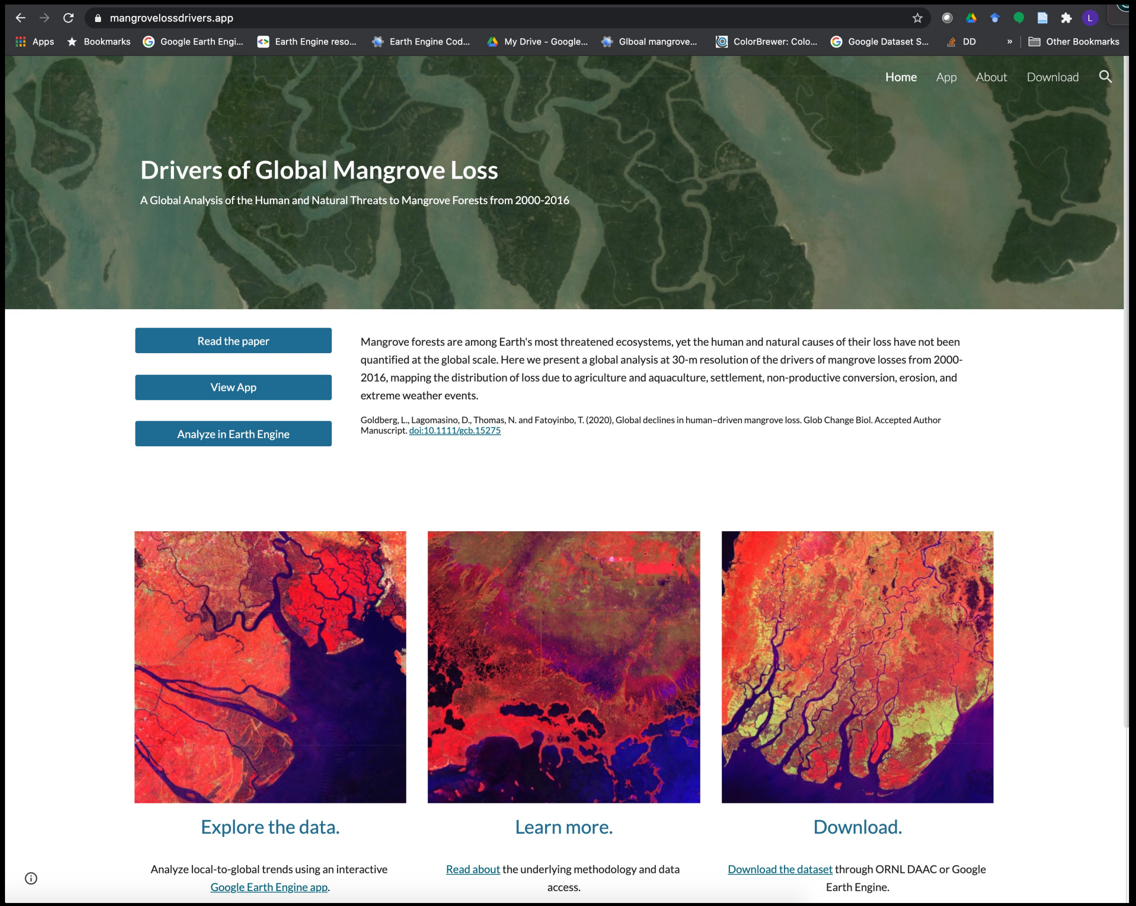
4) Select 4th priority:

Select a value...

Choose

Legend

- 🟦 Atwood et al. 2017
- 🟦 Bunting et al. 2019
- ■ CIFOR 2016
- 🟪 Giri et al. 2011
- ⬜ Hamilton and Casey 2016
- 🟥 Hutchinson et al. 2014
- 🟨 Jardine and Siikamaki 2014
- 🟧 Rovai et al. 2018
- 🟩 Sanderman et al. 2018
- 🟩 Simard et al. 2019



Drivers of Global Mangrove Loss

A Global Analysis of the Human and Natural Threats to Mangrove Forests from 2000-2016

Mangrove forests are among Earth's most threatened ecosystems, yet the human and natural causes of their loss have not been quantified at the global scale. Here we present a global analysis at 30-m resolution of the drivers of mangrove losses from 2000-2016, mapping the distribution of loss due to agriculture and aquaculture, settlement, non-productive conversion, erosion, and extreme weather events.

Goldberg, L., Lagomasino, D., Thomas, N. and Fatoyinbo, T. (2020), Global declines in human–driven mangrove loss. Glob Change Biol. Accepted Author Manuscript. doi:10.1111/gcb.15275

Explore the data.

Analyze local-to-global trends using an interactive Google Earth Engine app.

Learn more.

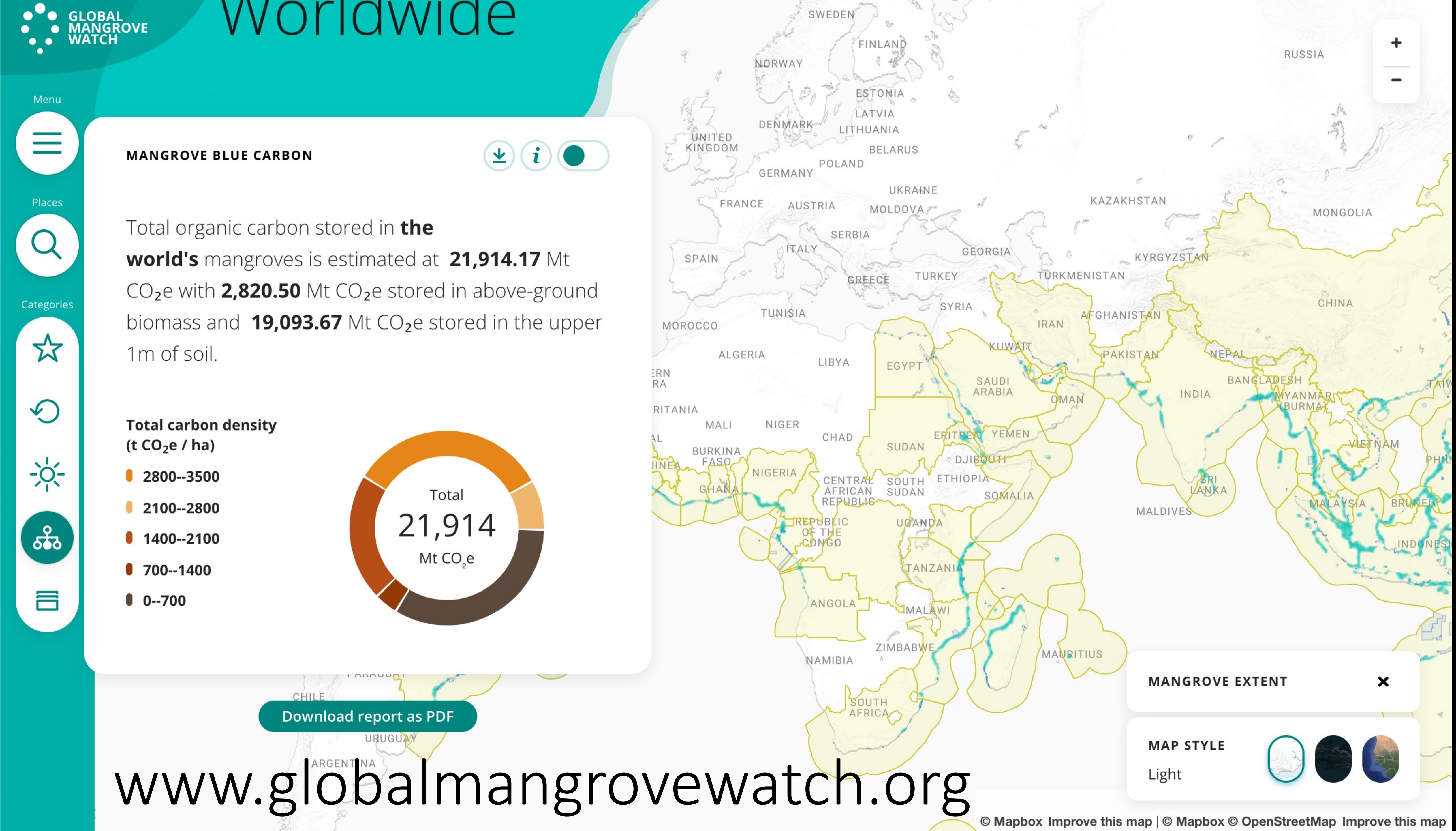
Read about the underlying methodology and data access.

Download.

Download the dataset through ORNL DAAC or Google Earth Engine.

www.mangrovescience.earthengine.app

www.mangrovelossdrivers.app



MANGROVE BLUE CARBON

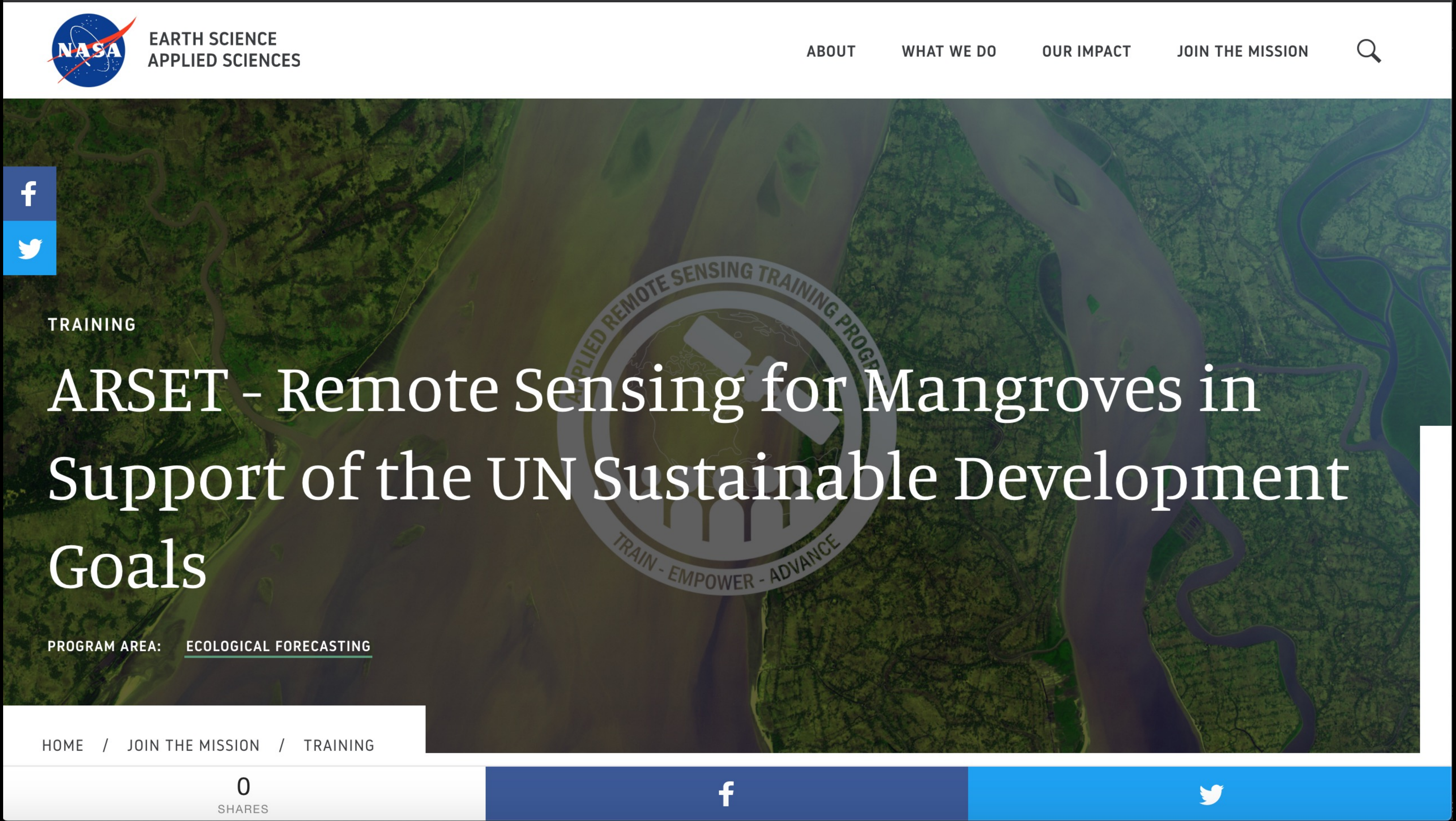
Total organic carbon stored in **the world's** mangroves is estimated at **21,914.17** Mt CO_2e with **2,820.50** Mt CO_2e stored in above-ground biomass and **19,093.67** Mt CO_2e stored in the upper 1m of soil.

Total carbon density ($t\ CO_2e$ / ha)

- **2800--3500**
- **2100--2800**
- **1400--2100**
- **700--1400**
- **0--700**

Total
21,914
Mt CO_2e

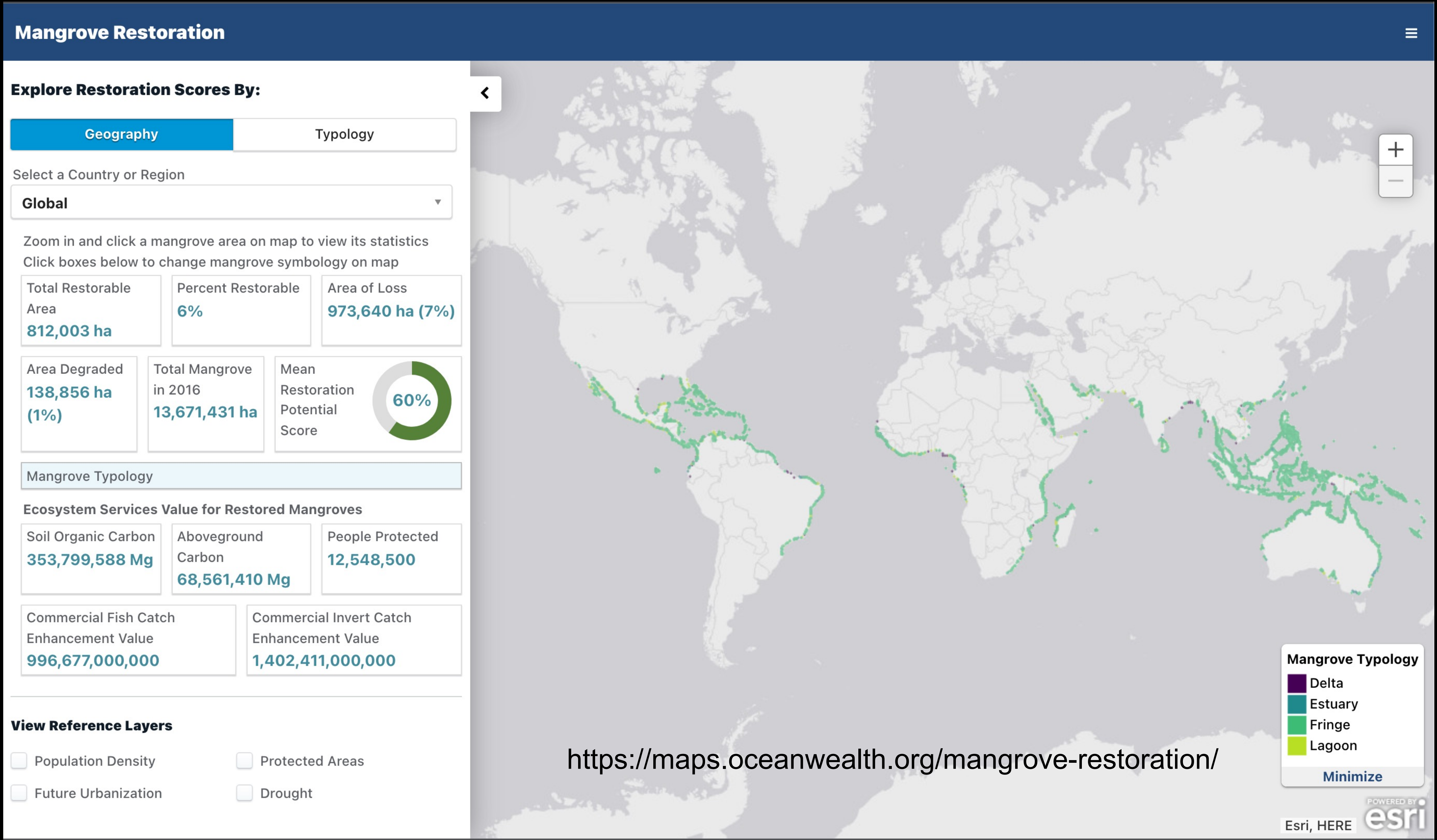
www.globalmangrovewatch.org



TRAINING

ARSET - Remote Sensing for Mangroves in Support of the UN Sustainable Development Goals

PROGRAM AREA: ECOLOGICAL FORECASTING



Mangrove Restoration

Explore Restoration Scores By:

Select a Country or Region: Global

Zoom in and click a mangrove area on map to view its statistics
Click boxes below to change mangrove symbology on map

Total Restorable Area: 812,003 ha

Percent Restorable: 6%

Area of Loss: 973,640 ha (7%)

Area Degraded: 138,856 ha (1%)

Total Mangrove in 2016: 13,671,431 ha

Mean Restoration Potential Score: 60%

Mangrove Typology

Ecosystem Services Value for Restored Mangroves

Soil Organic Carbon: 353,799,588 Mg

Aboveground Carbon: 68,561,410 Mg

People Protected: 12,548,500

Commercial Fish Catch Enhancement Value: 996,677,000,000

Commercial Invert Catch Enhancement Value: 1,402,411,000,000

View Reference Layers

☐ Population Density
☐ Protected Areas
☐ Future Urbanization
☐ Drought

Mangrove Typology

🟪 Delta
🟦 Estuary
🟩 Fringe
🟨 Lagoon

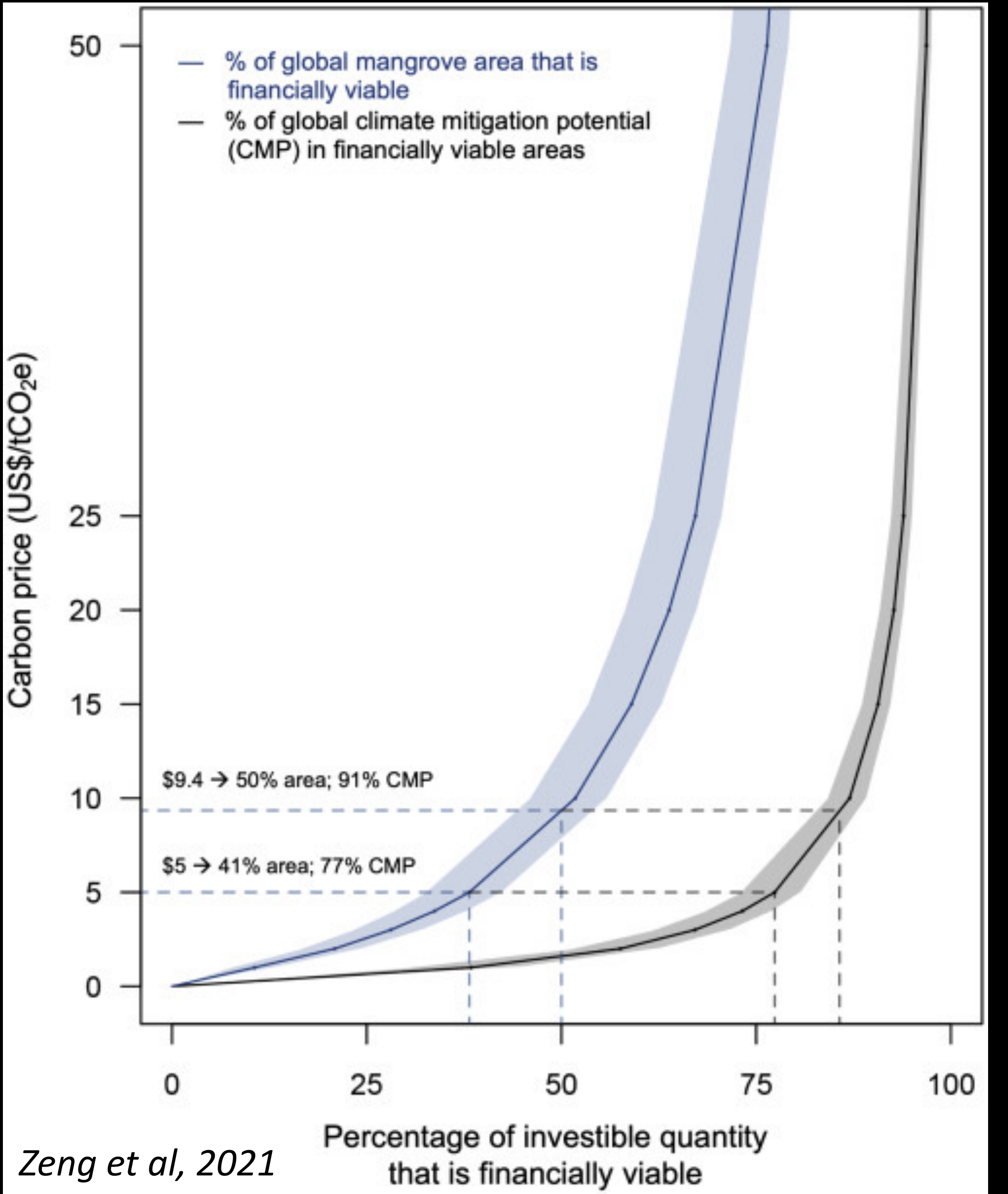
https://maps.oceanwealth.org/mangrove-restoration/

Thank you!

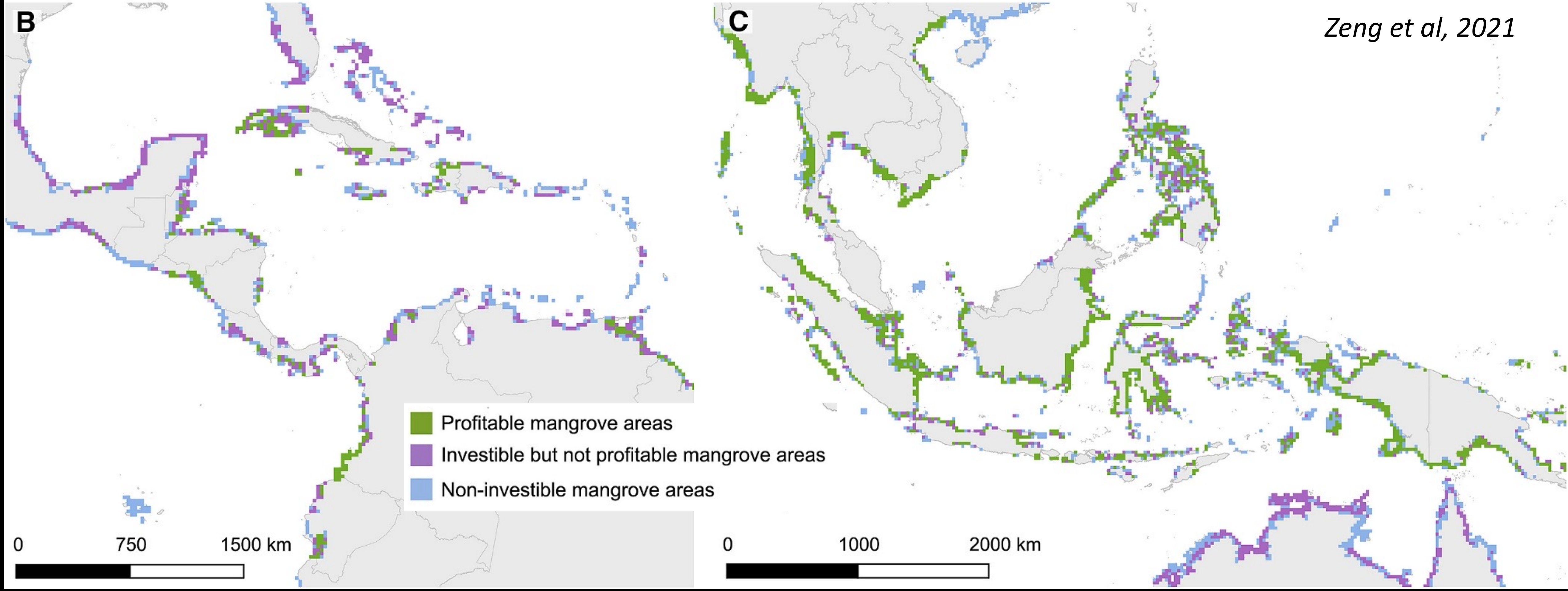
Thank you

Global potential and limits of mangrove blue carbon for climate change mitigation

- Bundling other ecosystem services alongside carbon credits would increase the range of mangrove financing mechanisms such as coastal protection insurance
- Return-on-investment analyses will help to inform national and international policy interests in mangrove blue carbon and the small scale of current carbon project implementation

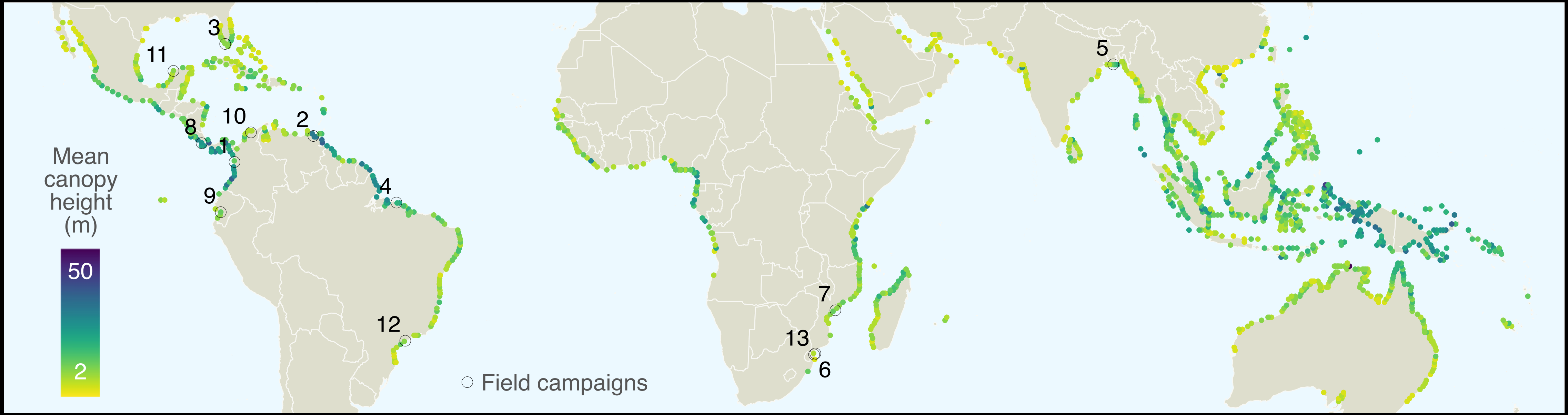


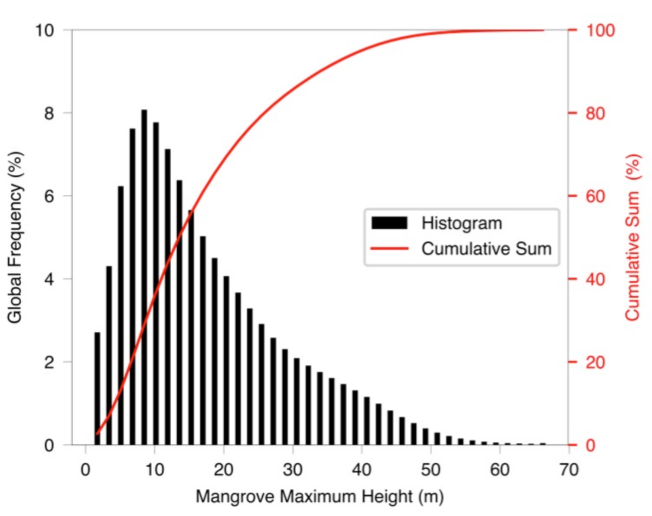
Zeng et al, 2021

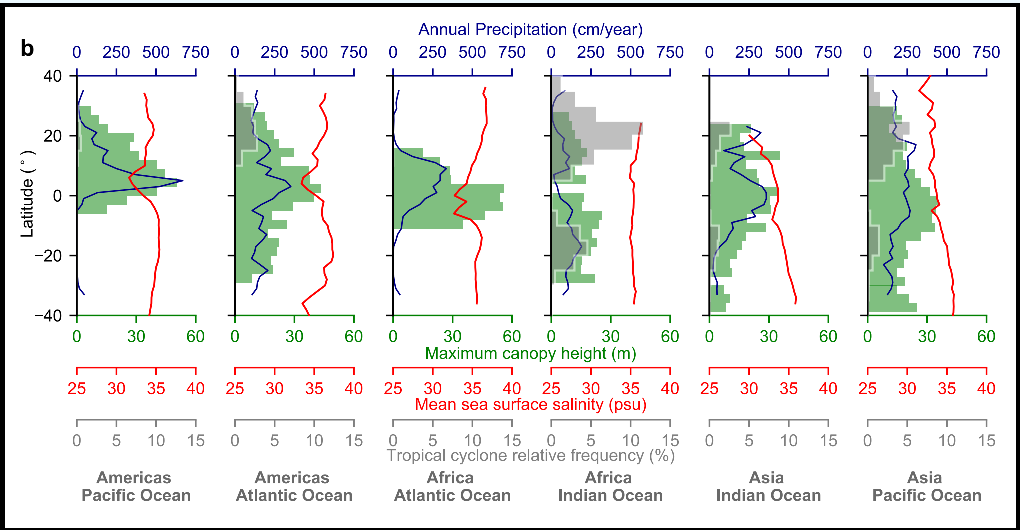


Zeng et al, 2021

- ~20% of mangrove forests can qualify for blue carbon financing
- ~10% will be financially sustainable—contributing up to 29.8 MtCO$_2$eyr^{-1}
- Blue carbon financing is important at a national level, but has limited global potential


3
11
5
10
2
8
1
4
9
7
12
13
6
Mean canopy height (m)
50
2
○ Field campaigns


Global Frequency (%)
Cumulative Sum (%)
Mangrove Maximum Height (m)
Histogram
Cumulative Sum
0
2
4
6
8
10
0
20
40
60
80
100
0
10
20
30
40
50
60
70


b
Annual Precipitation (cm/year)
0 250 500 750
Latitude (°)
40
20
0
−20
−40
0 30 60
Maximum canopy height (m)
25 30 35 40
Mean sea surface salinity (psu)
0 5 10 15
Tropical cyclone relative frequency (%)
Americas Pacific Ocean
Americas Atlantic Ocean
Africa Atlantic Ocean
Africa Indian Ocean
Asia Indian Ocean
Asia Pacific Ocean