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The topic of presentation is

- Lecture 6: Identification of the Potential Degraded Forests for Restoration in the Tropics – Implications for Carbon Sequestration and Revenues

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TRAINING: AFoCO-ITTO Capacity Building Workshop on Forest Landscape Restoration in the Asia-Pacific Region

30 August – 3 September 2021

Identification of the Potential Degraded Forests for Restoration in the Tropics

– Implications for Carbon Sequestration and Revenues

Dr. Manjunatha Venkatappa

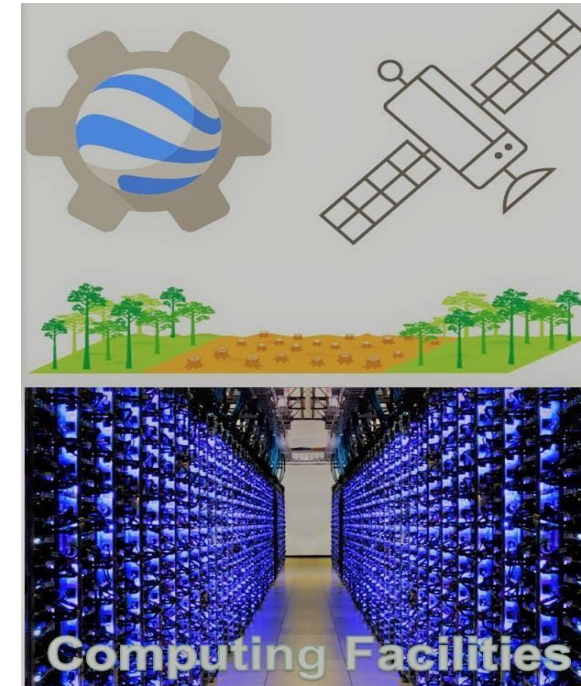
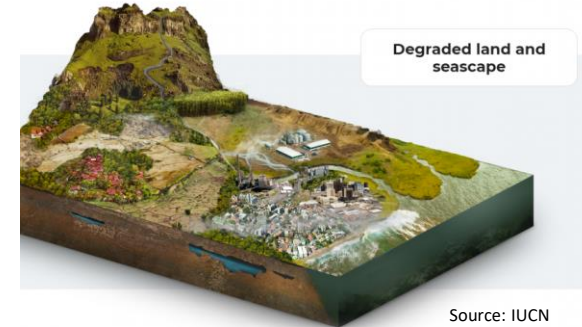
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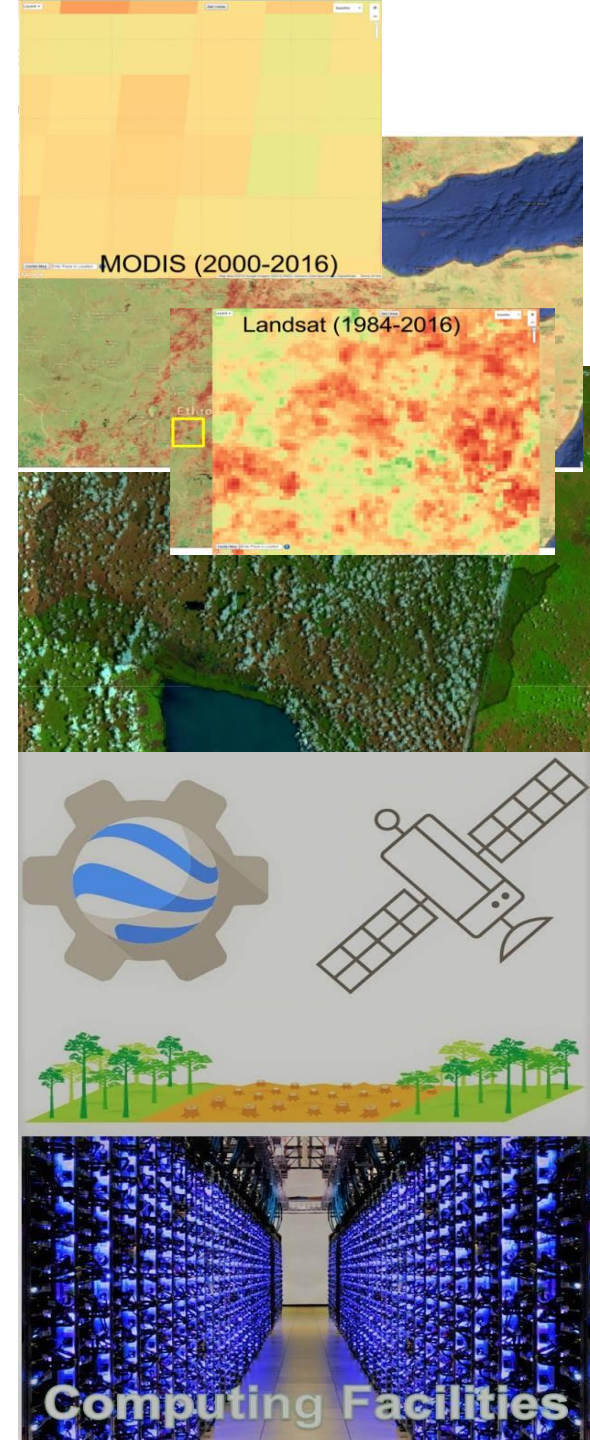
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Motivation

- Effective restoration of the degraded forests is essential for ongoing global climate and biodiversity crisis and to restore degraded forests.
- The New York Declaration on Forests and the UN Decade on Ecosystem Restoration (2021-2030) set the target to achieve restoration on the 350-500 million hectares of the degraded ecosystems (**700,000,000,000 trees!**)
- Although passive restoration are possible, there are questions remain to be addressed:
 - Where are those degraded forests?
 - How can we identify them?
 - What methods to be used for such identifications in addition to the cost-effective methods for restoration?
 - Moreover, as many target areas for restoration are also covered by the REDD+ scheme, assessments on how much carbon can be sequestered in the restored forests is also needs to be undertaken.
- To monitor the performance, tracking system is critically needed.



- Transparent methods for monitoring, reporting and verification are needed but previous methods rely on remote sensing methods that are required high technical skills.
- Various methods were developed using Remote sensing and spatial data, but the challenges are – accessing VHR imagery, their low spatial extent, relatively low temporal resolution and lack of global coverage, the influence of acquisition conditions, computing time.
- With Big Earth-Data and Cloud computing platform, tracking and monitoring of the Forest Land Restoration (FLR) areas and planted trees become possible at scale and speed.
- Digital technologies equipped with Machine Learning (ML) and Deep Learning (DL) for such tracking and monitoring are useful for transparency and quick policy interventions.





Google Earth Engine

Cloud-based platform for massive computational capabilities.

- Big Data
- Massive Computation
- Scientific Algorithms

Customized for geospatial data

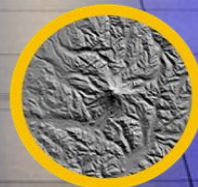
APIs for application development



Landsat
4, 5, 7, and
8



MODIS
Daily, NBAR,
etc.



Terrain
SRTM, NED,
etc.



Land Cover
GlobCover, NLCD,
etc.



Atmospheric
NOAA NCEP,
etc.

What we did

- **Data:** 2199 Landsat collections using GEE
- **Enhanced Vegetation Index (EVI)** along with harmonic regression methods to identify phenological behaviors for 12 land cover categories as per IPCC Guidelines in GEE
- **Phenological Behaviors** were analyzed
 - Dry Season (November – April) : Leaf-shedding phenology
 - Rain Season (May – October): Leaf-flushing phenology
- 722 mean EVIs were generated and respective thresholds were determined for 12 land cover categories
- **Reference Data:** 300 sampling points in forest permanent sample plots, field observations and drone-based locations
- Developed **Phenology-based Threshold classification method**
- Developed **Potential Degraded Forests for Restoration (PDFR)**
- Assessed forest cover change, degraded forest lands and **Carbon stocks and sequestration in degraded forest lands**



$$EVI = G \times ((NIR - RED) / (NIR + C1 \times RED - C2 \times BLUE + L))$$

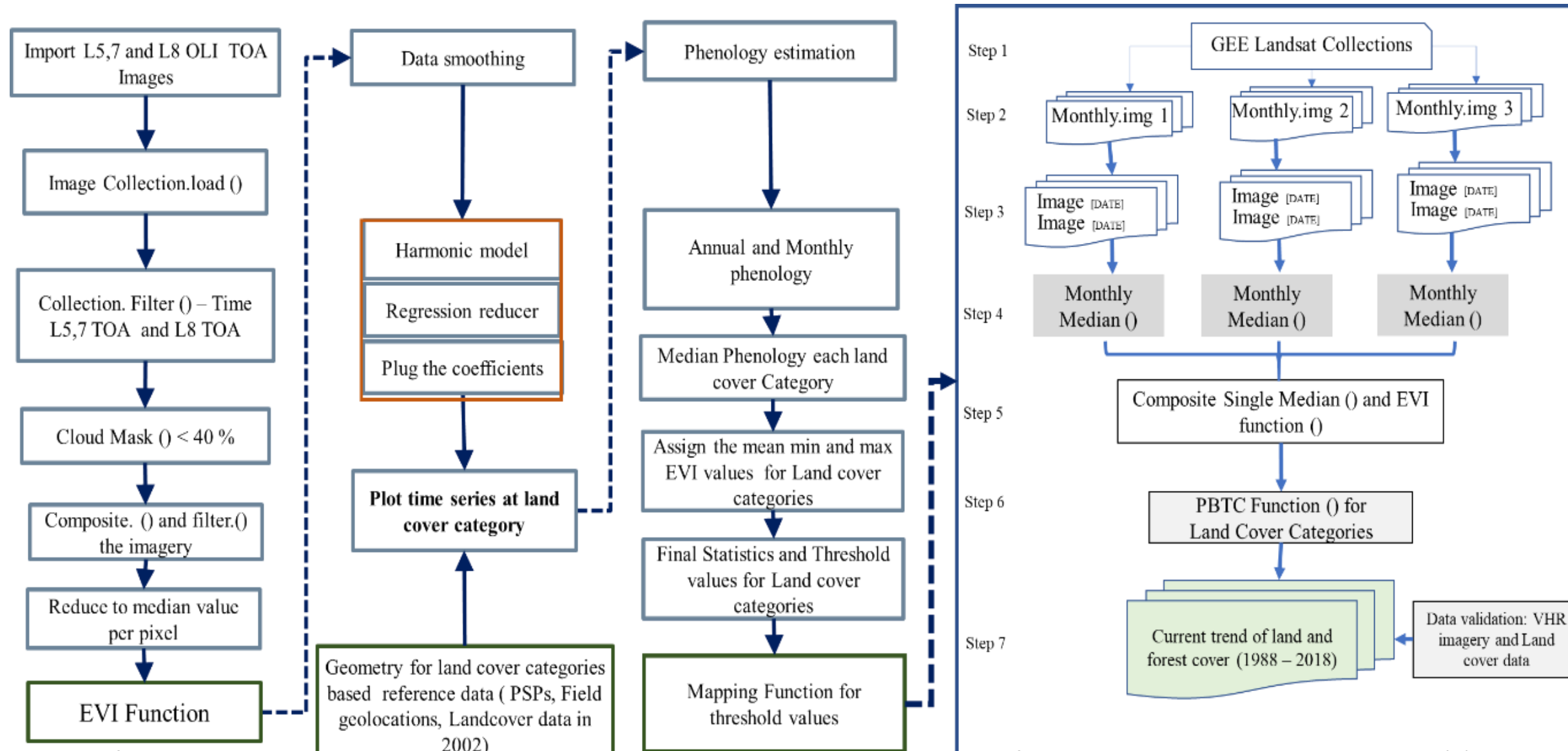
where the coefficients of the EVI equation are L = 1 (canopy background adjustment factor); C1 = 6, and C2 = 7.5 (aerosol correction factors); and G = 2.5 (gain factor). NIR represents the near-infrared band (TM band 4 and OLI band 5); RED represents TM band 3 and OLI band 4

Land Cover Categories

- Evergreen forest
- Semievergreen forest
- Deciduous forest
- Mix wood and shrub
- Flooded forest
- Mangrove forest
- Bamboo
- Rubber plantation
- Croplands
- Built-up area
- Sand
- Water



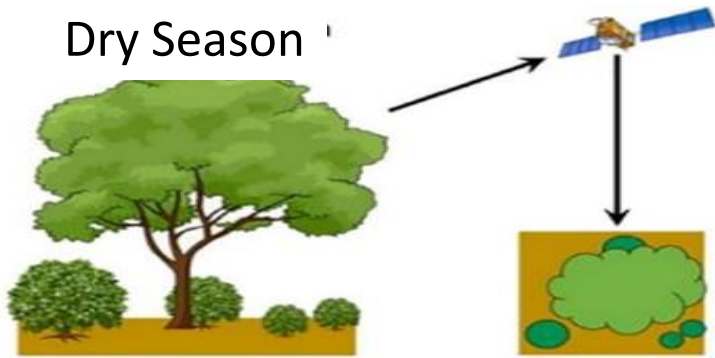
Phenology-based Threshold classification (PBTC)



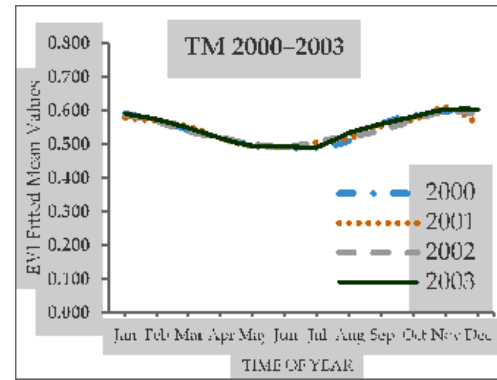
(a) Flowchart of the methodology adopted to estimate phenology and determine the thresholds for selected land cover categories and (b) Landsat single image composite PBTC method for land use and land use change in this study.

Phenological Behaviors of 12 Land Cover Categories

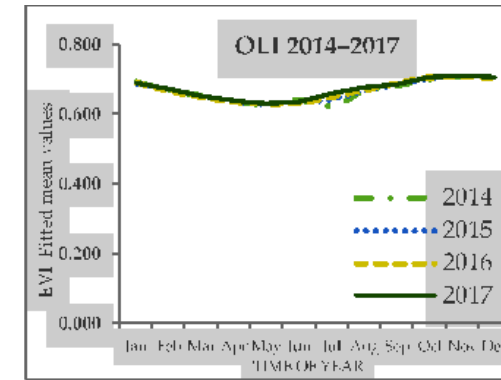
Dry Season



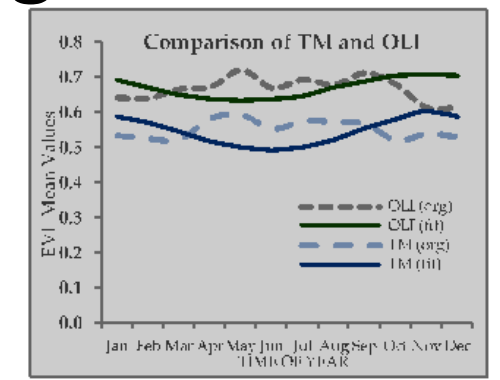
EG



(a)

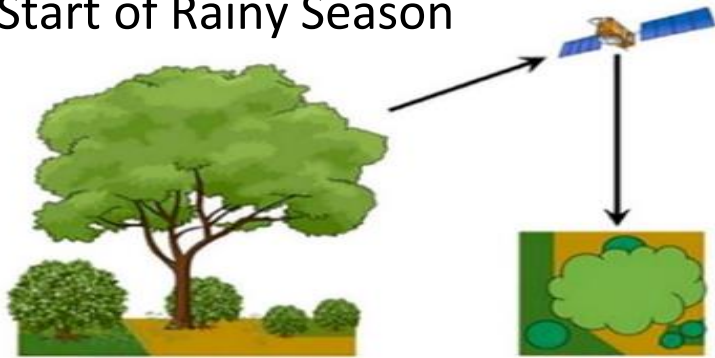


(b)

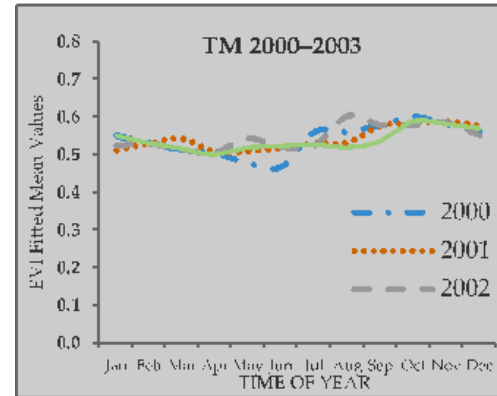


(c)

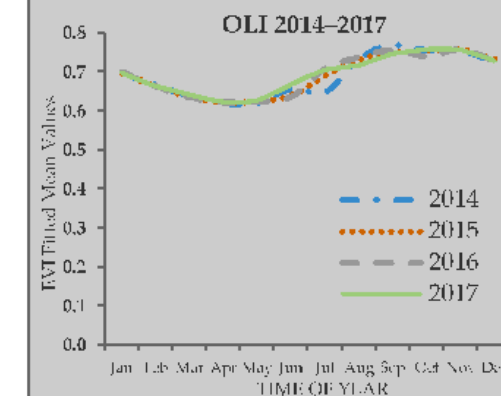
Start of Rainy Season



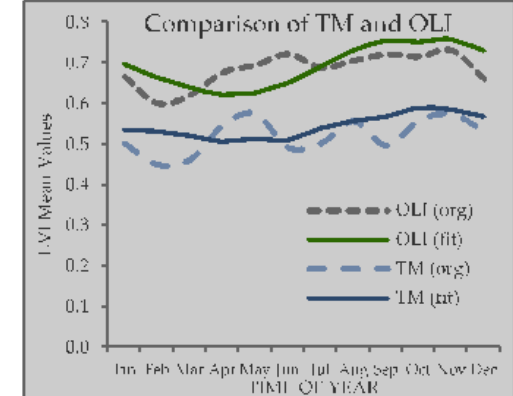
SEG



(d)



(e)

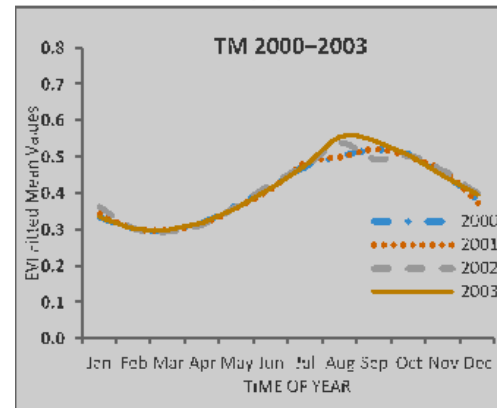


(f)

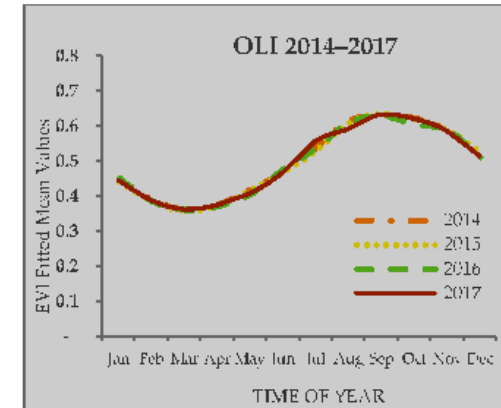
Peak of Rainy Season



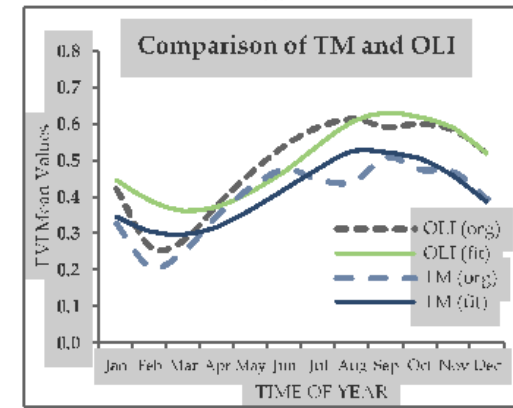
DD



(g)

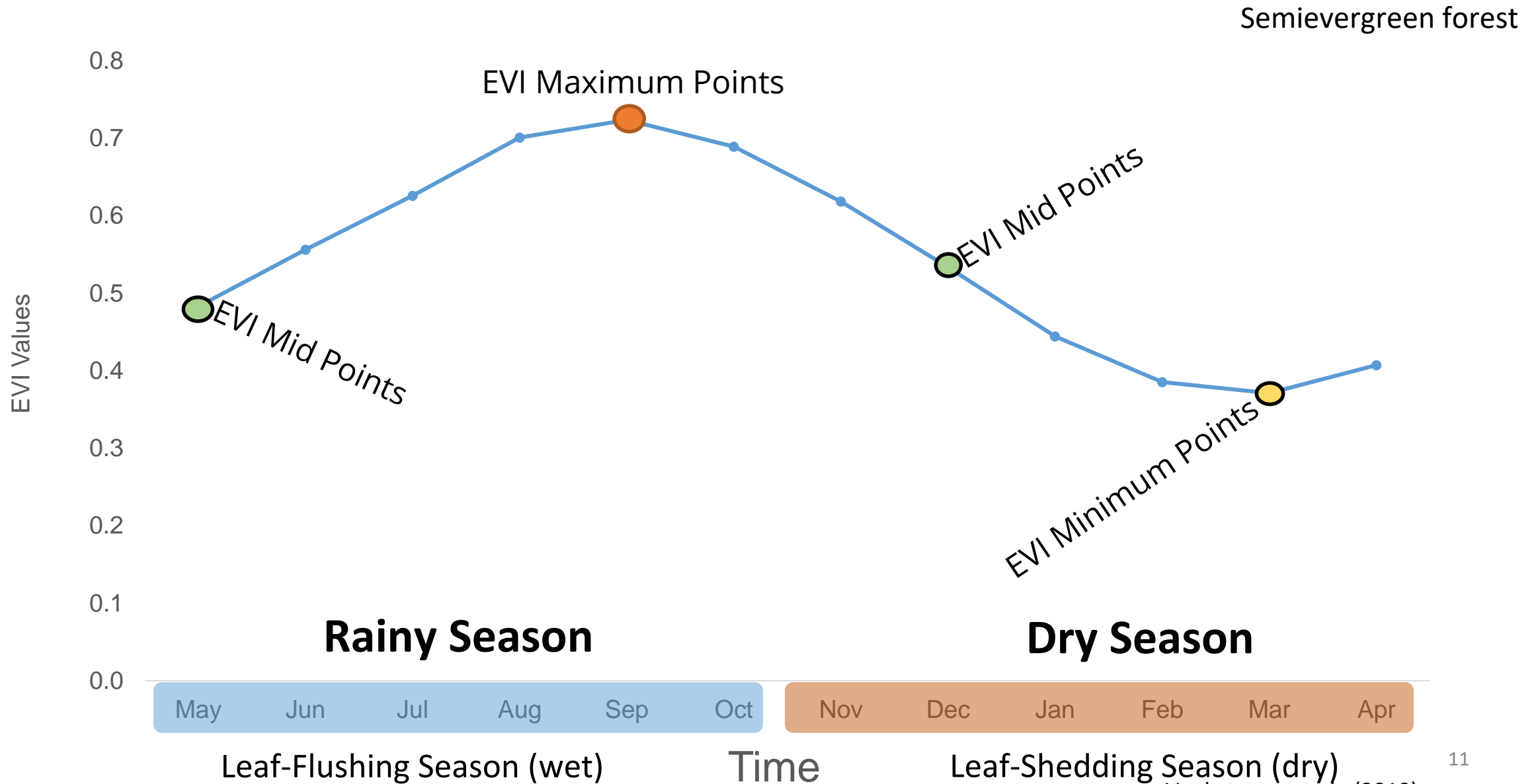


(h)

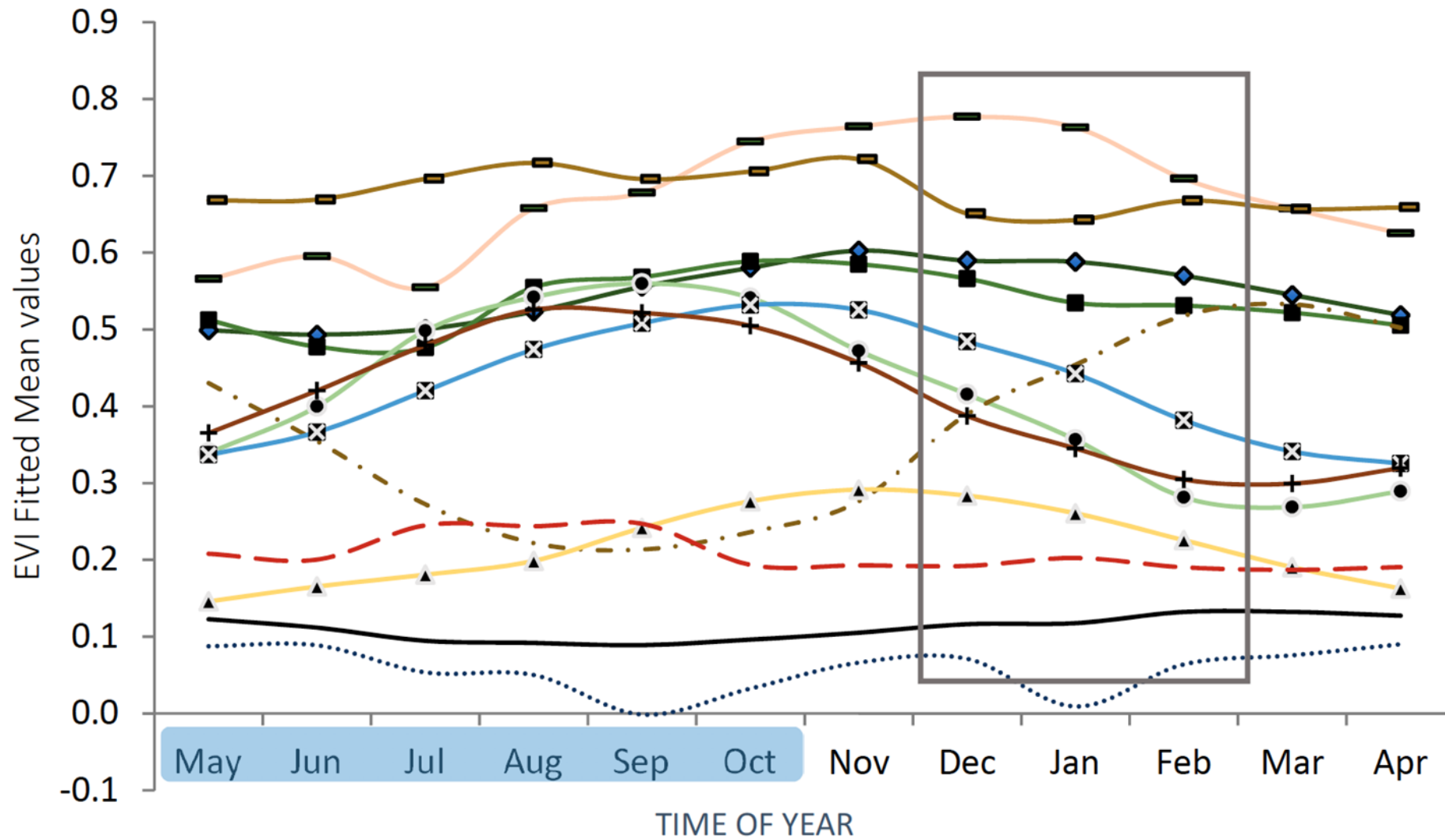


(i)

Leaf-Shedding and Leaf-Flushing Phenology



Phenology profiles of the individual 12 land cover categories



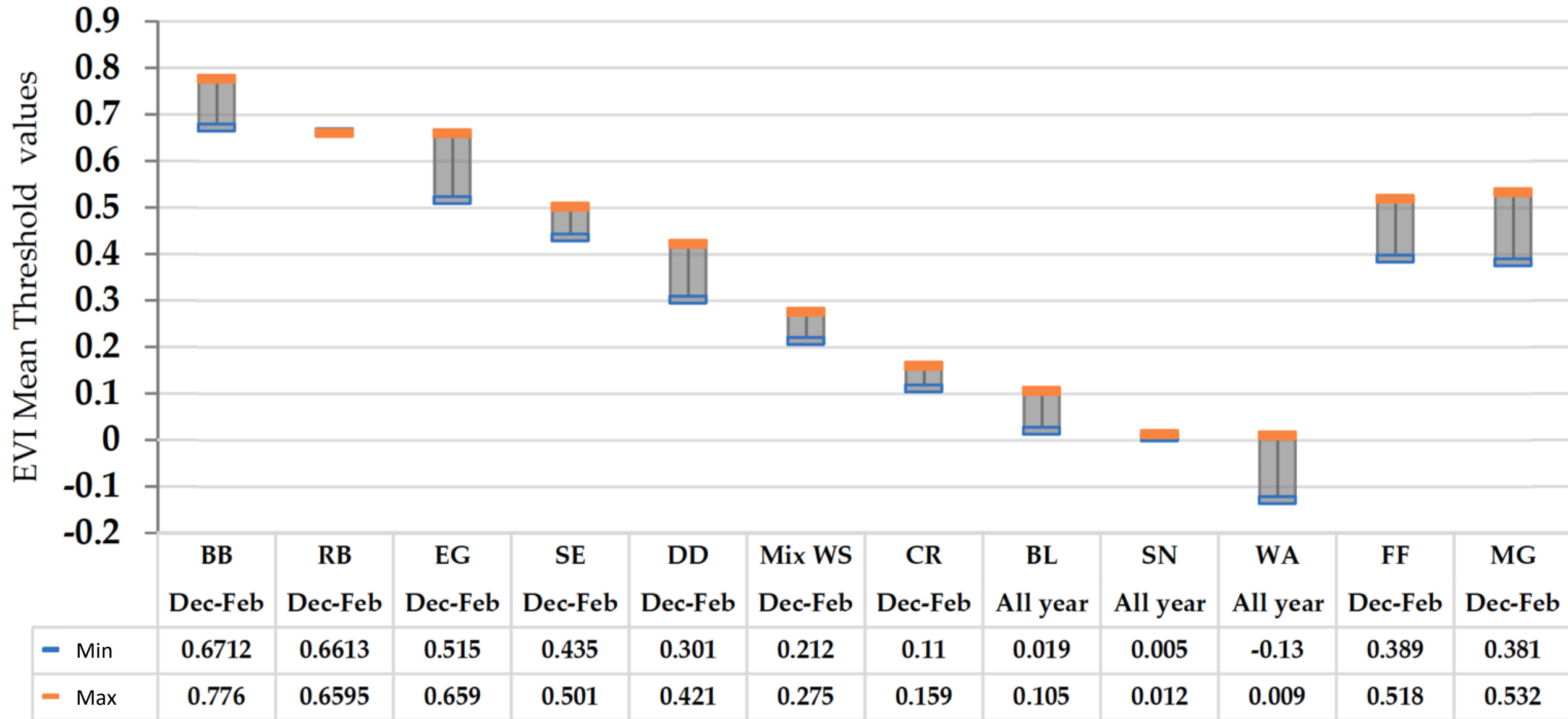
Note

EG: Evergreen
SEG: Semievergreen
DD: Deciduous
FF: Flooded Forest
MG: Mangrove Forest
BB: Bamboo
MixWS: Mix wood and shrub
RB: Rubber plantation
CR: Croplands or paddy fields
BL: Built-up area
WA: Water
SN: Sand or soil

This is based on Landsat data

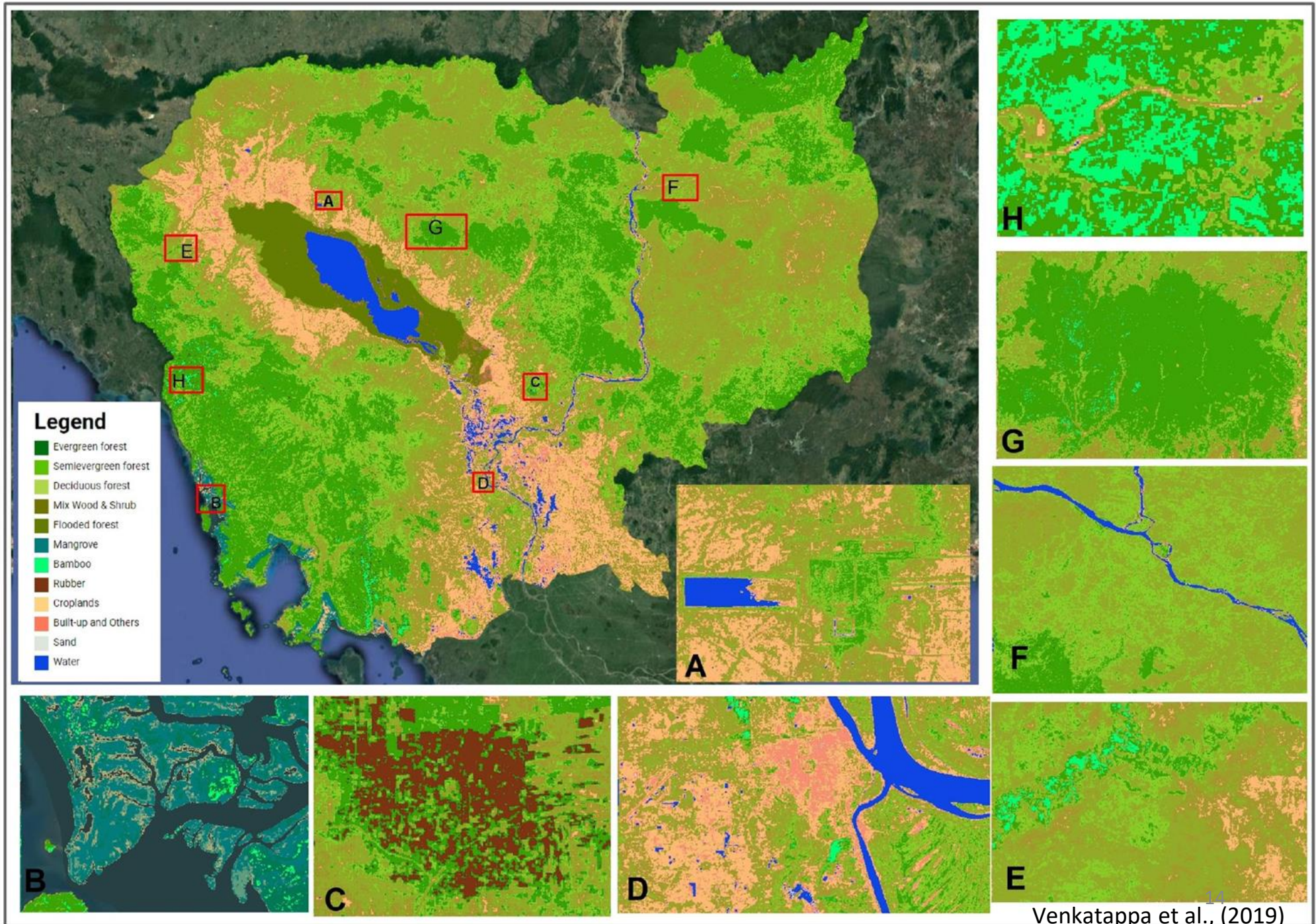
Venkatappa et al., (2019)

Determined Threshold Values for Landsat imagery



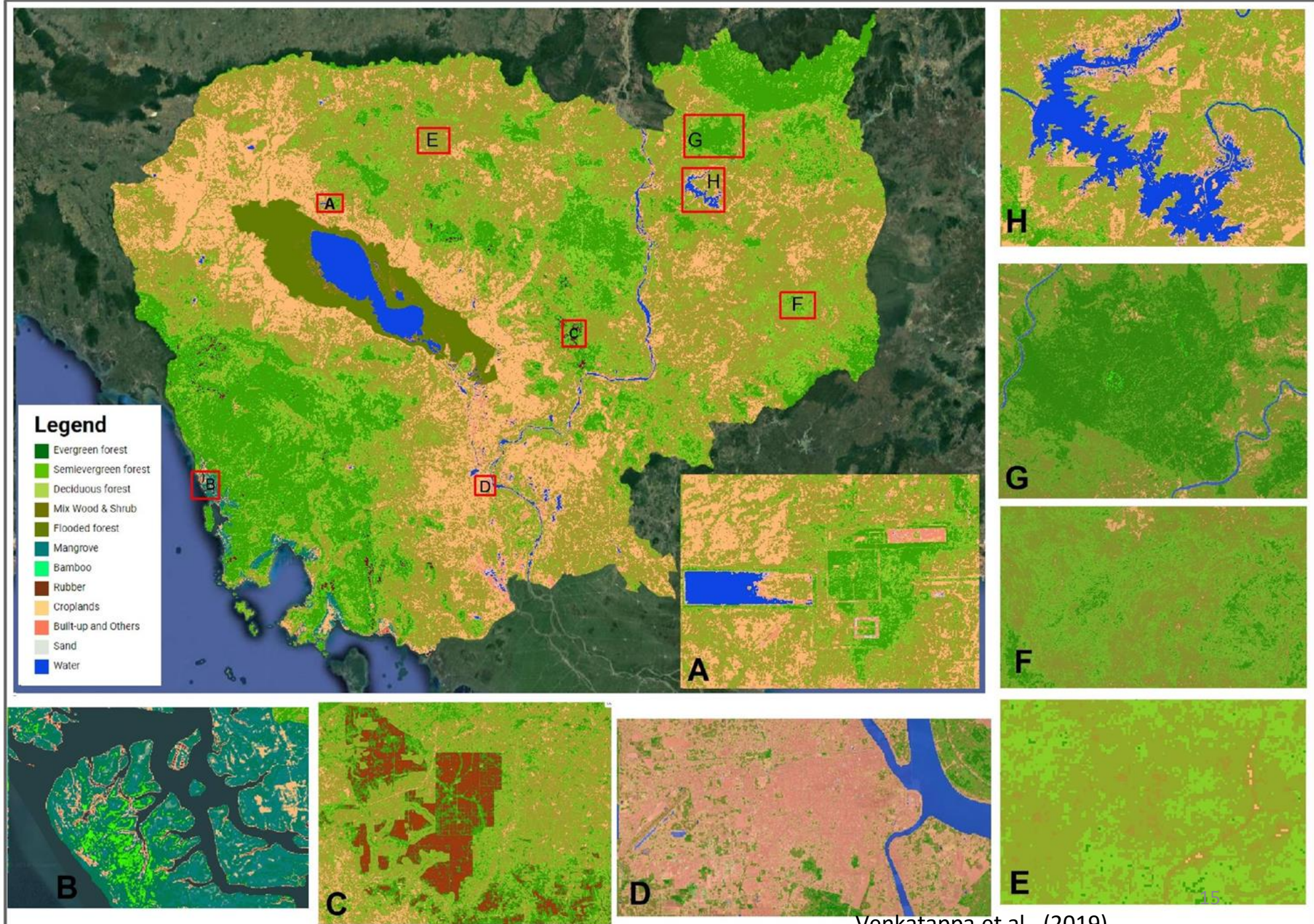
Using Thresholds for Land cover Mapping

(Landsat TM Collections in 2000 and GEE)



Using Thresholds for Land cover Mapping

(Landsat 8 Collections in 2018 and GEE)



Accuracy Assessment and Validation using VHR Imagery

(a) 2018 and 2000 Assessment VHR Reference Class (Total Reference points 355)

2018 Classified Class	EG	SE	DD	Mix WS	FF	MG	BB	RB	CR	BT	SL	WA	User's accuracy
EG	50	2			2	2	1	2					84.7%
SE	3	31	1	1	2	1		1					77.5%
DD			38						1				95.1%
Mix WS		1	2	41	1				1				89.1%
FF					10	1							90.9%
MG					1	20							95.2%
BB	1						25	1					92.6%
RB							2	14					87.5%
CR			1	2					54	1			93.1%
BT									1	4			80.0%

Overall Accuracy 89.58%

Kappa 0.88

2000 Classified Class	EG	SE	DD	Mix WS	FF	MG	BB	RB	CR	BT	SL	WA	User's accuracy
EG	47	9			2						1		100%
SE	2	40	1		2	1	1	7				10	100%
DD			75	1									100%
Mix WS	1	1	3	35					2				83.3%
FF					3	8							84.6%
MG					1	8							88.9%
BB	2	1					29	2					85.3%
RB							2	14					87.5%
CR				2					19				90.5%
BT									1	6			85.7%
SL										1	3		75.0%
WA												16	100%

Overall Accuracy 87.89%

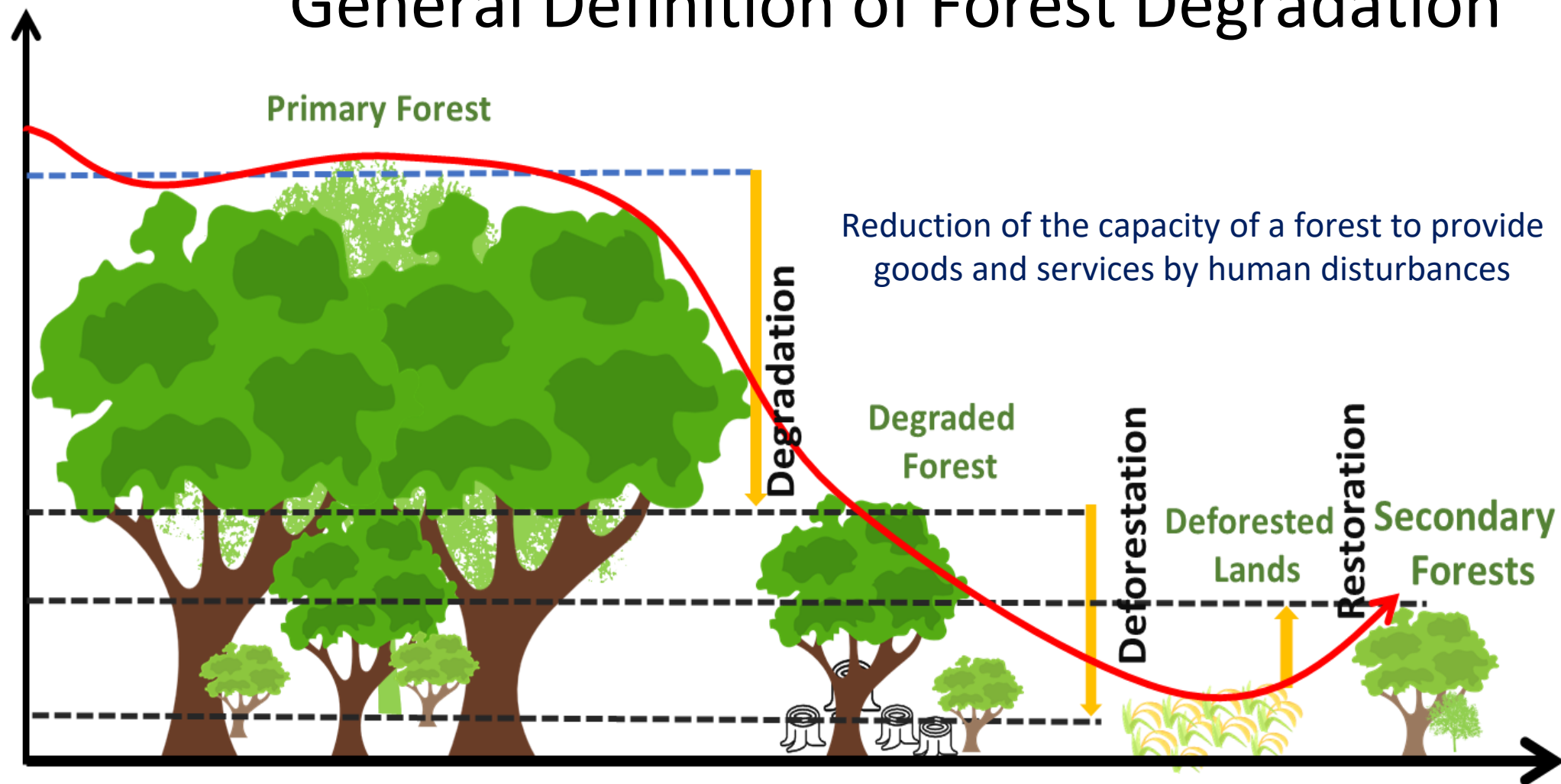
Kappa 0.86

Identification of the Potential Degraded Forest Lands for Restoration

An inclusive, potential degraded forest land restoration approach that can help reverse forest land degradation, increase carbon storage, conserve biodiversity and create sustainable livelihoods for local communities



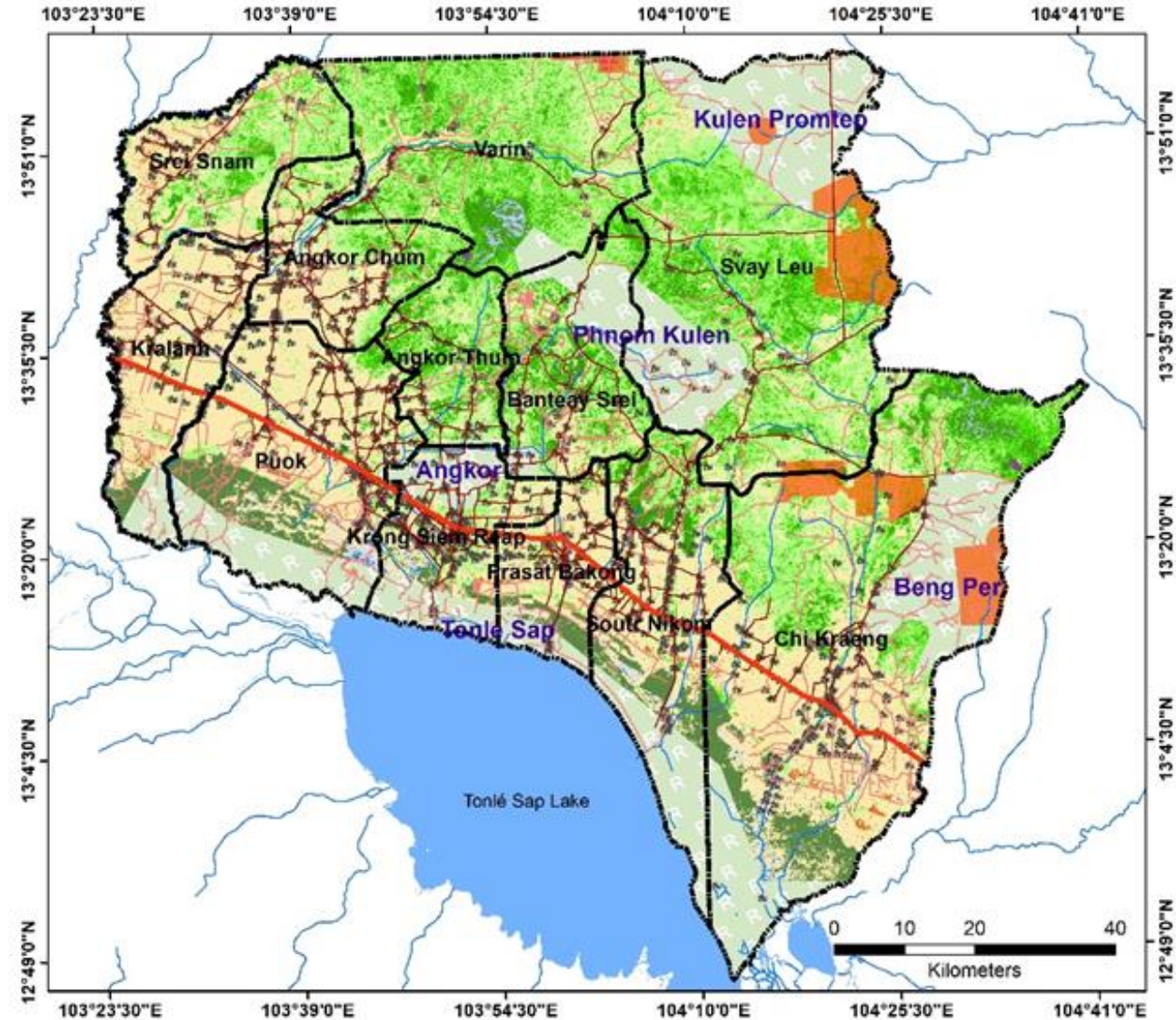
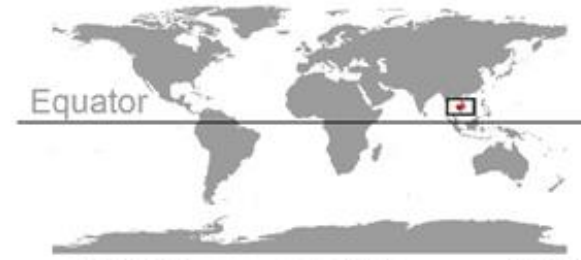
General Definition of Forest Degradation



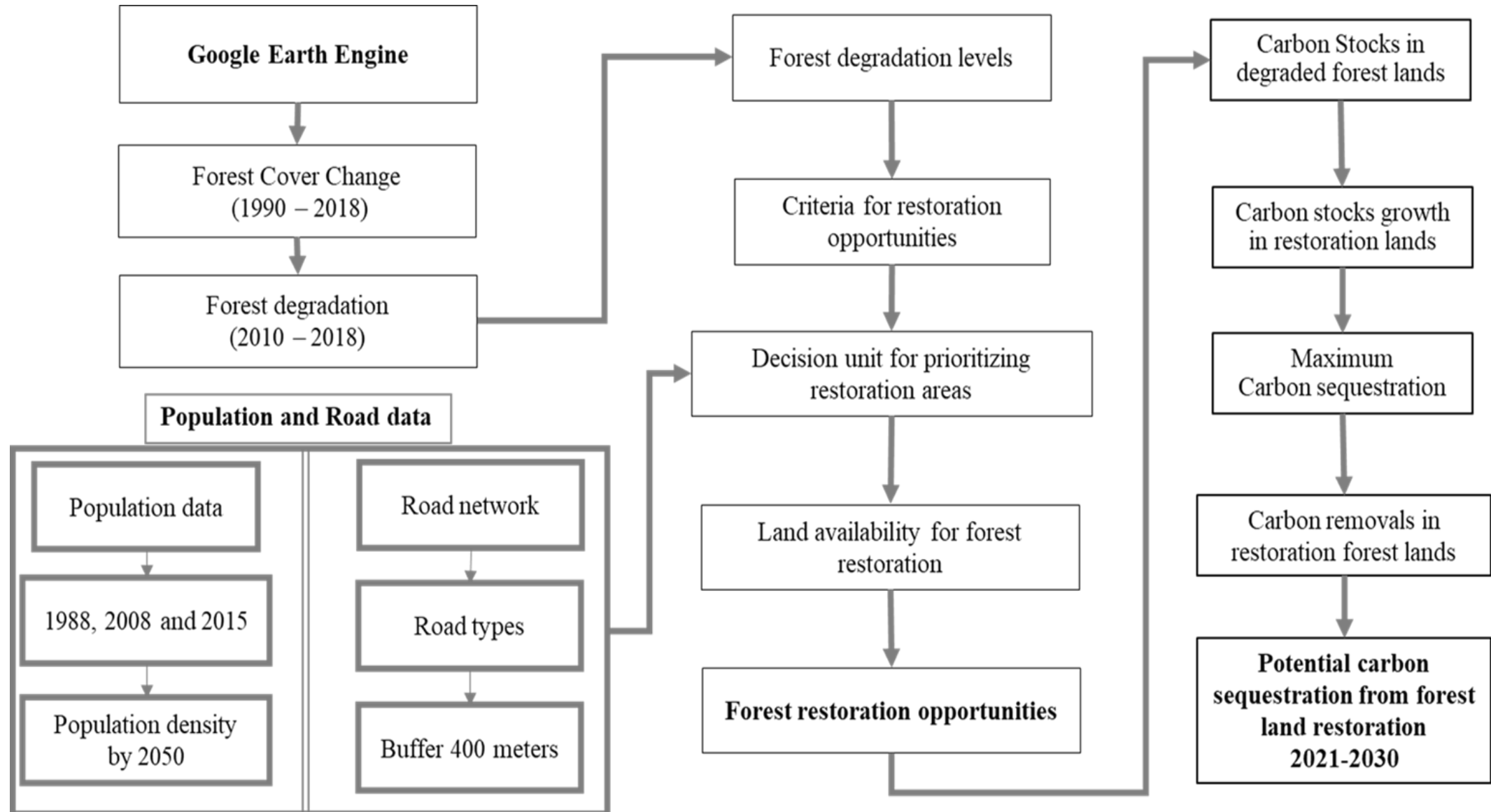
Tropical forests are degraded in a way that reduces tree cover and carbon stocks through the removal of trees or woody (e.g., logging or infrastructure construction, shifting cultivation, and harvesting tree for charcoal production) or through the collection of non-timber forest products.



Siem Reap Province, Cambodia



Potential Degraded Forests for Restoration (PDFR)



Carbon Stocks and Sequestration in Degraded Forest Lands

(Sasaki, 2021; Sasaki et al., 2016).

$$\dot{CS}_i(t) = \frac{CS_{MAX,i} \times CS_i(0) \times e^{r_i \times t}}{CS_{MAX,i} + CS_i(0) \times (e^{r_i \times t} - 1)} \quad (1)$$

where,

$CS_i(t)$: Carbon stocks of the degraded forests i at time t (MgC ha^{-1}),

$CS_i(0)$: Initial carbon stocks of the degraded forests i in t (MgC ha^{-1})

$C_{MAX,i}$ = Maximum carbon stocks a restored forest can reach;

r_i = growth rate of degraded forest i (%).

Total carbon stocks in the restored forests over time can be derived by:

$$TCS_i(t) = PDFR_i \times CS_i(t) \quad (2)$$

Where

$TCS_i(t)$: Total carbon stocks in degraded forests i at time t (MgC year^{-1})

$PDFR_i$: Area of the PDFR i (ha)

Carbon sequestration or removals due to forest restoration can be obtained by:

$$CSS_i(t) = (TCS_i(t_2)) - (TCS_i(t_1)) \times \frac{44}{12} \quad (3)$$

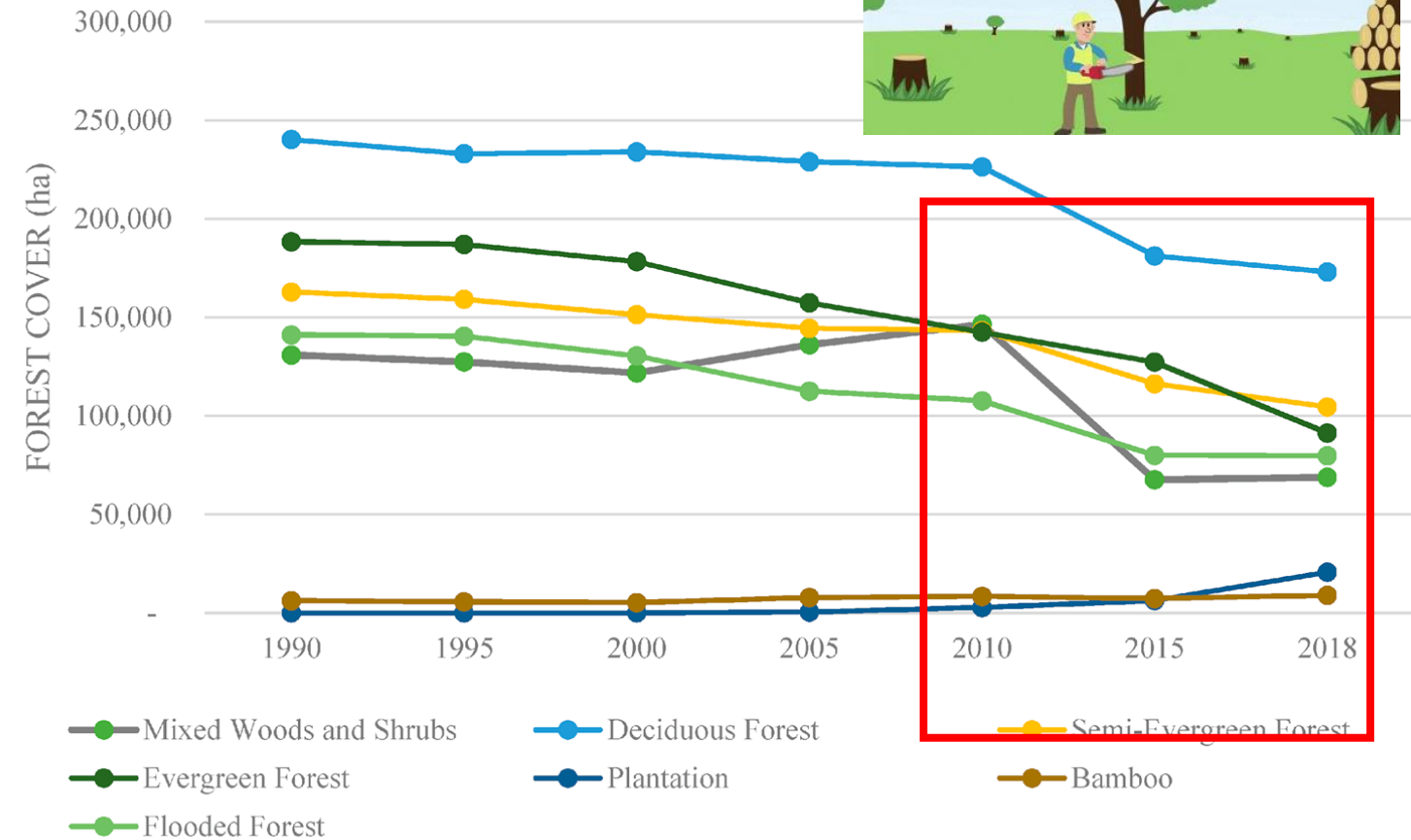
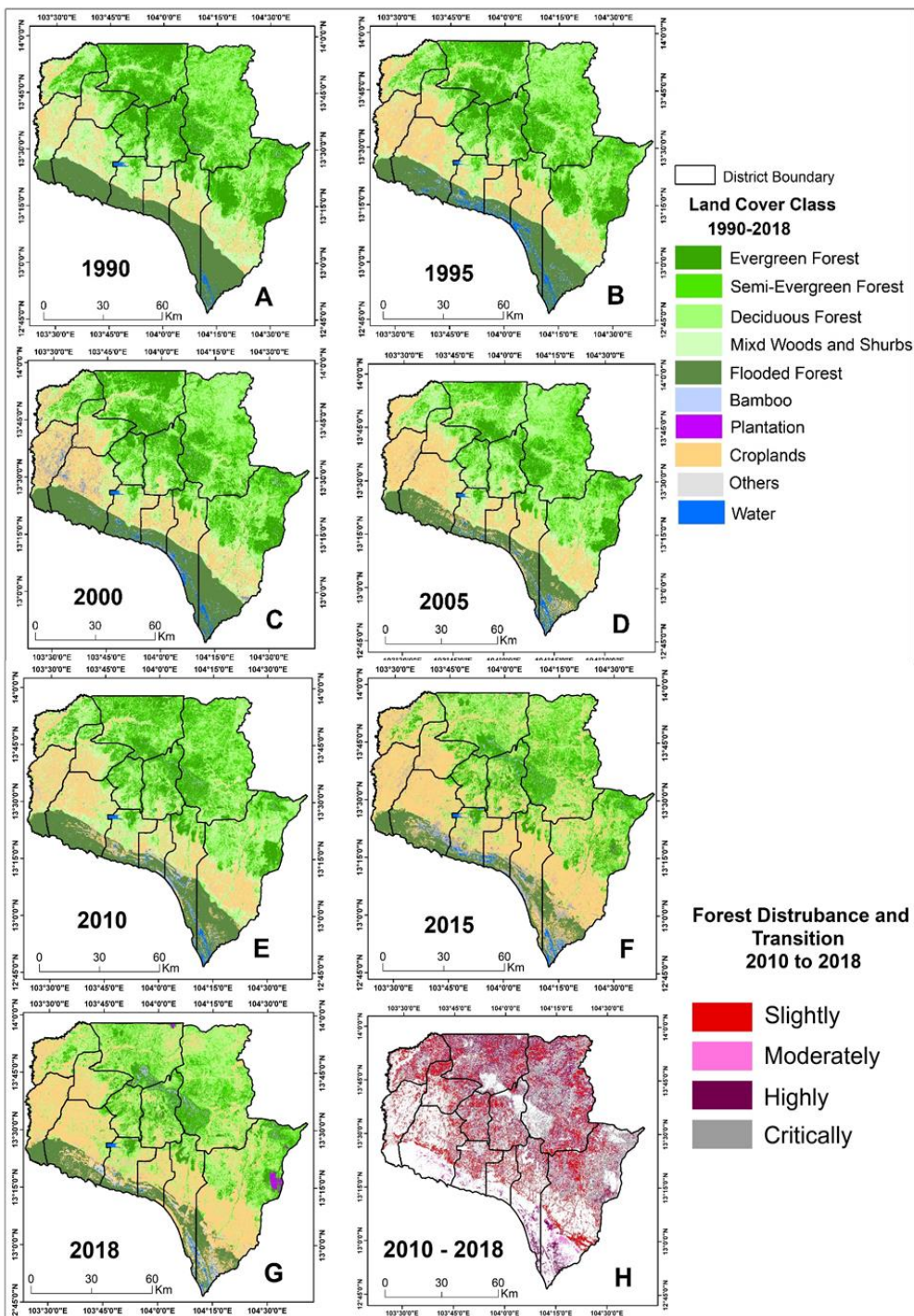
Where

$CSS_i(t)$: Carbon sequestration (removals) in degraded forest i at time t ($\text{MgCO}_{2e} \text{ year}^{-1}$)

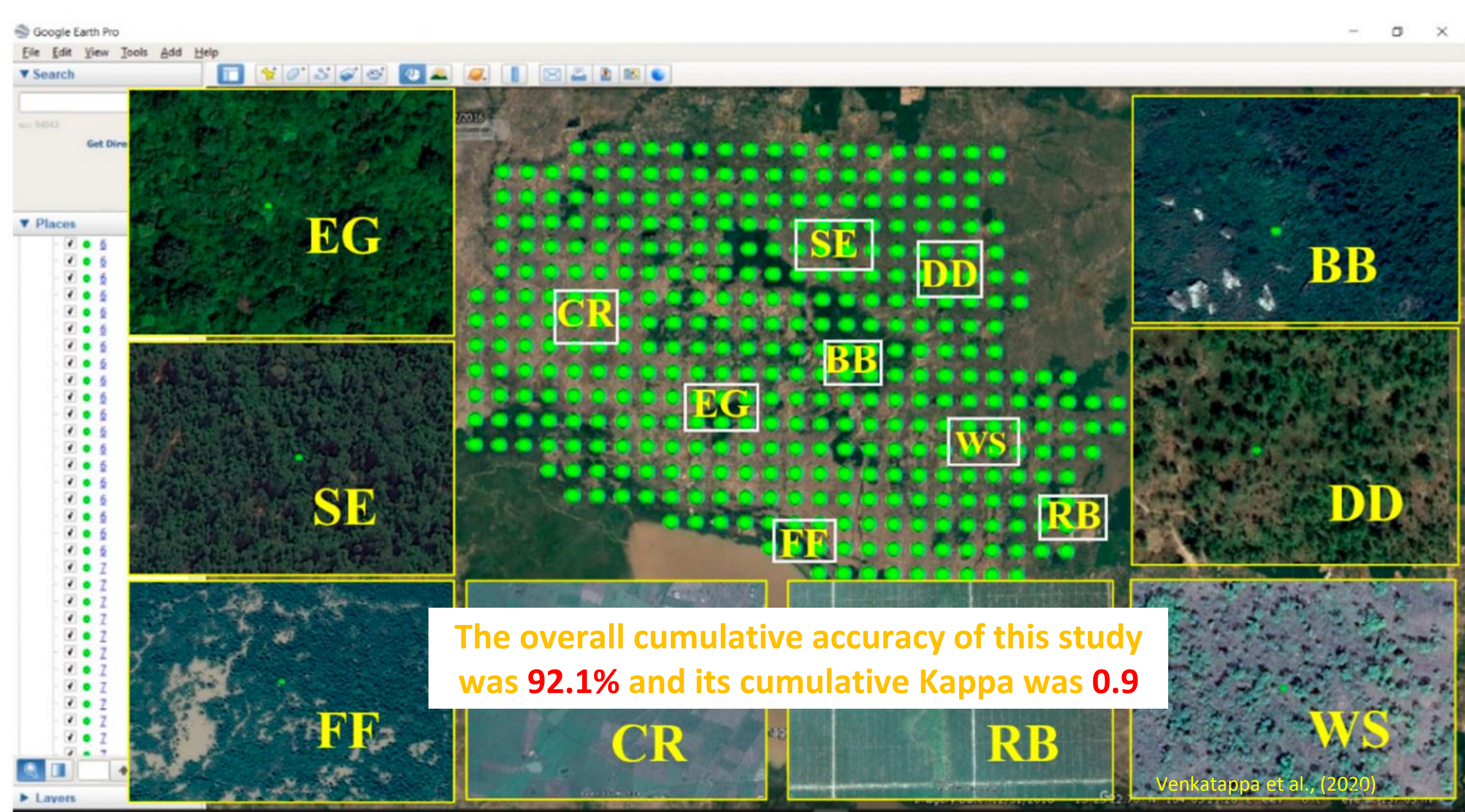
44/12 is the molecular weight of CO_2 over carbon

t_2 and t_1 is the different time intervals to base for calculation of carbon sequestration (year)

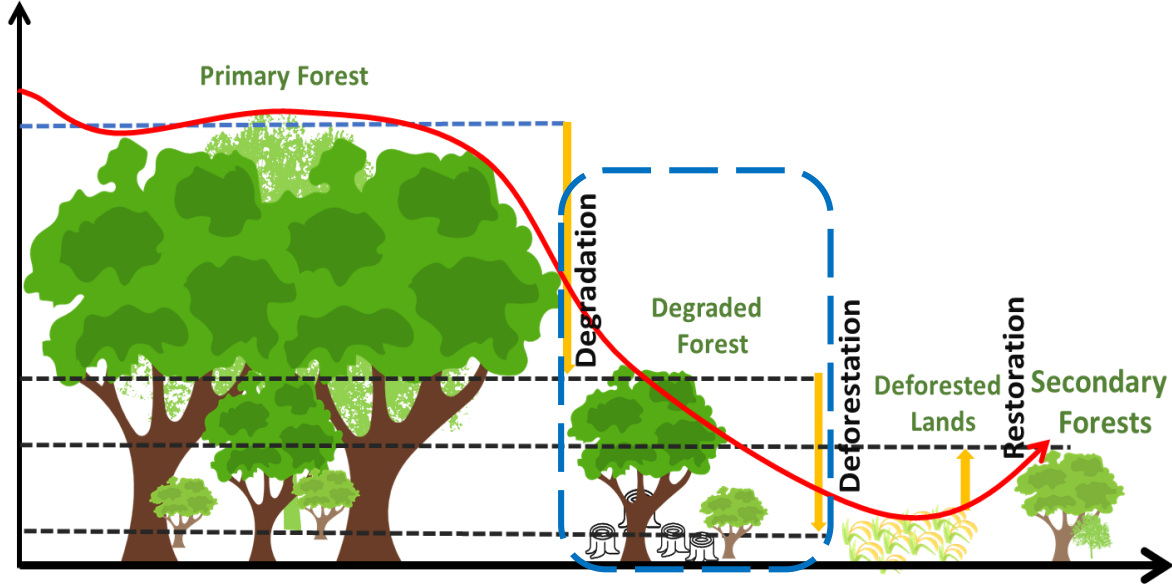
Siem Reap Forest Cover Change from 1990 to 2018



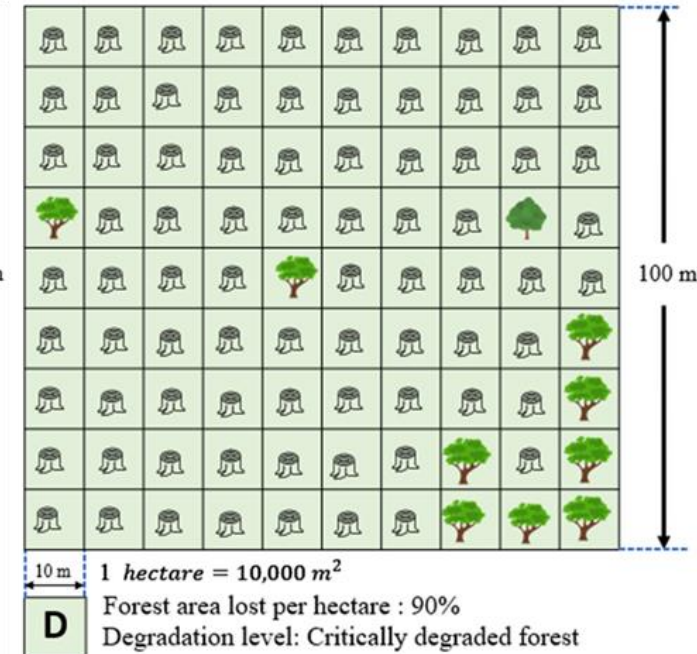
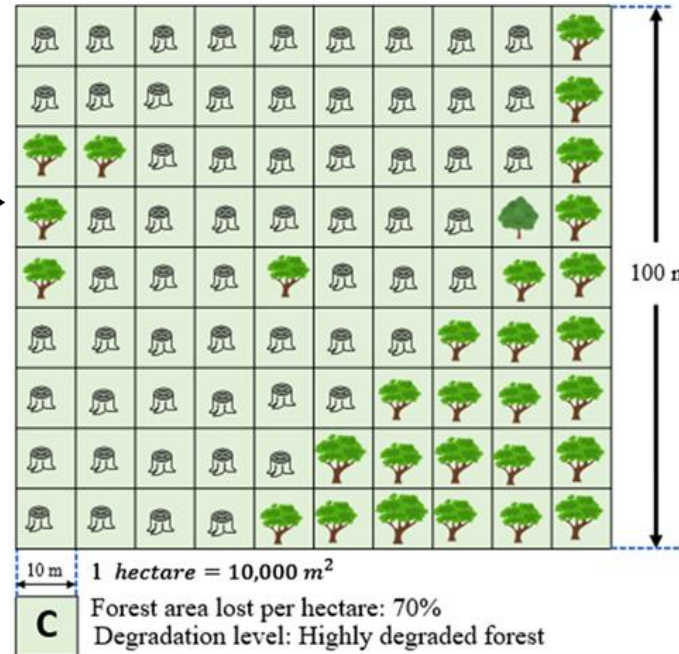
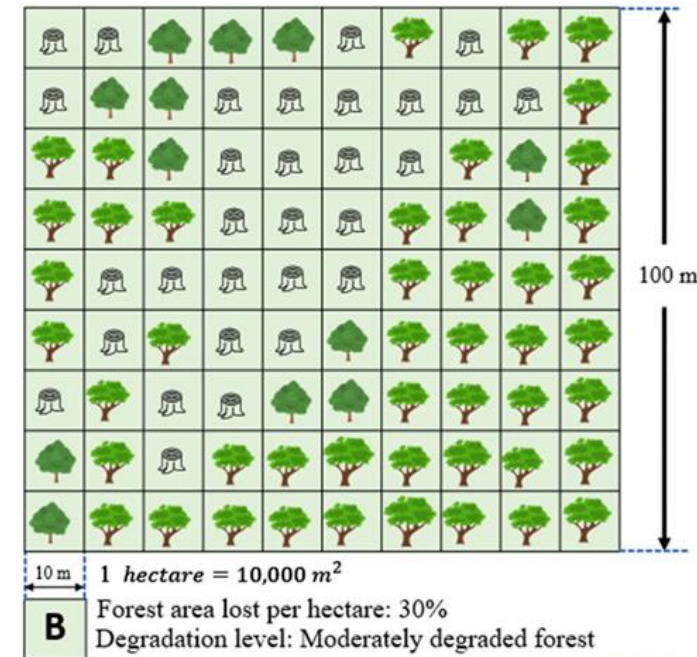
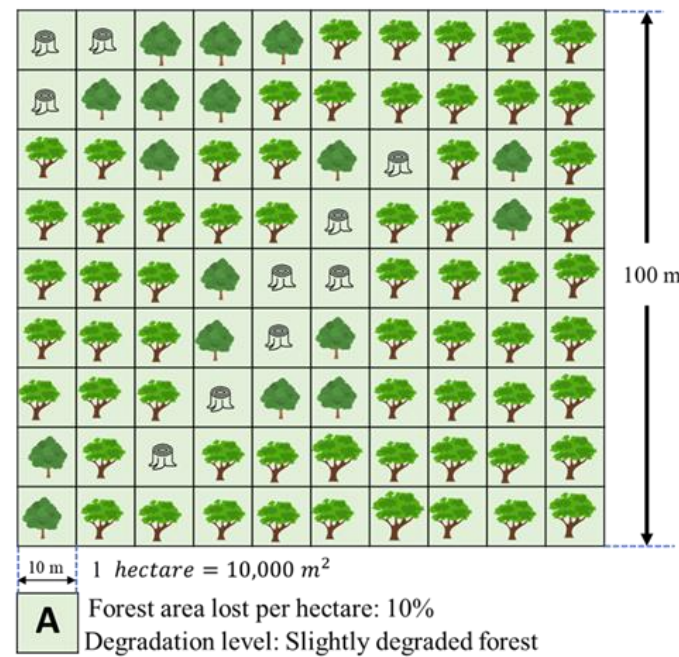
Technical details, please refer to Venkatappa et al., (2020),
<https://doi.org/10.3390/rs12183110>



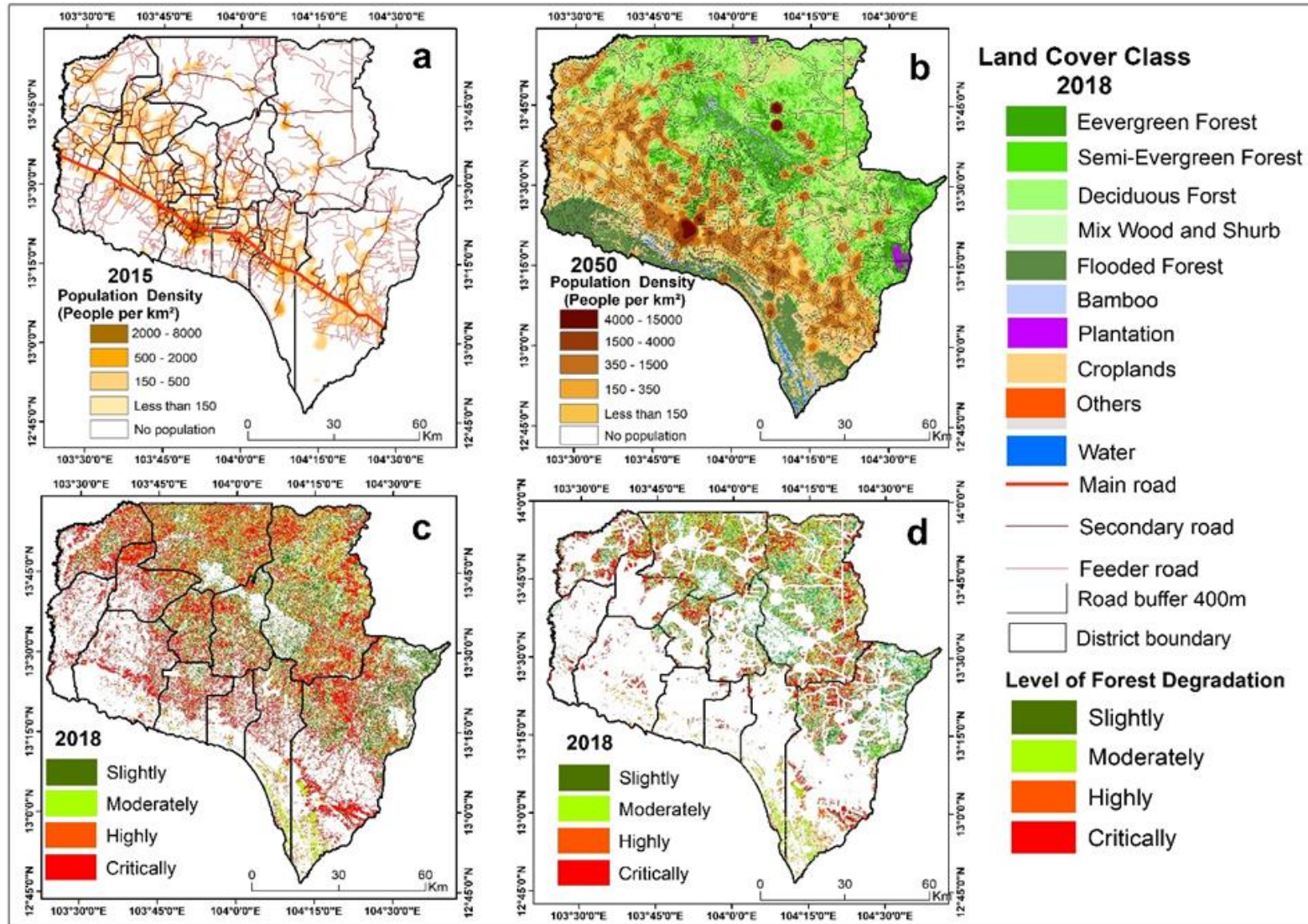
Forest Degradation Levels



- However, still considered as a forest in the « legal » sense
- Action that reverse degradation to restoration



Forest transition and level of forest degradation



Note

a Population density and road network data.

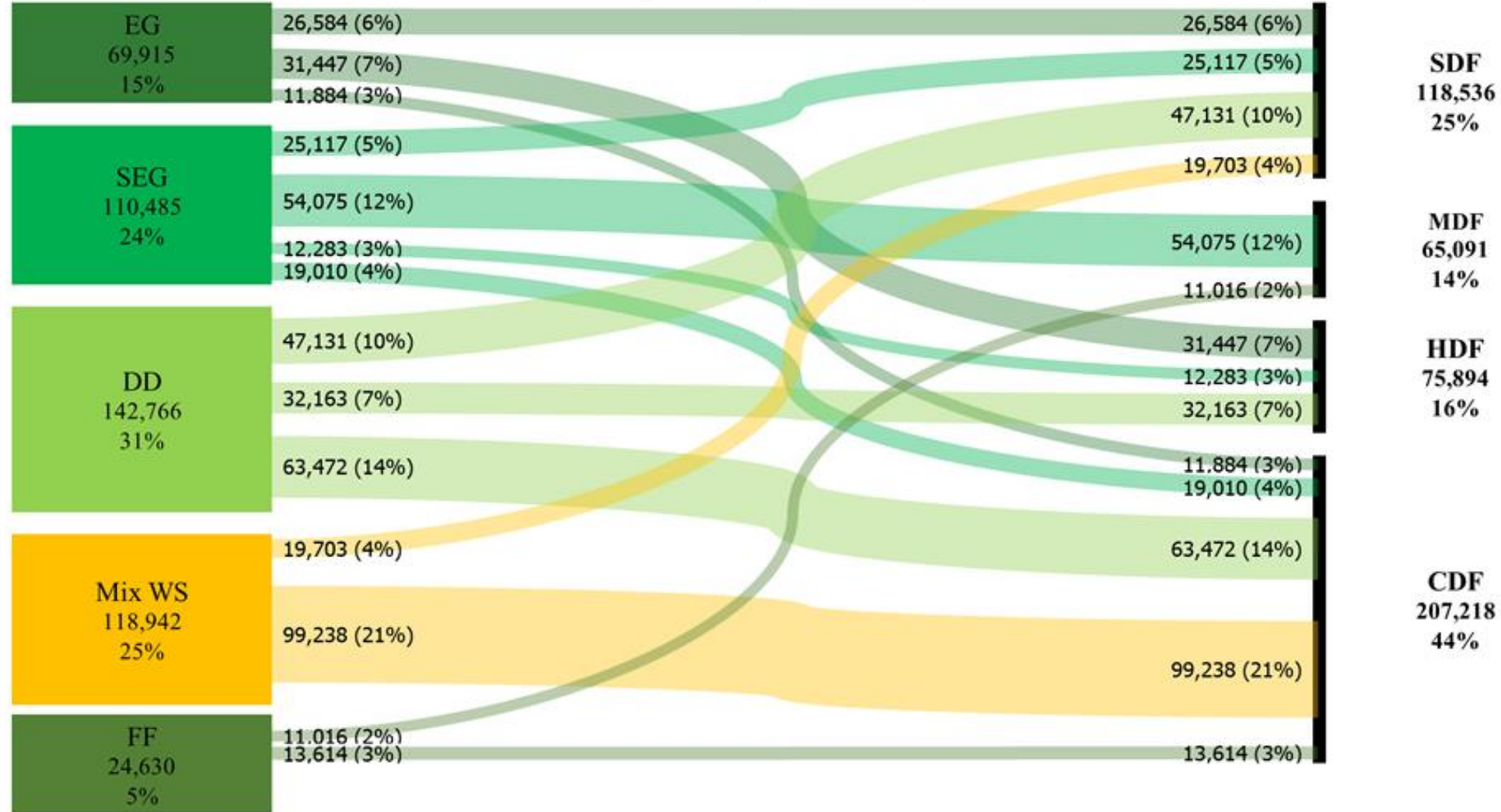
b Forest cover in 2018 and predicted population density.

c Forest degradation levels before the PDFR framework.

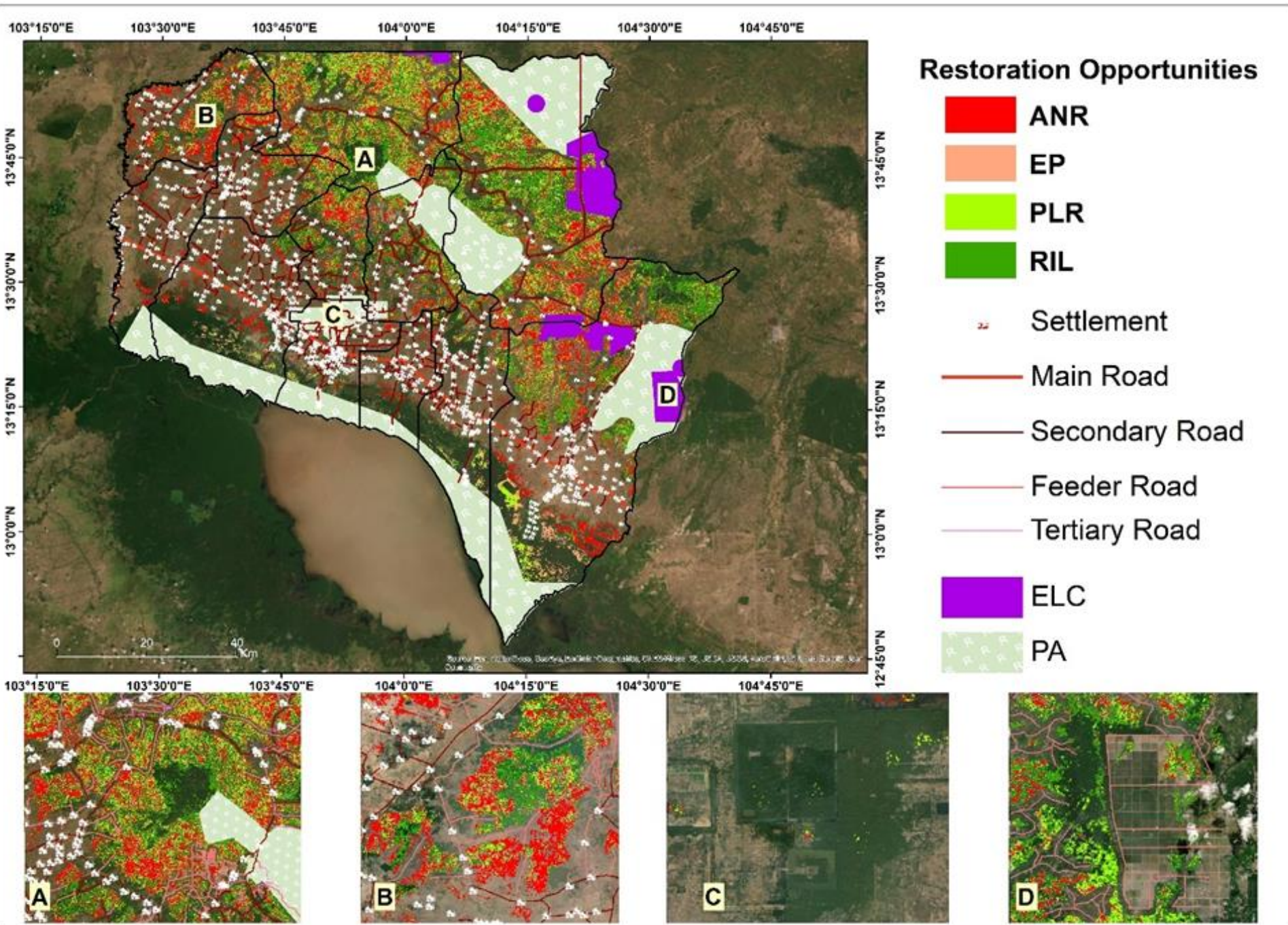
d the level of forest degradation after PDFR framework and recommended areas for restoration to achieve the maximum carbon stocks.

Forests Degradation

Forest degradation | Total = 466,738 ha



Forest degradation, based on the percentage of the forest degradation per hectare across five forest categories. The four levels of degradation categories are Slightly degraded forest (SDF), Moderately degraded forest (MDF), Highly degraded forest (HDF), Critically degraded Forest (CDF).



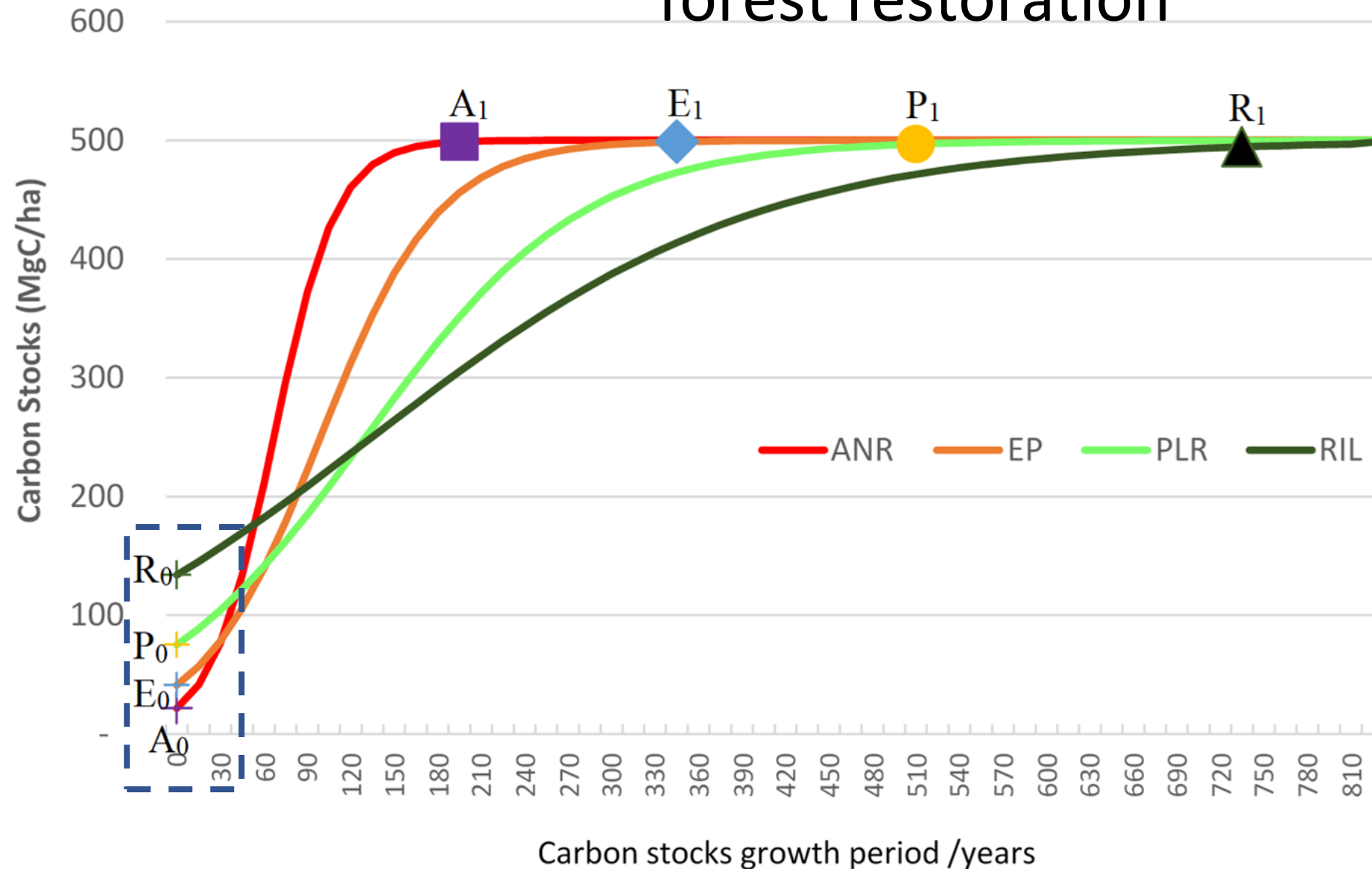
Prioritized
areas for
forest
restorations

Available forest land for restoration and conservative estimated cost in Siem Reap province.

Degraded Forests by Levels	Restoration Strategies	PDFR	
		Forest Area (ha)	Costs (US\$ Millions) US\$ 2000 per hectare
Critically degraded Forest	Assisted natural regeneration	96,693	193.39
Highly degraded forest	Enrichment planting	48,878	97.76
Moderately degraded forest	Preventing logging reentries	46,487	92.97
Slightly degraded forest	Reduced impact logging	75,567	151.13
	Total	267,625	535.25

Lof et al. (2019)

Potential carbon sequestration or removals through forest restoration

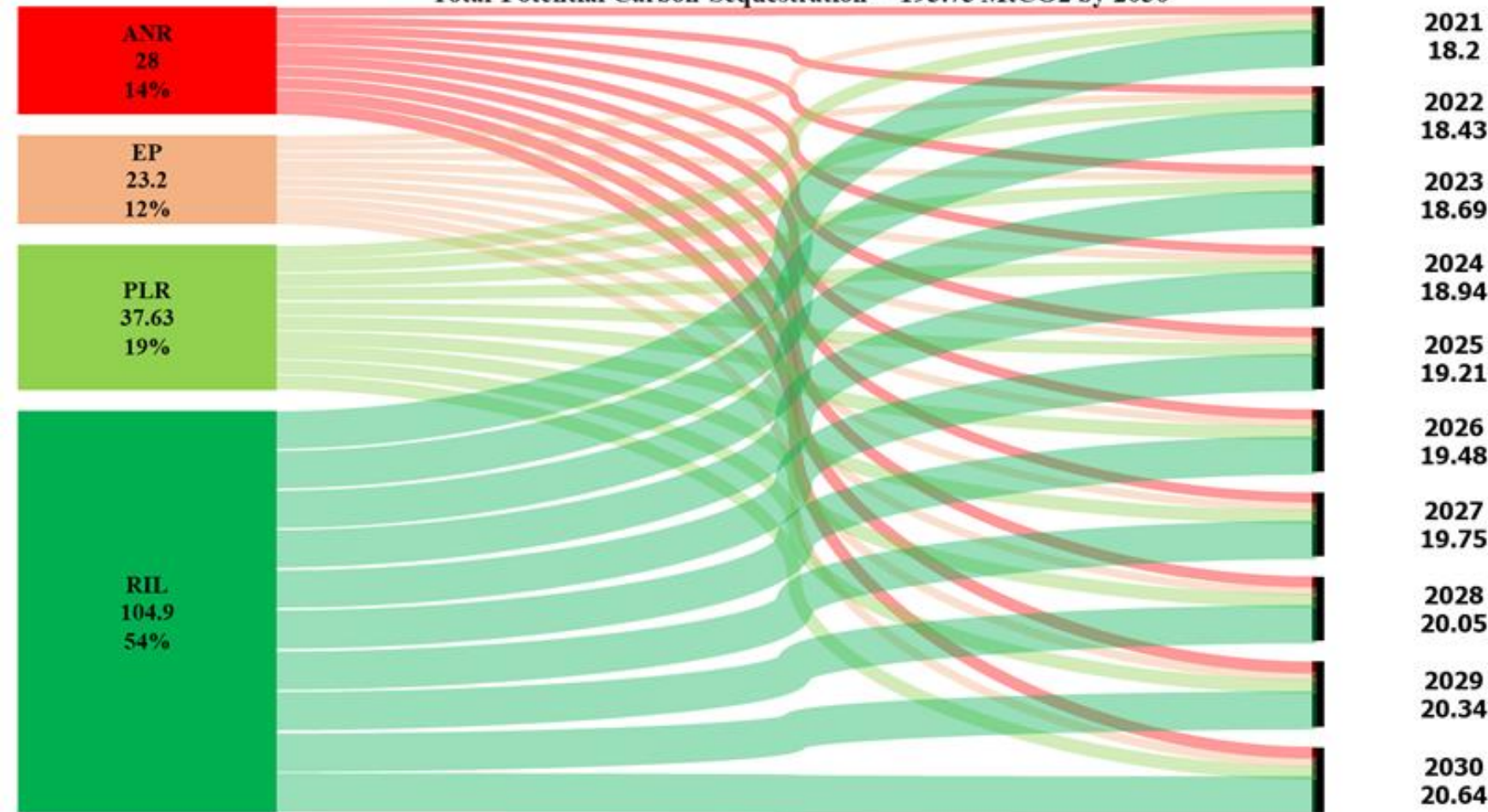


Note:

- A = ANR curve represents achieving the maximum carbon stocks and time in assisted naturally regenerated restoration approach,
- E = EP for enrichment planting,
- P = PLR for the preventing logging reentries and
- R = RIL for reducing impact logging.

Potential carbon sequestration /removals and benefits

Total Potential Carbon Sequestration = 193.73 MtCO₂ by 2030

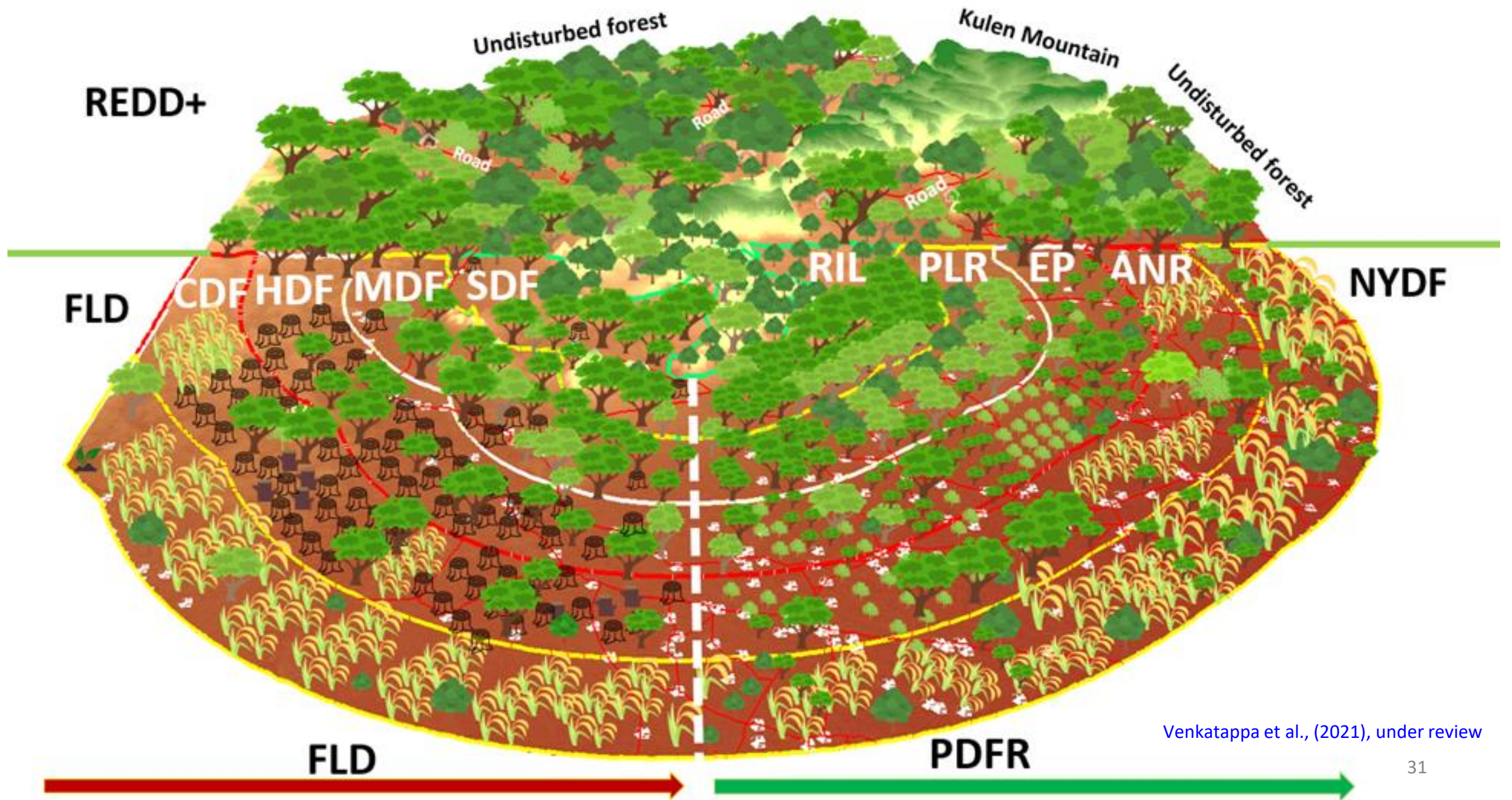


Benefits

- China Emissions Trading Systems (ETS) **US\$ 837 M** at the rate of US\$ 4.32 MgCO₂⁻¹,
- Voluntary market **US\$ 1,937 M** at US\$ 10 MgCO₂⁻¹,
- UK carbon price support **US\$ 4,804 M** at US\$24.8 MgCO₂⁻¹,
- Netherlands Carbon Tax **US\$ 6,827 M** at US\$ 35.24 MgCO₂⁻¹,
- EU ETS **US\$ 9,644M** at US\$49.78 MgCO₂⁻¹ and
- Sweden Carbon Tax about **US\$ 26,587 M** at US\$ 137.24 MgCO₂⁻¹.

Note: ANR = assisted naturally regenerated restoration, EP = enrichment planting, PLR = preventing logging reentries and RIL = reducing impact logging.

Strategies for New York declaration on Forests Restoration



Bring Home message

- Google Earth Engine (GEE) is open-source platform capable of assessing land cover changes at scale but yet it requires minimum kills and at no cost.
- Depending on levels of the degradation, we could also propose the restoration strategies to ensure the high success of the restoration. Accordingly, we estimated the costs for forest restoration and the related carbon sequestration and revenues.
- Our novel PDFR approach makes it possible to identify the degraded forests in the tropics at scale.
- With the increasing data availability such as population distribution, road networks as well as earth data and cloud-computing technologies, our PDFR approach could become a useful tool to assist the large-scale forest restoration planning on automation.
- The PDFR approach could also contribute to the achievement the NYDF goals 1 and 5 by 2030.
- The PDFR approach may also be used to facilitate the monitoring, reporting, and verifying activities as required under the REDD+ scheme of the UNFCCC.
- Nevertheless, the applications of PDFR to different locations, regions or countries would need to customize the forest categories as such categories would be different from one location to another.
- Study on costs would also provide the better-informed information for effective prioritization of the restoration locations, especially when budget is limited.



THANK YOU

Plant a TREE Save the FUTURE

We provides data-driven solutions for addressing the environmental and social problems at speed and scales.

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