SURVEY OF BIOMASS, CARBON STOCKS, BIODIVERSITY, AND ASSESSMENT OF THE HISTORIC FIRE REGIME FOR INTEGRATION INTO A FOREST MONITORING SYSTEM IN SOUTH SUMATRA, INDONESIA

Aboveground biomass and tree community composition modelling

Work Package 3

BIOCLIME Workshop
Palembang 13 October 2016

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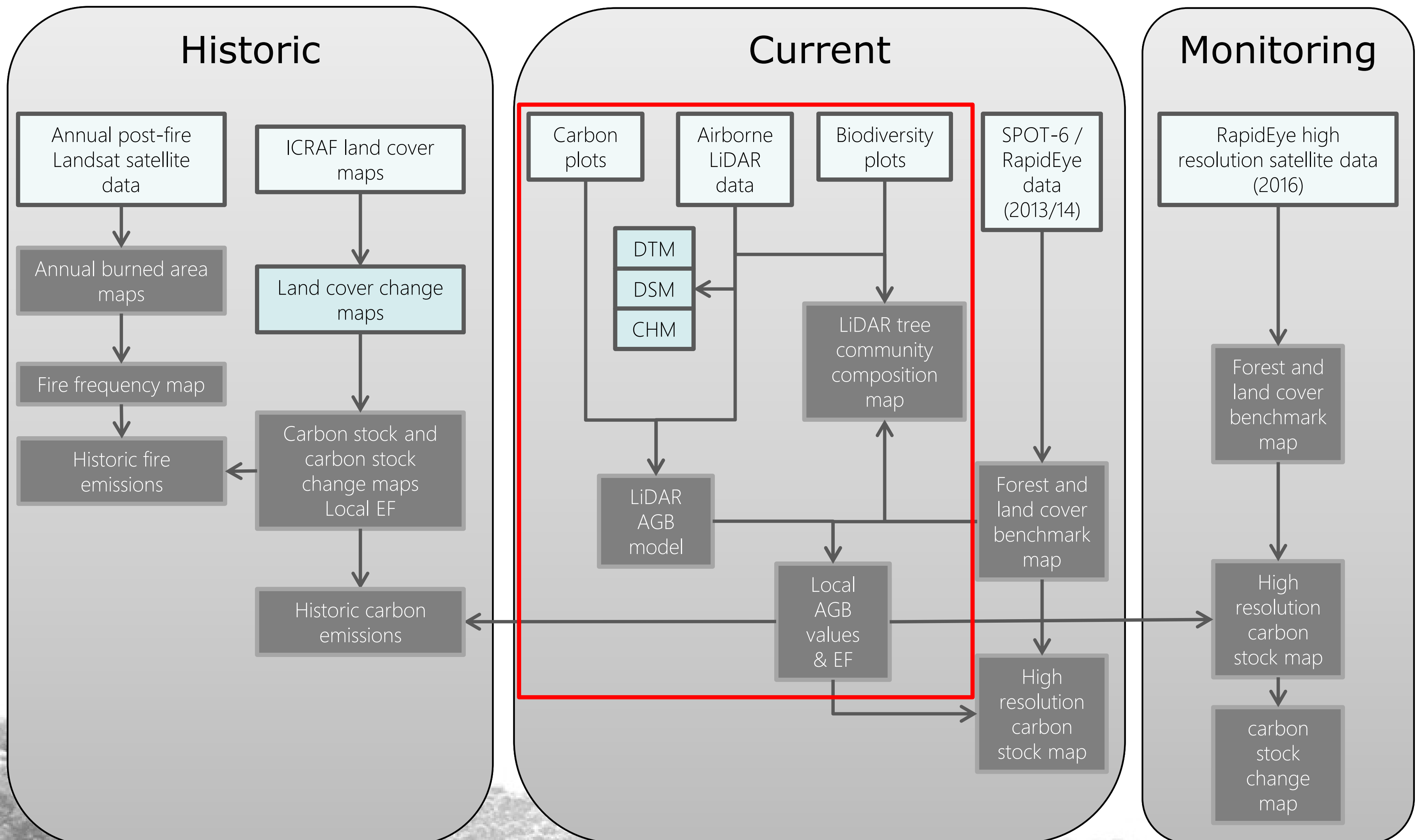
RSS Remote Sensing Solutions GmbH
Biodiversity and Climate Change Project

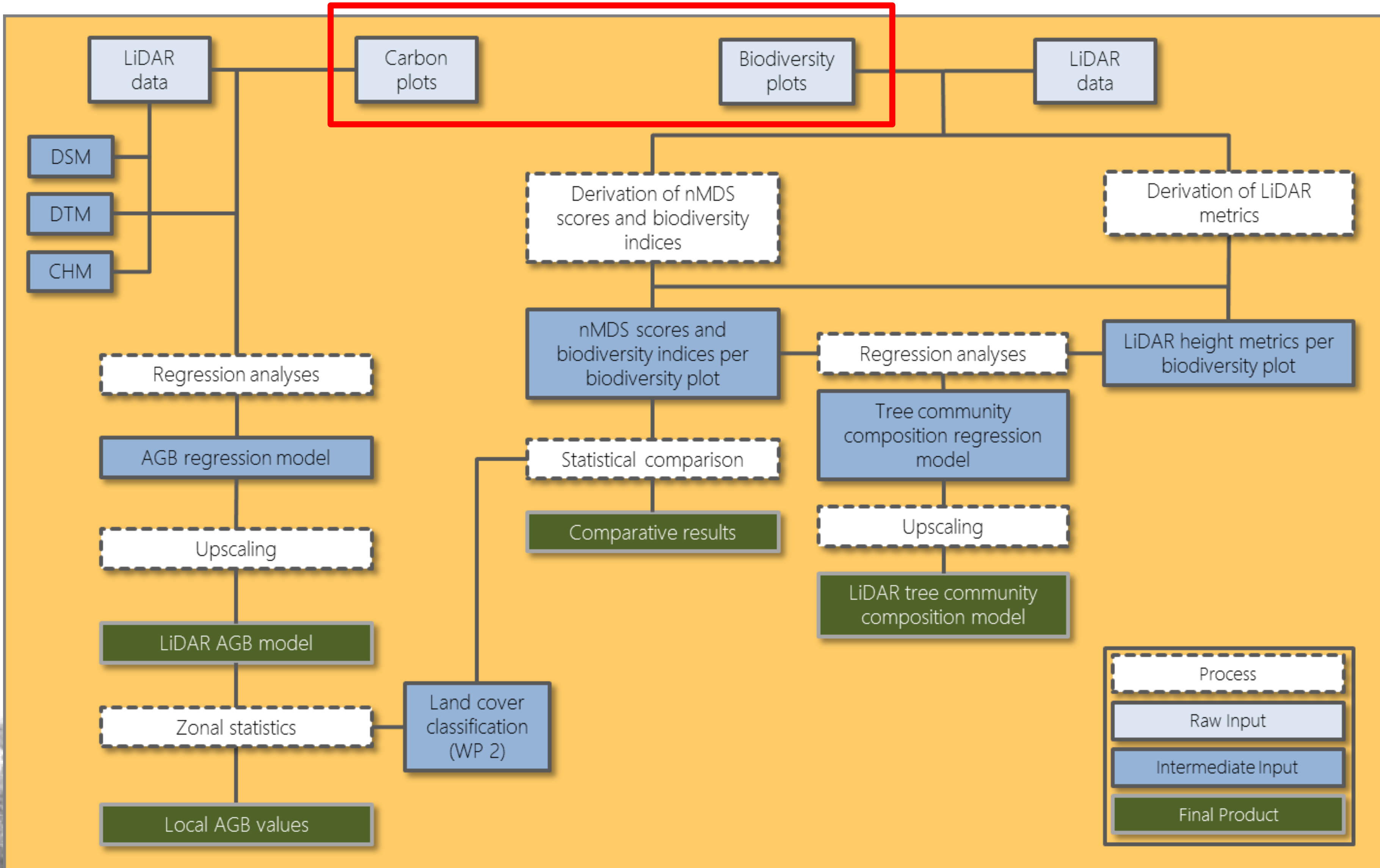
Concept of the monitoring system



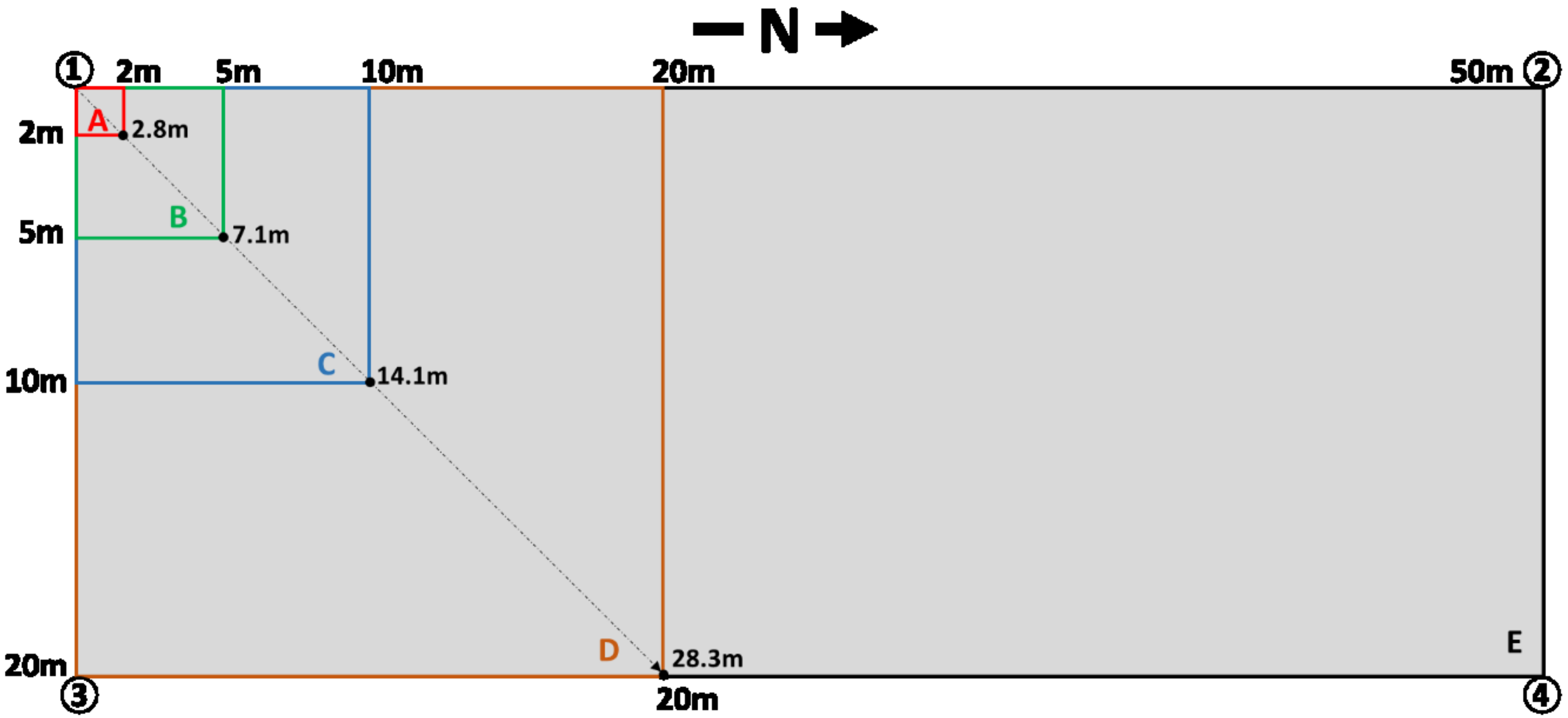
Objectives

- Filtering of the LiDAR 3D point clouds (acquired by Geosurvey) into vegetation and non-vegetation points
- Derive Digital Surface Models (DSM), Digital Terrain Models (DTM) and Canopy Height Models (CHM) from the airborne LiDAR data
- Advise BIOCLIME in the collection of forest inventory data to calibrate the LiDAR derived aboveground biomass model
- Derive an aboveground biomass model from the airborne LiDAR data in combination with forest inventory data (provided by the project)
- Deduce local aboveground biomass values for different vegetation classes from this LiDAR based aboveground biomass model
- Derive a tree community composition model of Lowland Dipterocarp Forest at various degradation stages from LiDAR data in combination with tree species/genera diversity data collected in the field (provided by the project)

Workflow

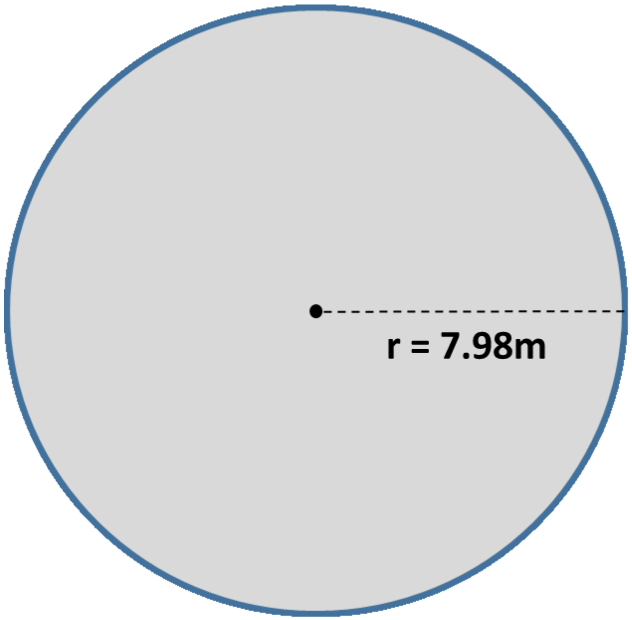

LiDAR data
Carbon plots
Biodiversity plots
LiDAR data
DSM
DTM
CHM
Derivation of nMDS scores and biodiversity indices
Derivation of LiDAR metrics
nMDS scores and biodiversity indices per biodiversity plot
Regression analyses
LiDAR height metrics per biodiversity plot
Regression analyses
Tree community composition regression model
AGB regression model
Statistical comparison
Comparative results
Upscaling
Upscaling
LiDAR tree community composition model
LiDAR AGB model
Zonal statistics
Land cover classification (WP 2)
Local AGB values
Process
Raw Input
Intermediate Input
Final Product

Carbon plot design: Forest

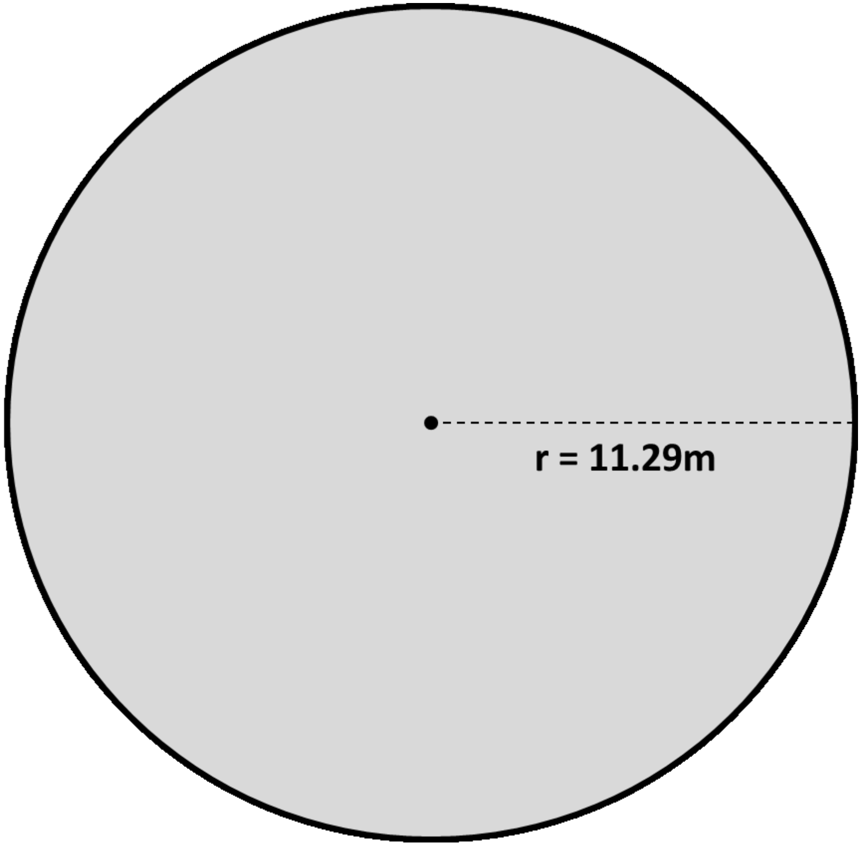


Subplot A: 2 x 2m (0.0004ha); seedlings, litter and undergrowth
Subplot B: 5 x 5m (0.0025ha); DBH 5-9cm
Subplot C: 10 x 10m (0.01ha); DBH 10-19cm
Subplot D: 20 x 20m (0.04ha); DBH 20-34cm
Subplot E: 20 x 50m (0.1ha); DBH ≥ 35cm

Carbon plot design: Plantation



age of plantation < 4 years
plot size = 0.02ha



age of plantation ≥ 4 years
plot size = 0.04ha

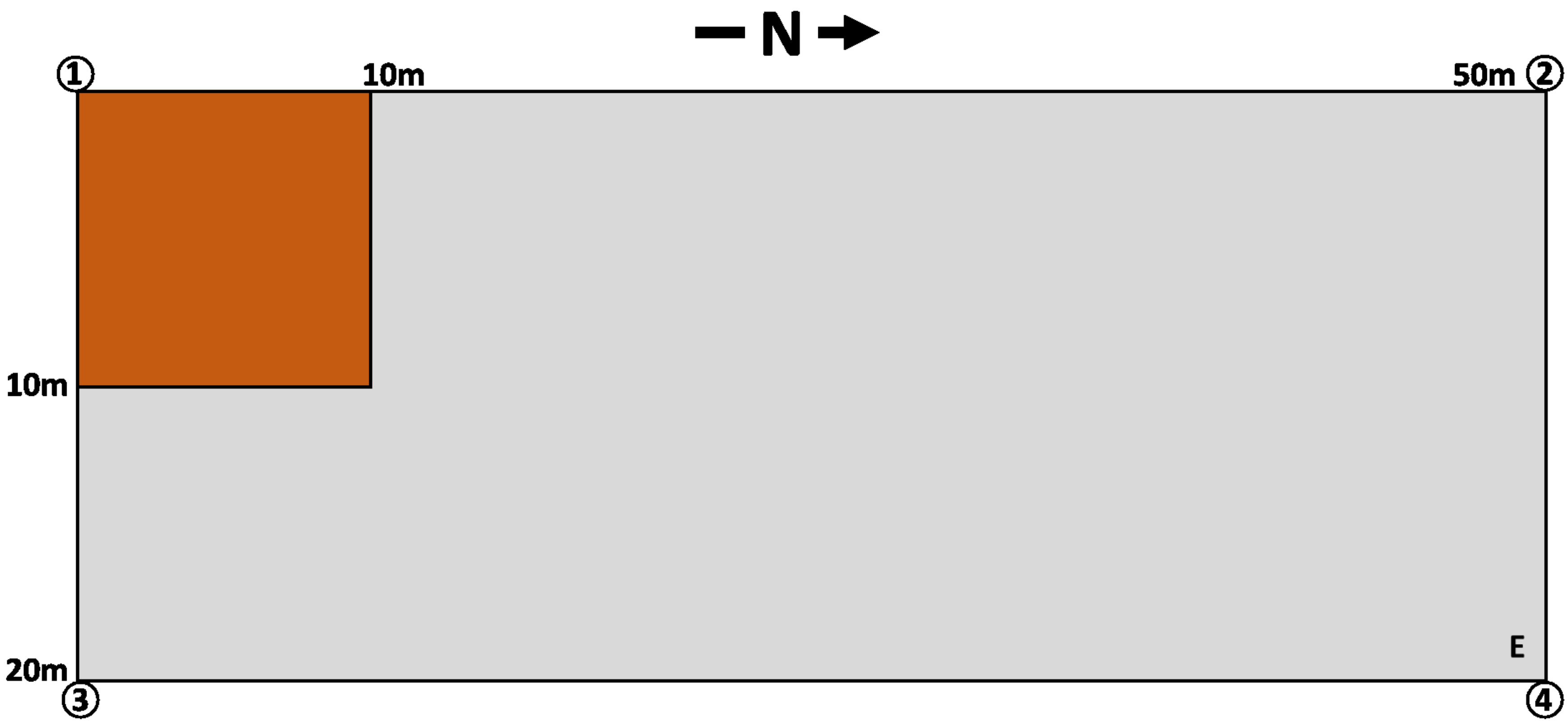
Carbon plot: Parameters recorded

- **Diameter at Breast Height** (DBH) at 1.3m above the ground (in cm)
- **Total tree height** (in m) measured with a Haga instrument or a Suunto clinometer
- **Tree species** (scientific name in Latin): All “in” trees were identified up to the species level by a trained botanist. This was necessary to determine wood densities. If it was not possible to identify up to the species level it was at least tried to record the genus or the family.
- **Four dead wood classes** (for the aboveground modelling estimates all dead trees were excluded)

➔ More information in the final report on the forest inventory:

Rusolono T., Tiryana T., Purwanto J. (2015). Panduan Survei Cadangan Karbon dan Keanekaragaman Hayati di Sumatera Selatan. Final Report. German International Cooperation (GIZ), Kementerian Lingkungan Hidup dan Kehutanan, Dinas Kehutanan Provinsi Sumatera Selatan.

Biodiversity plot design



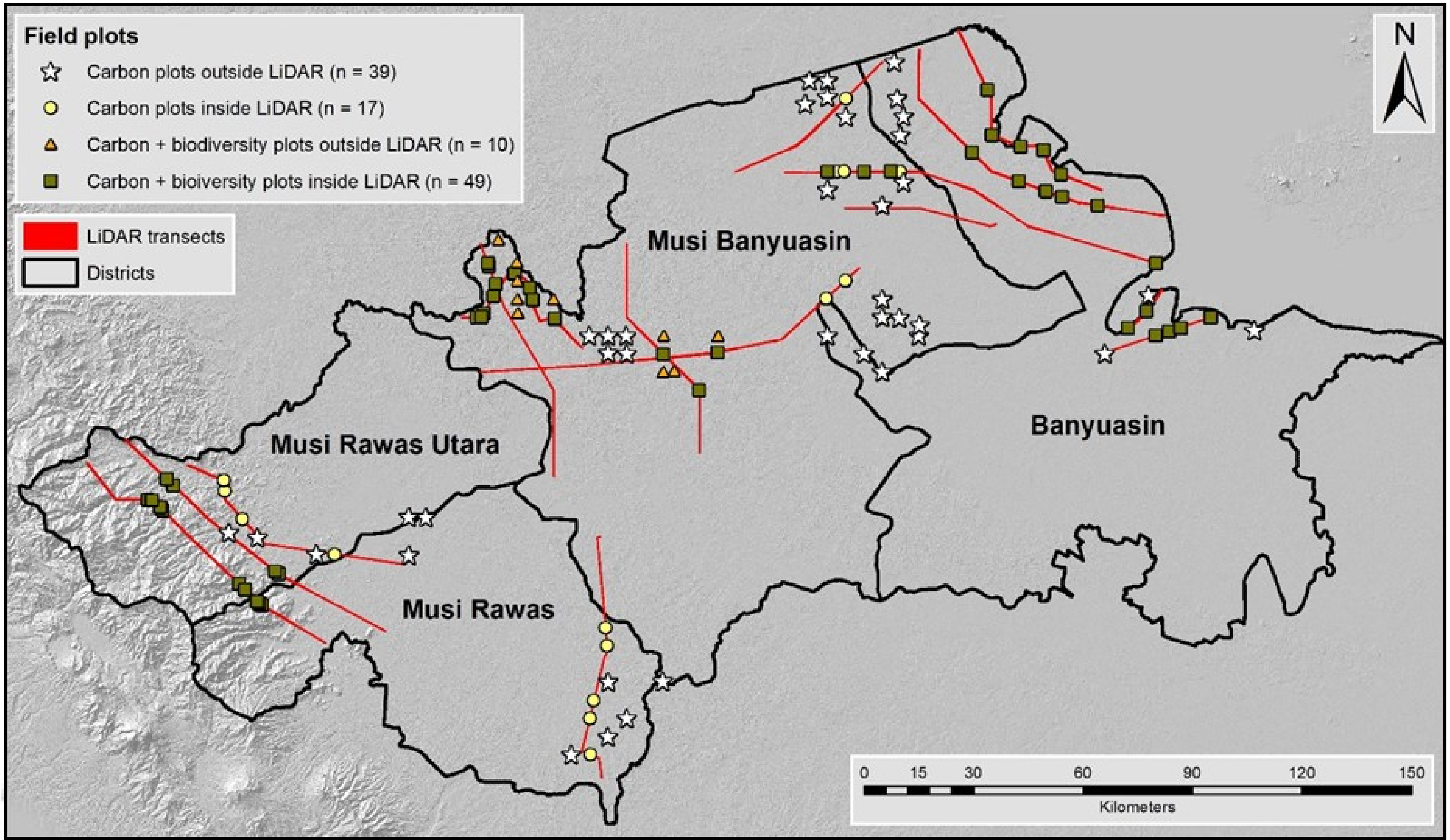
Small plot: 10 x 10m (0.01ha); DBH 5-10cm

Large plot E: 20 x 50m (0.1ha); DBH ≥ 10cm

Biodiversity plot: Parameters recorded

- **Spatial location** is exactly the same as the one of the respective carbon plot
- **Diameter at Breast Height** (DBH) at 1.3m above the ground (in cm)
- **Tree species** (scientific name in Latin): All “in” trees were identified up to the species level by a trained botanist. If it was not possible to identify up to the species level it was at least tried to record the genus or the family.

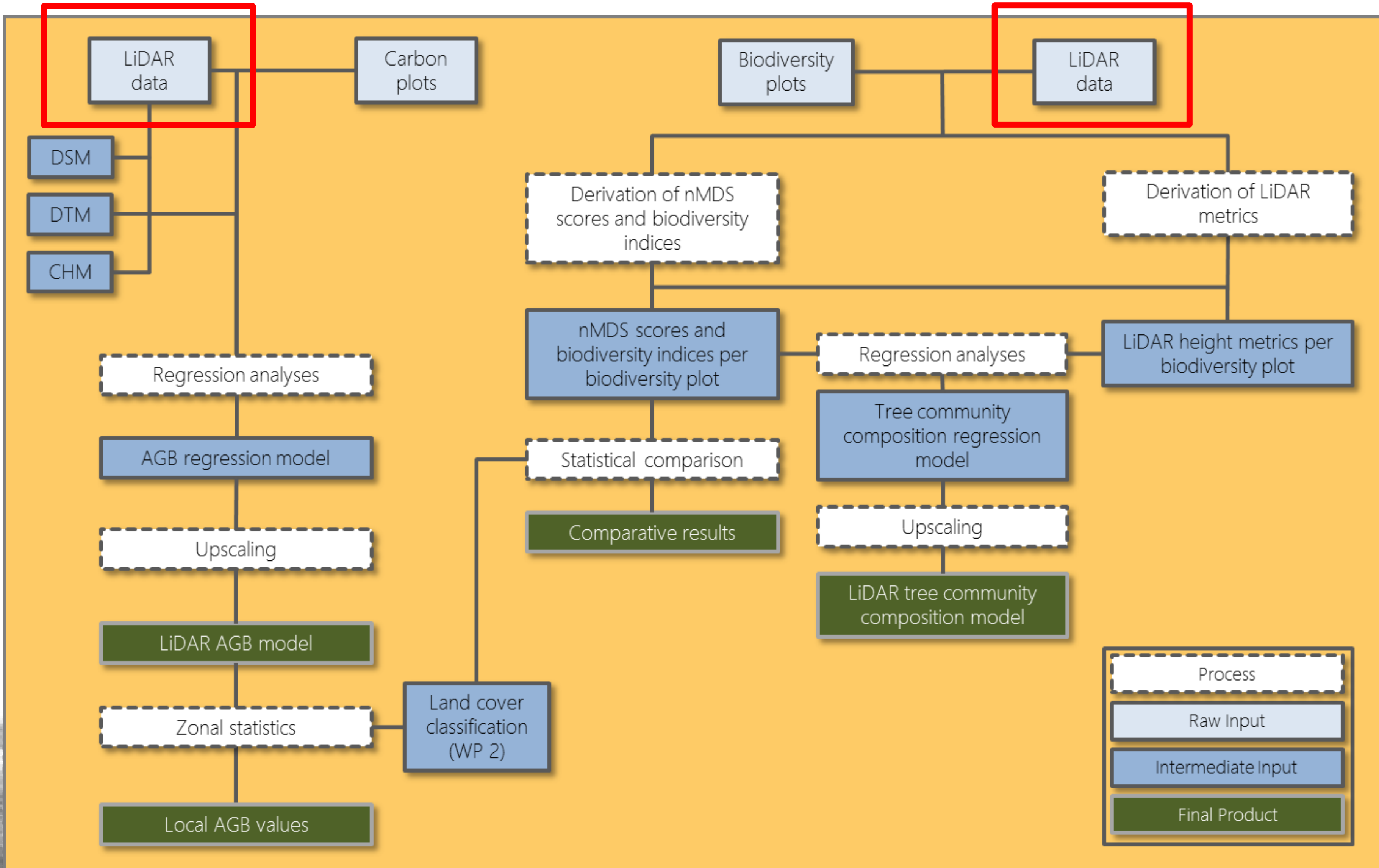
Overview carbon and biodiversity plots



Carbon plots	Biodiversity plots	Amount plots	Amount plots within LiDAR transects
X		56 (54[1])	17 (15[1])
X	X	59 (55[1])	49 (45[1])
	Sum	**115 (109[1])**	**66 (60[1])**

[1] Amount of plots after subtracting plots that were recorded after the fires of 2015

LiDAR data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LiDAR tree community composition model
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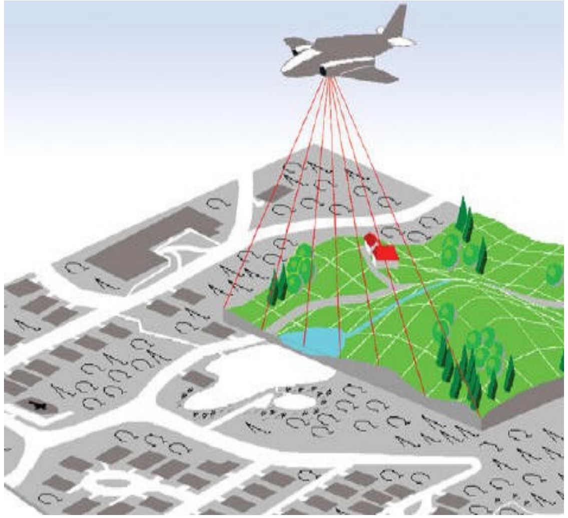
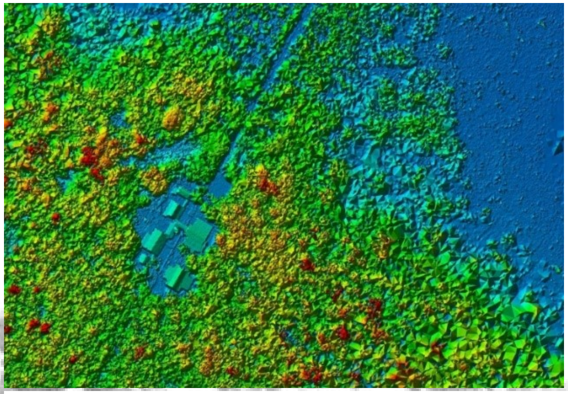
Raw Input
Intermediate Input
Final Product

LiDAR and aerial photo survey





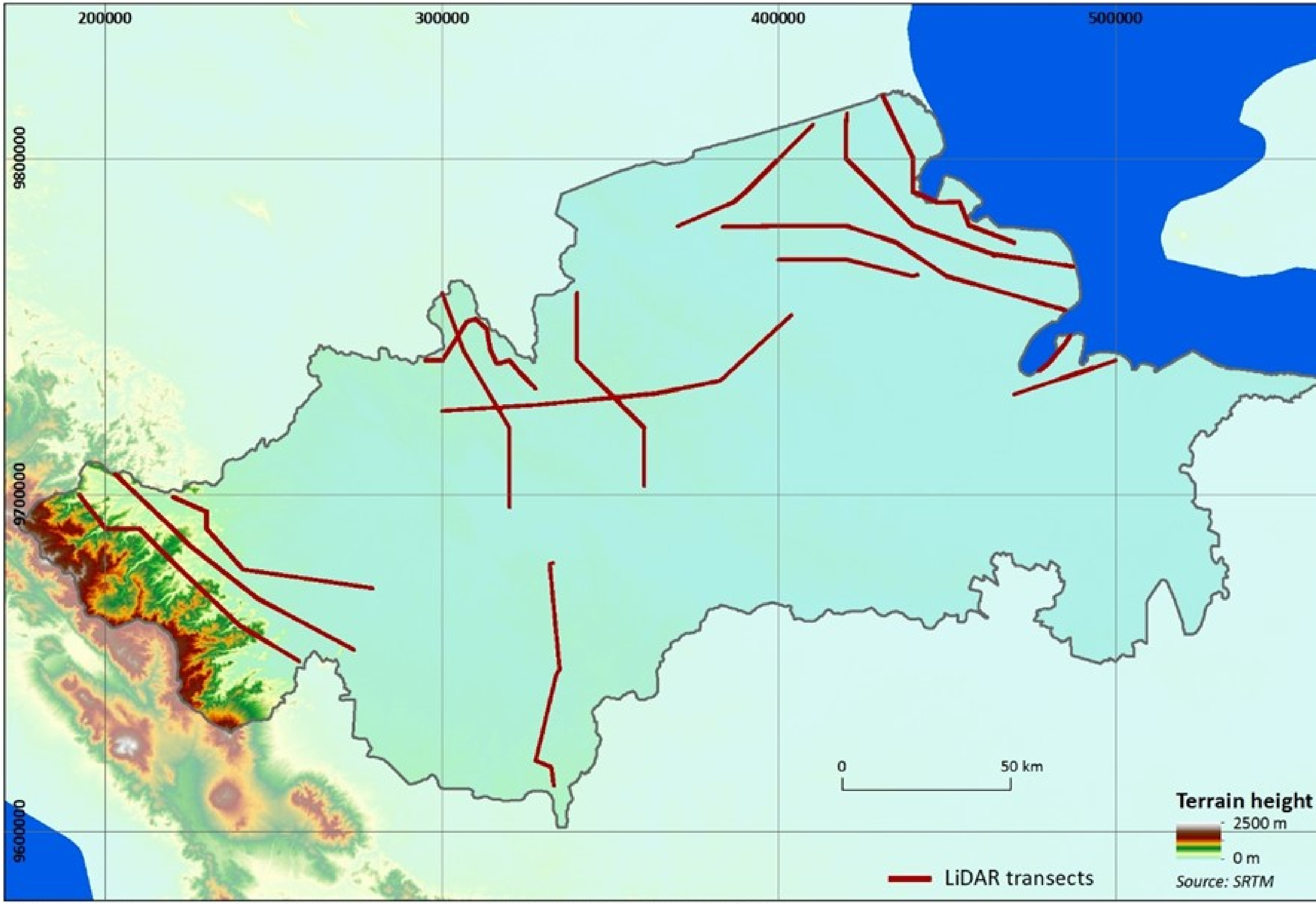
Parameter	Flight plan	Remark
LiDAR acquisition mode	Full Waveform (FWF)	Unlimited returns of laser reflectance
	Discrete Return	4 returns of laser reflectance
Flying height	800 m	The survey was conducted at 800 m above ground level to get the accurate laser reflectance and minimize cloud cover.
Laser pulse frequency	500 Khz	Product specification in ALS70 Leica used for the project.
LiDAR point density	Full Waveform (FWF)	8-15 points/m^2
	Discrete Return	6-8 points/m^2
Aircraft speed	110 knots	
Half scan angle	28 degrees	Field of view (FOV) 56 degrees. With this FOV LiDAR coverage will be embedded with aerial photo coverage.
Swath width	851 m	A scan angle (FOV) of 56 degrees and a flying height of 800 m will provide 851 m area coverage
Ground Sample Distance (GSD)	10-12.5 m	
Forward overlap	Full Waveform (FWF)	60% overlap
	Discrete Return	80% overlap
Aerial photo coverage	86 m x 644 m	Acquisition of aerial photos using a digital camera: Leica RCD 30 with 6 µm pixel resolution, with a GSD of 10 cm per pixel will results in a coverage of 860 m x 644 m.

➔ More information in the final report on the LiDAR survey from PT Asi Pudjiastuti Geosurvey:

PT Asi Pudjiastuti Geosurvey (2014). Final Report. Airborne liDAR survey for the mapping of different forest ecosystems for the modelling of aboveground biomass, carbon stock and biodiversity in the district Musi Rawas, Musi Banyuasin and Banyuasin, South Sumatra, Indonesia. Contract No.: 83179788.

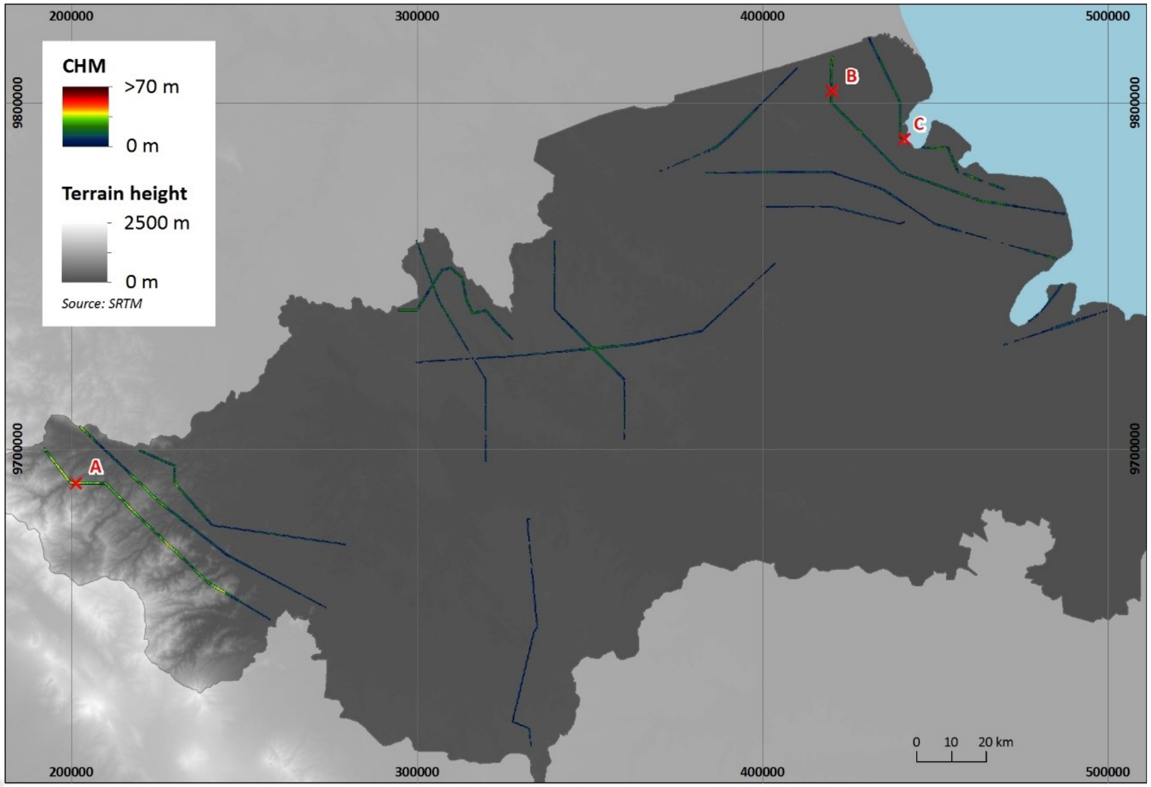
LiDAR and aerial photo survey

Location of the approximately 43,300ha of LiDAR transects

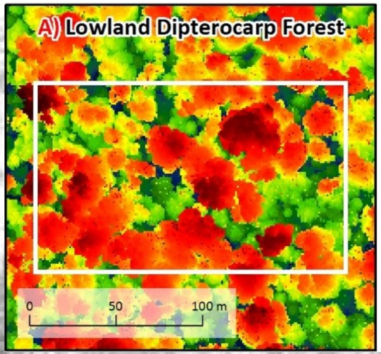


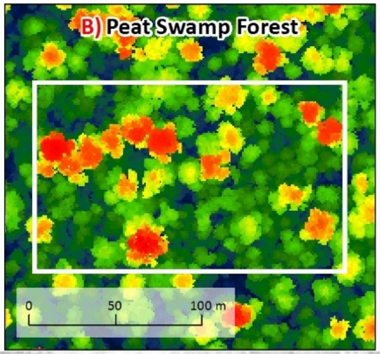
Projection: Universal Transverse Mercator (UTM) 48S, Central meridian: 105° East of Gr., Spheroid: WGS1984

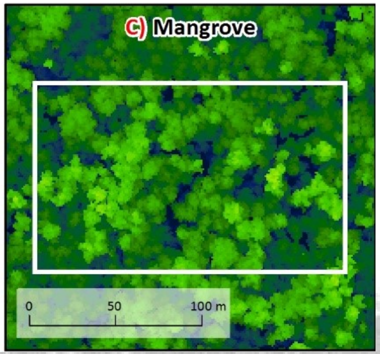
LiDAR processing, filtering and interpolation



Projection: Universal Transverse Marcator (UTM) 48S, Central meridian: 105° East of Gr., Spheroid: WGS1984



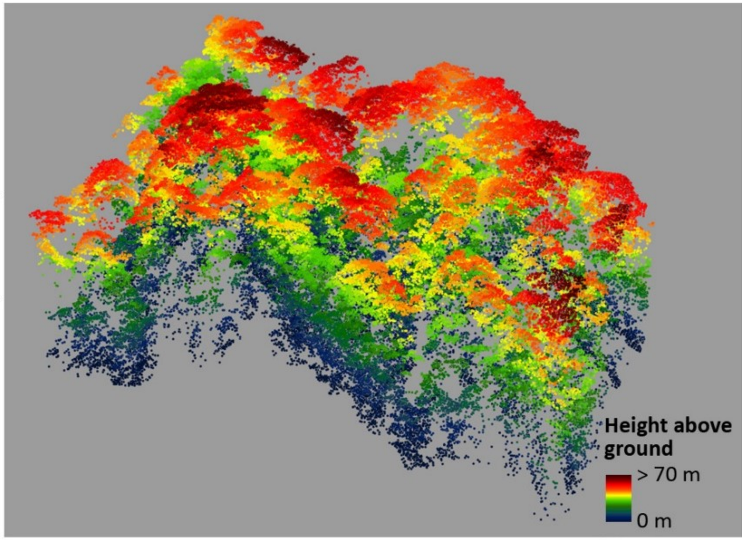




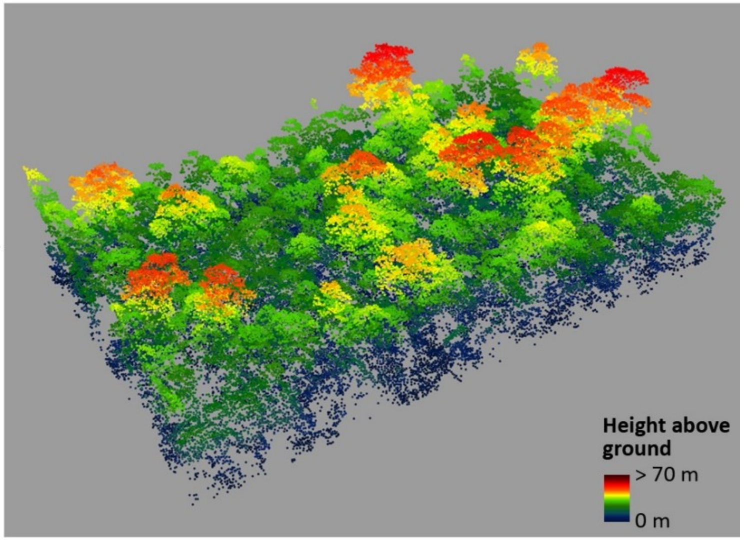
LiDAR processing, filtering and interpolation

Lidar 3D point clouds- Forest types

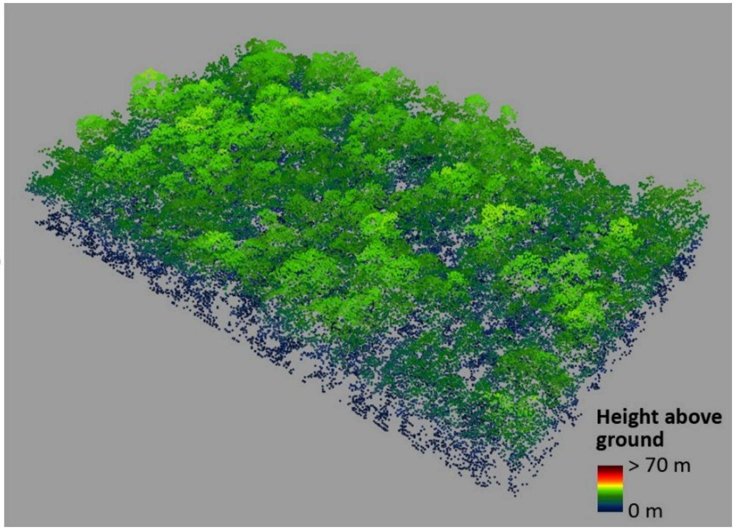
Lowland Dipterocarp Forest



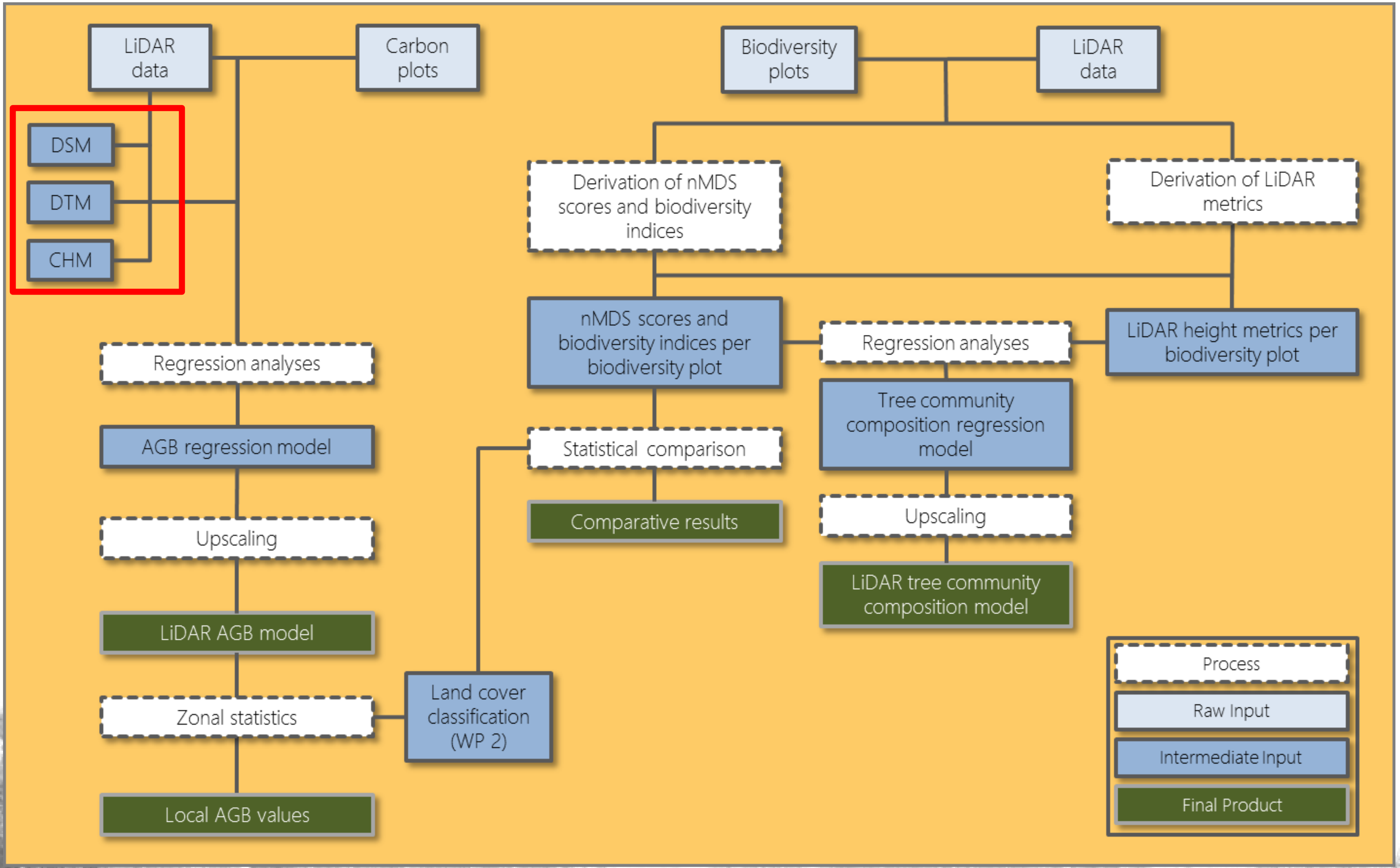
Peat Swamp Forest



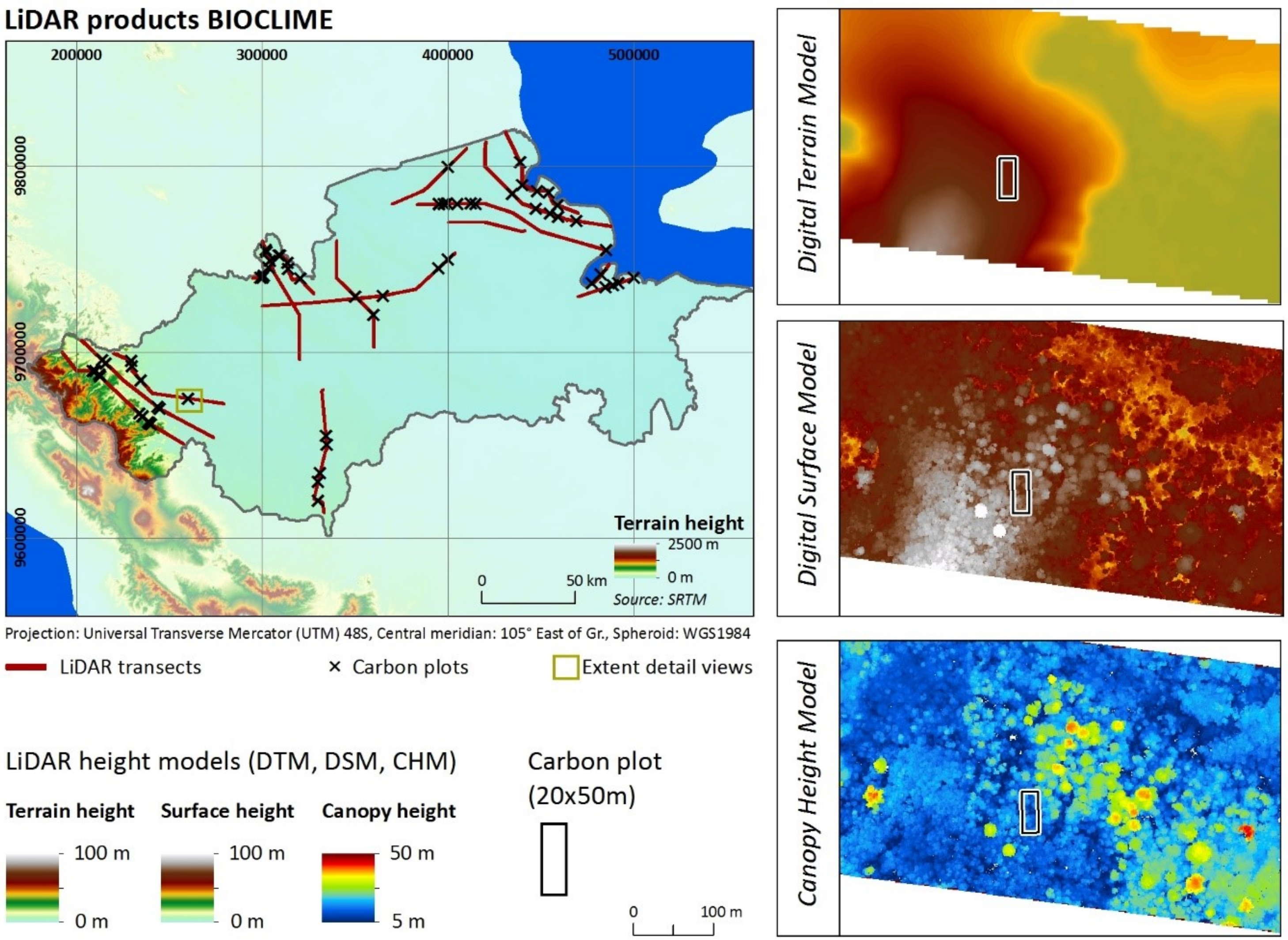
Mangrove



LiDAR products

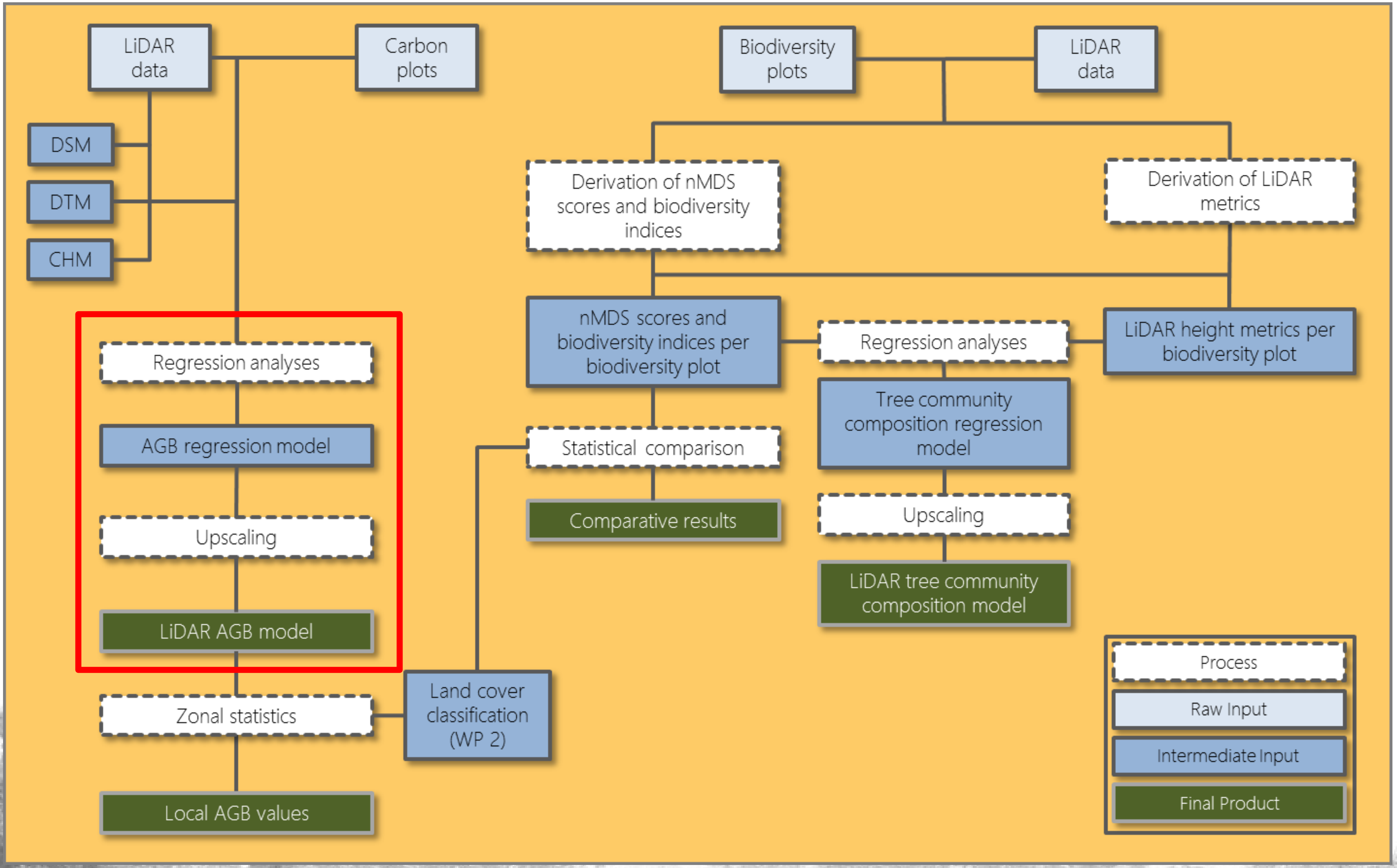


LiDAR products: DTM, DSM and CHM

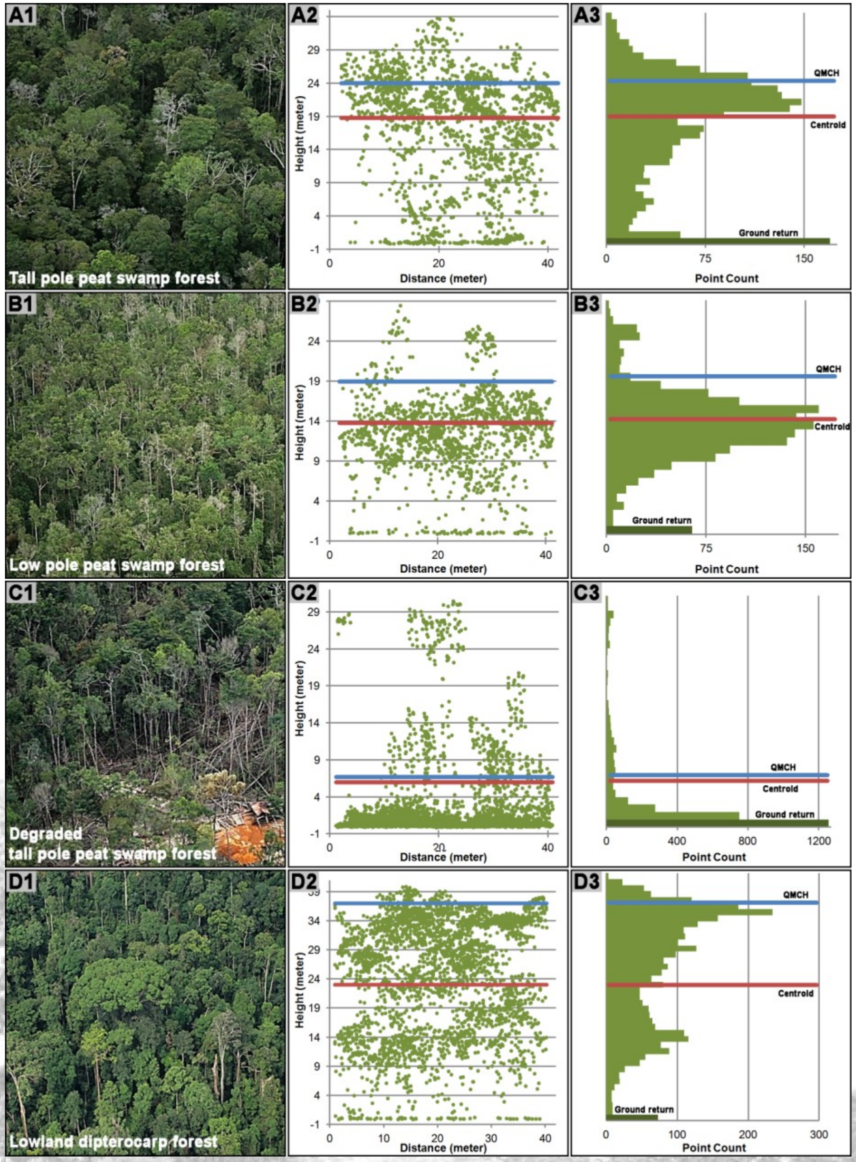


Example from the LiDAR products generated (DTM, DSM and CHM; 1m spatial resolution). Also shown are the position of the 66 carbon plots that are located within the LiDAR transects.

LiDAR based aboveground biomass model

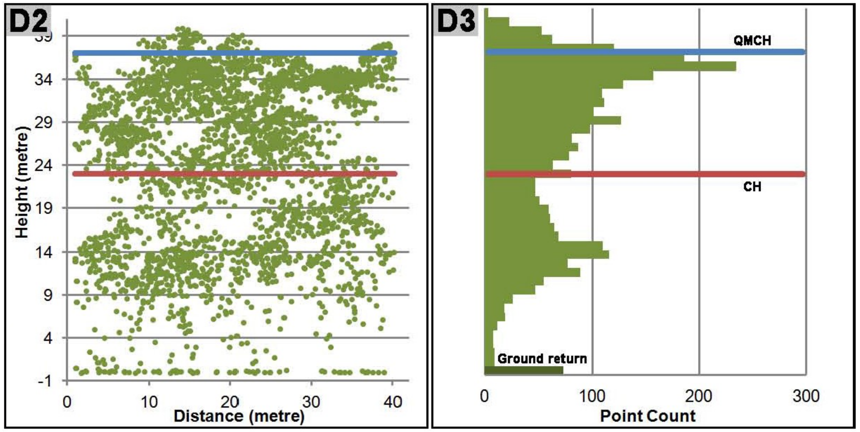


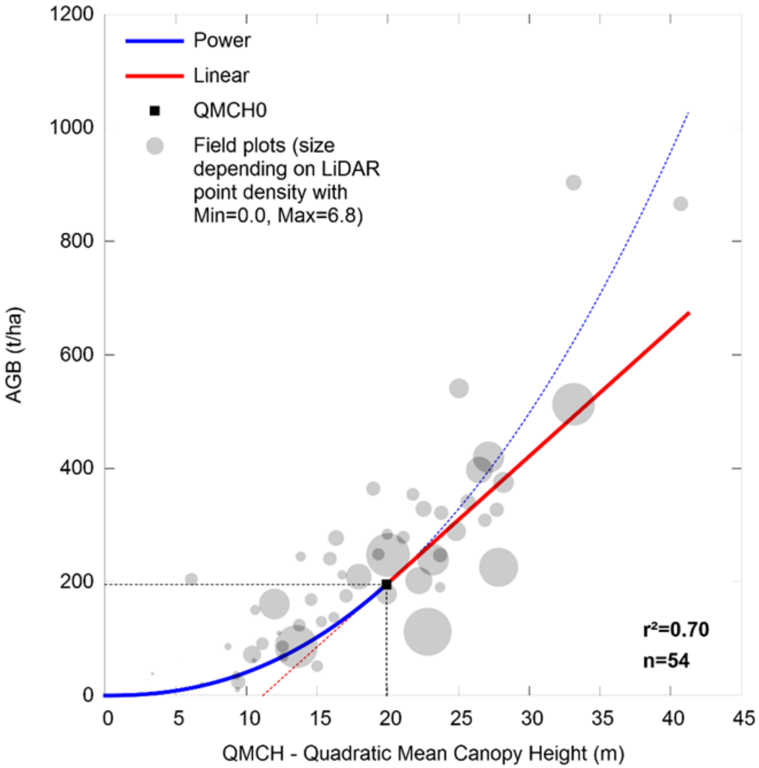
Aboveground biomass model development



Aboveground biomass model development

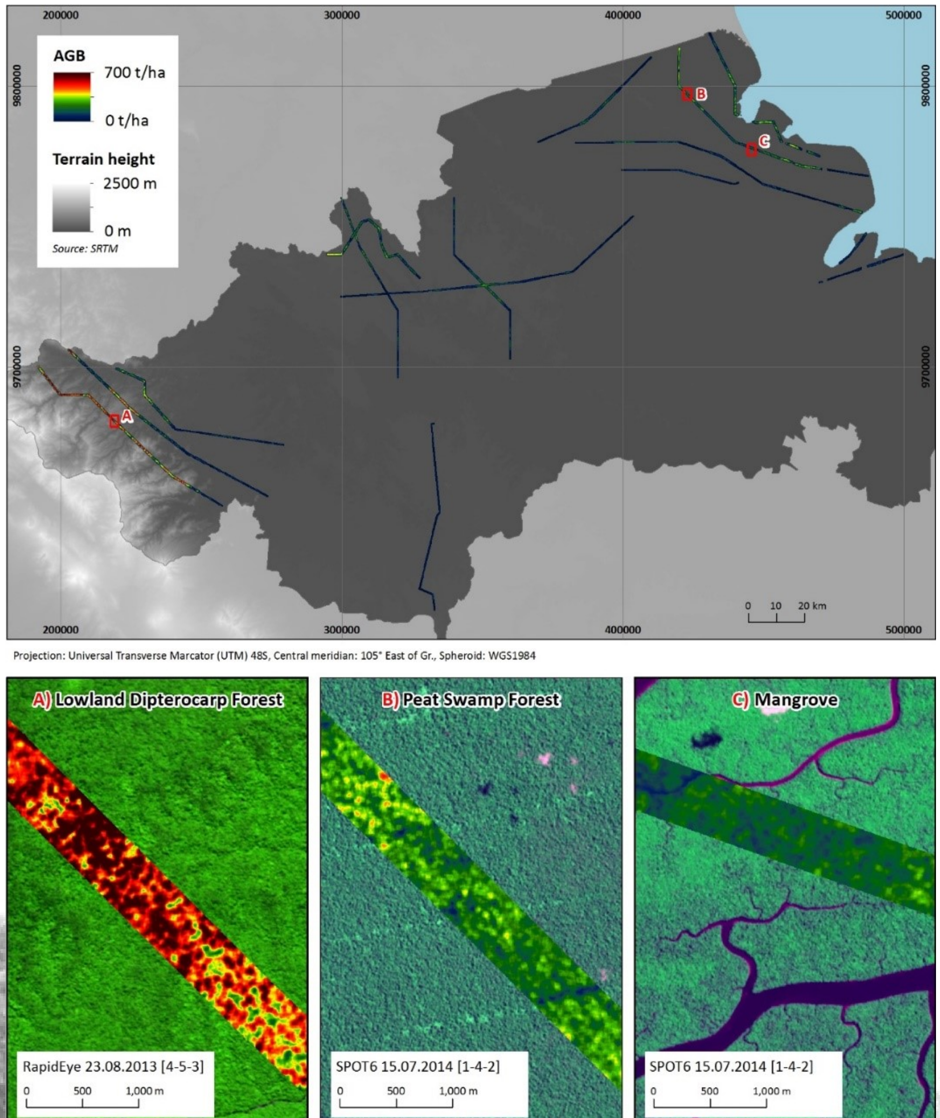
Quadratic Mean Canopy Height





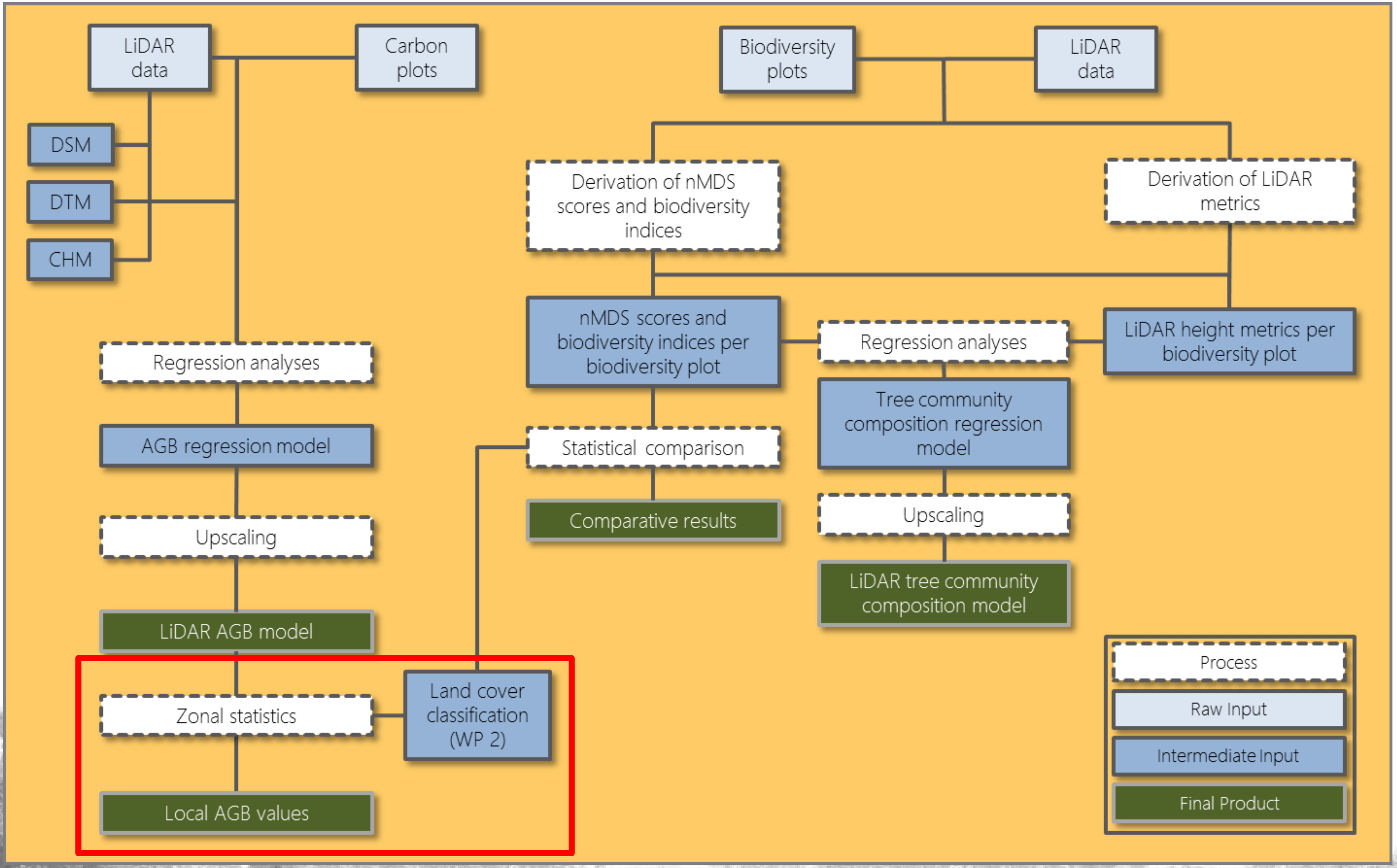
- Quadratic Mean Canopy Height (QMCH) best parameter
- Combined power and linear function
- Stepwise determination (0.001m) of function change (QMCH0)
- Including LiDAR point density

LiDAR based aboveground biomass model



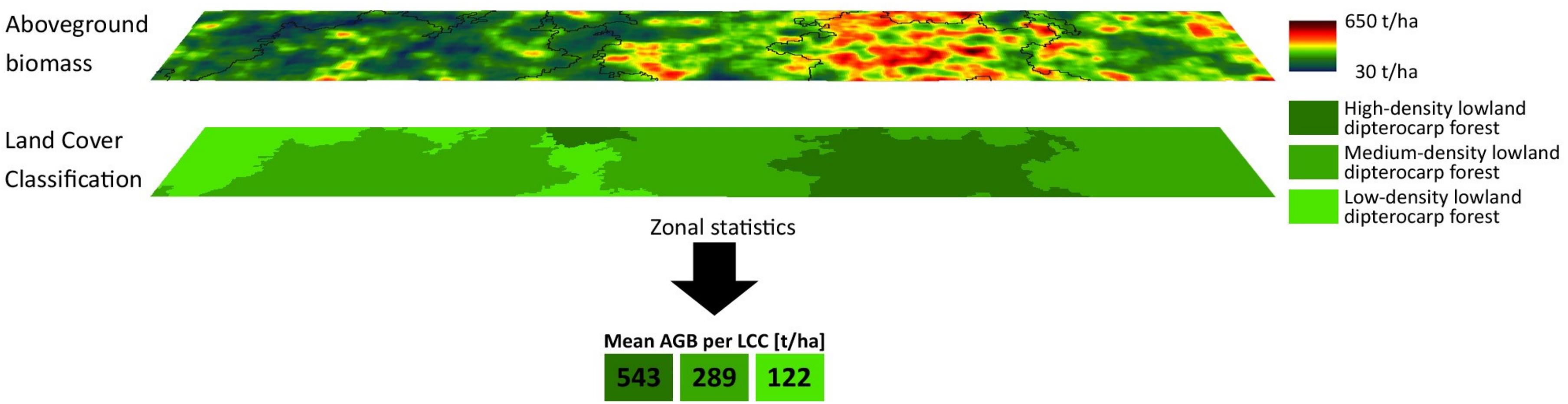
- Final model was created at 5m spatial resolution (i.e. each pixel represents an area of 0.1ha)
- For ease of interpretation the cell values were scaled to represent aboveground biomass in tons per hectare
- High aboveground biomass variability within classes could be identified (e.g. Primary Dryland Forest)
- Areas with the highest aboveground biomass were located around the Kerinci Sebelat National Park

Local aboveground biomass values



Determination of local aboveground biomass values

- Intersection of AGB model with land cover classification from WP 2
- For different forest types and degradation stages
- Descriptive statistics for each class: Minimum, Maximum, Mean, Standard deviation



Local aboveground biomass values

Translation into BAPLAN classification scheme

BAPLAN classification scheme	Indonesian name	Baplan Code	Bioclime class	Baplan-enhanced code
Primary dry land forest	Hutan lahan kering primer	2001	High-density Lowland Dipterocarp Forest	2001-1
			High-density Lower Montane Rainforest	2001-2
			High-density Upper Montane Rainforest	2001-3
Secondary/ logged over dry land forest	Hutan lahan kering sekunder/ bekas tebangan	2002	Medium-density Lowland Dipterocarp Forest	2002-1
			Low-density Lowland Dipterocarp Forest	2002-2
			Medium-density Lower Montane Rainforest	2002-3
			Low-density Lower Montane Rainforest	2002-4
			Medium-density Upper Montane Rainforest	2002-5
			Low-density Upper Montane Rainforest	2002-6
Primary swamp forest	Hutan rawa primer	2005	High-density peat swamp forest	2005-1
			Permanently inundated peat swamp forest	2005-2
			High-density back swamp forest	2005-3
			High-density freshwater swamp forest	2005-4
			Heath forest	2005-5
Secondary/ logged over swamp forest	Hutan rawa sekunder/ bekas tebangan	20051	Low-density peat swamp forest	20051-1
			Regrowing peat swamp forest	20051-2
			Low-density back swamp forest	20051-3
			Regrowing back swamp forest	20051-4
			Medium-density Freshwater Swamp Forest	20051-5
			Low-density Freshwater Swamp Forest	20051-6
Primary mangrove forest	Hutan mangrove primer	2004	Mangrove 1	2004-1
			Mangrove 2	2004-2
			Nipah Palm	2004-3
Secondary/ logged over mangrove forest	Hutan mangrove sekunder/ bekas tebangan		Degraded mangrove	2007-1
			Young mangrove	2007-2

Local aboveground biomass values

Translation into BAPLAN classification scheme

BAPLAN classification scheme	Indonesian name	Baplan Code	Bioclime class	Baplan-enhanced code
Mixed dryland agriculture/mixed garden	Pertanian lahan kering campur semak / kebun campur	20092	Dryland agriculture mixed with shrub	20092
Tree crop plantation	Perkebunan/ Kebun	2010	Oil palm plantation	2010-1
			Coconut plantation	2010-2
			Rubber plantation	2010-3
Plantation forest	Hutan tanaman	2006	Acacia plantation	2006-1
			Industrial forest	2006-2
Scrub	Semak belukar	2007	Scrubland	2007
Swamp scrub	Semak belukar rawa	20071	Swamp scrub	20071
Rice fields	Sawah/ persawahan	20093	Rice field	20093
Dry land agriculture	Pertanian lahan kering	20091	Dry land agriculture	20091
Grass	Rumput	3000	Grassland	3000
Open land	Tanah terbuka	2014	Bare area	2014
Settlement/ developed land	Pemukiman/ lahan terbangun	2012	Settlement	2012-1
			Road	2012-2
Water body	Tubuh air	5001	Water	5001
Swamp	Rawa	50011	Wetland	50011
Embankment	Tambak	20094	Aquaculture	20094

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Local aboveground biomass values

giz

Local aboveground biomass values based on BAPLAN classes

Forest type / land cover BAPLAN	Mean AGB (t/ha)	SD AGB (t/ha)	Min AGB (t/ha)	Max AGB (t/ha)	Area (ha)
Primary Dryland Forest	545	±165.5	20.8	1,405.0	2,285.2
Secondary / Logged over Dryland Forest	256	±160.3	0.0	1.196.8	5,685.3
Primary Swamp Forest	226	±97.2	1.8	674.3	1,806.5
Secondary / Logged over Swamp Forest	74	±64.4	0.0	460.5	1,363.3
Primary Mangrove Forest	198	±102.7	0.0	632.2	4,031.9
Secondary / Logged over Mangrove Forest	44	±25.1	6.4	228.5	71.7
Mixed Dryland Agriculture / Mixed Garden	105	±84.1	0.0	677.8	1,883.0
Tree Crop Plantation	32	±47.2	0.0	380.2	442.2
Plantation Forest	40	±32.2	0.0	356.7	517.5
Scrub	25	±42.6	0.0	730.4	964.6
Swamp Scrub	8	±11.8	0.0	81.6	3.3
Rice Field **(1)**	10	-	-	-	-
Dryland Agriculture	31	±47.9	0.0	441.2	126.3
Grass **(2)**	6	-	-	-	-
Open Land **(3)**	(0) 20	±65.9	0.0	716.4	13.4
Settlement / Developed Land **(3)**	(0) 12	±8.6	0.1	50.6	1.3
Water Body **(3)**	(0) 118	±58.5	0.3	422.2	83.2
Swamp	12	±12.3	0.1	49.9	1.3
Embankment **(3)**	(0) 1	±1.9	0.0	12.8	9.5

(1) Value for Rice Field from scientific literature (Confalonieri *et al.* 2009)

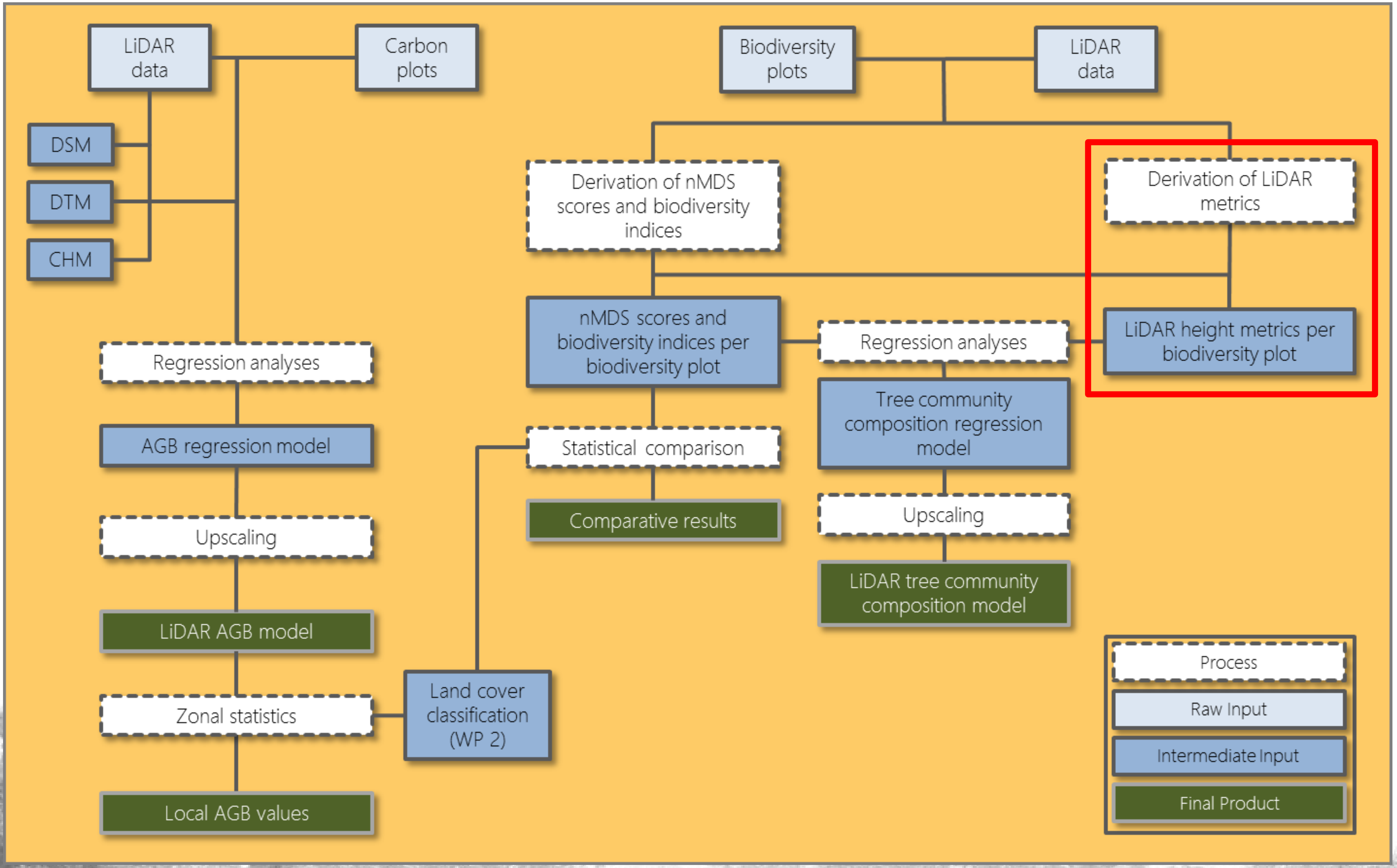
(2) Value for Grass from scientific literature (IPCC 2006)

(3) Value in brackets was finally used as local aboveground biomass value as the value from zonal statistics is obviously too high due to misclassification

Confalonieri R., Rosenmund A.S., Beruth B. (2009). An improved model to simulate rice yield. Agronomy for Sustainable Development, Springer Verlag/EDP Sciences/INRA, 2009, 29 (3).

IPCC (2006). IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme. Eggleston, H.S., Buendia, L., Miwa, k., Ngara, T.and Tanabe, K.(Eds).Published: IGES, Japan.

LiDAR height metrics



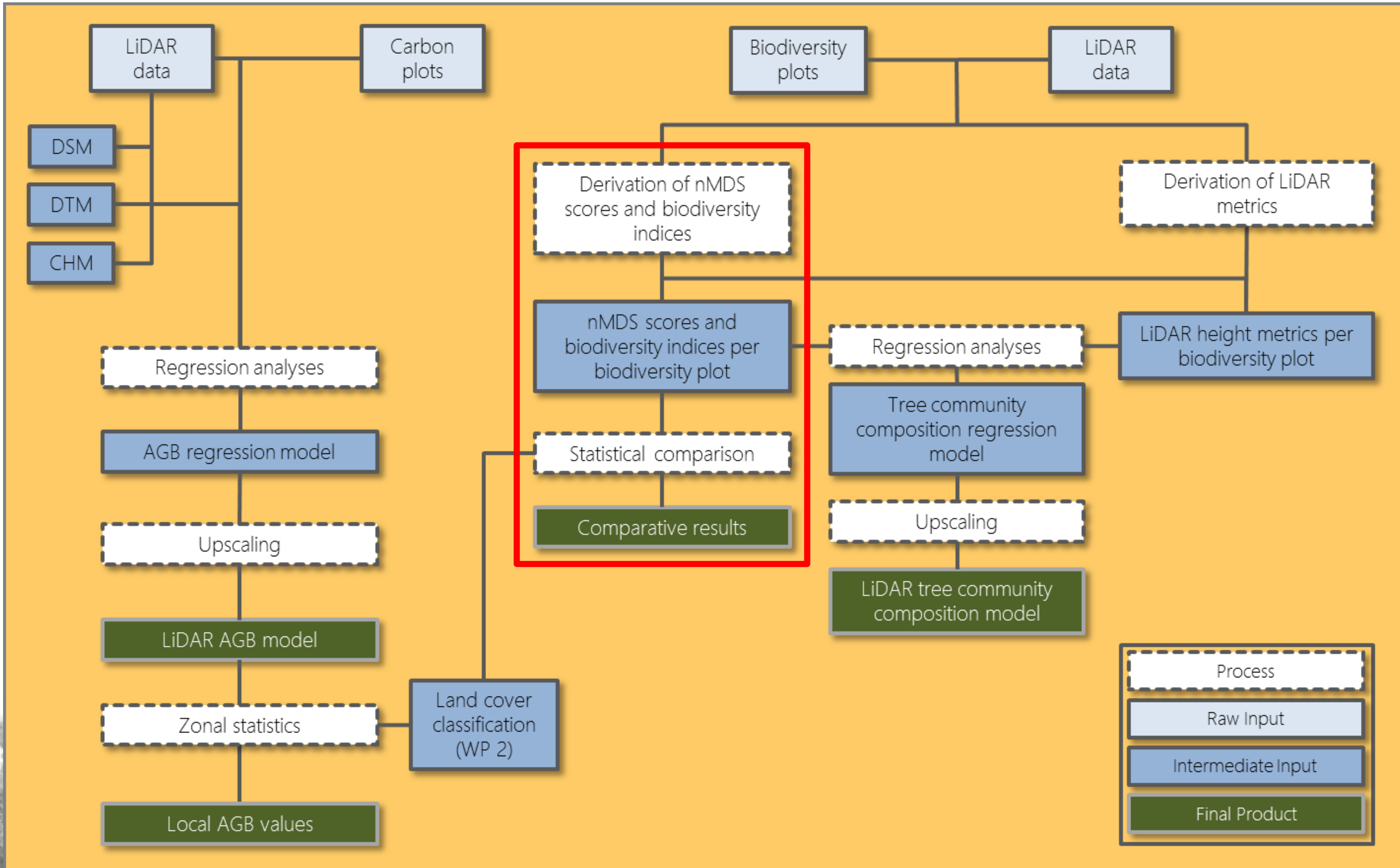
LiDAR height metrics

LiDAR height metrics derived for the 28 biodiversity plots located in LiDAR transects

LiDAR metric	Abbreviation	Software / method used
Quadratic Mean Canopy Height (QMCH)	QMCH	in house script
Centroid Height (CH)	CH	in house script
Maximum height	Max	LASTools **(1)**
Mean height	Mean	LASTools **(1)**
Standard deviation height	SD	LASTools **(1)**
Forest cover at 1 m height	cov 1m	LASTools **(1)**
Forest cover at 2 m height	cov 2m	LASTools **(1)**
Forest cover at 5 m height	cov 5m	LASTools **(1)**
Forest cover at 7 m height	cov 7m	LASTools **(1)**
Forest cover at 10 m height	cov 10m	LASTools **(1)**
Forest cover at 12 m height	cov 12m	LASTools **(1)**
5^{th} height percentile	p 5^{th}	LASTools **(1)**
10^{th} height percentile	p 10^{th}	LASTools **(1)**
25^{th} height percentile	p 25^{th}	LASTools **(1)**
50^{th} height percentile	p 50^{th}	LASTools **(1)**
75^{th} height percentile	p 75^{th}	LASTools **(1)**
90^{th} height percentile	p 90^{th}	LASTools **(1)**
95^{th} height percentile	p 95^{th}	LASTools **(1)**
99^{th} height percentile	p 99^{th}	LASTools **(1)**

(1) https://rapidlasso.com/lastools/

nMDS scores and biodiversity indices



Derivation of nMDS scores and biodiversity indices

Absolute and percentage of tree identification within biodiversity plots

	All trees recorded	Species identified	Only genus identified	Only family identified	Only common name	Unidentified
Absolute number	2733	2408	284	15	4	22
Percent (%)	100%	88%	10%	1%	0%	1%

Statistical basis

- All further analyses on tree community composition were conducted for lowland dipterocarp forest only
- Because some trees could not be identified to the species level all analyses on tree community composition were based on the genus level
- All statistics were calculated in PAST Version 3.13 (http://folk.uio.no/ohammer/past/) and were only based on the genera identified in the large plot of the biodiversity plots

Forest stratification

- Forest stratification based on forest cover at 10m height (derived from LiDAR metric)

Lowland dipterocarp forest density class	Stratification thresholds
	Forest cover at 10 m height above ground (%)
Low-density Lowland Dipterocarp Forest	0-<40
Medium-density Lowland Dipterocarp Forest	40≤-<80
High-density Lowland Dipterocarp Forest	80≤

Nonmetric multidimensional scaling (nMDS)

Nonmetric multidimensional scaling (nMDS) was applied to assess differences in tree community composition

Arranges points to maximize rank-order correlation between real-world distance and ordination space distance

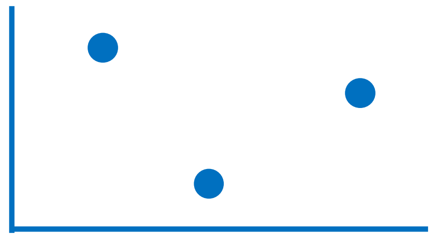
Multivariate data

	Genus A	Genus B	Genus C
Plot 1	…	…	…
Plot 2	…	…	…
Plot 3	…	…	…

User-defined distance matrix (real space)

	Plot 1	Plot 1	Plot 1
Plot 1	…	…	…
Plot 2	…	…	…
Plot 3	…	…	…

Ordination space

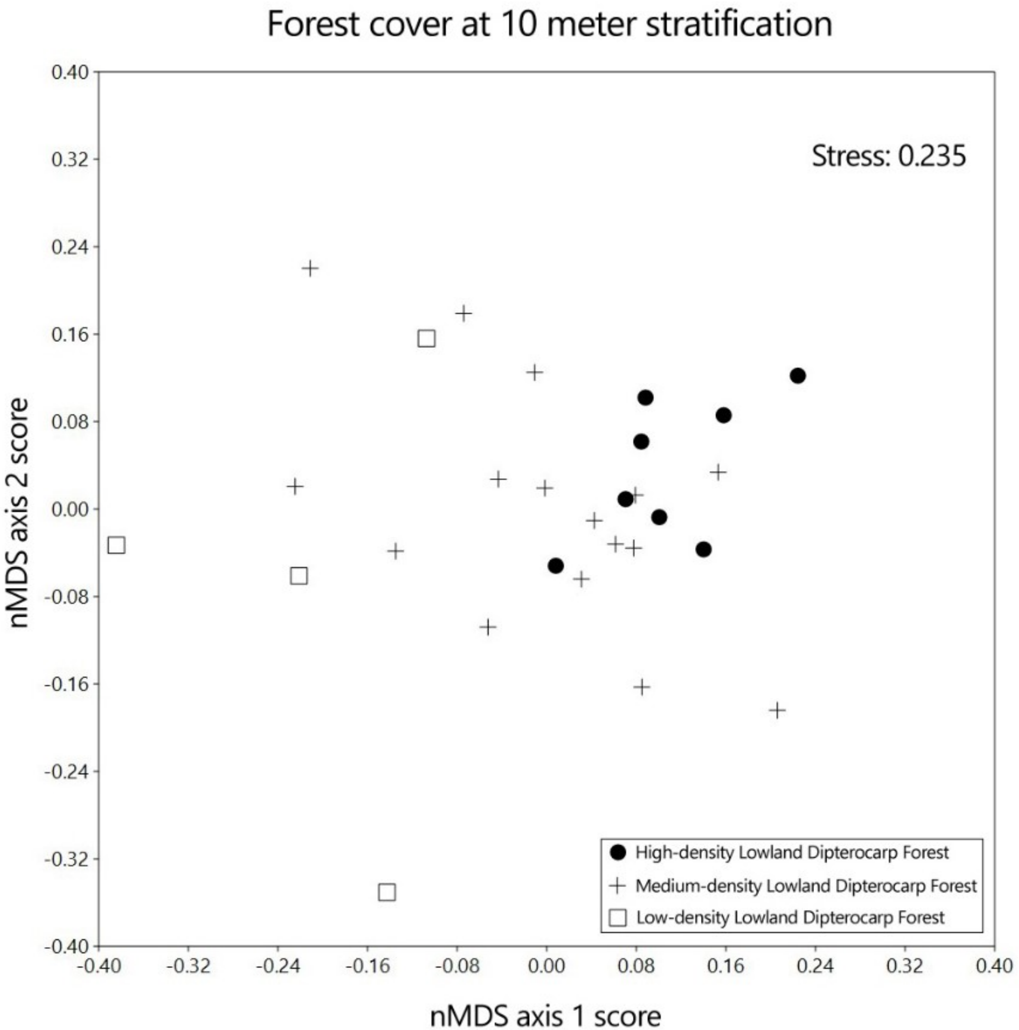


Distance matrix from ordination (correlation)

	Plot 1	Plot 1	Plot 1
Plot 1	…	…	…
Plot 2	…	…	…
Plot 3	…	…	…

- The Bray-Curtis similarity index was applied
- The stress value is used as indicator of the performance of the nMDS (the lower the stress value the better)

Nonmetric multidimensional scaling (nMDS)



- Axis 1 scores indicate the similarity in tree community composition among the 28 plots
- Axis 1 scores of High-density Lowland Dipterocarp Forest and Low-density Lowland Dipterocarp Forest are located at the opposite ends indicating a difference in tree community composition.
- Axis 1 scores of Medium-density Lowland Dipterocarp Forest is mostly located between the scores of the two other density classes

Biodiversity indices

Simpson index 1-D

- Index measures ‘evenness’ of the community from 0 (one taxon dominates the community completely) to 1 (all taxa are equally present)

$$D = -\sum_i \left(\frac{n_i}{n}\right)^2$$

where n_i is the number of individual of taxon i

Shannon index (entropy)

- Diversity index taking into account the number of individual as well as the number of taxa.
- Index increases as both the ‘richness’ and the ‘evenness’ of the community increases
- Generally between 1.5 and 3.5

$$H = -\sum_i \frac{n_i}{n} ln \frac{n_i}{n}$$

where n_i is the number of individual of taxon i

Biodiversity indices

Margalef's richness index

- 'Richness' index that attempts to compensate for sampling effects such as sample size
- The higher the index the higher the 'richness'

Equitability

- Shannon diversity divided by the logarithm of number of taxa.
- Measures the 'evenness' with which individual are divided among the taxa present
- The higher the index the higher the 'evenness'

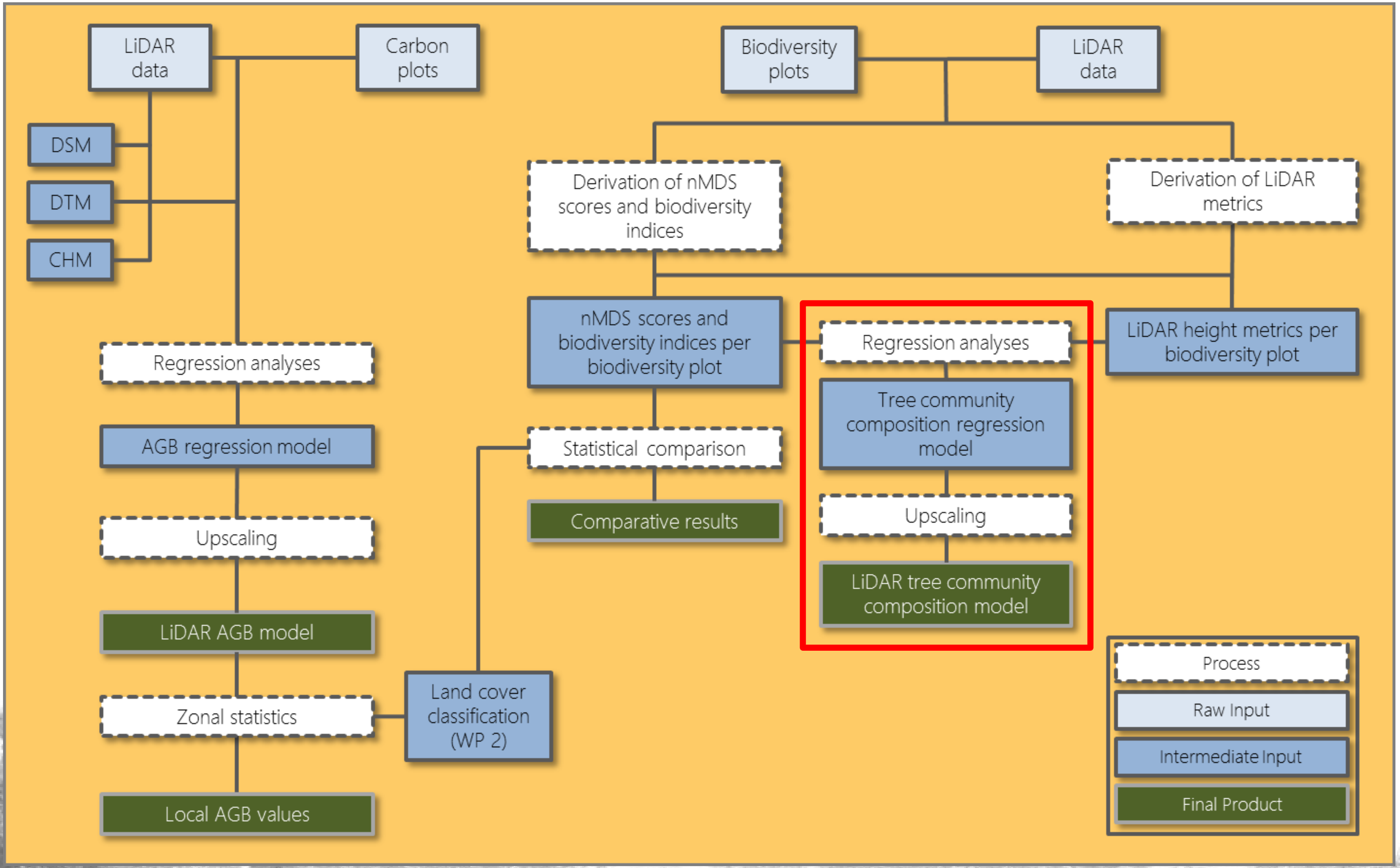
nMDS scores and biodiversity indices

Descriptive statistics

		Lowland Dipterocarp Forest		
		Low-density	**Medium-density**	**High-density**
nMDS axis 1 score	**n**	4	16	8
	Min	-0.384	-0.225	0.008
	Max	-0.107	0.206	0.224
	Mean	**-0.214**	**-0.001**	**0.109**
	SD	±0.123	±0.120	±0.065
Simpson index 1-D	**n**	4	16	8
	Min	0.392	0.720	0.870
	Max	0.810	0.955	0.964
	Mean	**0.677**	**0.898**	**0.935**
	SD	±0.193	±0.069	±0.029
Shannon index	**n**	4	16	8
	Min	0.807	1.632	2.383
	Max	2.069	3.310	3.453
	Mean	**1.623**	**2.703**	**3.008**
	SD	±0.560	±0.490	±0.318
Margelef's index	**n**	4	16	8
	Min	1.039	2.424	3.938
	Max	3.376	8.266	8.384
	Mean	**2.463**	**5.384**	**6.300**
	SD	±1.046	±1.574	±1.312
Equitability	**n**	4	16	8
	Min	0.501	0.667	0.880
	Max	0.840	0.987	0.964
	Mean	**0.725**	**0.892**	**0.932**
	SD	±0.154	±0.089	±0.027

- Mean nMDS axis 1 scores of Low-density Lowland Dipterocarp Forest lowest and of High-density Lowland Dipterocarp Forest highest
- The two indices for 'richness/diversity' (Shannon and Margelef's index) similar gradient, indicating that High-density Lowland Dipterocarp Forest has the highest biodiversity
- The other two biodiversity indicators for 'evenness' (Simpson index 1-D and Equitability) also similar gradient, indicating that High-density Lowland Dipterocarp Forest has the highest 'evenness'
- All these findings indicate that high nMDS axis 1 scores go hand in hand with higher 'richness/diversity' and 'evenness'

LiDAR based tree community composition model



LiDAR based tree community composition model

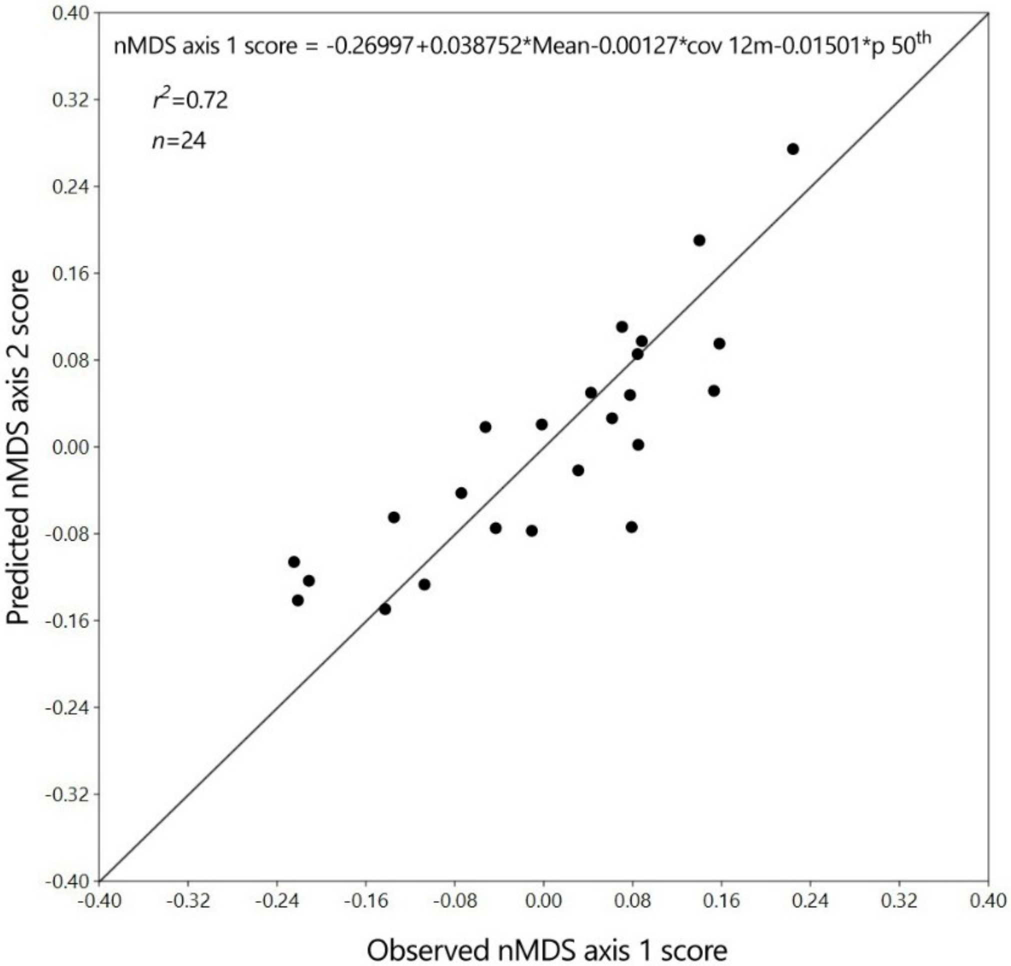
Correlation analysis

	nMDS axis 1	Simpson index 1-D	Shannon index	Margelef's index	Equitability
QMCH	0.83	0.60	0.55	0.55	0.62
CH	0.82	0.59	0.53	0.54	0.62
Max	0.70	0.57	0.51	0.51	0.67
Mean	0.82	0.59	0.53	0.53	0.61
SD	0.72	0.57	0.51	0.50	0.64
cov 1m	0.71	0.49	0.47	0.48	0.47
cov 2m	0.74	0.51	0.48	0.50	0.49
cov 5m	0.74	0.54	0.50	0.51	0.51
cov 7m	0.74	0.56	0.52	0.53	0.53
cov 10m	0.79	0.56	0.52	0.52	0.55
cov 12m	0.80	0.55	0.51	0.51	0.55
p 5th	0.73	0.51	0.50	0.51	0.48
p 10th	0.77	0.57	0.55	0.56	0.53
p 25th	0.77	0.57	0.53	0.53	0.54
p 50th	0.80	0.57	0.52	0.52	0.58
p 75th	0.82	0.59	0.54	0.53	0.61
p 90th	0.79	0.58	0.53	0.52	0.64
p 95th	0.71	0.56	0.51	0.50	0.64
p 99th	0.69	0.57	0.51	0.50	0.68

- nMDS axis 1 scores correlated best with LiDAR metrics with regard to Spearman's correlation coefficient (r_s)
- LiDAR metrics QMCH, CH, Mean, p 75th, cov 12m, p 50th the r_s was even equal or higher than 0.80

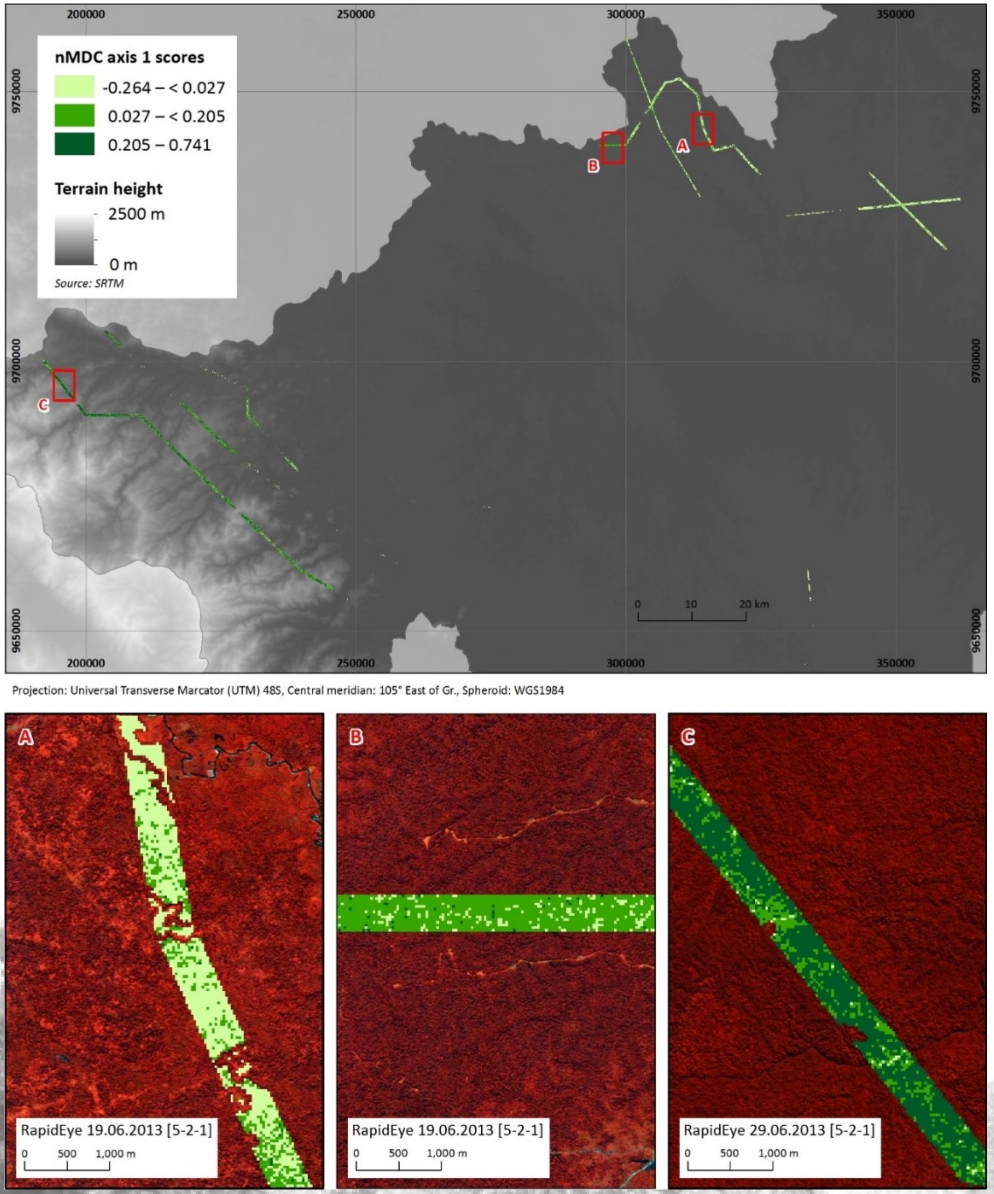
These scores were used to derive the predictive LiDAR based community composition model

LiDAR based tree community composition model



- Stepwise forward and backward multiple regression was performed (R software)
- The final model included three significant LiDAR metrics: Mean, cov 12m and p 50th
- Four biodiversity plots were excluded (outliers)
- r^2 = 0.72 (n = 24)

LiDAR based tree community composition model



- Final model was applied (spatial resolution 31.25 m) to the areas of the LiDAR transects that cover Lowland Dipterocarp Forest (based on the land cover classification from WP 2)
- Areas where the LiDAR metric Max was smaller than 6 m were excluded (non-forested)
- Predicted nMDS axis 1 scores of this map ranged from -0.264 to 0.741
- The highest nMDS axis 1 scores were found in Kerinci Sebelat National Park and the lowest in eastern lowlands of the Musi Banyuasin district
- These results indicate that the areas within the Kerinci Sebelat National Park have tree community compositions that indicate high biodiversity compared to the ones in the eastern lowlands of the Musi Banyuasin District

Conclusions

Aboveground biomass modelling

- Local above ground biomass values could be derived from the LiDAR aboveground biomass model for almost all identified land cover classes
- High aboveground biomass variability within classes could be identified (e.g. Primary Dryland Forest has a standard deviation of ±165.5 t/ha)
- Areas with the highest aboveground biomass were located around the Kerinci Sebelat National Park

Outlook

- Comparison of tree community composition model with aboveground biomass model

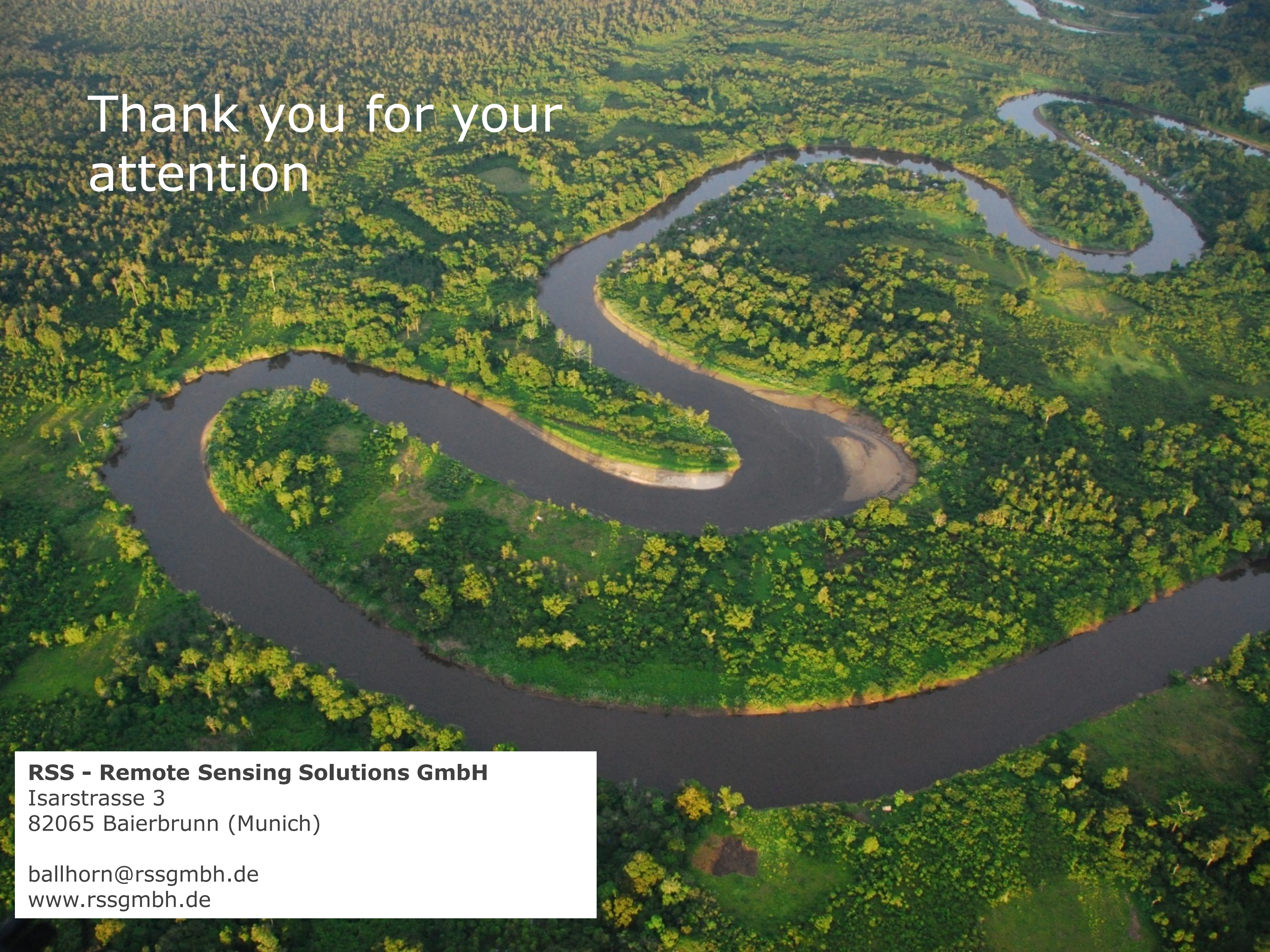
Conclusions

Tree community composition modelling

- The findings of this study indicate that the similarity in tree community composition can be predicted and monitored by means of airborne LiDAR.
- In addition to using airborne LiDAR data as a mapping tool for aboveground biomass this data could be further developed to provide a biodiversity mapping tool, so that biodiversity assessment could be carried out simultaneously with aboveground biomass analyses (same dataset).
- A further advantage of the approach is that the tree community composition can be carried out without identifying individual tree crowns in remotely sensed imagery.

Outlook

- Assessment on differences in pioneer and climax tree species
- Comparison of tree community composition model with aboveground biomass model



Thank you for your attention

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Local aboveground biomass values

Local aboveground biomass values based on BAPLAN enhanced classes

Forest type / land cover BAPLAN enhanced	Mean AGB (t/ha)	SD (t/ha)	Min AGB (t/ha)	Max AGB (t/ha)	Area (ha)
High-density Upper Montane Forest **(1)**	304	-	-	-	-
Medium-density Upper Montane Forest **(2)**	228	-	-	-	-
Low-density Upper Montane Forest **(1)**	192	-	-	-	-
High-density Lower Montane Forest	615	±135.5	171.8	1,092.0	52.0
Medium-density Lower Montane Forest	486	±81.2	306.0	758.3	5.5
Low-density Lower Montane Forest **(1)**	268	-	-	-	-
High-density Lowland Dipterocarp Forest	543	±165.8	20.8	1,405.0	2,233.2
Medium-density Lowland Dipterocarp Forest	289	±157.1	0.0	1,196.8	4,536.6
Low-density Lowland Dipterocarp Forest	122	±84.7	0.1	966.1	1,143.2
High-density Peat Swamp Forest	235	±99.7	2.1	674.3	1,430.7
Medium-density Peat Swamp Forest **(2)**	176	-	-	-	-
Low-density (Regrowing) Peat Swamp Forest	77	±73.7	0.3	460.5	590.7
Permanently Inundated Peat Swamp Forest	192	±83.9	1.8	526.4	301.1
High-density Swamp Forest (incl. Back- and Freshwater Swamp)	200	[illegible]	[illegible]	[illegible]	[illegible]
Medium-density Swamp Forest (incl. Back- and Freshwater Swamp) **(2)**	150	[illegible]	[illegible]	[illegible]	-
Low-density (Regrowing) Swamp Forest (incl. Back- and Freshwater Swamp)	73	[illegible]	[illegible]	[illegible]	[illegible]
Heath Forest **(1)**	224	[illegible]	[illegible]	[illegible]	-
Mangrove 1	216	[illegible]	[illegible]	[illegible]	[illegible]
Mangrove 2	153	[illegible]	[illegible]	[illegible]	[illegible]
Nipah Palm	77	[illegible]	[illegible]	[illegible]	[illegible]
Degraded Mangrove	46	[illegible]	[illegible]	[illegible]	[illegible]
Young Mangrove	39	[illegible]	[illegible]	[illegible]	[illegible]
Dryland Agriculture mixed with Scrub	23	[illegible]	[illegible]	[illegible]	[illegible]
Rubber Agroforestry	129	[illegible]	[illegible]	[illegible]	[illegible]
Oil palm plantation	16	[illegible]	[illegible]	[illegible]	[illegible]
Coconut plantation	35	±18.2	0.9	88.7	94.1
Rubber	135	±57.4	0.2	380.2	43.9
Acacia plantation	41	±33.7	0.0	178.7	360.2
Industrial forest	39	±28.6	0.1	356.7	157.3
Scrubland	25	±42.6	0.0	730.4	964.6
Swamp Scrub	8	±11.8	0.0	81.6	3.3
Rice Field **(3)**	10	-	-	-	-
Dryland Agriculture	31	±47.9	0.0	441.2	126.3
Grassland **(4)**	6	-	-	-	-
Bare Area **(5)**	(0) 20	±65.9	0.0	716.4	13.4
Settlement **(5)**	(0) 5	±8.7	0.1	50.6	0.4
Road **(5)**	(0) 15	±6.2	0.1	28.2	0.9
Water **(5)**	(0) 118	±58.5	0.3	422.6	83.2
Wetland	12	±12.3	0.1	49.9	1.3
Aquaculture **(5)**	(0) 1	±1.9	0.0	12.8	9.5

(1) Value from FORCLIME (Navratil 2012)

(2) Calculated as 75% of respective high density class

(3) Value for Rice Field from scientific literature (Confalonieri *et al.* 2009)

(4) Value for Grass from scientific literature (IPCC 2006)

(5) Value in brackets was finally used as local aboveground biomass value as the value from zonal statistics is obviously too high due to misclassification

Navratil P. (2012). Survey on the Land Cover Situation and Land-Use Change in the Ditricts Kapuas Hulu and Malinau, Indonesia. Final Report for assessment of district and KPH wide REL assessment. Forest and Climate Change Program (FORCLIME).

nMDS scores and biodiversity indices

Significant differences between density classes

- One-way ANOVA was performed to test statistical difference between the density classes
- Normality of data was tested by means of the Shapiro-Wilk test ($p > 0.05$ normally distributed)
- When ANOVA results significant Tukey's pairwise post-hoc test to identify different pairs ($p < 0.05$)

		nMDS axis 1			Simpson index 1-D			Shannon index			Margelef's index			Equitability		
Test normal distribution		Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
		0.477	0.752	0.896	0.079	0.000	0.033	0.187	0.097	0.574	0.509	0.976	0.914	0.164	0.003	0.500
One-way ANOVA		0.000			0.000			0.000			0.001			0.002		
Tukey's pairwise		Medium		High	Medium		High	Medium		High	Medium		High	Medium		High
	Low	0.003		0.000	0.000		0.000	0.001		0.000	0.003		0.000	0.005		0.001
	Medium	X		0.161	X		0.716	X		0.445	X		0.481	X		0.694

- Significant difference between different density classes for nMDS axis 1 scores, Shannon index and Margelef's index
- Tukey's pairwise post-hoc test showed difference between pairs Low vs Medium and Low vs High but not Medium vs High
- For Simpson index 1-D and Equitability no statement could be made as data was not normally distributed

These statistical results indicate that there is a significant different with regard to tree community composition between these different density classes and that the density classes Low vs Medium and Low vs High could be best differentiated.