



Supplement of

Canopy gaps and associated losses of biomass – combining UAV imagery and field data in a central Amazon forest

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Supplementary Material

Text S1-S2, Tables S1-S5, and Figure S1-S4.

Text S1. Description about data acquisition and light conditions

In general, the overflights were done starting at a time when there was no more fog (09:00 hours) and never done in rainy conditions. For our study area (18 ha), the overflights last ~15 min, so it was possible to achieve this amount of time without rain, even on a rainy day. The main recommendation is to perform the overflights in cloudy conditions, as these diffuse lighting conditions improve visibility deeper into the canopy and reduce problems associated with shadows.

Text S2. Description of the process for alignment of drone-based images collected on different dates

1. The first overflight (Only once)

(a) process the first overflight (once only), (b) process photographs using the Z of the flight plan (100 m takeoff point) in Agisoft Metashape, (c) align and georeference the orthomosaic using the LiDAR data as a baseline in a GIS environment, (d) extract control points and Z values from LiDAR, and (e) process photos in Agisoft Metashape using the control points as markers.

2. The second, third, etc overflights

After this first processing, the remaining overflights followed the following flow: (a) alignment of the photographs in Agisoft Metashape (b) chunk alignment of the two-point clouds based on the first overflight and (c) final processing in Agisoft Metashape.

Table S1. Data collection period at the INVENTA plot, Central Amazon, Brazil, from September 18, 2018 to January 19, 2021. Period of the overflight (UAV Imagery) and field data campaigns with their respective time intervals in days.

UAV Imagery		Field data	
Collection Date	Interval (days)	Collection Date	Interval (days)
9/18/2018			
10/24/2018	36		
12/27/2018	64		

01/12/2019	16		
04/05/2019	83		
5/28/2019	53		
6/24/2019	27		
7/15/2019	21		
8/17/2019	33		
8/29/2019	12		
9/25/2019	27		
10/21/2019	26		
11/01/2019	11	11/01/2019	
11/30/2019	29		
12/15/2019	15	12/15/2019	44
1/30/2020	46		
2/19/2020	20	2/19/2020	66
3/31/2020	41		
4/16/2020	16	4/16/2020	57
5/25/2020	39		
6/16/2020	22	6/16/2020	61
7/29/2020	43		
8/18/2020	20	8/18/2020	63
9/29/2020	42		
10/14/2020	15	10/14/2020	57
11/30/2020	47		
12/14/2020	14	12/14/2020	61
1/19/2021	36	1/19/2021	36

Table S2. Confusion matrix between each gap event observed in the UAV imagery and in the field data at the INVENTA plot, Central Amazon, Brazil, from November 01, 2019 to January 19, 2021. The gaps identified in the UAV imagery are considered as observed value that have been validated in the field (true value).

	Field data (True Value)	
	UAV Imagery (Observed values)	14 (True Positive – TP)
	1 (False Positive – FP)	0 (True Negative – TN)

Table S3. Paired t-test p-values between gaps measured by both methods (UAV imagery and Field Data) at the INVENTA plot, Central Amazon, Brazil, in the period from September 18, 2018 to January 19, 2021.

Paired t-test (p-value)		
Area	Perimeter	GSCI
0.8544	0.01019	< 0.001

Table S4. Cumulative frequency and area of gaps measured by UAV imagery and field data for 28 months, in the INVENTA plot, Central Amazon, Brazil, in the period from September 18, 2018 to January 19, 2021.

Method	Cumulative frequency (% of total number)				
	$\leq 20 \text{ m}^2$	$\leq 25 \text{ m}^2$	$\leq 30 \text{ m}^2$	$\leq 35 \text{ m}^2$	$\leq 40 \text{ m}^2$
Field data	10.34	24.14	27.59	37.93	44.83
UAV Imagery	13.79	24.14	37.93	44.83	51.72
	Cumulative area (% of total area)				
	$\leq 20 \text{ m}^2$	$\leq 25 \text{ m}^2$	$\leq 30 \text{ m}^2$	$\leq 35 \text{ m}^2$	$\leq 40 \text{ m}^2$
Field data	2.12	6.68	8.05	12.98	16.83
UAV Imagery	2.44	5.35	9.96	12.86	16.01

Table S5. Summary of fitting measures of the Exponential, Power-law, Weibull and Lognormal functions describing the size distribution of gaps identified on the INVENTA plot, Central Amazon, Brazil. Δ AIC- AIC (Akaike information criterion) differences to the best model; The best fit models for each data-set are highlighted in bold.

Detection method	Minimum size (m ²)	Distribution	λ (95 % CI)	α (95 % CI)	K-S	Log likelihood	Δ AIC
UAV imagery	10	Exponential	0.014 (0.008 – 0.031)		0.249	-152.99	9.89
	10	Power-law	1.650 (1.529 – 1.831)		0.224	-152.03	7.98
	10	Weibull	0.512 (0.266 – 1.460)	21.544 (0.770 – 65.311)	0.116	-148.08	2.077
	10	Lognormal	3.559 (2.230 – 4.017)	1.105 (0.691 – 1.846)	0.107	-147.04	0
	25	Exponential	0.013 (0.007 – 0.032)		0.2879	-117.62	13.41204
	25	Power	2.094 (1.901 – 2.501)		0.0760	-110.92	0
	25	Weibull	0.157 (0.078 – 1.685)	0.0002 (0.000 – 61.480)	0.0868	-110.75	1.661607
	25	Lognormal	-	-	-	-	-
Field data	9	Exponential	0.017 (0.009 – 0.032)		0.166	-146.79	4.9063
	9	Power-law	1.614 (1.490 – 1.746)		0.266	-153.01	17.3533
	9	Weibull	0.744 (0.477 – 2.186)	40.370 (15.850 – 68.667)	0.146	-145.61	4.5635
	9	Lognormal	3.741 (3.376 – 4.070)	0.836 (0.506 – 1.265)	0.108	-143.33	0
	25	Exponential	0.017 (0.008 – 0.043)		0.215	-111.134	4.5447
	25	Power-law	2.137 (1.811 – 2.670)		0.158	-109.306	0.8869
	25	Weibull	0.414 (0.121 – 2.878)	4.712 (0.000 – 67.811)	0.144	-108.277	0.8305
	25	Lognormal	3.4735 (-22.971 – 4.1895)	0.975 (0.3404 – 3.7346)	0.139	-107.862	0

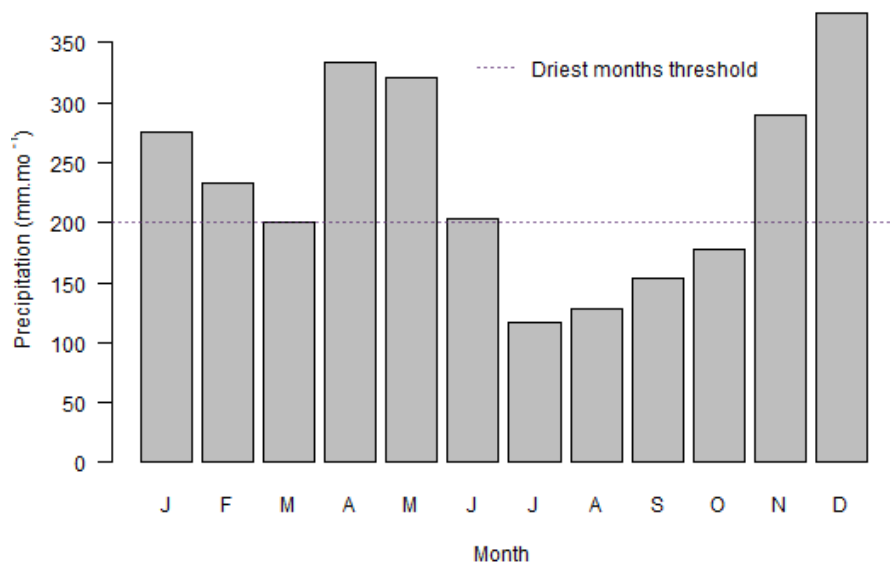


Figure S1. Mean monthly precipitation measured near (~2 km) the INVENTA plot, Central Amazon, Brazil during the study period.

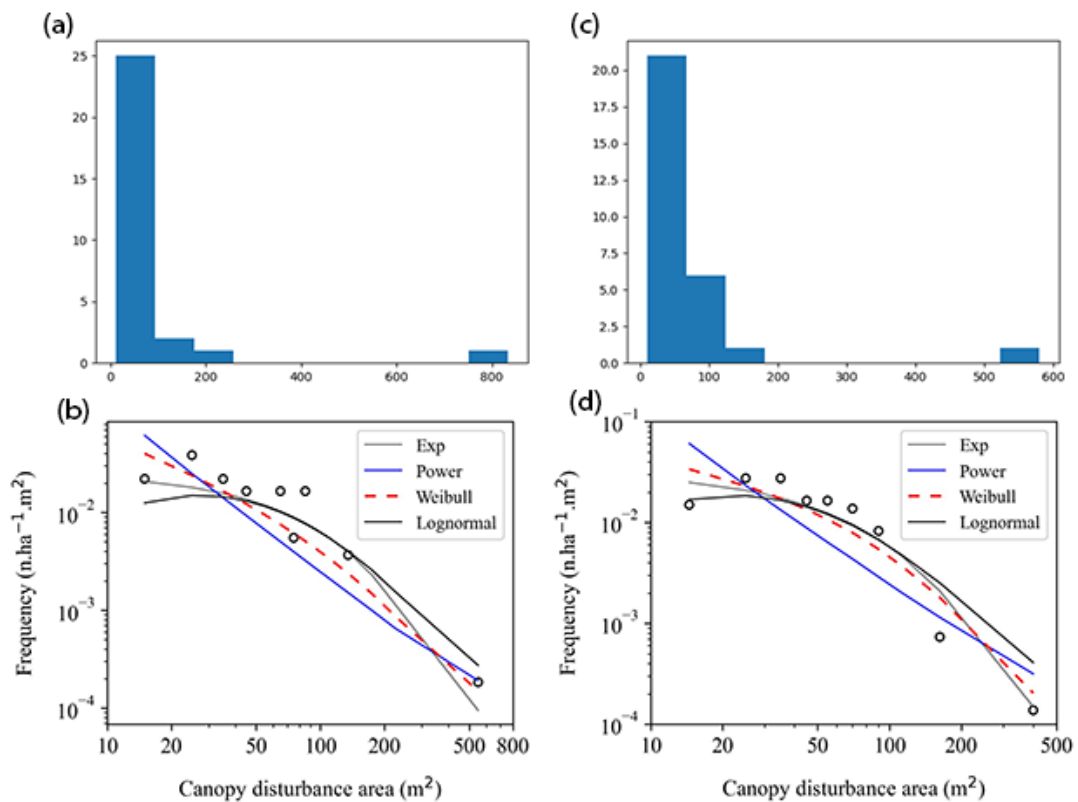


Figure S2. Size distribution of gaps at the INVENTA plot, Central Amazon, Brazil, for the period from September 18th, 2018 to January 19th, 2021. Size distribution of gaps detected with UAV photogrammetry (a) and field surveys (c). Fitted distributions of gaps larger than 10 m² detected with UAV imagery (b) and field data (d).

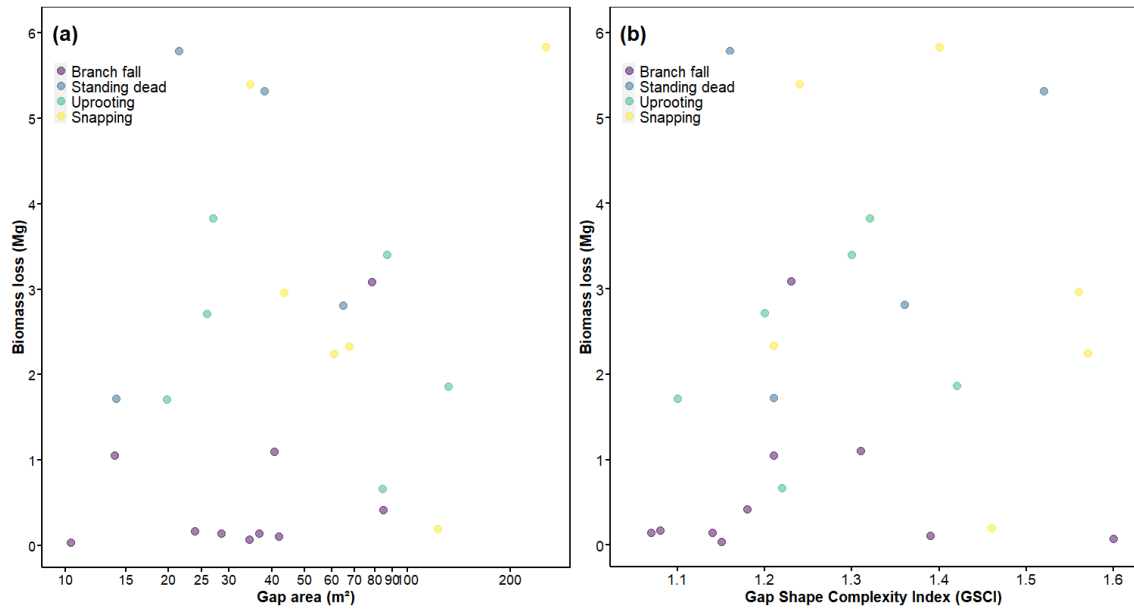


Figure S3: Relationship between biomass loss and gap area (a) and between biomass loss and Gap Shape Complexity Index (GSCI) (b) at the INVENTA plot, Central Amazon, Brazil. The data were collected from September 18th 2018 to January 19th 2021. Gap area was determined from UAV Imagery data. X-axis in panel a is log-scaled.

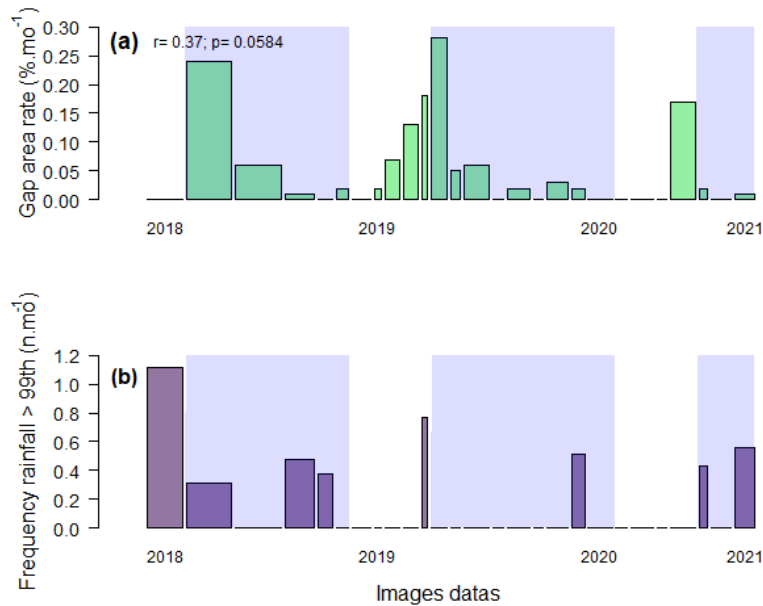


Figure S4: Cumulative area of gap formation per observation interval (gap area rate per month), expressed as the percentage of the total study area normalized to a 30-days interval; (a) and frequency of extreme rainfall events per month (b) at the INVENTA plot, Central Amazon, Brazil, during the period from 18th September 2018 to 19th January 2021. The blue shading indicates the rainy seasons (September to June) each year. The frequency of extreme rain events is given as absolute values normalized to a monthly rate for a 30-days interval. The area of the green rectangle (a) is proportional to the total area of gaps formed between respective observation dates.