Supplementary Data

Supplement 1: Summary tables of uncrewed aerial vehicle (UAV) papers reviewed in the systematic literature review (n = 50).

Table S1. Study design and uncrewed aerial vehicle (UAV) mission design decisions for each of the 50 papers identified following the PRISMA systematic literature review process.

Reference	Location	Type of Shrubland/ Savanna	Number of Sites	UAV Platform	Sensors	Flight Altitude (m)	Forward/ Side overlap (%)	GSD (cm/pixel)	GCP (#)	Grid Pattern	Camera gimbal position	Frequency of Data Collection	Biomass Ground Truth Data	Number of biomass samples	Biomass Sample size (m2)	Canopy height measures	Crown measures
Abdullah et al. [51]	Kuwait	Shrubland	1	fixed-wing	RGB & Multispectral	80	NR	7.5	NR	NR	nadir	1 time, Dec 2018	Fishnet grid % cover for allometry estimate	0	NA	DSM-DTM	$CA=R1*R2*\pi$ $SV=(4/3)*\pi r^2 h$
Abdullah et al. [52]	Kuwait	Shrubland	1	fixed-wing	Multispectral	80	80/80	7.2	NR	NR	nadir	1 time, Jan. 2019	Fishnet grid % cover for allometry estimate	0	NA	Ruler, DSM-DTM	$CA=R1*R2*\pi$ $SV=(4/3)*\pi r^2 h$
Alonzo et al. [73]	USA	Upper montane forest and subalpine	2	quadcopter	RGB	55	90/90	1.5-2.0	5/plot	Double grid	oblique	1 time, Jul 2018	DRC for allometry estimate	0	NA	DSM-DTM	NA
Brede et al. [47]	Global	European beech and oak, lowland tropical terra firme forest, logged rainforest, tropical savanna	4	quadcopter	UAV LiDAR & TLS	55-110	NR	NA	NA	NA	NA			0	NA	LiDAR DSM-DTM	
Chen et al. [81]	China	Grassland with shrub encroachment	2	quadcopter	RGB, Hyperspe	100-350	70/60, NA/50	3/15	NR	NR	NR	1 time, Jul 2022	harvest	22	Individual shrubs	Ruler – max height	Shrub height and

					ctral & LiDAR												crown diameter
Cheng et al. [96]	China	Park (trees, shrubs, grasses)	1	quadcopter	Multispectral	200	80/70	NR	NR	NR	NR	1 time	allometry				
Combs et al. [91]	USA	Parthenium argentatum experimental plot	1	quadcopter	RGB, Multispectral	25-100	NR	NR	NR	Double grid, freehand	nadir	8 times, Aug 2019 – Feb 2019	Harvest	NR	NR	Ruler – max height	Crown projected area (m^2)
Cunliffe et al. [74]	Canada	graminoid-shrub ecotone	1	hexacopter	RGB, Multispectral	19-121	75/65	0.5-12	26	NR	nadir & oblique	1 time, Jul 2016	Harvest	36	$0.5m^2$	Interpolated ground points with GNSS using IDW	Max height
Cunliffe et al. [53]	USA	Chihuahuan desert site, grasses, shrubs, juniper	1	hexacopter	RGB	15-20	70/65	0.4-0.7	10-18	Double grid	nadir & oblique	1 time, Oct 2014	Allometry	0	NR	DSM-DTM	Max height
Cunliffe et al. [48]	Global	Tundra, temperate grassland/desert, subtropical desert, woodland/shrubland, temperate seasonal forest	36	various	RGB	various	75/75	Various	13	Double grid	nadir & oblique	1 time, 2019	Harvest	741	Min $0.5m^2$	DSM-DTM	Mean canopy height
Ding et al. [54	China	Gobi desert shrubs	1	quadcopter	RGB	60	75/70	1.5	5	NR	nadir	1 time, 2018-2020	Harvest	143 shrubs	Individual shrubs	DSM-DTM	Imagery canopy size
Eames et al. [64]	Botswana & Mozambique	Tropical and subtropical grasslands, savannas, and shrublands	2	quadcopter	Multispectral	50	80/80	5	2	NR	NR	2 times, 2018-2019	Harvest	45	$1m^2$ (grass, litter), $5m^2$ (coarse), counts (shrubs, trees)	DSM	None
Elshikha et al. [92]	USA	Parthenium argentatum experimental plots	1	quadcopter	RGB, Multispectral	61	NR	NR	NR	NR	NR	Numerous times, Jun 2018 –	Harvest	NR	1-$3m^2$		Crown diameters / planting area/plant

												Mar 2020					ing density
Han et al. [75]	China	Alpine meadow, alpine steppe	1 national park, 96 UAV plots	quadcopter	RGB	110	85/85	3	NR	single	NR	NR	Harvest	2400	1m^2	None	None
Hartley et al. [82]	New Zealand	shrublands	1	hexacopter	RGB & LiDAR	50	80/80 & 85/85	3.5	41		nadir	1 time, Feb-Mar 2020	Harvest	16	1 x 4 m^2	DSM-DTM	Mean height, cover
Herzog et al. [84]	USA	Carolina sandhills	1	quadcopter	RGB	100	80/80	6	NR	NR	nadir & oblique	2 times, preburn, postburn	Harvest	4	0.5 x 0.5 x 2 m		TLS fuel density
Husson et al. [88]	Sweden	Middle boreal subzone	1	fixed-wing	RGB	150	NR	5	15-20		nadir	1 time, Jul 2011	Harvest	252	0.5m^2	None	Biomass, cover
Jucker et al. [86]	Australia	Great western woodlands	4+	hexacopter	LiDAR	90	NR	NA	NA	Double grid	NA	1 time, 2021	Allometry	128 plots			Max height, mean height, canopy cover over 2m
Leite et al. [65]	Brazil	Campo limpo, Campo sujo, and Campo ralo in Cerrado	4	hexacopter	LiDAR							1 time, Jul 2019	Harvest	50	1m2 (duff, litter, dw, herbs), 1x5m (shrubs & trees < 10 cm)	DSM-DTM	
Levick et al. [66]	Australia	Savanna woodlands	1	hexacopter	LiDAR	40				Single grid		1 time, Jul 2019	Allometry		Trees >3cm dbh, > 1.5m height	DSM-DTM	
Li et al. [89]	China	Mangrove national nature reserve	1	hexacopter	RGB	100	74/65	NR	24	NR	NR	1 time, Aug 2017	Harvest for the shrub, allome	10	1m^2	DSM-DTM	Canopy cover and height (shrub), DBH,

												try for the trees					height for the trees
Liu et al. [55]	China	Temperate arid forests, shrublands, grasslands and desert grasslands	1	quadcopter	Multispectral	NR		6			NR	1 time, Aug 2023	Harvest	7			Canopy area and crown volume tested, CA used
Madsen et al. [83]	Denmark	Temperate grasslands with shrub encroachment, national park	1	octocopter	LiDAR	40	NR/65		12+5	Single grid		2 flights, Oct. 2017, April 2018	Harvest	10		DSM-DTM	
Mao et al. [56]	China	Desert plateau rangeland	1	quadcopter	RGB	50	85/75	1.3	19	NR	NR	1 time, Aug 2021	Harvest & allometry	9+9	shrub	DSM-DTM	Crown Height, perpendicular diameters
Mao et al. [57]	China	Desert grassland research station	1	quadcopter	RGB	30-150	85/75	0.8-4.1	5	NR	NR	1 time period, Aug 2021	Harvest	14	Shrub	DSM-DTM	
Mao et al. [58]	China	Desert shrublands	1	quadcopter	RGB	10	90/75	0.4		5 different angle grids	Nadir & 45 deg oblique		Virtual allometry from 3D model, Field allometry	46, 7	Shrub	DSM-DTM	Crown volume, height (max, mean, sd), canopy area
Matyukira and Mhangara [67]	South Africa	Savanna, low-growing thorn savannas	1	quadcopter	RGB & Thermal	60		3.5					Existing raster dataset			DSM-DTM	Canopy height, chlorophyll
McCann et al. [68]	Australia	Low woodlands, floodplain woodlands	2	quadcopter	RGB	10	70/70			Manual grid	nadir & oblique	1 time, April 2017	Harvest	27	Shrub	Extracted Point cloud, convex hull	Max canopy height, max width and perpendicular width
Navarro et al. [90]	Australia	Subtropical shrub/dwarf mangrove, mangrove complex	2	quadcopter	RGB	30	85/70		10-15	Double grid	NR	1 time, Jan-May 2018	Allometry			DSM-DTM	Height, basal diameter, stem diameter,

																		average canopy diameter (crown area)
Orndahl et al. [49]	USA & Canada	Arctic and subarctic interior Alaska-Yukon lowlands	44	quadcopter	RGB & Multispectral	30	85/85	0.75, 2	5	Single grid	Nadir, sometimes oblique also	1 time, 2018 or 2019	Harvest	220	0.25 m^2	DSM-DTM	Average height, field biomass
Orndahl et al. [50]	USA & Canada	Boreal forest, dense shrublands, wet tundra, lichen barrens	44	quadcopter	Multispectral	30	85/85	0.75, 2	5	Single grid	Nadir, sometimes oblique also	1 time, 2018 or 2019	Harvest	266	0.25 m^2	DSM-DTM	Average height, field biomass
Osorio-Castiblanco [76]	Colombia	Andean high-mountain tropical, near a national park	1	not reported	RGB			12.51				1 time, Jul 2022	Allometry			DSM-DTM	
Pan et al. [69]	Taiwan	Subalpine dwarf bamboo	1	quadcopter & hexacopter	LiDAR	82	NR/30			Single grid		1 time, Nov. 2021	Harvest	74	1m^2	DSM - DTM	
Poley et al. [77]	Canada	National park	2	fixed-wing	RGB, Multispectral	70	70/80	1.5, 6	9	Double grid	NR	1 time, July 2018	Allometry	60 + 15	Shrub	DSM-DTM	Basal stem diameter, number of stems per plant
Putkiranta et al. [78]	Finland	National park, dry shrub tundra heath	1	not reported	Hyperspectral, Multispectral	60-200	NR	5-13, 10-19	NR	NR	NR	2 times, Aug 2020, Jul 2022	Allometry		PFT		Percent cover, height
Sagang et al. [70]	Camaroon	National park, forest savanna mosaic		hexacopter	LiDAR	70	NR/50					1 time, 2019	Allometry		Forest type	DSM-DTM	Height from CHM, land cover
Sankey et al. [59]	USA	Experimental forest, chaparral	1	fixed-wing	Multispectral	80		13				1 time, July 2017	Allometry	30	Shrub	DSM-DTM	Height, canopy diameter, basal radius (oak) estimated

Shrestha et al. [85]	USA	Experimental forest in flatwood pine savanna w/Eddy Covariance tower	1	hexacopter	LiDAR	65-80	NR/70-90					2 times, May 2018, Nov 2018	Harvest, allometry for saw palmetto	20	1m^2		Height,
Singh et al. [71]	South Africa	National park, trees/woodlands	4	hexacopter	RGB, thermal, LiDAR	100	NR/60%			Single grid		2020 (LiDAR)	Allometry of LiDAR trees		LiDAR trees	DSM-DTM	Canopy height, crown area, returns per voxel
Slavskiy et al. [87]	Russia	Forested areas	1	quadcopter	Hyperspectral, LiDAR	60-130		2.0-2.5					Allometry				Species, height, density (pcs/ha)
Sun et al. [60]	China	Shrub-encroached grasslands	1	quadcopter	RGB, LiDAR	120	80/80	3	NR	NR	NR	1 time, Jul 2021	Harvest, allometry	17, 227	Shrubs	DSM-DTM	Height, crown widths, perimeters
Talucci et al. [79]	Russia	Boreal forest fire regeneration	4	quadcopter	RGB, Multispectral	60-120		1.54-6.85	5-10			1 time, 2019	Allometry		1m^2		Basal diameter or DBH
Tamiminia et al. [93]	USA	Experimental fields	1	quadcopter	Multispectral	60	80/80	4.06				1 time, Jun 2019	Allometry	48	11.96 m^2	DSM-DTM	Diameter at 30cm,
Tao et al. [94]	China	Evergreen plantation	1	quadcopter	Multispectral, LiDAR	70	NR/70	5				1 time, Aug 2023	Allometry	825	trees	DSM - DTM	DBH, DGH, Tree height, Crown diameter
Teixeira da Costa et al. [72]	Brazil	Three national parks, one university forest, Brazilian cerrado (tropical savanna)	4	hexacopter	LiDAR	100	NR	NR	NR	NR	NR	1 time, Jul 2019	Harvest	94	1 x 5m^2	Ruler	Height, DBH,
Vega-Puga et al. [61]	Mexico	Subtropical shrubland	1	quadcopter	RGB	35	90/90				96°				Shrubs > 2m	Clinometer	Height, crown widths, DBH (estimate crown area and

																	crown volume)
Villoslada et al. [80]	Norway & Finland	Heathland and willow communities	1	fixed-wing	RGB, Multispectral			3.5/11	4 GCP, 4 MCP			1 time, Jul 2021	Harvest	105	0.5m^2	DSM-CHM	Canopy cover,
Zhang et al. [95]	China	Planted shrub belts	1	quadcopter	RGB	60	90/70	3	58	Single grid	NR	1 time	Allometry	209	shrub	DSM-CHM	Average height, average crown width
Zhao et al. [62]	China	Desert shrubland	1	fixed-wing	RGB, Multispectral, UAV LiDAR	80, 80, 16	80/80	4, 16	Some	NR	NR	1 time, Jul 2017	Harvest	48	Shrubs >10cm height	UAV & TLS CHMs	Thickness (distance from deepest point and the pixels around it – canopy size), canopy width at longest axis
Zi-chen et al. [63]	China	Sandy land of grassland, shrublands	1 (87 plots)	quadcopter	RGB	40	50/50	NR	NR	NR	nadir	3 years, NR for UAV	Harvest	187 shrubs,	Shrub, herb = 1m^2	Ruler	Field (Crown width, cover of grasses), hand digitized shrub canopy shape and extracted widths ArcGIS

Table S2. Data processing steps for LiDAR and SfM structural data, statistical frameworks, and top model predictor variables for each of the 50 papers identified following the PRISMA systematic literature review process. NR = Not reported.

Reference	Spectral Data	Structural Data	Other Data	Terrain model source	Ground Classification method	Classification method	Species or Plot-level	Statistical Methods Tested	Best Performing Statistical Method	R2 or Adjusted R2	Vegetation Index	Variables used in top performing model
Abdullah et al. [51]	RGB & Multispectral	Canopy area, volume, max height		SfM	Pix4D	None	Single species	Simple linear regression	Crown Area	LR = 0.815	None	Crown Area
Abdullah et al. [52]	Multispectral	Canopy area, volume, max height		SfM	Pix4D	None	Single species	Simple linear regression	Shrub Volume	LR = 0.740	None	Shrub Volume
Alonzo et al. [73]	RGB	LiDAR & SfM	airborne LiDAR & RGB	LiDAR & SfM	NR	None	Plot-level	Multiple linear regression	Varied by site	MLR = 0.70-0.88	None	Mean height of returns between 0.1-5m *mean height of returns divided by median height of returns * % canopy pixels between 1-4m
Brede et al. [47]	None	UAV LiDAR & TLS	TLS	LiDAR	CSF	Tree-QSM	Plot-level, individual level	logarithmic regression, RF	Reported for LF (savanna) site	RMSE = 0.42, RMSE = 0.34	None	Graph edge length (GEL), GEL*crown diameter, Max Height * crown diameter, volume, graph nodes
Chen et al. [81]	RGB, Hyperspectral	UAV LiDAR	Sentinel 1 & 2	UAV LiDAR	progressive TIN densification filtering algorithm	OB MaxEnt	Plot-level, individual level	Vegetation index weighted canopy volume model, XGBoost	CVM(water band index)	0.821	Water Band index	Canopy volume (CVM(WBI))
Cheng et al. [96]	Multispectral			SfM	NA	RF	Plot-level	RF	spectral and textural features	0.88	NDVI, RVI, GNDVI, WDRVI, NDRE, RECI	NDVI, RVI, GNDVI, WDRVI, NDRE, RECI, GLCM Mean, Ent, Cor
Combs et al. [91]	RGB, Multispectral	UAV CHM	Sentinel -2 NDVI	SfM	Pre vs Post ground		Plot-level	Generalized least	Height, tier2,	0		Mean pixel Height, tier2, tier3, tier 4

								squares regression	tier3, tier 4			
Cunliffe et al. [74]	Multispectral	UAV CHM		SfM			Plant-level, Plot-level	Least squares optimization of linear models	Canopy height linear model	0.90 plant, 0.7 plot	NDVI performed poorly	Max canopy height – plant, shrub leaf biomass - plot
Cunliffe et al. [53]	RGB	UAV CHM		SfM		Height bins	Functional group	linear regression	Canopy volume		None	Canopy volume
Cunliffe et al. [48]	RGB	UAV CHM		SfM			Plant functional group	Ordinary least squares regression	Mean canopy height	0.59 (shrubs), 0.71 (trees), 0.91 (succulents)	None	Mean canopy height
Ding et al. [54	RGB	UAV CHM		SfM		OBIA	Plot-level	power, exponent, quadratic, cubic, linear, logarithm	Power	0.847	EXG	Crown area
Eames et al. [64]	Multispectral	DSM		SfM		OBIA, CNN for trees and shrub number	Plot-level	OLS regression for each fuel class	OLS regression for each fuel class	0.51	Only used for classification, not in AGB	Time since fire, % grass, %foliage, %bare, tree/shrub #, precip, mean temp, mean solar rad, total evap, soil moisture
Elshikha et al. [92]	Multispectral						Plot-level	linear regression	NDVI linear regression	0.75	NDVI	NDVI
Han et al. [75]	RGB		Landsat 1990-2017			NDVI	Plot-level	Linear regression	NDVI linear regression, after UAS plot level GLI regression with field biomass	0.59-0.68	NDVI	NDVI
Hartley et al. [82]	RGB	LiDAR		UAV LiDAR	LidR package (R)	Semantic segmentation (CNN)	Plot-level	multiple regression	VOXPO at 5cm resolutions	0.89		VOXPO
Herzog et al. [84]	RGB	LiDAR – ALS, TLS		LiDAR				Linear regression	Fuel density	0.95-0.99		Rasterized fuel density from canopy area

Husson et al. [88]	RGB	UAV LiDAR			Manual vegetation mapping (GIS)	Plot-level		Cover class biomass			
Jucker et al. [86]		LiDAR	GEDI			Plot-level	linear mixed-effects model				Woodland type, Height, cover, aridity index, topographic wetness
Leite et al. [65]		LiDAR	GEDI	DSM-DTM			RF	RF	0.85 (shrubs), 0.97 (trees), 0.80 (herb)	None	Relative height (98th percentile), canopy cover fraction, foliage height diversity, plant area index, surface fuels, herbaceous fuels, shrub fuels, woody fuels, and total fuels
Levick et al. [66]		UAV LiDAR	TLS LiDAR, Mobile LiDAR				Multiple linear regression and RF		0.34	None	DBH, canopy height, crown area, crown width, crown volume
Li et al. [89]	RGB			DSM-DTM	OBIA-multi-resolution segmentation, also SVM		RF, ANN, SVM	RF	0.81	EXG top index, EXGR, Blue, Red, GLI, Green also included	30 variables, including species, height metrics, vegetation indices, and texture
Liu et al. [55]	RGB, Multispectral		Sentinel 1/2, Landsat 8/9,	None	RF	Plot level	RF	RF	0.62	DVI, SAVI2	DVI, SAVI2, VH, VV
Madsen et al. [83]		LiDAR		DSM-DTM	Height classes, ML	Plot level, species level	linear regression		0.77		Maximum volume from normalized height
Mao et al. [56]	RGB		Landsat 8, Sentinel 2A, PlanetScope	SfM	Context capture's algorithm	OBIA	Species level	crown volume linear regression, canopy area, canopy height (max), then GAM for satellite data		0.749-0.91 (species level), 0.93 plot level	SR, REDVI2, DVI	Species level – crown volume,

Mao et al. [57]	RGB		SfM		OBIA	Plot level, species level	simple linear regression	Crown area	0.72 VE		Crown area, regardless of height
Mao et al. [58]	RGB		SfM		OBIA	Species level	linear, power, exponential, polynomial, logarithmic regression for AGB	crown volume linear regression	0.928		Crown volume
Matyukira and Mhangara [67]	RGB	UAV Thermal (but not used for regressions)	SfM				PCA & stepwise linear regression	Non-riparian (RBVI, height, GRBI, GBVI)	0.66	RBVI, GRBI, GBVI	RBVI, height, GRBI, GBVI
McCann et al. [68]	RGB		Point cloud measurements		Manual segmentation	Species level	Linear regression				Convex hull volume (drone), field volume estimates
Navarro et al. [90]	RGB	UAV	SfM	PMF	Watershed segmentation	Plot level	Linear regression		0.917-0.932		Field allometry of AGB
Orndahl et al. [49]	RGB & Multispectral		SfM		RF	Plant functional group level	linear mixed effect models		0.28-0.78		avg. height x pixel area = volume
Orndahl et al. [50]	Multispectral		SfM		RF	Plant functional group level	Linear mixed effect models with LASSO regularization using glmmLasso	Varied for PFT	0.07-0.41	swir2, nbr autumn, evi autumn, tcw late autumn, red spring/summer, bluecc early spring to spring	Deciduous shrubs (shrub cover, swir2 summer, herb cov, tussock tundra cov, low shrub cov) Evergreen shrubs (nbr autumn, evi autumn, tcw late autumn, red spring/summer, bluecc early spring to spring).
Osorio-Castiblanco [76]	RGB	PlanetScope	SfM		OBIA & RF	Species level	allometric equation		0.7		Log height
Pan et al. [69]		LiDAR	LiDAR		RF		stepwise linear regression, PC, PLS, multivariate adaptive		0.27-0.53		Max height, 95% height, 65% height

							regression splines				
Poley et al. [77]	RGB, Multispectral			SfM	Agisoft and Pix4D defaults	OBIA (CHM, BGRI, RRVI)	Plot level	single and multiple linear regression	2 variable linear regression	0.732-0.76	Green ratio sum + MSRed Max & Red ratio sum + MSRed std	Green ratio sum + MSRed Max & Red ratio sum + MSRed std
Putkiranta et al. [78]	Hyperspectral, Multispectral	2-m ALS	0.5m NLS multispectral		Failed attempt	Fuzzy clustering using non-metric multidimensional scaling and fuzzy k-medoids	Plant functional type	RF	RF	0.60	435 soil and vegetation indices from HSI (not in spectral indices table), 18 soil and vegetation indices from MSI, 7 from NLS	DEM, blue, NGRDI, Red, NDVI, RVI, NDRE, TPI-100, TWI, bluevar, greenvar, redvar
Sagang et al. [70]		LiDAR	Landsat, Sentinel 2	LiDAR	PMF (lidR)		Forest type	Simple linear regression		No accuracy assessment for AGB		AGB = 3.2 x AGE +69
Sankey et al. [59]	Multispectral			SfM	BCAL (envi 5.2)	CART	Species or PFT	Simple linear regression		No accuracy assessment for AGB	No spectral indices used for biomass estimation	Estimated BR, used CHM canopy height, crown area
Shrestha et al. [85]		LiDAR		UAV LiDAR	LAS Tools	Map.hough TreeLS treeMap, and height classes	PFT	linear mixed-effect model with nested ANOVA & simple linear regression		0.579	No spectral indices used for biomass estimation	Soil moisture was a fixed effect, LiDAR height
Singh et al. [71]		LiDAR				watershed				No accuracy assessment for AGB		
Slavskiy et al. [87]	RGB, Hyperspectral	UAV LiDAR				YOLO Neural network		allometry			NDVI, EVI, CVI	DBH, height, average crown diameter
Sun et al. [60]	RGB	UAV LiDAR	GF6 WFV satellite			OBIA	Species	-	RF	0.81		Size, crown diameters, crown perimeter, elev canopy relief ratio, density metrics

Talucci et al. [79]	RGB, Multispectral			SfM		Field biomass, not segmented or classified		linear regression		0.55	NDVI, GCC	NDVI
Tamimini a et al. [93]	Multispectral			SfM	Pix4D procedure	None performed		RF, DT, CNN, SVM (2 types), multiple linear regression	RF	0.95	DVI, GLI, NDVI, Red, NIR	13 parameters used (DVI, GLI, NDVI, Red, NIR were most important), height added = 0.94
Tao et al. [94]	Multispectral	LiDAR	Jilin-1 0.5m & Sentinel-2		TIN based filtering	Watershed segmentation, CNN	Species	RF, XGBoost	RF	0.639	11 veg indices tested	EVI, DVI GNDVI, RDVI
Teixeira da Costa et al. [72]		UAV LiDAR		UAV LiDAR	LasTools (lasground) CSF I think		30 m pixel	Ordinary least squares (H98th, Canopy cover, HSke, H50th, HKur)	OLS with 2 variables	0.79	none	H98th, Cover
Vega-Puga et al. [61]	RGB			SfM	Pix4D procedure	Manual and ForestTools	PFT	Simple and multiple linear regression	Crown area	0.77	none	Manual digitized crown area, similar results with manually digitized crown volume
Villoslada et al. [80]	RGB, Multispectral			SfM	CSF	RF, XGBoost using Datt4	PFT	XGBoost & RF	XGBoost	0.60-0.90	GLCM-dis, CVI, Datt4, GRDI, GRVI, NDVI	For woody AGG (GNDVI, CVI, NDVI, Canopy height, dis, Datt4, GRDI, GRVI)
Zhang et al. [95]	RGB			SfM	Agisoft and kriging interpolation	Only 1 species planted, no classification needed		simple linear regression		0.74		Shrub belt volume
Zhao et al. [62]	RGB, Multispectral	UAV LiDAR	TLS LiDAR	UAV LiDAR	LasTools (likely CSF)	Decision tree	Shrub from all other classes	Multiple linear regression, RF, SVM	Multiple linear regression for combined data	0.86	NDVI, RVI, WDRVI, SAVI, DVI	Contrast-SUM, Volume, Thickness, RVI-SUM, Major axis, DVI-Range, Mean_Range, 50thPercentile_height, RVI-Max, Variance-sd
Zi-chen et al. [63]	RGB				None	OBIA, fixed thresholds, k-means clustering	PFT	Linear, quadratic, cubic, logarithmic	Power function (5 of 6 shrub species),	0.81	EXG, VARI, VEG, MGRVI, RGBVI	Cubic for shrub coverage - AGB model

				and power regressions	quadratic 1 species,

Table S3. Systematic literature review results listing all tested predictor variables used in models for AGB estimation.

Categories of Predictor Variables	Tested Predictor Variables	Used By:
Height	Mean height	48, 49, 57, 59, 69, 70,76, 77, 79, 80, 81, 82, 85, 86, 89, 90, 94
	Maximum height	51, 52, 53, 56, 57, 58, 66, 69, 71, 72, 74, 77, 79, 81, 82, 86, 87, 91, 94, (98% RH, top of canopy: 65)
	Minimum height	69, 81
	Standard deviation of height	57, 69, 82, 89, 94, 95
	Coefficient of variation of height	89
	Variance of height	69
	Skewness of height	69, 82, 94
	Kurtosis of height	69, 82, 94
	Entropy of height	69, 82
	Height percentiles	53, 69, 81, 82, 94, 95
	Cumulative percent of returns below deciles	82
	Percentage of points above mean height	69, 82
	Sum of all heights	69, 77
	Height of median energy	94
Area & Density	Canopy point density per voxel	71, 83
	Canopy density percentiles	60
	Canopy cover/ Canopy area	51, 52, 56, 57, 58, 59, 66, 71, 72, 88
	Canopy cover above 2m AGL	86
	Canopy cover above 2m, 5m, and 10m AGL	66
	Canopy cover (percent of first return above 1.3m)	94
	Canopy relief ratio	84
	Canopy width	60
	Canopy perimeter	60, 66, 80, 87, 90, 95 (longest width & thickness)
	Number of voxels that contain at least 1 return	60, 47
	Percentage of voxels that contain at least 1 return	82, 47
	Number of points returned in a plot, percentage of first and second return	82
	Rumple index (top surface of point cloud)	69, 83
	Mean leaf area density	69
	Median leaf area density	82
	Maximum leaf area density	82
Intensity	Maximum intensity	82
	Mean intensity	69, 81, 82
	Minimum intensity	69, 81, 82
	Standard deviation of intensity	81
	Skewness of intensity	69, 82
	Kurtosis of intensity	69, 82

	Intensity percentiles	69, 82
	Percentage of intensity returns classified as ground	69, 81
	Percentage of intensity returned below the percentile classes of height	82
Volume	Crown volume	82
	Crown volume (max, mean, CV)	49, 51, 52, 56, 57, 58, 68, 72, 95
	Volumetric percentage of returns	66
Topography or Site Condition-based	Elevation (DEM)	69
	Topographic wetness index (TWI)	78
	Topographic position index (TPI)	78
	Time since last fire	78
	Total precipitation	
	Total evaporation	58, 61, 81, 89, 96, (dissimilarity only), 95, (sum, range, sd)
	Mean soil moisture	58, 89, 96
	Mean surface net solar radiation	59
Texture-based		48, 49, 57, 59, 69, 70,76, 77, 79, 80, 81, 82, 85, 86, 89, 90, 94
Gray scale co-occurrence matrix (GLCM) textures	Mean, variance, homogeneity, contrast, dissimilarity, entropy, second moment	51, 52, 53, 56, 57, 58, 66, 69, 71, 72, 74, 77, 79, 81, 82, 86, 87, 91, 94, (98% RH, top of canopy: 65)
	Correlation	69, 81
	Mean texture of NDVI and NDRE	57, 69, 82, 89, 94, 95
Spectral Indices	**Equations**	
Blue		77, 89
Blue-mu	Mean((blue-green)/(blue+green))	73, 81
Blue-med	Median(blue-green)/(blue+green))	73
Blue-std	Standard deviation((blue-green)/(blue+green))	73
Blue-skw	Skewness((blue-green)/(blue+green))	73
Green		77, 89
Green-mu	Mean((Green -red)/(Green + red))	73, 81
Green-med	Median((Green - red)/(Green + red))	73
Green-std	Standard deviation((Green - red)/(Green + red))	73
Green-skw	Skewness((Green - red)/(Green + red))	73
Red		77, 89
Red-mu	Mean(-green)/(blue+green))	73, 81
Red-med	Median(blue-green)/(blue+green))	73
Red-std	Standard deviation((blue-green)/(blue+green))	73
Red-skw	Skewness((blue-green)/(blue+green))	73
Red edge		77
NIR		77
Bright-mu	Mean(red + green + blue)	73, 81
Bright-med	Median(red + green + blue)	73
Bright-std	Standard deviation(red + green + blue)	73

Bright-skw	Skewness(red + green + blue)	73
Color intensity index (INT)	(Red + Green + Blue)/3	58, 77
Low_green_mu	Mean greenness between 0.1-5m	73
Excess green vegetation index (EXG)	2× *Green – Red – Blue*	54, 58, 63, 67, 77, 79, 81, 89
Excess green minus excess red vegetation index (EXGR)	3x Green – 2.4 x Red - Blue	54, 89
Excess blue vegetation index (ExB)	1.4 x Blue – Green	58, 77
Excess red vegetation index (ExR)	1.4 x Red – Green	58, 77
Excess green minus excess red index (ExGR)	ExG - ExR	58, 77
Color index of vegetation (CIVE)	0.441 x Red – 0.881 x Green + 0.385 x Blue + 18.78745	58, 77
Combination (COM)	0.25 x ExG + 0.3 x ExGR + 0.33 x CIVE + 0.12 x VEG	58
Normalized green-blue difference index (NGBDI)	(Green – Blue)/(Green + Blue)	77, 81, 89
Normalized green-red difference index (NGRDI)	(Green – Red)/(Green + Red)	55, 56, 67, 77, 78, 79, 81, 89,
Visible atmospherically resistant index (VARI)	(Green – Red)/(Green + Red – Blue)	58, 63, 77, 79, 81, 89
Modified Visible atmospherically resistant index (MVARI)	(Green – Blue/(Green + Red – Blue)	77
Visible band difference vegetation index (VDVI)	(2 x Green – Red – Blue)/ (2 x Green + Red +Blue)	77
(GCC)	Green / (Red + Green + Blue)	79
Green-red ratio index (GRRI)	Green / Red	58, 77, 81, 89
Green-blue ratio index (GBRI)	Green / Blue	54, 58, 77, 89
Red-blue ratio index (RBRI)	Red / Blue	58, 77, 89
Red-green ratio index (RGRI)	Red / Green	77
Blue-green ratio index (BGRI)	Blue / Green	77
Blue-red ratio index (BRRI)	Blue / Red	77
Red, green and blue vegetation index (RGBVI)	$(Green^2 – Red \times Blue)/(Green^2 + Red \times Blue)$	54, 63, 77
Modified green red vegetation index (MGRVI)	$(Green^2 – Red^2) / (Green^2 + Red^2)$	63, 77
Green leaf index (GLI)	(2 x Green – Red – Blue)/(2 x Green + Red + Blue)	58, 75, 79, 89
Vegetation index (VEG)	$Green / (Red^{0.667} \times Blue^{0.333})$	54, 58, 63
Enhanced vegetation index (EVI)	(2.5(p800-p670))/(p800 + 6p670 – 7.5p470+1)	81
	2.5 x ((NIR–Red)/(NIR+6xRed – 7.5 x Blue +1))	50, 55, 56, 78, 87, 93
Enhanced vegetation index 2 (EVI2)	(2.5 x (NIR – Red))/(NIR + 2.4 x Red + 1)	55, 56, 78
Soil-adjusted vegetation index (SAVI)	(1 + L) x ((NIR – Red)/(NIR+Red+L)), L = 0.05	55, 56, 61, 79, 93, 95
	1.5 x ((NIR – Red)/(NIR + Red + 1))	78
Soil-adjusted vegetation index (SAVI2)	NIR/(NIR + (b/a)), b = 0.025, a = 1.24	55, 56
Modified soil-adjusted vegetation index (MSAVI)	$(2\rho800 + 1 - \sqrt{(2\rho800 + 1)^2 - 8(\rho800 - \rho670)})/2$	81
Modified secondary soil-adjusted vegetation index ($MSAVI_2$)	$0.5 \times ((2 \times NIR + 1) – sqrt((2x\ NIR +1)^2 – 8 \times (NIR – Red))$	56, 61, 78, 93
Optimized soil-adjusted vegetation index (OSAVI)	(1 + L) x ((NIR – Red)/(NIR+Red+L)), L = 0.16	55, 56, 93
Transformed soil-adjusted vegetation index (TSAVI)	[0.33 x (NIR – 0.33 x Red – 0.5)]/[0.5 x NIR + Red – 0.5 x 0.33 + 1.5 x $(1 + 0.33^2)$]	93
Normalized difference vegetation index (NDVI)	(p800-p670)/(p800+p670) OR	81
	(NIR – Red)/(NIR + Red)	50, 55, 56, 59, 60, 61, 64, 74, 75, 77, 78, 79, 87, 91, 92, 93, 95, 96
Kernal NDVI	$\tanh(((NIR – Red)/(2 \times \sigma))^2)$	55
Water band index (WBI)	p970/p900	81

Chlorophyll index ((CI1)	(p850 – p710)/(p850 + p680)	81
Chlorophyll index (CI2)	p750/p700	81
Chlorophyll index – green (CI green)	(NIR/Green) - 1	79
Chlorophyll index – red edge (CI red edge)	(NIR /RedEdge) - 1	61, 79
Modified red-edge normalized difference vegetation index (MRENDVI)	(p750 – p705)/(p750+p705-2p445)	81
Modified red-edge ratio (MRER)	(p759 – 1.8p419)/(p742-1.8p419)	81
Vogelmann index (VOG)	p742/p721	55, 56, 81
Difference Vegetation Index (DVI)	NIR – Red	55, 56, 79, 93, 95, 96 (range),
	NIR – α x Red, α = 0.96916	61
Ratio vegetation index (RVI)	Red / NIR	55, 56, 78, 95, 96 (sum, max)
Simple Ratio (SR)	NIR / Red	55, 56, 79, 93
Modified simple ratio (MSR)	((NIR/Red)-1)/sqrt((NIR/Red)+1)	55, 56, 93
Green normalized vegetation index (GNDVI)	(NIR – Green)/(NIR + Green)	55, 56, 61, 96, 93
Normalized difference water index (NDWI)	(Green – NIR) / (Green + NIR)	50
Renormalized vegetation index (RDVI)	NIR/Green	61, 96
Red edge simple ratio (SRre)	NIR/RedEdge	61
Green ratio vegetation index (GRVI)	(Red- Green)/(Red + Green)	96
Green difference index (GDI)	NIR – Red + Green	61
Normalized difference index (NDI)	(Red – Green)/(Red + Green + 0.01)	58
Wide dynamic-range vegetation index (WDRVI)	(0.2NIR – Green)/(0.2NIR + Green)	95, 96
	(0.1 x NIR – Red)/(0.1 x NIR + Red)	79
Modified chlorophyll absorption reflection index (MCARI)	[(RedEdge – Red) – 0.2(Rededge – Green)]/(RedEdge/Red)	96
Normalized red-edge vegetation index (NDRE)	(NIR – RedEdge)/(NIR + RedEdge)	55, 56, 59, 61, 77, 78, 79, 96
Near-infrared reflectance of vegetation (RNDVI)	((NIR – Red)/(NIR + Red) – C) x p(C = 0.08)	55
Renormalized Difference Vegetation Index (RDVI)	(NIR – Red)/sqrt(NIR + Red)	56, 93
Red chlorophyll index (RECI)	(NIR – RedEdge) – 1	96
Chlorophyll Vegetation Index (CVI)	(NIR/Green) x (Red/Green)	61, 87
	NIR x ($Red/Green^2$)	79
Triangular greenness index (TGI)	-0.5 x [(Red - Green) – (Red – Blue)]	92
	Green – (0.39 x Red) – (0.61 x Blue	77
Red edge triangular vegetation index (core only) (RTVIcore)	100(NIR – RedEdge) – 10(NIR – Green)	61
Anthocyanin reflectance index (ARI)	(1/Green) – (1/RedEdge)	55, 56
Woebecke index (WI)	(Green – Blue)/(Red- Green)	58, 77
DATT4	Red / Green x RedEdge	61
Blue Green Vegetation Index (BGVI)	(Blue – Green)/(Blue + Green)	67
Green Blue Vegetation Index (GBVI)	(Green – Blue)/(Green + Blue)	67
Green Red Blue Index (GRBI)	(Green – Red)/(Green + Blue)	67
Red Blue Vegetation Index (RBVI)	(Red – Blue)/(Red + Blue)	67, 77
Red Chromatic Coordinate (RCC)	Red/ (Blue + Green + Red)	50, 77
Green Chromatic Coordinate (GCC)	Green/ (Blue + Green + Red)	50, 77
Blue Chromatic Coordinate (RCC)	Blue/ (Blue + Green + Red)	50, 77

Satellite Vegetation Indices		
Blue	Landsat Band 1	50
Green	Landsat Band 2	50
Red	Landsat Band 3	50
NIR	Landsat Band 4	50
SWIR1	Landsat Band 5	50
SWIR2	Landsat Band 7	50
Brightness Temperature	Landsat Band 6	50
Land surface water index (LSWI)	(NIR – SWIR1) / (NIR + SWIR1)	50, 55, 56
Normalized Burn Ratio (NBR)	(NIR – SWIR2) / (NIR + SWIR2)	50
Infrared simple ratio (ISR)	NIR/SWIR1	55, 56
Moisture stress index (MSI)	SWIR1/NIR	55, 56
Stress-related vegetation index 1 (STVI1)	(SWIR1 x Red)/NIR	55, 56
Stress-related vegetation index 2 (STVI2)	NIR/(SWIR2 x Red)	55, 56
Stress-related vegetation index 3 (STVI3)	NIR/(SWIR1 x Red)	55, 56
Normalized difference snow index	(Green – SWIR1) / (Green + SWIR1)	50
Radar ratio vegetation index	VV/VH	55
Radar difference vegetation index	VV – VH	55
Radar normalized difference vegetation index	(VV-VH)/(VV+VH)	55
Normalized difference phenology index (NDPI)	(NIR – (0.74 x Red + 0.26 x SWIR1))/(NIR + (0.74 + Red + 0.26 x SWIR1))	55
Simple difference spectral index (DSI)	Band A – Band B	56
Reciprocal difference spectral index (RDSI)	(1/Band A) – (1/Band B)	56
Tasseled Cap Brightness (TCB)	0.2043*Blue+0.4158 * Green + 0.5524 * Red + 0.5741 * NIR + 0.3124 * SWIR1 + 0.2303 * SWIR2	50
Tasseled Cap Greenness (TCG)	-0.1603*Blue – 0.2819 * Green – 0.4934 * Red + 0.7940 * NIR + 0.0002 * SWIR1 + 0.1446 * SWIR2	50
Tasseled Cap Wetness (TCW)	0.0315*Blue + 0.2021 * Green + 0.3102 * Red + 0.1594 * NIR + 0.6806 * SWIR1 + 0.6109 * SWIR2	50
Tasseled Cap Wetness-Greenness Difference (TCWGD)	TCW – TCG	50