

SUPPLEMENTAL MATERIAL

A description of the ground sites imaged as part of the UAVSAR, LVIS, SETHI and F-SAR acquisitions in 2015 and 2016 is provided below.

Mondah Forest covers an area of 6747 ha of which 20% is protected (Lachenaud et al., 2013). Originally established as a timber production forest and research area in 1934, it lies on the Libreville peninsula, 20 km north of the center of the capital Libreville (Walters et al., 2016). Mondah Forest is the main forested area in the region with a mean tree species richness of about 55 species per hectare, but is highly dependent on disturbance status (Labriere, 2018).

The Mondah Forest ecosystem is characterized by high endemism due to the overlap of two forest types, very wet forest in the northwest and drier forest in the south and east of the country (Lachenaud, 2013). The ecosystem, which extends between the Libreville peninsula north into Equatorial Guinea (Vande Weghe, 2005), is characterized by rivers and valleys that create variation in both climate and vegetation types. Mondah Forest has been inhabited at least since 3400 BP (Clist, 2005) and exploited for forest resources at least since the 1400s (Patterson, 1975). Human disturbance has degraded the forest so that 55% of the area is classified as secondary forest (Nziengui et al., 2008). Moreover, due to its proximity to Libreville, the Mondah Forest area experiences the highest deforestation rate of the entire country (Hansen et al., 2013).

Several field plots were established in Mondah Forest between 2009 and 2016 airborne Lidar data is also available (Silva et al., 2018). Plot data collected before 2012 are available through

AfriTRON (Lewis et al., 2009), while field data collected as part of AfriSAR are described below and available through the NASA Oak Ridge DAAC. The area was imaged by SETHI, F-SAR, UAVSAR and LVIS.

Lopé National Park covers an area of 494,800 ha and is the first protected area in Gabon, originally established as a wildlife reserve in 1946 and then gazetted as a national park in 2002 (Mitchard et al., 2012). Lopé is known for its diverse bird and mammalian fauna, including forest elephants and western lowland gorillas. Elevation ranges from 72 to 980 m above sea level (asl), with slopes exceeding 20% in almost a quarter of the park. Closed-canopy tropical rainforest covers most of the park and its surroundings, with the exception of the most northern part that is composed of savanna and a mosaic of low-AGBD forest types including Okoumé (*Aucoumea klaineana*) and open canopy Marantaceae. During the Last Glacial Maximum, savanna covered the entire park area, but forest expanded and continues to expand into the savanna due to increasing precipitation (White, 2001). Tree species richness is an average of 35 species per ha, but varies largely between forest types (Labriere, 2018).

Lopé is the best studied forest site in Gabon with multiple permanent and semi-permanent field plots, including 12 new plots (9 of 1 ha and 3 of 0.5 ha) established by ESA as part of AfriSAR in 2016 (Labriere et al, 2018). The area was imaged by SETHI, F-SAR, UAVSAR and LVIS and airborne scanning Lidar in 2015 (Pardini et al., 2018; Silva et al., 2018)).

Mabounié and the Lower Ogooué: Mabounié is located in the Lower Ogooué River Basin, a Ramsar site (a wetland of international importance) that comprises a vast alluvial plain about 200 km long and 70 km wide. The Basin is covered in dense forest, alluvial lakes, flooded forests, wetlands and savannas and supports high animal biodiversity, including several threatened species. Tree species richness is about 55 tree species per ha (Labrière et al., 2018) and the site is commonly used for floodplain agriculture. Airborne Lidar data was collected over Mabounié in 2011 (Labrière et al., 2018), and twelve 1-ha field plots were surveyed by the IRD (Institut de Recherche et de Développement) in 2012 (Bastin et al., 2015). The area was imaged by UAVSAR, F-SAR and LVIS.

Rabi is a 25-ha permanent plot managed by the Smithsonian CTFs-GEO (Center for Tropical Forest Science Global Earth Observatory) ForestGEO program situated within the Shell Rabi Oil Concession (Anderson-Teixeira et al., 2015). It is located in the Gamba Complex of protected areas (see detailed description below). Within the 25-ha Rabi plot, every tree greater than 1 cm in diameter at breast height (130 cm) was measured to evaluate the contribution of small diameter trees to the abundance and distribution of small trees (Memighe et al., 2016).

Rabi was selected as one of the joint ESA/NASA sites because of the availability of field measurements from 2012 and ALS data from 2015 (Silva et al., 2018). For AfriSAR, the area was imaged by F-SAR, SETHI, UAVSAR and LVIS.

Pongara National Park is located on the southern bank of the Komo Estuary, close to Libreville. The park covers an area of 87,000 ha and is covered primarily by mangroves and some

terra firma rainforests (Dauby et al., 2008). As with much of the coastal forests in Gabon, the upland forests and their composition have not been well studied, although there are reports of high levels of plant endemism (Lachenaud et al., 2013). Pongara protects leatherback turtle nesting grounds and mangroves: Gabon hosts 30% of the global population of leatherback turtles (Bourgeois et al., 2009) and some of the tallest mangroves in the world, with individual trees attaining 65 m (Simard et al., 2019). This area was imaged by UAVSAR, F-SAR and LVIS.

Akanda National Park is situated to the northeast of Libreville, adjoining the Mondah Forest. The park is 54,000 ha in area and comprised primarily of mangrove forests, mudflats and the waters of the Corisco Bay, although some *terra firma* forests are also present. As with Pongara National Park, Akanda harbors important feeding and nesting habitat for four sea turtle species and is home to the largest population of migratory birds in Gabon (Lachenaud et al., 2013a; Vande Weghe, 2005). This area was imaged by LVIS and UAVSAR as part of the Mondah flight lines, but no Akanda-specific field measurements are available to our knowledge.

The Gamba Complex of Protected Areas is the largest protected area in Gabon, covering 5329000 ha or about 4% of Gabon (Memiaghe et al., 2016). The protected areas within the Gamba Complex include the Loango and Moukalaba Doudou national parks and the Iguela, Sette Cama and Ngove-Ndongo protected hunting domains. The Gamba Complex is located in the southern portion of Guineo-Congolian forest type, which includes swamp and mixed moist semi-evergreen forest types (M.E. Lee et al., 2006). Loango National Park, in particular, is famous for its mosaic of habitats from beaches and dunes to littoral forests, coastal scrub, mangroves,

extensive permanently- and seasonally-inundated forests, upland forest, rocky outcrops, various stages of secondary forest, and prairies. It has a high concentration of megafauna, including elephants, buffalos, hippopotami, gorillas and leopards (Lee et al., 2006). The coastal area of the Gamba Complex, within Loango and Sette Cama was imaged only by UAVSAR. No known field measurements were available.

Mouila is located in southwest Gabon, at the northern limit of the Western Congolian Forest Savanna Mosaic Region. The Mouila sites include the government leased Olam oil palm concessions consisting of Mouila Lots 1 (ML1, 35,300 ha) and 2 (ML2, 31,800 ha) in which Palm agriculture was initiated in early 2013 and 2014, respectively (Burton et al., 2017). ML2 is an old timber concession composed mainly of selectively logged, lowland mixed tropical forest. The concession consists of relatively flat plains to be developed for palm agriculture, with the remaining plains and plateau designated as High Conservation Value Forest due to its unique structure and biodiversity. This site was flown by UAVSAR only, and previous airborne Lidar data were acquired in 2011 (Burton et al., 2017). Field measurements belong to the Government of Gabon.

Transects: In addition to the sites described above, LVIS flew several long transect flight lines: the 'Biomass Gradient line' from east to west following the dense forest to savanna gradient; this line also transects the UAVSAR Lower Ogooué acquisitions. Two additional east-west lines cross over the Minkébé National Park in the far north of the country, while a long north-south line crosses over Lopé National Park. The aim of the long transects was to record additional variability

in canopy height across the country. In addition, the east-west data will be used as calibration data for the GEDI mission, which will be in a north-south orbit, and therefore, cross over the east-west line during several GEDI orbits.

References

- Anderson-Teixeira, K.J., Davies, S.J., Bennett, A.C., Gonzalez-Akre, E.B., Muller-Landau, H.C., Joseph Wright, S., Abu Salim, K., Almeyda Zambrano, A.M., Alonso, A., Baltzer, J.L., Basset, Y., Bourg, N.A., Broadbent, E.N., Brockelman, W.Y., Bunyavejchewin, S., Burslem, D.F.R.P., Butt, N., Cao, M., Cardenas, D., Chuyong, G.B., Clay, K., Cordell, S., Dattaraja, H.S., Deng, X., Detto, M., Du, X., Duque, A., Erikson, D.L., Ewango, C.E.N., Fischer, G.A., Fletcher, C., Foster, R.B., Giardina, C.P., Gilbert, G.S., Gunatilleke, N., Gunatilleke, S., Hao, Z., Hargrove, W.W., Hart, T.B., Hau, B.C.H., He, F., Hoffman, F.M., Howe, R.W., Hubbell, S.P., Inman-Narahari, F.M., Jansen, P.A., Jiang, M., Johnson, D.J., Kanzaki, M., Kassim, A.R., Kenfack, D., Kibet, S., Kinnaird, M.F., Korte, L., Kral, K., Kumar, J., Larson, A.J., Li, Y., Li, X., Liu, S., Lum, S.K.Y., Lutz, J.A., Ma, K., Maddalena, D.M., Makana, J.R., Malhi, Y., Marthews, T., Mat Serudin, R., McMahan, S.M., McShea, W.J., Memiaghe, H.R., Mi, X., Mizuno, T., Morecroft, M., Myers, J.A., Novotny, V., de Oliveira, A.A., Ong, P.S., Orwig, D.A., Ostertag, R., den Ouden, J., Parker, G.G., Phillips, R.P., Sack, L., Sainge, M.N., Sang, W., Sri-ngernyuang, K., Sukumar, R., Sun, I.F., Sungpalee, W., Suresh, H.S., Tan, S., Thomas, S.C., Thomas, D.W., Thompson, J., Turner, B.L., Uriarte, M., Valencia, R., Vallejo, M.I., Vicentini, A., Vrška, T., Wang, Xihua, Wang, Xugao, Weiblen, G., Wolf, A., Xu, H., Yap, S., Zimmerman, J., 2015. CTFS-ForestGEO: A worldwide network monitoring forests in an era of global change. *Glob. Chang. Biol.* 21, 528–549. <https://doi.org/10.1111/gcb.12712>
- Bastin, J.-F., Barbier, N., Réjou-Méchain, M., Fayolle, A., Gourlet-Fleury, S., Maniatis, D., de Haulleville, T., Baya, F., Beeckman, H., Beina, D., Couteron, P., Chuyong, G., Dauby, G., Doucet, J.-L., Droissart, V., Dufrêne, M., Ewango, C., Gillet, J.F., Gonmadje, C.H., Hart, T., Kavali, T., Kenfack, D., Libalah, M., Malhi, Y., Makana, J.-R., Pélissier, R., Ploton, P., Serckx, A., Sonké, B., Stevart, T., Thomas, D.W., De Cannière, C., Bogaert, J., 2015. Seeing Central African forests through their largest trees. *Sci. Rep.* 5, 13156. <https://doi.org/10.1038/srep13156>
- Bourgeois, S., Gilot-Fromont, E., Viallefont, A., Boussamba, F., Deem, S.L., 2009. Influence of artificial lights, logs and erosion on leatherback sea turtle hatchling orientation at Pongara

- National Park, Gabon. *Biol. Conserv.* 142, 85–93.
<https://doi.org/10.1016/j.biocon.2008.09.028>
- Burton, M.E.H., Poulsen, J.R., Lee, M.E., Medjibe, V.P., Stewart, C.G., Venkataraman, A., White, L.J.T., 2017. Reducing Carbon Emissions from Forest Conversion for Oil Palm Agriculture in Gabon. *Conserv. Lett.* 10, 297–307. <https://doi.org/10.1111/conl.12265>
- Clist, B., 2005. Des premiers villages aux premiers européens autour de l'estuaire du Gabon: quatre millénaires d'interactions entre l'homme et son milieu. Université Libre de Bruxelles, Brussels, Belgium.
- Dauby, G., Leal, M., Stévant, T., 2008. Vascular Plant Checklist of the Coastal National Park of Pongara, Gabon. *Syst. Geogr. Plants* 78, 155–216. <https://doi.org/10.2307/20649761>
- Hansen, M.C.C., Potapov, P. V, Moore, R., Hancher, M., Turubanova, S.A. a, Tyukavina, A., Thau, D., Stehman, S.V. V, Goetz, S.J.J., Loveland, T.R.R., Kommareddy, a, Egorov, A., Chini, L., Justice, C.O.O., Townshend, J.R.G.R.G., Patapov, P.V., Moore, R., Hancher, M., Turubanova, S.A. a, Tyukavina, A., Thau, D., Stehman, S.V. V, Goetz, S.J.J., Loveland, T.R.R., Kommareddy, A., Egorov, A., Chini, L., Justice, C.O.O., Townshend, J.R.G.R.G., 2013. High-Resolution Global Maps of. *Science (80-)*. 342, 850–854. <https://doi.org/10.1126/science.1244693>
- Labriere, N., Tao, S., Chave, J., Scipal, K., Toan, T. Le, Abernethy, K., Alonso, A., Barbier, N., Bissiengou, P., Casal, T., Davies, S.J., Ferraz, A., Herault, B., Jaouen, G., Jeffery, K.J., Kenfack, D., Korte, L., Lewis, S.L., Malhi, Y., Memiaghe, H.R., Poulsen, J.R., Rejou-Mechain, M., Villard, L., Vincent, G., White, L.J.T., Saatchi, S., 2018. In Situ Reference Datasets from the TropiSAR and AfriSAR Campaigns in Support of Upcoming Spaceborne Biomass Missions. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* 11, 3617–3627.
<https://doi.org/10.1109/JSTARS.2018.2851606>
- Labrière, N., Tao, S., Chave, J., Scipal, K., Toan, T.L., Abernethy, K., Alonso, A., Barbier, N., Bissiengou, P., Casal, T., Davies, S.J., Ferraz, A., Hérault, B., Jaouen, G., Jeffery, K.J., Kenfack, D., Korte, L., Lewis, S.L., Malhi, Y., Memiaghe, H.R., Poulsen, J.R., Réjou-Méchain, M., Villard, L., Vincent, G., White, L.J.T., Saatchi, S., 2018. *In Situ* Reference Datasets From the TropiSAR and AfriSAR Campaigns in Support of Upcoming Spaceborne Biomass Missions. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* 11, 3617–3627.
<https://doi.org/10.1109/JSTARS.2018.2851606>
- Lachenaud, O., Stévant, T., Ikabanga, D., Ndjabounda, E.C.N., Walters, G., 2013a. Les forêts littorales de la région de Libreville (Gabon) et leur importance pour la conservation: description d'un nouveau *Psychotria* (Rubiaceae) endémique. *Plant Ecol. Evol.* 146, 68–74.
<https://doi.org/10.5091/plecevo.2013.744>
- Lachenaud, O., Stévant, T., Ikabanga, D., Ndjabounda, Ngagnia,, E.C., Walters, G., 2013b. Les forêts littorales de la région de Libreville (Gabon) et leur importance pour la conservation: description d'un nouveau *Psychotria* (Rubiaceae) endémique. *Plant Ecol. Evol.* 146, 68–74.
<https://doi.org/10.5091/plecevo.2013.744>
- Lee, M.E., Alonso, A., Dallmeier, F., Campbell, P., Pauwels, O.S.G., 2006. The Gamba Complex of Protected Areas: an illustration of Gabon's biodiversity. *Bull. Biol. Soc. Washingt.* 12, 229–241.
- Lee, Michelle E, Alonso, A., Dallmeier, F., Campbell, P., Pauwels, O.S.G., 2006. The Gamba Complex of Protected Areas : an illustration of Gabon ' s The Gamba Complex of Protected Areas : An Illustration of Gabon ' s Biodiversity.

- Lewis, S.L., Lopez-Gonzalez, G., Sonké, B., Affum-Baffoe, K., Baker, T.R., Ojo, L.O., Phillips, O.L., Reitsma, J.M., White, L., Comiskey, J.A., Djuikouo K, M.N., Ewango, C.E.N., Feldpausch, T.R., Hamilton, A.C., Gloor, M., Hart, T., Hladik, A., Lloyd, J., Lovett, J.C., Makana, J.R., Malhi, Y., Mbago, F.M., Ndangalasi, H.J., Peacock, J., Peh, K.S.H., Sheil, D., Sunderland, T., Swaine, M.D., Taplin, J., Taylor, D., Thomas, S.C., Votere, R., Wöll, H., 2009. Increasing carbon storage in intact African tropical forests. *Nature* 457, 1003–1006.
<https://doi.org/10.1038/nature07771>
- Memiaghe, H.R., Lutz, J.A., Korte, L., Alonso, A., Kenfack, D., 2016. Ecological Importance of Small-Diameter Trees to the Structure, Diversity and Biomass of a Tropical Evergreen Forest at Rabi, Gabon. *PLoS One* 11, 1–15. <https://doi.org/10.1371/journal.pone.0154988>
- Mitchard, E.T.A., Saatchi, S.S., White, L.J.T., Abernethy, K.A., Jeffery, K.J., Lewis, S.L., Collins, M., Lefsky, M.A., Leal, M.E., Woodhouse, I.H., Meir, P., 2012. Mapping tropical forest biomass with radar and spaceborne LiDAR in Lopé National Park, Gabon: Overcoming problems of high biomass and persistent cloud. *Biogeosciences* 9, 179–191.
<https://doi.org/10.5194/bg-9-179-2012>
- Nziengui, M., Nana, A., Oslisly, R., Tchindjan, M., Mapaga, D., Ropivia, M.L., 2008. Suivi par télédétection de la dynamique des milieux savaniques et forestiers gabonais. Exemples de la forêt classée de la Mondah et du parc national de la Lopé. *Photo-Interprétation* 44, 14–23.
- Pardini, M., Tello, M., Cazcarra-bes, V., Papathanassiou, K.P., Hajnsek, I., 2018. L- and P-Band 3-D SAR Reflectivity Profiles Versus Lidar Waveforms : The AfriSAR Case. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* 11, 3386–3401.
<https://doi.org/10.1109/JSTARS.2018.2847033>
- Patterson, K.D., 1975. *The northern Gabon coast to 1875*. Clarendon Press.
- Silva, C.A., Saatchi, S., Garcia, M., Labriere, N., Klauberg, C., Ferraz, A., Meyer, V., Jeffery, K.J., Abernethy, K., White, L., Zhao, K., Lewis, S.L., Hudak, A.T., 2018. Comparison of Small- and Large-Footprint Lidar Characterization of Tropical Forest Aboveground Structure and Biomass: A Case Study From Central Gabon. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* 1–15. <https://doi.org/10.1109/JSTARS.2018.2816962>
- Simard, M., Fatoyinbo, L., Smetanka, C., Rivera-monroy, V.H., Castañeda-moya, E., Thomas, N., Stocken, T. Van Der, 2019. Mangrove canopy height globally related to precipitation, temperature and cyclone frequency. *Nat. Geosci.* 12.
<https://doi.org/10.1038/s41561-018-0279-1>
- Vande Weghe, J.P., 2005. *Les parcs nationaux du Gabon. Akanda et Pongara: plages et mangroves*. Wildl. Conserv. Soc. Libr. Gabon.
- Walters, G., Ngagniandjabounda, E., Ikabanga, D., Biteau, J.P., Ymas. O.H., White, L.J.T., Ndongobiang, A.M., Ndongondo, P., Jeffery, K.J., Lachenaud, O., Stévert. T., 2016. Peri-urban conservation in the Mondah forest of Libreville, Gabon: Red List assessments of endemic plant species, and avoiding protected area downsizing. *Oryx* 50, 419–430.
<https://doi.org/10.1023/A:1008165311026>