



Universiteit
Leiden
The Netherlands

Satellite remote sensing of plant functional diversity

Hauser, L.T.

Citation

Hauser, L. T. (2022, June 22). *Satellite remote sensing of plant functional diversity*. Retrieved from <https://hdl.handle.net/1887/3348489>

Version: Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/3348489>

Note: To cite this publication please use the final published version (if applicable).

Chapter 8.: References

- Abelleira Martínez, O.J., Fremier, A.K., Günter, S., Ramos Bendaña, Z., Vierling, L., Galbraith, S.M., Bosque-Pérez, N. a., Ordoñez, J.C., 2016. Scaling up functional traits for ecosystem services with remote sensing: concepts and methods. *Ecol. Evol.* <https://doi.org/10.1002/ece3.2201>
- Adams, J., Lewis, P., Disney, M., 2018. Decoupling Canopy Structure and Leaf Biochemistry: Testing the Utility of Directional Area Scattering Factor (DASF). *Remote Sens.* 10, 1911. <https://doi.org/10.3390/rs10121911>
- Aguiar, C.F.G., 2001. Flora e vegetação da Serra de Nogueira e do Parque Natural de Montesinho. Universidade Técnica de Lisboa, Instituto Superior de Agronomia.
- Aguirre-gutiérrez, J., Rifai, S., Shenkin, A., Oliveras, I., Patrick, L., Svátek, M., Girardin, C.A.J., Both, S., Riutta, T., Berenguer, E., Kissling, W.D., Bauman, D., Raab, N., Moore, S., Farfan-rios, W., Emanuelle, A., Figueiredo, S., Matias, S., Edzang, J., Evouna, F., Natacha, N., Mihindou, V., Maria, M., Seixas, M. De, Adu-bredou, S., Abernethy, K., Asner, G.P., Barlow, J., Burslem, D.F.R.P., Coomes, D.A., Cernusak, L.A., Dargie, G.C., Enquist, B.J., Ewers, R.M., Ferreira, J., Jeffery, K.J., Joly, C.A., Lewis, S.L., Marimon-junior, B.H., Martin, R.E., Morandi, P.S., Phillips, O.L., Quesada, C.A., Salinas, N., Schwantes, B., Silman, M., Arn, Y., White, L.J.T., Malhi, Y., 2021. Pantropical modelling of canopy functional traits using Sentinel-2 remote sensing data. *Remote Sens. Environ.* 252, 112122. <https://doi.org/10.1016/j.rse.2020.112122>
- Ahmed, D.A., van Bodegom, P.M., Tukker, A., 2018. Evaluation and selection of functional diversity metrics with recommendations for their use in life cycle assessments. *Int. J. Life Cycle Assess.* 1–16.
- Aiba, M., Katabuchi, M., Takafumi, H., Matsuzaki, S.I.S., Sasaki, T., Hiura, T., 2013. Robustness of trait distribution metrics for community assembly studies under the uncertainties of assembly processes. *Ecology* 94, 2873–2885. <https://doi.org/10.1890/13-0269.1>
- Aiba, S., Kitayama, K., 2010. Structure , Composition and Species Diversity in an Altitude-Substrate Matrix of Rain Forest Tree Communities on Mount Kinabalu , Borneo. *Plant Ecol.* 140, 139–157.
- Ali, A.M., Darvishzadeh, R., Skidmore, A., Gara, T.W., O'Connor, B., Roeoesli, C., Heurich, M., Paganini, M., 2020a. Comparing methods for mapping canopy chlorophyll content in a mixed mountain forest using Sentinel-2 data. *Int. J. Appl. Earth Obs. Geoinf.* 87, 102037. <https://doi.org/10.1016/j.jag.2019.102037>
- Ali, A.M., Darvishzadeh, R., Skidmore, A., Heurich, M., Paganini, M., Heiden, U., Mücher, S., 2020b. Evaluating prediction models for mapping canopy chlorophyll content across biomes. *Remote Sens.* 12. <https://doi.org/10.3390/rs12111788>
- Almeida, D.R.A. de, Broadbent, E.N., Ferreira, M.P., Meli, P., Zambrano, A.M.A., Gorgens, E.B., Resende, A.F., de Almeida, C.T., do Amaral, C.H., Corte, A.P.D., Silva, C.A., Romanelli, J.P., Prata, G.A., de Almeida Papa, D., Stark, S.C., Valbuena, R., Nelson, B.W., Guillemot, J., Féret, J.B., Chazdon, R., Brancalion, P.H.S., 2021a. Monitoring

restored tropical forest diversity and structure through UAV-borne hyperspectral and lidar fusion. *Remote Sens. Environ.* 264. <https://doi.org/10.1016/j.rse.2021.112582>

Almeida, D.R.A. de, Broadbent, E.N., Ferreira, M.P., Meli, P., Zambrano, A.M.A., Gorgens, E.B., Resende, A.F., de Almeida, C.T., do Amaral, C.H., Corte, A.P.D., Silva, C.A., Romanelli, J.P., Prata, G.A., de Almeida Papa, D., Stark, S.C., Valbuena, R., Nelson, B.W., Guillemot, J., Féret, J.B., Chazdon, R., Brancalion, P.H.S., 2021b. Monitoring restored tropical forest diversity and structure through UAV-borne hyperspectral and lidar fusion. *Remote Sens. Environ.* 264. <https://doi.org/10.1016/j.rse.2021.112582>

Anderson, C.B., 2018. Biodiversity monitoring, earth observations and the ecology of scale. *Ecol. Lett.* 21, 1572–1585. <https://doi.org/10.1111/ele.13106>

Andrew K. Skidmore, N.C.C., Neinavaz, E., Ali, A., Michael E. Schaepman, M.P., Kissling, W.D., Vihervaara, P., Darvishzadeh, R., Feilhauer, H., Fernandez, M., Fernandez, N., Gorelick, N., Wingate, V., et al., 2021. Priority list of biodiversity metrics to observe from space. *Nat. Ecol. Evol.* <https://doi.org/10.1038/s41559-021-01451-x>

Apichatmeta, K., Sudsiri, C.J., Ritchie, R.J., 2017. Photosynthesis of oil palm (*Elaeis guineensis*). *Sci. Hortic.* (Amsterdam). 214, 34–40.

Asbjornsen, H., Goldsmith, G.R., Alvarado-Barrientos, M.S., Rebel, K., Van Osch, F.P., Rietkerk, M., Chen, J., Gotsch, S., Tobón, C., Geissert, D.R., Gómez-Tagle, A., Vache, K., Dawson, T.E., 2011. Ecohydrological advances and applications in plant–water relations research: a review. *J. Plant Ecol.* 4, 3–22. <https://doi.org/10.1093/jpe/rtr005>

Asner, G.P., 1998. Biophysical and biochemical sources of variability in canopy reflectance. *Remote Sens. Environ.* 64, 234–253. [https://doi.org/10.1016/S0034-4257\(98\)00014-5](https://doi.org/10.1016/S0034-4257(98)00014-5)

Asner, G.P., Heidebrecht, K.B., 2002. Spectral unmixing of vegetation, soil and dry carbon cover in arid regions: Comparing multispectral and hyperspectral observations. *Int. J. Remote Sens.* 23, 3939–3958. <https://doi.org/10.1080/01431160110115960>

Asner, G.P., Martin, R.E., 2009. Airborne spectranomics: Mapping canopy chemical and taxonomic diversity in tropical forests. *Front. Ecol. Environ.* 7, 269–276. <https://doi.org/10.1890/070152>

Asner, G.P., Martin, R.E., Anderson, C.B., Knapp, D.E., 2015. Quantifying forest canopy traits: Imaging spectroscopy versus field survey. *Remote Sens. Environ.* 158, 15–27. <https://doi.org/10.1016/j.rse.2014.11.011>

Asner, Gregory P., Martin, R.E., Anderson, C.B., Kryston, K., Vaughn, N., Knapp, D.E., Bentley, L.P., Shenkin, A., Salinas, N., Sinca, F., Tupayachi, R., Quispe Huaypar, K., Montoya Pillco, M., Ccori Álvarez, F.D., Díaz, S., Enquist, B.J., Malhi, Y., 2017. Scale dependence of canopy trait distributions along a tropical forest elevation gradient. *New Phytol.* 214, 973–988. <https://doi.org/10.1111/nph.14068>

Asner, G P, Martin, R.E., Knapp, D.E., Tupayachi, R., Anderson, C.B., Sinca, F., Vaughn, N.R., Llactayo, W., 2017. Airborne laser-guided imaging spectroscopy to map forest trait diversity and guide conservation. *Science* (80-.). 355, 385–389. <https://doi.org/10.1126/science.aaq1987>

Asner, G.P., Scurlock, J.M.O., A. Hicke, J., 2003. Global synthesis of leaf area index observations: implications for ecological and remote sensing studies. *Glob. Ecol.*

- Biogeogr. 12, 191–205. <https://doi.org/10.1046/j.1466-822X.2003.00026.x>
- Azevedo, J.C., Moreira, C., Castro, J.P., Loureiro, C., 2011. Agriculture Abandonment, Land-use Change and Fire Hazard in Mountain Landscapes in Northeastern Portugal, in: Landscape Ecology in Forest Management and Conservation. Springer Berlin Heidelberg, pp. 329–351. https://doi.org/10.1007/978-3-642-12754-0_14
- Azevedo, J.C., Possacos, A., Aguiar, C.F., Amado, A., Miguel, L., Dias, R., Loureiro, C., Fernandes, P.M., 2013. The role of holm oak edges in the control of disturbance and conservation of plant diversity in fire-prone landscapes. *For. Ecol. Manage.* 297, 37–48.
- Azzeme, A.M., Abdullah, S.N.A., Aziz, M.A., Wahab, P.E.M., 2016. Oil palm leaves and roots differ in physiological response, antioxidant enzyme activities and expression of stress-responsive genes upon exposure to drought stress. *Acta Physiol. Plant.* 38, 1–12. <https://doi.org/10.1007/s11738-016-2073-2>
- Bacour, C., Baret, F., Béal, D., Weiss, M., Pavageau, K., 2006. Neural network estimation of LAI, fAPAR, fCover and LAI*Cab, from top of canopy MERIS reflectance data: Principles and validation. *Remote Sens. Environ.* 105, 313–325.
- Bacour, C., Jacquemoud, S., Tourbier, Y., Dechambre, M., Frangi, J.P., 2002. Design and analysis of numerical experiments to compare four canopy reflectance models. *Remote Sens. Environ.* 79, 72–83. [https://doi.org/10.1016/S0034-4257\(01\)00240-1](https://doi.org/10.1016/S0034-4257(01)00240-1)
- Baraloto, C., Timothy Paine, C.E., Patiño, S., Bonal, D., Hérault, B., Chave, J., 2010. Functional trait variation and sampling strategies in species-rich plant communities. *Funct. Ecol.* 24, 208–216. <https://doi.org/10.1111/j.1365-2435.2009.01600.x>
- Baret, F., Buis, S., 2008. Estimating canopy characteristics from remote sensing observations: Review of methods and associated problems, in: Advances in Land Remote Sensing. Springer, pp. 173–201.
- Baret, F., Vanderbilt, V.C., Steven, M.D., Jacquemoud, S., 1994. Use of spectral analogy to evaluate canopy reflectance sensitivity to leaf optical properties. *Remote Sens. Environ.* 48, 253–260. [https://doi.org/10.1016/0034-4257\(94\)90146-5](https://doi.org/10.1016/0034-4257(94)90146-5)
- Barnes, A.D., Jochum, M., Mumme, S., Haneda, N.F., Farajallah, A., Widarto, T.H., Brose, U., 2014. Consequences of tropical land use for multitrophic biodiversity and ecosystem functioning. *Nat. Commun.* 5, 1–7. <https://doi.org/10.1038/ncomms6351>
- Barton, P.S., Cunningham, S. a., Manning, A.D., Gibb, H., Lindenmayer, D.B., Didham, R.K., 2013. The spatial scaling of beta diversity. *Glob. Ecol. Biogeogr.* 22, 639–647. <https://doi.org/10.1111/geb.12031>
- Bastos, R., D'Amen, M., Marcos, B., Santos, M., Braz, L., Vicente, J., Honrado, J.P., Gonçalves, J., Monteiro, A., Cabral, J.A., 2018. Towards functional biodiversity predictions: a hierarchical modelling framework from primary productivity to biomass of upper trophic levels. *Landsc. Ecol.* 33, 2221–2237. <https://doi.org/10.1007/s10980-018-0735-8>
- Beier, P., de Albuquerque, F.S., 2015. Environmental diversity as a surrogate for species representation. *Conserv. Biol.* 29, 1401–1410. <https://doi.org/10.1111/cobi.12495>
- Belda, S., Pipia, L., Morcillo-Pallarés, P., Rivera-Caicedo, J.P., Amin, E., De Grave, C.,

- Verrelst, J., 2020. DATimeS: A machine learning time series GUI toolbox for gap-filling and vegetation phenology trends detection. *Environ. Model. Softw.* 127. <https://doi.org/10.1016/j.envsoft.2020.104666>
- Benedick, S., Hill, J.K., Mustaffa, N., Chey, V.K., Maryati, M., Searle, J.B., Schilthuizen, M., Hamer, K.C., 2006. Impacts of rain forest fragmentation on butterflies in northern Borneo: Species richness, turnover and the value of small fragments. *J. Appl. Ecol.* 43, 967–977. <https://doi.org/10.1111/j.1365-2664.2006.01209.x>
- Berger, K., Atzberger, C., Danner, M., D'Urso, G., Mauser, W., Vuolo, F., Hank, T., 2018a. Evaluation of the PROSAIL Model Capabilities for Future Hyperspectral Model Environments: A Review Study. *Remote Sens.* 10. <https://doi.org/10.3390/rs10010085>
- Berger, K., Atzberger, C., Danner, M., Wocher, M., Mauser, W., Hank, T., 2018b. Model-based optimization of spectral sampling for the retrieval of crop variables with the PROSAIL model. *Remote Sens.* 10, 2063.
- Berger, K., Pablo, J., Caicedo, R., Martino, L., Woher, M., Hank, T., 2021. A Survey of Active Learning for Quantifying Vegetation Traits from Terrestrial Earth Observation Data. *Remote Sens.* 13, 1–23.
- Bernard, H., Fjeldså, J., Mohamed, M., 2009. A case study on the effects of disturbance and conversion of tropical lowland rain forest on the non-volant small mammals in north Borneo: Management implications. *Mammal Study* 34, 85–96. <https://doi.org/10.3106/041.034.0204>
- Biswas, S.R., Mallik, A.U., 2010. Disturbance effects on species diversity and functional diversity in riparian and upland plant communities. *Ecology* 91, 28–35. <https://doi.org/10.1890/08-0887.1>
- Bivand, R., Anselin, L., Berke, O., Bernat, A., Carvalho, M., Chun, Y., Dormann, C.F., Dray, S., Halbersma, R., Lewin-Koh, N., others, 2011. spdep: Spatial dependence: weighting schemes, statistics and models.
- Blab, J., Klein, M., Ssymank, A., 1999. Biodiversity—Its Levels and Relevance for Nature Conservation in Germany, in: Biodiversity in Ecosystems: Principles and Case Studies of Different Complexity Levels. Springer, Dordrecht, pp. 199–214.
- Blonder, B., Lamanna, C., Violle, C., Enquist, B.J., 2014. The n-dimensional hypervolume. *Glob. Ecol. Biogeogr.* 23, 595–609. <https://doi.org/10.1111/geb.12146>
- Bongers, F., Poorter, L., Hawthorne, W.D., Sheil, D., 2009. The intermediate disturbance hypothesis applies to tropical forests, but disturbance contributes little to tree diversity. *Ecol. Lett.* 12, 798–805.
- Botta-Dukat, Z., 2005. Rao's quadratic entropy as a measure of functional diversity based on multiple traits. *J. Veg. Sci.* 16, 533–540. [https://doi.org/10.1658/1100-9233\(2005\)16\[533:RQEAM\]2.0.CO;2](https://doi.org/10.1658/1100-9233(2005)16[533:RQEAM]2.0.CO;2)
- Bozorg-Haddad, O., Solgi, M., Loaiciga, H.A., Others, 2017. Meta-heuristic and evolutionary algorithms for engineering optimization. John Wiley & Sons.
- Brede, B., Verrelst, J., Gastellu-Etchegorry, J.P., Clevers, J.G.P.W., Goudzwaard, L., den Ouden, J., Verbesselt, J., Herold, M., 2020. Assessment of workflow feature selection on

- forest LAI prediction with sentinel-2A MSI, landsat 7 ETM+ and Landsat 8 OLI. *Remote Sens.* 12. <https://doi.org/10.3390/rs12060915>
- Brodu, N., 2017. Super-Resolving Multiresolution Images With Band-Independent Geometry of Multispectral Pixels. *IEEE Trans. Geosci. Remote Sens.* 55, 4610–4617. <https://doi.org/10.1109/TGRS.2017.2694881>
- Brown, L.A., Ogutu, B.O., Dash, J., 2019. Estimating Forest Leaf Area Index and Canopy Chlorophyll Content with Sentinel-2: An Evaluation of Two Hybrid Retrieval Algorithms. *Remote Sens.* 11, 1752. <https://doi.org/10.3390/rs11151752>
- Bruelheide, H., Dengler, J., Jiménez-Alfaro, B., Purschke, O., Hennekens, S.M., Chytrý, M., Pillar, V.D., Jansen, F., Kattge, J., Sandel, B., Aubin, I., Zverev, A., et al., 2019. sPlot – A new tool for global vegetation analyses. *J. Veg. Sci.* 30, 161–186. <https://doi.org/10.1111/jvs.12710>
- Bryan, J.E., Shearman, P.L., Asner, G.P., Knapp, D.E., Aoro, G., Lokes, B., 2013. Extreme Differences in Forest Degradation in Borneo: Comparing Practices in Sarawak, Sabah, and Brunei. *PLoS One* 8. <https://doi.org/10.1371/journal.pone.0069679>
- Butler, D., 2014. Earth observation enters next phase. *Nature* 508, 160–161. <https://doi.org/10.1038/508160a>
- Butler, E.E., Datta, A., Flores-moreno, H., Chen, M., Wythers, K.R., Fazayeli, F., Domingues, T.F., Forey, E., Gross, N., Han, W., Hattingh, N., Hickler, T., Jansen, S., Kramer, K., Kraft, N.J.B., Kurokawa, H., Thornton, P.E., Valladares, F., Bodegom, P.M. Van, Williams, M., Wirth, C., 2017. Mapping local and global variability in plant trait distributions. *Proc. Natl. Acad. Sci.* <https://doi.org/10.1073/pnas.1708984114>
- Cadotte, M.W., Carscadden, K., Mirochnick, N., 2011. Beyond species: Functional diversity and the maintenance of ecological processes and services. *J. Appl. Ecol.* 48, 1079–1087. <https://doi.org/10.1111/j.1365-2664.2011.02048.x>
- Campos-Taberner, M., Moreno-Martínez, Á., García-Haro, F.J., Camps-Valls, G., Robinson, N.P., Kattge, J., Running, S.W., 2018. Global estimation of biophysical variables from Google Earth Engine platform. *Remote Sens.* 10. <https://doi.org/10.3390/rs10081167>
- Cao, K., 2000. Leaf anatomy and chlorophyll content of 12 woody species in contrasting light conditions in a Bornean heath forest. *Can. J. Bot.* 78, 1245–1253.
- Cardinale, B.J., Duffy, J.E., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P., Narwani, A., Mace, G.M., Tilman, D., A.Wardle, D., Kinzig, A.P., Daily, G.C., Loreau, M., Grace, J.B., Larigauderie, A., Srivastava, D.S., Naeem, S., 2012. Biodiversity loss and its impact on humanity. *Nature* 489, 326–326. <https://doi.org/10.1038/nature11373>
- Cardinale, B.J., Matulich, K.L., Hooper, D.U., Byrnes, J.E., Duffy, E., Gamfeldt, L., Balvanera, P., Connor, M.I.O., Gonzalez, A., 2011. The functional role of producer diversity in ecosystems. *Am. J. Bot.* 98, 572–592. <https://doi.org/10.3732/ajb.1000364>
- Castillo, J., Apan, A.A., Maraseni, T.N., Salmo, S.G., 2017. Estimation and mapping of above-ground biomass of mangrove forests and their replacement land uses in the Philippines using Sentinel imagery. *ISPRS J. Photogramm. Remote Sens.* 134, 70–85. <https://doi.org/10.1016/j.isprsjprs.2017.10.016>

- Cavender-Bares, J., Gamon, J.A., Townsend, P.A., 2020. Remote sensing of plant biodiversity, *Remote Sensing of Plant Biodiversity*. <https://doi.org/10.1007/978-3-030-33157-3>
- CBD, 2020a. Zero Draft of post-2020 biodiversity framework. *Secr. Conv. Biol. Divers.*
- CBD, 2020b. Update of the zero draft of the post-2020 global biodiversity framework.
- Chamagne, J., Paine, C.E.T., Schoolmaster, D.R., Stejskal, R., Volařík, D., Šebesta, J., Trnka, F., Koutecký, T., Švarc, P., Svátek, M., Hector, A., Matula, R., 2016. Do the rich get richer? Varying effects of tree species identity and diversity on the richness of understory taxa. *Ecology* 97, 2364–2373. <https://doi.org/10.1002/ecy.1479>
- Chandrasekhar, S., 1960. Radiative Transfer, Radiative Transfer. Dever, New York, USA.
- Chapin, F.S., Zavaleta, E.S., Eviner, V.T., Naylor, R.L., Vitousek, P.M., Reynolds, H.L., Hooper, D.U., Lavorel, S., Sala, O.E., Hobbie, S.E., Mack, M.C., Díaz, S., 2000. Consequences of changing biodiversity. *Nature* 405, 234–42. <https://doi.org/10.1038/35012241>
- Chase, J.M., Gooriah, L., May, F., Ryberg, W.A., Schuler, M.S., Craven, D., Knight, T.M., 2019. A framework for disentangling ecological mechanisms underlying the island species-area relationship. *Front. Biogeogr.* 11, 0–17. <https://doi.org/10.21425/F5FBG40844>
- Chaudhary, A., Verones, F., De Baan, L., Hellweg, S., 2015. Quantifying Land Use Impacts on Biodiversity: Combining Species-Area Models and Vulnerability Indicators. *Environ. Sci. Technol.* 49, 9987–9995. <https://doi.org/10.1021/acs.est.5b02507>
- Chaurasia, A.N., Dave, M.G., Parmar, R.M., Bhattacharya, B., Marpu, P.R., Singh, A., Krishnayya, N.S.R., 2020. Inferring species diversity and variability over climatic gradient with spectral diversity metrics. *Remote Sens.* 12, 1–21. <https://doi.org/10.3390/rs12132130>
- Chave, J., 2008. Spatial variation in tree species composition across tropical forests: pattern and process. *Trop. For. Community Ecol.* 11–30.
- Chiarucci, A., Bacaro, G., Scheiner, S.M., 2011. Old and new challenges in using species diversity for assessing biodiversity 2426–2437. <https://doi.org/10.1098/rstb.2011.0065>
- Clasen, A., Somers, B., Pipkins, K., Tits, L., Segl, K., Brell, M., Kleinschmit, B., Spengler, D., Lausch, A., Förster, M., 2015. Spectral unmixing of forest crown components at close range, airborne and simulated Sentinel-2 and EnMAP spectral imaging scale. *Remote Sens.* 7, 15361–15387. <https://doi.org/10.3390/rs71115361>
- Clevers, J.G.P.W., 2014. Beyond NDVI: Extraction of Biophysical Variables From Remote Sensing Imagery, in: In: Banko et Al. (2014), Land Use & Land Cover Mapping in Europe: Current Practice, Trends and Future. pp. 363–381. <https://doi.org/10.1007/978-94-007-7969-3>
- Cochrane, M.A., 2000. Using vegetation reflectance variability for species level classification of hyperspectral data. *Int. J. of Remote Sens.* 21, 2075–2087.
- Combal, B., Baret, F., Weiss, M., 2002. Improving canopy variables estimation from remote sensing data by exploiting ancillary information. Case study on sugar beet canopies.

Agronomie 22, 205–215.

- Combal, B., Baret, F., Weiss, M., Trubuil, A., Macé, D., Pragnère, A., Myneni, R., Knyazikhin, Y., Wang, L., 2003. Retrieval of canopy biophysical variables from bidirectional reflectance. *Remote Sens. Environ.* 84, 1–15. [https://doi.org/10.1016/S0034-4257\(02\)00035-4](https://doi.org/10.1016/S0034-4257(02)00035-4)
- Cornwell, W.K., Schwilk, D.W., Ackerly, D.D., 2006. A Trait-Based Test for Habitat Filtering: Convex Hull Volume. *Ecology* 87, 1465–1471. <https://doi.org/10.1890/0012-9658>
- Croft, H., Chen, J.M., Luo, X., Bartlett, P., Chen, B., Staebler, R.M., 2017. Leaf chlorophyll content as a proxy for leaf photosynthetic capacity. *Glob. Chang. Biol.* 23, 3513–3524. <https://doi.org/10.1111/gcb.13599>
- Curran, M., De Souza, D.M., Antón, A., Teixeira, R.F.M., Michelsen, O., Vidal-Legaz, B., Sala, S., Milà I Canals, L., 2016. How Well Does LCA Model Land Use Impacts on Biodiversity? - A Comparison with Approaches from Ecology and Conservation. *Environ. Sci. Technol.* <https://doi.org/10.1021/acs.est.5b04681>
- Dahlin, K.M., 2016. Spectral diversity area relationships for assessing biodiversity in a wildland-agriculture matrix. *Ecol. Appl.* 26, 2756–2766. <https://doi.org/10.1002/eap.1390>
- Damm, A., Paul-Limoges, E., Haghghi, E., Simmer, C., Morsdorf, F., Schneider, F.D., van der Tol, C., Migliavacca, M., Rascher, U., 2018. Remote sensing of plant-water relations: An overview and future perspectives. *J. Plant Physiol.* 227, 3–19. <https://doi.org/10.1016/j.jplph.2018.04.012>
- Danner, M., Berger, K., Woher, M., Mauser, W., Hank, T., 2021. Efficient RTM-based training of machine learning regression algorithms to quantify biophysical & biochemical traits of agricultural crops. *ISPRS J. Photogramm. Remote Sens.* 173, 278–296. <https://doi.org/10.1016/j.isprsjprs.2021.01.017>
- Danner, M., Berger, K., Woher, M., Mauser, W., Hank, T., 2019. Fitted PROSAIL parameterization of leaf inclinations, water content and brown pigment content for winter wheat and maize canopies. *Remote Sens.* 11. <https://doi.org/10.3390/rs11101150>
- Darvishzadeh, R., Skidmore, A., Abdullah, H., Cherenet, E., Ali, A., Wang, T., Nieuwenhuis, W., Heurich, M., Vrieling, A., O'Connor, B., Paganini, M., 2019a. Mapping leaf chlorophyll content from Sentinel-2 and RapidEye data in spruce stands using the invertible forest reflectance model. *Int. J. Appl. Earth Obs. Geoinf.* 79, 58–70. <https://doi.org/10.1016/j.jag.2019.03.003>
- Darvishzadeh, R., Wang, T., Skidmore, A., Vrieling, A., O'Connor, B., Gara, T.W., Ens, B.J., Paganini, M., 2019b. Analysis of Sentinel-2 and rapidEye for retrieval of leaf area index in a saltmarsh using a radiative transfer model. *Remote Sens.* 11. <https://doi.org/10.3390/rs11060671>
- Dauber, J., Hirsch, M., Simmering, D., Waldhardt, R., Otte, A., Wolters, V., 2003. Landscape structure as an indicator of biodiversity: Matrix effects on species richness. *Agric. Ecosyst. Environ.* 98, 321–329. [https://doi.org/10.1016/S0167-8809\(03\)00092-6](https://doi.org/10.1016/S0167-8809(03)00092-6)
- de Bello, F., Lavorel, S., Díaz, S., Harrington, R., Cornelissen, J.H.C., Bardgett, R.D., Berg, M.P., Cipriotti, P., Feld, C.K., Hering, D., da Silva, P.M., Potts, S.G., Sandin, L., Sousa, J.P., Storkey, J., Wardle, D. a., Harrison, P. a., 2010. Towards an assessment of multiple

- ecosystem processes and services via functional traits. *Biodivers. Conserv.* 19, 2873–2893. <https://doi.org/10.1007/s10531-010-9850-9>
- de Sá, N.C., Baratchi, M., Hauser, L.T., van Bodegom, P.M., 2021. Exploring the Impact of Noise on Hybrid Inversion of PROSAIL RTM on Sentinel-2 Data. *Remote Sens.* 13(4), 1–20. [https://doi.org/https://doi.org/10.3390/rs13040648](https://doi.org/10.3390/rs13040648)
- de Souza, D.M., Flynn, D.F.B., DeClerck, F., Rosenbaum, R.K., de Melo Lisboa, H., Koellner, T., 2013. Land use impacts on biodiversity in LCA: proposal of characterization factors based on functional diversity. *Int. J. Life Cycle Assess.* 18, 1231–1242. <https://doi.org/10.1007/s11367-013-0578-0>
- Delegido, J., Verrelst, J., Alonso, L., Moreno, J., 2011. Evaluation of sentinel-2 red-edge bands for empirical estimation of green LAI and chlorophyll content. *Sensors* 11, 7063–7081. <https://doi.org/10.3390/s110707063>
- DeLong Jr, D.C., 1996. Defining biodiversity. *Wildl. Soc. Bull.* 738–749.
- Dézerald, O., Srivastava, D.S., Céréghino, R., Carrias, J.F., Corbara, B., Farjalla, V.F., Leroy, C., Marino, N.A.C., Piccoli, G.C.O., Richardson, B.A., Richardson, M.J., Romero, G.Q., González, A.L., 2018. Functional traits and environmental conditions predict community isotopic niches and energy pathways across spatial scales. *Funct. Ecol.* 32, 2423–2434. <https://doi.org/10.1111/1365-2435.13142>
- Diaz, S., Cabido, M., 2001. Vive la difference: plant functional diversity matters to ecosystem processes: plant functional diversity matters to ecosystem processes. *Trends Ecol. Evol.* 16, 646–655.
- Díaz, S., Kattge, J., Cornelissen, J.H.C., Wright, I.J., Lavorel, S., Dray, S., Reu, B., Kleyer, M., Wirth, C., Prentice, I.C., Garnier, E., Bönisch, G., Westoby, M., Poorter, H., Reich, P.B., Moles, A.T., Dickie, J., Gillison, A.N., Zanne, A.E., Chave, J., Wright, S.J., Sheremet'ev, S.N., Jactel, H., Christopher, B., Cerabolini, B., Pierce, S., Shipley, B., Kirkup, D., Casanoves, F., Joswig, J.S., Günther, A., Falcuk, V., Rüger, N., Mahecha, M.D., Gorné, L.D., 2016. The global spectrum of plant form and function. *Nature* 529, 1–17. <https://doi.org/10.1038/nature16489>
- Díaz, S., Lavorel, S., Chapin III, F.S., Tecco, P. a, Gurvich, D.E., Grigulis, K., 2007. Functional diversity - at the crossroads between ecosystem functioning and environmental filters. *Terr. Ecosyst. a Chang. World* 81–91. https://doi.org/10.1007/978-3-540-32730-1_7
- Djamai, N., Fernandes, R., McNairn, H., Goita, K., 2018. Validation of vegetation biophysical parameters derived from Sentinel-2A over an agricultural study site located in Canada (Conference Presentation), in: *Remote Sensing for Agriculture, Ecosystems, and Hydrology XX*. p. 1078302.
- Döbert, T.F., Webber, B.L., Sugau, J.B., Dickinson, K.J.M., Didham, R.K., 2015. Can leaf area index and biomass be estimated from Braun-Blanquet cover scores in tropical forests? *J. Veg. Sci.* 26, 1043–1053. <https://doi.org/10.1111/jvs.12310>
- Dorigo, W., Richter, R., Baret, F., Bamler, R., Wagner, W., 2009. Enhanced automated canopy characterization from hyperspectral data by a novel two step radiative transfer model inversion approach. *Remote Sens.* 1, 1139–1170. <https://doi.org/10.3390/rs1041139>
- Duncan, C., Thompson, J.R., Pettorelli, N., 2015. The quest for a mechanistic understanding

- of biodiversity – ecosystem services relationships. *Proc. R. Soc. B Biol. Sci.* 282.
- Duraiappah, A.K., Naeem, S., Agardy, T., Ash, N.J., Cooper, H.D., Diaz, S., Faith, D.P., Mace, G., McNeely, J.A., Mooney, H.A., others, 2005. Ecosystems and human well-being: biodiversity synthesis; a report of the Millennium Ecosystem Assessment.
- Durán, S.M., Martin, R.E., Díaz, S., Maitner, B.S., Malhi, Y., Salinas, N., Shenkin, A., Silman, M.R., Wiczynski, D.J., Asner, G.P., Bentley, L.P., Savage, V.M., Enquist, B.J., 2019. Informing trait-based ecology by assessing remotely sensed functional diversity across a broad tropical temperature gradient. *Sci. Adv.* 5, 1–12. <https://doi.org/10.1126/sciadv.aaw8114>
- Edwards, F. a., Edwards, D.P., Larsen, T.H., Hsu, W.W., Benedick, S., Chung, a., Vun Khen, C., Wilcove, D.S., Hamer, K.C., 2014. Does logging and forest conversion to oil palm agriculture alter functional diversity in a biodiversity hotspot? *Anim. Conserv.* 17, 163–173. <https://doi.org/10.1111/acv.12074>
- ESA, 2020. Spectral Response Functions (S2-SRF).
- ESA, 2015. Sentinel-2 User Handbook.
- Ewers, R.M., Didham, R.K., Wratten, S.D., Tylianakis, J.M., 2005. Remotely sensed landscape heterogeneity as a rapid tool for assessing local biodiversity value in a highly modified New Zealand landscape. *Biodivers. Conserv.* 14, 1469–1485. <https://doi.org/10.1007/s10531-004-9786-z>
- Fang, H., Baret, F., Plummer, S., Schaepman-Strub, G., 2019. An Overview of Global Leaf Area Index (LAI): Methods, Products, Validation, and Applications. *Rev. Geophys.* 57, 739–799. <https://doi.org/10.1029/2018RG000608>
- Fang, H., Liang, S., Kuusk, A., 2003. Retrieving leaf area index using a genetic algorithm with a canopy radiative transfer model. *Remote Sens. Environ.* 85, 257–270. [https://doi.org/10.1016/S0034-4257\(03\)00005-1](https://doi.org/10.1016/S0034-4257(03)00005-1)
- Feilhauer, H., Schmid, T., Faude, U., Sánchez-Carrillo, S., Cirujano, S., 2018. Are remotely sensed traits suitable for ecological analysis? A case study of long-term drought effects on leaf mass per area of wetland vegetation. *Ecol. Indic.* 88, 232–240. <https://doi.org/10.1016/j.ecolind.2018.01.012>
- Féret, J.B., Asner, G.P., 2014. Mapping tropical forest canopy diversity using high-fidelity imaging spectroscopy. *Ecol. Appl.* 24, 1289–1296. <https://doi.org/10.1890/13-1824.1>
- Féret, J.B., Berger, K., de Boissieu, F., Malenovský, Z., 2021. PROSPECT-PRO for estimating content of nitrogen-containing leaf proteins and other carbon-based constituents. *Remote Sens. Environ.* 252, 112173. <https://doi.org/10.1016/J.RSE.2020.112173>
- Feret, J.B., François, C., Asner, G.P., Gitelson, A. a., Martin, R.E., Bidel, L.P.R., Ustin, S.L., le Maire, G., Jacquemoud, S., 2008. PROSPECT-4 and 5: Advances in the leaf optical properties model separating photosynthetic pigments. *Remote Sens. Environ.* 112, 3030–3043. <https://doi.org/10.1016/j.rse.2008.02.012>
- Féret, J.B., Gitelson, A.A., Noble, S.D., Jacquemoud, S., 2017. PROSPECT-D: Towards modeling leaf optical properties through a complete lifecycle. *Remote Sens. Environ.* 193, 204–215. <https://doi.org/10.1016/j.rse.2017.03.004>

- Féret, J.B., le Maire, G., Jay, S., Berveiller, D., Bendoula, R., Hmimina, G., Cheraiet, A., Oliveira, J.C., Ponzoni, F.J., Solanki, T., de Boissieu, F., Chave, J., Nouvellon, Y., Porcar-Castell, A., Proisy, C., Soudani, K., Gastellu-Etchegorry, J.P., Lefèvre-Fonollosa, M.J., 2018. Estimating leaf mass per area and equivalent water thickness based on leaf optical properties: Potential and limitations of physical modeling and machine learning. *Remote Sens. Environ.* 231, 110959. <https://doi.org/10.1016/j.rse.2018.11.002>
- Field, R., Hawkins, B.A., Cornell, H.V., Currie, D.J., Diniz-filho, J.A.F., Kaufman, D.M., Kerr, J.T., Mittelbach, G.G., Oberdorff, T., Brien, E.M.O., Turner, J.R.G., 2009. Spatial species-richness gradients across scales: a meta-analysis 132–147. <https://doi.org/10.1111/j.1365-2699.2008.01963.x>
- Fitzherbert, E.B., Strubig, M.J., Morel, A., Danielsen, F., Brühl, C.A., Donald, P.F., Phalan, B., 2008. How will oil palm expansion affect biodiversity? *Trends Ecol. Evol.* 23, 538–545. <https://doi.org/10.1016/j.tree.2008.06.012>
- Flynn, D.F.B., Gogol-Prokurat, M., Nogeire, T., Molinari, N., Richers, B.T., Lin, B.B., Simpson, N., Mayfield, M.M., DeClerck, F., 2009. Loss of functional diversity under land use intensification across multiple taxa. *Ecol. Lett.* 12, 22–33. <https://doi.org/10.1111/j.1461-0248.2008.01255.x>
- Fonseca, F., de Figueiredo, T., Ramos, M.A.B., 2012. Carbon storage in the Mediterranean upland shrub communities of Montesinho Natural Park, northeast of Portugal. *Agrofor. Syst.* 86, 463–475.
- Fornberg, B., Flyer, N., 2015. A primer on radial basis functions with applications to the geosciences. SIAM.
- Fourty, T., Baret, F., 1997. Amélioration de la précision des coefficients d'absorption spécifique de la matière sèche et des pigments photosynthétiques. INRA Bioclimatol. Avignon.
- Fowler, R.L., 1987. Power and Robustness in Product-Moment Correlation. *Appl. Psychol. Meas.* 11, 419–428. <https://doi.org/10.1177/014662168701100407>
- Frank, S.A., 2009. The common patterns of nature. *J. Evol. Biol.* 22, 1563–1585. <https://doi.org/10.1111/j.1420-9101.2009.01775.x>.The
- Fukami, T., Bezemer, T.M., Mortimer, S.R., Van Der Putten, W.H., 2005. Species divergence and trait convergence in experimental plant community assembly. *Ecol. Lett.* 8, 1283–1290. <https://doi.org/10.1111/j.1461-0248.2005.00829.x>
- Funk, J.L., Larson, J.E., Ames, G.M., Butterfield, B.J., Cavender-Bares, J., Firn, J., Laughlin, D.C., Sutton-Grier, A.E., Williams, L., Wright, J., 2016. Revisiting the Holy Grail: using plant functional traits to understand ecological processes. *Biol. Rev.* 92, 1156–1173. <https://doi.org/10.1111/brv.12275>
- Gamon, J.A., Somers, B., Malenovský, Z., Middleton, E.M., Rascher, U., Schaepman, M.E., 2019. Assessing Vegetation Function with Imaging Spectroscopy. *Surv. Geophys.* 40, 489–513. <https://doi.org/10.1007/s10712-019-09511-5>
- Gamon, J.A., Wang, R., Gholizadeh, H., Zutta, B., Townsend, P.A., Cavender-Bares, J., 2020. Consideration of scale in remote sensing of biodiversity, in: *Remote Sensing of Plant Biodiversity*. Springer, Cham, pp. 425–447.

- Gara, T.W., Darvishzadeh, R., Skidmore, A.K., Wang, T., Heurich, M., 2019. Accurate modelling of canopy traits from seasonal Sentinel-2 imagery based on the vertical distribution of leaf traits. *ISPRS J. Photogramm. Remote Sens.* 157, 108–123. <https://doi.org/10.1016/j.isprsjprs.2019.09.005>
- Gara, T.W., Rahimzadeh-Bajgiran, P., Darvishzadeh, R., 2021. Forest Leaf Mass per Area (LMA) through the Eye of Optical Remote Sensing: A Review and Future Outlook. *Remote Sens.* 13, 3352. <https://doi.org/10.3390/rs13173352>
- Garrigues, S., Shabanov, N. V., Swanson, K., Morisette, J.T., Baret, F., Myneni, R.B., 2008. Intercomparison and sensitivity analysis of Leaf Area Index retrievals from LAI-2000, AccuPAR, and digital hemispherical photography over croplands. *Agric. For. Meteorol.* 148, 1193–1209. <https://doi.org/10.1016/j.agrformet.2008.02.014>
- Gascon, F., Cadau, E., Colin, O., Hoersch, B., Isola, C., Fernández, B.L., Martimort, P., 2014. Copernicus Sentinel-2 Mission: Products, Algorithms and Cal/Val, in: Butler, J.J., Xiong, X. (Jack), Gu, X. (Eds.), *Earth Observing Systems XIX*. SPIE, pp. 455–463. <https://doi.org/10.1117/12.2062260>
- Gaston, K.J., 2010. *Biodiversity* 27–44.
- Gaveau, D.L.A., Sheil, D., Husnayaen, Salim, M.A., Arjasakusuma, S., Ancrenaz, M., Pacheco, P., Meijaard, E., 2016. Rapid conversions and avoided deforestation: Examining four decades of industrial plantation expansion in Borneo. *Sci. Rep.* 6, 1–13. <https://doi.org/10.1038/srep32017>
- Gaveau, D.L.A., Sloan, S., Molineda, E., Yaen, H., Sheil, D., Abram, N.K., Ancrenaz, M., Nasi, R., Quinones, M., Wielaard, N., Meijaard, E., 2014. Four decades of forest persistence, clearance and logging on Borneo. *PLoS One* 9, 1–11. <https://doi.org/10.1371/journal.pone.0101654>
- Gholizadeh, H., Gamon, J.A., Townsend, P.A., Zygielbaum, A.I., Helzer, C.J., Hmimina, G.Y., Yu, R., Moore, R.M., Schweiger, A.K., Cavender-Bares, J., 2019. Detecting prairie biodiversity with airborne remote sensing. *Remote Sens. Environ.* 221, 38–49. <https://doi.org/10.1016/j.rse.2018.10.037>
- Gholizadeh, H., Gamon, J.A., Zygielbaum, A.I., Wang, R., Schweiger, A.K., Cavender-Bares, J., 2018. Remote sensing of biodiversity: Soil correction and data dimension reduction methods improve assessment of α -diversity (species richness) in prairie ecosystems. *Remote Sens. Environ.* 206, 240–253. <https://doi.org/10.1016/j.rse.2017.12.014>
- Götzenberger, L., de Bello, F., Bråthen, K.A., Davison, J., Dubuis, A., Guisan, A., Lepš, J., Lindborg, R., Moora, M., Pärtel, M., Pellissier, L., Pottier, J., Vittoz, P., Zobel, K., Zobel, M., 2012. Ecological assembly rules in plant communities—approaches, patterns and prospects. *Biol. Rev.* 87, 111–127. <https://doi.org/10.1111/j.1469-185X.2011.00187.x>
- Granger, V., Bez, N., Fromentin, J., Meynard, C., Jadaud, A., Mérigot, B., 2015. Mapping diversity indices: not a trivial issue. *Methods Ecol. Evol.* 6, 688–696. <https://doi.org/10.1111/2041-210X.12357>
- Grime, J.P., 1998. Benefits of plant diversity to ecosystems: immediate, filter and founder effects. *J. Ecol.* 86, 902–910. <https://doi.org/10.1046/j.1365-2745.1998.00306.x>
- Grytnes, J.A., Beaman, J.H., 2006. Elevational species richness patterns for vascular plants on

- Mount Kinabalu, Borneo. *J. Biogeogr.* 33, 1838–1849. <https://doi.org/10.1111/j.1365-2699.2006.01554.x>
- Gu, C., Du, H., Mao, F., Han, N., Zhou, G., Xu, X., Sun, S., Gao, G., 2016. Global sensitivity analysis of PROSAIL model parameters when simulating Moso bamboo forest canopy reflectance. *Int. J. Remote Sens.* 37, 5270–5286. <https://doi.org/10.1080/01431161.2016.1239287>
- Guinée, J.B., Lindeijer, E., 2002. Handbook on life cycle assessment: operational guide to the ISO standards. Springer Science \& Business Media.
- Hadi, Pfeifer, M., Korhonen, L., Wheeler, C., Rautiainen, M., 2017. Remote Sensing of Environment Forest canopy structure and reflectance in humid tropical Borneo : A physically-based interpretation using spectral invariants. *Remote Sens. Environ.* 201, 314–330. <https://doi.org/10.1016/j.rse.2017.09.018>
- Hakkenberg, C.R., Zhu, K., Peet, R.K., Song, C., 2018. Mapping multi-scale vascular plant richness in a forest landscape with integrated LiDAR and hyperspectral remote-sensing. *Ecology* 99, 474–487. <https://doi.org/10.1002/ecy.2109>
- Hamilton, A.J., 2005. Species diversity or biodiversity? *J. Environ. Manage.* 75, 89–92. <https://doi.org/10.1016/j.jenvman.2004.11.012>
- Hardon, J.J., Williams, C.N., Watson, I., 1969. Leaf area and yield in the oil palm in Malaya. *Exp. Agric.* 5, 25–32.
- Hauser, L.T., Binh, N.A., Hoa, P.V., Quan, N.H., Timmermans, J., 2020. Gap-free monitoring of annual mangrove forest dynamics in ca mau province, vietnamese mekong delta, using the landsat-7-8 archives and post-classification temporal optimization. *Remote Sens.* 12, 1–16. <https://doi.org/10.3390/rs12223729>
- Hauser, Leon T, Féret, J.-B., An Binh, N., van der Windt, N., Sil, Â.F., Timmermans, J., Soudzilovskaia, N.A., van Bodegom, P.M., An, N., Windt, N. Van Der, Sil, F., Soudzilovskaia, N.A., Bodegom, P.M. Van, 2021. Towards scalable estimation of plant functional diversity from Sentinel-2: In-situ validation in a heterogeneous (semi-)natural landscape. *Remote Sens. Environ.* 262, 112505. <https://doi.org/https://doi.org/10.1016/j.rse.2021.112505>
- Hauser, Leon T., Timmermans, J., van der Windt, N., Sil, Â.F., César de Sá, N., Soudzilovskaia, N.A., van Bodegom, P.M., 2021. Explaining discrepancies between spectral and in-situ plant diversity in multispectral satellite earth observation. *Remote Sens. Environ.* 265, 112684. <https://doi.org/10.1016/j.rse.2021.112684>
- Hennessy, A., Clarke, K., Lewis, M., 2020. Hyperspectral Classification of Plants: A Review of Waveband Selection Generalisability. *Remote Sens.* <https://doi.org/10.3390/rs12010113>
- Hill, J., Buddenbaum, H., Townsend, P.A., 2019. Imaging Spectroscopy of Forest Ecosystems : Perspectives for the Use of Space - borne Hyperspectral Earth Observation Systems, Surveys in Geophysics. Springer Netherlands. <https://doi.org/10.1007/s10712-019-09514-2>
- Hinkes, C., 2020. Adding (bio)fuel to the fire: discourses on palm oil sustainability in the context of European policy development. *Environ. Dev. Sustain.* 22, 7661–7682.

<https://doi.org/10.1007/s10668-019-00541-y>

- Hoffmann, S., Schmitt, T.M., Chiarucci, A., Irl, S.D.H., Rocchini, D., Vetaas, O.R., Tanase, M.A., Mermoz, S., Bouvet, A., Beierkuhnlein, C., 2019. Remote sensing of β -diversity: Evidence from plant communities in a semi-natural system. *Appl. Veg. Sci.* 22, 13–26. <https://doi.org/10.1111/avsc.12403>
- Homolová, L., Malenovský, Z., Clevers, J.G.P.W., García-Santos, G., Schaepman, M.E., 2013. Review of optical-based remote sensing for plant trait mapping. *Ecol. Complex.* 15, 1–16. <https://doi.org/10.1016/j.ecocom.2013.06.003>
- Hooper, D.U., 2002. Species diversity, functional diversity and ecosystem functioning, in: *Biodiversity and Ecosystem Functioning: Synthesis and Perspectives*.
- Hooper, D.U., Chapin, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavelle, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S., Schmid, B., Setälä, H., Symstad, A.J., Vandermeer, J., Wardle, D.A., 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecol. Monogr.* 75, 3–35. <https://doi.org/10.1890/04-0922>
- Hortal, J., De Bello, F., Diniz-Filho, J.A.F., Lewinsohn, T.M., Lobo, J.M., Ladle, R.J., 2015. Seven Shortfalls that Beset Large-Scale Knowledge of Biodiversity. *Annu. Rev. Ecol. Evol. Syst.* 46, 523–549. <https://doi.org/10.1146/annurev-ecolsys-112414-054400>
- Hosgood, B., Jacquemoud, S., Andreoli, G., others, 1994. Leaf optical properties experiment 93 (LOPEX93) report.
- Huang, J., Zeng, Y., Kuusk, A., Wu, B., Dong, L., Mao, K., Chen, J., 2011. Inverting a forest canopy reflectance model to retrieve the overstorey and understorey leaf area index for forest stands. *Int. J. Remote Sens.* 32, 7591–7611. <https://doi.org/10.1080/01431161.2010.525259>
- Hubbell, S.P., 2001. The unified neutral theory of biodiversity and biogeography (MPB-32). Princeton University Press.
- Hulshof, C.M., Swenson, N.G., 2010. Variation in leaf functional trait values within and across individuals and species: An example from a Costa Rican dry forest. *Funct. Ecol.* 24, 217–223. <https://doi.org/10.1111/j.1365-2435.2009.01614.x>
- Huston, Michael A, Huston, Michael Alan, 1994. Biological diversity: the coexistence of species. Cambridge University Press.
- IPBES, 2019. Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Bonn, Germany, Germany.
- Isbell, F., Calcagno, V., Hector, A., Connolly, J., Harpole, W.S., Reich, P.B., Scherer-Loorenzen, M., Schmid, B., Tilman, D., Ruijven, J., Van, Weigelt, A., Wilsey, B.J., Zavaleta, E.S., Loreau, M., 2011. High plant diversity is needed to maintain ecosystem services. *Nature* 477, 199–202. <https://doi.org/10.1038/nature10282>
- Jacquemoud, S., Ustin, S., 2019. Leaf optical properties. Cambridge University Press.
- Jacquemoud, S., Baret, F., 1990. PROSPECT: A model of leaf optical properties spectra. *Remote Sens. Environ.* 34, 75–91. [https://doi.org/10.1016/0034-4257\(90\)90100-Z](https://doi.org/10.1016/0034-4257(90)90100-Z)

- Jacquemoud, S., Bidel, L., Francois, C., Pavan, G., 2003. ANGERS Leaf Optical Properties Database.
- Jacquemoud, S., Ustin, S.L., Verdebout, J., Schmuck, G., Andreoli, G., Hosgood, B., 1996. Estimating leaf biochemistry using the PROSPECT leaf optical properties model. *Remote Sens. Environ.* 56, 194–202. [https://doi.org/10.1016/0034-4257\(95\)00238-3](https://doi.org/10.1016/0034-4257(95)00238-3)
- Jacquemoud, S., Verhoef, W., Baret, F., Bacour, C., Zarco-Tejada, P.J., Asner, G.P., François, C., Ustin, S.L., 2009. PROSPECT + SAIL models: A review of use for vegetation characterization. *Remote Sens. Environ.* 113, S56–S66. <https://doi.org/10.1016/j.rse.2008.01.026>
- Jacquemoud, S., Verhoef, W., Baret, F., Zarco-Tejada, P.J., Asner, G.P., François, C., Ustin, S.L., 2006. PROSPECT + SAIL : 15 Years of Use for Land Surface Characterization. *Geosci. Remote Sens. Symp.* 2006. IEEE Int. Conf. 00, 1992–1995. <https://doi.org/10.1109/IGARSS.2006.516>
- Jaroenkietkajorn, U., Gheewala, S.H., Scherer, L., 2021. Species loss from land use of oil palm plantations in Thailand. *Ecol. Indic.* 133, 108444. <https://doi.org/10.1016/j.ecolind.2021.108444>
- Jarzyna, M.A., Jetz, W., 2018. Taxonomic and functional diversity change is scale dependent. *Nat. Commun.* <https://doi.org/10.1038/s41467-018-04889-z>
- Jay, S., Maupas, F., Bendoula, R., Gorretta, N., 2017. Retrieving LAI, chlorophyll and nitrogen contents in sugar beet crops from multi-angular optical remote sensing: Comparison of vegetation indices and PROSAIL inversion for field phenotyping. *F. Crop. Res.* 210, 33–46. <https://doi.org/10.1016/j.fcr.2017.05.005>
- Jensen, J.R., 2013. *Remote Sensing of the Environment: Pearson New International Edition: An Earth Resource Perspective*. Pearson Education Limited.
- Jetz, W., Cavender-Bares, J., Pavlick, R., Schimel, D., Davis, F.W., Asner, G.P., Guralnick, R., Kattge, J., Latimer, A.M., Moorcroft, P., Schaepman, M.E., Schildhauer, M.P., Schneider, F.D., Schrodt, F., Stahl, U., Ustin, S.L., 2016. Monitoring plant functional diversity from space. *Nat. Plants* 2, 1–5. <https://doi.org/10.1038/NPLANTS.2016.24>
- John, R., Dalling, J.W., Harms, K.E., Yavitt, J.B., Stallard, R.F., Mirabello, M., Hubbell, S.P., Valencia, R., Navarrete, H., Vallejo, M., Foster, R.B., 2007. Soil nutrients influence spatial distributions of tropical trees species. *Proc. Natl. Acad. Sci. U. S. A.* 104, 864–869. <https://doi.org/10.1073/pnas.0604666104>
- Johnson, J.W., 2000. A heuristic method for estimating the relative weight of predictor variables in multiple regression. *Multivariate Behav. Res.* 35, 1–19.
- Jong, H.N., 2022. Proposal could redefine palm oil-driven deforestation as reforestation in Indonesia. Mongabay.
- Jurasinski, G., Retzer, A.V., Beierkuhnlein, A.C., 2009. Inventory , differentiation , and proportional diversity : a consistent terminology for quantifying species diversity. *Oecologia* 159, 15–26. <https://doi.org/10.1007/s00442-008-1190-z>
- Kaennel, M., 1998. Biodiversity: A diversity in definition. *Assess. Biodivers. Improv. For. Plan.* 51, 71–81. https://doi.org/10.1007/978-94-015-9006-8_7

- Kampe, T.U., 2010. NEON: the first continental-scale ecological observatory with airborne remote sensing of vegetation canopy biochemistry and structure. *J. Appl. Remote Sens.* 4, 043510. <https://doi.org/10.1117/1.3361375>
- Karadimou, E.K., Kallimanis, A.S., Tsiripidis, I., Dimopoulos, P., 2016. Functional diversity exhibits a diverse relationship with area, even a decreasing one. *Sci. Rep.* 6, 1–9. <https://doi.org/10.1038/srep35420>
- Kattenborn, T., Fassnacht, F.E., Pierce, S., Lopatin, J., Grime, J.P., Schmidlein, S., 2017. Linking plant strategies and plant traits derived by radiative transfer modelling. *J. Veg. Sci.* 28, 717–727. <https://doi.org/10.1111/jvs.12525>
- Kattenborn, T., Schiefer, F., Zarco-Tejada, P., Schmidlein, S., 2019. Advantages of retrieving pigment content [$\mu\text{g}/\text{cm}^2$] versus concentration [%] from canopy reflectance. *Remote Sens. Environ.* 230, 111195. <https://doi.org/10.1016/j.rse.2019.05.014>
- Kattge, J., Bönisch, G., Díaz, S., Lavorel, S., Prentice, I.C., Leadley, P., Tautenhahn, S., Werner, G.D.A., Aakala, T., Abedi, M., Acosta, A.T.R., Wirth, C., et al., 2020. TRY plant trait database – enhanced coverage and open access. *Glob. Chang. Biol.* 26, 119–188. <https://doi.org/10.1111/gcb.14904>
- Kattge, J., Díaz, S., Lavorel, S., Prentice, I.C., Leadley, P., Bönisch, G., Garnier, E., Westoby, M., Reich, P.B., Wright, I.J., Cornelissen, J.H.C., Wirth, C., et al., 2011. TRY - a global database of plant traits. *Glob. Chang. Biol.* 17, 2905–2935. <https://doi.org/10.1111/j.1365-2486.2011.02451.x>
- Khamis, H., 2008. Measures of Association: How to Choose? *J. Diagnostic Med. Sonogr.* 24, 155–162. <https://doi.org/10.1177/8756479308317006>
- Khare, S., Latifi, H., Rossi, S., 2021. A 15-year spatio-temporal analysis of plant β -diversity using Landsat time series derived Rao's Q index. *Ecol. Indic.* 121, 107105. <https://doi.org/10.1016/j.ecolind.2020.107105>
- Khare, S., Latifi, H., Rossi, S., 2019. Forest beta-diversity analysis by remote sensing: How scale and sensors affect the Rao's Q index. *Ecol. Indic.* 106. <https://doi.org/10.1016/j.ecolind.2019.105520>
- Kim, D., Seo, S.C., Min, S., Simoni, Z., Kim, S., Kim, M., 2018. A closer look at the bivariate association between ambient air pollution and allergic diseases: The role of spatial analysis. *Int. J. Environ. Res. Public Health* 15. <https://doi.org/10.3390/ijerph15081625>
- Kitayama, K., 1992. An altitudinal transect study of the vegetation on Mount Kinabalu, Borneo. *Vegetatio* 102, 149–171. <https://doi.org/10.1007/BF00044731>
- Koetz, B., Sun, G., Morsdorf, F., Ranson, K.J., Kneubühler, M., Itten, K., Allgöwer, B., 2007. Fusion of imaging spectrometer and LIDAR data over combined radiative transfer models for forest canopy characterization. *Remote Sens. Environ.* 106, 449–459. <https://doi.org/10.1016/j.rse.2006.09.013>
- Koh, L.P., Wilcove, D.S., 2008. Is oil palm agriculture really destroying tropical biodiversity? *Conserv. Lett.* 1, 60–64. <https://doi.org/10.1111/j.1755-263X.2008.00011.x>
- Kraft, N.J.B., Valencia, R., Ackerly, D.D., 2008. Functional Traits and Niche-Based Tree Community Assembly in an Amazonian Forest. *Science* (80-.). 322, 580–582.

<https://doi.org/10.1126/science.1160662>

Kreft, H., Jetz, W., 2007. Global patterns and determinants of vascular plant diversity. Proc. Natl. Acad. Sci. U. S. A. 104, 5925–5930. <https://doi.org/10.1073/pnas.0608361104>

Kuenzer, C., Ottinger, M., Wegmann, M., Guo, H., Wang, C., Zhang, J., Dech, S., Wikelski, M., 2014. International Journal of Remote Sensing Earth observation satellite sensors for biodiversity monitoring: potentials and bottlenecks) Earth observation satellite sensors for biodiversity monitoring: potentials and bottlenecks Earth observation satellite sensors for biodiversity monitoring: potentials and bottlenecks. Int. J. Remote Sens. 35, 6599–6647. <https://doi.org/10.1080/01431161.2014.964349>

Kunin, W.E., Harte, J., He, F., Hui, C., Jobe, R.T., Ostling, A., Polce, C., Šizling, A., Smith, A.B., Smith, K., Smart, S.M., Storch, D., Tjørve, E., Ugland, K.I., Ulrich, W., Varma, V., 2018. Upscaling biodiversity: estimating the species-area relationship from small samples. Ecol. Monogr. 88, 170–187. <https://doi.org/10.1002/ecm.1284>

Kurokawa, H., Nakashizuka, T., 2008. Leaf herbivory and decomposability in a Malaysian tropical rain forest. Ecology 89, 2645–2656.

Kuusk, A., Nilson, T., 2000. A directional multispectral forest reflectance model. Remote Sens. Environ. 72, 244–252. [https://doi.org/10.1016/S0034-4257\(99\)00111-X](https://doi.org/10.1016/S0034-4257(99)00111-X)

Lahoz, W. a., Schneider, P., 2014. Data assimilation: making sense of Earth Observation. Front. Environ. Sci. 2, 1–28. <https://doi.org/10.3389/fenvs.2014.00016>

Laliberté, E., Schweiger, A.K., Legendre, P., 2019. Partitioning plant spectral diversity into alpha and beta components 1–38.

Lanaras, C., Bioucas-Dias, J., Galliani, S., Baltsavias, E., Schindler, K., 2018. Super-resolution of Sentinel-2 images: Learning a globally applicable deep neural network. ISPRS J. Photogramm. Remote Sens. 146, 305–319. <https://doi.org/10.1016/j.isprsjprs.2018.09.018>

Latifi, H., Holzwarth, S., Skidmore, A., Brůna, J., Červenka, J., Darvishzadeh, R., Hais, M., Heiden, U., Homolová, L., Krzystek, P., Schneider, T., Starý, M., Wang, T., Müller, J., Heurich, M., 2021. A laboratory for conceiving Essential Biodiversity Variables (EBVs)—The ‘Data pool initiative for the Bohemian Forest Ecosystem.’ Methods Ecol. Evol. 2021, 1–11. <https://doi.org/10.1111/2041-210X.13695>

Lausch, a., Bannehr, L., Beckmann, M., Boehm, C., Feilhauer, H., Hacker, J.M., Heurich, M., Jung, a., Klenke, R., Neumann, C., Pause, M., Rocchini, D., Schaeppman, M.E., Schmidlein, S., Schulz, K., Selsam, P., Settele, J., Skidmore, a. K., Cord, a. F., 2016. Linking Earth Observation and taxonomic, structural and functional biodiversity: Local to ecosystem perspectives. Ecol. Indic. 70, 317–339. <https://doi.org/10.1016/j.ecolind.2016.06.022>

Lawlor, D.W., Cornic, G., 2002. Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants. Plant. Cell Environ. 25, 275–294. <https://doi.org/10.1046/j.0016-8025.2001.00814.x>

LeBreton, J.M., Hargis, M.B., Griepentrog, B., Oswald, F., Ployhart, R.E., 2007. A multidimensional approach for evaluating variables in organizational research and practice. Pers. Psychol. 475–498. <https://doi.org/10.1111/j.1744-6570.2007.00080.x>

- Lee, S. II, 2001. Developing a bivariate spatial association measure: An integration of Pearson's r and Moran's I . *J. Geogr. Syst.* 3, 369–385. <https://doi.org/10.1007/s101090100064>
- Legras, G., Loiseau, N., Gaertner, J.C., Poggiale, J.C., Gaertner-Mazouni, N., 2020. Assessing functional diversity: the influence of the number of the functional traits. *Theor. Ecol.* 13, 117–126. <https://doi.org/10.1007/s12080-019-00433-x>
- Lehnert, L.W., Meyer, H., Obermeier, W.A., Silva, B., Regeling, B., Bendix, J., 2018. Hyperspectral data analysis in R: The hsdar package. *arXiv Prepr. arXiv1805.05090*.
- Levin, S.A., 1992. The problem of pattern and scale in ecology. *Ecology* 73, 1943–1967. <https://doi.org/10.2307/1941447>
- Lewis, P., Gomez-Dans, J., Kaminski, T., Settle, J., Quaife, T., Gobron, N., Styles, J., Berger, M., 2012. An Earth Observation Land Data Assimilation System (EO-LDAS). *Remote Sens. Environ.* 120, 219–235. <https://doi.org/10.1016/j.rse.2011.12.027>
- Li, S., Su, J., Lang, X., Liu, W., Ou, G., 2018. Positive relationship between species richness and aboveground biomass across forest strata in a primary *Pinus kesiya* forest. *Sci. Rep.* 8, 1–9. <https://doi.org/10.1038/s41598-018-20165-y>
- Lichtenthaler, H.K., 1987. Chlorophylls and Carotenoids: Pigments of Photosynthetic Biomembranes. *Methods Enzymol.* 148, 350–382. [https://doi.org/10.1016/0076-6879\(87\)48036-1](https://doi.org/10.1016/0076-6879(87)48036-1)
- Lin, B.B., Flynn, D.F.B., Bunker, D.E., Uriarte, M., Naeem, S., 2011. The effect of agricultural diversity and crop choice on functional capacity change in grassland conversions. *J. Appl. Ecol.* 48, 609–618. <https://doi.org/10.1111/j.1365-2664.2010.01944.x>
- Lomolino, M. V, 2000. Ecology's most general, yet protean pattern: the species-area relationship. *J. Biogeogr.* 27, 17–26.
- Louis, J., Debaecker, V., Pflug, B., Main-Knorn, M., Bieniarz, J., Mueller-Wilm, U., Cadau, E., Gascon, F., 2016. Sentinel-2 Sen2Cor: L2A Processor for Users, in: Proceedings Living Planet Symposium 2016. pp. 1–8.
- Lu, B., He, Y., Dao, P.D., 2019. Comparing the Performance of Multispectral and Hyperspectral Images for Estimating Vegetation Properties. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* 12, 1784–1797. <https://doi.org/10.1109/JSTARS.2019.2910558>
- Lucas, K.L., Carter, G.A., 2008. The use of hyperspectral remote sensing to assess vascular plant species richness on Horn Island, Mississippi. *Remote Sens. Environ.* 112, 3908–3915. <https://doi.org/10.1016/j.rse.2008.06.009>
- Ma, X., Mahecha, M.D., Migliavacca, M., van der Plas, F., Benavides, R., Ratcliffe, S., Kattge, J., Richter, R., Musavi, T., Baeten, L., Barroaiea, I., Bohn, F.J., Bouriaud, O., Bussotti, F., Coppi, A., Domisch, T., Huth, A., Jaroszewicz, B., Joswig, J., Pabon-Moreno, D.E., Papale, D., Selvi, F., Laurin, G.V., Valladares, F., Reichstein, M., Wirth, C., 2019. Inferring plant functional diversity from space: the potential of Sentinel-2. *Remote Sens. Environ.* 233, 111368. <https://doi.org/10.1016/J.RSE.2019.111368>
- Madonsela, S., Cho, M.A., Ramoelo, A., Mutanga, O., 2017. Remote sensing of species diversity using Landsat 8 spectral variables. *ISPRS J. Photogramm. Remote Sens.* 133,

- 116–127. <https://doi.org/10.1016/j.isprsjprs.2017.10.008>
- Maeshiro, R., Kusumoto, B., Fujii, S., Shiono, T., Kubota, Y., 2013. Using tree functional diversity to evaluate management impacts in a subtropical forest. *Ecosphere* 4, 1–17. <https://doi.org/10.1890/ES13-00125.1>
- Magurran, A.E., 2003. Measuring biological diversity. John Wiley & Sons.
- Májeková, M., Paal, T., Plowman, N.S., Bryndová, M., Kasari, L., Norberg, A., Weiss, M., Bishop, T.R., Luke, S.H., Sam, K., Le Bagousse-Pinguet, Y., Lepš, J., Götzenberger, L., De Bello, F., 2016. Evaluating Functional diversity: Missing trait data and the importance of species abundance structure and data transformation. *PLoS One* 11, 1–17. <https://doi.org/10.1371/journal.pone.0149270>
- Marceau, D.J., Hay, G.J., 1999. Remote Sensing Contributions to the Scale Issue. *Can. J. Remote Sens.* Vol. 25, 37–41. <https://doi.org/10.1080/07038992.1999.10874735>
- Marie Weiss, Frédéric Baret, Ranga B. Myneni, Agnès Pragnère, Youri Knyazikhin, 2000. Investigation of a model inversion technique to estimate canopy biophysical variables from spectral and directional reflectance data. *Agronomie* 20, 3–22. <https://doi.org/10.1051/agro:2000105>
- Marques, A., Verones, F., Kok, M.T., Huijbregts, M.A., Pereira, H.M., 2017. How to quantify biodiversity footprints of consumption? A review of multi-regional input–output analysis and life cycle assessment. *Curr. Opin. Environ. Sustain.* 29, 75–81. <https://doi.org/10.1016/j.cosust.2018.01.005>
- Marsh, C.W., Greer, A.G., Marshall, A.G., Swaine, M.D., 1992. Forest land-use in Sabah, Malaysia: an introduction to Danum Valley. *Philos. Trans. R. Soc. London. Ser. B Biol. Sci.* 335, 331–339. <https://doi.org/10.1098/rstb.1992.0025>
- Martin, R., Chadwick, K., Brodrick, P., Carranza-Jimenez, L., Vaughn, N., Asner, G., 2018. An Approach for Foliar Trait Retrieval from Airborne Imaging Spectroscopy of Tropical Forests. *Remote Sens.* 10, 199. <https://doi.org/10.3390/rs10020199>
- Mason, N.W.H., Mouillot, D., Lee, W.G., Wilson, J.B., 2005. Functional richness, functional evenness and functional divergence: the primary components of functional diversity. *Oikos* 111, 112–118.
- Maycock, C.R., Kettle, C.J., Khoo, E., Pereira, J.T., Sugau, J.B., Nilus, R., Ong, R.C., Amaludin, N.A., Newman, M.F., Burslem, D.F.R.P., 2012. A Revised Conservation Assessment of Dipterocarps in Sabah. *Biotropica* 44, 649–657. <https://doi.org/10.1111/j.1744-7429.2011.00852.x>
- Meatyard, B., 2005. Biodiversity, an introduction, *Biological Conservation*. <https://doi.org/10.1016/j.biocon.2004.07.009>
- Messier, J., McGill, B.J., Lechowicz, M.J., 2010. How do traits vary across ecological scales? A case for trait-based ecology. *Ecol. Lett.* 13, 838–848. <https://doi.org/10.1111/j.1461-0248.2010.01476.x>
- Moreno-Martínez, Á., Kramer, K., Reichstein, M., Baraloto, C., Reich, P., Laughlin, D.C., Minden, V., Craine, J.M., Bahn, M., Kattge, J., Peñuelas, J., Camps-Valls, GustauAllred, B., Robinson, N., Sack, L., Byun, C., Cerabolini, B.E.L., Niinemets, Ü., Soudzilovskaia,

- N.A., van Bodegom, P., Running, S.W., Cornelissen, J.H.C., 2018. A methodology to derive global maps of leaf traits using remote sensing and climate data. *Remote Sens. Environ.* 218, 69–88. <https://doi.org/10.1016/j.rse.2018.09.006>
- Mori, A.S., Furukawa, T., Sasaki, T., 2013. Response diversity determines the resilience of ecosystems to environmental change. *Biol. Rev.* 88, 349–364. <https://doi.org/10.1111/brv.12004>
- Morsdorf, F., Schneider, F.D., Gullien, C., Kükenbrink, D., Leiterer, R., Schaepman, M.E., 2020. The Laegeren site: an augmented forest laboratory, in: *Remote Sensing of Plant Biodiversity*. Springer, Cham, pp. 83–104.
- Mouchet, M. a., Villéger, S., Mason, N.W.H., Mouillot, D., 2010. Functional diversity measures: An overview of their redundancy and their ability to discriminate community assembly rules. *Funct. Ecol.* 24, 867–876. <https://doi.org/10.1111/j.1365-2435.2010.01695.x>
- Mouillot, D., Mason, W.H.N., Dumay, O., Wilson, J.B., 2005. Functional regularity: A neglected aspect of functional diversity. *Oecologia* 142, 353–359. <https://doi.org/10.1007/s00442-004-1744-7>
- Musavi, T., Mahecha, M.D., Migliavacca, M., Reichstein, M., van de Weg, M.J., van Bodegom, P.M., Bahn, M., Wirth, C., Reich, P.B., Schrödt, F., Kattge, J., 2015. The imprint of plants on ecosystem functioning: A data-driven approach. *Int. J. Appl. Earth Obs. Geoinf.* 43, 119–131. <https://doi.org/10.1016/j.jag.2015.05.009>
- Myneni, R.B., Maggioni, S., Iaquinta, J., Privette, J.L., Gobron, N., Pinty, B., Kimes, D.S., Verstraete, M.M., Williams, D.L., 1995. Optical remote sensing of vegetation: modeling, caveats, and algorithms. *Remote Sens. Environ.* 51, 169–188.
- Nagendra, H., Rocchini, D., Ghate, R., Sharma, B., Pareeth, S., 2010. Assessing Plant Diversity in a Dry Tropical Forest: Comparing the Utility of Landsat and Ikonos Satellite Images. *Remote Sens.* 2, 478–496. <https://doi.org/10.3390/rs2020478>
- Nakagawa, S., Johnson, P.C.D., Schielzeth, H., 2017. The coefficient of determination R² and intra-class correlation coefficient from generalized linear mixed-effects models revisited and expanded. *J. R. Soc. Interface* 14. <https://doi.org/10.1098/rsif.2017.0213>
- National Academies of Sciences Engineering and Medicine, 2018. *Thriving on our changing planet: A decadal strategy for Earth observation from space*. National Academies Press, Washington DC.
- National Ecological Observatory Network (NEON), 2020. Provisional data downloaded from <http://data.neonscience.org> on 01/04/2020. Battelle, Boulder, CO, USA.
- Neo, L., Tan, H.T.W., Wong, K.M., 2021. Too little, too late? Conservation exigencies for Borneo inferred from biogeographic considerations of its endemic plant genera against intense landscape modifications. *Biodivers. Conserv.* <https://doi.org/10.1007/s10531-021-02320-6>
- Nidamanuri, R.R., Ramiya, a. M., 2013. Spectral identification of materials by reflectance spectral library search. *Geocarto Int.* 29, 609–624. <https://doi.org/10.1080/10106049.2013.821175>

- Nieuwstadt, M.G.L. Van, Sheil, D., 2005. Drought , fire and tree survival in a Borneo rain forest , East Kalimantan , Indonesia. *J. Ecol.* 93, 191–201. <https://doi.org/10.1111/j.1365-2745.2005.00954.x>
- Noormets, A., 2013. Phenology of Ecosystem Processes, Climate Change 2013 - The Physical Science Basis. Springer Science & Business Media, New York, USA.
- O'Connor, B., Secades, C., Penner, J., Sonnenschein, R., Skidmore, A., Burgess, N.D., Hutton, J.M., 2015. Earth observation as a tool for tracking progress towards the Aichi Biodiversity Targets. *Remote Sens. Ecol. Conserv.* 1, 19–28. <https://doi.org/10.1002/rse2.4>
- Ollinger, S. V., 2011. Sources of variability in canopy reflectance and the convergent properties of plants. *New Phytol.* 189, 375–394. <https://doi.org/10.1111/j.1469-8137.2010.03536.x>
- Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G.V.N., Underwood, E.C., D'Amico, J.A., Itoua, I., Strand, H.E., Morrison, J.C., Loucks, C.J., Allnutt, T.F., Ricketts, T.H., Kura, Y., Lamoreux, J.F., Wettengel, W.W., Hedao, P., Kassem, K.R., 2001. Terrestrial ecoregions of the world: A new map of life on Earth. *Bioscience* 51, 933–938. [https://doi.org/10.1641/0006-3568\(2001\)051\[0933:TEOTWA\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2)
- Padalia, H., Sinha, S.K., Bhave, V., Trivedi, N.K., Senthil Kumar, A., 2020. Estimating canopy LAI and chlorophyll of tropical forest plantation (North India) using Sentinel-2 data. *Adv. Sp. Res.* 65, 458–469. <https://doi.org/10.1016/j.asr.2019.09.023>
- Pakeman, R.J., 2011. Functional diversity indices reveal the impacts of land use intensification on plant community assembly. *J. Ecol.* 99, 1143–1151. <https://doi.org/10.1111/j.1365-2745.2011.01853.x>
- Palmer, M.W., Earls, P.G., Hoagland, B.W., White, P.S., Wohlgemuth, T., 2002. Quantitative tools for perfecting species lists. *Environmetrics* 13, 121–137. <https://doi.org/10.1002/env.516>
- Pasqualotto, N., D'Urso, G., Bolognesi, S.F., Belfiore, O.R., Van Wittenberghe, S., Delegido, J., Pezzola, A., Winschel, C., Moreno, J., 2019. Retrieval of evapotranspiration from sentinel-2: Comparison of vegetation indices, semi-empirical models and SNAP biophysical processor approach. *Agronomy* 9. <https://doi.org/10.3390/agronomy9100663>
- Pausas, J.G., Vallejo, V.R., 1999. The role of fire in European Mediterranean ecosystems, in: *Remote Sensing of Large Wildfires*. Springer Berlin Heidelberg, pp. 3–16. https://doi.org/10.1007/978-3-642-60164-4_2
- Pereira, H.M., Ferrier, S., Walters, M., Geller, G.N., Jongman, R.H.G., Scholes, R.J., Bruford, M.W., Brummitt, N., Butchart, S.H.M., Cardoso, a. C., Coops, N.C., Dulloo, E., Faith, D.P., Freyhof, J., Gregory, R.D., Heip, C., Höft, R., Hurttt, G., Jetz, W., Karp, D.S., McGeoch, M. a., Obura, D., Onoda, Y., Pettorelli, N., Reyers, B., Sayre, R., Scharlemann, J.P.W., Stuart, S.N., Turak, E., Walpole, M., Wegmann, M., 2013. Essential Biodiversity Variables. *Science* (80-.). 339, 277–278. <https://doi.org/10.1126/science.1229931>
- Petchey, O.L., Gaston, K.J., 2006. Functional diversity: Back to basics and looking forward. *Ecol. Lett.* 9, 741–758. <https://doi.org/10.1111/j.1461-0248.2006.00924.x>
- Petchey, O.L., Gaston, K.J., 2002. Functional diversity (FD), species richness and community

- composition. *Ecol. Lett.* 5, 402–411. <https://doi.org/10.1046/j.1461-0248.2002.00339.x>
- Pettorelli, N., Wegmann, M., Skidmore, A., Mücher, S., Dawson, T.P., Fernandez, M., Lucas, R., Schaeppman, M.E., Wang, T., O'Connor, B., Jongman, R.H.G., Kempeneers, P., Sonnenschein, R., Leidner, A.K., Böhm, M., He, K.S., Nagendra, H., Dubois, G., Fatoyinbo, T., Hansen, M.C., Paganini, M., de Klerk, H.M., Asner, G.P., Kerr, J.T., Estes, A.B., Schmeller, D.S., Heiden, U., Rocchini, D., Pereira, H.M., Turak, E., Fernandez, N., Lausch, A., Cho, M. a., Alcaraz-Segura, D., McGeoch, M. a., Turner, W., Mueller, A., St-Louis, V., Penner, J., Viheravaara, P., Belward, A., Reyers, B., Geller, G.N., 2016. Framing the concept of satellite remote sensing essential biodiversity variables: challenges and future directions. *Remote Sens. Ecol. Conserv.* n/a-n/a. <https://doi.org/10.1002/rse2.15>
- Plotkin, J.B., Potts, M.D., Yu, D.W., Bunyavejchewin, S., Condit, R., Foster, R., Hubbell, S., LaFrankie, J., Manokaran, N., Seng, L.H., Sukumar, R., Nowak, M.A., Ashton, P.S., 2000. Predicting species diversity in tropical forests. *Proc. Natl. Acad. Sci. U. S. A.* 97, 10850–10854. <https://doi.org/10.1073/pnas.97.20.10850>
- Poorter, L., Bongers, F., 2006. Leaf traits are good predictors of plant performance across 53 rain forest species. *Ecology* 87, 1733–1743. [https://doi.org/10.1890/0012-9658\(2006\)87\[1733:LTAGPO\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2006)87[1733:LTAGPO]2.0.CO;2)
- Preston, F.W., 1960. Time and Space and the Variation of Species. *Ecology* 41, 611–627. <https://doi.org/10.2307/1931793>
- Price, J.C., 1994. How unique are spectral signatures? *Remote Sens. Environ.* 49, 181–186. [https://doi.org/10.1016/0034-4257\(94\)90013-2](https://doi.org/10.1016/0034-4257(94)90013-2)
- Rands, M.R.W., Adams, W.M., Bennun, L., Butchart, S.H.M., Clements, A., Coomes, D., Entwistle, A., Hodge, I., Kapos, V., Scharlemann, J.P.W., Sutherland, W.J., Vira, B., 2010. Biodiversity conservation: challenges beyond 2010. *Science* 329, 1298–1303. <https://doi.org/10.1126/science.1189138>
- Read, Q.D., Moorhead, L.C., Swenson, N.G., Bailey, J.K., Sanders, N.J., 2014. Convergent effects of elevation on functional leaf traits within and among species. *Funct. Ecol.* 28, 37–45. <https://doi.org/10.1111/1365-2435.12162>
- Rego, F.C., Monteiro, M. do L., Geraldes, A., Mesquita, J., 2011. Silvicultura de Povoamentos Mistos de Quercus pyrenaica e Quercus rotundifolia: O Caso da Tapada da Nogueira. *Silva Lusit.* 19, 135–148.
- Reichstein, M., Bahn, M., Mahecha, M.D., Kattge, J., Baldocchi, D.D., 2014. Linking plant and ecosystem functional biogeography. *Proc. Natl. Acad. Sci. U. S. A.* 111, 13697–13702. <https://doi.org/10.1073/pnas.1216065111>
- Reichstein, M., Camps-Valls, G., Stevens, B., Jung, M., Denzler, J., Carvalhais, N., Prabhat, 2019. Deep learning and process understanding for data-driven Earth system science. *Nature* 566, 195–204. <https://doi.org/10.1038/s41586-019-0912-1>
- Richter, K., Hank, T.B., 2021. Derivation of biophysical variables from Earth observation data : validation and statistical measures. <https://doi.org/10.1117/1.JRS.6.063557>
- Ricklefs, R.E., 2008. Disintegration of the ecological community. *Am. Nat.* 172, 741–750. <https://doi.org/10.1086/593002>

- Ricotta, C., Moretti, M., 2011. CWM and Rao's quadratic diversity: A unified framework for functional ecology. *Oecologia* 167, 181–188. <https://doi.org/10.1007/s00442-011-1965-5>
- Rivera, J.P., Verrelst, J., Leonenko, G., Moreno, J., 2013. Multiple cost functions and regularization options for improved retrieval of leaf chlorophyll content and LAI through inversion of the PROSAIL model. *Remote Sens.* 5, 3280–3304. <https://doi.org/10.3390/rs5073280>
- Rocchini, D., 2007. Effects of spatial and spectral resolution in estimating ecosystem α -diversity by satellite imagery. *Remote Sens. Environ.* 111, 423–434. <https://doi.org/10.1016/j.rse.2007.03.018>
- Rocchini, D., Bacaro, G., Chirici, G., Da Re, D., Feilhauer, H., Foody, G.M., Galluzzi, M., Garzon-Lopez, C.X., Gillespie, T.W., He, K.S., others, 2018. Remotely sensed spatial heterogeneity as an exploratory tool for taxonomic and functional diversity study. *Ecol. Indic.* 85, 983–990.
- Rocchini, D., Balkenhol, N., Carter, G.A., Foody, G.M., Gillespie, T.W., He, K.S., Kark, S., Levin, N., Lucas, K., Luoto, M., Nagendra, H., Oldeland, J., Ricotta, C., Southworth, J., Neteler, M., 2010. Remotely sensed spectral heterogeneity as a proxy of species diversity: Recent advances and open challenges. *Ecol. Inform.* 5, 318–329. <https://doi.org/10.1016/J.ECOINF.2010.06.001>
- Rocchini, D., Boyd, D.S., Feret, J.-B., He, K.S., Lausch, A., Nagendra, H., Wegmann, M., Pettorelli, N., 2015. Satellite remote sensing to monitor species diversity: potential and pitfalls. *Remote Sens. Ecol. Conserv.* 1–12. <https://doi.org/10.1002/rse2.9>
- Rocchini, D., Chiarucci, A., Loiselle, S.A., 2004. Testing the spectral variation hypothesis by using satellite multispectral images. *Acta Oecologica* 26, 117–120. <https://doi.org/10.1016/j.actao.2004.03.008>
- Rocchini, D., Marcantonio, M., Ricotta, C., 2017. Measuring Rao's Q diversity index from remote sensing: An open source solution. *Ecol. Indic.* 72, 234–238. <https://doi.org/10.1016/j.ecolind.2016.07.039>
- Rocha, A.D., Groen, T.A., Skidmore, A.K., Willemen, L., 2021. Role of Sampling Design When Predicting Spatially Dependent Ecological Data with Remote Sensing. *IEEE Trans. Geosci. Remote Sens.* 59, 663–674. <https://doi.org/10.1109/TGRS.2020.2989216>
- Rockström, J., Steffen, W.L., Noone, K., Persson, Å., Chapin III, F.S., Rockstrom, J., Steffen, W.L., Noone, K., Persson, a, Chapin, F.S., Lambin, E., Foley, J., et al., 2009. Planetary Boundaries : Exploring the Safe Operating Space for Humanity 14. <https://doi.org/10.1038/461472a>
- Roelofsen, H.D., van Bodegom, P.M., Kooistra, L., Witte, J.P.M., 2013. Trait Estimation in Herbaceous Plant Assemblages from in situ Canopy Spectra. *Remote Sens.* 5, 6323–6345. <https://doi.org/10.3390/rs5126323>
- Rosenzweig, M.L., others, 1995. Species diversity in space and time. Cambridge University Press.
- Rosindell, J., Cornell, S.J., 2007. Species-area relationships from a spatially explicit neutral model in an infinite landscape. *Ecol. Lett.* 10, 586–595. <https://doi.org/10.1111/j.1461-0248.2007.01050.x>

- Rossi, C., Kneubuehler, M., Schuetz, M., Schaepman, M., 2021. Spatial resolution , spectral metrics and biomass are key aspects in estimating plant species richness from spectral diversity in species-rich grasslands.
- Rossi, C., Kneubühler, M., Schütz, M., Schaepman, M.E., Haller, R.M., Risch, A.C., 2020. From local to regional: Functional diversity in differently managed alpine grasslands. *Remote Sens. Environ.* 236, 111415. <https://doi.org/10.1016/j.rse.2019.111415>
- Ruiz-jaen, M.C., Potvin, C., 2010. Tree Diversity Explains Variation in Ecosystem Function in a Neotropical Forest in Panama. *Biotropica* 42, 638–646.
- Sanders, N.J., Rahbek, C., 2012. The patterns and causes of elevational diversity gradients. *Ecography (Cop.)*. 35, 1–3. <https://doi.org/10.1111/j.1600-0587.2011.07338.x>
- Saura-Mas. S, L., 2007. Leaf and Shoot Water Content and Leaf Dry Matter Content of Mediterranean Woody Species with Different Post-fire Regenerative Strategies. *Ann. Bot.* 545–554.
- Scherer, L., Van Baren, S.A., Van Bodegom, P.M., 2020. Characterizing Land Use Impacts on Functional Plant Diversity for Life Cycle Assessments. *Environ. Sci. Technol.* 54, 6486–6495. <https://doi.org/10.1021/acs.est.9b07228>
- Schiefer, F., Schmidlein, S., Kattenborn, T., 2021. The retrieval of plant functional traits from canopy spectra through RTM-inversions and statistical models are both critically affected by plant phenology. *Ecol. Indic.* 121, 107062. <https://doi.org/10.1016/j.ecolind.2020.107062>
- Schimel, D., Pavlick, R., Fisher, J.B., Asner, G.P., Saatchi, S., Townsend, P., Miller, C., Frankenberg, C., Hibbard, K., Cox, P., 2015. Observing terrestrial ecosystems and the carbon cycle from space. *Glob. Chang. Biol.* 21, 1762–1776. <https://doi.org/10.1111/gcb.12822>
- Schlerf, M., Atzberger, C., 2006. Inversion of a forest reflectance model to estimate structural canopy variables from hyperspectral remote sensing data. *Remote Sens. Environ.* 100, 281–294. <https://doi.org/https://doi.org/10.1016/j.rse.2005.10.006>
- Schleuter, D., Aufresne, M.D., Assol, F.M., 2010. A user ' s guide to functional diversity indices. *Ecol. Monogr.* 80, 469–484. <https://doi.org/10.1890/08-2225.1>
- Schmidlein, S., Fassnacht, F.E., 2017. The spectral variability hypothesis does not hold across landscapes. *Remote Sens. Environ.* 192, 114–125. <https://doi.org/10.1016/J.RSE.2017.01.036>
- Schneider, C.A., Rasband, W.S., Eliceiri, K.W., 2012. NIH Image to ImageJ: 25 years of image analysis. *Nat. Methods.* <https://doi.org/10.1038/nmeth.2089>
- Schneider, F.D., Ferraz, A., Hancock, S., Duncanson, L.I., Dubayah, R.O., Pavlick, R.P., Schimel, D.S., 2020. Towards mapping the diversity of canopy structure from space with GEDI. *Environ. Res. Lett.* 15. <https://doi.org/10.1088/1748-9326/ab9e99>
- Schneider, F.D., Morsdorf, F., Schmid, B., Petchey, O.L., Hueni, A., Schimel, D.S., Schaepman, M.E., 2017. Mapping functional diversity from remotely sensed morphological and physiological forest traits. *Nat. Commun.* 8. <https://doi.org/10.1038/s41467-017-01530-3>

- Schober, P., Schwarte, L.A., 2018. Correlation coefficients: Appropriate use and interpretation. *Anesth. Analg.* 126, 1763–1768. <https://doi.org/10.1213/ANE.0000000000002864>
- Scholes, R.J., Walters, M., Turak, E., Saarenmaa, H., Heip, C.H.R., Tuama, ??Amonn ??, Faith, D.P., Mooney, H. a., Ferrier, S., Jongman, R.H.G., Harrison, I.J., Yahara, T., Pereira, H.M., Larigauderie, A., Geller, G., 2012. Building a global observing system for biodiversity. *Curr. Opin. Environ. Sustain.* 4, 139–146. <https://doi.org/10.1016/j.cosust.2011.12.005>
- Schrodt, F., de la Barreda Bautista, B., Williams, C., Boyd, D.S., Schaepman-Strub, G., Santos, M.J., 2020. Integrating Biodiversity, Remote Sensing, and Auxiliary Information for the Study of Ecosystem Functioning and Conservation at Large Spatial Scales, in: *Remote Sensing of Plant Biodiversity*. Springer, Cham, pp. 449–484.
- Schweiger, A.K., Cavender-Bares, J., Townsend, P.A., Hobbie, S.E., Madritch, M.D., Wang, R., Tilman, D., Gamon, J.A., 2018. Plant spectral diversity integrates functional and phylogenetic components of biodiversity and predicts ecosystem function. *Nat. Ecol. Evol.* 2, 976–982. <https://doi.org/10.1038/s41559-018-0551-1>
- Serbin, S.P., Wu, J., Ely, K.S., Kruger, E.L., Townsend, P.A., Meng, R., Wolfe, B.T., Chlus, A., Wang, Z., Rogers, A., 2019. From the Arctic to the tropics: multibiome prediction of leaf mass per area using leaf reflectance. *New Phytol.* 224, 1557–1568. <https://doi.org/10.1111/nph.16123>
- Settles, B., 2009. Active learning literature survey.
- Sheil, D., Bongers, F., 2020. Interpreting forest diversity-productivity relationships: volume values, disturbance histories and alternative inferences. *For. Ecosyst.* <https://doi.org/10.1186/s40663-020-0215-x>
- Shipley, B., 2010. Community assembly, natural selection and maximum entropy models. *Oikos* 119, 604–609. <https://doi.org/10.1111/j.1600-0706.2009.17770.x>
- Shoko, C., Mutanga, O., 2017. Examining the strength of the newly-launched Sentinel 2 MSI sensor in detecting and discriminating subtle differences between C3 and C4 grass species. *ISPRS J. Photogramm. Remote Sens.* 129, 32–40. <https://doi.org/10.1016/j.isprsjprs.2017.04.016>
- Sil, Â., Fernandes, P.M., Rodrigues, A.P., Alonso, J.M., Honrado, J.P., Perera, A., Azevedo, J.C., 2019. Farmland abandonment decreases the fire regulation capacity and the fire protection ecosystem service in mountain landscapes. *Ecosyst. Serv.* 36, 100908. <https://doi.org/10.1016/j.ecoser.2019.100908>
- Sil, Â., Fonseca, F., Gonçalves, J., Honrado, J., Marta-Pedroso, C., Alonso, J., Ramos, M., Azevedo, J.C., 2017. Analysing carbon sequestration and storage dynamics in a changing mountain landscape in Portugal: Insights for management and planning. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manag.* 13, 82–104. <https://doi.org/10.1080/21513732.2017.1297331>
- Sil, Â., Rodrigues, A.P., Carvalho-Santos, C., Nunes, J.P., Honrado, J., Alonso, J., Marta-Pedroso, C., Azevedo, J.C., 2016. Trade-offs and Synergies Between Provisioning and Regulating Ecosystem Services in a Mountain Area in Portugal Affected by Landscape Change. *Mt. Res. Dev.* 36, 452–464. <https://doi.org/10.1659/mrd-journal-d-16-00035.1>
- Sist, P., Saridan, A., 1999. Stand structure and floristic composition of a primary lowland

- dipterocarp forest in East Kalimantan. *J. Trop. For. Sci.* 11, 704–722.
- Skakun, S., Vermote, E., Roger, J.C., Justice, C., 2017. Multispectral Misregistration of Sentinel-2A Images: Analysis and Implications for Potential Applications. *IEEE Geosci. Remote Sens. Lett.* 14, 2408–2412. <https://doi.org/10.1109/LGRS.2017.2766448>
- Skidmore, A.K., 2015. Agree on biodiversity metrics to track from space. *Nature* 523, 5–7. <https://doi.org/10.1038/523403a>
- Skidmore, A.K., Coops, N.C., Neinavaz, E., Ali, A., Schaepman, M.E., Paganini, M., Kissling, W.D., Vihervaara, P., Darvishzadeh, R., Feilhauer, H., Fernandez, M., Fernández, N., Gorelick, N., Geizendorff, I., Heiden, U., Heurich, M., Hoborn, D., Holzwarth, S., Muller-Karger, F.E., Van De Kerchove, R., Lausch, A., Leitāu, P.J., Lock, M.C., Mücher, C.A., O'Connor, B., Rocchini, D., Turner, W., Vis, J.K., Wang, T., Wegmann, M., Wingate, V., 2021. Priority list of biodiversity metrics to observe from space. *Nat. Ecol. Evol.* <https://doi.org/10.1038/s41559-021-01451-x>
- Smith, A.B., Sandel, B., Kraft, N.J.B., Carey, S., 2013. Characterizing scale-dependent community assembly using the functional-diversity-area relationship. *Ecology* 94, 2392–2402. <https://doi.org/10.1890/12-2109.1>
- Socolar, J.B., Gilroy, J.J., Kunin, W.E., Edwards, D.P., 2016. How Should Beta-Diversity Inform Biodiversity Conservation? *Trends Ecol. Evol.* 31, 67–80. <https://doi.org/10.1016/j.tree.2015.11.005>
- Sodhi, N.S., Koh, L.P., Brook, B.W., Ng, P.K.L., 2004. Southeast Asian biodiversity: an impending disaster. *Trends Ecol. Evol.* 19, 654–660. <https://doi.org/https://doi.org/10.1016/j.tree.2004.09.006>
- Sodhi, N.S., Koh, L.P., Clements, R., Wanger, T.C., Hill, J.K., Hamer, K.C., Clough, Y., Tscharntke, T., Posa, M.R.C., Lee, T.M., 2010. Conserving Southeast Asian forest biodiversity in human-modified landscapes. *Biol. Conserv.* 143, 2375–2384. <https://doi.org/10.1016/j.biocon.2009.12.029>
- Sohn, Y., McCoy, R.M., 1997. Mapping desert shrub rangeland using spectral unmixing and modeling spectral mixtures with TM data. *Photogramm. Eng. Remote Sensing* 63, 707–716.
- Spacebook, 2021. SpaceBook: Realtime satellite viewer [WWW Document]. URL <http://apps.agi.com/SatelliteViewer/>
- Spitters, C.J.T., Toussaint, H., Goudriaan, J., 1986. Separating the diffuse and direct component of global radiation and its implications for modeling canopy photosynthesis Part I. Components of incoming radiation. *Agric. For. Meteorol.* 38, 217–229.
- Stein, A., Gerstner, K., Kreft, H., 2014. Environmental heterogeneity as a universal driver of species richness across taxa, biomes and spatial scales. *Ecol. Lett.* 17, 866–880. <https://doi.org/10.1111/ele.12277>
- Steinbauer, M.J., Dolos, K., Reineking, B., Beierkuhnlein, C., 2012. Current measures for distance decay in similarity of species composition are influenced by study extent and grain size 1203–1212. <https://doi.org/10.1111/j.1466-8238.2012.00772.x>
- Suárez-Castro, A.F., Raymundo, M., Bimler, M., Mayfield, M.M., 2022. Using multi-scale

- spatially explicit frameworks to understand the relationship between functional diversity and species richness. *Ecography* (Cop.). 1–18. <https://doi.org/10.1111/ecog.05844>
- Swenson, N.G., 2013. The assembly of tropical tree communities - the advances and shortcomings of phylogenetic and functional trait analyses. *Ecography* (Cop.). 36, 264–276. <https://doi.org/10.1111/j.1600-0587.2012.00121.x>
- Takashina, N., Economo, E.P., 2021. Developing generalized sampling schemes with known error properties: the case of a moving observer. *Ecography* (Cop.). 44, 293–306. <https://doi.org/10.1111/ecog.05198>
- Team, R.C., 2019. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
- Tello, J.S., Myers, J.A., Macía, M.J., Fuentes, A.F., Cayola, L., Arellano, G., Loza, M.I., Torrez, V., Cornejo, M., Miranda, T.B., Jørgensen, P.M., 2015. Elevational gradients in β-diversity reflect variation in the strength of local community assembly mechanisms across spatial scales. *PLoS One* 10, 1–17. <https://doi.org/10.1371/journal.pone.0121458>
- Tilman, D., Isbell, F., Cowles, J.M., 2014. Biodiversity and Ecosystem Functioning. *Annu. Rev. Ecol. Evol. Syst.* 45, 471–493. <https://doi.org/10.1146/annurev-ecolsys-120213-091917>
- Tonidandel, S., LeBreton, J.M., 2011. Relative Importance Analysis: A Useful Supplement to Regression Analysis. *J. Bus. Psychol.* 26, 1–9. <https://doi.org/10.1007/s10869-010-9204-3>
- Torresani, M., Rocchini, D., Sonnenschein, R., Marcantonio, M., Ricotta, C., Tonon, G., 2019. Estimating tree species diversity from space in an alpine conifer forest: The Rao's Q diversity index meets the spectral variation hypothesis. *Ecol. Inform.* <https://doi.org/10.1016/j.ecoinf.2019.04.001>
- Tsianou, M.A., Kallimanis, A.S., 2016. Different species traits produce diverse spatial functional diversity patterns of amphibians. *Biodivers. Conserv.* 25, 117–132. <https://doi.org/10.1007/s10531-015-1038-x>
- UNDP, 2012. Biodiversity conservation in multiple-use forest landscapes in Sabah, Malaysia. Sabah, Malaysia.
- Ustin, S.L., Middleton, E.M., 2021. Current and near-term advances in Earth observation for ecological applications. *Ecol. Process.* 10, 1–57. <https://doi.org/10.1186/s13717-020-00255-4>
- Vaglio Laurin, G., Puletti, N., Hawthorne, W., Liesenberg, V., Corona, P., Papale, D., Chen, Q., Valentini, R., 2016. Discrimination of tropical forest types, dominant species, and mapping of functional guilds by hyperspectral and simulated multispectral Sentinel-2 data. *Remote Sens. Environ.* 176, 163–176. <https://doi.org/10.1016/j.rse.2016.01.017>
- van Bodegom, P.M., Douma, J.C., Verheijen, L.M., 2014. A fully traits-based approach to modeling global vegetation distribution. *Proc. Natl. Acad. Sci. U. S. A.* 111, 13733–13738. <https://doi.org/10.1073/pnas.1304551110>
- Van Leeuwen, W.J.D., Huete, A.R., 1996. Effects of standing litter on the biophysical interpretation of plant canopies with spectral indices. *Remote Sens. Environ.* 55, 123–138.

[https://doi.org/10.1016/0034-4257\(95\)00198-0](https://doi.org/10.1016/0034-4257(95)00198-0)

Vanino, S., Nino, P., De Michele, C., Falanga Bolognesi, S., D'Urso, G., Di Bene, C., Pennelli, B., Vuolo, F., Farina, R., Pulighe, G., Napoli, R., 2018. Capability of Sentinel-2 data for estimating maximum evapotranspiration and irrigation requirements for tomato crop in Central Italy. *Remote Sens. Environ.* 215, 452–470. <https://doi.org/10.1016/j.rse.2018.06.035>

Vapnik, V.N., 1998. Adaptive and learning systems for signal processing communications, and control. *Stat. Learn. theory.*

Varsha, V., Stuart, L.P., Clinton, N.J., Sharon, J.S., 2016. The Impacts of Oil Palm on Recent Deforestation and Biodiversity. *PLoS One* 11, 1–19. <https://doi.org/10.1371/journal.pone.0152777>

Végh, L., Tsuyuzaki, S., 2021. Remote sensing of forest diversities: the effect of image resolution and spectral plot extent. *Int. J. Remote Sens.* 42, 5987–6004. <https://doi.org/10.1080/01431161.2021.1934596>

Vellend, M., 2010. Conceptual synthesis in community ecology. *Q. Rev. Biol.* 85, 183–206.

Verheijen, L.M., Aerts, R., Bönisch, G., Kattge, J., Van Bodegom, P.M., 2016. Variation in trait trade-offs allows differentiation among predefined plant functional types: Implications for predictive ecology. *New Phytol.* 209, 563–575. <https://doi.org/10.1111/nph.13623>

Verhoef, W., 2002. Improved modelling of multiple scattering in leaf canopies: The model SAIL++, in: Proceedings of the First Symposium on Recent Advances in Quantitative Remote Sensing, Torrent, Spain. pp. 11–20.

Verhoef, W., 1998. Theory of radiative transfer models applied in optical remote sensing of vegetation canopies.

Verhoef, W., 1984. Light scattering by leaf layers with application to canopy reflectance modeling: the SAIL model. *Remote Sens. Environ.* 16, 125–141.

Verhoef, W., Jia, L., Xiao, Q., Su, Z., 2007. Unified optical-thermal four-stream radiative transfer theory for homogeneous vegetation canopies. *IEEE Trans. Geosci. Remote Sens.* 45, 1808–1822. <https://doi.org/10.1109/TGRS.2007.895844>

Verrelst, J., Camps-Valls, G., Muñoz-Marí, J., Rivera, J.P., Veroustraete, F., Clevers, J.G.P.W.P.W., Moreno, J., 2015. Optical remote sensing and the retrieval of terrestrial vegetation bio-geophysical properties - A review. *ISPRS J. Photogramm. Remote Sens.* 108, 273–290. <https://doi.org/10.1016/j.isprsjprs.2015.05.005>

Verrelst, J., Malenovský, Z., Van der Tol, C., Camps-Valls, G., Gastellu-Etchegorry, J.P., Lewis, P., North, P., Moreno, J., 2019a. Quantifying Vegetation Biophysical Variables from Imaging Spectroscopy Data: A Review on Retrieval Methods. *Surv. Geophys.* 40, 589–629. <https://doi.org/10.1007/s10712-018-9478-y>

Verrelst, J., Rivera-Caicedo, J.P., Reyes-Muñoz, P., Morata, M., Amin, E., Tagliabue, G., Panigada, C., Hank, T., Berger, K., 2021. Mapping landscape canopy nitrogen content from space using PRISMA data. *ISPRS J. Photogramm. Remote Sens.* 178, 382–395. <https://doi.org/10.1016/j.isprsjprs.2021.06.017>

- Verrelst, J., Rivera, J.P., Alonso, L., Moreno, J., 2011. ARTMO: an Automated Radiative Transfer Models Operator toolbox for automated retrieval of biophysical parameters through model inversion, in: Proc. EARSeL 7th SIG-Imag. Spectrosc. Workshop. pp. 11–13.
- Verrelst, J., Vicent, J., Rivera-Caicedo, J.P., Lumbierres, M., Morcillo-Pallarés, P., Moreno, J., 2019b. Global sensitivity analysis of leaf-canopy-atmosphere RTMs: Implications for biophysical variables retrieval from top-of-atmosphere radiance data. *Remote Sens.* 11, 1–26. <https://doi.org/10.3390/rs11161923>
- Villéger, S., Mason, N.W.H., Mouillot, D., 2008. New multidimensional functional diversity indices for a multifaceted framework in functional ecology. *Ecology* 89, 2290–2301. <https://doi.org/10.1890/07-1206.1>
- Viloslada, M., Bergamo, T.F., Ward, R.D., Burnside, N.G., Joyce, C.B., Bunce, R.G.H., Sepp, K., 2020. Fine scale plant community assessment in coastal meadows using UAV based multispectral data. *Ecol. Indic.* 111, 105979. <https://doi.org/10.1016/j.ecolind.2019.105979>
- Vinué, D., Camacho, F., Fuster, B., 2018. Validation of Sentinel-2 LAI and FAPAR products derived from SNAP toolbox over a cropland site in Barrax and over an agroforested site in Liria (Spain). *Fifth Recent Adv. Quant. Remote Sens.* 248.
- Violle, C., Reich, P.B., Pacala, S.W., Enquist, B.J., Kattge, J., 2014. The emergence and promise of functional biogeography. *Proc. Natl. Acad. Sci.* 111, 13690–13696. <https://doi.org/10.1073/pnas.1415442111>
- Vivian, L.M., Cary, G.J., 2012. Relationship between leaf traits and fire-response strategies in shrub species of a mountainous region of south-eastern Australia. *Ann. Bot.* 109, 197–208. <https://doi.org/10.1093/aob/mcr263>
- Walter, J.A., Stovall, A.E.L., Atkins, J.W., Walter, J., 2020. Vegetation Structural Complexity and Biodiversity Across Elevation Gradients in the Great Smoky Mountains Running Title: Structure, Biodiversity and Elevation. <https://doi.org/10.20944/preprints202004.0415.v1>
- Wang, D., Wan, B., Qiu, P., Su, Y., Guo, Q., Wang, R., Sun, F., Wu, X., 2018. Evaluating the Performance of Sentinel-2, Landsat 8 and Pléiades-1 in Mapping Mangrove Extent and Species. *Remote Sens.* 10, 1468. <https://doi.org/10.3390/rs10091468>
- Wang, R., Gamon, J.A., 2019. Remote sensing of terrestrial plant biodiversity. *Remote Sens. Environ.* 231, 111218. <https://doi.org/10.1016/j.rse.2019.111218>
- Wang, R., Gamon, J.A., Cavender-Bares, J., Townsend, P.A., Zygielbaum, A.I., 2018a. The spatial sensitivity of the spectral diversity – biodiversity relationship : an experimental test in a prairie grassland. *Ecol. Appl.* 28, 541–556. <https://doi.org/10.1002/eap.1669>
- Wang, R., Gamon, J.A., Cavender-Bares, J., Townsend, P.A., Zygielbaum, A.I., 2018b. The spatial sensitivity of the spectral diversity-biodiversity relationship: An experimental test in a prairie grassland. *Ecol. Appl.* 28, 541–556. <https://doi.org/10.1002/eap.1669>
- Wang, R., Gamon, J.A., Montgomery, R.A., Townsend, P.A., Zygielbaum, A.I., Bitan, K., Tilman, D., Cavender-Bares, J., 2016. Seasonal variation in the NDVI-species richness relationship in a prairie grassland experiment (cedar creek). *Remote Sens.* 8.

<https://doi.org/10.3390/rs8020128>

- Wang, R., Gamon, J.A., Schweiger, A.K., Cavender-Bares, J., Townsend, P.A., Zygielbaum, A.I., Kothari, S., 2018c. Influence of species richness, evenness, and composition on optical diversity: A simulation study. *Remote Sens. Environ.* 211, 218–228. <https://doi.org/10.1016/j.rse.2018.04.010>
- Wang, W.Y., Foster, W. a., 2015. The effects of forest conversion to oil palm on ground-foraging ant communities depend on beta diversity and sampling grain. *Ecol. Evol.* 5, 3159–3170. <https://doi.org/10.1002/ece3.1592>
- Wang, X., Wiegand, T., Swenson, N.G., Wolf, A.T., Howe, R.W., Hao, Z., Lin, F., Ye, J., Yuan, Z., 2015. Mechanisms underlying local functional and phylogenetic beta diversity in two temperate forests. *Ecology* 96, 1062–1073.
- Wang, Z., Rahbek, C., Fang, J., 2012. Effects of geographical extent on the determinants of woody plant diversity. *Ecography (Cop.)* 35, 1160–1167. <https://doi.org/10.1111/j.1600-0587.2012.07786.x>
- Weiher, E., Keddy, P.A., 1995. Assembly Rules, Null Models, and Trait Dispersion: New Questions from Old Patterns. *Oikos* 74, 159–164. <https://doi.org/10.2307/3545686>
- Weiher, E., van der Werf, A., Thompson, K., Roderick, M., Garnier, E., Eriksson, O., 1999. Challenging Theophrastus: A common core list of plant traits for functional ecology. *J. Veg. Sci.* 10, 609–620. <https://doi.org/10.2307/3237076>
- Weiss, M., Baret, F., 2016. Sentinel-2 ToolBox Level 2 Biophysical Product Algorithms. Version 1.1.
- Weiss, M., Baret, F., 2010. CAN-EYE V6. 1 User Manual, INRA, Avignon, France.
- Weiss, M., Baret, F., Smith, G.J., Jonckheere, I., Coppin, P., 2004. Review of methods for in situ leaf area index (LAI) determination Part II. Estimation of LAI, errors and sampling. *Agric. For. Meteorol.* 121, 37–53. <https://doi.org/10.1016/j.agrformet.2003.08.001>
- Whittaker, R.H., 1972. Evolution and Measurement of Species Diversity. *Taxon* 21, 213. <https://doi.org/10.2307/1218190>
- Wilcove, D.S., Giam, X., Edwards, D.P., Fisher, B., Koh, L.P., 2013. Navjot's nightmare revisited: logging, agriculture, and biodiversity in Southeast Asia. *Trends Ecol. Evol.* 28, 531–540. <https://doi.org/10.1016/j.tree.2013.04.005>
- Winter, L., Lehmann, A., Finogenova, N., Finkbeiner, M., 2017. Including biodiversity in life cycle assessment – State of the art, gaps and research needs. *Environ. Impact Assess. Rev.* <https://doi.org/10.1016/j.eiar.2017.08.006>
- Wright, I.J., Reich, P.B., Westoby, M., Ackerly, D.D., Baruch, Z., Bongers, F., Cavender-Bares, J., Chapin, T., Cornelissen, J.H.C., Diemer, M., Flexas, J., Garnier, E., Groom, P.K., Gulias, J., Hikosaka, K., Lamont, B.B., Lee, T., Lee, W., Lusk, C., Midgley, J.J., Navas, M.-L., Niinemets, U., Oleksyn, J., Osada, N., Poorter, H., Poot, P., Prior, L., Pyankov, V.I., Roumet, C., Thomas, S.C., Tjoelker, M.G., Veneklaas, E.J., Villar, R., 2004. The worldwide leaf economics spectrum. *Nature* 428, 821–827. <https://doi.org/10.1038/nature02403>

- Wu, J., Chavana-Bryant, C., Prohaska, N., Serbin, S.P., Guan, K., Albert, L.P., Yang, X., van Leeuwen, W.J.D., Garnello, A.J., Martins, G., Malhi, Y., Gerard, F., Oliviera, R.C., Saleska, S.R., 2017. Convergence in relationships between leaf traits, spectra and age across diverse canopy environments and two contrasting tropical forests. *New Phytol.* 214, 1033–1048. <https://doi.org/10.1111/nph.14051>
- Xie, Q., Dash, J., Huete, A., Jiang, A., Yin, G., Ding, Y., Peng, D., Hall, C.C., Brown, L., Shi, Y., Ye, H., Dong, Y., 2019. Retrieval of crop biophysical parameters from Sentinel-2 remote sensing imagery. *Int J Appl Earth Obs Geoinf.* 80, 187–195. <https://doi.org/10.1016/j.jag.2019.04.019>
- Yin, G., Li, J., Liu, Q., Fan, W., Xu, B., Zeng, Y., Zhao, J., 2015. Regional leaf area index retrieval based on remote sensing: The role of radiative transfer model selection. *Remote Sens.* 7, 4604–4625. <https://doi.org/10.3390/rs70404604>
- Zarnetske, P.L., Baiser, B., Strecker, A., Record, S., Belmaker, J., Tuanmu, M.-N., 2017. The Interplay Between Landscape Structure and Biotic Interactions. *Curr. Landsc. Ecol. Reports* 2, 12–29. <https://doi.org/10.1007/s40823-017-0021-5>
- Zarnetske, P.L., Read, Q.D., Record, S., Gaddis, K., Pau, S., Hobi, M., Malone, S., Costanza, J., Dahlin, K.M., Latimer, A.M., Wilson, A.M., Grady, J., Ollinger, S. V., Finley, A.O., 2019. Towards connecting biodiversity and geodiversity across scales with satellite remote sensing. *Glob. Ecol. Biogeogr.* 1–9. <https://doi.org/10.1111/geb.12887>
- Zheng, G., Moskal, L.M., 2009. Retrieving Leaf Area Index (LAI) Using Remote Sensing: Theories, Methods and Sensors. *Sensors* 9, 2719–2745. <https://doi.org/10.3390/s90402719>
- Zheng, Z., Zeng, Y., Schneider, F.D., Zhao, Y., Zhao, D., Schmid, B., Schaepman, M.E., Morsdorf, F., 2021. Mapping functional diversity using individual tree-based morphological and physiological traits in a subtropical forest. *Remote Sens. Environ.* 252, 112170. <https://doi.org/10.1016/j.rse.2020.112170>
- Zuur, A., Ieno, E.N., Walker, N., Saveliev, A.A., Smith, G.M., 2009. Mixed effects models and extensions in ecology with R. Springer Science & Business Media.