Author: Israel Vallejo Muñoz

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Temporal Analysis of Deforestation in Central Borneo Through NDVI-Based Remote Sensing

Introduction

Forests cover approximately one-third of the Earth's land surface and provide essential ecosystem services, including regulation of the hydrological cycle, soil stabilization, climate mitigation, and biodiversity preservation (Sheram, 1993). Despite their importance, extensive deforestation remains a global environmental crisis, with at least 145 countries currently engaged in wood production (Chakravarty et al., 2012). For decades, the relentless destruction of forests has continued, and only recently have we begun to grasp its full magnitude. Although precise estimates are lacking, there is no doubt that significant portions of the world's rainforests have already been lost (Chakravarty et al., 2012).

Deforestation is defined as the conversion of forested land to permanent non-forested uses such as agriculture, urban development, or grazing, resulting in biodiversity loss and contributing to the greenhouse effect (van Kooten & Bulte, 2000; Angelsen et al., 1999). Forests act as major carbon sinks, storing more than 360 Pg of the 450–650 Pg of global vegetative carbon (Pan et al., 2013; IPCC, 2013). When soil is included, this figure exceeds 800 PgC, nearly equivalent to the total carbon in the atmosphere. Consequently, forest loss not only releases large quantities of carbon but also reduces future carbon sequestration potential (Houghton & Nassikas, 2018).

Tropical forests play a critical role in global and regional climate regulation due to their impact on hydrological and atmospheric dynamics (Kumagai et al., 2016). However, land use and land cover change (LULCC), driven by agriculture, logging, and development, continues to threaten these ecosystems, particularly in tropical regions. In Southeast Asia, deforestation rates are among the highest in the world (Canadell et al., 2007), with Borneo standing out as a deforestation hotspot over recent decades (Bryan et al., 2013; Gaveau et al., 2013, 2014). These changes have even been linked to reduced annual precipitation on the island (Kumagai et al., 2013).

Borneo, the third-largest island on Earth, is shared by Indonesia, Malaysia, and the Sultanate of Brunei. It harbors one of the most biodiverse and ecologically unique tropical forests in the world. Much of its lowland terrain is composed of peatland forests, which are naturally fire-resistant (Siegert et al., 2009; Page & Hooijer, 2016). However, increased fire frequency has been observed due to deforestation-driven drying, anthropogenic ignition, and land drainage (Herawati & Santoso, 2011; Wösten et al., 2008; Hoscilo et al., 2011). Between 2001 and 2016, Borneo experienced one of the highest rates of tropical peatland forest loss globally (Austin et al., 2019).

Deforestation is a major risk factor for wildfires and leads to measurable increases in local temperatures, compounding climate and fire vulnerabilities (Davies-Barnard et al., 2023). Unlike global climate change, the impacts of local deforestation can be addressed directly through national land-use policies, offering a tangible opportunity for intervention.

Beyond environmental concerns, Borneo's biodiversity is at risk. The island is home to iconic and endangered species such as the orangutan, the proboscis monkey, and countless other endemic species whose habitats are vanishing rapidly (Ramis, S. 2020).

Objective of the Study

Given this alarming context, this technical report aims to visualize and assess deforestation trends in a selected region of Borneo between 2008, 2020, and 2024. Through remote sensing and NDVI analysis, the objective is to evaluate the magnitude and direction of forest cover change, and determine whether deforestation has progressed, stabilized, or (although unlikely) shown signs of reversal.

Methodology

To assess the spatial and temporal changes in vegetation cover across a region of Central Borneo, a multi-platform geospatial workflow was implemented combining satellite remote sensing, land cover classification, and statistical modeling.

The study area is defined by the following geographic coordinates:

- North: −2.3
- South: −2.9
- West: 113.5
- East: 114.3
- Coordinate reference system: WGS 84 (EPSG:4326)

This region was analyzed for changes in NDVI between the years 2018, 2020, and 2024.

1. NDVI Calculation (Google Earth Engine)

Sentinel-2 Level-2A surface reflectance imagery was used to generate cloud-free median composites for the months of June to August in 2018, 2020, and 2024. The Normalized Difference Vegetation Index (NDVI) was calculated as:

NDVI = (B8 − B4) / (B8 + B4)

Two NDVI difference rasters were generated:

- NDVI_2024 − NDVI_2018 (long-term, 6-year period)

- NDVI_2024 − NDVI_2020 (short-term, 4-year period)

These rasters provided the basis for evaluating vegetation dynamics over time.

2. Land Cover Classification and Point Sampling

MODIS Land Cover Type 1 (MCD12Q1, year 2020) was used to classify the land cover types within the area. A random sample of 87 points was extracted from the NDVI difference raster using GEE. For each point, the following data were collected:

- NDVI values for 2018, 2020, and 2024
- NDVI difference (2024 − 2020)
- Land cover type (2020)

The sample was exported as a .csv file for analysis in R.

3. Statistical and Graphical Analysis (R)

In R, the sampled data were processed to:

- Rename and recode MODIS land cover classes into descriptive labels (e.g., *Deciduous Forest*, *Savannas*)
- Calculate the mean NDVI per land cover type for 2020 and 2024
- Visualize the results through:
    - A boxplot of NDVI change by land cover class
    - A scatter plot comparing NDVI 2020 vs 2024
- Tabulate NDVI means by land cover class

4. Raster Classification and Mapping (QGIS)

The NDVI difference rasters were imported into QGIS for categorical classification based on the following thresholds:

- Loss: NDVI difference < −0.1
- No change: −0.1 ≤ NDVI difference ≤ 0.1
- Gain: NDVI difference > 0.1

Thematic maps were produced for both time intervals:

- *Map 1:* NDVI Change Classification (2018–2024)
- *Map 2:* NDVI Change Classification (2020–2024)

Raster statistics were then used to compute the proportion of area within each change category.

Results

1. NDVI Classification and Area Change (QGIS)

The NDVI difference rasters were reclassified into Loss, No change, and Gain. The results revealed widespread degradation across both time periods, with the most significant losses recorded between 2020 and 2024.

- *NDVI Difference 2024 – 2018*
  - Loss: 87.58%
  - No change: 8.65%
  - Gain: 3.76%
    (*See Map 1*)
- *NDVI Difference 2024 – 2020*
  - Loss: 96.34%
  - No change: 2.70%
  - Gain: 0.96%
    (*See Map 2*)

These values indicate an acceleration in vegetation loss during the most recent four-year period. While nearly 9% of the area remained stable between 2018 and 2020, less than 3% showed stability between 2020 and 2024 (Figures 1 and 2).

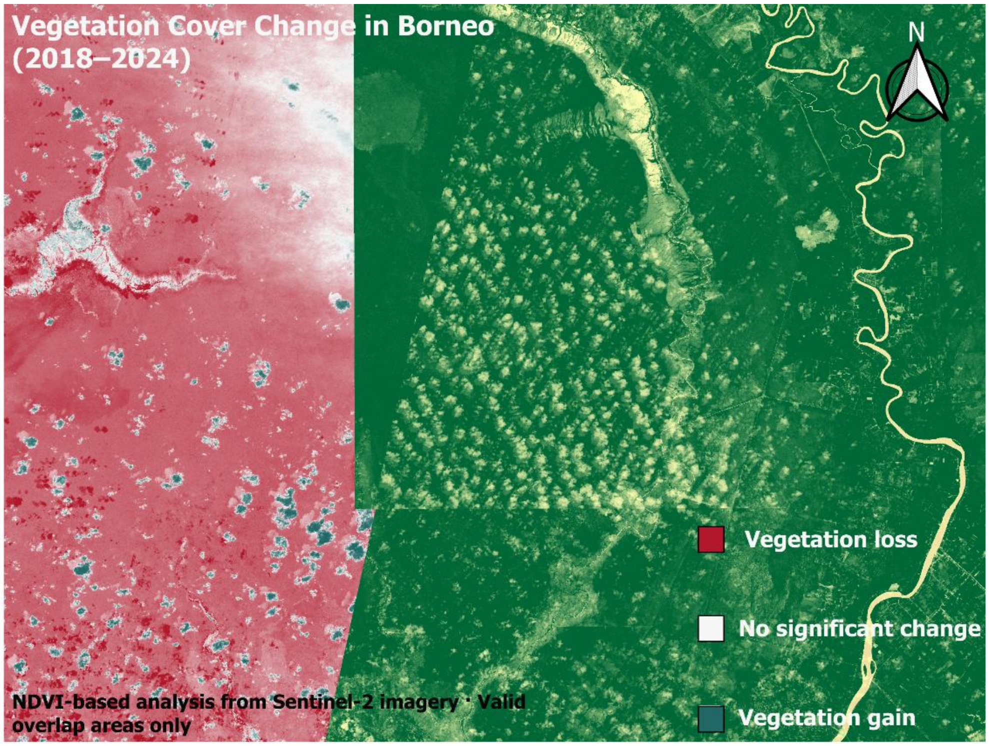

Figure 1 Vegetation Change Map (2018–2024)

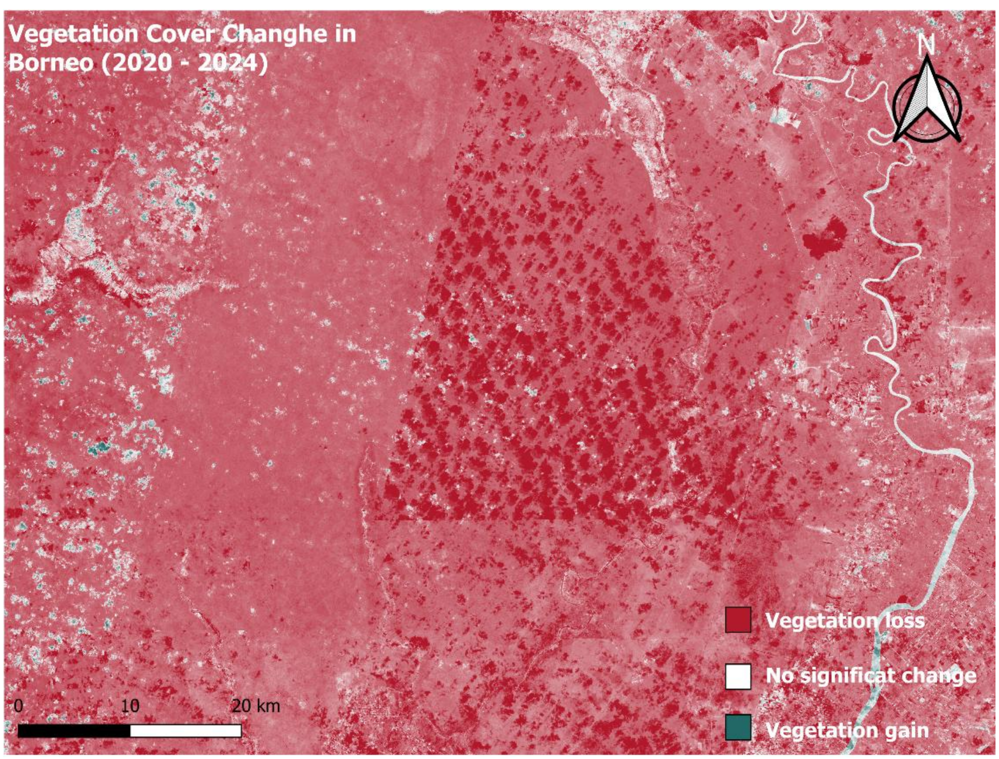

Figure 2 Vegetation Change Map (2020–2024)

2. NDVI Point-Based Analysis by Land Cover (R)

The 87 sampled points were analyzed according to their MODIS 2020 land cover class. The table below summarizes the average NDVI change per class.

Table 1 Mean NDVI by Land Cover Type (2020 vs 2024)

Land Cover Type	*NDVI 2020*	*NDVI 2024*	*Δ NDVI*	*n*
Deciduous Forest	0.798	0.444	−0.355	70
Savannas	0.805	0.415	−0.389	16
Grasslands	0.713	0.476	−0.237	1

Figure 3 displays a boxplot of NDVI differences across MODIS land cover classes for the period 2020–2024. The most notable decline occurred in Deciduous Forests, which represented most the sampled points, showing an average NDVI decrease of approximately −0.36. Savannas exhibited a similarly sharp decline (−0.39), indicating that vegetation loss is not restricted to forested areas but extends to open landscapes as well. Although only one point was classified as Grassland, it also showed a substantial reduction in NDVI (−0.24), reinforcing the general trend of vegetation degradation across the study area.

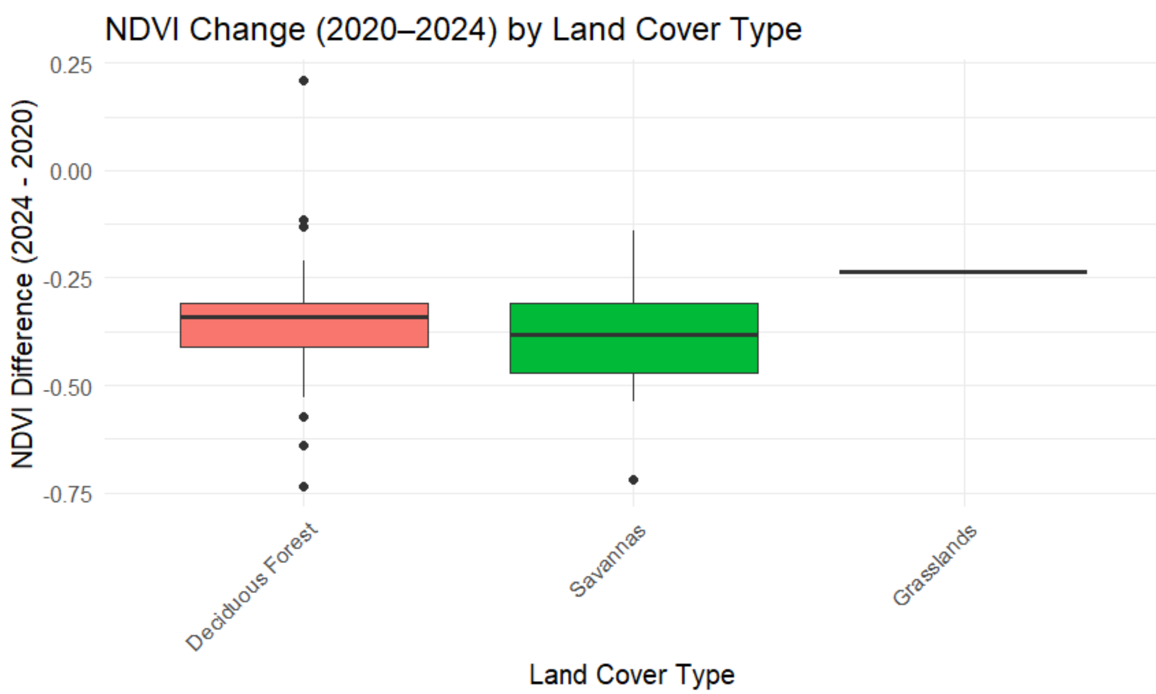

Figure 3 NDVI Change (2020–2024) by Land Cover Type

Figure 4 presents a scatter plot comparing NDVI values in 2020 and 2024 for all sampled points. Most points fall below the 1:1 reference line, clearly illustrating a consistent decline in NDVI between the two time periods. This pattern further supports the evidence of widespread vegetation loss observed in both the QGIS classification and statistical summaries.

3. Regional NDVI Mean Values (GEE Output)

A region-wide mean NDVI was calculated for both 2020 and 2024 directly in Google Earth Engine using the reduceRegion function. The results confirm the degradation trend:

- Mean NDVI 2020: 0.7799
- Mean NDVI 2024: 0.4492
- Difference: −0.3307

This sharp decline is consistent with both the QGIS classification and the R-based point analysis.

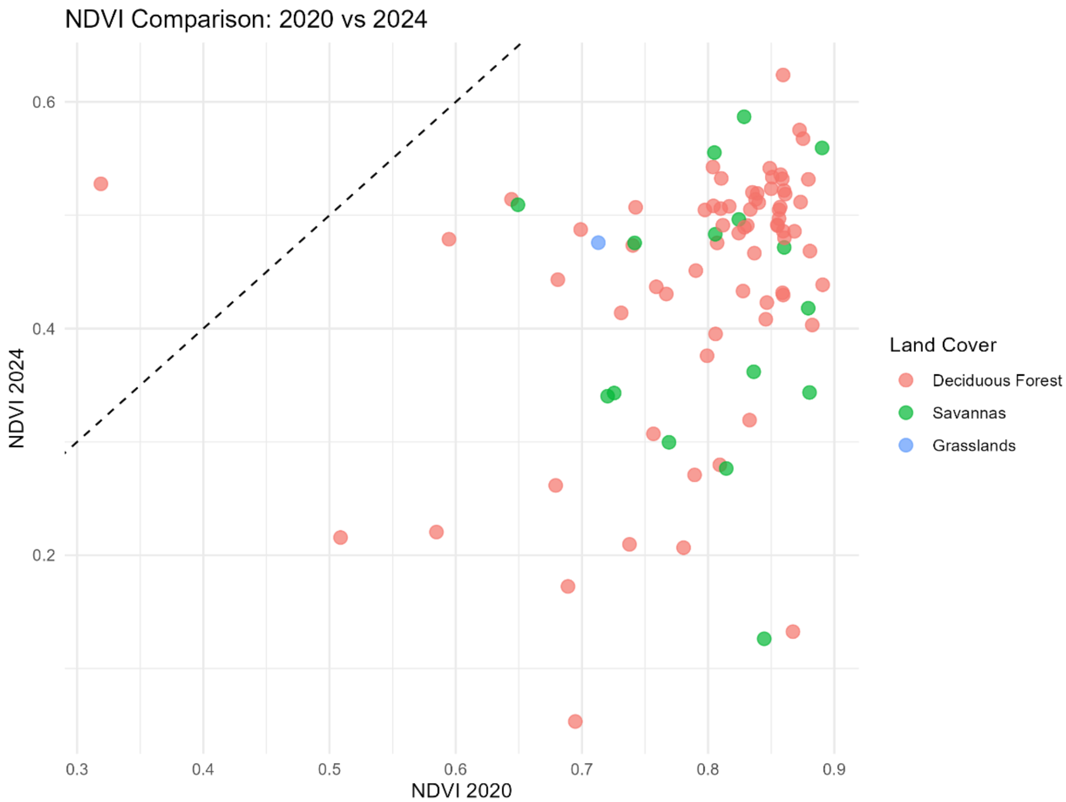

Figure 4 NDVI Comparison Between 2020 and 2024

Discussion

The results of this study clearly indicate a rapid and accelerating loss of vegetation cover in the selected region of Central Borneo between 2018 and 2024. NDVI-based analysis revealed that the proportion of area experiencing significant vegetation loss increased from 87.6% (2018–2024) to 96.3% (2020–2024), with a concurrent decrease in areas showing no change or vegetation gain. This dramatic trend suggests an intensification of deforestation and ecosystem degradation in recent years.

The boxplot and scatterplot analyses reinforce this finding, particularly in Deciduous Forests and Savannas, which showed mean NDVI declines of approximately −0.36 and −0.39, respectively. Although Grasslands were underrepresented in the sample, they too showed a noticeable NDVI decline, suggesting that degradation extends beyond dense forest areas to more open ecosystems.

These findings are consistent with previous reports highlighting Borneo as a deforestation hotspot (Bryan et al., 2013; Gaveau et al., 2014). The sharp reduction in vegetation cover aligns with documented land-use transitions, particularly those driven by oil palm expansion, illegal logging, and peatland drainage (Austin et al., 2019; Herawati & Santoso, 2011). The loss of forest cover not only impacts biodiversity but also exacerbates fire risk and regional climate alteration. Studies have shown that such land-use change reduces rainfall, dries out peatlands, and makes them more susceptible to ignition (Kumagai et al., 2013; Page & Hooijer, 2016).

The NDVI trend also mirrors larger-scale patterns of reduced forest resilience under anthropogenic pressure and climate stress (Davies-Barnard et al., 2023). Importantly, the regional NDVI drop of −0.33 in just four years reflects a shift severe enough to influence carbon dynamics, evapotranspiration, and local hydrology. As Pan et al. (2013) and Houghton & Nassikas (2018) pointed out, forests play a central role in global carbon balance, and Borneo's loss could undermine both local and global mitigation efforts.

It is worth noting that the NDVI method, while widely used, has some limitations. It does not distinguish between tree species or forest structure, and can be influenced by atmospheric conditions or understory vegetation. However, the use of multi-year Sentinel-2 composites and classification thresholds strengthens the robustness of this study.

Conclusion

This study reveals a concerning trend of intensified deforestation and vegetation degradation in Central Borneo between 2018 and 2024. Through NDVI analysis, the results demonstrate that:

- Vegetation loss has accelerated significantly in the last four years.
- Forested and non-forested ecosystems alike are experiencing degradation.
- The decline in NDVI is consistent across multiple data sources and analytical platforms (GEE, R, QGIS).
- These changes are consistent with known environmental drivers in the region, including land-use conversion, fire susceptibility, and climate impacts.

Given the ecological and climatic importance of Borneo's forests, the continued loss of vegetation poses a threat not only to local biodiversity, such as the orangutan and proboscis monkey, but also to broader climate stability. Immediate and targeted conservation policies are urgently needed to curb forest loss, protect peatland ecosystems, and ensure long-term sustainability.

Future work should integrate additional variables (e.g., precipitation, fire hotspots, elevation, human activity layers) to better understand the spatial drivers of deforestation. Higher-resolution land cover data and field validation would also strengthen the accuracy of remote sensing assessments.

References

- Angelsen, A., Shitindi, E. F. K., & Aarrestad, J. (1999). Why do farmers expand their land into forests? Theories and evidence from Tanzania. *Environment and Development Economics, 4*(3), 313–331.
- Austin, K. G., Schwantes, A., Gu, Y., & Kasibhatla, P. S. (2019). What causes deforestation in Indonesia? *Environmental Research Letters, 14*(2), 024007.
- 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*(7), e69679. https://doi.org/10.1371/journal.pone.0069679
- Canadell, J. G., Le Quéré, C., Raupach, M. R., Field, C. B., Buitenhuis, E. T., Ciais, P., ... & Marland, G. (2007). Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. *Proceedings of the National Academy of Sciences, 104*(47), 18866–18870. https://doi.org/10.1073/pnas.0702737104
- Chakravarty, S., Ghosh, S. K., Suresh, C. P., Dey, A. N., & Shukla, G. (2012). Deforestation: Causes, effects and control strategies. In *Global perspectives on sustainable forest management* (pp. 1–26).
- Davies-Barnard, T., Catto, J. L., Harper, A. B., Imron, M. A., & van Veen, F. F. (2023). Future fire risk under climate change and deforestation scenarios in tropical Borneo. *Environmental Research Letters, 18*(2), 024015.
- Gaveau, D. L. A., Sloan, S., Molidena, E., Yaen, H., Sheil, D., Abram, N. K., ... & Meijaard, E. (2013). Reconciling forest conservation and logging in Indonesian Borneo. *PLoS ONE, 8*(8), e69887. https://doi.org/10.1371/journal.pone.0069887
- Gaveau, D. L. A., Sheil, D., Husnayaen, Salim, M. A., Arjasakusuma, S., Ancrenaz, M., ... & Meijaard, E. (2014). Four decades of forest persistence, clearance and logging on Borneo. *PLoS ONE, 9*(7), e101654. https://doi.org/10.1371/journal.pone.0101654
- Herawati, H., & Santoso, H. (2011). Tropical forest susceptibility to and risk of fire under changing climate: A review of fire nature, policy and institutions in Indonesia. *Forest Policy and Economics, 13*(4), 227–233.
- Hoscilo, A., Page, S. E., Tansey, K. J., & Rieley, J. O. (2011). Effect of repeated fires on land-cover change on peatland in southern Central Kalimantan, Indonesia, from 1973 to 2005. *International Journal of Wildland Fire, 20*(4), 578–588.
- Houghton, R. A., & Nassikas, A. A. (2018). Negative emissions from stopping deforestation and forest degradation, globally. *Global Change Biology, 24*(1), 350–359. https://doi.org/10.1111/gcb.13876
- IPCC. (2013). *Climate change 2013: The physical science basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
- Kumagai, T., Kanamori, H., & Yasunari, T. (2013). Deforestation-induced reduction in rainfall. *Hydrological Processes, 27*(26), 3811–3814. https://doi.org/10.1002/hyp.10060
- Kumagai, T., Kanamori, H., & Chappell, N. A. (2016). Tropical forest hydrology. In D. M. Amatya et al. (Eds.), *Forest hydrology: Processes, management and assessment* (pp. 88–102). CAB International.
- Page, S. E., & Hooijer, A. (2016). In the line of fire: The peatlands of Southeast Asia. *Philosophical Transactions of the Royal Society B, 371*(1696), 20150176. https://doi.org/10.1098/rstb.2015.0176

- Pan, Y., Birdsey, R. A., Phillips, O. L., & Jackson, R. B. (2013). The structure, distribution, and biomass of the world's forests. *Annual Review of Ecology, Evolution, and Systematics, 44*, 593–622.
- Ramis, S. (2020, marzo 14). *Borneo, la isla esmeralda de Indonesia*. National Geographic Viajes. https://viajes.nationalgeographic.com.es/a/borneo-isla-esmeralda-indonesia_15293
- Sheram, K. (1993). *The environmental data book*. The World Bank.
- Siqueira, M., Katul, G., & Porporato, A. (2009). Soil moisture feedbacks on convection triggers: The role of soil–plant hydrodynamics. *Journal of Hydrometeorology, 10*(1), 96–112. https://doi.org/10.1175/2008JHM1027.1
- Takahashi, A., Kumagai, T. O., Kanamori, H., Fujinami, H., Hiyama, T., & Hara, M. (2017). Impact of tropical deforestation and forest degradation on precipitation over Borneo Island. *Journal of Hydrometeorology, 18*(11), 2907–2922.
- van Kooten, G. C., & Bulte, E. H. (2000). *The economics of nature: Managing biological assets*. Blackwell.
- Wösten, J. H. M., Clymans, E., Page, S. E., Rieley, J. O., & Limin, S. H. (2008). Peat–water interrelationships in a tropical peatland ecosystem in Southeast Asia. *CATENA, 73*(2), 212–224.