INBAR Technical Report No. 40

Remote Sensing-Based Regional Bamboo Resource Assessment Report of Madagascar

Tsinghua University, China and the International Bamboo and Rattan Organisation (INBAR)

Tsinghua University

INTERNATIONAL BAMBOO AND RATTAN ORGANISATION

International Bamboo and Rattan Organisation

INBAR, the International Bamboo and Rattan Organisation, is an intergovernmental organisation bringing together some 44 countries for the promotion of the ecosystem benefits and values of bamboo and rattan.

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ACRONYMS

FAO	Food and Agriculture Organisation
Ha	Hectares
Km^2	Square Kilometre
M	Metre
NDVI	Normalized Difference Vegetation Index
GCVI	Green Chlorophyll Vegetation Index
EVI	Enhanced Vegetation Index
LSWI	Land Surface Water Index
SRTM	Shuttle Radar Topography Mission
TM	Thematic Mapper
LISS	Linear Imaging Self Scanner

CHAPTER 1 INTRODUCTION

1.1 Bamboo resources

Bamboo is a variety of perennial woody grass. There are more than 1600 species of bamboo that are most widely distributed in tropical and sub-tropical regions of the world (Vorontsova et al. 2016). Bamboo grows in at least 37 million hectares (ha) worldwide and covers 3.2 per cent of the forest areas of its host countries, or about 1 percent of the global forest area (Lobovikov et al. 2007). It is widely recognised as a plant of great cultural and practical importance in many Asian, African and Central and Southern American countries (Banik 2000; Widenoja 2007). Bamboo plays an increasing role in ecosystem services, biodiversity conservation and socio-economic development. It has been recognised as an important carbon sink and has potential for mitigating climate change (Song et al. 2011; Dubey et al. 2016; Agarwal and Purwar 2017). Bamboo has also been proven to have an ecological function of soil and water conservation (Zhou et al. 2005). Bamboo is an irreplaceable habitat for a lot of wildlife, serving as a food source and escape cover (Schaller 1985; Kratter 1997; Bystriakova et al. 2004; Reid et al. 2004; Linderman et al. 2005). An annual crop with a wide range of product possibilities, bamboo offers opportunities for household, small-scale and medium-scale enterprises. Bamboo has traditionally been used by rural communities to meet their subsistence and income needs. Because of technological innovations in bamboo utilisation as well as an increased need for eco-friendly materials, bamboo is presently a value-added, high quality, durable material. In the past two decades, numerous value-added products in the form of wood substitutes, bamboo flooring, food and beverages, cloth, artefacts, bamboo charcoal, activated carbon, pharmaceutical applications and bamboo furniture have been developed (Zhang et al. 2002; Lobovikov et al. 2007; Kaur et al. 2016; Sofiana et al. 2017). Bamboo is a key component in lifting rural people out of poverty by providing job opportunities (Mishra 2015; Chen et al. 2017). For example, bamboo weaving is a good income-earning opportunity for disadvantaged groups (Das 2017).

1.2 Bamboo in the study area

Bamboo is widely distributed in Asia, Africa and Latin America, mainly in the tropical and subtropical regions. Based on the Food and Agriculture Organisation (FAO) and INBAR's world bamboo assessment report (Lobovikov et al. 2007), six countries in Africa (Madagascar, Kenya, Nigeria, Uganda, Tanzania and Zimbabwe) have over 2.7 million ha of bamboo. Other key African countries with bamboo resources include Angola, Benin, Burundi, Cameroon, Central African Republic, Comoros, Côte d'Ivoire, Democratic Republic of Congo, Eritrea, Gabon, the Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Madagascar, Malawi, Mozambique, Nigeria, Réunion, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Togo, and Zambia

(Personal Communication 2017). Ohrnberger et al. (1988) indicate that at least 25 countries in Africa have at least one bamboo species. It is important to note that the information on species diversity and quantity of bamboo resources in Africa is partial.

According to Lobovikov et al. (2007), Madagascar was recognised as the richest country in Africa in terms of biodiversity of bamboo species. However, the distribution of bamboo in Madagascar is unclear. African countries have the lowest diversity of bamboo species. The United Republic of Tanzania reports four native species, followed by Uganda, Malawi and Zambia. The greatest potential for bamboo biodiversity is in eastern Africa, around Lake Victoria, and in southern Africa, including Zambia and Zimbabwe. West Africa has fewer bamboo species with the most widespread being *Oxytenanthera abyssinica*. Madagascar is a special case. It has 33 bamboo species, including 32 native and one introduced pan-tropical species, *Bambusa vulgaris*, and is therefore richer in species diversity compared with continental Africa. *Bambusa vulgaris* is found mainly near villages and along rivers. Two-thirds of the species in Madagascar are endemic. The endemism of bamboo in Madagascar reflects its long isolation from continental Africa and its unique evolutionary path (Lobovikov et al. 2007).

Bamboo is extremely important to local people, especially rural communities, and is mainly used for house construction, rafts, production of handicrafts and musical instruments using *Valiha diffusa*. Moreover, a critically endangered lemur, the greater bamboo lemur *Prolemur simus*, is endemic to eastern Madagascar. Wild *P. simus* populations have diets dominated by bamboo (*Poaceae: Bambusoideae*), particularly large-culmed species of two endemic genera, *Cathariostachys* and *Valiha*, but also the endemic *Arundinaria* and the pantropical *Bambusa vulgaris*. *P. simus* is listed in the top 50 most evolutionarily distinct and globally endangered mammal species (Collen et al. 2011). In addition, the bamboo forests in western Madagascar are home to the world's rarest tortoise, the endangered angonoka tortoise, also known as the ploughshare tortoise (*Geochelone niphora*; Bystriakova et al. 2004). Bamboo forests are therefore critical to biodiversity conservation. Timely mapping of the distribution of bamboo is necessary for biodiversity conservation, resource management and policymaking for rural poverty reduction.

1.3 Previous inventories on bamboo resources

A review of inventories or mapping of bamboo resources shows that there is almost no information available for Madagascar, therefore, the accurate, comparable, up-to-date, spatially explicit data/maps of bamboo resources for Madagascar is important and urgent.

1.4 Application of remote sensing to bamboo resources assessment

Remote sensing has its advantages when mapping and monitoring the Earth's surface, providing up-to-date, comparatively cheap and dynamic information for many applications. Remote sensing techniques are widely used for vegetation mapping, natural resource assessment, change detection, management and monitoring (Hu et al. 2018)Rogan et al. 2002; Joshi et al. 2006; Lobovikov et al. 2007; Tucker and Townshend 2000;Gong et al.20). However, bamboo is very difficult to identify using remote sensing in comparison with other land cover classes. Firstly, some species grow as understorey or mixed forest with other canopies. Secondly, bamboo has similar spectral properties with other vegetation classes, implying that spectrum is not adequate to separate bamboo from other vegetation. Thirdly, many species of bamboo are distributed in smaller patches (planted in homesteads, farm boundary/linear planting), which require high-resolution imagery to locate them. Finally, bamboo is among the fastest-growing plants on Earth and is frequently changing, which heightens the difficulties of sample collection.

A few attempts have been made to identify bamboo using remotely sensed data. Wang et al. (2009) mapped the understorey bamboo in part of the Xinglongling and Tianhuashan giant panda habitats in the Qinling Mountains of China. They used an Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) image acquired in the month of May when the leaves on the canopy of trees started to emerge. Bharadwaj et al. (2003) used IRS 1D LISS III imagery for species-wise bamboo and other natural resource assessments. The study used supervised classification and knowledge-based classification techniques.

Linderman et al. (2004) used Landsat Thematic Mapper (TM)imagery and a non-linear artificial neutral network method to map the spatial distribution of understory bamboo in Wolong natural reserve (southwestern China). Satellite imagery during the growing season was acquired and their classification could achieve 80 per cent accuracy.

Nelson and Irmão (1998) used a Landsat TM image from 1975 to 1994 to study the phenomenon of bamboo flowering and susceptibility to fire in the Amazon forest. The study showed Band 3, 4, 5 as BGR false-colour composite is suitable for detecting synchronous bamboo flowering and fire scars. Hiroshi et al. (2009) used QuickBird satellite imagery (2.5 m multi-spectral scanner /0.6 m panchromatic image) and object-based land cover classification to extract areas of bamboo flowering. Han et al. (2014) mapped Moso bamboo in the northeast of Anji County, Zhejiang Province of China using a SPOT-5 image. Due to the high spatial resolution, they used an object-based image analysis method and texture measures derived from grey level co-occurrence matrices.

Ghosh and Joshi (2014) also made good use of high-resolution data in mapping bamboo. They used WorldView-2 imagery, which provides 2 m multi-spectral and 0.5 m panchromatic spatial resolution. The study area was in the lower Gangetic plains in West Bengal, India, and the study team used an image acquired in the returning monsoon season. Temporal information was not used in these bamboo-mapping studies since they only used one single image.

Li et al. (2016) tried to map the distribution of bamboo in Zhejiang Province of China using four Landsat images, and the importance of temporal information in bamboo mapping was proven. Zhao et al.(2018) used multi-temporal Landsat imagery at 30-meter spatial resolution to map bamboo of Ethiopia, Kenya and Uganda for the year 2016, where hotpots with large amount of highland and lowland bamboo were identified. Du et al.(2018) have an attempt to map global bamboo forest distribution using multisource remote sensing data and give an approximate area of global bamboo forest. These mapping works were primary limited to small study areas, and there has been a few studies focused on mapping bamboo at a national or a regional scale.

CHAPTER 2 METHODOLOGY

2.1 Data

2.1.1 Satellite imagery

United States Geological Survey Landsat 8 Surface Reflectance images acquired between 2015 and 2017 were used in this study, but the images acquired in 2017 were used in the highest priority. Ancillary data includes: (1) the global forest/non-forest map (FNF) data, which is generated by classifying the Synthetic-aperture radar (SAR) image (backscattering coefficient) in the global 25 m resolution PALSAR-2/PALSAR SAR mosaic so that strong and low backscatter pixels are assigned as 'forest' and 'non-forest', respectively, where 'forest' is defined as natural forest with an area larger than 0.5 ha and forest cover over 10 per cent, as per the FAO definition (Shimada et al. 2014); and (2) topography data (Shuttle Radar Topography Mission, SRTM).

2.1.2 Field sample

Ground truth samples were collected during several field trips. The location of ground truth samples is shown in Figure 1. The study team undertook field trips (see Figure 1) in Madagascar in August 2017, accompanied by local experts, and collected 1318 bamboo sample sets and several other land cover samples of location data mainly at seven regions, including Atsinanana, Vatovavy-Fitovinany, Atsimo-Atsinanana, Betsiboka, Boeny, Sofia, Diana.

Since the distribution of bamboo is scattered, local experts continued to contribute field samples to the dataset after this field trip. Moreover, Missouri Botanical Garden contributed 197 bamboo samples, and the Aspinall Foundation contributed 1344 sample sites of bamboo from Madagascar.

For each sample in the training dataset, the team measured the extended radius from the centre point to be a homogeneous sample, which determined how many pixels we could spatially expand in training. The reason for expanding the training sample temporally and spatially was to enrich the spectral diversity of the training dataset (Zhao et al. 2016).

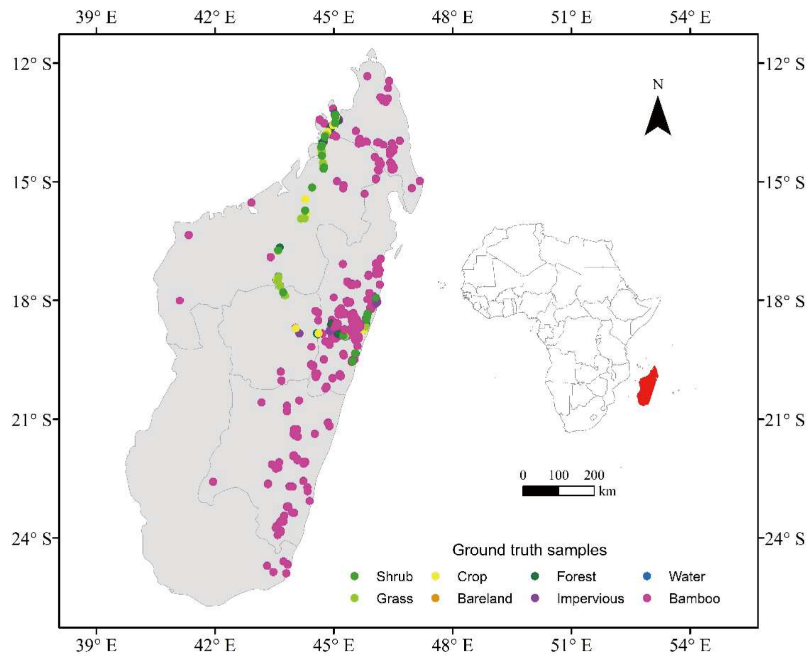


Figure 1: Ground truth sample collection location

2.2 Mapping scheme, class definition and limitation

The map produced during this study includes two classes, bamboo and forest, for better application. Here, ‘forest’ is defined as natural forest with an area larger than 0.5 ha and forest cover over 10 per cent. This definition is the same as the FAO definition.

Based on the FAO’s definition, a forest is defined as an area of land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10 per cent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban use. In this study, bamboo mapped areas are defined as land spanning more than 900 m^2 with a canopy cover consisting of at least 50 per cent bamboo. This limitation arises mainly due to the resolution of imagery used in the study (Landsat imagery – 30 m x 30 m pixels). In addition, the length and/or width of a bamboo patch may not always align with the Landsat image pixel. Therefore, there is a chance that the small bamboo patches (with an area of 900 m^2 or with a length/width of 30 m) may not be identified in the mapping result.

It should be noted that, during field visits to Madagascar, the study team observed a large number of bamboo patches growing along the rivers and in smallholder farms as block planting, farm boundary planting, shelter beds (linear planting) and homestead planting. The size of bamboo cover in most of the farms was small (< 900 m^2 contiguous patch) and/or did not meet the criteria (see above paragraph). So there is a high probability that the smallholder farm plantings and the bamboo growing along the river were not captured in the study result due to the resolution of imagery, small size of farm planting and alignment of imagery pixels versus bamboo plots. In addition, there could be a slight overestimation of bamboo in some areas due to similar spectral properties of bamboo with other vegetation classes as explained in Section 1.4.

2.3 Mapping process

Figure 2 shows the flowchart of bamboo-mapping process or methodology adopted in this study which includes data preparation, sample collection, image classification, post-processing and accuracy assessment.

The study team chose a random forest classifier and a combined feature set of spectral bands, phenological metrics, and topographic characteristics.

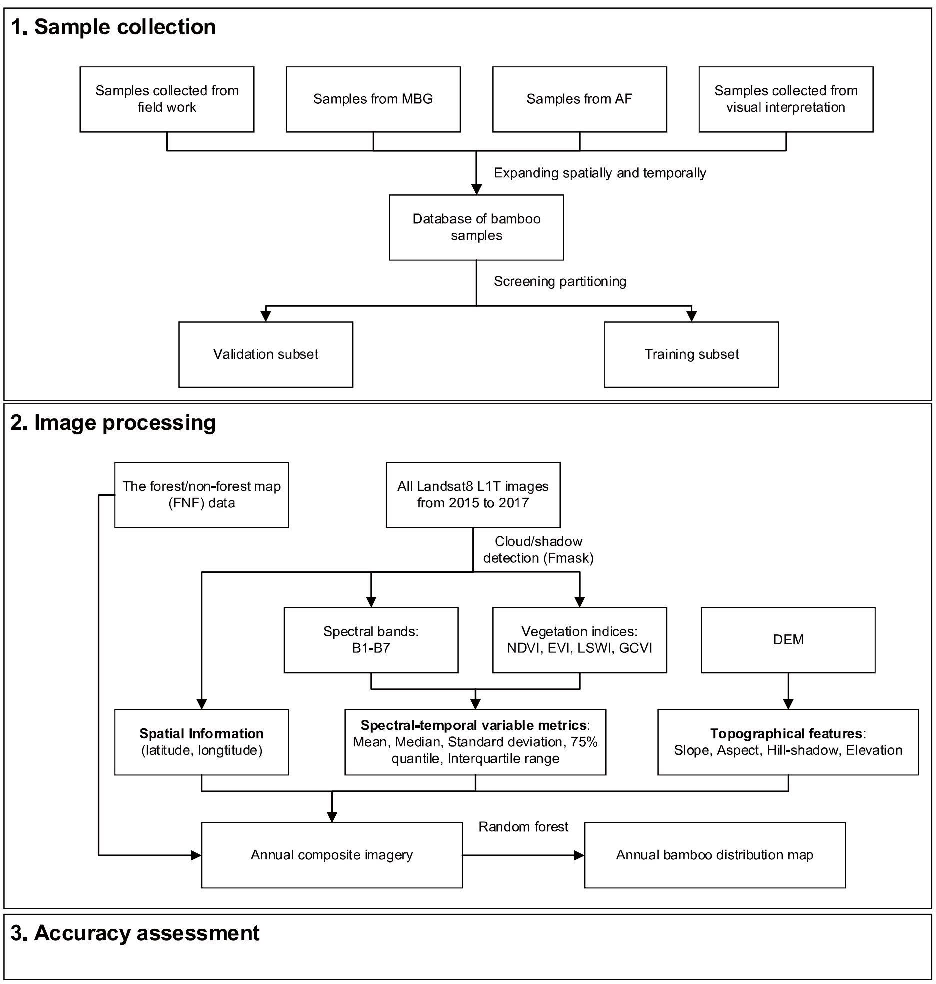


Figure 2: Workflow/methodology for bamboo mapping in Madagascar

CHAPTER 3 NATIONAL ASSESSMENT FOR MADAGASCAR

The bamboos assessed in this study are two predominant indigenous bamboo species of Madagascar, *Valiha diffusa* and *Bambusa vulgaris*.

3.1 Field identification and distribution of bamboos in Madagascar

There are two predominant bamboo species in Madagascar. They are *Valiha diffusa* and *Bambusa vulgaris.* Of the clumping bamboos, the most frequently encountered was *Bambusa vulgaris*, with both the green and the yellow forms commonly planted in or near rivers, towns and villages; we found it in the Makira, the Ankeniheny-Zahamena forest corridor, Nosivolo and Le Corridor Forestier Ambositra – Vondrozo survey regions. Of the non-clumping species*,* *Valiha diffusa* was easily recognisable within its range by its characteristic drooping culm tips, long lateral branches, stiff culm sheaths readily shed, and a thin whitish ring above the internodes following the shedding of the culm sheath. It occurs in the vast savanna woodlands, along the river valleys, and spreads around on the hills, mainly in Vatovavy-Fitovinany region, Atsinanana region and Diana region.

An example is shown in Figure 3A, which shows a location in the east of Vatovavy-Fitovinany that is dominated by *Bambusa vulgaris*. The River Maningory can be seen in it, flowing in a southwestern direction. Most of the hill slopes are covered with *Valiha diffusa*, see Figure 3B. The high-resolution image on Google Earth is also presented here for the same area. *Bambusa vulgaris* is usually grown on farms in small patches, along the river or as farm boundaries, which were not captured in this study, due to the spatial resolution of Landsat imagery.

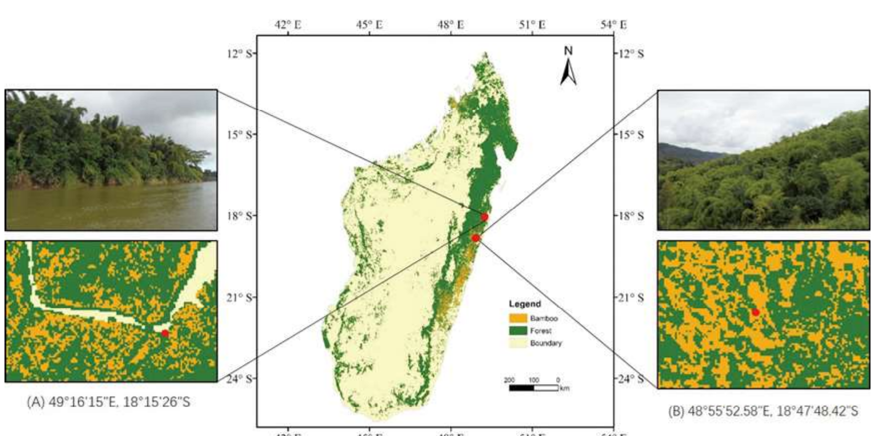


Figure 3: The bamboo cover map of Madagascar and four zoomed-in areas with abundant bamboo

Valiha diffusa and *Bambusa vulgaris* mainly cover a range of elevation between 7–942 m above sea level, according to the statistics of the filed dataset in this study. Figure 4 shows that the estimated bamboo growing area is mostly found in the eastern coastal region.

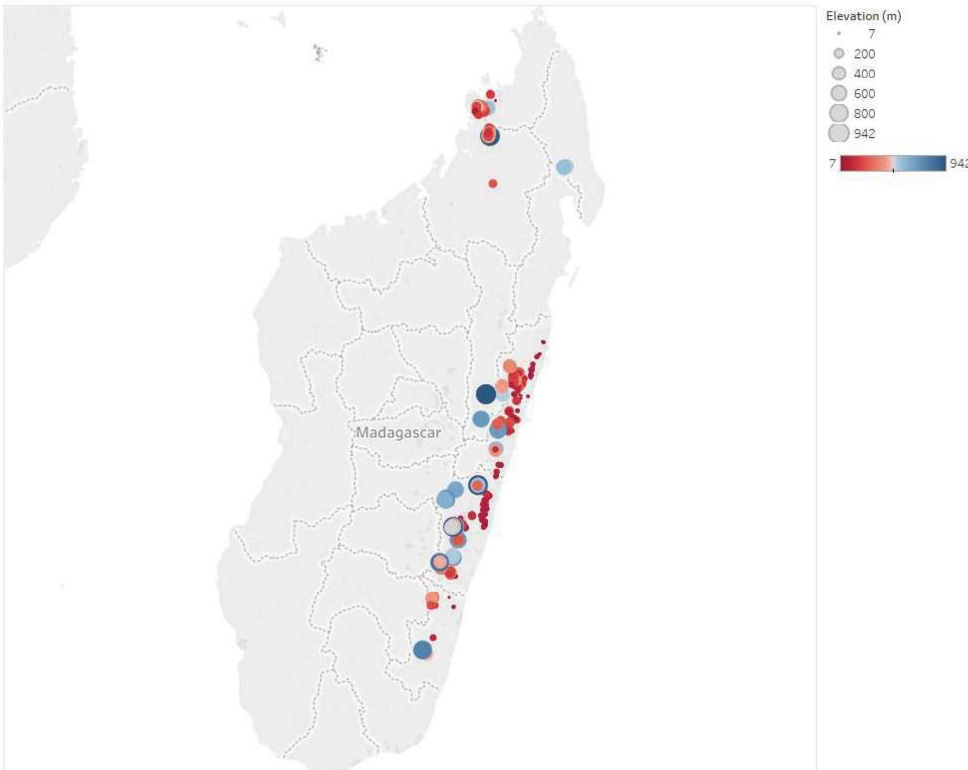


Figure 4: Distribution of the elevation range of bamboo in Madagascar

3.2 Area statistics

The total area of bamboo in Madagascar is 11236.94 km^2, shown by the administrative boundaries in Figure 5.

Madagascar is divided into 22 regions. These former second-tier administrative divisions became first-level administrative divisions when the former six provinces were dissolved on 4 October 2009. As can be seen in Table 1, bamboo is unevenly distributed across the regions. Among all regions in Madagascar, the most bamboo-rich region is Vatovavy-Fitovinany, accounting for 43.7 per cent of the country's total bamboo area, followed by the Atsinanana Region, the Diana Region and the Atsimo-Atsinanana Region.

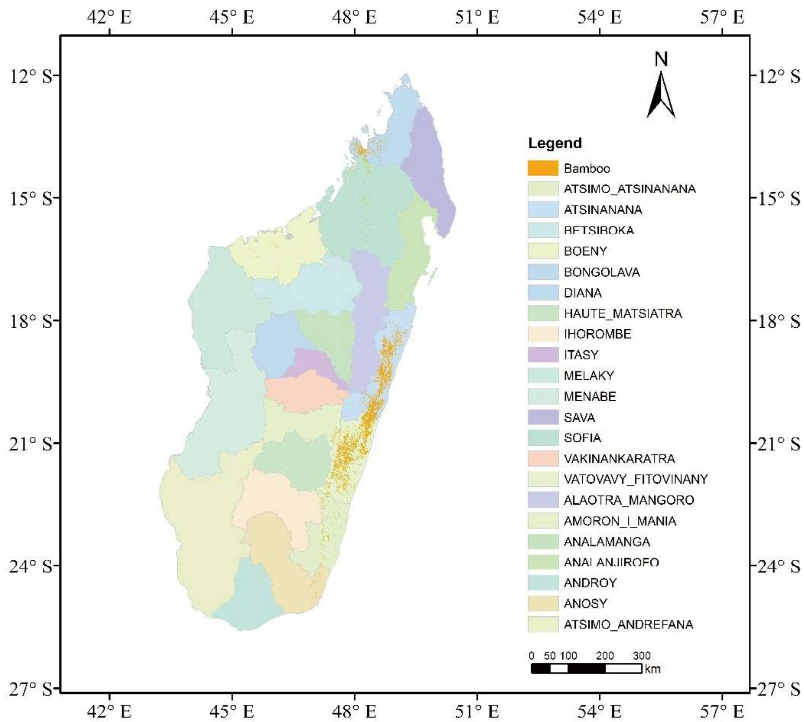
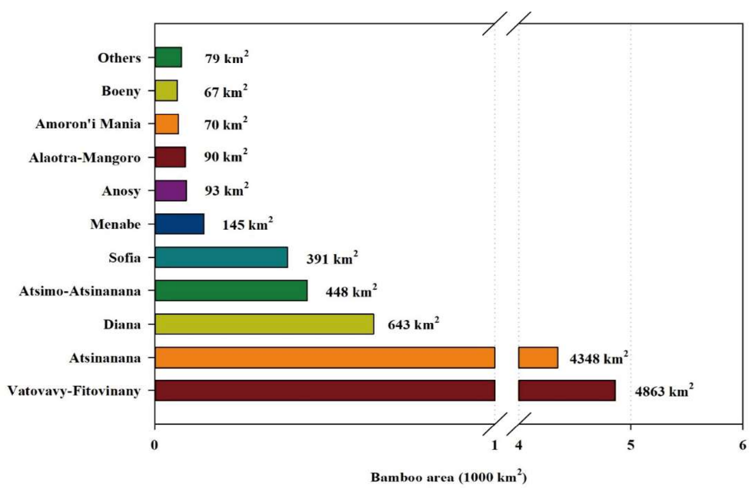


Figure 5: The bamboo cover map of Madagascar, overlaid on the administrative boundaries of regions

Table 1: Bamboo area by region in Madagascar

Number	Region	Bamboo area in km^2
1	Sava	18.86
2	Sofia	390.87
3	Analanjirofo	16.92
4	Boeny	66.54
5	Betsiboka	6.34
6	Alaotra-Mangoro	90.06
7	Melaky	30.99
8	Bongolava	0.00
9	Analamanga	0.06
10	Itasy	0.01
11	Vakinankaratra	0.05
12	Atsinanana	4347.95
13	Androy	0.00

Number	Region	Bamboo area in km^2
14	Anosy	93.03
15	Atsimo-Atsinanana	448.21
16	Ihorombe	5.30
17	Atsimo-Andrefana	0.32
18	Amoron'i Mania	69.88
19	Menabe	145.04
20	Matsiatra Ambony	0.25
21	Vatovavy-Fitovinany	4863.08
22	Diana	643.19
Total Area		11236.94



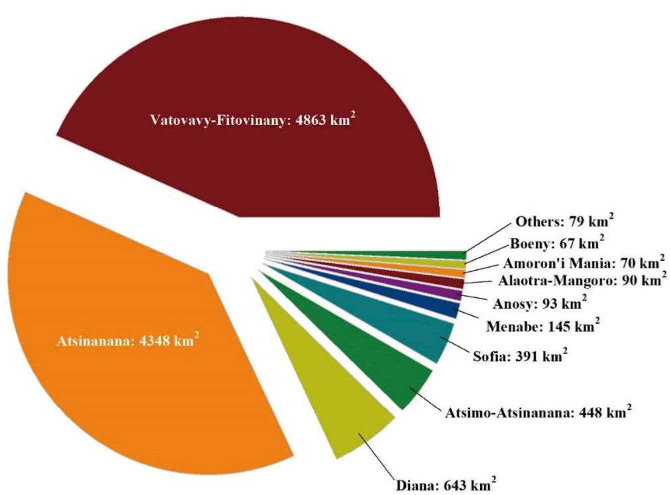


Figure 6: Bar and pie chart depictions of bamboo areas in each region of Madagascar

Table 2: Top 13 bamboo-growing regions in Madagascar

Number	Region	Bamboo area in km^2
1	Vatovavy-Fitovinany	4863.08
2	Atsinanana	4347.95
3	Diana	643.19
4	Atsimo-Atsinanana	448.21
5	Sofia	390.87
6	Menabe	145.04
7	Anosy	93.03
8	Alaotra-Mangoro	90.06
9	Amoron'i Mania	69.88
10	Boeny	66.54
11	Melaky	30.99
12	Sava	18.86
13	Analanjirofo	16.92

CHAPTER 4 CONCLUSION

Mapping the spatial distribution of bamboo is necessary for biodiversity conservation, resource evaluation and ecosystem service management. This study produced a contemporary bamboo map of Madagascar for the year 2017, using 30 m spatial resolution imagery. This is the first remote sensing-based bamboo resources map of its kind for Madagascar, which possesses the richest bamboo species of the African bamboo resources. The study team collected a highly reliable training and validation sample dataset by field survey and image interpretation, and developed an effective mapping process using multi-temporal image series of high temporal resolution. The producer's and user's accuracy of bamboo are 79 per cent and 87.5 per cent respectively,. Commission error and omission error are presented by 1 minus user's accuracy and 1 minus producer's accuracy respectively. Therefore, 12.5 percent of other vegetation is misclassified as bamboo, and 21 percent of bamboo is incorrectly divided into other categories.

According to our mapping result, the total coverage of bamboo is estimated to be 11236.94 km^2 in Madagascar. In Madagascar, bamboo is widely distributed in the eastern, southeast as well as northern parts (Vatovavy-Fitovinany, Atsinanana and Diana). The coverage of bamboo was also estimated for each region, as well as the elevation of its habitat.

The bamboo area was also calculated for the administrative units at different levels for Madagascar according to the available official administrative boundaries. The administrative units with the largest bamboo area were listed in this report for more applications.

It is important to note that due to usage of 30 m spatial resolution imagery, most of the bamboo grown in smallholder farms may not have been mapped by this study. Future studies on a country scale, as well as on a regional scale, could use high-resolution imagery. In addition, mobile/Android-based applications could be developed to inventory bamboo in smallholder farms.

BIBLIOGRAPHY

Agarwal, A. and Purwar, J. 2017. Carbon sequestration and above ground biomass produced by bambusa spp. in the mid-Himalayan region of Uttarakhand, India. *Indian Forester,* 143, pp. 303–306.

Banik, R. L. 2000. *Silviculture and field guide to priority bamboos of Bangladesh and South Asia*. Bangladesh Forest Research Institute: Chattogram.

Bharadwaj, S.P., Subramanian, S., Manda, S., Ray, T., Mukherjee, P. and Rao, I.R. 2003. Bamboo livelihood development planning, monitoring and analysis through GIS and remote sensing. *Journal of Bamboo and Rattan,* 2, pp. 453–461.

Bystriakova, N., Kapos, V. and Lysenko, I. 2004. *Bamboo biodiversity: Africa, Madagascar and the Americas: Number 19.* UNEP: Cambridge.

Chen, H., Yu, Y., Zhong, T., Wu, Y., Li, Y., Wu, Z. and Fei, B. 2017. Effect of alkali treatment on microstructure and mechanical properties of individual bamboo fibers. *Cellulose,* 24, pp. 333–347.

Collen B., Turvey S.T., Waterman C., et al. 2011. Investing in evolutionary history: implementing a phylogenetic approach for mammal conservation. *Philosophical Transactions of the Royal Society of London,* 366, pp. 2611-2622.

Coe, M.J. 2012. *The ecology of the alpine zone of Mount Kenya*. Springer Science and Business Media: Dordrecht.

Das, A. 2017. Bamboo growing and its marmet development potential for sustaining rural livelihoods and poverty reduction in eastern Nepal. *Banko Janakari,* 12, pp. 8–19.

Dubey, A., Trivedi, N. and Joshi, T. (2016). Bamboo: An effective carbon sequester and phytolith. *Agroforestry*, Jaya Publishing House: Delhi, India, page 85.

Du H, Mao F, Li X, et al. Mapping Global Bamboo Forest Distribution Using Multisource Remote Sensing Data[J]. IEEE Journal of Selected Topics in Applied Earth Observations & Remote Sensing, 2018, 11(5):1458-1471.

Ghosh, A. and Joshi, P. 2014. A comparison of selected classification algorithms for mapping bamboo patches in lower Gangetic plains using very high resolution WorldView 2 imagery. *International Journal of Applied Earth Observation and Geoinformation,* 26, pp. 298–311.

Gong, P., Wang, J., Yu, L., Zhao, Y., Zhao, Y., Liang, L., Niu, Z., Huang, X., Fu, H., Liu, S., et al. 2013. Finer resolution observation and monitoring of global land cover: first mapping results with Landsat TM and ETM+ data. *International Journal of Remote Sensing,* 34, pp. 2607–2654.

Han, N., Du, H., Zhou, G., Sun, X., Ge, H. and Xu, X. 2014. Object-based classification using spot-5 imagery for Moso bamboo forest mapping. *International Journal of Remote Sensing,* 35, pp. 1126–1142.

Hiroshi, M., Hisashi, H., Manoru, K. and Shozo, S. 2009. Gregarious flowering of *melocanna baccifera* around north east India: extraction of the flowering event by using satellite image data. In *VIII World Bamboo Congress Proceedings 5*, pp. 101–107.

Joshi, P. K., Roy, P., Singh, S., Agrawal, S. and Yadav, D. 2006. Vegetation cover mapping in India using multi-temporal IRS wide field sensor (WiFS) data. *Remote Sensing of Environment*, 103, pp. 190–202.

Kaur, P. J., Pant, K., Satya, S. and Naik, S. 2016. Bamboo: The material of future. *International Journal Series in Multidisciplinary Research,* 2, pp. 27–34.

Kratter, A. W. 1997. Bamboo specialization by Amazonian birds. *Biotropica,* 29, pp. 100–110.

Li, M., Li, C., Jiang, H., Fang, C., Yang, J., Zhu, Z., Shi, L., Liu, S. and Gong, P. 2016. Tracking bamboo dynamics in Zhejiang, China, using time-series of Landsat data from 1990 to 2014. *International Journal of Remote Sensing,* 37, pp. 1714–1729.

Linderman, M., Bearer, S., An, L., Tan, Y., Ouyang, Z. and Liu, J. 2005. The effects of understory bamboo on broad-scale estimates of giant panda habitat. *Biological Conservation,* 121, pp. 383–390.

Linderman, M., Liu, J., Qi, J., An, L., Ouyang, Z., Yang, J., and Tan, Y. 2004. Using artificial neural networks to map the spatial distribution of understorey bamboo from remote sensing data. *International Journal of Remote Sensing,* 25, pp. 1685–1700.

Lobovikov, M., Ball, L., Guardia, M., and Russo, L. 2007. *World bamboo resources: a thematic study prepared in the framework of the global forest resources assessment 2005.* Food and Agriculture Organization: Rome.

Shimada M., Itoh T., Motooka T., Watanabe M., Tomohiro S., Thapa R., and Lucas R. 2014. New global forest/non-forest maps from ALOS PALSAR data (2007-2010). *Remote Sensing of Environment,* 155, pp. 13-31.

Mishra, V. 2015. Bamboo and its connectivity to the different fields of economics: A potential resource of modern India. *International Journal of Innovative Research and Development,* 4, pp. 140–145.

Nelson, B. W. and Irmão, M. N. 1998. Fire penetration in standing Amazon forests. *Proceedings of the Ninth Brazilian Remote Sensing Symposium, Santos, Brazil*.

Ohrnberger, D. and Goerrings, J. 1988. *The bamboos of the world.* [Self published.]

Rakotonirina L, Rajaonson A, Ratolojanahary T, et al. 2001. New distributional records and conservation implications for the critically endangered greater bamboo lemur Prolemur simus. *Folia Primatologica,* 82, pp. 118-129.

Reid, S., Díaz, I.A., Armesto, J.J. and Willson, M.F. 2004. Importance of native bamboo for understory birds in Chilean temperate forests. *The Auk,* 121, pp. 515–525.

Rogan, J., Franklin, J., and Roberts, D.A. 2002. A comparison of methods for monitoring multitemporal vegetation change using Thematic Mapper imagery. *Remote Sensing of Environment,* 80, pp. 143–156.

Schaller, G. B. 1985. *Giant pandas of Wolong*. University of Chicago Press: Chicago.

Ravaloharimanitra M, Ratolojanahary T, Rafalimandimby J, et al. 2011. Gathering local knowledge in Madagascar results in a major increase in the known range and number of sites for critically endangered greater bamboo lemurs (Prolemur simus). *International Journal of Primatology,* 32, pp. 776-792.

Sofiana, Y., Sylvia, C.O. and Purbasari, M. 2017. Potential of bamboo as material for furniture in rural areas in Indonesia. *Advanced Science Letters,* 23, pp. 263–266.

Song, X., Zhou, G., Jiang, H., Yu, S., Fu, J., Li, W., Wang, W., Ma, Z. and Peng, C. 2011. Carbon sequestration by Chinese bamboo forests and their ecological benefits: assessment of potential, problems and future challenges. *Environmental Reviews*, 19, pp. 418–428.

Tan C.L. 2006 Behavior and Ecology of Gentle Lemurs (Genus Hapalemur). In Gould, L. and Sauther, M. (eds) *Lemurs: Ecology and Adaptation*. Springer: New York, pp. 369-381.

Tucker, C. J. and Townshend, J. R. 2000. Strategies for monitoring tropical deforestation using satellite data. *International Journal of Remote Sensing,* 21, pp. 1461–1471.

Vorontsova, M., Clark, L., Dransfield, J., Govaerts, R. and Baker, W. 2016. *World checklist of bamboos and rattans.* INBAR: Beijing.

Wang, T., Skidmore, A. and Toxopeus, A. 2009. Improved understorey bamboo cover mapping using a novel hybrid neural network and expert system. *International Journal of Remote Sensing,* 30, pp. 965–981.

Widenoja, R. 2007. *Sub-optimal equilibriums in the carbon forestry game: Why bamboo should win but will not*. PhD Thesis, The Fletcher School of Law and Diplomacy: Medford.

Zhang, Q., Jiang, S. and Tang, Y. 2002. *Industrial utilization on bamboo*. INBAR: Beijing.

Zhao, Y., Feng, D., Jayaraman, D., Belay, D., Sebrala, H., Ngugi, J., Maina, E., Akombo, R., Otuoma, J., Mutyaba, J., et al. (2018). Bamboo mapping of Ethiopia, Kenya and Uganda for the year 2016 using multi-temporal Landsat imagery. *International Journal of Applied Earth Observation and Geoinfor- mation,*, 66:, pp. 116–125.

Zhao, Y., Feng, D., Yu, L., Wang, X., Chen, Y., Bai, Y., Hernández, H. J., Galleguillos, M., Estades, C., Biging, G. S., et al. 2016. Detailed dynamic land cover mapping of Chile: Accuracy improvement by integrating multi- temporal data. *Remote Sensing of Environment,* 183, pp. 170–185.

Zhou, B.-Z., Fu, M.-Y., Xie, J.-Z., Yang, J.-Z. and Li, Z.-C. 2005. Ecological functions of bamboo forest: research and application. *Journal of Forestry Research,* 16, pp. 143–147

APPENDIX

Regional maps of bamboo-growing areas in Madagascar

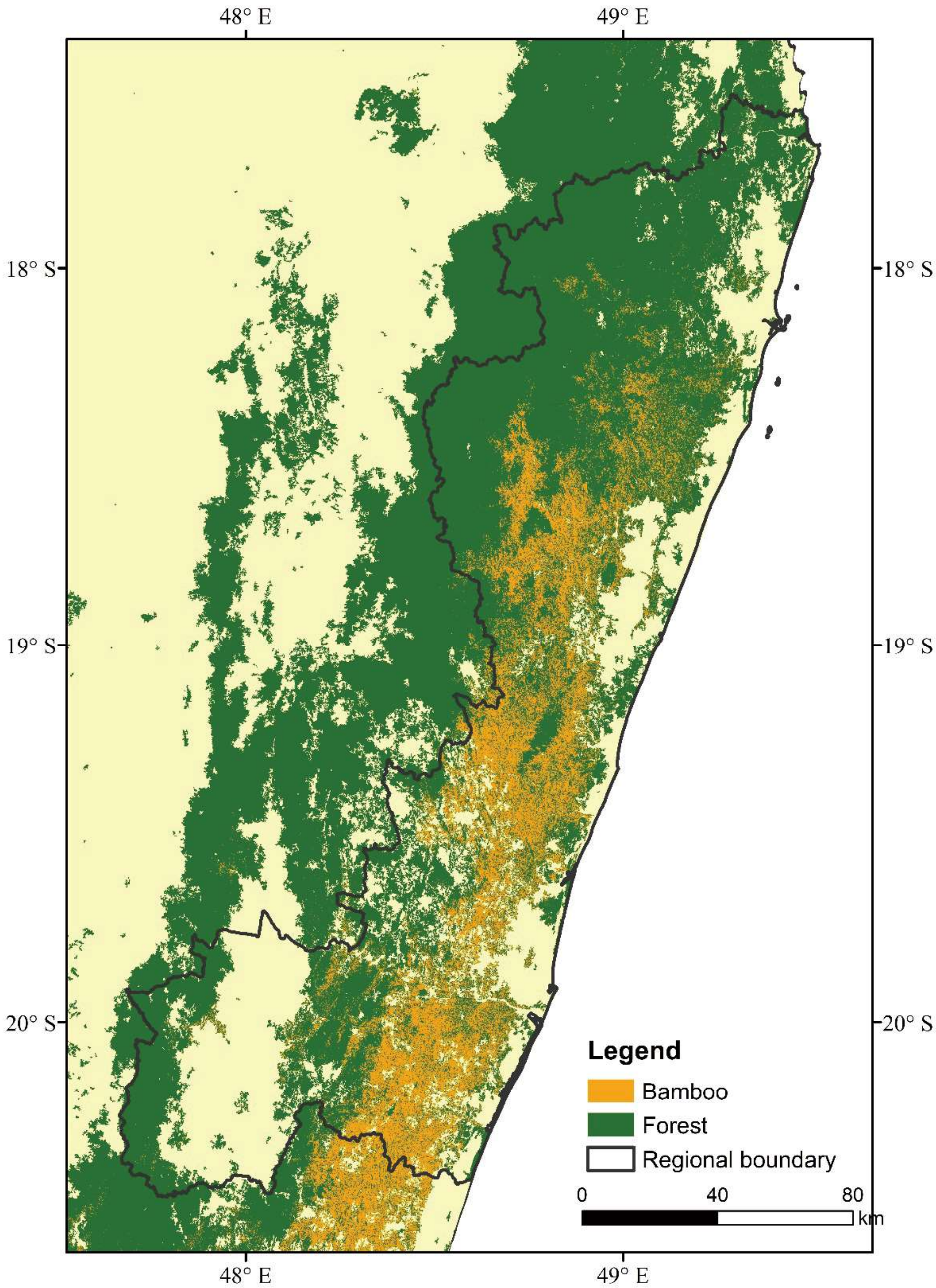


Figure 7: Bamboo distribution of Vatovavy-Fitovinany Region

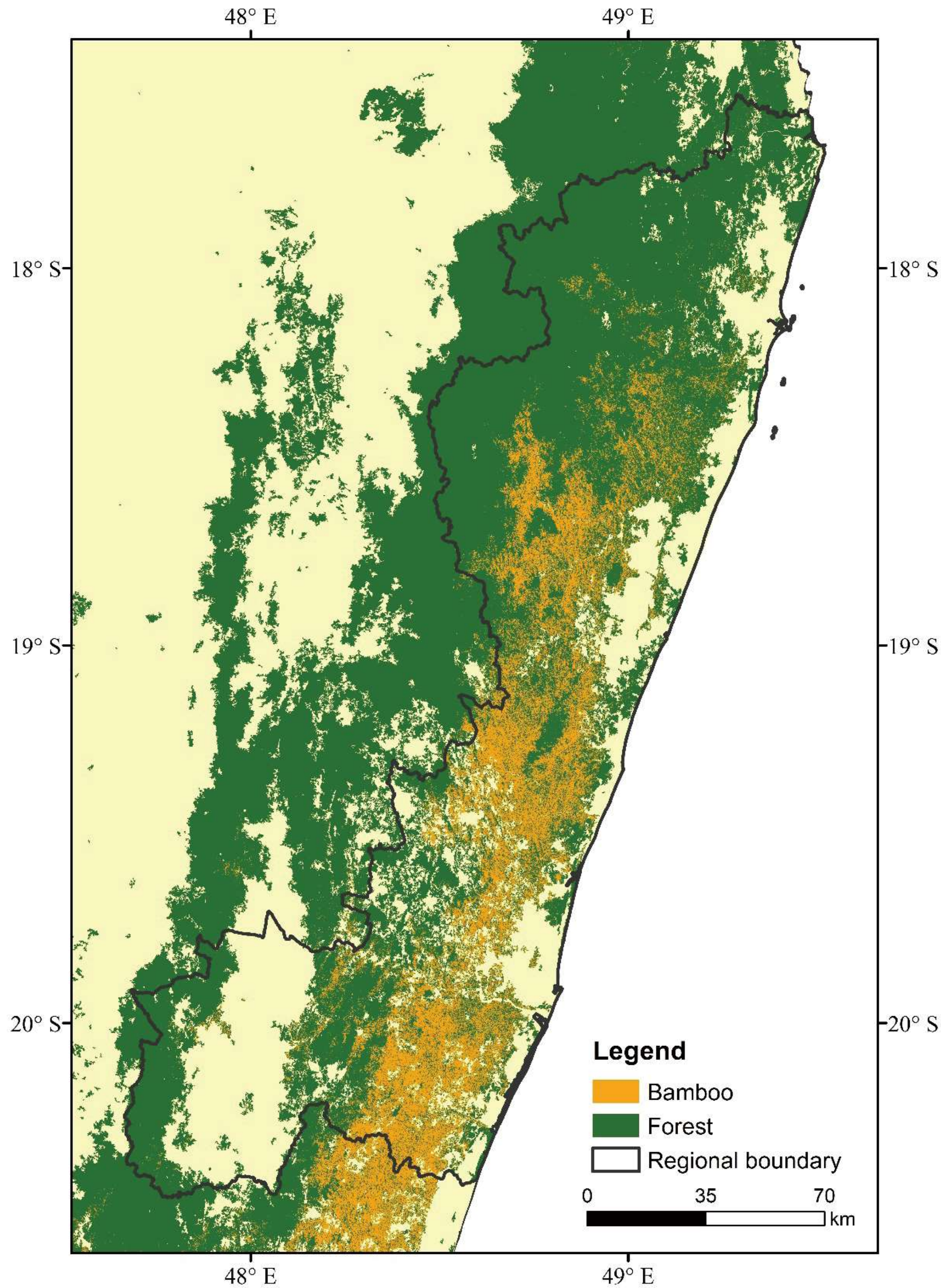


Figure 8: Bamboo distribution of Atsinanana Region

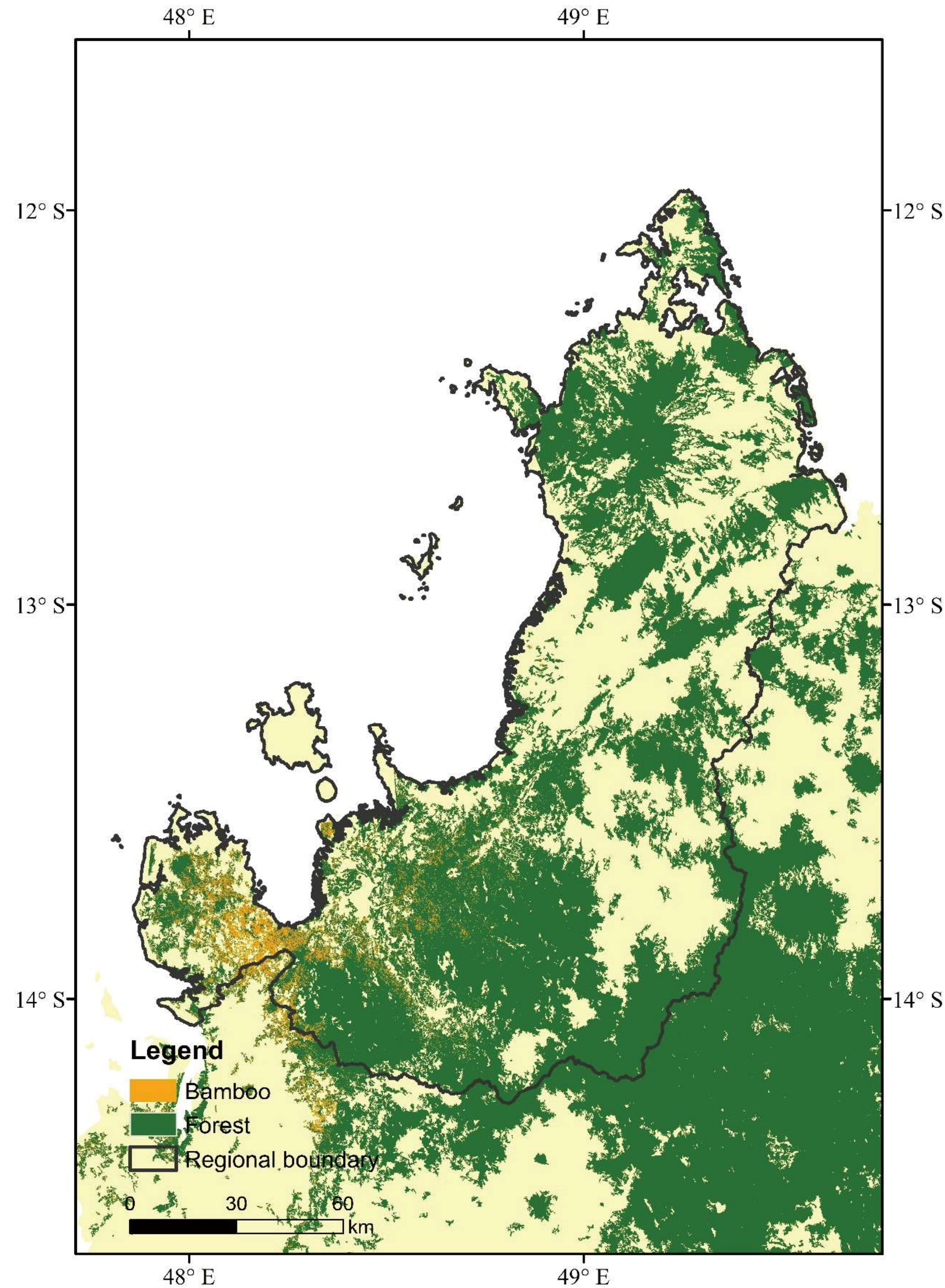


Figure 9: Bamboo distribution of Diana Region

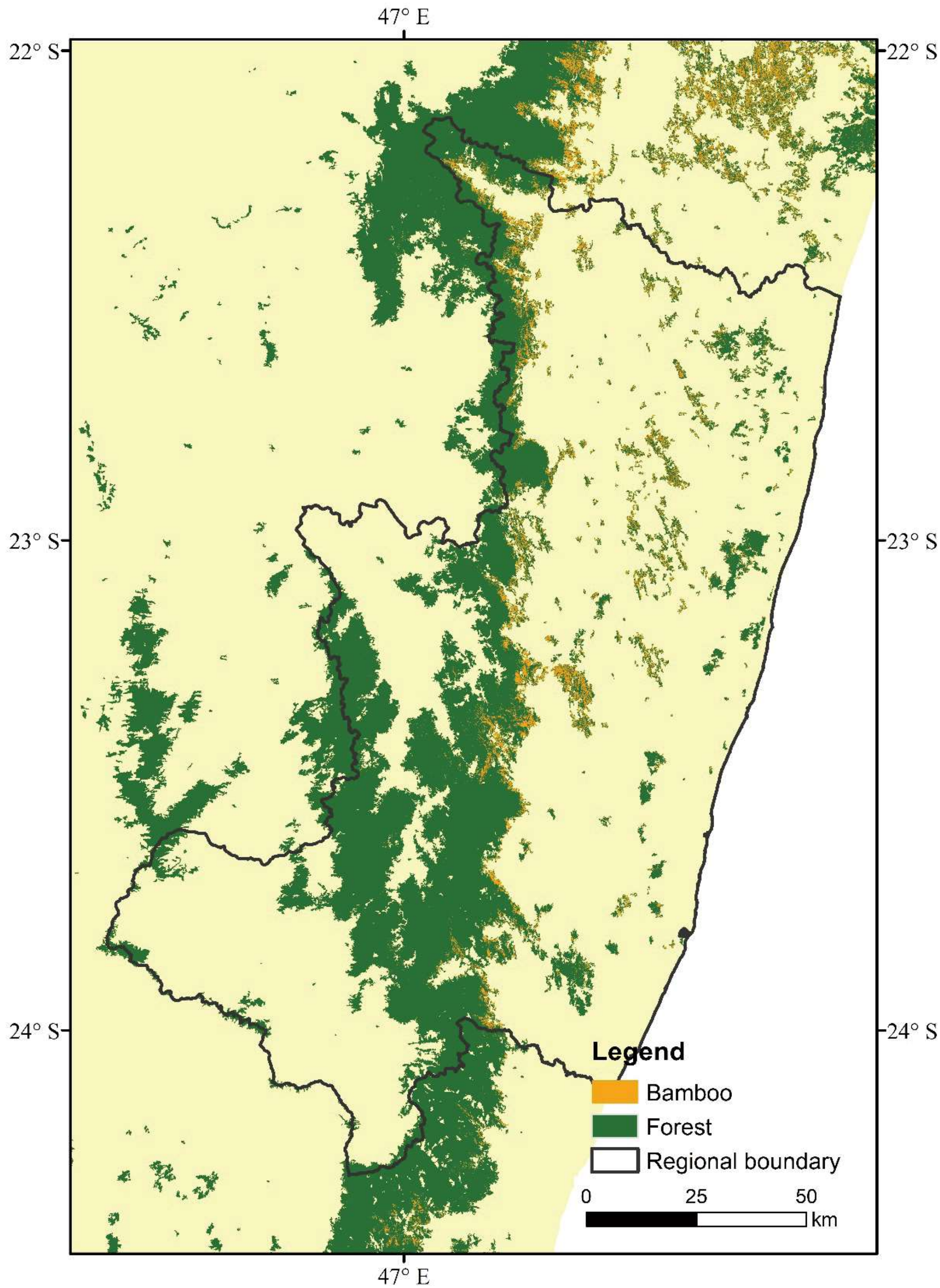


Figure 10: Bamboo distribution of Atsimo-Atsinanana

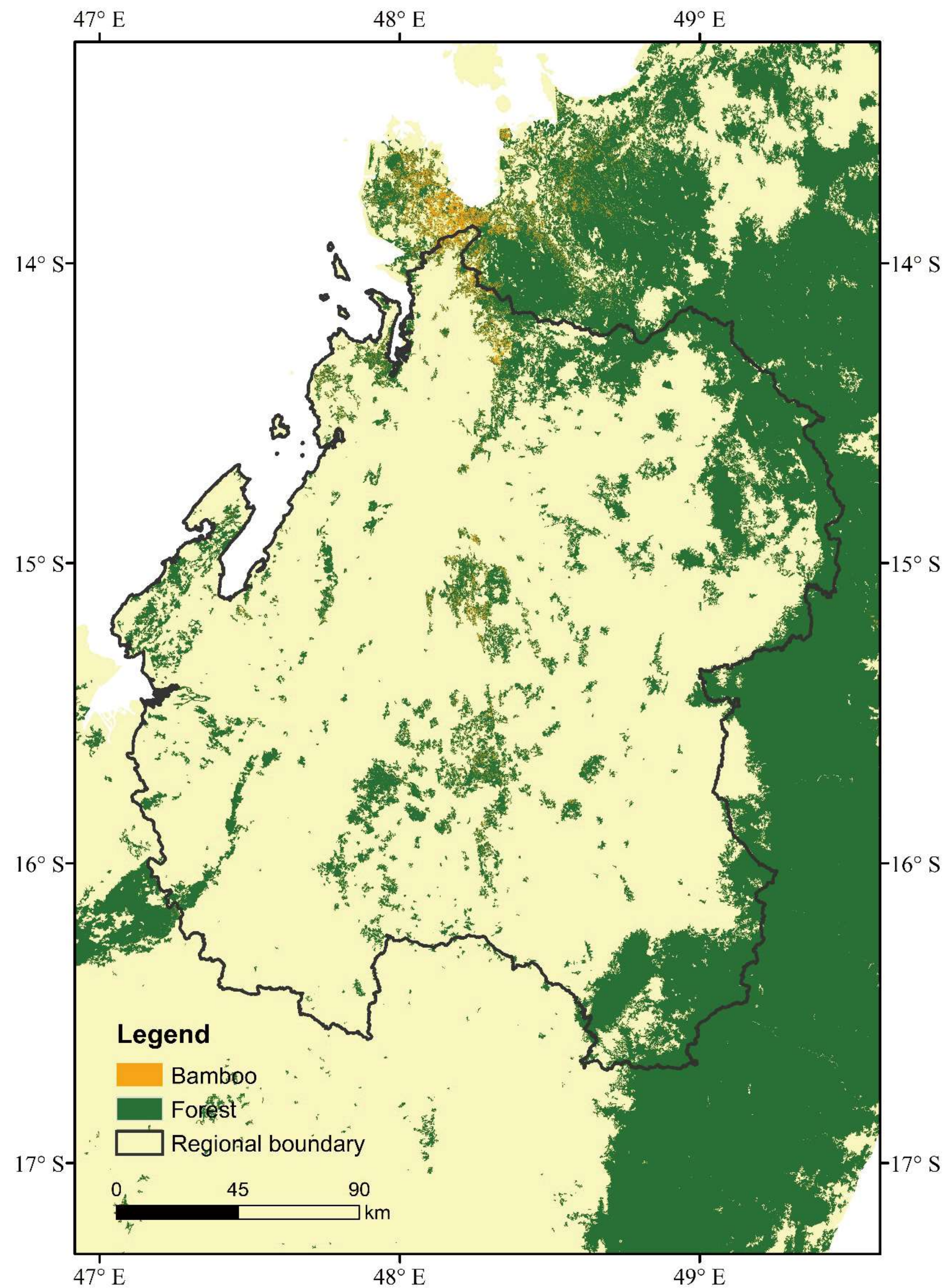


Figure 11: Bamboo distribution of Sofia

Ministry of Foreign Affairs

KENYA
Forest Service

NFA
National Forestry Authority

Cover illustration by Dr. Wan Tarmeze Wan Ariffin