2023 Asian Conference on Remote Sensing (ACRS2023)



**NOVEL GEOSPATIAL-BASED TROPICAL BAMBOO INVENTORY SYSTEM AND SITE SUITABILITY MAPPING OF**

**AREAS FOR COMMERCIAL BAMBOO PRODUCTION: ENHANCING THE CAPABILITIES OF DENR FIELD STAFF IN THE PHILIPPINES**

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**KEY WORDS:** tropical bamboo inventory system, bamboo spatial distribution, Sentinel-2, Google Earth Engine

**ABSTRACT:** Bamboo provides many ecosystem goods and services, including food, fiber and construction materials. In most developing countries in tropical Asia, data on bamboo resources such as species composition, clump density (clump/ha) and culm density (culm per ha) are, most of the time, not available, including the map of their current extent and the suitability maps for commercial bamboo species. The traditional mapping procedure being used for tropical bamboo requires downloading satellite imagery, a hardware/workstation with high processing capability, image processing software, and a fast internet connection. These requirements are real challenges, especially in developing countries where the internet connection is not fast enough to download the heavy files of satellite imagery, where workstation with high processing capability is wanting, and where funds to procure the software for satellite image processing is lacking.

To address these gaps, we developed a geospatial-based bamboo inventory system to: 1) determine the species composition, clump density and culm density of bamboo resources in the study site using a field inventory procedure; 2) model their extent using satellite data in a cloud-computing platform, and 3) map the areas suitable for growing selected commercial lowland bamboo using an open-source GIS software. We used field plots, Sentinel-2, Google Earth Engine platform, geophysical layers and QGIS software to achieve the tasks and address the above challenges.

Our geospatial-based bamboo inventory system was able to provide an estimate of bamboo clump density (clump per ha) and culm density (culm per ha), with error within + 10% of the true mean at 95% confidence level; map the extent where bamboo stands are located; and identify areas suitable for planting a commercial bamboo species (*Bambusa spinosa)*.

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We shared the above techniques to selected field staff of the Department of Environment and Natural Resources offices in the provinces of Pangasinan, Rizal and Ilocos Norte through a series of pilot training to teach them how to conduct field inventory of their bamboo resources, map their extent, and map the areas suitable for growing *B. spinosa*. Results from these pilot training suggest that updated bamboo information (species composition, clump density, culm density, map of bamboo extent and map of suitable areas for growing *B. spinosa)* could be generated per district or province, given the needed support and training.

The bamboo inventory system we developed demonstrated that timely and updated information on the country’s bamboo resources could be generated, at least in the district or province level, addressing the absence of bamboo inventory data and maps. We can tap the trained field staff of the government to help generate these bamboo inventory data and maps. The new information and procedure generated by the project should serve as important inputs for the bamboo industry in the country, both for the government office regulating the harvest of bamboo resources and doing rehabilitation of degraded areas using bamboo, and the public that invest in bamboo production and commercial utilisation.

**INTRODUCTION**

Bamboo provides many ecosystem goods and services, including food, fiber and construction materials. They provide important ecosystem goods and services to people: sources of food and raw materials for construction (Houdanon et al., 2018), plants for soil erosion control, water conservation and land rehabilitation (INBAR, 2014). With the threat of climate change, deforestation and food security, use of bamboo could be an important nature-based solution in the tropics (Ben-zhi et al., 2005; Houdanon et al., 2018).

In most developing countries in the tropics, data on bamboo resources such as species composition, clump density (clump per ha) and culm density (culm per ha) are most of the time not available. Furthermore, maps of bamboo extent are almost always absent, as well as the maps showing the specific suitable areas for commercial bamboo species production.

Moreover, the traditional mapping procedure being used for tropical bamboo requires downloading satellite imagery, a hardware/workstation with high processing capability, image processing software, and a fast internet connection. These requirements are real challenges, especially in developing countries in tropical Asia where internet connection is not fast enough to download the heavy files of satellite imagery, where workstation with high processing capability is wanting, and where funds to procure the software and hardware for satellite image processing and crop suitability mapping is lacking.

To address these gaps, we developed a geospatial-based bamboo inventory system able to: 1) determine the species composition, clump density and culm density of bamboo resources in the study site using a simple field procedure; 2) map the extent of bamboo resources in the area using satellite imagery in a cloud-computing platform, and 3) identify/locate and map the areas suitable for growing selected commercial lowland bamboo species using an open-source GIS software. We piloted the developed bamboo inventory and mapping techniques to selected field staff of the Department of Environment and Natural Resources (DENR) of the government through a series of training to see if the developed procedure can be followed at the field level.

The generated new information should serve as baseline information for future studies and strong basis for evidenced-based management of bamboo resources in the study site, while the newly developed inventory system procedure for bamboo and the training of DENR field staff should be able to contribute in address the absence of bamboo resources field data and maps in the country.

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**METHODS**

We developed the bamboo inventory system using field data, free satellite imagery and open-access software, with the province of Pangasinan as the test site. The province is located in the northwestern part of Luzon Island in northern Philippines. The whole province was divided into 3 sections/districts (West, Central and East). We used 30m x 30m field plots to inventory the bamboo clumps and culms, and determine their densities (clump per ha, culm per ha). We used Poppens (2004) to estimate the age of the culm.

To map and determine the extent (ha) of bamboo, we used Sentinel-2 imagery, Random Forest algorithm, and the field locations of the bamboo and non-bamboo as training and validation points. We processed the data in Google Earth Engine (GEE) cloud-computing platform. We used 80% of the data for model building and 20% for validation. Finally, we used the open-access software QGIS to locate and map the suitability of the area for *Bambusa spinosa* using weighted overlay analysis, with elevation, slope, soil type and rainfall as input layers,each with 25% weight.

The developed field inventory and mapping procedure for bamboo resources was piloted to selected field staff of the DENR in the provinces of Pangasinan, Rizal and Ilocos Norte, all in the island of Luzon in northern Philippines. The pilot training consist of modules on bamboo field inventory, bamboo mapping using GEE and GIS-based site suitability mapping for *B. spinosa* using QGIS. Both GEE and QGIS are open-source software.

**RESULTS AND DISCUSSION**

Our geospatial-based bamboo inventory system was able to provide an estimate of bamboo clump density (clump per ha) and culm density (culm per ha), with error within + 10% of the true mean at 95% confidence level. The clump density (clump per ha) ranges from 66 to 74, while the density of harvestable (> 2 year-old) culms ranges from 762 to 1,231 culms per ha. We were also able to map the extent of bamboo in the province and preliminary estimated an area of more than seven thousand hectares. Most of the area in the province is highly suitable to *Bambusa spinosa,* except for areas in the easternmost section of the province, characterised with high elevation (>900 masl).

The developed geospatial-based bamboo inventory system procedure was piloted to selected field staff of the DENR through a series of pilot training. They were trained for a week on how to conduct field inventory of their bamboo resources, map their extent, and map the areas suitable for growing *B. spinosa*. Over 100 field staff of DENR were trained in all on the conduct of field inventory, mapping of extent and suitability mapping of bamboo resources in their districts and province. Results from these pilot training suggest that updated bamboo information (species composition, clump density, culm density, map of bamboo extent and map of suitable areas for growing *B. spinosa)* could be made available per district or province, given the needed support and training.

Good internet connection and average computer are a few of the challenges encountered while doing the pilot training on bamboo mapping using satellite imagery and GEE, as well as when mapping the suitability of the area for a preferred species. More than a week of training is necessary, especially on the portion of bamboo mapping using GEE and collection of field training data.

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**CONCLUSION**

The bamboo resource inventory system we developed has shown that it could potentially address the absence of bamboo inventory data and maps of bamboo extent and areas suitable for bamboo production in the country and elsewhere in developing countries in tropical Asia. It has demonstrated that timely and updated information on the country’s bamboo resources could be generated, at least in the district or province level. Our results suggest that we can tap the field staff of the government agency mandated to manage and regulate natural resources (DENR in our case), to help in generating the above needed information on bamboo resources, provided that proper support and training are in place.

The new information and procedure we generated should serve as important inputs for the bamboo industry in the country, both for the government offices regulating the harvest of bamboo resources and doing rehabilitation works using bamboo, and the public that invest in bamboo production and commercial utilisation.

**ACKNOWLEDGEMENT**

The authors would like to thank the *Ecosystems Research and Development Bureau, Department of Environment and Natural Resources* (DENR), Philippines for allowing the corresponding author to presentthis study at the ACRS 2023, the *Foreign Assisted and Special Project Service,* DENR for funding the Phase 1 (development of technique) of the project, and the *Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development, Department of Science and Technology* for providing the funds forthe Phase 2 (Training) of the project.

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