**Ph.D. Thesis proposal**

Objectives:

* Calibrate an earth system model to simulate regeneration processes in restoration sites in Panama.
* Develop a large-scale monitoring tool for restoration sites derived from publicly available data.
* Improve algorithms that represent secondary forest regrowth.
* Predict suitability of land for specific restoration strategies across the landscape.

Roughly 70% of forested areas has been affected by forest management, clearing and abandonment (FAO,2010). Regeneration of forests has the largest potential for long term adaptation to climate change, as it presents new species composition and forest structure. Natural regeneration processes have an important role in the resilience of forest during mortality events. Regeneration processes such as reproductive allocation, seed dispersal, germination and seedling survival are influenced by environmental variables such as light availability, water, temperature and soil composition. These variables can have a deterministic effect in where trees regrow and at what rate.

Non-governmental organizations dedicated to tropical forest restoration often struggle to meet the goals set by the funds that finance their operations. It is even more difficult to set out a monitoring strategy that allows them to report the total restored land at a low cost. Large scale monitoring of forest regrowth is possible by using remote sensing techniques such as drone imagery, LIDAR technology, and satellites.

The representation of secondary forest regrowth can be done through models of forest dynamics, either empirical models or mechanistic models. In the one hand empirical models are site specific and require long term monitoring, whereas mechanistic models seek to generalize the underlying processes driving succession and carbon accumulation. To calibrate a forest dynamic model, we must first understand population dynamics such as mortality and recruitment. Most known restoration sites in Panama are regenerated by artificial means like planting and naturally regenerated forest remains unsampled.

The idea behind this study is to conduct large scale monitoring of known restoration sites and acquire data from the governmental institutions and non-profits that manage them. To understand the underlying processes driving forest succession in this site as well as identifying sites that have undergone regeneration in the recent years. To achieve such an ambitious task, we must first develop more efficient monitoring methods to improve the regeneration parameters. An example is The Agua Salud Project’s long‐term secondary forest dynamics study located in Panama Canal watershed, which has been extensively studying the successional trajectories and dynamics in a landscape dominated by cattle pasture.

The proposed research thesis in this document is subjected to change the specific goals given the problems that may arise from the literature review, study design and limitations related to field work. The motivation behind the study is the high vulnerability of my home region to climate change due to hundreds of years of deforestation for cattle pastures and general deficiency of scientific studies documenting the effects of climate change in the forest of the Azuero region. It has always been my dream to contribute to the conservation and restoration of the tropical dry forest of Panama. The applications of earth system model calibrated with purely managed restoration sites have the potential of identifying appropriate land for tree planting and increasing the cost-effectiveness of reforestation initiatives.

**STRI- Auto Crown project**

There is available drone imagery for sites such as 50 ha plot in BCI and the Ava plot, which are processed into point clouds, digital elevation models and orthomosaics by using photogrammetry. STRI has conducted monthly flights during several years, and now have weekly flights. There is potential to conduct analysis on tree mortality, phenology and flowering. However, crown mapping has been done manually with ground truthing by experienced field technicians, which is laborious and time consuming. The rate at which we are collecting RGB imagery calls for automatization of crown delineation and the consolidation of the multiple datasets collected in this site. Artificial intelligence and neural networks have been used to map crowns in other sites and require large training datasets to perform.

The Auto Crown project aims to consolidate the latest years datasets into timeseries that track most of the crowns in the 50 ha BCI plot. To achieve this goal, we are testing available deep-learning tree crown delineation tools such as *DeepForest* and *Detecttree2* in our datasets and comparing F1 scores. *Detectree2* is a python package deriving from the detectron2 framework for object detection. They offer methods for transfer learning and pre trained models for tree crown detection on the Linux platform. *Deepforest* is another python package for training and prediction of individual tree crowns, which is trained with data from the National Ecological Observatory network. Furthermore, we explore alternative neural network framework to derive an algorithm trained in tropical forest crowns. Examples of neural network frameworks used for crown segmentation are YOLO-v4.

The algorithms mentioned are convolutions neural networks (CNN) and are difficult to develop due to the large datasets required to detect trees. We are limited on time and resources to develop large training datasets from manual crown delineation. CNNs perform two complexes set of operations, first it creates multiples convolution layers to detect areas in which the probability of an object is high, second it creates another set of convolutions to determine which pixel in each area of interest belong to the object. The idea of transfer learning is to initialize the training of a new neural network from a previously trained CNN, to preserve the features learned from other datasets. Gan et al. reported an increase in F1 scores from 0.22 to 0.52 in a transfer-trained algorithm of *DeepForest.*

Freudenberg et al. adopted a different approach than CNNs, it employs two neural networks to create a polygon around tree images from WorldView-3. It uses U-net and ResNet18 to create a mask around the trees and outlines that are then concatenated according to a Heaviside function and a distance transform function. The output is used as a seed for a morphological watershed segmentation tool which restricts R to a certain threshold. This approach works better for urban areas or less dense areas. In homogeneous closed canopy cover, there is too many ambiguities, over segmentation or missed detection of small trees. Nonetheless, their approach introduces the idea of using multiple segmentation tools to increase precision of detection, and in our case the usage of the DEM and point clouds as sublayers could prove beneficial.

Scores to evaluate models are intersection over union (IoU) defined as the intersection area between the predicted and ground truth area. A threshold is then defined to distinguish between True positives, false positive, or false negatives. Precision is defined as the true positives divided by the sum of true positives and false positives. Recall is defined as true positives divided by the sum of the true positives and the false negatives. The F1 score is given by . The total crown area can be compared between ground delineation and AI delineation datasets with R-square and RMSE scores.

Crow projection area (CPA) is defined as the vertical projection of the tree in a horizontal plane, and it can be used to predict diameter at breast height, volume and growth rates of individual. Wyckoff & Clark found that exposed crown area (ECA) is an excellent predictor of tree growth (R2= 0.69). Ramírez-Mejía et al. compared biomass estimations from field surveys of Quercus spp. against estimations derived from tree crowns photos. They found a high determination coefficient between the crown area derived from allometric equations and the crown area from aerial images (R2= 0.88). Song et al. makes use of superpixel-based Residual Networks 50 and SP-ResNet50 to derive a leaf fraction from 6 phenocams in Panama and demonstrates its efficacy at differentiating leaves from non-leaves in phenocams timeseries.

We have crown maps manually delineated from 2014 to 2020, only include maps for 1 month of each year. These datasets can be used for training and validation of a neural network. The issue is that training the AI algorithm with crowns delineated from BCI 50 ha and then predicting with the same plot results in overfitting. Alternatives to this issue is to train the dataset with newly delineated crowns from the AVA plot, which is relatively close, the flights images are at the same altitude and collected in the same day. Other issues arise from the quality of the training datasets, which need to be more extensively evaluated. The instance segmentation of the individual tree crown is challenging in complex forest structures, given the overlaps of branches and the geometrical complexity of tree crowns. We lack crown maps for 2021 and 2022, and a new crown mapping campaign is expected to start in 2023. We must improve the field crown delineation tools to create a more precise ground-truth dataset. We need to process the drone images from august 2020 onwards into orthomosaics, DEM and pointclouds. Finally, the implementation of automatic crown segmentation algorithms to recent years imagery and the creation of timeseries for analysis of crown area changes.

**Evaluation of global gridded climate products in reproducing spatial and temporal variation in precipitation in central Panama**

This study has been submitted for revision and inclusion in the BCI 100th anniversary book in the physical monitoring volume. It encompasses my latest months’ work with STRI, and it wouldn’t be possible without the long-term monitoring of the Panama Canal watershed by the ACP. Data acquisition was possible by interinstitutional collaboration between ACP and STRI and previous data cleaning by KC Cushman and Steve Paton. Find the complete study attached.

**Abstract**

Tropical forests vary widely in their precipitation regimes and seasonal water availability, but

high-quality in situ (ground-based) meteorological data are rare, and few studies have evaluated

the performance of global gridded climate products in the tropics. We compared the

performance of eleven high-resolution gridded climate products against in situ datasets spanning

high rainfall variation in central Panama. The gridded products almost all captured the broad

trends of spatial and seasonal rainfall variation in central Panama, and all underestimated

precipitation in the wettest sites, especially in the dry season, but differed widely in their

performance. Seasonal and interannual variation were best captured by CHIRPSv2, while spatial

variation was best captured by CHELSA 2.1, which has finer spatial resolution. Our ability to

quantify performance was constrained by limited data availability, even in this region with

relatively many high-quality long-term in situ datasets, highlighting the need for more.

investment in ground-based data collection.

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