Integrating land-use simulation models and riparian decision-support systems to guide restoration planning and management in the Lake Victoria Basin

1. Problem identification and proposed solution and dataset

Climate change is affecting East Africa's ecosystems and threatening the economic system, livelihoods and availability of natural resources [1,2]. In the flood and drought-threatened regions of the Lake Victoria Basin, ecosystem-based adaptation (EbA) has gained significant attention and importance in public and private sector climate policies as promising solutions in rehabilitating degraded, over-exploited lands aimed at stabilizing water supply, reducing desertification, and improving regional climatic conditions [3]. With the rapid population growth, economic development and urbanization in the past decades, deforestation, driven by slash and burn agriculture and high demand for fuel wood, has gradually become a major environmental burden in the region [4, 5]. Projected changes in the basin's climate pose a further challenge on grassland, forest and freshwater ecosystems, as relatively small changes in the moisture balance may lead to considerable ecological shifts [6]. To address this issue, the Protocol for Sustainable Development of Lake Victoria Basin (Articles 6, 7, 8 and 9) emphasizes the need for Partner States to jointly promote Agriculture, Forestry and other Land Uses (AFOLU) mitigation policies and measures to advance ecosystem restoration and increase carbon sequestration in ways that generate synergies with productive efficiency, competitiveness, conservation and food security [7]. These include supply-side interventions on natural forest and other ecosystems regeneration (to protect, manage, restore and enhance carbon sequestration), agroforestry and climate-smart agriculture (sustainable land use management to reduce emissions and enhance carbon sequestration), and bioenergy (to reduce fossil fuel emissions and sequester carbon), as well as demand-side interventions on sustainable resource use.

As of 2020, Kenya, Rwanda and Uganda had included land-based mitigation measures in their updated Nationally Determined Contributions (NDCs) under the Paris Agreement, either by specifically listing actions or by including AFOLU mitigation measures in their broader GHG reduction targets, with most focus on natural forest regeneration and restoration of degraded, over-exploited lands to stabilize water supply, reduce desertification, and improve regional climatic conditions [8, 9, 10]. Achieving the NDC AFOLU mitigation targets and addressing other land-related challenges synergistically at national levels remains a large challenge and regional progress is lacking [3]. Understanding the effectiveness of the AFOLU mitigation actions is important for assessing the successes of restoration efforts across the region. Since the inclusion of mitigation actions in partner states' revised NDCs, many conservation agencies and development practioners in the Lake region are still struggling to assess the impacts of their transboundary restoration efforts due to the lack of ground truth data [3]. This knowledge gap not only impedes a better understanding of the synergistic effects of restoration interventions at various levels across key ecosystems, but it also hinders the generation of data needed to drive private and public restoration investments [11, 12]. Accordingly, Parties to the United Nations Framework Convention on Climate Change (UNFCCC) have requested that the Intergovernmental Panel on Climate Change provides more focused assessments of regional AFOLU mitigation measures and their feasibility to guide national and international actors to better target restoration investments and efforts to areas of promise and need [13].

Given the magnitude of the rate of deforestation in the region, citizen science, artificial intelligence, machine learning, and remote sensing technologies hold great promise to better understand land use and land cover trends and inform actions to mitigate and adapt to the impacts of a changing climate on forest ecosystems across the Lake region. This study aims to address these data needs by building machine learning algorithms that provide (1) new and/or updated, regional-level land use and land cover geospatial data that defines priority areas for conservation and restoration opportunities; (2) updated regional tree species suitability models, that combine distribution and species assemblages with the most recent soil, precipitation, temperature and evapotranspiration datasets, to inform strategic restoration interventions (e.g. agroforestry, reforestation and forest conservation, forest regeneration etc.) best suited for different locations; (3) new, regional forest cover scenarios to help identify potential pathways for the design of national forest strategies and policies across the region; and (4) an open source spatial decision-support interface presenting end user-relevant scenarios of forest cover change to inform and monitor strategic restoration interventions. User tutorials on the use of the web application and in-person trainings on updating the machine learning models as new information comes to light will be critical in supporting the adaptive element of an adaptive forest restoration strategy.

2. Methodology

The project will be implemented through the below four work packages (WPs):

Work Package 1. Design and development of an integrated database for machine learning models.
(LEAD: RCMRD; Partners: ICIPE, Sunbird,ICRAF, SEI)
The objective of this WP is to develop and provide an integrated platform, comprised of a comprehensive database, which includes existing observational data, models and simulations produced within the project. The database is one of the core components of the restoration machine learning algorithms. It will be designed to be a single and unified catalogue for the collection, storage, and normalization of observational data, models and scenario simulations conducted in WP2. The result will be a relational SQL database with geospatial extensions, storing validated data in various formats, e.g., metadata, time series, and spatial data. Moreover, the database will include the possibility of integrating selected data from third parties, including end-users, enabling a dynamic interaction process with the platform.

Task 1.1 Documentation of input and output datasets (LEAD: RCMRD; Partners: ICIPE, Sunbird, ICRAF, SEI)
Table 1 depicts the available input and output datasets from existing data sets in the Lake Victoria Basin that will be used to develop the database. These data will be analysed with QA/QC procedures before being stored in the database.

Table 1. Input and output datasets

Data set	**Variables to be used**	**Existing data source**
Forest cover distribution	Forest cover	Modis, LiDAR, Sentinel 2 cloud-free level 3A, drone imagery (automated flight paths), ground sampling points (GCP) to check processing results of different drone images
Valid geometry parcels/tree images where scientific data needs have not been met, incentivizing citizens to increase monitoring effort at afforestation locations	Tree planting fields and tree location points	Citizen science: Use of Open Data Kit (ODK) to geotag tree location points
Climate	temperature, precipitation, and evapotranspiration	ERA5-Land and Regional weather stations
World digital soil map	Soil types	FAO/UNESCOWise3 created by International Soil Reference and Information Centre (ISRIC).

Tree species	Tree species suitability	GlobalTreeSearch developed by Botanic gardens Conservation International TreeGOER: a database with globally observed environmental ranges for 48,129 tree species by bioRxiv https://www.biorxiv.org/content/10.1101/2023.05.15.540790v1.full Climate Appropriate Portfolios of Tree Diversity - https://www.cifor.org/publications/pdf_files/Infobrief/8850-Infobrief.pdf. Global Tree Knowledge Portal, available viahttps://www.worldagroforestry.org/tree-knowledge

Task 1.2 Data preprocessing and analysis (LEAD: ICIPE; Partners: Sunbird, RCMRD, ICRAF, SEI)
Python library 'Rasterio' will be used to read satellite data, retrieve geographic metadata, transform the coordinates, crop and merge multiple images and save the data in various formats. Python libraries Earthpy and Matplotlib will be used for data visualization. Citizen smartphone field images will be labelled and cleaned using open source software QGIS with the plugin KMLTools to extract valid polygon parcels for potential restoration sites. Python library will be used to extract metadata stored in EXIF tags of drone images to get useful information on centroid, date and time of image collection, flight altitude, and camera information like height, width, and focal length. The images will be georeferenced using OpenDroneMap (WebODM) software to convert simple 2D images into Georeferenced Orthorectified maps (orthomosaics), Georeferenced Digital Elevation Models (DSM), and 3D Textured Models. Ground Sample Distance (GSD) will be extracted using OpenDroneMap to estimate the number of trees from an image.

Task 1.3 Applying super-resolution on images (LEAD: ICIPE; Partners: Sunbird, RCMRD, ICRAF, SEI)
A number of pre-labelled super-resolution drone, satellite and citizen smartphone field data will be tested to build a SRCNN model for the super-resolution of satellite, drone and smartphone field images. The weights given in the repo will initially be trained on satellite imagery by transferring learning from these weights. The model training will be carried out in two steps. First, the model will be trained on relatively high-resolution drone images provided by the project. After reaching good accuracy, re-training on medium-level resolution images will be done and the model tested on lower resolution images. Model outputs will be compared with the original images for loss calculation. The model, acting as a convolutional filter, will convert images of any shape to their super-resolution state, sharpen and add any missing details in between the upscaled images. **Deliverable:** Design and final implementation of the open access database.

Task 1.4. Data Quality Assurance and Quality control (LEAD: ICIPE; Partners: Sunbird, RCMRD, ICRAF, SEI)
The main goal of this task is to define a Quality Assurance and Quality Control (QA/QC) tool for integrating data provided from third parties or platform end-users into the forest restoration platform/database. Submission of new data for subsequent QA/QC and integration will be possible through a dedicated automated feature in the platform's web interface. The QA/QC tool will be based on several analytical parameters and procedures designed to support evolution, during the project, from manual operations

to a specific set of automated routines. According to the availability and nature of data, different operations are identified:

- **Quantitative Data:** Initial quality checks will be implemented before data are stored in the database. QA/QC procedures for real-time data will be defined to avoid slowing down the data collection and transfer process. Further quality checks are foreseen to be performed regularly on data once stored in the database. Particularly, crowdsourced quantitative data will be checked since they are not pre-processed.
- **Qualitative Data:** QA/QC procedures will be performed by trusted users within the user community developed in task 4.5. After the QA/QC procedures, additional tags (e.g., social media analysis for identification of an event, image quality) will be added to metadata information for filtering data. The task will result in the definition of a set of statistics and key performance indicators over data availability and quality that can be used for quantifying improvements. **Deliverables:** QA/QC tool collection and implementation requirements.

Task 1.5 Data management and licensing (LEAD: ICIPE; Partners: Sunbird, RCMRD, ICRAF, SEI)

The project heavily relies on available open source data for model simulations in the form of time series and spatially distributed information (maps). Data will be stored, according to the Lacuna Fund's Dataset Hosting and Documentation Guidelines, at the long-term archive of The Regional Centre for Mapping of Resources for Development (RCMRD), which also provides the disk space for data analysis. To maximise the impact of the project, data generated by the project will be managed, collected in a structured and transparent way, and well curated and preserved in order to enable good exploitation, dissemination, and subsequent use by other parties beyond the project. The data will eventually be made publicly accessible via the Earth System Grid Federation (ESGF), which comprises quality checks, documentation, and provision of permanent identifiers (doi) to make the data reusable and citable, in accordance with good scientific practice. The technical model developments made within the project will be made open source on github and documented for further open access use, with the intention of initiating a community of users and developers.

Task 1.6 Database sustainability plan (LEAD: ICIPE; Partners: Sunbird, RCMRD, ICRAF, SEI)

This task will be based on resources capacity planning (profiling CPU, RAM, and bandwidth) and high availability assessment to guarantee that the database can operate efficiently and continuously without fail. Both local and cloud hosting solutions will be considered to ensure the long-term sustainability of the database. Thus, the database will be designed to be an ensemble of containers deployable in open source runtime environments, guaranteeing its scalability and the possibility of studying local offline installations of the Forest Restoration Platform as a practical solution to limited access to a high-speed internet connection in local contexts. The database design will include the development of APIs for data ingestion, querying and data sharing with the web user interface and external systems. Both local and cloud hosting solutions will be considered to ensure the long-term sustainability of the database. **Deliverable:** Data Management and Sustainability Plan

Task 1.7 Risk management

An ethics review will be conducted prior to the start of the project to address any potential privacy and ethical concerns. Adequate information about the research will be carefully, and clearly explained to the prospective subjects for them to personally decide and provide consent on research participation. Privacy and confidentiality of subjects will be paramount. Any personal identifiable data would be anonymized before publication. The project will address the need for gender equality in its capacity building and peer-to-peer-exchange, to ensure that women are represented and involved in all aspects of the project. We also propose to address the spatial analyses of equity by overlaying existing riparian restoration priority maps, population, and the Human Development Index (HDI) to promote equity-centered restoration.

Work Package 2. Development of machine learning training models (LEAD: ICIPE; Partners: Sunbird, RCMRD)
The objective of this WP is to develop machine learning training models to predict the spatial and temporal distribution of forest cover change over time.

Task 2.1 Development of Meteorological time series model (LEAD: ICIPE; Partners: Sunbird, RCMRD)
Temperature, precipitation, and evaporation will be used to monitor the environmental impact on the health of trees. Time series models for these variables will be built using the Facebook prophet library. Python library xarray will be used to compute hourly data retrieved from ERA5-Land (1950 to the present) at the closest grid point to a parcel.

Task 2.2 Development of vegetation indices model (LEAD: ICIPE; Partners: Sunbird, RCMRD, ICRAF)
The python library rasterio will be used to calculate two vegetation indices namely Normalized Difference Vegetation Index (NDVI), and Normalized Difference Water Index (NDWI). The models will be trained using the following equations [11]:

$$NDVI = \frac{Near\ infrared - red}{Near\ infrared + red} \tag{1}$$

where red and near infrared are reflectance measurements for red (640–670 nm wavelength, band 4) and near infrared (850–880 nm wavelength, band 5), respectively

$$NDWI = \frac{Near\ infrared - shortwave\ infrared\ 1}{Near\ infrared + shortwave\ infrared\ 1} \tag{2}$$

The above calculation will be performed using QGIS 3.12 (Free Software Foundation, Inc., MA, USA).

Task 2.3 Land-use and land-cover change modelling (LEAD: RCMRD; Partners: ICIPE, Sunbird, SEI)
Task 2.3 will generate a land use and land-cover change model (LULCCM), consisting of a set of discrete choice equations of site-based land-cover transitions derived from observed land-cover change, that will be applied to geographic information system (GIS) layers to predict forest boundaries that are likely to be affected by agriculture in order to (i) identify forest hotspots/risk zones prone to anthropogenic stressors and (ii) define priority areas for conservation and alternative land use opportunities for ecosystem restoration and conservation (RCMRD and SEI). **Deliverable:** Geospatial data and metadata on land cover and land uses, and potential forest hotspots/risk zones prone to anthropogenic stressors in various media formats (e.g., digital atlas, map layouts)

Task 2.4 Tree cover modelling (LEAD: ICRAF; Partners: Sunbird, RCMRD, ICIPE, SEI)
A machine learning model UNet++ will be trained to detect and estimate the number of trees in a given area for a given georeferenced image using the following equations:

$$\text{Number } of\ tress = \frac{Number\ of\ Tree\ Pixels\ in\ Predicted\ Mask}{Average\ Tree\ Size\ in\ cm2\ /\ Ground\ Sampling\ Distance\ in\ cm} \tag{3}$$

$$Vegetation\ Percent = \frac{Number\ of\ Tree\ Pixels\ in\ Predicted\ Mask}{Image\ Width\ X\ Image\ Height} \tag{4}$$

The outputs of the model, pixel-wise detections of tree patches, will be processed to get the approximate number of trees and vegetation percentage in a georeferenced image based on ground sampling distance (GSD) in centimeters and average tree size in the area in centimeter square. **Deliverable:** Geospatial data and metadata on tree cover and vegetation indices.

2.5 Tree species suitability modelling (LEAD: ICRAF; Partners: Sunbird, RCMRD, ICIPE)
Six machine learning models will be trained to derive tree species suitability by combining species distribution data with four environmental predictors: soil properties, temperature, precipitation, and evaporation. The models will be trained using equations 5, 6, 7, 8, 9 and 10 below:

CQI = P/PET (5)

Where: CQI is climatic quality index; P is average annual precipitation and PET is average annual potential evapotranspiration.

The Climatic Quality Index depicts variables that affect plant water availability, such as rainfall, air temperature, and aridity, as well as climate hazards that may limit plant growth.

$SI_a = (CQI * VQI * SQI)^{1/3}$ (6)

Where:

SI_a is the actual/current soil suitability index

CQI is climatic quality index calculated by Equation (11).

VQI is vegetation quality index = $(I_{Ep} * I_{Dr} * I_{Vc} * I_{RS} * ....)^{1/n}$ (7)

where: I_{Ep} index of erosion protection, I_{Dr} index of drought resistance and I_{Vc} index of vegetation cover, I_{RS} index of remote sensing indices (NDVI, …), n number of parameters used.

SQI is Soil quality index = $(I_p * I_t * I_d * I_s * I_{EC} * I_{pH} * I_{ESP} * I_{CEC} * ....)^{1/n}$ (8)

where I_p index of parent material, I_t index of soil texture, I_d index of soil depth, I_s index of slope gradient, I_{EC} soil salinity, I_{pH} index of soil pH below about 5.6 is considered low for most crops. Generally, the ideal pH range is between 6.0 and 7.0., I_{ESP} index of Exchangeable Sodium Percentage, I_{CEC} index of soil's cation exchange capacity, n number of parameters used. The equation modified to be flexible to include all soil parameters which could affect soil quality and consequently influence the result of soil suitability.

$SI_p = (SQI * VQI * CQI * S)^{1/4}$ (9)

where SI_p is the potential soil suitability index, SQI is Soil quality index calculated by equation (8), VQI is vegetation quality index calculated by equation (7), CQI is climatic quality index calculated by equation (5), and S is the suitability calculated by Equation 10.

$$S = \sum_{i=0}^{n}(WiXi) \quad (10)$$

The trained models will help growers select the most suitable tree species and types of land restoration (e.g. agroforestry, reforestation and forest conservation, forest regeneration etc.) best suited for different locations, thus ensuring the success of restoration programmes. **Deliverables:** Tree species suitability map and land restoration opportunity map.

Task 2.6 Forest cover scenario simulations (LEAD: ICIPE; Partners: Sunbird, RCMRD, ICRAF, SEI)
Task 2.6 will generate statistical relations that estimate how climate stressors are influencing forest cover and build a software workflow around these relations that allow scenario simulations of forest cover change under future climate change and climate extremes. The task will test multiple statistical approaches to evaluate potential relationships and association of information generated from tasks 2.1-2.5. The framework will combine the CLUE-S and Markov models to simulate future forest cover scenarios, including a business as usual scenario, afforestation/reforestation-forest conservation scenario and afforestation/reforestation-forest degradation scenario to help identify possible pathways for sustainable

future scenarios. The task will equally combine the logistic regression-cellular automata-Markov chain (LR-CA-Markov) and FLUS models to assess the driving forces steering forest cover change including climate change scenarios, socio-economic drivers (e.g. fertility, mortality and migration rates, exports and consumption patterns), and policy alternatives (zoning regulations, impact restrictions and construction of infrastructure). It applies the InVEST model to simulate past, current and future forest biodiversity change under the three forest cover scenarios. Results from the scenario framework will feed into WP3 which will be disseminated through online interactive scenario visualizations (e.g. using the Plotly Python library), where both experts and non-experts can easily toggle through key results. **Deliverable:** Future forest cover simulations under different climate scenarios.

WP 3. Deployment of a web-based data visualization dashboard (Lead: Sunbird; Partners: ICIPE, RCMRD, ICRAF, SEI)

The objective of this WP is to develop and provide a user-friendly web application for visualizing information that supports decision-making, planning and monitoring of forest and landscape restoration. The web application seeks to integrate the results of various machine learning models into one system thereby overcoming current challenges by focusing on suitability, applicability, sustainability, and complementarity of the different models to ensure highest level of uptake across the Lake Victoria Region.

Task 3.1. Design, development, and implementation of a web-based spatial decision-support system (LEAD: Sunbird; Partners: ICIPE, RCMRD, ICRAF, SEI)

An open source web-based application will be developed to allow end-users to interrogate and visualise data stored in the database in a quick and user-friendly manner, making the web interface an efficient Decision Supporting System (DSS). The UNet++ model developed in task 2.3 will be integrated into the web-based application to detect and estimate the number of trees in a given region for a given georeferenced image. The vegetation indices time series and meteorological parameter forecasting time series developed in task 2.1 and the forest cover scenario simulations developed in task 2.4 will also be integrated into the web-based application to provide insights on the spatiotemporal distribution of forest cover change over time. End-users will select specific scenario conditions and visualise the corresponding information promptly in an intuitive web interface with a web-GIS platform. Furthermore, specific features will be implemented and integrated into the web interface to allow data download and upload of extra data to be processed by the QA/QC teams and then stored in the database.

The Web Application will be composed of a backend and a frontend. The backend component will consist of REST APIs interacting with the database to provide information to the end-user interface (frontend component). The application will be designed to manage queries to the platform’s vast and heterogeneous database in a timely-efficient manner, guaranteeing easy and fast access to data to all end-users. Furthermore, considering the wide range of data formats stored in the database, the backend will be designed and developed with reliable components to convert specific formats to OGC standard ones. Each part of the Web Application will be designed to be a container deployable in open source runtime environments able to guarantee usage and scalability through dedicated features. This will be crucial for testing the platform through capacity-building activities (Task 4.5), firstly using catchment-based datasets (prototype phase) and then with large-scale case studies based on scenario simulations conducted in task 2.4 (final release). To face limited access to a high-speed internet connection in local contexts of the case studies countries, the possibility of providing an offline version of the Forest Restoration platform for local installations, including a specific database sample, will be studied, and tested in its feasibility and usability. **Deliverable:** Design and final implementation of an open source web application system.

Work Package 4. Exploitation, governance and long-term sustainability of the restoration spatial decision-support system (Lead: SEI; Partners: ICRAF, Sunbird, RCMHD, ICIPE)
The objective of this work package is to ensure the decision-support platform achieves optimal uptake by end-users and long-term sustainability, through appropriate testing, analysis, demonstration, capacity building and feedback on the platform's usability to iteratively improve the system according to user needs.

Task 4.1. Testing the restoration spatial decision-support system (Lead: Sunbird; Partners: ICRAF, RCMHD, ICIPE)
The role of this task is to ensure the general usability of the web application and to assess its limits and usage constraints. The task will also ensure coherency and transferability of data, information as well as user needs, and acceptance to ensure the platform is fully exploitable. To ensure that the information generated and provided by the web application is useable and adds value to restoration efforts in the Lake Victoria Basin, the user audience will test the functionality and the information provision features of the platform. Therefore, a user community network of actors in the Lake Victoria Basin, consisting of national forest resources management agencies or institutions of the riparian countries, ministries, directorates, commissions, agencies in charge of forestry, national forest and research institutions, and basin agencies (i.e. Lake Victoria Basin Commission) will be established. The goal is to enable the user community to undertake science-based assessments of land restoration across borders and within the sub-region based on the information provided by the Platform. Testing of the platform's functionality, usability, and information provision goes hand in hand with technical capacity building (Task 4.3), feedback on user information needs for further improvements (Task 4.2) as recommendations to improve the Platform in an iterative manner.

Task 4.2. Feedback to improve uptake and acceptability of the restoration spatial decision-support system (Lead: SEI; Partners: ICRAF, Sunbird, RCMHD, ICIPE)
An essential output of this task will be the communication of feedback on the usability of the information gained from the restoration web application to WP2 and WP3. To ensure optimal uptake of the web application, the system will be improved in iterative steps based on user feedback. It aims at applying the platform on real-life case studies to assess its performance and applicability with respect to user needs. The selection of the case studies will be done in collaboration with the stakeholders. This will ensure that stakeholders are able to contribute to scientific based assessment and planning of land restoration interventions using the interactive web application. It will also contribute to the promotion and demonstration of the web application among ongoing and new land restoration interventions across borders within the sub-region for adequate feedback.

Task 4.3. Regional training and capacity building (Lead: SEI; Partners: Sunbird, RCMRD, ICRAF, ICIPE)
The task will establish in-person and virtual regional training and innovation centres for capacity building and train-the-trainer activities as well as living lab support centres, which will multiply the number of individuals trained by the project directly (SEI, ICRAF, Sunbird, RCMHD). The regional exchange will allow for synergistic giving and receiving of knowledge, skills and experience between the project partners and local-level actors in the region (SEI, ICRAF, Sunbird, RCMHD). The regional team will engage living lab partners and seek support from thematic experts in trainings directly related to land restoration and the use of the interactive web application that will be developed in WP3.

Task 4.4. Peer-to-peer exchange to facilitate knowledge transfer beyond formal capacity building activities (Lead: SEI; Partners: Sunbird, RCMRD, ICRAF, ICIPE)
Task 4.4 will facilitate knowledge transfer among policy makers and planners, practitioners and researchers from the academia by offering insights on the interactive web-based land restoration application in a two-way dynamic exchange. By means of these exchanges, good practices and examples

will help in strengthening partnerships with stakeholders and facilitate future relations, motivating participants in identifying and upscaling forest restoration interventions (e.g. agroforestry, reforestation and forest conservation, forest regeneration etc.) best suited for their respective different locations.

Task 4.5. Regional restoration community of practice and e-learning (Lead: SEI; Partners: Sunbird, RCMRD, ICRAF, ICIPE)
A regional restoration community of practice targeted at decision makers, practitioners and modelers will be implemented to scale forest restoration to other Regions beyond the project (SEI). Selected conferences, in which consortium members are active, will be targeted as platforms for regional and international networking such as the World Environment Day, UN Environment and UN Habitat Assemblies, the climate Conference of Parties (COP), Desertification Convention, Convention on Biological Diversity and others. A complete list will be developed at project start and updated annually. Open Source e-learning activities, including animations/videos, will be developed and hosted on the project website (as candidates for Digital Public Goods (DPGSs) to enable stakeholders globally to participate in knowledge sharing activities. In addition, recorded webinars held by experts in the field will be shared as learning material for the eLearning participants. **Deliverables:** Testing of the Restoration Web application and feedback of its usability; Capacity building manuals and modules for the Forest Restoration Web application; Regional Restoration Community of practice and e-learning tools.

5. Project's transformational impact

5.1. Better understanding of forest restoration trends across the Lake Victoria Basin

The project will provide an in-depth understanding of current restoration information needs and build the capacities of national, regional, and local stakeholders to utilize the digital Forest Restoration application in the region. Proposed changes will be assessed considering existing infrastructure, capacity, human skills, and institutional frameworks.

5.2. Implementation of database and user interface for forest restoration interventions

The project will develop a system database that will handle all types of relevant data and information needed to inform strategic restoration interventions, including soil, tree species, forest cover and climate data (temperature, precipitation, and evaporation). The database will be available to end-users (policy planners, implementing agencies, research institutions) as a general source of information and as necessary input for planning and monitoring restoration interventions. The tailor-made user interface connected to the database will ensure intuitive access to data for end-users. By developing the database and user interface, the project will improve the big data handling skills of the user community built around forest restoration models. The necessary training for system operators and users will ensure transferability to other parts of Africa.

5.3. Optimized and scalable forest cover scenarios at appropriate spatial-temporal scales

The project will develop and analyze three plausible but divergent forest cover scenarios that depict the future of the Lake Victoria Basin from 2010 to 2060. The scenarios will highlight the magnitude and spatial distribution of forest cover under the different land-use regimes as well as the synergies and trade-offs between climate action, forest conservation and forest resource use. Based on the scenario analysis with forest modelling tools, end-users will be able to monitor forest restoration interventions. This will help to simultaneously mitigate climate change, improve climate resilience, and efficiency and security. The project will also develop a set of dedicated tools and solutions for technical and policy management by improving modelling skills, IT infrastructure, data storage and analytical capacities of targeted groups to better service the forest restoration web application.

5.4. Strengthened partnership across the Lake Victoria Basin. The project will enhance partnership through its capacity building events (e.g., Joint technical seminars, trainings of technicians, decision-makers and students) and encourage scientific mobility, co-supervision and exchange of students, and research collaboration between partners across the region. The interaction between the consortium members and the stakeholder groups will increase cross-sectoral networking of individual institutions in the region. The innovation in the web application, the network of stakeholders, the user forum, and the whole restoration framework will strengthen the capacity of stakeholders in planning and monitoring restoration interventions.

5.5. Demand-driven transformations at basin and community level

Transparency in the models and results, and capacity building activities will make it possible for policymakers, stakeholders, and other scientists to use the dedicated tools continuously to help measure restoration efforts at various levels across key ecosystems and generate the data needed to drive private and public investments in restoration at the small-scale basin levels.

6. Qualifications - Complementary disciplinary and interdisciplinary expertise of the consortium

The project consortium consists of 5 partners, in the Lake Victoria Basin, with diverse skill sets and knowledge to ensure the complementarity of partners' expertise. The coordinating partner, the Stockholm Environment Institute's (SEI) Artificial Intelligence Division is exploring the use of artificial intelligence, machine learning, and remote sensing technologies to develop a global monitoring system that detects environmental changes and management options to inform climate strategies. Its core research focuses on automated decision-making and predictive analytics using AI, in combination with sensor technology and robotics to change the way individuals, communities, governments and private actors perceive and respond to climate and ecological change. The Regional Centre for Mapping of Resources for Development (RCMRD), is Africa's leading institute in Remote Sensing, Geodesy and Cartography. Its mission is to develop geospatial solutions to support decision making in science, planning, business and politics from local to regional scales. Its core research foci are towards addressing problems related to the provision of relevant, timely and reliable geospatial information and allied Information Communication Technology (ICT) services and products through the execution of demand-driven research projects, including natural resource and environmental management. The International Centre of Insect Physiology and Ecology (icipe) is a non-profit international research institute that develops and applies advanced mathematical, physical and statistical methods to shape decision making, address societal issues, create wealth, and contribute to the development of Africa. The Data Management, Modelling, and Geo-Information (DMMG) Unit uses advanced methods and analytics including earth observation (EO), remote sensing, spatial analytics, geo-information, machine learning (ML), artificial intelligence (AI), design thinking, system thinking and system dynamics and computer vision algorithms to exploit and interpret 'big data' to develop geospatial cloud-based tools and mobile apps that can be operationally utilized for 'real-time' surveillance, monitoring and forecasting. The World Agroforestry's (ICRAF) Tree Productivity and Diversity Programme pursues research on tree species suitability modelling and mapping, combining ensemble suitability modelling algorithms with information on distribution and species assemblages of potential natural vegetation types found in interceptive tree species mapping tools. It specialises in co-research and co-development of gender-responsive guidelines, decision support tools and proofs of concept in partnership with relevant institutions and networks to domesticate and safeguard tree diversity, boost the availability and access to quality tree-planting materials (foods, fodder, timber, medicinals, etc.) suited to location and purpose which are serious global constraints to tree planting. Sunbird AI is a non-profit organization that develops artificial intelligence systems for social impact in Africa. Its AI systems combine the stability and flexibility of open source with support and training to build a fully intelligent, integrated, process-based IT infrastructure that leverages the power of data virtualization to turn data into information that generates evidence for policy and decision making. Its IT infrastructure integrates assets in both the cloud and on-premise to enable organizations to become more flexible, agile, and intelligent in how they respond to critical business needs.

7. References

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