High Carbon Stock Approach and Analysis of Cherangany Hills, Mt. Kenya and Aberdare Forest

1. Background

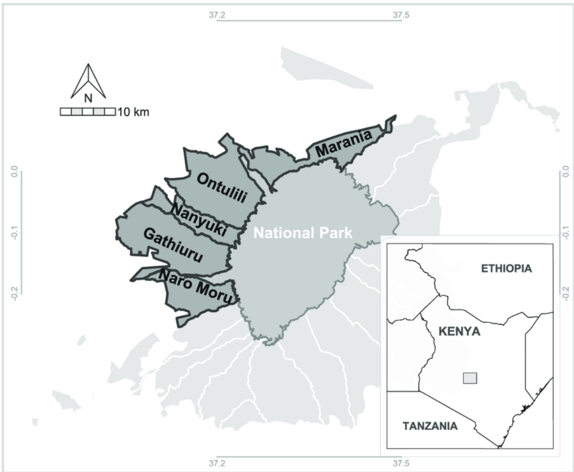
High carbon stock areas refer to landscapes or ecosystems that store large amounts of carbon in their vegetation, soil, and other organic matter. These areas are critical for mitigating climate change because they play a crucial role in absorbing and storing carbon dioxide from the atmosphere, which helps to reduce the concentration of greenhouse gases in the atmosphere. Examples of high carbon stock areas include tropical forests, peatlands, mangroves, and other wetlands. Forests in Kenya such as Mount Kenya, Aberdare forest and Cherangany hills act as a high carbon stock area due to their richness in biodiversity and high levels of carbon storage in its vegetation and soils. For example, Mt. Kenya forest is located on the slopes and peaks of Mount Kenya, which is the second-highest mountain in Africa after Kilimanjaro. The forest is home to a wide variety of plant and animal species, including many endemic species that are found nowhere else in the world. These species contribute to the high carbon stock of the forest by sequestering carbon through photosynthesis and storing it in their biomass and in the soil.

Additionally, Mount Kenya forest plays a crucial role in regulating the regional climate and hydrological systems. The forest helps to maintain the water balance of the surrounding areas by regulating the flow of water into rivers and streams, which is important for supporting agricultural production and other human activities. However, the Mount Kenya forest is facing a number of threats that put its high carbon stock at risk. These threats include deforestation, illegal logging, charcoal production, and climate change. The importance of high carbon stock areas has been increasingly recognized in recent years, as the world grapples with the challenges of climate change. Deforestation, degradation, and other forms of land-use change in these areas have resulted in the release of large amounts of carbon into the atmosphere, contributing to global warming. As a result, there has been growing interest in protecting and conserving high carbon stock areas as a means of mitigating climate change. Efforts to protect high carbon stock areas are often accompanied by debates and challenges, as these areas can also have economic and social value. For example, some high carbon stock areas may be used for agriculture, forestry, or other forms of development that can bring economic benefits to local communities. Balancing the need to protect these areas with the need for economic development is an ongoing challenge, but one that is critical to address if we are to effectively address climate change.

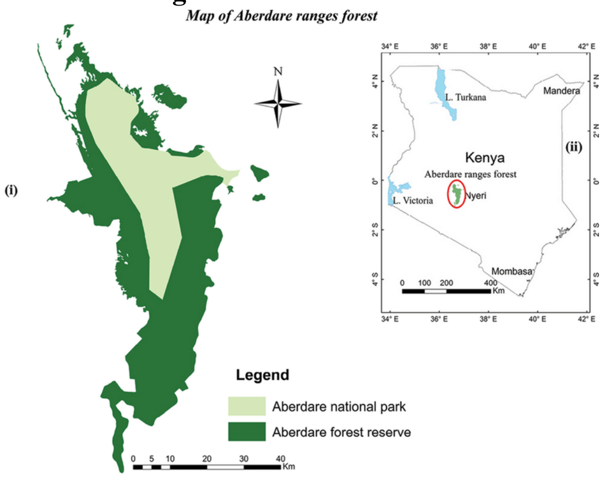
1.2 Study area

This report focuses on three forests and their environs in Kenya which are the Mount Kenya forest, Aberdare forest and the Cherangany hills as shown on the maps below.

Mt. Kenya Forest



Aberdare ranges forest



Cherangany Hills

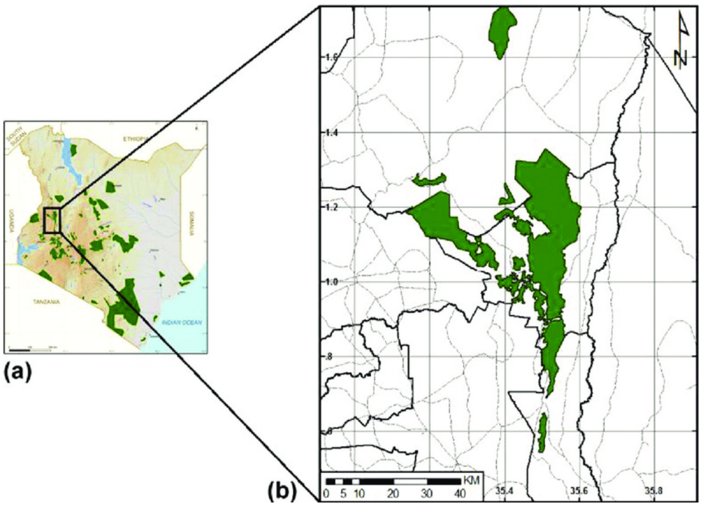


Figure 11: Mt. Kenya, Aberdare forest and Cherangany hills study area

1.3 Problem statement

Deforestation, land fragmentation, and climate change are all major threats to the Mount Kenya forest, Aberdare forest, and Cherangany hills, which are all high carbon stock areas. Deforestation is a major issue in all three forests, with significant areas of forest cover being lost each year due to agricultural expansion, logging, and infrastructure development. In the

Mount Kenya forest, deforestation rates have been estimated to be around 1% per year, while in the Aberdare forest and Cherangany hills, deforestation rates are estimated to be much higher. Illegal logging is also a significant threat to all three forests, with organized criminal networks exploiting the forests for valuable timber species. This activity leads to significant carbon emissions from the destruction of trees and soil disturbance from illegal logging activities. Charcoal production is also a significant driver of deforestation and forest degradation in all three forests. Charcoal is a widely used fuel in Kenya, and many households rely on charcoal for cooking and heating. However, the demand for charcoal has led to significant areas of forest cover being cleared for charcoal production, leading to the release of large amounts of carbon into the atmosphere.

Land fragmentation is another major issue in all three forests, with forests being divided into smaller fragments due to human activities such as agriculture, infrastructure development, and logging. Land fragmentation leads to reduced carbon storage capacity, as well as changes in microclimate and soil moisture. Finally, climate change is affecting all three forests, leading to changes in rainfall patterns, increased temperatures, and more frequent droughts. These impacts are leading to increased stress on forest ecosystems and reducing the capacity of the forests to store carbon. This study will mainly focus on identifying viable forest patches that are of the most conservation importance. These efforts will aim at promoting the sustainable use of forest resources while protecting the high carbon stock and other ecosystem services provided by these forests.

1.4 Objective

- To find viable forest patches that are of the most conservation importance through a series of patch analysis.

2. Methodology

2.1 Data collection

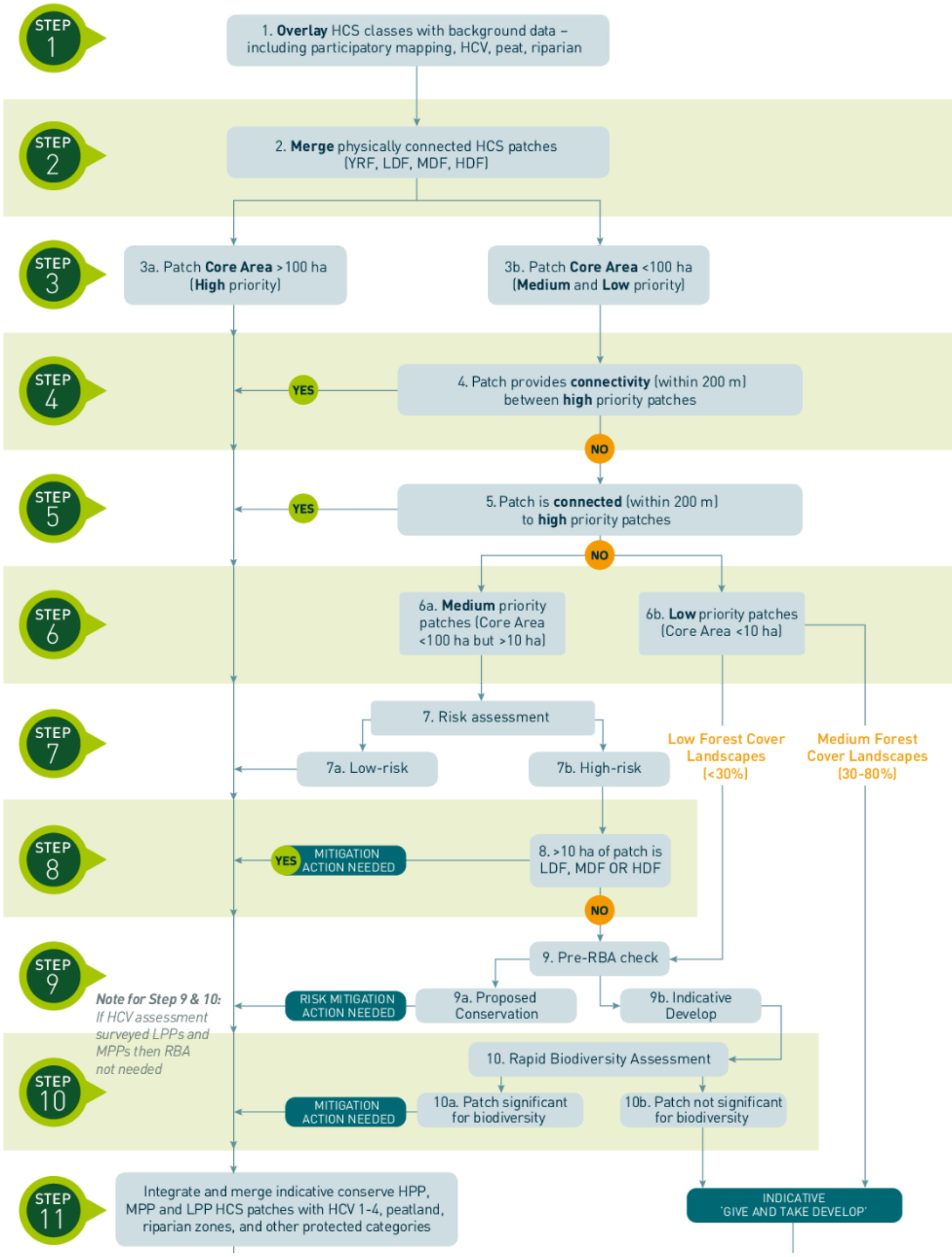
Secondary data was used in this project which is open-sourced. The datasets used are raster images as described in the table below by their theme, resolution and source.

Table 3: Data sources, period and resolution

Theme	**Resolution**	**Source**
WHRC Pantropical National Level Carbon Stock Dataset	500 meters	WHRC Google Earth Engine
GLCF: Landsat Tree Cover Continuous Fields	30 meters	NASA, Google Earth Engine
DMSP OLS: Nighttime Lights Time Series	927.67 meters	Payne Institute for Public Policy, Colorado School of Mines, Google Earth Engine
GlobCover: Global Land Cover Map	300 meters	ESA, Google Earth Engine
JRC Yearly Water Classification History	30 meters	EC JRC / Google, Google Earth Engine
Global Multi-resolution Terrain Elevation Data 2010	231.92 meters	USGS, Google Earth Engine

Tool used to conduct the analysis was Google Earth Engine(GEE). Due to the fact that GEE can take inputs from its own repository, this analysis can be easily replicated in other regions of the world.

2.2 Flow Chart



Source:http://highcarbonstock.org/wp-content/uploads/2018/04/Def-HCSA-Module-5-16_04_2018_Web.pdf

Figure 12: methodology flow diagram

2.3 Classifying High, Medium and Low Priority Patches

This study concentrated on Kenya's three primary forests: Mt. Kenya, the Aberdare ranges forest, and the Cherangany Hills. Carbon stock data is imported into the GEE program to identify patches in these locations based on their carbon stock The raster image used is the WHRC: Pantropical National Level Carbon Stock Dataset. This dataset describes the above-ground carbon stock for tropical countries where its value ranges from 0 to 503 Mg/Ha at a resolution of 500 meters. According to Greenpeace's description of high carbon stock forests, these forests contain carbon stocks greater than 35 Mg/Ha. The size of the core area of each forest patch is then determined by the user entering a value (in meters) into a buffer in response to a user query that is generated. The recommended separation is 200 meters. The buffer-defined distance is utilized to locate the centre of each forest patch in order to identify the core patches. Using the functions connectedPixelCount() and pixelArea(), the area of each disconnected patch is determined. Following that, these core patches are HCSA-filtered. High, medium, and low priority forest patches are defined as core areas of more than 100 ha, between 10 and 100 ha, and less than 10 ha.

2.4 Check Connectivity between Patches

In order to establish connectivity between forests and forest biodiversity, low priority patches that are 200 meters or less from high priority patches must be conserved. During the pre-rapid biodiversity check, low priority patches that are too remote from high priority patches are checked later. The buffered low priority patches layer and the high priority patches layer are added to test for connectivity, and the results are compared with the initial low priority patches using the connectedComponents() and reducer methods. To establish connectivity between forests and forest biodiversity, medium priority patches that are 200 meters or less from high priority patches are also subject to conservation. The technique is comparable to the first one. The unconnected medium priority patches will move on for risk assessments. Lastly, the patches that are in proximity with high priority patches are merged with high priority patches in the same layer.

2.5 Check Unconnected Low Priority Patches

Global land cover map from globcover is loaded in GEE. This raster image has a 30 meter resolution with values from 0 to 100. The high carbon stock approach states that forests with cover rates of less than 30%, between 30% and 80%, and above 80% develop in various ways in various situations. Reclassify the forest cover information into the high, medium, and low categories (high, medium, and low, respectively). Unconnected, low-priority areas with a medium amount of forest cover will be designated as "Indicative develop" or "Give and Take" for community development, according to HCSA. Pre Rapid Biodiversity Assessment will be conducted on disconnected low priority regions with little forest cover since they might be appropriate for conservation.

2.6 Check Unconnected Medium Priority Patches - Risk Assessments

Begin by loading raster images that will act as our risk factors. Load nighttime lights time series version 4 by the defense meteorological program operational linescan system. This dataset describes the night light received from satellites at a resolution of 30 arc seconds. The stable lights band used in this analysis is used to represent human settlements from cities, towns and villages. The settlement layer is then buffered outwards for 2km for later analysis. The next risk factor to add is the land cover data provided by the European space agency. This dataset is at a resolution of 300 meters. Plantation and croplands categories are used to further represent human settlement. This layer is then buffered outwards for 1km for analysis. All risk factors are then combined to one dataset.

Unconnected medium priority patches within risky regions are labeled as high risk and will be further examined for forest density. These patches are colored purple as. Unconnected medium priority patches outside the risky regions are labeled as indicative to conserve. To reclassify forest density map, derive it from the carbon stock dataset. Identifying High Carbon Stock (HCS) Forest for protection by Greenpeace outlines the possible ranges for six types of vegetation types: Cleared/Open Land, Young Scrub, Old Scrub, Low Density Forest, Medium Density Forest and High Density Forest. Check the patches that are labeled as high risk for their area size. Patches that are larger than 10 ha are labeled as Indicative to Conserve with Mitigation. Other patches are moved forward as Pre rapid biodiversity assessment.

2.7 Pre-Rapid Biodiversity Assessment

Begin by merging all patches that require pre rapid biodiversity assessment, that is the medium priority patches and the low priority patches. Next, load the water layer provided by JRC which is in yearly water classification history. This data shows water classifications generated from Landsat 5, 7, and 8. 2021 data is used at a resolution of 30 meters. Permanent water band is used. As outlined in the high carbon stock assessment, close to or containing water could make the patch have more conservation value. In this study, proximity is 1 km distance to the water feature. Patches within this distance are labeled as “near water” and are shown as white patched. Next load elevation layer from global multi-resolution terrain elevation data 2010 to GEE. This data shows the elevation world wide. Value ranges from -457 meters to 8746 meters. Resolution is at 7.5 arc seconds. After loading the data, find the slope and filter steep areas. Slope is identified by using the Terrain.slope() function. Patches on steep slopes might not be appropriate for development, thus steeper regions are categorized as conservation with mitigation. The same method is used with water proximity.

3. Results and Discussion

3.1 Conservation layers

Conservation layers include original high priority patches, connecting medium priority patches and low priority patches, and low-risk unconnected medium priority patches. The study area conservation patches are as shown in figure 13.

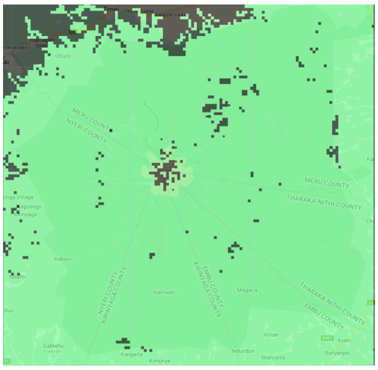
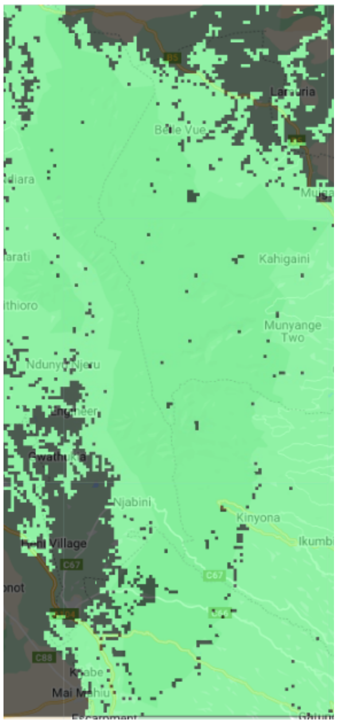
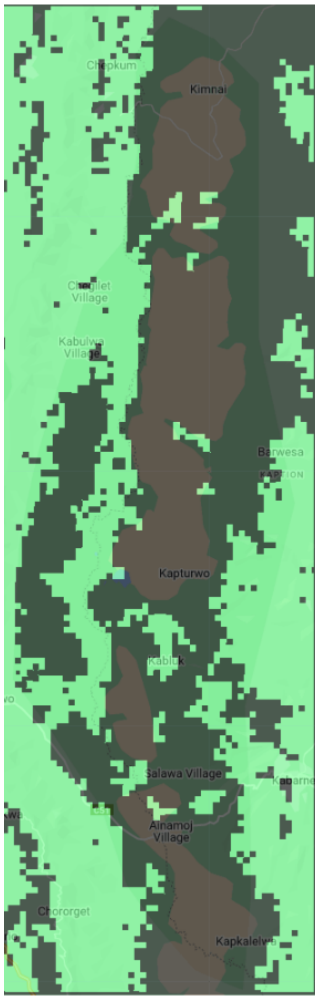
Mt. Kenya	Aberdare Forest	Cherangany Hills
		

Figure 13: Patches that require conservation in Mt. Kenya, Aberdare forest and Cherangany hills

From the figure above the layers in light green are the conservation layers. Both Mt. Kenya and Aberdare forest gazetted areas have the most conserved patches in the light green color. These areas should continue to be conserved. Cherangany hills conservation patches can also be seen.

3.2 Conservation layers with mitigation

Conservation with mitigation layer includes high-risk unconnected medium priority patches that are either greater than 10 ha or pass pre-rapid biodiversity assessment check. The study area conservation layers with mitigation are as shown in the figure 14 for the three zones.

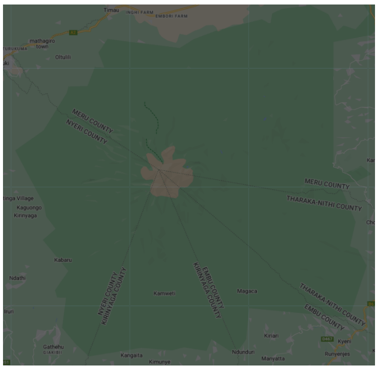
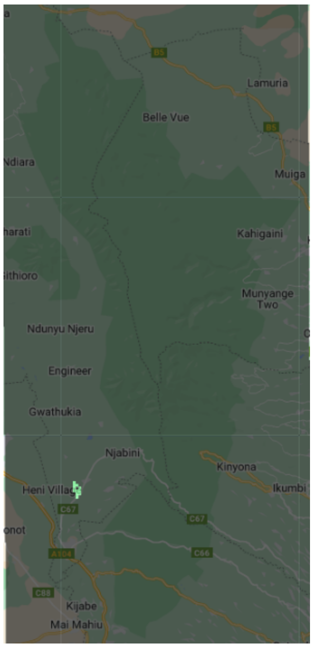
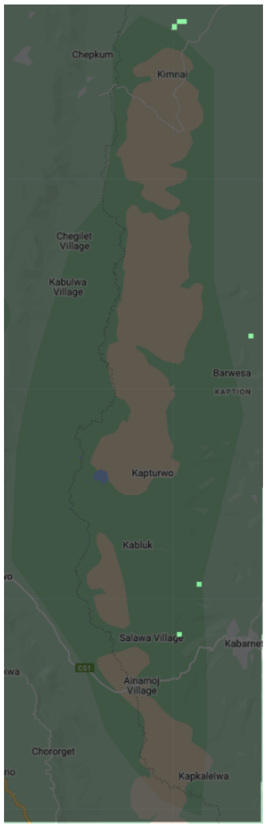
Mt. Kenya	Aberdare Forest	Cherangany Hills
		

Figure 14: Patches that require mitigation in Mt. Kenya, Aberdare forest and Cherangany hills

From the figure above, Mount Kenya has no patches that require mitigation. Aberdare forest has a single patch at the south west while Cherangany hills has a few patches that require mitigation.

3.3 Development layer

Development layer includes unconnected low priority patches with medium forest cover and unconnected low priority patches with low forest cover that do not pass pre-rapid biodiversity assessment check. The study area development layers are as shown in the figure below.

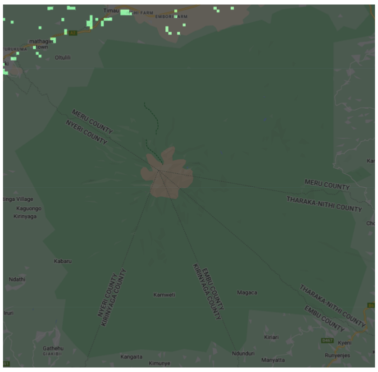
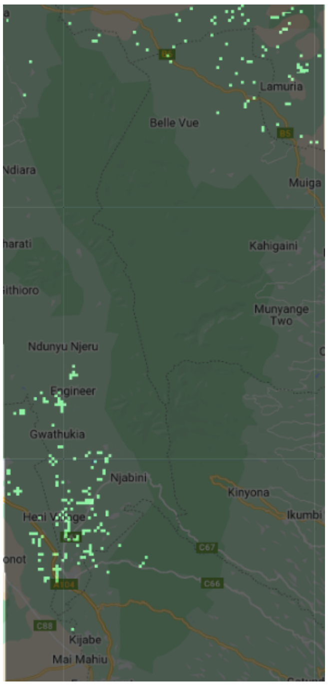
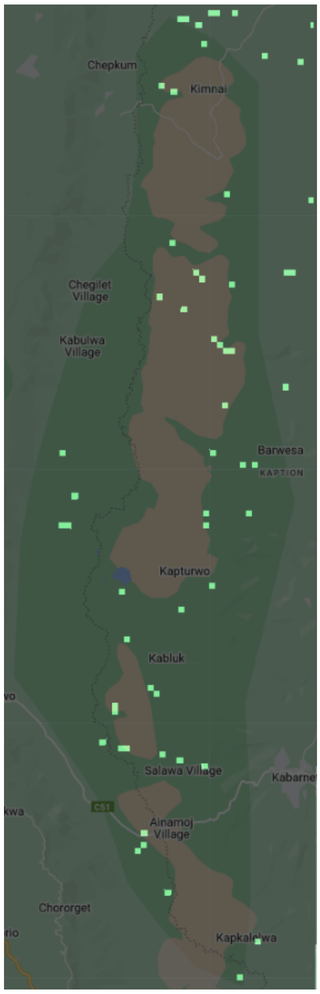
Mt. Kenya	Aberdare Forest	Cherangany Hills
		

Figure 15: Patches that require development in Mt. Kenya, Aberdare forest and Cherangany hills

From the figure above, Mount Kenya forest requires development in the north east. Aberdare forest requires development in the North and the south east of the forest. Cherangany hills also require development in the patches visualized above. These patches should be developed to return the forest to its original state.

4. Conclusion and Recommendations

This study has conducted a pre-Rapid Biodiversity Assessment through four primary processes, which included identifying High/Medium/Low Priority Patches, checking connectivity between patches, checking unconnected patches and conducting risk assessments, and finally pre-Rapid Biodiversity Assessment. The study has also visualized conservation layers, conservation layers with mitigation, and development layers. A tool in google earth engine for determining which forest sections are acceptable for conservation or development has also been built.. The program enables the planner to rapidly determine which areas are more important than others for conservation, allowing them to make the best selections for the natural environment. In addition a dialog requesting the user to enter the buffer distance has been incorporated This allows the user to simply tweak the algorithm and obtain feedback with various inputs. Even though this study focuses on a small region of some forests in Kenya, this tool is easily replicable to different regions all over the world.

5. References

Mburu, J., Skutsch, M., & Lusiana, B. (2015). Reducing emissions from deforestation and forest degradation (REDD+) in Kenya: readiness, challenges and opportunities. Climate Policy, 15(1), 100-121. doi: 10.1080/14693062.2014.974337

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Munishi, P. K. T., Shirima, D. D., Lewis, S. L., & Burgess, N. D. (2011). Carbon storage and patterns of tree diversity in understudied forest types of Eastern Arc Mountains, Tanzania. African Journal of Ecology, 49(3), 332-342. doi: 10.1111/j.1365-2028.2011.01250.x

United Nations Environment Programme. (2012). Forests in a Green Economy: A Synthesis. Nairobi, Kenya: United Nations Environment Programme.

United Nations Framework Convention on Climate Change. (2015). Intended Nationally Determined Contributions: Kenya. Bonn, Germany: United Nations Framework Convention on Climate Change.

High Carbon Stock forest patch analysis and protection http://highcarbonstock.org/wp-content/uploads/2018/04/Def-HCSA-Module-5-16_04_2018_Web.pdf

6. Appendix

```
Imports (6 entries)
  var geometry: Polygon, 4 vertices
  var imageVisParam: remapped
  var geometry2: Polygon, 4 vertices
  var geometry3: Polygon, 4 vertices
  var geometry4: Polygon, 4 vertices
  var imageVisParam2: remapped

// Load Mt. Kenya geometry
var aoi = geometry3;

// Import carbon stock level data
var CarbonStock_c = ee.Image("WHRC/biomass/tropical").clip(aoi).select('Mg');

var visParams = {min: 0.0,
  max: 350.0,
  palette: [
    'FFFFFF', 'CE7E45', 'DF923D', 'F1B555', 'FCD163', '99B718', '74A901',
    '66A000', '529400', '3E8601', '207401', '056201', '004C00', '023B01',
    '012E01', '011D01', '011301'
  ],};

Map.centerObject(aoi, 10);
Map.addLayer(CarbonStock_c, visParams, 'Aboveground Live Woody Biomass');

// Identify High/Low carbon stock
var lcs = CarbonStock_c.lte(35);
var hcs = CarbonStock_c.gte(35);

Map.addLayer(lcs, {palette:['aedbf5', 'bab98c']}, 'Low carbon stock level', false);
Map.addLayer(hcs, {palette:['aedbf5', 'bab98c']}, 'High carbon stock level', false);

// User define buffer distance, default 200m
var response = prompt("Hello! Welcome to the High Carbon Stock Approach Planner. Please ent
var response = ee.Number.parse(response);

// Identify core patches
var bufferlcs = lcs.cumulativeCost({source: lcs, maxDistance: response}).lt(35)

// Get core hcs
var raster1 = ee.Image(1)
var bufferlcs = bufferlcs.unmask(-1)
var core_hcs = raster1.subtract(bufferlcs).clip(aoi);
var core_hcs = core_hcs.remap([0,1,2],[0,0,1]);
var core_hcs = core_hcs.mask(core_hcs);
Map.addLayer(core_hcs, {palette:['000000','4a8762']}, 'Core HCS', false);

// Compute the number of pixels in each patch
var patchsize = core_hcs.connectedPixelCount(1024, false);
var patcharea = patchsize.multiply(ee.Image.pixelArea());
Map.addLayer(patchsize, {}, 'patch size', false);
Map.addLayer(patcharea, {}, 'patch area', false);

// Filter high, medium, low priority patches
var HPP = patcharea.gt(1000000); // greater than 100 ha
var MPP = patcharea.lte(1000000).and(patcharea.gte(100000)); // 10-100 ha
var LPP = patcharea.lt(100000); // less than 10 ha
```

```
// Buffer around the core HPPs, MPPs, LPPs to get original carbon stock area
var HPP_ = HPP.mask(hcs).distance(ee.Kernel.euclidean(response, "meters")).gt(0).remap([0,1],[1,1]);
var MPP_ = MPP.mask(hcs).distance(ee.Kernel.euclidean(response, "meters")).gt(0).remap([0,1],[1,1]);
var LPP_ = LPP.mask(hcs).distance(ee.Kernel.euclidean(response, "meters")).gt(0).remap([0,1],[1,1]);

Map.addLayer(HPP_, {palette:['000000', '2b632b']}, 'High Priority Patch', false);
Map.addLayer(MPP_, {palette:['000000', '6a9c6a']}, 'Medium Priority Patch', false);
Map.addLayer(LPP_, {palette:['000000', 'c0ccc0']}, 'Low Priority Patch', false);

var HPP_ = HPP_.unmask(0);
var MPP_ = MPP_.unmask(0);
var LPP_ = LPP_.unmask(0);


// Connectivity between LPPs and HPPs
var distL = LPP_.distance(ee.Kernel.euclidean(200, 'meters')).gt(0).remap([0,1],[1,1]).unmask(0);
var TheREDUCER = ee.Reducer.sum();

var L_H = distL.add(HPP_).mask(LPP_).unmask(0);
Map.addLayer(L_H, {}, 'L+H', false);
var low_fsum0 = LPP_.addBands(LPP_);
var low_fsum = L_H.addBands(LPP_);
var low_fsum0 = low_fsum0.reduceConnectedComponents(TheREDUCER, 'remapped_1', 256)
var low_fsum = low_fsum.reduceConnectedComponents(TheREDUCER, 'remapped_1', 256)
Map.addLayer(low_fsum0, {}, 'L + H focal sum previous', false)
Map.addLayer(low_fsum, {}, 'L + H focal sum after', false)

var low_connect = low_fsum.subtract(low_fsum0).gt(0);
var low_connect = low_connect.mask(low_connect);
print("low connecting", low_connect);
Map.addLayer(low_connect, {palette: "fc0303"}, "Low connecting", false);

// Connectivity between MPPs and HPPs
var distM = MPP_.distance(ee.Kernel.euclidean(200, 'meters')).gt(0).remap([0,1],[1,1]).unmask(0);
var TheREDUCER = ee.Reducer.sum();

var M_H = distL.add(HPP_).mask(MPP_).unmask(0);
Map.addLayer(M_H, {}, 'M+H', false);
var med_fsum0 = MPP_.addBands(MPP_);
var med_fsum = M_H.addBands(MPP_);
var med_fsum0 = med_fsum0.reduceConnectedComponents(TheREDUCER, 'remapped_1', 256)
var med_fsum = med_fsum.reduceConnectedComponents(TheREDUCER, 'remapped_1', 256)
Map.addLayer(med_fsum0, {}, 'L + H focal sum previous', false)
Map.addLayer(med_fsum, {}, 'L + H focal sum after', false)

var med_connect = med_fsum.subtract(med_fsum0).gt(0);
var med_connect = med_connect.mask(med_connect);
print("low connecting", low_connect);
Map.addLayer(med_connect, {palette: "fc0303"}, "Median connecting", false);

// Merge low and med patches that can connect with high patches together
var HPP_1 = HPP_.add(low_connect.unmask(0)).add(med_connect.unmask(0)).gt(0);
Map.addLayer(HPP_1, {}, 'Old HPPs and New conserve from MPPs and Lpps', false);

// Import forest cover dataset
var treeCanopyCover = ee.ImageCollection("GLCF/GLS_TCC").select('tree_canopy_cover').filter(ee.Filter.date('2010-01-(
var treeCanopyCoverVis = {
  min: 0.0,
  max: 100.0,
```

```
// Merge all patches that require Pre0RBA check
var preRBA = MPP_preRBA.unmask(0).add(LPP_pre_RBA.unmask(0)).gt(0);
print("preRBA", preRBA);
Map.addLayer(preRBA, {palette: ['000000', '2b632b']}, 'pre-RBA patches', false);

// Load Water Layer
var water = ee.ImageCollection("JRC/GSW1_4/YearlyHistory").select('waterClass').filter(ee.Filter.date('2021-01-01'
Map.addLayer(water, {palette: '036ffc'}, 'water', false);

// Proximity to water
var water_buff = water.distance(ee.Kernel.euclidean(1000, 'meters')).gt(0).remap([0,1],[1,1]).unmask(0);
var pRBA_water = preRBA.add(water_buff).mask(preRBA).unmask(0);
Map.addLayer(pRBA_water, {}, 'pRBA + water', false);
var pRBA_water_fmean = pRBA_water.addBands(preRBA);
print("pRBA_water_fmean", pRBA_water_fmean);
var pRBA_water_fmean = pRBA_water_fmean.reduceConnectedComponents(ee.Reducer.mean(), 'remapped_1', 256);
var pRBA_near_water = pRBA_water.neq(pRBA_water_fmean).unmask(0);
Map.addLayer(pRBA_near_water, {}, 'preRBA patches near water', false);

// Load elevation layer
var elevation = ee.Image("USGS/GMTED2010").select('be75');
var elevationVis = {
  min: -100.0,
  max: 5000.0,
  gamma: 3.5,
};
Map.addLayer(elevation, elevationVis, 'Elevation', false);

// check slope
var slope = ee.Terrain.slope(elevation);
var steep = slope.gt(30);
Map.addLayer(steep, {}, 'steep slope', false);

// Proximity to steep areas
var steep_buff = steep.distance(ee.Kernel.euclidean(1000, 'meters')).gt(0).remap([0,1],[1,1]).unmask(0);
var pRBA_steep = preRBA.add(steep_buff).mask(preRBA).unmask(0);
Map.addLayer(pRBA_steep, {}, "pRBA + steep", false);
var pRBA_steep_fmean = pRBA_steep.addBands(preRBA);
print("pRBA_steep_fmean", pRBA_steep_fmean);
var pRBA_steep_fmean = pRBA_steep_fmean.reduceConnectedComponents(ee.Reducer.mean(), 'remapped_1', 256);
var pRBA_near_steep = pRBA_steep.neq(pRBA_steep_fmean).unmask(0);
print("pRBA_near_steep", pRBA_near_steep);
Map.addLayer(pRBA_near_steep, {}, 'preRBA patches near steep', false);

// FINALIZE
// conservations that require mitigation
var finVisParams = {
  palette:["000000", "73fd90"]
};

var opacity = 0.6;

var con_miti = pRBA_near_steep.add(pRBA_near_water).add(MPPm.unmask(0)).gt(0);
print("con_miti", con_miti);
Map.addLayer(con_miti, finVisParams, 'conservations that require mitigation', true, opacity);

// conservation for sure
var con = MPP_con.add(HPP_1).gt(0);
Map.addLayer(con, {palette: ["000000", "73fd90"]}, 'conservations for sure', true, opacity);

// development / give and take
var develop = preRBA.neq(pRBA_near_steep.add(pRBA_near_water).gt(0)).add(give_take.unmask(0)).gt(0);
print("Develop", develop);
```