Drone Mapping of Mangrove Swamps in Goa – Phase II

Final Project Report

by

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1. INTRODUCTION

Finding a reliable method of mapping forests of a certain species has proven to be a very difficult and time-consuming process when the intention is to acquire up-to-date data to study the dynamics of change within the flora population. In the past, area estimation was done by travelling to the outskirts of the forest to mark coordinates, and an area is determined by constructing a polygon of the coordinates on a map. This method proved highly inaccurate since the process was reliant on infrastructure to allow persons to access the edge of the forest to get an accurate coordinate. When the forests in question are characteristically dense or swampy, access to it becomes difficult. In such cases, there may be changes deep within the forest that may not be recorded from the limited points of access. Another recent method available for accurately mapping forests is the use of satellite imagery. While this gives a clear and accurate picture of the size and shapes of forests, no other details can be extracted.

The task assigned to us is devising an accurate method of mapping dense forests in the Goan swamplands. The type of forest in question is mangroves, which come with all the challenges mentioned above, the lack of infrastructure, high density, and a lot of variety to be studied. In addition to mapping the forests, we are required to build a computer-based identification system to identify species or genera of the mangrove trees present in the forest. Achieving this requires close inspection of the forested area, as the differences between various species often come down to buds, flowers, and leaf shapes.

To get an accurate picture of the state of the mangrove forests in Goa, we needed to get close to the trees to identify minute features and get an aerial view to access the depths of the forest. This is achievable using a Quadcopter, specifically one that is commonly used for photography and videography. Images of the forest can be captured from a low altitude to be able to distinguish necessary features, and the endurance of commercial drones today can help cover the entire forest in a relatively short time, compared to manual coordinate marking. Advancements in the autonomous flight of drones, area coverage, and path planning have taken all effort out of the process of data collection.

With the help of DJI's Phantom drone and the mapping software DroneDeploy, we were able to get a high-resolution map of most mangrove forests of Goa. The team travelled to each site where the presence of forests was known and let the drone fly over the forested regions. The images captured by the drone were uploaded to DroneDeploy, wherein they were stitched into a large, 2D map of the entire region covered. Additionally, photogrammetry techniques allow for an accurate point cloud to be produced, from which a 3D model of the forest is also available.

Estimating the area is a far more simple and more accurate endeavour, thanks to DroneDeploy. The software, with its access to critical drone camera details and telemetry, can give an accurate pixel density and scaling number, meaning we know for every image, what length in the mapped region corresponds to what number of pixels in the image. On marking the forested area on the image, this conversion scale will help us get a very accurate area estimate of the region.

There are some drawbacks to the process. Drone flight is a very novel technology that is yet to mature to the point of being cheap or energy-efficient for small-scale commercial use. Altitude restriction on flights means longer mapping times, as lower altitude means every image covers a smaller area, hence more images have to be captured over a longer time. The higher the drone flies, the lower will be the quality of the images and, thus, the maps. In such cases, it is advisable to procure drones specifically built for the purpose of mapping, but they tend to be too costly as of 2021.

These drawbacks led us to reduce the scale of the project to an extent. The requirement for an application to identify species was separated from the requirement to accurately map most mangrove forests of Goa. To capture fine details with the drone that may be used for identifying individual species, we needed to fly the drone at very low altitudes, which would make mapping all of the Goan mangroves impossible in the given time frame. One estimate of time for mapping at this altitude was 500 minutes for every square kilometre; this, with a daily battery limit of 120 minutes and a goal of 40 square kilometres (estimated), would have taken a lot of time that was not afforded by studying college students.

The separation of the species identification process allowed for an app that is robust and accurate for hand-held applications. Convolutional Neural Networks trained on publicly available images were used to identify the species of trees from images taken on the ground by our phone cameras. The accuracy achieved in the training is modestly high, though mislabelling of public data may cause some misidentifications. A lot of scope for improvements in both sectors of the project has been discussed previously and proposed in the report.

2. General Objectives

Map significantly large areas of Mangrove Forests in the state of Goa.

Significantly large regions encompass what can be feasibly covered by the drone without too much battery wastage. Large swathes of forests like Dr Salim Ali Bird Sanctuary come in the category, as well as marshlands where forest cover is scarce. Thin lines of mangrove cover along the river banks are too time-consuming and difficult to map. To cover these areas, we would need multiple locations to cover these areas, to prevent the drone from losing signal.

Estimate the area of forest cover in Goa

Find the area of mangrove cover across the different rivers and estuaries of Goa. Using the maps generated of the various mangroves, we will be able to find the total mapped area. This will require post-processing of the maps to identify the mangroves in the map and find the total mangrove area.

Species Identification

Using machine learning and convolutional neural networks, we aim to create a model that can classify a mangrove tree into one of the many species of mangroves found in Goa, as listed on the Forest Department website. We plan to collect a database of images of different species, with a focus on images of important identification features like fruit, leaf, flower, and buds. These images will then be augmented to account for different angles, lighting conditions, etc. This model should allow for species identification using close-up images of a mangrove tree with good accuracy.

Mobile Application

We aim to create a mobile application, which will interface with the ML model to allow any user to identify a particular species of mangroves, using their phones. The application will have a simple interface to allow easy interaction. Users will be able to take photos of mangrove trees with their phones, and the model will identify the species with the associated degree of probability.

3. METHODOLOGY AND EQUIPMENT

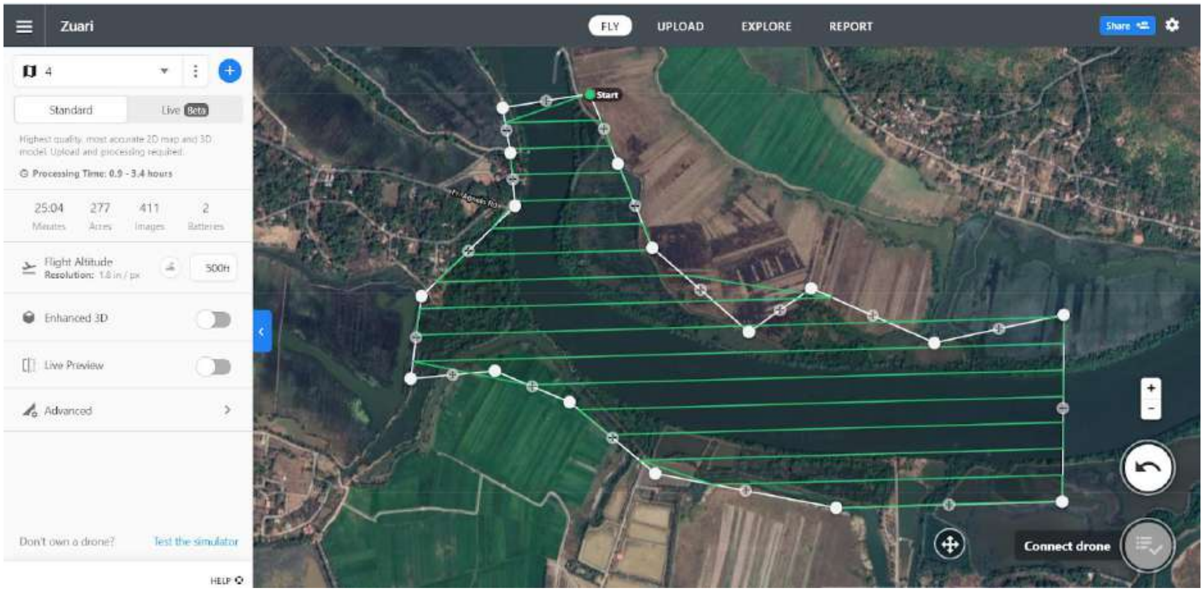
a. EQUIPMENT

The two main components that were used in the project were: The drone and the path-planning and mapping software. For the drone, we had to finalize a drone capable of providing high-resolution images from high altitudes, considerable battery life, and long-range capabilities. On top of that, it had to be compatible with third-party software for path planning and automated flight. Keeping these requirements in mind, we chose the **DJI Phantom 4 Pro V2** quadcopter drone with 5 additional batteries and charging hubs.

Specifications:

- Weight: 1375 gms
- Max. Speed: 72 km/hr horizontal speed and 21.6 km/hr vertical speed
- Service Ceiling: approx. 6000m
- Flight time: maximum 30 minutes at a single charge, number of batteries: 6
- 1 inch CMOS, 20 Megapixel Camera
- 84-degree FOV with auto-focus upwards of 1 m
- Mechanical shutter speed: 1/2000s
- Mounted on a 3-axis gimbal for stable photography and a pitch range of -90 to +30 degrees
- 2.4 GHz controller with an unobstructed range of up to 10 km, realized range of 4 km from open fields and 1 km in the obstructed environment. Battery life: 72 hrs
- It houses an array of infrared sensors, depth cameras, and ultrasound sensors to achieve obstacle avoidance and active flight stability.

The software used is **Dronedeploy.** It is a web and app-based solution that automates the process of coverage planning, area estimation, and photogrammetry and allows users to complete all tasks simultaneously. The software plans the path of the drone for optimum coverage, takes images at necessary intervals and stitches them into 2D maps, and uses Photogrammetry to construct a 3D model using the top-down images.



b. Methodology

Firstly, we compiled a database of images of the various species of Mangroves that are present in Goa, using the Forest Department website on mangroves as a reference. These images were curated from various online platforms and were sorted and classified manually by our team members and stored in Google Drive. The next phase was to test the procured hardware and software. The drone was tested in terms of flight capabilities on the college campus, and a free version of the Dronedeploy software was available to test path planning, map stitching and annotating features. We then consulted an expert on mangrove forests, Dr Aman, and identified areas with a decent probability of mangrove forests using past data from the forest department and google maps.

We started this phase of the project on 17th October with a visit to the forest Department, Panaji Goa. The meet was aimed at discussing the objectives for the next phase of the project. We went over the timeline along with the deliverables expected. We also looked at the previously existing apps to incorporate some of the features in our application. After a break of 1 month due to the mid-semester examinations of the team members, we resumed our visits to the forests. This was followed by our visit to Dr Salim Ali Bird Sanctuary, Chorao Islands. The island houses around nine mangrove species, including *Rhizophora mucronata*, *Rhizophora apiculata*, *Bruguiera cylindrica*, *Kandelia candel*, *Aegiceras corniculatum*, *Avicennia alba*, *Avicennia marina*, *Sonneratia alba*, *Acanthus ilicifolius*, *Excoecaria agallocha*, and *Derris heterophylla*. We collected around 100- 200 images of each species.

The images were taken from different plants at different locations along the island. These plants ranged from plantations in the nursery at the bird sanctuary to fully grown trees. We also used other cameras to incorporate any differences that could occur due to camera quality and differences in operating systems. It was also essential to ensure that the collected images were labelled accurately to prevent any errors from creeping into the ML model.

The team was guided through the sanctuary to identify species. We were able to capture characteristic features of different species that are easily distinguishable. We differentiated the species through features like the shape of the leaves, the colour of the leaves and bark, fruits and flowers, root structure etc. One more parameter to distinguish species is the distance from the shoreline. As the distance increases from the river's bank, the soil's salinity changes. Different species are highly suited to certain degrees of salinity, which means that varying salinity would change the kind of mangroves that can grow in the soil. The team used the book Mangroves of Goa as a reference to learn more about the characteristics of mangrove species.

The team covered three species in a day, as mangrove swamps are considered hostile ecosystems with hot, humid conditions. Therefore, we could stay for around 3-4 hours in the sanctuary per trip. Over a period of four months, we could cover 9 species prominently available in the sanctuary.

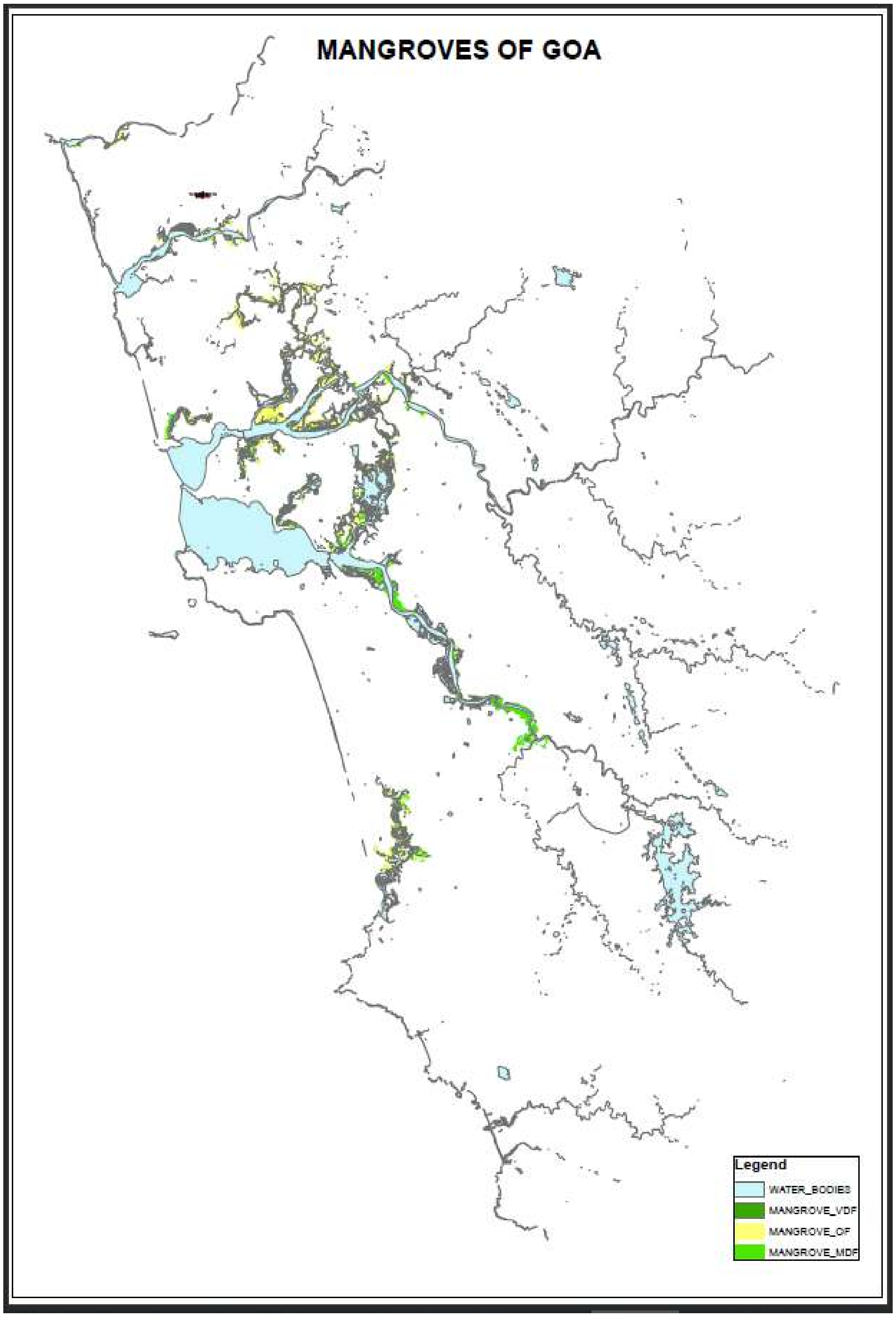
Along with image collection, we also had to complete the mapping of the areas remaining in phase I. We increased our frequency of visits per week and divided ourselves into pairs to cover as much ground as possible. We bought the paid version of the software so as to generate downloadable maps of the forests in various formats. Before each visit, we would create a bounding box of the estimated area in which the mangroves are present on the software. Then on the visit, we would find the closest location to the forest from where we can safely fly our drones. The drone would be linked to the software using an app of the software loaded on a mobile device connected to the drone controller. The software would generate an optimised path for the drone to follow and time the instants at which the images had to be taken. Some maps required the batteries of the drone to be changed multiple times, for which it would return to the home location. Once all the images are collected, the images are uploaded into the software. We were provided special internet facilities to upload the huge volume of data from our college. Once uploaded, the software would stitch the images together to generate different maps like Orthomosaic, Elevation, and point cloud maps of the area. These can then be downloaded in the desired format. In our second round of visits, during the one-month subscription period of the software, we covered an area of about 2100 acres (8.5 square kilometres).

Once we had generated the maps, we had to separate out the forested areas from the non-forested areas like rivers, roads, farms, etc. This post-processing work to narrow down to find the exact area of mangroves was done manually by our team members, who were advised and had developed experience in identifying mangrove forests. The percentage of the area of the whole map that is mangrove forests varies from 98% in areas that are huge, continuous mangroves to 20-30% in areas where there is small mangrove patched near populated areas. On average, about 70% of the mapped area comes under mangrove forests, as our initial stage of identifying areas to map had been drawn to eliminate non-forest cover as much as possible.

On our many trips, we also took close-up images of mangrove trees found in each region from points that were physically accessible by us or the drone. With these images, we used transfer learning to fine tune pre-trained models for the task of mangrove species identification. Several architectures were trained and the final model was a voting ensemble of three of these. After optimization of the model, we made a basic mobile application to create an interface between the model and a user, in which the user has to input a close-up image of the mangrove, and the application will display the results as probabilities and mention which species of mangrove found in Goa is the plant most likely to belong to. However, the accuracy of the predictions was limited by the amount of on-site data that could be collected. The dataset was limited to images found online and augmented to account for variations.

4. REGIONS OF CONCERN

Goa has multiple river bodies that have the potential to host mangroves on their banks. To identify regions of mangroves that need to be mapped, we used satellite imagery from Google Maps accompanied by the data provided by the Forest Department regarding the locations of mangrove forests of different densities, shown in the Figure below.



In the second phase, we mapped the following areas: -

1. Cumberjua Canal
    a. Gandaulim
    b. Cumberjua
    c. Banastari Bridge
    d. Corlim

e. Tivrem
f. Betqui
g. St. Estevam Island

2. Zuari River
    a. Agacaim
    b. Adpai
    c. Quelossim
    d. Durbhat
    e. Undir
    f. Madkai

Most of these regions have very narrow patches of mangroves along the river bank, but cumulatively add up to a significant part of the mangrove cover in Goa.

5. DATA STATISTICS AND OBSERVATIONS

The mangrove forests of Goa are scattered all across the state, lying mainly on the banks of rivers and estuaries. Certain mangrove areas are lush green with high mangrove density, thus the mapped areas are comprised majorly of the Mangrove forests, for example, The Salim Ali Bird Sanctuary, an estuarine mangrove habitat at the island of Chorao at Ribandar boasts a massive 818 acres of lush green Mangroves with a whopping 93.76% of the mapped area comprising Mangrove forests. However, this was not the case everywhere, as areas of that Cumberjua, Zuari, Sal, etc had less than 50% of the mapped area as Mangroves, and the rest being Barren lands, residential localities, pools of water, etc. On average, the total mangrove area out of the mapped area was estimated to be around 60%. It is impossible to get a tree count for all the mangroves mapped by the drone, as they coexist more like a thick bush interwoven with each other, and interspersed at the mapping site. However, we got accurate data on the total mangrove area that was mapped by us.

The detailed breakdown of all the areas marked in Phase - I of the project is given below

Name of Area	Total Mangrove Area (acres)	Total Mangrove Area (Hectares)	Total Mapped Area (acres)	Total Mapped Area (Hectares)	Percentage area mangrove
Mandovi River	**2835.477**	**1147.47**	**6046.89**	**2447.09**	**46.89**
Divar Island	904.13	365.88	1398	565.75	64.67
Vanxim Island	146.95	59.46	241	97.52	60.97
Area around Mapusa	739.97	299.45	2040.9	825.92	36.25
Panaji	592.457	239.75	1394	564.13	42.49
Naroa and St. Estevam	115.06	46.56	155.28	62.83	74.1
Salim Ali Bird Sanctuary	766.68	310.26	817.71	330.91	93.75
Cumberjua Canal	**490.35**	**198.43**	**1057**	**427.75**	**46.38**
Banastari Wetlands	227	91.86	286	115.74	79.36
Goa Velha, Gandaulim,etc	263.35	106.57	771	312.01	34.15
Zuari River	**947.64**	**383.49**	**2041.3**	**826.08**	**46.42**
Curtorim, Loutolim, Borim	119.41	48.32	701.4	283.84	17.02
Durbhat, Adpai	455.49	184.33	729.4	295.17	62.44
Mercurim, Zuari Bridge	372.74	150.84	610.5	247.06	61.05
Terekhol River	**99.09**	**40.1**	**161**	**65.15**	**61.55**
Chapora River	**283.83**	**114.86**	**323**	**130.71**	**87.87**
Siolim	22.55	9.12	25	10.11	90.2
Oxel	57.21	23.15	67	27.11	85.39
Pernem	204.07	82.58	231	93.48	88.33
Sal River	**1025.07**	**414.83**	**2433**	**984.6**	**42.13**
Talpona River	**45.39**	**18.36**	**56**	**22.66**	**81.02**
Galgibaga River	**62.594**	**25.33**	**129**	**52.2**	**48.52**
Total:	**5789.441**	**2342.905**	**12247.19**	**4956.26**	**47.27%**
		(23.429 sq. km)		(49.563 sq. km)	

The detailed breakdown of all the areas marked in Phase - II of the project is given below:

Name of Area	Total Mapped Area(hectares)	Total Mapped Area(acres)	Total Mangrove Area(hectares)	Total Mangrove Area(acres)
Zuari Riverbank	622.8	1539	476.93	1178.49
Agacaim	161.9	400	112.37	277.66
Adpai	99.6	246	87.26	215.62
Quellosim	291.8	721	220.94	545.94
Durbhat	21.9	54	20.10	49.66
Undir	27.1	67	25.14	62.13
Madkai	20.6	51	11.12	27.48
Cumberjua	227.2	561.4	138.83	343.06
Gandaulim	21.0	52	15.81	39.06
Cumberjua	44.7	110.4	16.11	39.81
Banastari Bridge	23.1	57	11.68	28.86
Corlim	12.5	31	4.26	10.53
Tivrem	12.5	31	7.10	17.55
Betqui	14.6	36	7.81	19.29
St. Estevam Island	98.7	244	76.07	187.96
Total	850.0	2100.4	615.76	1521.55
	(8.5 sq. km)		(6.157 sq. km)	

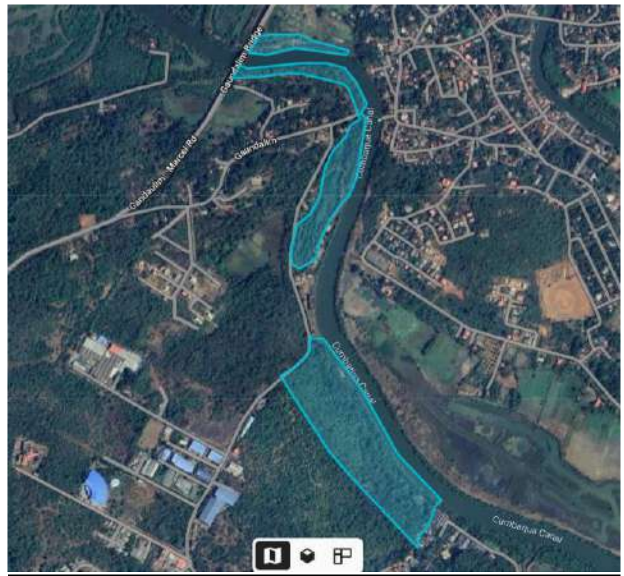
IMAGES BY REGION

1. **St Estevam Island**

   Given below are the annotated maps, marking the regions identified from the drone images as mangroves. We've eliminated as many non-forested areas, buildings, water bodies and non-mangrove vegetation as we can identify. The regions cover a large portion of St. Estevam Island along the Mandovi River, as well as the inlet to the Cumberjua Canal.


Mandovi River
Mandovi River
Valvanti River


2. **Cumberjua Canal**
   Much of the regions along the Cumberjua Canal are in narrow strips along the canal itself, with very few regions extending more than 10 metres inside. This necessitated mapping from multiple locations along the river. The annotated regions are given below.



3. Zuari River

Observed Species

1.Sonneratia Alba

This species was identified majorly at Chorao Island. Sonneratia alba (White Mangrove) is a tropical mangrove species. It is characterised by rounded leaves with white fruits. The species plays a crucial role in coastal ecosystems by providing habitat and shoreline stabilisation. The picture below depicts the features mentioned above.

2.Kandelia Candel

Kandelia candel, commonly known as the "Mangrove Apple" or "Sundari," is found in the mangrove ecosystems of Goa, India. Kandelia candel thrives in the intertidal zones of estuaries and tidal rivers in Goa, where freshwater and saltwater mix.

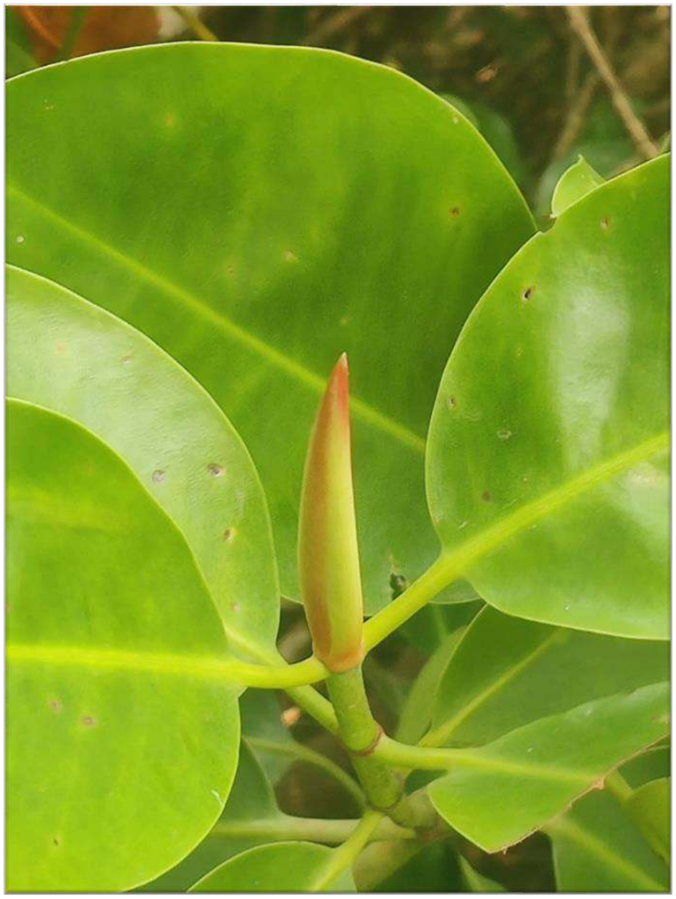
It’s distinctive features are its elliptical, leathery and glossy appearance. The flowers have small, white flowers with a tubular shape. The fruit is similar to a green apple. Kandelia candel exhibits a high degree of salt tolerance, allowing it to thrive in brackish water conditions common in mangrove habitats. Kandelia candel has evolved unique adaptations, such as the ability to excrete excess salt through its leaves, allowing it to survive in saline environments.

3. **Sonneratia Caseolaris**

In the coastal regions of Goa, Sonneratia caseolaris stands as a notable representative of the local mangrove ecosystems. Flourishing in brackish water environments and tidal zones, this species forms dense stands along the estuarine and intertidal areas, contributing significantly to the coastal landscape. The distinctive appearance of Sonneratia caseolaris is characterized by its specialized aerial roots called pneumatophores. These roots emerge from the soil and play a crucial role in aiding gas exchange in waterlogged conditions. The elliptical, glossy green leaves of the tree feature a unique adaptation – specialized salt glands that excrete excess salt, allowing the mangrove to thrive in saline environments characteristic of coastal areas. During the flowering period, Sonneratia caseolaris displays fragrant blooms with five petals and a prominent central style. The tree's fruits, resembling small apples, are large, round, and fleshy capsules with a hard woody exterior. These fruits serve as an important food source for various wildlife species, contributing to the overall biodiversity of the coastal ecosystem. Ecologically, mangrove apples in Goa play a vital role beyond their distinctive features. They provide a habitat for diverse marine and bird species, contributing to the overall health and resilience of the coastal environment. The dense stands of mangrove trees act as a natural buffer, protecting coastal areas from erosion and serving as a critical component in mitigating the impacts of climate change. Preserving and conserving these mangrove ecosystems in Goa is essential not only for the unique features of Sonneratia caseolaris but also for the broader ecological services they provide, including supporting fisheries, maintaining biodiversity, and safeguarding coastal communities against the effects of environmental changes.

4.Rhizophora Mucronata

Rhizophora mucronata, commonly known as the Red Mangrove, is a vital component of Goa's coastal ecosystems. Thriving in saline environments, this mangrove species is characterized by its prop roots that provide structural support and enable nutrient absorption. Its distinctive feature is the pointed or mucronate tip of its leaves, contributing to easy identification. These mangroves are strategically positioned along estuaries and



tidal zones, offering a unique ecological niche. In Goa, they play a crucial role in shoreline protection, mitigating the impact of erosion and storm surges. The extensive root system not only stabilizes the coastline but also provides habitat for various marine species, including fish and crustaceans. Rhizophora mucronata is well-adapted to Goa's brackish waters, demonstrating a remarkable ability to thrive in fluctuating salinity levels. The species actively contributes to nutrient cycling and water purification, enhancing overall coastal water quality. Additionally, the mangrove acts as a buffer against climate change, sequestering carbon dioxide and serving as a carbon sink. Conservation efforts in Goa are increasingly recognizing the significance of preserving Rhizophora mucronata and its associated ecosystems to ensure the sustainability of coastal biodiversity and the well-being of local communities dependent on these resources. It has pink fruiting branches which distinguish it from other mangrove species, especially the rhizophora apiculata.

5.Rhizophora Apiculata

Rhizophora apiculata, is a significant component of coastal ecosystems, exhibiting unique adaptations that enable its survival in intertidal zones. This mangrove tree, belonging to the Rhizophoraceae family, is characterized by stilt roots providing stability in the muddy coastal soils it inhabits. With glossy green and leathery leaves featuring a pointed apex, Rhizophora apiculata stands out in mangrove habitats across Southeast Asia, South Asia, and Australia. Its reproductive strategy involves seeds germinating while attached to the parent plant, ultimately falling into the water for dispersal by tides. The relevance of Rhizophora apiculata to Goa lies in the manifold ecosystem services it provides. These mangroves act as vital nurseries for numerous fish species, supporting the fishing industry in Goa by offering a sheltered environment for juvenile fish. Additionally, they serve as natural buffers, safeguarding coastal areas from erosion and storm surges. The biodiversity harbored within mangrove ecosystems contributes to the overall health and resilience of Goa's coastal environments. The carbon sequestration capacity of mangroves aids in climate change mitigation, a global concern. Moreover, the aesthetic value of mangroves attracts eco-tourism, providing opportunities for individuals to appreciate and learn about these unique coastal ecosystems. In Goa, where urban and natural landscapes coexist, the conservation of Rhizophora apiculata and mangrove ecosystems is paramount. Beyond their ecological significance, these mangroves play a crucial role in sustaining the livelihoods of coastal communities and ensuring the well-being of the region. Efforts directed at preserving and restoring mangrove habitats are essential for maintaining the delicate balance of coastal ecosystems and securing the numerous benefits they offer to both the environment and society. It is distinguished with green fruiting branches.

6. Avicennia Marina

Avicennia alba, another noteworthy mangrove species, contributes significantly to coastal ecosystems, particularly in the Asia-Pacific region. This mangrove, belonging to the Avicenniaceae family, thrives in saline and brackish waters, displaying distinct features that adapt it to intertidal environments. Avicennia alba is characterized by its pneumatophores, specialized aerial roots that aid in oxygen uptake in waterlogged soils. Its leaves are opposite, leathery, and often have a silvery-gray appearance, providing a unique visual identity in mangrove habitats. Distinguishing features of Avicennia alba include its pneumatophores, which rise vertically from the mud to facilitate gas exchange, a crucial adaptation to the anaerobic conditions of mangrove soils. Additionally, the opposite arrangement of its leaves and their silvery-gray coloration set Avicennia alba apart from other mangrove species, contributing to its recognition within coastal ecosystems. The relevance of Avicennia alba to regions like Goa is multifaceted. Like other mangroves, it serves as a crucial nursery for various fish species, supporting local fisheries by offering a safe haven for juvenile fish to grow. Additionally, Avicennia alba plays a pivotal role in coastal protection, acting as a buffer against erosion and mitigating the impacts of storm surges. The biodiversity hosted within Avicennia alba habitats enhances the overall resilience of coastal ecosystems, contributing to the ecological balance of the region. Furthermore, the carbon sequestration potential of Avicennia alba aids in climate change mitigation, underscoring its global environmental significance. In areas like Goa, where tourism is prominent, the aesthetic appeal of mangroves, including Avicennia alba, can attract eco-tourists, offering opportunities for environmental education and awareness. Preservation efforts directed towards Avicennia alba and its associated mangrove ecosystems are crucial for maintaining the ecological integrity of coastal regions. Beyond their ecological functions, these mangroves are integral to the socio-economic fabric of communities, providing resources and services that support the well-being of local populations. The conservation and sustainable management of Avicennia alba underscore the importance of recognizing and safeguarding the invaluable contributions of mangrove ecosystems to both the environment and society.

7. Acanthus Ilicofolius

Acanthus ilicifolius, a distinctive mangrove species belonging to the Acanthaceae family, plays a vital role in coastal ecosystems, particularly in regions like Southeast Asia and parts of Oceania. Flourishing in intertidal zones with brackish and saline waters, Acanthus ilicifolius exhibits unique features that enable it to thrive in challenging coastal environments. This mangrove is characterized by its thorny leaves, which resemble those of holly plants, and it is commonly known as the Holly-leaved Acanthus. Distinguishing features of Acanthus ilicifolius include its spiny leaves and prominent holly-like appearance, setting it apart from other mangrove species. The thorny nature of its leaves

serves as a defense mechanism, deterring herbivores and contributing to its ecological niche within mangrove habitats. The relevance of Acanthus ilicifolius to regions like Goa is significant. Like other mangroves, it functions as a crucial nursery for various fish species, supporting local fisheries by providing a safe and nutrient-rich environment for juvenile fish. Acanthus ilicifolius also plays a role in stabilizing coastal areas, acting as a natural buffer against erosion and helping mitigate the impacts of storm surges. The biodiversity hosted within Acanthus ilicifolius habitats contributes to the overall resilience of coastal ecosystems, fostering ecological balance. Moreover, the carbon sequestration capacity of Acanthus ilicifolius contributes to global climate change mitigation efforts. In areas with a focus on eco-tourism, the unique appearance of Acanthus ilicifolius and its mangrove counterparts can attract nature enthusiasts, offering educational opportunities and raising awareness about the importance of mangrove ecosystems. Preserving Acanthus ilicifolius and its associated mangrove habitats is essential for maintaining the ecological health of coastal regions. Beyond their ecological functions, mangroves like Acanthus ilicifolius are integral to the well-being of local communities, providing resources and services that support livelihoods. Recognizing and safeguarding the distinctive contributions of Acanthus ilicifolius underscore the importance of sustainable mangrove conservation practices for the benefit of both the environment and society.

These were the main species we identified.

6. OUTPUT DATA FROM MAPPING

Using the Dronedeploy software, we obtained five different formats for each map. These are-

i. Orthomosaic Model
ii. Elevation Model
iii. DTM model
iv. 3D object
v. Point Cloud

They were downloaded in the best available resolution Dronedeploy could offer, depending on image quality and resolution. The maps are stored as GeoTIFF files, .obj, and. xyz formats. The maps and all the images collected will be handed over / have been handed over to the Forest Department.

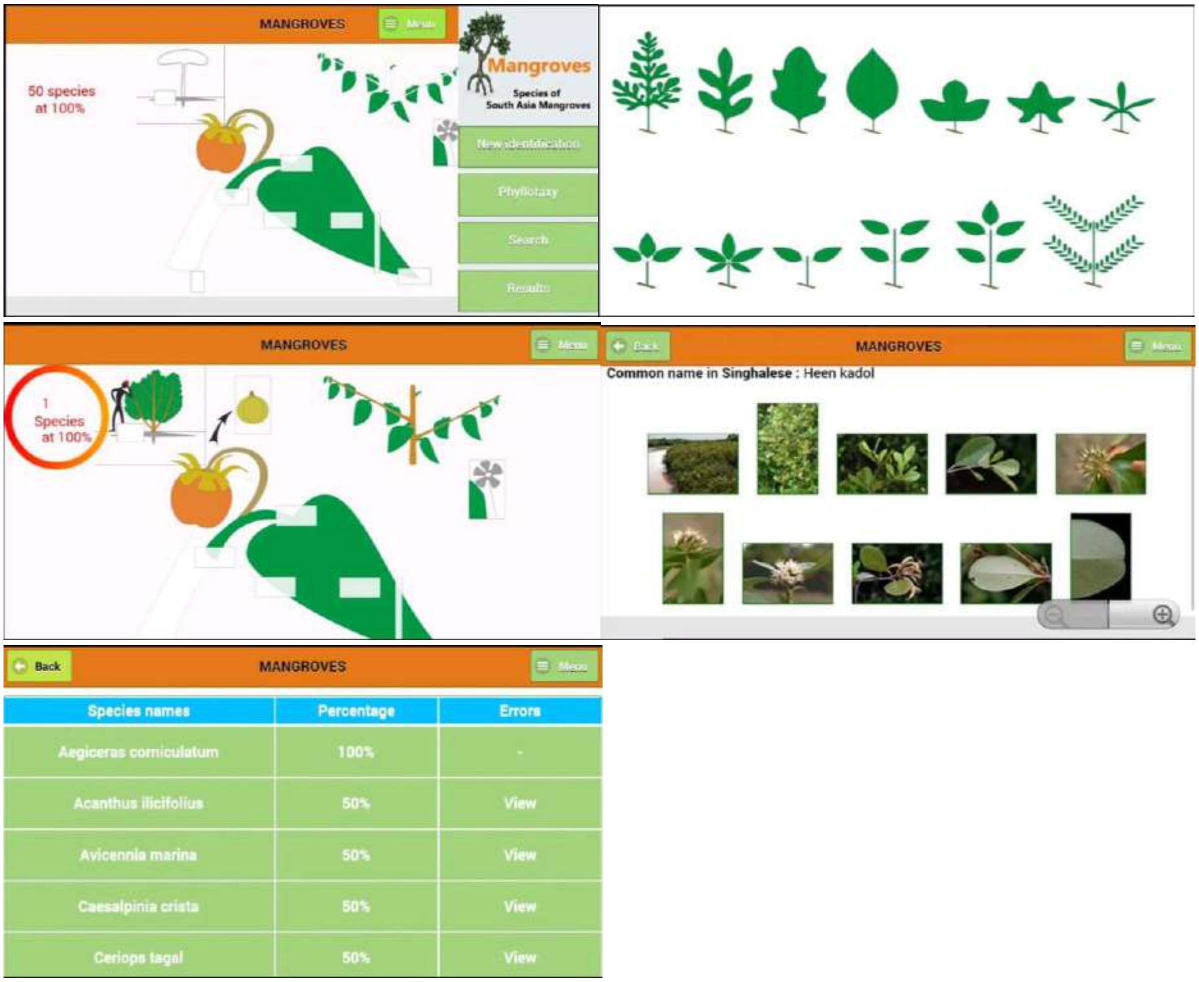
7. SPECIES IDENTIFICATION MODEL AND APPLICATION

Similar Applications Available Currently

1. Mangroves - Identification Kit

   "Mangroves" is a graphical identification system for the tree species of the South Asian Mangroves. The "IDentification Assistée par Ordinateur (IDAO)" was implemented to generate identification keys for tree species under the Project "Biodiversity Informatics and co-Operation in Taxonomy for Interactive Shared Knowledge Base (BIOTIK) ". This system, entirely graphic, enables specialists and non-specialists to make determinations with the help of just a few characters, chosen according to their availability for the particular tree to be identified. The use of vegetative characters, as well as an extensive illustration of species, is the mainstay of the application. Most of the characters used in the tool can be observed with the naked eye. The user-friendly identity kit was developed with two interfaces: a graphical interface and a result interface. (Link: https://mangroves-identification-kit.soft112.com/)

   In comparison, our application makes the job of the user easier as he/she doesn't have to manually look at each feature of the mangrove tree and type it into the app. All the user has to do is take a picture of the tree, and our application takes care of identifying the features and classifying the species of mangroves.



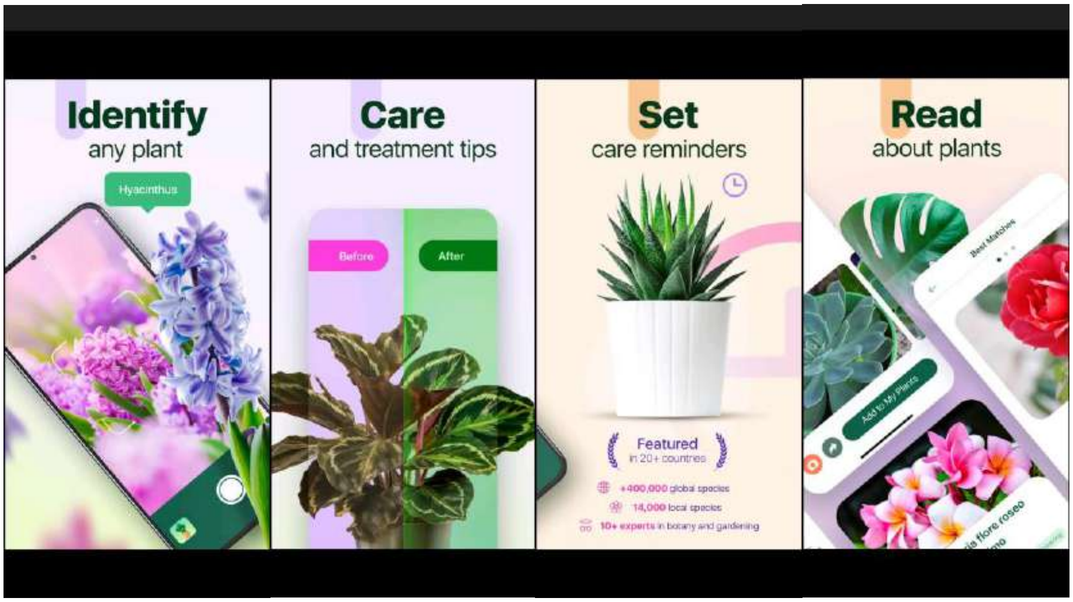
2. NatureID- Plant Identifier App

NatureID is one of the best plant identification apps for Android and iOS devices. NatureID uses photos of your plants to deliver the information you need. What sets it apart is it's almost so accurate it’s creepy, the ability to diagnose any issues with your plant. As NatureID’s bread and butter, the function allows users to get the quickest diagnosis and solution to ensure your plant's speedy recovery. The app also comes with advanced features such as care reminders and plant disease identifiers.

Furthermore, you can use this app to diagnose various plants and vegetables; it is a comprehensive, handy mobile app for student gardeners and nutritionists. The app also features some fun holiday tips to make sure your plant-filled holiday season turns out the best.

NatureID is free to use with unlimited plant identifications but only allows for a single plant health diagnosis.

Although this application is pretty accurate, it cannot accurately guess the species of a particular mangrove tree, which is exactly what our application does. If a picture of a tree from a mangrove is put into this application, it would only identify it as a mangrove tree and not the exact species.



3. Google Lens

Google Lens can help you identify plants, trees, flowers, and even animals around you. This is also an excellent app to translate information in real-time using your camera utilizing the real-time translator to do the job. As you can expect from any Google app, Lens is extremely well-designed and works perfectly on Android devices. While it may not be as accurate as some of the plant identification apps we've discussed today, it is certainly worth a try.

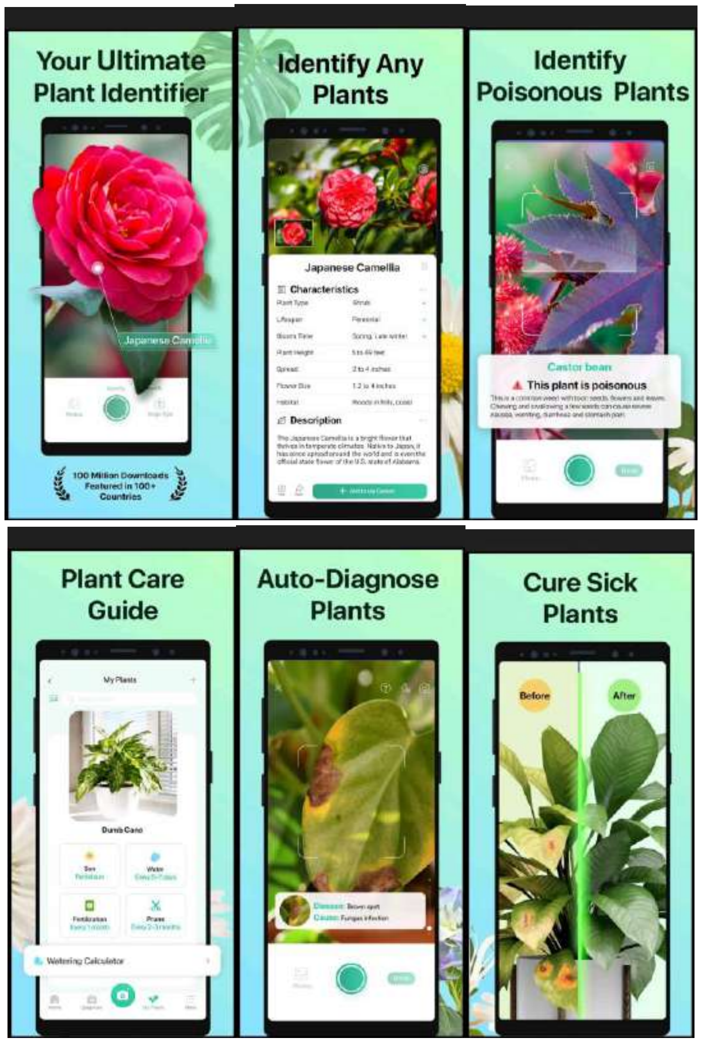
Users can also use an image from their photo gallery to learn the name of that flower or fruit. Overall, plant lovers will definitely like Google Lens thanks to its versatility and the large database it offers. The app is completely free to download and has no ads or in-app purchases.

4. PictureThis - Plant Identifier

PictureThis is a plant identifier app that identifies 1,000,000+ plants daily with 98% accuracy-better than most human experts, and hence it is one of the best plant identification apps available. It is a free plant or tree identification app and comes with a simple and easy-to-use user interface so that anyone can easily download and install it on their smartphone.

To use this “PictureThis” plant identifier app on your smartphone, only you have to take a picture of any flower, plant, or tree and submit it to get instant results on your smartphone screen. By using this plant identifier on your Android smartphone, you can identify plenty of plants, flowers, or trees by just using this plant identifier and the primary camera of your smartphone. It is an entertaining, educational and comprehensive app for students, teachers, gardens, nature lovers, botanists, and people who love being around plants.

Similar to NatureID, this application cannot accurately predict the species of a mangrove tree, which is something that our app is able to do since it is trained with a model containing pictures of various species of purely mangrove trees.



Architectures

To move from a desktop application in the previous phase to a mobile application in this one, it was necessary to reduce the model size from 500+ Mb. To do this, we used a deeper model, ResNext, in an ensemble with two lighter-weight models, GoogleNet and MobileNet. The ensemble of the three models performs better and boosts classification accuracy by at least 4% for each model.

Model	Epochs Trained	Accuracy	F1-Score
GoogleNet	60	81.56	81.65
MobileNet	25	84.38	84.44

ResNeXt	25	87.09	87.10
Ensemble	-	91.00	91.04

Transfer Learning

We used the models to extract the features from a 299 x 299-pixel image that is randomly cropped. The extracted features were passed through additional fully connected layers, eventually to an output layer of 16 nodes- one for each class. We used a softmax activation function to get the probability of a class in a picture at each node. We used Cross-Entropy loss to backpropagate the loss function and used an RMSprop optimizer with a learning rate of 0.0005 to update the weights of the network. The same process was done for all models. We trained the GoogleNet network for 60 epochs and MobileNet and ResNeXt for 25 epochs each. We found that training the networks for additional epochs resulted in overfitting and poor model performance on Val Data. The complete confusion matrix visualising the results of the test data can be seen below.

DenseNet

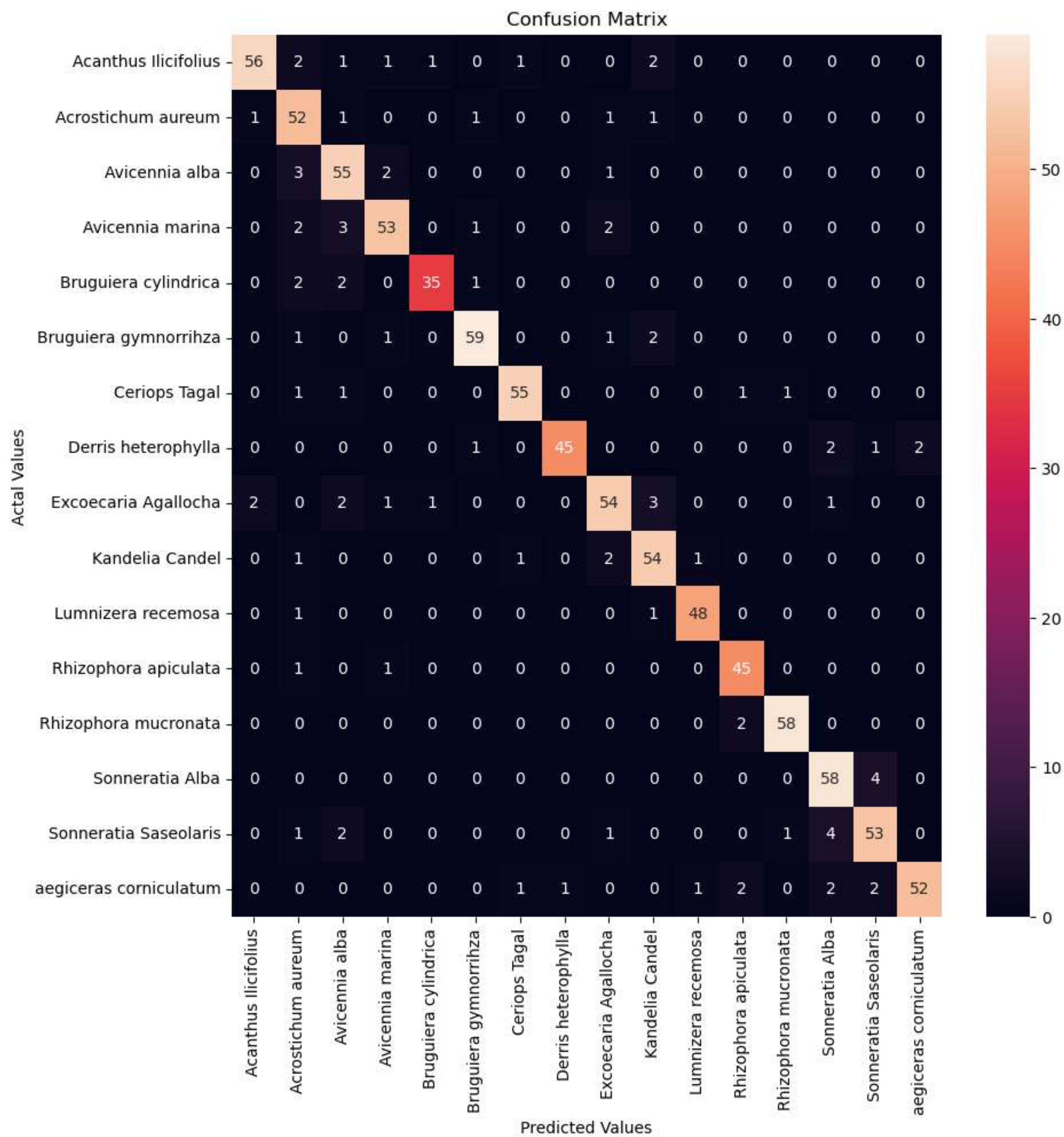
We used the models to extract the features from a 224 x 224 - pixel image that is randomly cropped and rotated.

The extracted features were passed through additional fully connected layers, eventually to an output layer of 16 nodes - one for each class.

We used a softmax activation function to get the probability of a class in a picture at each node. We used Cross-Entropy loss to backpropagate the loss function and used an AdaDelta optimizer with a learning rate of 0.001 to update the weights of the network. We trained the DenseNet for 30 epochs.

Updating the architecture increased the accuracy to more than 90%.

Further gains could be obtained by using a better optimiser, and choosing models with a lower epoch time.



Mobile Application

Originally, the plan was to have the application send the images the user takes to a server where we run inference and send the results back to the user. However, we were able to reduce the size of the model enough to make it viable to store on a mobile device, so we decided to run inference locally. This required converting and optimising the three architectures to run on Android and then combining the results for each image in the application itself. This decision to have the model run locally also allows the user to be untethered and use the application in areas without network coverage.

8. CHALLENGES AND FUTURE SCOPE

A. CHALLENGES:

One of the major challenges in the second phase of the project was the nature of the areas to be mapped. Long narrow stretches of mangroves along the banks of canals and rivers couldn’t be mapped from a single location, due to limitations on the range of the drone, and the possibility of signal loss. In order to solve this issue, we had to break down a single stretch into multiple smaller stretches, centred around locations from where we could fly the drone within the transmission range. This process required multiple trips for relatively small locations and ended up taking far more time than our initial estimate. There were also instances where the regions were very remote and inaccessible, leading us to spend significant time finding suitable locations where the drone could be launched for mapping. Multiple take-off and landing procedures also drained the batteries at a faster rate, reducing the amount of area that we could cover in a single trip.

In order to collect the datasets for the species identification model, we had to find locations where a variety of species could be found. We also needed a guide, someone who could ensure the accuracy of the dataset that we were collecting, which was crucial to the training of the model. For this reason, we chose Dr Salim Ali Bird Sanctuary on Chorao Island, since it housed a large collection of mangrove species and the guides there were willing to help us in identifying the species.

Since mangroves typically grow in swampy, humid conditions, the environment inside the Sanctuary was not suitable for long-duration stays. We could only collect images for two to three hours at a stretch before experiencing significant physical discomfort and fatigue. Some of the species weren’t accessible from within the sanctuary itself. In order to collect images for these species, we had to use boats and reach the species from the river.

B. FUTURE SCOPE

In order to ensure we map the remaining mangrove regions within the timeline, we had to collect images while flying the drone at an altitude of 400 feet. While this is optimum for mapping, we need better resolutions in order to develop a species segmentation model that can segregate and identify species based on the mangrove cover. We would also need additional data, such as the salinity of the region, and the distance from the coastline. In most locations, multiple mangrove species are intertwined deeply with one another, which further complicates the segmentation model using only aerial imagery.

To cover the other species, we would require to visit other areas in Goa that house the different mangrove species. These species aren't available in the Salim Ali Bird Sanctuary, and we need to research locations where we can access and collect images of species and ensure the accuracy of the data we are collecting. We could collect images of the species during different seasons since flowering and fruiting take place at other times of the year. One constraint we would face will be the occurrence of high tides during the rainy season.

The developments in the mobile application were delayed due to time and effort spent into improving model accuracy. These updated architectures had to be reoptimized to allow the models to run locally, allowing the user to be untethered and use the applications in area without good network. This process took longer than expected and delayed the completion.

Another major setback faced by the team was due to issues in the gimbal of DJI Phantom. The servicing and constant repairs inhibited us from recording any aerial footage over the past three months. This further limited on-site data which would have been used to generate the 3D maps of the area.

9. CONCLUSION

Phase II of the Project concluded with the team achieving the following deliverables

1. Completion of mapping of the area and covering altogether of mangroves in Goa
2. Collection of the dataset of 9 species present in Goa to build the training set of the Machine Learning Model for classification
3. An accuracy of 90% was achieved, meeting the goal set for this phase of Project
4. The transition from a desktop application to a mobile application was successfully completed, reducing the size of the package by 60%

10. APPENDIX

A. Mangrove Data Spreadsheet with detailed areas and distribution of mangroves in the areas mapped. **Unit of Measurement used is Acres.**
    a) In the data provided, we have followed the area distribution as provided in the table in section 5.

b) Under each region, we have sub-regions, under which each column is a map made in that sub-region. The data points in each column are the individual annotations made in the subregion to group mangrove areas.
c) In the end, we have added the areas of all annotated areas in that subregion to get the total mangrove area, followed by the total mapped area.
d) Values in point c) are obtained for all subregions and added to get the total mapped area in the region, total mangrove area and mangrove percentage in the region by area.