USING LOW-COST DRONES TO MAP HABITAT CHANGE IN BAHAMIAN NATIONAL PARKS

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Abstract

Habitat monitoring can be challenging as conservation organizations are typically under resourced and areas can be remote or inaccessible. In a world where environmental issues like climate change and habitat degradation are detrimental to biodiversity and human health, monitoring remains important. Low-cost (<$2,000), "off-the-shelf" drones (also called UAVS) are small, aerial vehicles. They are ideal for field work, as they are portable, can have automated flight missions, and supply affordable, high-quality aerial imagery. One use for drone images is the creation of orthomosaics; larger images made by amalgamating many overlapping images which can be imported to a GIS for remote sensing and land cover classifications. In The Bahamas, low-cost drone orthomosaics were used to create three habitat maps and two change detection maps using supervised and unsupervised classifications for two national parks: The Retreat Gardens (RG) in New Providence and Lucayan National Park (LNP) in Grand Bahamas. At the Retreat, infrastructure area increased by 788 m^2 between 2022 and 2023 due to the installation of a new roundabout and park entrance. At Lucayan National Park, the effects of Hurricane Dorian (2019) and subsequent recovery were mapped, with clusters of forest habitat changed to barren from 2018 to 2020 and forest habitat recovering from 2020 to 2021. Low-cost drones are an effective method to use for high-quality, small-scale habitat mapping and monitoring, particularly to assess the impacts of climate change and other external factors and can be used to inform conservation planning and national park management.

Introduction

Background Information

The Bahamas is an archipelagic nation located southeast of the Floridian peninsula, north of Cuba, and northwest of Hispaniola. Its geographic coordinates are between the latitudes of 21° and 27 ° North and longitudes of 72° and 79° West. The Bahamas has a total land area of 13,943 km^2 and a marine area of more than 260,000 km^2 (The Commonwealth of The Bahamas, 2014). Its highest point is Mount Alvernia on the island of Cat Island, peaking at a modest 63 meters above sea level. Politically an independent nation, British Commonwealth, and CARICOM country (meaning that it geopolitically belongs to the Caribbean), the country gained independence in 1973. Its current population, according to preliminary 2022 census data (Census Office, The Bahamas National Statistical Institute, 2023) is 399,314 people. The main economic drivers of The Bahamas are tourism, offshore banking, and fisheries exports, with the vast majority of the country's sizable GDP of $12.9 billion dollars in 2022 (The Bahamas National Statistical Institute, 2023) coming from the tourism industry.

Due to its geographic location, The Bahamas finds itself on the border of both tropical and subtropical climate zones. This means that its climate is classified as semi-tropical, which is classified as having warm and humid conditions year-round. Its location in the center of the hurricane belt means that it is particularly exposed to hurricanes during the Atlantic Hurricane Season, which runs from June 1st to November 30th each year (The World Bank Group, 2021). The country is home to many different environmental biomes across its islands. Typically categorized into one of three types (terrestrial, coastal, and marine), each plays an important role in the country's biodiverse flora and fauna. From endemic bird and plant species found nowhere else in the world to beautiful white sand beaches and vibrant coral reefs that attract tourists from far and wide, the country's diverse habitats are both economic gems that should be capitalized on (in a sustainable fashion) well protected and managed to ensure they continue to exist for future generations to come.

The Problem

Habitat or environmental monitoring is the process by which natural areas are observed over time to assess their condition, health, and quality. It is a common practice in ecology and conservation, as characteristics of an environment such as the number of species, number of individuals of those species, and their condition or status can indicate the health of an overall ecosystem. Habitat monitoring can take place on different temporal scales. Factors like the type or size of the area in question, if any external factors (like fires) have affected the area recently, or the managing organization all inform how often monitoring exercises take place. Habitat monitoring can be conducted for many different reasons, such as managing national parks, assessing changes by a recent disturbance, or to assess the population of an at-risk species and its environment.

Figure 1: *Photograph of a typical terrestrial Bahamian habitat and fieldwork conditions; broadleaf evergreen (coppice, usual ground cover layer for pine habitat) is 1-2 meters high and comprised of thick vegetation, spiny plants, ground-blanketing vines, and dangerous karst features. Image credit: The Bahamas National Trust, 2018.*

One of the main and most current drivers of more regularly scheduled monitoring exercises in The Bahamas is climate change. Climate change is a change in the overarching and long-term weather patterns that affect an area and is typically understood to be anthropogenically inflated due to industrialization and related greenhouse gas emissions. Related is global warming, which refers to the heating of the overall average global temperature. It is a factor that plays into climate change, but they are not the same. Climate change has many different "side effects" and include but are not limited to increased heat waves, droughts, increased flooding, sea level rise, and increased hurricane intensity and frequency. All these effects of climate change impact The Bahamas, but the most prominent are hurricanes. Since 2015, the country has been impacted by 10 tropical cyclones, with four of those being major (category 4 or 5) hurricanes.

Of these four, Hurricane Dorian (September 2019) is regarded as the worst disaster to affect the country in recorded history. The storm spent nearly three full days over the second and third most populated islands of The Bahamas: Abaco and Grand Bahama. The official death toll stands at 74 people, but many more remain missing and unaccounted for almost four years later. The power grid was completely knocked out for months on the island of Abaco, hundreds of homes were damaged or outright destroyed, and many people ended up permanently moving from the islands to the capital of Nassau (Deopersad, et al., 2020). The natural environment was also permanently altered in different ways. Saltwater inundation of the freshwater lens on the island of Grand Bahama was determined to be the most likely cause for the almost-complete decimation of pine trees and pine forest on that island, with 100% of the habitat having died in some areas (Bahamas Forestry Unit, 2019). Red mangroves (*Rhizophora mangle*) and coral reefs were also disproportionately impacted by the storm, meaning that two of the barriers protecting the coast from storm surge and sea level rise were removed from those two islands, and the storm even permanently altered the coastline in certain parts of those islands (Bahamas National Trust, 2022). The Bahama Warbler (*Setophaga flavescens*) was declared as Endangered by the IUCN after the storm due to habitat loss (it lives solely in Bahamian pine forests) and its complete disappearance from the island of Grand Bahama (BirdLife International, 2020).

Habitat monitoring in The Bahamas can be a challenge. The lack of transportation between islands often means that anyone who wants to conduct any kind of fieldwork must have access to a boat or be able to afford air transportation. This is especially true for terrestrial habitat monitoring, which often involves having to navigate on foot through dense evergreen broadleaf forest (called coppice) or rocky pine forests, both of which are environments full of hazards like stinging insects, brambles, or poisonous vegetation. Conservation organizations are also often understaffed and have very few and limited resources available to help them. This is usually encapsulated by conservation practitioners being stretched thin on projects and tasks (which is true for conservation across the board). Real, science-based habitat monitoring involves dedicated time, not just for data collection, but also data processing, analysis, and reporting. This is often a challenge to achieve, and in The Bahamas and wider Caribbean, tasks are often executed inefficiently or in outdated fashion due to lack of technological advancements. Finally, funding is a challenge in many parts of conservation. In a still-developing country like The Bahamas, funding often goes toward improving the number one economic input, which is tourism. The natural environment often takes a backseat or is even thrown under the bus to make way for more hotel or resort developments, so much of the small amount of funding available to conservation efforts is very competitive.

The Solution

So how are monitoring efforts improved while dealing with the limitations of time, resources, and funding? Adopting the use of modern technology is one way to solve the problem, and a small part of this would be to implement remote sensing efforts specifically using drones. Unmanned aerial vehicles (UAVs), more commonly called drones, are remotely operated flying vehicles typically. There are many different types that serve a variety of functions, from surveying agricultural plots to military reconnaissance. Often outfitted with sensors, from basic cameras to full spreads of spectral instruments, they are often used in remote sensing exercises. Remote sensing is simply defined as being able to detect what is on the earth's surface from afar (USGS, n.d.) and has been used in habitat monitoring and surveillance since the beginning. Modern remote sensing typically involves using some form of aerial or satellite imagery and GIS software to glean information from those images.

UAVs can be used to collect aerial imagery in ways that are more time efficient, resource saving, and cost-effective than other remote sensing techniques. For example, using satellite imagery is good for large-scale areas like U.S. counties, but for very small parts of already small islands, freely available satellite images are much too coarse for habitat detection at the park-level, and finer resolution images typically come at a cost. Aerial imagery from planes or LiDAR (Light Detection and Ranging) are other remote sensing options, as they provide much finer spatial and spectral resolutions, but both are often very costly and therefore unlikely to be funded by underfunded conservation organizations in The Bahamas. Drones supply a neatly packaged solution to these issues, in the form of low-cost off-the-shelf drones. They are often easy to set up and pilot (with basic training), flight missions to collect imagery can be very easily automated through simple mobile applications, which typically need very little input from users, and basic models typically cost between $1,000 to $2,000 (Schaefer, et al., 2020).

Figure 2: Free satellite image from Google Earth Pro of a feature (a pavilion) within a Bahamian national park (left) compared to how it has been captured by a low-cost drone (right).

This project seeks to test the capabilities of drones as an effective habitat monitoring tools in The Bahamas. The data used for this project is sourced from the Bahamas National Trust (shortened to BNT; (Bahamas National Trust, 2023)), which is the national parks management agency of the country. Unique among national park services across the world, the BNT is a non-governmental and non-profit organization that manages all 32 national parks in the country, provides advice on environmental issues to the government, and educates many different demographics of Bahamians on the environment and local species of flora and fauna. The BNT's GIS Unit, which is part of its Science & Policy department, currently has a small fleet of drones of different makes and models which it has used for several different projects, including park management and habitat monitoring. Many images have been collected over the years but not much in terms of post-collection processing has been done with them. A remote-sensing and photogrammetry endeavor, this project will involve processing photographs taken with the BNT's drones to create GIS products such as orthomosaic photographs, Digital Surface Models, and habitat or land cover classifications of two Bahamian National Parks, The Retreat, located on New Providence, and Lucayan National Park, located on Grand Bahama.

This project seeks to answer the following questions:

1. How can low-cost UAVs be used to the advantage of national park management and monitoring in the Caribbean?
2. Can drone-obtained orthomosaic images be used to create habitat classifications and change detections for two Bahamian national parks?
3. What were the impacts of external factors (infrastructure installation and a major hurricane) on the two focus parks?

Through answering these questions, the project will test the hypothesis that Unmanned Aerial Vehicles (UAVs) or drones are an effective way to collect aerial imagery for monitoring, remote sensing, and national park management in The Bahamas, with examples highlighting change detections due to climate change and infrastructure installation.

Literature Review

Unmanned Aerial Vehicles (UAVs) are a tool that is increasing in popularity in various fields of study and work. Typically comprised of a body, which often stores sensors, and some kind of flight mechanism (usually quadcopter, with four rotating propellors for flying or hovering, or fixed wing, with large wings for gliding long distances), drones come in a variety of shapes, sizes, and functionalities. There has been work done across the globe where drones have been used in habitat monitoring efforts.

Figure 3: A photograph of the control scheme of a low-cost drone (DJI Mavic 2 Pro, smartphone & controller setup) where aerial footage of an island in The Bahamas was collected to assess damage to the environment. Image credit: The Bahamas National Trust, 2020.

It is generally agreed that drones are a more cost-effective alternative to classic spatial imagery sources (satellite and LiDAR) and often have higher resolution-outputs (Lowe, Adnan, Hamylton, Carvalho, & Woodroffe, 2019; Pin Koh & Wich, 2012; Schaefer, et al., 2020; Ventura, Bonifazi, Gravina, Belluscio, & Ardizzone, 2018), which gives them great potential in habitat monitoring and conservation, especially for small areas like insular national parks. Modern drones are typically equipped with a variety of sensors including high resolution cameras, gyroscopes, temperature and windspeed gauges, and built-in Global Positioning Systems (GPS). One such use for drone-collected images is orthomosaic imaging, which is the creation of larger (typically georeferenced) images through the amalgamation of many overlapping images, like panoramic images.

Orthomosaics have existed for a very long time and are a large portion of what makes up photogrammetry, which is the practice of garnering 3D information from photographs. They can be used for a variety of different reasons including for GIS purposes, like fine-scale remote sensing and habitat classifications. Drone-collected orthomosaics can even be used to obtain updated and more accurate maps. This was shown in the case of the UTHM Wetland Conservation Research Station in Johor, Malaysia, which used a drone to create an updated orthomosaic map of a newly built research station at a conservation site in Malaysia (Kamarudin & Wei, 2022). The research station did not exist yet on Google Earth Pro nor Google Maps because the Google imagery that informs these services was very outdated (2014 in this example), and this is often the case in isolated locations.

Low-cost UAVS are a much cheaper alternative to both commercial remote sensing sources and high-end drones. They consist of several different makes and models, from "homebrewed" options like Pin Koh & Wich's 2012 modified model airplane to off-the-shelf models like DJI's extensive suite of ready-made models, like the Mavic and Phantom series. The main similarity between low-cost models is just that- their affordability. According to Schaefer (2020), a low-cost UAV ranges in price from $1,000 to $2,000. When paired with software such as Pix4D Capture, ArcGIS products, or AgiSoft PhotoScan (now Metashape), combining drone imagery into orthomosaics can give users extremely high-resolution georeferenced models of areas for various uses. When compared to the monetary costs of purchased satellite or aerial imagery, it is easy to see why drones are more appealing. A LiDAR flight can often cost several thousand dollars, which adds up quickly depending on what needs to be surveyed like an area's size and how long it takes (FlyGuys, 2023). On the other hand, while there are free satellite imagery options, they usually have low spatial resolution, which is practically useless in small insular settings like national parks.

As for the orthomosaic images generated by UAVs, there are many uses in a variety of different fields. Since this project is focusing on habitat and ecosystem monitoring, there will be a focus on those in this review. Traditionally, habitat mapping and monitoring involves a lot of manual groundwork and surveying (Pin Koh & Wich, 2012; Boger, Low, & Nelson, 2020) which can be extremely time consuming and sometimes inefficient. Drones offer both an alternative to on-the-ground surveys and a way to supplement them. According to Lowe et. al, 2019, drones can be used to detect and analyze changes in shoreline structures on small islands through the creation of orthomosaics and digital surface models. This was also demonstrated in Schaefer's 2020 paper, which mapped changes to Dominica's natural landscape using similar methodology after Hurricane Maria in 2017. Both papers show the usefulness of drones, particularly in small island developing states (SIDS), where there are typically limited resources and capacity. In the context of climate change and its effects, these examples demonstrate how low-cost drone orthomosaic imagery can be used to assess the impacts of two different impacts of climate change in insular settings.

Similarly, UAVs can also be used for habitat classification. Images are obtained at a scale much finer than the often-used free satellite images (Amami, Elmedwhi, Borgaa, Buker, & Alareibi, 2022), which can have resolutions up to 30 meters (as is the case with Landsat). Having access to orthorectified drone imagery can make a huge difference in the case of small areas like national parks in the Caribbean. The low resolution of satellite images would be near-useless in the case of these small areas, which can be only a few acres in size. Drones make short work of collecting high resolution imagery such areas and allow conservation practitioners to collect data on sensitive habitat with minimal interference. This was demonstrated by Ventura *et al.*'s research in 2016 and 2018, where a drone was used to map underwater marine habitats in the Mediterranean Sea. From orthorectified images, a classification algorithm was trained, and a study area classified into habitats using object-based imagery analysis (OBIA), which is just one of several classification techniques (Ventura, Bruno, Jona Lasinio, Belluscio, & Ardizzone, 2016; Ventura, Bonifazi, Gravina, Belluscio, & Ardizzone, 2018)

Of course, low-cost drones and the orthomosaics produced by using them aren't without their challenges. Ventura's 2016 publication discusses that limitations like short battery life, flight range, and area size should be considered before investing in a drone for remote sensing (Ventura, Bruno, Jona Lasinio, Belluscio, & Ardizzone, 2016). In Walter's 2018 paper, the issues of environmental factors like lighting, time of day, and wind conditions can change the quality of images captured (Walter, et al., 2018). Additionally, the precision of a drone's position has been shown to be higher at the center of an orthomosaic compared to the edges (Hung, Unger, Kulhavy, & Zhang, 2019), meaning that there can be georeferencing and other related errors caused by using orthomosaics for map creation. Despite these challenges, the consensus seems to be that the benefits far outweigh the costs.

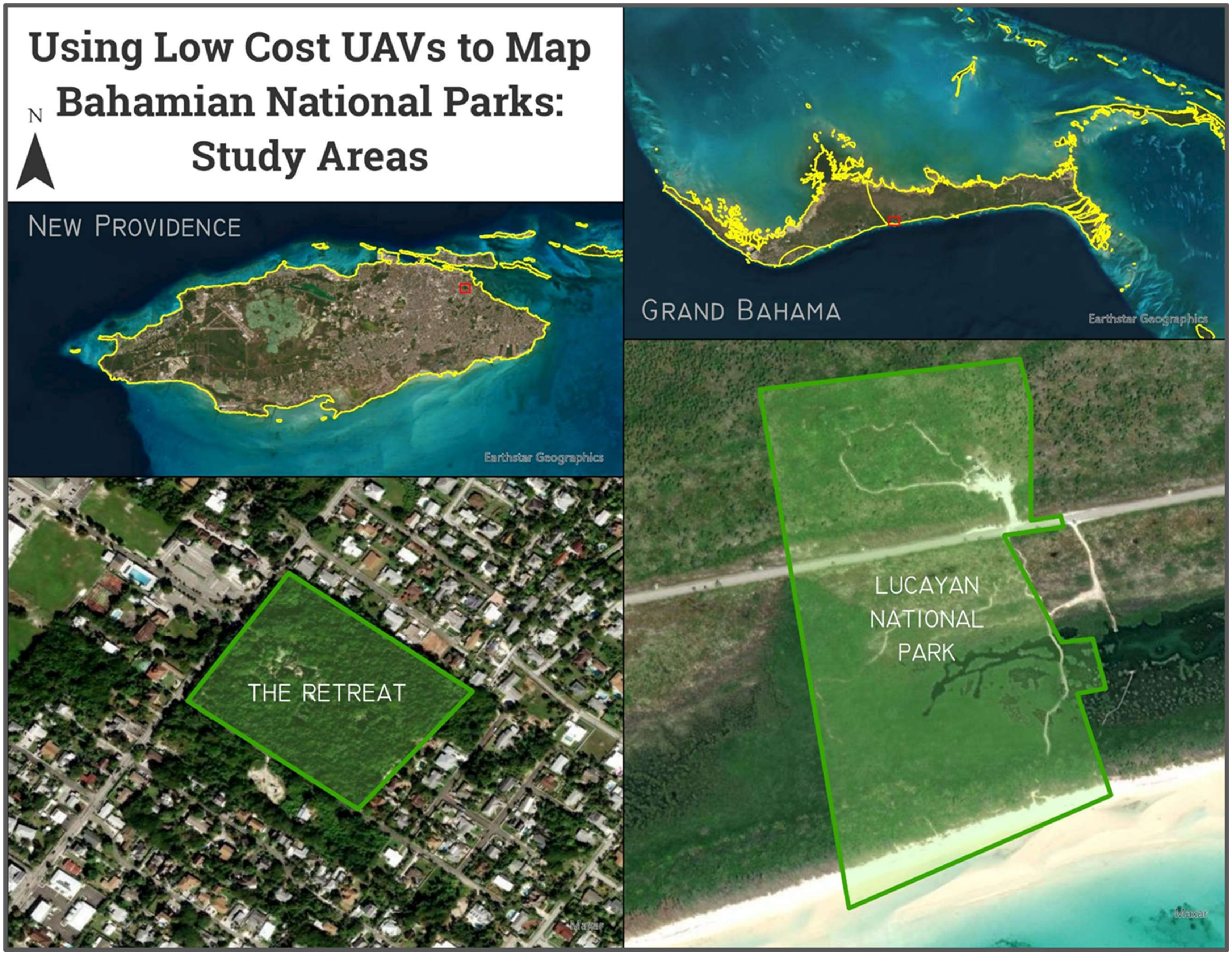
In The Bahamas, research done by the Perry Institute of Marine Science (PIMS) used drone imagery to examine the health of coral reefs and mangrove systems within different areas of the Bahamas. While PIMS has focused on overall tropical wetland health and monitoring, and more recently, the deadly outbreak of Stony Coral Tissue Loss Disease in the Northern Caribbean, the use of drones is a newer development, having only began within the last four years or so. To date, they have mapped more than 20,000 acres (81 km^2) using a multispectral imaging drone and creating orthomosaics, which is used to support their and other conservation organizations' work, making recommendations to the Bahamian government, and monitoring the situation in a post-hurricane Dorian Bahamas (Dahlgren, et al., 2022).

Methodology

Study Areas

The study areas for this project are two national parks managed by The Bahamas National Trust. The first park, The Retreat (also known as The Retreat Gardens) is an 11-acre (0.04 km^2) park in the heart of the urban Bahamian island-capital of New Providence. Established in 1985, this terrestrial park was formerly one of the largest collections of palm trees in the western hemisphere and is now partially a botanical gardens and partially native Bahamian coppice habitat. It is a particularly important stopover and overwintering site for various species of migratory birds and the former headquarters of the BNT (Bahamas National Trust, n.d.). All drone missions for this park capture the park in its entirety due to its small size and ease of accessibility.

The second study area, Lucayan National Park (LNP), is a much larger national park, standing at 1937 acres (3.79 km^2) and found in central Grand Bahama. Established in 1982, LNP is a unique park in that it contains examples of five different Bahamian ecosystems: pine forest, coppice (broadleaf evergreen) forest, mangrove wetland, sandy shoreline, and coral reef. It is also the site of accessible cave system, which has been the source of archaeological artefacts including bones of prehistoric creatures and The Bahamas' original indigenous inhabitants, the Taíno (Bahamas National Trust, n.d.). This park is a popular tourist attraction on the island of Grand Bahama and is also the location of one of the most famous and beautiful beaches in the country, Gold Rock Beach. In fact, it was the second most-visited national park in 2018 according to the BNT (Bahamas National Trust, 2018). The drone missions for this park capture the entire terrestrial and coastal portions of the park boundaries as they exist currently, but do not show the marine area due to flight safety concerns and limitations by the drones in the possession of the BNT's GIS Unit.



Map 1: Context map showing the study areas for this project, with Bahamian islands outlined in yellow, national parks outlined in green, and their location on each island outlined in red. It should be noted that Lucayan National Park's boundaries extend into the ocean but will be excluded from this project.

UAVs Used

Three different UAVs were used for the collection of the aerial imagery used in this project. The first was a 3DR Solo, which is currently regarded as an older but still reliable drone optimized for GoPro cameras. The second and third drones used were both made by DJI, which is the largest drone company in the world and holds about 76% of the drone market (Arc Group, 2021). The specific models used were the Mavic 2 Pro and the Mavic 3T. All three drones' specifications are summarized in Table 1.

Table 1: Specifications of the three drones used to collect the imagery used as a part of this project.

	3DR Solo	DJI Mavic 2 Pro	DJI Mavic 3T
Weight (grams)	1,497	907	920
Camera	GoPro Hero 4	Hasselblad L1D-20c	DJI M3T
Sensor size (MP)	8.3	20	48
Max Speed (m/s)	24.5	20	15
Max Flight Time (mins)	20	31	45
Price at Launch ($USD)	$999.95	$1,499.00	$5,498.00

It should be noted that while the 3DR Solo and the DJI Mavic 2 Pro are considered low-cost drones, the DJI Mavic 3T is a specialized drone and does not fit into the cost range which describes low-cost UAVs. It was the drone available for use when the 2023 updated imagery for The Retreat was due to take place, however.

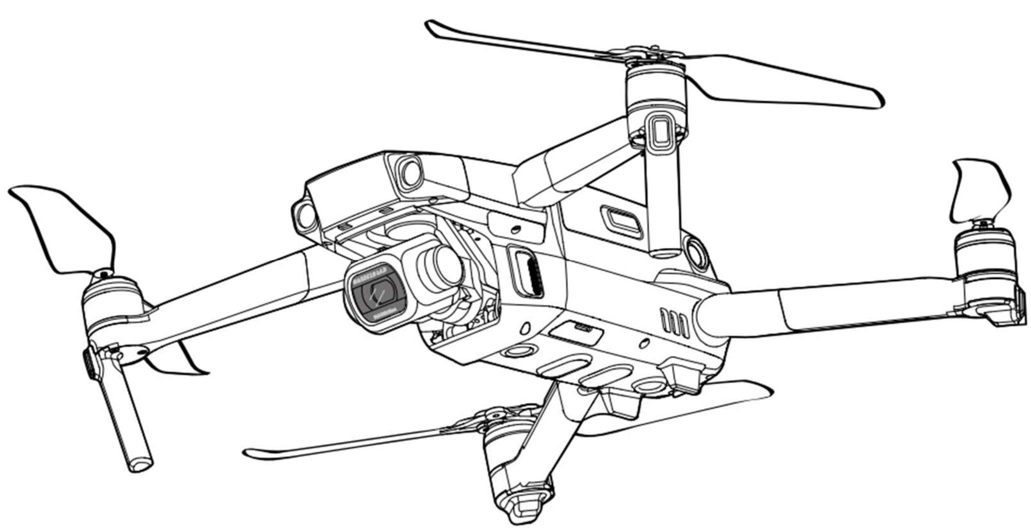


Figure 4: A drawing of the DJI Mavic 2 Pro, a low-cost UAV priced at $1,499 at launch in 2018. Image credit: Mavic 2 Pro's Quick Start Guide v 1.4. (DJI, 2020)

Flight Missions

To collect the aerial images, several different drone missions were flown by staff from the Bahamas National Trust. Missions are flight routes where a drone flies in a set path and takes photos with user-input settings such as photo overlap (which is used to line up individual photos to make orthomosaics), flight altitude, and starting location. While they can be flown manually, there are many different software applications to pre-plan and automate missions as well. The images for this project were collected with different mission software and criteria, depending on the area and person flying. Missions flown with the 3DR Solo used ArduPilot's Mission Planner, the Mavic 2 Pro used the mobile version of Pix4D, and the Mavic 3T used DJI's app, which is built into the drone's controller. Images collected in flight were stored on micro-SD cards and uploaded to BNT hardware and Dropbox folder as soon as possible.

More specific flight mission details can be found in Table 2, which lists the mission date, park, drone used, number of images taken, size in gigabytes of all photos from each flight, altitude, and approximate flight time. The rows highlighted are the photosets being used for this project.

Table 2: Statistics on the various missions flown for the two Bahamian national parks over the last 5 years. The rows highlighted in green indicate the missions that orthomosaic photographs, habitat maps, and change detection will be made from

Mission Date	National Park	Drone Used	Image Count	Folder Size (GB)	Flight Altitude (m)	Flight time (approx., mins)
19-Nov-2018	LNP	3DR Solo	265	1.47	120	45
16-Dec-2019	LNP	DJI Mavic 2 Pro	333	4.38	30	30
18-Feb-2020	LNP	DJI Mavic 2 Pro	1088	12	N/A	30
24-Feb-2020	LNP	DJI Mavic 2 Pro	1346	15.7	N/A	30
19-Jul-2021	LNP	DJI Mavic Pro 2	200	2.65	135	25
29-Mar-2018	The Retreat	3DR Solo	276	1.64	120	15
30-Mar-2018	The Retreat	DJI Mavic 2 Pro	310	8.12	120	15
4-Apr-2018	The Retreat	DJI Mavic 2 Pro	129	7.07	120	6
12-May-2022	The Retreat	DJI Mavic 2 Pro	153	1.88	120	6
21-Sep-2022	The Retreat	DJI Mavic 2 Pro	97	1.16	120	5
29-Jun-2023	The Retreat	DJI Mavic 3T	84	0.69	75	2

Image Processing

In the early stages of drone use, images were uploaded into image processing software, like Adobe's Photoshop Elements or Microsoft's Image Composite Editor (ICE). These software programs stitch the overlapping photographs into panoramic images, which often took several hours to overnight to complete processing. The results were very good however, and no seams would be detectable within the stitched together images. However, because they were simple panoramic images, they needed to be manually georeferenced to become fully-fledged orthomosaics. This was typically done using ArcMap 8.x software. In later stages, upon adoption of ArcGIS Pro, the images collected during drone missions could be collected and run through the software's Ortho Mapping functionality, which involves a similar but more complex version of image stitching. The process typically pulls location data directly from the EXIF (Exchangeable Image File Format) data, or the GPS point added to each image upon capture by the drone. This is very convenient, as it means the location data is already attached to each image, and therefore will be present before the orthomosaic is created. While the intent for this project was to create all orthomosaics from scratch, it could not happen due to the sheer size and difficulty in transferring individual drone photos, and so much of the imagery used was from previously composited orthomosaics.

Once all images were made into orthomosaics, they were set up in an ArcGIS Pro 3.x project, which is the software used for all major geoprocessing and spatial analysis. Images were visually assessed and geocorrected for minor errors to ensure the maximum overlap to set up for future geoprocessing and analysis. The images were also clipped to the boundaries of their respective national parks, with shapefile data from The Bahamas National Trust and The Nature Conservancy (Bahamas National Trust, 1977; Bahamas National Trust & The Nature Conservancy, 1977). Leaving the orthomosaics unclipped or using a buffer to account for edge effects was considered but it was ultimately decided to leave them out so that the results would focus solely on areas within the parks.

Classifications

Two types of classifications were used to create maps for this project. The first type of classification used was unsupervised classification, which used the same segmentation values as the supervised classification. ISO Clustering was used as the unsupervised classifier methodology, which is standard. The maximum number of classes created from each was 10, and all other training settings were left as the ArcGIS Pro Wizard's defaults. This included the maximum number of iterations at 20, cluster merges per iteration was 5, and minimum number of samples per cluster also 20. Reclassifying after class assignment was not conducted as a part of this project to minimize the human interaction with the unsupervised classification results. This was so the results of the unsupervised classifications would have as little human influence as possible. However, assigning classes did occur and classes and generally involved the same or similar classes as the supervised classification. Class habitat types and their respective colors and symbology remained consistent across both supervised and unsupervised classifications for both parks.

The second type was supervised classification, which is where the user inputs portions of an image and an algorithm is used to match spectral signatures of the images to what was input. For this project, Object-Based Image Analysis (OBIA) was used, meaning that pixels identified were used as a group and not on an individual basis. Additionally, because no classification schema for The Bahamas is readily available, the default NLDC2011 schema was used and edited to better suit the local habitats. These edited versions were saved to be park-specific schemas. The values for supervised classification segmentation were as follows: spectral detail was set to 10 (15 for 2018 imagery), spatial detail to 5, and minimum segment size to 20 pixels. Nine classes were used for Lucayan National Park (pine forest, coppice forest, water, mangrove forest, freshwater wetland, sand, barren, infrastructure, and bracken fern, which is an invasive species found in the park) and four for The Retreat (coppice forest, grass, buildings, and pavement), with the difference being that LNP has more habitat types than the Retreat, and thus needs more classes. A minimum of five and maximum of ten samples were used to inform each class to prevent under sampling and oversampling. Since The Bahamas' geology is entirely made of limestone, soil and exposed rock (classed together as 'barren') and sand were initially separate classes but ended up being combined into one for Lucayan National Park's supervised classifications. Similarly, infrastructure and pavement were combined for the Retreat's maps, given that all pavement is infrastructure. Reclassification of obvious misclassifications for supervised classifications did take place based on earlier, unpublished work done at The Bahamas National Trust (Bahamas National Trust, 2019). Supervised calculation rasters were also converted into vectors for easier geospatial analysis.

Change Detection

Change detections were conducted using ArcGIS Pro's Change Detection Wizard and only on the supervised classification results. This was so the most accurate and correct versions of the data were used. There were two sets of change detections done for each park: a time series for the Retreat between 2018 and 2022 and then 2022 and 2023, and another for Lucayan National Park between 2018 and 2020 and then 2020 and 2021 for a total of four outputs. This was done with the thought that the Retreat remained unchanged for the duration of the drone flights (except for in 2023 where major changes occurred due to government road works), while Lucayan National Park changed substantially after Hurricane Dorian in 2019 and incurred additional changes as a part of its recovery from that storm. The Categorical Change Detection method was used since each park was classified as the same categories and outputs were saved as feature datasets so that geoprocessing, spatial analysis, and related calculations would be easier.

Results

Orthomosaics

A total of six orthomosaics were produced and used for this project: three for each park. The Retreat used images taken in 2018, 2022, and 2023. The frequency was somewhat irregular because not much change occurred to this park until recently, although imagery of The Retreat exists for every year since 2018. Lucayan National Park on the other hand, used imagery from 2018, 2020, and 2021. This is because Hurricane Dorian severely impacted the park in September 2019, and the BNT thought to monitor the park through its recovery using drone images. The resulting orthomosaics can be seen in maps 2 and 3, which show the three results for each park next to each other and demonstrates visual differences in terms of both drone or camera type and any kind of changes that may have occurred within the bounds of the national parks.

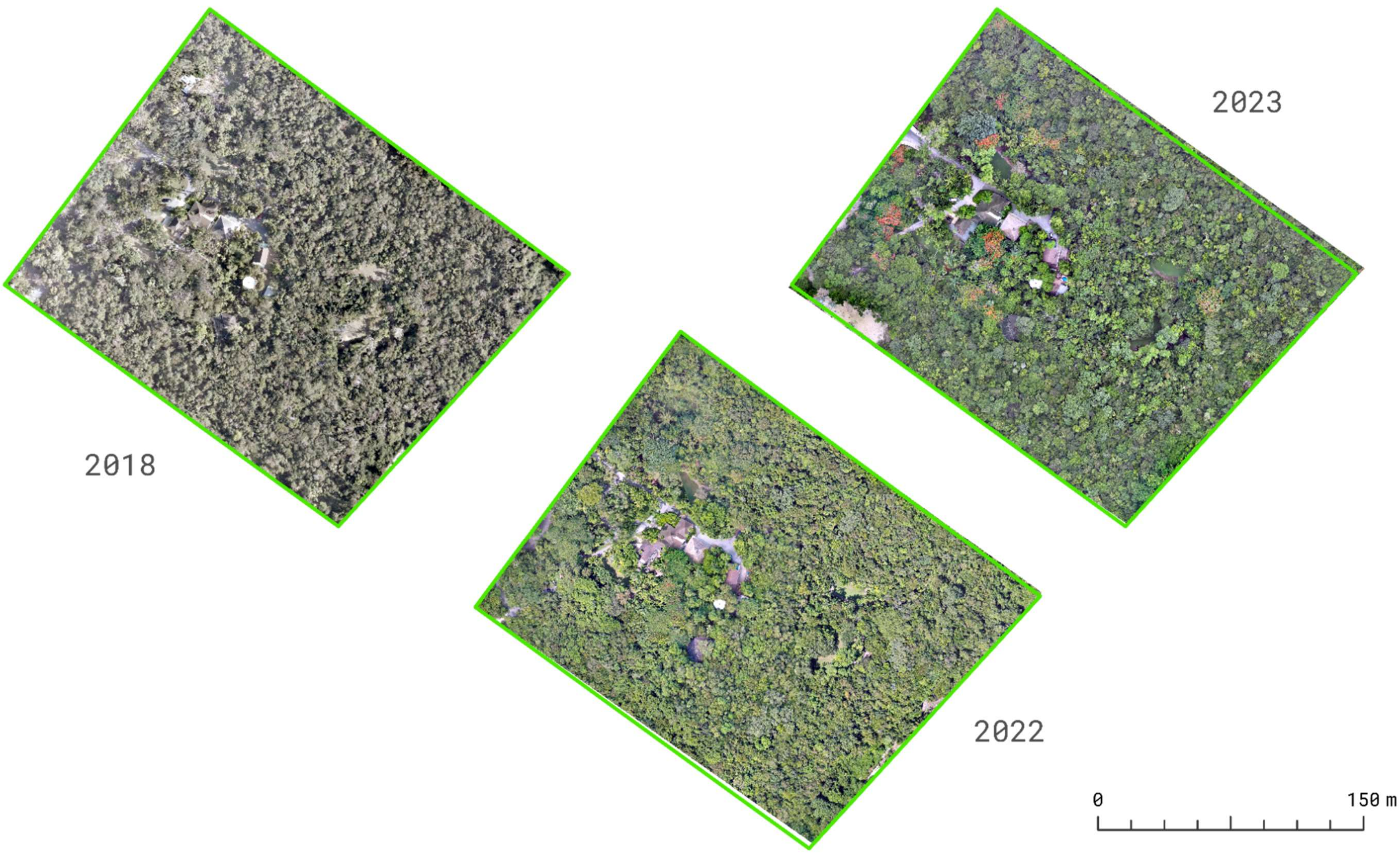
As shown by the imagery, while the entirety of the Retreat was captured by all three drone missions used, the Lucayan National Park imagery has some places that were not captured. This can likely be attributed to the somewhat awkward shape of the park as it exists currently, making a simple rectangle drawn as flight mission bounds more likely to not capture the whole park.

Additionally, the shoreline was the most inconsistently captured part of the park, as different drone pilots took different risks when it came to flying over the ocean.

Although statistics cannot be gleaned from simple visual comparisons of the images, there are changes that can be seen in the orthomosaics. For the Retreat, the imagery remains nearly identical between 2018 and 2022, but 2023's imagery shows the government roadworks that occurred between 2022 and 2023, which involved the installation of a roundabout at the park's main entrance (seen in the northwestern part of the park) and creation of an alternate entrance along a side street in the southwestern corner of the park. On the other hand, in Lucayan National Park, it is obvious that overall vegetation level after Hurricane Dorian (images from 2020 and 2021) is less than before the storm (2018) due to the greyer color the area has taken on. Additionally, the pavilion found in the northeast quadrant of the park lost its grey roof in the storm, and the only part that remained was the while concrete foundation. The most obvious change, however, is the massive area in the southeastern portion of the park's study area where a large area of whiteland (coastal) coppice forest was washed out by the storm at the end of the boardwalk, leaving a large body of water for months after. This was mostly filled in with sand by the time the imagery from 2021 was captured, but a small pool remains.

Orthomosaic Images of The Retreat

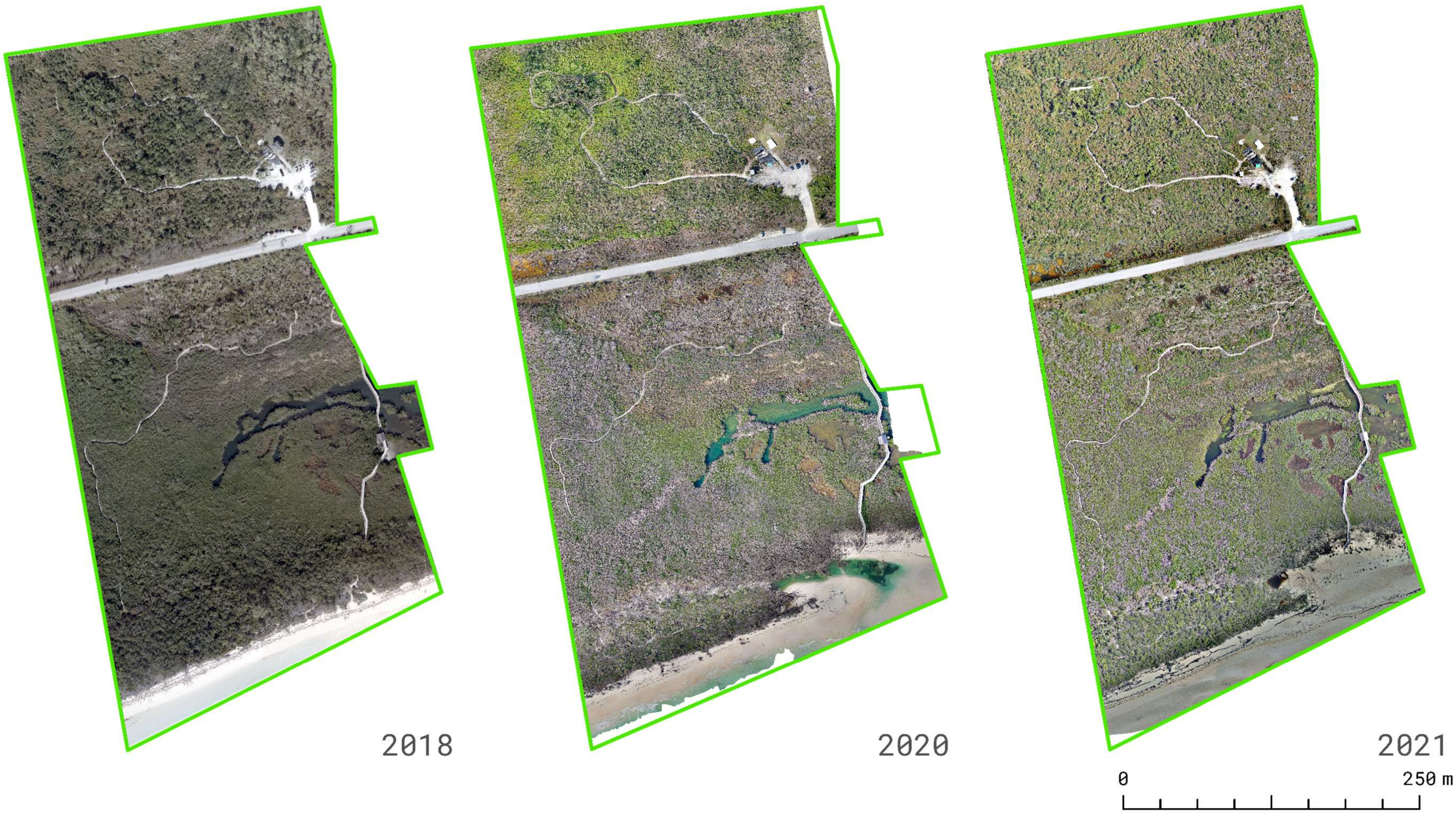
These are three orthomosaic images of The Retreat (National Park), located on the island of New Providence in The Bahamas. The imagery used to create the orthomosaics are all sourced from Unmanned Aerial Vehicles (UAVs) or drones.



Map 2: Resulting orthomosaic photographs The Retreat made from drone images taken in 2018, 2022, and 2023. Park boundaries are shown in green.

Orthomosaic Images of Lucayan National Park

These are three orthomosaic images of Lucayan National Park, located on the island of Grand Bahama in The Bahamas. The imagery used to create the orthomosaics are all sourced from Unmanned Aerial Vehicles (UAVs) or drones.



Map 3: Resulting orthomosaic photographs of Lucayan National Park made from drone images taken in 2018, 2020, and 2021. Park boundaries are shown in green

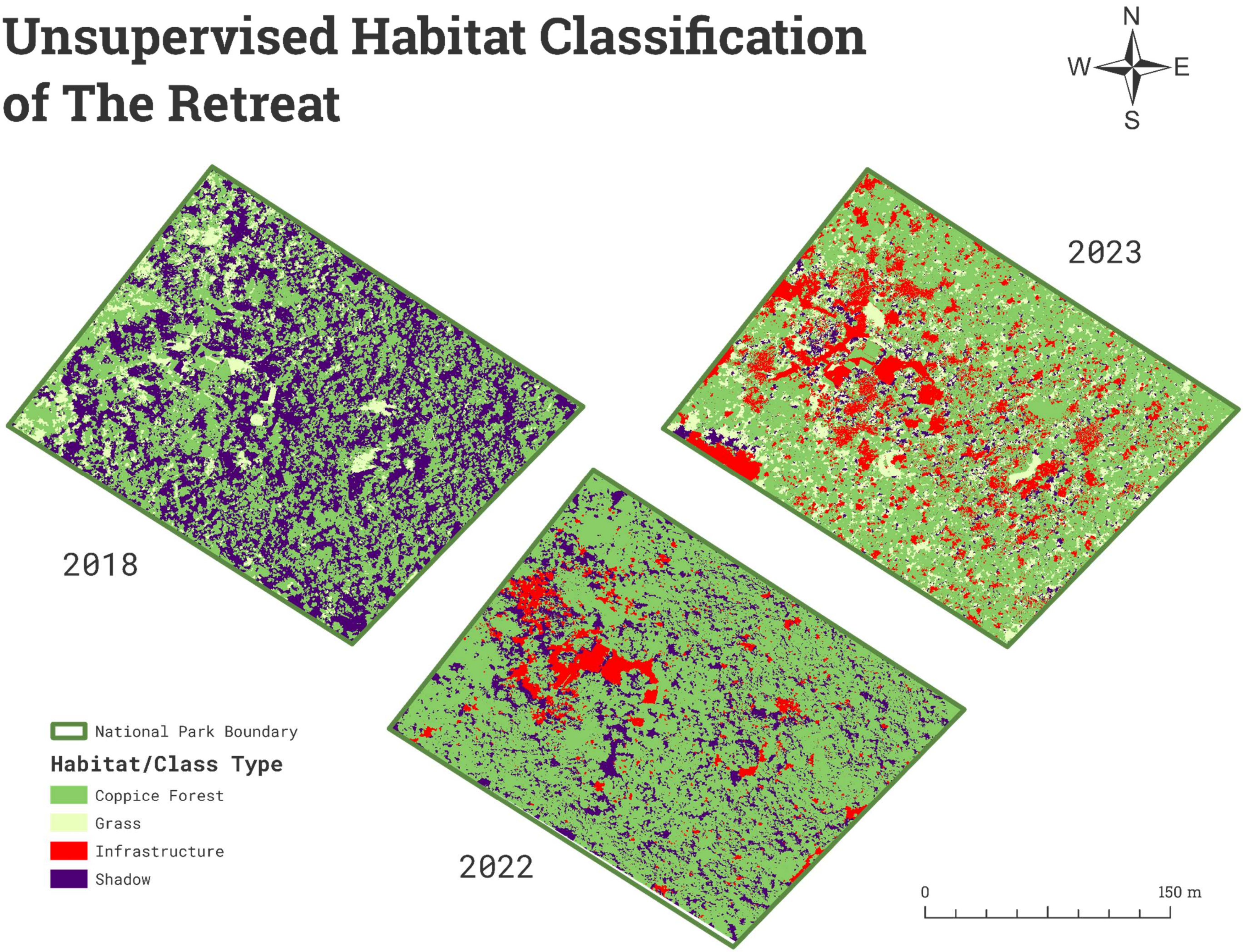
Habitat Classifications

Like the orthomosaics, a total of six outputs were produced for the project for each type of classification, one each for the two parks for each year that the orthomosaic was taken, for a total of 12 classification products.

Unsupervised classification had varying degrees of success depending on the drone used, image quality, and park itself. It did a fairly good job at picking up anthropogenic structures such as buildings and infrastructure and even did a pretty good job at picking out paths through vegetation, which are outlined clearly in the LNP maps. The gaps in LNP's 2020 imagery were classified as their own class, which was a good decision by the algorithm as it was unlike anything else in the image. It was assigned to its own class labeled "Blank" as it was just missing parts of the drone photographs. Additionally, another class called "Shadow" was added to both parks, as the algorithm did a great job of recognizing darker areas of the imagery. In the same vein, the newer, higher-quality drone cameras did a better job of differentiating between spectral signatures in the imagery, and much more granular detail was present in the 2020s imagery compared to the 2018 (although this could also be seen as a boon, as it resulted in very specific classification results).

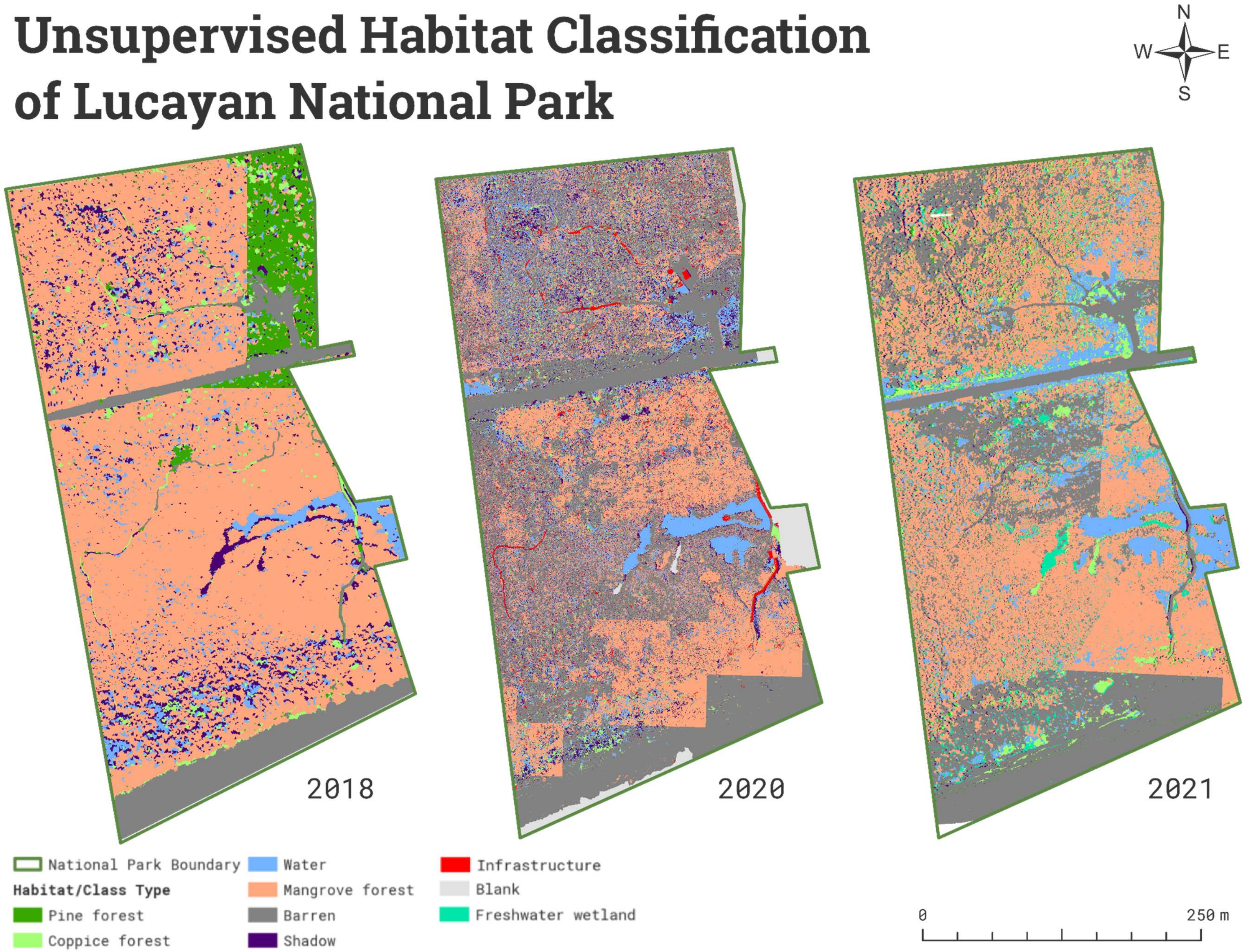
The unsupervised classifications also came with their own set of issues. For example, in the Retreat's 2018 unsupervised classification, no infrastructure was detected, and the algorithm decided to classify infrastructure as grass. Similarly, the Retreat's 2023 orthomosaic resulted in an overestimation of infrastructure. For LNP, the types of vegetation were grouped together, meaning that while vegetation was recognized to be relatively well, it wasn't differentiated particularly well, and so different habitat types ended up being lumped together. Some of these issues could be explained by the fact that each unsupervised classification was limited to ten classes per image, which is very limited for unsupervised classifications. Finally, it seems that some of the stitching from the orthomosaics were picked up by the classification algorithm and were present in the results in the form of stark linear separations between portions of the maps.

Unsupervised Habitat Classification of The Retreat



Map 4: Results of unsupervised classifications for the orthomosaics for The Retreat.

Unsupervised Habitat Classification of Lucayan National Park

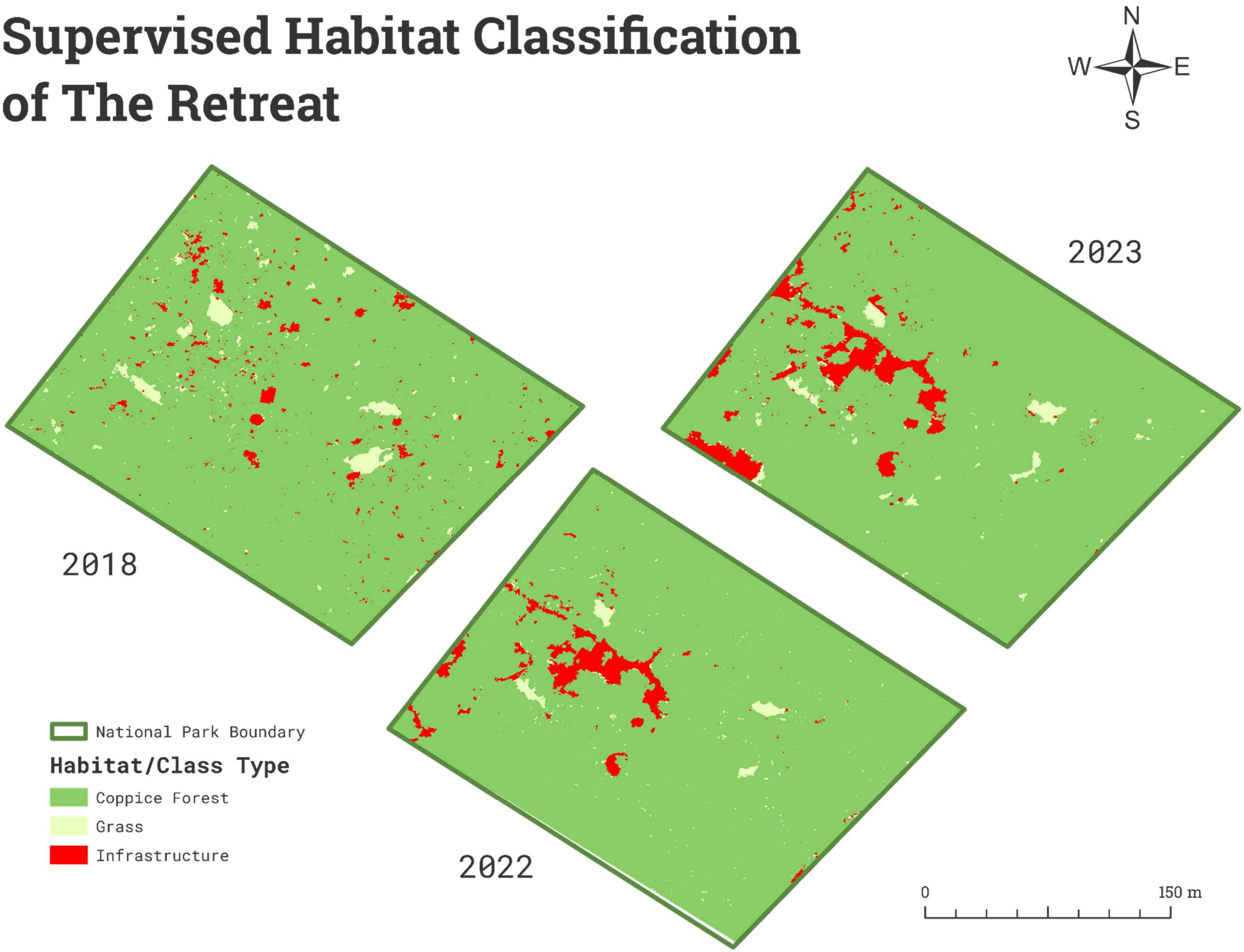


Map 5: Results of unsupervised classifications for the orthomosaics for Lucayan National Park.

Supervised classifications went somewhat more smoothly than unsupervised classifications in some respects and less smoothly in others. Generally, the Retreat's simple 3-4 class model worked well for the park due to its small size and the fact that there were not many classes for the algorithm to have to deal with. The results clearly show the most obvious changes in class, although some of these changes are less actual change and more real-life conditions that replicate change, such as certain trees being in bloom or having been trimmed recently. As for Lucayan National Park, some results turned out well, such as 2020's imagery being classified to be mostly barren, a result of defoliated vegetation exposing the bare earth, and the real-life hot spots of bracken fern being classified accurately to their locations in the park.

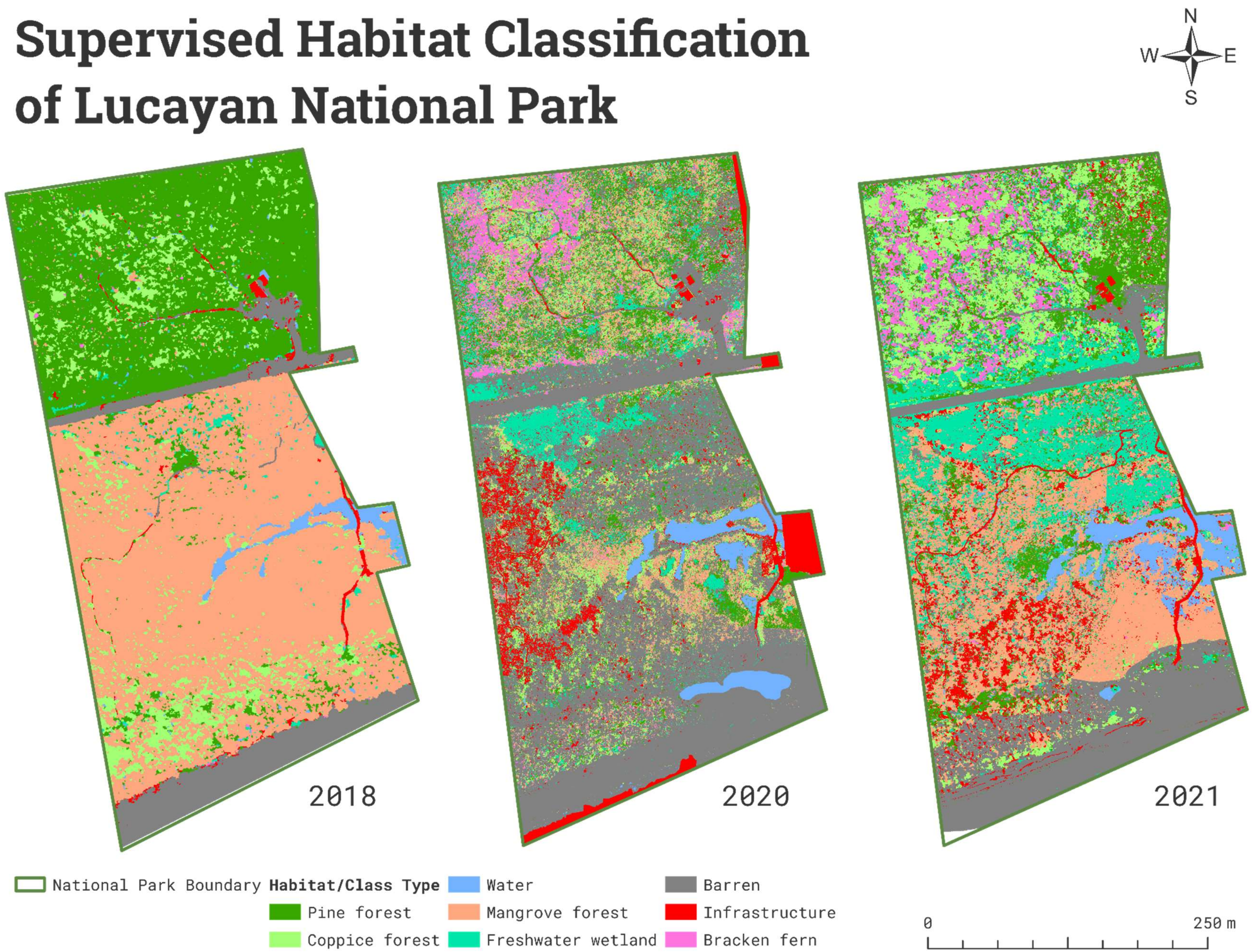
On the other hand, LNP's larger range of habitat classes made things more complicated for classifications. While some classes were picked up well and could be reassigned easily (especially in the older 2018 result), others were more complicated, either having spectral signatures that were too similar each other (sand and barren classes) or overlap in actual habitat confused the algorithm, as was likely the case with the pine and coppice forest classes. The empty portions of LNP's 2020 imagery ended up being classified as infrastructure, which is incorrect and will skew the results of the habitat change. Infrastructure was also overestimated in the southern portion of the park for both sets of classifications from the Mavic 2 Pro drone. Additionally, with the higher quality drone cameras, the micro-classifications of the imagery made things more complicated than necessary in some instances, although this wasn't nearly as bad as LNP's unsupervised results. Examples of this include are especially obvious in LNP's 2020 imagery which has its vegetation classes mixed up on a very, very small scale.

Supervised Habitat Classification of The Retreat



Map 6: Results of supervised classification of The Retreat.

Supervised Habitat Classification of Lucayan National Park



Map 7: Results of supervised classification of Lucayan National Park. The impacts of Hurricane Dorian can be seen in 2020's results.

The vectors resulting from the transformation of the supervised classification rasters were used to calculate summary statistics for each park's habitat type areas each year. The Retreat's data is small enough to fit into a table (Table 3), but area data had to be summarized and presented in the form of pie charts (Figure 5) for Lucayan National Park due to the larger amount of data and number of classes.

Table 3: Summary of the area in square meters for each of The Retreat's habitat types over three years.

Class Type	Year	Area (m^2)
Infrastructure	2018	1,140
Coppice forest		44,430
Grass		1,231
Infrastructure	2022	1,729
Coppice forest		43,567
Grass		585
Infrastructure	2023	2,517
Coppice forest		43,427
Grass		769

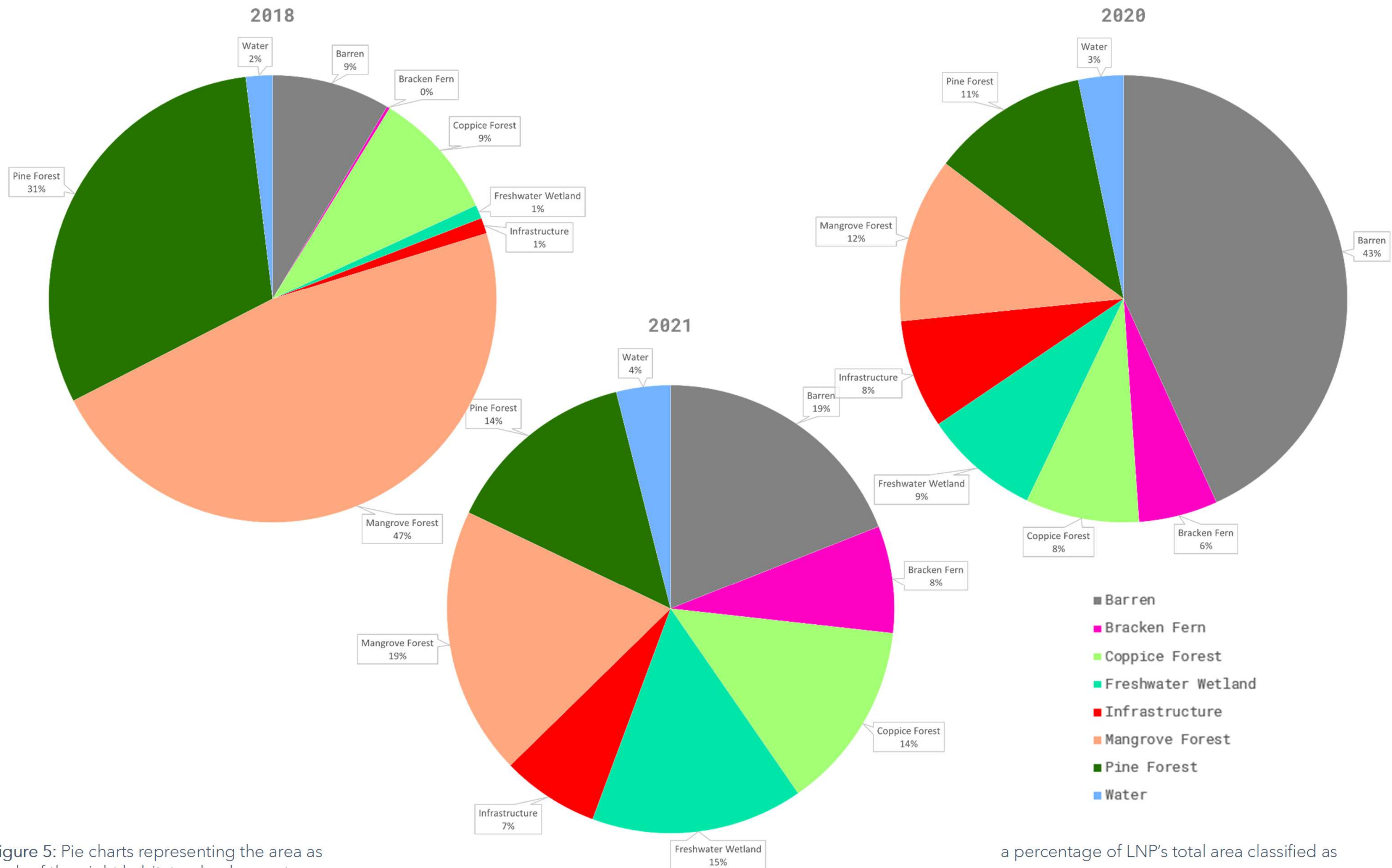


Figure 5: Pie charts representing the area as a percentage of LNP's total area classified as each of the eight habitat or land cover types.

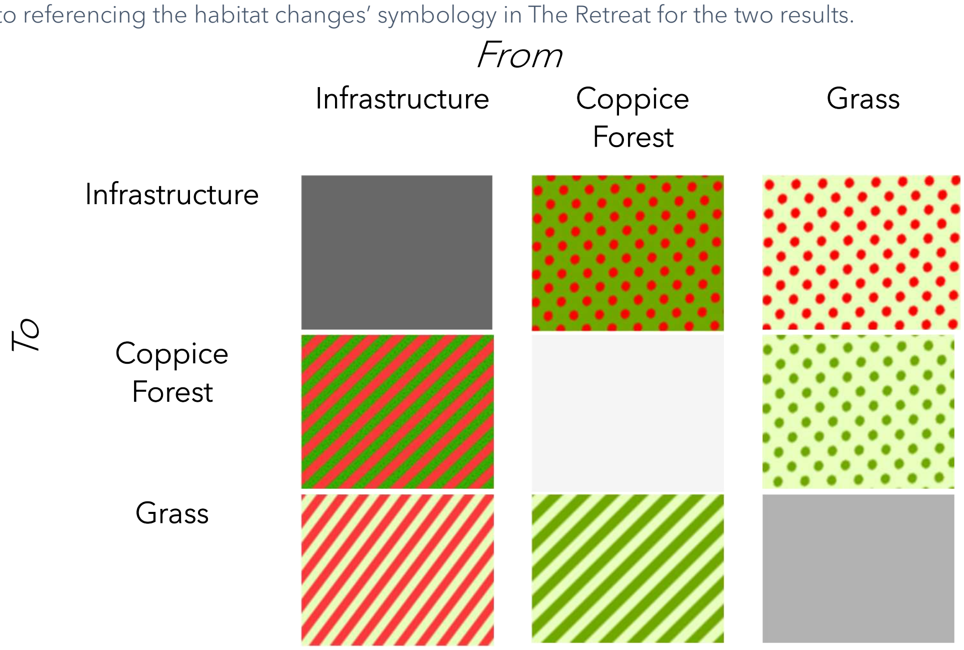
Change Detection

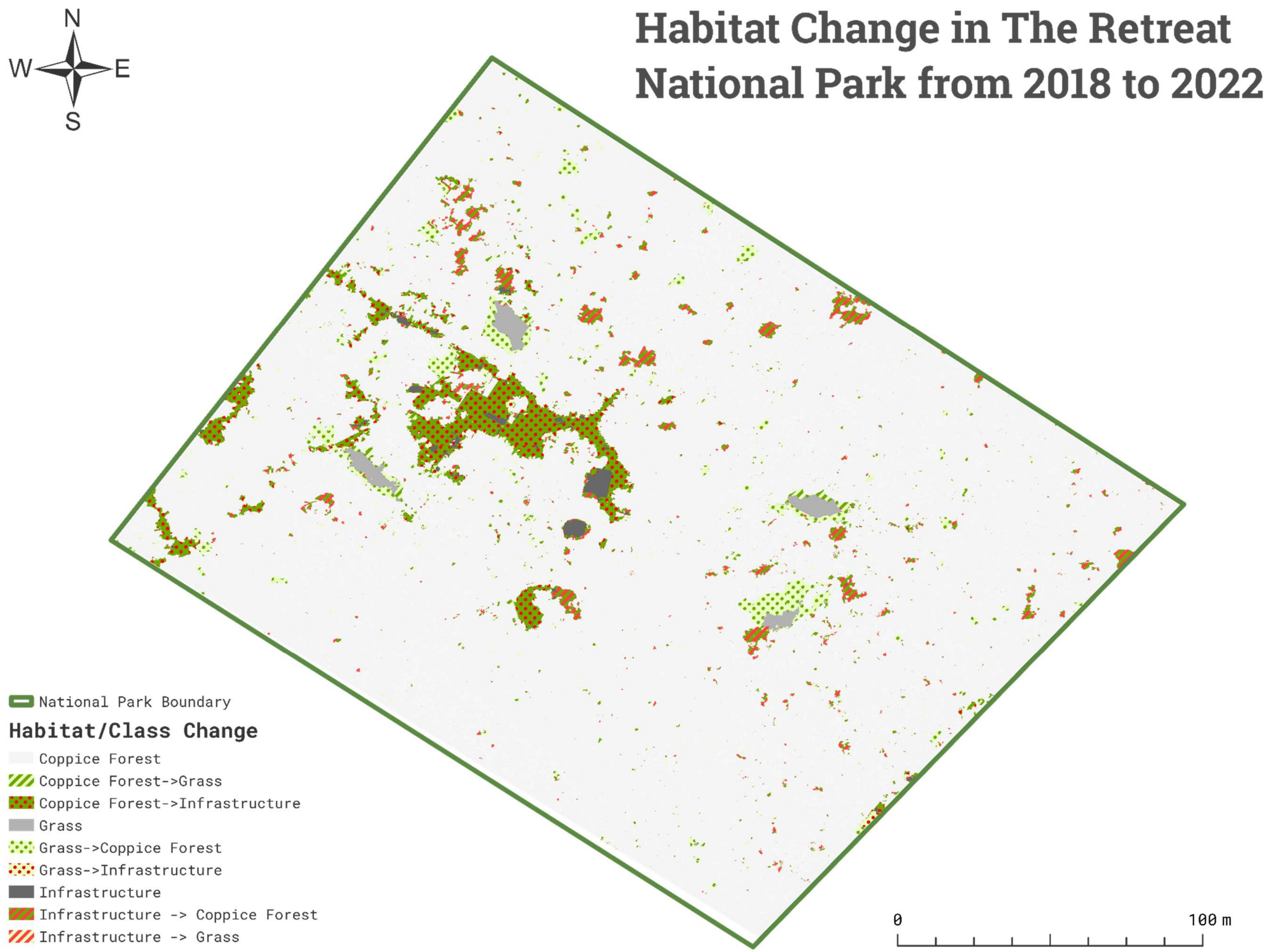
The change detections conducted were also relatively successful. The output of each resulted in a map in feature class format, which allowed for the area of each class change in square meters to be calculated (Table 4). Generally, for the mapped results, unchanged areas are represented by different shades of gray, which allows for changes to be more obvious. Changed areas are represented by colored hashed or dotted polygons (the new habitat type) on top of a base color (the old habitat type). A key showing the change symbology can be referenced in Table 5.

Table 4: Habitat change detection results for The Retreat National Park for the two change detection outputs, measured in meters squared.

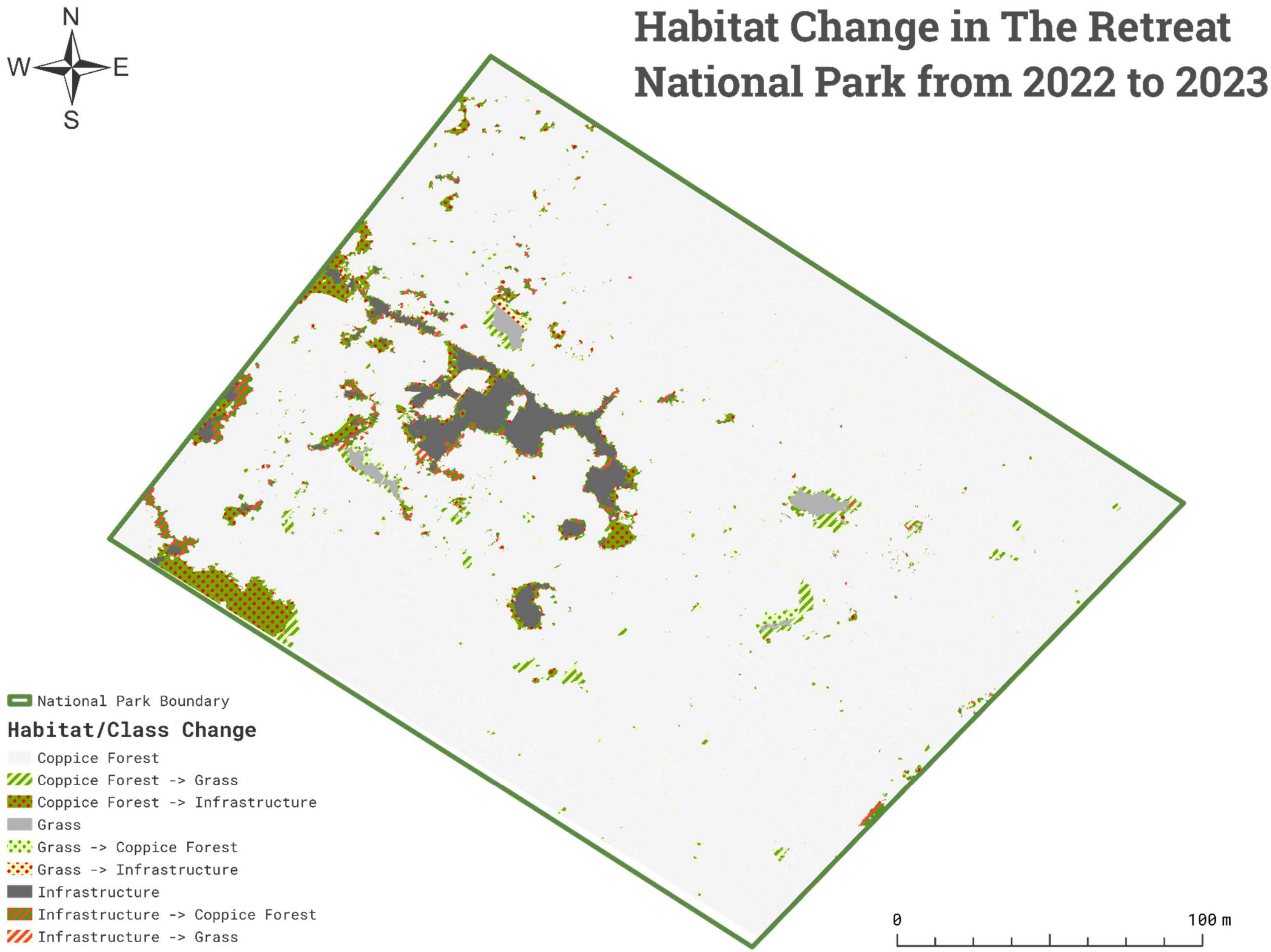
Class Type	Area (m^2) 2018-22	Area (m^2) 2022-23
Infrastructure	178	1,164
Infrastructure → Coppice Forest	930	535
Infrastructure → Grass	11	30
Coppice Forest	42,257	41,948
Coppice Forest → Grass	277	469
Coppice Forest → Infrastructure	1,506	1,238
Grass	298	256
Grass → Coppice Forest	871	279
Grass → Infrastructure	45	52

Table 5: Key to referencing the habitat changes' symbology in The Retreat for the two results.





Map 8: Result of the change detection for the Retreat from 2018 to 2022. Gray areas represent areas that were unchanged and colored areas represent areas that were determined to have changed habitat class.



Map 9: Result of the change detection for the Retreat from 2012 to 2023. Gray areas represent areas that were unchanged and colored areas represent areas that were determined to have changed habitat class.

While the Retreat resulted in manageable and easily digestible maps due to only having three classes, the change detection for Lucayan National Park must be presented in non-map format. This is because the sheer number of changes is difficult to present in a palpable map format. The top 5 habitat changes by area for each of the two change detections are presented in raw area format Table 6.

Table 6: Top 5 habitat change detection results by area (in square meters) for Lucayan National Park for the two change detection results.

2018-2020		2020-2021	
Class Type Change	Area (m^2)	Class Type Change	Area (m^2)
Mangrove Forest → Barren	33,737	Barren	21,626
Barren	11,096	Barren → Mangrove Forest	11,985
Pine Forest → Barren	10,943	Barren → Freshwater Wetland	11,138
Pine Forest	9,159	Barren → Pine Forest	6,795
Mangrove Forest	8,209	Barren → Infrastructure	5,515

However, with a total of 64 habitat changes, it was decided that the best way to represent the overall habitat change for Lucayan National Park would be through clustered heatmaps, which were created using R code in RStudio and the package pheatmap. These are which habitats changed to which in a statistical correlation visualization and are seen in Figures 6 and 7.

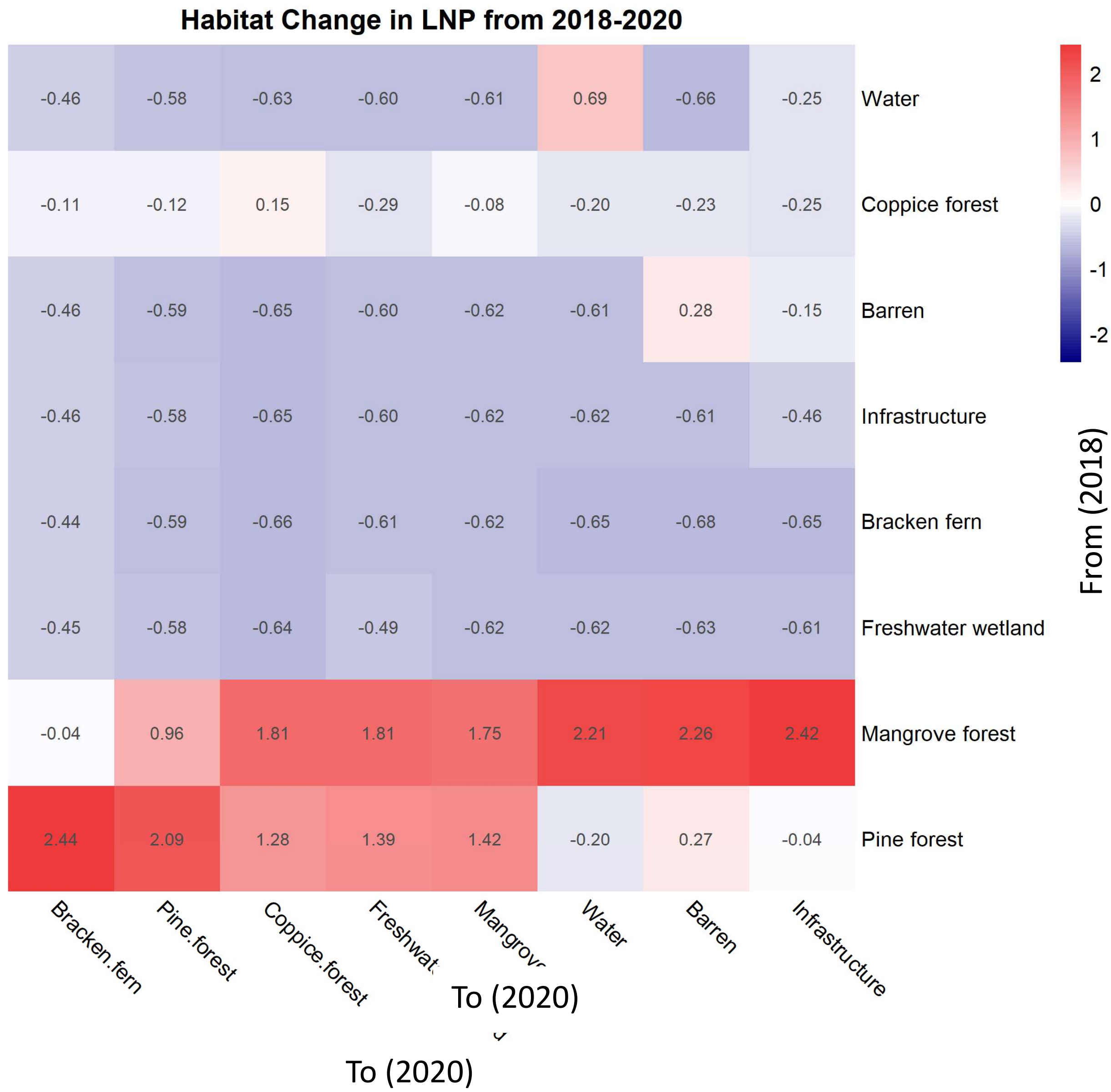


Figure 6: Heatmap showing the correlation between change in habitat classification from 2018 (Y axis) to 2020 (X axis).

In this heatmap, which represents classified habitat change from 2018 to 2020, there is a strong, positive correlation with change in mangrove forest's area to almost all other habitat types (except for bracken fern) and pine forest (except for infrastructure, water, and barren, which is a weaker correlation). There is also a medium inverse relationship between infrastructure, bracken fern and freshwater wetland, although this could have to do with the results of the classification from the 2018/3DR Solo's camera.

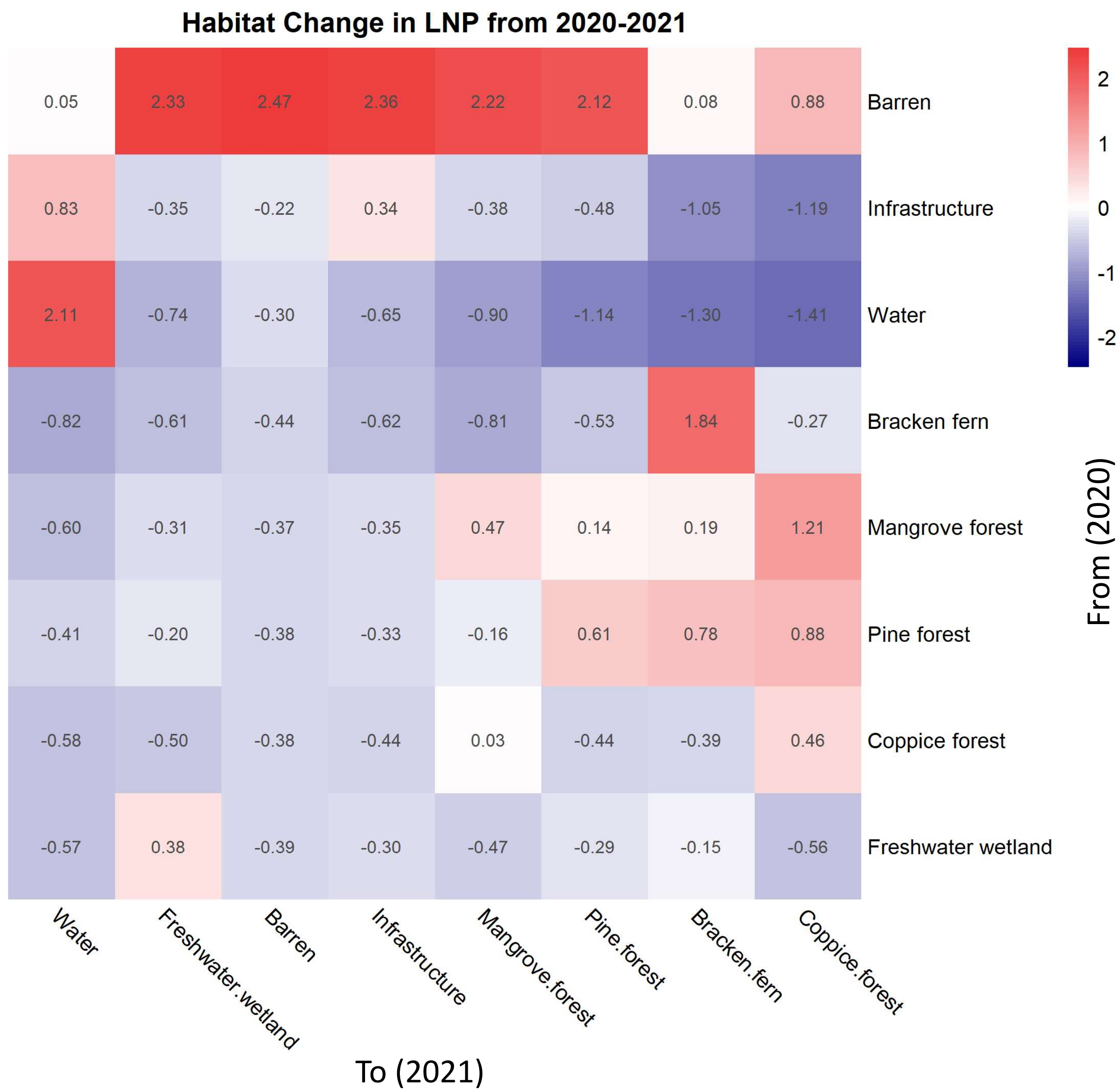


Figure 7: Heatmap showing the correlation between change in habitat classification from 2020 (Y axis) to 2021 (X axis).

The second heatmap, which shows change from 2020 to 2021, shows a cluster of correlation between changes in forest types, which could be attributed to misclassifications in the classification results. There is another cluster around water and infrastructure, which shows that there was a decrease in those two classes when changed to forest types. However, most significantly, there is a large cluster of positive correlation showing changed from barren land use cover to several different types of other cover, including pine forest, mangrove, and infrastructure.

Discussion

Significance of Results

Initially, the Retreat was meant to act as a control where not much happened between the different drone images that were used. However, there did end up being some differences in habitat classifications and change detections. These can mostly be attributed to classification errors in the 2018 imagery, which resulted in more infrastructure than existed while also misclassifying existing infrastructure as coppice, likely due to spectral similarities. However, some of the results can be explained by real changes like vegetative cover of certain trees, as the images were taken at different times of year. One such example is the Powderpuff Tree (*Calliandra haematocephala*), found on a grassy area in the eastern part of the park known as Pergola Lawn. This tree flowers drops its leaves every year and flowers in the spring before growing leaves. Since the specimen at the Retreat is quite large, it takes up quite a bit of canopy space when it does have leaves, which can be seen in the orthomosaic imagery.

Figure 8: A portion of the Retreat's 2018 (left) and 2022 (right) orthomosaic showing the area known as Pergola Lawn with the Powderpuff Tree without leaves and with leaves, seemingly causing a decrease in grass and increase in coppice forest habitat.

Another reason is that for the difference in coppice area is that it typical to trim trees before hurricane season to minimize damage to buildings and decrease potential cleanup if a tropical cyclone does come through. Finally, as previously mentioned, the Retreat did face some infrastructural changes between 2022 and 2023 with some government road works and creating a new entrance on the southwestern corner of the park. This explains some of the change in area from coppice forest to infrastructure, as the area in the drone imagery is still under construction.

Lucayan National Park is much different from the Retreat. It is a much larger area and there are more habitat types. That said, its habitat classification and change detection results do align with what would be expected after a major external factor, like a hurricane. The fact that the 2020 imagery was collected less than 6 months after such an intense storm meant that much of the immediate impact was still present in the park, which manifested in the results as many of the vegetation classes being changed to barren. The explanation for this is the defoliation of red mangroves (*Rhizophora mangle*), which make up most of the mangrove forest in the park, deaths of pine trees, which was the case for the vast majority of pine habitat on Grand Bahama

(Bahamas Forestry Unit, 2019), and the complete loss of portions of coppice habitat along the shoreline. In terms of recovery efforts, some of the barren areas in LNP were correctly changed to infrastructure, which reflects the installation of new boardwalks along the barren paths in the mangrove section of the park, as seen in Figure 9. Other examples of this were the 2020 to 2021 change detection results mostly showing that it was barren classes changing to other classes, signaling vegetative regrowth as plant species recovered their leaves and covered their bare roots, branches, and the ground.

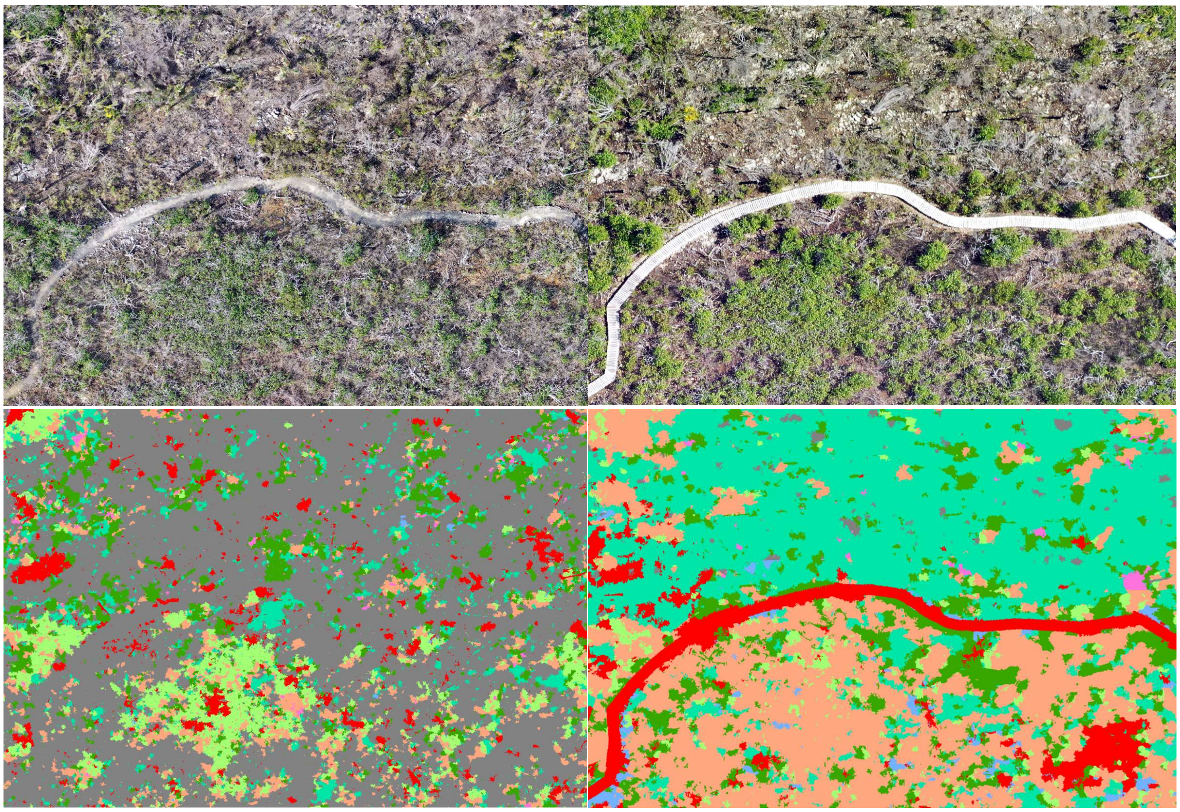


Figure 9: Comparison of orthomosaic imagery from Lucayan National Park in 2020 and 2021 and their respective habitat classification results, showing the installation of a boardwalk along a pre-existing path.

Furthermore, the invasive bracken fern (*Pteridium* sp.), was able to survive the impacts of the storm and remained as one of the prominent vegetation habitats in the northern part of the park. However, although it does not appear to be present in the 2018 imagery, the plant was present in the park before the storm, in areas that are consistent with what is reported by the 2020 and 2021 imagery (Bahamas National Trust, 2019).

If there is a time series of drone imagery, the methods used in this project could be relatively easily replicated across other areas. While there is further configuration needed for each part of the process, such as better training samples and perhaps more fine tuning of the classification settings, there is strong evidence that low-cost drone imagery can be used for habitat monitoring of national parks. While they do not solve every problem (and will still need supplementary data like ground-truthing and some forms of traditional biodiversity surveys) the benefits of using drones include decreased cost and decreased field time, increased monitoring efficiency, and of course, accurate habitat and change maps of each park. These can be used for park management, outward-facing documentation, public-engagement, and as support for further funding and resource applications. The BNT should continue to do this for as many of its parks as is feasible.

Challenges

This project did not take place without its fair share of challenges, which all may have influenced results. The drone orthomosaics, whether premade or made during this project, had some errors, like stitching or capture issues (seen in Figure 10) or user error, where pilots did not accurately capture areas (mostly a problem for Lucayan National Park). These were just raw data errors that had to be adapted to.

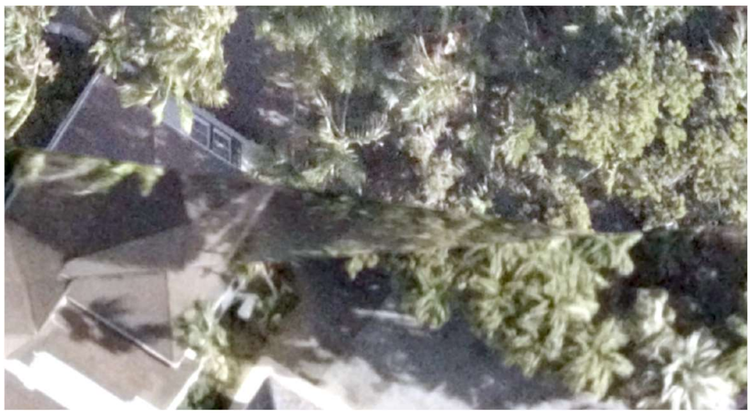


Figure 10: Orthomosaic stitching error in the 2018 Retreat orthomosaic image. Despite rerunning the orthomosaic from scratch, it still was present.

The orthomosaic creation and classification processes meant that the processing power of using a person took quite some time depending on the park and quality of imagery. For example, LNP's 2020 image specifically took more than 6 hours to undergo supervised classification. There were also some issues during sample training, as long load times, also likely attributed to insufficient hardware. These could be solved by having access to better machinery, and perhaps using slightly less high-quality imagery.

For the processes themselves, higher quality drone images made segmentation difficult as it produced a lot of different segments. Additionally, some of the georeferencing results ended up being a bit off for an unknown reason, and this affected the area of orthomosaics captured within park boundaries. This was most obvious with The Retreat's imagery. Finally, there seemed to be an issue where the algorithm had difficulty differentiating between the different types of green spectral signatures, particularly in the Lucayan National Park images. This could be explained by algorithmic error or the fact there is a real-life mixing of these habitat types in this park.

Conclusion

Low-cost drones are a useful tool across many different disciplines. Most often thought of for videography, they also have their uses in science and data collection, including conservation and habitat monitoring. Through use of GIS tools and geoprocessing, they can be used to create high-quality orthomosaic images of the Earth's surface, which can then be turned into different kinds of maps and products, providing an alternative to traditional field surveys while also being more cost-efficient and producing quality results. Some of these products include habitat or land cover maps, which can be created through supervised or unsupervised classification. Once you have a time series of classified images, you can also create change detections, which are products that can be used to monitor an area's differences over time. These are very appealing and useful options in the fields of Caribbean conservation, where funds and resources can be limited, and climate change, where documenting change is one of the first steps in solving it.

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