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The Use of Unoccupied Aerial Systems (UASs) for Quantifying Shallow Coral Reef Restoration Success in Belize

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Abstract: There is a growing need for improved techniques to monitor coral reef restoration as these ecosystems and the goods and services they provide continue to decline under threats of anthropogenic activity and climate change. Given the difficulty of fine-scale requirements to monitor the survival and spread of outplanted branching coral fragments, Unoccupied Aerial Systems (UASs) provide an ideal platform to spatially document and quantitatively track growth patterns on shallow reef systems. We present findings from monitoring coral reef restoration combining UAS data with object-oriented segmentation techniques and open-source GIS analysis to quantify the areal extent of species-specific coverage across ~one hectare of shallow fringing reef over a one-year period (2019–2020) in Laughing Bird Caye National Park, southern Belize. The results demonstrate the detection of coral cover changes for three species (*Acropora cervicornis*, *Acropora palmata*, and *Acropora prolifera*) outplanted around the caye since 2006, with overall target coral species cover changing from 2142.58 to 2400.64 square meters from 2019 to 2020. Local ecological knowledge gathered from restoration practitioners was used to validate classified taxa of interest within the imagery collected. Our methods offer a monitoring approach that provides insight into coral growth patterns at a fine scale to better inform adaptive management practices for future restoration actions both within the park and at other reef replenishment target sites.

Keywords: remote sensing; photogrammetry; drone-based mapping; acroporids; spatial ecology; image segmentation; local ecological knowledge (LEK)

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1. Introduction

Coral reefs are a vital component of tropical marine ecosystems, providing a variety of ecosystem service benefits such as habitat for a quarter of all marine species, shoreline protection and flood reduction, fisheries production, and climate regulation [1–3]. Globally, coral reefs have experienced large-scale decline resulting from anthropogenic influence and climate change impacts. Regionally, Caribbean acroporid corals were included in the US Endangered Species Act (2006) and designated as critically endangered on the IUCN Red List (2008). Marine scientists and ecologists have responded by initiating coral restoration activities to enhance the resiliency of vulnerable reefs, with active restoration techniques becoming a popular practice for many acroporid species [4–6]. Due to the increase in coral restoration work around the world, there is a need for improved monitoring techniques to measure the success of coral growth across increasingly larger restoration sites [7,8]. To address this issue, we investigated the utility of an Unoccupied Aerial System (UAS) to quantify the spatial extent and growth of three acroporid species (A. cervicornis, A. palmata, and A. prolifera) outplanted at sites located in Laughing Bird Caye National Park (LBCNP) in Belize since 2006. We demonstrate the use of UAS and photogrammetric techniques to collect and process multitemporal orthophoto mosaics and analyze changes in species population density between 2019 and 2020 using object-based segmentation and manual interpretation of imagery. We provide a quantitative UAS-based monitoring framework at a local scale for stakeholders in need of measuring coral restoration success. We were interested in documenting the natural spread of these reintroduced species over time over a larger area, which could not be captured by diver-based photomosaics or other traditional benthic monitoring methods, which sample at smaller spatial scales [4–8] (Figure 1).

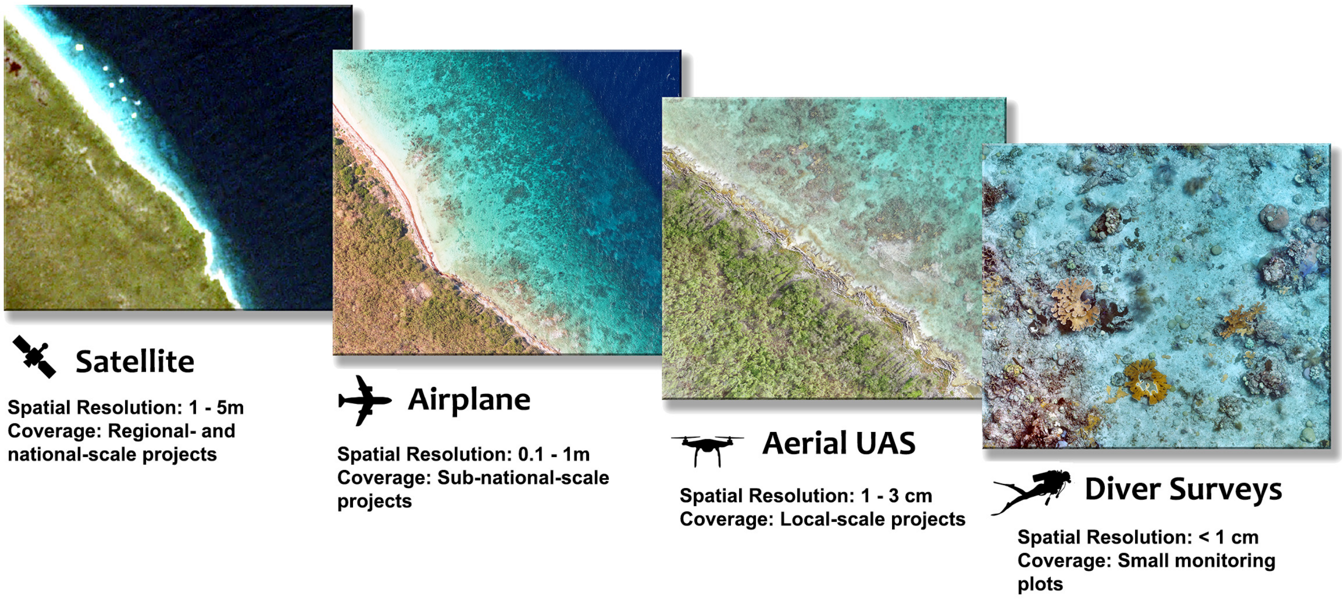

Figure 1. The platform used to collect remotely sensed data needs to match the scale of the research question. Here are examples of how the spatial detail in the data and the area coverage changes, based on the platform used to collect data. Each have their own advantages and disadvantages; however, the platform and the sensor used should be based on the project area and resolution required to answer the research question.

Optimizing site selection of restoration sites and measuring coral growth is of utmost concern to researchers and practitioners alike [4,9]. Documenting the success of most restoration programs is limited by a lack of quantitative monitoring during the post-outplanting and post-nursery stages, as indicated by NOAA's 2015 recovery plan for acroporid species, which highlighted concerns over a lack of standardized methodology for assessing the success of restoration programs [5]. Indeed, 60% of coral restoration projects report monitoring restoration sites for a period of less than 18 months, due to the lack of funds and capacity to apply a standardized monitoring approach to the program [4]. Historical means of monitoring have included single colony growth measurements, point intercept transects, and benthic quadrants. An increasingly used technique for quantitatively measuring changes in coral growth both above and below the water is Structure from Motion (SfM), a photogrammetric method for generating models of three-dimensional structures using multiple overlapping images [10–13]. Although underwater photogrammetric models generated by SfM techniques are well suited for monitoring small plots (up to 1000 m^2), this approach becomes more laborious and unpractical to use as the area to be monitored increases. In addition, it can be difficult to conduct underwater surveys in extremely shallow areas where acroporids often grow; hence, the aerial perspective provided by a UAS offers a potential monitoring solution in these areas.

The inclusion of monitoring at broader scales than possible with divers alone allows the integration of new findings from relevant research into restoration practice and understanding long-term trends, such as how storms naturally spread branching corals [14].

As spatial patterning may influence ecological processes relating to population assemblages and dispersal, understanding and quantifying the spatial aspects of the long-term post-outplanting step within the coral restoration process is imperative [15,16]. Having a holistic overview of the changes before and after outplanting from year to year will provide indicators of success, inform overall adaptive management of restoration programs, and lead to improved decision making based on spatially explicit information.

The advancement of UAS technologies and availability of low-cost consumer models provide an emerging monitoring tool at centimeter-scale spatial resolution (e.g., <4 cm) that was previously difficult to acquire. This highly adaptable "personal" remote sensing platform permits the collection of data on demand, providing a new monitoring tool for acquiring high-spatial- and temporal-resolution data that are customizable. Typically flown at altitudes below 120 m, UASs can be rapidly deployed below cloud cover, capturing very detailed data using specialized sensors and payloads to map and analyze ecological spatial patterns at precise temporal scales [17]. Being able to map pre-determined areas at precise times offers a distinct advantage for environmental monitoring, such as tracking coral reef restoration success. When flown at lower altitudes (e.g., <30 m), UAS technology has been used to analyze coral reefs and their associated changes in composition and biodiversity over shallow reef systems at very high spatial resolutions (e.g., <1 cm), providing the ability to detect individual coral colony species and quantify coral cover [16–18]. A UAS fills a niche for acquiring monitoring data at a local scale while covering a larger area (e.g., 2–4 km^2) than the typical spatial extent of monitoring data acquired through close-proximity photogrammetry underwater survey methods (e.g., 10 $\times$ 10 m^2) [18–22].

2. Materials and Methods

2.1. Study Area

Laughing Bird Caye National Park (LBCNP) is a 40.96 km^2 faro atoll that was declared within the broader Belize Barrier Reef Reserve System (BBRRS) in 1996 [23] (Figure 2). LBCNP makes up one of seven Marine Protected Areas (MPAs) within the BBRRS. LBCNP has retained a full-time ranger presence since 2003 and fosters a large tourism component due to its close proximity (~19.5 km southeast) to Placencia, Belize [21]. Fragments of Hope (FoH)—a community-based organization based in Placencia—has been actively replenishing acroporids at Laughing Bird Caye National Park since 2006 and is recognized as one of the most successful coral restoration sites in the world by the UN Decade on Restoration, not only for the longevity and extent of work at LBCNP but also for expanding their efforts (2015–present) to over 20 other sites in seven MPAs in Belize [23,24]. Our UAS monitoring research focused on the shallow fringing (<1–4 m depth) coral reefs surrounding Laughing Bird Caye, with an areal extent of ~2km^2. LBCNP was hit directly by Category 4 Hurricane Iris in 2001, decimating the caye and reducing the live shallow coral cover to less than 6%, which was the impetus for restoration efforts. Since active restoration began, the use of diver-based mosaics has demonstrated an increase of up to 60% in live coral from 2014 to 2020. However, these taxa naturally spread outside of these plots as they are less than 800 m^2 and as Caribbean acroporids are adapted to high wave energy and spread asexually, which has hitherto not been captured by diver-based mosaics, nor have any of the other outplanted sites outside of the diver-based mosaic plots, necessitating a new approach to quantify total coral growth.

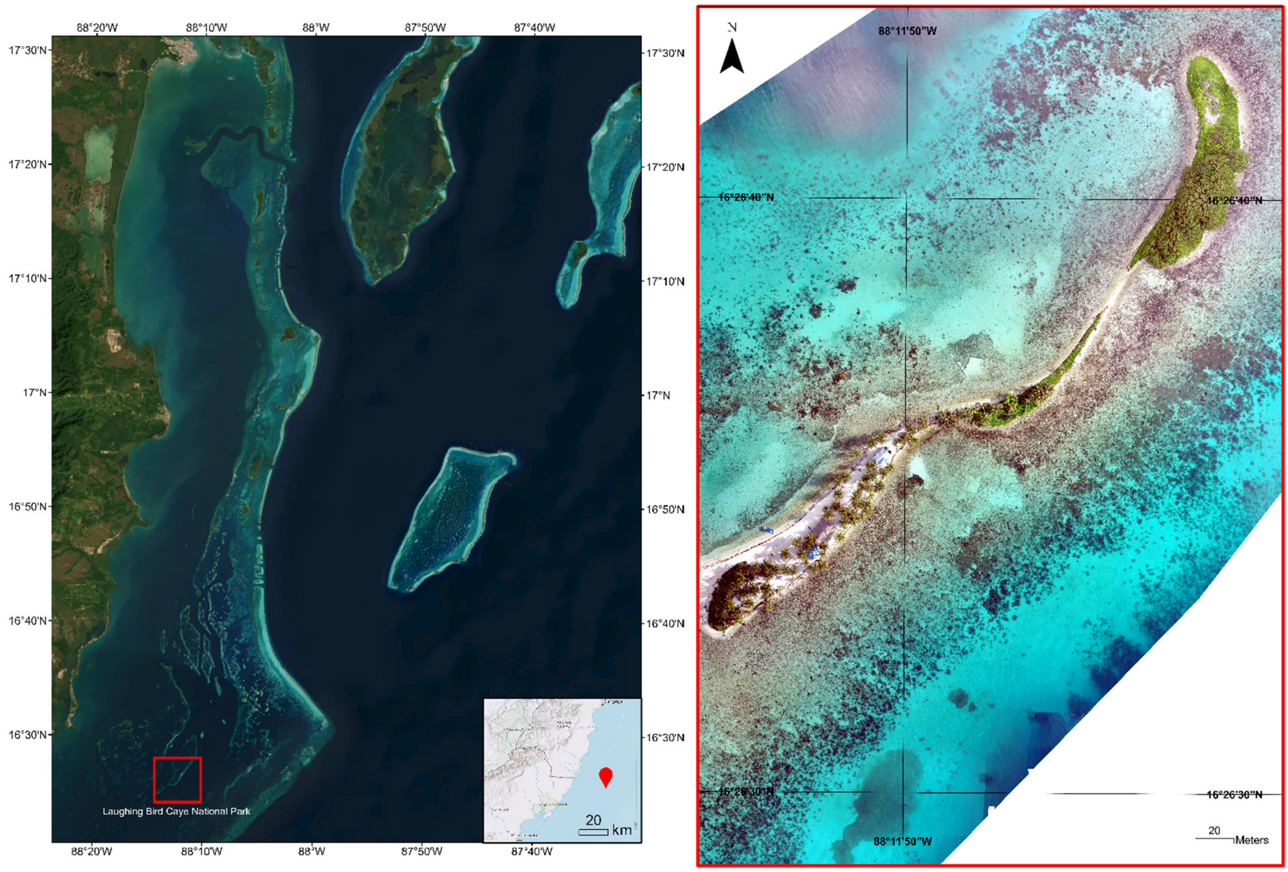

Figure 2. Location of Laughing Bird Caye National Park (LBCNP), a 40.96 km^2 faro atoll within the broader Belize Barrier Reef Reserve System (BBRRS) and 19.5 km southeast of Placencia, Belize. The orthophoto mosaic on the right was collected using a UAS on 19 September 2020 at a flying height of 70 m (1.9 cm spatial resolution) and was used to map ~1 ha of shallow reef area surrounding Laughing Bird Caye.

2.2. Coral Restoration Methods and Species of Interest

The ability to repopulate acroporids through asexual fragmentation has increased interest in restoration programs throughout the Caribbean [25,26]. Asexual restoration techniques, also known as coral gardening, can be summarized within three general steps: coral fragment collection, nursery stage, and subsequent outplanting [11,26,27]. Coral fragments are collected from wild colonies and tended to within an underwater "nursery" where they are grown to the stage appropriate for reintroduction onto the reef. Fragments are then replanted out to sites chosen with specific criteria and expected to grow and replenish local populations.

Following initial outplanting in 2006, restoration activities by FoH were scaled up with in situ coral nurseries and mass outplantings in 2009–2010 at LBCNP, with 87,267 fragments outplanted in LBCNP through 2021 [5,24,28]. FoH cultivates restoration for three Acroporid taxa: *Acropora prolifera*, *Acropora cervicornis*, and *Acropora palmata* (Figure 3). Elkhorn coral, *Acropora palmata*, is a fast-growing, branching coral that was once the most dominant species in southern Belize and is most often found within the shallow reef crest where high wave energy is prevalent [29,30]. *A. palmata* abundance has decreased throughout the Caribbean over the past 40 years, including southern Belize, where estimated losses are over 97% [31]. Elkhorn coral provides storm protection to coastlines in addition to providing habitat to fish and invertebrate species. Staghorn coral, *Acropora cervicornis*, is an additional branching, fast-growing stony coral whose range has also been reduced within the Caribbean [32]. Both of these species are increasingly targets for coral restoration, with reports of success [33]. *Acropora prolifera* is a coral hybrid of staghorn and elkhorn coral, considered a putative first-generation hybrid between *A. palmata* and *A. cervicornis* [34].

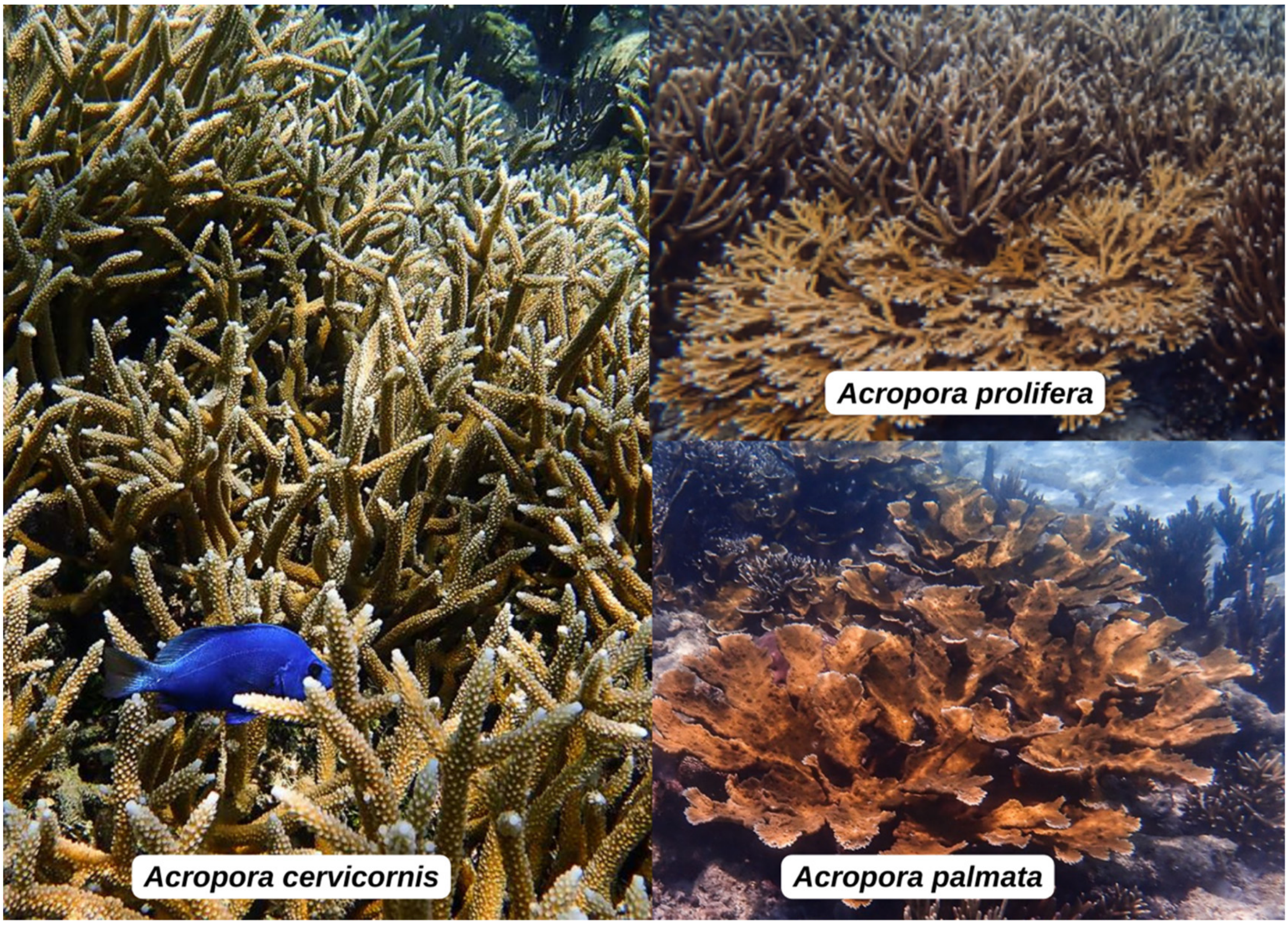

Figure 3. Examples of three endangered Acroporid species that were mapped using a UAS: *Acropora prolifera*, *Acropora cervicornis*, and *Acropora palmata* that are target species for asexual coral restoration within Laughing Bird Caye National Park. Photo credit: Fragments of Hope.

2.3. UAS Data Collection

Table 1 shows the dates and flight parameters when imagery was collected over LBCNP using a DJI Phantom 4 Pro v2 multi-rotor UAS with a fully integrated 3-axis gimbal. This consumer drone costs approximately USD 1800–2500 and weighs 1375 g. It has a maximum data collection time of 20–25 min depending on environmental and weather conditions and can typically map ~90 ha at 3.3 cm spatial resolution flying at an altitude of 120 m using one fully charged battery. The 1-inch CMOS sensor in the RGB camera (20 MP (5472 × 3648)) operates using a mechanical (global) shutter with shutter speeds up to 1/2000 sec. Although fixed-wing UASs are able to map larger areas on a single battery, multi-rotor UASs have the advantage of being more easily deployed and recovered from a boat. In addition, they have the ability to hover at variable heights over coral colonies to acquire more detailed images that can be used for field verification and accuracy assessments of the resulting classification as well as further analysis of coral health. This approach can be useful in shallow, high-wave-energy areas that are difficult and dangerous for snorkelers to access.

Table 1. Dates and flight parameters when photogrammetric imagery was collected over LBNP. All flights were collected using 70% front and side overlap.

Date/Time	Flying Height (m) (AGL)	Spatial Resolution (cm)	Area Mapped (ha)	Conditions	RMSE (m)
01-08-2019	60	1.8	12.4	Flat seas, scattered clouds	2.95
20-08-2020	63	1.9	20.8	Flat seas, scattered clouds	3.01

All missions were planned and executed using DJI Ground Station Pro (DJI GS Pro), an Apple iOS iPad mission planning app. Stereo imagery with 70% front and side overlap was acquired at an altitude of 60m Above Ground Level (AGL). When determining the appropriate flying height, it is recommended to first acquire test data at varying heights (e.g., 50 m, 75 m, 100 m) under the same ocean surface and solar conditions to assess the resulting spatial resolution and ability to discriminate and identify individual coral species. There is a trade-off when flying at lower altitudes to acquire higher resolution images since the area one is able to map is exponentially reduced. Ideally, the optimal combination would be to have the UAS fly as high as possible to map a larger area, while still having sufficient spatial resolution to accurately identify individual coral species (Table 2). To ensure maximum water penetration in the shallow zone (<3 m depth) and detailed capture of the intertidal reef surrounding LBCNP in the UAS imagery, data were acquired during calm sea state (minimal waves), low wind speed (<5 knots), low sun angle (e.g., early morning at 07:00–09:00 or 16:00–18:00 local time) to minimize sunglint on the water surface. For optimal data collection, it is recommended to use the fastest shutter speed possible based on light conditions (e.g., 1/1000s) and to let the aperture and the ISO autoadjust as necessary to ensure proper image exposure. This approach will minimize image blur and thereby facilitates photogrammetric reconstruction and interpretation of the images. It is important to recognize that both refraction at the water surface and scattering and absorption within the water column will spectrally and spatially alter the appearance of the seabed [35].

Table 2. Flying heights and resulting spatial resolution and corresponding area mapped using a DJI Phantom Pro v2 when image capture is set to 70% front and side overlap.

Flying Height (m) (AGL)	Spatial Resolution (cm)	Area Mapped (ha) on One Fully Charged Battery (Optimal Conditions)
25 m	0.7	5
50 m	1.4	21
75 m	2.1	45
100 m	2.7	78
120 m	3.3	94

2.4. Photogrammetric Processing

The photogrammetric software package Pix4DMapper (version 4.5.2, Pix4D SA, Lausanne, Switzerland, https://pix4d.com/, accessed on 1 August 2019) was used to process the UAS data into a point cloud, digital surface model, and orthophoto mosaic. Pix4D is available in both the desktop and cloud modules and has a fully automated workflow for orthophoto generation and surface modeling which is flexible and scalable. The process for generating the UAS products first starts with orientation and alignment of all images using the EXIF header geotagged image information and then advanced bundle block adjustment (position and orientation of each image). As part of this process, an algorithm searches for and matches millions of image features (known as "key points") between overlapping images and calculates each point's three-dimensional coordinates. These key points (sometimes called the sparse point cloud) are used to fix the positions and orientation of the camera at the time each image was taken. Once this is completed, additional points are identified to create a dense point cloud. The resulting dense point cloud is then used to create a digital surface model (DSM). Finally, the software uses the DSM to project every pixel and generate the orthophoto, which is a planimetrically corrected image with, ideally, all geometric distortions removed. The geometric correction root mean square error (RMSE) is reported in Table 1. It is important to note that without high-precision GPS correction (either Real-Time Kinematic (RTK) or Post-Process Kinematic (PPK)), the geometric accuracy of the resulting orthomosaic using the onboard GPS is typically between 2 and 5 m horizontally (depending on the UAS model used). When conducting change detection between image collection dates, it is important to align the pixels using RTK or PPK methods or by using Ground Control Points (GCPs) based on accuracy requirements. If the processing of the orthomosaic fails, it is typically the result of low key point generation within overlapping images. This can be due to insufficient overlap, low texture of the seabed, or poor image quality, such as image blur (shutter speed too slow), which can be due to environmental variables such as sunglint or wave action.

2.5. eCognition Segmentation

An Object-based Image Analysis (OBIA) segmentation was applied to all resulting RGB orthophoto mosaics using Trimble eCognition v9.5 software. The derived objects represent pixels of similar spectral value ranges and are treated as entities. A multiresolution segmentation was applied to the orthophoto mosaics using a double-layer weight assigned to the blue and green channels of the RGB image and blue/green ratio layer (due to the deeper water penetrating characteristics) as well as the following parameters: scale: 60, shape: 0.1, compactness: 0.5. The scale parameter guides the size of the objects and limits the level of heterogeneity. The smaller the number, the smaller the size of the objects. Segmentation works by identifying single image objects of one pixel in size and merging them with their neighbors, based on relative homogeneity criteria. This criterion is a combination of spectral and shape properties. A higher shape criterion value means less value will be placed on color (i.e., spectral properties) during segmentation and a higher compactness criterion value will result in more compactness of the objects after segmentation. The scale, shape, and compactness parameters were determined by experimenting with different values until coral colonies appeared to be well segmented in the UAS imagery. While eCognition also has a classification ability, due to the small spatial extent of the study area and relative ease of manually identifying taxa of interest, only the software's segmentation ability was employed.

2.6. Manual Classification of Segmented Polygons

Local ecological knowledge (LEK), largely understood as the unique perspectives and knowledge held by groups of people regarding their local ecosystems, was provided by FoH staff integral to both our manual classification and accuracy assessment process [36]. Once the image objects were derived from the high-resolution orthoimage, FoH staff assisted a non-FoH-affiliated individual by showing areas within the aerial imagery where there were GPS ground-truthed points where taxa of interest were initially outplanted. These examples of each taxon from the aerial view was instrumental in helping the outside individual acting as classifier to identify key detectable features of each coral taxon discernable from UAS imagery. These reef features were distinguished based on their unique color, shape, and pattern. From there, the individual classifying the imagery did so independently, without input from FoH staff. The manual classification process was conducted using Quantum GIS open-source software [37]. Classes used in the manual classification solely focused on the taxa of interest, with APRO, ACER, and APAL representing *A. prolifera*, *A. cervicornis*, and *A. palmata*, and with other benthic structure unquantified. Classified objects of each species were then used to calculate the area in square meters, using the area calculation functionality in QGIS.

2.7. Accuracy Assessment

LEK has been shown to effectively integrate with remote sensing accuracy assessments, with LEK being used to verify species identifications utilizing the unique insights provided by those with expert in situ knowledge [20]. Within Caribbean marine planning, LEK has been widely utilized in the geospatial process via participatory mapping and the integration of local stakeholder knowledge to inform and validate final results [38]. Indeed, by integrating LEK within a more traditional geospatial methodology, including data collection, analysis, and accuracy assessments, more nuanced and customized ecological monitoring programs can be crafted [18]. Coupling UAS technology with LEK has primarily focused on terrestrial applications, with accuracy assessment through LEK proving as accurate as those gathered by professional scientists, but with lower operational costs and more detailed, nuanced perspectives [39,40]. Likewise, ocean- and coral-reef-focused monitoring can improve when combined with the perspectives of local experts to improve monitoring efforts and create more effective and sustainable approaches by combining methodologies [41].

In our study, FoH staff provided LEK through their experience working on the reef, which was used to qualitatively review and validate the resulting classification conducted by the independent classifier. FoH staff drew upon a vast amount of knowledge regarding LBCNP to review and validate the outside classification, as FoH staff have monitored all outplants in water at LBCNP monthly from 2006 to the present. In addition, FoH monitors all outplants in situ using cameras every 1–2 months. Every outplant is recorded with the date of outplanting, species, source, number of outplants, and subsites, complete with GPS coordinates.

In parallel to the qualitative, LEK-led accuracy assessment, the independent individual who conducted the manual classification also completed an additional accuracy assessment using a random stratified point sample that consisted of 100 sampling points total per imagery dataset (2019, 2020), randomly placed across the one-hectare study area, each a minimum distance of 1 m apart. Classes used for the accuracy assessment included separate classes for each taxon of interest, and an additional class for other taxa including a non-coral benthic structure.

A traditional field accuracy assessment was not conducted due to existing FoH in situ monitoring schemes, in addition to imagery providing sufficiently high spatial resolution. At 1.8 cm resolution, the UAS imagery provided the required detail to identify each taxon of interest, which had distinctive features that were easily detectable. This is the first method that has allowed quantification of the entirety of replenished reefs at LBCNP, detecting annual changes from natural spread, and verifying appropriate coral selection. This approach has been successfully demonstrated for small restoration areas, but for larger reef tracts deep learning methods may be applied using trained libraries to automatically identify the features of interest [42,43].

3. Results

3.1. Coral Cover Quantification

As the acquired UAS imagery had a spatial resolution of 1.8 cm, we were able to identify individual species and quantify coral cover for each species for both the 2019 and 2020 datasets (Figure 4). Each species had unique spatial attributes (e.g., color, tone, texture, and shape) that were easily discernable from an aerial perspective, making the classification and validation a simple process with the aid of local ecological insight and input from FoH staff. *A. cervicornis* was demonstrated to be the dominant coral species with cover throughout the caye, with *A. prolifera* and *A. palmata* represented in only a few colonies.

The results from the accuracy assessment show an overall 98% accuracy for 2019 and 100% accuracy for 2020, derived from the random point sample.

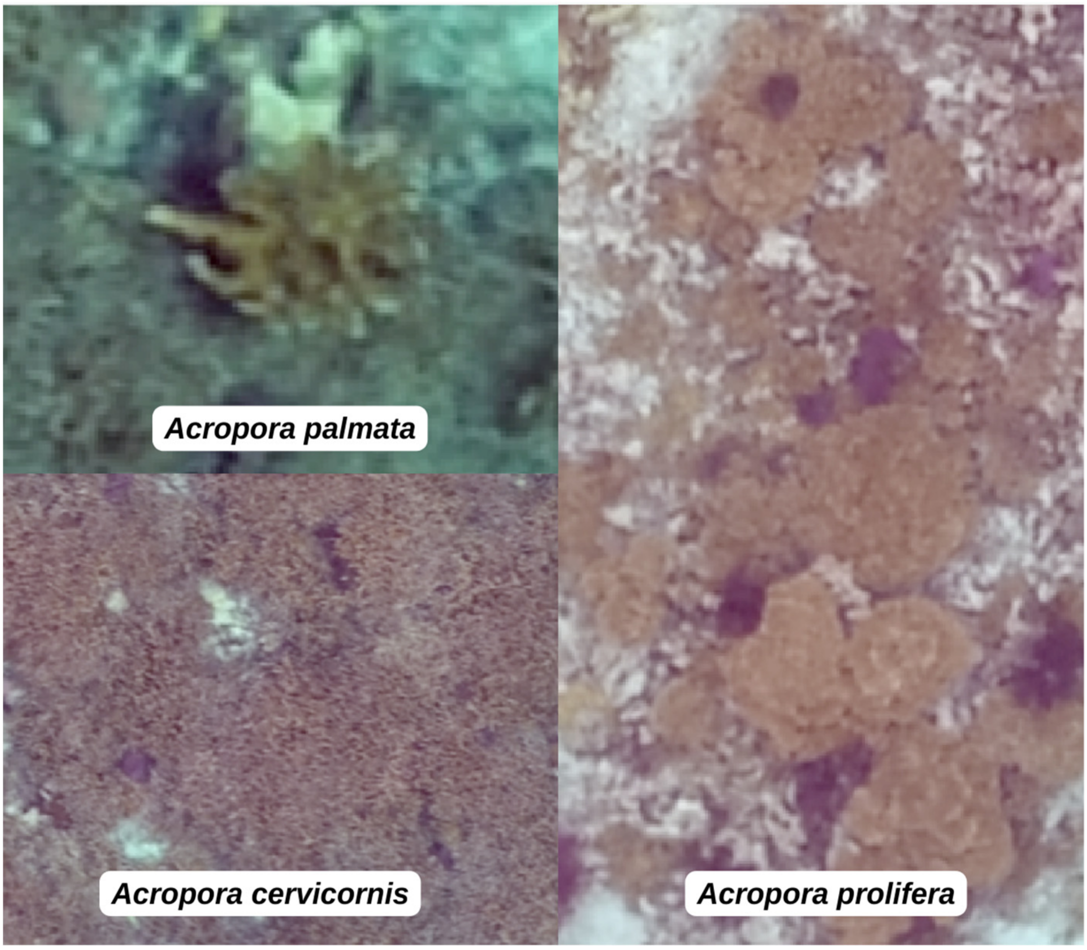

Figure 4. Aerial view of species from UAS imagery.

3.2. LBCNP Change Detection, 2019–2020

The classification of each taxon and calculation of each taxon's spatial extent permitted the successful quantification of spatial changes in coral cover from 2019 to 2020 (Figure 5). *A. cervicornis* was the most abundant species and represented the most change in calculated coral cover, with positive one-year growth (Table 3). The results demonstrated that *A. cervicornis* accounted for the entirety of positive calculated growth change within LBCNP, with overall losses by the other two taxa. Thus, *A. cervicornis* overcame the losses by the other two taxa to result in 157.46 new square meters of coral growth on the caye.

Table 3. Coral density in Laughing Bird Caye National Park from 2019 to 2020.

Species	2019 m^2	2020 m^2	Percent Change
Acropora cervicornis	1938.01	2268.43	+17%
Acropora palmata	151.7	90.30	−40%
Acropora prolifera	52.87	41.91	−21%
TOTAL	2142.58	2400.64	+12%

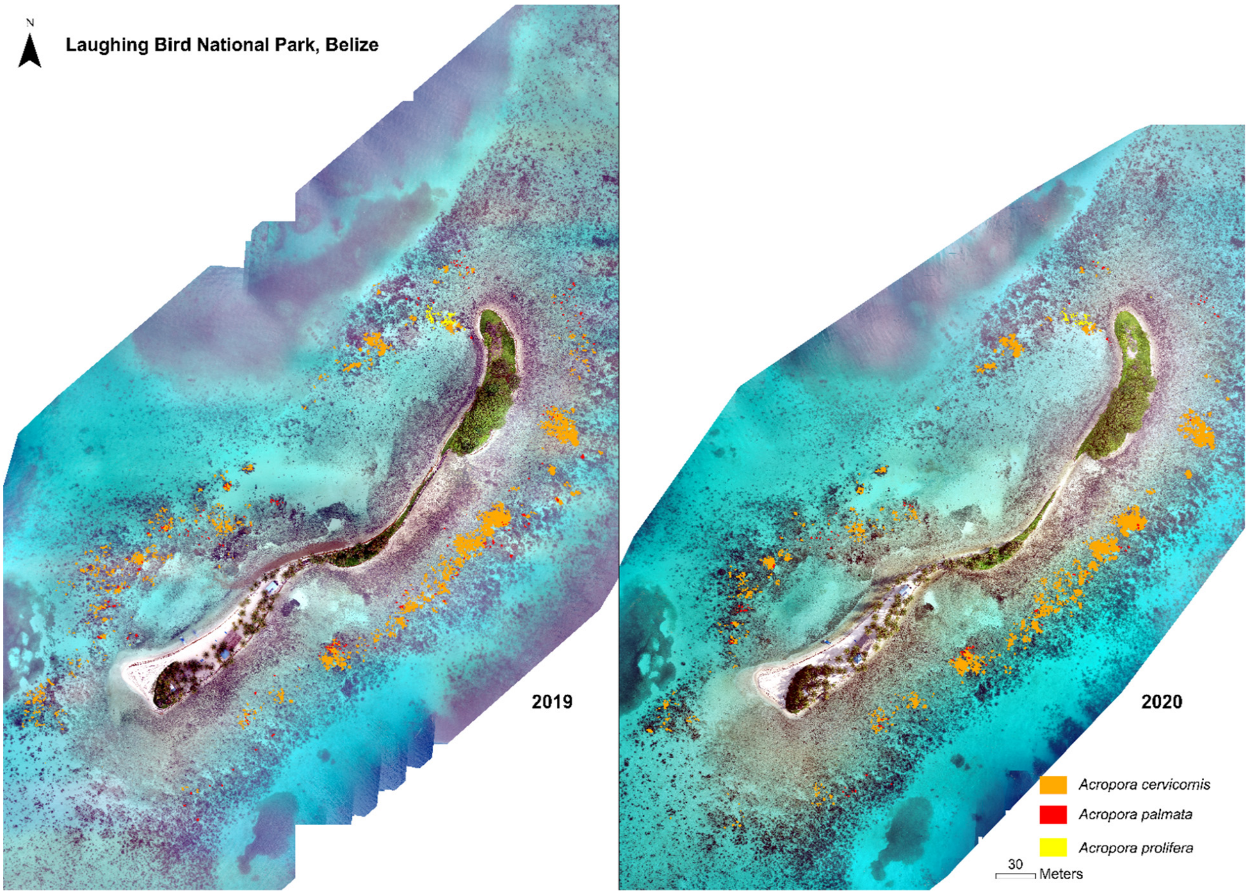

Figure 5. Change detection of three acroporid coral species in LBCNP from 2019 to 2020 based on image segmentation and manual classification of the derived objects.

4. Discussion

UAS imagery allowed FoH to quantify the spatial extent of three shallow replenished acroporid coral species for the first time at LBCNP. Due to the success of these results, ongoing mapping of coral restoration sites using a UAS is currently being applied to multiple replenished shallow sites across Belize on an annual basis for quantifying the change in coral cover. Additionally, FoH is mapping several natural, wild *A. cervicornis* stands in southern Belize to detect changes each year and compare the results with replenished sites. At one known *A. cervicornis* stand near Loggerhead Caye, a new *A. prolifera* stand of significant size (approximately 50 m^2) was discovered when the entire patch reef was imaged and classified. Subsequent genetic analyses revealed that it is an *A. prolifera* genet distinct from the others in the FoH gene banks (nurseries and outplants sites), adding to the overall genetic diversity of the replenished reef sites in southern Belize.

One of FoH's short-term goals was to answer the question, "How much coral reef has been restored at LBCNP?" which previously was answered qualitatively. A longer-term goal, relevant for shallow reef restoration, is determining the minimum number and density of outplants needed to establish a self-replicating population. Using long-term annual datasets with this method documents the natural spread of these branching coral taxa and verifies both the site and coral selection process utilized. The methodological framework utilizing UAS technology and LEK is proving essential for FoH to address both these long- and short-term objectives. This method may be applicable to restoration practitioners working on shallow reef systems both regionally and globally as a means of (1) mapping source/donor corals, (2) mapping resilient reefs before/after bleaching/disease/storm events, (3) quantifying larger scales of replenishment work, and (4) monitoring change detection of replenished sites as a means of documenting success (or failure). FoH will continue using this methodology annually in its monitoring programs to detect reef replenishment. Quantifying restoration efforts through annual, long-term monitoring could provide additional insight into coral restoration best practices. Since acroporids thrive in shallow reefs and can be detected using UAS techniques, it is hoped that these results encourage more practitioners to work in these corals' preferred depth ranges, where appropriate.

One of the main limitations in applying this approach is the depth of the feature to be detected. Successful recognition of coral taxa using UAS imagery typically occurs in clear water columns at depths of <~3 m. Other caveats include the collection of UAS imagery during periods of calm sea conditions and low sun angles (i.e., minimal sunglint) in order to acquire optimal detail in the imagery. The process involves investment in a suitable UAS data collection platform, post-processing photogrammetry software, and local capacity building and data management to maintain a long-term monitoring program. Based on the knowledge that the top 1 m of reef (reef crest) provides the majority of shoreline protection [44], our results may encourage coral restoration practitioners to invest in monitoring corals at these shallow depths (1–3 m), when and where applicable. Other limits to this approach include the availability of local expertise to provide in situ insight, as well as the capacity to fund UAS missions and their associated costs.

5. Conclusions

While UASs have proven heavily effective in terrestrial environmental sectors, there is a growing need for integrating monitoring protocols within benthic restoration programs to increase the resiliency of long-term goals [45,46]. A UAS coupled with LEK provides a unique opportunity to train and diversify the participation of local stakeholders in the management and monitoring of restoration programs. This may lead to more resilient and adaptive management actions due to the diverse voices represented within these programs [27]. Coupling UAS and LEK provides a more nuanced method of monitoring to establish an evidence base for optimizing the practice, enabling practitioners to identify the techniques and processes that work well within their study area and to understand the impacts of ecological intervention.

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