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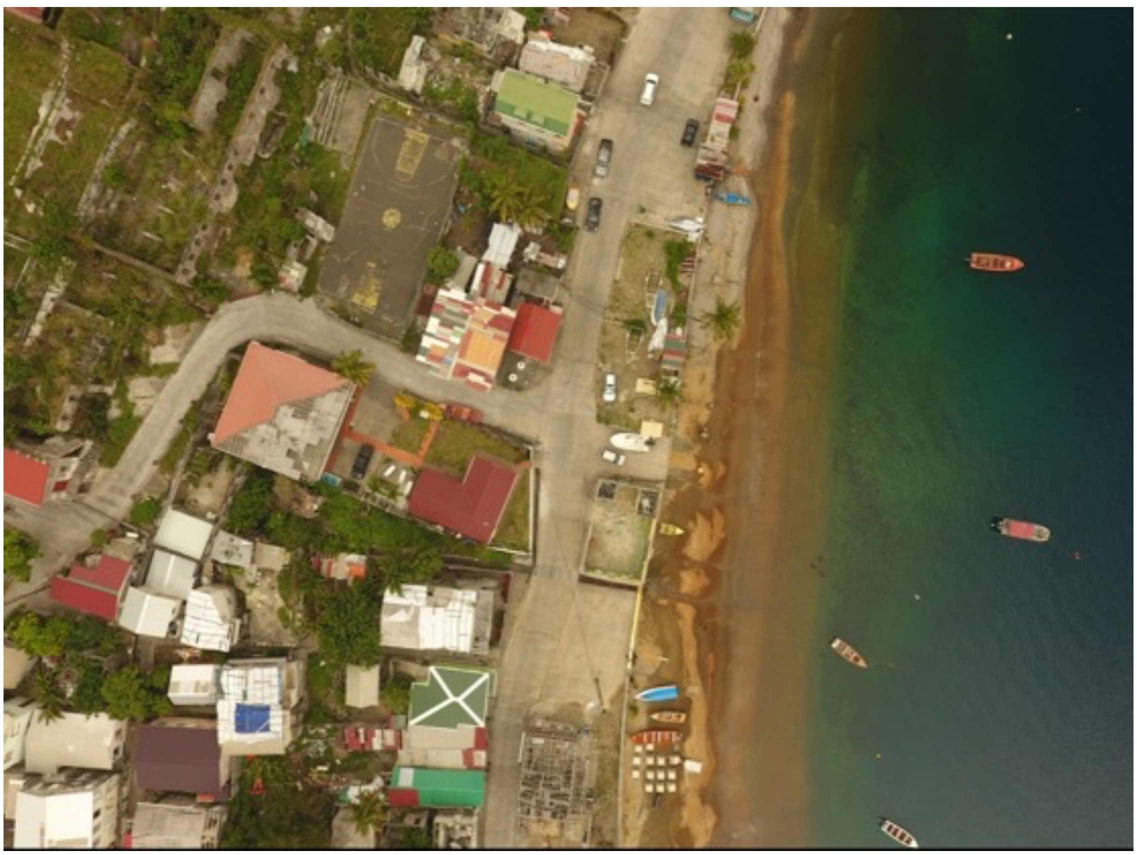
An introduction to the use of drones for participatory mapping of climate, poverty and fisheries information in Caribbean coastal communities

K. BALDWIN, P. McCONNEY AND R. SANDOVAL



Centre for Resource Management and Environmental Studies

University of the West Indies, Cave Hill Campus, Barbados

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ACRONYMS

AGL	Above Ground Level
ATC	Air Traffic Control
CAA	Civil Aviation Authority
CARPHA	Caribbean Public Health Agency
CATS	Caribbean Aqua Terrestrial Solutions
CERMES	Centre for Resource Management and Environmental Studies
CCA	Climate change adaptation
DRM	Disaster risk management
EAF	Ecosystem approach to fisheries
EbA	Ecosystem-based adaptation
ECCCA	Eastern Caribbean Civil Aviation Authority
FAA	Federal Aviation Authority
FAO	Food and Agriculture Organization
FSA	Flight Safety Assessment
GIS	Geographic Information System
GPS	Global Positioning System
HD	High Definition
ICM	Integrated Coastal Management
IWM	Integrated Watershed Management
MPI	Multidimensional Poverty Index
NbS	Nature-based solutions
PGIS	Participatory Geographic Information System
PUAS	Participatory use of Unmanned Aerial Systems
PIC	Pilot in Command
RGB	Red, green, blue (camera)
SDGs	Sustainable Development Goals
SIDS	Small Island Developing States
SocMon	Socio-economic Monitoring
SSF	Small Scale Fisheries
UAS	Unmanned Aerial System (or drone)
UAV	Unmanned Aerial Vehicle (or airframe)
UWI	University of the West Indies

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1 INTRODUCTION

The use of drones for a growing range of tasks has the potential to massively improve the cost-effectiveness and efficiency of information systems worldwide. This report builds upon a project publication on *An introduction to using drones in Caribbean coastal communities for participatory mapping of climate, poverty and fisheries information*. It is based mainly on literature assembled and fieldwork done under applied research projects undertaken by the Centre for Resource Management and Environmental Studies of the University of the West Indies (UWI-CERMES) at the Cave Hill Campus in partnership with the Food and Agriculture Organization of the United Nations (FAO). The projects were implemented largely in 2020 amidst the global COVID-19 pandemic. The impacts of COVID-19, and the public health protocols instituted to reduce its spread, brought into sharp focus the utility of several approaches to data and information gathering that did not necessitate conventional fieldwork.

The projects underpinning this report primarily investigated the nexus between fisheries, climate and poverty in the coastal areas of select Caribbean countries as well as the influxes of sargassum seaweed on these coasts. This report is widely applicable to participatory coastal mapping especially in Caribbean small island developing states (SIDS) where the use of unmanned aerial systems (UAS, but 'drone' being a more commonly used catch all term) is not yet widespread. This guidance on coastal mapping highlights synergies of using drones (i.e. UAS) together with participatory geographic information system (PGIS) methodologies and outputs. We introduce PUAS as shorthand for Participatory UAS. The applied science and technology associated with PUAS can range from being fairly simple to extremely complex. This introductory publication strikes a practical balance, providing sufficient information for understanding drones, PUAS and PGIS without overwhelming the reader with excessive detail.

The report has two main parts. The brief first part provides a policy context for using drones in Caribbean coastal communities for participatory mapping of climate, poverty and fisheries information. The second part offers management-level information on what is involved, including the capacities required, along with examples. The target audience for this introductory publication is primarily senior policy advisers and technical officers in blue economy sectors, coastal and fisheries management, climate change adaptation, disaster risk management and poverty alleviation. Most of these women and men may be in state agencies, but non-state actors are also potential audiences. This coastal emphasis complements FAO and CERMES terrestrial initiatives for use of UAS in upland watersheds and in agriculture to promote island system or ridge to reef geographic coverage.

PART 1: ENABLING POLICY AND PLANNING

This part elaborates on enabling policy and planning from global, through regional, to national and local levels. It sets the context for managing change to make the most of available resources for integrated management, and also for developing new capacity. FAO and CERMES encourage and assist their partners in making, and taking advantage of, these high-level linkages. There is some redundancy among sections to facilitate extracts being used as stand-alone supporting evidence should a reader wish to present arguments for a drone programme.

2 POLICY NEXUS OF COASTS, CLIMATE AND POVERTY

Challenges facing environmental management are complex and dynamic. They are characterised by high levels of uncertainty and interlinked processes with multiple scales (e.g. ecological, jurisdictional, social) and levels (e.g., global, regional, national, local) of interaction and governance (Bavinck et al. 2005). Likewise, the vulnerability and resilience of small-scale fisheries (SSF) and coastal communities in the Wider Caribbean have different spatial and jurisdictional scales interacting in complex ways which can be exacerbated by poverty, natural hazards and climate change (Fanning et al. 2011). Coastal communities often rely heavily on ecosystem services from nearby natural resources for livelihoods and well-being. Environmental degradation puts their livelihoods at risk, adding another obstacle in the way of poverty reduction. The effects of climate change and variability are expected to have critical consequences for the poor on coasts by reducing SSF harvests, increasing the uncertainty of and threats to rural livelihoods, endangering coastal dwellings and infrastructure, and much more (Johnson et al. 2019; Nurse 2011).

Adaption and adaptive management in SSF in SIDS must focus on minimizing exposure and sensitivity to the impacts of climate change and maximizing coastal community capacity to be resilient (Bahri et al. 2021). Appropriately designed and implemented spatial management plans can be used to control activities that damage critical ecosystem habitat and resources through destructive or irresponsible practices that erect poorly-designed coastal infrastructure, that permit land-based and marine source pollution, that encourage sand mining and reward the unsustainable harvesting of mangroves. Climate-informed, ecosystem-based management (EBM) and ecosystem approaches to fisheries (EAF) that incorporate individual and collective action for stewardship are required to pursue sustainable SSF (McConney et al. 2014). Moreover, sustainable fisheries management coupled with the development of alternative livelihoods, can improve the resilience of poor fishing communities and poor women in particular (Pena et al. 2020).

Coastal social-ecological system variability and spatially fragmented marine governance arrangements, even at national level, make the Caribbean one of the most complex marine areas in the world on several scales and levels (Mahon et al. 2010). Weak marine governance is a root cause of problems facing Caribbean SIDS (Fanning 2013). Since conventional, top-down, single-sector management has been inadequate to respond to environmental governance challenges, more integrated participatory approaches including co-management and citizen science are becoming accepted (Pomeroy et al. 2004). More integrated, multi-level, approaches that link local practice to national and regional policies are essential to ensure the future sustainability of SSF and coasts. Community-based approaches incorporating extensive local consultation, co-management, education as well as social learning, networking and empowerment are essential to foster the necessary social changes required to alleviate poverty and successfully implement climate-smart coastal and fisheries management approaches (Monnereau and Oxenford 2017). The convergence of climate and poverty impacts on coasts is challenging in SIDS worldwide.

Charles et al. (2019) address the climate change and poverty nexus on coasts. They outline the policy context for enabling action from global to local levels (Figure 1). The authors advocate policy and tools that contribute towards greater integration and achievement of both the Sustainable Development Goals (SDGs) and the Paris Agreement climate targets. The SDGs provide a comprehensive global vision for reducing poverty and vulnerability to climate change and natural hazards, including in coastal and marine areas. The FAO has special responsibility for the implementation of SDG 14 on Life Below Water, but this is practically linked to almost every other SDG (even above water) in a social-ecological system perspective. SDG 1 (No poverty) and SDG 13 (Climate Action) are critical to this nexus. SDG 13 is bolstered by the provisions and processes of the Paris Agreement through national commitments. The ability of the global instruments, downscaled to regional and national levels, to enhance societal benefits requires practical, integrated, multi-sector, adaptive approaches at the lowest level feasible (i.e., those that emphasize local knowledge to complement and validate scientific data at appropriate spatial and temporal scales). Caribbean regional instruments such as the Caribbean Community Common Fisheries Policy (CCCFP) and its two protocols also strongly support participatory approaches to securing SSF and climate action.

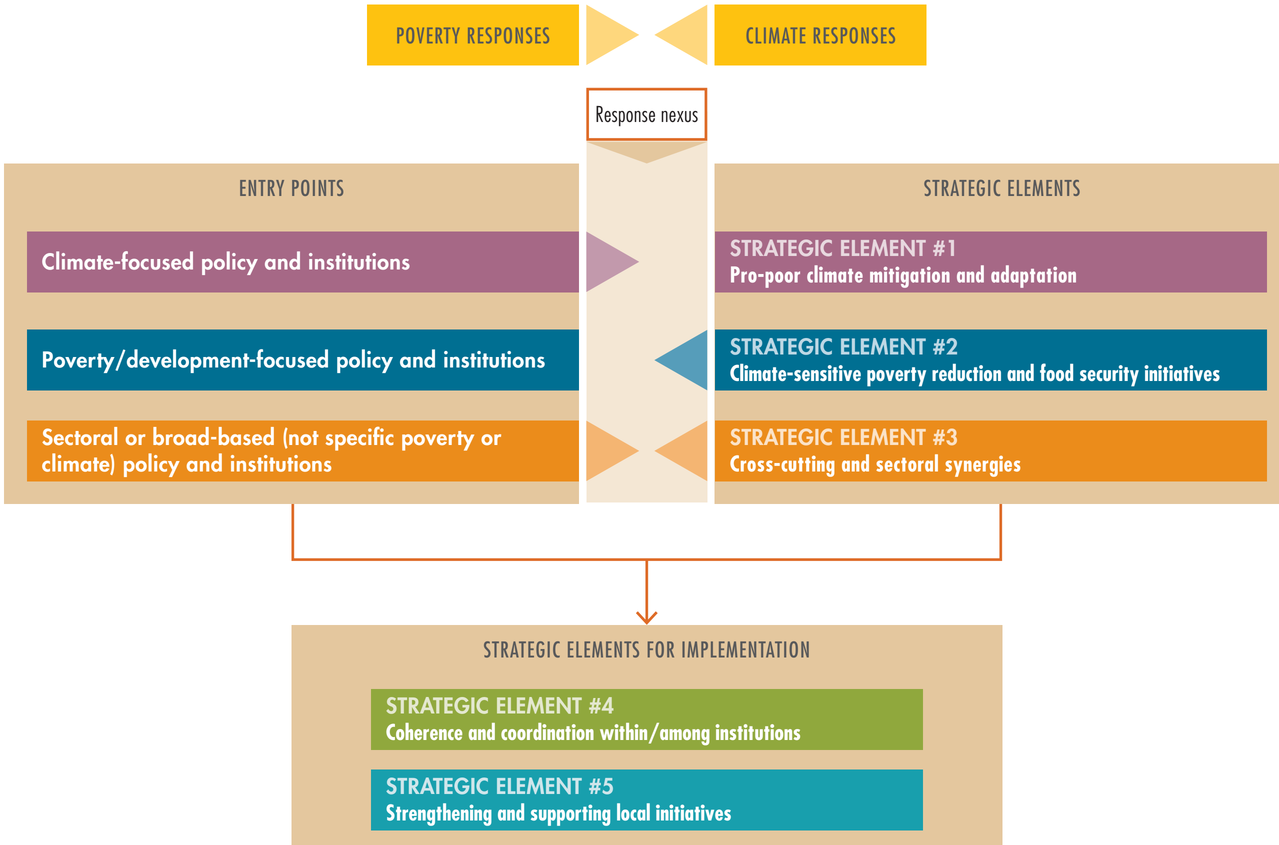


Figure 1. Strategic elements of the nexus approach
(Source: Charles et al., 2019)

To accurately measure progress towards achieving the global and regional goals, reliable, timely, comprehensive, and consistent community-level spatial data, including the interactions occurring within ecosystems and associated cumulative impacts, are critical to evaluate trade-offs and design appropriate strategies. These features are also key to the blue economy initiatives that are increasingly becoming part of Caribbean policy and practice (Clegg et al. 2020). Local information and knowledge shared in ethical participatory processes don't only help to fill scientific information gaps (Baldwin and Oxenford 2014), but they often complement national formal information and official records through improved timeliness and higher spatial resolution (Baldwin and Mahon 2014). The synergistic framework for mapping and participation not only fosters the capacity necessary for equitable and informed decision-making for the implementation of ecosystem-based approaches and nature-based solutions (i.e. EbA and NbS in IWM, ICM, CCA, DRM, EBM, EAF, MSP, etc. [see list of acronyms]) but facilitates local level empowerment through several interdisciplinary methods and tools (Pomeroy et al. 2014). We examine these more closely in the next section.

3 SPATIAL PLANS, COASTAL MAPS AND PARTICIPATION

Strategic plans and directions provide additional context and rationale for coastal mapping using drones with PGIS (i.e. P-UAS) to tackle climate and poverty, among other challenges. Some fairly generic arguments are introduced in these sections, but a national situation analysis will be needed to fully articulate these more specific conditions.

3.1 Participatory spatial methods

Adaptive coastal and marine management has not always been effective in part due to a failure to use all available sources of information and knowledge, ignoring in particular the local knowledge of resource users. We need local knowledge to enhance our understanding of the real contribution of SSF to food security, nutrition, health, sustaining livelihoods, poverty alleviation, wealth generation, trade and human well-being generally. FAO has been doing this type of investigation in a project on Illuminating Hidden Harvests (visit www.fao.org). This understanding will allow monitoring and measurement of the impacts and implications of trends and changes such as migration, urbanization, construction, climate and technology on SSF and on coasts in general. A concerted effort is needed to build a practical framework for the collection and integration of local knowledge, scientific data and new technology to bear upon responsive societal problem-solving and proactive creation of opportunities. Although coastal resource users and residents typically possess large amounts of relevant knowledge, they are rarely involved in all stages of policy, planning and management decision-making on natural resource uses, especially in the marine environment (Fanning et al. 2011). However, it is recognized that for environmental management to be effective, these stakeholders must be a part of governance processes, and their resource-use or dependence profiles must be clearly understood (Berkes et al. 2001; Bunce and Pomeroy 2003). Since the majority of Caribbean state authorities lack capacity at national and local levels for comprehensively implementing EBM and EAF, practical participatory interventions targeted at building, enhancing and networking adaptive capacity are needed to strengthen Caribbean multi-level coastal governance (Fanning et al. 2011).

Land use planning and marine spatial planning (MSP; see Box 1) offer constructive ways of dealing with complex coastal systems by focusing on the distinctive features of physical spaces and tailoring management to local circumstances through an adaptive learning cycle. MSP, which typically incorporates the coastal margins, provides the strategic, integrated and participatory planning framework required for the achievement of SDGs in which ecological, economic and social objectives can be simultaneously accommodated (Douvere and Ehler 2009). MSP necessitates a comprehensive understanding of the social-ecological system in a location, including the quantification of the spatial distribution of biophysical resources and associated human interactions, to develop management scenarios and evaluate the trade-offs between protecting ecosystems and developing the services they provide to humans. Transparent planning, that can accommodate diverse information types in an accessible format, is required to improve stakeholder understanding, effective involvement and be used for decision-making and management as stated before (Carocci et al. 2009; Mackinson et al. 2011; Pomeroy and Douvere 2008).

Box 1. Characteristics of MSP (Ehler 2013), many are common to other sectoral planning approaches and ecosystem-based management.

- Integrated and multi-objective, across sectors and agencies, among levels of government, including social, economic and ecological objectives
- Continuing and adaptive, capable of learning from experience
- Strategic and anticipatory, focused on the long-term
- Participatory, stakeholders actively and effectively involved in the process
- Place-based or area-based, focused on a specific marine area or place; and
- Ecosystem-based, balancing ecological, economic, and social goals and objectives toward sustainable development.

The use of geographic information systems (GIS) to create, display, query and analyse coastal and marine ecosystem-based information for planning and management is now widely practised (FAO 2013). GIS has become a MSP decision-support tool. With stakeholder participation (via PGIS) it can produce comprehensive information displayed in maps with a high degree of ownership by area users and interests. Such information includes trends in human activity and conflicts or threats among and between uses and the environment (Tallis et al. 2010). Site-level socio-economic information helps fisheries and coastal managers to monitor coastal resources and uses, identify potential problems, mitigate negative impacts and focus adaptive management on what is of most critical importance given the need to prioritise (Berkes et al. 2001; Bunce and Pomeroy 2003). The importance of participatory coastal mapping is clear, but still most often focuses on ecological characteristics, downplaying the social aspects of the system (DeFreitas and Tagliani 2009; Pena et al. 2013).

Socio-economic Monitoring for Coastal Management (SocMon) addresses social aspects. SocMon is an iterative multi-method, participatory monitoring tool primarily for site-level use. The tool promotes affordable and flexible adaptive management inputs of social and economic data into fisheries and coastal management decision-making while also supporting social and institutional learning. See the methodological guide for the Caribbean (Bunce and Pomeroy 2003) and selected use cases (Edwards et al. 2019) for quick familiarisation. Key informant interviews, structured household surveys, secondary sources of data and observations are used to compile background information, identify stakeholders, tally existing resources and their uses, inventory infrastructure and fill gaps in knowledge. The SocMon methodology is based on suites of variables, some of which cover climate change. These are linked to coastal monitoring goals and objectives usually derived from country or sector policies and plans. The survey questionnaires are used to capture a range of site-level household information including demographic data; coastal and marine activities; types of resource use; household orientation; attitudes and perceptions on resource conditions; and perceived threats. Additionally, governance data on the awareness of rules and regulations, compliance, enforcement, participation in decision-making and management actions are commonly collected during site monitoring. SocMon includes determination of suitable communication mechanisms and informational products for select audiences. Stakeholder validation and feedback of results is a crucial step for fostering trust, ownership and support for management initiatives, ultimately paving the way for community empowerment (Bunce and Pomeroy 2003).

Many of the SocMon variables designed to collect socio-economic information on the community and interactions occurring within the ecosystem are spatially explicit in nature. Since the methodology mainly uses interviews and survey questionnaires to obtain attribute information, its spatial planning and coastal mapping potential is often underestimated (Wood et al. 2014). However, conventional natural science methods for collecting and mapping biophysical data (i.e. by extensive underwater surveys and *in situ* measurements), GIS and MSP can be financially and logistically burdensome. Regular research-oriented coastal graphical data and maps alone can lack relevance to local resource users unless properly contextualized. Adding local knowledge to the mapping process can enrich the information and produce cost-effective, scientifically valid and locally relevant information that often cannot be obtained through conventional scientific approaches (Baldwin and Oxenford 2014). Likewise, stakeholder collaboration in the mapping process (e.g. participatory mapping by use of drones) can be an important tool for learning and understanding the linkages between marine resources and human communities. When scientific marine habitat maps, together with local knowledge, are hosted within a GIS framework, spatial visualization of multiple overlapping layers showing habitat features and use patterns becomes possible (Ban et al. 2010). Furthermore, this process can facilitate the identification of environmentally, socially and economically critical areas. Such information facilitates negotiation of the optimal allocation of resources and aids conflict management (Douvere and Ehler 2009). A spatial version of the SocMon participatory methodology has been under development in the Caribbean to evaluate how it can be applied to add value to the assessment and monitoring framework (Baldwin 2012; Wood et al. 2014). SocMon Spatial uses simplified methods to marry SocMon with PGIS in applied research and development. PUAS can also be integrated.

The use of participatory GIS (PGIS) has emerged as a tool for interdisciplinary community development and environmental stewardship (Rambaldi et al. 2006). Stakeholder empowerment through the application of principles that reflect good governance (e.g., participation, transparency, accountability, efficiency, inclusiveness, legitimacy, respect and equity) underlies the approach (Chambers 2006). This is both in terms of the participatory processes involved in the development of the conceptual framework and the construction of an appropriate (locally relevant) product. Technically, PGIS also provides a means to collect and represent local knowledge and empower stakeholders to more effectively participate in governance. This is achieved not only by demonstrating the legitimacy of information provided by the community members, but also by allowing a more comprehensive understanding of the social-ecological characteristics of resource use and conservation (De Freitas and Tagliani 2009). Broad engagement facilitates increased dialogue, understanding, respect and trust among stakeholders, thereby balancing power through transparency, inclusiveness and ownership in governance (Chuenpagdee and Jentoft 2009). Most of these benefits can be further enhanced by the judicious integration of drone technology.

3.2 Drones in coastal research and development uses

Rapid advances in geospatial technologies (e.g. computer processors, sensors, analysis platforms) together with increasing demand for drones have resulted in UAS applications increasingly becoming more user-friendly (less technical) and more affordable. Drones now allow field researchers to survey specific areas at regular intervals to establish baseline conditions and monitor change in the natural, social and built environment. UAS information technologies can fill an important gap in environmental management by aiding participatory coastal mapping. They are particularly well-suited for mapping at an intermediate spatial scale (i.e. 1-10 km^2) at a fraction of the cost, training needed and time required to both conduct and process conventional aerial remote survey data. Furthermore, low flight ceilings allow for the collection of data with high spatial resolution (1 cm) which is not vulnerable to cloud cover and some other weather conditions typical of Caribbean SIDS. UAS provide cost-effective means of acquiring highly accurate spatial information. This enhanced capability can facilitate rapid identification of important human activities, the documentation of coastal hazards (e.g. oil spills, coastal erosion, flooding events) and expedite informed decision-making in emergency planning, disaster risk management and mitigation efforts.

Recent improvements in the capabilities of UAS information technologies allow for the capture of on-demand, spatially referenced, in-situ aerial data, with mapping results being accessible even while the drone is flying. Consequently, the integration of drone surveys together with participatory mapping now holds incredible potential to amalgamate ecosystem-based information and understand how humans interact with marine and coastal areas. By combining UAS and PGIS in PUAS it is feasible to map and measure indicators relevant to coasts, climate and poverty that diverse stakeholders and interested parties can use in various ways for formal and informal collective and individual purposes. This supports evidence-based decision-making and intervention. Since natural resource and environmental degradation creates or exacerbates underlying risks and vulnerabilities, the more accurate and reliable information generated through the use of PUAS with drones can significantly enhance our ability to better understand risks and vulnerabilities, and hence determine actions to better manage these. This improvement has become more relevant given the increasingly multi-hazard and systemic nature of risks which requires multiple layers of structured, high resolution and high temporality risk information.

In Part 2 we illustrate how a PGIS approach (Figure 2), specifically the use of participatory mapping together with recent advances in UAS and information technologies, can be practically applied along with the SocMon Spatial methodology and various means of SSF monitoring in the Caribbean. A showcase of how drones (but not extra-expensive professional systems) can potentially be used to aid the collection of appropriately scaled data and easily produce ecosystem-based conventional biophysical information (i.e. habitats, resources, infrastructure) as well as represent socio-economic spatial interactions of the community occurring within the coastal ecosystem (via mapping exercises) is briefly presented.

We focus on how local knowledge can easily be incorporated by 'geo-coding' corresponding spatially based socio-economic information (as textual attributes) and leveraged to fill information gaps. This creates locally appropriate, multi-scaled information on the social-ecological system to support adaptive management and strengthen the resilience of SSF and other coastal uses to the impacts of poverty and climate change, particularly of relevance in resource-limited SIDS regions such as the Caribbean, are provided.

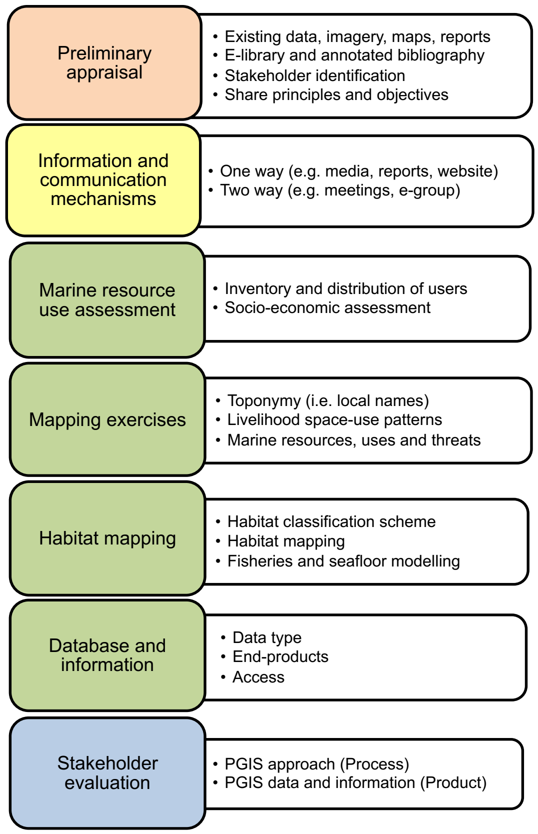


Figure 2. Schematic of the application of PGIS listed with corresponding sub-components in which stakeholder feedback was applied

PART 2: DRONES AND COASTAL MAPPING PARTICIPATORY PRACTICES

For readers who lightly perused Part 1 it is useful to reiterate some of the main points here before proceeding. Comprehensive information (including biophysical, social and local knowledge) is essential for effective planning and management of national fisheries, coastal areas, marine protected areas, climate change adaptation and disaster risk management strategies. Notwithstanding the central role of human agency in these concepts, the scope of 'human dimension' information included is often inadequate relative to its actual importance and spatial complexity (St. Martin and Hall-Arber 2008). The application of PGIS combined with the use of drones (PUAS) supports the production of appropriate and accessible information. As important, this also aids empowerment, building the capacity for learning, and fostering pluralistic problem solving, all of which ultimately facilitate improved governance by building adaptive capacity and resilience (Pomeroy et al. 2014). In this Part we take a closer look at this useful combination of approaches and technologies that can comprise PUAS.

4 INFORMATION USE AND AUDIENCE

The main intention of this Part two-fold: (1) to showcase how drone surveys can be leveraged to quickly map and easily obtain a range of baseline spatial information on the monitoring site (i.e. extent, distribution of marine resources, associated patterns of use and the identification of threats for use in a fishing community); and (2) to demonstrate the ways in which a PGIS approach can potentially applied improve EAF and the understanding, design, implementation and monitoring via SocMon. The latter also highlights synergies with other methodologies such as the Multi-dimensional Poverty Index (MPI) (UNDP and OPHI 2019) as well as CCA, DRM and MSP (see list of acronyms). We do not report on new analyses, but we assess existing drone data to consider how they can be used to address data gaps and linkages at the fisheries, climate and poverty nexus. We also examine the capacity required to generate and apply EAF within coastal fishing communities to strengthen governance, management and policies in Caribbean SIDS, also applicable elsewhere.

This Part will first provide a broad overview (more technical than in Part 1) of remote sensing and UAS technologies, along with examples of marine and coastal environmental applications and primary workflows to conduct baseline drone mapping surveys. The ways in which multi-knowledge ecosystem-based information on coastal community, marine resources and human activities can be spatially mapped and brought together via the development of scenarios to improve discussions regarding fisheries, climate change and poverty is illustrated. Technical details on the ways in which spatial information can potentially be created for use in SocMon, both in terms of how stakeholders can be engaged in the approach (process) and the final geodatabase (product), will be discussed. We conclude by justifying how the application of PGIS enhanced by UAS can be realized to complement SocMon. Details on the requirements of this approach, in terms of the necessary resources (e.g. UAS equipment, software, and training capacity) are also provided to argue for its relevance in fisheries, climate and poverty assessments in the Caribbean and the wider SIDS context as a simple, low-cost, practical mechanism to strengthen coastal and marine governance in the achievement of the global SDGs and regional or national goals.

5 INTRODUCTION TO UNMANNED AERIAL SYSTEMS

In this section we use the term drone interchangeably with unmanned aerial system (UAS), as the former is the widely used term. Drones are transforming the possibilities of what we can understand about the environment; they are arguably the most revolutionary research tool available today. However, careful planning and investment is required to make full use of this opportunity. An overview of drones and the capabilities of UAS technologies and recommendations on the platforms, software and resources required to produce accurate data and relevant information, based on widespread testing and research by the lead author is provided. An overview of legal and ethical issues surrounding the use of drones will also be briefly discussed to inform participatory coastal mapping.

5.1 Remote sensing

A central pillar of effective environmental management is accurate, reliable, and up-to-date information for decision-making. Basemaps are a fundamental requirement for marine resource conservation and management (Crowder and Norse 2008). Remote sensing data acquired from satellites and piloted aircraft have traditionally been useful to map and quantify the abundance and distribution of habitats and resources. In recent years the utility of collecting remote sensing data with GIS has allowed for the production of basemaps over larger geographical areas with better accuracy, resolution and lower budgets than previously possible. Despite these advances, the use of remote sensing platforms for many environmental applications still poses a number of challenges due to the high cost, technical expertise needed, lack of operational flexibility (extent, timeliness) both in terms of spatial and temporal resolution of data traditionally associated with production of these basemaps.

To address a growing demand for spatial data on the state of the environment, recent advances in information technologies and remote sensing have seen the development of applications using small drones. UAS technology is being employed in a multitude of ways for environmental management around the world. Drone photography and videos are commonly used for documentaries and education through social media and journalism. However, drones also present great opportunities for enhancing watershed management, including habitat, resource and space-use base mapping; elevation and flood modelling; feature detection such as animal/plant enumeration, reflectance and vegetative health analysis; search and rescue and disaster management efforts; risk and impact assessments; surveillance and monitoring activities. Core functionality derives from georeferenced, high-resolution images that UAS can capture, and the speed with which a number of additional spatially based products can be easily generated. The recent emergence of low-cost, user-friendly, small drones that are now commercially available together with web-based UAS remote-sensing and IT software platforms allow for execution of user-defined aerial surveys and the production of three-dimensional models of the environment. Ultimately, UAS data can be easily collected, processed and brought into a GIS or an industry-specific derivative software application to allow for visualization, data extraction, advanced spatial analyses and the ability to remotely share information to support informed decision-making.

5.2 Applications

The use of UAS in marine science is rapidly growing with applications focused on coastal ocean processes, habitats and species. Scientists are using drones to rapidly collect high-resolution data to map and monitor coastal and marine ecosystems (Koh and Wich 2012), quantify the abundance of marine mammals and other vertebrates (Pirotta et al. 2017) and to assess climatic events such as flooding and coastal erosion (Casella et al. 2014). Researchers are now also able to measure sea surface temperature from drones (Inoue and Curry 2004), investigate coastal geomorphology (Mancini et al. 2013), determine bathymetry and macroalgae concentrations (Xu et al. 2018) and more. Tremendous growth is predicted in the coordinated use of aerial, surface, and underwater drone platforms for marine research and monitoring on coral reefs including marine protected areas (Johnston 2019), and surveillance of illegal, unreported, and unregulated (IUU) fishing (Toonen and Bush 2018). Although drones can benefit a multitude of environmental management applications, few studies have focused primarily on their use to research human interactions within and with coastal ecosystems (Johnston 2019).

6 UAS COMPONENTS

It is of key importance to carefully consider the UAS as an integrated system and examine the complete workflow of the intended application including how the flight planning, data collection, post-processing of data, mapping and spatial analysis fit together. UAS comprise individual system elements consisting of an airframe or unmanned aerial vehicle (UAV), the ground control station and any other system elements necessary to enable remote flight (i.e. mobile viewing device). The UAS with its cameras/sensors and mapping software allows for autonomous flights by following programmed paths to obtain high quality spatial data. Thus, the UAS can be divided into three distinct but connected elements: the vehicle or airframe itself (UAV), the sensors or payload carried, and the ground control system (GCS). These elements are further described in the following subsections.

6.1 Airframe

The airframe or UAV is the means to deliver the payload sensor(s) to optimal position. UAV can operate at a range of altitudes and the propulsion system has to be tailored to the mission. The flight control system ensures the UAV follows the pre-programmed mission flight path in the most economical way, avoiding obstacles and other air users. The UAV or airframe comprises:

- The propulsion system (or aircraft)
- The flight control computer or system
- The precision navigation system

Multi-rotor aircraft are compact, easy to use and highly manoeuvrable, making them the most commonly used drone models today. They are made of a central body with multiple rotors that power propellers to enable flight and manoeuvre the aircraft (Figure 3). These usually have four rotors (quadcopter) but can have as many six or eight (hexacopter and octocopter). Once in the air, multi-rotor drones use fixed-pitch propeller blades to control the vehicle motion by varying the relative speed of each rotor to change the thrust and torque produced, allowing a unique range of movement. This presents some advantages when used for mapping.

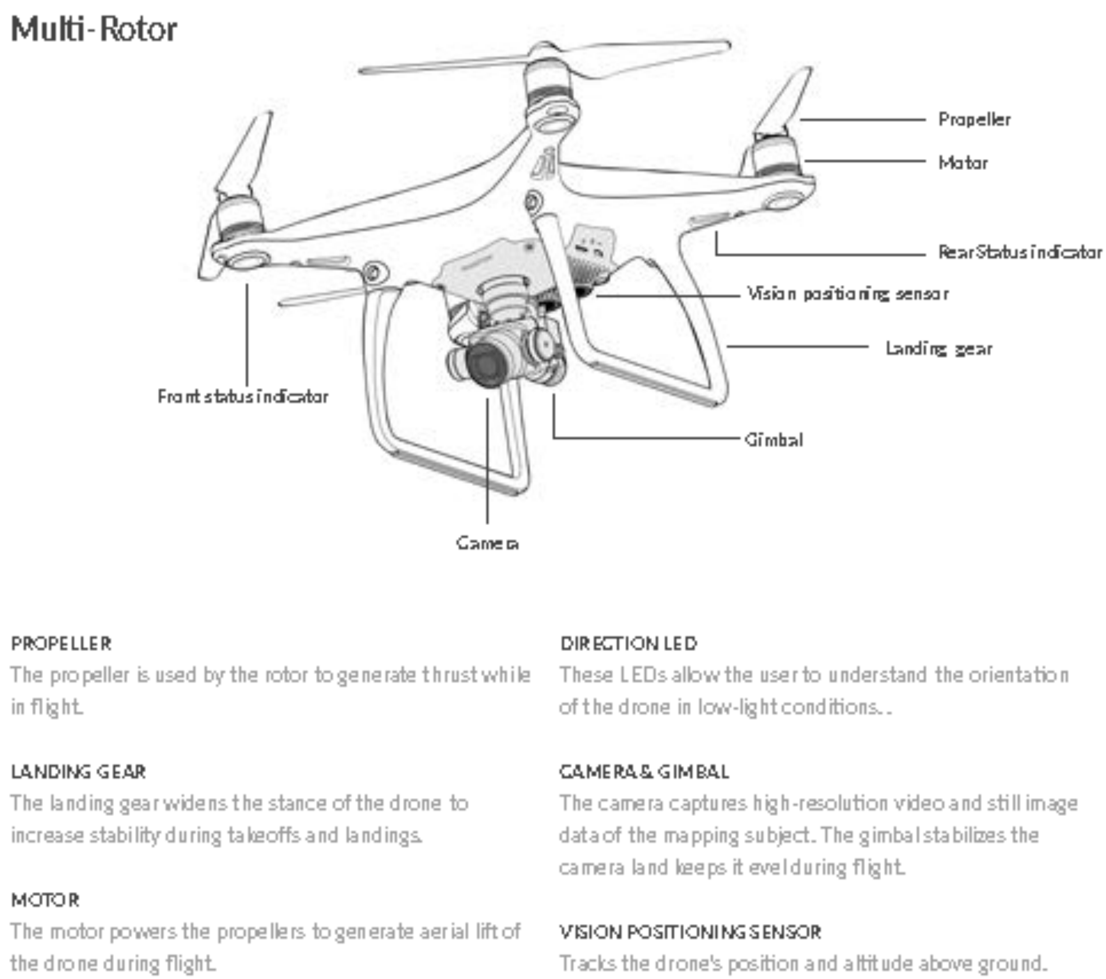


Figure 3. Schematic of the main components of a multi-rotor quadcopter UAV. (Source: DroneDeploy 2017)

The airframe uses a ground control system (GCS) for secure remote communications with the airframe; its global positioning system (GPS) information (latitude, longitude, and altitude) to the drone's autopilot to maintain stable flight; as well as to the international, national, regional and/or local air traffic management infrastructure. A GCS comprises:

- An avionics flight display
- Navigation systems
- System health monitoring and prognostics display
- Graphical images and position mapping
- Secure communications systems
- Inward data processing

Although the term ‘drone’ is most often used by the general public to describe only the UAV and payload that are seen airborne, the controller and other supporting systems are needed complete the UAS (Figure 4).

Figure 4. Author with UAS comprising UAV (DJI Phantom 3 Pro) and the GCS (remote controller and a tablet computer).

6.2 Payload sensors

The purpose of a UAS is to collect data from an aerial location. To accomplish this, one or more sensors (or the payload) can be carried on a UAS at any time. The payload (i.e. cameras, infrared systems, radar and various environmental sensors) is therefore the most important element of the whole UAS as this determines the ‘payback’ or data collected. The airframe or UAV itself does not collect the data; it merely gets the payload to the best aerial location. These small and flexible remote sensing platforms are also emerging with a wide array of commercially available out-of-box payload sensor systems (e.g. RGB, thermal, multispectral, Lidar) that can be tailored to or selected for specific management needs (Table 1).

Table 1. Types of UAS payload sensors and potential environmental applications

Sensor type	Environmental applications
True Color Camera (RGB)	Habitat mapping, elevation, surveying, species identification
Multispectral Near Infrared	Reflectance, vegetation health index
Forward Looking Infrared (FLIR)	Thermal mapping and heat signatures
Light Detection and Ranging (LiDAR)	Elevation base mapping and modeling
Radiometer	Solar radiation and temperature
Optical probes	Size and distribution of aerosol particles

Today most commercially available '*off the shelf*' drones employ high resolution red, green and blue wavelength (RGB) camera payload and mapping-grade GPS (with minimum vertical +/- 0.5m and horizontal +/- 1.5m absolute accuracy). It is now possible to use drones to collect higher survey-grade 'absolute' accuracy (less than 2cm) mapping data using a GPS system called Real Time Kinematics (RTK). Although this system is slightly more expensive it can be used for monitoring small changes in sea level, erosion or damage caused by climatic events. Drones are revolutionizing traditional surveying techniques as they do not require the use of ground control points that can be dangerous or even physically impossible to properly establish in the rugged terrain common to mountainous SIDS. DJI® is the largest producer of drones. Table 2 summarizes five of their most popular mapping platforms recommended for drone mapping surveys. These are listed by type, standard payload sensors, average accuracy and average cost.

Table 2. The most popular commercial DJI 'off the shelf' multi-rotor drone mapping platforms in 2020.

Platform	Type	Payload Sensor(s)	Accuracy	Cost (US$) Drone Kit
Mavic 2 Pro	Quadcopter	RGB Camera	Mapping-grade	$2,000
Phantom 4 Pro v2	Quadcopter	RGB Camera	Mapping-grade	$3,500
Phantom 4 RTK	Quadcopter	RGB Camera	Survey-grade	$7,500
Phantom 4 Multispectral RTK	Quadcopter	RGB Camera, Red Edge, Near Infrared	Survey-grade	$10,000
Matrice Series	Octocopter	Interchangeable	Survey-grade	$15,000 +

Which drone platform is most suitable will ultimately depend on its intended application, the budget and the experience/technical capacity of the user(s). In terms of mapping fisheries information in the Caribbean at present, the Phantom 4 Pro v2 is recommended as a good all-around drone, providing high accuracy and resolution data (including high definition 4K video) as well as suitability in terms of cost, ease of use and climatic conditions typically found in Caribbean and other SIDS. Detailed specifications of the DJI Phantom 4 Professional version 2.0 drone are provided in Appendix 1.

6.3 UAS and spatial analysis software

There are two main ways to control a UAS platform. Drones can be flown manually with a handheld controller, used, for example, to collect data on moving animals or capture video from specific perspectives. Yet recently the majority of UAS missions are conducted with considerable autonomy, whereby a ground control station and a mobile tablet computer run flight planning software to follow predetermined paths and conduct aerial sampling surveys (e.g. automatically acquiring images at designated points). Figure 5 provides an example of a typical flight survey plan for drone mapping. The flight path is shown in green, the left panel provides details on the mapping mission itself, including the predicted flight time, survey area (ha), number of images and batteries required, flight altitude (m) and expected resolution of aerial data to be collected.

Acquired drone images are uploaded to a UAS photogrammetry software package, whereby Structure from Motion (SfM) post-processing algorithms are applied to produce high quality 'professional-grade' three dimensional (3D) maps capable of obtaining a ground resolution of less than 2cm/pixel (as compared to 25cm/pixel typically obtained from satellite imagery). Today several commercial SaaS (Software as a Service) UAS photogrammetry packages have emerged (e.g. Maps Made Easy, Pix4D, Drone Deploy) with the ability to easily plan drone surveys, post-process data and leverage spatial analysis tools. These software packages provide application-specific, user-defined flight survey template plans (e.g. grids, lines, videos, 3D models, 360 panoramas, tracking), cloud-based platforms for data visualization (via web mapping applications, 3D models, field surveys), analytic dashboards and reporting tools. Correspondingly recent advances in computing power and drone photogrammetry now provide users with the ability to quickly capture geo-referenced pictures and videos 'on the fly' or during flight to create real-time high-resolution photogrammetric products (e.g. orthomosaic and elevation surfaces, 3D models) that then can be used together with conventional 'in-situ' field surveys. Moreover, SaaS UAS platforms allow drone-derived data to be seamlessly integrated with a number of popular third-party analysis packages (i.e. ArcGIS, Google Earth, AutoCAD) and online mapping portals to support remote access, subsequent data extraction and spatial analysis of information by various industries and across a number of audiences.

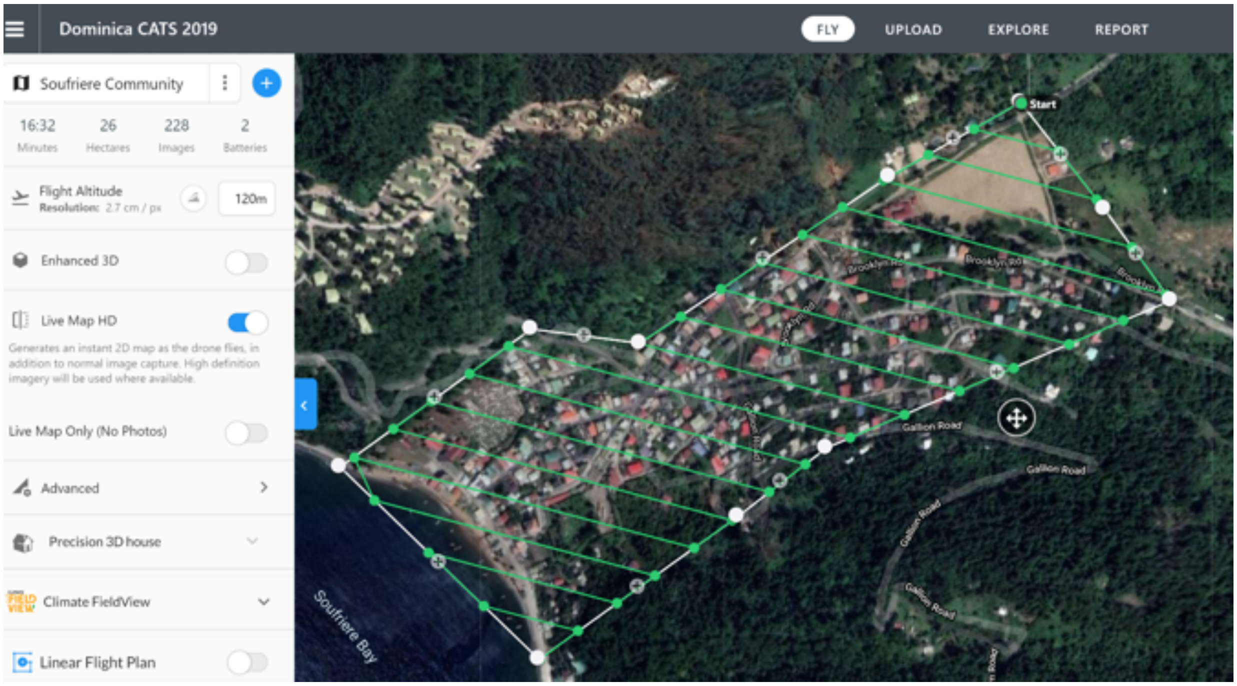


Figure 5. Example of a typical flight plan for drone mapping. The flight path is shown in green, the left panel provides details on the mapping mission itself, including the predicted flight time, survey area (ha), number of images and batteries required, flight altitude (m) and expected resolution of aerial data to be collected.

6.4 Data and information

The leading UAS mapping software platform, DroneDeploy®, enables users with the ability to easily plan drone surveys, create a range of spatial data and information. They can also conduct spatial analyses and produce a variety of mapping data, multi-media products and informational reports that can be remotely shared and seamlessly integrated with other popular third-party software packages (e.g. ArcGIS, Google Earth, Autodesk).

The following lists common types of data and file formats that can be produced with UAS software packages.

1. Aerial (2D) Maps
   - Orthomosaic (.jpeg, .tif, .kml, .pdf)
   - Elevation and contours (.jpeg, .tif, .kml, .pdf, .shp, .dbx)
   - Plant variability / health (.jpeg, .tif, .kml, .pdf, .shp, .kml)
2. Elevation (3D) Surfaces
   - Hillshade image (.jpeg, .tif, .kml, .pdf)
   - Point cloud (.las, .x,y,z)
   - 3D model (.obj)
3. Web-based links (.url)
   - Web maps: orthomosaic, elevation, plant health
   - Multi-media: video, pictures, 360 panoramas

- 3D models: embed code for websites, social media

4. Reports (.pdf)
    - Accuracy assessment: flight parameters and processing results
    - Annotation: summarises mapping analytics and textual information
    - Photo plan: site overview and textual information template

6.5 System software

A number of system software applications are required to safely operate the airframe and the payload to enable the collection of spatial data and the production of spatial mapping information. We recommend, as a minimum, the use of an iOS mobile device (e.g. iPad tablet) and a personal computer (with at least Windows 10, 64 bit, 8 GB RAM as a minimum, Intel Core i7 2.3 GHz four-core processor) to view and analyse spatial data, edit multi-media, produce maps and share all of the produced data and information.

The following system software applications (most of which can be downloaded for free) are recommended.

MOBILE DEVICE SYSTEM SOFTWARE

1. UAS (UAV, GCS, Payload) Control
    - DJI Pilot: https://www.dji.com/goapp
2. Weather and UAS Flight Restrictions
    - Hover (real-time weather & UAS news): http://www.hoverapp.io/
    - AIRMAP: https://www.airmap.com/
3. Automated Flight Planning
    - Drone Deploy (iOS & Android)
    - Map Pilot for DJI (iOS only)
    - Pix4DCapture (iOS & Android)

DESKTOP SYSTEM SOFTWARE

4. Post-processing and mapping software packages
    - Drone Deploy: https://www.dronedeploy.com/
    - Maps Made Easy: https://www.mapsmadeeasy.com/
    - Drone2Map: https://www.drone2map.com/ or Pix4D: https://pix4d.com/
5. Spatial analysis software
    - Drone Deploy Dashboard: https://www.dronedeploy.com/
    - ArcGIS: http://www.esri.com/software/arcgis/arcgis-for-desktop/
    - Google Earth: https://www.google.com/earth/
6. Editing multi-media
    - DJI Go: https://www.dji.com/goapp
    - Final Cut Pro X (iOS): https://www.apple.com/final-cut-pro/
    - Adobe Photoshop: https://www.photoshop.com/products
    - Lightroom CC: https://lightroom.adobe.com/

Note, however, that UAS are rapidly evolving, and readers should consult the most recent sources of information.

6.6 Equipment and accessories

Additional hardware equipment and drone accessory components are also recommended as follows.

DATA STORAGE DEVICES

1. Mobile device/tablet: storage of flight paths and times (log files) and photos / videos
    - A minimum at the time of compiling (January 2021) of the DJI Go iOS V4.3.12 requires iOS 10.0.0 or later and is compatible with iPhone X, iPhone 8 Plus, iPhone 8, iPhone 7 Plus, iPhone 7, iPhone 6s Plus, iPhone 6s, iPhone 6 Plus, iPhone 6, iPhone SE, iPad Pro, iPad, iPad Air 2, iPad mini 4. Optimized for iPhone X. Please note - although DJI Go is also available in Android (V4.3.11 requiring a minimum of Android 5.0 or later) this operating system is not recommended as many of the most common flight planning and mapping apps are using an iOS.
2. Scandisk (SD) memory cards (2 for each UAV): recording aerial flight log data and images / videos
    - A storage capacity of 64 GB microSD (XC) card with a minimum transfer speed of 10 MB/s is recommended for most recreational drones but will depend on camera quality.
3. External hard drive, cloud storage and/or server: storage of raw aerial imagery & processed data
    - A dedicated portable hard drive USB 3.0 or cloud-based server with a minimum of 3TB of storage is recommended but will depend on the amount of photos to video captured with the UAS.

ACCESSORIES

- Spare UAV batteries (minimum of three batteries are recommended per drone)
- Component chargers: UAS controller, UAV batteries, Mobile device or tablet
- Rapid charging hub (for three batteries and GCS controller)
- Tablet to GCS controller USB cables (minimum of two)
- Spare UAV parts (extra blades and set of propeller clips)
- Drone screwdriver tool kit set
- GCS hood (to reduce glare)
- Landing pad (one for each UAV)
- High visibility vests (identification of the UAS crew) clearly labelled 'UAS Crew and name of organisation'

Caution: GCS with a built-in screen are not recommended for drone mapping as these UAS controllers are not compatible with third-party (i.e. non-DJI) flight planning and mapping software packages.

Note, however, that UAS are rapidly evolving, and readers should consult the most recent sources of information.

7 METHODS FOR USE AND MANAGEMENT OF DRONES

The methods presented here are based on the view that they should be low cost and require limited technological expertise. They can be widely applied in SIDS situations. Since 2016 the lead author has been testing and comparing the use of commercial 'off-the-shelf' drones (i.e. equipped with a RGB camera payload), drone flight planning mobile applications and various cloud-based photogrammetry mapping software to determine the most suitable methods for the Caribbean context (i.e. technological, human and financial resources). DJI® 'off the shelf' recreational multi-rotor drones equipped with a standard high-definition (RGB) camera payload are easy to fly, relatively inexpensive and found to be an excellent tool for rapidly surveying and mapping coastal marine areas (Baldwin et al. 2019). Moreover, the DroneDeploy UAS flight planning and mapping software package provides a non-technical, cloud-based processing environment, and requires only basic technological skills. This software platform allows for drone surveys to be planned and conducted 'in-situ' and mapping products created during flight, without the use of cellular data that can be costly in Caribbean SIDS remote field research situations. An additional benefit is that this functionality allows for simultaneous 'ground-truthing' or collection of field survey attributes on these current 'real-time' drone mapping products easily adding value to standard drone mapping data and conventional field surveys.

The drone survey protocol presented is under development (as part of the Centre for Resource Management and Environmental Studies (CERMES) SargAdapt Project; see Baldwin and Oxenford 2021). It comprises a number of components including procedures for conducting an initial site assessment and planning an aerial drone survey (and flight plans) to create a basemap of the coastal monitoring site and mapping conventional biophysical data with field surveys for monitoring and informing environmental management initiatives. The main steps are briefly outlined in the following sections.

7.1 Drone surveys

The key equipment (drone equipment and UAS software) being used includes an off-the-shelf recreational quadcopter drone (DJI Phantom 4 Pro version 2 drone integrated with a standard RGB camera 20 MP HD optical lens system payload system) to fly the survey missions and record the remote images and an offline (Wi-Fi-only) tablet (iPad 7^{th}Generation) together with the DroneDeploy interface. The tablet and interface are used both to plan the drone survey flights and allow for the processing and production of orthomosaics (multiple images stitched together to form a single geospatial image), plant health condition indices (Visible Atmospherically Resistant Index (VARI) tested to work with RGB camera sensors), three-dimensional stereo point cloud elevation models (DEM, LAS), mapping products, 360^{o} panoramic images, as well as landscape photo and video footage of the monitoring site. DroneDeploy 'Live Map' functionality to produce offline mapping data is leveraged as part of the drone monitoring protocol allowing feature attributes to be annotated directly on drone maps and in-situ measurements (*e.g.* location, distance, area, volume) to be conducted during field surveys. Table 3 sets out the drone, field equipment and supporting software for the monitoring protocol presented.

Table 3. Description and quantity of all equipment, hardware and software packages used in the drone monitoring protocol.

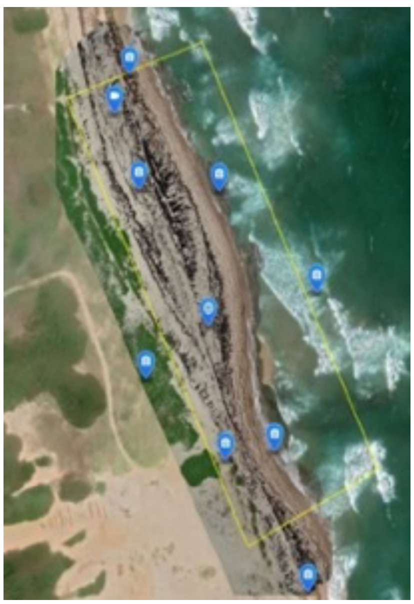
Item	Description	Quantity
DJI Phantom 4 Pro Version 2 Quadcopter	1-inch 20-megapixel sensor with 4K/60fps video	2
DJI Intelligent Flight Battery	P4P LiPo (15.2V) Batteries	4
DJI Propellers	Low-Noise Quick-Release	4
SanDisk MicroSD Cards	Extreme 64 GB U3	4
GPC Backpack	P4P and Accessories Carrying Case	2
Apple IPad	7^{th}Generation (10.2") 64 GB (Wi-Fi only)	1
Landing Pad	Lightweight UAS Landing Pad	1
UAS Polarizer Lens	P4P ND Filters	2
UAS Software	DroneDeploy (Enterprise License)	annual
GIS Software	ESRI (ArcPro 2.5 & ArcOnline License)	annual
Brightly coloured bucket lids/flags/rope	Marking of ground-truthing validation features	5
Buckets	Measurement of sargassum volume	2
Ruler	Measurement of the height of sargassum piles	1
Clipboard and data sheets	Recording of flight and ground-truthing data	1

7.1.1 Preliminary site assessment

A baseline drone survey plan is designed first to map the ecosystem of the monitoring site and encompass the length of the coastline (beach or bay). This covers the full geographic extent of the coastal community inshore, extending out to sea to include all of the affected coastal infrastructure, resources, space-uses, activities and any areas of concern or impact (recall Figure 2). First, a preliminary site assessment is undertaken comprising a visual examination of existing aerial imagery and secondary data (e.g. Google Earth, topographic maps, aerial photos) of the monitoring site. The preliminary assessment not only aids the determination of technical flight parameters for each site, it also aids the collection of supplementary site-specific information providing a means of better understanding activities occurring within the ecosystem, the associated biophysical features, livelihoods and spatial interactions to be mapped.

7.1.2 Flight planning

Drone survey flight plans are created using the DroneDeploy mobile and desktop platforms (Figure 6). Mapping survey parameters include the predicted flight time, survey area (ha), number of images and batteries required, flight altitude (m) and expected resolution of aerial data to be collected are chosen to produce an orthomosaic map and an elevation point cloud surface. A short video (less than 60 seconds) of the site as well as photo and 360^{o} panorama plans are also flown at each monitoring site.



The following drone flight plans are recommended

1. Mapping survey: production of orthomosaic and elevation point cloud
2. Panorama plan: production of a 360^{o} view of the site
3. Photo plan (~7-10 photos): landscape shots spread along site extent boundaries with reporting template for addition of textual information
4. Video plan (< 60 seconds): flown down the length of beach, slightly offshore and of onshore mapping extent to capture aerial footage of the site

The 'Live Map' should be carefully examined on the tablet and checks made in the field to verify that the full extent of the monitoring site is included and that ground features are clearly identifiable before leaving the site. This drone mapping data will be used with a site assessment questionnaire to aid in the determination of the final monitoring site extent, flight plans and corresponding attribute features parameters to be mapped.

Figure 6. Mapping extent (yellow polygon), examples of the locations of various drone survey flight plans (blue icons).

7.2 Creation and sharing of drone mapping information

After all drone flight surveys are conducted, data are uploaded using the DroneDeploy desktop platform and post-processed in the cloud to produce a point cloud, orthomosaic and elevation maps, georeferenced 360^{0} panorama picture, photo plan and aerial video of the monitoring site (Figure 7).

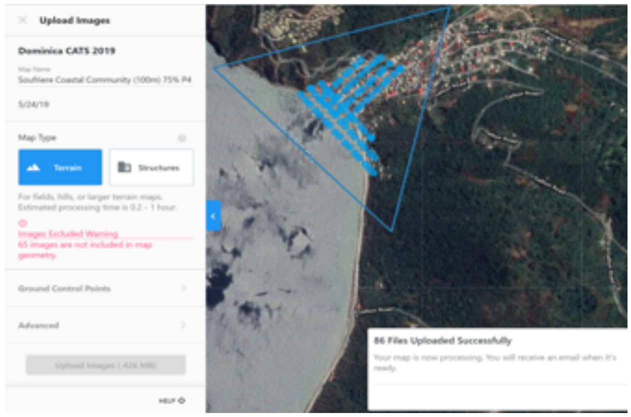


Figure 7. Drone surveys are uploaded using the DroneDeploy desktop platform and post-processed in the cloud.

These baseline mapping results together with the site assessment questionnaire are then used to determine the final extent of the monitoring site, identify mapping features and attributes parameters to be collected. Supplementary attribute information collected on the site is annotated to drone basemaps (represented as point, line, polygon and text) using the DroneDeploy web-mapping dashboard interface. Additionally, integrations with a number of popular third-party spatial analysis software packages (i.e. GIS, Google Earth, AutoCAD) allow for other spatial datasets (i.e. jurisdictional boundaries such as parcels, buildings, houses, protected areas) to be easily overlaid on maps and create a range of information that can be easily shared via the internet (.url) to enable teams to work remotely in a collaborative fashion.

8 APPLYING PARTICIPATORY DRONE MAPPING IN SOCMON

Here we illustrate how the main phases of the SocMon methodology can be complemented with drone survey data and participatory mapping together as a sound basis for practically collecting social-ecological information. Although SocMon variables do not explicitly and comprehensively address poverty as in a full Multidimensional Poverty Index (MPI) (UNDP and OPHI 2019), it is easy to adapt SocMon to include more aspects of poverty than covered in the standard variables. It is also feasible to apply drone technology to MPI data and information separate from SocMon.

The SocMon methodology comprises six main steps to establish a socio-economic monitoring programme for coasts and fisheries: (1) preparatory activities, (2) planning and scoping, (3) data collection and observation, (4) data analysis and validation, (5) key learning and communication, and (6) decisions and adaptive management. SocMon is a highly iterative process with loops, feedbacks and checks, but for simplicity it is shown here a (Figure 8) and described below as a linear flow.

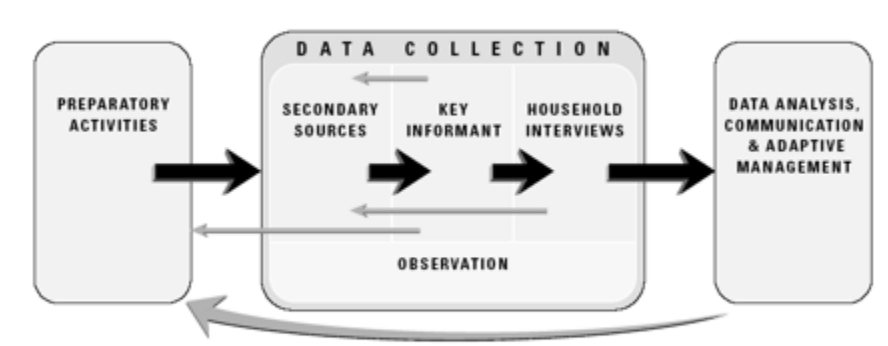


Figure 8. Main steps of the SocMon methodological approach (Source: Bunce and Pomeroy 2003).

The first phase of SocMon entails 'preparatory activities', specifically the collection and review of literature and other secondary data on the monitoring site (e.g. policies, management plans, GIS data, imagery and maps, collateral information). This phase of SocMon can be improved to delineate the geographic extent for the coastal monitoring site. Drone maps can be used for preliminary identification of the distribution of the coastal/marine resources, various uses, potential issues (i.e. erosion, dumping, household proximity to features) and existing management efforts presently occurring in the coastal ecosystem. This assessment of the drone mapping information can be used to obtain an initial understanding of the ecosystem, existing marine resources and corresponding communities' users in terms of its biophysical features (i.e. habitat, resources and infrastructure), resource uses and threats, fill data gaps and thereby validate the results of the SocMon preliminary assessment preparatory exercise.

Next, as part of the 'planning and scoping' phase of the SocMon methodology, a careful review of the drone basemap is undertaken during interviews with key informants having an intimate knowledge of the ecosystem should be undertaken. Drone mapping products can be shown using a mobile tablet to facilitate discussion on the spatial interaction occurring within the monitoring site, and applied to aid the definition of the SocMon survey variables before undertaking household interviews and mapping-exercises with the community. Key mapping features of interest (i.e. locally-used place names for the beaches, bays and cays, coastal marine habitats, infrastructure, resource use and users) should be discussed with key informants. Any additional site-specific information provided can be spatially annotated directly on the drone map during interviews using a mobile tablet and the DroneDeploy annotation tools and used to create a composite basemap (i.e. orthomosaic, elevation and plant health) of the coastal community and surrounding ecosystem. Drone mapping and annotation information can be viewed on a mobile tablet, printed as hard copy maps or exported into third-party mapping software (i.e. Google Earth, ArcGIS, Photoshop). This preliminary validation step allows key informants to help improve local understanding of the monitoring site by identifying and including features of importance on the composite basemap thereby aiding the participatory mapping exercises and the relevance of the information provided by the stakeholders during household interviews.

The third phase of SocMon, 'data collection and observation', entails the use of household interviews and questionnaires to obtain a variety of site-level information (as textual attributes) on the demographics, livelihood strategies, resource uses and environmental practices occurring within the ecosystem. Here the composite drone basemap is leveraged to improve visual understanding of the monitoring site and its' spatial interactions and used to complement discussions with the community. Participatory drone mapping exercises are linked to corresponding SocMon variables and conducted alongside the administration of the survey questionnaire. For example, local knowledge of space-use patterns (e.g. anchorages, dive sites, ferry routes, fishing grounds, shipping lanes), distribution and perceptions on the quality of coastal resources (e.g. baitfish bays, nursery grounds, seabirds, turtle nesting), areas of cultural importance and livelihood (e.g. aquaculture, tourism, historical sites, recreation, vending) and threat (e.g. dumping, dredging, erosion, flooding, mangrove cutting, sand mining) can be annotated on the drone basemap, spatially represented and quantified for analysis.

These types of participatory mapping exercises can be of use to spatially capture the local knowledge of resources users' whose livelihoods depend on coastal marine resources (e.g. dive operators, day-tour operators, water-taxi operators, fishers, ferry operators, yacht charter companies, cargo ships, community). Moreover, this information can be quantified, mapped and integrated with survey results to create 'spatial resource use profiles' for marine livelihoods. Participatory mapping may also be of relevance to collect information on community perceptions of the impacts of climatic events, their assessment of risk and vulnerability, and their spatial relationship with poverty indicator variables. These types of questions have often not been posed during socio-economic interviews (both SocMon and MPI), primarily due to limitations in community understanding of climate change at its nexus with multi-dimensional poverty. Therefore, the use of drone composite maps when discussing exposure, impacts and vulnerability with the community can thereby help to supplement information collected and fill gaps traditionally found in socio-economic, poverty and climate change data.

9 PRACTICAL OUTPUTS FROM A USE CASE

In the case that follows, drone data from Dominica's Soufriere Watershed was collected in 2019 as part of a UAS training course undertaken for the CARPHA CATS project. Data were collected in 2019 as part of the Ridge to Reef CATS Programme's "Adaptation of Rural Economies and Natural Resources to Climate Change" and the "Management of Coastal Resources and Conservation of Marine Biodiversity". The existing drone data are showcased here to draw attention to how a participatory mapping approach can be employed within a coastal community to quickly and easily produce and share a range of fisheries information and mapping products. The following sections briefly present a demonstration of the potential of drones to support the production of fisheries information for socio-economic, climate change and poverty assessments. The overall focus is to identify spatially based socio-economic information relevant to climate change and poverty, to showcase how this information can be incorporated into the SocMon methodology to improve understanding and target key areas of vulnerability in coastal communities. We also discuss considerations on how such an approach can be applied in the Caribbean to implement a practical framework to support EAF in similar SIDS contexts. Figure 9 illustrates generically how UAS may be used in EAF.

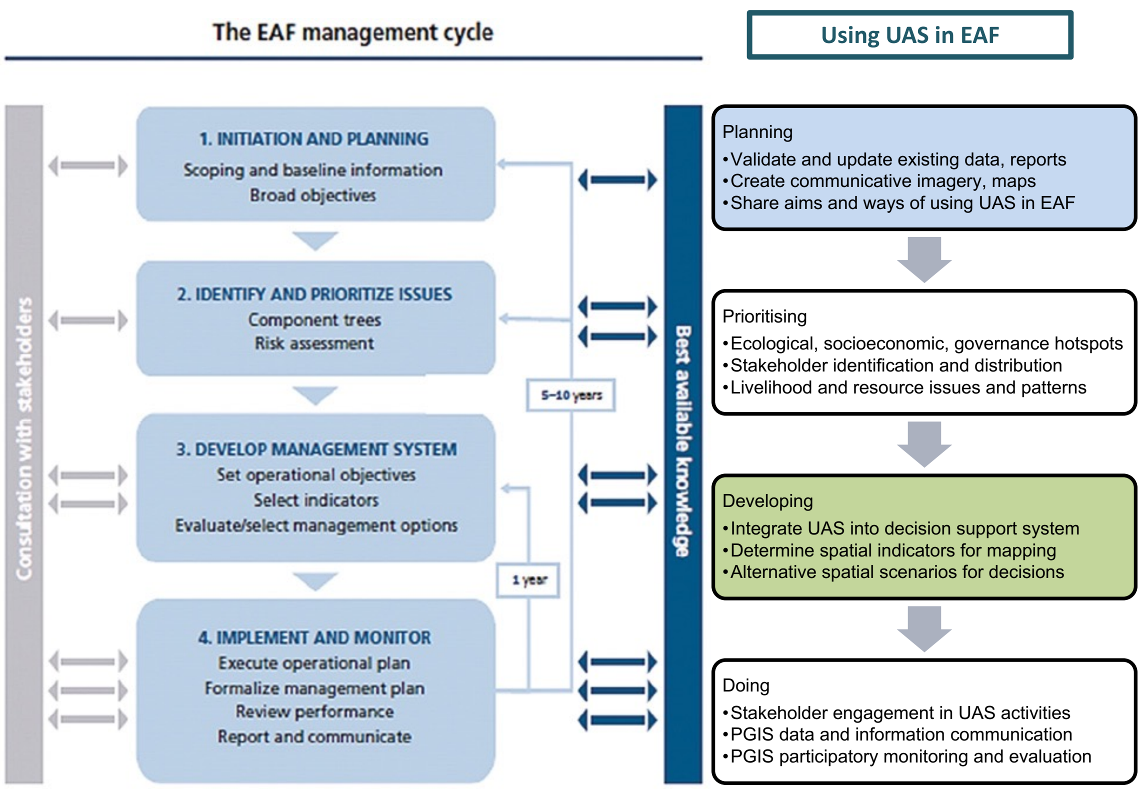


Figure 9. Using UAS in the EAF management cycle (Adapted from Bianchi et. al. 2016)

9.1 UAS survey data products

Here we present the results of two UAS mapping surveys of the coastal community and watershed in Soufriere, Dominica, that were planned and flown using a DJI Phantom 4 drone (at 100m AGL using 75% overlap) with an iPad tablet running the DroneDeploy flight planning mobile application. A total of 86 aerial images were uploaded and post-processed using the desktop DroneDeploy platform to create a 3D point cloud (.las), orthomosaic and elevation maps (.jpeg, .geotiff, .kml) and 3D model (.obj) of the site. Additionally, the video plan and an aerial 360^{o} panorama view of the ecosystem were also produced. Figure 10 shows the results of the orthomosaic and elevation data created and includes information on the type, resolution and file format. The web-based maps, 3D model and video of the monitoring site can be viewed online at Soufriere Coastal Community. Drone survey assessment reports on the flight plans and accuracy of the processing results are also created (see Appendix 2).

Soufriere Coastal Community

Data type	Resolution	Formats
Orthomosaic	5 cm/pixel	Jpeg, Geotiff
Elevation	21 cm/pixel	Jpeg, Geotiff
Video	4K @100Mbps	MP4, MOV

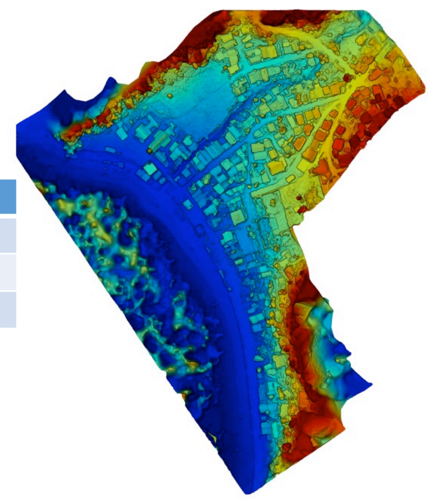


Figure 10. UAS data products (by type, resolution and format) created of the Soufriere Coastal Community in Dominica.

9.2 Mapping of coastal fisheries information

Initial examination of drone mapping data along with SocMon 'prepatory information' gleaned from secondary sources, a number of infrastructure, habitat, resources and space-use features can be easily identified, mapped and validated. An example of a typical geodatabase structure of fisheries information that can be easily be created from drone and mapping execises is provided in Table 4 listed by feature class, spatial data model, source of information and any additional geoprocessing steps required.

9.3 Analysing coastal fisheries information

Understanding the amount and distribution of ecosystems, structurally and functionally, is essential for EAF and MSP initiatives. Geoprocessing tools can allow for the integration of data layers to help explore spatial patterns that occur between and among habitats and resources as well as the relationships between the resource users. One benefit of cloud-based drone and GIS information technology platforms is the ability to quickly create maps and easily share a variety of spatially based mapping and multi-media products using existing computer hardware internet infrastructure regardless of some of the challenges that may be experienced in many SIDS in the Caribbean. Modern GIS and UAS IT now enable stakeholders with tools to support collaborative remote working environments. These platforms leverage cloud-based technology to provide stakeholders with widespread access to information produced and simple analytical and reporting tools to allow for a better understanding of the interactions occurring within a particular environment and support decision-making.

Table 4. Example of a fisheries geodatabase structure listed by feature class, data model, source and geoprocessing steps

Feature dataset	Feature class	Data	Source	Geoprocessing
Bathymetry	Depth contours (100 m)	Line	Nautical chart	
Infrastructure	Roads	Line	UAS imagery	None
	Hotels	Point	UAS & socio-economic surveys	Digitised; Join related tables
	Airports			
	Seaports			
Marine habitat	Shallow water habitat	Polygon	Mapping exercise & field survey	Digitised and ground-truthed
	Shoreline type	Polygon	Mapping exercises	Digitised
	Wetlands			
Resources	Seabird nesting areas	Polygon	Mapping exercises	Digisited
	Mariculture (seamoss)	Point	Mapping exercises	Digitised
	Sea turtle nesting			
	Shipwrecks		Nautical charts, mapping exercises	
	Baitfish bays	Polygon	Mapping exercises	Digitised
	Nursery areas			
	Oyster beds			
	Whelks	Line	Mapping exercises	Digitised
Resource users	Day-tour operators	Point	UAS & socio-economic surveys	Digitised; Join related tables
	Dive shops			
	Ferry operators			
	Fishers			
	Water-taxi operators			
	Yacht companies			
Space-uses	Fish landing sites	Point	Mapping exercises	Digitised
	Recreation (community)			
	Vending		UAS & socio-economic surveys	Digitised; Join related tables
	Shipbuilding			
	Anchorages	Polygon	UAS imagery	Digitised
	Dive sites		Mapping exercises	
	Shipping lanes	Line	Mapping exercises	Digitised
Fishery (areas)	Conch	Polygon	Mapping exercises; field survey	Digitised
	Lobster			
	Fish			
Fishing gear	Diving (tank)	Polygon	Mapping exercises; field survey	Digitised
	Spear gun			
	Fish trap (pots)			
	Net (siene)			
	Line			
	Fishing pressure (density)	Polygon	Modeled	GIS (weighted overlay)
Threats / Pollution	Landfills	Point	Mapping exercises	Digitised
	Illegal dumping			
	Artificial structures	Polygon	Mapping exercises	Digitised
	Sand-mining			
	Flooding			
	Dredging			
	Quarries			
	Mangrove cutting			
	Erosion	Line	UAS & mapping exercises	Digitised
	Desalination outfalls			
Jurisdictional	Marine protected areas	Polygon	GPS coordinates; maps	Download online
	Exclusive economic zone		VLIZ Maritime Boundaries	Download online
Other	Scope of monitoring site	Polygon	UAS data & mapping exercises	Digitised
	Local names of coastal	Annotation	Mapping exercises	Digitised
Imagery	UAS data	Image	Drone mapping survey	Processed using Drone Deploy
Basemaps	Nautical charts	Map	Fisheries Division	Scan and georeferenced
	Topographic maps		Lands and Survey Dept.	

9.4 Spatial socio-economic, climate and poverty information

The Soufriere coastal community drone maps are used to briefly discuss the following analyses

- Mapping of habitat, resources, infrastructure, associated human activities and community issues
- Quantification of resource use and fishing activities
- Evaluation of climate change vulnerability (exposure, sensitivity, adaptive capacity)

9.4.1 Mapping habitat, resources, infrastructure, activities and issues

The boundary of the community monitoring site can be overlain to quickly allow for a visual inventory of coastal habitat occurring within the ecosystem; an assessment of the types of resources, users and infrastructure within each community; as well as to identify impacts and evaluate vulnerabilities at the nexus of climate change and poverty and useful to support decision-making, the effective development of monitoring targets and assessment towards the progress of management strategies. Easy to use cloud-based dashboard mapping analytic tools (i.e. location, distance, area, volume, count) allow for a number of biophysical features seen within the coastal ecosystem to be quickly quantified from drone mapping data. For example, a line feature of a stream emanating from the watershed catchment can be created to three-dimensionally map the length, slope and vertical height characteristics of the elevation profile (Figure 11).

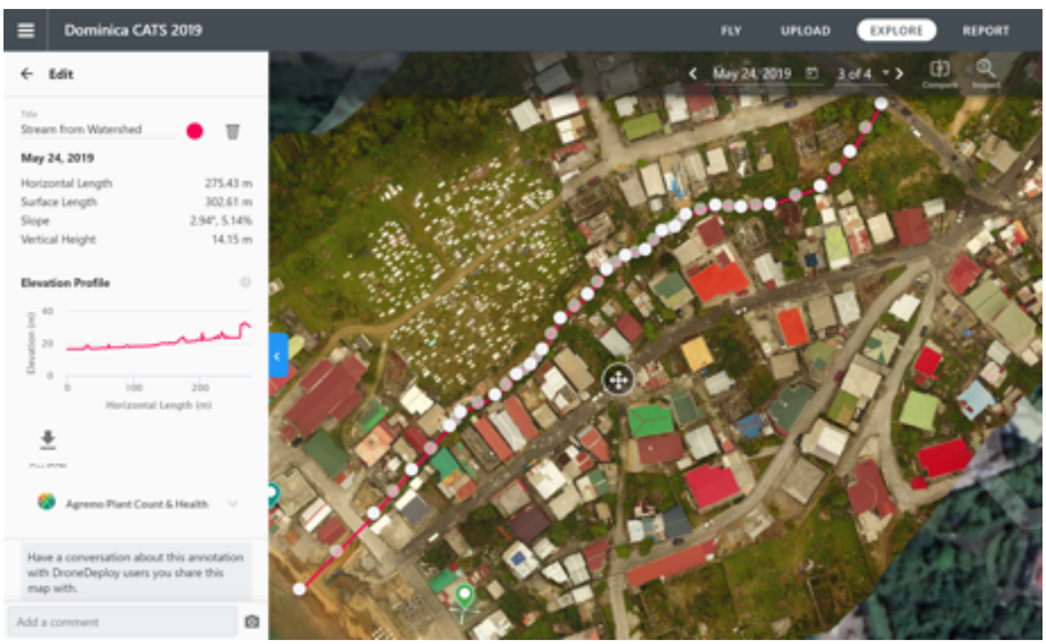


Figure 11. Example of a line feature and the resulting elevation profile data created (showing length, slope and vertical height) of a stream emanating from the Soufriere watershed catchment in Dominica using the Drone Deploy's mapping dashboard.

To further demonstrate functionality, a number of coastal habitat and resources, fishing infrastructure and human activities occurring within the Soufriere coastal community were annotated using the UAS mapping software's analytic dashboard tools and in which results are quantified into a sharable summary report document (Figure 10). Example of the location of important marine habitat and resources (e.g. mangroves, reefs, bird and sea turtle nesting), existing infrastructure (boats, fishing complex, MPA office, police station), and human activities (landing sites, vending, shipping lanes, community gatherings) and potential issues (dumping, mangrove clearing) occurring within the coastal community can be quickly identified from drone mapping products (Figure 12).

Figure 12. Example of a Drone Deploy summary report showing the drone map annotated with the location of coastal habitat and resources, fishing infrastructure and human activities that occur within the coastal community (see Appendix 3 to view full size pages).

9.4.2 Quantification of resource use and fishing activities

An important aspect of ecosystem-based management is to understand not only the location of resources but the influence that humans are having on them. Drone mapping surveys can be used to explore the interactions among variables, evaluate trade-offs and prioritize management objectives. For instance, the location, abundance and proximity of the various coastal resources, space-use patterns and fishing infrastructure can be visually examined, and local knowledge of interactions assimilated using participatory mapping exercises. Additionally, GIS analysis can then be leveraged for decision-support to quantify information and better understand the resource use, as well as prioritize spatial management measures and community recommendations.

This has several important implications for EAF. First, there may be a certain degree of either environmental degradation or 'natural' protection of habitats and resources taking place by virtue of the communities' practices currently in use (e.g. the limitations of fishing methods, infrastructure and vessels). Those who may seek to develop the fishing industry should be conscious of how their initiatives may affect this current situation. Additionally, local knowledge and information on community perceptions may be of use in the determination of feasible management measures, such as conservation or fishing zones, by aiding the selection of areas which are not of high priority. These types of spatial analyses and mapping products can contribute to the development of fair and equitable management approaches as they may meet with low resistance from or have little impact upon fishers thereby assisting acceptance and compliance within the community.

9.4.3 Evaluation of climate change and poverty vulnerabilities

An evaluation of vulnerability and monitoring progress towards targets is essential to the achievement of strategies developed to mitigate the impacts of climatic change. The vulnerability of fisheries to climate change are generally examined in terms of exposure, sensitivity and adaptive capacity. Exposure is the degree to which a community experiences climate change. Sensitivity determines the impact from climate exposure. Adaptive capacity is therefore the ability of a system to anticipate, respond and recover from climate impacts. These areas are essential for community and fisheries resilience, and important for evaluating the locations of current management efforts or for selecting future locations for management interventions.

Exposure captures the amount of the resource or infrastructure that is likely to be impacted in a community as a result of a climate change scenario (i.e. storm surge and sea level rise). Drone-generated elevation data can be used to model erosion, sea level rise, storm surge events and the impacts of flooding events. Mapping products can then be used to visualize scenarios and better understand potential impacts on the coastal community. For example, drone maps overlain with elevation data can be used to identify the type and number of households and coastal infrastructure at risk. Socio-economic and poverty information (obtained from SocMon and MPI) attribute data tables can be spatially joined to mapping features to quantify multi-dimensional vulnerabilities and quantify impact in the coastal community in a more holistic fashion.

Measurement of SSF sensitivity is examined through community dependence on fisheries (e.g. primary income, number of fishing facilities and distance to fish markets) which may be negatively impacted by climatic events. Drone maps can be used to quantify climatic impacts and assess damages such as the spatial location of building footprints, roofing material, debris, calculating the distance to fishing infrastructure as well as the ability to document live 'on-the-ground' video footage critical for disaster mitigation and management planning.

Adaptive capacity assesses the diversity of livelihoods available, social networks and cohesion, such as membership in a fishing association and access to resources and information present in the community. Although not necessarily spatial in nature, adaptive capacity can be supported with participatory drone mapping. Much of this information is captured as textual attributes as part of the SocMon and MPI assessments and can be mapped by joining attribute table data to associated spatial information. This can allow for household-level of demographic and poverty information to be incorporated into spatial analysis and visualised graphically (Baldwin et. al 2013). Merging multiple types of datasets and assessments could be a tremendous added value to these methodologies, and the implementation of EAF yet require additional support (i.e. technical and human capacity) in terms of GIS skills. Baldwin et al. (2013) and Baldwin (2012) provide more detailed explanations of this application and its' value in terms of EAF or EBM and strengthening governance.

10 REFLECTIONS AND FUTURE DIRECTIONS

Effective management of diverse and dynamic coastal social-ecological systems must be adaptive, based on the best available information, address issues of multiple scales, allow for inter-sectoral cooperation and promote broad stakeholder participation (Armitage et al. 2009). Emerging perspectives on social-ecological systems and interactive governance in SIDS call for an effective framework that is scalable from local to regional levels (with vertical and horizontal connections) encompasses human dimensions to resonate with local frames of reference (e.g. governance, socio-economic and cultural beliefs) and fosters cross-scale linkages to support adaptation and resilience (Christie et al. 2005). With this appreciation, the need to develop practical tools that make such an approach operational, particularly in marine and SIDS contexts is long overdue (McCall 2003). The use of drones and PGIS or a PUAS framework in coastal mapping falls squarely into the category of development required at the nexus. As with all applied science and technology, the approach must be fit for purpose from conceptualization to fieldwork.

10.1 Policy, ethics and safety

The extensive growth of UAS applications and the availability of drone platforms has rapidly outpaced many regulatory frameworks. Although many countries now have implemented legal frameworks to register and fly drones for commercial purposes, national rules and regulations vary considerably. Globally UAS policy focus primarily on the safe management of airspace, and to a lesser extent, public privacy and security issues (Johnston 2020). Many Caribbean SIDS still have not yet implemented national drone policies, most countries have UAS flight permitting processes. Although policy and public perceptions regarding the use of drones and negative connotations (i.e. reduced privacy and security issues) exist, they are becoming less of an issue globally as drones are increasingly being used by the general public for photography and entertainment purposes. Despite this, there are many challenges associated with using drones to study humans in marine systems. Some are obvious regulatory limitations associated with safety (i.e. flight restrictions over congested areas or critical infrastructure, within the pilot's visual line of sight), whereas some are more technological (i.e. UAV platform flight endurance, payload sensor capabilities, data processing, spatial analysis). The most concerning and difficult to resolve are ethical and legal, where researchers must apply best practices and conduct their work in a manner that does not invade the privacy or erode the security and well-being of people being studied (Sandbrook 2015). Unfortunately, no comprehensive set of best practices yet exists to guide researchers in their efforts to explore the use of drones in the study of human behaviour and marine ecosystem management (Johnston 2020).

10.2 Geospatial analysis and data management

Coastal social-ecological systems require comprehensive ecosystem-based information to appropriately assign management priorities and address climate and poverty impacts within coastal communities. Drone mapping and analyses described in the above case can be of great value to understanding the extent and distribution of existing resources and their relationship to livelihoods. Although this is a significant first step, many times more advanced GIS analyses and technical skills are required for these maps to be used and integrated amalgamated with multiple sources and scales of information to develop potential scenarios (i.e. sea-level rise, space-use plans) and facilitate the prioritization of trade-offs and evaluate the feasibility and impacts of potential management measures on livelihoods. In the case of coastal fisheries nexus, the identification of areas with higher environmental integrity such as a well-connected reef ecosystem and identified threats can be explored to prioritize conservation efforts. In terms of social acceptance and feasibility of management, human activities which occur in the community can be assessed to identify the possible displacement of resource users and potential impacts on livelihood can be determined, highlighting areas of poverty and vulnerability to climate hazards. GIS allows for multi-scaled types and dimensions of information (e.g. fisheries, climate and poverty) to be integrated to identify multiple-use areas, and their proximity to critical resources which can be important to assess vulnerability and prioritize management efforts. For example, overlaying infrastructure and poverty information with identified areas of high climatic risk and community perceptions of threat can enhance the assessment of vulnerability and conflicting space-uses which can aid the development of effective management strategies. Scenarios can be assigned a rank (or weighted based on socio-economic information, existing infrastructure, or community priorities) to develop 'cumulative impact' surfaces. These GIS decision-support tools help collaboratively identify potential vulnerabilities by underscoring areas of importance thereby informing spatially based evaluation of management considerations (livelihoods interactions, development and disaster risk scenarios, etc.) and the identification of appropriate and cost-effective actions.

There is tremendous opportunity to utilize operational GIS workflows with UAS technologies to increase efficiency for socio-economic monitoring and resource management. We have initially demonstrated how participatory mapping can be integrated to create a range of ecosystem-based information and how a participatory approach can be leveraged for EAF to address managing multi-scaled complex systems and support the monitoring of targets and achievement of global strategies such as the SDGs. Unfortunately drone mapping information, spatial data and GIS analyses described can quickly create large amounts of data, whereby easy to use data management workflows are essential for the creation of information and effective use for decision-making. Often the data collected from drone surveys must also be assessed and processed manually requiring an analyst to quantify resources and quantify density, abundance and changes in an ecosystem. GIS data management and spatial analysis therefore requires additional resources in terms of time and hardware, and capacity in technical skills. To address these issues, automated techniques including computer vision and machine learning to automate analysis and reduce the amount of investment in building capacity in technical skills and hardware required are being leveraged. Moreover. modern GIS paradigms have evolved to include web mapping applications, automated models and field surveys, analytic dashboard interfaces as well as 'scaffolded' instructional approaches for problem solving, critical thinking, and spatial thinking. Likewise, the advent of crowdsource-able field apps, rigorous consumption and creation of web maps and mapping applications such as story maps, coding and building expressions, performing spatial analysis, and other components of the web infrastructure as enabled by SaaS tools and data as services are revolutionising the functionality of GIS for citizen science in environmental management.

10.3 Importance of implementing an integrated PGIS/PUAS approach

We have illustrated how enhancement of SocMon and MPI data collection with PGIS and PUAS can be applied to create integrated spatial data and information outputs. These approaches produce 'site-level' community-based and validated coastal and fisheries information to better understand the impacts of climate change and poverty. They inform planning and management efforts to reduce the vulnerabilities and improve resilience of coastal fishing communities. Transparent and inclusive communication as well as the production of 'locally-relevant' information in an accessible format is central to ecosystem approaches (i.e. EBM, EAF, DRM, CCA, MSP, ICM, IWM). Considering the geographical and socio-political complexity of coastal uses and SSF in Caribbean SIDS, the significance of such wide-ranging, cross-scale collaboration (or connectivity) is worthy of emphasis. The use of UAS and web-based mapping and analysis SaaS platforms can provide widespread access to information and transparent communication advantageous in creating a common space of understanding amongst a range of audiences. This not only fosters the legitimacy of local knowledge but supports a collaborative learning environment that can serve to build capacity, ownership and support for management measures.

Aspects of participatory drone mapping and monitoring to create a standard drone monitoring protocol for monitoring and managing sargassum in the Caribbean and a suitable geospatial framework leveraging the use of a web-based mapping and analysis platform are being developed by CERMES under the SargAdapt Project (2018-2022). Methods are based on the view that they should be of low cost and require limited technological expertise so that they could be widely applied in SIDS situations. This protocol is currently being developed with the use of the DroneDeploy and ArcGIS Online SaaS commercial platforms to enable regional multi-scaled collaboration required to collect, analyse and widely share ecological and management information using minimal resources (i.e. equipment, technical skills, geospatial training and financial). The development of the wider PUAS monitoring framework is being undertaken as part of an FAO Drones for Agriculture and Geospatial Training Initiative in the Caribbean. This initiative includes the establishment of Ministry of Agriculture drone teams, developing a drone policy and operations manual as well as a practical training curriculum comprising a series of drone-based mapping and monitoring courses in participatory mapping, spatial analysis, data management and the creation and sharing of information using web-based UAS and GIS software platforms. Although the curriculum is being developed for agricultural mapping applications within SIDS it is easily applicable across scales and disciplines such as for disaster risk management**.** These initiatives will scale-up good practices for dissemination to encourage replication of useful experiences, foster cooperation and strengthen technological capacity and governance in the Caribbean SIDS. Ultimately, the aim is to fully institutionalise the use of PGIS/PUAS to be a standard operating practice for marine, coastal and terrestrial work rather than an occasionally used approach requiring external intervention.

10.4 Future directions

There is an urgent need for a more concerted effort to bring available science and technology to bear upon societal problem-solving and creation of opportunities. The availability of smaller, lower-cost, easier-to-use information technologies including the coordinated use of aerial, surface, and underwater drone platforms for research and monitoring is transforming environmental management and is anticipated to grow tremendously over the next decade (Johnston 2020; Shkurti et al., 2012). The PUAS approaches described here can assist in providing a better understanding of the contribution of SSF to food security, sustainable and alternative livelihoods, poverty alleviation etc. as well as impacts and implications of global processes such as climate change on these social-ecological systems. The use of science and technology set out in this introductory report has an important role to play in enhancing the adaptive capacity of management authorities, communities and fisherfolk organizations. It links with SSF stewardship through developing and building capacity (knowledge and skills), informing strategies for intervention and improving the ability of SSF and stakeholders to adapt to shocks and uncertainty. Furthermore, such innovation can also be applied to complement a number of initiatives that link PUAS with other coastal, fisheries and resource management applications developed through approaches that seek to improve the visualization of data and information for decision-making.

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12 APPENDICES

Appendix 1. Specifications of the DJI® Phantom 4 Professional (version 2.0) UAS

UAV Airframe (*should be labelled with the UAS license number, name of organisation and phone number*)

- Model: WM331S
- Frequency: 2.400 - 2.483 GHz and 5.725 - 5.850 GHz
- Weight: 1375 g (with battery)
- Dimensions: 350 mm (diagonal)
- Motors: (4) DJI 2312S Motors
- Propellers: (4) 9455S Phantom 4 Pro Low-Noise Quick Release propellers
- Autopilot: DJI Go Application, Built-in return to home feature
- Flight Time: Approximately 30 minutes
- Max Transmitter Range: Up to 0 – 7km
- Max Speed: S-mode: 45 mph (72 kph), A-mode; 36 mph (58 kph); P-mode: 31 mph (50 kph)
- Max Ascend: S-mode: 6 m/s, P-mode: 5 m/s
- Max descent speed: S-mode: 4 m/s, P-mode: 3 m/s
- Max Payload: n/a (*cannot add payload*)
- Max Altitude: N/A
- Max Service Ceiling Above Sea Level - 19685 feet (6000 m)

Camera

- Camera model: Built-in RGB Camera
- Sensor: 1'' CMOS 20 Mega Pixel
- Lens: FOV 84° 8.8 mm/24 mm (35 mm format equivalent) f/2.8 - f/11 auto focus at 1 m - ∞
    - ISO Range: Photo: 100 - 3200 (Auto); 100- 12800 (Manual)
      Video: 100 - 3200 (Auto); 100 - 6400 (Manual)
- Shutter speed: 8 - 1/2000 s(Mechanical) or 8 - 1/8000 s (Electronic)
- Still photo file formats: JPEG, DNG (RAW), JPEG + DNG
- Video file formats: MP4/MOV (AVC/H.264; HEVC/H.265)
- Micro SD card Max Capacity: 128GB (Write speed ≥15MB/s, Class 10 or UHS-1 rating required)
- Operating Temperature: 32° to 104°F (0° to 40°C)
- Software: DJI Go 4
- Communication: Wifi connection
- Dual user capability: No

Gimbal

- Stabilization: 3-axis gimbal (pitch, roll, yaw)
- Controllable Range: Pitch: -90° to +30°
- Max Controllable Angular Speed: Pitch: 90°/s
- Angular Vibration Range: ±0.02°
- Detachable from Airframe: No

Battery

- Model: Phantom 4 Intelligent Flight Battery (PH4-5870)
- Capacity: 5870 mAh
- Voltage: 15.2v
- Weight: 468g
- Type: Rechargeable Lithium-ion (LiPo 4S)

Appendix 2. Map processing and accuracy assessment report (Soufriere Coastal Community)

Dominica CATS 2019 - Soufriere Coastal Community (100m) 75% P4

Captured: May 24, 2019, Processed: Jan 13, 2021

Map Details Summary

Project Name	Dominica CATS 2019 - Soufriere Coastal Community (100m) 75% P4
Photogrammetry Engine	DroneDeploy Proprietary
Date Of Capture	May 24, 2019
Date Processed	Jan 13, 2021
Processing Mode	Standard
GSD Orthomosaic (GSD DEM)	3.81cm/px (DEM 15.23cm/px)
Area Bounds (Coverage)	368734.56m^2 (39%)
Image Sensors	DJI - FC330

Quality & Accuracy Summary

Image Quality	High texture images
Median Shutter Speed	1/186
Processing Mode	['**Standard Mode** - Designed to produce the best photogrammetry output based on the input imagery. Include predominantly nadir imagery for most efficient mapping of large fields and crops, natural open terrain, and generating topographical maps. Entirely nadir collects are not recommended for reconstructing the sides of buildings, overhangs, or complex equipment. Include horizontal and oblique imagery to optimize processing for high resolution 3D reconstruction of buildings, pipework & conveyors.']
Images Uploaded (Aligned %)	86 (100%)
Camera Optimization	Focal length varied from reference value by 11.97%.

Appendix 3. Annotation report showing the location of important coastal habitat and resources, fishing infrastructure and human activities occurring within the Soufriere coastal community.

Annotation Report

Dominica CATS 2019

MARINE SPATIAL INFORMATION SOLUTIONS

Report created on January 14, 2021

Captured: *May 24, 2019*

Location

Label	Title	Elevation	Coordinates
1	Fishing Complex	20.77 m	15.2328330, -61.3618264
2	MPA Office	21.72 m	15.2325151, -61.3611955
3	Police Station	24.72 m	15.2312936, -61.3606297

Distance

Label	Title	Horizontal Length	Surface Length	Slope	Vertical Height
4	Stream from Watershed	275.43 m	302.61 m	2.94°, 5.14%	14.15 m

Area

Label	Title	Area	Surface Area
5	Area affected during flooding events	0.51 ha	0.77 ha
6	Basket ball court	388.00 m2	464.78 m2
7	Fish ponds	535.96 m2	568.24 m2
8	Monitoring Site Extent	10.79 ha	15.16 ha

Volume

Label	Title	Area	Volume	Cut	Fill
9	Volume of Debris	116.59 m2	402.69 m3	410.41 m3	-7.72 m3

Count

Label	Title	Quantity
10	Fishing vessel count	33

Appendix 4. FAO PUAS and Geospatial Capacity Training Programme

FAO is undertaking a 'Drones for Agriculture' PUAS Project comprising:

- UAS Policy and Operations Manual will be developed to guide the use, management and implementation of a UAS Unit and provide guidelines on the management of the UAS data and production of information. Next technological capacity and needs of the MoA's field extension unit will be assessed to guide the selection of suitable spatial analysis and IT tools and development of an appropriate agricultural-based UAS mapping, spatial analysis and monitoring programme.
- A series of four training short courses designed to incrementally build on each other in the operation of UAS technologies, aerial surveys and participatory mapping techniques, data management, mapping and spatial analysis geared towards agricultural and disaster risk management applications.
- Strategies for developing PUAS monitoring plans will be developed in which practical skills will be reinforced via the planning, collection, processing and analyses of UAS data at two agricultural demonstration monitoring sites.

Curriculum includes: UAS flying, surveys and participatory mapping for agricultural monitoring, data management, spatial analysis, introduction to ArcGIS Online and data sharing IT tools.

- Included practical coursework and a variety of field and computer-based exercises applied to guide participants in the creation and sharing of maps, data and a variety of reporting and informational products to support agricultural decision-making and disaster risk management applications.