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UAV-Based Photogrammetry and Remote Sensing for Sustainable Coastal Monitoring

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Abstract:

Coastal zones are characterized by dynamic interactions involving erosion, flooding, habitat degradation, pollution, and intensive development, all occurring over short spatial and temporal scales. While conventional field surveys offer crucial control measurements, they often fall short in providing the comprehensive coverage, frequent revisits, or detailed three-dimensional data necessary for adaptive coastal management. This review explores the use of unmanned aerial vehicle (UAV)-based photogrammetry and remote sensing as an integrated framework for sustainable coastal monitoring. It synthesizes literature on various aspects such as platform and sensor selection, mission planning, georeferencing, Structure-from-Motion processing, point-cloud and elevation-product generation, change detection, and the increasing application of machine learning. Current applications are categorized into areas like shoreline and erosion analysis, topographic and volumetric monitoring, hazard assessment, habitat mapping, thermal and pollution observation, and documentation of coastal infrastructure and heritage. The synthesis highlights that UAV systems effectively bridge the gap between ground observations and satellite data, especially when centimetre-level precision, flexible acquisition timelines, and rapid post-event surveys are needed. Nevertheless, their reliability is contingent upon factors like image geometry, ground sampling distance, control distribution, surface conditions, regulatory compliance, and transparent reporting of uncertainties. Future advancements will necessitate standardized protocols, multi-sensor fusion, automated quality control, interoperable data infrastructures, and monitoring designs that transform repeated surveys into actionable indicators. Therefore, UAV technology proves most beneficial when integrated into a long-term coastal observation strategy, rather than being used as a standalone mapping tool..

Keywords: Coastal Erosion, Digital Elevation Model, Photogrammetry, Remote Sensing, Shoreline Change, Structure-From-Motion, Sustainability, Unmanned Aerial Vehicle

Introduction

Coastal zones are characterized by dynamic interactions involving erosion, flooding, habitat degradation, pollution, and intensive development, all occurring over short spatial and temporal scales. While conventional field surveys offer crucial control measurements, they often fall short in providing the comprehensive coverage, frequent revisits, or detailed three-dimensional data necessary for adaptive coastal management. This review explores the use of unmanned aerial vehicle (UAV)-based photogrammetry and remote sensing as an integrated framework for sustainable coastal monitoring. It synthesizes literature on various aspects such as platform and sensor selection, mission planning, georeferencing, Structure-from-Motion processing, point-cloud and elevation-product generation, change detection, and the increasing application of machine learning. Current applications are categorized into areas like shoreline and erosion analysis, topographic and volumetric monitoring, hazard assessment, habitat mapping, thermal and pollution observation, and documentation of coastal infrastructure and heritage. The synthesis highlights that UAV systems effectively bridge the gap between ground observations and satellite data, especially when centimetre-level precision, flexible acquisition timelines, and rapid post-event surveys are needed. Nevertheless, their reliability is contingent upon

factors like image geometry, ground sampling distance, control distribution, surface conditions, regulatory compliance, and transparent reporting of uncertainties. Future advancements will necessitate standardized protocols, multi-sensor fusion, automated quality control, interoperable data infrastructures, and monitoring designs that transform repeated surveys into actionable indicators. Therefore, UAV technology proves most beneficial when integrated into a long-term coastal observation strategy, rather than being used as a standalone mapping tool [1-3]. These foundations now converge with small UAVs, compact sensors, automated flight planning, and Structure-from-Motion with multi-view stereo (SFM-MVS) [4].

Unmanned Aerial Vehicles (UAVs) fill a crucial observational gap between field instruments and satellite or crewed aircraft surveys. They are capable of capturing high-resolution imagery, including centimeter-scale RGB images, multispectral data, thermal readings, and laser measurements as needed. UAVs can be quickly deployed before or after storm events. The photogrammetric outputs they produce include orthomosaics, dense point clouds, digital surface models, digital terrain models, textured 3D models, and time-series change maps. The quality of these products depends on factors such as flight altitude, overlap, camera calibration, surface texture, image sharpness, ground sampling distance, control geometry, and processing decisions [5-9].

The existing literature on UAVs is spread across various fields such as photogrammetry, geomorphology, environmental monitoring, surveying, computer vision, and asset documentation. This dispersion can lead to technology-driven data collection that lacks a clear connection between the coastal management question, the sensor used, the necessary accuracy, and the resulting indicators. This review aims to bridge these gaps. It assesses the methods and applications, highlights common limitations, and suggests a forward-looking framework where information derived from UAVs aids in making sustainable decisions for coastal management.

Review Methodology

The review utilized the three bibliographic source files provided for this study as its primary documentary corpus. Initially, entries were standardized based on title, author, year, and DOI. Exact duplicates and multiple versions of the same record were eliminated. The records were then evaluated for their direct relevance to areas such as UAV photogrammetry, remote sensing, georeferencing, three-dimensional reconstruction, terrain modeling, environmental change, erosion, water bodies, landslides, or methods involving transferable point-clouds and artificial intelligence.

The synthesis is presented as a critical narrative review, rather than a meta-analysis, due to the diversity of the included studies. These studies encompass journal articles, conference papers, reviews, and application studies that employ varied sensors, sites, accuracy metrics, and outputs. The evidence was organized into five themes: acquisition systems, photogrammetric workflow, coastal applications, uncertainty and implementation constraints, and emerging directions. Studies centered on buildings, cultural heritage, mining, forestry, or industrial measurement were included only if their methodologies provided valuable insights for coastal mapping, such as multi-sensor integration, point-cloud processing, quality control, or repeat-survey design.

A final citation audit was conducted after drafting the review. Every work cited in the main text is listed in the References section, and all author-year citations in the main text have a corresponding reference entry. As per the journal's guidelines and the review's requirements, citations are omitted from the Abstract and Conclusion sections.

UAV Platforms and Sensor Configurations

Multirotor UAVs are often chosen for small, intricate coastal areas due to their ability to take off vertically, hover, navigate low-altitude terrain, and capture convergent or oblique images. However, their main drawback is limited endurance. In contrast, fixed-wing systems can efficiently cover longer stretches of shoreline but typically need more space for launching and recovery, making them less ideal for close-range inspections. Vertical-take-off fixed-wing designs aim to merge extensive coverage with operational flexibility. The selection of a platform should consider factors such as coastline length, wind exposure, terrain relief, payload capacity, regulatory constraints, and the desired ground sampling distance, rather than merely the availability of the aircraft.

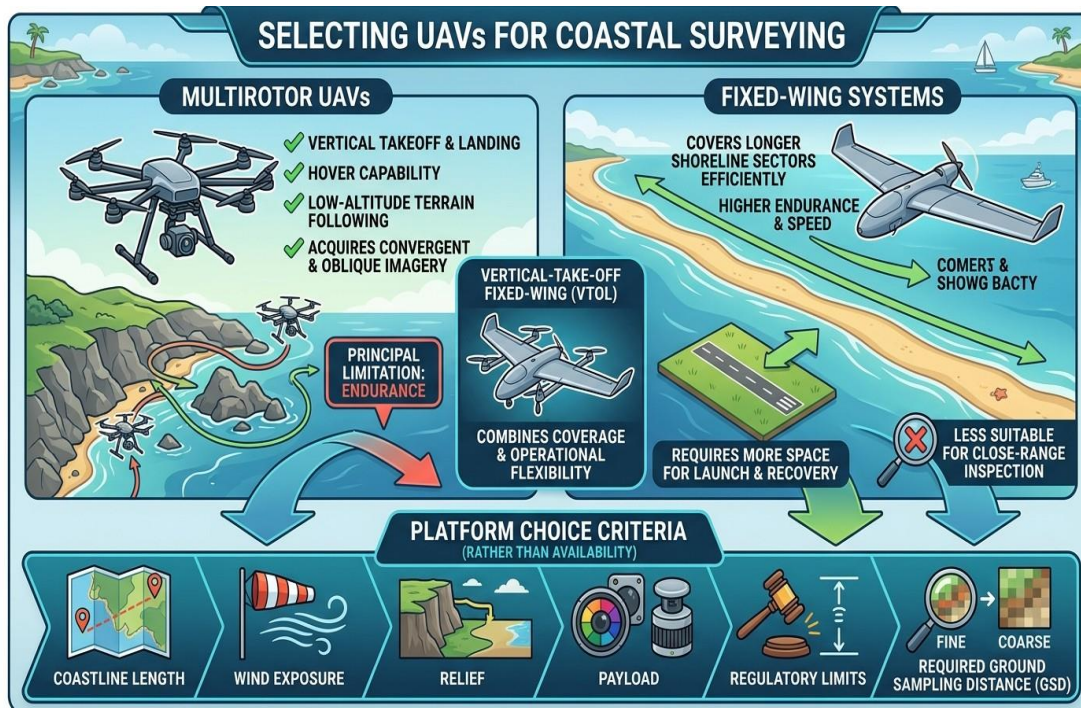


Figure 1: UAV Platform Selection Framework for Coastal Surveying

Multirotor systems provide high operational flexibility for small, complex sites, whereas fixed-wing platforms deliver efficient coverage over extended shorelines. Final platform choice should be determined by coastline length, wind exposure, terrain relief, payload capacity, regulatory constraints, and target Ground Sampling Distance (GSD).

Here's a rewritten version of the input text in a more human-like tone, mimicking the style and structure of the provided human samples: When it comes to capturing images, RGB cameras are still the go-to choice because they're affordable, lightweight, and work seamlessly with SfM-MVS. If designed correctly, image networks can produce highly detailed orthomosaics and point clouds from both nadir and oblique imagery. Studies on close-range and UAV documentation have shown that using convergent geometry and having adequate texture can significantly improve the reconstruction of vertical or irregular surfaces. On the other hand, weak geometry and repetitive or reflective surfaces can lead to gaps and deformation in the final product. This highlights the importance of careful planning and execution in image capture to ensure accurate and reliable results. By understanding the strengths and limitations of RGB cameras and image networks, we can unlock their full potential and achieve high-quality outcomes in various applications [10-14]. These lessons are particularly relevant to cliffs, seawalls, rock platforms, and harbour structures.

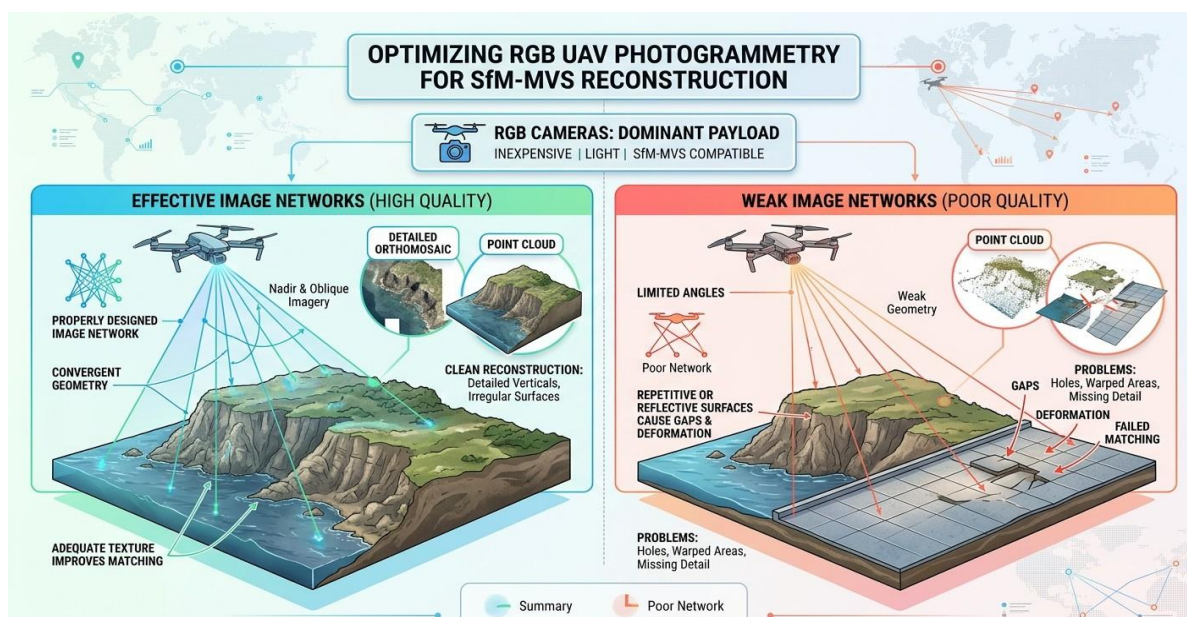


Figure 2: Impact of Image Network Geometry (Convergent vs. Weak) and Surface Characteristics on SfM-MVS 3d Reconstruction Accuracy in UAV Surveys

Multispectral cameras extend mapping from geometry to surface condition by recording bands useful for vegetation, water-edge, moisture, and habitat discrimination. Thermal sensors can reveal relative surface-temperature patterns, groundwater discharge zones, heat anomalies, or pollution-related contrasts, although thermal products require careful calibration and cartographic design [15,16].

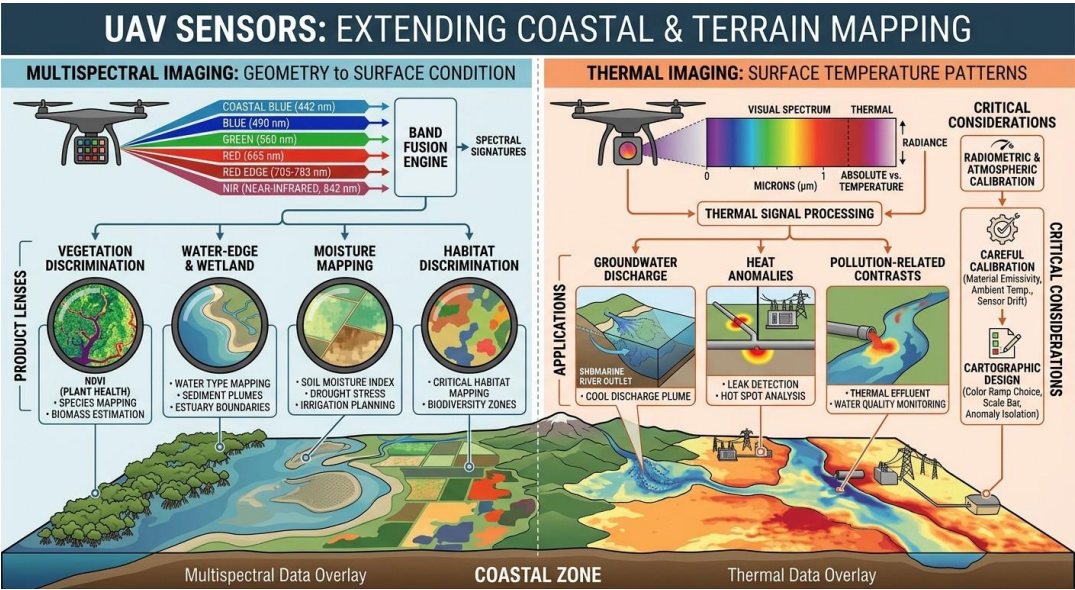


Figure 3: Overview of Multispectral and Thermal UAV Payloads, Highlighting their Key Application Domains and Processing Requirements for Environmental Surface Condition Mapping

UAV laser scanning is advantageous where vegetation penetration, sharp microtopography, or direct three-dimensional sampling is needed. Mapping experiments with airborne LiDAR and studies of direct georeferencing emphasize the importance of trajectory quality, boresight calibration, strip alignment, and independent checkpoints [5,17-19].

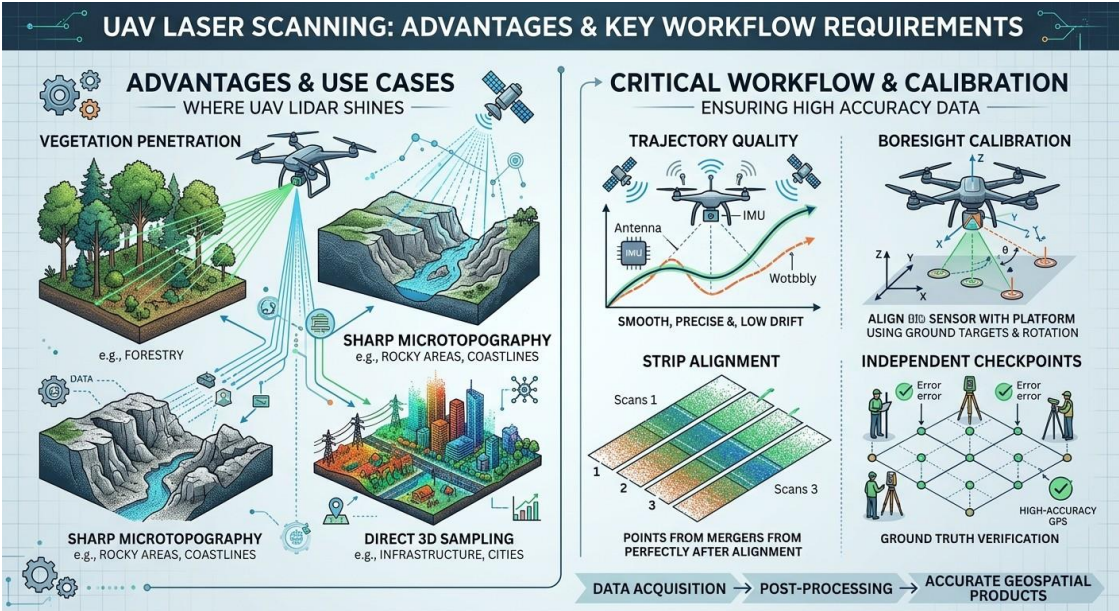


Figure 4: Overview of UAV Laser Scanning Advantages in Complex Terrain and the Critical Processing Steps Required to Achieve High-Precision 3d Point Clouds

Sensor fusion is increasingly valuable. RGB texture can assist interpretation of LiDAR geometry, multispectral bands can distinguish habitat classes, and GNSS/IMU observations can improve direct georeferencing. Cross-domain studies combining laser scanning, photogrammetry, and information modelling demonstrate that no single sensor is universally optimal; complementary observations reduce occlusion and provide geometric and semantic redundancy [20-22].

Acquisition and Processing Workflow

Sensor fusion is becoming increasingly important. The integration of RGB texture can enhance the interpretation of LiDAR geometry, while multispectral bands are effective in differentiating habitat classes. Additionally, GNSS/IMU

observations play a key role in enhancing direct georeferencing. Studies that bridge different domains—such as laser scanning, photogrammetry, and information modeling—illustrate that no single sensor is universally optimal. Instead, complementary observations help minimize occlusion and offer both geometric and semantic redundancy [8].

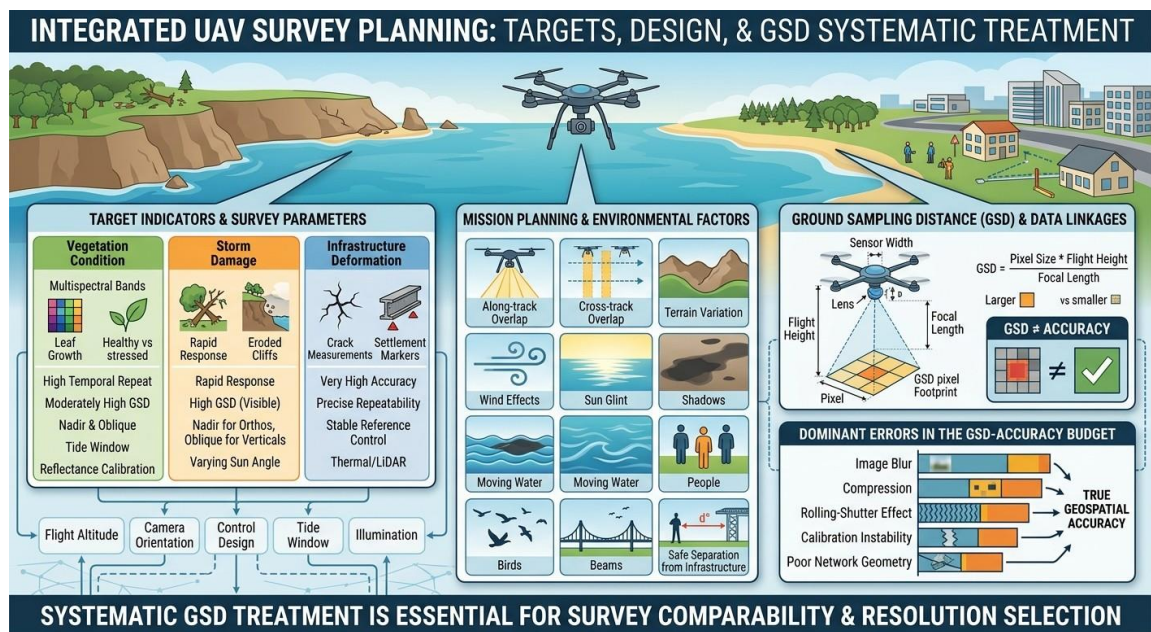


Figure 5: Systematic Workflow for Target-Driven UAV Survey Design, Environmental Risk Management, and GSD Error Budget Evaluation

Georeferencing is a process that uses various methods to assign coordinates to a location on the earth’s surface. It can use ground control points, checkpoints, real-time kinematic or post-processed kinematic positioning, or a combination of these approaches. When it comes to control points, it’s essential to distribute them evenly around the area, taking into account variations in elevation. If control points are clustered in one corner, it can lead to visually convincing but distorted models. Research has shown that the distribution of control points has a significant impact on the accuracy of UAV position-product generation. Additionally, studies on direct georeferencing have highlighted the difference between precision and external accuracy, emphasizing the need for careful consideration of control-point distribution to achieve reliable results. By understanding the importance of control-point distribution, researchers and practitioners can improve the accuracy and reliability of georeferencing methods, leading to more effective and efficient use of UAV technology [5,7]. For beaches and tidal flats, durable or temporary targets must also remain visible under changing illumination, sediment moisture, and visitor activity.

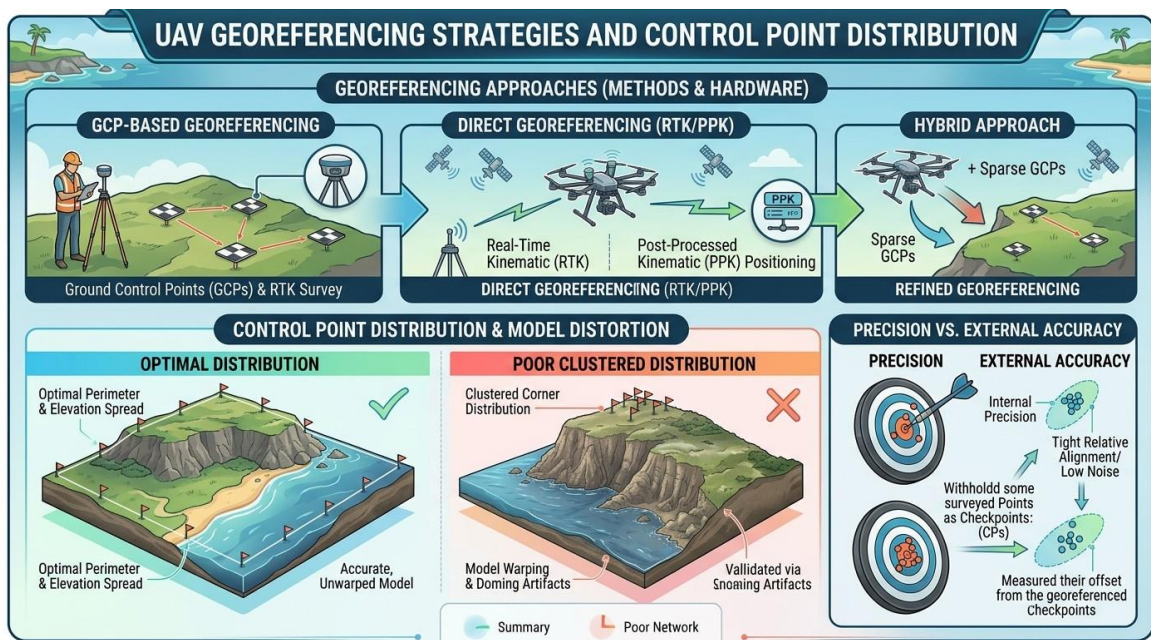


Figure 6: Comprehensive Overview of UAV Georeferencing Workflows (GCPs vs. RTK/PPK) and the Critical Role of Spatial Control Distribution in Mitigating Geometric Model Distortion

The standard photogrammetric chain comprises image quality screening, feature detection and matching, bundle adjustment, sparse reconstruction, dense matching, point-cloud filtering, surface generation, orthorectification, and export to GIS. Point-cloud resolution and interpolation settings affect the resulting terrain representation; grid size should therefore be chosen with respect to landform scale and point density rather than treated as a cosmetic output setting [23,24]. General point-cloud research also shows that filtering, segmentation, registration, meshing, and classification choices materially influence downstream measurements [25,26].

Water can be tricky to work with when it comes to taking pictures from the air, because the waves are always moving and the way the light reflects off the surface changes depending on the angle you're looking at it from. Plus, when the water is clear and shallow, it can bend light in weird ways, making it hard to get a clear picture. That's why it's usually easier to use drones to take pictures of things on land, like buildings or plants, rather than trying to map out the surface of the water or what's underneath it. But there are some things you can do to make it work better, like taking pictures when the tide is out, using special filters to reduce glare, and using rules to help figure out where the shoreline is. It's also a good idea to process the pictures of the land and water separately, to get the best results.

Multi-temporal comparison requires common datums, stable control, harmonized point density, comparable tidal and seasonal conditions, and a stated minimum level of detectable change. Cloud-to-cloud, cloud-to-mesh, DEM-of-difference, profile, and object-based comparisons answer different questions. The central principle is that mapped change must exceed combined survey and registration uncertainty. Without that threshold, colourful difference maps may represent processing noise rather than coastal dynamics.

Coastal Monitoring Applications Shoreline Change and Erosion

Using repeated images, we can clearly see the edges of vegetation, where the land meets the water, and the shape of dunes and cliffs. This helps us understand how the shoreline is changing over time. By creating detailed 3D models of the surface, we can also measure how much material is being lost or gained, which is important for understanding how the coastline is evolving. Previous studies have shown that taking repeated measurements of the surface can provide valuable insights into how coastal areas are changing, and these principles can be applied to different types of coastal features, such as cliffs and dunes. This information can be used to better understand and manage the dynamic nature of our coastlines. [2,3,27,28]. UAV surveys strengthen this approach by shortening mobilization time and increasing spatial continuity.

COASTAL MONITORING VIA REPEAT UAV SURVEYS: FROM 2D PROXIES TO 3D VOLUME

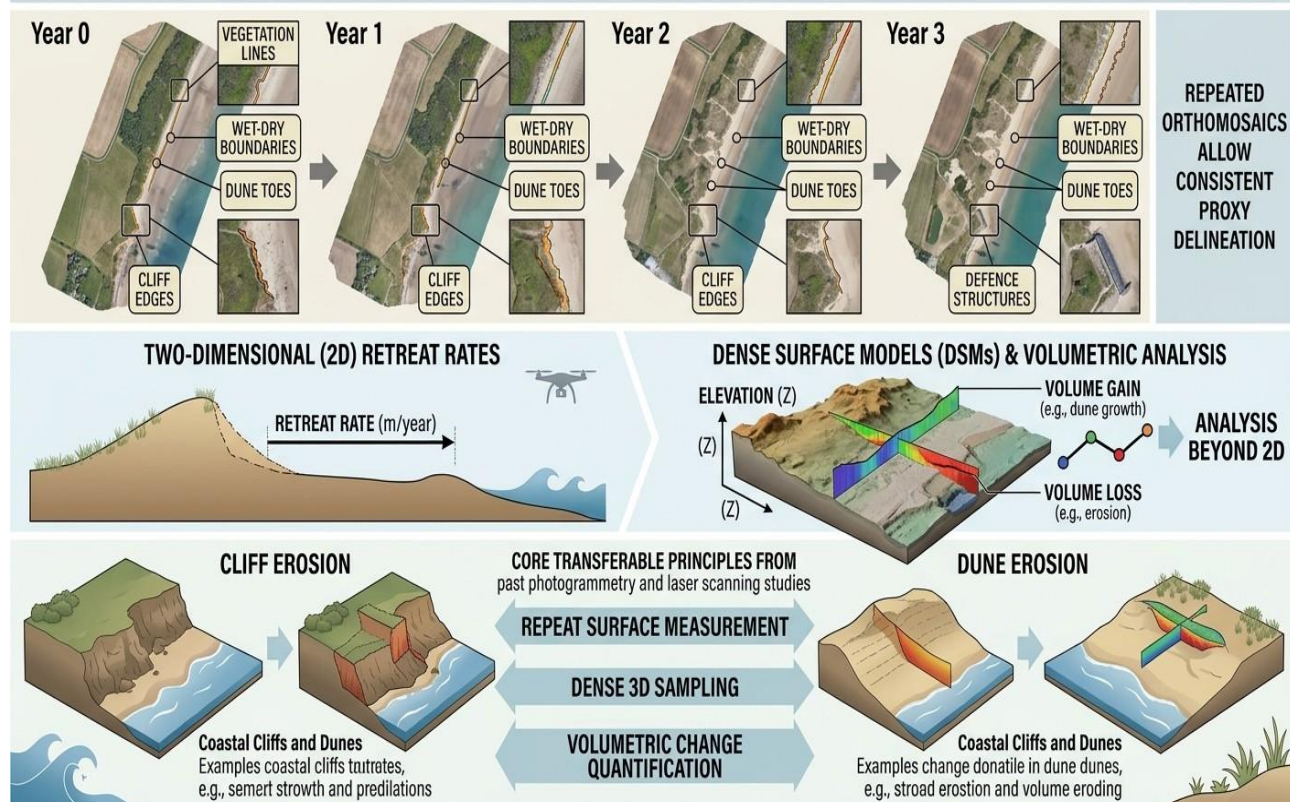


Figure 7: Application of Repeat UAV Photogrammetry and Surface Models for 2d Shoreline Proxy Extraction and 3d Volumetric Erosion Analysis

Beaches, Dunes, Cliffs, and Sediment Budgets

Using special cameras on drones, we can create detailed maps of the ground, which helps us measure how beaches are changing, how sand dunes are moving, and how landslides are happening. These maps can even show us how much soil is being cut away or filled in. By using drones to take pictures of landslides, we can make models that help us understand and prepare for dangers in areas that are hard to reach. This is really useful for figuring out how likely it is that a landslide will happen and how bad it could be. [29,30]. Volume estimation is sensitive to surface definition, interpolation, vegetation, and the choice of stable reference areas; therefore, repeat surveys should preserve processing settings and report uncertainty alongside net volume.

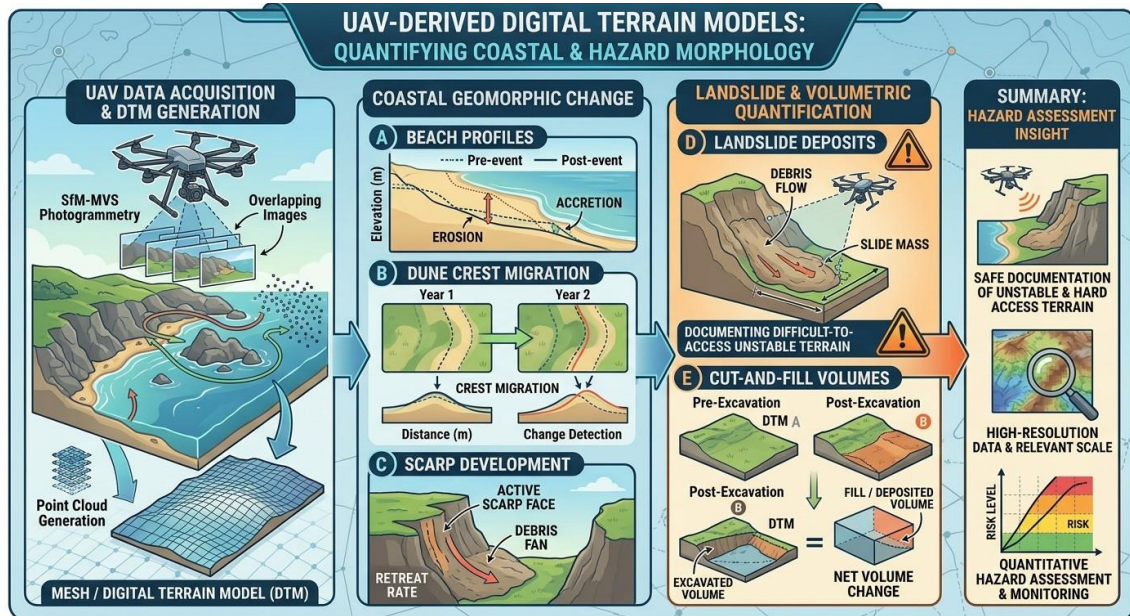


Figure 8: Quantification of Coastal Geomorphic Change, Landslide Mass Movements, and Net Cut-and-Fill Volumes Using High-Resolution UAV Digital Terrain Models (DTMS)

Coastal Flooding and Hazard Response

High-resolution terrain models improve local representation of flow paths, barriers, drainage features, and low-lying assets. Rapid post-event flights can map overwash, breaching, debris, damaged roads, and altered channels. UAV products should complement, not replace, tide gauges, wave observations, hydrodynamic models, and regional elevation data. Their greatest value is local refinement and timely validation of conditions that coarser datasets may omit [31].

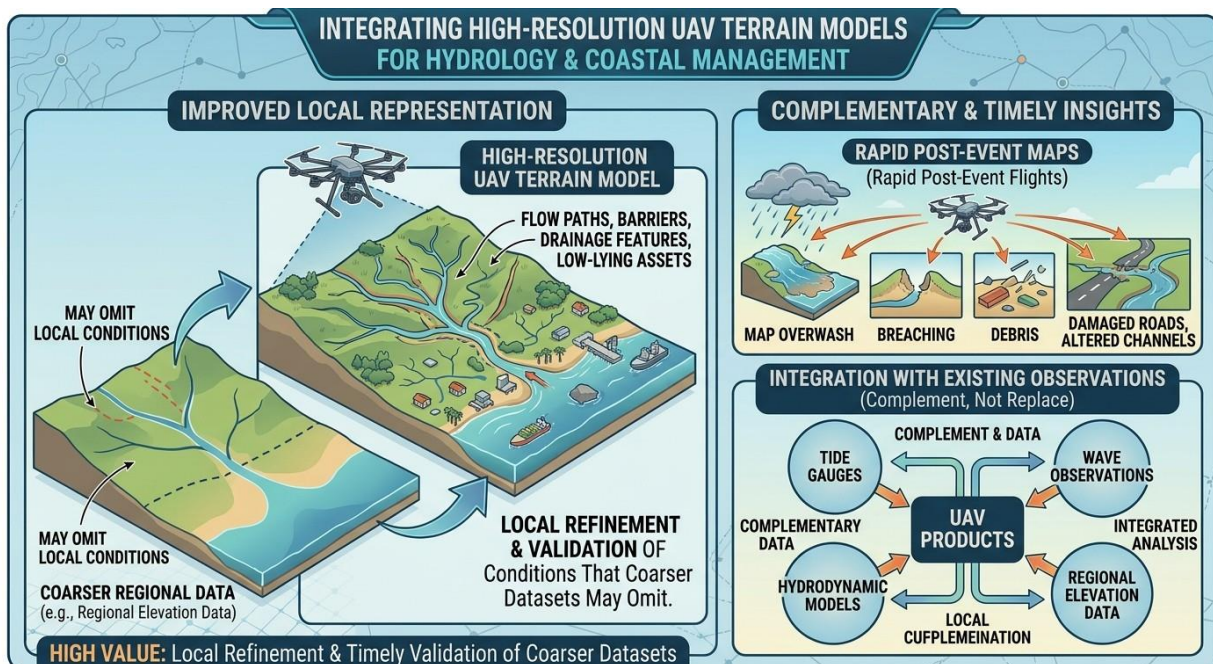


Figure 9: Role of UAV High-Resolution Terrain Mapping in Refining Local Hydrological Flow Paths, Rapid Post-Event Damage Mapping, and Enhancing Regional Hydrodynamic Monitoring Networks

Wetlands, Dunes, and Coastal Vegetation

RGB and multispectral images are invaluable for mapping vegetation extent, assessing canopy conditions, identifying invasive species, detecting bare sediment, and analyzing habitat fragmentation. The use of drones to integrate LiDAR with multispectral imagery in areas with structurally complex vegetation highlights the benefits of combining height and spectral data for precise object delineation. [32]. Terrestrial laser-scanning research in forest ecology further shows how three-dimensional structure can become an ecological variable rather than merely a visualization product [33]. In coastal wetlands, however, tidal stage, phenology, water background, and canopy movement must be controlled to make classifications comparable.

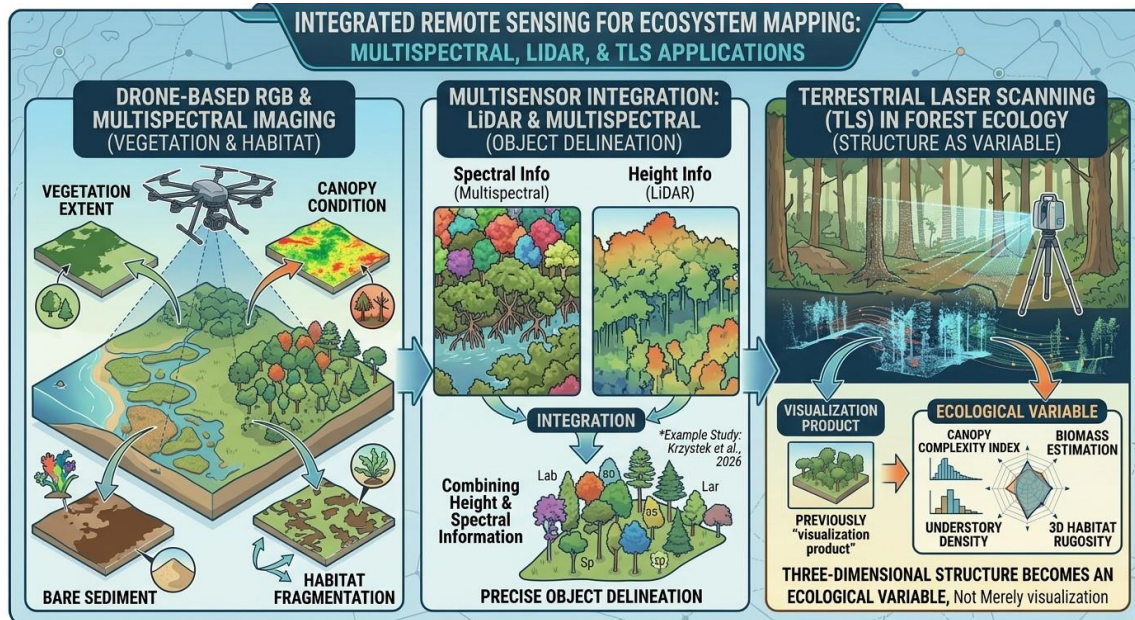


Figure 10: Multi-Sensor Remote Sensing Framework Combining Spectral Signatures (RGB/Multispectral) and 3d Structural Metrics (UAV Lidar/TLS) for Ecological Object Delineation and Habitat Condition Assessment

Water-Edge, Thermal, and Pollution Observation

UAV imagery can document floating litter, surface films, turbidity contrasts, algal accumulations, drainage outlets, and localized thermal anomalies when conditions permit. These are primarily surface observations and require field sampling for chemical or ecological interpretation. Map colours, shading, and resolution can influence perceived severity, so thermal and thematic outputs should include legends, uncertainty, acquisition time, and validation information [15].

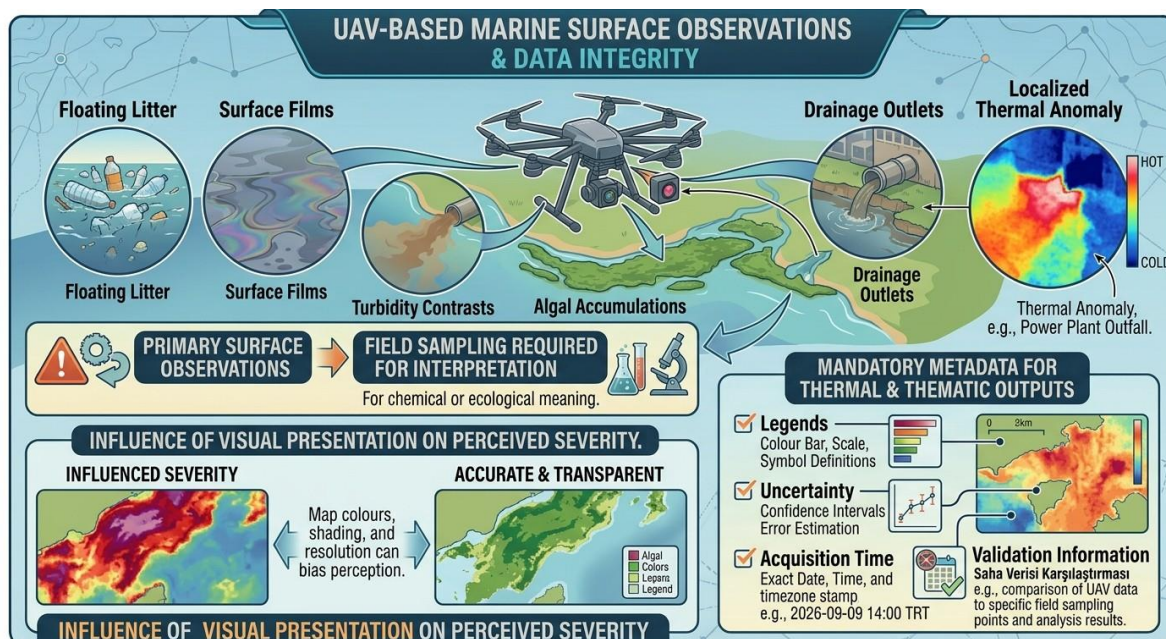


Figure 11: Framework for UAV-Based Marine Surface Feature Identification and Standardized Reporting Protocols for Thermal and Thematic Map Integrity

Coastal Infrastructure and Cultural Assets

Ports, breakwaters, seawalls, lighthouses, archaeological remains, and historic waterfronts can be represented as textured three-dimensional models for inspection and conservation. UAV documentation studies show the usefulness of oblique imagery, dense matching, and integrated aerial-ground acquisition for complex assets [34-36]. Although asset documentation differs from geomorphic monitoring, both require stable reference systems, repeatable geometry, visibility of vertical surfaces, and explicit accuracy testing.

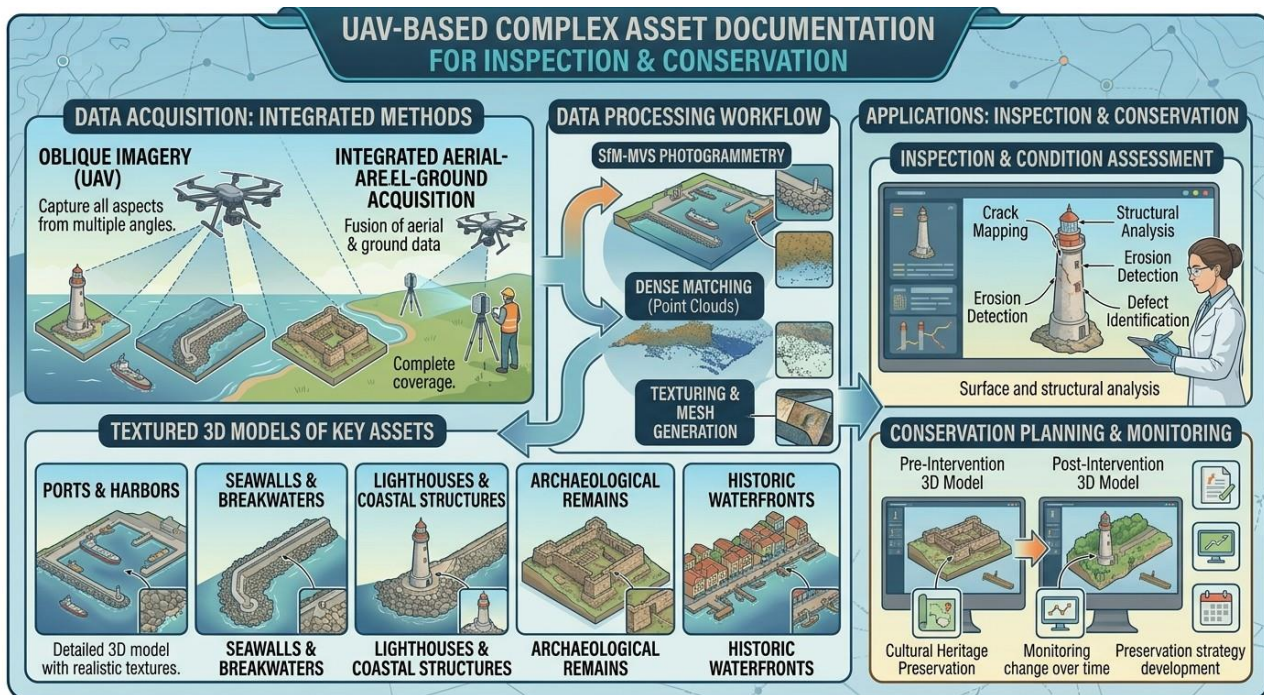


Figure 12: Digital 3d Asset Modeling Workflow Integrating Oblique UAV Imagery and Ground Photogrammetry for Coastal Infrastructure Inspection and Heritage Conservation

Results of the Thematic Synthesis

When it comes to monitoring coastlines with drones, it's not just about using one method, but rather having a system that can be adjusted to suit different needs. After looking at the evidence, four key points stand out. Firstly, being able to monitor the coast at the right time is just as important as getting high-quality images. For example, taking surveys at specific times like during a storm or when the tide is out can provide more useful information than just taking a lot of detailed pictures at a random time. Secondly, using 3D images can be really helpful when looking at complex changes to the coastline, like when the shape of the land is changing in a big way. This can give us a much better understanding of what's happening. Thirdly, a lot of the mistakes that are made when monitoring the coast with drones don't actually come from the quality of the images themselves, but from things like the angle of the pictures, how the images are linked to the real world, the weather, and how the data is processed. Lastly, the information gathered from drone monitoring is more useful when it's turned into simple, stable measures that can be compared over time. This helps us see how the coastline is changing and makes it easier to make decisions about how to manage it..

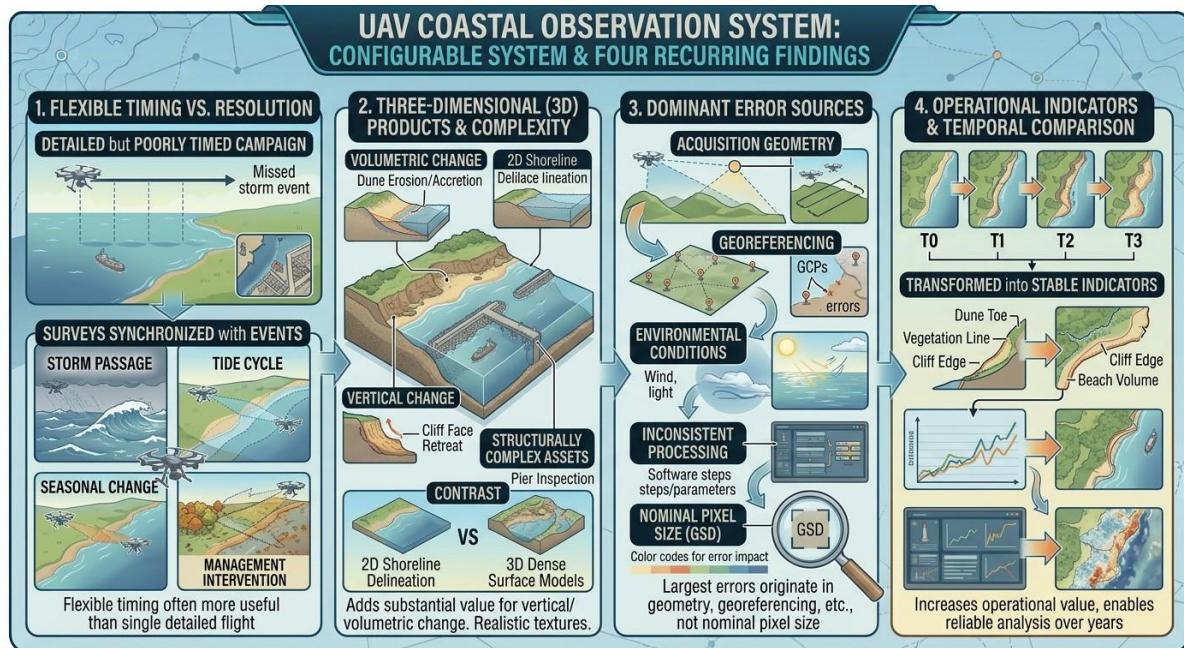


Figure 13: Conceptual Framework Summarizing the Four Key Operational Principles of UAV-Based Coastal Monitoring Systems: Event-Driven Timing, 3d Volumetric Capability, Geometric/Environmental Error Control, and Multi-Temporal Proxy Tracking

Table 1 summarizes the relationship between monitoring questions, preferred observations, principal outputs, and dominant constraints. The table should be interpreted as a decision aid rather than a universal prescription because local relief, water conditions, vegetation, regulations, and available control data modify the appropriate design.

Monitoring objective	Preferred data	Main output	Dominant limitation
Shoreline position	Nadir RGB; repeat flights	Orthomosaic and shoreline vectors	Proxy definition, tide, waves, wet sand
Beach and dune change	RGB SfM or UAV LiDAR	DTM, profiles, DEM of difference	Vegetation, control stability, interpolation
Cliff retreat and failure	Oblique RGB; LiDAR where feasible	3D point cloud, mesh, change distance	Occlusion, safety, weak surface texture
Flood and storm impact	Rapid RGB and terrain data	Inundation evidence, breach and debris maps	Access, weather, datum consistency
Wetland and habitat condition	Multispectral plus RGB/LiDAR	Classification and structural metrics	Phenology, tide, training-data transferability
Thermal or pollution screening	Thermal/multispectral with field samples	Anomaly and surface-condition maps	Calibration and indirect interpretation
Coastal assets	Nadir and oblique RGB; laser scanning	Textured 3D model and inspection layers	Occlusion, reflective surfaces, data volume

Table 1: Decision Matrix for UAV-Based Coastal Monitoring

Discussion

Here's the rewritten text in a more human-like tone: One of the biggest advantages of using drones, or UAVs, is that they can provide a scale that matches what's happening on the ground with what's seen from space. Satellite images give us a broad view of the area and a long history of what's changed over time, while measurements taken on the ground provide precise information at specific points. Drones fill in the gap between these two extremes, offering detailed views of specific sites. This middle ground is especially useful for studying things like erosion that happen quickly, the paths that floods take, areas where restoration is happening, and the corridors where infrastructure is built. But even though the maps and 3D models created from drone data can look very realistic, they can still have systematic errors hidden beneath the surface. To make sure the information is accurate, we need to check it against independent reference points, analyze any discrepancies, look at cross-sections, and set a threshold for uncertainty that's suitable for the decisions that will be made based on the data.

Standardization is the central requirement for long-term monitoring. A repeatable protocol should document aircraft and sensor, firmware, lens, calibration status, flight altitude, overlap, camera angle, speed, tide, weather, control

coordinates, reference system, processing software and version, quality settings, filters, grid resolution, and validation statistics. Longitudinal datasets lose value when undocumented changes in equipment or workflow are mistaken for environmental change.

Sustainability also has an operational meaning. A technically sophisticated workflow that depends on rare expertise, proprietary settings, or excessive processing may not be sustainable for local agencies. Efficient monitoring balances detail with repeat frequency, cost, staff capacity, and decision deadlines. The experience of UAV mapping in environmental and resource contexts shows that repeatable acquisition and fit-for-purpose products are more important than maximizing model density in every mission [37-40].

Artificial intelligence is likely to accelerate shoreline extraction, habitat classification, object detection, damage assessment, and point-cloud segmentation. Very-high-resolution UAV object detection demonstrates how deep learning can convert imagery into mapped features, while integrated object-based deep learning shows the potential for mapping complex land-surface impacts [41,42]. Nevertheless, training data must represent different coasts, seasons, sensors, tides, and illumination. Model accuracy should be reported by class and location, and automated outputs should retain a route for expert review. Data governance deserves equal attention. High-resolution coastal images may reveal people, private property, sensitive habitats, or critical infrastructure. Flight operations can disturb birds and other wildlife. Responsible programmes require legal permissions, privacy protection, ecological flight windows, safe operating procedures, and clear rules for data retention and access. These requirements are part of scientific quality because they affect where and when observations can be repeated. The review has limitations. The documentary corpus was supplied in advance and contains a strong concentration of photogrammetry, point-cloud, cultural-heritage, and engineering applications. It is therefore not a comprehensive census of all marine UAV literature, and quantitative effect-size comparison was not possible. The benefit of this corpus is methodological breadth: studies outside the coast reveal transferable solutions for reconstruction, direct georeferencing, surface modelling, sensor integration, and machine learning. Future systematic reviews should search multiple bibliographic databases with a registered protocol and should compare accuracy, cost, area, processing time, and temporal frequency using standardized units.

Future Directions

Future coastal observation will increasingly combine UAVs with satellites, fixed cameras, tide and wave sensors, GNSS stations, autonomous surface or underwater vehicles, and field sampling. Such integration can connect event-scale detail to regional processes and reduce the risk of interpreting a local snapshot in isolation. UAV-ROV integration already demonstrates the broader logic of coordinated platforms for complex documentation [34].

Real-time kinematic and post-processed kinematic positioning will reduce dependence on dense ground control, but they will not eliminate the need for independent checks. Automated flight replication, permanent control, standardized tide windows, and cloud-based processing can make monitoring more consistent. At the same time, direct georeferencing must be assessed through absolute accuracy and precision rather than accepted from equipment specifications alone [5].

Point clouds are becoming a common spatial data type across airborne, mobile, and terrestrial systems. Their growing ubiquity creates opportunities for unified classification, change detection, digital twins, and scalable archives [43]. Coastal programmes should adopt open metadata, stable coordinate reference systems, versioned processing, and preservation of source imagery and quality reports so that future methods can reproduce or improve earlier products.

The next step in improving our methods should be to focus on making decisions easier with automation. Instead of just creating a detailed map, our workflows should give us useful indicators like how much the shoreline has moved, how much sediment has been gained or lost, whether habitats are being destroyed or created, how many assets have been damaged, how well restoration efforts are working, or how exposed we are to certain risks. Machine learning can help with this process, but we still need humans to oversee it, especially when it comes to defining shorelines, classifying ecosystems, or setting thresholds for intervention, as these things often depend on local policies and contexts.

Conclusion

UAVs equipped with photogrammetry and remote sensing functions can collect data flexibly, rapidly and in detail to complete three-dimensional monitoring of coastal zones. Whether it is a rush to investigate a sudden coastal anomaly, or long-term tracking of changes in a certain section of shoreline, this method is not restricted by site requirements of large-scale observation equipment, can take off and operate at any time, and can integrate the captured coastal information into a three-dimensional model, fully recording details that ordinary people would fail to notice.

It can be used to analyze a wide range of contents, covering coastal erosion status, terrain features, habitat conditions, pollution levels, potential disasters, and the status of various coastal infrastructure—from small-scale issues such as whether a beach is gradually eroded and retreated by seawater, to large-scale concerns such as whether coastal breakwaters have experienced displacement, all can be clarified with this technology.

To obtain reliable monitoring results, one must not only focus on whether the image output by the final model is realistic enough; instead, it is necessary to first anchor to specific project objectives and design a rigorous, standardized monitoring plan for implementation. After all, if the only goal is to produce a visually striking three-dimensional render, any convenient approach works. But if monitoring data is to be used to solve practical coastal management problems, every step—from takeoff points, shooting intervals, to data processing—must follow standardized rules aligned with the specific objectives of that project, rather than prioritizing visual appeal alone.

If multiple rounds of monitoring need to be carried out repeatedly, each round must adopt unified measurement benchmarks, consistent environmental conditions, and identical thresholds for determining changes. For example, if a general elevation benchmark is used to measure altitude in the current round, another benchmark cannot be arbitrarily adopted for the next round; if the current round of shooting is conducted on a sunny day during the dry season, the next round should not be scheduled for a rainy day during high tide; the critical value used to judge whether a real change has occurred to the shoreline must also be completely consistent between the current and previous rounds. Otherwise, the generated data cannot be compared at all, and may even lead to erroneous conclusions.

The next generation of monitoring systems in the future will integrate data from multiple types of sensors, AI and automated processing technologies, making the entire monitoring workflow—whether field data collection or indoor analysis—operate more smoothly. No longer will extensive effort be spent piecing together scattered data from different devices, and much time spent on manual data processing will also be saved.

In the final analysis, to achieve sustainable coastal monitoring, priority should be given to developing open, transparent, and replicable monitoring projects, rather than creating models with extremely high data density. Such projects can provide timely data for coastal management work, clearly mark the error range of the data itself, and produce information that is truly usable and reliable, to support long-term coastal management decision-making.

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