INTRODUCTION

Unmanned Aircraft System (UAS) Applications to Land and Natural Resource Management

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Unmanned Aircraft Systems (UASs) have made dramatic technical advances in the past decade. Their use domestically is currently tightly constrained by existing Federal Aviation Administration (FAA) regulations. Within the next few years, the FAA is expected to provide a regulatory framework that allows for a greatly expanded role for UASs in domestic airspace for a wide variety of applications. One of those will be remote sensing for land and natural resource monitoring. While there has recently been a large body of published research on UAS applications to environmental monitoring, in practice, very little has been operationalized by private or public entities to date. In July 2014, Argonne National Laboratory hosted a workshop dedicated to environmental monitoring UAS applications with attendance by representatives from 11 federal agencies as well as academics. The workshop reviewed the UAS state-of-the-art within the federal arena and barriers to broader UAS use. While a number of agencies, the including National Oceanic and Atmosphere Administration, the United States Geological Survey, National Aeronautics and Space Administration, and the Bureau of Land Management have conducted proof-of-concept UAS demonstrations, typically using surplus Department of Defense equipment, the promise of UAS systems at the moment remains untapped for a variety of reasons. The consensus was, however, that UAS systems will play an increasingly important role in cost-effectively supporting timely natural-resource and land-management monitoring needs.

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Unmanned Aircraft Systems (UASs) have made dramatic technical advances in the past decade. Their use domestically is currently tightly constrained by existing United States (US) Federal Aviation Administration (FAA) regulations. Within the next few years the FAA is expected to provide a regulatory framework that allows for a greatly expanded role for UASs in domestic airspace for a wide variety of applications [Figure 1 (Department of Transportation 2013)]. One of those will be remote sensing for land and natural-resource monitoring. From hazardous-waste site characterization to assessing and monitoring land-resource quality, UASs can be expected to revolutionize the quantity and quality of data sets available to decision makers while significantly reducing the cost of acquiring data sets. Examples include wildfire assessment and response, threatened and endangered-species monitoring and assessment, climate change-related ecosystem monitoring, land-disturbance evaluation, and atmospheric measurements.

Research in the area of UAS use for land and natural-resource monitoring is a rapidly evolving field. Colomina and Molina (2014) provide an excellent, although already dated, overview of potential applications, including photogrammetry and remote sensing. Recent published research literature includes a wide variety of applications. Hugenholtz et al. (2015) explored the spatial accuracy of UAS-based photogrammetry applied to soil-excavation monitoring and concluded errors were at least as good as, if not better than, those obtained from using airborne light detection and ranging (LiDAR). Woodget et al. (2015) demonstrated the use of Structure from Motion algorithms combined with through-water photogrammetry to obtain reasonably accurate, inexpensive measurements of channel-bed topography for clear-water streams. Barasona et al. (2014) described the use of unmanned systems for supporting epidemiological work involving tuberculosis in

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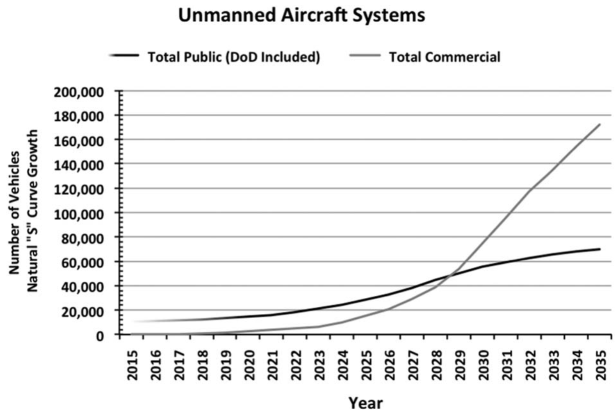

Figure 1. UAS Forecast 2015–2035

ungulates (in particular, collecting data on host abundance and the spatial aggregation of hosts facilitating the spread of disease). Ortega-Tero et al. (2014) developed a methodology for describing the presence of large woody debris in channels based on low-cost optical imagery obtained using UASs. The methodology was used to support stream-habitat management. Hung, Xu, and Sukkarieh (2014) discussed feature learning techniques as applied to weed classification using high-resolution optical imagery obtained via UASs and used the approach to explore performance improvements in correctly identifying water hyacinth, tropical soda apple, and serrated tussock in an Australian landscape. Wang et al. (2014) used UAS imagery to develop estimates of above-ground biomass in tallgrass prairies. They found that Normalized Difference Vegetation Index (NDVI) values computed from the imager could explain up to 94% of the variance in above-ground biomass measurements, but that imagery spatial resolution was a key factor. Casella et al. (2014) applied UAS-acquired imagery combined with numerical models to understand and predict coastal erosional processes from wave action. They found the combination provided a much faster and cheaper method for acquiring information on beach topography and geomorphology as compared to more traditional methods, without any loss in accuracy. Neumann et al. (2014) described the use of autonomous carbon dioxide-sensitive micro-UASs for potentially monitoring greenhouse gas emissions over spatial extents as part of leak detection for carbon-capture and storage systems.

Actual applications of UASs to land and natural-resource monitoring by federal agencies in the US significantly lags research. In July of 2014, Argonne National Laboratory hosted a two-day workshop on the topic of UAS and their application to land and natural-resource monitoring, with a special focus on US federal agencies (Envirnomental Science Division, 2014). Workshop participants represented 11 US federal agencies: the Bureau of Land Management (BLM), Department of Energy, the Environmental Protection Agency (EPA), the Department of Defense (DOD), the FAA, the Fish and Wildlife Services (FWS), the Forest Service, the National Aeronautics and Space Administration (NASA), the National Geospatial-Intelligence Agency, the National Oceanic and Atmospheric Administration (NOAA), and the US Geological Survey (USGS). They also included researchers from eight different academic/research institutions.

UASs and Land/Maritime/Atmospheric/ Natural Resource Applications

Currently, use of UASs for domestic land, maritime, atmospheric, and natural-resource applications is constrained by a number of factors (discussed below). The net result of those constraints is that commercial applications of UASs for resource monitoring are virtually non-existent. Public applications by federal agencies have largely, to date, been proof-of-concept initiatives, with a few exceptions. There is a richer set of application demonstrations by the research community, but again, while these have been very promising, they have not yet been operationalized in a routine way.

For a number of federal agencies such as the Forest Service, the FWS, and NOAA, there is a long and rich history of using manned aircraft for agency missions (e.g., wildlife population census work, wildfire response, atmospheric and oceanographic data collection). The value of aerial assets for collecting land and natural resource data has been firmly established, and these agencies have the institutional infrastructure (e.g., policies and internal procedures, mission planning, and support experience) in place to support those applications. In this context, the availability of UASs raises the natural question of how UAS data-collection platforms fit into a larger aeronautical data-acquisition program.

UAS systems provide the following potential advantages over manned systems for land and natural-resource monitoring: reduced data-acquisition costs, reduced risk to pilots/crew in hazardous environments (Figure 2), ability to "loiter" over a particular area of interest for a much greater period of time than a manned craft, ability to be deployed more rapidly, and the ability to fly closer to the ground than a typical manned fixed-wing aircraft. In general, federal-agency experimentation with UAS systems has revolved around surplus DOD equipment and has

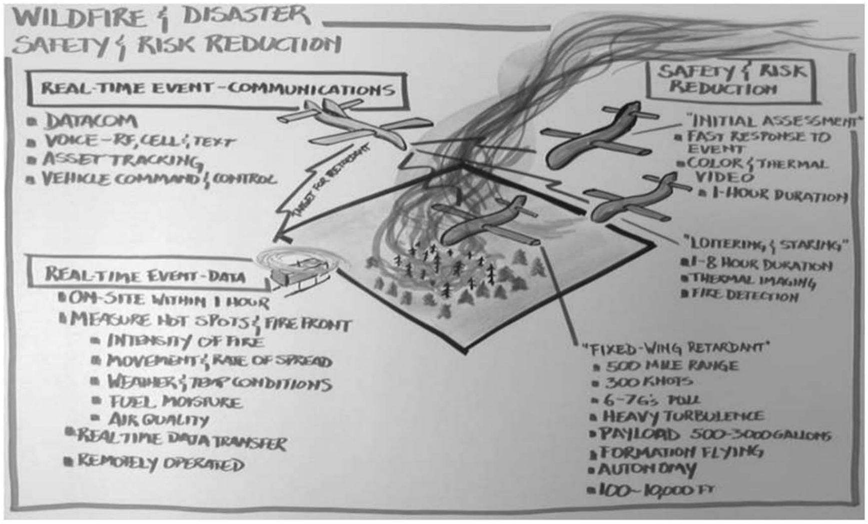

Figure 2. National Aeronautics and Space Administration/Forest Service conceptualization of UAS applications to wildfires, courtesy of Vince Ambrosia (National Aeronautics and Space Administration)

Figure 3. Kansas State University small UAS Fleet, courtesy of Mark Blanks (Kansas State University)

included a significant amount of work with large fixed-wing UASs, such as the equivalent of the Global Hawk, Predator, and Reaper. In contrast, academic research has focused on a variety of small UAS technologies, which can be launched by hand and include a mix of fixed-wing and rotary systems (Figure 3). Federal-agency use of UASs has, to date, been concentrated within a couple of agencies and associated with particular key staff. Academic research involving UASs, in contrast, has exploded, with one estimate that 175 universities within the US currently have active UAS research underway.

Proof-of-concept applications of UAS technologies to land and natural-resource management by federal agencies and academia have included:

1. Air Sampling. The EPA and NOAA have developed payload packages suitable for deployment on a UAS that integrate a variety of air-monitoring sensors and samplers. The parameters covered include carbon dioxide, carbon monoxide, semi-volatile organic compounds, volatile organic compounds, brown carbon, black carbon, and particulates.
2. Animal Census. UAS platforms have been used by the USGS to perform population counts in a variety of settings including sand hill crane population estimation in Colorado, counting pelican and colonial water bird nests in North Dakota, and elk population estimation in California. The USGS, working with the USFWS, has piloted UAS water bird survey techniques at three wildlife refuges in California and Nevada. The USFWS, in collaboration with NOAA, has also tested fixed-wing and rotary UAS platforms for seabird and marine-mammal surveys at the Washington Maritime National Wildlife Refuge Complex. University of Florida researchers have demonstrated the use of UAS for chinook salmon redd (spawning nest) identification in Idaho on the Snake and Clearwater Rivers and estimated brown pelican reproduction and nest turnovers in Florida. They also have applied UAS to a variety of near shore/estuary Floridian species including dolphins, manatees, saltwater crocodiles, and sea turtles, among others. The automation of target acquisition and animal counting is being evaluated by the USGS and NOAA.

3. Animal Monitoring. UAS platforms have been used by the environmental program at Dugway Proving Ground to monitor species individuals, such as nesting raptors, to document presence and activity for environmental-compliance purposes.
4. Habitat Assessments. Researchers at the University of Florida have used UAS systems for identifying pygmy rabbit habitats in Idaho. They have also used them for identifying and evaluating habitat damage caused by feral hogs in Florida. Researchers with Central Michigan University have deployed hyperspectral cameras on small UAS platforms for mapping wetland plant biodiversity and Pitcher's Thistle.
5. High-Resolution Digital-Terrain Models. The USGS has explored the use of UAS for developing high-resolution digital-terrain models using orthophotography generated by small UAS platforms, providing spatial resolution down to around 3 cm (Figure 4). The USGS has used high-resolution digital-terrain models for monitoring landslides/hill-slope stability, calculating volumetric earth removal in surface-mining operations, and assessing emergent sand-bars and sediment transport in river systems.
6. Infrastructure Monitoring. The USGS has demonstrated the use of UAS for inspecting mining operations in West Virginia and inspecting boundaries/fence lines at Haleakala National Park in Maui. Researchers at Kansas State University have used UAS to monitor cattle feed lot conditions over large scales, including feed bunker line performance.
7. Polar Monitoring. NOAA, in collaboration with the US Coast Guard, NASA, and others, has conducted a number of UAS missions for various purposes in Polar Regions. These have included black carbon data collection, marine awareness/oil spill detection, and Marginal Ice Zone experiments.
8. Vegetation Assessments. Experimental UAS work has been conducted at Kansas State University to assess biomass production over rangelands, monitor crop health, estimate yields, and characterize plant phenotypes. This work has demonstrated high degrees of correlation between NDVI estimates using UAS imagery and NDVI estimates determined in more traditional ways. At Purdue University, thermal imaging has been used to estimate evapotranspiration, and when coupled with multi-spectral information, to quantify plant stress. At the University of Nebraska, researchers have used UAS platforms to autonomously fly very close to corn crops, precisely following rows, to determine crop height. Researchers at the Desert Research Institute have used UAS imagery to more accurately estimate green leaf cover in arid environments.
9. Surface-Water Sampling. Researchers at the University of Nebraska have developed a UAS platform capable of autonomously acquiring multiple water samples before returning to base (Figure 5).
10. Surface-Water Quality. Researchers at the Kansas State University are developing UAS NDVI-based methods to monitor for the appearance of harmful algal blooms in bodies of water. At Purdue University, researchers use thermal imaging to determine stream surface-water temperatures and multi-spectral imaging to evaluate water quality (e.g., presence of chlorophyll, total suspended solids).
11. Weather Monitoring. NOAA has been exploring the application of UAS platforms for high-impact weather monitoring. Some of this work has been in collaboration with NASA and the National Science Foundation. This has included oceanic weather system observations using a NASA Global Hawk system, development of drop-sonde systems for the Global Hawk (Figure 6), and Lower Mississippi River Forecast Center demonstration work using small UASs. Researchers at the Desert Research Institute, using small UAS from Scripps, measured a number of atmospheric parameters in boundary layers over the Maldives, including wind velocity, temperature, humidity, aerosol-particle concentration, black carbon concentration, and cloud droplet sizes and concentrations.
12. Wildfire Response. NASA has had an active UAS wildfire-response research program for a number of years with the intent of developing systems that can augment the manned systems currently routinely used for a variety of purposes in a wildfire response. NASA, working with its federal land-management partners, has identified a number of potential uses for large UAS platforms during a wildfire event. These include providing airborne data communications support, fast, real-time monitoring information during an event using a variety of sensors and platforms, post-fire burn assessments, and retardant application. NASA has been involved with UAS wildfire demonstrations in collaboration with the Forest Service since 2006. More recently, the USGS has demonstrated the use of small UASs for providing real-time monitoring of controlled burns.

UAS Land/Natural Resource Application Maturity

Table 1 presents an assessment of the maturity of various sensors deployed via UAS or small UAS for different land and natural-resource management applications.

Information shared at the July 2014 workshop suggests that a few sensor types are relatively mature and ready for application. These include still photography, videography, thermal-imaging systems, and air quality-monitoring equipment. Other sensors are promising but are still in the research and development stage.

Barriers to Domestic UAS Applications

Workshop participants engaged in a focused discussion on barriers to domestic UAS use, particularly in the context of federal agencies for land and natural-resource management. Those identified fell into several natural categories:

1. Public Barriers
   - Private landowner concerns
   - Private small UAS use creating issues
   - Private aviation concerns
   - Media misconceptions/sensationalism (e.g., use of the word "drone")
   - Privacy issues
   - Perception of fairness (who is allowed to use the systems and who is not)
   - Education and, more specifically, the lack of education/accurate information that clearly identifies to the public the benefits UASs bring (safety and cost)
   - Fear of UAS use as a regulatory hammer or law enforcement platform
2. Regulatory Barriers
   - Delays and confusion regarding forthcoming FAA regulations and their appropriateness
   - Lack of communication to and engagement with the public
   - Trust and the role it potentially plays in gaining regulatory acceptance of specific applications
   - Roles of approved test sites and misunderstandings regarding those roles
   - Confusion about current rules (e.g., separation between commercial UAS use and hobby/model aircraft activities)
   - Additional state and local regulations, particularly as they result in inconsistencies either with FAA requirements and/or between adjacent or overlapping jurisdictions
   - National Environmental Policy Act considerations for federal agencies
   - Preclusion of stacked formation or swarm flying in current regulations, even though scientifically these would be valuable
3. Institutional Barriers
   - Agency-specific obstacles, some of which are tied back to state regulations

Table 1. Summary of sensor maturity related to UAS applications to land and natural resource management

Sensor	Example applications	maturity
Still photography	Photogrammetry, species identification and census, habitat assessment, disturbance monitoring	High resolution commercial cameras readily available, readily adaptable to UAS platforms, combination of low-altitude flights and large number of pixels provides unprecedented spatial resolution, common applications well documented
Videography	Visual monitoring (e.g., infrastructure, boundaries, nesting raptors, etc.)	High-resolution commercial videography cameras readily available, readily adaptable to UAS platforms
Multi-spectral imaging systems	NDVI, ecosystem performance, species identification	Some academic work completed to date
Hyper-spectral imaging systems	Ecosystem performance, remote sensing of near surface atmospheric phenomena, species identification	Promising but not yet proven on UAS platforms
Thermal-imaging systems	Surface-water temperatures, cultural-resource identification	Thermal-imaging systems suitable to UAS platforms already exist and applications have been successfully demonstrated
On-board analytics for air quality monitoring	Air quality assessment (controlled burns, wildfires, stack emissions, non-point source emissions)	Simple sensors currently available for UAS systems, research and development work underway to adapt existing sensor payloads suitable for larger manned aircraft to smaller UAS platforms
LiDAR	Land disturbance, vegetative-canopy assessment	Emergent research for small UAS platforms
Physical sampling capabilities (e.g., surface water, surface soil, biota)	Soil quality, hazardous-materials characterization, water quality, DNA	Emergent research demonstrating possibility using small UAS platforms

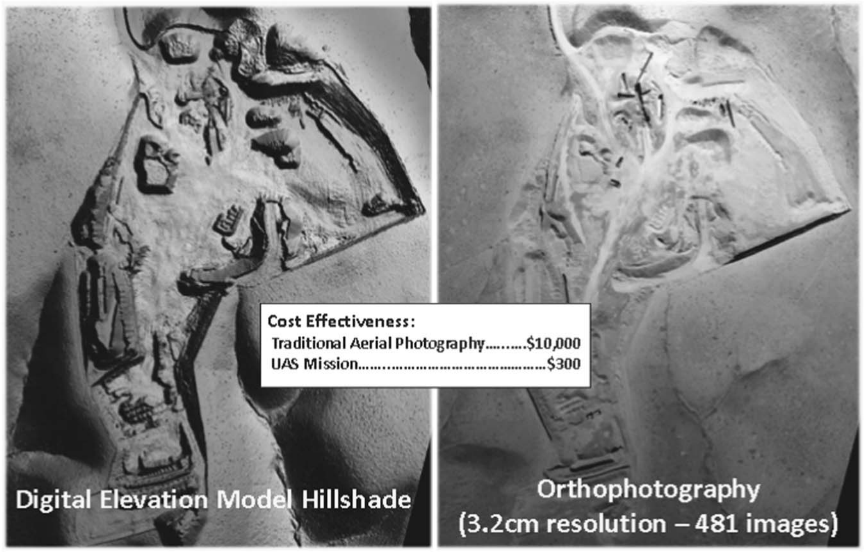

Figure 4. Digital elevation modeling using small UAS orthophotography, courtesy Jeff Sloan (United States Geological Survey)

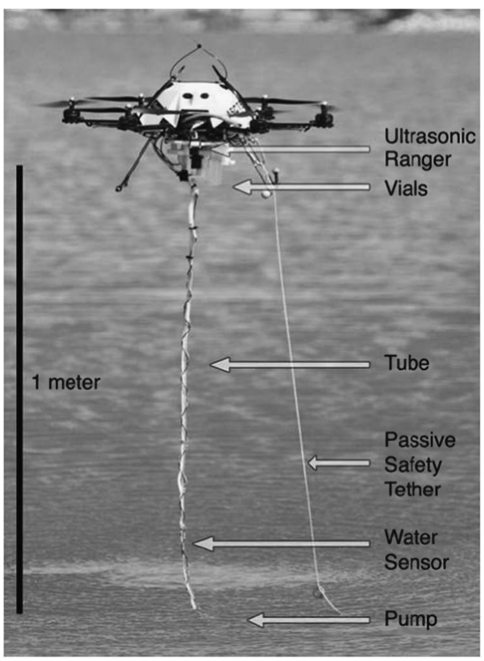

Figure 5. Small UAS Water Sampler, courtesy of Carrick Detweiler (University of Nebraska, Lincoln)

- Agencies lacking protocols appropriate for implementing UAS
- Volumes of information UASs have the potential for generating and the lack of information technology infrastructure to analyze/manage/archive these data (both technical and institutional obstacles)

Figure 6. NASA Global Hawk deploying a dropsonde, courtesy of the National Aeronautic and Space Administration and the National Oceanic and Atmospheric Administration

- Insurance and liability concerns (flight safety)
- "Proven/Verified" operating procedures, particularly for the way particular types of data are collected that might be used for regulatory purposes (e.g., EPA methods)
- Data sets inconsistent with historical data collection and data sets
- Competition with manned programs (e.g., established fire programs based on manned systems)
- Commonality (or lack thereof) across agencies in requirements and protocols (e.g., flight readiness, flight safety, etc.)
- Differences between agencies (internal) and contractors in procedures and protocols

- Cultural resistance (risk-taking, public-image perceptions)
- Lack of rules for sharing information across agencies
- Cost of sustained, mature programs

4. Technical Barriers
   - Metadata and data format standards
   - Data processing capabilities and storage for archiving
   - Small, standardized calibration standards/protocols
   - Level of autonomy/staffing requirements for flights
   - Multiple concurrent UAS use
   - Data validation and verification, particularly for derived parameters/spectral information (e.g., NDVI)
   - Lack of a standardized technical motivating force
   - Sensor miniaturization
   - Extended power supplies (particularly for electric UASs)
   - Payload integration and associated standardization
5. Other
   - Market forces (where will the market drive technology and whether that does or does not match scientific/federal agency needs)
   - One size does not fit all (operating environment, data-collection goals, sensor packages appropriate for specific applications)

Conclusions

A recent Forbes article (2014) explained why UASs are a disruptive innovation—an innovation that will likely cause fundamental changes in existing markets and businesses over time in unexpected ways. Those changes will touch many areas, including the way federal agencies collect information pertinent to land and natural resources that fall under their domain.

While organized conferences and workshops dedicated to the military applications of UASs have been convened for years, the domestic application of these technologies for land and natural-resource applications is nascent, partly due to the constraints imposed by existing regulations and partly due to the general lack of federal-agency experience with these technologies. As became clear throughout the July 2014 workshop, while there has been a significant amount of work to date by several agencies, including NOAA, NASA, BLM, and the USGS, in demonstrating UAS capabilities and applicability, these have largely been proof-of-concept. Routine operational use remains elusive, but is undoubtedly coming. Work to date, both by federal agencies and universities, has clearly demonstrated that existing, relatively inexpensive, off-the-shelf technologies such as commercial cameras and video systems can provide significant monitoring benefits when coupled with small UASs.

Part of the definition of a disruptive innovation is that although its effects over time are pervasive, they can also be very unpredictable. In the case of UAS, impact unpredictability partly stems from the barriers that currently exist, how they might change, and the impact they will have on future applications and partly originates with the natural innovation that takes place both with traditional research settings such as universities and national laboratories and within the commercial/private-use sphere. The consensus among workshop participants was that while the exact future of federal agency use of UAS remains murky as part of their missions, the role UASs play going forward will steadily grow in significance as technology, policy, regulation, and procedures mature and align with the application opportunities—those already obvious, and those yet to be discovered.

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