RECLAMATION

Managing Water in the West

Application of Unmanned Aerial Systems (UAS) for Ecological Monitoring at Reclamation

Research and Development Office
Science and Technology Program
(Final Report) ST-2019-19012-01

East Side Bypass, San Joaquin River

U.S. Department of the Interior
Bureau of Reclamation
Research and Development Office **2019**

Mission Statements

Protecting America's Great Outdoors and Powering Our Future

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities

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14. ABSTRACT *(Maximum 200 words)* Unmanned aerial systems (UAS) have the potential to improve Reclamation's ability to manage water resources in the western United States. This research explored potential applications of UAS to invasive species management at Reclamation. The most promising applications include aquatic vegetation monitoring and surveys. Overstory habitat in sensitive areas could also be surveyed. Wetland mapping is already possible using remote sensing technology, and applying UAS to these projects could significantly reduce costs. Although understory surveys in complex environments are not currently possible using UAS, research in this area should be monitored, as the technology is rapidly progressing.

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Application of Unmanned Aerial Systems (UAS) for Ecological Monitoring at Reclamation

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Executive Summary

Invasive species limit Reclamation's ability to fulfill its mission to manage, develop, and protect water resources in the Western U.S. Quagga mussels and aquatic weeds foul infrastructure, clog waterways, and change the ecosystem of reservoirs. Invasive terrestrial plants often outcompete native species and require costly impact mitigation. Burrowing rodents and crayfish may cause seepage or failure in critical canals. Regardless of how each species impacts Reclamation, all pests increase management costs and threaten the success of our mission.

The Ecological Research Laboratory at the Technical Service Center (TSC) provides technical expertise on a variety of invasive and pest species. Regular monitoring is a critical element of integrated pest management plans, but it is often a labor-intensive process. Clients of the Ecological Research Lab have shown interest in utilizing unmanned aerial systems (UAS) to reduce the time and cost associated with pest monitoring. The capabilities of UAS, or drones, have advanced rapidly over the last decade, and researchers have begun incorporating them into ecological projects to track wildlife, map vegetation, sample remote locations, and protect conservation areas. The UAS team at the TSC possesses airframes and sensors that have the potential to improve monitoring of invasive species.

The objective of this study was to determine how UAS can be applied to invasive species management at Reclamation. A comprehensive literature review of recently published articles was conducted. Potential applications, sensor and platform capabilities, and post-processing requirements were assessed.

UAS have been successfully deployed for a variety of ecological monitoring and studies. Although most studies were not specific to invasive species, many could be adapted to support Reclamation's mission. Potential areas of application include:

- **Aquatic Vegetation –** Emergent and submerged aquatic macrophytes can be surveyed, mapped, and linked to hydraulic parameters. UAS reduced time spent in the field and eliminated watercraft costs. Accurate maps and models allow managers to track the spread of pest species, predict future effects, and plan treatment efforts. Harmful algal blooms were also monitored spatially and temporally, giving water managers the ability to provide accurate public safety warnings.

- **Invasive Terrestrial Vegetation –** Invasive flowering shrubs, grasses, and seedlings can be monitored and mapped. Routine monitoring after the release of a biological control agent allows resource managers to evaluate the success of the treatment over a large area. All studies were performed in relatively open habitats and mapping accuracy decreased in more complex environments.

- **Terrestrial Vegetation Overstory –** Canopy cover, canopy height, aboveground biomass, and other overstory parameters can be extracted from UAS derived data. Sapling and woody stem densities can also be estimated. In sparsely vegetated environments, trees can be classified to the species level. The success rate is reduced in highly complex habitats or areas with significant shadows.

- **Terrestrial Vegetation Understory –** In open areas, UAS imagery can be used to discriminate between similar herbaceous communities. Traditional vegetation transects may miss rare species if the survey area is large, but aerial platforms can cover significantly more ground. UAS imagery can potentially provide a more accurate assessment of the vegetation composition.

- **Wetlands –** UAS imagery allows natural resource managers to clearly map critical wetland habitat. Repeated monitoring of wetland borders could link water releases upstream to habitat changes downstream.

- **Water Samples –** UAS equipped with a 3D-printed sampling device have been used to collect surface water samples and DOI has approved the use of a water sampling sleeve with new platforms. Although sampling from the air is likely not a viable option for invasive mussel monitoring, surface samples could be collected to evaluate the toxicity of harmful algal blooms.

- **Animal Pest Management –** Burrowing rodents can be tracked using infrared sensors. Pest insects can be captured and monitored using a UAS equipped with a net system. UAS have also been used with varying degrees of success to survey fish and bird species.

- **Ecosystem Restoration –** UAS can provide an overview of restored areas and identify seeds and seedlings. Ecologists and engineers can use this data to evaluate the progress of the restoration plan and to identify necessary changes.

Future projects can expand upon this study by demonstrating the capabilities of UAS in the field. The TSC can partner with area offices to find projects that may benefit from UAS-based data collection. The most promising immediate applications likely involve aquatic vegetation monitoring and invasive understory monitoring in simple environments. Overstory habitat in sensitive or complex areas could also be surveyed. Both options are possible with platforms and sensors in the current TSC portfolio. Wetland mapping has been done using remote sensing and applying UAS to these projects could significantly reduce costs. Although most understory surveys are not currently feasible, future research in this area should be examined as the technology is rapidly progressing. Other applications, including water sampling and wildlife management, may offer additional opportunities to apply UAS technology in the future.

Unmanned aerial systems can improve the TSC's ability to meet the pest management needs of regional and area offices. Applying UAS to invasive species control will reduce costs and establish the TSC as an innovative force in the field of pest management. UAS could also be used as part of a rapid response team to investigate new reports of invasive species throughout the western US.

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Background

Pest organisms adversely impact Reclamation's mission by fouling water conveyance systems and reducing the efficiency of infrastructure. Environmental requirements also necessitate monitoring of rare and threatened species that are impacted by Reclamation activities. The Ecological Research Laboratory (formerly RDLES) at the Technical Service Center (TSC) provides expertise on a variety of pest species. Current projects include investigations of invasive quagga and zebra mussels, vegetation monitoring in restored areas, and aquatic plant control. Invasive species detection, monitoring, and treatment costs continue to rise as additional species of concern, such as burrowing crayfish, are identified. The lab has received requests to investigate the use of unmanned aerial systems (UAS) to detect and monitor invasive species and to survey restoration areas. UAS may offer a lower-cost alternative to traditional ecological monitoring strategies.

The capabilities of unmanned aerial systems (UAS) have advanced rapidly over the last decade, and researchers have begun incorporating them in a variety of studies. UAS platforms continue to evolve, expanding upon a wide range of flight capabilities and payload capacities. Fixed-wing aircraft provide longer flight times and the ability to carry multiple instruments at the same time, while rotary platforms are generally smaller, but more agile, and allow an operator to hover over an area of interest. New payload options are being developed, and payload performance is improving while instrument weight decreases. Potential payloads include high-resolution cameras, thermal or multispectral sensors, telemetry antennas, and light detection and ranging (LiDAR) systems. In addition, payloads are being developed to facilitate water sampling or dispersal of biocontrol organisms. As UAS technology continues to advance, additional payloads will be developed, and autonomous flight capabilities will likely become standard features across platforms. The variety of sensors and attachments available should allow Reclamation to effectively detect, track, and treat new invasive species.

In the field of ecology, scientists now routinely use UAS to track wildlife, map vegetation, sample remote locations, and monitor conservation areas. Natural resource managers have also begun exploring applications for UAS in the detection and control of invasive or nuisance species. Although the technology is still evolving, possible applications of UAS for invasive species research within Reclamation appear promising.

The UAS team at the TSC has been conducting surveys of infrastructure and mapping topography since 2017. The presence of an in-house UAS team is a valuable resource that can be applied to other areas of concern for Reclamation. Current airframe and sensor capabilities should allow the UAS team to immediately contribute to invasive species research and pest management.

Methods

This project investigated potential applications of UAS to ecological studies, with a focus on invasive and pest species. A comprehensive literature review of recently published articles was conducted. Potential applications, sensor and platform capabilities, and post-processing requirements were assessed. A literature database was created on the TSC shared drive, and relevant studies were highlighted in this report.

Results

This section highlights a few relevant studies. Researchers have used UAS to survey invasive plant species, sample waterbodies, and monitor harmful algal blooms. Some applications have been successful, while others have demonstrated limitations. A summary of platforms, sensors, project objectives, and literature sources is presented in Appendix A. The collected literature is stored on the TSC shared drive. This review will allow Reclamation to prepare for potential UAS missions and utilize the most appropriate methods.

Aquatic Vegetation Studies

Emergent and submerged water soldier (*Stratiotes aloides*) was monitored in the Trent-Severn Waterway in Ontario, Canada (Chabot et al 2018). The procedure developed successfully classified emergent features with 92% accuracy, while submerged features were classified with 84% accuracy. Chabot et al (2018) used a fixed-wing UAS with a relatively inexpensive multispectral camera. This study demonstrates the feasibility of separating above and below water features to monitor the spread of invasive aquatic weeds.

Biggs et al (2018) linked the geometry and spatial distribution of the aquatic macrophyte *Ranunculus penicillatus* to specific hydraulic parameters in the River Urie, Scotland. Imagery was collected using a DJI Phantom 1 quadcopter with a 12MP GoPro camera. The data collected was used to visualize flow redirection around large vegetation patches and to predict sedimentation and bank erosion (Figure 1). Macrophyte abundance was conclusively linked to water velocity, Froude number, and stream power.

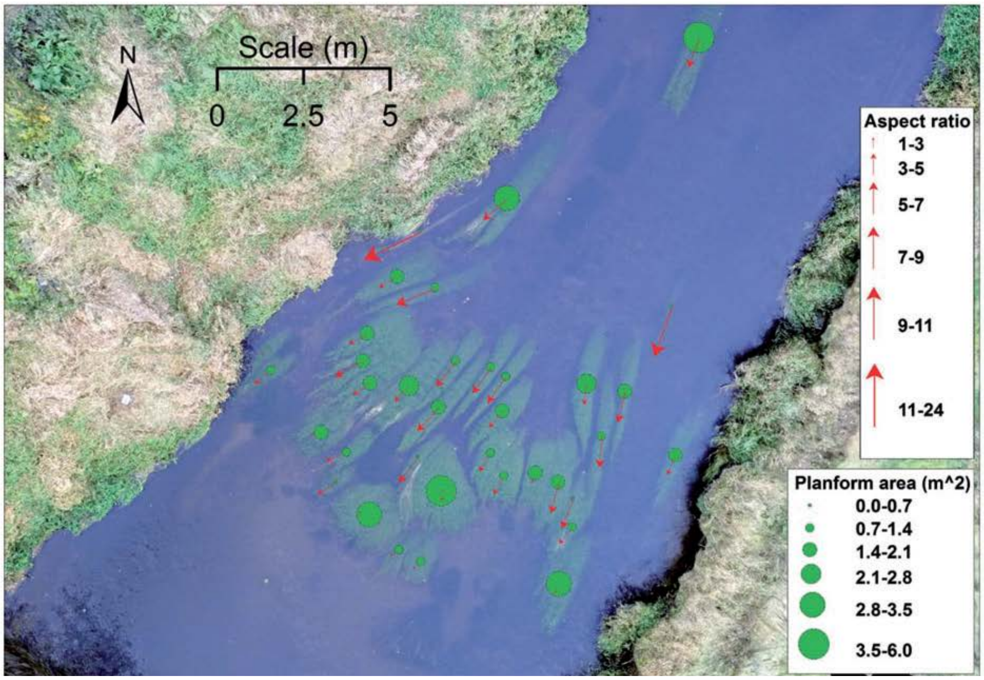

Figure 1. *Ranunculus penicillatus* patches in the River Urie, showing flow redirection around a dense macrophyte cluster that may have caused bank erosion and changes to river morphology, Red arrows are patch orientation vectors scaled by aspect ratio, green circles show patch plan-form area. From "Coupling Unmanned Aerial Vehicle (UAV) and hydraulic surveys to study the geometry and spatial distribution of aquatic macrophytes," by H.J. Biggs et al, 2018, *Journal of Ecohydraulics*, 3(1), 45-58. https://doi.org/10.1080/24705357.2018.1466666.

Invasive Vegetation Studies

Monitoring invasive vegetation in remote areas is often challenging and labor-intensive. While the ground sampling resolution of satellite or aircraft data may be insufficient to discriminate invasive grasses, low-level UAS flights can provide the necessary data in simple environments. In Western Australia, invasive buffel grass (*Cenchrus ciliaris*) and spinifex (*Troidia* sp.) were monitored using a DJI S800 hexacopter airframe with a Canon EOS camera (Sandino et al 2018). The detection rate was 97% for buffel grass and 96% for spinifex. The surrounding environment was arid or semi-arid (Figure 2), and this lack of complexity likely increased the accuracy of detection. In highly complex habitat, understory vegetation will be more difficult to assess.

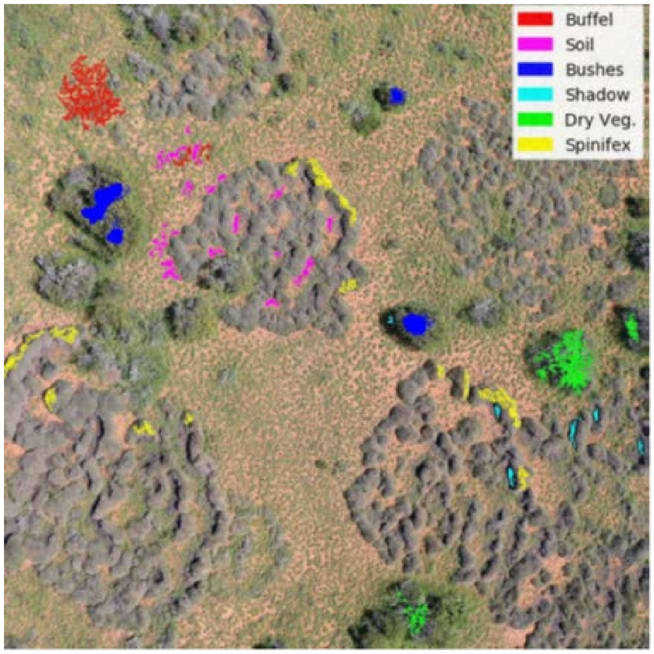

Figure 2. Representative sample of study area. From "UAVs and Machine Learning Revolutionising Invasive Grass and Vegetation Surveys in Remote Arid Lands," by J. Sandino et al, 2018, *Sensors*, 18(605), doi:10.3390/s18020605

In addition to detecting invasive vegetation, UAS imagery can be used to assess the impact of management methods. In Portugal, a biocontrol wasp (*Trichilogaster acaciaelongifoliae*) was released to decrease the flowering of invasive *Acacia longifolia*. UAS were deployed to determine if changes in the number of flowers could be detected from aerial imagery (de Sá et al 2018). Although there was not a strong correlation between the collected imagery and ground-based measurements, the authors identified several changes to the UAS protocol that would likely improve flower identification and count. In any project that requires a plant to be flowering, the timing of the data collection and the ability to see flowers from the air will be critical.

Terrestrial Overstory Studies

Assessing changes to vegetation overstory can allow natural resource managers to evaluate the health of stressed ecosystems. In the western US, management of western juniper (*Juniperus occidentalis*) relies on knowledge of tree density and canopy cover. Durfee et al (2019) used RGB and multispectral imagery collected from a UAS to estimate canopy cover and sapling density. Canopy cover estimates were within 0.9% to 2.3% of ground-based results. Imagery collected in the fall season provided the best estimation of sapling density because overstory cover was thin.

The use of LiDAR sensors could allow researchers to extract additional information from UAS overstory data. Vegetation structure parameters such as canopy height, canopy cover, and aboveground biomass, were derived from a LiDAR sensor flown over various forest ecosystems (Guo et al 2017).

Water Sampling and Monitoring Studies

UAS have been deployed to collect surface water samples using a custom 3D-printed device (Benson et al 2019), and DOI recently approved the use of a water sampling payload called Hydrasleeve for use on the DJI Matrice 600 hexacopter platform. Both options could be used in remote areas where it is impractical or dangerous to launch a boat.

When harmful algal blooms (HABs) occur, it is important to monitor the spread of the bloom in both space and time. The spread of the HAB can threaten public safety and require Reclamation to modify access to resources. Van der Merwe & Price (2015) conducted flights using a near infrared (NIR) sensor over a HAB in Centralia Lake, KS to track the spread of a cyanobacteria outbreak. The rapid response capability of the UAS allowed the researchers to track the HAB and provide timely risk assessments to resource managers.

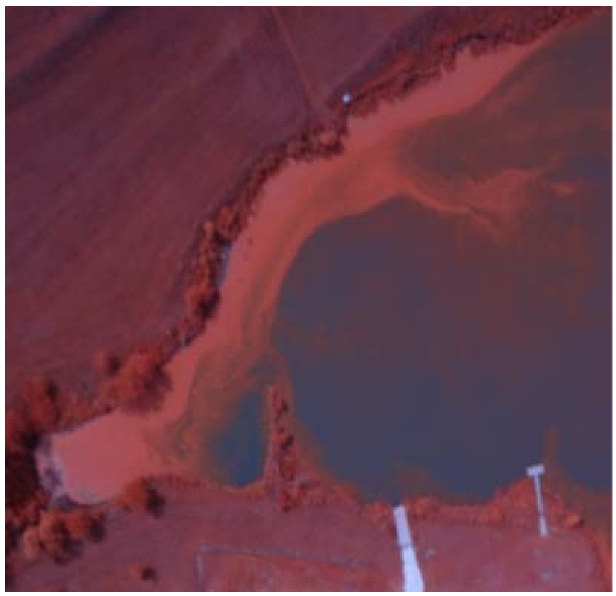

Figure 3. Color-infrared image of a HAB collected from a UAS at Centralia Lake, KS on 14 September 2012. From "Harmful Algal Bloom Characterization at Ultra-High Spatial and Temporal Resolution Using Small Unmanned Aircraft Systems," D. Van der Merwe & K.P. Price, 2015, *Toxins*, 7, 1065-1078, doi:10.3390/toxins7041065.

Ecological Restoration Studies

Reclamation has implemented a variety of restoration projects to improve habitat for threatened species or to mitigate the impacts of construction. UAS can be used to evaluate the success of these projects by monitoring restored vegetation or stream channels. Imagery collected using a DJI Inspire 1 Pro quadcopter allowed resource managers to assess deviations from planned ecological restoration along an urban stream (Langhammer 2019). New channels were identified, and eutrophication in shallow ponds was revealed. Although the stream was significantly different from the planned layout, the data collected from the UAS allowed managers to determine that the restoration goals were still being met.

Performing ground-based assessments of restoration seeding success can be labor-intensive. Buters et al (2019) demonstrated that the imagery collected from a standard DJI camera on the Phantom 4 Pro quadcopter had enough resolution to identify target seeds and seedlings using an automated classification program. Although their study was limited to experimental plots, the results suggest that UAS could provide a rapid, cost-efficient method for assessing new plantings in disturbed areas.

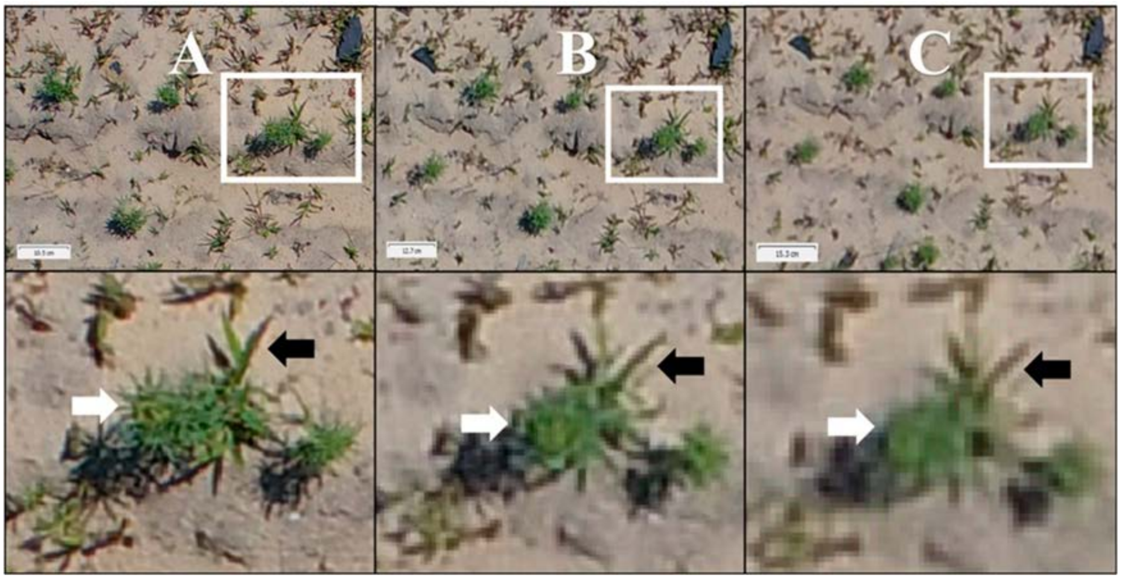

Figure 4. Variable image resolution from imagery at (A) 5 m, (B) 10 m, and (C) 15 m altitude. Target seedling is indicated by white arrow and non-target grass by black arrow. From “Seed and seedling detection using unmanned aerial vehicles and automated image classification in the monitoring of ecological recovery,” by T. Buters, D. Belton, and A. Cross, 2019, *Drones*, 3(53), doi:10.3390/drones3030053.

Recommendations for Next Steps

Reducing the impact of invasive species will improve the delivery of water and limit environmental impacts, while also reducing labor costs throughout Reclamation facilities. When equipped with the appropriate sensor, UAS can perform vegetation and wetland mapping surveys, sample water in remote locations, and disperse biocontrol organisms with high precision (Appendix A). Additional applications could include treating harmful algal blooms, controlling invasive rodents, or monitoring the effects of burrowing crayfish.

The most promising application, as it applies to Reclamation, is likely vegetation monitoring and mapping. UAS have been successfully deployed to identify vegetation to the species level, and to locate areas of critical habitat. These missions are possible using sensors and platforms that are currently part of the TSC portfolio. Additional technical capabilities, such as LiDAR or hyperspectral imaging, may be available in the future and could enhance the data collected during vegetation surveys.

Applying UAS to invasive species control has the potential to reduce costs and establish the TSC as an innovative force in the field of pest management. UAS could also be a critical component of a rapid response team to investigate new reports of invasive species throughout the western U.S. The TSC should look to partner with regional and area offices to find suitable projects to demonstrate the capabilities of UAS. Initial efforts should focus on vegetation mapping. Partnerships to be explored include mapping infestations of giant salvinia along the Lower Colorado River and classifying Southwestern willow flycatcher habitat along the Rio Grande. The members of the Ecological Research Laboratory and the UAS team will continue to pursue opportunities to apply this emerging technology to fulfill Reclamation’s mission.

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Appendix A –

Table 1. This table lists sources, platforms, sensors, and the mission objective for relevant literature. It is divided by application area, including: aquatic vegetation, invasive vegetation, terrestrial overstory, terrestrial understory, wetland delineation, water sampling, wildlife management, and ecological restoration.

	Source	Platforms	Sensors	Purpose
Aquatic Vegetation	Biggs et al (2018)	DJI Phantom 1 (R)	GoPro Hero 3 Black - digital camera	Surveyed aquatic macrophyte patches and linked presence to hydraulic parameters
	Chabot et al (2018)	SenseFly eBee (F)	Parrot Sequoia - multispectral camera	Mapped aquatic macrophytes (84-92% accuracy)
	Flynn and Chapra (2014)	DJI Phantom 4 (R)	GoPro Hero 3 Black - digital camera	Surveyed nuisance green algae cover in river system (90-92% accuracy)
	Willis and Holmes (2019)	3DR Solo (R)	Canon Powershot S100 - digital camera	Mapped riverine canopy (emergent vegetation) to model effect on stream temperature
Invasive Vegetation	de Sa et al (2018)	SenseFly eBee (F)	Canon IXUS/ELPH - RGB or color-infrared	Mapped invasive flowering shrub (96% accuracy) and monitored biocontrol performance
	Lehmann et al (2017)	SkyWalker 2014 (F)	Canon PowerShot - RGB and color-infrared	Identified invasive flowering tree in savannah ecosystem (83% accuracy)
	Martin et al (2018)	DRONESYS DS6 (R)	Sony Alpha 7 - RGB, Sonnar T* - Near-IR	Mapped invasive knotweed in open and complex landscapes
	Sandino et al (2018)	DJI S800 (R)	Canon EOS - digital camera	Monitored invasive grasses (97% detection rate)
Terrestrial Overstory	Baena et al (2017)	SenseFly eBee (F)	Customized digital camera	Identified tree species in equatorial dry forest (94% accuracy)
	Durfee et al (2019)	3DR Solo (R) DJI Matrice 100 (R) DJI Phantom 3 (R)	MicaSense RedEdge - multispectral, DJI camera - RGB	Calculated sapling density and canopy cover in western juniper stands
	Guo et al (2017)	Custom octocopter (R)	Velodyne Puck - lidar	Extracted forest overstory parameters (cover, height, etc) from lidar data
	Lopatin et al (2019)	HiSystems octocopter (R)	Canon 100D - RGB, OXI-II - snapshot hyperspectral	Investigated effect of shadows on misclassification of woody species
	Sankey et al (2017)	Service-Drone (R) SenseFly eBee (F)	Velodyne - lidar, Headwall - hyperspectral, Multispectral sensor	Fused lidar and hyperspectral data to identify tree and grassland species (88% accuracy)

Terrestrial Understory	Diaz-Delgado et al (2019)	DJI Phantom 4+ (R)	Parrot Sequoia - multispectral camera	Confirmed ground-based measurements in grassland rain-exclusion experiments
	Melville et al (2019)	DJI S1000 (R)	PhotonFocus - hyperspectral snapshot	Classified lowland grassland communities based on phenology (72-93% accuracy)
	Rominger & Meyer (2019)	DJI Phantom 3	DJI camera - RGB	Censused endangered poppy during flowering season in Mojave Desert
Wetlands	Boon et al (2016)	AKS Y-6 multirotor (R)	Unknown digital camera	Assessed wetland health and delineated extent
	Diaz-Delgado et al (2018)	SenseFly eBee (F)	Parrot Sequoia - multispectral	Mapped wetland inundation and aquatic plant cover at long-term ecological research sites
	Pande-Chhetri et al (2017)	NOVA 2.1 (F)	Olympus ES 420 - RGB	Classified wetland vegetation classes (71% accuracy)
Water Sampling	Benson et al (2019)	DJI Phantom 4+ (R)	3D-printed sampling device	Collected surface water samples
	Koporan et al (2018b)	Custom multirotor (R)	Custom sampling device	Collected surface water samples
Wildlife Management	Bushaw et al (2019)	DJI Inspire 1 (R)	DJI Zenmuse XT2R - thermal imaging camera	Surveyed mesocarnivores in prairie ecosystem with 32 detections
	Kim et al (2018)	Custom quadcopter (R)	Remote controlled nets	Collected insects at various altitudes above rice field
	Park et al (2017)	Custom quadcopter (R)	Custom dispersal system	Dispersed biocontrol weevil in remote locations
	Tyler et al (2018)	DJI Phantom 4 Pro (R)	DJI camera - RGB	Identified and sized endangered Taimen (fish) in depths over 2 m
Ecological Restoration	Buters et al (2019)	DJI Phantom 4 Pro (R)	DJI camera - RGB	Detected target seeds and seedlings in restoration areas (80-90% accuracy)
	Langhammer (2019)	DJI Inspire 1 Pro (R)	DJI Zenmuse X5 -RGB DJI Zenmuse X3 - RGB	Monitored stream restoration and found deviation from plan and eutrophication

Data Sets that Support the Final Report

- **Share Drive folder name and path where data are stored**: Z:\DO\TSC\Programs\Exotic Species Detection Laboratory\DATA\PROJECTS\Research Office\UAS Scoping – X9012
- **Point of Contact:** Aaron Murphy, amurphy@usbr.gov, 303-445-2157
- **Short description of the data**: pdf files of literature collected, final report
- **Keywords**: UAS, ecology
- **Approximate total size of all files**: 750 MB