Watchful Electronics Eliminating Destructive Species

WEEDS - Phase 1

By

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A proposal prepared for the

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I. Problem Statement

The Montana Department of Transportation (MDT) is tasked with maintaining thousands of miles of roadways and associated rights-of-way (ROW) across diverse and often challenging terrain. Noxious weed infestations along these ROW pose significant threats, including compromising roadway integrity, competing with desirable vegetation, reducing land productivity, degrading habitat, and increasing long-term maintenance costs (Kuni, 2025). Managing these weeds effectively is crucial but is particularly difficult in areas that are hard-to-reach, steep, or hazardous, where traditional ground-based spraying methods are inefficient, unsafe, and cost-prohibitive. MDT requires innovative solutions to augment existing Integrated Weed Management (IWM) efforts, prioritizing crew safety and fiscal responsibility while effectively controlling infestations across large geographic regions. There is a specific need to accurately identify the location and species of weeds to enable targeted, rather than broadcast, treatment, thereby optimizing herbicide use and minimizing environmental impact.

II. Executive Summary

This proposal outlines a research project to investigate the feasibility, effectiveness, and cost-benefits of employing Unmanned Aircraft Systems (UAS), integrated with remote sensing and Artificial Intelligence/Machine Learning (AI/ML), for the precision identification, mapping, and spot treatment of noxious weed infestations within Montana Department of Transportation (MDT) ROWs. MDT faces challenges managing weeds in inaccessible or hazardous areas using traditional ground-based methods. This research proposes a technology-driven solution involving UAS image acquisition, AI/ML analysis for species identification (initially focusing on high-priority species like Scotch broom and rush skeletonweed), generation of precision treatment maps, and leading to eventual targeted herbicide application using agricultural spray drones.

This proposal addresses Phase I of the project, which includes evaluating appropriate imaging technologies and AI/ML techniques, assessing FAA regulatory challenges for agricultural UAS operations, and conducting a comprehensive cost-benefit analysis. Drawing upon promising results from academic research in agriculture and environmental management (i.e. Esposito, et al., 2021, Meesaragandla, et al., 2024, and Johnson, 2025, Mundt et al., 2006, 2006, Hill et al., 2016), this project aims to develop methodologies, prototype implementations and guidelines compatible with MDT systems. Successful outcomes will demonstrate a safer, more cost-effective, and environmentally responsible approach to weed management; thereby significantly enhancing MDT's ability to maintain its infrastructure and protect ecological balance. The research is estimated to cost $284,154 over a 2-year study period and will lay the groundwork for a phased statewide implementation.

A later Phase II of the WEEDS project, outside the scope of this initial proposal, will focus on the precision treatment of invasive weeds using spray-equipped UAS data and processes developed in Phase I. This Phase I project aims to develop methodologies, prototype implementations, and guidelines compatible with MDT systems, delivering georeferenced precision treatment maps in standard GIS formats (e.g., Shapefiles, GeoJSON). This will ensure direct translation into UAS mission plans for a safer, more cost-effective, and environmentally responsible weed management approach. Successful outcomes will significantly enhance MDT's ability to maintain its infrastructure and reduce the risk of invasive plant species introduction and spread through transportation vectors.

III. Background and Significance

Impacts of Noxious Weeds on Transportation Infrastructure and Environment

Invasive plant species cause significant ecological and economic impacts (Rangel, 2024). Along transportation corridors, weeds can destabilize roadbeds, reduce visibility, impede drainage, and require costly manual or mechanical removal. Environmentally, they outcompete native flora, reduce biodiversity, alter soil properties, and can increase wildfire risk (Mensah, et al., 2024). Effective management is essential for maintaining the safety, functionality, and environmental health of transportation Right of Way.

Limitations of Traditional Weed Management Methods

Traditional weed management often relies on ground crews using backpack sprayers, truck-mounted sprayers, or potentially manned aircraft for large or inaccessible areas. Ground methods are labor-intensive, time-consuming, and expose personnel to safety risks on steep or hazardous terrain (Schramm, 2024). Manned aerial applications are costly and may not offer the precision needed for spot treatments, potentially leading to unnecessary herbicide use and drift. Broadcast spraying, a common traditional method, can harm non-target plants and contribute to herbicide resistance development (Esposito, et al., 2021). There is a clear need for methods that are safer, more efficient, provide greater spatial precision, and reduce chemical inputs and cost.

Advances in Remote Sensing and UAS Technology for Weed Management

Recent advancements in Unmanned Aircraft Systems (UAS) and associated sensor and data processing technologies offer a promising alternative (Meesaragandla et al., 2024). UAS lowers the research cost barrier by providing versatile platforms for rapidly collecting a wide variety of aerial data only previously available by utilizing expensive aircraft or lower resolution satellite images. Precise remote sensing UAS operations also have the advantage of covering transects or swaths of area quickly and overcoming difficult to access areas that are unsafe for ground crews.

Sensors: Various sensor types can be deployed on UAS for weed detection, including high resolution RGB (color), multispectral cameras, and hyperspectral sensors. There are detection limit tradeoffs that depend on the vehicle, radiometric calibration, flight parameters, target species characteristics, and project objectives. While hyperspectral sensors are generally considered more accurate due to higher spectral resolution, studies show that RGB or multispectral imagery, especially when combined with high spatial or temporal resolution from UAS, can achieve overall accuracy rates of 80% and higher (i.e. Amarasingam et al., 2024; Meyer et. al., 2024; Evans et al., 2024). The ability to capture detailed spectral signatures during peak bloom can be key to differentiating a target weed species from surrounding vegetation (e.g., Ajamian et al. 2021, Mitchell et al., 2009). On the other hand, for some species the key to detection can be high repeat collections of dominant species over a growing season using a multispectral sensor (e.g., Bradley et al., 2014).

AI/ML: Acquired imagery can be processed using Artificial Intelligence (AI) and Machine Learning (ML) techniques, such as deep neural networks, Convolutional Neural Networks (CNNs), and object-based image analysis, to automatically identify and classify weed patches based on their spectral characteristics, shape, or texture (Nikolova, et al., 2025). These techniques have shown high accuracy in distinguishing weed species. Existing ML models can be trained on new datasets in a process called transfer learning to expand their object detection capabilities. These newly trained models are then further optimized for their new specific object detection tasks.

Precision Application: Once weeds are identified and mapped, this spatial data can create a prescription map for precision spot treatment. Agricultural spray drones can then utilize these maps to autonomously navigate and apply herbicides directly to the targeted weed locations (Meesaragandla et al., 2024). This site-specific approach significantly reduces herbicide use compared to broadcast spraying, leading to cost savings and reduced environmental impact.

Relevant Previous Research and Applications

Academic research has explored the use of drones and machine learning for weed identification and management extensively, primarily in agricultural contexts (i.e. Mensah, et al., 2024; Catlin, 2023), with broader studies also focusing on remote mapping and spatial modeling for noxious weed management in regions like the Intermountain West (Mattilio, 2022). Studies have demonstrated the ability to identify specific weed species like *Cirsium arvense* (Canada thistle), *Chenopodium album* (fat-hen), and *Amaranthus palmeri* (Palmer amaranth) using UAS imagery and machine learning (Murad, et al., 2023), and others have focused on specific sensor types like hyperspectral data for species such as common milkweed (Papp et al., 2021). Research has also investigated mapping invasive weeds in specific environments like wetlands (*Phragmites australis*, water hyacinth) (Anderson, et al., 2021), water hyacinth, and other aquatic species (Bolch et al., 2021) and rangelands (*Cytisus scoparius* - Scotch broom) and demonstrated the effectiveness of UAS for monitoring herbicide treatment response. Locally relevant research in Montana has also addressed specific invasive species like *Ventenata dubia*, exploring control treatments (Fighter, 2023). While highly promising, some research notes challenges such as achieving consistent accuracy across varied landscapes and the need for further refinement.

Crucially, some states and counties are beginning to implement these technologies (Johnson, 2025). The Washington Department of Fish and Wildlife (WDFW) has used drones for mapping invasive species like reed canary grass and invasive cattail to guide targeted treatments. WDFW used a drone to map and spray invasive plants in areas of the Skagit Wildlife Area (WDFW, 2023). In North Dakota, a significant grant was awarded for UAS detection of noxious weeds in agricultural fields with multiple partners (ND DOA, 2024), and Ward County Weed Board has used UAS for spraying in challenging terrains. Fremont County, Idaho, has integrated UAS into operations, treating thousands of acres annually in difficult terrain and finding the method effective for species like hound's tongue and musk thistle. These examples, while not always resulting in formal published research, signal the growing adoption and practical potential of this technology for land management, including in transportation corridors, highlighting a gap in published DOT-specific research.

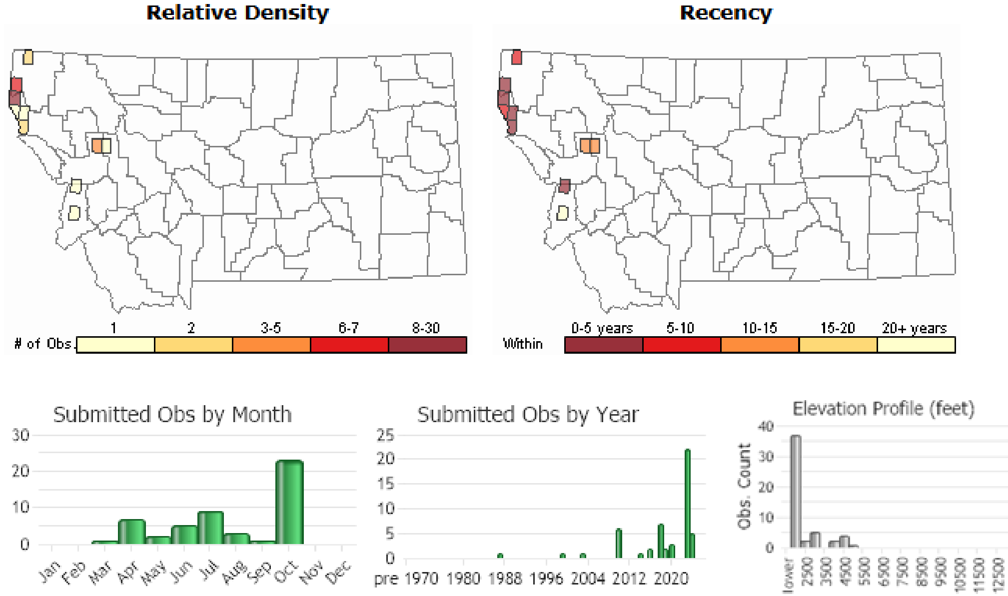
The National Heritage Program lists invasive species relative density, recency of observation, month, year, and elevation of observation, as well as the spatial extent of species range within Montana (National Heritage Program, 2025. Figure 1 shows the details for Scotch broom and Figure 2 shows the details for rush skeletonweed.

Observations in Montana Natural Heritage Program Database

Number of Observations: 51

(Click on the following maps and charts to see full sized version) Map Help and Descriptions

Relative Density **Recency**



(Observations spanning multiple months or years are excluded from time charts)

Habitat

Shrubs grow in disturbed areas, particularly along moist roadsides and in utility right-of-ways, pastures, open forests, gravel pits, and cultivated fields (Graves et al. 2010; Lesica et al. 2012). In other states it has also colonized undisturbed shrubland, grassland, and forests below 4,000 feet elevation (Graves et al. 2010).

Predicted Suitable Habitat Model

This species has a Predicted Suitable Habitat Model available.

To learn how these Models were created see here

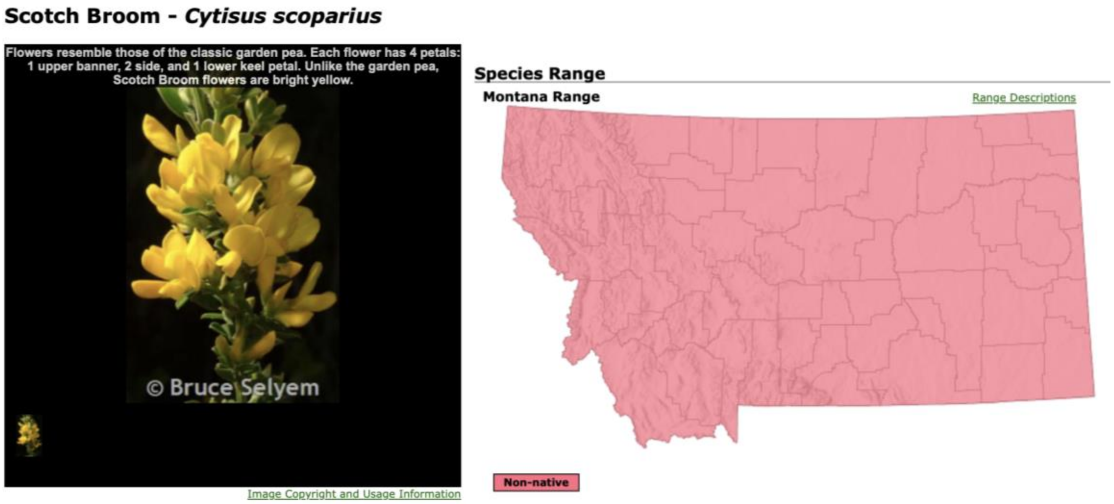


Figure 1: Scotch broom (Cytisus scoparius) Observations from Montana Field Guides (National Heritage Program, 2025).

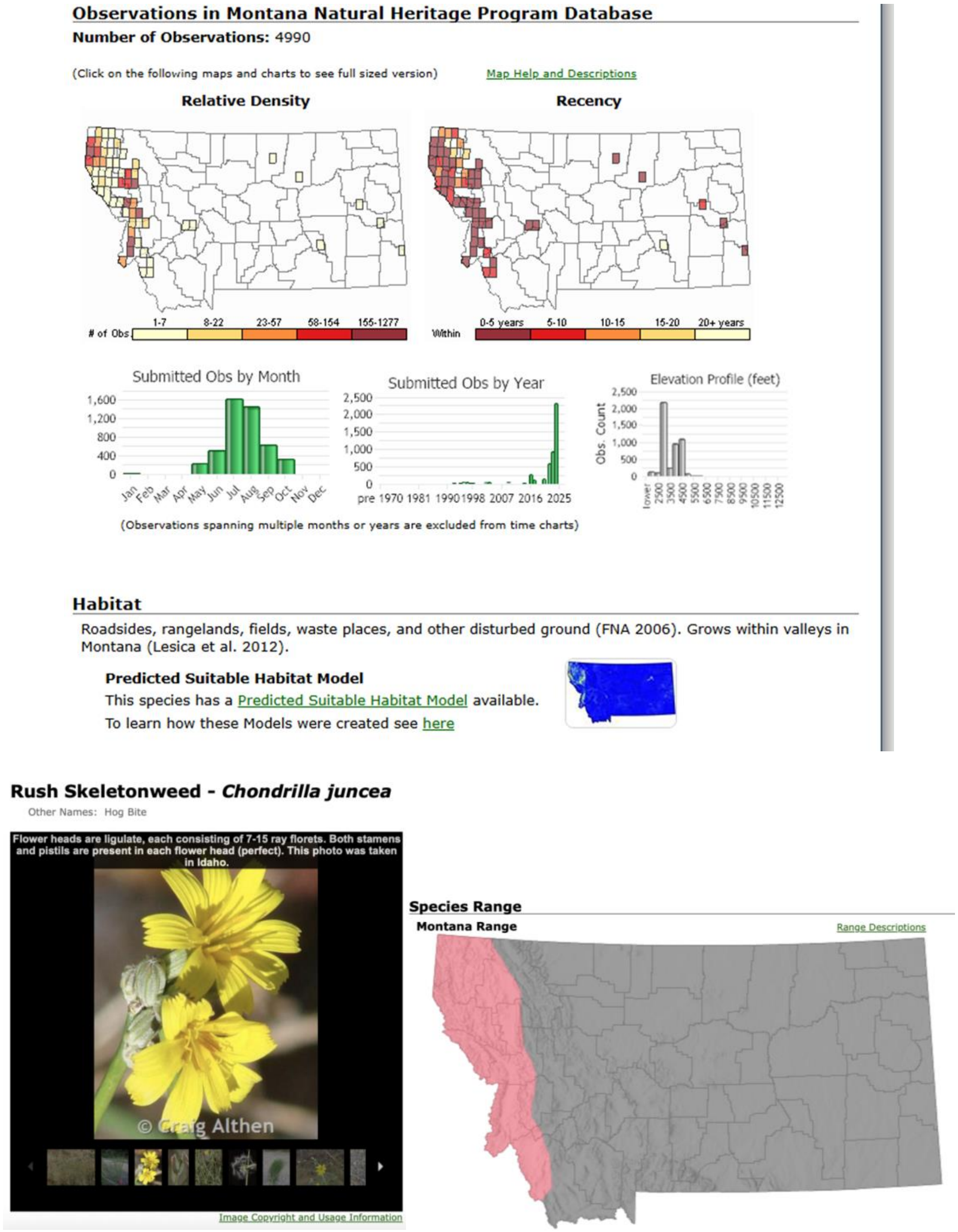


Figure 2: Rush skeletonweed (Chondrilla juncea) Observations from Montana Field Guides (National Heritage Program, 2025).

IV. Research Objectives

The primary goal of this research is to determine the viability and benefits of implementing a UAS-based system for precision noxious weed management within MDT ROW with particular emphasis on AL/ML/CV model development for the detection, identification, and mapping of the target weed species. This will be achieved by addressing the following specific objectives, derived from MDT's key questions and goals:

1. **Identify and Evaluate Appropriate Technology:** Determine the most suitable combination of UAS platforms, sensor configurations (RGB, multispectral, hyperspectral), and AI/ML methodologies for accurately detecting, classifying, and mapping high-priority noxious weed species (initially focusing on Scotch broom and rush skeletonweed) within MDT ROW areas, especially in hard-to-reach terrain.

2. **Conduct Cost-Benefit Analysis:** Quantify the costs and benefits of using the UAS-based precision treatment system compared to traditional weed management methods, evaluating factors such as herbicide savings, reduced labor/time, improved safety, and environmental impact factors.
3. **Assess Regulatory Compliance and Pathways:** Analyze the challenges posed by current FAA and MT regulations and identify the necessary steps, including obtaining Part 137 authorization for MDT to legally conduct agricultural flight operations using UAS for weed treatment spraying operations.

4. **Validate Workflow and Efficacy:** Implement and test the proposed end-to-end workflow, from data acquisition and AI-driven detection to precision spray maps suitable for uploading to spray drones, in selected test areas.

5. **Develop Implementation Resources:** Produce research findings, detection methodologies, a trained AI/ML model based on captured data, and comprehensive guidelines that are compatible with MDT's existing systems and support the department's ability to implement the precision UAS weed management approach.

V. Research Plan and Methodology

This research project will be conducted over multiple phases, building from technology evaluation and data collection to system testing, validation, and the development of implementation resource recommendations. The initial focus will be on identifying and mapping Scotch broom and rush skeletonweed in selected test areas.

Task 1: Planning and Technology Selection (Est. 4 months)

This phase focuses on reviewing existing technologies and research, making informed decisions about the specific equipment and software to be used.

1. **Identifying Appropriate UAS Platforms:** Evaluate available fixed-wing and multi-rotor UAS platforms suitable for both imagery acquisition and, later, precision spraying. Consider factors like payload capacity (for sensors and spray tanks), flight time limitations, range, durability for ROW conditions, and cost-effectiveness.

2. **Evaluating Sensor Technologies (RGB, Multispectral, Hyperspectral):** Review the latest research on sensor performance for weed identification, specifically for target species if possible. Compare the trade-offs between sensor types in terms of spectral and spatial resolution, cost, weight, and data volume. Determine the optimal sensor(s) to capture the necessary data for species differentiation via spectral signatures.

3. **Selecting/Developing AI/ML Models and Software:** Research and select appropriate AI/ML techniques (e.g., CNN variants, object detection models, spectral classification algorithms) and software for processing UAS imagery to identify and map target weed species. Evaluate existing weed identification models and databases or plan for creating a project-specific database.

Task 2: Data Acquisition and Model Development (Est. 14 months)

This phase includes data collection and developing the core weed identification system over 2 growth seasons. During spring, summer, and fall periods we will focus on collecting and validating data, while winter will be dedicated to AI/ML model building, with some overlap between activities.

1. **Conducting Field Surveys and Ground Truth Data Collection:** Select representative MDT ROW test sites. Conduct detailed ground surveys at these sites to accurately map the location, species, and extent of target weed infestations. This "ground truth" data is essential for training and validating the AI/ML models. Collect spectral measurements of target species and native vegetation under varying conditions if necessary.

2. **Defining Target Weed Spectral Signatures:** Based on existing literature and initial lab or field measurements, if necessary, refine the understanding of the unique spectral characteristics of Scotch broom and rush skeletonweed at different phenological stages relevant to MDT ROW conditions, as leveraging phenological variability can improve classification accuracy (Wood et al., 2022). This information is critical for training AI/ML models.

3. **Developing Data Acquisition Protocols:** Design detailed flight plans and data collection protocols. This includes determining optimal flight altitudes and speeds for required spatial resolution (e.g., Ground Sample Distance - GSD), flight patterns, timing relative to weed growth stages for best spectral contrast, and considerations for lighting and weather conditions.

4. **Performing UAS Imagery Flights over Test Sites:** Execute the data acquisition protocols developed in Phase 1 using the selected UAS platforms and sensors over the chosen test sites.

5. **Preprocessing and Integrating Geospatial Data:** Process the raw UAS imagery (e.g., stitching orthomosaics, atmospheric correction, radiometric calibration) and integrate it with other relevant geospatial data, such as MDT ROW boundaries, terrain data, and the ground truth data collected.

6. **Training and Validating AI/ML Models for Weed Detection:** Use the processed imagery and ground truth data to train and refine the selected AI/ML models. Rigorously test the model accuracy in identifying and mapping target weed species across different test site conditions. Iteratively improve the models based on validation results.

Task 3: Precision Treatment Planning (Est. 4 months)

This phase applies the developed detection system to the treatment process and converts it to an output file compatible with existing spray drones.

1. **Generating Precision Spot-Treatment Maps:** Utilize the output from the validated AI/ML weed detection model (detailed weed location maps) to create precision spot-treatment prescription maps. These maps will specify the exact coordinates and boundaries of weed patches requiring treatment, minimizing herbicide application outside these zones.

Task 4: Data Analysis, Evaluation, and Reporting (Est. 2 months)

The final phase focuses on synthesizing the results, evaluating the overall system, and preparing deliverables for MDT.

1. **Analyzing Detection Accuracy and Treatment Efficacy:** Compile and analyze all data collected during Phases 2 and 3. Quantify the accuracy of the weed detection methodology.

2. **Developing Implementation Guidelines and Best Practices:** Based on the research findings, develop comprehensive guidelines for MDT covering technology selection, data acquisition, processing, AI/ML model use, treatment planning, spray drone operation planning, regulatory compliance, and safety procedures.

3. **Performing Cost-Benefit Analysis:** Compare the measured costs (equipment, software, personnel time, estimated herbicide use) of the UAS-based system with estimated costs of traditional methods for treating the same areas. Quantify benefits such as herbicide savings, reduced labor, improved safety, and potential long-term cost reductions due to more effective control.

4. **Final Reporting and Knowledge Transfer:** Prepare a detailed final report summarizing the research methodology, findings, conclusions, and recommendations. Present the results to MDT

stakeholders. Ensure deliverables are in universal formats compatible with existing MDT systems.

VI. Intellectual Property

During this research, particularly in the development of a novel Machine Learning (ML) model for weed detection and identification, the generation of new intellectual property (IP) is anticipated. The University of Montana, as the entity conducting this research and development funded by MDT, will be the creator of this IP. We are committed to proactive and transparent consultation with MDT to establish a clear agreement regarding the management, ownership, potential licensing, and usage rights of any IP generated. This process will be guided by university policies and our collaborative agreement, ensuring that MDT's interests as the project sponsor are appropriately addressed.

VII. MDT and Technical Panel Involvement

The research team will seek guidance from the MDT Technical Panel on any major decisions necessary to achieve the research goals. Examples of potential topics to be addressed include refinements to data acquisition procedures, selection of specific UAS equipment or sensors, software integration, ML model parameters and validation, data processing workflows, and suitable field trial locations for weed detection. We are committed to respecting the time of the Technical Panel members, providing reasonable advance notice for reviews, and aiming to respond to any questions within approximately two weeks. We will also request that the Technical Panel review final drafts of deliverables, reports, publications, and presentations, allowing 2-3 weeks for their feedback prior to due dates.

As this research involves field data collection, we will require access to MDT-managed Right-of-Way (ROW) areas that are representative of the diverse conditions and weed infestations MDT encounters, including hard-to-reach or hazardous locations where UAS technology offers significant advantages. As the project progresses, we anticipate the need to consult with MDT personnel, such as Maintenance staff involved in current weed management, GIS specialists, and environmental compliance officers, to ensure our research aligns with practical needs and integrates effectively with existing MDT data systems.

A key anticipated request, ideally within one month of contract initiation, will be for access to any relevant existing MDT databases or GIS data. This would include information on known noxious weed locations, historical treatment data and types, ROW boundaries, ecologically sensitive areas, and any available aerial or satellite imagery that MDT may possess for target regions. Access to this data will be invaluable for training and validating the ML model and for planning efficient data acquisition campaigns.

For the successful execution of Phase I, particularly during field trials and operational validation, we request MDT’s collaboration in facilitating access to diverse and challenging test sites. This may include logistical support or coordination, especially for UAS operations in or near active ROWs requiring safety measures. Furthermore, collaboration with MDT field crews for ground-truthing exercises and input from MDT staff on the practical application and integration of the developed weed detection tools will be crucial for ensuring the project's outputs are actionable and beneficial for MDT.

VIII. Risks and Mitigation Strategies

Several potential risks are associated with this research and the proposed system implementation.

Regulatory Hurdles (FAA Part 137): Obtaining necessary FAA and state authorization (specifically FAA Part 137 for agricultural operations and a state-issued aerial commercial applicator license) and compliance with MT Pesticide Act for spray drone use can be a complex process and may cause implementation delays.

Mitigation: Engage early and maintain close communication with the FAA and MT regulators regarding the research plan and regulatory requirements. Leverage existing knowledge from other entities that have obtained similar waivers.

Technical Challenges (Accuracy, Data Processing): Achieving high detection accuracy across diverse ROW environments (varying vegetation density, terrain, lighting) can be challenging. Processing large volumes of high-resolution imagery requires significant computational resources and expertise.

Mitigation: Select or develop robust AI/ML models capable of handling environmental variability. Plan for thorough ground truth data collection and model validation. Allocate sufficient resources for data storage and processing infrastructure.

Operational Constraints (Weather, Flight Time, Landscape): UAS flight operations are susceptible to adverse weather conditions (i.e. wind, rain, etc.). Current battery technology limits flight time and coverage area per flight. Steep or complex terrain can present unique operational challenges. The relatively small operational footprint of individual UAS can make covering large areas inefficient compared to manned aircraft.

Mitigation: Build flexibility into the schedule for weather delays. Optimize flight planning and battery management. Carefully select test sites that represent the target operational environments but are feasible within research constraints. The implementation plan envisions "targeted deployment" rather than broad-scale coverage by a single drone.

Data Management and System Compatibility: Integrating data from UAS platforms, sensors, AI/ML software, and potentially existing MDT GIS or vegetation management systems can be complex.

Mitigation: Prioritize the use of open standards and universal data formats for all project outputs. Design the system architecture with integration in mind. Work closely with MDT IT and relevant personnel to ensure compatibility.

Need for Skilled Personnel: Operating UAS, processing remote sensing data, developing and training AI/ML models, and conducting agricultural spray operations requires specialized skills and training.

Mitigation: Ensure the research team possesses the required expertise. The implementation plan includes training for MDT personnel.

IX. Implementation Plan

Should the research successfully demonstrate the effectiveness and cost-benefits of the UAS-based precision weed management system, the implementation plan would involve a new Phase II project the following steps:

Post-Research Steps for Adoption (future Phase II):

Obtain FAA Part 137 Authorization and MT Commercial Applicator License: Secure the necessary MT and FAA certification for MDT personnel to legally conduct agricultural aerial application operations using UAS.

Procure Equipment and Software: Acquire recommended UAS platforms (mapping and spray UAS), sensors, data processing software, and related support equipment. MDT already possesses some support equipment like trucks and chemical tanks.

Train Personnel: Provide comprehensive training to MDT Maintenance personnel, including existing UAS pilots and Weed Management staff, on operating the specific UAS platforms, using the software, applying treatment maps, and adhering to safety and regulatory protocols.

Phased Rollout Strategy:

Initial Test Group: Implement the system with an initial test group of MDT districts or crews during the first growing season post-research to further refine best practices in a real-world operational setting.

Statewide Implementation: Based on the success and lessons learned from the initial test group, scale the program gradually. It is estimated that statewide implementation could take two to three years.

Responsible Parties:

The MDT Weed Management Manager in Maintenance, in conjunction with the MDT UAS Manager, would be primarily responsible for overseeing the implementation and ongoing operation of the program.

X. Project Schedule

Assuming a project start date of July 1, 2025, the research is anticipated to be completed within 24 months, leading to shovel-ready recommendations for implementation.

Table 1: Monthly Schedule

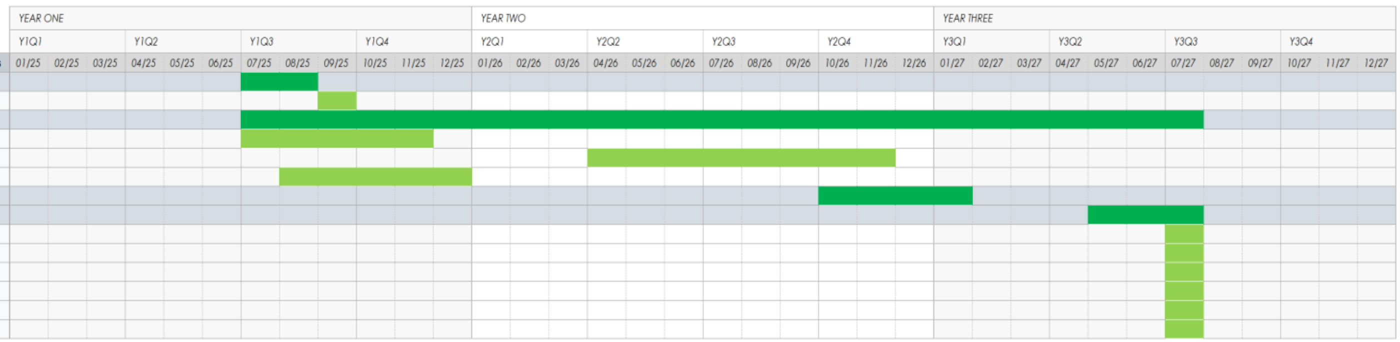
Task	Duration (Months)	Estimated Start	Estimated End	Key Activities
1: Planning & Technology Selection	4	Month 1	Month 4	Tech Review, Sensor/Platform Selection, Protocol Design, AI/ML Evaluation
2: Data Acquisition & Model Development	14	Month 1	Month 20	Site Selection, Ground Truth, UAS Flights, Data Processing, Model Training/Validation
3: Precision Treatment Planning Map	4	Month 16	Month 20	Treatment Map Generation, Spray Drone Efficacy Data
4: Data Analysis, Evaluation, & Reporting	2	Month 20	Month 24	Accuracy/Efficacy Analysis, Cost-Benefit Analysis, Guidelines, Final Report

Note: Specific task durations and overlaps will be detailed in a full project work plan upon award.

Table 2: Project Schedule Gantt Chart

MDT WEEDS

PROJECT NAMES + TASK TITLES	START DATE	END DATE	# of Days
1: Planning & Technology Selection	**07/01/25**	**08/31/25**	**44**
Deliverable: UAS, Sensor, and AI/ML Analysis	*09/01/25*	*09/01/25*	*1*
2: Data Acquisition & Model Development	**07/01/25**	**07/01/27**	**523**
Season 1	*07/01/25*	*11/01/25*	*89*
Season 2	*04/01/26*	*11/01/26*	*153*
Season 3	*08/05/25*	*12/19/25*	*99*
3: Precision Treatment Planning Map	**10/01/26**	**01/31/27**	**87**
4: Data Analysis, Evaluation, & Reporting	**05/01/27**	**07/01/27**	**44**
Deliverable: Trained AI/ML model	*07/01/27*	*07/01/27*	*1*
Deliverable: Spot treatment export map	*07/01/27*	*07/01/27*	*1*
Deliverable: Written Guidelines	*07/01/27*	*07/01/27*	*1*
Deliverable: Project Summary Report	*07/01/27*	*07/01/27*	*1*
Deliverable: Implementation Report	*07/01/27*	*07/01/27*	*1*
Deliverable: Final Presentation	*07/01/27*	*07/01/27*	*1*



XI. Estimated Budget

Based on similar research and the scope of work, the total estimated cost for this research project is anticipated to be **$284,154**. A detailed budget breakdown follows:

Table 3: Detailed Project Budget

Labor Expenses											
Person	**Role**	**Task 1**	**Task 2**	**Task 3**	**Task 4**	**Total Hours**		**Total Wages**	**Hourly Benefit Rate**		**Total Cost**
Josh Kornoff	PI/ AI	87	303	87	43	520					
Bart Bauer	Pilot/GIS	49	169	49	24	291					
Jessica Mitchel	Spatial	35	121	35	17	208					
Total:								**$88,895**			**$131,347**
Direct Expenses											
In State Travel – 14 field data collection or meetings trips											$23,285
Hardware, Software, and Expendable Supplies											$13,500
Capital Equipment											$37,000
Indirect Costs Assessed on Direct Expenses (Facilities and Administration) @ 47%											$79,022
Total Project Cost:											**$284,154**

Travel Budget

Figure 4 details the required travel for the WEEDS Phase I research. We are estimating travel for three key personnel, totaling approximately 42 nights, including rental vehicle and per diem. This estimate covers approximately 14 days for an initial field data acquisition campaign in the late spring through fall at selected MDT Right-of-Way (ROW) sites, and travel to Helena for the project Kickoff Meeting and Final Phase I Presentation. The total for this travel is estimated at **$23,285**. The University of Montana's Autonomous Aerial Systems Office (AASO) verifies that travel will be in accordance with FHWA 48 CFR 31. Per diem will be charged at GSA rates, the entire per diem amount will be paid to the traveler, and alcohol is not an allowable charge.

Table 4: Travel Budget

Travel				
Assumption		**Number**	**Unit Cost**	**Total**
Airfare				$0
Hotel/Incidentals	14 trips for 3 persons	42	$154	$10,316
Rental Car	42 trips, 1 day per trip	42	$75	$6,395
Meals	14 trips for 3 persons	42	$44.10	$3,760
Fuel	14 trips for 3 persons	72	$33	$2,814
Total (excluding F&A @47%):				**$23,285**

Table 5: Task and Deliverable Budget

Task, Meeting, and Deliverable Cost Breakout			
Item	**Labor**	**Travel**	**Total**
Task 1 - Planning & Technology Selection	$21,935		$21,935
Deliverable: UAS, Sensor, and AI/ML Analysis and Recommendations			
Task 2 - Data Acquisition & Model Development	$76,575	$21,067	$97,642
Task 3 - Precision Treatment Planning Map	$21,935		$21,935
Task 4 - Data Analysis, Evaluation, & Reporting	$10,639	$2,218	$12,857
Deliverable: Trained AI/ML model tuned for the target weed species based on collected dataset			
Deliverable: Spot treatment export map file compatible with chosen UAS spray drone platform			
Deliverable: Written Guidelines and Best Practices based on final sensors and UAS platform used for data collection			
Deliverable: Project Summary Report			
Deliverable: Implementation Report			
Deliverable: Final Presentation			
Total (excluding F&A @47%):	**$131,084**	**$23,285**	**$154,351**

Table 6: State Fiscal Year (SFY) Breakdown

Item	State Fiscal Year (SFY)		Total Cost
	2026	2027	
Salaries	$43,683	$45,212	$88,895
Benefits	$20,942	$21,510	$42,452
In State Travel	$11,470	$11,815	$23,285
Capital Equipment	$37,000	$0	$37,000
Hardware, Software, and Expendable Supplies	$7,500	$6,000	$13,500
Total Direct Costs	$120,595	$84,537	$205,132
Indirect Cost – 47%	$39,290	$39,732	$79,022
Total Project Cost:	**$159,885**	**$124,269**	**$284,154**

Table 7: Project Staffing

Name of Principal, Professional, Employee, or Support Classification	Role in Study	Task 1	Task 2	Task 3	Task 4	Total	Percent of Time vs. Total Project Hours (total hrs./person/total project hrs.)	Percent of Time - Annual Basis (total hours/ person/2080 hr.)
Josh Kornoff	PI	87	303	87	43	520	51%	25%
Bart Bauer	Pilot & GIS	49	169	49	24	291	29%	14%
Jessica Mitchell	Spatial Analysis	35	121	35	17	208	20%	10%
Total		171	593	171	84	1,019		

XII. Personnel and Team Qualifications

The research team will comprise experienced professionals with expertise directly relevant to the project's success. Key personnel roles include:

Josh Kornoff, Principal Investigator: Extensive experience in managing complex research and product development projects, particularly those involving the integration of UAS, remote sensing, and other advanced technologies. His background includes a strong understanding of UAS operations, sensor technology, and AI/ML applications, ensuring effective project leadership and coordination. Mr. Kornoff will be responsible for overall project delivery, budget management, and maintaining effective communication with MDT.

Bart Bauer, AASO Associate Director: Will lead the remote sensing and data analysis efforts, contributing his expertise in processing and analyzing geospatial data. His qualifications include specialization in big data analytics, drone operations and piloting, and GIS, with a focus on developing efficient image processing workflows. Mr. Bauer’s skills in spatial statistics, time-series analysis, and complex analytics will be crucial for extracting meaningful information from the UAS-acquired data.

Jessica Mitchell, Weed Science and Ground Truth Coordinator: Dr. Mitchell serves as Director of the Spatial Analysis Lab at University of Montana and brings expertise in remote sensing of invasive species. Her MS in GIScience at Idaho State University (ISU) focused on sensor comparisons and subpixel unmixing for leafy spurge detection. Her PhD in Engineering and Applied Science and Post Doctoral work with Idaho National Lab included hyperspectral predictions of canopy chemistry using field, UAS and airborne spectroscopy. More recently, Mitchell has led five years of field sampling campaigns throughout Montana to survey the extent of *Ventenata dubia* invasion for Federal land managers and leads a team of image analysts who are optimizing machine learning workflows for VEDU invasion and monitoring (e.g. Random Forest, Convoluted Neural Networks, Support Vector machine). Her work in scaling vegetation structure, canopy chemistry, and biodiversity variables will directly inform the ground truth data collection and analysis.

XIII. Facilities and Equipment

The research will require access to:

University of Montana Office and Lab Space: For project management, data analysis, AI/ML model development, and reporting. This includes a UAS and sensor integration workshop.

University of Montana High-Performance Computing (HPC): Access to significant computational power or cloud resources will be necessary for processing large volumes of high-resolution UAS imagery and training complex AI/ML models. An additional high performance desktop computer will be required to perform local ML model development and setup prior to running large inference tasks on the HPC.

Additionally, 3rd party SAAS subscription software tools will be required to organize, annotate, and train various models quickly during initial development for later inference on the HPC.

Montana Department of Transportation Field Test Sites: Selected MDT ROW locations that represent the challenging terrain and weed infestations targeted by the project, specifically including areas with Scotch broom and rush skeletonweed.

University of Montana UAS and Sensors: The project will use various existing UM UAS and sensor (RGB, multispectral/hyperspectral). Some sensors will require periodic maintenance and calibration throughout the course of the project.

The Autonomous Aerial Systems Office (AASO) at the University of Montana maintains several models of RGB, multispectral (5-band, 10-band), and a 400 - 1000 nm hyperspectral sensor. Other sensors exist across the broader university ecosystem in Montana that could be available for this research.

Additionally, AASO operates a fleet of small and medium-sized drones suitable for deploying these types of sensors. This fleet offers a solid baseline for evaluating performance, operational simplicity, and cost-effectiveness in a research context.

University of Montana Support Equipment: Batteries, charging stations, data storage devices, ground truth collection tools (e.g., GPS units, cameras, spectral measurement devices if needed), safety equipment, and potentially, vehicles for transportation. We will require internet connectivity at all remote test sites and will subscribe to Starlink on a month-to-month basis during the data capture season.

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I. Addendum 1

Response to Technical Panel Review

This document addresses the comments provided by the MDT technical panel. Responses are outlined below.

1. Cost-Benefit Analysis

- Panel Comment: It would be good if a cost breakdown could be made available to MDT as part of the final report or cost-benefit analysis to include estimates for: AI computing costs, Storage costs, Collection activity costs.
- Response: A detailed cost-benefit analysis will be a key deliverable in the final report. This analysis will include specific, itemized estimates for all projected costs, including:
  - AI Computing Costs: Costs associated with the cloud-based or local processing required to train and run the AI detection models as well as estimates for personnel costs to label new training datasets for classification.
  - Data Storage Costs: Costs for the secure, long-term storage of the high-resolution imagery and associated training datasets.
  - Data Collection Activity Costs: Operational costs related to field data acquisition, including personnel, travel, and equipment maintenance.
  - Additional Costs: Spatial/ESRI processing costs.

2. Data Management & Preservation

- Panel Comment: Details will need to be determined for the data exchange from/to MDT... At completion of the research project, AI model training images and other training data should be preserved and made available to MDT to ensure MDT's investment continues to yield value.
- Response: The researchers will develop a comprehensive Data Management Plan (DMP) in direct collaboration with MDT. This DMP will define:
  - Data Inventory: A full catalog of all data to be collected.
  - Data Exchange Protocol: The specific formats (e.g., GIS-ready shapefiles, GeoTIFFs), access requirements, and secure transfer methods for all data.
  - Data Archiving: At the conclusion of the project, all raw imagery, labeled training data, and the final trained AI models will be delivered to MDT in an organized and accessible format. This ensures MDT retains full ownership and can leverage this foundational work for future research and operational use.

3. "Good Neighbor" Policy & Scope

- Panel Comment: *Emphasis on lands adjacent to transportation corridors... MDT being a good neighbor... stopping the spread of high priority weeds... from moving along or out of our right of ways into new areas.*
- Response: We believe the panel raises a critical point regarding MDT's role as a "good neighbor" and the importance of preventing the spread of invasive species from transportation corridors. We agree wholeheartedly with this principle. The most effective way this project can support that role is by ensuring the MDT right-of-way (ROW) is managed with maximum efficiency, preventing it from becoming a source of infestation for adjacent lands. Therefore, our approach is defined as follows:
- Scope and Focus: Our project's data collection and the direct application of the AI tool will be focused exclusively within the MDT-managed ROW. Direct survey or management activities on adjacent, often privately-owned, lands fall outside the legal and logistical scope of this specific project.
- Achieving the "Good Neighbor" Goal: We will amend the proposal to state explicitly that the project's primary goal is to transform the ROW from a potential vector into a well-monitored buffer zone. By creating a highly accurate tool to detect invaders like rush skeletonweed *early and effectively within the corridor*, we empower MDT to control these threats before they can spread to neighboring agricultural and wildlands.
- Collaborative Vision: The ultimate value of this work is creating a tool and a dataset that can be shared. We envision the AI model and the resulting data serving as a valuable resource for collaborative efforts with county weed districts and other agencies. This provides them with critical intelligence on threats emerging from the transportation corridor, allowing for a more coordinated, statewide response.

4. AI Model Accuracy Target

- Panel Comment: Is this [80% accuracy] high enough when we're talking about an early invader? ...Technical panel discussed this and agreed that 80% was a good target to aim for... I am hoping this is much higher in the end.
- Response: The 80% figure represents an initial project goal. Setting a realistic goal like this is a key part of developing a useful model and avoiding the common pitfall of "overfitting," where a model can achieve deceptively high accuracy on its training data but fails to perform well in the real world. While we share the panel's hope for higher accuracy, particularly for high-priority species like rush skeletonweed, the final report will document the specific accuracy achieved for each target weed.
- To ensure this accuracy metric is robust, the final model's performance will be assessed using an independent validation dataset. This is a final test using a completely new set of ground-truth data collected after the model has been trained. This method provides the most realistic measure of how the model will perform in new, real-world operational conditions, rather than relying solely on error metrics generated from the initial training data.

5. Nomenclature and Formatting

- Panel Comment: Throughout, for clarity and uniformity, I recommend italicizing all scientific names and capitalizing only the proper nouns in the common name... Two different species - need to include both common and scientific names for these 2 plants.
- Response: The entire document will be reviewed and updated to meet these standards for clarity and scientific accuracy. All scientific names will be italicized, and common names will be formatted as requested. We will explicitly add both the common and scientific names for European common reed (P*hragmites australis ssp. australis*) and the other relevant reed species to eliminate ambiguity.

6. Figure and Table Corrections

- Panel Comment: Should Table 6 say FY26 and 27 (instead of 24 and 25)? ... Figure 2 shows the Scotch broom observation maps again, not rush skeletonweed.
- Response: These corrections will be made. Table 6 will be updated to reflect FY26 and FY27. Figure 2 will be replaced with the correct observation map for rush skeletonweed.

7. Analysis of Misidentified Species

- Panel Comment: Will we learn what species, if any, are commonly misidentified as the target weed?
- Response: This is an important part of the AI model validation process. The final report will include an analysis, often called a "confusion matrix," that details which non-target plant species are most commonly misidentified by the classification model as the target weed. This information is valuable for understanding the model's limitations and for guiding future surveyor training and model improvements.