FISHERY RESEARCH

ESTABLISHING SAFE, EFFECTIVE, AND EFFICIENT UNPILOTED AIRCRAFT SYSTEM (UAS) PROTOCOLS FOR REDD DETECTION IN IDAHO RIVERS

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Idaho Fish and Game, Boise

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ABBREVIATIONS AND ACRONYMS

UAS – Unpiloted Aircraft System
IDFG – Idaho Department of Fish and Game
VTOL – Vertical Takeoff and Landing
EMS – Electromagnetic Spectrum
RGB – Red, Green, Blue; typically used when referring to the visible light wavelengths
UV – Ultraviolet
IR – Infrared
DEM – Digital Elevation Model
LiDAR – Light Detection and Ranging
GSD – Ground Sampling Distance
SfM – Structure from Motion
RPIC- Remote Pilot in Command
ND – Neutral Density
CPL – Circular Polarized Filter
DoD – Department of Defense
AGL – Above Ground Level

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ABSTRACT

Unpiloted aircraft systems (UAS, or drones) are an emergent technology in environmental monitoring. In salmon-bearing streams, resource agencies commonly survey salmon nests (termed redds) for estimating salmon populations. Idaho Department of Fish and Game (IDFG) employs UAS to conduct redd surveys in remote areas as an alternative to time-intensive ground surveys or expensive/risky helicopter surveys. The goal of this report is to review UAS systems (the UAS and their sensors) to improve understanding of the technology to help create cost efficient workflows for redd monitoring. We provide a case study comparison of current UAS methods employed by IDFG with newer technology and an upgraded workflow. The study illustrates how rapid technological changes in sensors, UAS, and software (mission planning and data analysis) can influence UAS methods to improve efficiency and accuracy in aerial redd surveys. As with any emergent technology, methods often change rapidly, and this report is a point in time review of the current methods and suggested improvements. We suggest that protocols be updated frequently to maintain safe and cost-efficient methods. Further, pertinent protocols should be in place to allow those new to the field of remote sensing to design and implement UAS operations for redd detection.

INTRODUCTION

The use of unpiloted aircraft systems (UAS, drones) has rapidly increased in ecological research during the last decade. Applications have increased due to the ability of the UAS platform to cover large areas and carry multiple sensor types. For example, in aquatic environments UAS have been used to evaluate habitat, identify species, and locate human fishing activity (Harris et al. 2019; Kopaska 2014; Provost et al. 2020), map large woody debris (Liang et al. 2022; Sanhueza et al. 2022; Spreitzer et al. 2020), evaluate geomorphic and vegetation changes after dam removal (Evans et al. 2022), quantify variability and biomass of riparian corridors (Matese et al. 2021; Resop et al. 2021), and count salmon redds (Auerbach and Fremier 2023). Most of the literature from UAS-based research is to develop methods, but some studies used UAS surveys to answer ecological questions and for environmental monitoring.

One potential application of UAS in environmental monitoring is to count salmon redds. Appropriate use of a UAS could provide a more cost-effective method than ground surveys and reduce the use of expensive helicopter surveys in remote areas (Groves et al. 2016; Auerbach and Fremier 2023). Redd counts are a metric of population size of reproductive adult salmon in a section of stream. Trained technicians either walk a stream or river or fly in helicopters to identify and enumerate redds. Although subject to observation error, these counts provide estimates of spawning escapement in a logistically feasible manner. However, redd counts still have inherent uncertainty. Multiple peer-reviewed papers have indicated bias in field counts based on observer and environmental factors (Dunham et al. 2001; Howell and Sankovich 2012; Muhlfeld et al. 2006; Murdoch et al. 2019). Helicopter surveys, and to a lesser extent ground surveys, involve risk to the observers, whereas drone flights pose less danger. Redd surveys as currently conducted typically require 1-2 observers to identify the redd through visual cues, and therefore, it is difficult to estimate variability among observers over time. The use of UAS is emerging as a potential alternative to traditional redd counting methods, because they are less intrusive to the study organism and safer for the surveyors. Furthermore, identifications can be cross validated by multiple observers by viewing archived images. While validation of redds still remains an issue, UAS provide an alternative method for redd counting, particularly when redds are densely positioned or when long distances need to be covered in remote locations.

The Idaho Department of Fish and Game (IDFG) has begun to use UAS to reduce risk and increase efficiency compared to other survey techniques (Copeland et al. 2019). Groves et al. (2016) flew UAS in the Hells Canyon reach of the Snake River and found that UAS can successfully identify redds and determined that counts were as accurate as those obtained from helicopter surveys. Additionally, IDFG has begun to use UAS in spawning areas where walking surveys require significant travel distances (e.g., 10-20 miles). In these surveys the UAS is flown down the centerline of the channel with imaging covering the width of the river. Biologists count redds after survey flights on individual images and not a single stitched image. Because UAS and image analysis software is rapidly advancing, survey protocols need to be revisited to determine the best practices for survey efficiency and obtaining clear images.

The goal of this report is to develop guidance for the use of UAS to conduct redd surveys beyond the initial summary given in Copeland et al. (2019). The following protocols and recommendations outline advancements in UAS technologies and considerations for updated flight procedures, which will increase efficiency while maintaining clarity during image acquisition. These recommendations are based on a study conducted during the summer 2022 in central Idaho. The study was a comparison of the current UAS operation and an upgraded operation with a research-grade UAS and supporting technology. The purpose of this report is to provide background information for UAS operations and to recommend a workflow for effective and efficient UAS flights for redd detection over longer distances (>5 km). This report covers general topics, such as UAS types and sensors, designing flight missions, data and analysis workflow, and recommendations for continuing UAS operations for redd counts.

UAS OPTIONS

The scale of the project and the sensor requirements determine the best UAS for the project. Different types of UAS can fly longer distances and carry different sensors. For the purposes of this document, we only consider commonly used research-grade UAS. This includes multirotor, fixed wing, fixed wing hybrid vertical takeoff and landing (VTOL), and small/micro UAS (Figure 1).

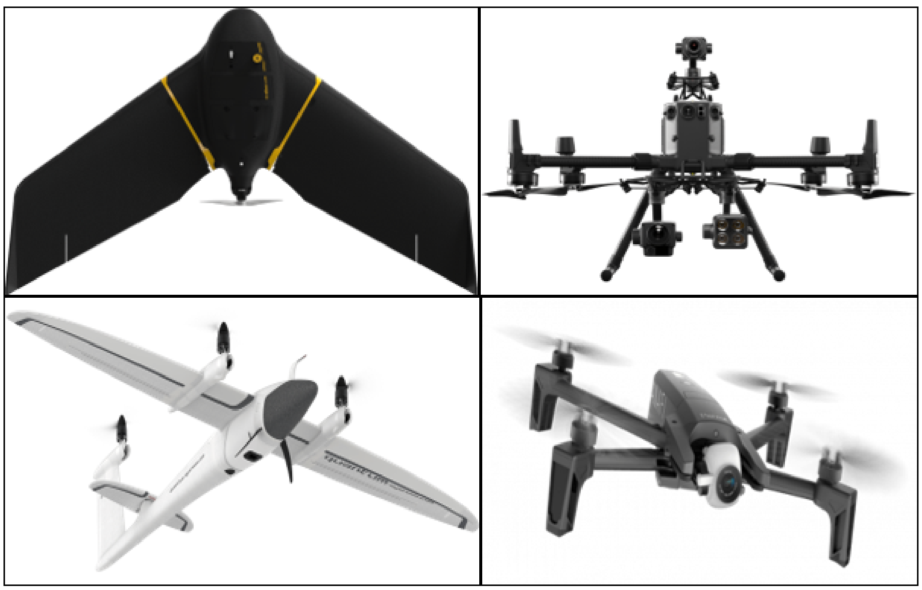

Figure 1. Four types of research-grade UAS. Top Left: Fixed wing. Top Right: Multirotor. Bottom Left: Fixed wing hybrid VTOL. Bottom Right: Small/Micro.

UAS Types

Multirotor UAS are the mostly commonly used research drone (e.g., the DJI Matrice 210, DJI Matrice 300 RTK, Yuneec H520 RTK, and many others). Multirotor UAS have 4-8+ propellors and cost from $5,000 to $75,000 depending on the company and sensor package. The benefit of multirotor UAS is increased stability and maneuverability, vertical take-off and landing, and ability to carry multiple sensors and heavier payloads (i.e., the weight it can carry). A higher payload UAS can support a larger array of project types. Drawbacks include high energy usage coupled with limited battery capacity, which restricts their range.

Small/micro UAS are also multirotor (typically consisting of only four propellers) and are most common for recreational pilots. They have a fixed sensor and typically have a shorter battery life with a more limited range of operation compared to larger multirotor UAS. Given advances in camera and drone technology, small “hobby” UAS can still carry high resolution sensors and produce high quality datasets, such as orthorectified images and topography using a structure from motion (SfM) algorithm. These small/micro UAS are typically lower in cost ($500 to $5,000) and some can carry dual sensors, e.g., in visible light and infrared spectra. Small/micro UAS are limiting for large projects and for projects that require use of multiple sensors. This constraint is particularly important when UAS are purchased to support multiple projects and not a single-use case.

Fixed-wing UAS function similar to airplanes and do not take off vertically. Fixed-wing UAS can cover long distances because of lower energy consumption with flight times up to two hours; yet, research-grade fixed-wing UAS are typically small and cannot carry multiple sensors. They are typically used in long distance/large area applications, such as agricultural or forestry settings. Fixed-wing UAS require a greater area for takeoff and landing, and training is necessary for safe flying. Commercially available research-grade fixed-wing UAS have a comparable cost to multirotor UAS, ranging from $30,000 to $99,000.

Hybrid VTOL UAS combine the capabilities of multirotor and fixed wing UAS. The VTOL UAS utilize the best traits of research UAS and can take off and land in compromised areas while covering large extents, because they can take off, land, and hover, but also convert to a fixed-wing state when flying longer distances. Currently, VTOLs are still in development, with few available and generally quite costly. Of all drone types, VTOLs are the newest, and technological improvements are needed to lower the price and make them more effective at data acquisition.

Sensors

Specialized sensors are needed to collect environmental data that can be linked to the flight data (altitude, time, etc.) that the UAS collects and stores. The UAS payload determines the type of sensors it can support. Ecological applications with UAS typically use either passive sensors (receive reflection only) or active sensors (emits and receives pulses of light). We do not address sonar and radar (both active sensors) in this document, because they are not commonly used.

How Sensors Work

Sensors mounted to the UAS collect the environmental data of interest. To understand sensor-collected data, we need to understand the basics of the electromagnetic spectrum. All sensors receive some kind of electromagnetic radiation. This radiation is measured in wavelength (m) and energy (eV), where a smaller wavelength has increased energy and vice versa (Figure 2). The human eye can only see in the visible light spectrum, ranging from 400 to 700 nm containing blue (~400-500 nm), green (~500-600 nm), and red (~600-700 nm); hence, this sensor type is often called an RGB sensor. Specialized sensors have the ability to capture wavelengths outside of the visible spectrum, such as infrared (75nm – 1mm). Depending on the sensor, a filter is applied to isolate the energy intensities at different bands of wavelengths. The intensity readings at a single or multiple bands of wavelengths are the recorded data used for analysis.

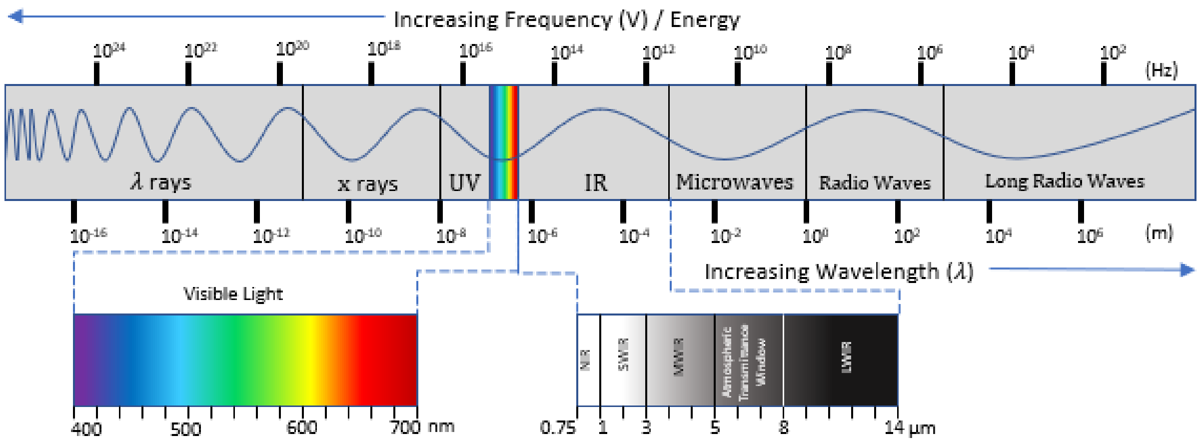

Figure 2. Schematic of the electromagnetic spectrum. Humans can only see in the visible light wavelengths (400-700 nm), whereas some sensors can detect radiation outside of visible light, most commonly in the infrared (IR) but also the ultraviolet (UV) wavelengths.

Passive versus Active Sensors

There are two main general types of sensors deployed on UAS – passive and active. Passive sensors capture reflected energy from an object. Most passive sensors collect reflected light in the RGB light spectrum. However, sensor range may be extended into the ultraviolet (UV) or infrared (IR) wavelengths. An active sensor emits its own energy and then records the time or phase change that occurs after being reflected back from the receiving surface. The easiest way to think of this mechanism is with a handheld camera. When the sun is out, the flash is not used. This is a passive sensor because it is only capturing the reflected energy from the sun. If it was dark, a flash would be used to illuminate an object. The sensor is now active as it is both emitting light and measuring the reflection. Two common active sensors use lasers as their light source.

A common color camera captures images using the visible light spectrum (Figure 3a), and this is the most common sensor on UAS. An RGB sensor can be used for visual surveys such as redd detection, fish detection, and habitat evaluation, among others. Most RGB sensors can also be used for orthorectified images and digital elevation models (DEM) from SfM (the creation of 3D structures from overlapping 2D images). An RGB sensor can be coupled with a neutral-density (ND) polarizing filter (which reduces the total amount of incoming light regardless of rotation) or circular polarized lens (CPL) to limit glare and enhance color within images (Appendix A). Both filters work by allowing wavelengths to enter only in a specific direction, which can be altered by rotating the filter. A CPL has a quarter waveplate behind the polarizing filter that rotates the polarizing state (Bentley 2019). A CPL is preferred as it helps reduce glare from light that was previously polarized from a non-metallic object. The quarter wave-plate converts the light into a form that is more suitable for auto-exposure and auto-focus systems (Steiner 2019).

Multispectral and hyperspectral sensors utilize optical filters to capture precise bands of wavelengths (e.g., 400-500 nm). Multispectral sensors typically collect three to ten bands within the RGB to IR wavelengths (Figure 3b). Multispectral sensors are common in vegetation studies, particularly in agricultural applications, but are also being used in plant ecology for estimating plant health and community structure (e.g., Hall and Lara 2022). There are many ecological applications with these wavelengths.

Hyperspectral sensors are less common and far more expensive than multispectral sensors. They can record hundreds of smaller bands or individual wavelengths (Figure 3c). Hyperspectral sensors are used when data from a singular band, containing a small portion of the wavelength, are needed for analysis. Because hyperspectral sensors are capturing tens to hundreds of bands as compared to RGB and multispectral sensors, data storage and analysis require more sophisticated methods. Furthermore, hyperspectral sensors for UAS are less common.

Figure 3. Three examples of sensor spectra: (a) RGB. (b) Multispectral. (c) Hyperspectral.

The most commonly used active sensor on UAS is a light detection and ranging (LiDAR) sensor. A LiDAR sensor actively emits laser pulses and either records the time for the emitted light to return back to the sensor or the phase change in the wavelength that occurs after it returns. There are two common LiDAR sensors used, terrestrial and bathymetric. Terrestrial LiDAR uses infrared lasers to map elevation or topography, while bathymetric LiDAR uses lasers in the green spectrum that penetrate deeper into water and therefore can be used for bathymetric surveys.

FACTORS INFLUENCING UAS SELECTION

Multiple factors influence UAS and sensor selection. The choice requires balancing single- and multiple-project applications, sensor type and UAS needs, budget, and potential restrictions on certain UAS manufacturers. Typically, UAS and sensors are purchased for data collection across multiple projects, which will affect selection criteria for individual projects. We provide five questions to guide the choice.

1. What is the scale of the project?

There are two considerations with project scale: survey time and survey extent. Survey time refers to the frequency of flights and the flight time to adequately cover the project area. Single-flight projects may not require UAS purchase because contracting with a specialty remote-sensing company will likely be more cost-efficient. Developing the in-house equipment and expertise is likely more cost-efficient for projects that are long term, contain complex analysis, and have a high frequency of flights.

The extent of the survey area directly influences the type of UAS. For example, multirotor drones are more appropriate for small, forested areas while fixed wings and hybrid VTOL UAS are better for large area surveys with clearly defined locations for take-off and landing. If survey areas are constantly changing and the takeoff/landing locations are unknown, a multirotor UAS would be the most beneficial as it allows more flexibility and needs less space for takeoff and landing.

2. What sensor data are required?

The most common sensor installed on a UAS is an RGB camera. For this reason, many small UAS, as well as some research-grade UAS, only support carrying a single fixed sensor. More sophisticated data collection and analysis will require different sensors and likely a larger, research-oriented UAS. Many research groups purchase higher payload drones that can carry multiple sensors and/or different sensors to be able to collect data for a wider array of analyses.

The extent and grain of the data needed for projects directly influences sensor selection. Most use cases in ecological research use RGB cameras that contain 24 million pixels per image (6000 x 4000), i.e., 24 mega-pixels (MP). This is cost efficient for small – low grain, low extent – projects. However, with 48-MP sensors, projects can significantly reduce flight times because fewer images taken at higher altitudes with such a camera will retain the same image resolution as those from a 24-MP sensor.

3. How compatible is the UAS/company with third party software?

Selecting a UAS may be straight-forward for individual use cases, but pre-flight and data analysis software must also be part of the investment decision. Mission planning and data software tools are essential and can be costly. Moreover, if the software around UAS uses is not integrated, then there can be considerable financial costs for manipulating and transferring data. By integrated, we mean that third-party mission planning software is compatible with the UAS. If the software is not integrated, it will require greater technical understanding and expertise to fly the UAS to effectively meet survey objectives. Research-grade UAS often now include mission planning and initial data analysis software. Software functionalities need to be considered in UAS platform purchases.

4. What is the total cost of UAS equipment?

Base UAS and sensor costs increase with payload and versatility. Other cost considerations include software, controllers, and batteries. See Table 1 for an example summary for currently available UAS, their specifications and costs. Depending on the UAS, battery costs could be upwards of $700 per battery (Matrice 300 RTK). Multiple batteries and battery chargers will be needed for larger projects. Many fixed-wing UAS require a laptop or tablet for mission flights. Datasets can be large, and post-survey image processing can require a lot of power from computers, thus computer upgrades may be needed. Make sure to create a full list of all potential items needed for planning, implementation, and analysis prior to purchasing.

5. Is the UAS approved to fly over U.S. government land?

The rules and regulations of UAS use must be considered (Appendix B). The federal government has highlighted security concern for certain overseas UAS manufacturers. This may ultimately lead to a ban on UAS flights over government or privately-owned land. Most notably, UAS manufacturer DJI (China) was blacklisted and banned from use by government employees in 2022. While consumers can still purchase DJI-manufactured UAS, servicing and flight authorizations for them may be more challenging in the future. This ban also prohibits flights over government-owned land, which may also apply to state and private land. Future sanctions may further limit purchases to public consumers in the US.

Table 1. Comparison of different UAS specifications and cost estimates from the manufacturer's website (2022). Flight time is in minutes. The effective pixels (in MP) are for the fixed sensor except for the Matrice 300 RTK and Yuneec H850 RTK. CMOS-complementary metal oxide semiconductor. Costs are estimates from 2022.

UAS Model	Country of Origin	Maximum Flight Time	Effective Pixels	Sensor Type	Drone Cost	Battery Cost
DJI Mavic 3	China	46	20	4/3 CMOS	$2,049	$209
DJI Mavic 3E	China	45	20	4/3 CMOS	$3,810	$209
DJI Mavic 3T	China	45	48	1/2-inch CMOS	$5,780	$209
Matrice 300 RTK	China	55	45	Full Frame	$13,700	$700
Parrot ANAFI AI	USA	32	48	1/6 inch	$4,000	$399
Yuneec H850 RTK	China	65	20	1-inch CMOS	$7,399	$730
Autel EVO II Pro RTK	USA	36	20	1-inch CMOS	$3,289	$199

The case of DJI is the most notable due to the company's notoriety in the UAS world, but similar sanctions could be passed down on any UAS manufacturer. The Department of Defense (DoD) has created a Blue UAS cleared list (Blue List), which are DoD-approved UAS that have gone through a rigorous clearance process and can be purchased and operated by government employees. The updated list can be found at https://www.diu.mil/blue-uas-cleared-list. Just because a specific UAS is not on the Blue List does not mean it cannot be purchased or flown within the U.S. Unapproved UAS can still be purchased and flown in many instances but may need to go through a separate approval process to be flown on specified lands. If the operator knows the UAS will be flown over government lands, it is best practice to refer to the Blue List prior to UAS purchase to make the flight authorization process easier.

DESIGNING FLIGHT MISSIONS

All UAS studies require proper mission planning to attain survey objectives while meeting logistical and legal requirements. It is important to preplan missions to ensure accurate data collection. Considerations include sensor position, image overlap, and consistency (especially in cases of repeated surveys). Mission-planning software helps researchers balance research objectives with flight constraints (e.g., flight time). In this section, we discuss planning software, the elements of flight planning, and the value of pre-mission reconnaissance. This section provides a broad overview of each topic and differs from the Workflow section, which gives safety and legal considerations that are more specific to redd surveys.

Mission-Planning Software

Mission-planning software supports effective and repeatable missions. The software semi-automates the process of mission planning and is customized to the UAS system. Freeware are available but many times are not integrated well, which will require further learning. Customized mission-planning software can be expensive and still require learning, depending on the complexity of the mission.

Certain UAS manufacturers provide their own mission-planning software. For instance, Yuneec's mission planning software is DataPilot, which is available as a controller app for onsite mission creation and as a desktop application for preplanned missions. The DJI company has a drone planning software called DJI GS Pro, which is free for certain UAS models and pay-to-play for others.

Post-survey image processing software should be considered in UAS purchase because some UAS packages include one or the other (mission planning or post processing), and some include both. Post-processing software includes tools to stitch images and analyze data. We will cover post-processing software in its own section.

Mission Environment

The survey environment affects mission efficacy and safety. The flight direction and hour of the day interact with the angle of sun to affect subsurface visibility of the streambed via glare and shadows (Appendix A). For example, Thurow (2010) recommends redd surveys should be done between 0930 and 1800 hours for best visibility of redds on the streambed. For safe and consistent UAS operations, missions should be planned with three safety considerations in mind: land, obstacles, and signal.

Land refers to the ownership of land surrounding the area being surveyed. This includes public, state, or federally owned land, but in some cases adjacent private land. For example, while surveying rivers it is likely that images will contain portions of land, or the UAS will fly over land. To avoid conflict, it is best to contact landowners, so they are aware flights are taking place, even if the mission is technically not over private land. For this reason, it important to know land ownership to obtain necessary flight permits. Flights can be adjusted to avoid areas where ownership is an issue, if necessary.

The second consideration is avoidance of obstacles. Obstacles may be physical (e.g., tall trees and power lines), legal (e.g., fire closures), or impediments to detection and measurement (e.g., glare and shadows). A key aspect of mission design is ensuring that the object of the mission, in this case redds on a streambed, can be viewed within the imagery. Ideally, the mission flight is at a low altitude to increase resolution, but this can pose problems with obstacle avoidance. To ensure safe mission execution, the length of the survey should either be manually flown at a high altitude or driven to determine where obstacles are present and the safest altitude to avoid them. It is helpful to fly a reconnaissance flight to set the appropriate mission altitude.

Loss of signal between controller and UAS should be avoided. Many UAS have features that either return the UAS to the takeoff location or hover in place if the signal is lost. The two main factors contributing to signal loss are distance between UAS and operator and presence of obstacles, such as trees or topographic features. As with obstacle avoidance, a pre-mission evaluation of the entirety of the area to be flown should be done to determine locations where obstructions are present or where distance to the UAS may cause transmission interference. It is a Federal Aviation Administration (FAA) requirement to keep the UAS within line of sight; this is also important because in most cases, if you can see the UAS, you are able to keep transmission between the UAS and operator.

Flight Path Type

Surveys use four primary flight paths. The first type is a continuous linear flight path which can be used to survey things such as coastlines and rivers (Figure 4a). Linear flight paths take less time and are effective in studies where stitching and orthorectified images may not be needed. If stitching of images is required, then a larger percentage of front-to-back image overlap needs to be considered in flight planning. If increased overlap is needed, it is best practice to decrease flight speeds to avoid image blurring. Linear flight paths may also be more intensive in mission planning, particularly when following a sinuous river channel. This means accurately and manually tracing (placing turn points) along the river corridor. In addition, given the changing sun angle, the camera angle (not the drone angle) should be adjusted to be parallel with the sun's azimuth to limit glare.

The second flight path is a series of flights between pre-set waypoints (Figure 4b). Waypoint missions are customizable both in flight path and camera adjustments. Often waypoint missions are used if camera adjustments need to be made in a point-by-point basis, or if flight paths do not follow a linear course. Depending on settings, waypoint flight paths take longer than linear flight paths because the UAS stops at each point to either capture an image or make an adjustment to the sensor or UAS. Waypoint flight paths are the most time consuming for the mission planner. For example, in surveying underwater features such as a redd, camera angle needs to be adjusted to limit sun glare (Appendix A). Here the sensor needs to be parallel to the sun's azimuth. This will require manually adjusting either the camera angle or drone angle at each waypoint along the flight path. Waypoint missions allow the operator to adjust some parameters at each waypoint but this flexibility comes with a tradeoff. For long, complicated flights, a waypoint mission is time consuming during mission planning as well as during flight time.

The third flight path is a called a grid flight (Figure 4c). Grid flights follow a systematic X and Y pattern of waypoints over a defined area (e.g., Harrison et al. 2020; Auerbach and Fremier 2023). The benefit of a grid flight path is simplicity and assurance of even aerial coverage. Typically, images taken would be stitched together to make a single, orthorectified image. An overlap of 75% side-to-side overlap and 75% front-to-back overlap should be used for the greatest accuracy. Keep in mind that increasing side-to-side overlap will increase the time of the mission. Back-to-front overlap does not increase flight time but may increase blur in images. Finally, mission alterations for glare are less time consuming as only the flight angle will need to be adjusted to maintain parallel flight to the sun's azimuth.

The fourth type of flight plan is called a cross or double grid (Figure 4d). A double grid uses the same principles as a normal grid but with a second grid being flown perpendicular to the direction of the first grid. This flight path is the longest of the missions per area, and a circular polarized lens (CPL) should be adjusted mid-flight. A double grid is typically used with SfM to create digital elevation models. The first flight is flown with an offset to the camera angle, with the second higher flight being done at or near nadir with the ground. These flights also collect a large amount of data, increasing processing times.

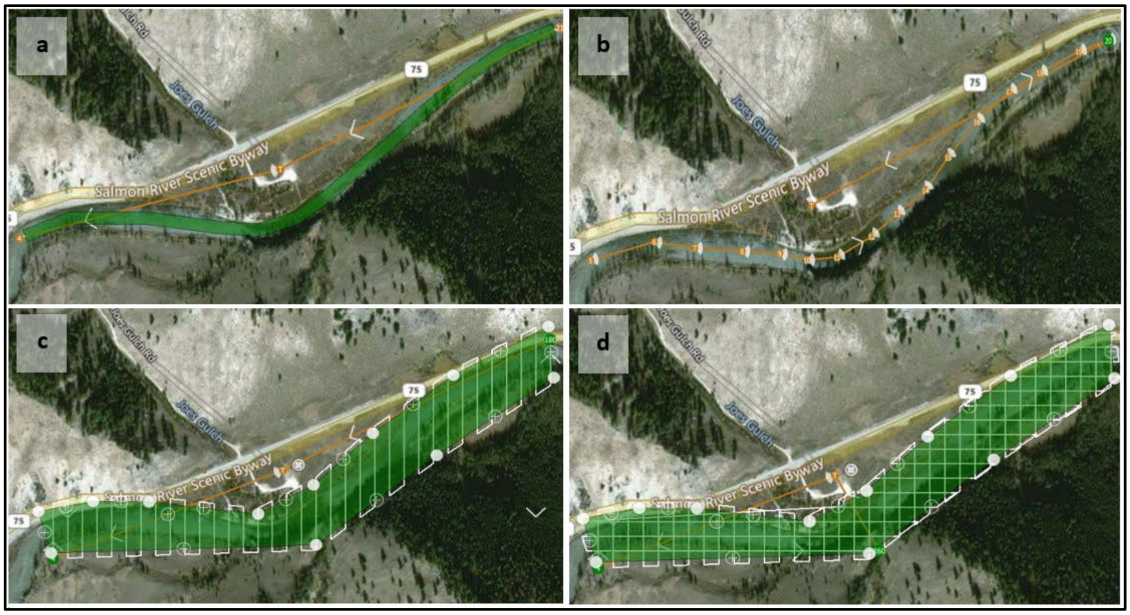

Figure 4. Four flight path types. (a) Linear flight path. (b) Waypoint flight path. (c) Grid flight path. (d) Cross-grid flight path. Flight path location is on the Salmon River just north of Lower Stanley, Idaho. Flight paths were designed using Yuneec's DataPilotPlanner (version 2.1.22).

Takeoff and Landing

The first step for a successful flight is locating the appropriate area to take off and land. Depending on the UAS being used (multirotor versus fixed wing), a larger area may be required. The UAS manufacturer's manual should specify the necessary area needed to ensure safe takeoff and landing. The flight range of the UAS may also dictate the takeoff and landing location. Selecting a location in the middle of a stream reach may make it easier to cover a longer distance while maintaining line of sight compared to one that is at the extreme of the reach. Often overlooked is the ability to move from the takeoff and landing location to maintain line of sight. This is particularly important in heavily forested areas or in areas where topographic gradients change drastically. A small clearing surrounded by trees or dense underbrush may be the only suitable location, but as soon as the UAS moves, the line of sight may be lost, and the ability to move to maintain line of sight may be unachievable. Such a location is not ideal for takeoffs and landings.

Altitude

Altitude affects flight times and image resolution, making altitude important for target identification. The target refers to the object of focus during a mission. This can be a singular object (e.g., a redd) or the entire river. Finally, obstacle avoidance and line of sight are considerations for a safe operating altitude. An increased altitude will avoid obstacles and may make visibility of the UAS greater.

The optimal altitude at which a flight is conducted is directly correlated to the survey distance and inversely related to the ground sampling distance (GSD). The GSD is the ground length of the individual pixels in the image (Appendix C). In most use cases, the mission GSD is determined based on the size of the object needing to be identified. The GSD is important for balancing image grain and extent with flight time. Higher altitude flights can survey longer distances with a larger instantaneous field of view but at decreased resolution. The opposite holds true for lower altitude flights. Below are key factors that must be considered when deciding the appropriate altitude to fly:

1. Flights must be below 400 ft (122 m). This is an FAA restriction.
2. The target must be clearly identified, for instance an object in a river (e.g., a redd).
3. Airspace must be identified (UAS flight restrictions may be in effect).
4. Obstacle clearance.
5. Line of sight to the operator and observer.

There are two types of FAA restrictions when it comes to altitude: ceiling height and airspace. The maximum ceiling height for drones is 400 ft (122 m) above ground level (AGL). Airspace, more specifically controlled airspace, refers to restricted areas that are necessary for air traffic control. Operators learn and are tested on airspace as part of the Part 107 certification (see Workflow section). Airspace classes A through E are all controlled in some capacity and, depending on the type, need clearance from the FAA and air traffic control to fly in. Class G is uncontrolled, but UAS operators must be aware of airplanes and helicopters in the vicinity. This is why an independent observer is required for each UAS mission.

Flight Speed

Flight speed choice is a tradeoff between flight logistics (airtime and battery life) and sensor function. If the flight speed is too slow, logistics will be limiting; whereas, if flight speed is too fast, the images will be blurry. There are two principal components to a camera that have an impact on image blur: aperture and shutter speed. The aperture is an adjustable lens that controls the amount of light entering the sensor. The shutter speed increases or decreases the time the aperture is open. So, shutter speed is the time that light is allowed to enter, and aperture is how much of that light enters. Both influence field of view and image quality. Best practice is to keep the camera on auto.

There is an additional complication to how image quality is affected by flight speed. We have all seen photographs of beautiful rivers where the water appears to be moving in the photo. Shutter speed allows photographers to either capture motion or freeze it. Generally speaking, in data collection, we want to freeze motion and capture as high a quality image as possible. What makes achieving good image quality difficult is we are capturing images of moving water from a moving UAS. To ensure clear images, shutter speed must remain high for most data collection events in rivers.

If we increase the flight speed, we increase the likelihood that images will become blurry, especially under low light conditions or with the use of a polarizing filter. These factors must be considered when designing flight plans and may need to be adjusted based on the prevailing environmental conditions. Further, many research-grade UAS will adjust speeds during mission creation. In instances when speeds are not automatically adjusted, it is advised to keep the suggested speed from the mission planning software. With improved sensors, it is recommended to keep the sensor on automatic so that adjustments will be made through the sensor rather than through flight parameters. It is also recommended that the focus is checked during a reconnaissance flight to make sure images are clear.

Overlap

Overlap refers to the percentage of an image that intersects with subsequent images in the front-to-back and side-to-side aspects (Figure 5). A safe overlap of 75% is recommended for successful stitching and orthorectification, with a minimum of 60% side-to-side and 75% of front-to-back. It is important to note that increasing side-to-side overlap will increase mission length. Side overlap only needs to be accounted for during grid and cross grid flight paths. Most mission-planning software packages have a front-to-back overlap adjustment for linear flight paths. This is an important feature to consider when selecting software. Special attention to overlap needs to be paid for waypoint flight paths as these are manually adjusted when waypoints are entered. In certain instances, the mission planning software can account for overlap between waypoints, but if each waypoint is dedicated for an image with no mission-planning assistance, missions may need to be flown and post-processed such that there is sufficient image overlap for stitching.

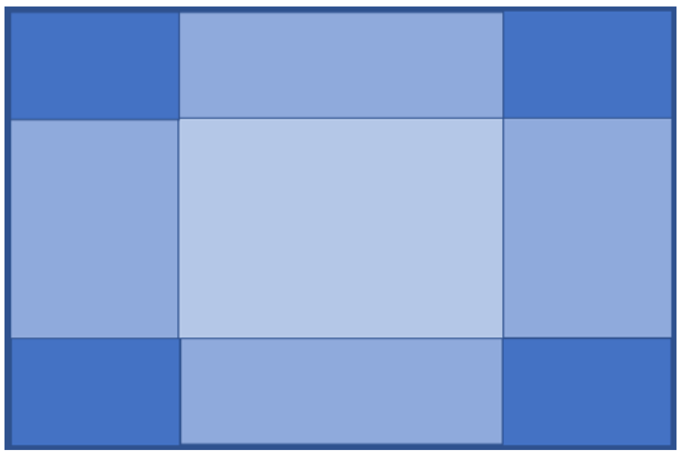

Figure 5. Schematic of an image with side-to-side and front-to-back overlap. The outer rectangle represents the focal image that overlaps eight surrounding images. The dark corners show areas where two other images overlap with the focal image. The light center represents an area with no overlap.

Turn Margin

Turn margin (often referred to as error margin) is an extension of the mission path when the UAS is turning (Figure 6). Turn margins are used to ensure the totality of the survey area is captured and that images within the focal area are not blurry. Increasing the turn margin will increase mission time but ensures clear images of the target area. Turn margins are only used in grid or cross-grid flight paths. Depending on the location of the mission and surrounding terrain and obstacles, turn margins may need to be adjusted (shortened) to avoid property or obstacles. In the case that turn margins need to be shortened but image clarity cannot be compromised, flight speeds will need to be adjusted. Images are still being taken within the turn margin, so an increased turn margin increases the total number of images.

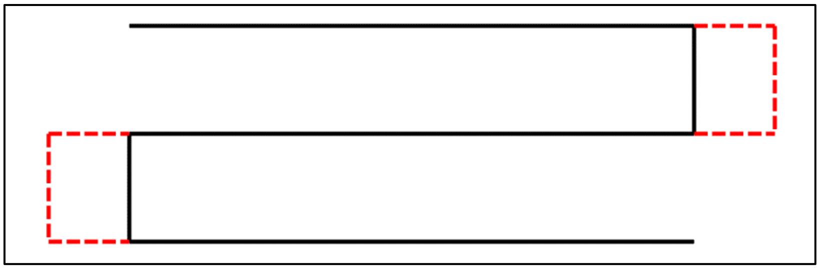

Figure 6. Example of a turn margin. The black lines are a grid pattern, the red dashed lines are the turn margins that extend beyond the designed flight plan.

Reconnaissance Flights

Once an area is selected for a UAS survey, it is a good idea to perform a reconnaissance flight. In areas where a suitable takeoff/landing location and optimal altitude is in question, a preliminary manual flight may be the best course of action to ensure a safe mission. The primary purpose of the reconnaissance flight is to determine the safest possible altitude for the mission, which clears the highest tree and avoids obstacles (such as powerlines). In areas with steep topography, a preliminary flight can be used to obtain a safe altitude in changing topography. Manually flying to the extent of line of sight from the operator location is necessary and useful when planning a mission. The mission can be modified, or the takeoff/landing location moved, to ensure line of sight is maintained throughout the entirety of the flight. Even on established UAS survey routes, reconnaissance flights can help optimize all elements of the flight plan (e.g., flight speed versus image blur), thus improving data quality and survey efficiency.

WORKFLOW

All missions must conform to the applicable rules and regulations (Appendix B). The following section describes an end-to-end workflow from obtaining the FAA Part 107 license to image stitching and storage, with a brief overview of analysis (Figure 7). This workflow is designed for redd surveys but may be broadly used for other research applications.

Part 107 Pilots License

To fly a UAS for research or commercial reasons, the FAA requires an individual to obtain a Remote Pilot Certificate. The certificate (often referred to as a Part 107 license) is earned by taking the FAA pilot license test at a physical testing facility (i.e., not online). The minimum requirements are below and can be found at https://www.faa.gov/uas/commercial_operators/become_a_drone_pilot:

- Be at least 16 years or older.
- Be able to read, speak, write, and understand English.
- Be in a physical and mental condition to safely fly a UAS.
- Pass the initial knowledge examination.

After passing the qualifying examination, the individual is considered a Remote Pilot in Command (RPIC). The RPIC can fly and oversee flight operations, which includes operation of UAS by non-licensed personnel in the RPIC's presence. A RPIC must have their certificate with them during all UAS operations. All RPIC's must undergo recurrent training within 24 calendar months.

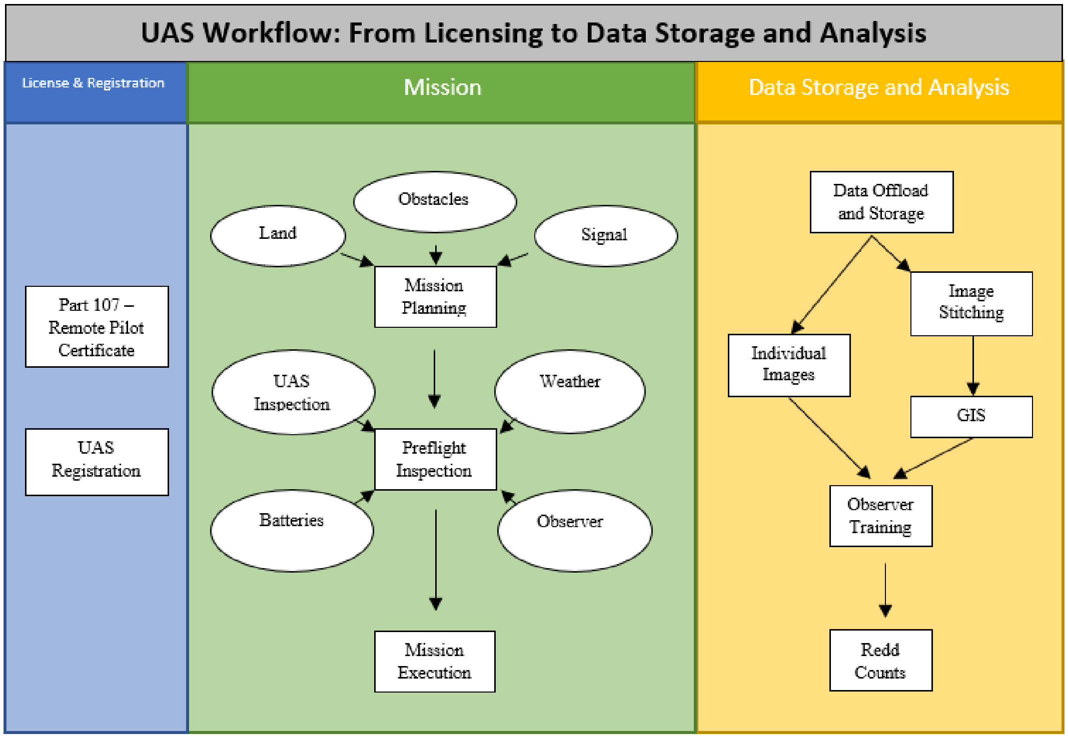

Figure 7. A broad workflow of steps taken to use a UAS for aerial redd surveys.

UAS Registration

The RPIC is responsible for registering all UAS being flown. The UAS registration is done at the FAADroneZone website (https://faadronezone-access.faa.gov/#/). As described by the FAA (https://www.faa.gov/uas/getting_started/register_drone), the following information is needed:

- Address (both physical and mailing).
- Email.
- Phone number.
- Make and model of drone.
- Remote identification number provided by manufacturer (if applicable).
- Form of payment.

Registration costs $5 for each drone and is valid for three years. Once registered, the UAS must be labeled with the registration number in a manner that is legible. The UAS must be reregistered after the three-year mark through FAADroneZone.

In the future, all UAS must comply with the FAA's new remote identification rules and regulations, which begin on September 16, 2023. Remote identification means the UAS broadcasts identification and location information during the flight. Remote identification improves safety, given the rapid increase in UAS use. It is up to the RPIC to adhere to regulations and to adjust the UAS to allow for remote identification. More information on remote identification can be found at: https://www.faa.gov/uas/getting_started/remote_id/drone_pilots.

Mission Planning

Missions are planned using the selected mission planning software, as detailed in the Designing Flight Missions section. After the flight mission plan is finalized, the software will display estimated flight time and expected number of batteries that will be needed. These numbers vary and should be used as a minimum for planning logistics, i.e., flight time may be longer and more batteries will be needed during the actual mission because of winds.

Preflight Inspection and Safety Meeting

Prior to flights taking place, multiple steps should be implemented in the field to ensure safe mission execution:

- Review of the preplanned mission.
- Weather brief (expected winds and visibility).
- Safety meeting. This is to review the mission as well as cover specific steps in case of an emergency. Plans should be in place for battery changes and other mission breaks.
- Check the number of available batteries and their charge levels.
- Preflight inspection of UAS. Typically, the manufacturer will provide a list of preflight inspection items, but if that it is not found, a suitable UAS-specific inspection protocol may be found online.

The purpose of these preflight steps is to provide a final check to ensure all equipment is in a safe flight state and that all individuals involved are comfortable with the mission proceeding under the prevailing conditions. If not, the mission should be postponed until it is safe to proceed.

Mission Execution

Missions are executed using the preplanned mission parameters, as detailed in the Designing Flight Missions section. During all missions, flight line of sight must be maintained to stay within FAA guidelines and to ensure constant and uninterrupted transmission between the drone and the controller. As stated above, plans should be in place for battery changes and other breaks.

Data Offload and Storage

After mission completion, images should be uploaded to the selected storage device as soon as practical. It is best practice to backup survey images to devices kept in multiple locations. A post-flight inspection and debrief should be done to ensure batteries are charged/discharged, images are stored, and the UAS is cleaned and inspected.

Maintenance

To ensure a longer lifespan and to avoid accidents, the UAS should go through maintenance per the manufacturer's recommendations. Inspection and cleaning should occur both pre- and post-flight (Table 2). If at any point during the inspection an item is found to be damaged or broken, it is best practice to either replace the part or cease flying until the item is fixed and in operable condition. If mission schedules are constraining, it is useful to have at least one backup drone available.

Table 2. Example of pre- and post-flight protocols to ensure safe practices and UAS longevity.

Preflight	Post-flight
Inspect structure for cracks	Clean drone/camera of dust and debris
Check for loose screws	Re-install gimbal protector
Check for loose wires	Inspect batteries for bulges, leaks, and dents
Check for propellor damage	If needed, discharge batteries before storage
Check that propellors are free spinning	
Check motors for obstructions	
Check camera unit	
Check landing gear	
Ensure gimbal protector (if equipped) is removed	
Inspect batteries for bulges, leaks, and dents	
Update drone/controller firmware	

Much like any vehicle, many UAS manufacturers recommend sending the UAS to a certified service provider or to the company after a certain number of flights or hours. Check the manufacturers website to determine what is recommended for your UAS.

Crashes

Unfortunately, crashes occur for various reasons. A report must be filed by the RPIC with the FAA within 10 days if the crash causes serious injury to a person or loss of consciousness or causes damages to property (other than to the UAS) in excess of $500. Regardless of the extent of damage, it is best practice to have protocols in place in case of a crash. These include knowing the property owners, having replacement parts, and understanding the obstacles to retrieval from the crash site. It is also highly encouraged (although not required by the FAA) to obtain liability insurance prior to UAS flights in case of accidents. There are a number of companies that offer UAS liability that is highly customizable.

Post-Survey Image Processing

After the field surveys are completed, the images must be exported, checked for quality, prepared, and properly archived before they are ready for analysis. Image preparation may include stitching images together and georeferencing them. The appropriate method for image preparation will depend on the image analysis method, which could be one of two types.

The first analysis type is looking at individual images in sequence, which is current IDFG practice. Images where redds are identified are isolated and moved to a separate folder where geotags are extracted and waypoints are created. Currently, two individuals count each set of images and then come together to verify redd identification (Copeland et al. 2019; Poole et al. 2022). The second method involves multiple steps. First, the images are stitched together to create an orthomosaic. This orthorectified image is then uploaded to a GIS software where individuals can place points or circle redds within the system. A verification process can still be used to verify redd calls and resolve observer discrepancies.

Observer training plays an essential role in redd identification. It is important for observers to understand how redds are formed, the characteristic features (e.g., substrate contrast, trenching, female guarding), how diagnostic features appear in a 2-dimensional image, and the enumeration process. For this reason, a standardized training protocol should be utilized to obtain the most accurate and precise counts. That is a complex topic beyond the scope of this report.

UAS COMPARISON CASE STUDY

Methods

We conducted a field study to understand how technological advancements impact survey efficiency by comparing the current UAS and workflow used by IDFG for redd counts (Copeland et al. 2019; Poole et al. 2022) to an upgraded UAS and the planning guidelines provided here, which were based on Auerbach and Fremier (2023). The study goal was to compare the time required to complete the full workflow under both scenarios. Time was recorded by mission phase to understand where efficiencies could be achieved.

We flew approximately 31 km of the Yankee Fork divided into two unequal sections, 25% of the total distance in the lower section and 75% of the total distance in the upper (Figure 8). The current UAS used by IDFG was the DJI Phantom 4 Pro quadcopter, released in 2016, with a fixed 20-MP, 1” CMOS sensor camera. The Phantom 4 Pro has a maximum flight time of 30 minutes and capabilities to withstand windspeeds of 10 m/s. The second UAS flown was DJI’s enterprise research drone released in 2020. The DJI Matrice 300 RTK quadcopter has a non-fixed 45-MP, 35.9 x 24 mm full frame sensor (P1). The Matrice 300 has a maximum wind resistance of 15 m/s with a maximum flight time of 55 minutes.

The flight line planned for the Matrice 300 RTK was based on the current mission plans used by IDFG for the Phantom 4 Pro (Table 3), with center of the line roughly following the center of the Yankee Fork. A major difference between the planned missions was the flight path type. Currently, IDFG uses a waypoint system, where the UAS flies to the waypoint, hovers, captures an image, and then moves to the next waypoint. The speed set in between each point was the maximum speed for the make and model, 33 m/s. The Matrice 300 RTK utilized a linear flight path, continuously flying and capturing images at 10 m/s. Both UAS obtained imagery of the river with an approximate image front-back overlap of 80%. Altitudes were standardized based on the GSD of the Phantom 4 at 1.26 cm/px (see Appendix C). Our evaluation focused on differences in time and resource use between the two missions, but we also made a qualitative check on image quality.

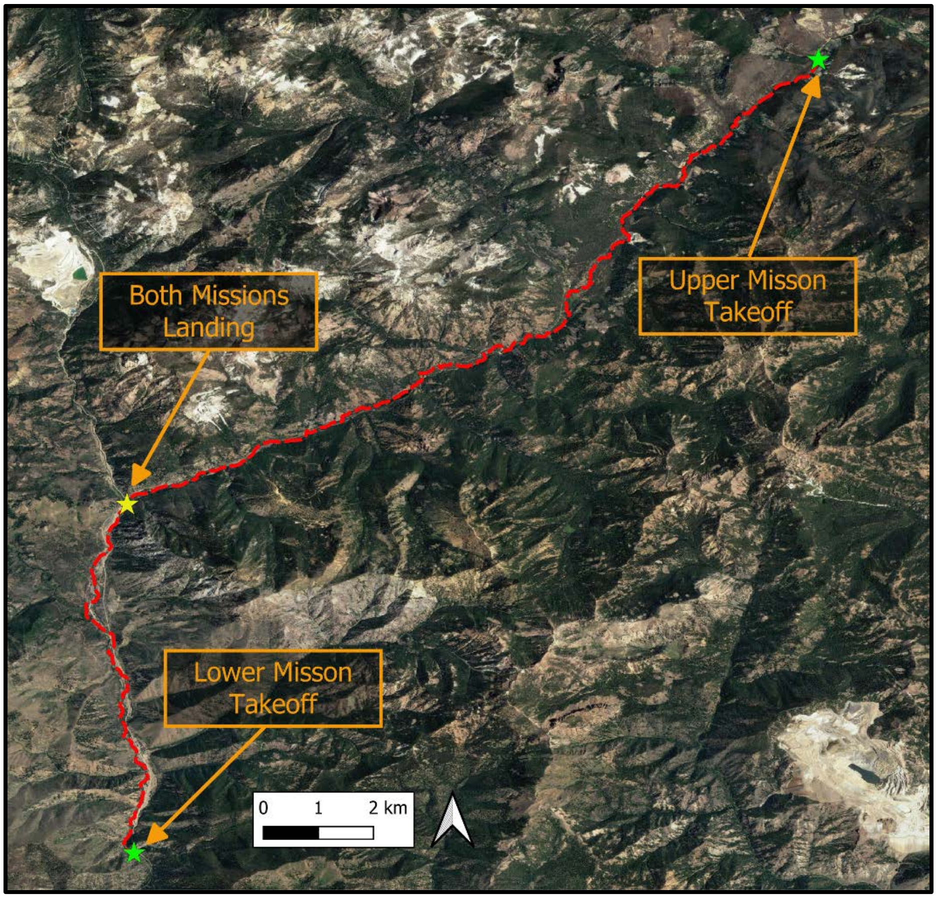

Figure 8. The flight path (red dashed line) of the Yankee Fork flown by both UAS. Two flight missions were used to encompass the entirety of the survey area. The take-off locations are indicated by the green stars and the landing location for both missions is indicated by the yellow star. Base map: Google Earth Satellite.

Table 3. Mission parameters used in the case study comparing current and upgraded UAS technology and workflow scenarios.

UAS	Flight Path	Overlap	Altitude	GSD
Phantom 4 Pro	Waypoint	80%	45-46 m	1.26 cm/px
Matrice 300 RTK	Linear	80%	100 m	1.26 cm/px

Results

The Matrice 300 RTK took more images despite being in the air less time than the Phantom 4 Pro (Table 4). The flight time and number of batteries used were the major differences between the two scenarios. It took nearly five times as long using four times the number of batteries for the Phantom 4 Pro to complete the image acquisition process as compared to the Matrice 300 RTK. Costs in terms of battery needs for flying the mission was about 10% less for the upgraded UAS, despite the much greater cost per battery of the Matrice 300 RTK. There was minimal blur between image sets.

Table 4. Comparison of flight performance between the DJI Phantom 4 Pro and the DJI Matrice 300 RTK. Parameters were number of images taken, flight time (minutes), number of batteries used, and costs for batteries. Costs per battery were $185 for the Phantom 4 Pro and $700 for the Matrice 300 RTK.

Drone/Flight	Images	Flight Time	Batteries	Cost
Phantom 4 Pro				
Upper Mission	2,261	286	9	$1,665
Lower Mission	1,281	143	16	$2,960
Matrice 300 RTK				
Upper Mission	2,813	69	2	$1,400
Lower Mission	1,020	20	4	$2,800

The upgraded workflow was also more efficient in almost all aspects (Table 5). The upgraded workflow took 275 minutes to complete, whereas the current workflow took 820 minutes. The greatest efficiency gain was in time to execute the mission. Post-processing and analysis time was also greatly reduced. Total time of the upgraded workflow was about 30% of the current workflow.

Table 5. Approximate times (minutes) to complete each mission phase by the current and upgraded scenarios for the Yankee Fork UAS surveys. N/A- not applicable.

	Scenario	
Mission Phase	**Current**	**Upgraded**
Mission Planning	60	45
Pre-flight Inspection	20	10
Mission Execution	480	60
Data Offload	20	10
Post Processing	N/A	60
Analysis	240	60

DISCUSSION

In this report, we provided background information for UAS flights to conduct safe, effective, and efficient redd surveys. This report expands beyond the initial methods summary given in Copeland et al. (2019). Below, we discuss the implications of the Yankee Fork field study and make several recommendations to improve use of UAS for redd surveys in Idaho. The use of updated UAS technologies and flight procedures will increase survey efficiency but additional steps will need to be taken to ensure consistency in methods and to set standards for data quality. Therefore, we close with some suggestions to guide use of UAS for spawning ground surveys that are beyond the scope of this document.

Recommended Technology and Workflow

There were three primary reasons for differences in time between the current and upgraded workflows. The first was battery use. Although the survey reach was the same for both UAS, the Phantom 4 required landing for battery changes eight additional times to complete the lower section of the river and 24 times in the upper section. An additional landing means deviating from the river to find a suitable landing location, as well as taking off again, which increases the time needed to execute the mission.

The second difference was flight path type. The Matrice used a linear mission with the centerline on the river, not pausing, instead continuously flying and capturing images. The Phantom 4 missions are built around waypoints, and use the option where the UAS pauses at each waypoint to acquire an image. This means that the drone paused in air a total of 3,542 times. This flight path type is problematic for efficiency and battery life. It takes a greater amount of battery life to move the drone from point to point when it must pause before moving to the next waypoint rather than moving continuously. This is further complicated with the flight speed set for the mission under the current scenario, 32 m/s. Every time the UAS moves from point to point, it accelerates to achieve the set speed (the maximum possible), further increasing battery usage. We noted there was minimal blur between image sets regardless of flight path type.

The final difference was mission altitude. It is typical to plan missions at the lowest possible altitude needed to avoid hazards (trees, powerlines, etc.), while maintaining high resolution of the river. Because of the effective pixels of the on-board camera, the Matrice was able to fly over double the height of the Phantom, capturing a higher proportion of the river per image due to an increased field of view. That is, the higher-MP camera significantly increased data capture efficiency. This issue is not as pressing as the aforementioned ones, but it does bear on mission safety. In multiple instances, sight of the Phantom 4 was lost because of the lower height at which it was flown. Further, reception between the drone and operator was lost, most likely because of interference and distance. Flying at higher altitudes will alleviate these issues while staying within FAA regulations.

Redd surveys by UAS will be made more efficient by upgrading the currently employed drone technology and through mission planning. Upgraded technology, to include both the UAS and sensor, increases survey time in the air through improved battery capacity. Upgraded sensors allow for higher resolution imagery, ultimately allowing flights to be done at increased altitudes, decreasing flight times, and further improving distance per battery. Ultimately an upgraded UAS is correlated to better batteries and improved sensors, leading to greater survey efficiency. This is coupled with updated flight parameters such as mission flight type, which will increase flight distance per battery and overall efficiency of flights. The following four recommendations are being made to increase the efficiency of UAS use while maintaining high quality imagery.

1) Missions for redd surveys should use continuous flight paths and image capture. Waypoint missions may be necessary when adjustments to drone positioning or camera actions are needed, but this should not be the case for most redd surveys. Continuous flights will allow for the UAS to be in the air longer per battery.

2) Missions can be flown at a higher altitude, decreasing the number of pictures needed, avoiding potential hazards, and maintaining the link between the controller and the operator as well as meeting the FAA line-of-sight requirement. The size of a Chinook Salmon redd is large enough that an increase in flight altitude will not affect detection. Flying at 75 m with the current UAS and sensor would increase the GSD to 2.06 cm/px, which is still precise enough to see redds in images. It is best practice to have the GSD half the size of the target object (Appendix C). Thurow et al. (2010) found redd sizes in Idaho to be 4.7 m^2, meaning redds will be easily visible in UAS imagery with GSD ~2 cm/px. Even so, with FAA regulations setting flight ceiling at 122 m, GSD will remain well below the threshold needed to detect Chinook Salmon redds.

3) Currently, the Phantom 4 Pro is equipped with an ND16 filter, which may actually decrease visibility of the water due to the amount of light it is filtering out. A CPL is recommended to reduce glare and reflections while still capturing a clear image of the riverbed.

4) Upgrading the UAS platform to newer technology will increase efficiency of flights for both mission time and area covered. There have been major advancements in battery technology allowing for flight times up to 55 minutes for commercial UAS (DJI Matrice 300 RTK) or upwards of 45 minutes for recreational UAS. Sensor technology has also improved with many platforms carrying 20-48 MP cameras, which will decrease GSD at current flight altitudes. The combination of sensor and UAS technological improvements will allow for higher altitude flights while achieving the same GSD, longer time in the air, and ultimately safer and more efficient UAS operations.

Beyond these recommendations, UAS flights should always be conducted in accordance with FAA, state, and local regulations, and should be flown within the limits of the UAS being used.

The technology associated with UAS continues to change quickly. We advise to upgrade only when a new piece of equipment significantly benefits the operation (efficiency or accuracy). The case study presented in this report is an example of how upgraded technology (sensor, batteries, missions) can greatly reduce flight times and increase efficiency. However, industry changes are unpredictable and it is up to program personnel to keep an eye on the market for things that could affect efficiency.

Survey Consistency and Data Quality

There are other quality assurance and quality control considerations that IDFG should implement when conducting redd surveys via UAS. These topics are beyond the scope of this report, so we mention them here as a starting point for further improvements. The first consideration is to ensure that there are adequate training protocols in place to teach new and unskilled drone pilots how to conduct aerial missions and pilot the UAS. The Part 107 training course required to operate a UAS does not teach a pilot how to fly; rather it informs them about rules and regulations pertaining to air space controlled by the FAA. Providing new pilots experience with different habitats and survey conditions prior to data collection flights is crucial to ensuring safe and effective missions.

Secondly, it is critical to develop a protocol to teach observers how to identify the desired object (i.e., a redd). Standardized and rigorous steps in image interpretation will ensure data accuracy and precision. It is often helpful for new observers to look at images with known objects in them, to help direct their focus toward distinguishing features of those objects. Similarly, it is important to add yearly training for veteran observers to recalibrate their eyes to identify objects. The Nampa Research Anadromous Ageing Laboratory uses a similar framework to ensure the accuracy and consistency of ages assigned from scale images by veteran and new observers alike (Wright et al. 2015). A formal protocol for processing, viewing, and interpreting UAS images will serve as a starting point for developing similar approaches during the post-processing and image-viewing phases. Taken together, pre-flight operational training and post-flight standardization of procedures will contribute to producing the best possible estimates of Chinook Salmon redds using UAS.

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APPENDICES

Appendix A: Problems with Illumination: Glare and Shadows

Image quality can be reduced by too much or too little light. The opposing problems of glare and shadows are major considerations for effective aerial surveys of streams and rivers.

<u>Glare</u>

Reflected light can cause difficulties in seeing an object. There are multiple types of reflection, but when using sensors over water, specular reflection is the most problematic. Specular reflection is produced by incident energy reflected from a water body at an equal but opposite direction to the incoming incident energy. The reflected incident energy becomes linearly-polarized light. Polarized light entering the eye or a camera lens is commonly known as glare. Glare is caused by light entering the field of view of a camera. When too much light reaches the sensor such that it saturates sensor capacity, typically white spots appear on the image, which can obscure the target.

When using a UAS over a water body, glare causes a visual obstruction, preventing the observer from viewing the area below the UAS. Glare has been noted numerous times as an obstacle during UAS data acquisition over water. For instance, glare was detected when observing sharks in Australia (Butcher et al. 2019) and caused numerous false positives during automatic jelly fish counts in Denmark (Hamel et al. 2021). Similar instances of glare are present in other aquatic ecosystems, yet the complications have not been documented within the literature. This may be because fewer studies have been conducted in riverine systems, or because the focal point of studies have not been subsurface detection, thus glare has not been a major concern. Whether it be in the marine or riverine setting, there are two methods to reduce glare within images.

The use of a polarized filter may arguably be the most cost-effective means to combat glare in UAS imagery (Reis-Filho and Giarrizzo 2022). There are two types of polarized lenses: linear and circular. A linear polarized lens only allows light to enter in a certain direction. Linear polarized lenses can be adjusted dependent on the direction of the light that you want to allow to come in. To reduce glare, a linear polarized lens should be adjusted perpendicular to the incoming light waves. A circular polarized filter (CPL) still uses a polarized lens but adds a quarter-wave plate behind it. The quarter-wave plate shifts the wave by a quarter, allowing circular polarized light to reach the sensor, further reducing glare and reflections (Bentley 2019). Despite the strengths of polarizing lenses, camera angles often change with direction of flight. For this reason, mission planning parameters must be used in conjunction with a polarized filter to reduce the effects of glare.

To ensure maximum reduction in glare, the flight direction can be adjusted. A polarizing filter is most effective when tilted 90 degrees from the direction of the incoming radiation. As mentioned above, camera angles change as UAS direction changes. For this reason, flights should be adjusted so that the direction of flight, and thus the direction of the polarizer, is always parallel to the sun’s azimuth. For instance, if the sun’s azimuth is 179 degrees, the flight direction should be 179 degrees as well. In instances when a linear flight is occurring (see flight path for more details) a fixed camera angle should be used and adjusted by waypoint for the given sun direction. Using the example from above, at each waypoint the drone may adjust course, but the camera would stay fixed at 179 degrees.

Another measure to reduce glare is to adjust flight schedule. To maximize penetration of solar radiation to the target, the flight should be done during solar noon, but this may increase reflections and glare (Raoult et al. 2020). Provost et al. (2020) note that glare can be reduced by flying on overcast days or considering sun angles and making adjustments accordingly. Raoult et al. (2020) recommend adjusting the camera angle between nadir and 45 degrees. Keep in mind that this has been mostly studied in the marine environment, but other complications exist in the freshwater setting. For example, a lower sun angle increases the length of shadows cast by riparian vegetation. A lower sun angle also means reduced radiation reaching the sensor through the polarized filter. A multifaceted approach must be used to mitigate glare and shadowing at the same time.

<u>Shadows</u>

The presence of shadows in UAS imagery has been well documented across multiple studies and is a well-known source of error (Zali et al. 2022). Shadows can be caused by terrain, buildings, clouds, and most notably in riverine setting, riparian vegetation such as trees. Shadows block full solar radiance and create blur and/or poor contrast (Liu et al. 2022). Shadows are often unavoidable but flight schedule adjustments and post-processing image manipulation can be used to dampen shadow impacts.

Flights can be scheduled around solar noon (the time at which the sun is at its highest point), to eliminate or reduce shadows. Unfortunately, only at the equator can shadows be completely eliminated at solar noon, because the sun angle deviates to the south at northern latitudes (Kalogirou 2022). This means that shadows will always be cast but are at their smallest length during solar noon. The shadow ratio can be used to calculate the length of shadows at a given time and sun elevation, $L = H/\tan(\alpha)$, where L is the length of shadow, H is the height of an object, and α is the sun's elevation. Many phone apps, such as Sun Seeker, provide the shadow ratio to be multiplied by the height of an object. Reconnaissance of the survey reach can establish if any riparian objects are tall enough to affect images during the flight schedule. If shadows need to be reduced, it is best practice to split the mission around solar noon.

Post processing techniques can also be used on images with shadows to lighten darker objects. Typically, one of two techniques is used to reduce shadowed areas: data fusion and/or radiometric enhancement. Data fusion uses surrounding pixels to fill in the shadowed pixels. In radiometric enhancement shadowed pixels are brightened using neighboring pixels, but this may lead to over-corrected or under-corrected errors due to diversity in shadows (Pons and Padro 2019). Shadow compensation can be used to restore texture in shadowed areas, but this may lead to overcompensation and distortion in the darker areas (Liu et al. 2022), potentially leading to inaccuracies. Further, post processing techniques may be time consuming as each image will need to be manipulated, particularly in cases where the severity of shadows changes between images. It is best to proceed with caution when using post-processing techniques, ensuring that images are not enhanced to the point where false detections are made.

Safe Flight Practices

To ensure safe flight practices the following must be taken into consideration:

- Rules and regulations outlined by the Federal Aviation Administration (Part 107).
- Check state and local regulations on UAS use.
- Be aware of and abide by any IDFG policies for UAS use.
- Apply and obtain any permits necessary for flights.
- Check Notice-to-air-missions (NOTAMs), Temporary Flight Restrictions (TFRs) and vicinity to airports to note potential aircraft activity.

FAA Regulations

The Federal Aviation Administration (FAA) is the overarching governing body for both recreational and commercial UAS rules and regulations. For commercial flights, UAS operators must obtain a Part 107 license and be up-to-date with FAA Part 107 regulations. The specifics of these regulations often change, but mandated operating requirements are highlighted below (https://www.faa.gov/newsroom/small-unmanned-aircraft-systems-uas-regulations-part-107):

- Always avoid piloted aircraft.
- Never operate in a careless or reckless manner.
- Keep your drone within sight. If you use First Person View or similar technology, you must have a visual observer.
- Always keep your drone within unaided sight (for example, no binoculars).
- You cannot be a pilot or visual observer for more than one drone operation at a time.
- Do not fly a drone over people unless they are directly participating in the operation.
- Do not operate your drone from a moving vehicle or aircraft unless you are flying your drone over a sparsely population area and the mission does not involve the transportation of property for compensation or hire.

A full set of rules and regulations can be found here: https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107.

For Part 107 eligibility and requirements see: https://www.faa.gov/uas/commercial_operators/become_a_drone_pilot#:~:text=In%20order%20to%20fly%20your,procedures%20for%20safely%20flying%20drones.

State and Local Regulations

While the FAA sets the overall rules and regulations for UAS use, state and local agencies may also impose rules and no-fly zones (commonly called “No Drone Zone”) for UAS. It is necessary to check specific state, county, city, or town websites for specific rules and regulations. For example, Washington State has specific rules for flying in Washington State Parks https://uavcoach.com/drone-laws-washington/.

Idaho has UAS laws that don’t allow drone operators to fly on land managed by IDFG without prior authorization https://www.idaho.gov/driving/aircraft-drones/. Counties or municipalities may also have ordinances within their jurisdictions, and it is the RPIC's responsibility to know them. It is also important to be aware of any county parks, state parks, or recreational areas within a municipality that have posted no-fly zones.

Agency Policies

Like federal and state regulations, it is important to understand agency regulations. Currently, IDFG does not have a policy specific to UAS but that may change in the future. Regardless, the policy for agency property always applies.

Permits

Depending on the location and object of study for a project, a permit may be required. Permits are more commonly obtained for research areas that are in national or state land that prohibits drone flights. Examples include:

National Park Land: https://www.nps.gov/articles/unmanned-aircraft-in-the-national-parks.htm

US Forest Service: https://www.fs.usda.gov/managing-land/fire/aviation/uas

NOTAMs and TFRs

Notice to Air Missions (NOTAMs), are created for pilots that contain information regarding flight operations. A NOTAM may contain information about special flights, low flying aircraft, or hazards regarding flights along a particular route. It is essential to check for NOTAMs prior to UAS flights. NOTAMs can be checked at https://notams.aim.faa.gov/notamSearch/nsapp.html#/

It may be good practice to file a NOTAM prior to drone flights (although not currently required), particularly in areas of high air traffic. This can be done at:

https://www.dronelaw.pro/how-to-file-faa-notam-drones/#:~:text=The%20NOTAM%20system%20for%20drones,planning%E2%80%9D%20under%20the%20UAS%20option.

Temporary Flight Restrictions (TFRs) restrict flights in certain areas and are presented through the NOTAM system. Permission may be obtained to fly in these areas through a waiver process. TFRs can be found at: https://tfr.faa.gov/tfr2/list.html. Wildfires often affect redd surveys and active wildfires often have an associated TFR to protect aircraft engaged in fire suppression. Permission to survey an affected reach will need to be obtained from the fire's Incident Command.

Airports and Aircraft

Part of the Part 107 certification is understanding airspace and regulations surrounding airports. All UAS must remain 5-7 miles outside of airports. If flights need to be conducted within that radius, prior authorization must be given from the FAA through LAANC.

The FAA has an app and desktop version called B4UFLY that should be used for planning and airspace purposes. It can be found at https://www.faa.gov/uas/getting_started/b4ufly

Appendix C: Ground Sampling Distance (GSD)

A standard metric of image quality is the pixel count of an image, which is typically in megapixels (MPs). For instance, a common 20-MP camera accurately records 5,472 by 3,648 pixels across an array. As we increase the pixel count within an image, we increase clarity and refinement of the object of focus. In a lower-MP camera, current technology averages adjacent pixel values to increase the effective number of pixels, but that also reduces sharpness and removes edge boundaries (Byrne et al. 2019). To understand how the sensor factors mentioned above influence image quality, we need to include the distance between the sensor and the object.

Ground sampling distance (GSD) is a common metric used in remote sensing that incorporates both the camera specifications and flight altitude to define the resolution of an image. The GSD measures the distance between pixels as measured on the ground (Byrne et al. 2019) and incorporates flight altitude, focal length, sensor width/height, and image width/height (in pixels). The GSD is calculated using the following equations:

$$GSD_{height} = \frac{Flight\ Altitude\ \times Sensor\ Height}{Focal\ Length\ \times Image\ Height}$$

and

$$GSD_{width} = \frac{Flight\ Altitude \times Sensor\ Width}{Focal\ Length\ \times Image\ Width}$$

The greater of the two GSD values should be used to measure image resolution.

Ground sampling distance is important for measuring image resolution, which is related to utility in data analysis. The GSD is indicative of the ability to identify, enumerate, and measure features within an image; therefore, lower GSD values mean greater precision. Imagery with large GSD contain numerous components within each pixel, making the differentiation between objects harder to achieve. Large GSD images (e.g., obtained from low MP cameras at higher altitudes or satellite imagery) are often used for land cover classifications but are not useful for analyses needing finer-grain data. With small GSD images, we can accurately identify and measure target objects with relative precision. When identifying an object on a remotely-sensed image, a rule of thumb is the GSD must be smaller than the target object, with even smaller GSD to allow for measurements of the object. O'Neill et al. (1996) proposed that grain size should be 2-5 times smaller than the feature of interest. Thurow et al. (2010) stated average area of a summer Chinook redd in Idaho to be 4.7 m^2 with total redd lengths of 1.8-5.3 meters. Also, smaller GSD increases our ability for surface reconstruction (e.g., in a digital elevation model). Haala et al. (2013) found that a small GSD allowed for reliable generation of dense point clouds in lieu of large image texture.

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