Small Unmanned Aerial Vehicle Monitoring Protocol for Operational Forestry

Chama Peak Land Alliance

By: Caleb Stotts and *Nicholas Dolecek*

Contents

Executive Summary

Dating back to the 1700's and beyond land managers have used field based mensuration and plot based methods to quantify impacts that natural and human caused events have had on the landscape. With the modern advent of fast and cost effective computing power coupled with small Unmanned Aerial Vehicles (sUAV's) the way we evaluate and quantify changes in the natural landscape will become much more efficient, precise and accurate. The following protocol details the process, equipment and work flow to implement a monitoring program for the forest land manager.

Flight Planning

While sUAV monitoring programs are much more accurate and cost effective than traditional ground based plot methods, great care needs to be taken to ensure flights are planned in a safe way to minimize risk. All commercial flights require a remote pilot in command who has a FAA part 107 license. This license is not only required, but also ensures that the pilot in command of the UAS takes into account critical elements of aviation to ensure a safe, productive and organized flight mission. Some elements that always should be addressed before any flight are:

- Weather and elevation of flight plan are conducive to flying without endangering the UAV, humans, infrastructure and the natural environment such as trees.
- Pilot in Command is fit for flight.
- All applicable FAA rules and regulation such as airspace are being followed.

Process

For the intents and purposes of a land manager looking to monitor their forest there are four stages to accurately gain as much information as possible from a drone based system and they are Pre-Treatment, Mid-Treatment, Post-Treatment and Long Term Monitoring. In the following sections we will detail the following stages and show how the land manager can utilize them to streamline workflow.

Pre-Treatment-

Upon identification of an area to monitor/treat the first step is to determine the area of treatment and map this area using ground based GPS systems for the greatest accuracy or via GIS from the office. This will be the carry through file for all subsequent monitoring files to ensure homogeneity in the data analysis.

Utilizing the shapefile or KML the perimeter of the monitoring/treatment area can be imported into a software program such as Green Valley International's LiPlan or DroneDeploy to create a flight plan. This flight plan should be saved and used for all subsequent stages of monitoring so the flight data is homogeneous from pre-treatment through post treatment. For photogrammetry the higher the flight plan's elevation Above Ground Level (AGL) less photos will be required to capture the treatment area, however this will lessen the detail and accuracy of the resulting orthomosaic imagery and/or point cloud information. Conversely, flying too close to the tree-tops can result in serious safety issues. Some issues to be aware of when planning the height above ground level of a flight are:

- Topographical/Digital Elevation Model inaccuracies. Many treatment areas will have significant changes in elevation and the best flight data can be derived from flying the whole treatment area at a static height above ground level. For the UAV to accomplish this the flight plan will use topographic and digital elevation models. These models in most areas are accurate to 90 feet in elevation (1/9 arc second).
- Heights of the tallest trees/obstruction. Once you have accounted for the 90 feet of potential error in the digital elevation model a pilot in command must factor in the tallest obstruction in the monitoring/treatment area as well as the flight path to get from the take-off zone to the monitoring/treatment area. For instance, if the tallest trees in the flight area are 120 feet tall, add this to the possible error of the digital elevation model for your area(assume 1/9arc sec) and you have a safe flight plan elevation of 210 above ground level.
- Always check the derived flight plan to ensure that the Above Ground Level(AGL) flight plan match what the topo and/or flight sectional for your mission area shows.
- Time of day greatly affects the quality of photogrammetry, but isn't an issue for LiDAR. Midday flights when the sun is directly overhead can produce the best images and post processing data for photogrammetry due to the lack of shadows from canopies and tree

boles. Post processing software can have difficulty differentiating between actual trees and shadows causing errors in trees per acre, volumes and other metrics needed to make informed and accurate decisions.

- Wind in the canopies can also affect post processing data due to the sway of boles and the motion of the canopies. This can affect the differentiation of species, volume, heights and other metrics used to make informed and accurate decisions.

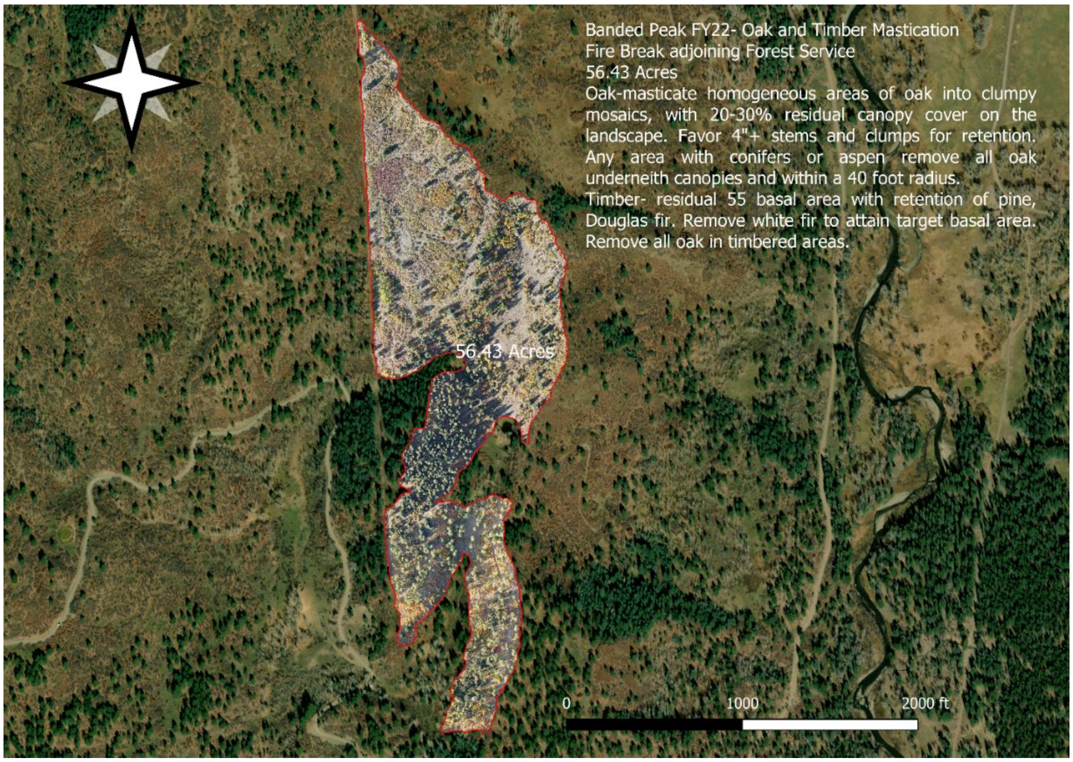
Once you have built and double checked the flight plan it is time for implementation. Make sure to perform the preflight check list (addendum A) and ensure that all batteries are charged as well as your landing and take-off zone is close enough to the drone flight path to keep reception between the drone and controller throughout. As this point you can initiate the drone take-off and commencement of the flight plan keeping a close watch on the drone visually as well as through the control screen's First Person Viewer (FPV) camera. It is always good practice to watch the location of the UAV in case of an emergency so you can re-locate the UAV in case of catastrophic failure. Additonally it is smart to always carry a small fire extinguisher in case of battery failure on the drone while in operation.

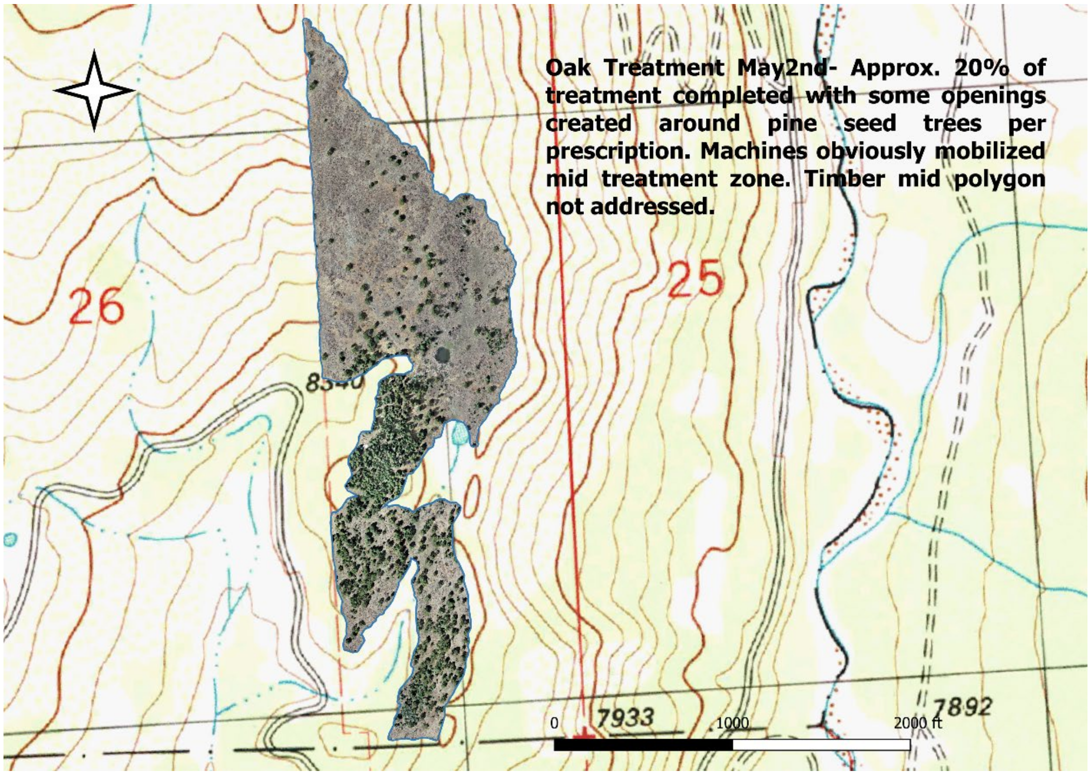
Assuming all goes according to plan a flight mission can take 1 battery to several to complete. Typically when a UAV has approximately 30% battery charge left it will return to its takeoff point. When it returns, replace the battery with a freshly charged and intact battery and commence the flight mission. All of the data that is being captured during each mission will be stored on a microSD card, and make sure that the storage card you have purchased will work with your drone as well as have ample storage space. As of this writing 32GB micro-SD's work well.

Post processing data can be achieved in various ways depending on the outputs you are looking for. For our intents and purposes we have utilized Green Valley International's LiMapper and DroneDeploy to create orthomosaics of our treatment areas. Utilizing the resulting orthomosaic stitched photo a land manager can utilize various programs such as Agremo and ESRI to analyze trees per acre, canopy cover, etc.

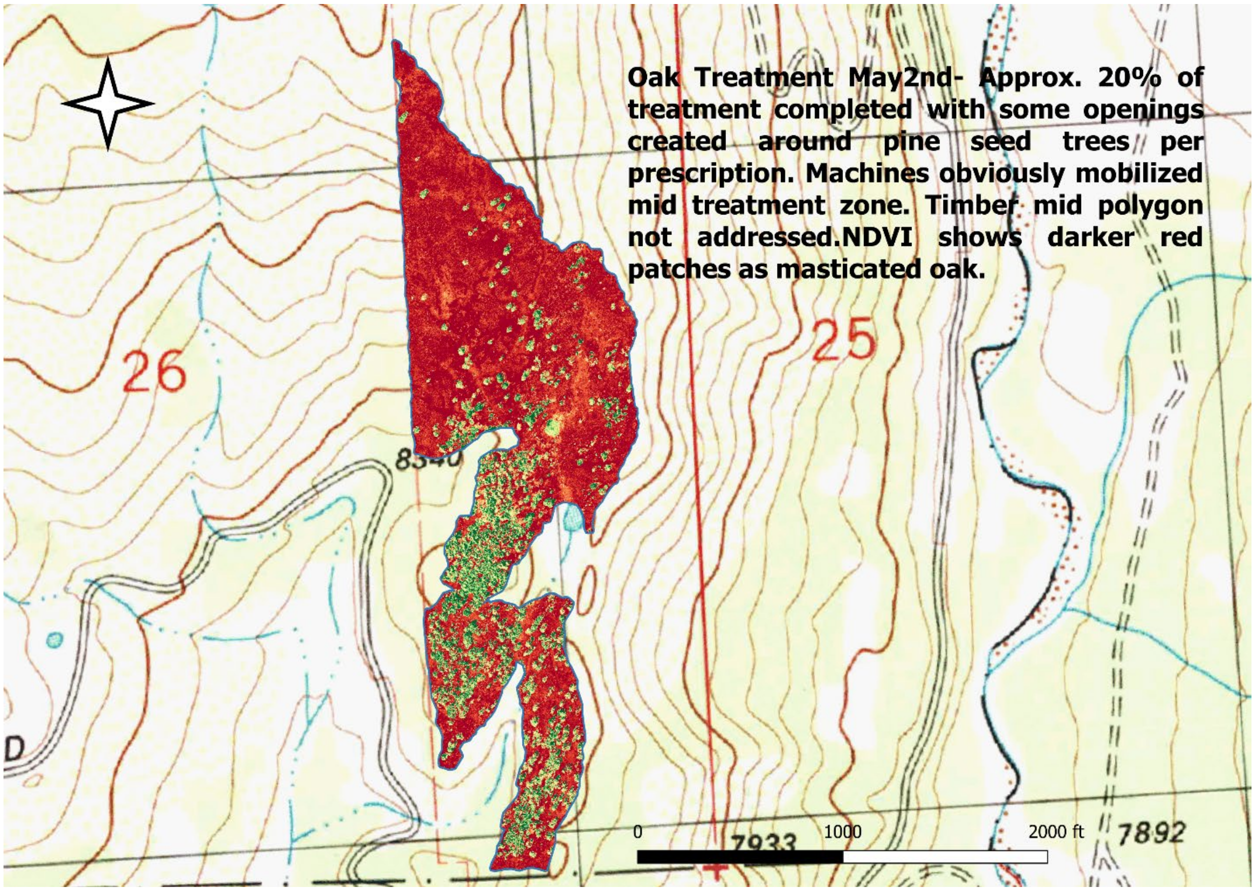
The orthomosaic image or LiDAR package will have a plethora of data, but before analyzing data bring the raw data into a geospatial suite such as ESRI Arcpro or QGIS to "mask clip" the raster image/LAS file so just the imagery inside the treatment shapefile or KML is visible. This will ensure that the data that is analyzed between all stages of the process is congruent in area and location.

The resulting pre-treatment orthomosaic and/or LiDAR point cloud will act as your control for the rest of the projects work and should form a baseline referred to in the future stages of monitoring. This pre-flight data should yield metrics that correspond to prescriptions for work to be completed and can include trees per acre, volumes, ground fuel loading etc. All of this data can greatly inform the land manager about the desired treatment and how much time and money it will take. Additionally, recent orthomosaics are great in bid solicitations and RFP's to contractors because they show very accurately conditions on the ground including fuel loading, volume, access in very high levels of detail. In some cases, contractors don't even require a site visit if the orthomosaics are of good enough detail, and this level of competency on the land manager's part can ultimately drive down the bid price for treatment work.



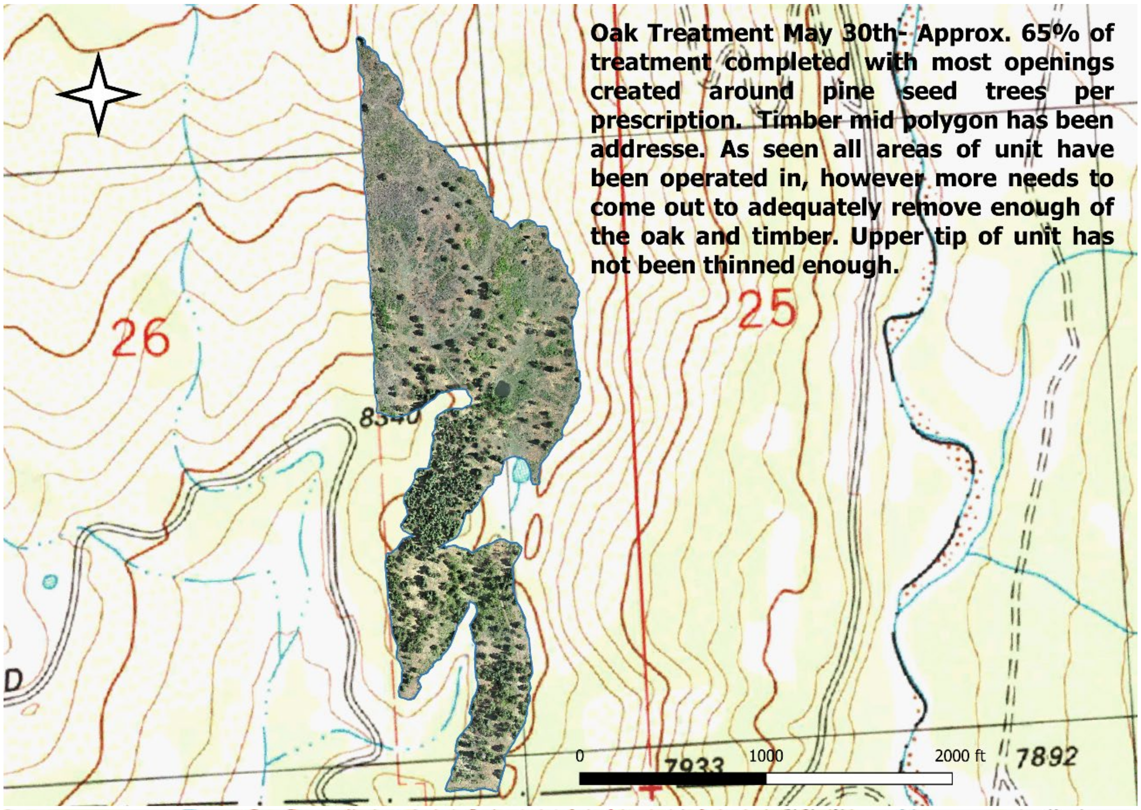


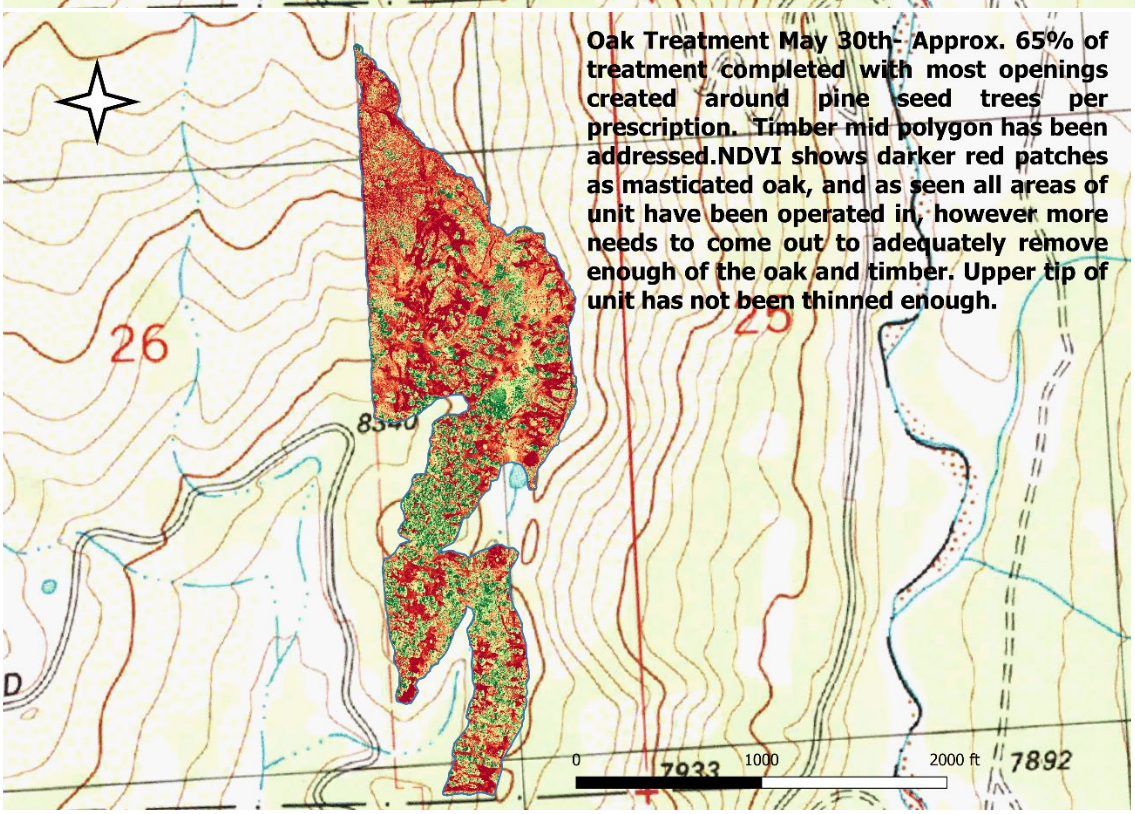
<u>MID- TREATMENT OAK- May 2nd, 2021 NDVI</u>-Note that the initial pre treatment photo was taken in fall and the leaf color helps distinguish canopy metrics opposed to the above orthomosaic photo where leaves are not present yet. This is where NDVI greatly helps for decidous tree canopy cover. See below that darker red patches represent treated areas and orange represents undisturbed oak.



MID TREATMENT-OAK May 30th, 2021

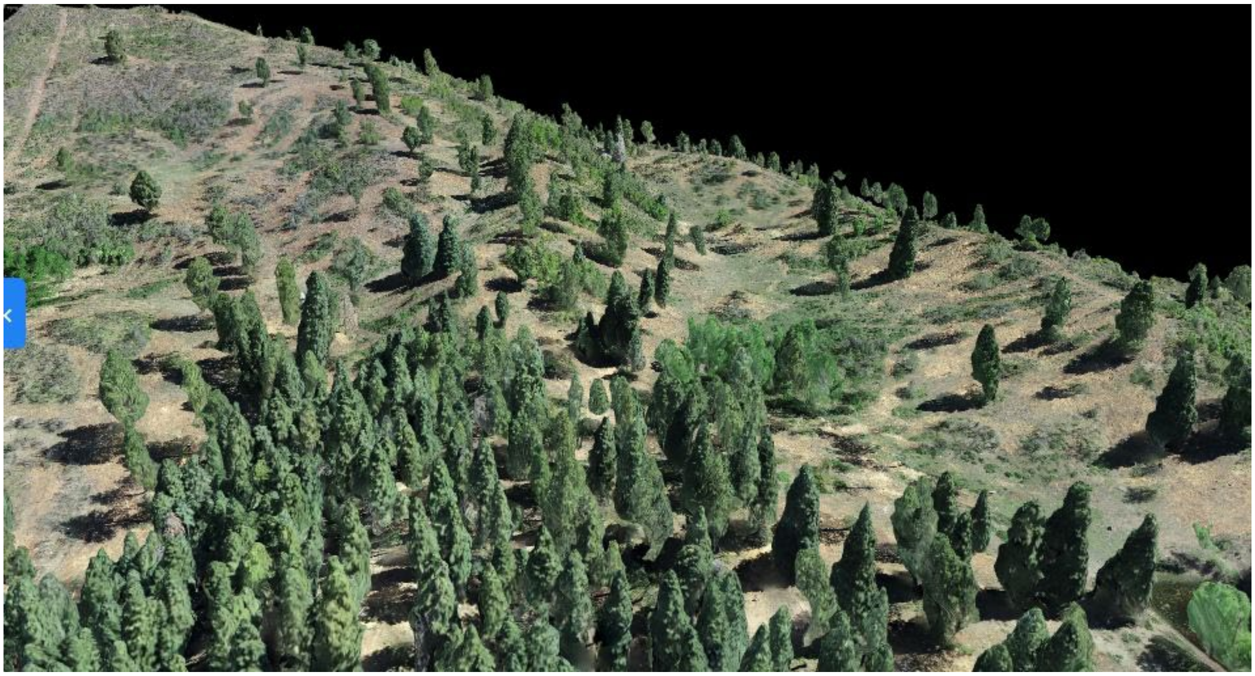
The contractor has now been mobilized and worked onsite for roughly 40 days. Here in both the green leaf on orthomosaic and the NDVI we can clearly see that the 56 acre polygon has been treated in its entirety, however more canopy cover needs to be removed to meet the prescripted 20-30% canopy in Oak. Also the timber in the center section could be opened up slightly more to crown fire spread. Additionally, the upper northwest portion of the unit hasn't been touched and this represents roughly 4.405 acres as quantified in GIS. This represents 7.8% percent of the 56.43 acre work area. Between this and the additional clean up and additional opening the unit is approxiamatly 85% complete as of May 30th, 2021.



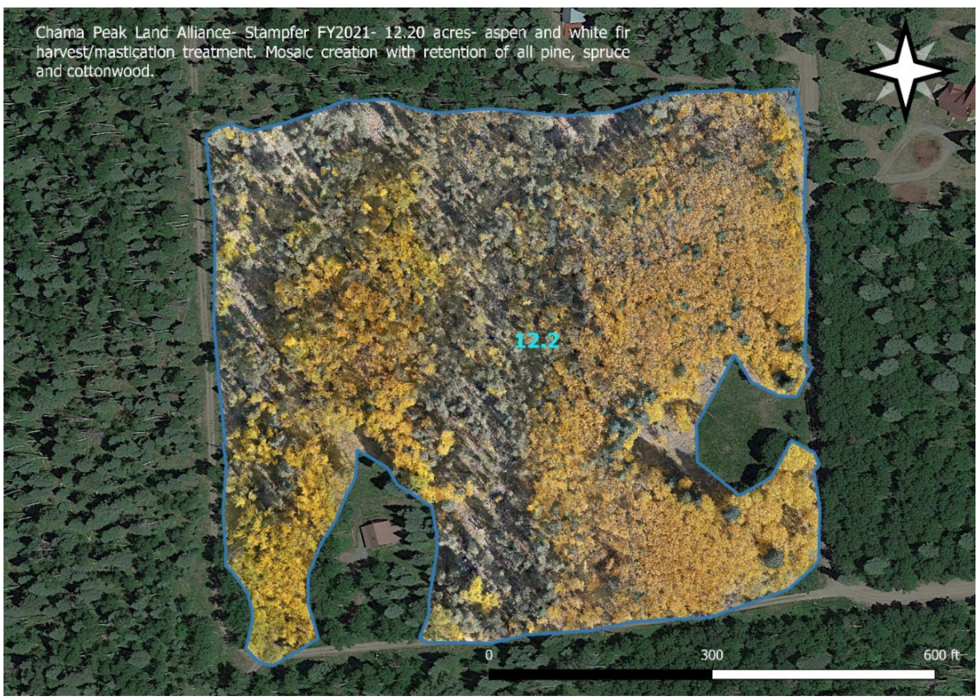


<u>MID TREATMENT-OAK-3D MODEL- May 30th, 2021</u>

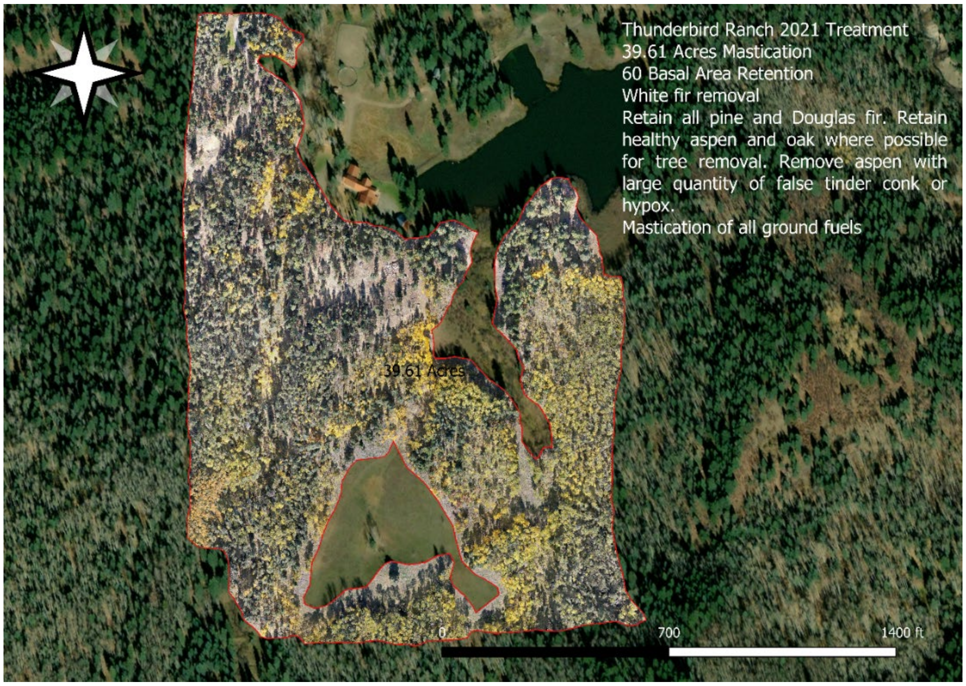
The image below is from a 3D model built from the above orthomosaic and NDVI from the same flight of 869 photos stitched together. Note the property boundary fire break on the upper left that was placed along with the masticated and clean nature of the understory and ladder fuels.



PRE TREATMENT- ASPEN/MIXED CONIFER



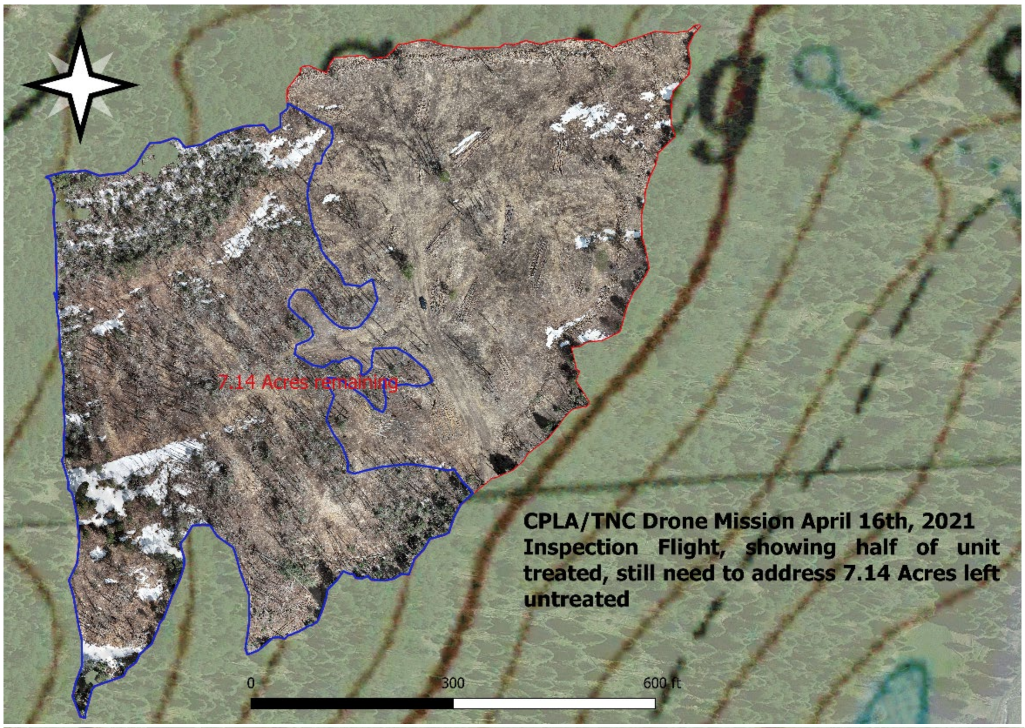
PRE TREATMENT- MIXED CONIFER

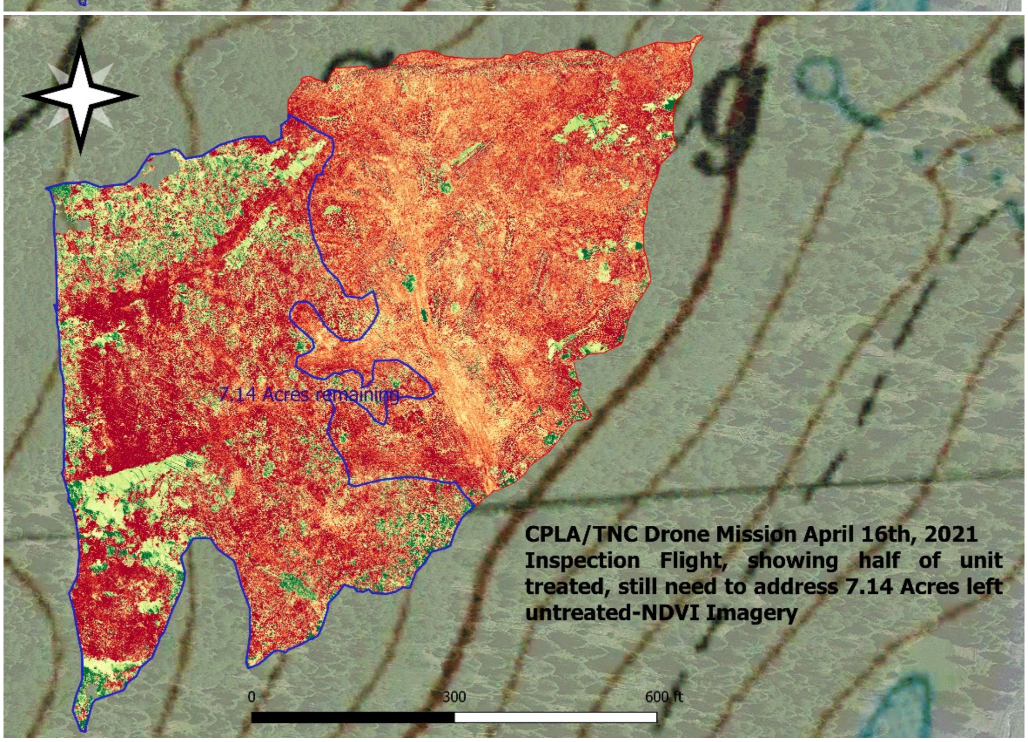


Mid-Treatment

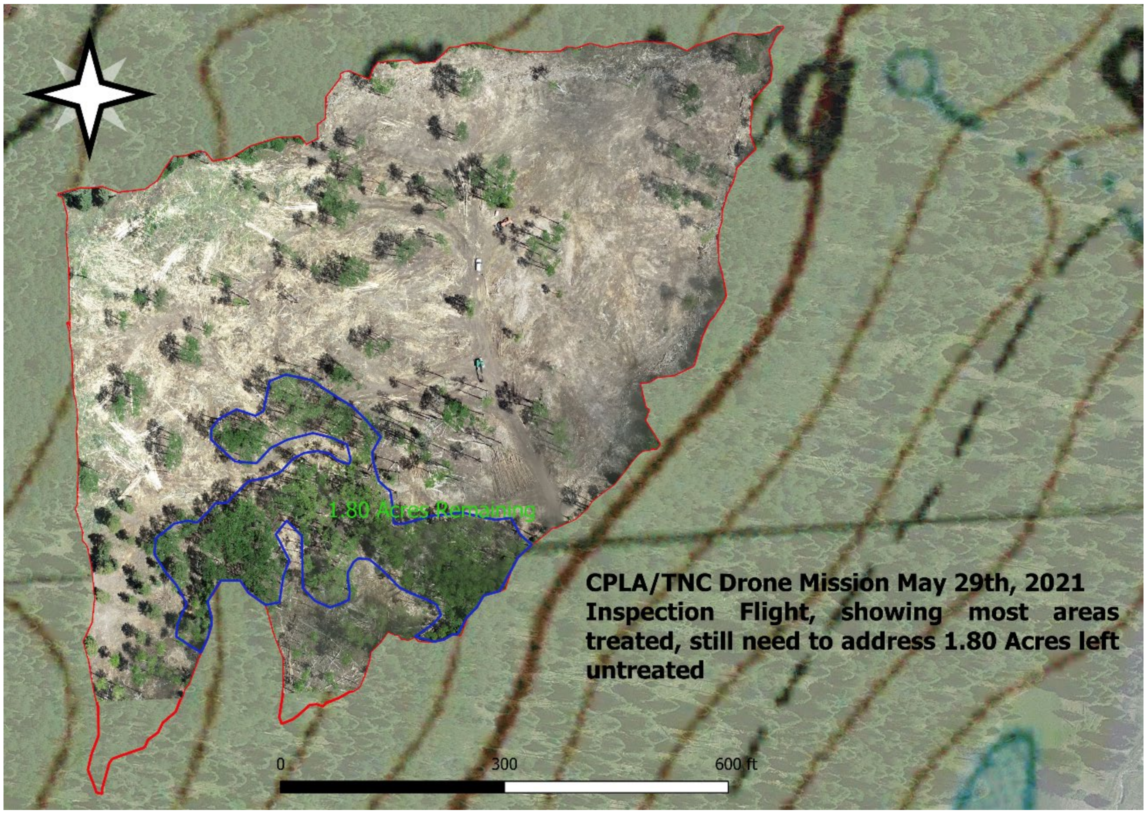
Once treatment work has commenced the land manager can effectively use drone monitoring to form solid conclusions about work being performed on the ground. As an inspection tool UAV's can isolate bias and help a land manager to show an operator areas that are not being performed to contract/prescription and other areas that are meeting and or exceeding expectations. For this method to work, timely and rapid deployment of the UAV must occur. Typically this works best weather permitting 2 days after and operator has commenced work for immediate feedback, and then on weekly or biweekly flights to ensure that quality is still being met on homogeneous treatment zones and capturing additional data in heterogeneous forest conditions and/or prescriptions for work being performed. The pre-treatment orthomosaic/point cloud coupled with a mid-treatment file side by side in a GIS suite can really help show the change visually to ensure that TPA and Canopy Metrics are being achieved as well as break down and/or utilization of ground fuels. Typically this is an overnight process when the mid-treatment photos or LiDAR data is brought back to the office and a fast computer working with a software suite built by Green Valley International or Drone Deploy stitches the individual photos into an orthomosaic overnight. In the morning a land manager can call the contractor or make a site visit to give feedback. This UAV data coupled with ground based visual inspections such as rutting of soils or scaring of residual trees can create a timely, qualitative and quantitative feedback loop that will enhance treatment quality. Additionally the time saved in performing UAV versus plot based rapid inventories saves significant amounts of money.

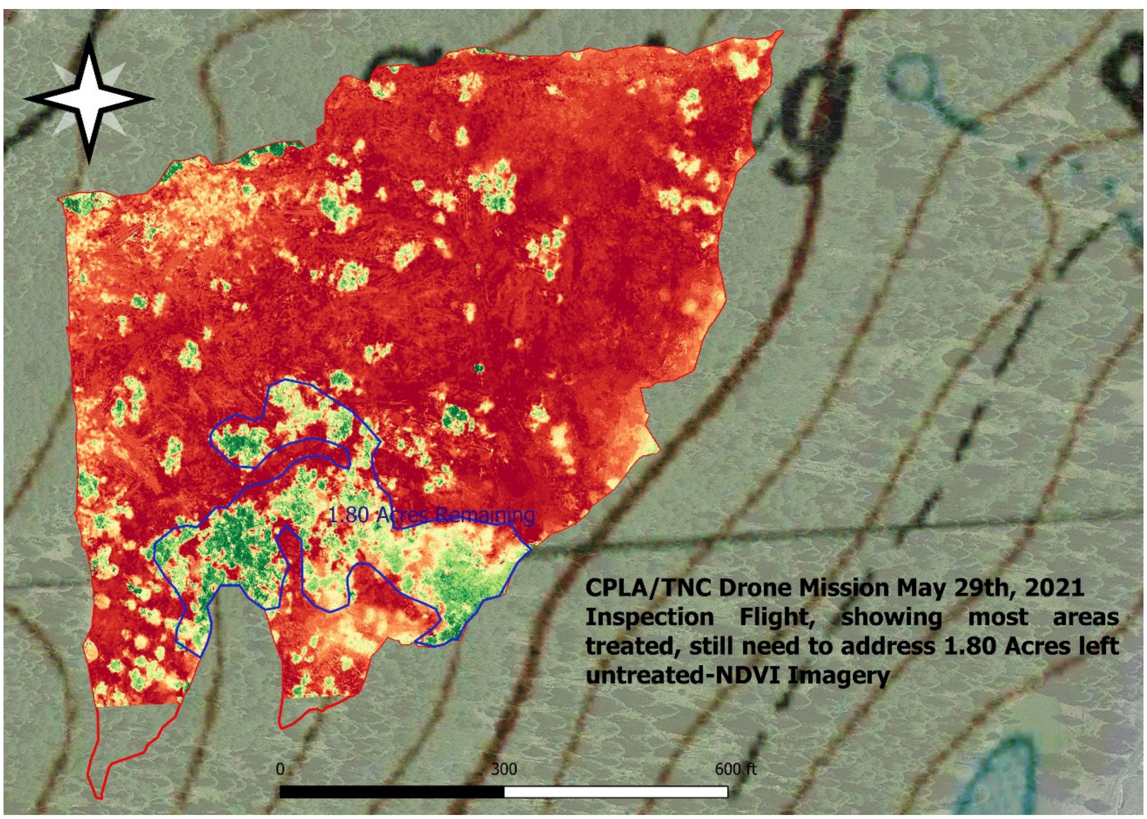
For the typical land manager a plot based inventory costs around $30 per plot and post analysis can cost anywhere from $500-$10,000. On projects greater than 100 acres a plot is needed every 5-10 acres and on smaller projects a plot can be needed every 2-5 acres for statistical relevance. These costs not only prohibit mid-treatment biometrics but also make monitoring pre, post and long-term very hard to justify monetarily. UAV's allow a properly trained pilot in command the ability to collect 100's-1000's of acres of data per day weather permitting for quantitative analysis from the office. The costs are fixed to an hourly wage of 5-10 hours. The inventory materials for a UAV are similar to that of plot based mensuration equipment currently. Additionally, instead of a sub-sample of the treatment by using a plot method, UAV's collect a 100% sample increasing the accuracy of the monitoring.





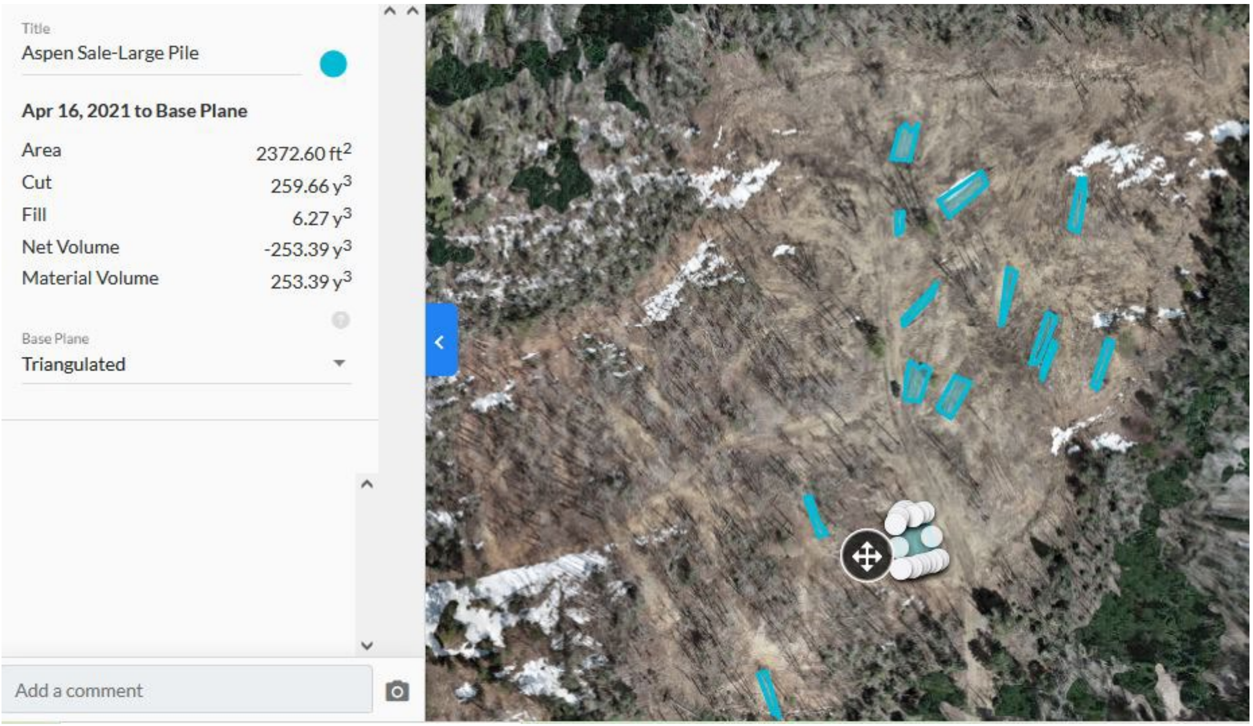
MID TREATMENT - 47% Completed - Regular and NDVI Outputs





MID TREATMENT - 87% Completion - Regular and NDVI Outputs

Mid Treatment Aspen Volumetric Quantification of Log Decks

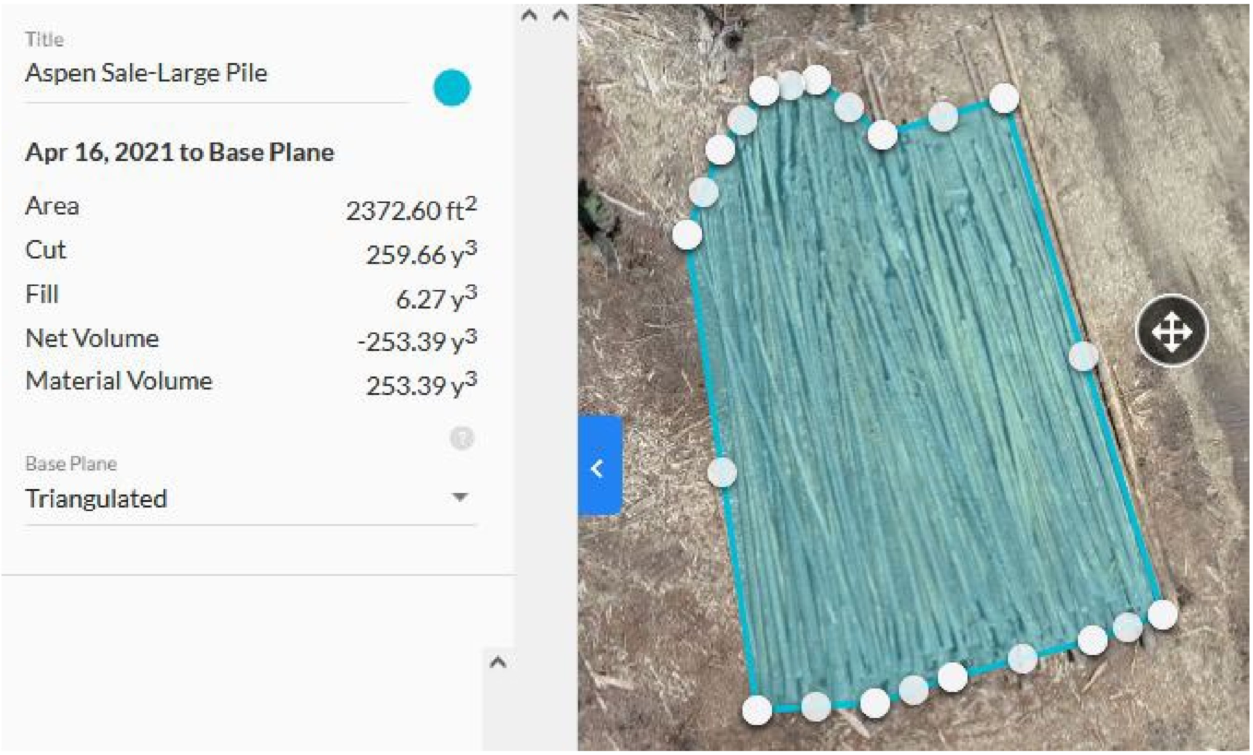


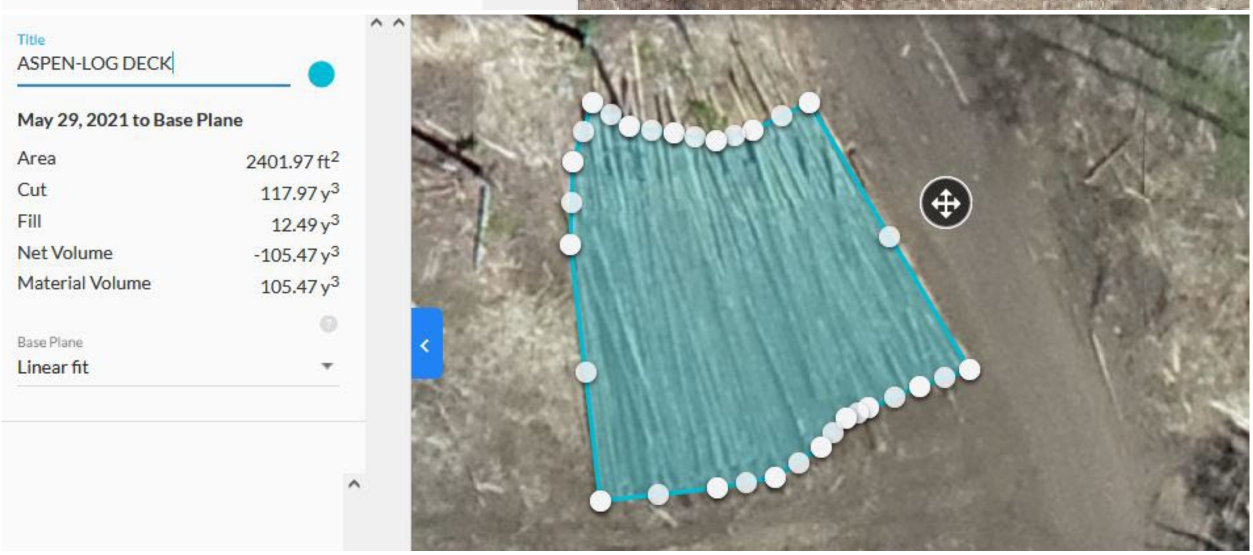
Based on this imagery collected for 3D model we are able to calculate volumes of wood piles decked onsite for removal. Knowing how much wood is decked allows us to check on payments for removed product and potential timelines for project completion. By outlining the bulk of the piles and then using the triangulated base plane we are able to get reasonably accurate volumes of wood. By then taking the material volume and dividing by 38 cubic yards which is what a standard log truck can haul, we can determine the truckloads onsite. See the excel spreadsheet below which is calculating the total of the log piles volume.

Log Piles Remaining on "XYZ Sale" 4.16.21 Contract End Date 6.25.21	
Log truck holds 38 Cubic Yards of wood on average	
Cubic Yard Pile volumes based on Drone Deploy-Triangulated NOT Linear	
12.74	
17.53	
8.6	
42.28	
23.62	
9.34	
11.9	
58.8	
24.81	
17.14	
86.58	
54.46	
57.96	
253.39	
679.15	**Cubic Yards of Wood Decked**

17.87 Truck loads of Wood Decked on site as of April 16th, 2021

Below highlights the process of looking at individual log piles and comparing size between different times. The top model is taken on April 16th, 2021 and the lower model is taken on May 29th, 2021. As you can see it went from 253 cubic yards down to 105 cubic yards. This shows that wood is being moved offsite and from this pile in particular the operator removed roughly 4 truckloads.





Post-Treatment

A post-treatment flight utilizing the same flight plan as pre-treatment and mid-treatment can give a great comparison of what has been accomplished on the ground. Utilizing photogrammetry and orthomosaics or even more accurate is LiDAR to allow the land manager to quantify the work done. By analyzing the pre-treatment flight data to look at trees per acre, canopy closure, height and diameter metrics and then comparing this to the same post-treatment metrics a land manager can be accurately informed if their prescriptive goals were achieved. This information can be used to quantify every portion of a treatment area with a 100% sample opposed to plot methods that take a small subset of the project area for analysis. Additionally land managers can accurately see how much volume came off a treatment, especially if there are merchantable wood products. This can then be compared to weight tickets to ensure that harvesting contractors are being fair with payments for wood removed and sold from a project. Post data can also look at slash piles and/or down wood to ensure that merchantable wood is not left on the project area and/or fuel loading exceeds a certain size and diameter.

Qualitative post treatment UAV imagery and video is an excellent tool for showcasing work accomplishments to those unfamiliar with biometrics and other quantitative sampling methods used in forestry. While qualitative information may not inform the traditional land manager as much as quantitative data, it is extremely useful to those in other fields and sectors such as administration, finance and ownership to name a few. This imagery, point cloud comparisons and 3D models is interactive and can really highlight the positive impact a land manager has had. Furthermore, various treatments can be highlighted in geospatial systems to showcase landscape level projects area and strategy.

Long-Term Monitoring

The ability of the UAV to effectively and relatively cheaply evaluate past treatments may be the largest benefit of this technology to the fields of science and land management. Traditionally land mangers against their best intentions have not had the time or resources to make re-visits to past treatments to see how the prescriptions worked. Often times when a prescription is written it is based on a certain amount of know variables such as covertype, slope, aspect, latitude, stocking level, vegetation and fuel loading. Based on these variables often times generic prescriptions and treatments are implemented and immediate post monitoring/inspection takes place. Due to the lack of monetary resources the typical land manager must then focus on the next projects without having the time or finances to look back at treatments. The UAV allows for rapid deployment, quick flights and easy post quantification which should incentivize the typical land manager to make periodic long term monitoring flights of previous treatments to inform best practices in the future such as:

- Did the treatment prevent an insect/disease/wildfire from propagating?
- Did the intended regeneration occur and in the species expected?
- What species are encroaching over time?
- Did the treatment increase volume and/ or species composition intended?
    - And if so, how were the growth rates of diameter, height and canopy over various time periods?

These are just a few questions that UAV’s could answer and help sharpen land managers understanding and common practice into the future.

Equipment-

The equipment listed below will be items that are needed to safely and precisely fly a UAV flight mission:

- Federal Aviation Administration Part 107 commercial sUAV license
- Computer with preferably 3.4GHZ or faster CPU and 32 GB RAM as well as fast GPU and SSD hard drive
- GIS software
- Flight planning and post processing software such as Green Valley International or Drone Deploy
- Flight insurance: Payload, General Liability, Airframe
- GPS for layout of treatment area on the ground(Optional)
- Internet-preferably 150MBPS download and 25MBPS upload
- Drone
    - For photogrammetry flight missions almost any commercial grade sUAV will work, such as the DJI Mavic 2 pro or the Phantom 4 Pro V2. With these drones the use of a submeter GPS with Ground Control Points will greatly increase the accuracy of the resulting orthomosaic by removing image distortion. Drones with RTK which will give centimeter grade image locations without the necessity of Ground Control Points. These drone platforms come with the payload (camera) and the drone, controller, rotors and a small battery package.
- Batteries- make sure to purchase extra batteries so you have 9 batteries fully charged for any given flight.
- First Person Viewer (FPV) camera. Most commercial drones have this capability however the enterprises level drones will require this purchase separately.
- Carrying case to safely transport the drone, payload and batteries to the take-off zone.
- Fire extinguisher, satellite phone and other safety equipment

Workflow

1. Determine area to be analyzed or potentially treated.
2. Insert this area KML into DroneDeploy to plan the flight mission that will safely and accurately get the data needed. Ensure that your flight plan is saved so subsequent flights utilize the same flight plan for continuity of data collection.
3. Prepare all equipment and ensure batteries are charged.
4. Check weather and other briefings for the flight area to ensure safe operations
5. Activate insurance on flight plan

6. Arrive at takeoff zone and ensure remote pilot in command is capable of safe flight and drone preflight check passes inspection
7. Place 4-6 ground control points (GCP’s) across unit with high and low elevations captured. GCP’s should be 2’x2’ in size with a bulls-eye pattern. At the center of the GCP a sub-meter GPS point should be taken with X,Y and Z plane coordinates taken. A minimum of 120 GPS points should be taken at each location with at least 8 satellites, however 240 or 360 plots are preferable using the Two Trails program so a choice can be made of which 120 plot cluster has the best RMSE accuracy of collection.
8. Fly flight mission keeping attention for other aircraft and the position of your sUAV.
9. Finish flight safely and return to office
10. Upload data into software suite for post processing
11. Upload Ground Control Point data into software suite and geo-tag each photo with GCP.
12. Output Orthomosaic, Point Cloud and Digital Elevation Model as well as 3D models of specific areas of interest.
13. Clip the post processed data to the extent of your treatment area so any data or photos out of your treatment area are removed. This will minimize data size and clutter in post processing.
14. Analyze data for the needed metrics:
    a. CANOPY COVER %-Convert Orthomosaic to isolate canopy and trees using VARI or TGI algorithm. VARI looks at leaf area and the TGI looks at chlorophyll. Both of these can be effective tools depending on how much hardwood, conifer and shrubbery exists on the site. Once you have set your red, green and blue at 243,7,11 you can then calculate the amount of blue, white and purple saturated area which corresponds to trees, oak and masticated opening cover using QGIS. This is a great metric to see what has been accomplish pre, mid and post treatment and to ensure that enough canopy is coming out to prevent crown fire propogation.
    b. TREES PER ACRE- Take the Orthomosaic created in DroneDeploy and import into the linked application Agremo to do a trees per acre analysis. This is a great way to see pre, mid and post what percentage your tree count has come down. If you know your average size class of tree from the preliminary walk through you can use the following chart to ensure that the residual overstory meets spacing and trees per acre metrics for a basal area reduction:

BA/ a c		60 sq. ft.			70 sq. ft.			80 sq. ft.			90 sq. ft.			100 sq. ft.			110 sq. ft.			120 sq. ft.			BA/a c

Leave-tree Dbh	Bole-to-bole Spacing	Average # Trees per Acre.	Bole-to-bole Spacing	Average # Trees per Acre.	Bole-to-bole Spacing	Average # Trees per Acre.	Bole-to-bole Spacing	Average # Trees per Acre.	Bole-to-bole Spacing	Average # Trees per Acre.	Bole-to-bole Spacing	Average # Trees per Acre.	Bole-to-bole Spacing	Average # Trees per Acre.	Leave-tree Dbh
In.	Ft.	#	Ft.	#	Ft.	#	Ft.	#	Ft.	#	Ft.	#	Ft.	#	In.
22"+	44'	23	41'	26	38'	30	36'	34	34'	38	32'	42	31'	45	22"+
20"	40'	27	37'	32	34'	37	33'	41	31'	46	29'	50	28'	55	20"
18"	36'	34	33'	40	31'	45	29'	51	28'	57	26'	62	25'	68	18"
16"	32'	43	29'	50	28'	57	26'	64	25'	72	24'	79	23'	86	16"
14"	28'	56	26'	65	24'	75	23'	84	22'	94	21'	103	20'	112	14"
12"	24'	76	22'	89	21'	102	19'	115	18'	127	18'	140	17'	153	12"
10"	20'	110	18'	128	17'	147	16'	165	15'	183	15'	202	14'	220	10"
8"	16'	172	15'	201	14'	229	13'	258	12'	287	12'	315	11'	344	8"
6"	12'	306	12'	357	10'	408	10'	459	9'	510	9'	561	8'	612	6"
5"	10'	441	9'	515	9'	588	8'	662	8'	735	7'	809	7'	882	5"

Michelle Satterfield, Silviculturist
February 2014

c. DOWN WOOD AND SUB CANOPY- In DroneDeploy take the created orthomosaic and view it as a 3D model. Utilizing this tool you will be able to zoom in through and under the canopies. This will allow you to inspect to ensure that ground fuels were properly removed and or broken down. By viewing the 3D model as a point cloud you should also be able to get a rough view of the sub canopy trees to ensure that the treatment addressed the removal/retention of these trees depending on prescriptive intentions.
d. DOWN WOOD MEASUREMENTS- Utilizing the measuring tool in DroneDeploy you can measure the ground fuels with centimeter grade accuracy to ensure that down wood reductions and retentions are in line with the treatment and prescription. These same orthomosaics should allow a user to subsample fuel models pre and post to roughly calculate the fuel model change.

15. Repeat these steps for various stages of treatment monitoring.

Conclusion

Unmanned Aerial Vehicles present a very cost effective and accurate way for land managers to analyze, assess and make informed decisions. This positive and efficient feedback loop will enhance the decision making process into the future. The cost of these technologies is dropping rapidly and the technology is increasing just as quickly resulting in a paradigm shift in land management decision making.

Addendum A: Preflight Checklist

Drone Preflight Checklist:

1. Take the differentially corrected polygon maps and plug into GIS to gain altitudes AGL for the plan and strategic line of sight landing and takeoff zones that comply with FAA part 107 regulations in term of airspace and operability requirements.

2. Program a flight plan taking into account wind and weather forecasts (METAR) as well as using Airmap.com to check for Temporary Flight Restrictions (TFR's) and Notice to Airmen(NOTAM'S). Tune in to nearest airports AWOS for winds aloft in local municipality.

3. File flight-plans with insurance carrier. For LiDAR flights 2-3 million in coverage with $35,000 in payload insurance as well as ensuring CPLA's General Liability policy covers drone operations.

4. Ensure that drone is in working condition with a pre-inspection of the following:

a. Remote Control

i. Antennas

ii. Control Sticks

iii. Buttons

b. Propellers

c. Check all batteries to ensure they are fully charged

d. Check battery on payload

e. Check battery on controller

f. Landing Gear

g. Moving Parts (Legs of Drone)

h. Gimbal

i. Camera

j. Power Cords

k. Firmware updates

l. App Updates

5. Crew Resource Management- If there are crew involved in flights, ensure that mental capacities and equipment capacities are in a safe place as well as attitudes (Avoid anti-authority, impulsivity, invulnerability, macho and resignation).