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BIOAg Project Report

Report Type: Final

Title: Development of multi-scale remote sensing methodologies to classify and monitor riparian vegetation structure and composition to improve agricultural sustainability

Principal Investigator(s) and Cooperator(s): Alexander K. Fremier (alex.fremier@wsu.edu), Amanda T. Stahl, Laura Heinse (formerly Palouse Conservation District)

Abstract: Sustainable agriculture in Washington State (WA) pushes to be economically viable while being environmentally responsible through improvements made to both on- and off-farm practices. Riparian (streamside) conservation measures are a primary off-farm field strategy to protect and enhance ecosystem functions and values, such as improving water quality and creating wildlife habitat. Two significant state administered programs incentivize these actions – the USDA Conservation Reserve Enhancement Program (CREP) and Voluntary Stewardship Program (VSP) overseen by the WA State Conservation Commission (SCC). Both programs require monitoring and reporting to reflect compliance and participation. Yet, to date, few states, including WA, take full advantage of available remotely sensed data, such as NAIP (National Agriculture Imagery Program) or Sentinel (satellite) imagery, or data collected from UAVs (Unpiloted Aerial Vehicles, a.k.a. drones). In particular, the VSP program lacks a standard monitoring methodology utilizing these data sources. We hypothesize that underutilization of remotely sensed data in these programs is due to the lack of specific technical methods for monitoring riparian and natural vegetation in the agricultural setting and setting up a pipeline to integrate these methods into existing VSP and CREP monitoring programs. We propose to develop a robust methodology for monitoring riparian structure as a proxy for ecosystem function that utilizes publicly available satellite and NAIP imagery, combined with field data collected by UAVs and on the ground. We will use BIOAg funding as a seed grant to develop this approach in Whitman County in cooperation with the Palouse Conservation District. With this approach, we will demonstrate the potential to improve the monitoring methods for large-scale programs, such as VSP and CREP.

Project Description:

Objective 1 VSP Review: Review all recently approved (as of November 30, 2018) VSP Work Plans (27 in total) to codify a statewide list of county-level monitoring metrics.

Objective 2 UAV surveys: Perform a field study to examine vegetation characterization using UAV deployed sensors and satellite imagery over multiple riparian locations in Whitman County. Design method for potential application in VSP monitoring.

Objective 3 Satellite data analysis: Perform a county scale analysis using satellite data to help monitor riparian structure and composition to infer ecosystem functions and values (such as habitat value and buffer strip filtering capacity).

Objectives 4-5 Technical Transfer: Create a transferable method for monitoring riparian structure and composition on agricultural lands using remotely sensed imagery. To assure transferability we will continue to coordinate with the PCD, SCC, and USDA program leads throughout the project. Prepare documents detailing our methods, strategies for extramural support, recommendations to the SCC, and a peer-reviewed manuscript. Our methods will be transferable to other counties; however, further field validation might be required given environmental variability. We envision documents and post-project communication playing an important role for agency decisions when designing monitoring protocols. Additionally, we will further our understanding of the application of emergent technologies in remote sensing, which will create lasting benefits to WSU, the state and sustainable agriculture.

Outputs

Overview of Work Completed and in Progress:

Objective 1: review existing riparian monitoring strategies and metrics

- Amanda Stahl reviewed existing plans to determine the role of riparian conservation actions, strategies, and metrics for monitoring in each of the 27 counties' VSP Work Plans.
- <u>Summary of Work Plans Review</u>:
  - Twenty-six of twenty-seven VSP Work Plans propose using aerial imagery for change detection in at least one critical area. Current protocols focus on NAIP imagery, Landsat imagery, and WDFW's High Resolution Change Detection program.
  - Metrics and action levels for riparian-related functions and values are typically in terms of % area with vegetative cover or impervious cover. Where specified, NDVI is the vegetation index used as a proxy for vegetation condition.
  - Nearly all plans emphasize the necessity of maintaining producer privacy throughout the monitoring and reporting processes under VSP.
  - Counties that are not covered by WDFW's High Resolution Change Detection Program (primarily the dryland counties of eastern Washington) lack equivalent formalized processes for change detection with available imagery.
  - None of the plans provide sharable protocols for integrating drone-based imagery into VSP monitoring. The use of aerial photos for monitoring is limited to ~2-3 counties that have existing resources for aerial image collection.
- <u>Deliverable</u>: Summary Table posted on https://labs.wsu.edu/ecology/bioag_monitoring/

Objectives 2: design UAV data collection and analysis

- <u>Training on drone imagery for change detection</u>

- Amanda Stahl received her FAA remote pilot (sUAS) certification on April 23, 2019. She has since gained experience flying three drones: 3DR Solo, DJI Mavic Air, and DJI Matrice 210 V2 with a total of ~24 remote pilot hours logged.
- Amanda has gained experience with manual flights, automated mission planning and flight using several applications, including
  - 3DR Solo mobile app
  - QGroundControl desktop app (laptop)
  - DJI Go 4 mobile app
  - DJI Pilot app
  - DJI GS Pro mobile app (tablet)
  - Pix4DCapture mobile app
- We developed a field protocol for RTK GPS data collection for high-precision measurements of reference positions calibrated for accurate change detection over time, meeting the requirements for SfM image processing, our ground-based vegetation survey, and field validation of heights in DSMs generated from SfM.
- Amanda trained Ian Barnes (undergraduate) and Ames Fowler (PhD student, WSU Civil Environmental Engineering) in the field on the protocols for working with the 3DR Solo, DJI Matrice, and RTK GPS system.

o <u>UAV field data collection, Summer-Fall 2019</u>

- Amanda communicated with eight producers to plan site visits, learn about historical and current land use, conservation practices, describe our project and answer any questions.
- We collected drone-based imagery and completed field surveys at nine riparian sites that collectively represent the range of variability in riparian vegetation across Whitman County. Analysis of this imagery is nearing completion. We constructed 3D surface models (DSMs) and calculated vegetation indices[1] to determine which metrics may be feasibly applied to riparian monitoring given the range in riparian characteristics and conservation practices across Whitman County. See images below that show initial results.
- Amanda completed 27 site visits for field and drone data collection. During that time, with the assistance of Ian Barnes, these tasks have been completed:
  - Conducted rapid field assessment of vegetation and collected drone imagery at 9 sites across Whitman County with varying characteristics in terms of riparian area and land use
  - Collected high-overlap, multi-altitude imagery for SfM with RTK GPS data to construct and validate DSMs of vegetation surface and topography at 6 out of the 9 sites

[1] NDVI = Normalized Difference Vegetation Index; NDRE = Normalized Difference Red Edge Index

  - Collected 5-band data for calculation of vegetation indices and image classification at all 9 sites

Objectives 3: satellite data collection and analysis

- Analysis and classification of satellite imagery

  We worked in partnership with PCD staff to develop a workflow using Google Earth Engine cloud computing capability to increase the efficiency and effectiveness of image analysis for monitoring. We focused on areas and metrics most relevant to periodic reporting needs under VSP, CREP, RCPP programs. Our analysis detects inter-annual change by tracking senescence patterns in potential riparian areas, naturally vegetated areas, and drylands using NDVI and Sentinel-2 imagery from 2016-2019.

  As part of a graduate course (CE543), student Neda Khosravi used our imagery data for illustrating how to use machine learning for image classification. We will be using this data to crosswalk UAV data with satellite data.

Objectives 4-5: technical transfer

- Integrating Cloud-based Remote Sensing into environmental monitoring
  - We presented this work to the PCD to evaluate the initial map (12/19/2019), assisted with the 5-year VSP reports due for Garfield and Whitman Counties (in October-November 2020), and consulted iteratively with PCD staff in the interim to refine the workflow and products.
  - Upon request, we also adapted the workflow to fit the riparian reporting needs of Walla Walla County VSP and provided products (maps and statistics) to Walla Walla Conservation District for this purpose (September-October 2020).
  - More work is needed to communicate how cloud-based remote sensing can enhance monitoring programs and address the capacity-based barriers to implementation (as discussed in our manuscript). We have outlined the steps needed, but this process has not yet been completed for integrating these technologies into VSP, CREP, RCPP, or state agency habitat monitoring programs. Details are provided in the Recommendations for future research section below.
  - Deliverable: We have submitted a manuscript for peer-review to Bioscience (Impact Factor: 8.3; draft manuscript provided) describing how cloud-based remote sensing can be better utilized in VSP and more generally in environmental monitoring. We describe the general approach using monitoring metrics and riparian ecosystem functions at the cross-watershed scale by analyzing Sentinel satellite imagery with Google Earth Engine to document riparian condition using patterns of senescence through the dry season from year to year. Validation of these models will utilize knowledge of PCD contacts, drone-based imagery, NAIP imagery, and field survey data.

Methods, Results and Discussion:

- Objective 2: Collection of drone-based imagery (see attached photos)

  We have collected field data and drone-based imagery at 9 sites across Whitman County. At 6 of those sites, we collected data for two types of analysis: (1) multispectral (5-band: blue, green, red, red edge, and near-infrared) using the MicaSense RedEdge MX and (2) RGB imagery for structure from motion (SfM) to construct a 3D surface model of the vegetation or land surface. At the remaining 3 sites we collected only multispectral data.

  - Multispectral data collection: MicaSense RedEdge MX with DJI Matrice 210
    Missions were planned in DJI GS Pro to minimize flight time while sampling the representative riparian characteristics of the site. Altitudes varied by site, ranging from 30-50m to accommodate the tallest vegetation and avoid any other potential hazards. The MicaSense RedEdge MX cannot be triggered by the DJI software and was thus operated separately via direct wifi connection with a mobile device. Front and side overlap were 75%. Missions were flown within 2 hours of solar noon according to the manufacturer's recommendations. Images of reflectance calibration panels were collected immediately before and after each flight.
  - RGB imagery: GoPro Hero 4 with 3DR Solo
    Missions were planned in QGroundControl to minimize flight time while sampling the representative riparian characteristics of the site. Mission altitudes varied by site, ranging from 18-40m to capture the highest possible ground resolution while accommodating the tallest vegetation and avoiding any other potential hazards. Each mission included a double grid (i.e., re-flying the mission at 90 offset) with 85% front and side overlap as well as image collection along an upper transect at least 5 meters above the grid altitude. Ground control points (GCPs; 6 per mission area) were placed randomly and RTK GPS coordinates were collected for each GCP before flight. Missions were flown within approximately one hour of solar noon to minimize shadowing.
  - Rapid field assessment/vegetation survey
    Field data were collected to coarsely document the vegetation characteristics at each site. These included an estimated % cover or number of individuals of vegetation types of interest. RTK GPS data were collected for each vegetation type. Where applicable, plant heights were measured from RTK GPS points for ground-truthing heights modeled by SfM.
  - Processing drone-based imagery (see attached example outputs)
    Images collected from the GoPro Hero 4 are rendered using AgiSoft Metashape Professional. RTK GPS data are corrected for the Washington State Plane South spatial reference system to ensure accurate comparisons by location over time. The corrected RTK GPS data are imported into AgiSoft and each GCP location is inspected by hand before rendering. The AgiSoft workflow produces a DSM and georeferenced 5-band orthomosaic from the input drone-acquired imagery. Vegetation indices can be calculated within AgiSoft or the 5-band orthomosaic can be exported as a GEOTIFF for subsequent analysis in GIS software.

Images collected from the MicaSense RedEdge MX are rendered in AgiSoft Metashape Professional and for the purpose of this study do not require the input of GCP coordinates. We use the AgiSoft workflow for a multi-camera system with MicaSense reflectance calibration procedure to generate a georeferenced orthophoto in the WGS84 spatial reference system.

- Objective 3: Sentinel data collection and analysis in Google Earth Engine (GEE) and ArcGIS

  We investigated the potential to streamline the process of accessing and analyzing satellite remote sensing data for monitoring through the Google Earth Engine platform. We have developed scripts for querying available data sets, clipping to areas of interest, coarsely classifying vegetation within potential riparian areas as "evergreen" or early-senescing (agricultural land use), and computing differences in vegetation indices to document seasonal patterns of senescence within each class. With these scripts, the user can easily repeat processes on new imagery as it becomes available and potentially compare images across years by season to detect change. This workflow is designed to make natural inter-annual variability in vegetation vigor (e.g. due to moisture availability) transparent so that we can reduce uncertainty in detecting change due to restoration or agricultural practices.

  - We repeated a subsample of the spatial analysis in ArcGIS to confirm the accuracy of area-based statistics in GEE. The results were nearly identical (with errors < 0.02 NDVI, much less than the standard deviation in NDVI values by vegetation class).
  - All satellite image classification in this study is scripted in Google Earth Engine (GEE). The first step is a coarse cover classification to distinguish natural from agricultural or dryland vegetation. The next step applies a set of nested conditional statements to categorize pixels by patterns of change in cover class over the years of interest. The resulting "stability classification" can be used to (1) assess whether detected change is natural vs. anthropogenic and (2) *provide more accurate context for evaluating changes in NDVI or other metrics through time.*
  - We worked with PCD staff to determine the capability of this GEE-based approach to accurately detect change in a way that can be reasonably integrated into VSP, CREP, RCPP monitoring and reporting processes.
  - NOTE: We did not complete (2) in the list for multiple reasons. (1) With COVID restrictions (travel and no day care) we could not collect a second field season of data. (2) We intentionally focused on maximizing what can be done with freely available satellite data in GEE; and (3) The technical capacity for this integration is beyond what the CDs can incorporate in to monitoring.

Publications, Handouts, Other Text & Web Products:

Objective 5: produce documents and other deliverables.

- The manuscript for Chapter 3 of Amanda's dissertation is in review at Bioscience: *Cloud-based environmental monitoring: dynamically incorporating remotely sensed imagery into decision-making*
- Amanda presented this work at
  - The 2020 Virtual Geo for Good Summit, Public Sector Meetup: *Streamlining access to remotely sensed imagery with Google Earth Engine to increase ecosystem monitoring efficiency and effectiveness*. https://earthoutreachonair.withgoogle.com/events/geoforgood20
  - The 2020 GPSA Research Exposition (WSU): *Applying drone and satellite data to natural vegetation monitoring for agricultural sustainability.* https://showcase.wsu.edu/2020/04/22/applying-drone-and-satellite-data-to-natural-vegetation-monitoring-for-agricultural-sustainability/
- Ian Barnes is preparing a data for a manuscript entitled *Topographic accuracy of SfM using UAVs for vegetation monitoring.* Undergraduate thesis for SOE student (Ecosystem and Environmental Science Major). This publication is slated for preparation in 2021. Alex and Amanda will take the lead using Ian's data.
- We will prepare documents detailing our methods, strategies for extramural support, and recommendations to the SCC.
  - Initial versions of the documents detailing our methods are attached.
- We will work with PCD contacts to develop a report with guidelines for delivery to CDs, counties, and the Conservation Commission. With the support of PCD, we will conduct and record a *webinar* that can subsequently be posted online to help transfer new knowledge of these methods and potential applications to those involved in documenting and reporting change for VSP & CREP.

Outreach & Education Activities:

Objective 4: ensure transferability

- We have met with Laura Heinse (PCD), Brad Johnson (PCD, VSP for Whitman and Garfield Counties), Ryan Boylan (PCD), Brian Cochrane and Levi Keesecker (WA Conservation Commission) to guide the development and implementation of this project. Brad Johnson contacted producers engaged in riparian conservation practices to ask permission to include their riparian buffers in this study.
- Amanda Stahl has had conversations repeatedly with each of the participating producers. Altogether, these interactions have provided us with individual, county-level, and state-level perspectives on what is currently planned for riparian monitoring and VSP reporting, what is needed, useful, or desirable (e.g. in securing future funding for voluntary riparian conservation projects).
- We have consulted repeatedly with Brad Johnson (PCD), Levi Keesecker (SCC) and several times with Renee Hadley (Walla Walla CD) to refine our analysis and products to fit their needs.

- We have communicated with Alex Case-Cohen at the Pend Oreille Conservation District on the use of GEE in VSP monitoring.
- Conversations with them about the current capacity of CDs for monitoring/image analysis suggest that integration of our methods into monitoring protocols would require one or more of the following:
    - Training of CD staff through workshops/webinars and online resources
    - Ongoing support from us or other experts for image acquisition, analysis, interpretation
- Contracting with consultants for image acquisition, analysis, interpretation via the workflow developed in this study could streamline the process and minimize costs, while potentially maintaining consistency in reporting across counties. We plan to conduct a webinar with accompanying documents to disseminate knowledge, methods, potential applications in monitoring to other CDs, counties across the state as well as the WACC and any other individuals involved in the technical review of VSP reports.
- We will host all documentation and links to online resources on our website once the paper is accepted for publication.

Impacts

- Short-Term: PhD Student Ames Fowler and undergraduate Ian Barnes have been trained in the field methods and drone image processing aspects of this project. Graduate student Neda Khosravi evaluated supervised classification techniques using drone imagery acquired during this study for a class project and plans to pursue that line of research in future.
- Intermediate-Term: We are developing methods for using drones and satellite data for vegetation change analysis and habitat condition monitoring at WSU.
- Long-Term: Publication submission to Bioscience on CBEM

Additional funding applied for/secured:

- Amanda Stahl submitted a Smith Fellowship application in fall 2020 for postdoctoral funding at WSU
- Ames Fowler has applied for funding to support detection of geomorphic change using similar methods, informed by the knowledge gained from this study. (BioAg recipient 2020)
- We began discussions with WDFW about employing this method for riparian monitoring across the State.
- Working with MS student and full time Spokane CD employee Seth Flanders. Two studies with Ames using field measured soil erosion to validate estimates from UAVs.

Graduate students funded:

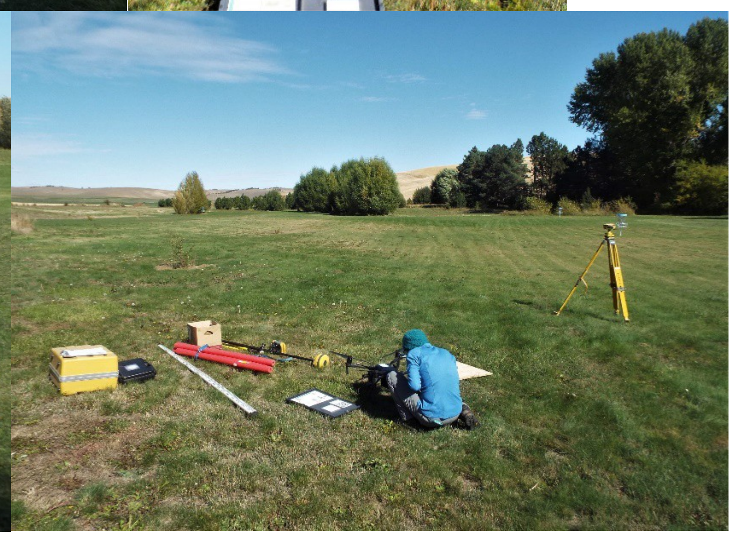
- Amanda T. Stahl (PhD completed, Summer 2020)
- Ian Barnes (BS completed, Spring 2019, Undergraduate, senior thesis)

Recommendations for future research:

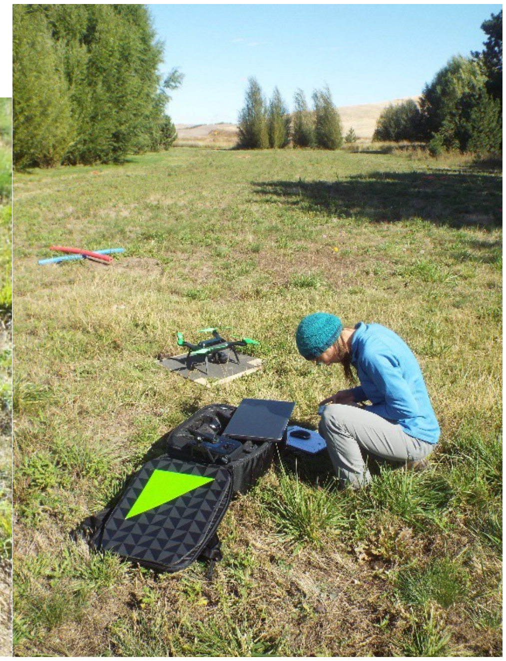
- Another season of data – drone AND satellite data to enable us to crosswalk seasonal patterns of change in vegetation indices (across image sources); an additional Fall season would be best to improve the phenological method for vegetation characterization
- Coordinate with PCD and producers to compare images collected before and after riparian restoration actions (drone, UAV and handheld)
  - We already have “before” images for one site where they were planning to do more plantings Fall 2020. Owner amenable to providing access for post survey.

- Additional time to transfer cloud-based image analysis workflow: prepare webinars, online documentation (YouTube channel with instructional videos for other conservation districts, state agencies and NRCS)
- Development of an Earth Engine App to increase ease of use by providing a user-friendly interface of the satellite image analysis workflow,
  - Apps can be accessed with a URL that does not require a GEE user account or any coding ability.
  - Only minimal training is needed for the user to access or query satellite imagery, with our scripts running in the background to execute the workflow.
  - We can give more experienced users access to the script so that they can modify and then adapt the app to suit needs of different reporting entities or other programs.
- Provide technical support to refine and implement protocols for drone-based image collection and analysis for riparian monitoring with technical transfer to PCD staff.
  - Drone and sensor purchases are feasible/planned by PCD
  - Knowledge gained from this study could be transferred via a series of several field sessions and accompanying documentation of drone protocols
  - PCD staff would need initial training in drone image processing, which could be completed in a series of Zoom workshops and/or instructional videos



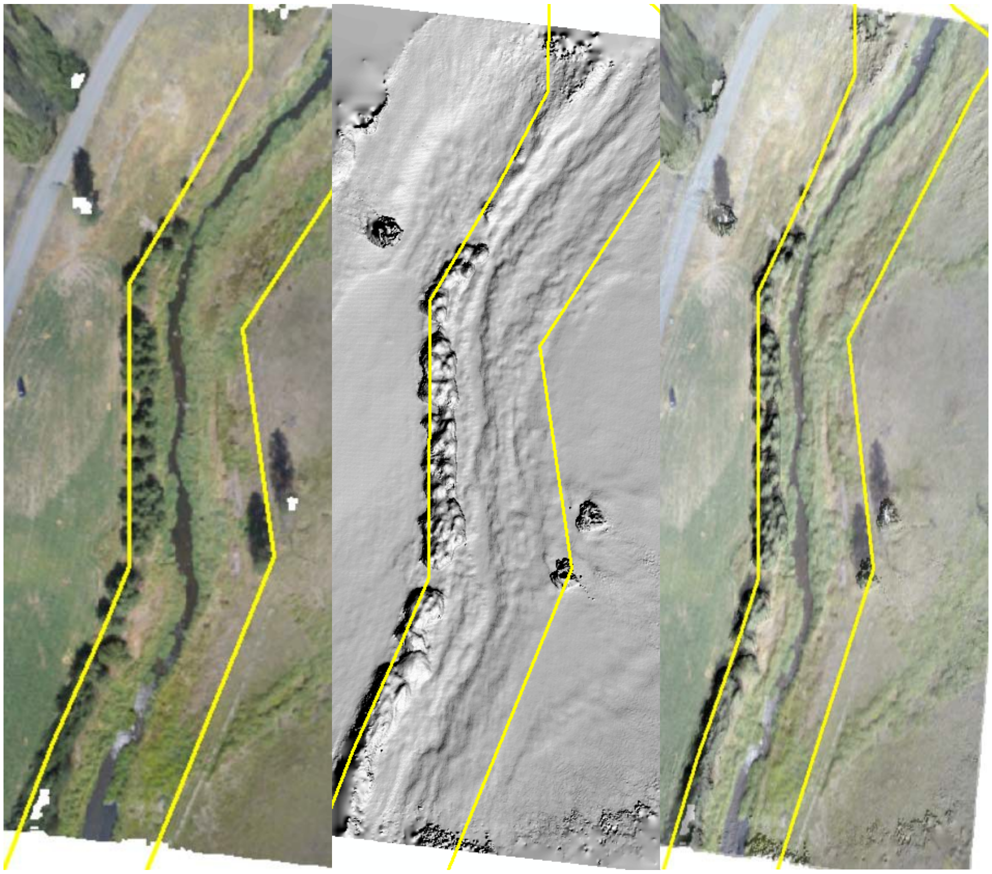




Amanda Stahl preparing the Matrice for a mission. Photo Credit: Tom Schierman



Amanda Stahl refining and executing automated mission plans to collect imagery for 3D surface (DSM) modeling. Photo credit: Tom Schierman

Left: Ian Barnes placing the rover to collect RTK GPS coordinates of a control point.
Right: Ian Barnes documenting a location during a vegetation survey.

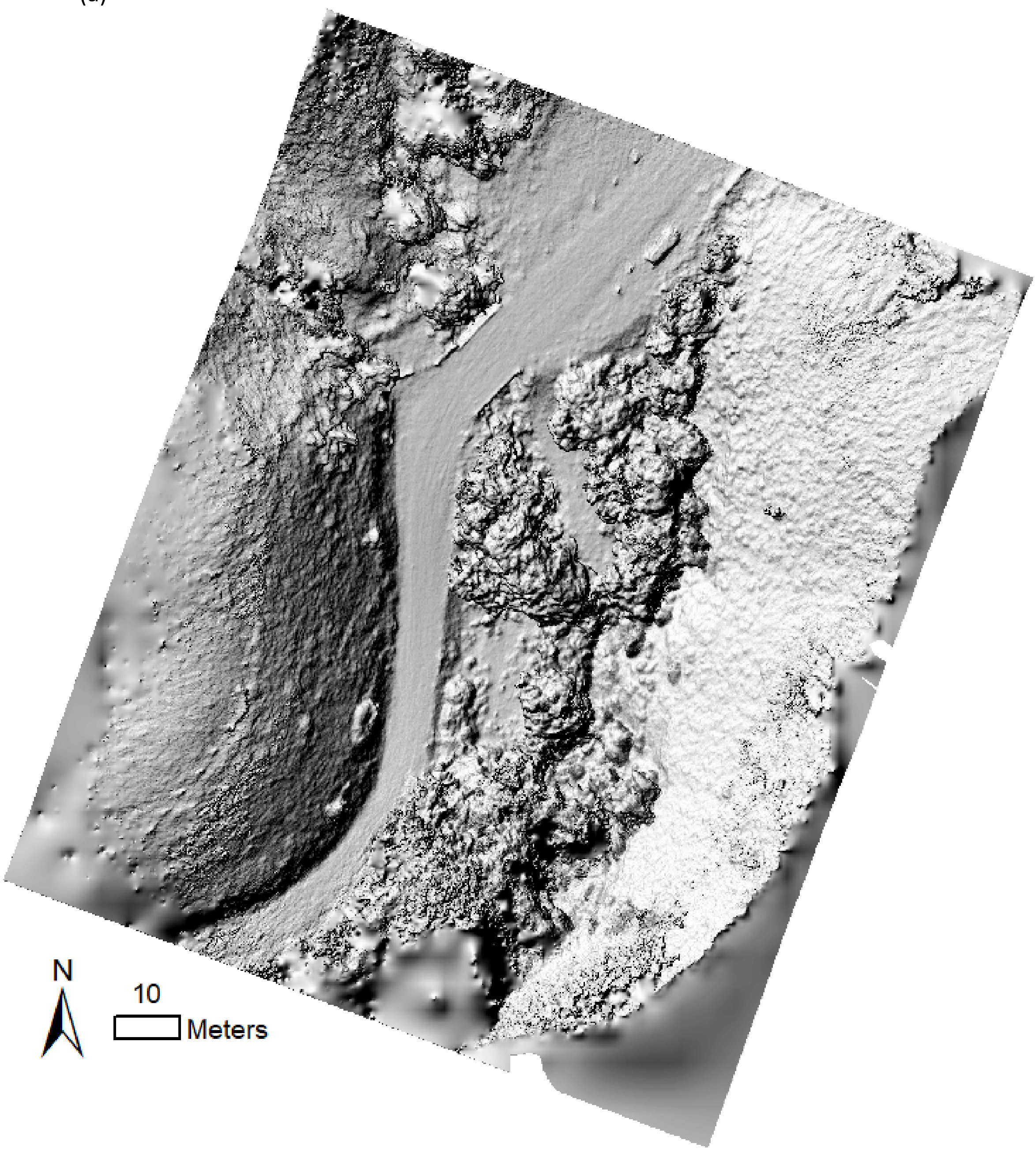


(a) (b) (c)

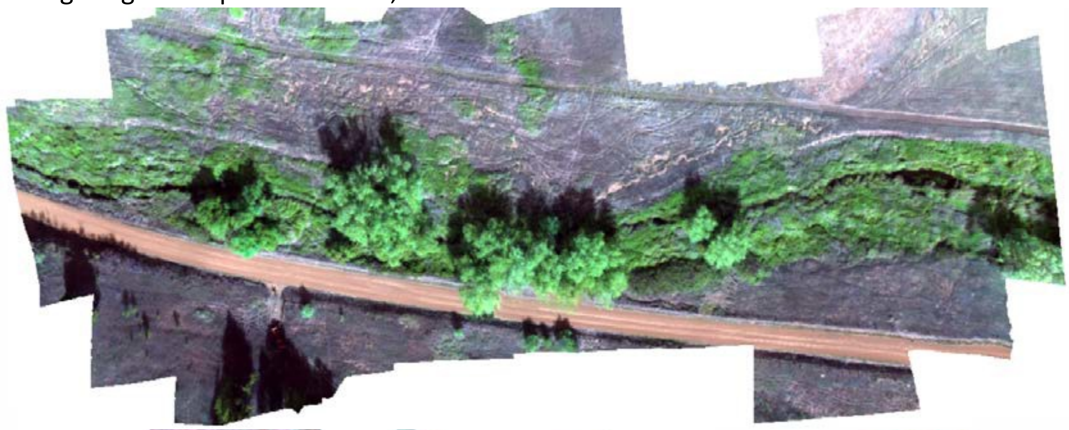
Above: Example of (a) georeferenced orthomosaic and (b) digital surface model (DSM) from SfM processing of RGB drone imagery in AgiSoft Metashape. The image in (c) shows the RGB orthomosaic draped over a hillshade layer generated from the DSM. Data collected Aug. 28, 2019 covers ~5 acres of a riparian buffer near Colfax, WA. Mission altitude: 35-40m.

Below: Another example of (a) digital surface model (DSM) from SfM processing of RGB droneimagery in AgiSoft Metashape. This site is located in a side canyon of the Snake River canyon. The image in (b) (next page) shows the RGB orthomosaic draped over a hillshade layer generated from the DSM.

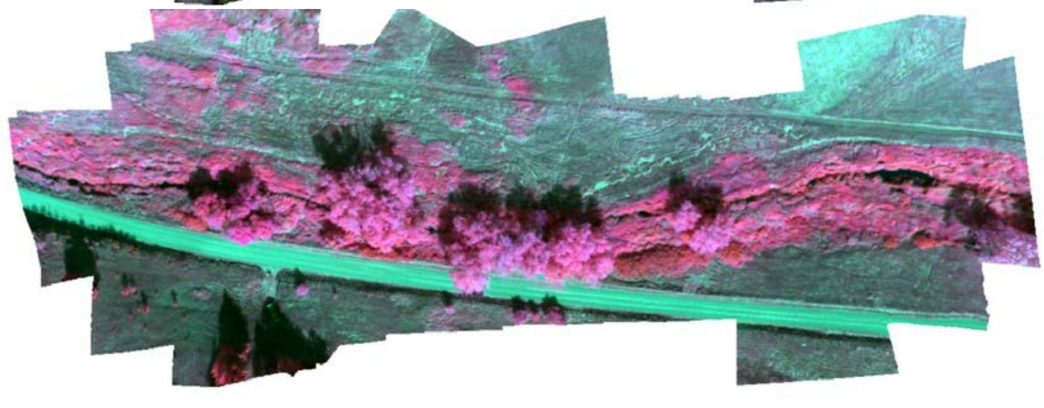
(a)

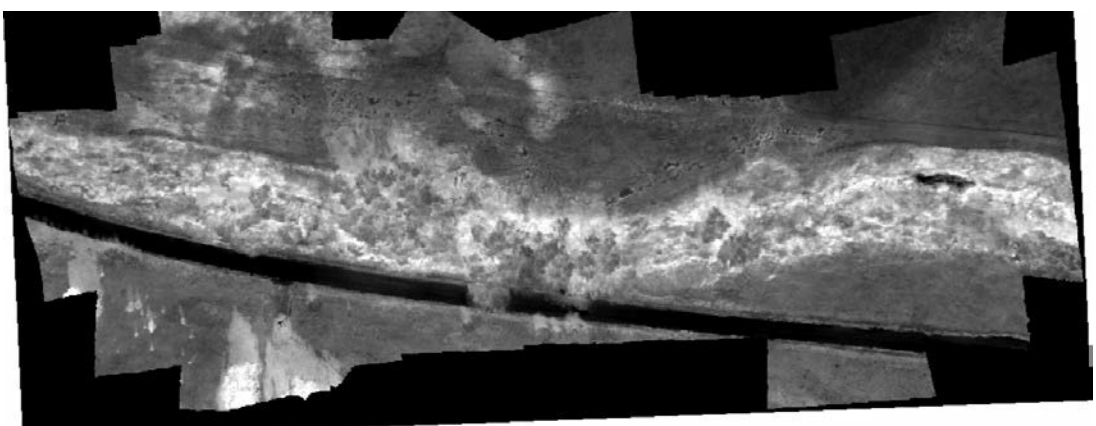


Next page: Orthomosaic generated from images collected by the RedEdge MX multispectral sensoraboard the DJI Matrice at a riparian area within the Hudson Biological Reserve at Smoot Hill (WSU).Highest values for NDVI and NDRE are white; lowest are black. Data collected Sept. 25, 2019.



(a) true color





c) NDVI