Klamath Meadows Delineation

Introduction

The Sierra Nevada Meadows Compilation dataset (UC Davis, Center for Watershed Sciences & USDA Forest Service, Pacific Southwest Region 2017) has served as a useful resource for multiple purposes in restoration and management (Viers et al. 2013). Interest in expanding and generating similar meadows data for forests outside the Sierra Nevada spurred a pilot effort to apply the approach to the USFS Region 5 Northern Province.

With limited pre-existing data, one of the primary goals of digitally mapping meadows was identifying the best method for accurately and efficiently mapping meadows in the Northern Province. Two hydrologic basins (HUC10), East Fork Scott River and Tangle Blue Creek-Trinity River were selected in order to capture an area that contained a variety of meadow types.

Objectives

The primary objectives were to map all meadows that were greater than one acre in area on USFS lands within the selected basins (Figure 1), following methods used in Sierra Nevada meadow delineation. In addition, identifying and refining the steps used, as well as describing common issues and challenges, were detailed to help guide future meadow mapping efforts in other areas with limited pre-existing data.

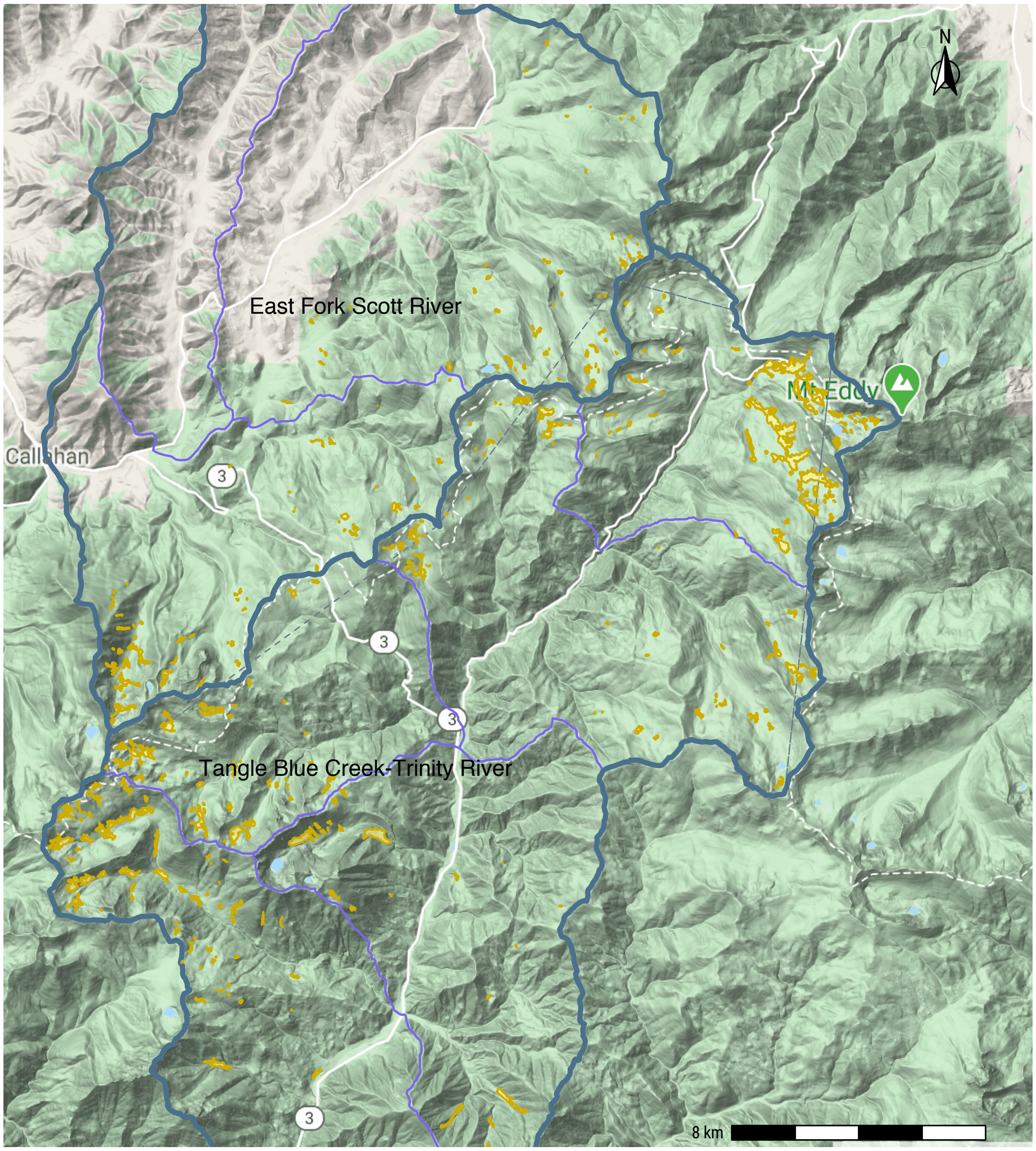

Figure 1. Map of study area and meadow polygons.

Methods

The methods used in delineating meadows in the Klamath region are detailed below. Where possible, exact file names and tools used (software or package) have been identified. All meadow polygon delineation was conducted in ArcMap (ESRI), and subsequent data and spatial analysis was done in R (R Core Team 2019).

Compile Layers

The first component of digitizing meadows is to compile all the necessary spatial layers required for mapping. The layers used in digitizing meadows were as follows:

Focus area layers:

- Area of interest
    - HUC 10 and HUC12 watershed boundaries
    - USFS property boundaries
- Layers used while delineating meadows
    - ESRI hi-res aerial imagery basemap (imagery dates vary across extent, always check imagery date at delineation location)
    - Sentinel2 10m resolution imagery from other times of year (compare to the basemap at various locations within area of interest)
    - NDVI greenest pixel compilation from LANDSAT and MODIS imagery (generated using Google Earth Engine (see attached code))
    - National Wetlands Inventory (NWI) polygons
    - National Hydrography Dataset (NHD+ streamlines) to check for stream presence
    - A 500 m x 500 m grid to help keep track of search coverage (optional depending on region)

Meadow Delineation Attributes

For each meadow that was delineated, a set of attributes was collected. These were generated based on a template table (Table 1) which provided some basic information about the delineation.

Table 1. Meadow attribute table template (created once, exported copies for each block that was digitized).

Field	Description
BLOCK_ID	Forest service block ID
STREAM_YN	Stream present in polygon (Yes or No)? Visual inspection and NHD+ streamline
TREES_YN	Trees present in polygon (Yes or No)?
TREES_G25	Tree extent greater than 25% of polygon extent (Yes or No)?
ROAD_YN	Road present in or immediately adjacent to meadow polygon (Yes or No)?
NWI_FID	FID of the NWI polygon overlapping meadow polygon (if more than one, select largest polygon, prioritize emergent wetland polygon over forested polys)
CONFIDENCE	Confidence of whether polygon is a meadow, boundary accuracy
NOTES	Additional notes (details about confidence, other NWI polygon FIDs, etc) (Tip: put text field character limit to at least 150)

Delineate Meadow Boundaries (using ArcMap unless specified otherwise)

The following steps outline the method and approach used in digitizing meadows.

1. *Divide USFS property boundary shapefile into manageable blocks*
    a. Use the tool **Multipart To Singlepart** (Data Management toolbox) to split parcels into individual polygons (one polygon per row in the attribute table).
    b. For larger features, split polygons into approximately 1 mi x 1 mi blocks using the **Split Polygons** tool in the Editor toolbar
        i. Right click the newly created single-part feature layer, click **Edit Features → Start Editing**
        ii. Select an individual polygon using the select tool or by clicking a row in the attribute table. Click the "**Split Features**" icon in the Editor toolbar and draw a line from one edge of the polygon to the other. You can draw multiple line segments; double-click on the second edge to complete the split. If you do not

fully separate the polygon into two pieces with the line (either by not splitting the selected polygon, or not fully crossing each boundary edge) the split will not work.

   c. Once polygons have been split into blocks, create a unique ID field (BLOCK_ID) and number polygons sequentially (e.g., useful to start with 3 or 4-digit numbers, 101 or 1001, to avoid issues with leading zeroes)

2. *Track completed and in-progress meadows*: Create a new spreadsheet (i.e., Excel) with one row per unique polygon/unique ID (BLOCK_ID).
   a. Recommended fields:
      i. BLOCK_ID
      ii. FORESTNAME
      iii. HUC10_ID
      iv. HUC12_ID
      v. HUC12_NAME
      vi. INITIALS (of person delineating)
      vii. STATUS (in progress, complete)
      viii. QC (initials of person who did QA/QC on that block)
      ix. NOTES (any delineation notes such as things that should be checked during QAQC, what was observed if nothing was delineated, etc)
3. *Create a sampling grid to keep track of search within blocks (OPTIONAL)*
   a. Use the tool "**Create Fishnet**"; use the study extent (e.g. watershed) as the template extent, which should auto-fill the origin coordinates. In this pilot cell size width and height = 500 m. Uncheck "**Create Label Points**" and use Geometry Type = POLYGON.
   b. Even more optional: select an individual block, and use the **Select Features** tool to select grid cells that overlap that block. Export the grid file (Right click the grid in the table of contents → Data → Export, ensure that "**Selected Features**" is checked) to create a search grid only for the FS Block of interest.
   c. To use the grid, set the polygon fill to No Fill and the outline to something pale (easier to see against the darker imagery)
4. *Create a template file to keep block-specific meadows files identical* (see Table 1)
5. *Export new meadow shapefile*
   a. Right click template file in Table of Contents → Data → Export
   b. Name convention: Meadows_[FS Block ID].shp
6. *Start Editing the new shapefile*
   a. Right click Meadows_[FS Block ID].shp, click Edit Features → Start Editing
7. *Click **Create Features** button in Editor toolbar*
   a. Make sure shapefile of interest is visible
   b. Click on shapefile of interest in **Create Feature** window/pane
   c. Click on **Polygon in Construction Template** panel
8. *Start delineating using the high-resolution basemap*
   a. Make sure zoom is at a scale of 1:1500
   b. For the identified meadow, click along boundary, and double click to close off polygon
   c. Fill out attributes in attribute table
   d. SAVE EDITS FREQUENTLY (Editor dropdown in Editor toolbar)
   e. When block is complete, save edits and stop editing before exporting meadow template to create a new meadow shapefile for the next block

Delineation Tips

When searching for meadows in a given forest block, it's often easier to search at 1:3000 – 1:5000 scales depending on your monitor size and search area. When delineating at 1:1500, it can still be beneficial to zoom out to see the larger context before zooming back in to continue drawing the polygon. It is also very useful to toggle back and forth between the basemap and other rasters (NDVI greenest pixel, Sentinel 2 imagery from different times of year, see Figure 9) to check boundaries. This can be useful detect whether a given patch appears brown year-round (bare rock/soil) or whether it is significantly greener early in the season (meadow grass). Confidence in meadow delineation ("high", "moderate", or "low") reflects a combination of confidence in whether or not the area delineated was a meadow and in the accuracy of the boundary drawn. Open areas that were clearly bare rock or dry upland scrub, or wetlands that show up in NWI but are entirely forested, should not be delineated.

Additional Meadow Attributes

Once the final set of meadow polygons was created, additional attributes were generated for each individual meadow, based on a subset of attributes from the Sierra Nevada Meadows Compilation (Table 2). These attributes were generated with scripts in R with RStudio. These attributes were calculated using the same methods as described in the Sierra Nevada Meadows dataset to make future comparisons possible. Additional attributes may be calculated with additional effort to make attributes identical across the two datasets.

Table 2. Additional polygon attributes generated with R.

Field	Description
UID_CH	Unique identifier (generated using R package ids::proquint)
UID_INT	Integer unique identifier generated from character unique ID
PERIMETER_M	Perimeter in meters (sf::st_perimeter)
ELEV_MEAN	Extracted from 10 m DEM
ELEV_RANGE	Extracted from 10 m DEM
EDGE_COMPLEXITY	Index of meadow edge complexity (meadow perimeter/perimeter of a circle of equal area)

Results

In this pilot study we delineated a total of 377 meadows across eight sub-watersheds in the Tangle Blue Creek/Trinity River and East Fork Scott River (Table 3). A total of 106 meadows were delineated with "high confidence", 192 with "moderate confidence", and 75 with "low confidence".

Table 3. Summary statistics for meadows delineated on USFS land in the Tangle Blue Creek/Trinity River and East Fork Scott River HUC10 watersheds. Observations include total number of meadows delineated, total meadow area delineated, and those observed containing a stream, trees, tree cover greater than 25% of meadow area, or roads.

Total Meadows	Stream Present (total %)	Trees Present (total %)	Tree Cover > 25%	Road Present	Total Area (ha)	Total Area (acres)
377	205 (54%)	292 (77%)	57 (15%)	42 (11%)	672.1	1661.0

Examples of Meadow Delineations

Examples below provide examples of meadow delineations across different mapping confidence levels, as well as areas that were excluded or not delineated as meadows.

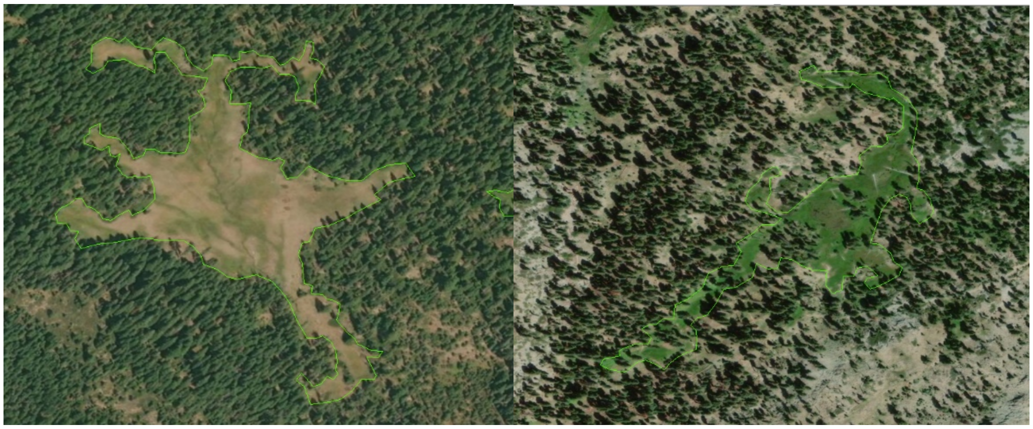

Figure 2. Examples of meadows delineated with "high confidence".

Figure 3. Examples of meadows delineated with "moderate confidence".

Figure 4. Examples of meadows delineated with "low confidence".

Figure 5. Examples of open areas not considered meadows, such as areas dominated by dry upland shrub and bare ground (left) or open timber harvesting/cut areas (right).

Challenges and Limitations

Some of the challenges associated with delineating meadows in the Northern Province included uncertainty arising from a lack of on-the-ground regional familiarity, seasonal variation within high-resolution imagery (somewhat mitigated by low-resolution sentinel and NDVI imagery, but finer details were lost in those images), and variation in the accuracy of digitized NWI polygon locations. A particularly challenging aspect of digitizing meadow boundaries was identifying boundaries within forested areas (Figure 6B).

Limitations associated with meadow delineation using remote-sensing methods included difficulty differentiating different vegetation types from aerial imagery, particularly in different seasonal periods (see Figure 6). While digitizing a large area is feasible given the above approach, it is nonetheless a time-intensive process. Without fine-scale soil and/or hydrology data, it may be difficult to assess and evaluate the boundaries of these polygons. Ground-truthing of digitized meadows is an important step towards refining and improving these data.

Figure 6. Examples of uncertain boundaries: some meadows appear to be hydrologically connected through forested areas (A), and the boundaries between dry grass, scrub, and bare ground are often unclear in satellite imagery (B).

Figure 7. Examples of open wetland areas that are borderline wetland cases. Should wetlands with complete shrub coverage (A) be included, or should the dataset be restricted to wetlands with at least some open areas? Should wetter streamside areas that are shrub-dominated (B) compared to drier scrubby upland areas be included?

Figure 8. Importance of time of year: meadows look very different early (A) and late (B) in the growing season.

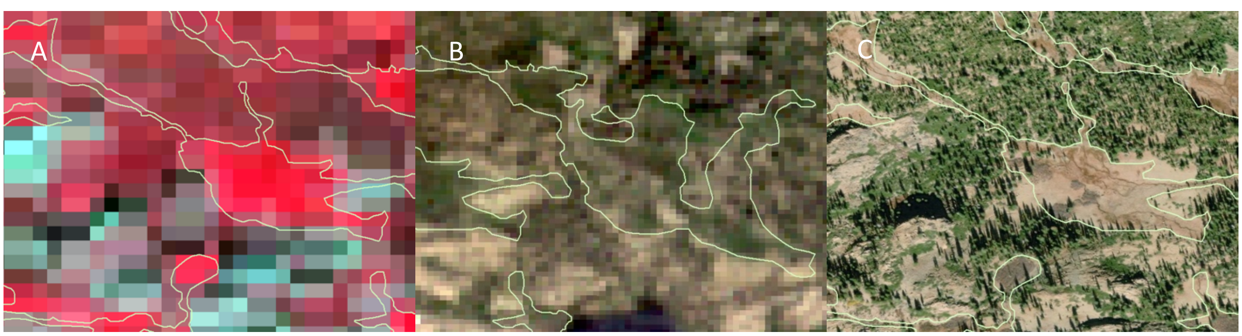

Figure 9. Utility of NDVI greenest pixel (A) and Sentinel 2 imagery (B) from different time of year in distinguishing bare ground from dry grass in late-season high-res ESRI imagery (C).

Next Steps

It would be valuable to conduct ground-truthing at a select set of meadows. A sample of potential meadows for validation has been provided within the above dataset. On the ground delineation of the meadow edge/boundary with a hand-held high-resolution GPS (i.e., Trimble) would be useful to identify certainty in the remote-sensing delineation. Hydrogeomorphic typing would also help identify meadow classifications, following Weixelman et al. (2011). In addition, if a streamline exists, delineating the streamline, and identifying vegetation types at a set of random points within and immediately adjacent to the meadow polygon would help inform mapping.

In addition, regional or local knowledge about meadows can be invaluable in developing a training meadow dataset. Ideally this would include a range of meadow types that could be encountered within a region. This can be combined with detailed ground-truthing data to provide a useful resource for additional remote-sensing delineation. If high-resolution imagery exists for a given Forest (i.e., LIDAR), these data can also be incorporated in polygon delineation to provide a more comprehensive and robust dataset.

Code

Code used to generate analysis and summary data is located on a version-controlled repository at:
https://github.com/ucd-cws/klamath_meadow_mapping

This repository contains:

- Shapefiles used/and created (**data/shps.zip**)
- Code (R) used to generate and view the meadows in R (**code/**)
- Code (Javascript) used to generate/export GeoTiffs of the greenest pixel and Sentinel2 imagery from Google Earth Engine (**code/GEE**)
- A summary report and html based maps of the study results (**docs/*.zip**)
- Figures showing side-by-side comparisons of mapped meadows used in the report (**figs/**)

Additional materials are shared on a Box folder.

References

R Core Team. 2019. *R: A Language and Environment for Statistical Computing* (version 3.6.2). Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/.

UC Davis, Center for Watershed Sciences & USDA Forest Service, Pacific Southwest Region. 2017. "Sierra Nevada Multi-Source Meadow Polygons Compilation (v2.0)." *Sierra Nevada Multi-Source Meadow Polygons Compilation*. http://meadows.ucdavis.edu/.

Viers, Joshua H., Sabra Purdy, Ryan A. Peek, Anna Fryjoff-Hung, Nicholas R. Santos, Jacob V. E. Katz, Jason D. Emmons, Danielle V. Dolan, and Sarah M. Yarnell. 2013. "Montane Meadows in the Sierra Nevada: Changing Hydroclimatic Conditions and Concepts for Vulnerability Assessment." CWS-2013-01. Davis, California: Center for Watershed Sciences, University of California, Davis.

Weixelman, D. A., B. Hill, D. J. Cooper, E. L. Berlow, J. H. Viers, S. E. Purdy, A. G. Merrill, and S. E. Gross. 2011. “A Field Key to Meadow Hydrogeomorphic Types for the Sierra Nevada and Southern Cascade Ranges in California.” *US Forest Service, Pacific Southwest Region, Vallejo, California, USA*.