Lessons Learned in Historical Mapping of Conifer and Oak in the North Coast[1]

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Abstract

Conifer encroachment into oak woodlands is becoming a pressing concern for oak conservation, particularly in California's north coast. We use Object-Based Image Analysis (OBIA) with historical aerial imagery from 1948 and recent high-spatial-resolution images from 2009 to explore the potential for mapping encroachment using remote sensing. We find that pre-processing historical aerial imagery is time-consuming and that OBIA requires training and experience but has promise for mapping the phenomenon of interest. We also find that identifying conifer and oak in the imagery without ground-based information is not consistently possible. We recommend iterative mapping and field work, both for obtaining field samples to map encroachment and for mapping woody versus herbaceous cover as a way to screen for locations with potential oak recruitment.

Key words: conifer encroachment, high spatial resolution images, historical aerial images, National Agricultural Imagery Program, object-based image analysis, orthorectification, supervised classification

Background

Loss of oak woodlands is a widespread concern. Though some threats have been well studied, such as sudden oak death (Swiecki and Bernhardt, *Phytophthora ramorum* canker (sudden oak death) disease risk and progress in coast live oak, 2000-2012, these proceedings) and gold-spotted oak borer (Seybold and Coleman, The goldspotted oak borer: revisiting the status of an invasive pest six years after its discovery, these proceedings), quantifying encroachment from other woody species is just beginning. Encroachment and conversion of oak woodlands to closed-canopy forest is a frequent occurrence (Cocking and others 2012), and many species can encroach into woodlands (Cocking and others, Conifer encroachment in California oak woodlands, these proceedings). We focus in this study on Douglas-fir (*Pseudotsuga menziesii*) encroachment into Oregon white oak (*Quercus garryana*) and California black oak (*Q. kelloggii*) woodland in the north coast of California.

University of California Agricultural and Natural Resources supported a study of conifer encroachment in Humboldt and Mendocino Counties. This larger project included 1) a policy analysis and review of forest practice rules (Valachovic and others, Can the California Forest Practice Rules adapt to address conifer encroachment? these proceedings), 2) a field study of understory diversity, canopy species composition, and age and size structure at 10 sites (Schriver and Sherriff, Establishment patterns of Oregon white oak and California black oak woodlands in northwestern California, these proceedings), and 3) the work described here:

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exploring the capabilities of historical aerial imagery for mapping encroachment over larger scales.

Given that the goal of the mapping component of the project was to understand the rate and extent of conifer encroachment, and that the time to replace oak with conifer can be 60 to 100 years (Cocking and others, Conifer encroachment in California oak woodlands, these proceedings), we need a source of geographical information that dates back far enough. Fortunately, historical aerial imagery does exist from the 1930s and 1940s and increasingly the discipline of historical ecology is developing rigorous methods for reconstructing historical landscapes (Grossinger 2012, Whipple and others 2011). Therefore we refined the goals of the mapping component of this study of encroachment to focus on exploring the use of historical aerial black-and-white imagery for quantifying the change from oak to conifer over the last 60 years. What is involved in obtaining, pre-processing, and classifying historical aerial imagery? Can we map encroachment? If so, what is the rate and extent of encroachment at our sites? If not, what can we map from the historical imagery, and what else would be needed in order to map encroachment?

For the larger study, we chose 10 sites throughout Humboldt and Mendocino Counties (fig. 1). They reflect a variety of latitudes as well as coast-to-inland locations for oak woodlands. They include both public and private lands. They were specifically chosen because they contained examples of the full spectrum of encroachment, from pure oak stands ranging up to highly encroached stands with Douglas-fir forming the majority of the canopy.

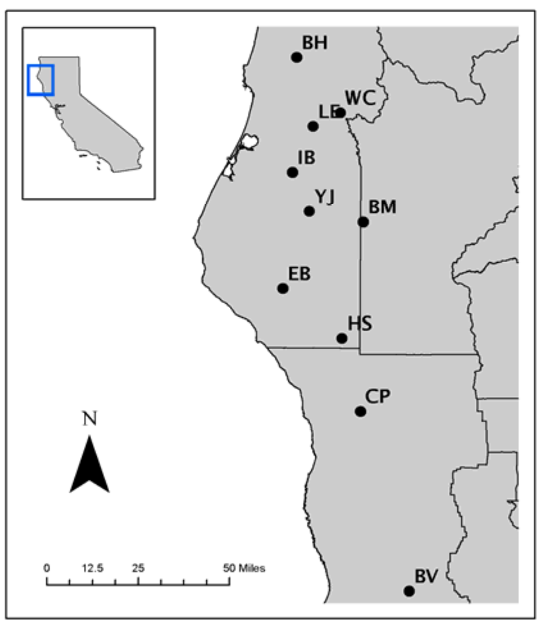

Figure 1—Study sites (named for their U.S. Geological Survey quad).

Our black-and-white historical images come from a 1947-1948 flight commissioned by the U.S. Department of Agriculture, Forest Service. They were scanned at 800 dots per inch by the California Geological Survey (CGS), which, after pre-processing, results in a spatial resolution of less than a meter. The recent images come from the 2009 National Agricultural Imagery Program (NAIP) of the U.S. Department of Agriculture. These one-meter resolution images contain four bands: red, green, blue, and infra-red, and are already pre-processed (georegistered and orthorectified).

We have broken our study into four parts: 1) locating and pre-processing the historical imagery, 2) segmenting the imagery into objects to use Object-Based Image Analysis (OBIA) techniques on the high-resolution imagery, 3) determining what is visible in the imagery without ground-based data, and 4) using information from the field component of the study to attempt a supervised classification. We give details and lessons learned about each stage below, followed by comments on opportunities and recommendations.

Part 1: Pre-processing historical imagery

Several steps are involved in locating and pre-processing historical imagery. First, the images themselves (called 'frames') are found in a variety of university map and imagery libraries, museums, counties, and other sources. They may or may not be digitized. For our project, we obtained scans of frames covering all of Humboldt County from CGS. At the time of this project, we were only able to locate historical images for the Humboldt County sites, so analysts should be aware that finding imagery can be difficult. In order to identify frames for our study sites out of the hundreds of images which cover all of Humboldt County, we georegistered the flight map to county boundaries using a spline resampler (also called 'rubber sheeting') in ArcGIS 10.2 (ESRI 2013). We then overlaid the polygons for our sites and located frame numbers that were likely to contain our sites. We also obtained NAIP imagery based on a similar strategy. Using the NAIP and features which were unchanged over 60 years (for example, shapes of tree clusters, roads, or rocks), we confirmed which frames to use.

The next step in pre-processing the imagery involved georegistering (locating in space) and orthorectifying (correcting for topography and lens distortion) the historical images to the current NAIP image. We used Leica Photogrammetry Suite (LPS) to pre-process the imagery (Intergraph 2014). This involved locating metadata on the focal length of the camera and flight height associated with the images, which we were able to find at the University of California, Santa Barbara map library. We obtained a digital elevation model (DEM) from U.S. Geological Survey's national elevation dataset to use as a vertical reference for orthorectification and used the NAIP as a horizontal reference. We then located 50 to 150 ground control points (rocks, roads, and tree clusters which are identifiable in both NAIP and historical images) and used LPS to georegister and orthorectify the historical images, warping them into the correct locations. In some cases we then mosaiced the images together in ArcGIS to cover the analysis area. We orthorectified three to six images for each site, though we only use one or two per site for analysis. Note that finding control points was more difficult in heavily forested areas and for images with poor contrast. Even with adequate control points, there are still areas of misregistration. That said, using LPS to correct for topography is still more systematic and faster than the time-consuming and subjective method of using ArcGIS's georegistration tool with spline resampling as we did with the flight key.

Lesson 1:

Finding and pre-processing the imagery is time-consuming. Therefore mapping change over a large area would require a great deal of analyst time to pre-process the imagery.

Part 2: Segmenting imagery into objects

Object-based image analysis is an appropriate method for high-spatial-resolution imagery as opposed to traditional pixel-based methods of analysis. In pixel-based analysis, single pixels are classified independently. If the objects of interest are larger than the pixels in the image, this leads to problems (for example, the shaded side of a tree might be classified differently from its illuminated side). Instead, the image is segmented into objects (for example, an entire tree crown or stand of trees), which are then classified. One advantage of OBIA is that the classifier can use information about the object as well as its pixels. The texture within the object can be used for classification, as well as its context with respect to other objects (for example, nearness of objects of the same class), or the shape or size of the object.

We use eCognition Developer 8 (Trimble 2013) to segment the images. eCognition has several segmentation algorithms, but the most commonly used is multi-resolution segmentation, which creates objects by grouping similar pixels. This algorithm takes three parameters, scale (which controls the size of the objects created), and shape and compactness (which together control how much the pixel values influence the grouping and how compact the objects are). Choosing these parameters can be a trial-and-error process and is somewhat subjective. However, correctly segmenting the image is a prerequisite for later classification, as the objects constrain what can be classified. Procedures for selecting these parameters systematically are still being developed (Drăguţ and others 2010) and were not appropriate for our images (these methods resulted in objects much larger than we needed). For our exploration of historical and NAIP imagery, we chose fairly small, compact objects and required them to be fairly homogenous.

Lesson 2:

Training and experience are necessary to choose adequate segmentation parameters. Even with training and experience, choosing segmentation parameters can be an art as well as a science.

Part 3: Looking for the process in the images

Before attempting to classify the image, we assessed whether we could identify oak versus conifer in the images without any ground information. This was a useful step because the field information collected as part of the project was not intended for classification of aerial images, and because classification of larger areas would be more feasible if field information were not necessary.

Unfortunately, it was impossible to consistently identify conifer and oak in the NAIP or historical images (fig. 2). The NAIP imagery tends to be captured in the middle of the day to minimize shadows and therefore the texture from the rougher, piercing crowns of the Douglas-fir is less apparent. The historical imagery shows a great deal of variation in sun angle, texture, and contrast from image to image and site to site. In some cases, we checked our guesses about species composition in the

NAIP image against the field crews' information and found we had guessed incorrectly.

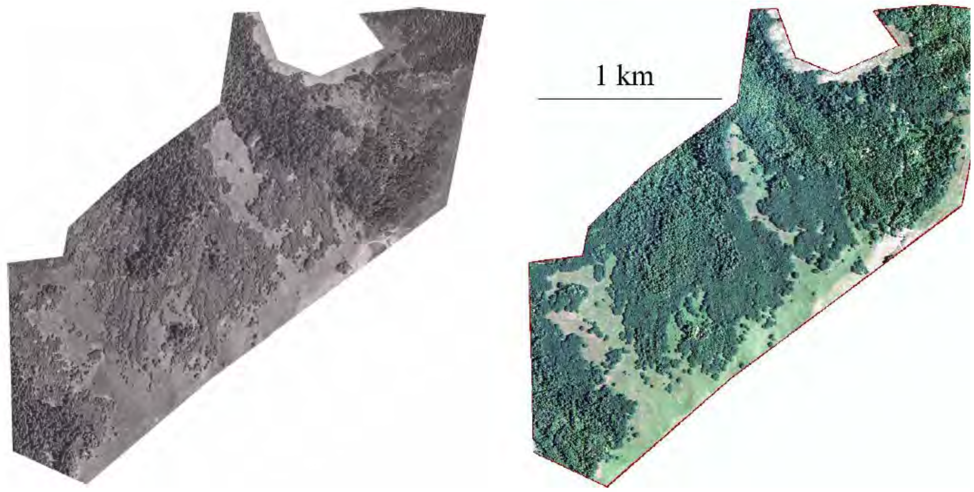

Figure 2—Example of historical imagery (left) and NAIP imagery (right) from site BH where conifers and oaks can be distinguished. Other sites are not so clear.

Lesson 3:

It was only possible to differentiate between species by eye in very localized areas of some sites in some years.

Part 4: Supervised classification

Therefore, to classify the NAIP and historical images, we used the plots from the field component of the project (Schriver and Sherriff, Establishment patterns of Oregon white oak and California black oak woodlands in northwestern California, these proceedings). There were nine 1/10 ha plots at each site, stratified by level of encroachment: three plots had no conifer in the canopy in 2013, three had mixed dominance between oak and conifer, and three were dominated by conifer with only a few oaks in the canopy. None of these sites was pure conifer in 2013, nor were any plots chosen in the nearby prairie. Because the field crews were studying the age and size structure of the plots, we can be reasonably certain that because the age of nearly all Douglas-fir on the plots was less than 100 years in 2013, they were not visible in the canopy in 1948.

We used a supervised classification strategy where the field sites were samples of oak or conifer. We chose additional samples in pure conifer for 1948 and for prairie in both years. The resulting classifications are flawed but show promise (fig. 3).

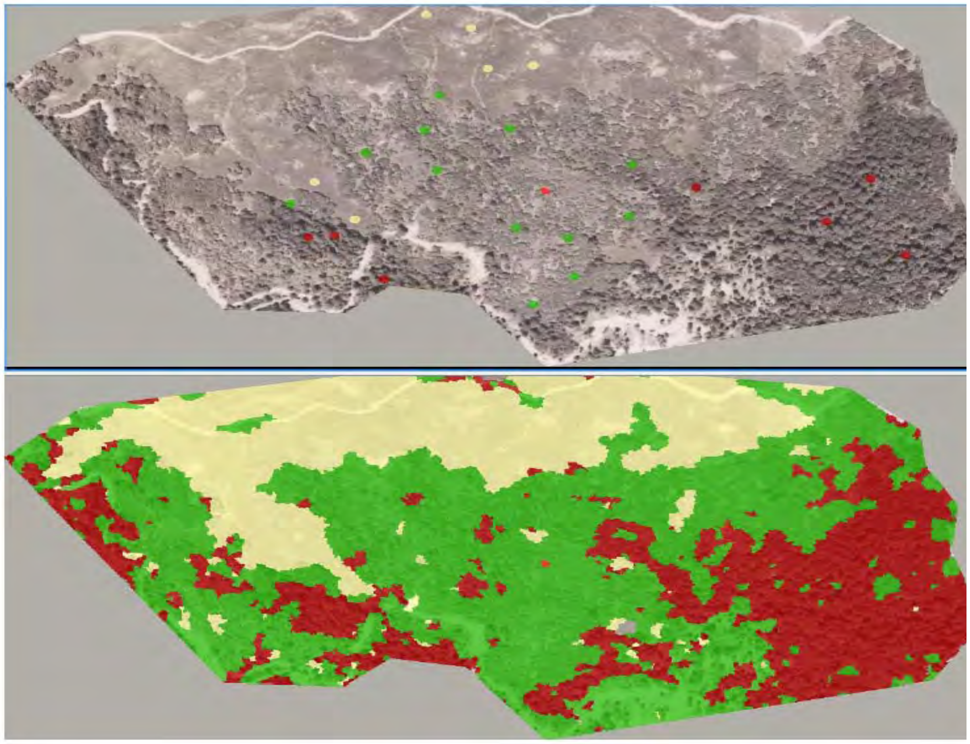

Figure 3—Historical image (1948) from Iaqua Buttes (IB) site showing samples based on field sites (upper) and preliminary supervised classification (lower). Conifer is red (darkest), oak is green (medium), and prairie is yellow (lightest). Note areas of poor classification: for example, the oak and conifer classes do not exist in reality on the side of the road near the top of the image.

***Lesson 4*:**

Supervised classification, with samples in pure classes of oak, conifer, and prairie, has potential for mapping encroachment.

Opportunities and recommendations

At the general level it is possible to map woody versus herbaceous cover in these images without field-based samples (Eitzel Solera 2014). Mapping changes in woody cover alone may be useful for processes other than encroachment, for example oak recruitment. Anecdotally we found the potential for oak recruitment in valleys outside of forested areas. We recommend iterative mapping and field work, in which the map of woody cover change screens for locations to investigate in the field for potential oak recruitment. Iterative mapping and field work would also be necessary to obtain field samples for the supervised classification in order to map conifer encroachment. It may also be possible to classify encroached areas as oak, conifer, or mixed, and to observe the mixed class expanding.

One opportunity associated with mapping oak and conifer using field samples is the potential for validation of historical imagery. A trained forester could core the largest conifer on a plot and make a determination of whether it is old enough to have been in the canopy in the 1940s. The analyst could then use this point and others as samples in a supervised classification of the historical image and later for validation of the classification, something that is rarely done for historical imagery.

Large-scale mapping of either woody cover or conifer encroachment will require both trained analysts and a large amount of time. One additional impediment to larger-scale mapping of these processes is unknown land use history. For five of our sites, the field crews found evidence of widespread harvest due to the tax on standing timber in the time between the historical photos and recent imagery. This invalidates the interpretation of the recent imagery as simply following standard forest dynamics from the condition depicted in the historical imagery.

Finally, a land-owner without access to the software or trained analysts could at least informally use historical imagery to locate areas which were woodland in the 1930s and 1940s to plan for conifer removal, if the forest practice rules are changed to allow it.

Acknowledgments

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