

datasets if they are to be effectively used in addressing issues such as climate and land cover and land use change which both span spatial and temporal dimensions (Tingley and Beissinger 2009). Many of the studies reviewed here employ data synthesis between historical VTM and modern vegetation data (e.g., FIA, CalVeg) to discuss change both qualitatively and quantitatively in vegetation structure (e.g. Goforth and Minnich 2008; Dolanc et al. 2013b), composition (e.g. Minnich et al. 1995), and abundance (e.g. Fellows and Goulden 2008; Table 2). There are additional datasets and approaches that might be used. The VTM database can be linked to much of the ecological data collected at UC Berkeley, among them about 5M records from museum specimen, soil and pollen data, field station records, sensor readings, as well as biophysical base layers such as climate and land use (Figure 2). There is great potential in these data synergies to further expand the scope and scale of VTM analysis. For example, first, synergies between genome sequencing of biological specimens with historical and future vegetation allow us to move beyond single species vegetation type analysis and understand the dynamic nature of ecological communities (Rubidge et al. 2011; Preston et al. 2012; Bi et al. 2013). Second, more can be done using historical vegetation data with current and future climates using new species distribution models. For example, the floristic detail found in both the maps and plot data might be used to look at historical ranges of important taxa. Third, there has been a significant focus on interactions between fire and vegetation in the VTM scholarship for example in conifer forest (Dodge 1975; Minnich 1978; Taylor 2000; Fellows and Goulden 2008; Goforth and Minnich 2008) and shrubland communities (Franklin et al. 2004; Talluto and Suding 2008; Lippitt et al. 2013). McIntyre et al. (2015) used VTM field notes to identify plots with recent fires and were able to detect coarse differences in tree density in multiple size classes between burned and unburned plots within the VTM data and across time in comparisons of burned and unburned FIA plots. More might be done to examine historical vegetation structure and pattern in modern mega fires such as the Rim fire. Conditions influencing fire overlap, fire severity and fire regimes might be explored through synthesis with contemporary fire data (Collins et al. 2007, 2009).

Open data frameworks

The multiple recent discussions in the scientific community around open, transparent, and reproducible science (Jones et al. 2006; Wolkovich et al. 2012) have fostered technological advances in more flexible and user friendly data storage and documentation systems that incentivize researchers to enter, store, and make datasets available to the broader community. Such participation has engendered a need for a more transparent system of data collection and distribution. Contemporary large-scale citizen science efforts promote and alleviate some issues of data transparency and sharing by promoting open data collection, distribution, and assessment (Kearns et al. 2003; Kelly et al. 2012). Technological advances in computer science have increased our ability to query, visualize and use large heterogeneous collections in meaningful ways (Baird 2010; Fox and Hendler 2011; Reichman et al. 2011; Hampton et al. 2013). New web applications such as APIs linked to structured ecological databases allow the rapid generation of maps, charts, timelines, graphs, word clouds, search interfaces, RSS feeds, and many others capabilities (Fox and Hendler 2011).

The voyage from paper to API

Although focused on a single dataset, the VTM collection's voyage from paper archive to API can be seen as a cautionary tale about the importance of finding, archiving, and sharing historical ecological datasets that should resonate more broadly. Despite being well-known and well-documented, in the decades since its creation, the VTM collection has faced the possibility on several occasions of partial destruction (Wieslander 1986). Even today, locations of portions of the collection remain unknown. Thus, its journey from analog to digital is exemplary of a number of important themes facing the scientific community today: the importance of finding and rescuing historical or "dark" data; the need for best practices and standards for data digitization including uncertainty estimation and error control; the value of spatial data visualization and web-based portals for data sharing; the priority in modeling of data fusion and analytical integration; and the critical role of data infrastructures such as APIs for sharing scientific data. Other important detailed records of past biological, ecological, agricultural, and management conditions may exist

across the state of California in paper archives, historical imagery, and/or physical biological specimens. These hidden “dark archives” are currently invisible to researchers, but with the kind of focused work described here, become invaluable.

CONCLUSIONS

There is ample evidence that the rescuing, digitizing, and sharing of historical ecological data is an important scientific endeavor. These data provide benchmarks from which to compare change, they can be linked to modern ecological data to create new knowledge, and they can be modeled to help predict future changes. A. Everett Wieslander anticipated many modern uses of the VTM data in 1935. He wrote that it provided: 1) a partial explanation of the current (as of 1930s) distribution of vegetation types and dominant species; 2) a better understanding of vegetation changes that have occurred in the past, those now in progress, or those to be expected to occur in the future; and 3) further contributions to the knowledge of the values of certain plants and vegetation types as indicators of particular soil and climatic conditions (Wieslander 1935b). He was perceptive in this analysis, but did not anticipate all of the uses of the data. The maps, plot data, and photographs have been used in isolation or paired with contemporary data to great effect to study California’s historical flora and land use, for documenting and finding mechanisms for decadal-scale vegetation changes, and for predicting and planning for California’s future.

The digitization and sharing of the VTM collection has expanded the scope and scale of possible analyses. Any analyses larger than a single or few quads were impossible when the analog data were scattered around the state in libraries and research collections; or when plot or map data required laborious digitization. Currently, most papers using VTM plot data explore the full complement of scale and detail. Yet there is more that can be done. Researchers might also use more of the vegetation map data, as well as the georeferenced photographs; they might embark on modeling that fuses data from more than one part of the collection, and synthesizes data from other sources. Additionally, we hope more researchers will explore the connections between vegetation change and other biological signals of change such

as isotopic signatures derived from spatially coincident animal specimens (e.g. Rubidge et al. 2011; Bi et al. 2013).

Finally, we want to highlight the increasingly critical role of data structures that foster scientific sharing and collaboration, such as APIs, especially in their capacity to link at-risk historical data with contemporary ecological data. The digital VTM collection is an example of a web-based data framework that expands the potential of large-scale research through the integration and synthesis of data drawn from numerous data sources. We suggest here that the potential linkages and multi-disciplinary connections waiting to be made with the use of the collection are numerous and important.

Understanding past, present, and future interrelationships between flora, fauna, land use, society, and climate is of paramount importance in ecology. The VTM dataset serves as a valuable and underutilized resource in this regard. The digital and shared data are an expansive historical reference that continues to provide exciting avenues for the modern geographer and ecologist to create connections between diverse datasets to tell the story of a region’s ecological past and better inform the future.

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