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RE: Sabbatical report, 2019-2020.

Dear sabbatical committee and officials:

My sabbatical was for the Fall 2019 semester. However, I also used NASA grant funds to buy out all classes in Spring 2020. My sabbatical thus spanned a whole academic year and allowed me to be more productive than with a single semester. Here I report on activities from June 2019 to August 2020.

Soundscapes to Landscapes (S2L) project

I am the Principal Investigator of a NASA-funded project called "Soundscapes to Landscapes (S2L): Monitoring Animal Biodiversity from Space Using Citizen Scientists". This science-based project is advancing the monitoring of bird diversity from space using data from current and next-generation Earth-observing satellites. The project is driven by "citizen scientists" (CS) that help collect sound recording data and provide validation of bird calls in recordings. We then process these sound data with deep learning algorithms (e.g., artificial intelligence) to identify bird species by their calls and then predict their presence at sites.

The S2L project science team includes myself and colleagues at Northern Arizona Univ, Point Blue Conservation Science, and UC Merced. We developed a species distribution modeling (SDM) framework based on machine learning, bird diversity data, and several predictor spatial variables related to forest structure, phenology and climate. Part of my sabbatical was used to help co-author a manuscript that describes the SDM methodology and assesses predictor variable importance in explaining bird diversity. The paper is now published, Burns et al. (2020). I am the principal remote sensing scientist on the team, and I also dedicated time to prepare for a new Sonoma county bird SDM analysis that will include new *in situ* bird data from our bioacoustics work. During the last year, I processed LIght Detection and Ranging (lidar) forest structure metrics for and worked with colleagues in Humboldt University, Berlin to process imaging spectrometer data collected by NASA into spatial metrics related to canopy chemistry.

I was also engaged with the bioacoustics part of S2L during my sabbatical. I attended multiple "bird blitzes" at Point Blue during Fall 2019. In these events, our team worked with citizen scientists to identify, tag and validate bird calls in recordings using our cloud-based bioacoustics analysis platform (ARBIMON, https://www.sieve-analytics.com/products). Our science team is exploring state-of-the-art deep learning algorithms, called "convolutional neural networks" (CNN), for bird call identification. I have had weekly meetings with UC Merced, NAU and Point Blue collaborators to develop CNN classifiers to improve bird-call identification accuracy and minimize the need for manual review. We have several approaches to accomplish this research, including training the model on local computers at UC Merced and processing our 500,000 minutes of recordings at NAU on a high-performance cluster (HPC). My work has been to work with an Amazon Web Services deep learning specialist to build a bioacoustics data processing pipeline in a cloud environment. The AWS pipeline will allow us to process large amounts of sound data coming from S2L and future projects. A substantial part of my AWS work was to learn CNN technology, which at the start of sabbatical was a rather vague concept. Although I am not a deep learning expert, I am more comfortable with the process after spending research time with our S2L bioacoustics application. In Spring 2020, I worked with

Dr. Gurman Gill to use S2L sound data in his Computer Science capstone class. We organized 5 teams to explore aspects of the bird species classification problem with different techniques.

3D Forests project

I am co-Investigator in two linked projects focused on using technology to improve our ability to estimate carbon (aboveground biomass) and fire fuels in forests. Funding for this research comes from CAL FIRE and the CSU Agricultural Resources Institute (PI Lisa Bentley in Biology), and was funded in Spring 2019, before I applied for sabbatical. I thus changed some of my sabbatical plans to engage this new research. My role in the project is to use aerial images from unmanned aerial systems (UAS), or drones, to generate 3D data for estimating carbon and fuels. I led the drone campaign at Pepperwood Preserve in October, 2019 and then in forest sites in Mendocino, Shasta and Sonoma County during summer 2020. In Fall 2019, I managed undergraduate students to process the images using a process called Structure from Motion. During the last year, I also helped plan the sampling design at our four project field sites and assisted the terrestrial laser scanner team with their geospatial data processing tasks, including coding several steps in the R open-source language.

Additional research

I used my sabbatical to work on several other research collaborations that resulted in peer-reviewed papers based on past work. In Ackerly et al. (2020), I collaborated with the Ackerly lab at UC Berkeley to understand how climate and topography influence plant distributions in the face of global warming. A key part of this research was a fine-scale species map that I produced from imaging spectroscopy data collected by NASA. I also participated as a co-author on two papers with collaborators at Humboldt University in Berlin, Germany (Jänicke et al., 2020; Cooper et al., 2020). These papers used reference and image data that were collected in my previous NASA grant focused on using imaging spectroscopy for mapping vegetation. During sabbatical, I also collaborated with Tukman Geospatial, Inc, a local geospatial contractor, and the Ag + Open Space District in Sonoma County in a machine learning modeling analysis of factors that predicted the Sonoma Complex fires of 2017. We wrote a manuscript in Spring 2020, and I am happy to report that the paper was accepted for publication (Green et al., *accepted*). Finally, I spent December 2019 working intensively on an old analysis of lidar in the Fairfield Osborn Preserve. This was an undergraduate project that investigated how lidar point density affects our ability to estimate aboveground biomass. I completely re-worked the analyses and graphics with new R code and finished the Results section. However, 2020 became busy with 3d Forests and S2L research priorities, and so this manuscript remains unfinished.

Grant proposal development

In May to June 2020, I managed as Principal Investigator the submission of a NASA proposal in the Biodiversity program. The proposed 3-year research project was to scale our S2L project to the Sierra Nevada Mountains and takes advantage of 10-year data on bird diversity collected and managed by Point Blue Conservation Science. This proposal is currently pending review.

Publications developed during sabbatical

Ackerly, D. D., Kling, M. M**., Clark, M. L.**, Papper, P., Oldfather, M. F., Flint, A. L., & Flint, L. E. (2020). Topoclimates, refugia, and biotic responses to climate change. Frontiers in Ecology and the Environment, 18(5), 288-297.

Burns, P., **Clark, M.**, Salas, L., Hancock, S., Jantz, P., Leland, D., Dubayah, R., Goetz, S. (2020). Incorporating canopy structure from simulated GEDI lidar into bird species distribution models. *Environmental Research Letters*.

Clark, M. L. (2020). Comparison of multi-seasonal Landsat 8, Sentinel-2 and hyperspectral images for mapping forest alliances in Northern California. *ISPRS Journal of Photogrammetry and Remote Sensing*, 119, 228-245.

Clark, M.L. & Romero, M. (*in preparation*). Assessing LiDAR pulse density for estimating aboveground biomass in an open-canopy mixed forest in Northern California. Remote Sensing.

Cooper, S., Okujeni, A., Jänicke, C., **Clark, M.**, van der Linden, S., & Hostert, P. (2020). Disentangling fractional vegetation cover: Regression-based unmixing of simulated spaceborne imaging spectroscopy data. Remote Sensing of Environment, 246, 111856.

Green, K., Tukman, M., Loudon, D., Schichtel, A, Gaffney, K, **Clark, M.** (*accepted*). Sonoma County Complex Fires of 2017: Remote sensing data and modeling to support ecosystem and community resiliency. *California Fish and Wildlife Journal*.

Jänicke, C., Okujeni, A., Cooper, S., **Clark, M.**, Hostert, P., & van der Linden, S. (2020). Brightness gradient-corrected hyperspectral image mosaics for fractional vegetation cover mapping in northern California. *Remote Sensing Letters*, 11(1), 1-10.

Sincerely,

Dr. Matthew L Clark