Mapping Maine's Land Cover - A New Approach

...using innovative Machine Learning approaches for land cover and land use mapping...

THE UNIVERSITY OF MAINE 1865 · Center for Research on Sustainable Forests · Intelligent GeoSolutions · Wheatland Geospatial Lab forest.umaine.edu

Background & Historical Context

Accurate and up-to-date geospatial data are a modern requirement for resource management and conservation, land use planning, economic development, and policy making. Satellite remote sensing can address much of this need, but the technical expertise and computing resources required to manipulate raw imagery into usable knowledge have always acted as barriers. Consequently, digital land cover data for the state of Maine have typically been developed by national programs whose products support national mapping objectives but do not necessarily align with state interests. Exceptions include the 1993 Maine Gap Analysis Program (GAP) land cover map and 2004 Maine Landcover Dataset (MeLCD). After 15 years, landscape conditions have changed considerably across much of the state, and the MeLCD has lost much of its value for decision making (Figure 1).

Maybe the most important legacy of the MeLCD project was a collaborative framework in which state, federal, and private resources were combined to reduce the cost of an innovative land cover product. State agencies partnered with the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, and a geospatial services company to develop a high-resolution land cover map (5 m pixels) at reduced cost by leveraging federal resources committed to the production of the 2001 National Land Cover Dataset. Design decisions related to the use of high-resolution imagery made the MeLCD difficult to update, and the methods used to produce the MeLCD are unlikely to be replicated in any next-generation land cover product. However, a similar collaborative project framework would serve the state well in the production of a successor to the MeLCD, and opportunities to innovate at low cost have grown with new remote sensing programs and access to new analytical tools including machine learning (ML) methods.

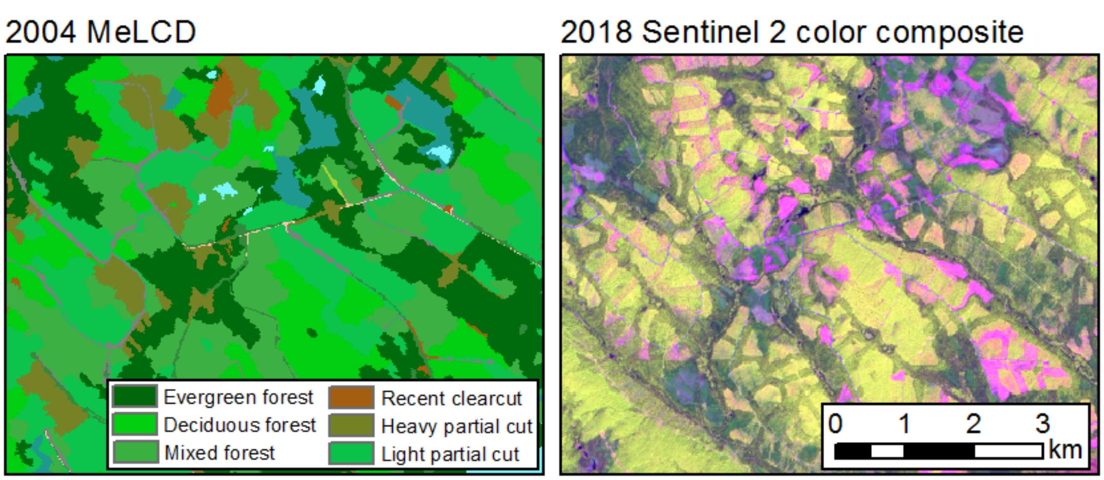

Figure 1: The MeLCD is now of little value where landscape change is prevalent, as in this rather extreme example of clearcut harvesting in Maine's commercial forest.

UMaine Intelligent GeoSolutions

Over the past 15 years, applied R&D programs at the University of Maine have advanced to the point that UMaine research centers offer a unique, local resource for advanced geospatial services. Intelligent GeoSolutions (IGS), housed within the UMaine Center for Research on Sustainable Forests (CRSF), was recently initiated to address a clear lack of broad-scale, up-to-date geospatial information about forest and landscape conditions relevant to natural resource management, conservation, and land use planning in Maine. Building from more than five years of ML algorithm development and use in forest research applications (Figure 2), IGS partnered with the UMaine Advanced Computing Group to implement a semi-automated image processing and machine learning software system referred to as the Supervised Adaptive Multi-objective Mapper (SAMM).

Typical image classification methods almost universally fail to control systematic map error in the form of over- or under-estimation of class extent. Imperfect reference data, predictor uncertainty associated with satellite imagery, algorithm bias, and analyst error can contribute to dramatic misrepresentation of class extents and spatial distributions. Evidence of this misrepresentation is found in error matrices of land cover maps including the MeLCD, where class omission and commission errors are often imbalanced. This systematic error impacts map use in ways that are difficult to predict or correct, and can make a map unsuitable for use.

SAMM utilizes an innovative set of multi-objective ML algorithms designed to fit accurate and unbiased predictive models of forest attributes including: forest type, tree species abundance (e.g., % above ground biomass), and the occurrence and intensity of canopy disturbance (e.g., % biomass change). The ML methods developed for SAMM control or eliminate systematic patterns of map error by combining the strength of support vector machines (SVMs) to model complex, nonlinear relationships with the adaptability of a multi-objective genetic algorithm (GA). The GA drives the evolution of SVMs to simultaneously increase accuracy and reduce or eliminate systematic error including over- or under-estimation of class extent. SAMM integrates our multi-objective ML algorithms into semi-automated image processing and map production workflows executed on the cloud. SAMM enables efficient, high throughput processing of raw image data into high-quality output products.

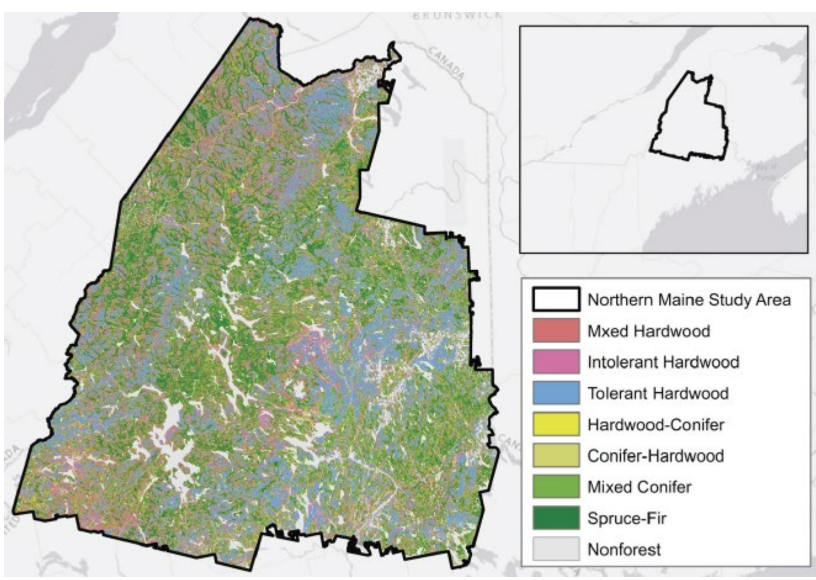

Figure 2: Forest type map produced for a ~10 million acre northern Maine study area using multi-temporal Landsat, USFS FIA data, and UMaine machine learning methods.

Proposed Approach

Borrowing from the MeLCD legacy, we propose that a next-generation land cover mapping project for the state of Maine be approached as a partnership between state and federal agencies, the University of Maine, and other private stakeholder organizations. The NOAA Coastal Change Analysis Program (C-CAP) has recently completed a beta version of a 10 m land cover product, available statewide. Wetland types are represented in detail, but other important categories of land cover are not adequately resolved – the beta product includes only a single forest cover class and no agricultural classes. IGS and CRSF scientists have extensive expertise in forest and vegetation mapping, and have initiated several statewide forest mapping projects using both Landsat and Sentinel imagery. Through collaborative agreements with the U.S. Forest Service, Forest Inventory and Analysis (FIA) program, IGS maintains access to data from an extensive network of field plots for use in model training and map validation (>3000 plots statewide). IGS is well positioned to contribute detailed forest cover information to a statewide land cover project, but our software system and ML approach are also generalizable to any land cover classification problem, with the same benefits of high accuracy and control of systematic error. IGS contributions could be extended to other land cover types, provided we partner with agencies and stakeholder groups that are able to contribute reference data and domain knowledge. We propose our service as part of a land cover mapping consortium that integrates resources and expertise from state, federal, university, and private stakeholder groups.

Outline of Potential Deliverables, Budget, & Timeline

We propose that the NOAA C-CAP 10 m land cover product provide the foundation for a new statewide land cover map, with more detailed classes embedded based on Maine stakeholder requirements identified through outreach and engagement. We propose that IGS integrate forest cover information matching the 10 m resolution of the C-CAP product, replacing the forest class of the existing C-CAP product, pixel by pixel, with more detailed forest cover classes. Classification would be based on Sentinel imagery and USFS FIA reference data. Forest classes could be consistent with the MeLCD (i.e., evergreen, deciduous, mixed) or, alternatively, with more detailed forest types defined by the FIA program and used for state and national reporting (e.g., maple/beech/birch, spruce/fir, etc.). IGS would provide all relevant metadata as well as comprehensive project reporting. Anticipated costs for a project of this scope would range from $60,000 to $90,000 (+ university indirect costs) depending on the number of classes required and their prevalence across the state. The time needed to execute this work including reporting would be 9-12 months.

The approach outlined above could be readily expanded into a more comprehensive land cover mapping project, and IGS is prepared to provide additional services as part of a larger project. We could, for example, integrate forest age or disturbance/harvest history from the 30+ year archive of Landsat TM, ETM+, and OLI imagery (resampled and embedded within a 10 m land cover map). We could provide supplementary data layers that map the distribution and abundance of individual tree species of high economic or ecological value to the state, also at 10 m resolution. We could provide annual updates of forest cover classes using semi-automated Sentinel workflows already built into SAMM. By partnering with state agencies and private stakeholder groups with expert knowledge, we are prepared to apply our ML framework to map other land cover types including, for example, ag classes not included in the 10 m C-CAP data. Our ML algorithms are fully generalizable to any geospatial prediction problem, and our image processing software was designed to be modular and extensible, permitting us to quickly modify or build new workflows around new problems. We ultimately wish to align our expertise with stakeholder needs to deliver products of high value to the people of Maine.

Outreach & Stakeholder Engagement

The Maine land cover mapping workshop held on August 14th, 2019 in Orono will serve as an initial effort to engage stakeholders throughout the state. Our goals during this first meeting will be: (1) to gather feedback from users of MeLCD data and other products on their strengths and weaknesses, (2) identify what users would like to see in a new, next-generation land cover map of Maine, and (3) lay out a framework and vision for a new land cover mapping effort that is efficient, cost-effective, flexible, and adaptable to stakeholder needs.

Once the project has secured funding and is underway, a series of stakeholder meetings and awareness seminars will be undertaken statewide to consolidate expertise and information needed for mapping objectives and to generate interest and support in local communities. Local support could be leveraged with citizen science-based activities that further education and outreach goals associated with this project. The Maine Geospatial Institute (MGI) and the Wheatland Geospatial Lab (WGL) would serve as key partners in outreach and engagement activities throughout the project. This project would also provide important opportunities for undergraduate and graduate student participation by assisting in certain activities as identified by the project team. We envision a project framework that will effectively identify and address stakeholder needs while building local capacity to meet current and future demand for accurate and up-to-date geospatial data.

Team

Dr. Kasey Legaard, Research Assistant Professor of Geospatial Analytics and Machine Learning. Dr. Legaard completed his PhD in Forest Resources at the University of Maine, during which he developed a unique machine learning algorithm that addresses critical issues associated with nearly all existing spatial products. He has expertise in data/computer science, remote sensing, and machine learning. Dr. Legaard has been working closely with the University of Maine's Advanced Computing Group to implement his developed algorithm on the university's supercomputer and provide a web-based interface to the spatial outputs to help guide forest planning efforts in the region.

Dr. Erin Simons-Legaard, Research Assistant Professor in Forest Landscape Modeling. Dr. Simons-Legaard has a PhD in Wildlife Ecology from the University of Maine and has since developed a successful research program in forest landscape ecology and wildlife habitat modeling/monitoring. Recently, she has primarily focused on implementing the forest landscape model, LANDIS-II, for Maine's complex working forest to address landscape-scale questions concerning the next spruce budworm outbreak, climate change, and forest policy.

Dr. Aaron Weiskittel, CRSF and Center for Advanced Forestry Systems Director, Irving Chair of Forest Ecosystem Management, Professor of Forest Biometrics and Modeling. Dr. Weiskittel has been on the University of Maine faculty since 2008, after completing graduate degrees at Oregon State University. He is an internationally recognized scientist with 120 peer-reviewed publications and a highly cited textbook. He has worked directly with multiple landowners across North America on issues ranging from forest growth and yield modeling, inventory, LiDAR, and certification.

Tony Guay, Remote Sensing Specialist with the Wheatland Geospatial Lab. Tony provides remote sensing and geospatial training to stakeholders in Maine's forest sector, including industry professionals, small woodland owners, and conservation partners. He supports geospatial science teaching and research efforts in SFR, and is responsible for outreach and coordination with various stakeholders throughout the state. Tony is a founding member of the Maine Geospatial Institute and serves on its Executive Committee. Tony holds two degrees in Forestry (B.S. and M.S.) from the University of Maine.