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Imputing plant community classifications for forest inventory plots

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ABSTRACT

Native plant community (NPC) classifications typically require on-site visits and in-depth observations by trained ecologists. The goal is to identify unique floristic and environmental characteristics indicative of a particular plant community, ecosystem, or demographic condition. Such data are often desired to inform management decisions on sustainable timber and ecosystem services production over local to large landscapes. Yet, the time and funding needed to identify, assess, catalogue, and map these communities is often limited. Lacking these classifications, we rely on imprecise determinations of the prevalence of various NPCs. Further, extrapolating statewide NPC extent from previously imputed classifications for state managed stands is difficult without a representative sampling design including all ownerships. As a solution to the NPC sample coverage limitation, we describe an extension of a previously reported imputation model to provide the desired statewide classifications and corresponding estimates of the ecological landscape state indicator provided by NPC extent.

First, NPC observations from the Minnesota Department of Natural Resources (MNDNR) Division of Ecological and Water Resources for 1964–2015 were linked with MNDNR Forest Inventory Management (FIM) stand data to provide a set of observed polygons for training the imputation model. Then, USDA Forest Service Forest Inventory and Analysis (FIA) plot data, were associated with the observed stands to provide NPC classifications for a subset of plots (e.g., training plots) contained in the FIA database for Minnesota. NPC information was then linked to forest inventory and physiographic layers via spatial association techniques in a geographic information system. Soils data describing drainage, productivity, thickness of the rooting zone, and land position were also used. Finally, validation of resulting imputed classifications shows that application of the model to the statewide FIA inventory will result in an error rate between 8% and 30% with a mean of 83% of imputations correct at the class level.

We then updated the publicly accessible FIA database for Minnesota with imputed NPC classifications and scripted labeling schemes integrated with the EVALIDator report building tool to produce estimates of forestland extent. Here, we focus on estimates of NPC class by FIA Survey Unit and inventory year. Finally, quantified estimates of landscape state (e.g., NPC extent and condition) are enabled for inventories ending between 1977 and 2014. Imputed data from this series of statewide inventories enables the analysis of landscape change, and facilitates strategic planning to move the bioregional landscape in a desired ecological direction, or to provide specific ecosystem services.

1. Introduction

To make use of detailed ecological information in strategic management planning processes, we must first categorize systematic observations of ecosystem state and function across the bio-regional landscape. Indeed, De Groot et al. (2010) include quantification of the relationship between landscape and ecosystem characteristics, functions, and services in their list of primary research questions to be resolved to enable the integration of ecosystem services in landscape planning and management. Chan et al. (2006) similarly describe the need for better characterization of communities and ecosystems as a precursor to assigning targets for ecological functions or services to be provided by these features. The aim in both papers is to develop and apply a formal quantitative planning framework to integrate ecosystem service values into biodiversity conservation. To facilitate this planning, we illustrate a method for quantifying and assigning state values to individual management units and regional landscapes sampled by systematic forest inventories.

Although the native plant community (NPC) sampling program managed by the MNDNR has been conducting ecosystem sampling and analysis for several decades, a representative sample providing complete coverage of relevant management units is still likely a decade away (John Almendinger personal communication). At this time,

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roughly 17,000 of 202,000 stands managed by MNDNR have been observed and classified by a professional ecologist. As a consequence of this data gap, desired ecological information are seldom available with the level of detail, regional coverage, and site specificity needed for timely analysis of potential management trade-offs. With forests, desired ecological data may influence harvest scheduling, and would also inform strategic planning for wildlife habitat, water quality, biodiversity, and possibly other values. This research bridges the data gap by leveraging what we know about NPC distribution and landscape associations to assign appropriate NPC categories to individual forest inventory units (stands) or field plot records. Results of this research may, in turn, help to resolve a primary challenge faced by ecologists and foresters attempting to integrate values associated with ecosystem services into landscape planning and management.

Many methods exist for classifying plant communities according to various physical and ecological characteristics and associations (Barbour and Major, 1977; Holland and Keil, 1995; Teague et al., 2006; Faber-Langendoen et al., 2012a,b; Zimmerman et al., 2012). However, this research is not meant to critique, revise, or even catalogue existing ecological classification methodology. Table 1 and the overview below are intended only to aid understanding of the methodology applied here.

These classification systems are almost as diverse as the plant communities they describe, and tend to be updated and adapted to new understanding as time passes and our knowledge grows. Classifications for NPCs on the ecologically diverse landscape of Minnesota are based on 4 components defining the ecological system, floristic region, moisture, and nutrient conditions occurring at a site (Fig. 1). The Minnesota Biological Survey determines the ecological system based on the unique associations of plants able to occupy a site. The ecological system is assessed through analysis of relevés, or lists of plants observed on standardized sample plots drawn from plant communities not subjected to human disturbance (Aaseng et al., 2011; MNDNR, 2013) (see Table 1). Floristic region is related to the mostly latitudinal gradient imposed on plant community development by climatic forces (e.g., temperature, precipitation, glacial history, etc.). Moisture and nutrient scores range from 0 to 9 for a site, and correspond to the physical availability of these growth limiting factors. These classifications, based on the observations of trained ecologists visiting specific forested stands, represent a substantial investment in vegetation sampling and landscape analysis. Additionally, they serve as a starting point for the imputation methodology.

Table 1
Common ecological system examples and habitat associations[a] from Minnesota's forestland.

System	Name	Example	Habitat
AP	Acidic Peatland	APn81	Forest-Lowland Coniferous
FD	Fire Dependent	FDn12	Forest-Upland Coniferous (red-white pine)
FD	Fire Dependent	FDn43	Forest-Upland Deciduous (Aspen), Forest-Upland Coniferous (pine flats)
FD	Fire Dependent	FDs38	Forest-Upland Deciduous (Oak)
FD	Fire Dependent	FDw44	Forest-Upland Deciduous (Aspen)
FF	Flood-plain Forest	FFs59	Forest-Lowland Deciduous
FP	Rich Forested Peatlands	FPn71	Forest-Lowland Coniferous
FP	Rich Forested Peatlands	FPn82	Forest-Lowland Coniferous
MH	Mesic Hardwoods	MHc26	Forest-Upland Deciduous (Oak)
MH	Mesic Hardwoods	MHn44	Forest-Upland Deciduous (Aspen), Forest-Upland Coniferous (red-white pine)
MH	Mesic Hardwoods	MHs37	Forest-Upland Deciduous (Oak)
MH	Mesic Hardwoods	MHs38	Forest-Upland Deciduous (Hardwood)
UP	Upland Prairie	UPs14	Shrub/Woodland-Upland (oak savanna, brush prairie)
WF	Wet Forest	WFn53	Forest-Lowland Coniferous
WF	Wet Forest	WFn55	Forest-Lowland Deciduous

[a] Habitat associations are taken from Minnesota's wildlife action plan (MNDNR, 2006).

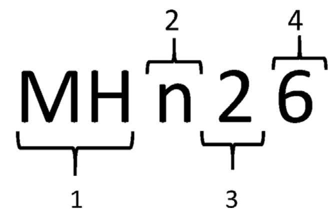

Fig. 1. Native plant community class code example.
The system employed for constructing NPC class codes uses four separate components: 1.) Ecological system, 2.) Floristic region, 3.) Moisture regime, and 4.) Nutrient regime. Moisture and nutrients are ranked from low (0) to high (9).

Machine learning and, more specifically, imputation provide a means to efficiently apply available ecological classifications to substantively similar management units or sample plots. Imputation assigns likely values or characteristics to entities for which we have incomplete data. This assignment is based on associations made with similar entities for which we do have complete data. Observed characteristics of the entity to be imputed serve to inform the most likely value or characteristic chosen by the imputation model.

We hypothesize that the spatial intersection of the subset of stand polygons for which we have associated NPC observations with permanent sample plots established by the FIA program, will allow for extension of the imputation process to the remaining entities (e.g., the balance of the FIA permanent sample plots). Extension of attributes from point observations to coincident stand polygons is justified on the premise that stands are nominally homogenous forest management units. Further, by introducing additional descriptive detail included in the spatially representative FIA sample to the imputation model, we hope to improve on the results reported by Wilson and Ek (2017), while enabling estimation of NPC extent across all ownerships.

In testing these hypotheses, we extend previously reported classification capabilities to include a statewide sample of forest inventory plots established by the FIA program between 1977 and 2014. Imputations are then integrated with the FIA DataMart Access database for Minnesota (Miles, 2014), and estimates of NPC distribution and abundance are produced.

2. Methods

2.1. Study area

The study area includes the full set of ecological landscapes falling within the state boundaries of Minnesota, USA (Fig. 2). Minnesota is located in central North America at the head of the Great Lakes chain and the Mississippi River. Minnesota spans the transition zones between the Eastern Tall Grass Prairie, Temperate Deciduous, and Boreal Forest biomes. Particular emphasis is placed on lands managed by MNDNR for forestry and timber production (~2.2 million hectares). These management and forest inventory sample units serve as the basis for associating native plant community observations with more representative forest inventory records (e.g., FIA). The polygons for individual management units (e.g., stands) are used in consecutive spatial join processes to achieve this goal. The first step associates NPC classifications and observations with spatially coincident stand records. The second step links information from the NPC and auxiliary layers with FIA sample plots via another spatial overlay with the augmented stand polygons. We then assign the NPC classifier with maximum likelihood to sample units lacking these ecological observations. The data and process are described in more detail below.

2.2. Data and pre-analysis

Forest inventory data are collected from sample plots distributed