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Representing site productivity in the basal area increment model for FVS-Ontario

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ABSTRACT

The utility of site index as a predictor variable in models for complex, mixed species stands is limited because the site index concept is not well suited for these stand types. Additionally, there is no standard protocol of estimating site index for uneven-aged mixed species stands, which is evident in permanent sample plot (PSP) and co-operative (COOP) data sets available from the Province of Ontario, Canada. Under such circumstances, an alternative to site index in a basal area increment model was explored, using a combination of climate and Forest Ecosystem Classification (FEC) variables from the Ontario boreal region. Among the four candidate climate variables chosen, mean annual temperature (MAT) explained the most variability in basal area increment for the four selected tree species – trembling aspen (*Populus tremuloides* Michx.), balsam fir (*Abies balsamea* (L.) Mill.), jack pine (*Pinus banksiana* Lamb.), and black spruce (*Picea mariana* (Mill.) B.S.P.). Our results indicated that a combination of the climate variable, MAT, and FEC explained a substantially higher proportion of variation in the basal area increment than site index alone. Thus, climate and FEC variables are superior substitutes in the basal area increment model even when error-free site index values are possible to obtain.

1. Introduction

The terms *site*, *site quality*, and *site productivity* have been used interchangeably in forestry, though they are not synonymous (Skovsgaard and Vanclay, 2008). *Site* is generically considered as place or geographic location of land. However, in a forestry context, "site is an area considered as to its physical factors with reference to forest producing power, the combination of climatic and soil conditions of an area" (Frothingham, 1921). *Site quality* reflects a measure of productivity potential for a given site at a given time (Carmean, 1975; Daniel et al., 1979; Clutter et al., 1983; Vanclay, 1992). Site quality is the combination of physical and biological factors that govern the site properties (Skovsgaard and Vanclay, 2008). Vanclay (1994) and Skovsgaard and Vanclay (2008) defined *site productivity* as a quantitative estimate of the potential of a given site to produce wood/timber or biomass for a particular species. For instance, site index (SI), or the height of a specific population of dominant or co-dominant trees at a reference age, is a widely accepted measure of site quality, and is the most commonly used quantitative index of site productivity in forestry (Kayahara et al., 1998). In a forestry context, site productivity emphasizes the timber or biomass production capability as a major indicator of site, regardless of its ecosystem concept.

The concept of site classification has long and rich history in agriculture and forestry. Alternative approaches have been developed for representing site, depending on the intended purpose. For instance, plant communities, or even attributes of single plants, have been used as relative indicators of productivity potential of an ecosystem, sometimes referred as "phytometers." In forests, site index is an important proxy of site quality and has been used in many conceptual and simulation models of ecosystem dynamics. There are numerous reasons for using site index as a means for quantifying site. For example, height can be accurately measured with minimal cost. Also, site index is simple to use, widely applicable, considered free from the effects of stand density, and highly correlated with volume production in normally stocked stands (Mader, 1963; Carmean, 1975).

The concept of site index was developed for single species, even-aged stands, but over the last two decades, it has been applied in mixed species uneven-aged stands (Monserud, 1984; Huang and Titus, 1993; Peng, 2000). As a result, numerous drawbacks to site index have been identified, discussed, and reported (Monserud, 1984). For instance, site index is often not observable because free-growing and undamaged dominant or co-dominant trees may not be present; a situation that is common in degraded stands or stands managed using uneven-aged silviculture. Even if suitable trees are present, they may not be the species desirable for estimating site index. These limitations of

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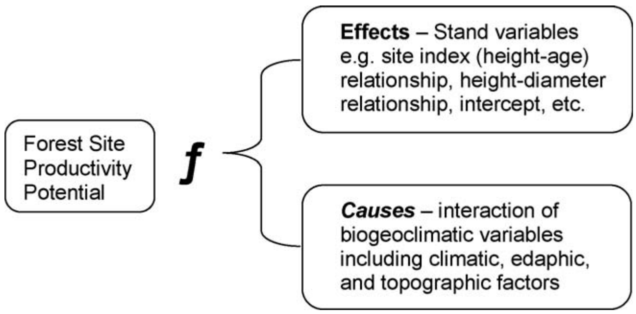

Fig. 1. Conceptual frameworks for estimating potential productivity of a given stand.

estimating site index become more and more noticeable as the scope of forest management widens towards multiple use, mixed species or uneven-aged management. Such changes in the scope of forest management have not only limited the application of site index, but also exerted pressure to explore alternate methods of evaluating site productivity.

Site productivity has been used in forestry in the context of both cause and effect (Fig. 1). For instance, site index is used as an *index* or *proxy* of potential site productivity, which integrates the effects on tree growth from numerous site variables. Alternatively, use of topographic, climate or soil variables to predict potential site productivity emphasizes a cause and effect relationship with tree growth. A shift in emphasis in forest management from yield to more holistic approach of sustainable ecosystem management favors environmental variables over site index as an alternate approach to site productivity evaluation.

It has been well-recognized that the potential productivity of an ecosystem can be characterized by an interaction of biogeoclimatic factors that include climatic, edaphic, and topographic factors (Zon, 1913; Cajander, 1926; Hägglund, 1981). A number of studies have demonstrated a relationship between the site productivity potential index and biogeoclimatic factors (Chen et al., 2002; Gustafson et al., 2003; McKenney and Pedlar, 2003; Wang et al., 2004; Monserud et al., 2006, 2008; Stage and Salas, 2007). These studies showed the application of biogeoclimatic variables while estimating productivity potential for a given tree species; however, these studies are confined to a geographical area with a large spatial heterogeneity, most particularly the western parts of the United States and Canada.

Site characterization in the form of indices or classes has numerous advantages in forestry and forest management. An accurate characterization of site allows for efficient land use allocation, integrated ecosystem planning, evaluation of ecosystem productivity and diagnosis, and prescribed ecosystem management. As a result, the majority of research has been concentrated on estimating site productivity using causal proxies, such as climatic, edaphic, and topographic factors (Fig. 1). However, very few studies have investigated the usefulness of these factors in a diameter or basal area increment model (Wykoff and Monserud, 1988; Froese, 2003). As discussed elsewhere, site productivity is an important fundamental predictor variable in the diameter or basal area increment model. It is essential to include site productivity in the model in either form (causes or effects) in order to explain site level variation in diameter or basal area increment of an individual tree.

A flexible and robust regional aspatial individual tree diameter or basal area increment model can be developed by deliberately choosing an appropriate base function along with a model structure that can accommodate the most important predictor variables including size, site, and competition (Pokharel, 2008). In the context of the Forest Vegetation Simulator (FVS), it is increasingly important to account for geographic variability of the growing conditions as FVS is intended to cover the scope of many thousands of hectares (Crookston and Dixon, 2005; Froese and Robinson, 2007). Site index has been used as a predictor variable in many FVS growth engines developed and used elsewhere (Bush, 1995a,b; Bush and Brand, 1995). Even though site index is extensively used in growth modelling, often it has received substantial criticism when used in degraded stands or stands managed using uneven-aged silviculture. There is a need to search for an alternate to site index to represent site quality in the diameter or basal area increment model that is intended to be used at regional scale, such as FVS.

1.1. Prior representation of site effects in FVS-Ontario

Site is considered one of the fundamental factors in an increment model designed for regional use. However, its utility in the increment model depends on the consistency and reliability of its field estimation. In the case of Ontario's FVS development efforts (Woods and Robinson, 2008), incorporating site effects have always been problematic for many tree species. For instance, site index is non-significant in the diameter increment model developed by Lacerte et al. for every tree species, except jack pine and black spruce (FVS-Ontario Version 1 – Lacerte et al., 2005, 2006b). In the process of refining and enhancing the diameter increment model Woods and Penner (2007) took Wykoff's (1990) approach to selecting the base function and structuring the basal area increment model, expanded the data sets, and formulated a new model for the most common tree species in Ontario, and continued to used site index as a site quality variable. In that study, however, site index was still non-significant for most tree species.

Obtaining estimates of site index to accompany available Ontario inventory data is especially problematic. Most data sets lack identification of individual site trees, total height and individual tree age data. Often, if age is available, it is the stand age, not the breast height age of an individual site tree. While this could be corrected for using age to breast height models (USDA Forest Service, 1975), we cannot ensure that trees otherwise would meet acceptability criteria for site index estimation, such as being free of evidence of past suppression or top damage. Ignoring this issue will result in unknown bias in estimates because it is impossible to identify the population of trees for which site index prediction equations were designed.

Estimating site index is essentially impossible in the Great Lakes – St. Lawrence (GLSL) data sets. These sets include measurements of overwhelmingly shade-tolerant hardwood stands or stands with silvicultural treatments that involve selective harvesting. Thus, some past suppression of height growth is almost certain in measured trees, irrespective of the absolute or relative size of any given individual tree. Because these sets usually have height and age data available, it is possible to select a certain number of the largest trees in the plot and calculate a site index from those trees. However, such site index calculations are almost certainly under-estimates of the site index that would be expected if trees had grown without past height suppression.

Thus, while large array of data is available through the Ontario Ministry of Natural Resources (OMNR), the associated estimates of site index have limited utility in diameter or basal area increment modelling. In order to make these Ontario data sets usable, an alternative approach of including site variables in the increment model is over-due. Alternative approaches have shown promise in conceptually related studies. McKenney and Pedlar (2003) used climate and soil variables to estimate site index for jack pine and black spruce in Ontario, and Gustafson et al. (2003) used site and climate variables to generate a potential site productivity map for aspen in the Upper Great Lakes region. Both of these studies