DEPLOYMENT AND PROCUREMENT OF LOBLOLLY PINE (*PINUS TAEDA* L.) SEED SOURCES GUIDED BY THE APPLICATION OF CATEGORICAL UNIVERSAL RESPONSE FUNCTION (CURF)

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Loblolly pine (*Pinus taeda* L.) is a commercially and ecologically important forest tree species dominant in the southeastern USA. Throughout its history it has likely experienced recurrent climate changes (Millar, 1993). The most recent period of glaciation that ended about 15 thousand years ago was thought to have limited the natural range of loblolly pine to two southern refugia (Wells *et al.*, 1991; Schmidtling, 2003). Subsequent climate warming allowed for the gradual northward expansion of the species, likely causing adaptational lag between evolutionary adaptations expressed as growth rate vs. local climate conditions. This mismatch was quantified by Schmidtling who showed that the optimal height growth could be achieved when seed sources are moved northward to zones experiencing minimum winter temperatures cooler by about 2-3°C (5°F) (Schmidtling, 1994). These recommendations formed the basis for loblolly pine seed movement guidelines in the southeastern USA. Today foresters essentially assist selected families migrate northward to optimize the match of growth adaptations to local climate, exploiting the growth potential of the families. Survival is an additional factor, therefore maladaptation to such environmental factors as e.g. cold or drought could lead to increased mortality, and consequently compromised timber yield. To better understand these relationships, and to investigate factors that may be potentially limiting to species expansion to the west and north, we developed Categorical Universal Response Function (CURF) (Koralewski *et al.*, 2015). CURF models the timber yield vs. climate relationship, providing support for loblolly pine assisted migration decisions. However, much within-family and within-provenance variability has been observed for growth traits, which limits the utility of performance models based solely on climate for predicting growth.

Research is ongoing to identify approaches to best match evolutionary adaptations with local environment. Some of the notable advances include transfer functions (e.g., Matyas, 1994; Rehfeldt *et al.*, 1999), population response functions (e.g., Rehfeldt *et al.*, 1999; Wang *et al.*, 2006), and the universal response function (URF) (Wang *et al.*, 2010) which combines the former two methods. The major difference between the URF and CURF is that CURF implements multinomial logistic regression and thus operates on a categorical level. In brief, CURF follows a preliminary step in which the response variable is categorized according to a predefined scheme. Next, probabilities are calculated that a performance of a given family will fall within each of the predefined categories on a given planting site.

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We applied CURF to 15-year loblolly pine planted tree volume as a response to mean minimum temperature of the coldest month and growing season precipitation. We also considered the annual variation of these two metrics, as this may help explain range limiting factors in the west and north where the species is not bound by geographical barriers. The individual tree measurements originated from the Geographic Seed Source Study (GSSS) established and maintained by the members of Western Gulf Forest Tree Improvement Program (WGFTIP). Estimated climate conditions at the provenance sites over a 30-year period using PRISM data (PRISM Climate Group; Daly *et al.*, 2008) were considered as surrogates for long term effects shaping evolutionary adaptations. The weather conditions during the 15-year progeny testing period corresponded to the actual environmental impact upon the tested families. Therefore, the weather at the test site could be seen as a shift in climate from the local conditions at the site of origin to which the families are presumably adapted. Furthermore, this effect could be seen as a surrogate for a potential future climate change.

The model generally confirmed the guidelines proposed by Schmidtling (1994). South to north movement was well supported, with some local variability that could probably be attributed to precipitation and variation in the two climate variables. All, or almost all (depending on the evaluation criterion) selected interactions among climate variables were significant. Although interactions did not cause major differences when compared to the model without interactions, their effect was more evident for sites near the edge of the loblolly pine distribution range. Since all explanatory variables are solely climate-related, and thus the method operates in a climate space, extrapolation beyond the spatial boundaries of the studied region is possible. Such exercises, however, must be verified with practical trials as growing conditions in the areas to which the model is extrapolated may be influenced by factors other than climate, e.g. soil type or water table level. This is especially important when focusing on areas along the edge of the distribution range where climate conditions are generally harsher. For example, in practice, seed movement in east Texas generally involves selection of better quality soils to facilitate survival. The model did not support the provenances located along the northern edge of the distribution, such as those in southern Oklahoma and southern Arkansas, as good candidate procurement sources. However, due to exposure to harsher and more variable continental climate these sources have likely developed essential survival adaptations, and may be valuable for novel areas beyond loblolly pine range located in the north – e.g., in Tennessee or Kentucky. For the same reason, they may be considered in wide crosses with fast growing seed sources (e.g. Atlantic coastal).

The model performed well and is consistent with current understanding of the risk-benefit balance in loblolly pine seed movement in the Western Gulf area. As the model is purely climate-based, it does not account for other factors that may impact species performance, including soil type, elevation, aspect, or silvicultural practices. Moreover, when considering future climate projections, one should be aware of climate models' sensitivity to long-term assumptions, and thus uncertainties that may result from both stochasticity of natural phenomena and unknown direction of human actions. As the ultimate procurement and deployment decisions are made by practitioners, the categorical output and probabilistic nature of CURF make it a good candidate approach to consider for Decision Support Systems.

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