

the spatial distribution of soil nutrients (organic carbon, N, P, K), as well as Na and Li. Soil samples were taken under and around a pistachio (*Pistacia atlantica* Desf. var. *Kurdica*) tree in the Zagros region of western Iran. The samples were taken every 2 m and then at 50-cm intervals in a regular grid of 20 m × 20 m around the tree, in order to analyze the spatial properties using geostatistics. Total N content and soil organic carbon were higher under the tree canopy. Phosphorus content also was higher under the tree. Potassium decreased with distance from the tree base. Sodium had a medium spatial distribution related to tree canopy; Li showed a sparse spatial pattern and its distribution seems to be independent of the tree position. These results support the hypothesis that the presence of a tree differentially affects the spatial distribution of the various nutrients depending on their chemical characteristics.

**Three experiences with geostatistics application for estimation and mapping of forest stock in the Caspian region of northern Iran.** Akhavan, R. (*Research Institute of Forests and Rangelands, Iran; akhavan@rifr-ac.ir*).

The purpose of this paper was to compare the application of geostatistics for estimation and mapping of forest stock attributes among a natural hardwood unmanaged forest (intact without any intervention), a natural hardwood managed forest (harvested two times), and a plantation forest (18-year-old pure maple) in the Caspian region of northern Iran. Different systematic grids with proportional plot sizes were set up for sampling. Experimental variograms were calculated and plotted for basal area (BA) and stem density in these forests based on the inventoried georeferenced plots fitted by appropriate models. Estimation and mapping were made by ordinary block kriging and evaluated by cross-validation. Results showed that there is no spatial structure for BA and stem density in the natural managed forest. In the natural unmanaged forest spatial structure was found only for stem density, and in the plantation forest spatial structure was found only for BA. Therefore, it was concluded that geostatistics is able to capture and accurately describe the spatial variability as well as estimates and maps for some tree attributes in unmanaged and plantation forests; however, due to high spatial variability, it has no application in managed forests.

**Ecological adaptation of the shea butter tree (*Vitellaria paradoxa* C.F. Gaertn.) along a climatic gradient in Benin, West Africa.** Akpona, T. (*University of Abomey-Calavi, Benin; ajeandidier@gmail.com*).

This study assessed the ecological adaptation of shea butter trees based on their dendrometric and production traits in four shea parks established in different climatic zones of Benin. A total of 99 rectangular plots of 50 m × 30 m were established within the four parks using a random sampling scheme. In each plot, all trees with DBH 10 cm were inventoried and measured for stem and crown diameters, and total height. Production of 120 productive shea trees was quantified in the four parks. Data collected were used to compute structural parameters for each park. Moreover, stem diameter and height structures of the trees were established. Principal component analysis was performed on the dendrometric variables and the first three components were correlated with climatic parameters. Results revealed significant differences between parks in most of the dendrometric and production parameters of shea trees. For all four parks, stem diameter and height structures present a Gaussian shape; for Sudanian parks, the curve has left dissymmetry. In regions with relatively high rainfall and relative humidity, shea trees developed large crowns, but produced few fruits whereas in the drier regions, the opposite trend was observed.

**Tree cork caliber evolution in two consecutive cork extractions: trends and possible causes.** Amaral Paulo, J., Tomé, M., Pereira, H. (*Technical University of Lisbon, Portugal; joanaap@isa.utl.pt; magatome@isa.utl.pt; hpereira@isa.utl.pt*).

The objective of the study was to research the influence of precipitation, tree variables, site characteristics, and debarking intensity on the evolution of cork caliber at the individual tree level. A mixed model approach was used in addition to partial least squares analysis. In 23 permanent plots two consecutive cork extraction operations were followed and cork samples were collected. The cork samples, from a total of 357 trees, covered growth years from 1984 to 2010. Since cork samples presented different numbers of years of growth, cork caliber was evaluated with the trough cork growth index (CGI). It was demonstrated that mean CGI from the two consecutive cork extractions, at plot level, decreased significantly in 16 out of the 23 plots for  $\alpha = 0.05$ . Results show that, although precipitation explained the larger part of the CGI evolution, tree diameter and stand density were also important variables. Debarking intensity was not as important an explanatory variable. The significance of site characteristics indicates that other variables are relevant, pointing out the need for further research.

**Validation of five non-linear growth models for plantation-grown *Terminalia superba* in Ibadan, Nigeria.** Awosusi, B., Oyeleye, B., Akinyemi, G., Ayodele, O. (*Forestry Research Institute of Nigeria; monisola.bola@yahoo.com; gbemioyebolarinwa@gmail.com; akinyemigab@yahoo.com; yehmmy2010@yahoo.com*).

Five non-linear mathematical models were developed and validated using growth data from one of the indigenous tree species in Nigeria (*Terminalia superba*). The selected models were: Malthusian, Gompertz, logistic, Von Bertalanffy, and Richard. These non-linear growth models were used to predict tree height using tree age as the independent variable. Methods of integrating the differential forms of the models used were also reviewed. Parameters of the models were estimated using the Marquardt iterative method of non-linear regression relating tree height to age. The data used were collected from the Forestry Research Institute of Nigeria, Ibadan, Nigeria. Formulas that provide good initial values of the parameters are specified. It was discovered that the logistic model showed very promising results. It fitted the data very well with a smaller relative standard error (0.4797) and higher  $R^2$  (0.899). Results suggested that the models derived were statistically and biologically acceptable and could be satisfactorily used to predict tree height. The results also show the fundamental importance of growth models in forestry since any of the models here can be used to predict the tree growth and yield at a very early stage.

**Climate change impact in the Uruguayan forest sector: an empirical evidences analysis.** Bennadji, Z. (*Instituto Nacional de Investigaciones Agropecuarias, Uruguay; zbennadji@tb.inia.org.uy*).

Since 1990, Uruguay has undertaken actions on climate change mitigation and adaptation, especially in the policy area. At the international level, Uruguay subscribes to the United Nations Framework Convention on Climate Change and complies with the preparation of periodic national-scale reports on greenhouse gas emissions. At the national level, an inter-ministerial committee

was created to follow up on the climate change impact on the main economic activities in the country. However, information for the forest sector was too scarce to allow any objective assessment of its exposure, sensitivity, and adaptive capacity to climate change. The objective of this work was to present empirical evidence as the basis of an analysis of climate change impacts in *Eucalyptus* and *Pinus* spp. plantations. The relationship between disturbance of forest tree phenology and growth, pest outbreaks, and extreme frost, drought, rainfall, and storm events from 1998 to 2012, and temperature and precipitation variations as the main climatic factors was investigated. The aim was creation of the first long-term data series in the country on climate change impacts on forest plantations. The need to consolidate this data series for use in modeling and prediction of climate change impacts on forest plantations at the local level and as a tool for practitioners is discussed.

**‘Carbon debt’ – lost in the forest?** Bentsen, N., Graudal, L., Madsen, P., Felbu, C. (*University of Copenhagen, Denmark; nb@ign.ku.dk; lgr@life.ku.dk; pam@ign.ku.dk; cf@gmail.com*).

The concept of ‘carbon debt’ and carbon payback time with reference to bioenergy and biofuels was probably launched by an article in *Science* in 2008. The concept is increasingly seen as an indicator of the sustainability of bioenergy supply chains. Particularly for forest bioenergy supply chains the time lapse between harvest and regrowth may be a significant factor for the modeled carbon debt. A meta-analysis of more than 250 model scenarios was conducted to evaluate the factors and assumptions determining carbon debts and payback time of forest bioenergy supply chains. Factors such as spatial and temporal scale, biome, origin of the wood resource, which fossil fuels are displaced, forest history, baseline scenario, accounting principle, and data background were included in the analysis. This paper discusses the evolution of the carbon debt concept, how different factors and assumptions influence the outcome of carbon debt studies, the reproducibility of carbon debt analyses, and the applicability of the concept as a measure of sustainability of forest bioenergy supply chains.

**Assessing forest change across Canada using successive kNN-based maps of imputed forest inventory data.** Bernier, P., Beaudoin, A., Guindon, L., Villemaire, P., Stinson, G. (*Canadian Forest Service, Canada; pbernier@rncan.gc.ca; abeaudoin@rncan.gc.ca; lguindon@rncan.gc.ca; philipe.villemaire@rncan.gc.ca; graham.stinson@rncan.gc.ca*).

The authors recently produced a suite of national maps of forest attributes for Canada at a resolution of 250 m for the 2001 base year. The non-parametric kNN approach was applied on a set of Canada-wide layers of predictive variables, most notably multi-spectral information from the MODIS sensor, as well as climate variables, topography, and land cover to impute National Forest Inventory baseline measurement data. Yearly maps at 250-m resolution were also produced showing severe forest disturbances, i.e., yearly areas affected by either harvesting or fire from 2001 to 2011. This paper presents updated maps of forest properties for 2011 and evaluates the extent to which changes between these maps and those for 2001 are able to capture the patterns of changes expected based on the yearly disturbance maps. Limitations of the approach as well as avenues for improvements of the kNN products are discussed.

**Estimating stand heights and crown structure of subtropical broad-leaved forest using LiDAR data in Okinawa island, Japan.** Binti Ahmad Zawawi, A. (*Kagoshima University, Japan; azitazawawi@gmail.com*), Shiba, M. (*Faculty of Agriculture, University of the Ryukyus, Japan; mshiba@agr.u-ryukyu.ac.jp*), Jemali, N. (*Kagoshima University, Japan; idiana0303@yahoo.com*).

The application of LiDAR to extract data at the single-tree level has long been recognized in providing valuable information about forest stands. Most studies involving crown detection and tree height estimation have focused on analysis of plantations, boreal forests, and temperate forests, and less study has been done in subtropical or tropical forests. This study presents an approach for estimating tree heights, stand density, and crown structure using LiDAR in the complex subtropical forest of Okinawa island in Japan. A digital canopy height model (DCHM) was derived from the LiDAR data for tree height estimation, and the watershed segmentation method was applied for individual crown delineation. Dominant tree canopy layers were estimated using multi-scale filtering and local maxima detection. Information on crown structure characteristics such as crown diameter and fractal dimension was also produced. The computed result was compared to field data and validated using IKONOS imagery over the forest area. The results of this study suggested that LiDAR data have huge capability to estimate tree height in subtropical forests, but were not sufficiently capable in the detection of small understory trees and in single-tree delineation. We found that LiDAR computation results underestimated the frequency of trees and overestimated the crown size.

**Comparing alternatives for increasing sampling intensity in forest inventories.** Blackard, J., Patterson, P. (*U.S. Forest Service, USA; jblackard@fs.fed.us; plpatterson@fs.fed.us*).

Each of the U.S. Forest Service’s Forest Inventory and Analysis (FIA) regions has an occasional need to intensify the national sampling grid. A variety of methodologies exist within the various FIA regions and National Forest Systems regions for constructing plot intensifications, and there is no consensus on a national procedure. The primary objectives of this paper were to identify various intensification methods being implemented by FIA or used by other groups, examine their advantages and disadvantages for establishing intensified plots within the existing FIA framework, and recommend a potential national FIA plot intensification procedure that might adequately address the needs for all FIA regions.

**Paired catchment experimental methodology: a critique.** Bren, L. (*University of Melbourne, Australia; lbren@ncable.net.au*), Nettles, J. (*Weyerhaeuser Company, USA; jami.nettles@weyerhaeuser.com*).

Paired catchment experiments have been around for almost a century. This paper examines how the technique has been used since the first project at Wagon Wheel Gap in Colorado, USA. Recent Australian work on the units and length of the calibration period showed that there is a rapid buildup of information in the first year of calibration and there may be little gain in long calibration periods. For this paper this hypothesis was tested in other countries using international data sets. Errors of measurement with this method were compared to alternative approaches such as plots or modeling. Although the presence of a “control” catchment is a great asset, the assumption of this control as a constant is examined given the long duration of some projects, and supplementary