Using sphere packing models to explain the structure of forests

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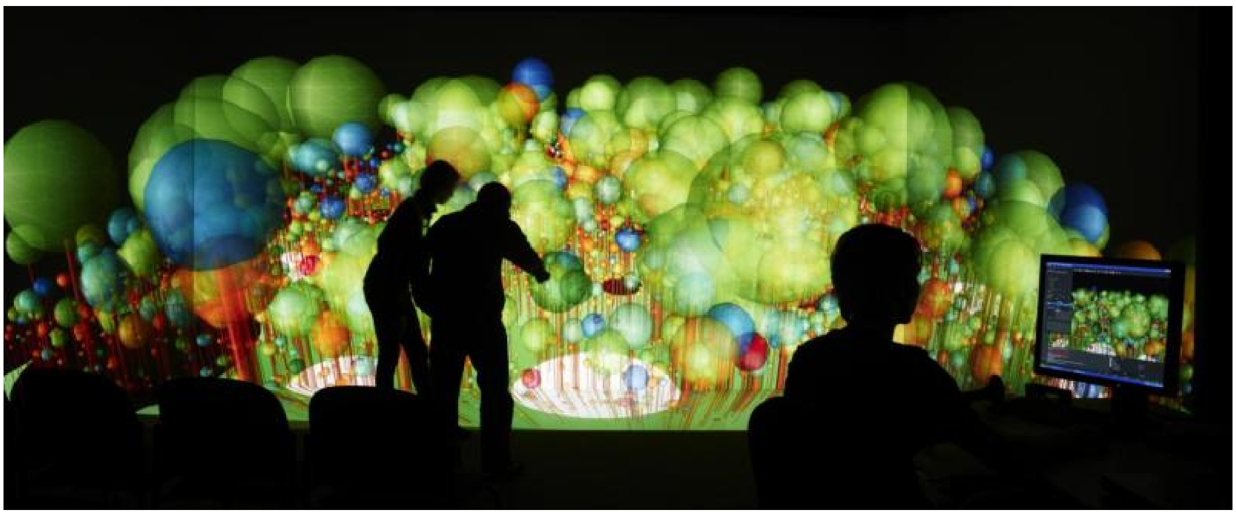

Image showing tightly packed tree crowns in a natural tropical forest, for investigating the forest's structure. Tree crowns of different sizes are shown as spheres. Credit: André Künzelmann, UFZ

Explaining the complex structure of tropical forests is one of the great challenges in ecology. An issue of special interest is the distribution of different sizes of trees, something which is of particular relevance for biomass estimates. A team of modellers from the Helmholtz Centre for Environmental Research (UFZ), working together with research partners, has now developed a new method which can be used to explain the tree size distribution in natural forests. To do so, the scientists use principles from stochastic geometry, as they have reported in a contribution to the *Proceedings of the National Academy of Sciences* (*PNAS*, Early Edition). Using this approach, it is possible to assess the structure of natural forests across the world more quickly, and produce more accurate biomass estimates.

For over one hundred years, the distribution of different sizes of trees in forests has been one of the core attributes recorded by foresters and ecologists world-wide, as it can be used to derive many other structural features, such as biomass and productivity. "We wanted to explain this important pattern", said Dr. Franziska Taubert. Working with her UFZ colleagues Dr. Thorsten Wiegand and Prof. Andreas Huth, and other research partners in the Leipzig University of Applied Sciences (HTWK) and the Karlsruhe Institute of Technology (KIT), they have applied the theory of stochastic sphere packing, which is usually used in physics or chemistry. This theory describes how spheres can be placed in an available space. To apply the theory, the scientists randomly distributed tree crowns of different sizes in forest areas. These tree crowns were not permitted to overlap, - just like packing apples into a box. The distribution of the trees that have been successfully placed in the packing process was then used to determine the tree size distribution.

"Many forest models are based on a dynamic approach: they take into account processes such as growth, mortality, regeneration and competition between trees for light, water and soil nutrients", said Taubert. "These models are complex and data-hungry", added Thorsten Wiegand," so we decided to take a radically different approach, which is fundamentally simpler and only based on spatial structures". This model approach proved its effectiveness by enabling observed forest structures, especially the tree size distribution, to be reproduced accurately. The rules of stochastic geometry are thereby enriched by tree geometry relationships, and the resulting tree packing system is compared to inventory data from tropical forests in Panama and Sri Lanka.

Although one might imagine that a tropical forest is very tightly packed, the scientists came to a surprising conclusion: the packing density of the tree crowns, which averages 15 to 20%, is astonishingly low. "In particular, the upper and lower canopy levels are less tightly packed with tree crowns", said Taubert. High packing densities of around 60%, which are also possible according to stochastic geometry, only occur at tree heights between 25 and 40 meters.

The findings concerning the distribution of tree crowns are important, because they can be used to draw conclusions about, for example, the carbon content or productivity of a forest. Using this modelling approach, the researchers were also able to show that the decisive factor in shaping the tree size distribution is competition for space. "In classical forest models", said Andreas Huth, "the trees instead compete for light, or water and nutrients".

The theory opens up several new perspectives. The team plans to assess how the model can be applied to natural forests in the temperate and boreal zone. They believe that the model can be used to identify disturbed forests. "That is of special interest because it will enable us to develop a disturbance index", said Taubert, "and to better interpret remote sensing observations by using the structure of natural forests as a reference". Another benefit of the new theory is that this simple forest packing model takes much less effort than classical forest models. The new approach is an important step toward identifying a minimal set of processes responsible for generating the spatial structure of natural forests.

More information: Franziska Taubert et al. The structure of tropical forests and sphere packings, *Proceedings of the National Academy of Sciences* (2015). DOI: 10.1073/pnas.1513417112

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