"Ashes to Ashes and Rising Above: the global threat of alien invasive forest pathogens and opportunities to exploit host resistance to conserve populations"

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Increased connectivity and globalization have greatly accelerated the frequency and magnitude of biological invasions around the globe by facilitating the long-distance movement of species into regions outside their historical distribution range. Although most non-native species have negligible effects on forests, some have the potential to cause massive and irreversible damage by eliminating keystone tree species in many areas of the world, and permanently altering trophic structures, nutrient dynamics and primary productivity of forest communities. Such wide ranging ecological impacts can compromise the maintenance of ecosystem services upon which humans rely, including those associated with health and wellness.

Ash dieback – a disease caused by the alien invasive fungus *Hymenoscyphus fraxineus* (native to east Asia), has caused large-scale population decline of European ash (*Fraxinus excelsior*) across Europe, and is threatening to functionally extirpate this tree species. This is concerning not only for European ash as a tree species, but also for its associated biodiversity. Genetically controlled host resistance is a key element to ensure European ash's survival and to restore this keystone species where it has been eliminated. A low proportion of the natural population of European ash appears to express quantitative resistance against the fungus and such resistance is heritable, and stable across environments. Some efforts have been made towards developing a more resistant population of ash for Swedish forests, cities and landscapes including 1) broad-scale mapping, identifying and selecting more than 500 putatively resistant genotypes from wild populations, 2) screening resistance in established clonal trials of selected genotypes, and 3) assessing the heritability of resistance in progeny of known European ash families.

Phenotyping tools that allow rapid identification and deployment of superior genotypes, with the advantage of reduced time and cost, can effectively expedite breeding and restoration efforts. One such tool is chemometrics using vibrational spectroscopy, which is based on the absorption of infrared radiation resulting from fundamental molecular (bond) vibrations. This technique works by fingerprinting a wide range of biological samples and using multivariate statistical classification models, to identify and delineate target classes. We analyzed the Fourier transform mid-infrared spectral region of phenolic extracts of uninfected tissue samples from genotypes collected across six European countries that were previously phenotyped as either resistant or susceptible to *H. fraxineus*. Fourier-transform infrared (FT-IR) chemical fingerprints were processed using a chemometric approach by using soft independent modeling of class analogy (SIMCA) to discriminate between resistant and susceptible trees. Model validation was performed on a blind set of samples randomly selected from each of the six European countries. Results demonstrated that European ash possesses readily exploitable levels of resistance that can be detected using FT-IR spectroscopy. These findings suggest a major advancement the future process of tree selection, thus making breeding for resistance, *ex situ* and *in situ* conservation, restoration, and long-term sustainable management of this threatened tree species a feasible and realistic strategy. Despite these positive steps however, long-term restoration planning is hindered by low interest levels among authorities in sharing the burden of responsibility for saving 'noble' tree species from extinction.

Future research aimed at identifying plant specialized metabolites (biomarkers) that are uniquely associated with resistant phenotypes, including those associated with congeneric species of *Fraxinus* (e.g. Asian Fraxinus for which the fungus exists as a benign associate), and developing more practical solutions for rapid phenotyping in the field (i.e. with a portable FT-IR spectrometer) will be important for future work aimed at developing a more resistant population for Sweden and Europe overall.

More broadly, the management of forest threats caused by alien invasive pathogens requires society's recognition of the global nature of the problem and a global effort to, e.g. understand the drivers of biological invasions, vulnerabilities in the existing regulatory frameworks, and the necessary investments in global research initiatives aimed at promoting forest health.