Bridging modeled and measured data to evaluate forest health and vitality

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Project born from collaboration with ICP-Forests community

The core parameter for a description of forest health within the ICP Forests program is the tree crown defoliation.

Modelling of crown defoliation is challenging at the European scale because the tree defoliation integrates a wide range of mutually interacting predictors (de Vries et al., 2000)

Epidemiological approach is useful to give information in field and provide scenarios analysis

An example of merging modelled and measured data in order to achieve relevant results at European level.

Nitrogen deposition is a critical issue not only for agriculture but for forest protection as well (loss of biodiversity, increase-decrease growth)

“crown defoliation is probably still the best available criterion on tree condition” (Zierl, 2004)
Although climate change and air pollution are closely linked, they have been largely separated in applied research and even more in political negotiation and policies (Serengil et al., 2011)

Temperature is expected to increase between 3°C in central Europe and 4-5°C in the Boreal region and parts of the Mediterranean area by 2100 (Loustau et al., 2005)

Increase of plant mortality rates and die-off events (Allen et al., 2010; Breshears et al., 2005), long-term shifts in vegetation composition (Mueller et al., 2005), reduced radial growth (Andreu et al., 2007) and increased crown defoliation (van Mantgem et al., 2009) especially in semiarid and Mediterranean forest ecosystems
• What are the most relevant factors affecting tree health and vitality on a European scale?

• Is it possible to model, satisfactorily, a complex variable like tree crown defoliation by general regression models?

• How does crown defoliation respond to future nitrogen deposition and climate change scenarios?

• How are different tree species affected by expected changes in climate and air pollution?
Methodology: building the starting database

Defoliation database
- Defoliation
- Age of the forest
- Type of forest

Soil data
- C/N ratio
- pH CaCl$_2$
- pH H$_2$O

Air pollution
- $N_{\text{red}}$ deposition
- $N_{\text{ox}}$ deposition
- Total N deposition
- $N_{\text{crit}}$ critical load exceedances

Meteorological parameters
- Mean yearly temperature
- Cumulated yearly precipitation
- Number of days with daily mean temperature below 0°C
- Number of days with daily mean temperature above 20°C

Three years of data 2001, 2006, 2011 and the year before for meteo and deposition
Methodology: selection of representative species

12 species have been selected on the basis of their representativeness (almost 100 plots)

Betula pendula
Carpinus betulus
Castanea sativa
Fagus sylvatica
Fraxinus excelsior
Picea abies
Pinus nigra
Pinus sylvestris
Quercus petraea
Quercus pubescens
Quercus robur
Quercus ilex
Methodology: statistical analysis

Linear statistics:

*Pearson’s correlation*

*Multiple linear regression model*

- a linear model has been built on 2001 and 2006 defoliation and cross-validated for 2011

Non linear statistics:

*Random Forest Analysis*

- RFA has been performed on the year 2001 and 2006 for selecting relevant parameters (threshold of importance set to 0.6) for elaborating a linear regression model
- RFA has been performed on the three year (2001, 2006 and 2011) for selecting relevant parameters (threshold of importance 0.5) for elaborating a general regression model (RGM, non-linear model)

*Surface plot*

*General Regression model*

- model built taking into account the most important predictors (random sampling of the 70% of data) and cross-validated with the remaining 30% of the data.
Defoliation in different countries in comparison with EU average

- **Picea abies**
  - 2001
  - 2006
  - 2011

- **Fagus sylvatica**
  - 2001
  - 2006
  - 2011

Countries: Denmark, Estonia, France, Germany, Italy, Latvia, Lithuania, Czech Republic, Slovakia, Slovenia, Spain, Hungary, Europe.
Defoliation in different countries in comparison with EU average

**Quercus ilex**

**Pinus sylvestris**

- **Denmark**
- **Estonia**
- **France**
- **Germany**
- **Italy**
- **Latvia**
- **Lithuania**
- **Czech Republic**
- **Slovakia**
- **Slovenia**
- **Spain**
- **Hungary**
- **Europe**

**France**

- 2001
- 2006
- 2011

**Italy**

- 2001
- 2006
- 2011

**Spain**

- 2001
- 2006
- 2011

**Europe**

- 2001
- 2006
- 2011
Multiple Linear Regression by leaf type

**Broadleaved Deciduous_2001**
\[ y = 0.119x + 18.452 \]
\[ R^2 = 0.118 \]

**Broadleaved Evergreen_2001**
\[ y = 0.2348x + 16.699 \]
\[ R^2 = 0.2171 \]

**Conifer_2001**
\[ y = 0.1808x + 15.58 \]
\[ R^2 = 0.1745 \]

**Broadleaved Deciduous_2006**
\[ y = 0.0884x + 22.074 \]
\[ R^2 = 0.0888 \]

**Broadleaved Evergreen_2006**
\[ y = 0.3047x + 17.243 \]
\[ R^2 = 0.2856 \]

**Conifer_2006**
\[ y = 0.1194x + 19.232 \]
\[ R^2 = 0.1119 \]

**Broadleaved Deciduous_2011**
\[ y = 0.0603x + 23.545 \]
\[ R^2 = 0.0601 \]

**Broadleaved Evergreen_2011**
\[ y = 0.486x + 10.9 \]
\[ R^2 = 0.4321 \]

**Conifer_2011**
\[ y = 0.1194x + 19.232 \]
\[ R^2 = 0.1119 \]
Linear Multiple Regression Model realised for the 5 species widely diffused in Europe

- Fagus sylvatica
- Picea abies
- Quercus ilex
- Pinus sylvestris
- Quercus petraea
Defoliation cannot be explained by a Multiple Linear Regression Model, even if using the most important predictors derived by RFA.

The non-linear approach
Adjustment of defoliation values on the basis of latitude and longitude values was applied, in order to reduce the high variability of the observed defoliation values.

Random Forest Analysis was applied to the new database with reduced variability of the defoliation values.

New selection of the most important predictors affecting defoliation was made.

A General Regression Model (non-linear model), in consideration of the RFA was built for each specie.

Selection of the scenarios for climate and air pollution.

Application of the scenarios and prediction of future defoliation in 2030.
• Random Forest Analysis performed to select more important parameters to explain crown defoliation to build up a Multiple Regression Model

• RFA is a collection of simple tree predictors, each capable of producing a response when evaluated in relation to a set of predictor values.

• The final predictor importance values are computed by normalizing those averages so that to the highest average is assigned the value of 1, and the importance of all other predictors is expressed in terms of the relative magnitudes (Svetnik et al., 2003).
RFA results (predictor importance)

A

- Pinus sylvestris
- Pinus nigra
- Betula pendula
- Picea abies
- Fagus sylvatica

B

- Carpinus betulus
- Quercus ilex

Relative importance:

- Mean T
- Precipitation
- days T<0
- days T>20
- C/N
- pHCaCl2
- pH2O
- CluT
- Exceedance
- Nox
- Nred
Cross-validation of the models

Betula pendula
Carpinus betulus
Castanea sativa
Fraxinus excelsior
Fagus sylvatica
Quercus petraea
Quercus pubescens
Quercus robur
Cross-validation of the models
Next phase
Climate change scenarios: Representative Concentration Pathways (RCP) scenarios

The RCPs are named according to their 2100 radiative forcing level as reported by the individual modeling teams. The radiative forcing estimates are based on the forcing of greenhouse gases and other forcing agents - but does not include direct impacts of land use (albedo) or the forcing of mineral dust.

The RCP 2.6 is developed by the IMAGE modeling team of the Netherlands Environmental Assessment Agency. The emission pathway is representative for scenarios in the literature leading to very low greenhouse gas concentration levels.

The RCP 4.5 is developed by the MiniCAM modeling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI).

The RCP 8.5 is developed by the MESSAGE modeling team and the IIASA Integrated Assessment Framework at the International Institute for Applies Systems Analysis (IIASA), Austria. It is characterized by increasing greenhouse gas emissions over time representative for scenarios in the literature leading to high greenhouse gas concentration levels.
Three climate change scenarios (total annual precipitation)
Three climate change scenarios (mean annual temperature)
Three climate change scenarios (number days T<0)
Three climate change scenarios (number days $T>20$)

- **Rcp26**
- **Rcp45**
- **Rcp85**

**Delta %**
- -25 - -15
- -15 - 0
- -10 - 0
- 0 - 10
- 10 - 20
- 20 - 30
GAINS estimates emissions, mitigation potentials and costs for the major air pollutants (SO$_2$, NO$_x$, PM, NH$_3$, VOC) and for the six greenhouse gases included in the Kyoto Protocol.

**Goth_NAT_July2011**

Starting point is Goth_Nat_March2011 but then emission vector and control strategies are aligned with the GOTH_PRIMES2009_July2011 while activity data are the National pathways including updates in the last round of comments in May-June-2011
Change in N deposition and exceedances

Delta (%)
-100 -70
-69 -50
-49 -30
-29 -10
-9 - 0
-9 - 0
1 - 20

NOx

Nred

Exceedance
Conclusions

Defoliation is a highly variable parameter in forest, between species and between geographical distribution in according to previous observations.

The important predictors in affecting defoliation have been identified and ranked through the use of Random Forest Analysis.

It is interesting that Nitrogen deposition, both in the form reduced or oxidized seems to be generally more important than nutrient nitrogen critical loads exceedances,

However, it was not possible to predict defoliation by use of linear statistical model, because it was not able to explain the high variability of defoliation.

It was necessary to use a non-linear statistical model (GRM) in order to obtain a good prediction of defoliation, relatively to some important plant species widely diffused in Europe.

The non-linear model, when applied to the future climatic and air pollution scenarios (2030), highlighted a change of defoliation with respect to actual condition correspondingly to the variation of predictors in the future.

Climate change and air pollution scenarios showed a decrease in defoliation in some areas, and an increase in others and this is very variable between species.
In some cases, vitality may increase for a combination of more favourable climate for growth (CO$_2$ and temperature) and nitrogen fertilization.

Increasing drought and disturbance (e.g. growth of insect populations) could cause adverse effects.

*Quercus ilex* and *Fagus sylvatica* showed severe increasing defoliation in the plots located in the continental part of Spain and in Italy, but beech populations growing in central-northern Europe revealed a slight decrease in future crown defoliation.

The carbon sink efficiency of the southern European forests may be reduced by drought and, as a consequence, may contribute to the reduction in carbon sink in the Northern hemisphere.