

CoFoRD

Final Report

BETTERFOR

DAFM Project Reference No: 13/C/451

Start date: 01/03/2014

End Date: 28/02/2016

Principal Coordinator and Institution: Maarten Nieuwenhuis, UCD Forestry

Email: maarten.nieuwenhuis@ucd.ie

Collaborating Research Institutions and Researchers: FERS Ltd.

Please place one "x" below in the appropriate area on the research continuum where you feel this project fits

Basic/Fundamental	—————▶	Applied/Pre Commercial				
			x			

Please specify priority area(s) of research this project relates to from the National Prioritisation Research Exercise* (NRPE) report:

Priority Area (s)	Priority Area I: Sustainable Food Production and Processing Priority Area B: Data Analytics, Management, Security and Privacy
--------------------------	--

Key words: (*max 4*) growth, model, evaluation, assessment

1. Rationale for Undertaking the Research

This section should outline the rationale for carrying out the research and identify the need / problem to be addressed

Previously funded COFORD projects have resulted in the development of robust single tree model Carbware (CW) and the stand based growth model Growfor (GF) for forest resource assessments. Both modelling frameworks were developed using the Coillte experimental permanent sample plot (PSP) dataset. The National Forest Inventory (NFI) is a statistically produced database of the forest estate in Ireland. The second cycle of measurements in the NFI has recently been completed and together with the first set of measurements, growth increments and change in the forest estate may be obtained. Using the NFI, the two models can be evaluated since it is an independent dataset and has the potential to highlight aspects of each model that may be improved through re-parameterisation. The NFI can allow for more accurate growth models, improved volume and assortment functions.

Following model recalibration, if required, comparison of stand outputs such as, volume increment and timber assortments from the GF and CW model against NFI information will be carried out to identify the most suitable modelling approaches and future research requirements for accurate timber forecasts and greenhouse gas forecasts. The project also plans to include site specific factors in CW to improve growth predictions as well as an assortment function which will make use of the outputs from the Treemodel project.

In addition, the project will test the suitability for using the two different frameworks for resource assessment in mixed and uneven stands. Single tree models can, in theory, deal with such stand types while stand based model have been suggested not to be suitable.

2. Research Approach

Specify the research methodologies employed, emphasising novel techniques and also outline any modifications from the original approved project proposal

Task 1

Evaluation of Growfor

Tree level measurements from both cycles of the NFI were aggregated to produce stand variables. Stand variables derived from the 1st cycle of measurements were used as input into GF. Inputs included top height, stems per hectare and basal area as well as age. Model outputs were compared to the stand variables derived from the 2nd cycle of measurements. Evaluation statistics include Bias% and Rmse% which are the relative bias and relative Rmse, i.e. total Bias / Rmse of a variable of the GF model as a % of the mean of that variable. A linear regression of predicted variables against the output variables was undertaken and the coefficient of determination (R^2) was recorded as a goodness of fit. Predictions producing R^2 above 0.95 would be considered accurate.

Data were stratified into thinned and unthinned and also into strata corresponding to the concentric plots used in NFI sampling system of measurements.

For the production of assortments, the stem taper model from the Treemodel project was ported into a Python implementation. However, a problem remained in the implementation that could not be

identified or fixed. The closed-source software Treemodel has no issues but is less flexible than a Python implementation. Correspondence between the post-doc and Martin Cerny (IFER) was not productive and the problem remains. This prevented complete analysis of the assortment functions in both GF and CW.

Evaluation of CARBWARE

We validated the calibrated growth models on the NFI data from the 2005 and 2012 inventories.

Specific consideration was focused towards identifying sampling errors associated with the methodology employed by the Forest service (NFI data providers):

- a) Accuracy of repeated DBH measurements. An infield validation check was used to ensure the corresponding tree was measured in the repeat inventory based on a spatial query of mapped trees.
- b) Partial sampling of trees within a plot. Data of trees within three diameter classes (<12, 12-20 and >20 cm) are recorded if they are observed within a certain distance from the plot centre in three concentric plots within the 0.5 ha plot. This represents an additional sampling area and increases the probability of a lower representative sample of smaller, compared to larger trees.
- c) The performance of the CW model across different silvicultural conditions, such as pure vs. mixed stands, thinned versus non thinned stands was also investigated.

Task 3

Re-calibration of the CARBWARE model

For this study, growth and mortality models, based on the PROGNOSIS family of single tree models (Monserud and Sterba, 1999), were recalibrated using data from both cycles of NFI. Detailed methodologies used are published by Black (2016). The new models included climatic factors and other site factors, which are known to influence tree growth, were derived using the Irish ecological site classification system (ESC, Ray *et al.*, 2009; Black *et al.*, 2014). To model the probability of tree mortality, we used the same state variables used in PROGNOSIS, such as *DBH*, crown ratio (*CR*), basal area of the largest tree (*BAL*) (Monserud and Sterba, 1999) and predicted growth increment (*Dinc*) as described by Monserud (1976). Models were optimised (maximum likelihood) using the highest goodness-of-fit and the calculated area under the receiver operating characteristic (ROC) curve (Heagerty *et al.*, 2000).

The growth increment modelling framework is based on *DBH* increment (normalised to an annual increment, *Dinc*), described as a function of tree size (*fSIZE*), competition (*fCOMP*) and site factors (*fSITE*). Site factors used in this study vary considerably to those described for the PrognAUS model (Monserud and Sterba, 1996). Site factors were subdivided into ecological site factor variables, derived from climatic and soil information (*fESC*), and topographical factors (*fTOPO*), such as elevation (*E*).

New model selection techniques

Selection, grouping and formulation of variables used in the models were initially based on formulations used by Monserud and Sterba (1996) with additional site, climatic and topographical variables added or removed in a stepwise manner using the R studio package MASS (Venables and Ripley, 2002). The procedure uses Akaike's information criteria (AIC) for model selection in order to avoid over parameterisation of the model (see Burnham and Anderson, 2002) based on the condition that the AIC values should decrease at each step.

In order to evaluate the proportion of variation in tree growth, as explained by factors, the individual contribution of the sub-models was assessed using the multiple coefficient of determination (R^2) assuming that there are no inter-correlations between these main factors (Monserud and Sterba, 1996). Original model formulations published by Monserud and Sterba (1996) were recalibrated and used as an

internalised benchmark (based on ΔAIC) to test if model performance did improve when new model formulations and site factors were included in the final model.

Model performance

Goodness of fit of final calibrated models was assessed using root mean squared error (Rmse) and Bias (van Laar and Akça, 2007). Regression analysis of predicted and observed values was performed together with a normality test on model residuals using the Shapiro-Wilk statistic in R studio. The distribution frequency was considered not to be normal if the p-value of the Shapiro-Wilk estimate was less than 0.05. Analysis of variance (ANOVA) was also used to derive F-values, as measure of goodness on fit in terms of how well the predicted model estimates described the variation in observed data.

Task 4

Mixed species investigation

Growfor

As there were insufficient data available for developing a mixed species stand level model, coupled with the unavailability of Garcia for collaboration, it was not possible to devise a new method to model stand level mixed species stand dynamics. Instead, a simulation of the single species models run simultaneously to represent a mixed species stand was carried out and compared to NFI mixed species data.

Carbware

Mixtures with Sitka spruce and lodgepole pine were evaluated using goodness of fit statistics Rmse, Bias, regression analysis and Anova-derived F-values when comparing projections to those of the NFI.

References:

- Black, K. 2016. Description, Calibration and validation of the Carbware single tree-based stand simulator. *Forestry* 89(1) p55-68
- Black, K., Creamer, R.E., Xenakis, G., Cook, S. 2014. Improving the YASSO forest soil carbon model using spatial data and geostatistical approaches. *Geoderma*. 232-234, 487-499.
- Burnham, K., Anderson, D. 2002. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*. 2nd edition Springer-Verlag, New York.
- Heagerty, T.L., Pepe, M.S. 2000. Time-dependent ROC curves for censored survival data and a diagnostic marker. *Biometrics*, 56:337 - 344.
- Monserud, R. A. 1976. Simulation of forest tree mortality. *Forest Science*. 22, 438-444.
- Monserud, R. A., Sterba, H. 1996. A basal area increment model for individual trees growing in even- and uneven-aged forest stands in Austria. *Forest Ecology and Management*. 80, 57 - 80.
- Monserud, R. A., Sterba, H. 1999. Modelling individual tree mortality for Austrian forest species. *Forest Ecology and Management*. 113, 109-123.
- Ray, D., Xenakis, G., Tene, A., Black, K. 2009. Developing a site classification system to assess the impact of climate change on species selection in Ireland. *Irish Forestry*. 66, 101-122.
- Van Laar, A., Akça, A. 2007. *Forest Mensuration. Series: Managing Forest Ecosystems*, Vol. 13. Springer, Dordrecht, the Netherlands, p 383.
- Venables, W. N., Ripley, B. D. 2002. *Modern Applied Statistics with S*. Fourth edition. Springer.

3. Research Achievements/Results

Outline main results achieved

CARBWARE

- Initial validation of the CW model against NFI identified that there was a significant over estimation of diameter increment in trees less than 7 cm in diameter. This was associated with an underrepresentation of small trees in the NFI sampling framework (stratified random sample used in the concentric circle design) and insufficient model calibration. The initial validation also showed that the CW model did not accurately estimate diameter growth in broadleaf stands due to insufficient PSP data available for initial calibration.
- Numerous NFI data quality issues were detected during the validation and calibration such as negative diameter increments. These data had to be excluded from the validation and calibration. Furthermore the use of nearest neighbour statistics in the NFI to derive information on previously unmeasured trees, resulting from the random systematic sampling approach, meant that absolute model error could not be determined. This was particularly evident when plot by plot comparisons of standing volume or volume increment were made. Most of these inconsistencies could be associated with the sampling regime adopted in the NFI.
- Re-calibration of the CW model using NFI data and incorporation of climatic and site factors resulted in a 10 - 30% increase in model accuracy across conifer and broadleaf species.
- Tree competition factors explained most of the variation in single tree growth, followed by tree size and site factors (Black, 2016). This contrasts with other research findings in regions where intensive forest management is not commonly practiced.
- The CW model was demonstrated to accurately predict tree growth in mixed species stands and uneven aged stands. However, further model refinements are required:
 - to improve growth function for broadleaves species
 - refine mortality function in mixed stands
 - develop recruitment models for application to naturally regenerating stand and semi-natural forests.
- Inclusion of climatic and site factors as predictors of single tree growth only explained 3% of the observed growth variation in the NFI dataset. In contrast, site factors such as topography soil nutrient status explained 11% of the variation in tree growth, suggesting that climate is not a major factor influencing tree growth in Ireland.

GROWFOR

- NFI data are unsuitable for stand level model development. The issues with the data include the lack of top height measurements, ingrowth trees causing stocking irregularities between measurement cycles and there being insufficient numbers of suitable plots available for a quality model.
- There is no facility in the GF model to incorporate competition dynamics and to produce a model for mixed species stands. It may be possible should the expertise of Garcia become available for collaboration. This would involve the 'doubling up' of the state vector (BA, N, TH) to include both species. However, a source of good quality data would need to be made available for that purpose.

4. Impact of the Research

A summary of the impact of the research should be provided through the project outputs and outcomes however please provide a synopsis of the benefits / improvements the research has made to the area under investigation. Outline the benefits of the research to end users, e.g. industry, consumers, regulatory authorities, and scientific community etc.

- The re-calibrated CW model can be used for regional or national timber and greenhouse gas forecasts based on NFI data. However, low model precision at the plot level, means that plot based forecast should be treated with caution.
- The CW pre-processing models can be used as a species specific and global estimate of tree height, crown ratio and crown radius where these attributes are not measured in the NFI. It is recommended that these models should only be issued when stand specific to model cannot be used.
- The CW growth model can be used as a QC tool to verify DBH measurement in successive NFIs. This will assist in reducing the data quality issues when measuring diameter increment over NFI cycles.
- The NFI should consider adjusting the measurement threshold of 7 cm trees in the sample design to reduce forecasting estimate errors. More detailed measurements of smaller trees within the NFI plots are required. To increase efficiencies, less data can be collected on crown characteristics because the CW model can provide robust estimates of these variables.

4(a) Summary of Research Outcomes

(i) Collaborative and Industry links developed during this research

- Link between FERS Ltd. and UCD Forestry further strengthened.

(ii) Outcomes where new products, technologies and processes were developed and/or adopted

(iii) Outcomes with economic potential

- The improvement of stem profile and assortment functionality to the CW model was not possible due to problem associated in obtaining the correct algorithms from a previous project partner. Therefore, development of this functionality is still required before the model can be used as a commercial application.

(iv) Outcomes with national/ policy/social/environmental potential

- Validation of the CW model was included in the Irish national greenhouse gas inventory as part of Ireland's submission to the UNFCCC (Duffy *et al.* 2014).
- Greenhouse gas projections for the forestry sector are routinely done using the CW model and refinement of model leads to reduced uncertainty.

4 (b) Summary of Research Outputs

(i) Peer-reviewed publications, International Journal/Book chapters.

Black, K (2016) Description, Calibration and validation of the Carbware single tree-based stand simulator. *Forestry* 89(1) p55-68

McCullagh, A., Black, K., Nieuwenhuis, M. Evaluation of tree and stand level growth models using national forest inventory data. (submitted to *Forest Ecology and Management*)

McCullagh, A., Nieuwenhuis, M. (2015) Review of tools for growth forecasting and productivity assessment in forestry in Ireland. *Irish Forestry* (72), p78 - 86

(ii) Popular non-scientific publications and abstracts including those presented at conferences

(iii) National Report

- The improved CARBWARE model is now routinely used for greenhouse gas inventories under the second commitment period of the Kyoto protocol projection and submissions as required under the 2013 EC decision 529.
- Duffy P., Hyde B., Hanley E., O'Brien P., Ponzi, J. and Black, K. 2014. National inventory report Greenhouse gas emissions 1990 – 2013. Reported to the United Nations Framework convention on climate change, EPA, Dublin.

(iv) Workshops/seminars at which results were presented

(v) Intellectual Property applications/licences/patents

(vi) Other

5. Scientists trained by Project

Total Number of PhD theses: _____

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date

Total Number of Masters theses: _____

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date

6. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (person years)
UCD	1	0.1

Total

7. Researchers Funded by DAFM

Type of Researcher	Number	Total Time contribution (person years)
Post Doctorates/Contract Researchers	1	2
PhD students		
Masters students		
Temporary researchers		
FERS Ltd (External assistance)	1	67 (days)
Total		

8. Involvement in Agri Food Graduate Development Programme

Name of Postgraduate / contract researcher	Names and Dates of modules attended
--	-------------------------------------

9. Project Expenditure

Total expenditure of the project: € 148,379.56

Total Award by DAFM: € 148,379.56

Other sources of funding including benefit in kind and/or cash contribution(specify): € 0

Breakdown of Total Expenditure

Category	UCD	Name Institution 2	Name Institution 3	Name Institution 4	Total
Contract staff					
Temporary staff					
Post doctorates	89,729.72				
Post graduates					
Consumables	211.53				
Travel and subsistence					
Sub total	89,941.25				
Durable equipment	803.78				
Other	30,652.15				

Overheads	26,982.38
Total	148,379.56

10. Leveraging

Summarise any additional resources'/funding leveraged by this award from other sources i.e. Additional Staff, National/EU funding secured, EI Commercialisation Fund

11. Future Strategies

Outline development plans for the results of the research.

- Redevelop the CW software to include model improvements from both the BETTERFOR and CForRep projects.
- Incorporation of stem profile models in to CW software for application to commercial forestry.

12. Consent to Publish Final Report on the DAFM Website and/or Through Other Dissemination channels

I consent to this report being made available to the public, through the Department's website and other dissemination channels. *

Yes No

13. Declaration

I declare that the information contained in this final report is complete and true to the best of my knowledge and belief.

Signed: _____ Project Coordinator

Date: _____

*IPR sensitive information that the coordinator does not wish to make public should be highlighted in red font. All text in red font in this report will not be made publicly available by DAFM.

Guidelines for the Completion of Final Report

The attached Final Report Template should be completed for DAFM projects funded under the 2006, 2007, 2008, 2010 and 2011 Calls.

The aim of the final report is to provide a summary of all aspects of the research project. A final report is required for all projects and a percentage of the grant award will be withheld until it is submitted and deemed satisfactory.

Please note that the Department of Agriculture, Fisheries and the Marine may publicise information included in the Final Report. **All sections of the report must be completed.** Incomplete reports will not be accepted by DAFM and will be returned to the project coordinator for completion.

Two copies of the final report are required, 1) a signed hard copy and 2) an electronic copy.

A guideline of up to 400 words per relevant section is recommended.

Project Details

The project title, project reference number and actual start and actual finish date should be noted. Indicate on the research continuum from basic/fundamental research to applied/pre-commercial research where you feel the research project fits by placing 'x' in the most appropriate box. Indicate in the section provided **the priority area of research this project relates to from the National Prioritisation Research Exercise* (NRPE) report**, There are 14 priority areas of Research as follows;

A Future Networks & Communications	H Food for Health
B Data Analytics Management, Security & Privacy	I Sustainable Food Production and Processing
C Digital Platforms, Content & Applications	J Marine Renewable Energy
D Connected Health & Independent Living	K Smart Grids & Smart Cities
E Medical Devices	L Manufacturing Competitiveness
F Diagnostics	M Processing Technologies and Novel Materials

In addition, key words relating to the project should be included in this section.

***<http://www.agriculture.gov.ie/research/14researchprioritisationactionplans>**

1. Rationale for Undertaking the Research

This section of the final report should provide background information on why the research was needed. It should clearly outline the reason for carrying out the research and identify the problem / knowledge gap that needed to be addressed. It should address the question **'why was this research needed?'**

2. Research Approach

Information provided on research approach should address the questions **'how the research was carried out?'** Details should include work carried out and research methodologies used to address the issues identified in the 'rationale for undertaking the research'. Emphasis should be placed on novel techniques, materials, technology and equipment used. Scientific or technical difficulties encountered in the research and any significant modifications from the original proposal must be noted. Please note that this section does not require fine scientific detail, but is designed to give the reader an overall view of the research methods employed.

3. Research Achievements/Results

This section is simply designed to address the question **'what are the results of the research'**. Emphasis should be placed on novelty and innovation. Tabulated scientific results are not required but a succinct summary of results obtained from each task should be illustrated.

4. Impact of the Research

A summary of the impact of the research should be provided through the project outputs and outcomes. The benefits / improvements the research has made to the area under investigation should be elucidated. Specifically, describe how the outcomes of the research have benefited the end users such as industry, consumers, regulatory authorities, policy makers and the scientific community.

4(a). Summary of Research Outcomes

The outcomes reported must detail the wider effect of the project from a sectoral or national perspective; these may be in the medium or long term. The summary of research outcomes is a critical component of the final report. It is imperative that this section is completed fully and precisely, as DAFM is required to report on the outcomes of all research projects. In addition, this data is essential to DAFM in justifying value for money of its research programmes and in securing future funding. Therefore, please ensure that information in this section is accurately reported.

4(b). Summary of Research Outputs

Research Outputs are what are produced by the project in terms of activities, events, services that reach people. The summary of research outputs is a critical component of the final report as it provides quantitative data on the research. It is imperative that this section is completed fully and precisely, as DAFM is required to report on the outputs of all

research projects. In addition, this data is essential to DAFM in justifying value for money of its research programmes and in securing future funding. Therefore, please ensure that information in this section is accurately reported.

5. Scientists trained by the project

The total number of PhD and MSc theses produced as a direct result of work carried out on this DAFM project should be noted. In addition, the authors, institutions and titles of the theses and submission dates should be specified. If theses have not been submitted before completion of the final report, please give details including the anticipated submission date.

6. Permanent Researchers

The number of permanent research staff who contributed to the project (on a cost neutral basis) per institution and associated time contribution must be captured.

7. Researchers Funded by DAFM

Details of numbers, total time contribution (in months) and of all, post doctorates (PD) & contract researchers; PhD students; Masters students; temporary researchers and other staff funded by DAFM should be included.

8. Involvement in Agri Food Graduate Development Programme

The names of students / researchers that participated in the Agri Food Graduate Development Programme should be included in addition to the names and dates of modules undertaken.

9. Project Expenditure

The aim of this section is to provide a summary of expenditure during the lifetime of the project. Please note that it is imperative that all figures included in this section correspond to figures included in the last progress report submitted and evaluated by DAFM. The names of the institutions involved must be included in the tables provided.

10. Leveraging

The aim of this section is to summarise any additional resources'/funding leveraged from this award from other sources e.g. Additional Staff (type of staff, value of staff secured), National/EU funding secured, EI Commercialisation Fund

11. Future Strategies

Future strategies to further develop the outputs of the research should be indicated. If the outputs of the research have not been taken up by end users, explain why this is the case. What further advances / work is required in your area of research in order for the outputs to be taken up by industry / consumers / end users? What follow-on research is

required in this area to realise an end product? If further funding is required for research in this area, where do you intend to apply for funding e.g. Enterprise Ireland?