dECO$_2$ carbon sequestration model

Technical manual (versions 1.24+)

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Confidential

ECO SECURITIES

Contents

dECO$_2$ is a model for calculating carbon sequestration by forestry projects. It functions within Microsoft Excel, and produces its outputs as Excel worksheets. It starts from a consideration of forest growth, applying expansion factors to estimate crown and root biomass, and dynamically evaluates additions and losses to the plant, necromass and soil carbon pools. It also tracks carbon sequestered in forest products derived from the project and any substitution of fossil fuels that might occur when some of these products are used for energy production.

dECO$_2$ is an evolution of the ECO2 model developed by Wilson (1998), and used by EcoSecurities since that time. It includes many additional facilities and modifications. The following are the main differences and features:

❑ All modelling functions are now carried out by Visual Basic macros rather than worksheet functions. This improves speed, makes the resulting workbook much more compact, reduces errors, and increases security. The program comprises about 4042 lines of Visual Basic code in 43 separate sub-programs.

❑ Input and output are via Excel worksheets and charts. Input sheets define the project and baseline management, the species growth functions, the product definitions, and model coefficients for species, carbon pool components, and site factors and attributes. These sheets must conform to exact specifications as described in this manual.

❑ The output sheets and charts are generated automatically by the model. They provide tables and graphs of carbon pools by species and by type (phytomass, necromass, soils, products), total project and baseline pools for each management unit, and comparisons of net carbon sequestered.

❑ The model can work with multiple species as mixtures or discrete blocks.

❑ Species may be uniform, even-aged crops, uneven-aged natural forest, non-tree vegetation (grasses, shrubs, etc.) , growing in any mixture within a management unit.

❑ There can be several management units within a project, each with its own species mixture, site or soil related coefficients.

❑ The model automatically 'assembles' planting or conversion sequences, where a baseline forest management or other ecosystem is progressively converted to the project management system over a period of years.

❑ Harvesting can include both forest products and non-timber products. Purely agricultural scenarios can be simulated, as can agro-forestry projects, natural forest management, and conventional plantation management.

❑ Baseline scenarios can be of the same complexity as the project.

❑ Plantation or even-aged crops are modelled by a growth function that can be defined from mean annual increment, gross volume, or current annual increment data using a graphical modelling tool to calibrate parameters. This can give exact conformance to published yield tables for volume, where available.

❑ The model correctly represents competitive processes between vegetation layers in complex ecosystems, and allows, for example, a developing plantation to shade out a pasture or agricultural crop.

❑ A report generator is included which summaries all details of the project in a table which lists the management regimes, and for each species and site type, detailed coefficients applied, together with notes supplied by the user on each coefficient, with its assumptions, observations of any kind, and source citations.

Units and baselines

A project within $dECO_2$ consists of a number of *Units*. Each unit represents a type of ecosystem under a specified management regime, and covers an indicated area of land. Units can be *project units*, or *baseline units*. The baseline units comprise the pre-existing vegetation and management system. The project units define the species and management system to be adopted under the project. There is a 1:1 correspondence between project units and baseline units. That is, each project unit will have a defined baseline unit of the same area.

$dECO_2$ gives detailed outputs for carbon sequestration by species components and carbon pools for each project and baseline unit as a series of graphs and tables.

In most cases, large projects will not be established in a single year, but will involve the progressive conversion of the baseline land use to the project over a number of years. $dECO_2$ allows the total unit area (*eg.*. 10,000 ha) to be converted over a fixed period (*eg.* 20 years). Output graphs show both the per ha carbon pools and those for the whole project over time. The difference between the baseline and the project can be shown in two ways:

❑ **By conversion**. In this case the total unit area is shown from the start of the project, and is assumed to be converted progressively from the baseline to the project vegetation and management system.

❑ **By establishment**. In this case the unit area is assumed to increase by fixed amounts each year up to the stipulated maximum. The net sequestered carbon is shown as the difference between the project and baseline units of the same areas, each comprising a mosaic of equal annual age classes.

In each case, the net sequestered carbon will be the same. The total carbon for the project and the baseline will differ according to the area assumptions. The first method is appropriate for conversion of a large area of natural forest to a new management system. The second method is more suitable when establishing plantations.

Vegetation types and management systems

$dECO_2$ is configured to work with three basic types of model for vegetation growth and interaction through competition and shading. These three basic types can occur together in a single ecosystem. They are:

❑ **Planted tree species**. These may be forest plantations, or tree crops such as coffee or cocoa which are planted. Within the model, plantation crops have an age parameter, and a rotation. Trees can be felled and re-planted at the end of the rotation. Importantly, harvesting operations are specified relative to age within the rotation. Growth is handled via a growth model that can be calibrated to

correspond to published yield tables or curves. Mortality is handled via a life-expectancy function that is age-dependent.

- **Natural forest tree species.** These are assumed to be mixed-aged, naturally regenerating groups of species. There is no age within the model for these components, and harvesting operations must be specified relative to the start of the project. A logistic growth model is used that is based on current annual increment, initial volume, and annual mortality rate.

- **Other vegetation species.** This can include any type of shrub, herbs or grasses, and can be used for planted species such as bananas which are difficult to characterise with tree-type biomass parameters. A logistic growth model based on above-ground biomass productivity and maximum biomass is used.

These vegetation types can be established in mixtures. A competition and shading model controls the interaction of the vegetation layers.

Harvesting for trees can be specified in terms of volume or percentage of standing volume. For other vegetation, it can be specified in terms of biomass or percentage of standing biomass.

Harvesting for plantation species must be specified relative to age within the rotation. For other crops, it is given relative to year zero within the unit.

Three special types of harvesting are allowed:

- **A clearing operation**, in which the crop is entirely removed and does not regenerate within the model. This is usually applied to removing a baseline crop within the project unit.

- **A regular annual harvest** can be specified to simulate agricultural cropping of any type. This can also be applied to the gathering of dead wood on the ground as a necromass harvesting operation.

- **A clearfell and replant operation** can be specified for plantation trees.

Each harvesting operation is specified relative to a particular species. Any mixture of different types of harvesting for species is allowed, in the same or in different years.

For trees, harvesting normally is assumed to come from stem volume, but a percentage of the crown wood can also be stipulated for harvesting if required.

This mixture of vegetation components and harvesting operations gives a very flexible scheme that can represent almost any type of forestry or agro-forestry situation, including pure agriculture and unmanaged natural vegetation types or conservation scenarios.

The basic carbon model

The diagram below shows the basic carbon model for trees. Increment is calculated in terms of stem volume current annual increment (see **Tree growth models** on page 7). This is converted to increment in terms of carbon via the wood density and carbon:biomass ratio coefficients. Crown fine and coarse biomass, and

Basic structure of the carbon model for tree vegetation
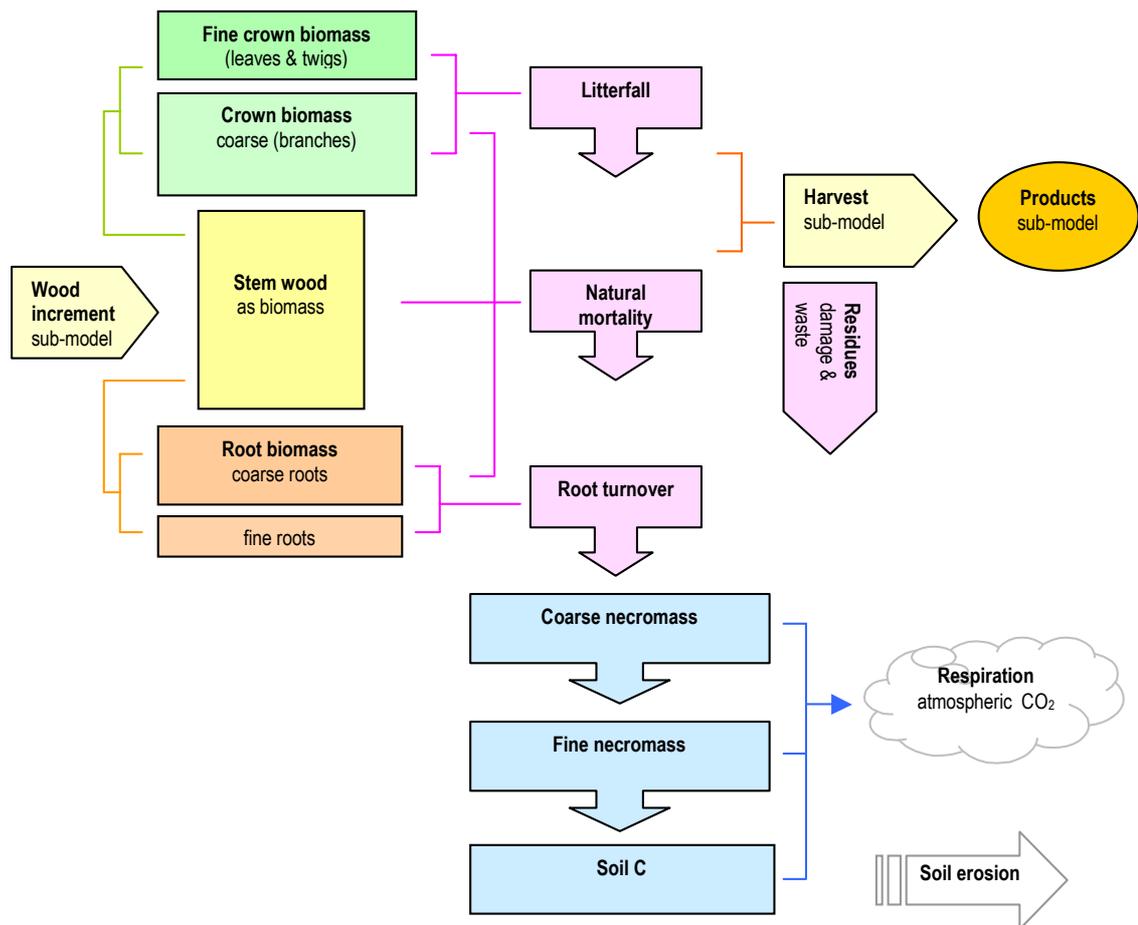
root fine and coarse biomass are then calculated via expansion coefficients. Litterfall is deducted from coarse and fine crown components and added to the coarse and fine necromass pools according to the litterfall turnover rate for the species. Root turnover is handled similarly. Natural mortality includes stem wood, as well as coarse and fine crown and root components, all of which are added to necromass, with dead stem wood added as coarse necromass.

Harvested products are removed from the system, except for residues. The roots and crowns of harvested trees are allocated to coarse and fine necromass. Stem residues are allocated to coarse necromass. If a percentage of the crown is harvested, it is deducted from the proportion of the felled tree crowns added to coarse necromass.

Coarse necromass decays to fine necromass at a specified rate, during which a percentage of the decaying material is lost to the atmosphere as respiration. A similar process occurs as fine necromass decays to soil carbon. Soil carbon itself is respired to atmospheric CO_2 at a given rate or is lost from the system due to erosion processes.

The calculations for non-tree components are similar except that there is no separate pool for coarse crown and stem wood. The entire above ground plant is treated similarly to tree crowns. Increment is in terms of above-ground biomass productivity.

These calculations are carried out annually. Separate vegetation pools are maintained for each species within each unit. Separate necromass pools are maintained for each unit.

Tree growth models

Growth of plantation trees is modelled using the modified Schumacher function (Alder, 1980; Stage 1963):

$$V = \alpha.exp(-\beta.t^{-\gamma}) \qquad \{eq.1\}$$

where V is total volume (standing volume plus accrued thinnings) and t is stand age. α, β and γ are coefficients. A growth modelling tool forms part of $dECO_2$ which allows this function to be fitted to supplied yield table data using the mouse (see page 26).

Within $dECO_2$, the derivative of this function is used to calculate increment directly for plantation trees, in the form

$$dV/dt = \alpha\beta\gamma.exp(-\beta t^{-\gamma})/t^{\gamma+1} \qquad \{eq.2\}$$

In the growth modelling tool, control points on the graph define the asymptote, or maximum attainable volume, and the age and value of the maximum mean annual increment. These points can be adjusted to give the α, β and γ coefficients directly because of the following relations:

❑ The asymptote (maximum value) on the volume-age curve is the α coefficient.

❑ The γ coefficient is related to maximum mean annual increment ΔV_m at age t_m through:

$$\gamma = -1/\{ln(\Delta V_m. t_m/\alpha)+1\} \qquad \{eq.3\}$$

❑ The β coefficient can then be determined from:

$$\beta = - ln(\Delta V_m. t_m/\alpha). t_m^{\gamma} \qquad \{eq.4\}$$

These calculations are carried out automatically by the growth modelling tool to give the coefficients required for the growth function in the carbon model for plantation trees $\{eq. 2\}$.

Growth models for natural forest trees and other vegetation

Natural forest trees use a growth function based on current annual increment (I), and annual mortality rate (m). The relation between CAI and AMR defines a maximum volume assuming a simple logistic growth function, of the form:

$$V_{t+1} = V_t + I - V_t.m \qquad \{eq.5\}$$

At its limit, $V_{t+1}=V_t$, (ie. there is no net volume growth), and therefore:

$$V_{max} = I/m \qquad \{eq.6\}$$

Thus for example, if current annual increment is 6 m^3/ha/yr and mortality is 2%, then the maximum volume will be 6/0.02 or 300 m^3/ha for that species.

For the other vegetation species, there will rarely be information about mortality rates, but there will usually be data on equilibrium biomass and on biomass productivity. Using a variant of equation {6}, the turnover rate (a combination of litterfall and mortality) can be calculated as:

$$r = P/B \qquad \{eq. 7\}$$

where P is the biomass productivity, in t/ha/yr, and B is the equilibrium or maximum biomass.

Data for these simple models are available for many forest and other plant species (*eg.*. Cannell, 1982), whereas more complex models would be difficult to calibrate for many cases.

Competition and shading models

dECO$_2$ has a competition model that influences growth rates and mortality of species depending on the density of competing vegetation layers. This process is controlled by two species coefficients: The *maximum vegetation height* (MVH), and the *shade persistence factor* (SPF). The height index H_i of a vegetation layer is estimated from the following function:

$$H_i = (B_t/B_m)^{1/3}.MVH \qquad \{eq. 8\}$$

where B_t is the current biomass of a species component, and B_m is its asymptotic value. The competition index for a given species is then taken as:

$$C_{i,s} = 1 - \Sigma B_{t,k}/\Sigma f_k.B_{m,k} \qquad \{eq. 9\}$$

where the k subscript indicates any species whose H_i value is greater than the subject species *s*. The *shade persistence factor* (SPF), f_k, can be used to control the light-

sensitivity of a species. As f_k tends to zero, the competitive effect is amplified, simulating a more pioneer-type, light demanding species.

This index will be zero if the subject species is overtopped by other species at their asymptotic biomass, or 1 if there are no competing species. It is used to modify calculated increment or mortality as follows:

$$\Delta B^* = \Delta B.C_i$$

$$m^* = m^{C_i}$$

$$\left.\right\} \quad \{eq.\ 10\}$$

where ΔB, m are increment and mortality rate as calculated without competition, and ΔB^*, m^* are after competition is allowed for, C_i is the competition index as per equation {9}.

For plantation trees where spacing is controlled and which are managed according to a planned thinning schedule which is implicit in the yield function supplied, the competition model is not applied. This is accomplished in the dECO$_2$ setup by defining a percentage of growing space occupied by the plantation species at canopy closure. In this case growth will follow exactly the supplied yield function.

For natural forest and other vegetation species, the competition model is always applied. However, setting a shade persistence factor (SPF) to 1 or higher will reduce competition effects to a minimum.

Life expectancy and mortality models

Mortality in natural forests and in non-tree species is modelled as a percentage of the current biomass that dies in each year, or *annual mortality rate* (AMR). A constant mortality rate is equivalent to an exponential decay model for the population (Sheil *et al.*, 1995), with the quantity remaining after time t (N_t) being derived from the initial population N_o by:

$$N_t = N_o.exp(-\lambda t) \qquad \{eq.11\}$$

λ is related to AMR by transformation as:

$$\lambda = - ln(1 - \text{AMR}) \qquad \{eq.12\}$$

The exponential function in terms of AMR is written as:

$$N_t = N_o.(1 - \text{AMR})^t \qquad \{eq.13\}$$

The exponential function is commonly defined by the *half-life parameter*, which is the time taken for the population to be reduced by half. Half-life and AMR are related by the equation:

$$t_{1/2} = -0.69315/ln(1 - \text{AMR}) \qquad \{eq.14\}$$

Any process of decay or turnover described by a constant percentage rate can also be characterised by a half-life. The figure below shows the relationship between half-life and AMR for rates from 1% to 99%, based on equation {14}.

Exponential half-life and Annual Mortality Rate

As well as being true for AMR, these relationships expressed in equations {11} to {14} and the figure above are also true for non-tree vegetation turnover. For non-tree vegetation, litterfall and stem mortality are combined into a single population turnover rate, which is calculated implicitly by the model from the coefficients for maximum biomass and biomass productivity (see equation {7}).

For plantations, another mortality model is used, as a constant mortality rate is inappropriate for even-aged crops. Such crops have a defined life span, which depends on the longevity of the species. For this, dECO$_2$ allows the input of a life span as a range of years (*eg.* 20-30 years). This is interpreted by the model as representing the 5% and 95% points on a cumulative mortality distribution; the intermediate mortality rates are defined by a Weibull function (Bailey & Dell, 1973; Alder, 1995):

$$N_t = N_o.exp(-[t/\alpha]^\beta) \qquad \{eq.15\}$$

The coefficients of the Weibull distribution, α and β, can be calculated from the life span, assuming this represents the 5% and 95% points of the cumulative mortality distribution, via the relationships:

$$\alpha = exp[-ln(t_1) - k_1.ln(t_2)]/[1 - k_1]$$

$$\beta = k_2/[ln(t_1) - ln(\alpha)]$$

{eq.16}

where t_1 and t_2 are the lower and upper age range defining the tree life span, k_1 is the constant -2.7070961[*] and k_2 is the constant -2.97019525[**].

In the simple case where $\beta=1$, then it can be seen that the Weibull function is the same as the Exponential (*cf.* equations {11} and {15} with $\lambda = 1/\alpha$). To cater for this, dECO$_2$ allows a single age to be input as the life expectancy, instead of a range. This is then taken as the half-life, and will result in constant annual mortality being applied. For example, a half-life of 68 years is equivalent to 1% AMR (see figure above).

Example of a Weibull function for a life expectancy from 20-30 years
Red line shows residual population [*right axis*]; blue histogram shows annual mortality rates [*left axis*]
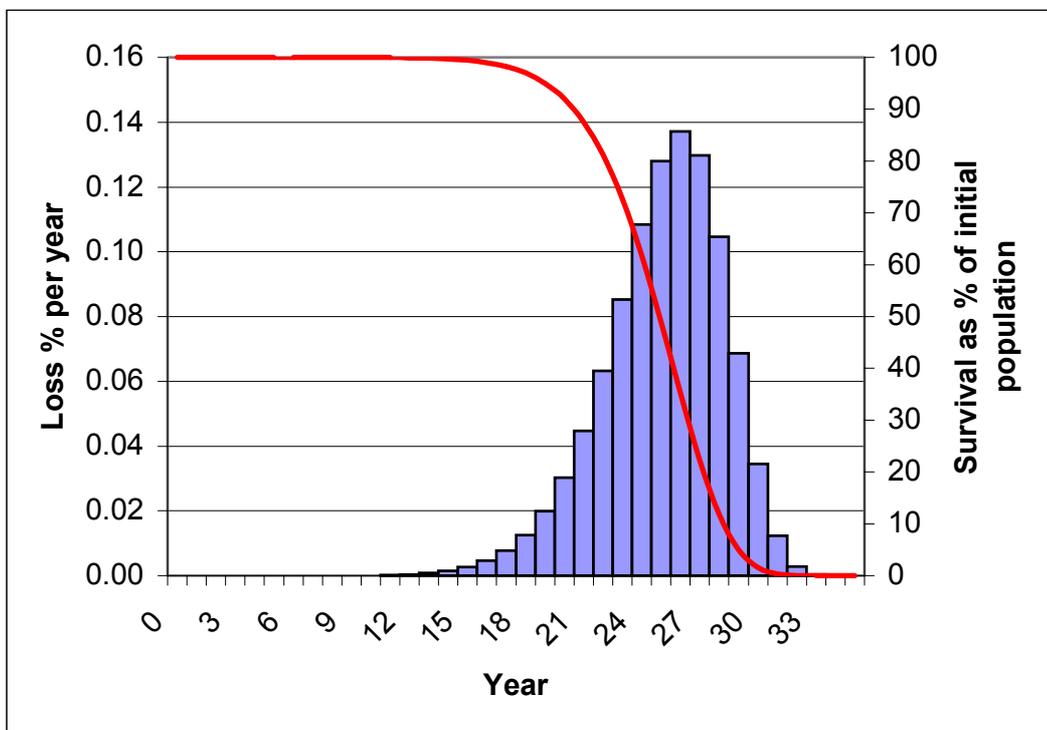
It will be noted that these basic mortality rates will be modified in the model due to competition from taller vegetation layers, as noted by equation {10}.

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[*] calculated from $ln(-ln(0.95))/ln(-ln(0.05))$
[**] calculated from $ln(-ln(0.95))$

The products sub-model

When a harvest is performed on a species, a number of products may be removed from the forest, say $P_1, P_2, \ldots P_n$. In addition, residues are produced during harvesting, including waste, offcuts etc. left in the forest, and waste produced during wood processing operations. These are symbolised by R_f (forest residues) and R_c (conversion residues) respectively. The total quantity specified for harvesting for that species and year, H will be:

$$H = \Sigma P_i + R_f + R_c \qquad \{eq.17\}$$

The harvest H is determined by the model from the growth function and the harvest level, which may be specified as a percentage of the standing crop or in absolute units of volume or biomass (for non-timber products).

The forest residues R_f are assumed to go directly to coarse necromass. The processing residues are assumed to decay to atmospheric CO_2 within 1 year.

Products can include various types of biomass-based fuels (solid fuelwood, charcoal, sawdust waste recycled for energy during processing, *etc.*). The model treats these as fossil fuel substitutes if they are specified, and requires that a *fossil fuel substitution factor* be specified for them. This factor is the ratio of carbon in the fuel product to the carbon in the fossil fuel which is being substituted, in terms of actual quantities used in the technical systems (boilers, ovens, kilns, *etc.*) in question to achieve a given result. As a first approximation, this may be the ratio of the calorific values.

Fuel products are assumed to be used within one year of production. The model does not allow for their extended storage.

Non-fuel products will decay back to atmospheric CO_2 after a longer or shorter period, depending on their use, via a variety of processes (fungal decay, burning, saprophytic digestion, etc.). Product life expectancy is specified using the same Weibull model as described in equations {15} and {16}. It may be specified as a range of years (*eg.* 5-10) or as a single value (*eg.* 5). In the first case, cumulative decay would be less than 5% up to 5 years, and more than 95% after 10 years, with the Weibull model calculating intermediate decay rates. In the second case, the exponential model would be applied (a constant annual decay rate), with a half-life of 5 years.

Products with a very sharply defined lifespan can be specified using a range such as 9.5-10 years. Life span can be a range less than one year. As noted above, for fuel products, lifespan is automatically assumed to be less than 1 year.

This scheme gives almost complete flexibility to the definition of products, and can allow complex wood processing and agro-forestry processing situations to be simulated.

Initial installation

The dECO$_2$ model is contained in an Excel add-in file called DECO2.XLA. Initial installation proceeds through the following steps:

- Copy the DECO2.XLA file to a suitable directory on the C:\ drive. This could be for example, C:\DECO2.

- Start Excel, and select the menu Tools/Add-Ins. In the resulting dialog, click on the Browse button, and navigate the directory system until the target file is located. Click on it or select OK.

- Close the Add-in dialog, which should have Deco2 checked as shown opposite, via the OK button.

- The dECO$_2$ bar will now appear in the Excel menu bar system, as shown below.
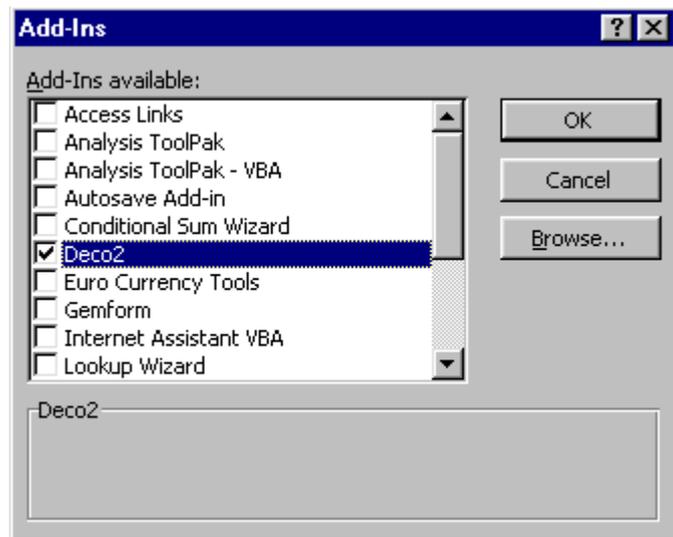
Setting the unlocking code

When dECO$_2$ is first installed it is locked by a copy prevention device. Attempts to use the program will bring up the dialog shown opposite. The appropriate unlocking code should be entered where shown and the OK button clicked. If the code is correct, it will be remembered, and not required again in future. If it is wrong, then an error message will appear when the dialog is closed.

The locking code is specific to a particular C drive. If dECO$_2$ is copied to another computer, a new code is required; the code will also be required if the C drive has to be changed or re-formatted due to technical problems. dECO$_2$ cannot be installed as a shared application on a network drive. If you have purchased dECO$_2$ please contact eco2@ecosecurities.com quoting your personal/company details, the purchase no. and
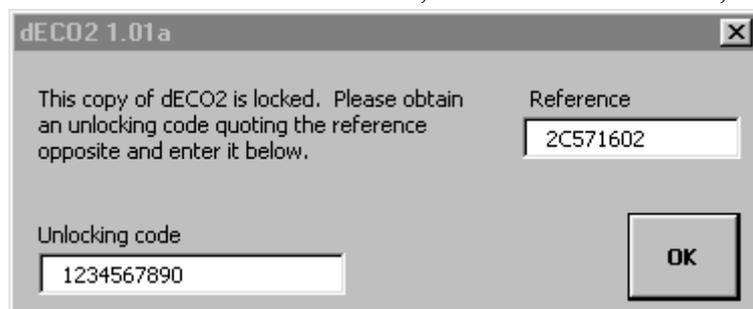
the reference number given to you by the programme and you will be sent the unlocking code. The locking code cannot be set unless $dECO_2$ is used with a project workbook with the appropriate structure, as described in the next chapter.

Removing $dECO_2$

Once $dECO_2$ has been installed, it will always be available via its toolbar when Excel is started. To remove its linkage to Excel, the hide $dECO_2$ button can be clicked. This is equivalent to unchecking the *Add-in box* in the dialog shown on the previous page, and hiding the $dECO_2$ toolbar via the *View/Toolbars* Excel menu. If removed in this way, it can be re-activated simply by opening the Excel *Add-ins* dialog and checking $dECO_2$. The unlocking code does not need to be re-entered or the file located via the browse button unless either:

❑ The DECO2.XLA file has been re-copied or updated, or

❑ The file has been moved to a new directory.

Updating $dECO_2$

Updates of $dECO_2$ are installed by copying a new version of the DECO2.XLA file to the directory where the presently installed copy exists, and thereby overwriting it.

To avoid confusion, do not install a new version of DECO2.XLA into another directory whilst retaining the older version in use. The taskbar buttons in Excel will continue to point to the older copy, so that the new one will not be activated.

The version number appears on each dialog form, and on the Excel status bar when any $dECO_2$ module is used. This version number should be checked to ensure that the expected version is being used. If it is not, follow the **Remove dECO2** procedure noted above, and then re-install it. The version number can be tested by opening a *blank workbook* and clicking on any of the $dECO_2$ module buttons. The dialog shown opposite should appear, with the version number indicated (version 1.23e in the example).
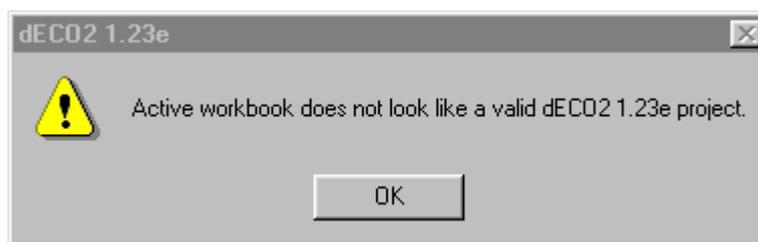
When a new version of $dECO_2$ is installed, the *Unlocking Code* (as described on page 13) will be required to be re-entered. This will be the same as for the previous installation provided the computer hardware configuration has not been changed in the meantime.

Required workbook sheets

The dECO$_2$ add-in will only work in conjunction with a correctly configured Excel workbook. This must have sheets with the tags *Project*, *Coefficients*, *Growth*, *Products* and *Baseline*, as shown opposite, as a minimum content. Other sheets may be present but will be ignored by the application. The order of the sheets is not important, and sheet names are not case-sensitive. If one of the dECO$_2$ toolbar buttons is used without all these required sheet names being found, then the error message shown below right will appear, and no action will occur.

Each of these required sheets has a specific structure and content, as described in the following sections. The easiest way to set up a new dECO$_2$ project is to copy and modify an existing one. As a starting point the file *deco2demo.xls* can be used. This file is used in the examples which follow.
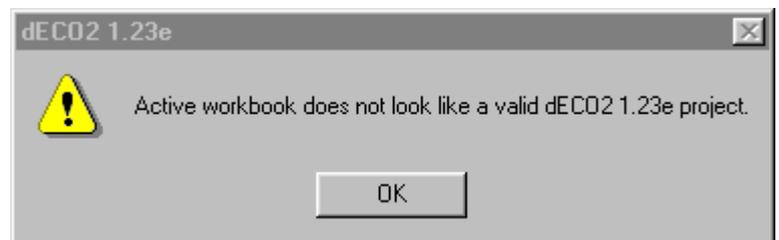
The *Project* sheet

The *Project* sheet defines the management units that comprise the project. Each unit defines a particular combination of species and management regime, and refers to a specific land area. Each unit is linked to a specified baseline, or original land use, although several units can share the same baseline. The example below shows the layout for a single unit. Additional units can be appended after the first, up to a maximum of about 50-60[*]. The detailed contents of the unit specification are discussed below using the cell references in this figure; however, it should be noted that for additional units, the row numbers would differ.

As a fixed item of information applicable to the whole project, a title should be given in cells D1:G1. *This should be a short, simple title* identifying the project, as it appears as a sub-title on output graphs and tables. Extended comments and explanations about the project can be added as an Excel comment to cell G1. These remarks are reproduced by the report generator.

In the table of explanations below, the *Comments* column refers to how cell comments are used by the report generator. If this column is marked →*RG* then any cell comments attached will be used by the Report Generator and appended into the Notes section for that item. For cells which are not marked in this way, the comments will serve only as documentation, and will not be processed by the report generator.

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[*] The exact maximum is determined by the Excel limit of 255 sheets in a workbook. Depending on output options and the baselines employed, each unit may generate about 4-5 output sheets.

Item	Cell ref.	Details	Comments
Unit code	D3	A code that defines the unit. This should be short and symbolic. It appears as a column heading on output tables of unit total and net carbon.	
Description	H3:K3	A title for the unit. This will appear on graph headings for units and should not be too long. Extended information should be added as a comment.	→RG
Total area	D6	The total area to be planted or converted to this management unit, in hectares. Explanations can be added as a comment.	→RG
Conversion period	D7	The number of years taken to convert the unit total area from its baseline land use. The model assumes that equal areas will be converted in each year from the start of the project.	→RG
Site code	D9	This gives a code for a soil/site type that is defined on the *Coefficients* sheet. This allows soil and necromass coefficients, erosion rates and a logging damage factor to be specified for the unit.	→RG
Tree species codes	I6	A list of tree species codes that occur on the project. There may be no trees, in which case this may be blank. The codes must be present and defined on the *Coefficients* sheet and the *Growth* sheet. Species codes can have a * suffix. These are assumed to be naturally regenerated; they should not appear on the *Growth* sheet, but require additional parameters on the *Coefficients* sheet.	→RG
Cover area ratios	I7	A list of ratios indicating the relative mixture of species in terms of *area coverage at canopy closure*. This can be left blank, in which case the competition model determines the relative mixture of species. One more ratio may be listed than the number of species, in which case the additional area is assumed to not be under tree crown cover. This option may be used in scenarios where total tree cover never reaches 100%, e.g. agroforestry systems.	→RG
Other vegetation codes	I8	A list of codes representing non-tree species, such as shrubs, grasses, agricultural crops. These codes must be defined on the *Coefficients* sheet.	→RG
Baseline code	I9	Code of the baseline for this unit. This must correspond to one of the baseline unit codes on the *Baseline* sheet. The comment to this cell is added by the report generator to the comment on the baseline unit *description* field.	→RG

The above items occur as the heading to the unit, and always occupy the first 7 lines. dECO$_2$ recognises the unit as starting from the keyword defined in cell C3, which is here the text '*Forest unit code:*'. It will search for this text in column C to identify the start of subsequent units. Consequently, if this text is different between units, they will not be recognised by the program. The actual text does not matter (*eg. Código de unidade* would work equally well) provided it is exactly the same in each unit (including case, spaces, and accents).

Below this unit heading is a block of lines representing harvesting treatments. The merged cells starting in C11:C17 in the above example define how many rows will be read. *Any rows between the last merged cell and the next row which has the unit keyword in column C will be ignored.* The contents of the harvesting specification rows are shown in the following table. There is one row for each operation. If there are several species, two or more of which are harvested in the same year, then they should be entered as separate rows, one per species. The order of rows is immaterial except that continuous harvesting (+ suffix, see table below) must be specified after periodic harvests.

Item	Column ref.	Details	Comments
Harvest year	D	The year in which the crop is harvested. This will be relative to crop age for tree species, excluding those marked with a * in the *Tree species codes* list. For species marked as naturally regenerated, and for other vegetation species, the year is relative to the start of the project. Three suffix codes may be used with the year: + indicates annual harvesting starting in that year. This is intended mainly for agricultural or NTFP cropping. ~ the species will be cleared in that year and will not regenerate. This is intended to simulate removal of baseline vegetation. The quantity harvested *must be* 100% with this suffix. * the species will be clearfelled and then replanted. It must be a tree species, not naturally regenerated, and the harvest quantity *must be* 100%. Only comments on this cell are used by the report generator for notes about a harvesting operation. Comments on other cells on the row will be ignored.	→RG
Harvested species	E	This should be a single species code, which must occur in either the *Tree species* or *Other vegetation* code lists for the unit. The harvest will be applied only to that species. If left blank, the harvest will be applied to the first listed tree species.	
Quantity harvested	F	This is the quantity to be harvested. Depending on the code in the units field, this may be a % of stem volume or m^3/ha for tree species, or % of above-ground biomass or tons C/ha for other vegetation. For % values, a fraction from 0-1 should be entered, or the cell formatted as a % value, and a value from 0-100% entered.	
Units of quantity	G	One of the values %, v or t may be entered, to indicate % of stem volume or biomass, m^3/ha, or tC/ha. If the quantity specified is greater than the standing quantity, a 100% harvest is assumed. If the ~ or * suffixes are used in column D, then the units *must be* %, and the quantity 100%.	

Product list	H	A list of product codes produced from the harvesting should be given. These product codes must be listed on the *Products* sheet. If forest residues are 100% (felling to waste), then this list can be left blank. Otherwise there must be at least one product.	
Product ratios	I	The ratio of the products by volume should be listed. There must be the same number of entries in this list as in the products list. The ratio list can also be left blank, in which case the products will be assumed to have equal ratios.	
Crown usage	J	This is applicable only to *tree species*; for *other vegetation*, the entry is ignored. It designates the percentage of the crown wood that is used as volume during the harvest.	
Forest residues	K	This indicates the percentage of the *harvested volume* that is left in the forest as waste. It includes such things as lopped ends of logs, abandoned logs, and offcuts and kerf for in-forest milling. It should be set to 100% for pre-commercial thinnings in plantations or for silvicultural operations in natural forest.	
Conversion residues	L	This is the percentage of the harvested volume that is lost in processing the products.	

The example shown above is of a simple plantation of teak, with an understorey or original vegetation of grassland (GSL) and woody shrubs (WSR). The teak is thinned in year 10 by 30% of the standing volume to produce equal quantities of poles and fuelwood. There is no crown usage, and 5% of residues are left in the forest. 20% of the extracted volume is lost as waste during conversion to products.

Below is another example of a unit specification. In this case there are two species, CO (coffee) and LA (laurel), with 80% and 20% ground cover respectively. This is a coffee plantation with Laurel shade trees. The other vegetation types, GSL and WSR are grass and wood shrubs. The baseline scenario is GZU (upland grazing).

	Year	Species	Harvest Qty	unit	Products	Product ratios	% crown used	Residues in forest %	Conversion residues %
	1~	WSR	100%	%	Fuelwood			50%	
	15*	CO	100%	%	Fuelwood			50%	
	15*	LA	100%	%	Timber, Poles, Fuelwood	50,30,20		20%	20%
	3+	CO	1	t	Coffee				

Forest unit code: Coffee Description: Coffee plantation with Laurel shade trees

Planting area and site
Total area: 1,000 (ha)
converted over: 5 (yrs)
Soil/site code: MUS

Vegetation information
Tree species code: CO, LA
Cover area ratios: 80,20
Other vegetation code: GSL, WSR
Baseline code: GZU

Four harvesting operations are indicated. In year one, the woody shrubs are cleared, with some 50% of above ground biomass used as fuelwood. The ~ suffix on the year indicates that there is no regeneration of this vegetation component after clearing. In year 15 both the coffee and the Laurel shade trees are clearfelled and replanted. 50% of the coffee stems are used as fuelwood. The Laurel give a mixture of timber, poles and fuelwood in the ratios 50:30:20 by volume, with some 20% residues in the forest, and 20% conversion losses. From year 3 in each rotation, coffee is harvested annually (+ suffix) at a rate of 1 ton (carbon equivalent) per ha of beans.

The final example of a unit specification, also from the DECO2DEMO.XLS example, shows an area of pasture which is allowed to revert to natural woodland. In this case the tree vegetation is specified as NWR (natural woodland regeneration), with a * suffix to indicate that it is modelled as uneven-aged, naturally regenerated forest, not as plantation. The other species are, as before, grassland and woody shrubs (GSL and WSR). The baseline, GZU, is the same vegetation type but with grazing and suppression of woody regeneration. There are no harvesting operations as this is purely a conservation unit.

It will be noted that whereas for the Teak and Coffe/Laurel examples, there is a conversion period of several years as the new land use is established, for the conservation unit, the entire area is effectively converted at once (*cf. converted over* parameter in above examples).

The *Baseline* sheet

The baselines for the project are defined on the *Baseline* sheet. These collectively define the original, or alternative land use, vegetation type and management system that provides the basis for calculating net carbon sequestered by the project.

Each project unit must have a defined baseline. However, as several units could share the same baseline, there may be fewer baselines defined than project units.

The layout of the baseline specifications is essentially the same as for the project units, except for details of the area, conversion period, and baseline code. These parts of the format, if filled in, will be ignored on the *baseline* sheet. An example is shown below from the DECO2DEMO.XLS workbook.

In this example, the baseline land use comprises grassland and wood shrub regeneration (GSL, WSR) on a soil type LGS (lower slope and gully soils). No harvesting operations are specified. The baseline unit code is GZL. This code is referred to on the project unit, and is used to specify which baseline will be used by which forest unit in the project scenario.

Cell comments in appropriate places are processed by the Report Generator (see page 31). These may be placed in cells D8 (*soil/site code*), I6 (*tree species*), I8 (*other species*), or D12:D16 (*harvesting year*). These comments will appear in the BASELINE SPECIFICATIONS section of the Report Generator output. Comments on the *Description* (H2) appear against the *Baseline* entry for the related Project Unit. The row numbers noted above are relative to the first line of the unit, and would differ for additional units. Comments on other cells (including those that are applicable on project units, such as area and conversion schedule) will be ignored by the Report Generator.

The *Coefficients* sheet

The *coefficients* sheet defines all the coefficients used by the carbon model except those relating to products and plantation growth models. The sheet appears as shown below. There are three sections, whose rows are defined by the merged cells in column A. Each section has a title which must not be changed (these are used by the program to find the data). Within each section, column B gives the coefficient code. This again must not be altered or an error will result when the program runs. Column C gives a coefficient description. These appear in the report generator as coefficient titles, and can be modified if desired.

There are then several columns, one for each tree species, other vegetation type or soil/site type. There is no limit on the number of columns (except the Excel sheet limit of 255 columns) and redundant entries (not referred to by the project or baseline units) may be present.

Each coefficient value may be commented in Excel. These comments will be reproduced in the report generator, and can include explanations, sources and citations. Comments placed in columns A-C will not be used by the report generator.

Note that in the example overleaf, the coefficient values shown are purely for the purposes of illustrating the operation of the program and should not be taken as a basis for any real study.

	A	B	C	D	E	F	G
1		**Symbol**	**Carbon model parameter**				
2		SPP	Species code (trees)	**CO**	**LA**	**TK**	**NWR**
3		NAME	Short species name	Coffee	Laurel	Teak	Woodland
4		WSG	Wood density	0.500	0.500	0.600	0.500
5		CEF	Crown expansion factor	2.000	1.300	1.800	1.800
6		RSR	Root:shoot ratio	0.500	0.200	0.400	0.400
7		CCF	Coarse crown ratio	0.100	0.800	0.800	0.300
8	Tree species	RCF	Coarse root ratio	0.100	0.800	0.800	0.300
9		LFALL	Litterfall rate	0.250	0.250	0.250	0.250
10		FRTO	Fine root turnover	0.250	0.250	0.250	0.250
11		LFEX	Life expectancy	15-25	50-150	150-300	
12		MVH	Maximum vegetation height	3	25	35	30
13		CAI	Current annual increment (m3/ha/yr)				8
14		AMR	Mortality (%/yr)				2.0%
15		INIV	Initial volume (m3/ha)				0
16		SPF	Shade persistence factor	0.5	0.5	0.5	0.5
17		CBR	Carbon:Biomass ratio	0.5	0.5	0.5	0.5
18		SPP	Species code (other vegetation)	**GSL**	**WSR**		
19		NAME	Short species name	Grass	Shrubs		
20		IBM	Initial biomass, t/ha	20	20		
21	Other vegetation	MBM	Maximum biomass, t/ha	20	200		
22		MPV	Maximum productivity, t/ha/yr	1	5		
23		MVH	Maximum vegetation height	0.5	10		
24		RSR	Root:shoot ratio	1	0.3		
25		CFR	Coarse:fine ratio	0	0.5		
26		SPF	Shade persistence factor	0	0.3		
27		CBR	Carbon:Biomass ratio	0.5	0.5		
28		SITE	Site/soil code	**MUS**	**LGS**		
29		IFNM	Initial fine necromass (t/ha)	32.700	32.700		
30		ICNM	Initial coarse necromass (t/ha)	0.000	0.000		
31		ISC	Initial soil organic matter (tC/ha)	80.000	80.000		
32		LDF	Fine necromass decomposition rate	0.330	0.330		
33	Soil & site	LDC	Coarse necromass decomposition rate	0.330	0.330		
34		NFRL	Fine necromass respiration	0.880	0.880		
35		NCRL	Coarse necromass respiration	0.950	0.950		
36		SRR	Soil respiration rate	0.010	0.010		
37		CBR	Carbon:Biomass ratio	0.500	0.500		
38		LDM	Logging damage multiplier	1.000	1.000		
39		ERLV	Erosion loss,vegetated areas	0.050	0.030		
40		ERLG	Erosion loss,bare ground	0.100	0.060		
41							

Eco2Info / Project / Baseline \ **Coefficients** / Growth / Products / Report / Fig 1.1 / Fig 2.1

	Symbol	Carbon model parameter	Description
Tree species	SPP	Species code (trees)	The code by which the species is referred to on the Project and Baseline sheets. Note that if a * suffix is used on the Project or Baseline sheet to denote an uneven-aged, naturally regenerating species, it should not be included as part of the species code.
	NAME	Short species name	A name which appears as a column heading and graph legend label, and should therefore be kept as short as practicable. It is recommended that this cell is commented with the full botanical name or description if the 'species' is a mixture or group.
	WSG	Wood density	The wood density or specific gravity, used to convert volume to biomass (g/ml or tons/m^3).
	CEF	Crown expansion factor	The ratio of crown+stem biomass to stem biomass.
	RSR	Root:shoot ratio	The ratio of root biomass to total above ground biomass (stem+crown).
	CCF	Coarse crown ratio	The proportion of crown biomass comprising woody (lignified) material (excluding leaves and green shoots).
	RCF	Coarse root ratio	The proportion of root biomass comprising woody material.
	LFALL	Litterfall rate	The percentage of crown biomass which falls each year as litter.
	FRTO	Fine root turnover	The percentage of root biomass which dies each year.
	LFEX	Life expectancy	For plantation species only. The approximate life span of the crop as a range (eg. 20-30) or as a half-life (eg. 60). The former gives a Weibull mortality model, the latter an Exponential model (constant mortality rate). See page 9 for more detail.
	MVH	Maximum vegetation height	Approximate height at maturity, in metres.
	CAI	Current annual increment	*Only required for natural forest species with a * suffix.* The growth rate of the species, excluding the effect of mortality losses, in m^3 ha^{-1} yr^{-1}.
	AMR	Mortality	Annual mortality rate: The average percentage of volume which dies each year excluding logging damage effects.
	INIV	Initial volume	The volume of the species at the start of the simulation, in m^3 ha^{-1}.
	SPF	Shade persistence factor	A value from zero to one indicating shade tolerance. A zero value will cause species to die out as soon as any shading by a taller vegetation layer occurs. A value of 1 indicates a very shade tolerant species.
	CBR	Carbon:Biomass ratio	The ratio of carbon mass to dry weight biomass for the species.
Other vegetation	SPP	Species code (other vegetation)	The code by which the species is referred to on the Project and Baseline sheets.
	NAME	Short species name	A name which appears as a column heading and graph legend label, and should therefore be as short as practicable. It is recommended that this cell is commented with the full botanical name or description if the 'species' is a mixture or group.
	IBM	Initial biomass, t/ha	The total above-ground biomass of the species at the start of the simulation.
	MBM	Maximum biomass, t/ha	The maximum biomass attained by the crop (including accrued value of any removed harvests) in t/ha.
	MPV	Maximum productivity, t/ha/yr	Biomass productivity of the species, in t/ha/yr.
	MVH	Maximum vegetation height	Approximate height at maturity, in metres.
	RSR	Root:shoot ratio	The ratio of root biomass to total above ground biomass.

	CFR	*Coarse:fine ratio*	*The ratio of woody or lignified biomass to total biomass, including leaves, green shoots and fine roots. It may be zero for non-ligneous plants such as grass.*
	SPF	*Shade persistence factor*	*A value form zero to one indicating shade tolerance. A zero value will cause species to die out as soon as any shading by a taller vegetation layer occurs. A value of 1 indicates a very shade tolerant species.*
	CBR	*Carbon:Biomass ratio*	*The ratio of carbon mass to dry weight biomass for the species.*
Soil & site	SITE	*Site/soil code*	*The code by which the soil/site is referred to on the Project and Baseline sheets. This should be commented with a full description.*
	IFNM	*Initial fine necromass*	*The quantity of fine necromass at the start of the simulation. Fine necromass includes dead non-ligneous material and broken down ligneous material not yet incorporated as soil organisms and organic matter. In tC/ha.*
	ICNM	*Initial coarse necromass*	*The quantity of coarse necromass at the start of the simulation. This includes dead ligneous material: branches, dead trunks, dead roots. In tC/ha.*
	ISC	*Initial soil organic matter*	*Soil organic matter at the start of the simulation, in tC/ha.*
	LDF	*Fine necromass decomposition rate*	*The annual percentage rate at which fine necromass decomposes to soil organic matter.*
	LDC	*Coarse necromass decomposition rate*	*The annual percentage rate at which coarse necromass decomposes to fine necromass.*
	NFRL	*Fine necromass respiration*	*The percentage of carbon respired to the atmosphere during the decomposition of fine necromass to soil organic matter.*
	NCRL	*Coarse necromass respiration*	*The percentage of carbon respired to the atmosphere during the decomposition of coarse necromass to fine necromass.*
	SRR	*Soil respiration rate*	*The annual percentage loss of soil organic matter to the atmosphere through respiration.*
	CBR	*Carbon:Biomass ratio*	*Although shown in the dECO$_2$ worksheet, this is not used in the model as soil organic matter and necromass should be expressed in tC/ha units. A value can be inserted for documentation in the report generator.*
	LDM	*Logging damage multiplier*	*Logging intensity (LI) in the model is calculated as volume logged/volume before logging. The LDM x LI gives the volume loss % from the residual stand due to logging damage. It may be zero if logging damage is negligible (as in good plantation practice).*
	ERLV	*Erosion loss,vegetated areas*	*Percentage of soil organic matter lost to the project each year from normally vegetated areas.*
	ERLG	*Erosion loss,bare ground*	*Percentage of soil organic matter lost to the project each year from areas disturbed by logging or clearfelling.*

Note that in many cases the soil/site coefficients may be different for the project and baseline scenarios. Even though they (obligatorily) have the same initial values, the other coefficients (decomposition and respiration rates, logging damage multiplier and erosion losses) are likely to be different in the different micro-environments created through vegetation changes.

The *Products* sheet

The *Products* sheet lists all the various product codes referred to in the *Project* or *Baseline* sheets. It defines the life span of the product, before it decays back to CO_2 (through natural decay or burning), and it specifies any fossil fuel substitution factor that is applicable if the product is a wood fuel. If any product is specified on the *Project* or *Baseline* sheets that is not listed, then an error occurs when the model is run.

	A	B	C	D
1	**Wood product coefficients**			
2	Code	Description	Probable life (years)	Fossil fuel substitution factor
3	Poles	Fence posts, telegraph poles, poling	5-10	
4	Timber	Quality lumber for durable uses	5-10	
5	Pulp	Wood converted to pulp	1	
6	Chips	Semi-durable chipwood	5	
7	Paper	Short lived paper products (eg. Newspapers)	0.5	
8	Bark	Bark for tannin extraction (SETA project)	1	
9	Cases	Non-durable lumber uses	2	
10	Fuelwood	Wood used directly as fuel	1	
11	Coffee	Coffee beans	1	
12	Charcoal	Wood used to make charcoal	0	1

|◄ ◄ ► ►|\ Eco2Info / Project / Baseline / Coefficients / Growth \ **Products** / Report / Fig 1

The product life may be specified as a range of values or as a single value. If a range is given, then the Weibull decay model is used, with 5% of the product decaying before the first specified year, and 95% decaying by the last specified year. The details of the function are given on page 12.

If a single year is given, then the Exponential decay model is applied, with the year given being the half-life. The figure on page 10 shows the relation between half-life and annual decay rate.

The fossil fuel substitution factor (FFSR) should be left blank unless the product is a wood-based (or biomass-based) fuel. In this case the ratio of product carbon to the substituted fuel carbon should be given, based on the relative technical systems that would be employed in each case (*eg.* open hearth fire versus kerosene stove, for example). If the FFSR is non-blank, then the product-life entry is ignored: storage of fuels will be assumed by the model to be less than one year.

All the columns A-D can be commented with notes, references or explanations, which are picked up by the Report Generator.

**Plantation species and the
Growth worksheet**

Each tree species that is identified on a project or baseline unit will be either be classed as naturally regenerated, or a uniform-age artificially-regenerated stand . This latter situation is termed a *plantation*, for simplicity, although uniform forest could be maintained by other silvicultural means such as coppicing.

Each plantation species must have a growth model given on the *Growth* worksheet. The appearance of this sheet is shown below.

	A	B	C	D	E	F
1	**Species** *Teak*			*Code*	**TK**	
2	**Growth data (MAI)**		*Coefficients*	9.7881E-01	1.4470E+01	5.0000E+02
3	*Year*	*MAI*				
4	2.92	0.9				
5	12.64	12.0				
6	25	10.5				
7						
8						
9						
10	**Species** *Laurel*			*Code*	**LA**	
11	**Growth data (Volume)**		*Coefficients*	1.3015E+00	1.3315E+01	5.5000E+02
12	*Year*	*Volume*				
13	5	100.0				
14	25	450.0				
15						

Eco2Info / Project / Baseline / Coefficients \ **Growth** / Products / Repor

For each species, there must be a code (*eg.* TK, LA) in column E opposite the keyword *Species* in column A. On the next line down, in cells D,E and F are given the coefficients γ, β, α of the growth function in equation {1} (page 7). These are not entered directly, but are written to the sheet by the *Growth modelling tool*, discussed in the next section.

Two lines below the *Species* keyword, empirical data about growth rates can be written. This can be based on one of three parameters: Volume, mean annual increment, or current annual increment. The codes *Vol* (or *Volume)*, *MAI* or *CAI* should be written as a heading to indicate the variable being used. Then paired yield table years and values should be entered. The growth modelling tool will plot these data on the graph, where they can be used as guide points to calibrate the model.

Volume data, if used, must be *cumulative volume* including both standing volume, and the accrued value of any thinnings.

Column B of the data table can be commented for the Report Generator. These comments will be shown on the report output. Comments elsewhere are not used.

The growth modelling tool

The growth modelling tool is used to set the coefficient values of the growth function, given a set of empirical data, or purely conceptually if there is no data. It is activated from the dECO₂ tool bar, as shown in the diagram opposite. This will bring up the dialog box and graph shown below. As soon as the dialog box is closed via the *Cancel* or *OK* buttons, then the graph will disappear again.
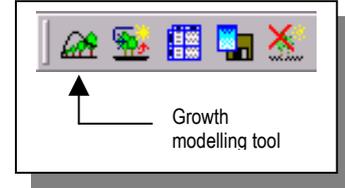
The pull-down list on the dialog box shows all the species that are defined in the *Growth* sheet. The selected species from the list will be shown on the graph. The *OK* button saves the current coefficients from the graph to the *Growth* worksheet for the designated species. The *Cancel* button will close the dialog and hide the graph without any changes being made. The *Reset graph* box, if checked, re-copies the graph from the *deco2.xla* template. This may be necessary if the graph is altered in a way that prevents the tool from working (*eg.* by deleting one of the data series).

On the graph, the current growth function is shown as a total volume line (green), and MAI line (red), or a CAI line (blue). The data is plotted as circular points in a colour appropriate to the parameter used.   If the data is given as MAI, it is shown in red; if as volume, it is given in green, and if as CAI, then it will be shown in blue. There are two control points on the graph, which control the shapes of the curves. The diamond gives the value of the maximum possible volume, or α parameter.
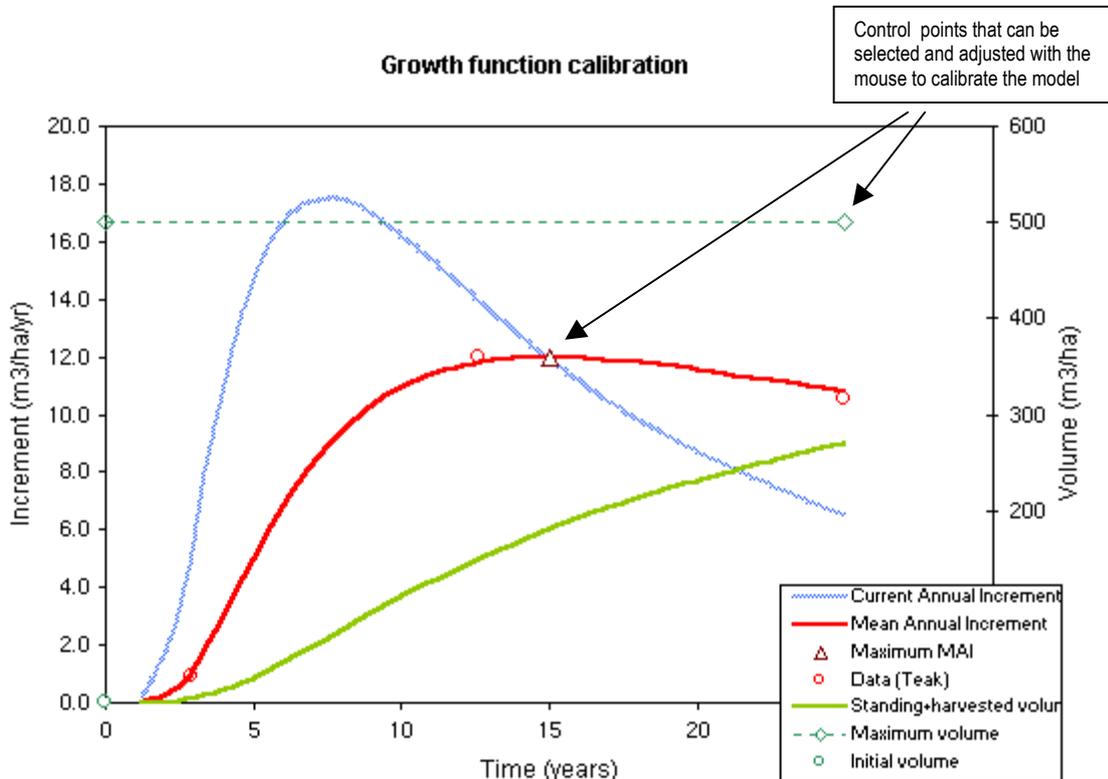
The triangle is located at the point of maximum MAI on the MAI curve. As this is adjusted with the mouse, the curve shapes will change, reflecting modifications in the β and γ parameters. The curve can be adjusted to fit the data as well as possible.

Note that the changes will not be saved to the *Growth* sheet unless the *OK* button is clicked on the dialog form.

If there is no available data, then the curve can be adjusted to reflect expert opinion over maximum MAI and age of maximum MAI.

Moving the diamond-shaped point to the right will automatically extend the age range of the axis.

Note that playing with the growth modelling tool will change the values produced by simulations. It is therefore desirable to have data points as a check on the graph, as it is otherwise easy to overlook unintended changes.

The report generator picks up comments in column B against the data points, which may note the origin and assumptions of the yield data. It also shows the function used in the simulation, with coefficients.

Importing existing growth functions

Yield tables for plantation species are normally imported into $dECO_2$ by taking points off the volume-age table, and entering them into columns A:B of the Growth sheet (see page 25) as data. It is important to note that the volume in this case must be gross volume, including both standing volume, and the accrued value of any thinnings. Using standing (net) volume alone will underestimate volume growth substantially. Once the points have been imported, the growth model can be adjusted with the mouse to fit them as accurately as possible, as described above.

In some cases however, the coefficients of the Schumacher equation for gross volume on age (see {eq.1}, page 7) may already be known, either because they have been fitted using another statistical package, from earlier applications of $dECO_2$, or because they have been published as such with the yield table. In this case they can be entered directly, with the coefficients γ, β, and α of the growth function in cells D,E and F as shown on page 25.

Once the basic project sheets have been set up, as described in the preceding chapters, then the model can be run to generate updated output tables and graphs. This is done via the *Run*

The Run dialog

Run icon

carbon model icon on the dECO₂ tool bar, as shown at the right.
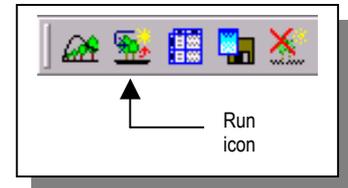
Provided that dECO₂ is properly installed and the workbook correctly configured, the dialog form shown below will appear when the *Run* icon is clicked.
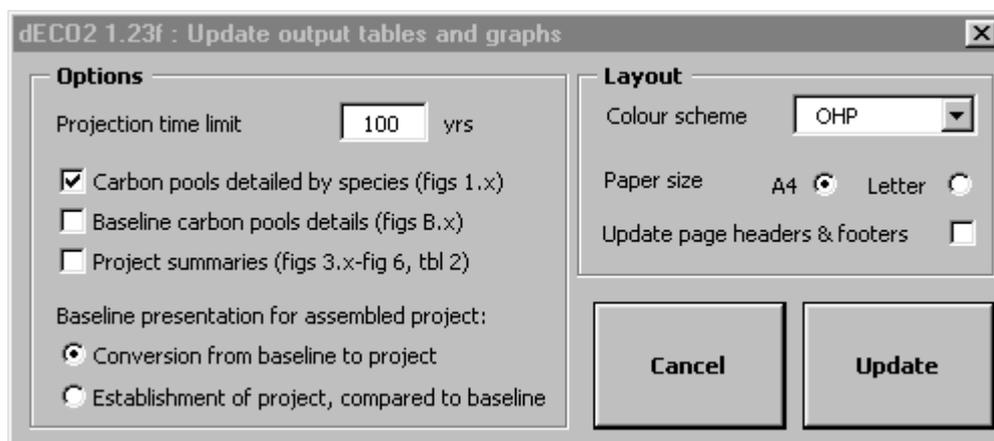
The following options can be set from this screen:

❑ *Projection time limit*: This can be set to any period appropriate for the analysis in question. The model will stop after simulating the period in question, and all graphs and tables will be adjusted accordingly.

❑ *Carbon pools detailed by species*: If checked, graphs will be produced for each unit detailing the carbon sequestered by the phytomass (plant biomass) by species.

❑ *Baseline carbon pools details*: If checked, a series of graphs will be produced detailing baseline carbon pools. In the early stages of calibrating a project, with frequent re-runs, faster turnaround is achieved if this is unchecked.

❑ *Project summaries*: If checked, the unit and project net and gross carbon analysis will be produced. Again, in the early stages of calibration and setup, faster turnaround results if this is unchecked. However, only project unit carbon pool details are produced if this is the case.

❑ *Baseline presentation*: This affects the appearance of Figures 4 and 5 and table 2. The *conversion* option implies the whole area is considered to be under the baseline initially, which is progressively converted to the project land use over the designated period. The *establishment* option compares increasing areas under project or baseline alternatives over time as the project is established. The net

carbon calculated under both methods will be the same. See page 4 for further discussion.

❑ *Colour scheme*: Three colour schemes are listed on the pull down: *OHP, Colour* or *B&W*. These affect graphs and table colouring. Each scheme has predefined or default settings, and can also be redefined to a user setting. The *OHP* setting is optimised for on-screen presentation. The *Colour* setting is designed for printing in colour on white paper. The *B&W* setting is optimised for black and white printing of tables and graphs. See page 33 for more detail.

❑ *Paper size*: Printing of graphs and tables will be adjusted for either A4 or US Letter layouts. Note that other sizes can be accommodated via the Excel page layout menu.

❑ *Update page headers and footers*: A header and footer will be inserted which includes the project title, EcoSecurities copyright notice, date, and workbook and sheet names. *This process significantly slows down the running of the model*, especially with many output sheets, so that it is recommended that it is left unchecked until a final run of the model is prepared.

The **Cancel** button will close the dialog without any action. The **Update** button will run the model. The selected options are saved in this case, and will appear as defaults when the model is next run.

Output figures and tables

$dECO_2$ generates the output tables and graphs that it makes from scratch. When the program first runs, all generated sheets are removed, and then recreated. The figures all have sheet names in the format *Fig n.u*, where *n* is a figure number relating to its function, and *u* is a unit number. Figures 1-4 are constructed at the unit level, with one figure per unit. Figures *B.u* are produced optionally, to show carbon pools for each baseline unit. Figures 5 and 6 are project summaries, with only one copy each. Figures 1-4 have the unit title as the main title, and the project title as a sub-title. Figures 5 and 6 have the project title as a sub-title.

All the data series on the figures correspond to columns in the tables. Figures 1-3 relate to Table 1 (sheet names *Tbl 1.u*), which has a different version for each unit. Figures 4-6 relate to Table 2, (*Tbl 2*) for which there is a single copy for the project. The tables are optimised for printing or cut and paste operations into Word documents, and have page breaks inserted at appropriate points for best appearance.

The following table describes the various types of output produced.

Sheet	Contents
Tbl 1.*u*	A table giving for each year of the projection, carbon sequestered in tons per ha by species components (one column per species) and by carbon pools: phytomass, necromass, soil carbon, products, and total. The phytomass column is the sum of the species columns. One table is produced for each unit.
Tbl B.u	This is the equivalent of *Tbl 1.u* in layout, but is produced for each baseline unit.
Fig 1.u	Based on the data in *Tbl 1.u*, this shows a line for each species component, giving carbon sequestered in tC/ha over time.
Fig 2.u	Based on the data in *Tbl 1.u*, this shows a line for each carbon pool (phytomass, necromass, soil carbon, products, and total) giving carbon sequestered per ha.
Fig B1.u	The equivalent of *Fig 1.u*, but for each baseline unit.
Fig B2.u	The equivalent of *Fig 2.u*, but for each baseline unit.
Fig 3.u	Based on the data in *Tbl 1.u*, shows lines for total carbon sequestered by the project unit, by the baseline, and the net carbon sequestered by the project, on a per ha basis (tC/ha).
Tbl 2	Gives three columns for each unit, showing total carbon sequestered by the project, by the baseline, and net carbon, for the total area of the unit according to either the *establishment* or *conversion* comparison methods. Project total columns sum the unit gross, baseline and net carbon. A final column gives net carbon by the average accounting method.
Fig 4.u	For each unit, shows the gross, baseline and net carbon sequestered over the total unit area, according to either the *establishment* or *conversion* comparison methods for the baseline.
Fig 5	Shows the project gross, baseline and net carbon on the total area.
Fig 6	Shows project net carbon together with the net carbon according to the average carbon accounting method over the period of the projection.

Running the Report Generator

The report generator can be run by clicking on the *Report Generator* icon on the dECO$_2$ toolbar, as shown at the right.
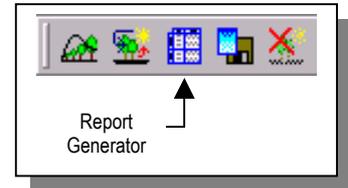
When it runs, the Report Generator reads all the unit and baseline descriptions and coefficient settings, and produces a tabular, readable description of the project parameters on a worksheet called *Report*. If the sheet *Report* already exists, it is deleted and replaced. There are no options required, and the program will run as soon as the above icon button is clicked with the mouse. The output sheet is designed to be cut and pasted, or linked directly into MS Word as a table.

Report outputs

The report is divided into 3 columns and several sections. The first column gives a parameter description. The second gives its current value. The third column includes any comments that have been made on parameters or coefficients as notes. This will include normally a citation describing the source of data, together with any necessary explanations or assumptions. In processing cell comments, the Report Generator ignores the initial text up to the first colon; this is normally inserted automatically by Excel with the name of the comments author.

The main sections of the report are:

❑ *Project title and total area*: The title is taken from the *Project* sheet, cells D1:G1. The total area is calculated as the sum of the unit areas. The comment on cell G1 is added as a note; it is recommended that this should be a brief resumé of the project.

❑ *Project unit summaries*: This lists the species used, substituting full names for the codes on the *Project* sheet, soil types, and baseline. It assembles the harvesting schedule into a text description, and includes comments on the unit specification as detailed on pages 15-19. A unit summary is produced for each unit on the project.

❑ *Baseline unit summaries*: These have a similar format to the project unit summaries described above, and include details of species, harvesting operations, and soil/site types for the baseline units. Cell comments in applicable cells are transcribed as notes (see page 19).

❑ *Species coefficients*: This lists the detailed species coefficients including the growth models used for all species occurring on any of the project units. Cell comments are transcribed as notes, as detailed on pages 20-25.

❑ *Soil and site coefficients.* Necromass and soil coefficients are listed in this section, with transcribed cell comments according to the specifications on page 20, for all soil or site types occurring on any unit within the project.

❑ *Product coefficients.* All products defined in the project are listed, with life expectancy parameters, fuel substitution factor if applicable, and cell comments as specified on page 24.

The default colour schemes

Three default standard colour schemes are built into dECO$_2$. These are labelled the *OHP, Colour* and *B&W* schemes. The *OHP* scheme is designed for copying to MS PowerPoint slides or for direct on screen use, and uses thick lines and bright colours including a coloured graph background. The table sheets (*Tbl x.u*) have pale coloured backgrounds and heading text.
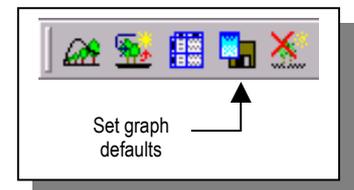
The *Colour* scheme is designed for colour printing, or merging with MS Word documents that are to be colour printed. It has white backgrounds, and colours and line styles suitable for a printer.

The *B&W* scheme is optimised for printing on a monochrome laser printer. Tables have white backgrounds. Graphs use black lines, with different line thicknesses and styles to distinguish items.

The colour scheme to be used is indicated when the carbon model is run, as described on page 28.
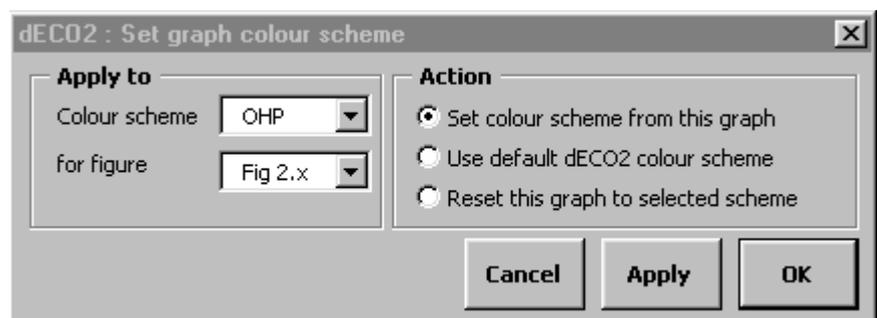
Changing the default schemes

The *set graph defaults* icon on the dECO$_2$ toolbar (right) brings up a dialog screen as shown below which allows any particular *figure/colour scheme* combination to be redefined. The *Action* option determines how the colour scheme may be modified.

Set graph defaults

With *set colour scheme from this graph*, the indicated colour scheme for the specified graph in the *Apply to* box will be changed to the colours, line styles and graph background setting of the graph underlying the

dialog box when either the **Apply** or **OK** buttons are clicked. To use this to change default settings, select an existing graph and modify its colour and line styles using standard Excel formatting options. Then bring up the above dialog and execute this option. To change the style for several graphs, use the **Apply** button to keep the dialog open, and select each figure to be affected in turn from the pull down list.

The _use default dECO$_2$ colour scheme_ option will reset the scheme for the graph indicated in the _for figure_ box to the default settings for the specified scheme when the **Apply** or **Ok** buttons are used. Note that this is not seen to happen in real time. The model must be re-run to regenerate the graph, or the third option, discussed below, must be affected to see the changes immediately.
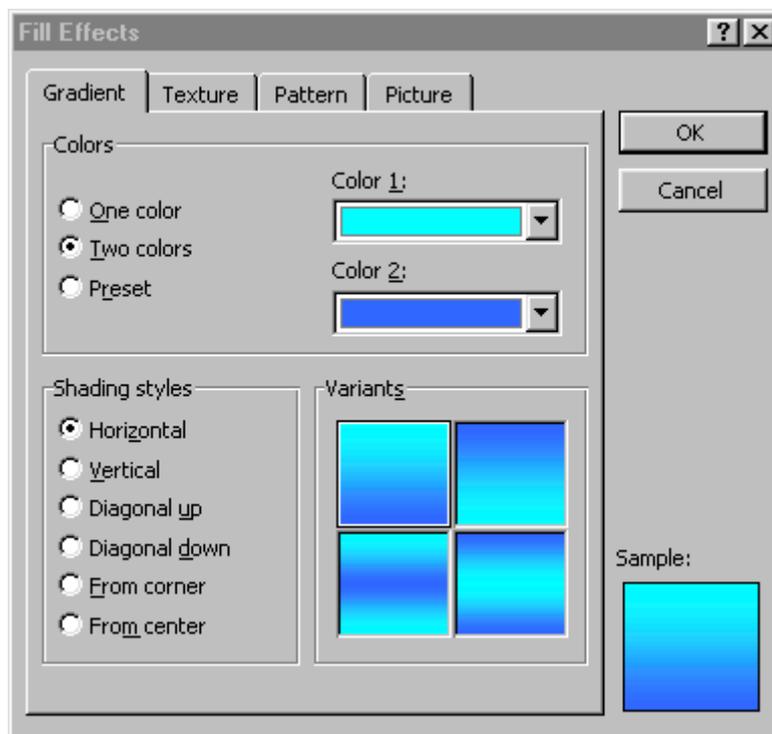
The _Reset this graph to selected scheme_ will activate the graph shown in the pull down list and apply the current colour scheme to it.

Restrictions on colour scheme changes

dECO$_2$ will not save all aspects of a graph format when changing the default schemes. Only <u>line colours</u>, <u>thicknesses</u> (weight) and <u>styles</u> (dots, dashes,etc.) are recorded. For the graph background, only a single type of background is allowed. This is a <u>horizontal</u>, <u>gradient</u> fill effect with <u>two colours</u>, as shown in the dialog below. A plain colour (_eg._ white) can be achieved from this by setting both colours the same. The fill effect dialog is obtained by choosing the _Format plot area_ option from the Excel _Format_ or _Chart_ menus, and clicking the _Fill effects_ button on it. _Setting any other type of fill effect will cause errors when trying to change graph defaults_, and may prevent the model running properly. These can be overcome by resetting the graph involved to the dECO$_2$ built-in defaults.

Changes to other details of graph formats, such as title fonts or colours, marker symbols,etc. are not recorded and will be lost if the model is re-run. If a graph requires to be further embellished for any reason, it should be copied together with its associated data table to another workbook.

Installation problems

There are four classes of general problem that will either prevent the model from running, or result in an older version of $dECO_2$, previously installed, running instead of the expected version.

If the model has not been installed at all, or has been removed, then the $dECO_2$ toolbar will not be visible (see right). In this case, follow the installation procedure on page 13. If $dECO_2$ has been installed, but the bar is not visible, follow the procedure for re-installation described on page 14.

If clicking on any of the $dECO_2$ icons produces the message "*Active workbook does not look like a valid dECO2 project*", then an attempt is being made to run the model with a project workbook that has not been properly constructed. Read the section **Setting up a dECO2 project** (page 15).

If clicking on any of the $dECO_2$ icons produces the dialog screen shown on page 13, then it is necessary to set the unlocking code before the model can be used. If the unlocking code is not known, email the author quoting the reference that appears on the dialog form (see **Technical assistance**, page 38).

If $dECO_2$ runs, but is an older or different version to that expected, then fellow the procedure to remove and re-install $dECO_2$, to correct the file reference on the $dECO_2$ toolbar (see page 14).

Missing reference codes for species, sites, baselines, or products

On a unit specification, several codes occur which must cross-link with other sheets to pick up information about species, soil or site types, products, or baseline units. If these are missing, several classes of error message may result when the model is run. The following are possible error messages:

❑ *Species '.....' not found on the {Coefficients} worksheet*: A species code has been used that does not exist on the *Coefficients* sheet in either the *Trees* or *Other vegetation* sections (see page 20). Note that codes are case sensitive, and trailing or leading spaces must not be present on the *Coefficients* sheet where they are declared.

❑ *Site code '.....' not found on the {Coefficients} worksheet*: A site code has been used that does not exist on the *Coefficients* sheet in *Soil & site* section (see page 20).

❑ *Baseline '....' not found on sheet {Baseline}:* The baseline code referenced by a unit does not exist on the *Baseline* sheet. This may mean that the code is wrongly constructed (upper/lower case, leading/trailing spaces) or has been entered in the wrong cell, as well as being simply missing. If the keyword at the start of the

baseline unit specification is wrong, then the unit will also not be recognised (see page 19).

❑ *Product '…...' not defined on the {Products} sheet at …* : A product name is listed in the harvests section of a unit that is not defined on the *Products* sheet. See page 24. Note also the above strictures about case sensitivity and leading or trailing spaces for codes. The cell address will be given where the erroneous code originated on the *Project* or *Baseline* sheets. This should be checked.

❑ *Cannot find parameter {…} in …* : A required coefficient is missing. The coefficient code will be given in the braces {}. See the example and table on page 20 *ff.* for a complete list of required coefficients.

Errors connected with harvesting or silviculture

Several classes of error can arise due to wrongly specified harvesting operations or to cover area ratios. The following are possible messages and symptoms:

❑ *There is no output for a unit in Fig 4.u (the graph is blank).*   This is probably caused by leaving the unit area blank or zero. The per ha graphs and tables will appear normally, but area totals will be zero.

❑ *Species list … is not compatible with cover areas ratio list ….*   On a unit specification, the cover area ratios must either be blank, or there should be same number of entries as there are species, or there may be one more entry than the species listed. The latter will indicate growing space not under plantation crown cover. See page 15.

❑ *Replanting of … has been specified at age …. 100% felling will be assumed.*: This message occurs when the * suffix has been used to indicate the end of a rotation, but it is not associated with 100% felling for an operation. (See page 17).

❑ *Ratio list not consistent with product list at …*: A list of product ratios is specified, but the number of items differs from the number of items in the product list. (See page 17).

❑ *A specified harvest is ignored by the model*: This will happen if two entries for the same species use the * suffix; or if the species code for the harvest is not recognised; or if a + suffix item is listed before a * item for the same species (they must be listed afterwards). Harvesting entries may also be ignored if the merged region of the harvest section has not been extended to cover all the entries for a unit. (See page 17).

The model runs, but results are unexpected

The growth of a species may be too high or too low because of an inappropriate growth model. If the species is naturally regenerated (* suffix on the species list for the unit) its growth depends on the

CAI, AMR, and INIV coefficients (see page 22, and concepts on page 8). Other coefficient values are also important, and wrong results will occur if they do not have reasonable values. It is a good idea to set up and calibrate one unit at a time in complex projects, starting with the baseline vegetation, which should behave in a stable and sensible way.

Missing units

If a unit is specified on the project sheet, but fails to appear in the output, then it is probable that the keyword at the start of the unit is misspelt, is not of the same case, or has different number of spaces.

The keyword is set from whatever text occurs in cell C3 of the *Project* sheet, on the first unit, as shown.

Keyword in cell C3 of first unit will be used to recognise subsequent units.

The same principle applies to units on the *Baseline* sheet. However, if these do not have a consistent unit keyword, an error will result indicating a missing baseline code when an attempt is made to run the program.


Unit keyword intentionally modified to remove a unit from a project.

Units can be intentionally omitted from a project, without deleting them, by prefixing the unit keyword with some marker character such as a *, as shown in the example at the left.

Options on error messages

Several types of error dialog can arise, depending on how the problem has been detected. The two types that commonly occur from within dECO$_2$ are shown below.
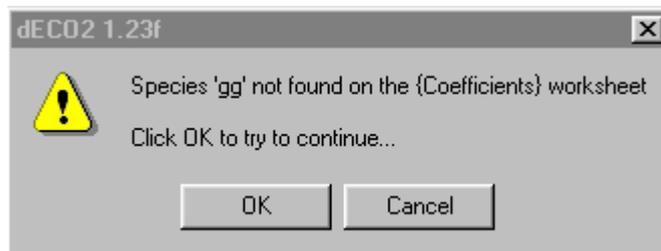
This type of message allows for recovery with the "*Click OK to try to continue…*" option. If the **OK** button is clicked, some output will be generated, but it will not be as expected. There is also a good chance of subsequent error messages arising as a result of the missing or corrupted information. It is generally better to select the **Cancel** option and try to identify the source of the problem.

The error message shown below is produced when an execution error occurs that is not from an identifiable problem. The actual error message will give little clue as to the source of the problem. The user will be invited to **Retry** or **Cancel**. Unless you
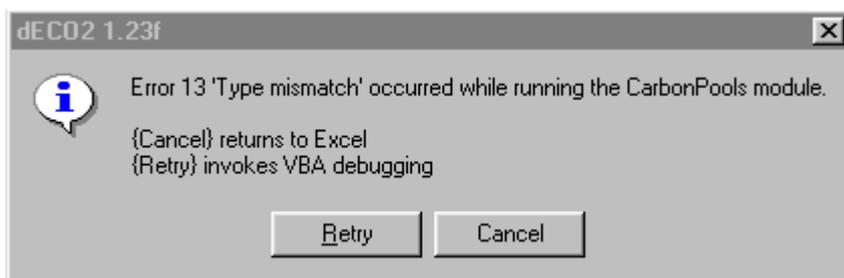
are knowledge-able in Visual Basic, the **Cancel** button should always be selected. The **Retry** button will not bring up any useful information unless the DECO2.XLA program has been opened in the Visual Basic editor. This requires a confidential password giving access to the program code. In the latter case, the **Retry** button will highlight the program statement where the error occurs.

To identify the source of this type of message, it is best to start with a simple project, and build it up step by step, adding species, units, harvesting operations progressively.

Problems with graphics

Two types of problems can occur while generating figures. Both are easily corrected. The first relates to the use of the growth model tool (page 26). If lines or other objects are deleted from this graph, then it may not function properly, or in extreme cases, Visual Basic error messages will occur such as *"Object not found.."*. In such cases, the **Reset graph** checkbox should be clicked on the *Growth function tool* dialog (see page 26). This will regenerate the graph correctly.

The second type of problem occurs because default colours and lines have become corrupted for the *Fig...* sheets. This can be overcome by using the features described in the section **Graph colour schemes** (page 33) to reset the default colours for the graph where the problem occurs.

Technical assistance

If it is not possible to resolve a problem with dECO$_2$, then assistance can be obtained by email from the program author. Please proceed as follows:

❑ Remove all generated pages from the workbook where the error occurs (use the Excel *Edit→Delete sheet* menu). These are the sheets *Report*, and those prefixed *Tbl...* or *Fig....* Only the sheets shown on the diagram at the top of page 15 should be present.

❑ Zip up the workbook using WinZip or a compatible utility to produce a zip file.

❑ Send it to *denis@bio-met.co.uk* as an attachment. Explain the problem encountered as clearly as possible. Please put DECO2 on the subject line. Note that unless otherwise authorised, only messages received from *ecosecurities.com* addresses will be answered directly. *It is very important that the dECO$_2$ version number is clearly indicated.*

Alder, D (1980) Forest volume estimation and yield prediction : Vol. 2 - Yield prediction. *FAO Forestry Paper* **22**/2, 194 pp.

Alder, D (1995) Growth modelling for mixed tropical forests. Department of Plant Sciences, University of Oxford. *Tropical Forestry Paper* **30**, 231 pp.

Bailey, RL; Dell, TR (1973) Quantifying diameter distributions with the Weibull function. *Forest Science* **19**(2)97-104.

Cannell, MGR (1982) *World forest biomass and primary production data*. Academic Press, London.

Sheil, D; Burslem, DFRP; Alder, D (1995) The interpretation and misinterpretation of mortality rate measures. *Journal of Ecology* **83**:331-333.

Stage, AR (1963) A mathematical approach to polymorphic site index curves for Grand Fir. *Forest Science* **9**(2)167-180.

Wilson, C (1998) *Modelling carbon sequestration in forests: A tool for Joint Implementation Project investors*. M.Sc. Thesis, Imperial College, London.