Establishment Management Information System [EMIS]: delivering good practice tree establishment advice for the UK uplands.

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Abstract

The Establishment Management Information System [EMIS] is a decision support tool, which integrates existing tree establishment advice, on a site-specific basis. It draws upon current good practice information from a myriad of technical and scientific publications to provide the user with a 'walk through' system delivering acceptable (site constrained) tree establishment options. Site information (user input) allows calculation of environmental variables which constrain species choice and identify appropriate on-site management practices. EMIS currently provides advice encompassing the main commercial upland conifer species, plus birch. Whilst 'all' potential system inputs and interactions have been investigated, primary drivers were identified to ensure the system evolves guided by operational requirement & existing knowledge. The web-based decision support system integrates with another Forest Research tool (Ecological Site Classification, ESC) via shared components. Output of information from EMIS will be available as both HTML and pdf. EMIS will be a web delivered tool, but the constituent models are also available as document-wrapped style web services to allow integration with spatial data systems (e.g. ForesterGIS™ extension). This will enable delivery of spatially explicit good practice guidance in the future.

Introduction

In upland UK forestry, the reforestation and afforestation of sites requires knowledge of site constraints to ensure suitable species selection (when planting) and appropriate site management techniques. Effective application of this knowledge results in successful establishment. In forest policy worldwide, the concept of 'sustainability' has expanded to include 'sustainable forest management' (Lane & McDonald, 2002). The application of silvicultural knowledge at establishment is therefore the first step towards sustainable forest management, on which all other decisions are dependent (Ray and Broome, 2003). In the UK a number of measures have been introduced to improve sustainable forestry including the 'UK Forestry Standard' (Anon., 2004), and 'The UK Woodland Assurance Scheme' (Anon., 2000). Certified forests are monitored to ensure that good management is continually in practice (Anon., 2002).

In order to match species to a location, knowledge of site factors and their influence on tree establishment and growth is required. These include an understanding of the general site environment (e.g. soil type, lithology, soil moisture and soil nutrient status), an understanding of the local climatic environment (e.g. wind climate, oceanicity, elevation, temperature profile), and the interactions between these factors. The ability of the forester to assess site conditions and select well-suited tree species is therefore of fundamental importance, as is an understanding of the silvicultural principles (*i.e.* options) available to improve tree establishment and growth (Tabbush, 1988). Silvicultural considerations include plant species and provenance choice, plant type, plant quality, plant storage and time and method of planting (e.g. Morgan, 1999), site cultivation (Sutton, 1993; Paterson and Mason, 1999), fertilisation (Taylor, 1990a,b; Smith and McKay, 2002) and vegetation management (e.g. Willoughby and Dewar, 1995; Willoughby *et al.* 2004).

A 'method sophisticated approach' where complex interaction between ecological (and social) components must be known and considered, requires powerful decision support system (DSS) tools (Rauscher *et al.* 2000). DSS tools are computer-delivered programs that provide support to the decision makers engaged in solving various semi- to ill-structured problems involving multiple attributes, objectives and goals (Turban and Aronson, 2000; Nemati *et al.* 2002). A key feature of DSS tools is that the decision-maker is as important a part of a DSS as any other component. People do not simply use DSS outputs, rather they provide the system with judgement and values that are critical, and often dominate, the decision-making process.

Forestry can be defined as the intervention in ecological processes to meet human needs or goals. Forestry practice in general, and silviculture in particular, are based on the premise that any activity in the forest is intended to meet the goals of the manager. Indeed, identification of the landowner's objectives is the first step taught to silviculturists in forestry schools (Smith, 1986). It is reasonable to assume that if a tool does not address the needs of its stakeholder group, it will not be used. Therefore, decision-support systems intended to help forest landowners or managers determine appropriate actions must focus on meeting the goals defined by the user. EMIS is a decision support tool that aims to inform the user (forest planner, agent, owner) regarding appropriate species choice and silvicultural management options for the successful establishment and growth of trees, on UK upland restock sites (*i.e.* sites which previously have been used for the cultivation of trees). In particular strategic-level forest design planning has a wide range of 'competing' goals that the forester has to appreciate and account for (Bell, 1998). EMIS attempts to model the complex interactions represented by the varied silvicultural options, whilst taking into account sustainable forestry goals. Such considerations, applied to a restock setting, include forest soil condition (e.g. the selective use of cultivation with account of its potential impact), forest condition (e.g. minimising chemical use according to site specific needs) and timber production (e.g. identifying productive species well-suited to the site).

In the present study, we describe the development of a prototype expert system (EMIS), developed with compliance to sustainable forestry guidelines in the UK. In its current guise EMIS contains information relevant to upland restock sites. Good practice guidance is web-delivered to the user. The architecture to date provides decision support by highlighting good practice for cultivation, fertilisation and all aspects of 'plant quality', and species choice matched to site constraints.

The System

The EMIS framework (*i.e.* shared software code) integrates directly with ESC-DSS v.2 (Figure 1) and will ultimately allow other Forest Research DSS components to be 'plugged-in' in future (e.g. Herbicide Advisor, Hylobius Management Support System). The extensible service orientated framework allows easy incorporation of additional simulations, knowledge bases, and other decision support tools. The complex EMIS schema, which is presented here as stand alone constituent modules was developed, in the first instance, using the Simile modelling environment (Muetzelfeldt and Massheder, 2003).

For a given site, the suitability of individual species for timber production (on restock sites) is predicted on the basis of six Ecological Site Classification (ESC) factors as criteria for testing site-species suitability (Pyatt and Suarez, 1997; Pyatt *et al.* 2001):

four climatic factors: accumulated temperature, moisture deficit, windiness (by Detailed Aspect Method Scoring ; DAMS) and continentality,

two soil quality factors: soil moisture regime (SMR) and soil nutrient regime (SNR).

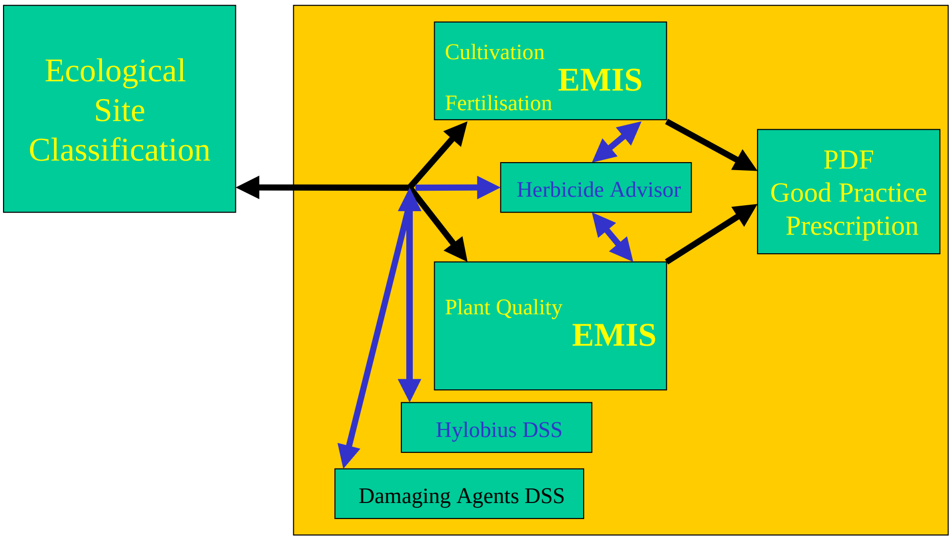

Figure 1. A schematic representation of the major functional components and interactions of EMIS. Yellow titled boxes are currently functional. The elements of the EMIS framework relating to conifer restocking and site treatment are shown in the yellow box. The integration with Herbicide Advisor and HylobiusMSS are currently in development, whilst the interactions with other damaging agents (e.g. deer, frost, pathogens, other insect pests) are included in the architecture but are not yet functional.

ESC–DSS (Ray, 2001) calculates the climatic indices from user input of grid reference and elevation of the site (Figure 2).

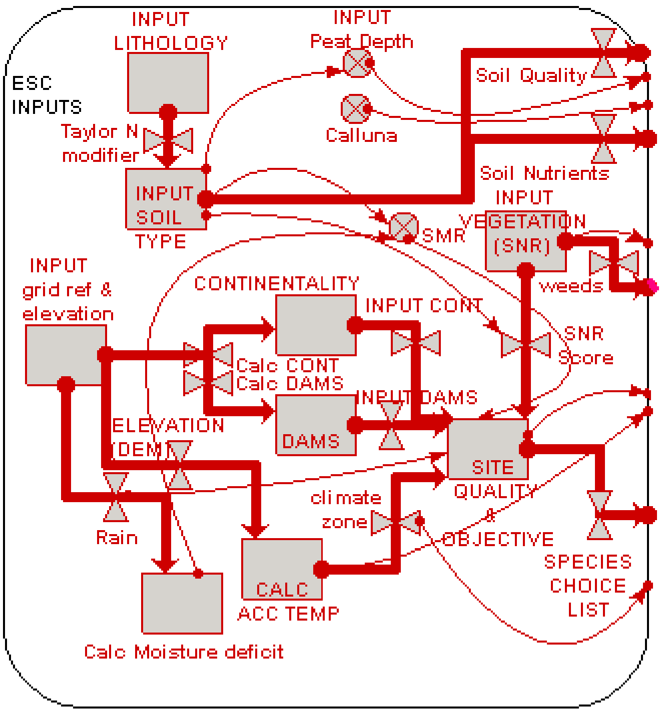

Figure 2. A detailed schematic representation of the climatic and soil quality components within ESC, which are accessed by EMIS after user input of location, elevation, soil type and lithology. The input of vegetation information to amend SNR is not required for restock sites.

A user is encouraged to enter soil information via a survey rather than depend on the admittedly coarse data in the database (Kennedy, 2000). Soil quality (SMR, SNR) is estimated through linkage to ESC directly from soil type as modification by site vegetation assessment is not required for restock sites. However, the finesse that site vegetation assessment offers has been retained, as an extension of EMIS to non-restock sites (e.g. farm forestry) is envisaged in the future. Further modification (input) with respect to underlying lithology, the presence of heather and the depth of peat (for peat based soil types) are required as these factors are known to affect site fertility (Taylor, 1990b). Soil quality is therefore the primary driver for good practice advice for cultivation (Figure 3A) and fertilisation (Figure 3B) silvicultural options.

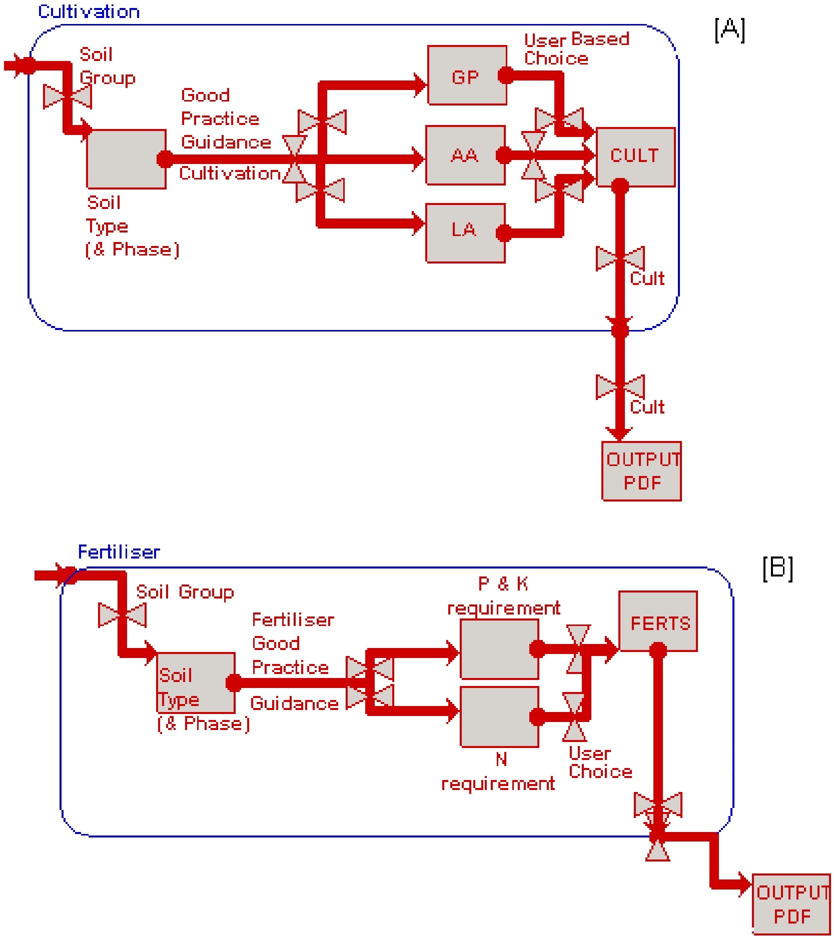

Figure 3. Detailed schematic representation of the influence of soil quality components on output guidance. [A] Cultivation, where options are delivered to the user denoted good practice (GP), acceptable alternative (AA), and lesser alternative (LA: *i.e.* with some penalties), and [B] Fertilisation, where nitrogen, phosphorous and potassium specifications are given.

Plant quality parameters are constrained in the first instance by suitable species choices, although multiple species scenarios, when several species are suitable for a site, can be considered. Plant quality parameters for consideration by the user include correct (constrained) choice of provenance, in the first instance. Users are presented with all currently common plant type specifications, by nursery production system (*i.e.* cell grown v bareroot stock types), acceptable physiological limits (as routinely assessed by the physiological plant quality test root electrolyte leakage, REL), plant morphometrics (size classes denoted by acceptable height and root collar diameter ranges), and cell size for container grown plants (Figure 3). Acceptable planting windows, dependent on plant specifications and climate zone (captured from accumulated temperature), are presented in tabulated format.

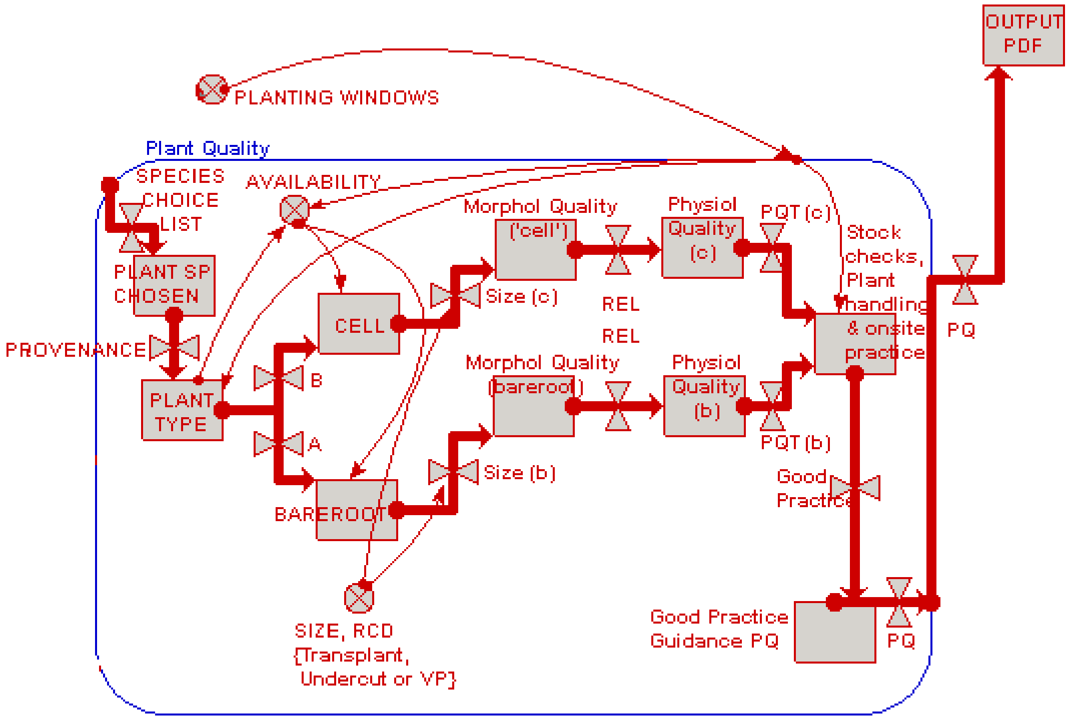

Figure 4. Detailed schematic representation of the plant quality components considered in output guidance. The user is able to view all currently available plant specifications (plant type, morphometrics and acceptable physiological 'limits'). Acceptable times for planting ('windows') are also tabulated.

The complex interactions between the modules are represented in the overall Simile model (Muetzelfeldt and Massheder, 2003). These interactions are many and varied, and whilst all possible interactions between compartments, variables, flows, and influences have been investigated, in the first instance, the primary drivers and major influences have been identified and used to ensure a system evolves which is guided by both operational requirement and existing knowledge.

The web-based user interface

Functional elements available in EMIS are accessed through a thin client web browser interface. EMIS is designed to take advantage of available graphical-user-interface, point-and-click technology to create an intuitive environment. Further development of the EMIS interface will include testing to ensure usability and allow bespoke development of supplementary training materials.

Development of an Integrated Treatment Prescription

On the opening screen, the user selects the EMIS programme, and is then instructed regarding the input parameter settings that are required to set-up the necessary background drivers. The user is then asked to input the first of these parameter settings in a 'site location' screen by choice of the appropriate 100km grid-square and input of a six-figure grid reference.

The user is then required to input site-based assessment information regarding the dominant soil type, chosen from a drop-down list of 14 FC soil groups, and their attendant soil types and phases (Kennedy, 2002). Underlying lithology is also chosen from a drop-down menu within EMIS: underlying solid lithology at 1:625000 scale is considered acceptable and can be obtained from British Geological Survey (BGS) maps or from the online BGS 'survey data portal'. The user is able to input information on peat depth and heather presence (*Calluna* / *Erica* sp.), by means of tick boxes, when appropriate. Where more accurate site information has not been collected, within the boundaries of the national forest estate, the Forestry Commission's sub-compartment database may provide sufficient soils information for quick and approximate site type evaluation. However, to meet the requirements of sustainable forestry, users will often require a more accurate site-based evaluation. The ESC models are interrogated and captured site values, for the six constraining factors, are then displayed within EMIS and the opportunity to amend one or many of them is afforded the user. The ESC models are then interrogated for species yield, and an initial predicted (potential) yield estimated from accumulated temperature is displayed. This value is then modified by the limiting ESC site factor and species suitability (and predicted yield class) are assessed against the continuous suitability functions that have been developed within ESC (Ray *et al.* 1998) for the ten conifer species and two birch species considered by EMIS (Figure 5). This process is entirely analogous to the ESC parameterisation, and operates by calling the relevant ESC models 'behind the scenes'.

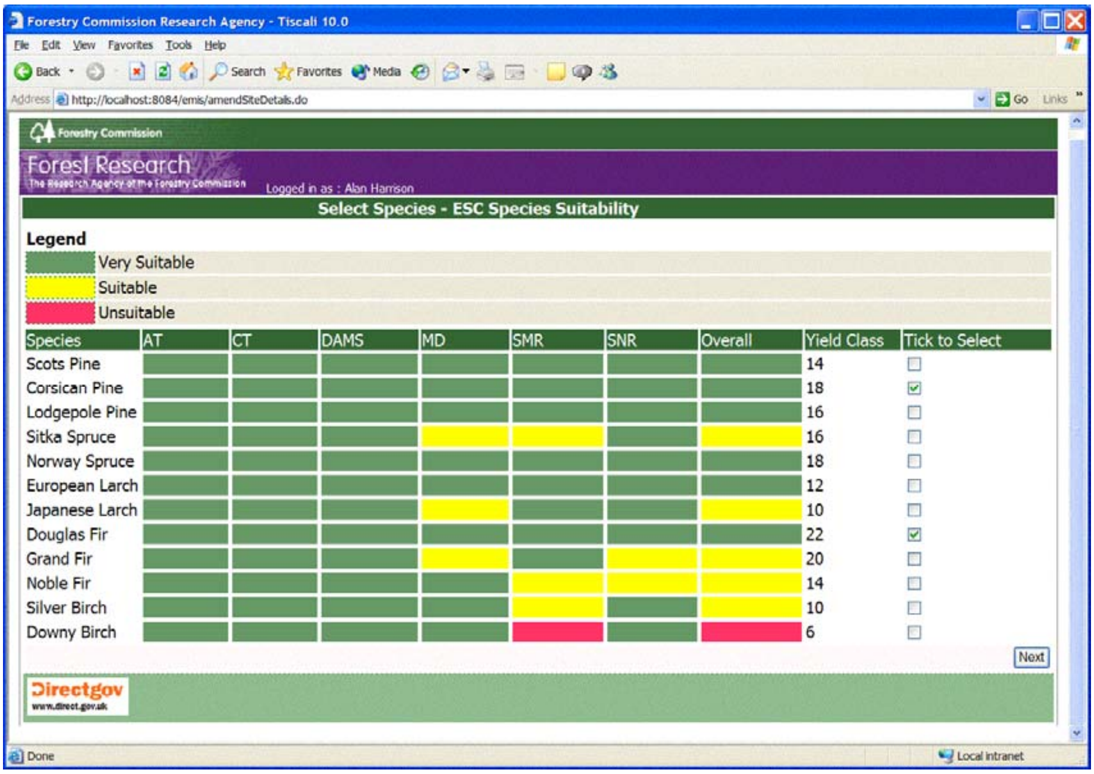

Figure 5. Screenshot of ESC-derived EMIS output for species suitability and predicted yield (productivity) class.

The user chooses, from the ESC derived suitability-yield table, species of particular interest for the site under consideration. EMIS then delivers relevant good practice guidance from the cultivation, plant quality and fertilisation modules via interrogation of the relevant XML file stores (Figure 6).

Output

The EMIS framework generates printable HTML (the web-browser interface) but also offers the user the option of capturing the output in pdf format, for any of the scenarios that have been run. The output includes all available good practice guidance for the species chosen.

Forestry Commission

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Input Data

OS GB Grid Reference	SE121214
Elevation (metres)	85.0

Soil Type	Lithology	Calluna Vulgaris Dominant
Brown Earths-Ericaceous Brown Earth	Lower Old Red Sandstone	No

AT	CT	DAMS	MD	SMR	SNR
1576.021	9.152233	9.989726	163.9453	Slightly Dry	Poor

Recommended Cultivation Practices

Key
A - Good practice for establishment.
B - Acceptable alternative for establishment.
C - Lesser alternative with some penalties.
Other - Other recommended establishment practices.

A	B	C	Other
Mounding	Patch scarification	Direct planting	Herbicide

Corsican Pine Guidelines - Fertiliser

Nitrogen	None required

Phosphate	Application Rate 60 kg/ha P = 450kg/ha Rock Phosphate	
Year Zero	Years 6 to 8	Years 12 to 16
Possible Benefit	Possible Benefit	No effect

Potassium	Application Rate 100 kg/ha K = 200kg/ha Muriate of Potash	
Year Zero	Years 6 to 8	Years 12 to 16
No effect	No effect	No effect

Corsican Pine Guidelines - Plant Specification - Cell

Type	Max REL	Height Range (cm)	RCD Range (mm)	Minimum Volume (cc)
1 y.o.	35	8-15	1-3	65
2 y.o. Rigipot	35	8-20	3-5	110
2 y.o. Jpp	35	8-20	3-5	65

Corsican Pine Guidelines - Plant Specification - Bareroot

Type	Max REL	Height Range (cm)	RCD Range (mm)	Minimum Volume (cc)
Small	30	8-12	4+	
Large	30	12+	4.5+	
X-large	30	20+	5+	

Corsican Pine Guidelines - Planting Windows

Key
A - Any stock suitable for planting.
D - Only use cold stored plants.
L - Only use cell stock.
N - Planting not recommended.
Planting outside recommended periods above can result in >10% losses.

Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
N	N	A	A	A	A	N	N	N	N	N	N	L	L	L	L	L	L	L	N	N	N	N	N

Figure 6. Screenshot of EMIS output, as HTML, after species selection by the user (the example shown is for Corsican pine).

Discussion

Implementation

During development linkages between EMIS modules, and among tools developed within the EMIS framework architecture, were considered within the Simile schema. EMIS alone has been developed with reference to approximately forty technical and scientific publications regarding site-species suitability and the attendant silvicultural management options.

EMIS employs open standards and technology as well good software engineering practice such as utilisation of design patterns and automated testing to offer extensibility and interoperability. To provide interoperability with GIS extensions written using .NET (e.g. ESRI Forester extension), some functionality was exposed as document-literal wrapped web services (Butek, 2003). Inclusion of this technology will enable EMIS to deliver decision support to both strategic and small-scale users, within the British forestry sector. Data relating to good practice guidelines for cultivation, plant quality and fertilisation are stored in extensible mark-up language (XML) files.

The climatic data is stored at 1 hectare resolution in an index organised table (using an Oracle 10g relational database), allowing query by UK Ordnance Survey six figure grid reference. To connect to the relational database from Java components, JDBC technology is used to pass SQL queries to the database via the Oracle thin driver. The conceptual design of the EMIS software is shown in Figure 7.

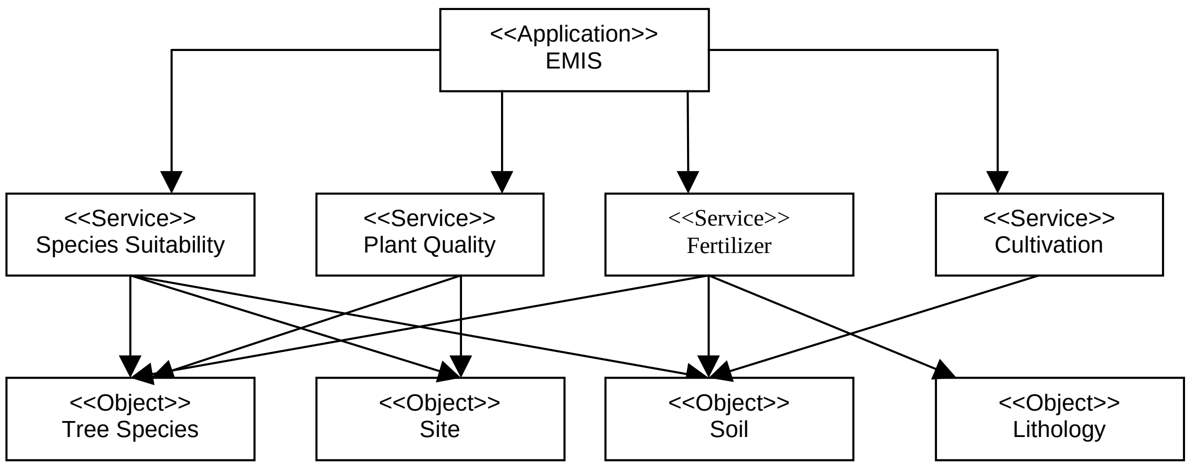

Figure 7. Schematic depiction of EMIS software architecture that illustrates how various models (services) and objects are composed to form the EMIS DSS tool. The service layer is exposed as document-literal wrapped web services for interoperability with other applications. While EMIS uses an Oracle database, the EMIS software framework is based on open source products and standards. The user interface was developed using XHTML and CSS to provide a clear separation between presentation and content. An open source Java Model View Controller framework known as Struts ensured that the Java server side components were developed in a standard manner while the Tiles plugin allowed the web pages to be constructed as discrete reusable elements. Java DSS model codes were unit tested using JUnit to provide extensive automated test coverage. Portable Document Format prescriptions were developed using a Java library known as iText. The XML library DOM4J was used to bring XML and XPATH capability to the Java code. To interoperate with GIS extensions web service (SOAP/WSDL) interfaces were created using Apache Axis tools, and prototype .NET clients created using the .NET SDK from Microsoft with C# as the implementation language. The EMIS framework can be deployed to any J2EE compliant container with minimal changes.

The object level associates key parameters with suitable entities, for instance SMR with soil, though there is no decision support functionality. At the intermediate level is the component model tier. This layer orchestrates the interactions between objects. Some models are available as services so applications such as Forester can invoke them. The top tier is the application layer. Currently we only have one application instance, namely EMIS. New DSS components can be introduced and access any of the existing models, objects and data.

Interoperability

A key to effective decision support for ecosystem management is the interoperability of a variety of systems. Interoperability is the ability of two or more components to co-operate by exchanging services and data with one another (Twery *et al.* 2000). Interoperable systems promote communication between components and facilitate the integration of legacy and newly developed modules. EMIS displays interoperability with the site classification DSS ESC. In the future linkage with the Hylobius Management Support System (HylobiusMSS: Moore, 2003) and Herbicide Advisor tool (Thomson and Willoughby, 2004) are planned. An example of the type of linkage required is the influence of time of felling, prior species and distance to nearest clearfell upon predicted hylobius (weevil) damage to newly established trees. Predicted incidence of damage may, therefore, affect appropriate seedling tree size class selection (Moore, 2003). As a consequence of this a pop-up window regarding plant size will alert the user of the HylobiusMSS tool or pre-select larger size classes if HylobiusMSS has already been run during the user session. Furthermore strategies, currently under development within Forest Research, to avoid peaks in *hylobius* populations may influence both cultivation and herbicide good practice advice. These interactions are captured in the EMIS Simile schema.

Operational scale

EMIS has been designed initially for use at the stand scale. Within the UK national forest estate a spatial planning tool has been developed (ForesterGIS^{TM}, Suarez *et al.* 2003) as an extension to ArcView-GIS platform (ESRI, Redlands, California). The development of ESC as an extension to ArcView-GIS has been demonstrated allowing the suitability of tree species to be analysed spatially, using the same six site factors (Clare and Ray, 2001). This ESC–GIS model derives climate factors from a digital elevation model, and calculates default values of soil quality (SMR and SNR) directly by data capture from digital soil maps. EMIS has therefore inherited this legacy and in recent trials remote calls from the Forester extension to EMIS modules have provided ‘proof-of-concept’ of the interoperability of these tools, thereby enabling a spatial landscape-scale delivery of good practice guidance to the forest planner in the future.

Future Developments

The non-spatial EMIS decision support tool described here is in an advanced stage of development, and following testing by research and field specialists will be released in 2006. It is then intended that the silvicultural management options will be critiqued against a set of sustainability criteria in order that the user may more clearly define the ecological and production elements that underpin forest management in the 21st Century. In addition a visualisation of the effects of such decisions upon establishment success and early growth is planned through integration with an initial growth model developed for the UK (McKay and Mason, 2001).

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