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How forest knowledge is used in forest planning – a case study

Malin Nilsson and Ljusk Ola Eriksson
Department of Forest Resource Management,
Swedish Agricultural University

Abstract
A company needs to know what it knows and how to take care of this knowledge. The way forest knowledge is handled within a forest company is a means to turn knowledge into a source of competitive advantage. Forest data and its information are important parts of the forest planning. The aim of this study is to describe and analyze how forest knowledge is used for timber production planning in a large forest owning company in Sweden. The study is conducted as a case study at Sveaskog - the largest forest owning company in Sweden. Concepts and theories from knowledge management are used. The study is limited to present the forest planning process from the long term felling strategy until the stands are transferred to the tract bank. Interviews with key persons within the organization were used to capture how forest knowledge is used. The information is presented through the four knowledge management processes: creation, storage-retrieving, transferring and applying. The planning system relies to a great extent on codified knowledge realized through a push strategy. It appears that the system works as a consistent whole.

Keywords: Forest planning, knowledge management, knowledge, information.

1. Introduction
The planning process of the forest owning company is customarily described as a sequence of three steps: strategic planning encompasses the entire forest in a long time perspective and focuses on sustainability and sets the frame for more short term planning; tactical planning is concerned with allocating harvest and silvicultural operations to stands in the next few years and where road construction may be an issue; operational planning schedules specified resources for harvesting and deliveries, often with a time frame of less than one year (Gunn 2007; Church 2007; Epstein et al. 2007). The major forest owning companies in Sweden, controlling about 40 % of the forested area, have followed this formula for decades. It is easy to

see the connection between planning step and forest information availability (Eriksson 2004; Söderholm 2002). You have the stand register, containing information on all stands and accompanied by a map, that supports all planning stages, a smaller sample of stands used for strategic planning, and a tract bank with data on stands for operational planning.

The planning procedures described above are essentially based on information retrieval techniques available in the 70's or earlier. Of new developments remote sensing techniques are of special interest. Air borne as well as space borne sensors offer, or are likely to soon offer, more detailed and accurate data than is normally available in the stand register today (see e.g. Lindberg et al. 2010). In case these or other techniques could motivate a redesign of the planning process it is important to understand the relation between forest information and the planning process as it is practiced today. In particular, since the forest information gathered and processed for strategic planning has implications throughout the planning process it seems pertinent to understand the decisions and processes that emanate from this stage.

In the beginning of the nineties, the knowledge management (KM) theory of the firm was developed, which held that a company´s performance is dependent on the knowledge it possesses and how this knowledge is used within the company (Conner and Prahalad 1996; Hansen, Nohria et al. 1999; Zack 1999; Eisenhardt and Martin 2000). A company needs to have a strategy for its KM, and since knowledge does not last long, the organization needs to be a learning organization to keep an advantage. Given the importance of information in forest planning it would be interesting to apply KM to this field.

The aim with this study is to describe and to analyze the forest planning of a large forest company in terms of KM. The study is limited to strategic and tactical planning and will only concern planning of harvests. Additionally, focus will be on KM associated with forest information and little or none on information from other sources. The study is based on interviews with functionaries of the largest forest owning company in Sweden.

2. Knowledge management

Knowledge can be viewed from different perspectives. Alavi and Leidner (2001) present five perspectives of knowledge where knowledge can be seen as: a state of mind, an object, a process, having access to information and as a capability. Knowledge as a state of mind means that a person wants to know more and wants to use the possessed knowledge, knowledge as an object can be manipulated and stored, knowledge as a process is when a person acts from what he/she knows, knowledge as access to information means that an organization must organize its knowledge to keep it accessible to those who need it, and knowledge as a capability refers to the capability to learn.

There is a relationship between data, information and knowledge where data is facts and raw numbers without meaning. When meaning is added to the facts data turns into information, and when information is put together and is personalized it turns into knowledge (Spender 1996; Alavi and Leidner 2001; Sensky 2002; Holsapple 2008).

Knowledge can be described along different dimensions or characteristics. These characteristics are, for example, tacit/explicit knowledge, individual/social knowledge and general/context-specific knowledge (Zack 1999; Alavi and Leidner 2001). Tacit knowledge is knowledge achieved that is not possible to put in words. Tacit knowledge within an individual is strongly connected to specific actions (Nonaka 1994). Explicit knowledge, on the other hand, can be written or told. A person can share this knowledge in words and action. Individual knowledge is the knowledge a person holds. This individual knowledge is the foundation for social knowledge. Social knowledge is the collective knowledge in a group: a result of all individual knowledge within the group. Both individual and social knowledge can be either tacit or explicit (Spender 1996). Knowledge can also be either general or situated context-specific knowledge (Zack 1999).

Knowledge within an organization is not static, it is constantly changing. Knowledge can be too old and it has to be replaced. It is important for an organization to be a learning organization and to keep track of the knowledge it possesses (Spender 1996). The organization also needs to ensure that knowledge is at the right place within the organization when needed. Four basic knowledge processes in the organization can be detected: creating, storage/retrieving, transferring and applying (Alavi and Leidner 2001).

- Knowledge creating – According to Nonaka (1994) the knowledge creating process within an organization is related to learning. The knowledge creating process within the organization is based upon both tacit and explicit knowledge. This process is described in four modes in the “Spiral of Organizational Knowledge Creation”. When people interact they create new tacit knowledge out of the tacit knowledge they already possess. This mode is called socialization. New explicit knowledge is created from tacit knowledge in a mode called externalization. New explicit knowledge can be created from explicit sources in the mode of combination. New tacit knowledge can be created based on existing explicit knowledge in the mode of internalization. These four modes are dependent on each other and are always interacting in knowledge creation process (Nonaka 1994).

- Knowledge storing and retrieving – To avoid loss of knowledge and to secure the access to knowledge and information, the organization needs a memory. Alavi and Leidner (2001) give five possible forms to organize the organizational memory which covers both tacit and explicit knowledge: written documents, information in data bases, codified human knowledge stored in expert systems, documented organizational procedures and processes and, finally, tacit knowledge acquired by individuals. Alavi and Leidner also present distinctions between individual and organizational memory. These distinctions implie that individual memory is possessed by a person's observations, experience and actions while organizational memory influences present organizational activities.
- Knowledge transferring – It is important to be able to transfer relevant knowledge possessed by one individual or a group to others. Transfer of knowledge can occur between individuals, from individuals to explicit sources, from individuals to groups, between groups, across groups and from the group to the whole organization. Based upon the basic elements of communication Gupta and Govindarajan (2000) have given elements needed for transfer of knowledge to occur: a message, a sender, a coding scheme, a channel, transmission through the channel, a decoding scheme, a receiver, and the assignment of meaning to the decoded message. In accordance with this Gupta and Govindarajan (2000) present five elements of knowledge flow: value of source unit´s knowledge stock;: motivational disposition of the source unit; existence and richness of transmission channels; motivational disposition of the target unit; and absorptive capacity of the target unit.
- Knowledge applying – "[T]he source of competitive advantage resides in the application of the knowledge rather than in the knowledge itself." (Alavi and Leidner 2001) In their study, Alavi and Leidner point out three processes, which initiate and keep the procedure of knowledge to organizational capability going. These three are: directives, organizational routines, and self-contained task teams. Both directives and routines within the organization are actions that create efficiency in the organization, while the self-contained tasks are groups that meet to share knowledge between different experts. These meetings are not efficient at first sight, but in the groups tacit knowledge is shared between the group members (Grant 1996).

When knowing how the knowledge processes exists within the organization a manager can apply a knowledge management strategy. Two types of strategy for knowledge management can be identified; the company can choose either a codification strategy (push strategy), where knowledge is coded and made accessible for the members of the organization to use when they need it, or the company can choose a personalization strategy (pull strategy), which is a web of persons holding important knowledge. When a member of the organization needs specific knowledge he or she needs to ask a person of this web to share the knowledge with him or her (Hansen et al. 1999).

3. Materials and methods

The study is performed as a case study at Sveaskog AB in Sweden. The company owns forests to a total area of 4, 3 million hectares, which is 15 % of the productive forest lands in Sweden. The holdings are distributed over the whole country with a majority in the northern part of Sweden. The company is geographically organized in five market areas and with a process organization consisting of three central processes: forest, production and market. The three processes are represented in each market area. The production process contains the sub processes for planning and harvesting. At each market area the production process is led by the production managers and the sub process of forest planning is led by planning managers. Each market area consists of approximately 3-5 harvesting manager areas. These harvesting manager areas are likewise divided into a number of harvesting planner areas. The central process of forest is led by the Vice President Forestry, and the sub process of planning is led by the Vice President Planning.

The study consists of interviews, thematically structured by interview guides (Kvale 1997). The intention was to find out how the interviewees related to the forest planning process. After reading the company’s process maps, interview guides were prepared in advance. These guides were systemized in three major themes: the plan, data used in the plans and how communication was performed around the plans. These themes were broken down into subcategories to guarantee coverage of the important parts of the major themes. The interviews were held with people employed by Sveaskog and these were selected for the interview by purposive sampling. The interviewees were persons in leading positions for the forest planning in the strategic and tactical steps: the Vice President Forestry, the Vice President Planning, the register specialist and planning managers from two market areas.

First the recorded interviews were processed into written form. Then these written interviews, together with the drawings from each interview, were transferred into mind maps, where focus was on information and knowledge. The mind maps were then joined and redrawn to create one mind map for the whole planning process covering the information and the knowledge management processes. From this emerged a new mind map. This last map has the focus upon the forest knowledge´s path through the organization from stand data collected for computing strategic plan alternatives to stands in the tract bank ready to be harvested. Finally, this last map formed the basis for the results presented here.

4. Results

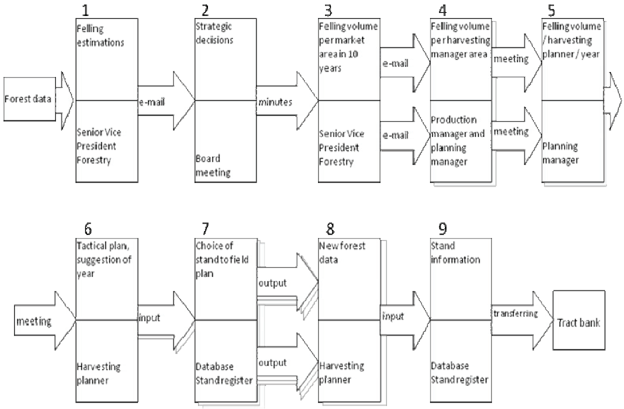

Figure 1. The path of forest knowledge through the forest planning organization.

Figure 1 follows the forest knowledge from the initial data collection for the long range plan through the organization of forest planning at the studied company to the tract bank. First, felling estimations are made for all the holdings of the company based on forest data captured in an inventory (step 1). An economic optimization is made based upon the inventory data together with other information, such as market information, assumptions about interest rates, the development of stands, prices and costs in the future, and other information about the holdings. This knowledge is used in the Forest Management Planning Package (FMPP; Jonsson et al. 1993) to create an optimization of the harvesting that extends over a period of more than 100 years. The felling estimations are presented at a board meeting (step 2) and the board makes a strategic decision of the felling volume for the coming ten years. This represents the new long term felling strategy. The felling strategy is announced to the Senior Vice President Forestry (step 3) who distributes this planned harvesting volume to the five market areas according to the figures given by the FMPP optimization. The decided volume is shared by e-mails and by meetings where the production staffs including planners are participating. This is made once per long term felling strategy and the volume distributed is for the whole ten year period.

The volume to cut per market area in the coming ten years is distributed on the harvesting manager areas (step 4). The distribution is made in meetings where the production manager at the market area, planning manager, the harvesting managers and the harvesting planners attend.

The volume to harvest during the coming ten years at each harvesting manager area is further distributed geographically on the harvesting planner areas in a meeting with the planning manager, the harvesting manager and the harvesting planner; the production manager can take part as well. This work is done once per strategic decision (step 5). Given the harvest volumes determined in step 5 for the harvesting planner area, decisions are made of which objects to harvest and, accordingly, inventory each year, i.e. a tactical plan covering 10 years is established (step 6). The tactical plan is stored as a part of the GIS-database; the stands are marked in the database to belong to four distinctive parts. First there is the tract bank, containing the objects prepared to be cut. This part should cover approximately the volume of 1.5 years harvesting. In the next part of the tactical plan are the objects ready to be inventoried. This covers a volume equivalent to approximately three years. These two parts is consequently covering the first 4.5-5 years. The rest of the tactical plan consists of objects to be consulted later on and is part of the plan where forest management is concerned in terms of, for example, fertilization. The tactical plan is repeatedly remade every year, to always be valid.

When the tactical plan is set for the harvesting planner area, the harvesting planner goes out into the forest to make an inventory of each stand (step 7). The stands to be inventoried are selected from the GIS-database (stand register).

The inventory data is added to previous data for the stand in the stand register in the GIS-database (step 8). The stand and its data are then exported to another database, which contains the tract bank (step 9), where it is available to a harvest manager to use in the operational planning.

5. Discussion

KM will here be studied from the perspective that the entire forest planning process is a realization of the KM process of applying (Alavi and Leidner 2001). That is, all the steps of the process are considered as a whole as an application process and will not be divided further, in contrast to the KM processes of creation, storing/retrieval and transferring. Before establishing the nature of the KM application process knowledge and KM processes will be characterized.

To characterize the kind of knowledge managed in the planning process, the following seems to hold:

- Knowledge can basically appear as tacit or explicit knowledge. It is obvious that the planning process handles large amounts of knowledge in explicit form. There also appears to be tacit knowledge; for instance, “gut feeling” is referred to when developing the long range plan proposals.
- The basis for social knowledge is individual knowledge. One aspect of this is that people need to meet to be able to share their knowledge and to create social knowledge (Nonaka 1994). Social knowledge should have a chance to develop in the meetings that occur in the planning process. Still, these meetings do normally not take place more than once each five-six years. There seems to be a common understanding of the planning process as such, its purpose and the routines it entails; this can also be seen as a form of social knowledge.

To characterize the KM processes, the following seems to hold:

- The KM process of creation is primarily designed to create and manage explicit knowledge. There are few instances where the planning process has built in, or where there are provisions for, observation or discussions to acquire tacit knowledge.
- As regards the KM process of storage and retrieval there is a designated system for where you will find knowledge and what knowledge you will find there. There is nothing that indicates that people in the line of the planning process are unaware of where and what they should report or that they are questioning where they could find the knowledge they need.
- As with storing/retrieval there is a well defined system for how and when transferring should be conducted. It is a top-down planning process in that knowledge in each step goes from one level of the organization to the next lower level. Valued in terms of the five elements of knowledge flow presented by Gupta and Govindarajan (2000) – value of source unit´s knowledge stock, motivational disposition of the source unit, existence and richness of transmission channels, motivational disposition of the target unit, and absorptive capacity of the target unit – there is nothing that contradicts the impression that these requirements are fulfilled to a reasonable degree.

The above indicates that the KM strategy is a push strategy with few elements of pull. Knowledge is to a large degree coded and made available to those needing it. The push strategy is implemented through directives and routines. Directives are floating through from the board room down to the harvest area and certain procedures are followed at each step.

Is this then a good application of KM to achieve a better competitive position? Or, to put it more precisely, are there possible weaknesses in the way the planning process is designed from a KM point of view?

- Transferring knowledge in several steps takes form of documents or database management. At a few steps there is participation of several functionaries in meetings which will consume valuable time. However, just distributing directives could reduce the motivational disposition of the receivers and a loss of an opportunity to enhance their absorptive capacity (Gupta and Govindarajan 2000).
- Given the centralized nature of the flow of knowledge, without built-in feed-back loops, is there a risk that strategic decisions are "diluted" along the road, that the harvest plan input into the tract bank will not actually match the long range plan? It is also true that the aspects that guide the FMPP solutions (Jonsson et al. 1993) disregard constraints and demands that need to attend to when doing the tactical plan. However, the risks for inconsistencies between plans should not be exaggerated, at least not under boreal forest conditions (Andersson and Eriksson 2007).
- The planning could give the impression of being inflexible; the long term plan normally lasts for five to six years. There are, however, good arguments for the long intervals. From an efficiency point of view, it is costly to develop the plans, and to implement the plans in the organization. Capacity variations of harvesting resources can also be high. Also, the relative stability of the business, the slow growth processes of the forest, and the long experience of how the planning process works, are indications that rather long cycles of planning could work.
- Forest data is expensive to obtain and the core theme of forest inventory research is to attain a certain precision at minimum cost. From that point of view it is noticeable that there are three instances of forest data: the all encompassing stand register, the data that is collected for the tract bank, and the data obtained for projections with FMPP. Let us focus on the relation between stand register and FMPP stands. One reason for the FMPP sample is that the stand register is not considered reliable enough. However, the stratification of the FMPP sample hinges on the quality of the stand register. If the register is biased this will translate into a bias of the representative areas of the strata. So, there seems to be a dilemma: either the register is good enough and could be used as it is, or it is not good enough and it fails as support stratification.

There are many ways of dividing the KM process into steps for analysis. The focus put here on forest information as defining element of the KM process could have contributed to the impression that the planning process on the whole appears to be orderly and consistent. Thus, we will necessarily find instances where knowledge is stored and where it is retrieved etc. By interviewing persons part of the planning process you capture what they say they do, not what they actually do. The data is not as deep as if observations of the actual planning had been done together with the interviews. Another consequence of the study methodology is that it was not possible to study the quality of data-information-knowledge; that would require quite other methods of study.

This study represents a first try to analyze the forest planning of large forest owners with a sophisticated planning system with KM as frame of reference. It reveals the complexity of getting a planning system working: you need to design components that are consistent in terms of messages, senders, channels, receivers, and to ensure that the quality is adequate along the line. Obviously, new information sources do not automatically translate into better planning.

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Appraising the economic impact of tree diseases in Britain: several shots in the dark, and possibly also in the wrong ball-park?

Colin Price
School of the Environment, Natural Resources and Geography,
Bangor University

Abstract
Tree diseases are becoming more problematic with changing circumstances. Plant pathologists are reluctant to make predictions of their likely spread and severity. Forest economists are thus thrown back on making speculations about these matters and trying to induce a response about their reasonableness. Impact on timber production and carbon effects may be met by treatment, by accepting mortality or loss of increment, by changing species, and/or by abandoning silviculture altogether, each with its costs and opportunity costs. Loss of environmental services is an additional possible outcome. Losses from landscapes seem particularly important; effects on hydrology, air conditioning and biodiversity less so.

Keywords: tree diseases, Britain, cost–benefit analysis, timber, carbon, landscape

1. Introduction

Increasing movement of plant material about the world, and new susceptibility due to climate change, have dramatically increased the incidence of tree diseases in Great Britain, and indeed elsewhere in Europe. Pathogens which have long been known as minor irritations have become the cause of major outbreaks. New pathogens are being discovered which threaten whole suites of species.

Even among non-economists, the question eventually arises: what are the economic costs of all this? For a recent conference on tree diseases, a request was made to address this question (Price, 2010). In answering, I found myself revisiting the territory of almost all environmental and forestry economics, and effectively re-running a cost–benefit analysis of trees in Great Britain. (Because Forestry Commission statistics are collected for Great Britain, not Northern Ireland, figures are generally not presented for the entire United Kingdom.)

The major problem lay in obtaining information on the underlying biological and physical realities. Plant pathologists are reluctant to make predictions of the likely spread and severity of new, or newly important, pathogens. In these circumstances forest economists are thrown back on making speculations, about these matters, and about the responses of forester managers. Sometimes it seemed that the best available approach was to assume that all states of nature were equally likely, unless a different probability was offered. Alternatively, figures were often suggested as no more than "shots in the dark". This sometimes provoked the biological experts to come up with a figure that they "preferred".

However, this paper focuses on the evaluative techniques required. After a note on general procedure, it considers in sequence the cost of tree diseases through reduced timber production and carbon sequestration; reduced landscape quality; and the compromised value of environmental services. Although a summary figure is given, the speculative nature of the physical data means that this should be considered as the roughest of estimates, possibly of the right order of magnitude, but not more accurate than that.

2. The evaluative framework

First, the general framework for evaluation should be established. The costs of crop establishment were supplied by the British Forestry Commission. Timber prices in Britain have been low since 1995, as a result firstly of an over-valued pound sterling, secondly of the recent recession; but an assumption was made that, during the life of the crops considered, the prices prevailing through most of the second half of the twentieth century would be restored. Net present values were calculated using the 3% discount rate advocated by the UK Treasury (undated) for forestry time scales. They were converted to annual equivalents, as such figures seemed easier to grasp.

A young and idealistic forest economist would base calculations of the cost of tree diseases on the difference of NPV between the nation's tree resources managed optimally in the absence of diseases, and in the presence of tree diseases. An elderly and sceptical one would compare NPVs based on what forest managers are actually likely to do in response to diseases and what the change to a with-disease situation entails: this approach has been adopted.

Management costs are ignored, on the grounds that they will not differ much between with- and without-disease situations. Crops are grown on their optimal rotation, and, unless disease makes this risky, there will be a perpetual succession of crops of the same species and productivity. It is customary in economic assessments of British commercial forestry to reduce figures to allow for unproductive areas within stands (rocky or swampy patches, or lines occupied by roads or firebreaks): hence a deduction of 10% has been made from what would result from multiplying per hectare figures by the number of hectares affected.

3. Timber production and carbon sequestration: red band needle blight

Because carbon sequestration is closely tied to the timber production cycle, the two effects are treated together. Carbon fluxes (sequestration and volatilisation) are priced at £80 *per tonne of carbon* (slightly revalued from Department of Trade and Industry (2003)). This is close to the recent recommended figure of £21 *per tonne of* CO_2 (Department of Energy and Climate Change, 2009). It is assumed that marginal change of available small dimension material will result in equal change in biomass combustion, with displacement of fossil fuel burning. At present it is unclear what the marginal effects of changed availability of large dimension material would be. For illustrative purposes, it is further assumed that, for each tonne of carbon incorporated in such material, combustion of 0.5 tonnes of carbon in fossil fuels is saved through displacement of materials such as steel and concrete.

For commercial forests, the current focal disease problem is that caused by *Dothistroma pini* (Brown and Webber, 2008). Known as a problem in nurseries for several decades, it has lately affected forests to such an extent, that a moratorium has been declared by the Forestry Commission on planting Corsican pine (*Pinus niger* var. *laricio*) and lodgepole pine (*Pinus contorta*). Other exotic pines are also affected badly: it has been particularly serious on *Pinus radiata* in New Zealand (but not Sjælland) and East Africa. It has been reported in many European countries. Fortunately, although it infects Scots pine (*Pinus sylvestris*), this does not seem to affect its increment much.

Spraying with copper compounds has proved effective in some countries, but environmental constraints have blocked this treatment's being used in Britain.

4. Lodgepole pine

The mean productivity of this species in Britain is about 8 m^3 ha^{-1} $year^{-1}$. It is not normally thinned. Wind often constrains the rotation, which for the following calculations is taken to be 56 years. The without-disease-in-Britain baseline assumes that at the end of this normal rotation 50% of the crop is replaced by Sitka spruce (*Picea sitchensis*), which generally grows faster than lodgepole pine, especially if one rotation of the latter species has partly drained the site. Replanting of lodgepole pine is undertaken on 25% of the area, and the remainder undergoes "habitat restoration" (to an unproductive species mix or to open moorland), with no subsequent commercial value.

Disease is taken to affect all age classes, with equal probability. Crop death has been the result of heavy infections. It is assumed that once again 50% of area is replanted with Sitka spruce, and that all the remainder undergoes habitat restoration.

Take as an example a crop in the age class 26-31 years, with NPVs for cost, timber and carbon calculated according to the models of Price and Willis (1993).

Table 1: Costing mortality of lodgepole pine

NPV of one disease-free rotation	£1353	
… compounded to present age	$\times 1.03^{28.5}$	= £3141
plus NPV of successor mix	£1450	
… discounted to present age	$\div 1.03^{(56-28.5)}$	+ £643
		= £3784
NPV on disease-curtailed rotation	£–1603	
… compounded to present age	$\times 1.03^{28.5}$	= £–3722
plus NPV of successor mix (immediate)	+ £1034	= £–2688
Without-disease less with-disease	£3784 – (£–2688)	= £6471

This cost of premature termination of rotation and perpetual replacement with a less valuable crop mix is repeated for all age classes and the results for each age class are multiplied by the area of productive crops in that class (Forestry Commission, 2003) and the proportion of crop estimated to be killed. Pending a new inventory of woodland and trees, the area statistics are slightly out-of-date, but there has been relatively little planting of lodgepole pine in the past decade.

The remaining areas of the crop are rolled forwards by five years, and the exercise is repeated, with the rate of infection increasing at 10% per year. The process continues until all lodgepole pine has been replaced, following either infection, or achievement of optimal rotation.

Although the disease eventually spreads to most of the remaining area of the species, by that time most of that is close to optimal rotation anyway, so the overall cost is not very large: a total reduction in NPV of £9 297 000, the annual equivalent being £279 000.

5. Corsican pine

So far, such mortality has been infrequent on Corsican pine, but a much greater area has been affected, 70% of the currently planted area. A major loss of increment has been found, in proportion to the severity of infection: with moderate infection (applying to 80% of the crop within infected areas), approximate mean productivity drops from 14 to 10 $m^3\ ha^{-1}\ year^{-1}$, and with severe infection (10% of the crop) to 6 $m^3\ ha^{-1}\ year^{-1}$.

Although some variation in resistance has been found in susceptible pine species, indicative calculations suggest that a tree breeding programme would not be economical. For comparison, the cost of the UK's breeding programme for the most common species, Sitka spruce, can be examined.

In the early 1990s, the programme was said to have cost £1½ million per year over 30 years, which gives a value compounded to the end of the programme of

$$\frac{£1.5\text{M} \times \left(1 - \dfrac{1}{1.03^{30}}\right)}{0.03} \times 1.03^{30} = £71.36\,\text{million at 3\% interest}$$

Assume that a similar programme cost would be involved for Corsican pine. Initiated now, and with costs indexed to 2010 prices, the programme would cost £130.3 million by 2040.

Substantial returns from this programme start in 40 further years (on average, allowing for some thinning and some early felling), as a result of improved yield from the first crop of improved Corsican pine, and remain at £*X* million per year thereafter, as succeeding age-classes are felled.

The value discounted to present of £*X* million every year from 40 in perpetuity is

$$\frac{£X\,\text{million}}{0.03} \times \frac{1}{1.03^{40}}$$

which must = £130.3 million in order to break even.

whence

$$£X\ \text{million} = £\,130.3\text{million} \times 0.03 \times 1.03^{40} \approx £12.76\ \text{million}$$

With 47 000 ha of Corsican pine felled on a short 47-year rotation at 1000 ha per year, this requires a *gain* of £12 760 per hectare felled. With an average price £25/m^3, this would require

$$£12\,760 \div £25 \div 47 = 10.86\ \text{m}^3\,\text{ha}^{-1}\ \text{year}^{-1}$$

of restored production per year. This is well beyond the differential of productivity between Corsican pine – supposing it to be completely resistant to infection – and the probable replacement crops, though no superior carbon fixing values have been included in this calculation.

The actual managerial response to infection has generally been to maintain thinning, despite some disease-induced reduction of canopy density, so as to improve air circulation; and to maintain planned rotations to avoid distorting planned timber supply. At the end of the planned rotation replanting will be with less susceptible species: speculatively, 25% of area with Douglas fir (*Pseudotsuga menziesii*), 25% with Japanese or hybrid larch (*Larix kaempferi/×eurolepis*) and 50% with Scots pine (*Pinus sylvestris*).

Lost increment can be modelled by maintaining the thinning regime laid down in Edwards and Christie (1981), but increasing the time interval between thinning interventions, in inverse proportion to the loss of productivity. Thus, for example, if moderate infection occurs at 27 years, a normal thinning takes place then, but the next one is delayed from 32 years to 27 + 5 × 14/10 = 34 years. Final felling takes place at 57 years, the available revenue being interpolated from a financial yield model stretched out over time from the age of infection. The time taken to reach given total volume production is shown in figure 1, which also shows the reduced volume available on a 57-year rotation.

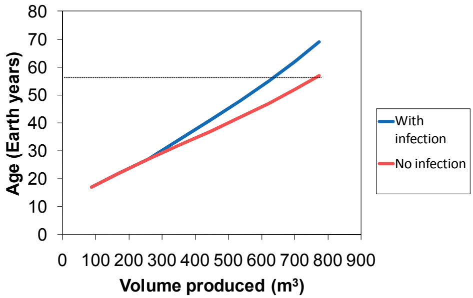

Figure 1: Effect of moderate infection at age 27 on volume production

This expedient of stretching the time scale avoids the need to create complicated single-tree growth models. The result for this age class is as follows:

Table 2: Costing disease on a hectare of Corsican pine

NPV of perpetual disease-free rotations	£8348	
… compounded to present age	$\times 1.03^{27}$	= £18 543
NPV of one disease-slowed rotation	£5226	
… compounded to present age	$\times 1.03^{27}$	= £11 608
Mean NPV of successor mix	£5121	
… discounted to present age	$\div 1.03^{(57-27)}$	= £2 110
Without-disease less with-disease	£18 543 – (£11 608 + £2 110)	= £4 825

As with lodgepole pine, the calculations are repeated for all age classes, and the per hectare figures multiplied by total area in each age class. Ten-year age classes are used, to accord with availability of decadal planting figures. Infection is assumed to progress linearly from the current 70% to affect the entire 47 000 hectares by the end of one rotation.

The total reduction in NPV is £166 325 000, of which the annual equivalent is £4 990 000.

6. Forgone expansion opportunities

Recent projections suggest that within decades the climate of southern Britain may resemble that of south-west France. In that case, Corsican pine might have become the most productive species over as much as 5% of Britain's forest area (Broadmeadow, 2002). Unless some efficacious treatment is identified, that possibility is now barred. The assumption is made that, without the disease, expansion to 5% of forest area would have occurred, Corsican pine replacing the mix of species which is now being replanted in its place. The annual equivalent of the forgone opportunity is a loss of £3 306 000.

7. Other diseases and timber/carbon effects

Sudden oak death, the result of infection by *Phytophthora ramorum/kernoviae*, does not actually cause the death of native British oaks, but does affect other species. It is a recent phenomenon in Britain, and pathological symptoms on timber species have only lately been noted, on Japanese larch. Premature sanitation felling has been undertaken. The economic effects are parallel to those shown above for lodgepole pine, except that a constant annual loss of 50 hectares has been assumed, spread equally across age classes; and replacement of Japanese larch having mean productivity of 10 m^3 ha^{-1} $year^{-1}$ is by a crop of equal productivity but zero susceptibility.

Figure 2 shows the profile of loss as older age classes are affected. At the outset of the rotation, the only cost is that of regenerating the crop again. Later, the forgone value of the crop's increment up to its optimal rotation is added to that. However, as the optimal rotation is approached, it becomes a matter almost of economic indifference whether the crop is felled according to plan or as a result of late-life infection.

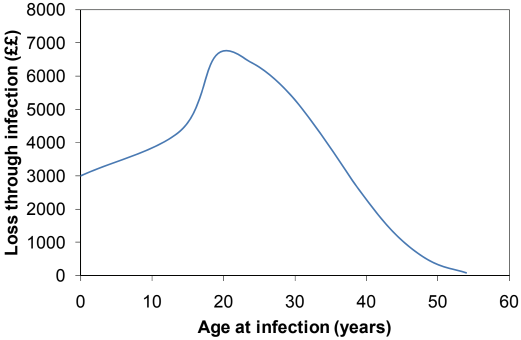

Figure 2: Effect of crop age on NPV loss through premature felling and replacement

The annual equivalent of the summed losses at this scale is £183 000. There is, however, a possibility that enough species might prove susceptible, over a sufficient area, that ten times the current area might be affected annually. Alternatively, it has been projected that a control programme for the source plants of infection (mostly *Rhododendron spp.*) could be implemented, with an annual equivalent cost of £225 000 (Defra, 2008). The mean of all the candidate figures is an annual equivalent of £746 000.

Acute oak decline, caused by an unidentified bacterium, is even less understood. Native oaks (*Quercus robur* and *Quercus Petrea*) over the age of 40 have suffered stem bleeding and rapid death.

A speculative account of economic loss is given once again as the cost of premature felling, and replacement by a species of equal profitability. Oak of productivity 6 m^3 ha^{-1} $year^{-1}$ is taken as representative, for which an economic rotation of 100 years is approximately optimal. The large area of oak already older than this is considered to be grown for non-commercial purposes, effects on which are dealt with later. Commercially, felling such trees incurs no loss.

Although the condition is presently localised, a pessimistic scenario sees it as capable of spreading to and killing the entire native oak population over a rotation. Thus in each succeeding 5-year period, 10% of the remaining crop in susceptible age classes is killed, and age classes reaching their optimal rotation without attack are replaced anyway. Over 100 years, all commercially grown oak disappears. The annual equivalent cost is £4 440 000. Figure 3 shows the profile of attrition of the species' area.

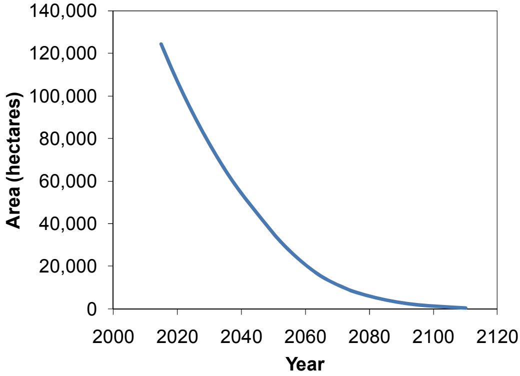

Figure 3: Loss of oak area to acute oak decline – pessimistic scenario

Such an outcome, for England's national tree (it is important in Wales too), can scarcely be contemplated, and it is certain that strenuous efforts would be made to avert it. But these would be expensive too. Because so little is known about the disease, an illustrative 25% probability of the above scenario's eventuating is assigned, giving a mean expected annual cost of £1 110 000.

8. Effects on landscape

At present two further diseases are of particular concern for their landscape effect in Britain. Common alder (*Alnus glutinosa*) has become susceptible to the recently identified *Phytophthora alni*, with around 20% of trees killed according to one study (Webber et al., 2004). Bleeding canker caused by *Pseudomonas syringae* has infected 50% of horse chestnuts (*Aesculus hippocastaneum*) and caused the death of many (Forestry Commission Plant Health Service, 2008). Both species are important for aesthetic purposes, alder in riverine settings, and horse chestnut as a parkland and street tree. These add to the earlier disappearance of nearly all English elms (*Ulmus procera*) from the rural landscape as a result of Dutch elm disease (*Ophiostoma novo-ulmi*) – and it is possible that oaks will follow them. In immediately past and forthcoming decades, it would be reasonable to assume a loss of 10% of amenity trees to these and other diseases.

Numerous approaches have been adopted to valuing tree losses:

> Costs willingly undertaken to protect elms against Dutch elm disease imply that individual trees were valued at not less than £1350 (Price, 2007). Helliwell's scheme (1967), based

on expert judgement of key tree characteristics, has attributed values between £2500 and £10 600 to a horse chestnut in Bangor. Curtailment of longevity by bleeding canker could halve such values, and decline in crown condition reduce them by two-thirds. Stated public willingness to pay to avert poor crown condition resulting from acid rain was $2 per person (Crocker, 1985); and similar valuations are now applied to the effects of sudden oak death (Mourato, 2010). A visually prominent group of churchyard weeping elms in Newcastle upon Tyne was valued at £149 000 relative to a scenario in which they succumbed without replacement (Cobham Resource Consultants and Price, 1991); the valuation being derived from urban house price differentials, where houses commanded views of different quality. (Price, 2010)

The following estimate of the effect of tree diseases on rural landscape values is based on a study of travel costs to landscapes of different quality (Bergin and Price, 1994); an assessment of the landscapes' quality on a widely tested aesthetic scale (Thomas and Price, 1999); and the record of visits to the British countryside (Anon, 2004).

Any replanted tree takes time, decades usually, to achieve the full aesthetic effect of a mature tree. Nevertheless, replanting can and will to an extent mitigate the effect of loss, and probably at a modest cost. On these grounds an illustrative mitigation factor of 0.5 has been used, for this and other calculations.

Table 3: Effect on rural landscape of disease-related tree loss

Visits to countryside	1,262,000,000
Value per landscape point £(1993)	× 0.44
Inflation factor to 2010	× 1.56
Mean contribution by trees (points)	× 2.25
Proportional loss of trees due to disease	× 0.1
Mitigation of loss	× 0.5
Total effect	£97,452,000

An argument could be made, that it is metaphysical to ascribe a cost to trees which are no longer in the landscape, as is the case with English elm. Yet lost potential contribution to the landscape is as relevant to the without-disease versus with-disease comparison, as is lost potential timber production.

There is a further argument, that the loss of a particular tree species to a particular disease is of little consequence, because there are other species that can take its place. This overlooks the precise aesthetic qualities of a given species, and the lack of exact substitutes, for example, for English elm.

For something barely deemed a species, all that trouble
could not be explained, except by *seeing* why
this tree was unlike other elms less vulnerable,
but less stately set against an English sky.
Black poplar's frivolous leaves and birch's light-twigged grace meant
that they lacked required solemnity; nor yet
were lithe-limbed lime or cloud-crowned ash a fit replacement
for that heavy, high and hanging silhouette.

The unassuming lowland landscape lost an icon,
little apprehended till it disappeared.
It was the place's genius – one cannot see the like on
canvasses that nations elsewhere engineered.
And, though the sun-stroked sheep and cattle still assemble
in the lesser shade of other remnant trees
and barley prairies shimmer, hedgerow hawthorns tremble,
they want *that* shape to share the shiver of the breeze. (Price, 2008)

So also it could also be said for the riverine alders, and for the parkland horse chestnuts …

That Christmas was the first to show
its real story starting to unfold:
entwining sacred oratorio
with nature's gifts, and gifts from long ago
the incense-gorse, myrrh-mindful herbs and glow
of chestnut leaves turned gold.

… and for all those other tree species that, whether we are conscious of it or not, have wound their way into nations' cultures. Perhaps it is not so strange that we need poetic language to unpack the nature of substitutability and uniqueness.

Whether landscape values should be reduced in proportion to loss of trees is a more serious matter of debate. Economists might argue that tree losses should be treated as marginal, less significant than the "average" effect that is calculated above. But losses due to disease cannot be so marginalised within landscapes. They may strike randomly at the most significant trees; trees are likely to be attacked in groups, all of whose members are lost. In any case, the base of the above evaluation might be termed a “sum of marginals”: it is constructed by summation of the effects of removing trees from individual landscapes *seriatim* rather than by visualising a national landscape from which all trees have been lost.

An equivalent assessment for urban trees has been based on the illustrative assessment (it is no more than that) in Cobham Resource Consultants and Price (1991).

Table 4: Effect on urban landscape of disease-related tree loss

1990 capital value (100 year horizon)	£62 500 000 000
Inflation factor 1990-2010	× 1.71
Spread over 100 years (not discounted)	× 0.01
% loss	× 0.10
Mitigation	× 0.50
Annual equivalent	= £33 681 057

To this may be added an estimated annual arboricultural expenditure of £12 500 000 to mitigate the effects of disease on urban trees – which seems to be at a reasonable level, given the annual equivalent value being defended, shown in table 4.

9. Other effects on ecosystem services

While trees offer many environmental services – and some disservices – the treatment below is confined to the effects on hydrology, microclimate and biodiversity, brought about by a net loss of 5% of trees attributed to disease. Effects on atmospheric CO_2, it will be recalled, have already been incorporated.

Trees have been ascribed many beneficial hydrological effects, not always on a sound scientific basis. At present in Britain the focus is on the capacity to mitigate floods, from whose effects …

> … the Environment Agency gives insurable losses in bad years (one in ten?) as £3000 million. But with climate change Stern (2006) indicates that £4000 million might become normal for annual losses. The Flood Risk Management Research Consortium (2008) surmises that optimally located tree planting might reduce extreme flooding by 5%, or 36% with complete forest cover. Taking all permutations of the above, combined with 5% net loss of tree cover due to disease, gives a highly speculative cost of £2.65 million. (Price, 2010)

Of the negative effects, loss of supply capacity due to excess evaporation is locally important on hydroelectric and abstraction catchments, and is mostly due to conifers on hydroelectric catchments in Scotland. The following calculations are built on the work of Barrow et al. (1986) and Price (1999a).

Table 5: Valuing savings of hydroelectricity losses

Lost energy per ha per rotation (for a 100 m generating head)	500 GJ	
Convert to kWh	× 1000/3.6	= 138 889 kWh
Per year of 50-year rotation	÷ 50	= 2 778 kWh
Price per kWh (⇨ annual loss)	× £0.14	= £389
Scotland's conifer area (ha)	× 900 000	
% on catchment	× 0.1	
Total Scotland loss		£35 000 000
Reduction due to disease loss	× 0.05	= £1 750 000

Similarly, work for South-West Region (Price, 2009) estimated the cost of increasing reservoir capacity to compensate for evaporative losses, based on the procedure developed by Collet (1970). As a working approximation this can be scaled up to the area of Britain, which is ten times that of the South-West Region.

Table 6: Overall water gains through tree disease

Extra costs of water supply (South-West Region)		£1 400 000
Scaled up to Great Britain	× 10	=£14 000 000
Reduction of effect due to disease	× 0.05	£700 000
Plus reduction of hydroelectricity losses		+ £1 750 000
Total gains		£2 450 000

Considering the completely different origins of the figures, the closeness of match between disease-attributable gains and losses is extraordinary. On these grounds, and given the highly speculative nature of the extrapolations made, it is not considered appropriate to include any net value for hydrological effects. I have seen no figures that challenge this conclusion.

With climate change, the role of trees in mitigating microclimate, particularly extremes of temperature in urban areas, will become increasingly important. The energy saving is based on the work of McPherson et al. (1999) in California; the estimated number of urban trees, on a variety of sources. Several speculative adjustments are made: for the spatial arrangement of Britain's urban trees as groups more than as street trees; for the less extreme climate (although Britain's is getting closer to California's); for a less extravagant culture of energy use; for efficiency gains.

Table 7: Value of air conditioning services

kWh saved per tree per year	122
Number of urban trees	× 100 000 000
Price per kWh	× £0.14
Spatial configuration factor	× 0.5
Climate factor	× 0.5
Cultural factor	× 0.5
Energy saving gain	× 0.5
% loss	× 0.10
Mitigation	× 0.50
Annual cost	= £5 338 000

Removing even one of the adjustments, which seems appropriate on the whole, brings the value to £10 676 000.

Biodiversity is potentially the most intractable problem in valuing ecosystem services. However, the effects of tree diseases are not altogether adverse (Kirby, 2010). For example, respondents in a choice experiment (Nielsen et al., 2007) expressed a certain willingness to pay for a token amount of dead wood within the mix of forest features. Moreover, after finding a willingness to pay for conservation of a small corner of north-east Scotland equivalent to 10% of the UK's GNP (Price, 1999b), I have been sceptical about such figures. On these grounds, no cash value is attributed for the cost of tree diseases to biodiversity. It may be that if acute oak decline severely reduces oak populations this provisional conclusion would have to be revisited.

10. Conclusion

The summary table 8 below for losses is revealing. It is notable that, while the losses of timber production and carbon values are considerable, the environmental losses collectively, particularly the landscape effects, are about an order of magnitude greater. This should not be altogether surprising, for a densely populated island such as Great Britain, one also where home timber production is a small proportion of total consumption. If one were to scale down the environmental effects in proportion to population, and to scale up the timber and carbon effects in proportion to production, then one would have the conditions of Finland, Norway and Sweden, and the orders of magnitude would be reversed. Denmark's figures would more resemble Britain's.

Table 8: Summary of annual losses due to tree diseases

Timber and carbon	
Red band needle blight on Corsican pine	£4 990 000
Lost opportunities for expanding Corsican pine	£3 306 000
Red band needle blight on lodgepole pine	£279 000
Sudden oak death	£746 000
Acute oak decline	£1 110 000
"Nasty surprise on Sitka spruce"	£6 986 000
Environmental services	
Rural landscape	£97 452 000
Urban landscape	£33 681 000
Water	- -
Air conditioning	£10 676 000
Biodiversity conservation	- -
Arboricultural expenditure	£12 500 000
Total	£171 726 000

Finally, it should be emphasised that these costs were compiled under pressure to provide at least some kind of figure. Few of the data can be considered accurate, and some are based on no more than guesswork. The term "horse and rabbit stew" was often used in relation to one well-known cost–benefit analysis in the UK, that for the Third London Airport (Adams, 1971). The ingredients for the recipe include one horse and one rabbit. It could be said that the rabbit represents the core of firmly-based knowledge underlying the above estimate: the horse represents the margin of error.

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