# The anatomy of a woodland: Stand profile diagrams as an aid to problem-based learning in undergraduate forestry education

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**ABSTRACT**

Forestry education is poorly served with published examples of teaching and learning methods that enable students to engage actively with the discipline. This is not the case in other professional disciplines, such as the biology, medicine and engineering, where sub-disciplines have emerged and are devoted to the development and evaluation of optimum learning strategies. In this paper we present a short field-based practical that introduces forestry students to forest stand dynamics, applied forest ecology and silviculture. Students measure a series of tree and stand parameters in 2 contrasting forest types. They then analyze and interpret the data to develop their understanding. Reflective practice is built in by setting questions designed to promote enquiry and the self-identification of future avenues for personal development. The project, as described here, was devised for students at the National School of Forestry, England, but the principles could be applied to almost any learning environment. Planning within curriculum teams would be required to identify the appropriate location for this exercise in specific undergraduate programmes.

**Key words**: forest stand dynamics, silviculture, problem-based learning, reflection, professional education

**RÉSUMÉ**

La formation académique en foresterie ne contient que très peu d'exemples de publication portant sur les méthodes d'enseignement et d'apprentissage qui pourraient permettre aux étudiants de s'engager sérieusement dans la discipline. Cela n'est pas le cas dans d'autres disciplines professionnelles, comme la biologie, la médecine et le génie, où se sont développés de sous-disciplines consacrées au développement et à l'évaluation de stratégies optimales d'apprentissage. Nous présentons dans cet article un petit exercice pratique réalisé sur le terrain introduisant les étudiants en foresterie à la dynamique des peuplements forestiers, à l'écologie forestière appliquée et à la sylviculture. Les étudiants mesurent un groupe d'arbres et les paramètres de peuplement de deux types forestiers totalement différents. Ils analysent et interprètent par la suite les données pour bien comprendre la situation. L'apprentissage itératif s'effectue au moyen de questions conçues pour pousser les recherches et l'identification par la personne des orientations futures de son développement personnel. Le projet, tel que décrit ici a été élaboré pour les étudiants de la National School of Forestry en Angleterre, mais les principes pourraient être appliqués à presque tout environnement d'apprentissage. Une planification de la part de l'équipe chargé du programme de formation serait requise pour identifier l'endroit appropriée pour cet exercice réalisé au cours de certains programmes du baccalauréat.

**Mots clés :** dynamique des peuplements forestiers, sylviculture, apprentissage à partir de cas, réflexion, formation professionnelle



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## Introduction

It has been long recognized that active learning is more effective than passive learning in many environments. Active learning involves students taking responsibility for the acquisition of knowledge, whereas passive learning requires the instructor to deliver knowledge to students who take notes. A maxim, often attributed to Confucius, succinctly states the case: "If I am told, I forget; if I am shown, I remember; if I do, I understand." Several disciplines, including medicine and engineering, have embraced this philosophy and are now pioneering new ways of teaching, making learning much more student-centred. These approaches represent a shift away from the traditional methods of teaching (the so-called "chalk and talk" model). The common criticism of traditional methods is that they can be confusing and sometimes unnecessar-

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ily abstract for some students and have contributed to a decline in uptake at university of many scientific disciplines (Leslie *et al*. 2006).

Central to a more active learning approach are problem-based learning (Wood 2003) and reflective practice (Stark *et al*. 2006). These methods are enabling students to apply and develop their knowledge through their own experiences. In this model, students are presented with real-world scenarios from the earliest stages of their undergraduate education, to ensure that their learning is closely tied to developing the skills needed within their future profession. However, unlike medicine and engineering, development of these approaches has been relatively slow in forestry, perhaps due to the lack of a recognized specialism dedicated to professional forestry education. However, a recent issue of *The Forestry Chronicle* included several papers that described new approaches to undergraduate teaching and course delivery, with examples from forest operations planning (Richards and Robak 2008), geomatics (Leblon *et al*. 2008) and social values (Beckley 2008). In our view, wider discussion and sharing of ideas about teaching and learning could help modernize and invigorate forestry education.

Problem-based learning may be particularly suitable in an undergraduate forestry curriculum. It usually involves groups of students being given a case study or scenario (Brown 2003, Wilson and Leslie 2008). Group work is advantageous, as it helps to develop strong communication and teamwork skills. The combination of technical and inter-personal competencies that are promoted is generally viewed as a desirable preparation for professional practice (Zundel and Needham 1996, 2000). In addition, problem-based approaches are a good vehicle for stimulating reflective practice (Zundel and Needham 2000). This encourages students to be more independent as learners and helps them establish individual learning objectives and priorities in their education (Wood 2003). A further key objective is to integrate knowledge across the curriculum and minimize some of the divisions between specific sub-disciplines. The perceived lack of structure in a problem-based approach, however, does present challenges for both the educator and some students. Advantages and disadvantages of problem-based learning need to be taken into account when devising the optimum strategy for specific elements of a curriculum (Table 1).

In our teaching practice, we have identified several topics where an approach based on problem-solving and learning through personal experience may be effective in the teaching of silviculture, especially in stand dynamics (e.g., Wilson and Leslie 2008). Forest stand dynamics is a core element of most forestry programmes and is concerned with the structure and development of forest stands and their responses to disturbances. It is an applied science that draws on knowledge in plant biology, ecology and a range of environmental sciences, including meteorology (Oliver and Larson 1996). In turn, an understanding of stand dynamics is important for the design of silvicultural prescriptions and in forest management planning.

A starting point for most investigations in forest stand dynamics is woodland structure. This is characterized by features such as species composition, the range of ages or sizes (a range of sizes may or may not indicate a range of ages) of the trees, the architectural form, and the spacing (regular or clumped) between the trees (Kerr 1999). In addition, forest stands can be characterized by the vertical structure or layers of vegetation and horizontal structure or patchiness. By collecting information on these features of a stand, it is often possible to make inferences about its past history and to predict potential future pathways for development.

**Table 1. Advantages and disadvantages of problem-based learning (Beringer 2007)**

| Advantages | Disadvantages |
|---|---|
| Nurturing and enjoyable[a] | Score lower on basic knowledge exams[a] |
| Engages in backward reasoning, where the student is given a problem and must identify the theories and methods needed to solve it. | Students view themselves as less prepared[a] |
| Promotes reflection on students' own learning[b] | Large costs associated with large class sizes[a] |
| Students memorize less[b] | Criteria for the assessment of student attainment can be less clear than in more structured approaches where recall of facts may form basis of assessment |
| Students preferred active learning[b] | High resource utilization[a] |
| Students more stimulated, challenged and satisfied[b] | Students find it difficult to gauge what and how much to study[b] |
| Students cram less for exams[c] | Interpersonal aspects can cause anxiety[b] |
| Students exhibit more autonomy and innovation[3] | Difficult for teachers to gauge how much direction is required[d] |
| Students become better able to direct their own learning | |
| Students show better integration of basic concepts[c] | |
| Students develop stronger analytical skills[d] | |

[a]Albanese and Mitchell (1993)
[b]Bligh (1995)
[c]Norman and Schmidt (2000)
[d]Hmelo and Ferrari (1997)

Forest stand structures have a profound influence on the extent to which conservation and forest management objectives can be achieved. For stands managed for fibre production, even-aged structures with regular inter-tree spacing and most often incorporating a limited range of species are generally established. For stands managed for biodiversity (Kerr 1999) or some social values, such as recreation (Gundersen and Frivold 2008), complex structures, with many ages and tree species may be favoured. Diverse vertical structure provides a variety of environmental conditions from strata in the canopy to the forest floor. In the upper canopy there is maximum incident solar radiation, considerable fluctuation in temperature and humidity, and exposure to extremes in temperature and wind. Under the canopy, there is a more stable environment, however with less light. The different environmental conditions at the various levels within the canopy creates a wide variety of ecological niches, which in general enables more structurally complex stands to support a higher number of species. For certain groups of organisms such as birds, stand structure is a strong determinant of diversity (Mitchell *et al.* 2006). Through management, such as the application of particular silvicultural systems (Kerr 2009) stand structures can be developed that best meet the mix of objectives for a particular site.

There are several approaches to describing stand structure, for example the use of indices. These include those that describe the extent of mixing of tree species, those that define the horizontal spatial arrangements within a stand and those that illustrate the range of sizes of trees in a stand (Pommerening 2002). In addition, graphical approaches to describing structure can be used. A simple method is the profile diagram, which represents a vertical cross section through an area of forest. This technique is used in research and woodland survey directed at biodiversity (e.g., Kirby 1988) and has been adopted widely to describe structure of both tropical forest types (Richards 1996, Whitmore 1998), as well as temperate forests (Peterken 1996). The profile diagram represents vertical forest structure and gives insights into the dynamics of forests, in essence providing a snapshot of succession. For example, inferences can be made of the shade-tolerance and variable growth habits of forest tree species by comparing colonization patterns in canopy gaps and under shaded conditions. Such techniques are important as silviculture becomes focused on managing forest ecosystems that are likely to have increasingly complex vertical and horizontal structures (Puettmann *et al.* 2009).

In this paper we focus on a simple field-based exercise that involves creating profile diagrams of 2 contrasting types of woodland in the Borrowdale Valley, part of the Lake District National Park in northern England. Our objectives are to: 1. Outline the field technique required to construct the diagrams; 2. Present data as a case study from one of our classes; 3. Provide information on interpretation that will be of value to the instructor. Getting our students out into the field at the earliest opportunity and connecting science with practice is an important motivation for our approach. Underlying principles have been developed from a review of methods in other professional disciplines, including engineering and medicine. The project is directed at the early stages of forestry education, and aims to combine field observation with techniques for data collection and interpretation. We have found that diagrammatic approaches are useful as the basis for comparison between stands, for interpretation of stand history and to infer past stand dynamics.

## Methods

Two contrasting areas of forest are selected; in this example an ancient semi-natural woodland (woodland that has been in existence since before 1600 AD) and an area of even-aged conifer plantation. The structure and species composition of these stands have been heavily influenced by management, which has however resulted in 2 very different stand types. While the measurements are being made a sketch of the profile is produced (not to scale) to allow a realistic drawing of the crown and tree shapes to be made back in the laboratory. Normally the exercise involves half a day in the forest and a further half a day for drawing the diagrams, discussing the results and further analysis of the data, including using graphs. Further analysis is undertaken by the students after the time-tabled sessions and forms the basis of a report on the ecology of Great Wood.

In the forest, students collect the data in teams of 4 by laying out plots of 40 m × 10 m. Plot size can be modified depending on the time constraints and the complexity of the forest ecosystem being investigated and objectives of the exercise. Several groups working together can lay plots end-to-end to establish a transect through the selected ecosystem. The location within the plot of mature trees, saplings, seedlings, shrubs and ground vegetation is recorded. Tree height, crown height and crown width is measured for all trees and shrubs.

A 40-m tape, representing the centre-line of the plot (or transect) is laid down through each stand. The following measurements or records are then made for each tree in the transect:

1. Distance of trees and shrubs (and major ground vegetation types) along the transect.
2. Slope of transect if it is greater than 5% (the diagram is easiest to plot if the transect is horizontal or near horizontal).
3. Distance of tree from transect and whether it falls to the right or left. Only vegetation up to 5 m on either side of the line should be recorded, though presence of crowns overlapping into the plot from trees outside the plot should be noted, as these cast shade and may influence ground vegetation. All trees should be recorded, although where dense carpets exist of small seedlings of less than 1 metre in height the extent and location of these groups of seedlings is noted rather than each individual. The names of all tree and shrub species should be recorded. A standard coding system should be agreed for the class to avoid later confusion. The Forestry Commission of Great Britain uses a coding system for species in its inventory work and this is recommended for the exercise (Table 2). On a wet day the minimum amount of writing is helpful.
4. Total height and crown height (recorded to the nearest metre). This is best done with a clinometer. If not available, total height and crown height of the trees can be estimated by a simple scaling technique using a stick or ruler (Kuhns 2003).
5. Diameter at breast height (1.3 m). This is a simple measurement that gives an indication of tree size.
6. Crown radius in front and behind the stem of the tree along the line of the transect. This is measured by holding

Table 2. Scientific names, common names and field codes for tree species mentioned in this study

| Scientific name | Common name | Code |
|---|---|---|
| *Populus tremula* L. | European aspen | Aspen |
| *Fraxinus excelsior* L. | ash | AS |
| *Fagus sylvatica* L. | beech | BE |
| *Betula pendula* Roth. | silver birch | BI |
| *Corylus avellana* L. | hazel | HA |
| *Ilex aquifolium* L. | holly | HO |
| *Larix kaempferi* (Lamb.) Carr. | Japanese larch | JL |
| *Quercus petraea* (Mattuschka) Lieblein | sessile oak | OK |
| *Acer pseudoplatanus* L. | sycamore | SYC |



one end of a measuring tape against the centre of the tree and then recording the distance to the drip line at the margin of the crown parallel to the line of the transect. An angle gauge is helpful in making accurate estimates of the crown margin.

7. Additional notes, for example whether the tree is a maiden (single) stem or coppice (multi-stemmed).

## Results

Profile diagrams from a recent practical at Great Wood are shown for the conifer plantation (Fig. 1) and for the semi-natural woodland (Fig. 2). Examples of how the data can be presented to highlight differences between the stands are shown in the Interpretation section of this paper. A complete set of field data for the practical is available from the corresponding author.

### Interpretation

A crucial part of a forester's education is to develop the ability to recognize elements of stand structure and understand the natural and human-induced processes that led to its development. Selecting 2 contrasting woodland types, with differing management histories allows students to appreciate more fully the influence of spatial patterns and different tree species on the development of forest ecosystems. In this example of the exercise a heavily thinned plantation of larch and an area of semi-natural woodland were selected. The structure of forests is characterized by features such as the number of tree species, the range of ages of the trees and the variation in distance between the trees. The profile diagram and data collected comprises the formal basis for the practical, while interpretation and analysis is largely left to the students and forms the basis of a report. The analysis can be in a written form but students are also encouraged to use other methods of presenting data, such as diagrams and graphs.

### Number and type of tree species

The mix of tree species present has a strong influence on the structure of the stand. Tree species adopt different growth forms and this physiognomy is dependent on the balance between endogenous growth processes and exogenous constraints (Barthelemy and Caraglio 2007). Different tree species exhibit vastly different architecture (Thomas 2001), which can be described through 4 broad morphological traits: growth processes, branching processes, morphological differentiation of axes and the position of reproductive structures (Barthelemy and Caraglio 2007). Some trees, such as most poplars and many conifers adopt an excurrent growth pattern or indeterminate growth (Barthelemy and Caraglio 2007), where the leader is strongly dominant and side branching is relatively light. This pattern of development is exhibited by the Japanese larch (Fig. 1). In contrast, other trees show a decurrent growth pattern or determinate growth (Barthelemy and Caraglio 2007), where lateral branches have considerable dominance, for example the beech (Fig. 2). As such, increasing the number of tree species in a stand will generally increase its structural complexity. Furthermore, mixing those trees with very different physiognomies will enhance this effect; for example a mix of conifer trees and broadleaved

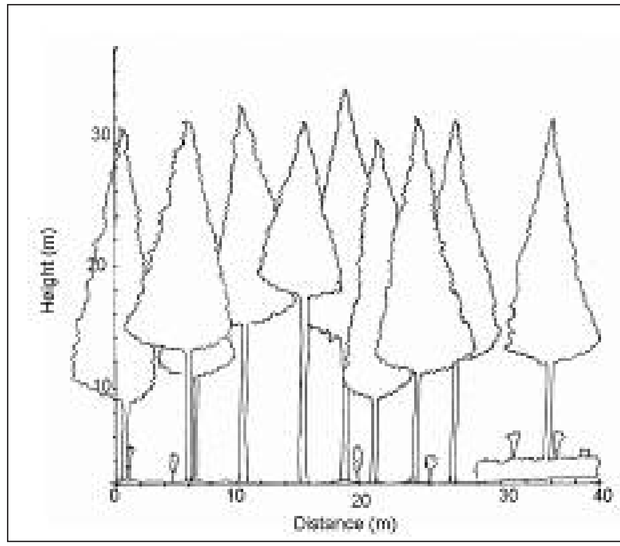


**Fig. 1.** Profile diagram of a conifer plantation at Great Wood, Cumbria.(Upperstorey is Japanese larch and understorey is ash.)

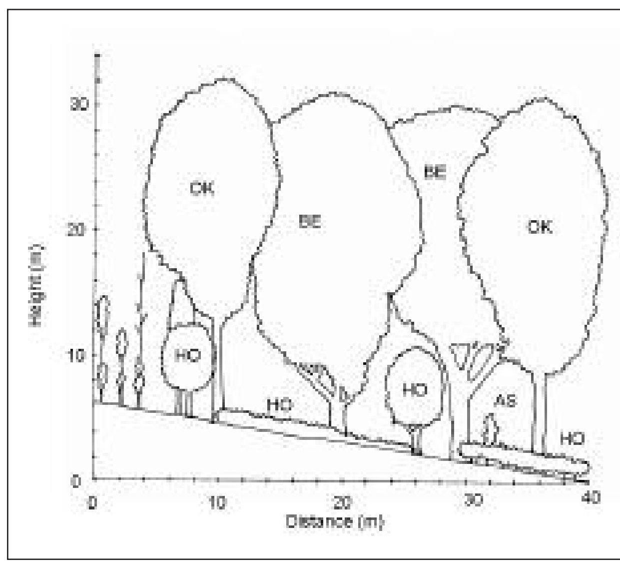


**Fig. 2.** Profile diagram of ancient semi-natural woodland at Great Wood, Cumbria.

Table 3. Light requirements of main UK tree species (adapted from Mason *et al.* 1999)

| Light-demanders | | Moderate shade-bearers | | Shade-bearers | |
|---|---|---|---|---|---|
| **Broadleaves** | **Conifers** | **Broadleaves** | **Conifers** | **Broadleaves** | **Conifers** |
| Oak | Larches | Sycamore | Douglas-fir[b] | Beech | Western red cedar[c] |
| Ash[a] | PinesPines | Lime | Coast redwood | Hornbeam | Western hemlock[c] |
| Elm | | Norway maple | Leyland cypress | Holly | Lawson cypress |
| Sweet chestnut[a] | | Hazel | | | Grand fir |
| Poplar | | | | | Noble fir |
| Birch | | | | | Yew |
| Alder[a] | | | | | |

[a]will tolerate some shade when young or coppice
[b]side shade only
[c]almost shade-demanding when young



trees is likely to provide a more varied structure than mixes of broadleaves alone or conifers alone.

The presence of particular species and their dominance in the stand can be used to infer past disturbance and stand dynamics. The light requirements of common trees used in British forestry are shown in Table 3. If there is a preponderance of light-demanding species in the stand it suggests that the trees regenerated, either naturally or artificially in an open area. A large open area can be formed by management activities such as a clear fell or through natural factors such as fire or major windthrow. Where shade-bearers are dominant, it implies that only small canopy openings have been made, for example through selective felling or the death, decay and falling of senescent trees. In the semi-natural woodland (Fig. 2) a blanket of holly has naturally regenerated under a large beech tree. Beech has a dense canopy and holly is a shade-bearing species and able to germinate in conditions of less light. In contrast, birch regeneration is confined to a canopy gap on the far left of the profile diagram. This tree is a pioneer and a light-demanding species and is most competitive in open areas or large canopy gaps. The larch (Fig. 1) was thinned recently to allow natural regeneration of seedlings under the canopy. Where the canopy has been broken (to the right of the diagram) regeneration of species that can tolerate shade, such as hazel and ash—which is shade-bearing when young—are appearing. There is no regeneration of the light-demanding Japanese larch and so succession is taking place. Early successional light-demanding trees are being replaced by those tree species suited to later stages in succession and a single-aged stand is being transformed into one with at least 2 distinct cohorts of trees (Fig. 3).

When describing the dynamics caused by the trees themselves, Brassard and Chen (2006) differentiate between gap-makers and gap-fillers. Gap-makers tend to be pioneer trees, whereas gap-fillers are later successional species, although this depends on the forest type and the nature of disturbance that determines its dynamics. In the woodlands surveyed, the gaps have been created by active management, but in natural forests it is gaps caused by trees falling that release natural regeneration and drive the process of forest dynamics.

### Range of sizes of trees

The structure of trees of the same species changes greatly as they age and grow larger, from the young seedling through to the mature tree, then as they begin to senesce and die, forming standing and fallen deadwood. For living trees there are profound differences between young and old trees; as trees are modular organisms an older tree does not exhibit the same structure as young tree made large (Thomas 2001). Very old trees or "veteran" trees have particularly complex structures and this in turn means they provide a wide range of habitats and support many organisms. As such, the range of ages of trees in the stand will considerably influence vertical and horizontal stand structure and also the level of biodiversity the stand supports.

The range of size and age of trees can provide information on the stand history and its dynamics; although in uneven-aged stands size can be a poor reflection of tree age. A stand composed of one cohort will have arisen from a stand-replacement disturbance (Oliver and Larson 1996). This could be natural, such as through fire or catastrophic windthrow or it could be through management such as a clear fell. The upper canopy of the conifer stand (Fig. 1) is made up of trees all the same size and age, having been planted during one year. In contrast, the semi-natural (broadleaved) stand (Fig. 2) shows a range of sizes and in this case this is likely to

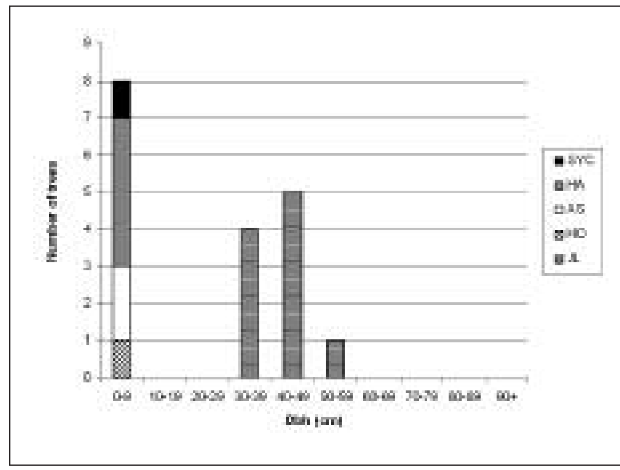

**Fig. 3.** Size class distribution by species for a conifer plantation at Great Wood, Cumbria (seedlings less than 1.5 m height excluded).

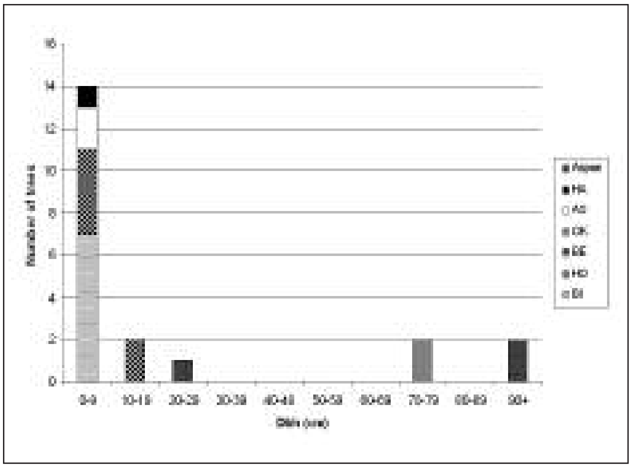


**Fig. 4.** Size class distribution by species for ancient semi-natural woodland at Great Wood, Cumbria (seedlings less than 1.5 m height excluded).

represent a similar variety of ages. Smaller, more frequent disturbances are likely to have characterized the development of this stand.

For those stands that are composed of 1 cohort, age still has a strong influence on their structure. Oliver and Larson (1996) identify 4 stages in the development of such stands; stand initiation, stem exclusion, understorey re-initiation and old-growth stages. In general, stand vertical structure becomes increasingly complex as the stand becomes older. The stand in Fig. 1 is somewhere between the stem exclusion stage and the understorey re-initiation stage, regeneration having been stimulated by thinning of the canopy. This new cohort is clearly shown in Fig. 3. This contrasts somewhat with the situation in the ancient semi-natural stand where there has been a more extended period where regeneration has occurred, with the younger cohort being of a wider range of sizes of trees (Fig. 4).

#### Variation in distance between the trees

There is a continuum between clumped groups of trees and those that are systematically and evenly distributed across a stand. The regularity in spacing is incorporated into certain indices for stand structure, such as the Aggregation Index of Clark and Evans (Pommerening 2002). Variation in spacing between trees is important in terms of habitat, as more varied conditions horizontally across the stand create a wider range of potential niches.

In silviculture its is understood that growing space has a profound influence on a number of characteristics of trees, such as speed of diameter growth and attributes of timber quality as well as those that have a stronger influence on stand structure—particularly crown development. As the tree has more growing space the following structural changes occur: branches become thicker and longer, the extent of live crown increases and the stem becomes more tapered, resulting in a tree of very different shape from one growing in crowded conditions.

#### Other factors

The management history of the stand also has a strong bearing on the structure. The silvicultural systems applied to a stand strongly influence its structure over time (Kerr 1999). In the stands selected for this practical, the larch stand, through thinning, has developed 2 distinct cohorts and might best be classed as a group shelterwood system. In contrast, a less organized and more random harvesting regime has been applied to the semi-natural woodland resulting in a more varied structure, as would be found in a group selection system. In other areas of the semi-natural woodland there is neglected coppice that adds yet another structural feature.

The influence of other factors such as wind will also leave its imprint on the structure of trees and stands. The mechanics of trees is directed at stability and trees will grow in a way to compensate for the stresses put on them, for example stresses such as losing a large limb or being subjected to a prevailing wind (Thomas 2001). The shape of trees can therefore be used to interpret exogenous factors influencing their growth.

## Application

The exercise was piloted in 2002 and has been successfully adopted in teaching ecology at the National School of Forestry. The sessions were largely directed at using the contrasting profile diagrams to stimulate discussion on the variety of niches present in the 2 stands and the species diversity they support. In providing direct field experience in generating and analysis of their own (albeit limited) datasets, students are able to engage with a number of theoretical concepts being presented in class with respect to forest development, succession and disturbance. Comparison of the profile diagrams with those of other forest types, such as tropical moist forest, can further enhance the students' understanding of the influence of forest structure on biodiversity and generally facilitates good reflective learning. Useful examples of profile diagrams for tropical moist forests can be found in Richards (1996) and Whitmore (1998) and for temperate, deciduous woodlands in Peterken (1996). These can be supported in lectures by images and video presentations, and provide a context for more advanced quantitative or analytical approaches to the study of forest structures.

We have found that stand profile diagrams provide an excellent foundation for classroom and tutorial discussions directed towards the processes that lead to the development of different stand structures. The practical can be further developed through:

1. Producing a diagram that shows horizontal structure in the transect. This diagram illustrates the variation in canopy cover across the stands, with the ancient semi-natural stand being much more varied and complex. Collection of data for this diagram is more complex as consideration needs to be taken of trees that are not within the transect, but which have crowns that extend into its area.
2. Sampling the ground vegetation under the stands, using quadrats. In this case, the ground vegetation in the 2 stands is relatively similar, as larch is a deciduous tree, but considerable difference would be apparent if the upper canopy were an evergreen conifer. In a complementary project we outline methods for the assessment of ground vegetation (Wilson and Leslie 2008).

In addition to the direct application to silviculture and ecology, students are encouraged to consolidate and re-enforce learning from other areas of the curriculum, to develop skills in critical reasoning and to become more self-reliant learners (Table 4). Wherever possible we consider it important to

Table 4. Summary of activities and learning outcomes associated with completion of the exercise. A selection of relevant source information are provided as a link to wider learning.

| Activity | Learning outcomes | Example sources of information |
|---|---|---|
| Measurements for profile diagram | • Understanding fundamental tree parameters<br>• Use of measurement equipment<br>• Basic maths (calculating heights from % and distance, live crown percent)<br>• Ecological survey methods (transects)<br>• Identification of tree and other plant species | Phillip 1994, Kirby 1988, Johnson 2006 |
| Understanding stand dynamics | • Understanding stand dynamics through Interpreting stand structure<br>• Linking tree species to the frequency and extent of disturbance<br>• Light and other requirements of different tree species | Oliver and Larson 1996; Kerr 1999, 2009; Mason and Kerr 2004 |
| Understanding ecology | • The range of niches provided by woodland<br>• Structure of different tree species<br>• Structure of different forest types | Read and Frater 1999, Barthelemy and Caraglio 2007, Thomas 2000, Young and Giese 2002, Kimmins 2004 |
| Recording field data | • Use of forms<br>• Recording data legibly, neatly, accurately | |
| Preparation of diagrams | • Use of an appropriate scale<br>• Understanding the labelling and other requirements of diagrams<br>• Creativity in data presentation<br>• Avoiding "chart-junk" | Tufte 2001 |
| Interpretation of diagrams | • Relating field experience to quantitative data | |
| Describing the main results | • Scientific writing skills<br>• Referencing | Many sources available, often specific to university departments |
| Professional competencies | • Working in a team<br>• Problem-solving<br>• Critical reasoning<br>• Organizing work<br>• Reflective practice | Zundel and Needham 1996, 2000 |

encourage students to link observations and measurements they have made in the forest to knowledge and theory that they have acquired from elsewhere in their studies.

Formal assessment is based on submission of a written report. In the briefing instructions it is made clear that a pass grade requires a text that describes the key structural characteristics in each stand and is supported by correctly labelled diagrams, graphs and tables of the main findings. A more advanced student will be able to articulate clearly some of the underlying eco-physiological processes and draw on relevant published literature, as well as provide a critical comparison of the similarities and differences between the 2 sites. Linking findings from the field project to their understanding of stand development processes provides good evidence of critical reasoning and independent thinking. Some of the technical skills being developed and aspects of working in a team can partly be assessed by asking students to include a short section in their report, a reflection, on the learning experience. Other areas of learning are developed through informal assessment, such as in-class discussions and/or a quiz.

The stand profile exercise provides a template, which can be modified and applied to forest types around the world. This makes the exercise a useful foundation for comparison of stand dynamics and structure across different ecosystems and biomes. While the exercise has been used in teaching for some years and has received favourable comments from students, it would be beneficial to assess the contribution such an approach has made to the students' knowledge of forest stand structure and dynamics.

## Conclusion

The measurement of stand parameters, drawing profile diagrams and subsequent analysis as described in this paper provides an example of problem-based learning in silviculture and forest ecology. The approach allows students to develop an understanding of the differences in the structure of 2 contrasting stands and to apply their knowledge of ecology and stand dynamics to data collected in the field. The profile diagrams can be interpreted at a number of different levels and the analysis can be more or less quantitative depending of the specific learning objectives. As presented we have found the project especially well-suited to early undergraduate studies, where students are gaining formative experience in measuring and describing stand structures. However, by passing more responsibility in design and interpretation to the student, the project can be adapted to meet the needs of students at more advanced under-graduate and post-graduate levels. This practical can also be applied to a wide range of stand types, being best when 2 contrasting types are selected.

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Data tables are available from the corresponding author.

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