9 Implications of Technological Development to Forestry

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Abstract: Technological development creates new opportunities and structures, and destroys existing ones. Despite the importance of technological development, it has rarely been the focus of research in the forestry literature. It is often taken as a given, like an "externality" that falls from heaven. This is probably partly due to the difficulties related to the phenomenon itself. The scope of technological development and its impacts are often dauntingly large. Think, for example, about information and communication technology (ICT). How to study such a vast phenomenon? On the other hand, forest researchers are rarely experts on technology development issues and, therefore, may find the topic out of their scope. We know, however, that technologies such as ICT and biotechnology are having, and will have, transformational impacts to the global forest sector. For example, technological changes may alter forest industries, as well as forest management, utilisation, and growth. The purpose of this chapter is to analyse the impacts of technological change on the forest sector by focusing on three technologies: ICT, biotechnology applications in forestry, and laser technology applications to forest inventories. How do these technologies impact forests and the forest sector? What are their links to forest sector economics, policies, and social issues? We invite readers to consider and reflect on the topics introduced in this chapter.

Keywords: technological development, technological change, innovation, technology transfer, information and communication technology, biotechnology, laser technology

9.1 Introduction

9.1.1 Technological Development and the Forest Sector

In the context of this book, one of the main purposes of which is to identify and analyse significant drivers of change in the forest sector, we investigate and analyse the impacts of technological innovations and methods so that readers may better understand their undeniable influences in all fields related to forests and forestry. The primary purpose of this chapter is to examine the key impacts of technological applications on the forest sector, both in the past and currently, and suggest what influences new technologies may have on the sector in the future.

Technologies are many and varied, and their implications within the forest sector are manifold. Here, the analysis is restricted to just touch upon three of them, which are introduced as illustrative examples: (1) the impact of information technology on the paper products and roundwood markets, (2) biotechnological applications in the forest sector, and (3) the utilisation of laser measurement for precision forest inventory and monitoring. In addition, we present an illustrative box on forest biorefinery technology and how policy can drive the development of technology.

The three technologies – information and communication technology (ICT), biotechnology, and laser technology in inventory and monitoring – are

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indicative of the different types and scales of technologies. ICT and biotechnology are *general purpose technologies* that are likely to have revolutionary implications to the whole forest sector. Laser technology in forest inventory and monitoring is much more specific, and its implications are likely to be evolutionary and more restricted.

In general terms, technological development is understood to be the application of scientific or other organised knowledge – including any tool, technique, product, process, method, organisation, or system – to practical tasks. In other words, technology could be interpreted as the set of knowledge, skills, processes, and techniques on how to combine resources to produce desired products, to solve problems, satisfy needs, or adapt to changes. Today, and throughout history, technology influences, and is influenced by, such factors as social values, economics, ethics, institutions, interested social groups, the environment, and government, among others. Technological development is often the result of science and engineering advances that typically result in the successful introduction of new and useful methods, tools, techniques, or practices, or new or altered products and services.

The image of the forest sector tends to be that of a static, natural resource-intensive, mature sector. This view obscures the fact that throughout its history the forest sector has adjusted to technological changes and innovations. For example, when wooden ship technology was replaced by iron ships, a new demand for wood emerged from a brand new pulp and paper industry. Now it seems that the development of information and communication technology sets, yet again, a challenge for the forest sector to find new ways to utilise wood and fibre. This time, more intensive uses for wood may be emerging from the energy sector.

Of course, technology implications to the forest sector are not restricted simply to different ways and purposes to use forests for wood production. Technology is also having important impacts, among other things, on the ways we manage forests, or on the various environmental and social services that forests provide. For example, technological innovation has made it possible to change the way in which, and where, tree species are grown. On the other hand, without modern transportation technologies, forest-related recreation and tourism would be of a very different nature and quantity.

Thus, the forest sector is continuously changing because of technological development and innovations. However, in the forest sector literature, technology and its role as a major driver of change in the management, utilisation, conservation, and even devastation of forest resources is rarely analysed in a comprehensive and explicit way. There are some exceptions, such as the study on the impacts of information technology (Hetemäki and Nilsson 2005) and bioengineering (Strauss and Bradshaw 2004) on the forest sector. Still, technology is often ignored, or is treated as an "externality" that falls from heaven.

The implications of technological change can be many. At a very general level, one characteristic feature of technological development is that it commonly increases productivity; that is, an increase in output per unit of input. This has been the case, for example, with the chainsaw (higher number of tree fallings per man hour) and genetic engineering (higher tree growth per unit of land). However, technological processes may also produce unwanted results, such as loss of biodiversity, increased deforestation, and pollution.

Another essential feature of technology is its dynamic nature. Technologies change all the time. One can distinguish different phases related to technology development: invention (discovery), innovation (first commercial application), and diffusion (widespread replication and growth) (Grubler 1998). Here, the main emphasis will be on the last phase: diffusion and its implications.

9.1.2 Technology and Innovation Systems

It is important to stress that technology consists of both the hardware (*what* things are made) and the software (*how* things are made). Technology has affected the forest sector in a number of ways. For example, the invention of making paper from wood fibre in the mid-19th century created a demand for pulpwood. Now, the development of electronic communication technology is threatening to partially reduce this demand. The chainsaw was a radical invention that replaced the traditional way of working in the woods. Sustainable development was an innovative idea that has changed the way we see and manage forests. Biotechnology enables us to increase forest growth, introduce more climate-adaptable species, and facilitate pest management. These and other technologies and innovations, along with their adaptation in the forest sector, have been closely related to general socio-economic development in recent times. There has been a growing need for these innovations, and their adaptation was encouraged by research and development (R&D) investments, policies, and entrepreneurial activities. For an example of a policy-driven technology, see Box 9.1.

In the technological change literature, technological development is increasingly being seen as an interaction between the technologies and the technological innovation system (Frenken and Faber 2009). By the latter, we mean government policies, demand conditions, changes in institutions, entrepreneurial activities, knowledge development, etc. This way of looking at technology directs our attention from purely the hardware and science issues over to the social and policy issues.

It is the co-evolution of these two factors and their feedback effects that is relevant for considering technological development and its impacts. This way of viewing technological change also brings forward the following questions: How can we enhance the innovation system so that new technologies are created? How do we create the optimal setting for new technologies and innovations to spread in large scale throughout society? How can we avoid and mitigate any negative impacts of new technologies? How should we adapt existing technological applications to a rapidly changing social and natural environment? How do we transfer technology from centres of excellence and innovation (developers) to a wider group of end users? How do we recognise the importance of traditional knowledge, particularly for adaptation purposes?

The innovation system approach has increasingly become a well-established heuristic framework for science and innovation policy by numerous public organisations around the world (Hekkert and Negro 2009). For example, the government of The Netherlands has adopted a wide approach system called *transition management* to transform the country from a fossil fuel-based economy to an economy totally based on renewable energy. The transition management approach was originally developed by Dutch technology and social science researchers in the 1990s (Kemp et al. 2007). Hartikainen and Hetemäki (2008) have analysed the application of the transition management approach for planning and implementing the Finnish national forest policy.

9.2 Information and Communication Technology

Information and communication technology is an umbrella term that includes the design, development, implementation, support, and management of computer-based information systems. In essence, the application of this technology deals with the use of computers and software to convert, store, protect, process, transmit, and retrieve information.

The expression "information and communication technology" should, by its very nature, include paper-based writing and printing, which are also technologies. Here, however, we restrict the concept to include only the electronic or digital communication technology.

ICT development has already fundamentally changed the global forest sector, and will continue to do so in the future. Hetemäki and Nilsson (eds. 2005) provide a wide analysis on the manifold impacts that ICT has had, and is likely to have, for the global forest sector. The study also shows that when discussing the impacts of ICT on the forest sector, it is like asking what have been the impacts of electricity, or the internal combustion engine, to the forest sector. Like these technologies, ICT belongs to a category known as *general purpose technologies*; essentially, they are everywhere and affect everything. It is thus difficult to precisely identify and quantify the role of a general purpose technology in the development of the forest sector. Another feature of general purpose technologies is that immediate, short-term, and visible changes tend to be seen in the technology in question, whereas long-term impacts tend to bring organisational, institutional, and cultural changes. Thus, the full impact of ICT on the forest sector will be apparent only after a long time lapse.

Within this large topic, the focus here is on the impacts of ICT to the pulp and paper industry, and how subsequent changes in this industry will affect the consumption of wood.

9.2.1 ICT and the Pulp and Paper Sector

From the perspective of the pulp and paper sector, the most important feature of ICT is that it provides alternative forms of communication to paper-based communication. For example, there could be a direct replacement of reading print newspapers by reading the news on the internet; or there could be indirect substitution. For example, people, especially the younger generation, are increasingly spending their time watching videos and playing video games instead of reading newspapers, magazines, or books. However, the total amount of time (and capacity) consumers can spend on information or entertainment is finite, that is, limited to the 24 hours in a day. Thus, there is inevitably a trade-off between different activities, and the time spent in consuming print media appears to be declining (see Table 9.2).

The impacts of ICT on print media and the paper industry are universal. Electronic communication supersedes print media whether one is in New York, Moscow, Peking, or Nairobi, in exactly the same way. However, there are large differences in the timing and magnitude of the impacts between countries. These differences are not related to geography, but to such social factors as income level and paper consumption level. What do we mean by this?

Table 9.2 shows the internet usage and per capita paper consumption in various regions of the world. The regions are separated into two categories labelled high- and low-income regions. It should be noted that the division between high and low income

Box 9.1 Forest biorefinery: an example of policy driven technology

Lauri Hetemäki

What is forest biorefinery?

The *forest biorefinery* (FB) is a facility that integrates biomass conversion processes and equipment to produce fuels (e.g., ethanol and biodiesel), electricity, power, and chemicals (e.g., polymers, acids), along with the conventional forest products (pulp, paper, sawnwood, etc.).

The FB can use multiple feedstocks, including harvesting residues, extracts from effluents, fractions of pulping liquors, as well as agri-biomass, recycled paper, and municipal and industrial wastes. It can be a large-scale industrial facility, integrated into a pulp and paper mill, or a medium- or small-scale facility integrated into a sawmill or plywood mill. Most of the discussions have focused on the former case.

An essential part of FB is the objective to more efficiently utilise the various fractions of woody biomass. This biomass is lignocellulosic material, which is made up of three primary chemical fractions: hemicellulose, cellulose, and lignin. All of these can be converted to carbon-neutral renewable energy or chemicals. As Figure 9.1 shows, the conversion technologies can be classified in three different pathways: biochemical, thermochemical, and physical-chemical processing and separation (e.g., Larson et al. 2006, Sivasamy et al. 2007). In addition, the different processes can, to some extent, be combined. Some of the conversion technologies are already mature and commercial; others require development to move to commercial applications.

What drives the development of this technology?

There are forest sector *internal* and *external* factors originating outside the sector that drive the FB development. The internal factors relate mainly to the structural difficulties of the forest industry in the traditional big forest sector countries, such as Canada, Finland, Sweden, and the USA. In these countries, the industry has been suffering from continuing profitability problems, and new investments are going mainly to Asia and South-America. In this context, the industry is re-thinking its strategies, and biorefineries are seen as potentially one important development that could enhance the profitability and viability of operations in the big forest sector countries.

The external factors are likely to turn out to be the more important ones. Not least because they will attract to the forest sector new industries and operators, and diversify the forest sector. These external factors are particularly related to increasing energy consumption, greenhouse gas emissions, and concerns over energy import dependence. These are, in turn, prompting changes in the sources from which energy is expected to be derived in the coming decades. In this context, forests and biorefineries are seen as potentially important sources and producers of carbon-neutral energy. The primary benefits generated by the biorefinery development to the forest industry, and society in general, are often seen to be the following:

1. Through new technology and synergies with current operations, increased production efficiency and profitability of current forest products;
2. Production of new products that are increasingly needed by society (e.g., bioenergy, bio-based polymers, and chemicals);
3. Help to meet regional policy targets (preserves and creates jobs in rural forest-based communities);
4. Help to meet climate change policy targets (replaces fossil fuel-based energy);
5. Help to meet energy security policy targets (replaces imported energy).

Reflecting these objectives, there have been large scale R&D efforts in developing technologies and pilot projects that promise to open up new and more efficient ways to utilise forests and wood fibres in energy production. In these efforts, forest biorefiner-

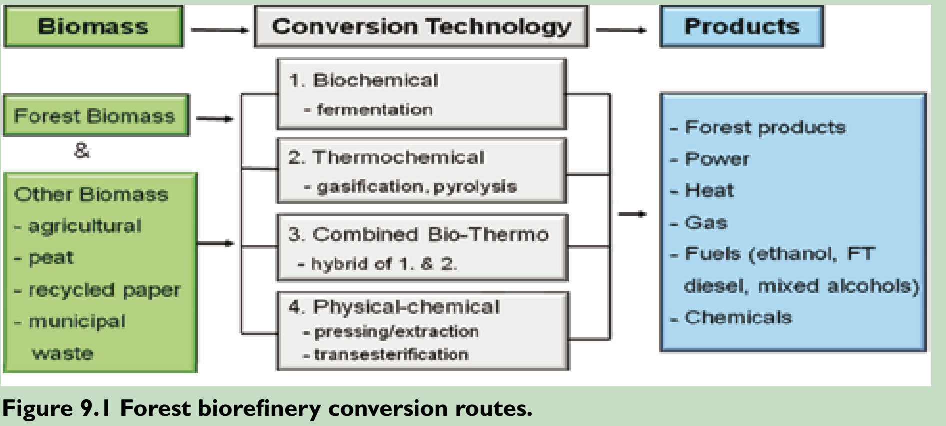

Figure 9.1 Forest biorefinery conversion routes.

Table 9.1 Examples of energy policy priorities and impacts.

	Policy Priority Options	
	Energy Security, Agricultural & Regional Policy	**Economic Efficiency & Costs to Consumers**
Policies / Regulations	tariffs, taxes, quotas, subsidies, standards	R&D support, tradable permits, taxes, investment support to risky projects
Positive Impacts	domestic production, rural employment and income, energy security	efficient resource allocation, cost efficiency, less administration, predictable operating environment
Negative Impacts	resource misallocations, trade wars, complex and bureaucratic, regional differences, uncertainty	loss of domestic production (at least in the short-to-medium term), more hardship in the rural areas, dependency on energy imports

Note: There are various positive and negative environmental implications under both policy priority options.

ies play a central role (a list of some of the current projects is given in Johnson et al. 2009).

Within the forest biorefinery platform, there are a number of different output mix and technology possibilities. Therefore, the number of investment opportunities and risk factors related to forest biorefinery are many. The viability of each specific forest biorefinery product-technology-mix depends on end markets (demand, supply, prices), substitute markets (e.g., oil), biomass markets, and on global, national, and regional policies. These may vary between countries, and even within countries. Also, the policies to support biorefinery development depend on the goals that biorefineries hope to target. For example, depending on the degree that the policy goal emphasises climate change mitigation, domestic energy production, rural employment, energy efficiency, or some combination of these, the optimal biorefinery concept may differ. In short, there is no single best uniform solution for FB, rather a large number of different concepts, raw material options, production processes, and output mixes, each tailored to be optimal for the local conditions and objectives.

Policy challenges and implications

Despite the global trend of market liberalisation, politics will play an ever more important role in the development of bioenergy markets. This is mainly a result of the following twin energy-related challenges: that of not having adequate supplies of energy at affordable prices, and that of environmental harm caused by energy consumption. In order to try to solve these two problems satisfactorily, regional, national, and local level policies are imposed to regulate energy market development.

An overview of the various national policies supporting the production of biofuels in OECD countries is given in Doornbosch and Steenbilk (2007). The study clearly illustrates the following points. First, the policies are necessary to make the production of biofuels viable in current circumstances. Without the subsidies, tariffs, or other forms of policy regulation, there would be no or very little national production of biofuels in most of the countries. Secondly, the policies vary across countries, and across regions within a country. Thirdly, the array of policy measures is large and complex. For example, countries may give subsides to anywhere in the value chain – from growing the raw material (agri- or forest-biomass) to setting mandatory requirements for biofuels usage in transportation. Finally, the current policies could be made more efficient. That is, more economic and environmental benefits could be generated from a given amount of biomass by re-designing the current policies.

Biorefinery development is no exception to the above trend. Various polices in different countries and at the global level are, and will be, implemented to speed up the building of forest biorefineries. The table 9.1 gives one taxonomy of the possible policies and impacts at a general level.

The interest in forest biorefineries is a very recent phenomenon, which means that societies and the forest sector have not yet had much time to reflect on the issues associated with it. Thus, although biorefinery landscape is promising, it is also broad, complex, and even confusing. More research is needed to understand the implications of FBs to society and to the forest sector.

So far, the research on biorefineries has been very much technology-driven and specialised. This is natural, since advances in the technology have been recent, and the possibilities for moving this technology to practice are only just opening up. However, now that the technology is close to the stage where it can be moved to commercial applications, there is a need for synthesis on current knowledge, and analytical assessment of future environmental, economic, and policy prospects. In what circumstances is forest biorefinery profitable? What are the socio-economic implications to the forest sector, at both the national and global levels? What are the environmental impacts?

Table 9.2. Media use by United States´s consumers in 2001, and projections for 2010 (hours spent annually).

Media	2001 hours	2010 p hours	% -change 1990–2010p
1. Newspaper	199	158	–20.6
2. Magazines	127	112	–11.8
3. Books	105	109	+3.8
Print media total	*431*	*379*	*–12.1*
4. TV	1 553	1 728	+ 11.3
5. Radio	792	758	–4.3
6. Videos, video games	113	164	+ 45.1
7. Internet	125	184	+ 47.2
Electronic media total	*2 583*	*2 834*	+9.7

Source: Statistical Abstract of the United States, US Census Bureau 2009.

Table 9.3 Population and internet users in 2009, and communication-paper consumption in 2007.

	Population (million)	Internet users (million)	Penetration (% pop.)	Newsprint per cap. (kg)	Print. writ. pap. per cap. (kg)
Africa	997	64	6.4	0.8	1.8
Asia (-Japan)	3 695	607	16.4	2.8	7.4
Non-EU Europe	314	93	29.6	5.1	10.2
Latin America	589	176	29.9	2.1	5.5
Low-Income Regions	5 595	940	16.8*	2.5*	6.4*
EU27	489	309	63.2	22	61.3
Japan	127	94	74.0	35	77.9
North America	341	252	73.9	25	88.2
Oceania	35	21	59.8	22	46.6
High-Income Regions	992	676	68.1*	24.7*	72.2*
TOTAL	6 790	1 664	24.5	5.7	16.2

Note. Internet Usage and Population Statistics are for June 30, 2009. Source: Internet World Stats paper consumption figures computed from FAOSTAT data. * The numbers are population weighted averages.

regions is not exact. For example, the low-income region Non-Eurepean Union Europe includes Norway and Switzerland, which clearly are high-income countries. Similarly, the low-income Asian region includes Singapore and South Korea, which clearly should be placed in the high-income category. However, their impacts at an aggregate level for the regional figures are minor.

There are three significant differences between these two types of regions. First, the total number of *population* in the low-income group is almost six times higher than in the high-income group; over 80% of the world's population lives in the low-income region. Secondly, the *per capita consumption* of newsprint and printing and writing paper is about ten times higher in the high-income region. The average person in the high-income region of the world consumed 72.2 kg of printing and writing paper in 2007, whereas the average person in the low-income region consumed only 6.4 kg. Thirdly, the *internet penetration rate*, that is, the percentage of the population using the internet, is also strikingly different between the regions. In the low-income region, on average, every sixth person is using the internet, while in the high-income region, more than one in two people are using the internet.

The above numbers reflect the fact that there is a clear dichotomy between the world regions with respect to the status of paper markets for communication purposes, and the magnitude of ICT impacts on this. In the high-income region, paper consumption has reached the saturation point, and the intensive spread of the internet and other electronic media has already begun to replace paper consumption. In contrast, in the low-income region, paper consumption is growing very rapidly due to economic growth, increasing urbanisation, and population growth. The intensity level of the internet and electronic media usage is still very low, and consequently the impact on paper consumption is also small.

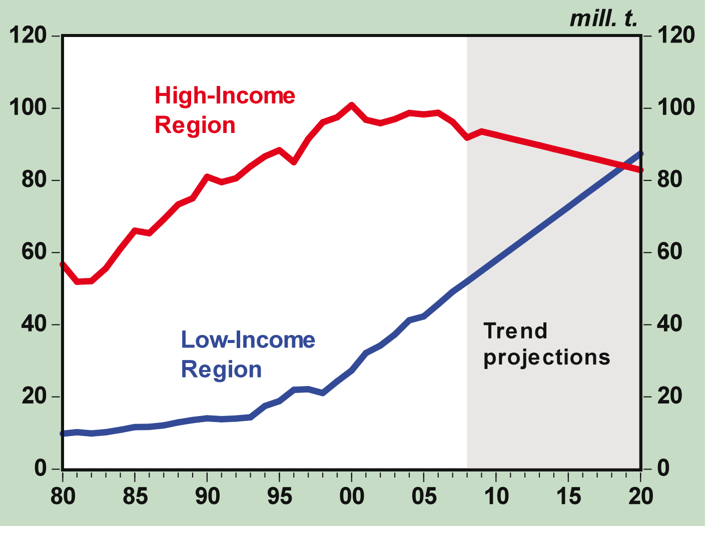

Figure 9.2 World graphics paper (newsprint + printing and writing paper) consumption 1980–2008, and trend projections to 2020.

The net impacts of the above development are illustrated in Figure 9.2 for the world's high-income and low-income regions. The high-income region is defined here to include North America, "Modified EU", Japan, and Oceania. "Modified EU" means the 27 EU countries minus the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovenia, and Slovakia, plus Iceland, Norway, and Switzerland.

At the turn of the century, the structural change in the world *graphics paper* (= newsprint + printing and writing paper) market started to take place. Up to the end of the 1990s, the high-income region had experienced an increased trend of graphics paper consumption. This started to stagnate at the beginning of this century, and eventually started to decline, despite economic growth. The single most important factor behind this development was the impact of electronic media (Hetemäki 2005, 2008). Businesses, consumers, and organisations increasingly moved their communication and media usage away from print to digital media.

The mirror image of the above trend is the steeply increasing trend of graphics paper consumption in the low-income region, which has doubled in the past decade. In 1999, the consumption of graphics paper in this region was only a quarter of what it was in the high-income region, and now it is about half of what the high-income region consumes. If the trend projections shown in Figure 9.2 are actualised, by 2019, the consumption in the low-income region will surpass that of the high-income region. The major factor behind this situation is the initially very low level of paper consumption per capita coupled with the rapid economic and population growth and urbanisation in the low-income region.

The trend projections for the high-income regions shown in Figure 9.2 were computed as follows. For each of the high-income regions – North America, EU, Japan, and Oceania – separate trends were estimated. For North America, the trend was estimated using data for the period 2000–2008. However, since the structural change in consumption in other high-income regions started later than in North-America, the trends for these regions were estimated using observations from only the 5-year period (2004–2008). Finally, the trend projections for different high-income regions were summed. For the low-income region, the trend was simply computed for the aggregate region using data for the period 2000–2008.

According to the projections, the consumption of graphics paper would decline in high-income regions by 18 million tonnes in 2020 from its maximum level in 2000. In contrast, over the same period, it would increase by 60 million tonnes in low-income regions. The world net increase would, therefore, be 42 million tonnes, which would be a 33% increase from 2000.

The trend projections in Figure 9.2 will probably capture the overall pattern of the future development. However, they are likely to turn out to be clear overestimates. First, the current economic slump is likely to strengthen the structural change in high-income regions. In 2009, the consumption of graphics paper in high-income regions is likely to end up being about 15–20% lower than in 2008. The lower demand is mainly due to cyclical reasons, but some of it may turn out to be structural or lasting. The reasons for this are described in the following paragraphs.

In order to save costs during an economic downturn, businesses adapt ways to reduce paper usage. For example, newspaper publishers may reduce the size of a newspaper from a broadsheet to a tabloid size, or they may move some material only to the

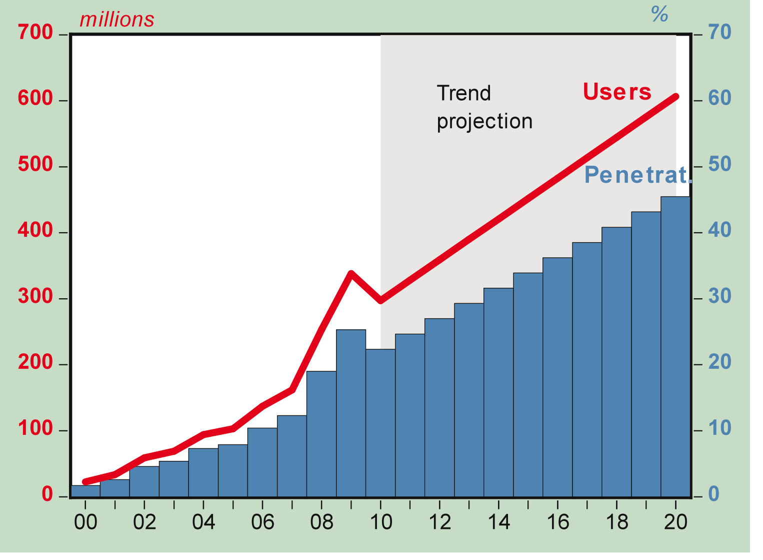

Figure 9.3 Internet Users and Penetration Rate in China 2000–2009 and Trend Projection to 2020 (Data source: Internet World Stats).

internet, such as stock exchange pages. Or banks, insurance companies, and federal and local government organisations may transfer business-to-business and business-to-consumer communication to digital form, such as by dropping paper forms and providing them online instead. Once these measures have been adapted, it is unlikely that they would return to the old modes when the economic slump is over. This pattern is what seems to have happened in the USA after the so called mini-slump in 2001. The implication of this development is that the consumption of graphics paper is likely to be lower than what the trend projection for high-income region suggests.

Secondly, the trend projections do not take into account new developments related to digital hardware, software, and services. These will undoubtedly strengthen the move from print to digital media. Consider, for example, e-books. They have been around for about a decade or so, but due to their incompleteness, they have not become popular. However, recent advancements in e-book technology and related services have given them a significant boost. The Amazon Kindle and the iPad, for example, have been major successes. There will be even further developments on this front that will make the devices and services more consumer-friendly. Also, the price of e-book devices is bound to decline. Similar developments are likely to take place on many other digital media fronts. Given this pattern, the trends in Figure 9.1 are likely to over-estimate the graphics paper consumption in the future.

In principle, the above arguments are valid in both the high-income and low-income regions. But the magnitudes of the impacts are likely to be greater in high-income regions, at least in the near future. The big question is, when will the electronic media start to replace the print media to a larger degree in the low-income regions? Currently, the low-income region population weighted average internet penetration rate is still only 16.8%, which is about the same as it was in the USA in 1997. But in some major low-income countries, such as China, change is taking place rapidly.

According to *Internet World Stats,* in China, there were 360 million internet users in September 2009, which is the largest number for any country. However, the internet penetration rate is about 27%; whereas, in the USA, it is about 74%. But the internet penetration in China grows very rapidly – the number of internet users has increased by ten times in the last seven years (see Figure 9.3). Just in the first half of 2009, 40 million more Chinese connected to the internet. Also, China's telecommunication firms – China Telecom, China Mobile, and China Unicom – plan to invest USD 40 billion in improving the 3G networks that support voice and video communications, high-speed mobile internet, and mobile television.

In summary, given the rapid spread of the internet and electronic media in the low-income regions, it is likely that the trend projection for low-income region graphics paper consumption shown in Figure 1 will turn out to be an over-estimate. In the coming decade, the currently very low internet penetration ratio will undoubtedly increase significantly in these regions. The impacts of this will also be large due to the fact that the bulk of the world's population lives in low-income regions.

9.2.2 Implications for the Forest Sector

What are the major implications of the ICT development for the global forest sector? First, the demand for graphics paper products will be lower than it would be without ICT development. In order to give an idea of the possible magnitude of the impact, consider the following case.

Assume that the historical pattern of graphics paper consumption in high-income regions had continued, and the trend between 1990–1999 was used to project the consumption up to 2020. Based on this trend, the consumption would be 137 million tonnes in 2020, instead of the 83 million tonnes projected in Figure 9.2. The difference is 54 million tonnes, and it is to a large extent due to the impact of ICT.

These 54 million tonnes equals the sum of graphics paper consumption in North America and Japan in 2007. How many pulp and paper mills are needed to satisfy the current level of North American and Japanese graphics paper consumption? What are the direct and indirect impacts of these mills to turnover, taxes, and employment? What about the implications to pulpwood consumption?

Assume that the graphics paper production in 2020 would be based on the mix of wood fibre we observe today in high-income regions. That is, the share of chemical pulp would be about 40%, mechanical pulp 13%, and recovered paper 54%. Then, the 54 million tonnes decline in paper consumption would imply about 128 million cubic meters less of pulpwood demand (assuming that one unit of chemical pulp requires 5 units of pulpwood, and one unit of mechanical pulp requires 2.8 units of pulpwood, according to Finnish Statistical Yearbook of Forestry 2008). This is more than the total sum of annual industrial roundwood production in Finland and Sweden in 2007.

Even though the above projections and calculations make many assumptions and simplifications, they help to point out that the impacts of ICT to the global forest sector will be of major significance. Moreover, the negative impacts are not restricted to declining paper, pulp, and pulpwood consumption, but also to declining prices and profits. The pulp and paper industry companies are not only competing against other paper companies, but also against the electronic media. Partly due to this, the real prices of graphics paper products have been significantly declining in this century. This also implies that the pulp and paper companies have increasing difficulties to pass their higher production costs onto paper prices (Hetemäki 2008).

The other side of the impacts of ICT on the global forest sector is that it helps to boost productivity and creation of new products. ICT hardware, software, and services are essential tools for increasing the productivity of pulp and paper mills, as well as forestry productivity. On the other hand, the convergence of print and electronic media is creating new products, such as the radio-frequency identification (RDIF) tags and intelligent packing products. These provide new opportunities for the pulp and paper companies, and re-structuring of their product mix.

9.3 Biotechnology Applications in Forestry

Biotechnology is any biology-based technology that develops or uses living organisms to produce, alter, or improve a product or organism for a specified purpose. It has many applications in industry and in the environment (environmental technology). Biotechnology is based on several methods and approaches. Plants can be multiplied by clonal propagation, giving identical offspring. Gene transfer of valuable genes has been conducted for the genetic improvement of forests. In plant breeding, genetic markers are used to develop better plants. Trees cannot exist without soil microbes that influence tree growth in many ways. This fact was only recognised some 20 years ago and has slowly resulted in more detailed data on how microbes can affect the growth of woody plants. Awareness of the immense biodiversity in the microbial world has contributed to the development of microbial ecology. Microbes can and will be used to improve plant performance, and the plant-microbe system may improve soil quality and forests. Although genetic techniques are fundamental in the biotechnology of plants and their associated microbes, this endeavour will not implicitly lead to the construction of transgenic plants and genetically modified organisms (GMOs) in the finalised technology. The challenge in this venture is to get products that are ecologically friendly and that will function well in changing environmental circumstances.

World demand for forest products has increased substantially with increases in population and wealth (FAO 2008). Meeting people's basic needs for living and providing a good quality environment could be better realised by more effective use of fundamental ecosystem services; this has become the great challenge. In general, technological advances in forest sciences followed in the footsteps of advances in agriculture, so it would not be a surprise to see many applications of biotechnology being used in forestry. Biotechnology has the potential to improve the quality and quantity of wooden raw material supplies in a long-term perspective and could also have a radical effect on pulping processes, waste-to-energy systems, and other aspects of the manufacture and use of forest products. Reduced costs and increased yields are the potential economic benefits of biotechnology, which implies that society could get more outputs for its expenditure of inputs. Biotechnology could also have environmental benefits. Plantation wood can reduce the commercial logging pressure on natural forests, and thus the threat to biodiversity and the natural habitats of important species.

In this section we will first cover the more traditional biotechnology applications in forestry, and then describe phytoremediation and its use.

9.3.1 Specific Forest Tree-Based Applications of Biotechnology

At present, forestry is facing great financial pressure to increase the production of wood and industrial wood fibre. Fast-growing plantations permitting lower costs, higher product quality, and reduced use of both chemicals and energy are needed. Biotechnology has significant potential to help the forest products industry overcome the challenges of meeting these needs.

Clonal Propagation

In forestry, most commercial-scale cloning methods have relied on the rooted cuttings method. Clonal propagation has opened up avenues for the development of new high-performance clonally replicated planting stocks in forest plantations (Sutton 2002). Clonal propagation can produce large numbers of genetically identical plants. Recently, the forest industry has focused increased research efforts on clonal propagation via somatic embryogenesis (the production of plants from plant cells that are not normally involved in the development of embryos; i.e., ordinary plant tissue). This approach appears to have several advantages over other clonal propagation systems, including its potential for high multiplication rates, and the potential for scale-up and delivery via bioreactor and synthetic seed technologies. Long-term storage of genetic lines is possible, and large-scale production from field-tested clonal lines is likely in a few species, such as loblolly (Gupta and Durzan 1987) and radiata pine (Christian et al. 2005). Often, work in conifer embryogenesis has been carried out by private forest companies and is thus mostly disclosed only in patents.

Marker-Aided Selection and Breeding

Marker-aided selection involves molecular genetics simultaneous analysis of parents and progeny to find individuals that carry genes associated with desirable traits. This technique is increasing in importance as more comprehensive genetic maps and the locations of quantitative trait locis (QTLs) are found for each species. QTLs are stretches of DNA that are closely linked to the genes that underlie the trait in question. In the candidate gene approach, genes assumed to be involved in the trait are genetically mapped and associations with QTLs for that trait analysed (Brown et al. 2003). QTL analysis can be applied to phenotypes with analysis of gene expression levels in a mapping pedigree. The candidate gene approach performed in *Eucalyptus* species suggested that growth and lignin characteristics are controlled by the same loci (Kirst et al. 2004). Recently, several research groups have suggested that association genetics might become an efficient tool to identify the genes that determine traits (Boerjan 2005, Ingvarsson 2005). Marker-aided selection in forest trees will become an increasingly applicable technology.

By using clonal propagation techniques, individuals with selected traits, or the highest performers from testing trials or breeding programs, can be replicated at a large scale, capturing both additive and non-additive genetic variation from traditional breeding.

Genetic Engineering

Genetic engineering involves insertion of one or more genes into cells of superior genotypes and *in vitro* propagation of transformed plants. Advancements in gene cloning and genomics technology have enabled the discovery and introduction of value-added traits for wood quality, resistance to biotic and abiotic stresses, and reducing flowering or sterility, into improved genotypes. Manipulation of lignin and cellulose content used for pulp and paper making is highly desirable from both an economic and an environmental point of view (Franke et al. 2000, Pilate et al. 2002). Some of the novel biotechnological approaches used recently for the genetic improvement of trees are as follows:

- Reduction of generation time, thus accelerating the genetic improvement program in citrus (Peña et al. 2001). This approach can be extended to other economically important trees.
- Genes important in the pathway of lignin development have been modified to produce unique wood in very young trees (Akim et al. 2001).
- *Populus* plants have been transformed with an insect-tolerance gene (McCown et al. 1991). Manipulation of production levels of natural products for increasing resistance to insects and diseases through genetic engineering has been undertaken in plum (Scorza et al. 2001) and elm trees (Newhouse et al. 2007), for example.
- The use of transgenic hardwoods for phytoremediation; i.e., the use of plants to stabilise, reduce,

or detoxify pollutants. Recently, several studies demonstrate the potential for enhancing phytoremediation of explosives using genetic engineering with poplar (Doty 2008).

- The development of gene-transformed trees for tolerance to drought and extreme temperatures, candidate gene testing, production of secondary compounds, site remediation, fibre quality, etc. could provide basic biological knowledge and even employment, and contribute to reducing global warming and other global environmental issues.

Genomics

The recent completion of a whole-genome sequence for *Populus* has laid the foundation for reaching a goal for model species (Tuskan et al. 2006). *Populus* trees are able to grow on polluted sites containing heavy metals and organic pollutants, and the mechanism for tolerance can be studied on the RNA-level by transcription analysis. The whole-genome data has allowed studies on plant responses to stressed conditions, such as drought and pollution. In the relatively near future, we can anticipate additional reference genome sequences, including the much larger *Pinus* genome.

The application of genomics to improve forest productivity and sustainability still entails capturing a large proportion of the total genetic variation controlling the component traits. Nonetheless, genetics and genomics are unifying disciplines that will serve well to dissect the variables and mechanisms of tree growth and development (Grattapaglia et al. 2009).

9.3.2 Trees for Environmental Restoration

As we know, people's basic needs are not only for food, water, clothing, and shelter, but also for a good quality environment. Forest trees have traditionally been grown taking only chemical and physical environmental factors into consideration, but the biological factors have significantly increased in importance. Phytotechnology is beginning to offer efficient tools and environmentally friendly solutions for the cleanup of contaminated sites, the development of renewable energy sources, and for contributing to sustainable land management.

Phytoremediation is a way to remediate polluted environments by using plants. In the 1990s, the field of microbial ecology developed strongly with increasing awareness of the immense biodiversity in the microbial world (Torsvik et al. 2002). Just as humans are dependent on microbes for their well-being in the form of microbial communities in the gut assisting in the digestion of food, so are trees dependent on below-ground microbes that break down and transform compounds to usable forms for the plant. With the help of new molecular genetic techniques, studies of the microbial communities in rhizospheres show specific rhizosphere effects that challenge the view of separate life forms in soils and plants (Sipilä et al. 2008). This finding is used in rhizo-remediation of hydrocarbon-polluted soils (Susarla et al. 2002).

Phytoremediation Using Woody Plants

Our environment has continuously been polluted by human activities and, since the 1960s, we have slowly become aware of the consequences of allowing heavy metals, DDT, and other toxic chemical compounds to spread out in soils, water, and sediments. Woody plants can be used to improve soil quality, and represent a more environmentally compatible and less expensive method to site restoration compared to physicochemical and engineering approaches. Plants can be used to accumulate toxic metals and organic pollutants from contaminated soils and water for cleanup purposes (Golan-Goldhirsh et al. 2004). In rhizo-remediation (a type of phytoremediation), for example, the microbes in the rhizosphere assist in breaking down hydrocarbon pollutants (Figure 9.4). It is a "green solution" that fulfils the criteria of sustainable development.

Rhizo-Remediation

Rhizo-remediation is a special form of phytoremediation where the plant root rhizosphere is well-recognised for its numerous effects on soil microbiota; it has a pivotal role in phytotechnologies (Kuiper et al. 2004). The plant rhizosphere is truly a hotspot for microbial interactions and a driving force for the formation of growing microbial populations with degradation capacities. This complex food web utilises the large amount of carbon fixed by the plant and releases it into the rhizosphere (i.e., rhizodeposits) (Salt et al. 1998). For example, the degradation of PAHs (polyaromatic hydrocarbons) in soil and groundwater is accomplished when poplar roots grow into the water table (Widdowson et al. 2005).

Microbes to Assist in Green Applications

In stressed soils, such as in petroleum hydrocarbon-polluted soils, the roots harbour bacteria that have degradation potential, but also mycorrhizal fungi, with their associated bacteria, which become impor-

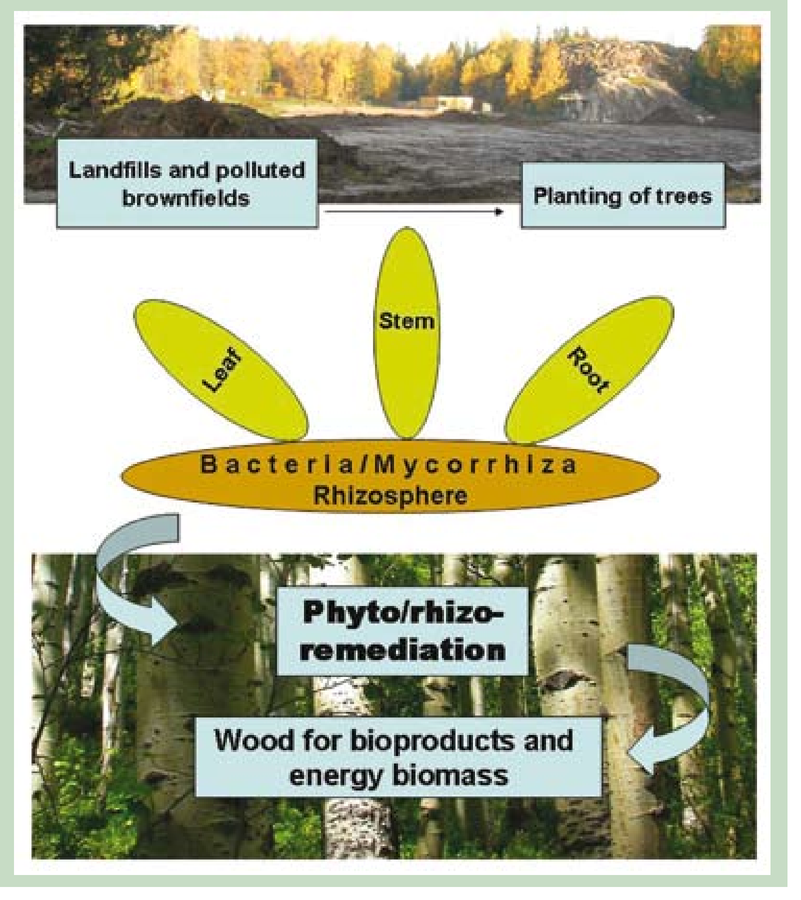

Figure 9.4 Phyto- and rhizoremediation to clean up and improve soil quality of landfills and brownfields polluted with heavy metals or organic compounds like petroleum hydrocarbons. The tree biomass can be utilized for energy production.

tant in a remediation process (Figure 9.4). Microbes also live above ground on plant surfaces, and even inside a plant in plant tissue. These endophytic bacteria were recently shown to have an active role in biodegradation (see Box 9.2). They metabolise toxic aromatic compounds inside the plant and prevent evapotranspiration (Moore et al. 2006). Rhizo-remediation of toluene, for instance, can be improved through horizontal gene transfer to endogenous endophytic bacteria in poplar (Taghavi et al. 2005). The behaviour and effect of mycorrhizae, and their interplay with bacteria in plants in bioremediation, is poorly understood, yet they are fundamental in the development of natural resources for environmental technology.

9.3.3 New Prospects for Forest Biotechnology

Environmental challenges open up new prospects for forest biotechnology. During the last three decades, oil crises, agricultural surpluses in developed countries, and global climate change have increased interest in short-rotation forestry (SRF). The importance of biofuels in the energy sector has recently initiated programs for the development of short-rotation forestry in the boreal climate zone (Walle et al. 2007). Bioenergy from biomass has been identified as having significant potential to contribute to reductions in greenhouse gas emissions and to the maintenance of a secure and sustainable energy supply (Figure 9.4). Short-rotation coppice (SRC) describes any high-yielding woody species managed in a coppice system. Typically, these crops are harvested on a 3–5 year rotation and remain viable for 15–30 years (Aylott et al. 2008).

A plausible and interesting development in phytoremediation is its integration with landscape architecture. In this context, the remediation of urban sites, like parks and nature areas, may be combined with other uses so that the area may be used by the public during and after the remediation process while minimising risk. In some locations, these types of areas can even be turned into wildlife sanctuaries (Pilon-Smits 2005).

A cornerstone in these applications is the recog-

Box 9.2 Endophytic bacteria to improve fitness of woody plants

Kim Yrjälä and Lu-Min Vaario

When not only microbial communities, but also individual microbial species, are identified from the rhizosphere, it has been shown that bacteria migrate to the plant tissues as well. Plants harbour endophytic bacteria so far best known as pathogens, but enthusiasm for this particular group of bacteria has arisen because of their beneficial properties (Lodewyckx et al. 2002). Endophytic bacteria are defined as those bacteria that can be isolated from surface-disinfected plant tissues, or extracted from within the plant, and do not visibly harm the plant (Hallmann et al. 1997). Endophytes are found in internal microenvironments of shoots and leaves, referred to as the endosphere, and additionally in the microenvironment of roots, defined as the endorrhiza. At least 82 genera have been detected from a broad range of plants, including woody plants (Araujo et al. 2002, Bent and Chanway 2002). Endophytic bacteria may contribute to the well-being of the plant, acting as growth promoters synthesising phytohormones and enzymes, and by fixing atmospheric nitrogen. Potentially, they can protect the plant from pathogenic fungi by their anti-fungal activity (Compant et al. 2005, Zachow et al. 2008).

nition that microbes live in association with woody plants in such a way as to confer, or mediate, beneficial effects to the plants (Box 9.2). When the "microbiome" of the woody plants functions for the good of the plant, this can be used in biotechnological applications. Phytoremediation is most conveniently used on areas having lower pollution levels. Large areas can be covered by the plant to improve the quality of the land, and expand the putative use of the area for a variety of human activities. The forest biotechnology envisioned here is not inherently part of the development of transgenic plants. The transgenic method to improve plant growth, wood quality, and other aspects to be improved is one technique, but is not necessarily needed for phytoremediation. The plant/microbe system is detrimental for remediation of polluted sites and biomass production.

Although many advances in forest biotechnology have produced important products and discoveries, there are several associated problems for forestry and forest resource managers that are surfacing from these technologies. The public belief is often that wherever selected woody plants are used for biotechnological purposes, they must be much debated transgenics. Trees are an invaluable part of our nature that appears as a key part in pristine unspoiled ecosystems, but also in city ecosystems heavily modified by humans. Understanding their ecological role locally and globally builds the foundation for future biotechnology applications in forestry. Trees can be planted and consequently utilised in a much more effective way when their associated microbes are recognised to improve growth and ecological functions. A wider perspective for forest biotechnology is needed that takes into account the huge challenges put forward regarding biodiversity and climate change. Innovations in forest biotechnology may make use of nature's own resources when scientific knowledge about plants and their associated microbes are acceptable to being used in practical applications. This does not mean we have to design transgenic plants to overcome the challenges, but to understand the biological basis for tree growth, which is dependent on below-ground processes and the microorganisms living in association with the plants.

Forest trees are world-wide resources that humankind has depended upon for fibre, fuel, food, shelter, and a living environment for millennia. Coming under greater pressure, this resource requires more and more efficient means for growth and management. Overall, biotechnological applications using clone propagation, markers-aided selection and breeding, gene transfer, and beneficial microbes are already having an impact on how some trees are being bred, propagated, developed, and managed. All can contribute to increasing the efficiency with which we produce and use our forest tree resource and thereby help make sure this resource is available for future generations.

9.4 Precision Forestry by Means of Advanced Laser Measurements

9.4.1 Precision Forestry

The management of today's forests has become increasingly complex. In addition to timber production, new objectives of forest management have been introduced, such as preserving biodiversity, carbon sequestration, deforestation estimates, creation of recreational opportunities, hunting considerations, and many others. Forest management decision support systems (DSS) have been developed to aid forest managers in their difficult tasks. However, in order to utilise all the advanced planning features of these systems, accurate and precise information on resources is a prerequisite.

The starting point for evaluating a forested area must always be the forest inventory data that describes the area's timber resources, sites, and possible values other than those related to timber production. If the computational input data are inaccurate, the simulation of DSS will produce an unrealistic output and suboptimal solutions. The accuracy of this information is strongly dependent on the inventory methodology used. To increase wood value and productivity in industry, better information on wood raw material quantity and quality, combined with logistic concepts that integrate transport systems and management models throughout the wood raw material supply chain, will be needed.

Technologies for acquiring spatial forest resource data have developed rapidly in recent years. Fieldwork has been enhanced by global satellite positioning systems (GPS), automatic measuring devices, field computers and wireless data transfer, and modern remote sensing, especially laser-based measurements, which are now able to provide cost-efficient spatial digital data that are more accurate than ever before. Information obtained by laser scanning and digital photogrammetric images will be utilised increasingly.

New technology allows a "Precision Forestry" approach. We define precision forestry as a combination of method by which we are able to accurately determine the characteristics of forests, treatments, biodiversity preservation, or recreational opportunities at the stand, plot, or individual tree level, as well as using individual tree level assessments for simulation and optimisation models of forest management DSS. In the Precision Forestry approach, airborne remote sensing (e.g., airborne laser scanning (ALS), imaging spectrometer, or digital photogrammetric imaging) field-measurements supported by terrestrial laser scanning and new positioning technologies and data from logging machines are combined and used to improve forest inventory and forest management planning, as well as logistics of the wood supply chain.

9.4.2 State-of-the-Art in Forest Inventory

According to Finnish experience, alternatives for obtaining input data for DSSs are the measurement of standing trees, plot sampling, compartment inventories in the field, remote sensing, and various combinations of remote sensing and field measurements. Rough, estate-level data may be obtained by interpreting mid-resolution satellite imagery. However, in order to obtain the compartment- or tree-level field measurements, detailed remote sensing, or a combination of these two techniques is required. The most accurate remote sensing methods provide data equivalent in accuracy to that of traditional standwise field inventory. In addition, measurements taken by logging machines provide information on felled trees.

Measurement of all trees on a strategic-level large area forest inventory is economically not possible by conventional means. Therefore, a representative sample of the total tree population is selected, the objective of which is to obtain reliable estimations of data for the whole tree population. In the case of large forest areas, sampling is based on plots. The most common sampling method used is systematic plot sampling. In Finland, the methodology used has been to combine satellite imagery, digital geographical information, and field measurements in forest inventories. The main idea of these systems is to derive forest resource information for smaller forest areas in a more cost-efficient manner than solely by using field sampling. In the National Forest Inventory (NFI) of Finland, multi-source inventory data measured in the field is generalised to mid-resolution (Landsat TM) satellite imagery pixels using a nonparametric estimation (Kilkki and Päivinen 1987, Tokola 1990, Tomppo 1990). As an advantage of this methodology, it can be pointed out that values for all characteristics measured in the field (more than 100 in NFI) can be assigned to the interpreted pixels simultaneously.

In practice, estimates obtained by multi-source NFI can be considered reliable in forest areas larger than 100 ha (Tokola and Heikkilä 1995) if the field data used as a ground reference represents well enough the forests in that region. The accuracy of estimates derived from medium resolution satellite image interpretations and NFI at the plot level has been about 65–100% for mean volume (e.g., Hyyppä et al. 2000, Tuominen and Poso 2001), i.e., the accuracy of estimates have not been high enough at operational stand-level forest inventories.

Usually, the basic unit of operational stand-wise forest planning is the compartment. It is defined as a uniform area that can be distinguished by some criteria from its surroundings (Poso 1983). In forest planning, compartments are usually delineated into uniform areas by future silvicultural treatments. Other factors taken into account are stand age, proportions of tree species, and ground vegetation. In the future, developing remote sensing techniques will probably lead to a transition into the use of smaller subcompartments or grid cells enabling analysis of variation within compartments.

Traditionally, stand-wise inventories have been based on the delineation of compartments by visually interpreting aerial photography and the measurement of subjectively placed relascope plots in the field. Sources of error related to compartment inventories are delineation of compartments, placing of relascope plots and relascope plot mensuration, and model errors. Compartment inventories are subjective by nature and therefore the related sampling error variance cannot be estimated without carrying out separate control measurements.

During the past ten years, three dimensional (3D) methodologies based on digital photogrammetry and laser scanning have experienced a major leap in conducting forest inventories. Airborne laser scanning (ALS) has been shown to be an accurate remote sensing technique for stand-wise forest inventories, and provides accuracies ranging between 10 to 30% for mean volume of the stand (e.g., Næsset 1997, Hyyppä and Hyyppä 1999, Maltamo et al. 2004, Næsset et al. 2004), and is far more accurate than other automatic remote sensing-based techniques (e.g., Hyyppä and Hyyppä 1999). The current data acquisition and processing cost is less than that of conventional stand-wise field inventory. Overviews of laser scanning technology can be found in Baltsavias (1999), and for using ALS in forest inventory in Næsset et al. (2004) and Hyyppä et al. (2009).

Measurements of the individual trees would be the ideal method for acquiring initial forest data. Unfortunately, traditional methods for acquiring tree level forest data are too time-consuming and costly to be adopted in practical forest mensuration. In addition to ALS, terrestrial laser scanning (TLS) and vehicle-based laser scanning (VLS) methods may provide measurements on individual trees in larger forest areas in the future. More detailed description of ALS, TLS, and VLS inventory methodology can be found in Box 9.3 and in Appendix 9.1.

9.4.3 Future Possibilities of Laser Measurement-Based Precision Forestry

Operative Forest Planning and Timber Harvesting

Forest inventory data in Finland, on which all planning activities rely, are currently acquired using stand-wise field inventory to homogeneous compartments typically having an area of 0.5–3 ha. The stand-wise inventory consists of delineation of a forest area into separate units, or forest stands. Each stand is further stratified into tree species strata and mean characteristics, including the basal area; mean height and mean diameter are estimated based on subjectively placed relascope sample plots on each stand.

Almost half of the total cost of stand-wise forest inventory consists of field measurements (Holopainen and Talvitie 2006). The main attributes driving the planning process are total stem volume, basal area, and mean height, for which the required accuracy (relative standard error) is approximately 15%. However, in practice, accuracy at the stand level ranges from 15% to 40% in boreal areas, depending on the heterogeneity of the forest (Poso 1983, Haara 2005). The stem volume for each tree species is obtained with significantly lower accuracy. In addition, stand-wise inventory often contains significant bias (0–25%), which varies with the person doing the inventory. If the stand-wise approach is used in tropical or temperate forest areas, accuracy is lower because of more heterogeneous forest structure.

Many forest organisations have adopted continuous updating as a part of their forest planning procedures. In the continuous updating, stand-wise forest inventory data act as a starting point. After the inventory, stand development and effects of silvicultural treatments are simulated using various models. In computational stand data, updating the quality of the input data describing the stand's present state has a decisive impact on the reliability of the output results (e.g., Haara 2005). When making decisions on the basis of updated stand data, it is important to be aware of the quality and reliability of the data in order to be able to take into account possible risks. Because of errors inherent to the stand-wise field inventory data, the reliability of current updated stand data is so poor that trustworthy treatment propositions cannot be made without field controls.

Economical Valuation of Forests

The economical value of forests is crucial information for landowners and various forestry organisations. Estimates of the value of forest estates are needed for many purposes, including real estate business, land divisions and exchanges, and for considering forestry investment. The need for determining the value of forests has become more important since forests are increasingly considered as one possible investment outlet among other real or financial assets. International Financial Reporting Standards (IFRS) also require that forest enterprises present systematically computed estimates of the value of their forested land annually. The methodologies used for assessing forest value vary among companies and organisations. Probably the most common method currently used for assessing forest estate value is computing the net present value (NPV) based on predicted future cash transactions. The sales comparison approach, in which the forest property market value is derived by comparing the property to recently realised transactions that resemble the property as much as possible, is also used to some extent.

Reliable inventory data are essential for forest planning and valuation of a forest estate. In assessing the state of a stand, the estimates may differ significantly from the real situation due to the inventory method used. More information on the economic valuation of forests is presented in Box 9.3.

Estimation of Biomass, Growth and Forest Damage

Forest growth and site productivity are also essential variables for forest management and planning, particularly in assessing the economical, ecological, or recreational values of a forest stand. Box 9.3 introduces more detailed information on ALS utilisation for measuring forest growth, and Appendix 1 contains additional information on laser applications in forest inventories.

Box 9.3 also describes additional considerations for the use of remote sensing (satellite imaging, digital aerial photography, and ALS) for estimating biomass and forest damage variables, which are essential data, particularly in forest inventories, planning, and valuation analyses. Increased damage to forests resulting from global climate change, such as invasions by alien species or infestations by insects, are just two of the likely results of global climate change. Successfully dealing with these is indicative of the great environmental challenges we face today. It is extremely important that we have the tools and models that enable us to predict changes in the distribution of organisms and carry out the ecological, forest, and biological research that we need to do.

Box 9.3 Laser measurement-based precision forestry

Markus Holopainen and Juha Hyyppä

Operative forest planning and timber harvesting

Most of the ALS (Airborne Laser Scanning) research in forest inventory has focused on the estimation of mean characteristics, such as plot or stand mean height or mean volume. However, from the standpoints of operational forest planning, timber harvesting, and forest value assessment, the prediction of species-specific assortment out-turn volumes is by far the most essential issue. For example, the economic value of a forest stand cannot be accurately determined on the basis of total stem volume only. Instead, information on tree species and stem distribution is required to reliably determine the distribution of the total stem volume in various timber assortments.

First studies to obtain tree species- or timber assortment-specific estimates by means of low-pulse ALS data were undertaken by Packalén and Maltamo (2006, 2008), Peuhkurinen et al. (2008) and Holopainen et al. (2010c). All of these studies showed that tree species- or timber assortment-specific estimates can be obtained by means of ALS inventory, but with lower accuracy than total volume.

In the future, very interesting option is the integration of ALS, TLS (Terrestrial Laser Scanning) and VLS (Vehicle Based Laser Scanning) data. Vehicle-based laser scanning mounted on a logging machine can be used to make a local tree map that contains information about individual tree stems. This information can be integrated with airborne data, giving good quality information from tree heights, positions, and crown characteristics; and with terrestrial data giving high accuracy measurements of selected plots. Since ALS and TLS are used to produce a basic inventory at the individual tree level, the real-time processing of VLS data from logging machines allows updating of the inventory data in real-time. Updating is needed, since ALS is not capable of accurately collecting stem curve and diameter, and sampling of diameter with TLS can result in too-high averaging of the data. After real-time updating and harvesting of a couple of trees, the updated inventory data can be used for the precise selection of trees to be cut; it also helps in the bucking of stems. VLS and ranging systems on the logging machine can also be used to help in improving the location information of the machine. The matching of VLS-derived trunk positions to ALS-derived trunk positions results in significantly higher accuracy in positioning, which is currently one of the information bottlenecks in the process.

Economical valuation of forests

Forest inventory data accuracy has a decisive impact on the success of forest-planning computations and determination of forest net present value (NPV). Errors in inaccurate inventory data increase in magnitude during the execution of long model chains and cause significant output errors. The longer the reference period, the larger the output errors; thus, inaccurate input data are especially problematic in the case of forestry yield value determination throughout the rotation period. In addition, inaccurate input data cause significant non-optimal losses in forest planning and forest silviculture if the timing of various treatments fails due to erroneous input data. This aspect can be studied using cost-plus-loss analyses in which the expected losses due to non-optimal decision-making are added to the total forest inventory costs. The cost-plus-loss approach was widely utilised in recent forest inventory- and planning-related research (e.g., Holmström et al. 2003, Eid et al. 2004, Holopainen and Talvitie 2006). Holopainen and Talvitie (2006) concluded that as a result of better inventory accuracies, 3D remote-sensing methods and stand-wise methods always produced better results than the 2D method when NPV losses were accounted for.

Holopainen et al. (2009) studied the sensitivity of tree- and stand-level forest management planning systems to the accuracy of the tree and stand level input data sources. They showed that input data accuracy had a significant influence on the timing of thinning and clear-cutting, and on predicting the net income of forest stands. They also concluded that the highly accurate height information obtained by ALS could not be fully utilised in either tree- or stand-level forest management planning simulations.

Holopainen et al. (2010a) compared the relative importance of various sources of uncertainties in determining the NPV of forest stands and forested property. They showed that errors in the growth projections and the quality of inventory data contributed more to the variation in stand net present value than did fluctuation in timber price. In applying the methodology developed, the effect of various sources of uncertainty on the outcome of forest NPV computation can be taken into account and confidence intervals can be set for the output results. The study also resulted in information on which uncertainty sources to focus attention to increase the certainty of the output results. This is currently needed because new ALS-based inventory methodologies are being used in operative forest planning.

Forest growth

Laser-based methods for measuring forest growth are relatively simple in principle. The height growth can be determined by several means: from the difference in the height of individual trees determined from repeated measurements (Yu et al. 2004) (see Figure 9.3), from height difference of repeated digital surface models (DSMs), from repeated height histograms (Næsset and Gobakken 2005), or from difference of the volumes of individual trees (Hyyppä et al. 2009). The changes in forests that affect the laser scanning response include the vertical and horizontal growth of crowns, the seasonal change of needle and leaf masses, the state of undergrowth and low vegetation, and the trees moving with the wind (especially for taller trees). The technique applied should be able to separate growth from other changes in the forest, especially those due to selective thinning or naturally fallen trees. The difference between DSMs is assumed to work in areas with wide and flat-topped crowns. In coniferous forests with narrow crowns, the tree top displacement between two acquisitions can be substantial, for example, due to wind. Height histogram changes also include changes from thinnings.

Yu et al. (2005) showed that height growth for individual trees can be measured with an accuracy better than 0.5 m using multi-temporal laser surveys conducted in a boreal forest zone for a four-year time series and higher point density. Laser data can also be used for change detection. Yu et al. (2004) examined the applicability of airborne laser scanners in monitoring harvested trees using datasets with a point density of about 10 pts/m^2 over a two-year period. The developed automatic method used for detecting harvested trees was based on image differencing.

Estimation of biomass and forest damage

The increase of forest damages and invasions by forest insects has been seen to be related to the global changes in the climate. Biological invasions and climate change are two of the components of global change comprising the greatest environmental challenges of today. Prediction of the changes in the distribution of organisms has become a topical issue in the ecological, forest, and biological research.

Remote sensing, such as optical and microwave satellite imaging, digital aerial photography, and ALS, is at its best in various forest monitoring tasks. Detailed remote sensing (aerial photographs and ALS) can also be well applied to the assessment and monitoring of forest health, either on the stand or single tree levels.

Hyyppä et al. (2010) studied the capability of TLS to derive changes on the standing tree biomass and defoliation degree by destructive, consecutive defoliation operations. Biomass changes of pine (Scots pine) and spruce (Norway spruce) trees were shown to be highly correlated with the number of hits in the TLS point cloud. The results explain why ALS is effective for stem volume estimation, since the number of hits recorded by ALS is most probably highly correlated with the biomass, and especially needle and branch biomass, which, in turn, are correlated with stem volume. Future test are needed to verify this, but we assume that laser measures of tree height, crown area, and biomass of needles and branches, are of a very high quality.

Input Data for Tree and Stand Level Forest Models

Terrestrial laser scanners have the potential to revolutionise measurement of the vegetation canopy structure by making rapid, semi-automatic measurements of key biophysical variables with unprecedented levels of accuracy. Variables such as leaf-area index, vertical foliage distribution, and tree-level data (stem curve, volume, diameter, biomass, tree species, branch orientation, crown height, tree height) can be determined from the TLS data. Terrestrial laser scanning can also be used in a multi-temporal way to produce a time series of these canopy components and their changes over time.

9.4.4 Conclusions on Laser Measurement-based Precision Forestry

The world's forestry is facing old and new challenges for which laser technology and precision forestry could help to address some of the bottlenecks in information. The most fundamental contribution these bring is to provide means to more accurately, more objectively, and more efficiently measure and monitor the quantity and quality of forest biomass. By doing this, the technology can help to answer the many information needs we have related to forests. Next, we summarise a few of the economical and ecological benefits that could be achieved by applying the concepts of precision forestry previously discussed.

Precision forestry can be applied to increase the efficiency and information basis of existing national forest inventories and operational forest management planning. The logistics chain from forests to end products can be planned in higher detail. In addition, precision forestry allows certification of wood origin, since the location of every stem is recorded by forest inventory and logging machines, and updated to maps.

Accurate information on stem dimensions and quality will aid in optimal cutting of stems, maximising the value of the stem for both forest owners and raw material buyers, and result in better knowledge of the value of forest resources, both as a source for industrial raw material and as a provider of other services.

Besides the local and national requirements discussed above, there are also increasing demands for global forest assessments. One of the most acute and important applications would be to enhance the implementation of the REDD (Reducing Emissions from Deforestation and Degradation) program. The program aims to generate resources that would help to significantly reduce global emissions from deforestation and forest degradation. These resources would be used to create incentives to ensure actual, lasting, achievable, reliable, and measurable emissions reduction while maintaining and improving the other ecosystem services forests provide. The countries and institutions that are financing these operations need information to verify that the actions being financed are actually implemented in the forests, and that the results can be monitored. For these purposes, precision forestry can provide a valuable tool, especially when biomass estimations and detection of changes are needed.

ALS is carried out at relatively low altitudes, which makes it relatively expensive per area unit. Other remotely sensed data will still be needed, especially when updated information is required several times per year in large forest areas. Of special interest are inexpensive images with favourable temporal resolutions that can be utilised in multiphase sampling and change detection in addition to the ALS measurements. A major advantage of radar images, compared with optical region satellite images, has been their ready availability (temporal resolution) under all imaging conditions. This makes radar imaging, especially the Synthetic Aperture Radar (SAR) carried by satellites, an intriguing option in developing methods for operational inventorying and monitoring of forest resources of large forest areas (e.g., Holopainen et al. 2010b).

In addition to integration of ALS and SAR data, future space-borne laser systems, probably in orbit within the next decade, are interesting options that will increase the possibilities to employ the precision forestry concept at the global level.

The costs of precision forestry described here are close to the traditional stand-wise inventory methods, about EUR 10 /ha, depending on the implementation. It is more costly than current area-based laser inventory, which costs about EUR 5–6 /ha. All remote sensing and field-based forest inventory techniques are less accurate in heterogeneous forests, such as in the tropics, but laser-assisted techniques are cost-effective compared to traditional field-based measurements.

Precision forestry technology is, however, comparatively expensive and its implementation requires human resources and institutions with the appropriate knowledge to use the technologies, all of which may be lacking in developing countries. Thus, in order to implement REDD or other programs, the technology transfer issue needs to be solved. Technology transfer must be a prominent consideration in helping solve the challenges we face in managing forests, locally, nationally, and globally.

By using more detailed information on forest resources, we can intensify the use and conservation of forest resources, as well as numerous practical forestry applications. It also brings new points of views to forest science. The more detailed information of forest resources can be utilised in more detailed development of models, which can be applied in analyses of scenarios of global climate change studies. Precision forestry can be seen as a linking factor for a variety of forest sciences, and is also a connection between forest sciences and surveyors responsible for land use planning.

9.5 Conclusions and Policy Implications

The development of the global forest sector is married to technological development and the socio-economic context that facilitates technology diffusion. Indeed, technological development has often been the activator of "creative destruction" in the forest sector. The concept of creative destruction was pioneered by Schumpeter (1942), and it refers to the process of transformation in which an established economic structure is destroyed by the emergence of a new, improved structure. The history of technological development, and the examples introduced in this chapter, illustrate that technology can act as a catalyst that *destructs* old economic structures while simultaneously providing new opportunities that help to *create* new, more viable structures. What exactly do we mean by this?

An analysis of the development of information and communication technology shows that electronic media is replacing printing and writing paper consumption, and this, in turn, is resulting in the closure of pulp and paper mills. This has been the case particularly in the traditional big forest industry countries, such as Canada and the USA and the Nordic countries. However, at the same time, the development of ICT clearly is essential for the advances that are taking place such as those in biotechnology and precision forestry-based laser technology, the other two examples presented in this chapter. As discussed, both of these technologies are creating many new and important opportunities that enhance the prospects for the forest sector globally.

The better we understand the nature of technological development and its numerous impacts, both current and potential, the better prepared we are to meet the inevitable changes that such development brings. Within this context, it is important to stress that as important as is the technology itself, so are the social needs, policies, and institutional settings that drive and define technology development. For example, in the box on forest biorefinery (Box 9.1 in section 9.1.2), it was demonstrated how the needs and policies related to climate change and renewable energy are driving the development. Just to give one example, policies requiring mandatory biofuels shares in transportation play an essential role in creating incentives to develop new technologies in forest biorefineries.

The above discussion illustrates at least three things. First, studying technologies and their impacts to the forest sector is important. This requires forecasting the technological trends and their likely impacts on the forest sector. Secondly, technological and innovative developments are closely tied to general socio-economic development. The extent to which there is a need in society for new technology and innovation (demand-pull) is as important as basic R&D in the hardware technology development (supply-push). A part of the demand can originate from the policy. This is, for example, currently the case with respect to renewable energy and climate change policy, both of which also encourage technological development in forest-based energy and materials. The latter factor brings forward the third important factor in technological development: it depends on what types of policies governments implement.

New technologies and innovations applied to the forest sector are increasingly needed to enhance sustainability. Since the early 1990s and the Rio Conference, there has been a re-orientation of economic and social activities towards sustainability. This trend has been labelled in the technological change literature as a process of *sustainable socio-technical change*, *industrial transformation*, and *technological transitions* (Hekkert and Negro 2009). In this literature, the emphasis is on the development of new policies, institutional changes, and wide-reaching system changes that transform societies away from unsustainable patterns to sustainable ones.

In the forest sector, the above line of thinking has materialised in new technology-driven innovation programs. For example, in North America and European Union countries, new forest sector-related technology programs have been started in recent years. The background and motivation for these programs stems from the structural change taking place in the forest sectors in these countries. Given this state of things, the forest sectors in these countries seek to innovate and re-direct their businesses in ways that provide new benefits from their forests. For example, forest biorefinery products and the merging of woodfibre manufacturing with ICT and nanotechnology can provide opportunities for new products, such as forest biomass-based biodiesel and woodfibre-based hybrid media products. Thus, it is again the socio-economic context that is driving the need to create new technologies and products that utilise forests. This also puts the need for studying and analysing technological development at the centre.

Technology, as such, is universal. For example, petrol and diesel engines were developed in Germany, but are used everywhere today. However, in practice, there may be long time lags before technology travels from one country to another. Also, different cultures may adapt differently to a given technology. Therefore, institutional settings, practices, and policies may hinder *technology transfer* between countries. This is particularly relevant in the context of technology transfer from industrialised countries to developing countries. Typically, new technology is, to a great extent, developed in high-income countries, which are better placed for this development in terms of financial resources and scientific and technical know-how.

To some extent, a mirror image of the technology transfer issue is the issue of *traditional knowledge transfer* for generating new opportunities for technological innovations and adaptation. Traditional knowledge can be understood to encompass the set of information, wisdom, practical skills, innovations, beliefs, arts, spirituality, and other forms of cultural experiences that belong to specific indigenous or local communities (Ingold 2000, Simeone 2004). Their knowledge is often embedded in a cosmological vision and bound to ancestral landscapes based on their life experiences over thousands of years. It is customarily transmitted from generation to generation in oral communications through specific cultural mechanisms such as stories, practices, rituals, proverbs, folklore, religious tales, and other means in the frame of a holistic approach. The knowledge is shared by the community, or certain individuals within the community, and is considered as a collective asset. Traditional knowledge is intrinsic to societies in both high- and low-income countries, but it is in the latter where it tends to play a particularly strong role today.

This chapter has only just touched on the above issues. Given that over 80% of the world's population is living in the low-income countries, the technology transfer and traditional knowledge issues are of major significance for the bulk of the world's population. These two issues are also very much policy related, since policies and institutions are likely to play major roles in overcoming some of the obstacles related to them. Consequently, it is warranted to discuss in some more detail what types of issues technology transfer and traditional knowledge bring forward.

Technology transfer can be defined as the process of sharing of knowledge, technologies, skills, and methods to ensure that scientific and technological developments are accessible to a wide range of users. An environment and institutional setting that encourages the adoption of new technology by new group(s) of users is needed for successfully mobilising technology and innovations from developer to "appliers." That requires, in practice, a favourable institutional setting that encourages and endorses the flow of new knowledge and innovations through proper information channels, education and training, commercialisation by market mechanisms, and human and/or material resources support. Such a setting is normally provided by bilateral or multilateral international cooperation between countries and institutions, international initiatives, or by markets.

In order to illustrate what types of challenges may arise with technology transfer, consider the laser technology used for forest inventory, and its possibilities in helping to implement the REDD programme. REDD stands for the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD Programme). The program aims to generate resources that will help to significantly reduce global emissions from deforestation and forest degradation. These resources would be used to implement payment structures and capacity support for developing countries so that they can create the incentives to ensure actual, lasting, achievable, reliable, and measurable emission reductions while maintaining and improving the other ecosystem services that forests provide.

Clearly, one essential part of being able to implement REDD, in practice, would be the ability to reliably monitor the actions and results in the forests resulting from the program. For this purpose, the laser technology and precision forestry could offer important tools.

Technology transfer is essential to overcome the existing asymmetries in the international arena, where rich and poor countries, wealthy and deprived organisations and individuals cohabit, and which often play the roles of providers and consumers of new technological development. Barton (2007) argues that the world is rapidly changing, and nowadays we can identify a number of developing nations that have become much more technologically sophisticated. He states that in a globalising world, the international relations and trade has spread, and economies of scale favour production facilities that serve more than one nation. He exemplifies these changes by referring to the "BRIC" (Brazil, Russia, India, and China) countries, which are likely to become not only a larger force in the global economy, but also major technology developers. However, the conventional North-South dichotomies are still a clear prevailing hindrance in many processes of finding a niche for emergent development initiatives and/or in international cooperation processes and trade arrangements. Climate change dialogues and agreements are good examples in which technology transfer is one of the four essential pillars of the negotiations, together with mitigation, adaptation, and financial measures.

There is a clear need in developing countries to enhance their technological capacity-building, and thus develop robust and competitive industries at the world level to allow them to face the challenges of building successful industrial branches and activities. This process involves the challenge of creating viable activities by upgrading technologies, or developing new technologies with a view to enhancing their productivity and staying financially viable on the frame of a sustainable national development (UNCTAD 2003).

It has been noted that there is a need to expand attention to, and recognition of, the traditional knowledge that people have of their environment, in particular of the local ecological relationships of flora and fauna with other natural resources. This knowledge, embedded in local experiences, has allowed people to respond to changing circumstances with flexibility and skilful adaptability (Colfer 2005). The same author has argued that it is time to expanding our current worldwide view, which is the result of the prevailing reductionist scientific method, with traditional ways of seeing and understanding the world. It would be beneficial to encourage and seek new ways of integrating these diverse approaches – both traditional and modern – of knowing and adapting to the changing conditions (Colfer 2005). There are positive experiences that have been carried out in this perspective, and a few can be cited, such as the development of forest management plans combining high-tech tools and traditional knowledge in Zambia (Polansky and Heermans 2004), and the support of forest preservation in Ecuador (Becker and Ghimire 2003).

Clearly, there is a need to more closely analyse the technology transfer and traditional knowledge issues, and their roles in the development of forest sector technology. Yet, this need points to an even wider lack of knowledge. With a few exceptions, there has been a general lack of research on the impacts of technological change to the forest sector. Given the importance of this issue, there is clearly a need for more activity on this front. Hopefully, the present chapter, for its part, helps to encourage further studies in the field.

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Appendix 9.1 New precision forestry-related technologies

Markus Holopainen and Juha Hyyppä

Basics of using remote sensing for forest measurements

The images produced by Earth observation satellites or aerial imaging systems are utilised in forest inventories by assuming that from these images it is possible to calculate features that correlate well with forest stand characteristics. The images may have multi-spectral (in optical imagery, you receive several channels depending on the received wavelength range), multi-polarisation (in radar systems, you can receive signals in several separate polarisations), multi-temporal (measurements taken at different acquisition times), and multi-frequency (in radar, instead of multi-spectral, multi-frequency measurements are applied) properties.

Airborne laser scanning

Small-footprint airborne laser scanning (ALS) is a method based on laser (Lidar) range measurements from an aircraft and the precise orientation of these measurements between a sensor (the position of which is known by using a differential-GPS technique) and a reflecting object, the position of which (x, y, z) is to be defined. The ALS gives the georeferenced point cloud, from which it is possible to calculate digital terrain models (DTM), digital surface models (DSM) corresponding to tree tops, and 3D models of an object (e.g., Canopy Height Model CHM, normalised DSM), which are the main products used for laser-assisted forest measurements. The two main approaches in deriving forest information from small-footprint ALS data have been those based on laser canopy height distribution (reported by Næsset 1997, 2002) and individual tree detection (reported by Hyyppä and Inkinen 1999). In the former method, percentiles of the distribution of laser canopy heights are used as predictors to estimate forest characteristics. By increasing the number of laser pulses per square metre, individual trees can be recognised. By analysing the canopy model by using pattern recognition methods, it is possible to locate individual trees, determine individual tree heights, crown diameters, tree species and, by using that data, to derive the stem diameter, age, development class, basal area, and stem volume for each individual tree. There have also been attempts at integrating ALS data with aerial imagery (e.g., Leckie et al. 2003), since digital aerial photos provide more details of the spatial geometry, and more colour information that can be used for classifying tree species and health.

Terrestrial laser scanning

Fixed-position (mounted on a tripod) terrestrial laser scanners offer a high potential for 3D mapping of smaller areas with high detail. The principle of terrestrial laser scanning (TLS) is simple – a highly collimated laser beam scans over a predefined solid angle in a regular scan pattern and measures the time of flight of the laser signal. The scanning range of the middle-range terrestrial system allows distance mea-

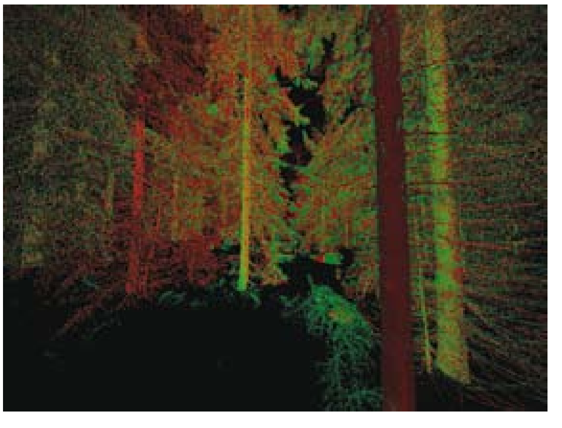

Figure 9.5 Forest measured two times by TLS: before and after harvesting. The trees having only red point clouds represent harvested trees (Copyright Harri Kaartinen, Finnish Geodetic Institute).

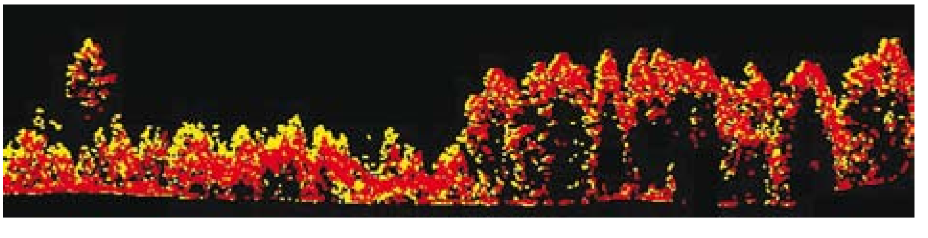

Figure 9.6 A 150-m-long and 6-m-wide cross-section produced from ALS point cloud taken at two times: white in summer 2003 and grey in summer 1998. The change of point clouds indicates removal of trees and growth of small trees (Copyright Xiaowei Yu, Finnish Geodetic Institute).

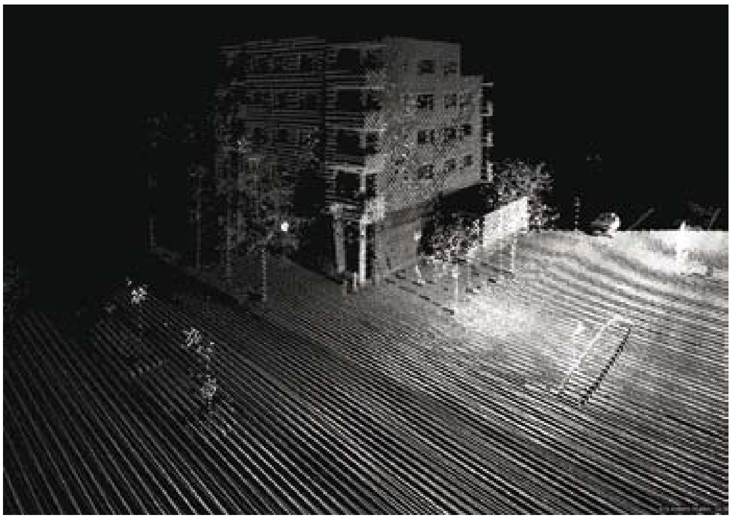

Figure 9.7 Representation of a point cloud collected with VLS from a city area. City trees are well characterised (Copyright Antero Kukko, Finnish Geodetic Institute).

surements between 2 and 800 meters. The potential of TLS is supported combining digital imagery. TLS has been used for detailed modelling of individual trees and canopies. Using TLS for plot-level inventories offers a fast and efficient means of determining basic tree parameters, such as the number and position of trees, diameter at breast height (DBH), and tree height, after the automation of the data processing has been solved properly. The use of multiple scans for plots requires registration of these scans. The use of single scans results in lower capability to reconstruct individual tree trunks.

Vehicle-based laser scanning

A vehicle-based laser scanning (VLS, mobile laser scanning, mobile Lidar) system is a modification of the ALS. It resemble ALS by having a laser scanner, a GPS receiver, an IMU and preferably camera(s), but it is operated from the top of the moving ground vehicle, such as car or a harvester, and it is used for shorter distances. Due to shorter operating distances, it can more easily have a higher pulse rate than an ALS. At present, it is possible to use software and methods developed for terrestrial and airborne laser scanning, but due to different scanning geometry, changing point density as a function of range and the fast processing needed, algorithms for VLS data processing need to be developed separately. The VLS also provides new possibilities to monitor city forests. Currently, there is work towards characterisation of the quality of city trees with the VLS.

Field data acquisition using logging machines and GNSS

Another new and interesting ground-truth data source is stock data recorded on logging machines. Modern logging machines are commonly equipped with GIS software and GPS devices, enabling data on each harvested tree to be positioned to an accuracy of a couple of metres. By combining harvested stock data with GPS positioning data, valuable ground-truth data on harvests and changes in forest resources can be efficiently obtained. Rasinmäki and Melkas (2005) introduced a method that can be used to estimate the tree composition and volume of arbitrary subdivisions of a harvested stand. The average root-mean-squared-error of the volume estimates varied from 4% for 0.4 ha subregions to 29% for 0.03 ha subregions. The development of a stem database for aggregating stem data after collecting has been initiated in Finland. One of the uses of the stem database could be as ground-truth data based on reference stands. Stem databases are now being compiled extensively by Finnish forest enterprises.

The major problem of using VLS technology with harvesters is the GPS signal shadows in forests; improvements to current positioning technologies are needed to fully use it with harvesters. In future, the Global Navigation Satellite System (GNSS) consisting of GPS, Russian GLONASS, European Galileo, and Chinese COMPASS, will provide improved accuracy in forested regions due to the increase in visible satellites. Also, improvements of personal positioning technologies will help in achieving the potential benefits of harvester technology to forest inventory.