Chapter 30
New Zealand

Stephen Wakelin, Thomas Paul, Nigel Searles, Joanna Buswell, Annemieke Sherwin and James McDevitt

30.1 The New Zealand National Forest Inventory

30.1.1 History and Objectives

The nature of New Zealand's woody vegetation and history of National Forest Inventory in New Zealand is described in more detail by Beets et al. (2010). There has not been a National Forest Inventory (NFI) in the past that completely covered the total New Zealand forest area. The current effort is motivated by requirements to report Land Use, Land-Use Change, and Forestry (LULUCF) activities under Article 3.3 of the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC), as well as the ongoing annual reporting of plantation forests established with the primary objective of wood production where the resource description is useful for policy advice and resource planning. The

S. Wakelin (✉) · T. Paul
Scion (New Zealand Forest Research Institute Ltd.), Rotorua, New Zealand
e-mail: steve.wakelin@scionresearch.com

T. Paul
e-mail: thomas.paul@scionresearch.com

N. Searles · J. Buswell
Ministry for the Environment, Wellington, New Zealand
e-mail: nigel.searles@mfe.govt.nz

J. Buswell
e-mail: joanna.buswell@mfe.govt.nz

A. Sherwin · J. McDevitt
Ministry for Primary Industries, Wellington, New Zealand
e-mail: annemieke.sherwin@mpi.govt.nz

J. McDevitt
e-mail: james.mcdevitt@mpi.govt.nz

objectives of the inventory continue to evolve from issues of wood supply or carbon sequestration to include biodiversity, ecological and environmental considerations.

The current national inventory activity is a cross-government programme managed and funded by the Ministry for the Environment (MfE) in partnership with the Ministry for Primary Industries (MPI) and the Department of Conservation, with support from several other government departments and two Crown Research Institutes; New Zealand Forest Research Institute Limited (Scion) and Landcare Research New Zealand Limited.

The Department of Conservation integrates the NFI into their National Biodiversity Monitoring and Reporting Programme, to provide comprehensive information on biodiversity across public conservation lands. The NFI also provides data on the state of New Zealand's forest for MfE's environmental reporting programme. These data also provide volume estimates for the United Nations Forest Resource Assessment and carbon stock for New Zealand's Montreal Process Criteria and Indicators report.

New Zealand's woody vegetation (excluding horticulture) can be divided into three distinct types:

1. Indigenous Forest Land (7.8 million ha)
2. Exotic Production Forest Land (2.1 million ha)
3. Grassland with Woody Biomass (Other Wooded Land) (1.4 million ha).

The characteristics of each type differ from the other so substantially that assessment techniques, sampling design and inventory management are also very different. Forest land area reported here includes forest roads, skid sites and unstocked areas within the mapped forest area, as reported in New Zealand's Greenhouse Gas Inventory 1990–2013 (Ministry for the Environment 2015).

Three-quarters of New Zealand's indigenous high forests are publicly owned and protected within the conservation estate. The upland forests are extensive and often remote, in difficult, steep, heavily-dissected country where weather can quickly deteriorate to impede ground access, and with some of the most difficult flying conditions in the world. The exotic production forest consists of moderately fast-growing, intensively managed planted forests, of which 90 % is radiata pine (*Pinus radiata* D. Don). Two-thirds of the forests are corporate-owned; the remainder is mainly under a variety of private ownerships, with many farm forests and woodlots.

Grassland with woody biomass is defined as wooded grassland that is unplanted and does not exceed 5 m height. Vegetation communities include indigenous alpine shrubs above the tree-line, regenerating shrubs and trees on lightly-grazed pasture and fast colonising "scrub" of exotic "weed" species such as gorse (*Ulex europaeus*). Lightly stocked riparian plantings are also included in this category.

The first NFI conducted using aerial photography and systematic sampling (pseudo-random sampling) was the National Forest Survey 1946–55, (Thomson 1946; Masters et al. 1957; McKelvey and Wardrop 1963) which was confined to indigenous forest. A National Exotic Forest Survey was carried out in planted forest

with data collected between 1959 and 1963. In both cases there was no commitment to remeasure these forests in any form of continuous large-scale inventory.

A regularly updated plantation forest resource information system was set up to produce the National Exotic Forest Description (NEFD) in a cooperative approach between government and forest owners (Butler et al. 1985). Administered now by MPI (see http://www.mpi.govt.nz/news-and-resources/statistics-and-forecasting/forestry/), this is a compilation of an annual postal survey of forest owners, managers and consultants who manage planted production forests, (Ministry for Primary Industries 2014). For many years from its beginning the NEFD acted as an effective NFI, updated annually with a level of age class detail that would have been too expensive for a conventional plot-based NFI.

The Land Use and Carbon Analysis System (LUCAS) has been developed over the last decade (see www.mfe.govt.nz), motivated by the need to meet New Zealand's reporting requirements under the UNFCCC and the Kyoto Protocol. A grid-based sample design with ground plots has been established across New Zealand as the basis for NFI in indigenous forest and shrubland, pre-1990 planted forests and post-1989 planted forests.

30.1.2 LUCAS NFI Sampling Methods and Periodicity

The pre-1990 indigenous forest has been sampled on an 8 × 8 km grid with 1256 nested Permanent Sample Plots (PSP's) of 0.12 and 0.04 ha established between 2002 and 2007 as the first inventory period (Payton et al. 2004). The initial remeasurement of this plot network took place between 2009 and 2014. This inventory covers natural forest, which includes self-sown introduced woody species. As mapping of pre-1990 natural forest improves over time, revision of the inventory plot numbers takes place to maintain the representativeness of the inventory. The full set of plots in pre-1990 natural forest will be remeasured again (third inventory period) across a 10 year period starting in 2014 (Ministry for the Environment 2015).

Pre-1990 planted forest was sampled using the same grid in 2010, resulting in 192 measured ground plots of 0.06 ha size. Airborne scanning LiDAR data was collected from 893 plots, including those that were ground measured. The LiDAR-only plots are located on a 1 km (north–south) by 8 km (east–west) grid within the mapped area of pre-1990 planted forest (Beets et al. 2012a). These LiDAR plots are part of a double-sampling approach and have been successfully used to improve the precision of the carbon stock estimates in pre-1990 planted forests (Beets et al. 2012a). The pre-1990 planted forest ground plots were re-measured for the first time during the New Zealand winter of 2015.

Post-1989 planted forest was sampled with 0.06 ha circular PSP's on a systematic 4 × 4 km grid coincident with that used for the pre-1990 forest inventories

(Moore and Goulding 2005). The initial post-1989 planted forest inventory was carried out during the New Zealand winters of 2007 and 2008 at 246 sites consisting of up to four sample plots in a cluster arrangement. A second inventory was carried out during the winters of 2011 and 2012 where only the centre plots (0.06 ha) of the earlier established cluster plots were re-measured and additional plots were established based on mapping improvements. In total, 342 plots were ground-measured from the mapped area of post-1989 planted forest in the second inventory period (Ministry for the Environment 2015). Twenty plots were also established in post-1989 natural forest and measured for the first time in 2012.

LiDAR data were captured for 25 post-1989 plots in 2007–2008 in addition to those that were ground measured (Beets et al. 2011a). This was originally to allow a double-sampling approach to overcome bias introduced by any failure to gain access to private land. In practice, access was generally unrestricted, so LiDAR was used to improve the precision of the carbon stock estimates using a ratio estimator procedure. LiDAR data were acquired at a minimum of three returns per square metre, with aerial photography captured at the same time to aid in data analysis for both post-1989 and pre-1990 planted forests (Ministry for the Environment 2015).

All ground plot centres in planted forests were located during ground inventories using a 12-channel differential GPS for sub-meter LiDAR co-location and for relocation in future inventories (Beets et al. 2011a). The pre-1990 and post-1989 planted forests sample plots were intended to be remeasured on a five-year cycle. The location of the LUCAS NFI forest plots is shown in Fig. 30.1.

30.1.3 LUCAS NFI Data Collection

Plots in indigenous forest are sampled using a method designed for the purpose of calculating carbon stocks and biodiversity (Payton et al. 2004). Carbon-specific data are collected to calculate the volume of trees, shrubs and dead organic matter present. For trees, species, diameter and height are collected. Stage of decay is estimated for dead wood, which is otherwise measured for volume as for trees. Shrub dimensions are measured while litter samples are taken on about one-third of plots. Wood densities collated from representative studies are used to estimate biomass and carbon from the estimated volume (Beets et al. 2012b).

The ground measurements in the planted forest inventories include: stem diameters of all live and dead trees at breast height; a sample of tree total heights for each tree species; pruned heights, measurement of dead wood and soil fertility samples for predicting wood density (Beets et al. 2011a). Silvicultural information, including tree age, stocking rate (stems per hectare) and timing of pruning and thinning activities, is gathered from forest owners and also estimated by field teams on site (Herries et al. 2013).
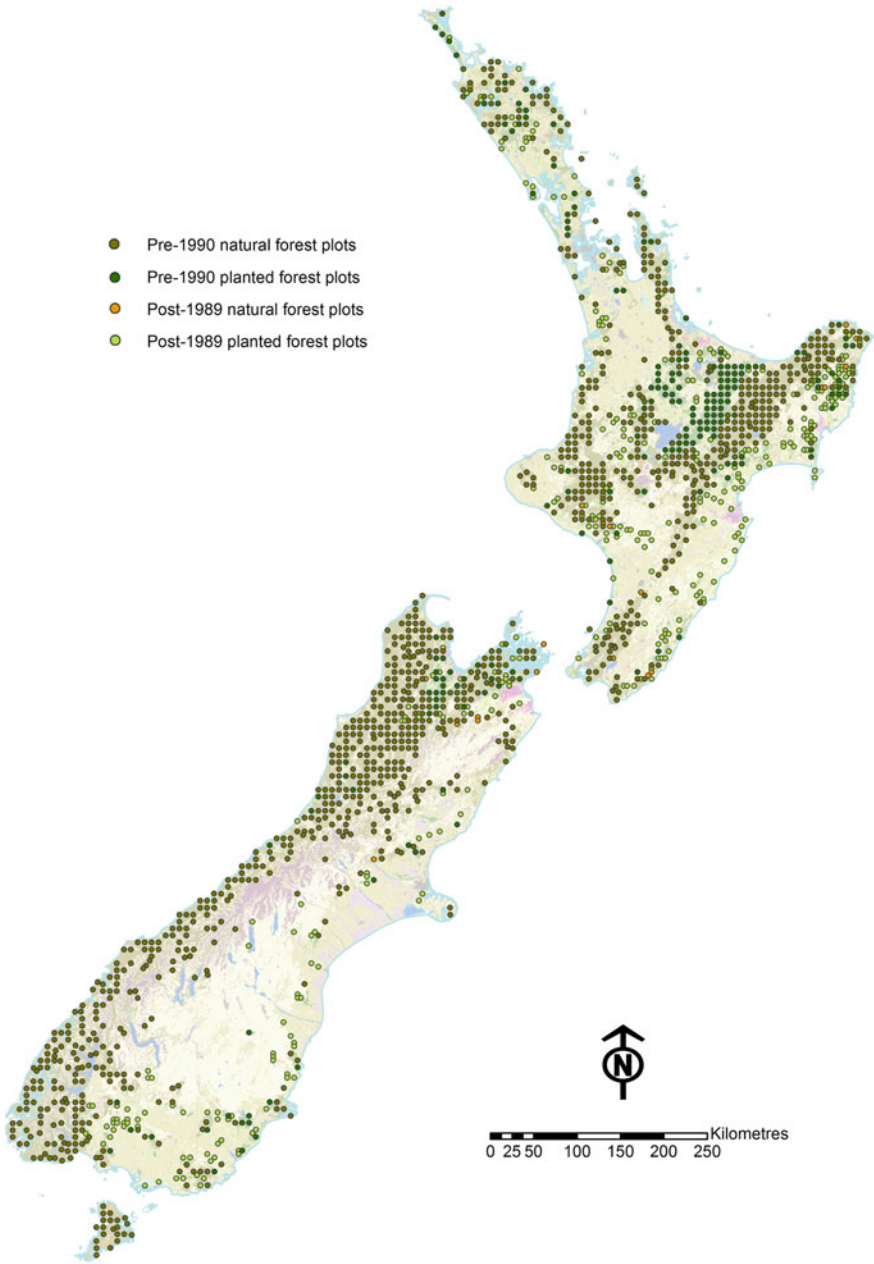
Fig. 30.1 Location of New Zealand's LUCAS NFI forest plots

30.1.4 LUCAS NFI Data Processing, Reporting and Use of Results

For indigenous forest plots, above-ground live tree biomass is estimated for trees (>2.5 cm dbh) from dbh and height by applying species-specific allometric equations and wood density (Beets et al. 2012b) to plot measurements. Below-ground biomass is estimated as 20 % of total living biomass. Dead wood (woody debris with a diameter over 10 cm) is estimated from plot measurements and allometric equations, while the litter pool is estimated from laboratory analysis of samples collected at one-third of the plots. Shrub volume is converted to carbon based on species and/or site-specific conversion factors determined by destructive harvesting of reference samples. Methods are currently slightly different for post-1989 (Beets et al. 2014) and pre-1990 natural forest subcategories (Holdaway et al. 2014).

Indigenous forest biomass in above ground, below ground, deadwood and litter pools is summed to allow calculation of carbon stocks and carbon stock changes for greenhouse gas inventory reporting (Ministry for the Environment 2015). These data are not used for reporting on, or planning the harvest of, merchantable timber stocks in indigenous forests. The Department of Conservation has integrated the NFI as an important component of their National Biodiversity Monitoring and Reporting Programme. This aims to provide comprehensive information on the status of New Zealand's indigenous forests and shrubland (e.g. biodiversity, health) on public conservation lands.

Crop tree data collected in the planted forest inventories is modelled using the Forest Carbon Predictor (Beets et al. 2011b), which incorporates growth models for the two main species, a wood density model, a stand tending model and the C-Change carbon allocation model (Beets et al. 1999). Carbon and volume yield tables are derived for each plot and combined into an average national age-based yield table for each of the two planted forest sub-categories (pre-1990 and post-1989).

A simulation approach combines the area by age class distribution from the NEFD (see Sect. 30.1.5 of this report) with the average national yield tables based on LUCAS and simulates afforestation, deforestation, harvesting and replanting over time. The simulation produces annual estimates of carbon stocks and stock changes since 1990 for greenhouse gas reporting (Ministry for the Environment 2015). This approach makes use of the higher resolution age class distribution available from the NEFD and the statistically defensible carbon stock information derived from the LUCAS NFI plot network. The planted forest simulation is carried out on a net stocked area basis. LUCAS mapping provides gross planted forest areas and uses plot data to estimate a ratio of gross to net stocked area. The yield tables represent carbon per net stocked hectare, with carbon in unstocked forest components estimated separately.

Carbon estimates are a critical part of UNFCCC and Kyoto reporting and are also reported in New Zealand's Montreal Process Criteria and Indicators report (Ministry of Agriculture and Forestry 2009). Stem volume, biomass and carbon estimates are provided for the Food and Agriculture Organization of the United Nations Forest Resource Assessment (FAO 2010). The inventory data from the LUCAS planted forest NFI may in future also contribute towards the forecasting of national and regional wood availability in planted forests. This is less of a requirement for natural forests which are not generally available for production.

The NFI also provides data on the state of New Zealand's indigenous and planted forests for MfE's environmental reporting programme and the natural forest inventory is the foundation for the Department of Conservation's national reporting on the status of New Zealand's indigenous forest and shrubland.

30.1.5 NEFD Data Collection, Processing, Reporting and Use of Results

In parallel to the plot-based NFI, New Zealand maintains a postal survey-based forest resource information system covering all major planted forests; the National Exotic Forest Description (NEFD). The NEFD is the primary source of national net stocked area data by species, age class and tending regime for planted forests. It is published annually by MPI to assist with resource policy planning and development. Each year the NEFD area dataset is compiled from a survey of forest owners and consultants who own or manage planted production forests (Ministry for Primary Industries 2014). These forests are managed intensively and most of the area is well described in the owners' databases with detailed information derived from their own inventory programmes. Methods are being developed to improve data capture from smaller forests.

NEFD area data are collected for 66 territorial authorities within nine wood supply regions. Six species or species-groupings are recognised: radiata pine, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), cypress species (*Cupressus* spp.), other softwoods, *Eucalyptus* species and other hardwoods. Four stand tending regimes are used for radiata pine (based on the intention to prune and/or production thin) and two for Douglas-fir (based on production thinning intentions).

The NEFD Regional yield tables for the main species groupings and management regimes are produced periodically to coincide with the preparation of regional and national wood availability forecasts. The yield tables are primarily based on yield information provided by large forest owners and consultants. The data collected for the NEFD are used to develop wood availability forecasts that present potential harvest volumes by broad log grades under various scenarios of yield regulation. These are developed within a forest estate modelling system and incorporate the harvest intentions of the major forest owners (Ministry of Agriculture and Forestry 2010). The NEFD yield tables are not used as a basis for

national carbon reporting because the LUCAS yield tables provide defensible unbiased estimates for which uncertainty limits can be calculated.

The NEFD annual survey and wood availability forecasts provide data; to inform government policy, for a range of international reporting obligations, to assist with infrastructure planning decisions, and to identify wood processing opportunities.

30.2 Land Use and Forest Resources

30.2.1 Classification of Land and Forests

30.2.1.1 General Land Classification

New Zealand uses a hierarchical land classification system for reporting in the national greenhouse gas inventory (Ministry for the Environment 2015) (Table 30.1). The key thresholds for defining forest land are:

– minimum area of 1 ha
– minimum tree species crown cover of 30 %
– minimum height of 5 m at maturity in situ.

A width criterion of 30 m is used to distinguish between shelterbelts and forests —narrower shelterbelts are included within the surrounding land use classification such as cropland or grassland. Wider shelterbelts of at least 1 ha are classified as forests. Similarly linear unstocked features such as roads that are associated with forests and are less than 30 m wide will be classed as forests and contribute to the gross area of forests.

The Forest Resource Assessment (FRA) forest class has the same 5 m threshold for height, but lower thresholds for area (0.5 ha) and cover (10 %). It also has a lower width criterion (20 m) for determining if roads and powerlines through forest land still qualify as forest.

The land use classes in Table 30.1 may be further stratified based on plot data from the NFI. For example, post-1989 forest can be divided into a regenerating natural forest component and a planted forest component. Stocked plantation forest can be identified separately from riparian forest and other non-productive areas. Natural forest can be stratified into regenerating forest and tall forest (Table 30.2).

More detailed stratification into natural forest types is available from the earlier forest survey maps (Nicholls 1977) and EcoSat (Shepherd et al. 2005) but the classes are not well aligned with NFI plot data and are not used for annual greenhouse gas inventory or forest production planning.

30.2.1.2 Classification by Ownership Categories

Forest ownership categories are not used in LUCAS NFI analysis and reporting. Most tall indigenous forest is owned by the State and managed for conservation

Table 30.1 Land use classes according to the national definition with area estimates (Ministry for the Environment 2015) and correspondence with FRA classes

Class name		Description	Gross area (1000 ha)	Corresponding FRA classes (FAO 2004)
Forest land	Pre-1990 natural forest	Areas that, on 1 January 1990, were and presently include • tall indigenous forest • dense self-sown exotic trees, such as wilding pines and grey willows • broadleaved hardwood shrubland • temporarily unstocked areas associated with this forest land use	7835	Forest, other land with tree cover, other wooded land, other land
	Pre-1990 planted forest	Areas that, on 1 January 1990, were and presently include • radiata pine (*Pinus radiata*), Douglas fir (*Pseudotsuga menziesii*), eucalypts (*Eucalyptus* spp.) or other planted species • harvested areas within pre-1990 planted forest • temporarily unstocked areas associated with this forest land use	1438	Forest, other land with tree cover, other wooded land, other land
	Post-1989 forest	Forest that was established after 31 December 1989 including • radiata pine (*Pinus radiata*), Douglas fir (*Pseudotsuga menziesii*), eucalypts (*Eucalyptus* spp.) or other planted species • forests arising from natural regeneration of indigenous tree species • self-sown exotic trees, such as wilding conifers or grey willows • temporarily unstocked areas associated with this forest land use	660	Forest, other land with tree cover, other wooded land, other land
Crop-land	Annual cropland	Annual crops, cultivated ground and associated linear shelterbelts	372	Other land, other land with tree cover
	Perennial cropland	Orchards and vineyards and associated linear shelterbelts	105	Other land, other land with tree cover, other wooded land
Grass-land	High producing	High quality pasture and associated shelterbelts of <1 ha or <30 m in width	5808	Other land with tree cover, other land
	Low producing	Low fertility pasture and tussock, montane and coastal herbfields, and associated linear shelterbelts of <1 ha or <30 m in width	7545	Other land with tree cover, other land
	Grassland with woody biomass	Grassland with woody species that are not expected to reach forest criteria over a 30–40 year period, including alpine shrubland and pasture with trees <30 % cover (e.g. rural golf courses)	1364	Other land with tree cover, other wooded land

(continued)

Table 30.1 (continued)

Class name	Description	Gross area (1000 ha)	Corresponding FRA classes (FAO 2004)
Wetlands	Includes open-water and vegetated sub-categories, which may include non-forest woody vegetation	681	Other land, other wooded land, other land with tree cover, forest
Settlements	Parks, gardens, golf courses associated with built-up areas	225	Other wooded land, other land with tree cover, other land
Other land	Montane rock, scree, river beds, sand dunes, permanent ice etc.	895	Other land
Total		26,925	

Table 30.2 Classes within forest land and their areas in 2013 according to the New Zealand NFI (Ministry for the Environment 2015)

Class name		Description	Area (1000 ha)	
Forest land	Pre-1990 natural forest	Tall forest	6628	7835
		Regenerating natural forest	1207	
	Pre-1990 planted forest	Productive area (net stocked area)	1223	1438
		Unstocked area	151	
		Riparian and soil control	63	
	Post-1989 forest	Productive area (planted forest net stocked area)	539	660
		Unstocked area (planted forest)	79	
		Regenerating natural forest	41	

purposes. The NEFD captures planted forest data by ownership category for planted forests (Table 30.3). It also reports regional planted forest area by six ownership size classes, ranging from owners with less than 40 ha to owners with more than 10,000 ha.

30.2.1.3   Forest Management and Cutting Systems

Most natural forest is not managed for timber production so little silviculture is carried out there. Where management of natural forest for timber does take place it may be under continuous cover, coupe harvesting or clearfell systems. Only 50,000 ha of natural forest is currently managed under Sustainable Forest Management plans.

Forest management and cutting system information is not reported by the LUCAS NFI, but stand management records, assumptions and field assessments are

Table 30.3 Forest area according to the national forest definition by ownership categories

Forest category	Ownership category	Area (1000 ha)
Planted forest[a]	State-owned enterprise	11
	Local government	47
	Central government	37
	Registered public company	1
	Privately-owned	1665
	Sub total	1765
Tall indigenous forest[b]	State-owned	5180
	Privately-owned	1448
	Sub total	6628
Total forest		8839

[a]*Planted forest*—NEFD net stocked area as at 1 April 2014 excluding harvested areas awaiting restocking and adjusted to the New Zealand NFI area (Ministry for the Environment 2015)
[b]*Tall indigenous forest*—total 2013 area from the New Zealand NFI (Ministry for the Environment 2015); state-owned from draft 2015 Montreal process report; privately owned from the difference

used when deriving yield tables from plot data. The NEFD planted forest survey asks respondents to classify their forest area into management regime for the main species based on the intended implementation of green crown pruning and/or production thinning. Planted forests are generally managed on a clearfelling system, and currently only 13 % of planted forest area is intended to produce logs from production thinning (Ministry for Primary Industries 2014).

The radiata pine tending regime categories are:

- pruned with production thinning
- pruned without production thinning
- unpruned with production thinning
- unpruned without production thinning.

The Douglas-fir tending regime categories are:

- with production thinning;
- without production thinning.

"Pruned" refers to pruning carried out before age 12 so that more than 50 % of the stems in the planned final crop stocking will contain a pruned butt log of not less than four metres in length. "Production thinning" refers to the extraction of thinnings for commercial use.

About 58 % (899,000 ha) of the radiata pine area in the NEFD is, or is expected to be, pruned to a height of at least four metres. The area of radiata pine classified under a production thinning regime is about 16 % of the total. Less than 0.5 % of total planted forest production in 2012 came from production thinning (Ministry for Primary Industries 2014).

30.2.1.4 Legal and Other Restrictions for Wood Use

Government policy is that indigenous forest on public conservation land will not be harvested. The two exceptions to this policy are: (1) 12,000 ha of indigenous forest in western Southland that was made available for timber production in exchange for the protection of virgin old growth forest adjoining Fiordland National Park; (2) The West Coast Wind-blown Timber (Conservation Lands) Bill passed in 2014 allows trees wind-blown during Cyclone Ita in April 2014 to be salvaged within a five-year period. Up to 8640 ha of forest on the West Coast was estimated to be eligible for salvage harvesting under this Act (Platt et al. 2014). Privately-owned indigenous forests are also available for harvesting under the provisions of the Forests Act. This requires harvesting of indigenous forests to have an approved Sustainable Forest Management Plan or Permit.

Forest clearance is governed under the Resource Management Act which is administered by Regional and District Councils. Subject to the provisions in Council plans, small areas of indigenous forest may be able to be cleared. The Resource Management Act also covers earthworks and harvesting in planted forests. The provisions of the Forests Act apply if forest is to be harvested for timber production.

Regulations under the Climate Change Response Act provide the rules for participation of forestry in the Emissions Trading Scheme including forest definition thresholds and liabilities associated with harvesting and deforestation, but do not place additional restrictions on forest management. Some private forests have legal protection under various covenant arrangements but these generally apply to indigenous forests—covenanted planted forest areas are outside the sample frame of the NEFD survey of production forests and therefore would not be included in wood supply forecasts.

30.2.1.5 Further Classification of Forests

Planted forest area by broad species grouping is provided by the NEFD (Table 30.4). Species proportions are provided by the NEFD (Ministry for Primary Industries 2014) and are adjusted to the NFI area (Ministry for the Environment 2015). The NEFD publishes planted forest area in five-year age classes for each of

Table 30.4 Productive planted forest area by species (2013)

Tree species	Area (1000 ha)
Radiata pine (*Pinus radiata*)	1583
Douglas fir (*Pseudotsuga menziesii*)	109
Cypresses	10
Other softwoods	24
Eucalyptus spp.	22
Other hardwoods	13
Total	1762

the 66 territorial authority boundaries, by species grouping (and tending regime in the case of radiata pine). It also reports total net stocked area, standing volume inside bark and area-weighted average age for each territorial authority. Standing volume estimates are based on the broad NEFD regional yield tables. The total national planted forest net stocked area is also published by single-year age classes.

30.2.2 Wood Resources and Their Use

30.2.2.1 Standing Stock, Increment and Drain

Data on standing stock volume and increment were obtained from the New Zealand NFI used for the national greenhouse gas inventory (Ministry for the Environment 2015) (Table 30.5). The inventory reports carbon stocks and fluxes annually from 1990. The standing stock volume is a precursor to the carbon stock and flux analysis.

Planted forests standing stock is generally reported as "under bark" in New Zealand. A multiplying factor of 1.17 was used to produce the "over bark" estimates provided here. Definitions used are given in Table 30.5. Approximately 85 % of the total growing stock at harvest age is commercial (i.e. recoverable merchantable volume). However, total growing stock reported here includes the volume of all trees at all ages with dbh over 2.5 cm and there is little or no merchantable component in young stands with small trees. The commercial growing stock has not been estimated.

Planted forest growing stock and increment are sourced from the New Zealand NFI area as reported in the Forest Resource Assessment (Ministry for Primary Industries 2015). Standing stock of planted forests was projected to 2015 using the average annual increment for the last 5 years for which data are available. Increment is reported net of drain from forest harvesting, while drain is sourced from MPI's roundwood removal data (Table 30.6).

New Zealand's standing stock estimates for tall indigenous forest, regenerating forest and shrubland are reported as "over bark" and in terms of dry matter of above-ground live biomass. Estimates provided here (Table 30.7) are taken or

Table 30.5 Definitions for volume of planted forest standing stock, increment and drain

Quantity	Definition
Growing stock	Volume over bark of all living trees with a minimum diameter of 2.5 cm at breast height (or above buttress if these are higher). Includes the stem from ground level up to a top diameter of 0 cm, excluding branches
Net increment	Average annual volume of gross increment over the given reference period less that of natural losses and harvesting (drain), measured to minimum diameters as defined for "growing stock"
Drain	Estimated annual volume under bark in roundwood harvest, derived from mill out-turn

Table 30.6 The volume of standing stock, increment, and drain on planted forest land

Tree species	Growing stock (million m^3) over bark	Net increment (million m^3/year) (net of drain)	Drain (million m^3/year)
All planted forest species	746 (2015)	15 (2015)	29.58 (2014)
…of which coniferous	735		
…of which broadleaved	11		

Table 30.7 The above-ground biomass standing stock, increment, and drain on pre-1990 natural forest land

Woody vegetation class	Above-ground standing biomass (million tonnes dry matter)	Biomass increment (million tonnes dry matter/year)	Biomass drain (million tonnes dry matter/year)
Tall forest	2337.8		
Regenerating forest and shrubland	145.4		
Sum: tall indigenous forest and regenerating forest and shrubland	2483.3	29.8	21.2
…of which coniferous	305.1		
…of which broadleaved	2175.5		
Grassland with woody biomass	47.7		

derived from Holdaway et al. (2014). The proportion of broadleaved (87.7 %) and coniferous (12.3 %) species is taken from Beets et al. (2009), which provides an estimate of the proportion of coniferous and broadleaved species in New Zealand's indigenous forest based on the LUCAS field inventory. Grassland with woody biomass is adapted from Wakelin and Beets (2013).

30.2.2.2   Tree Species and Their Commercial Use

By far the most economically important plantation species in New Zealand is radiata pine, a versatile timber species native to North America. This makes up 90 % of the planted forest resource and 95 % of roundwood production in 2013. Radiata pine sawn timber is used in many applications including construction, mouldings, furniture, and packaging. It is peeled and sliced for veneer which is used to make plywood and increasingly laminated veneer lumber. It is also used to make other panel products, including medium density fibreboard and particleboard. Both

mechanical and chemical pulps are produced from radiata pine as well as a range of paper and paperboard products. Treated roundwood is used for posts and poles and there is extensive use for energy. Douglas-fir, the second most common plantation species is mainly used for above-ground timber framing.

Wood processing waste is used extensively for energy generation, enabling the wood processing industry to be 70 % self-sufficient in energy. In 2014, 55 % of total roundwood production was exported as roundwood, mainly to East Asia. The relatively small volume of timber produced from natural forest is mainly used for speciality purposes including furniture and cultural uses.

30.3   Assessment of Wood Resources

30.3.1   Forest Available for Wood Supply

30.3.1.1   Assessment of Restrictions

The LUCAS NFI is not used for wood supply analysis so does not consider the availability of forests for harvest. No forecasting of future wood supply from indigenous forests is conducted.

By definition, all areas included in the annual NEFD survey is production forest planted for the purposes of timber harvesting and can be assumed to be technically and legally available. Separate assessments have been made of the economic availability of forests under difference scenarios, as some small, remote forests on steep sites may not be economic to harvest in all but the most favourable conditions. Some area may therefore be excluded from wood supply forecasts as a result of these analyses and on the advice of local experts.

The wood availability forecasts rely extensively on the knowledge of forest industry representatives within each region to verify the information contained within the NEFD database, provide growth and yield estimates and provide harvest intentions over the immediate 15 year period. In some regions the NEFD areas of small forest owners are reduced and further reductions are made to over-mature areas (e.g. Ministry of Agriculture and Forestry 2006).

The main focus of the wood availability forecasts is to present alternative scenarios for the harvest of the small grower resource, which is concentrated in a relative narrow band of ages due to a period of high but unsustained afforestation in the mid-1990s. In practice, harvesting of forests is managed to maximise the benefits to the enterprise that owns them. Each enterprise has its own harvesting strategy based on the forest owners' objectives, market conditions and the forest estate it owns or manages.

30.3.2 *Wood Quality*

30.3.2.1 Stem Quality and Assortments

Grade specifications for logs produced in New Zealand are determined by negotiation between the buyer and seller—there is no officially prescribed standard. Typically a planted forest log grade is defined in terms of factors including log size (minimum, maximum or average small end diameter; maximum large end diameter; length) and quality (species; straightness; branch/knot characteristics; internode length; clear-wood recovery; defect allowances; ovality; pith location; fibre stiffness; treatment e.g. debarked, sapstain treated, condition). Additional factors such as environmental certification may also be included as a grade requirement (Katz 2005).

For broad planning purposes, the NEFD maintains regional yield tables with three log grades: pruned veneer and sawlogs, unpruned sawlogs and pulp logs (Ministry for Primary Industries 2014).

30.3.2.2 Assessment and Measurement

The LUCAS NFI captures both physical stem attributes and silvicultural treatments from the plot network. Pruned height, timing and number of pruned lifts of all sample crop trees are captured. Thinning intensity and timing is captured for each sample plot. Green crown height of sample crop trees is captured. Descriptive codes describing stem form are also captured and include; broken stem, dead or defective top, toppled stem, crooked stem, forked primary stem, multi-leader, scar, sweep, leaning, hollow trunk and abrupt diameter reduction. Soil samples are taken for site fertility and wood density. Increment cores are taken for stem aging. Field assessment methodology is described in the LUCAS Planted Forest Data Collection Manual (Herries et al. 2013).

Planted forest owners carry out their own pre-harvest inventory programmes to characterise their stands in terms of potential log grade assortments. This involves detailed stem descriptions and measurements (including branch location, size and angle, wood density cores, stem acoustic speed for stiffness estimation, etc.) in stands of harvestable age, followed by analysis using software to simulate harvesting and optimise cross-cutting. Detailed stem descriptions of this nature are not carried out in the LUCAS NFI programme which deals with all age classes and does not attempt to characterise the resource by log grades.

30.3.2.3 Estimation and Models

Merchantable stem volume by log grade assortments is not estimated or reported by the LUCAS NFI, although the data collected could be used to broadly classify planted forest volume.

The crop tree plot data collected in the planted forest NFI is modelled using the Forest Carbon Predictor (FCP) developed for the two most common plantation tree species in New Zealand, radiata pine and Douglas-fir (Beets et al. 2011b). To enable predictions of carbon, and its precursor stem volume, in New Zealand's planted forests, the FCP integrates:

- the 300 Index growth model (Kimberley et al. 2005) for *Pinus radiata*
- the 500 Index growth model for Douglas-fir (Knowles 2005)
- a wood density model (Beets et al. 2007)
- a stand tending model (Beets et al. 2011b)
- the C_Change carbon allocation model (Beets et al. 1999).

The 300 Index and 500 Index growth models are widely used within the New Zealand forestry industry and produce a productivity index for forest plots derived from stand parameters. These stand parameters include: stand age, mean top height, basal area, stocking and stand silvicultural history. Plot latitude and altitude are also included in the models. The growth models use these parameters to predict stem volume under bark over a full rotation. The growth models account for past and future silvicultural treatments using plot data, stand records and assumptions of future management events (Beets et al. 2011b). The pruned component of stands is identified separately by the growth model, potentially allowing pruned log volume to be extracted.

The wood density model (Beets et al. 2007) uses site mean annual temperature, soil fertility, age and stocking to determine the mean density of stem wood growth sheaths produced annually in *Pinus radiata*. Wood density is an important variable in the estimation of carbon, and has been used as a surrogate for wood strength and stiffness.

The stand tending model (Beets et al. 2011b) is required because New Zealand's plantation forests are intensively managed and, therefore, pruning and thinning provide the majority of the inputs to the dead wood and litter pools. The FCP requires silvicultural history inputs to predict changes between live and dead biomass pools over time. A stand tending model has been incorporated into the FCP that makes use of existing data to identify and rectify potential gaps in the stand history.

The C_Change carbon allocation model (Beets et al. 1999) is integrated into the FCP and is designed to apportion carbon to needles, branches, stems, roots and reproductive parts via growth partitioning functions. Dead wood and litter pools are estimated by accounting for losses to the live pools from natural mortality, disease effects on needle retention, branch and crown mortality and silvicultural management activities.

The individual plot yield curves generated by the FCP are combined into estimates of above-ground live biomass, below-ground live biomass, dead wood and litter in an area-weighted and age-based carbon yield table for the productive area of each planted forest subcategory. Plots that are located outside the productive area within the mapped forest boundary are used to provide emission factors for

unstocked areas in the post-1989 and pre-1990 planted forest categories (Paul et al. 2014).

The FCP does not incorporate a model for predicting log yields. A modelling framework (Forecaster; West et al. 2013) is available that does include this functionality as well as the models for stand growth, tending, wood density and carbon allocation described above. It would be possible to analyse the plot data in Forecaster to produce volumes by log grade if there was a need for this information at the level of resolution available from the NFI.

30.3.3 Assessment of Change

30.3.3.1 Assessment and Measurement

Annual gains and losses in the LUCAS planted forest NFI are estimated using the FCP derived age-based carbon yield table in conjunction with subcategory specific area by age class distributions, harvesting statistics, afforestation and deforestation data. This simulation approach is used because New Zealand has good current and historical information on its planted forest estate from the NEFD. A simulation approach allows for estimates back to 1990 and projections forward in order to meet UNFCCC reporting requirements. However, direct permanent sample plot based stocks and stock changes can be estimated from the data at NFI measurement dates.

The pre-1990 and post-1989 planted forests sample plots are intended to be re-measured on a five-year cycle. This provides direct validation of the modelled growth and the assumptions used to create the age-based yield tables. The estimation of gains and losses of the LUCAS natural forest NFI is based on the field measurements on permanent plots at two consecutive points in time. Growing stock in planted forests is also estimated annually from the NEFD yield tables and the age class distribution.

30.3.3.2 Estimation of Increment

Annual gains in planted forests are estimated using the NFI derived age-based yield table in conjunction with the mapped planted forest area and NEFD derived areas by age class. The simulation approach groups same aged cohorts and gains are estimated as these cohorts transition from one year to the next in the yield tables. The yield tables are validated by the increment growth of crop trees recorded between NFI measurements.

30.3.3.3 Estimation of Drain

Annual carbon losses in the LUCAS planted forest NFI includes permanent sample plot based and national statistics derived estimates. Permanent sample plot-based

losses include; natural mortality, thinning, pruning and the subsequent decay of deadwood and litter. The NEFD provides annual harvested area and deforestation is mapped by LUCAS. Losses due to harvesting and deforestation are estimated by applying an emission factor from the appropriate yield table to the reported area. Harvest residues are decayed using a temperature-dependent decay profile as described in Garrett et al. (2010). Annual estimates of volume under bark in roundwood harvested are derived from wood processing sector returns.

30.3.4 Other Wooded Land and Trees Outside Forests

30.3.4.1 Assessment and Measurement

Grassland with woody biomass (other wooded land) consists of grassland where the cover of woody vegetation does not meet, nor has the potential to meet, the New Zealand forest definition. This can be due to the current management regime (e.g. periodically cleared for grazing), or to characteristics of the vegetation or environmental constraints (e.g. alpine shrubland). Grassland with woody biomass is therefore a diverse category. To account for these differences, grassland with woody biomass is split into permanent and transitional subcategories. Emission factors for each type of grassland with woody biomass are derived from the Land Use and Carbon Analysis System (LUCAS) plot network.

Unlike the forest subcategories in the NFI, the grassland with woody biomass sample is incomplete with partial coverage of sample points. The vegetation is assessed using satellite imagery where sample points in grassland with woody biomass have not been measured in the field.

Other land use classes reported in the greenhouse gas inventory can also include woody vegetation, such as perennial cropland, wetlands and settlements (including trees in parks). None of these non-forest lands are a significant source of industrial roundwood, although they may be used as a source of firewood for domestic heating.

30.3.4.2 Estimation

New Zealand's NFI currently only provides carbon stock in grassland with woody biomass (Table 30.7). Carbon stock change within grassland with woody biomass is currently not estimated. Emission factors are used for the other land uses.

30.4 Conclusion

The development of New Zealand's plot-based NFI was initially motivated by requirements to report LULUCF activities under the UNFCCC and the Kyoto Protocol. The NFI was established to estimate carbon stock and stock change in

New Zealand's forests. Estimation of potential timber production from natural forests has not been a priority as less than one percent of the total area of these forests is currently managed for timber production. Inventory objectives continue to evolve to include biodiversity, ecological and environmental considerations in both natural and planted forests.

The existing postal survey of planted forest owners provided a good basis for monitoring these forests and projecting wood supply while the resource ownership was concentrated within relatively few, large organisations. As planted forest ownership has fragmented it has become more difficult to obtain information from the many small forest owners through this approach. The plot-based NFI provides complementary data and has potential to contribute more towards the forecasting of wood availability in these forests in future.

References

Beets PN, Robertson KA, Ford-Robertson JB, Gordon J, Maclaren JP (1999) Description and validation of C_change: a model for simulating carbon content in managed *Pinus radiata* stands. N Z J For Sci 29(3):409–427

Beets PN, Kimberley MO, McKinley RB (2007) Predicting wood density of *Pinus radiata* annual growth increments. N Z J For Sci 37(2):241–266

Beets PN, Kimberley MO, Goulding CJ, Garrett LG, Oliver GR, Paul TSH (2009) Natural forest plot data analysis: carbon stock analyses and remeasurement strategy. Prepared for the Ministry for the Environment by Scion. Ministry for the Environment, Wellington

Beets PN, Brandon A, Geard BV, Goulding CJ, Lane PM, Stephens PR (2010) New Zealand. In: Tomppo E, Gschwantner Th, Lawrence M, McRoberts RE (eds) National forest inventories. Pathways for common reporting. Springer, Berlin

Beets PN, Brandon AM, Goulding CJ, Kimberley MO, Paul TSH, Searles NB (2011a) The inventory of carbon stock in New Zealand's post-1989 planted forest. For Ecol Manag 262:1119–1130

Beets PN, Kimberley MO, Paul TSH, Garrett LG (2011b) Planted forest carbon monitoring system. Forest carbon model validation study for *Pinus radiata*. N Z J For Sci 41:165–177

Beets PN, Brandon AM, Goulding CJ, Kimberley MO, Paul TSH, Searles N (2012a) The national inventory of carbon stock in New Zealand's pre-1990 planted forest using a LiDAR incomplete transect approach. For Ecol Manag 280:187–197

Beets PN, Kimberley MO, Oliver GR, Pearce SH, Graham JD, Brandon A (2012b) Allometric equations for estimating carbon stocks in natural forest in New Zealand. Forests 3(3):818–839

Beets PN, Kimberley MO, Paul TSH, Oliver GR, Pearce S, Buswell J (2014) The inventory of carbon stocks in New Zealand's post-1989 natural forest for reporting under the Kyoto protocol. Forests 5(9):2230–2252

Butler C, Levack H, McLean D, Sharp J (1985) A national exotic forest description system. Working paper 3. NZ Forestry Council. Wellington. New Zealand

FAO (2010) Global forest resources assessment 2010 country report: New Zealand. FRA2010/148 Food and Agriculture Organization of the United Nations, Rome

Garrett LG, Kimberley MO, Oliver GR, Pearce SH, Paul TSH (2010) Decomposition of woody debris in managed Pinus radiata plantations in New Zealand. For Ecol Manag 260(8): 1389–1398

Herries DL, Paul TSH, Beets PN, Chikono C, Thompson R, Searles N (2013) Land use and carbon analysis system—planted forest data collection manual version 6.1, Ministry for the Environment

Holdaway RJ, Easdale TA, Mason NWH, Carswell FE (2014) LUCAS natural forest carbon analysis. Prepared for the Ministry for the Environment by Landcare research. Ministry for the Environment, Wellington

Katz A (2005) Log specifications. In: Chavasse CGR (ed) New Zealand Institute of Foresters forestry handbook. New Zealand Institute of Foresters, Rotorua, pp 29–34

Kimberley MO, West GG, Dean MG, Knowles LR (2005) The 300 index—a volume productivity index for radiata pine. N Z J For 50(2):13–18

Knowles RL (2005) Development of a productivity index for Douglas-fir. N Z J For 50(2):19–22

Masters SE, Holloway JT, McKelvey PJ (1957) The national forest survey of New Zealand 1955. In: The indigenous forest resources of New Zealand, vol 1. Government Printer, New Zealand

McKelvey PJ, Wardrop TN (1963) Forest inventory experience in New Zealand. Commonwealth For Rev 42(2):112–123

Ministry for Primary Industries (2014) A national exotic forest description as at 1 April 2013. Ministry for Primary Industries, Wellington

Ministry for the Environment (2015) New Zealand's Greenhouse gas inventory 1990–2013. Ministry for the Environment, Wellington

Ministry of Agriculture and Forestry (2006) Nelson/Marlborough forest industry and wood availability forecasts. Ministry of Agriculture and Forestry, Wellington

Ministry of Agriculture and Forestry (2009) Sustainable management of New Zealand's forests. The 2008 New Zealand country report on the montreal process criteria and indicators. Ministry of Agriculture and Forestry, Wellington

Ministry of Agriculture and Forestry (2010) New Zealand wood availability forecasts 2020–2040. Ministry of Agriculture and Forestry, Wellington

Moore JR, Goulding CJ (2005) Sampling methods and associated levels of precision for a national carbon inventory in planted forests. Contract report prepared for Ministry for the Environment. Ministry for the Environment, Wellington

Nicholls JL (1977) A condensed classification of the native forests of New Zealand. In: Chavasse CGR (ed) New Zealand Institute of Foresters forestry handbook. New Zealand Institute of Foresters, Rotorua, pp 29–34

Paul TSH, Wakelin SJ, Kimberley MO, Beets PN (2014) Stocked plantation area in mapped post-1989 and pre-1990 forests, and associated crop yield tables and CRA Simulation input data. Contract report prepared for the Ministry for the Environment by Scion. Ministry for the Environment, Wellington

Payton IJ, Newell CL, Beets PN (2004) New Zealand carbon monitoring system indigenous forest and shrubland data collection manual. The Caxton Press, Christchurch

Platt I, Griffiths A, Wootton M (2014) Assessment of Cyclone Ita wind-blow damage to west coast indigenous forests. MPI technical paper No. 2014/41. Ministry for Primary Industries, Wellington

Shepherd JD, Ausseil A-G, Dymond JD (2005) Ecosat forests a 1:750,000 scale map of indigenous forest classes in New Zealand. Manaaki Whenua Press, Lincoln

Thomson AP (1946) Design for a forest survey. N Z J For 5(3):191–199

Wakelin SJ, Beets PN (2013) Emission factors for managed and unmanaged grassland with woody biomass. Contract report for the Ministry for the Environment. New Zealand Forest Research Institute (Scion), Rotorua

West GG, Moore JR, Shula RG, Harrington JJ, Snook J, Gordon JA, Riordan, MP (2013) Forest management DSS development in New Zealand. In: Tucek J, Smrecek R, Majlingova A, Garcia-Gonzalo J (eds) Implementation of DSS tools into the forestry practice. Technical University of Zvolen, Slovakia, pp 153–163