

Plugging the leaky sink

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The media has been full of stories recently related to climate change. Against a backdrop of climate disasters and doom and gloom scenarios, there are reports that the international community is taking the issue seriously and increasing their efforts to reduce greenhouse gas emissions. Meanwhile in New Zealand the carbon tax has been abandoned, and other aspects of the climate policy package are under review. Now is the opportunity to revisit the objectives and develop appropriate responses. Given their key roles in the New Zealand economy and the New Zealand greenhouse gas inventory, it is vital that the primary-based sectors participate effectively in this process.

Background

The United Nations Framework Convention on Climate Change (UNFCCC) established the objective and principles of protecting the climate systems for the benefit of present and future generations. Inside this overarching framework – but with some important differences – is the Kyoto Protocol (KP). Finally there are national strategies, developed in response to climate change, which can be entirely consistent with or totally different from the international approach.

The objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to stabilise atmospheric greenhouse gas (GHG) concentrations in the atmosphere to avoid dangerous interference with the climate system. Parties to the Convention – most of the countries in the world – have agreed to monitor and report GHGs they produce, and develop their own climate change strategies. Guidelines were developed by the Intergovernmental Panel on Climate Change (IPCC) to help Parties prepare consistent and transparent national inventories of emissions by sources and removals by sinks (Fig 1).

The Kyoto Protocol introduced legally binding targets for emissions reductions, but only for the more industrialised/developed countries. Each of these – except USA and Australia – made a commitment to reduce their average annual GHG emissions over the period 2008-12 to a percentage of their 1990 emission level. The international framework is more or less fixed for the first commitment period 2008-12: emissions targets have been established, the reporting guidelines have been accepted and the accounting system principles and rules have been agreed.

There are two key activities currently underway. Firstly, each Party is now working to “achieve its emission limitation commitments, in order to promote sustainable development, by implementing policies and measures in accordance with national circumstances”. Secondly, the international community is working collaboratively to develop an international climate agreement beyond 2012, and identify appropriate responses to climate change that will include Kyoto outsiders such as the United States and developing countries. There is therefore an opportunity to consider not only suitable domestic policies, but also how these might be incorporated in a future international agreement.

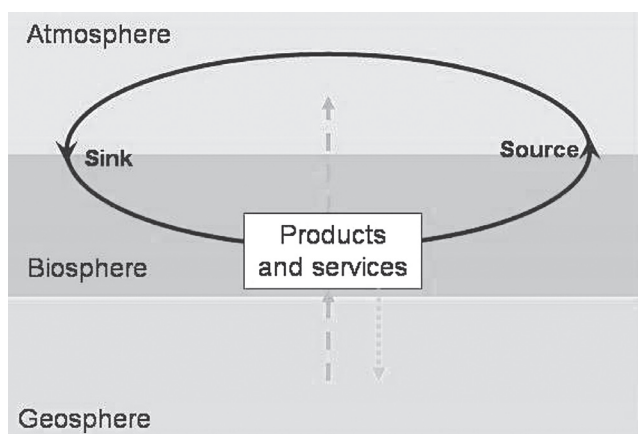


Fig 1: Removals by sinks and emissions by sources are defined in the UNFCCC as exchanges to and from the atmosphere. Biomass growth is a sink because it removes carbon from the atmosphere, and the combustion of biomass or fossil fuels are examples of source processes. Reservoirs are places where carbon is stored (retained) and could include fossil deposits as well as biomass and biomaterials. There is often a choice whether products (e.g. building materials) and services (e.g. energy) are derived from renewable or non-renewable resources. The former includes carbon in the current carbon cycle whereas the latter tend to be one-off flows of carbon from the geosphere. There is currently limited capture and deep sequestration of CO₂ in geological formations.

New Zealand situation

The New Zealand target under the Kyoto Protocol is to stabilise average annual emissions during 2008-12 at 100% of 1990 levels or to take responsibility for any emissions above this level; e.g. by using forest sink credits. Projections for the first commitment period suggest New Zealand will show a negative carbon balance, i.e. emissions are anticipated to exceed removals by around 36 MtCO₂-equivalent. In December 2005 the government reported that the climate policy package alone was insufficient to achieve either the Kyoto target, or the domestic target of setting a permanent downward path for emissions by 2012. (Emissions in 2003 were reported to be 22% higher than in 1990.) The policy review noted the inequity of some policy mechanisms which might have contributed to perverse incentives for activities such as deforestation.

The importance of the forest sector cannot be overemphasised. New Zealand forests remove carbon from the atmosphere, currently reported as a significant sink of 23 MtCO₂-equivalent (offsetting 30% of national emissions). There are global benefits of maintaining forest carbon stocks and providing biomass-based materials and fuels for fossil fuel substitution. If new planting rates could be maintained at levels enjoyed in the 1990s, this would contribute a massive and enduring sink both in terms of the Kyoto accounting system, and also in terms of what the atmosphere sees. Sadly new planting rates have plummeted meaning anticipated sinks will not materialise, and deforestation leads to both a loss of carbon stock and further emissions from the subsequent pastoral land use. This has consequences well beyond the climate debate.

Table 1: Potential GHG impacts of different types of forestry. The forest and its products need to be considered together as options for land use, and the production of renewable materials and fuels.

Forest type	Forest characteristics		Avoided emissions		Lifecycle
	On site stocks	Sequestration rate	Fuel substitution	Product substitution	
Protection forest	Highest	Low/none	None	None	Long/Indefinite
Sustained yield - sawlog	High	Moderate	Yes	High	Long
Sustained yield - pulp	Medium	Fast	Yes	Moderate	Short
Energy forestry	Lowest	Fast	Yes	None	Shortest

Forestry

The carbon cycle includes carbon sequestration by plants and its return to the atmosphere through processes such as combustion and decay. The UNFCCC refers to these processes as sinks and sources respectively, defined in terms of their relationship with the atmosphere. Carbon reservoirs are places where carbon is stored (retained) including living biomass or associated ecosystems (e.g. woody debris, soils) and products (e.g. food, materials, fuels).

The IPCC Guidelines explain that the sink that exists in forests is equal to the stock change in the forest and associated products. For a variety of reasons, the focus has been on the forest stocks alone based on a default assumption that the carbon in harvested biomass is emitted when and where it leaves the forest (or farm). In other words, responsibility for emissions is allocated to the producer who sequesters the carbon, rather than the consumer that releases it.

The instant oxidation assumption can create the impression that in order to mitigate climate change the objective is to maximise carbon stocks in the forest, rather than the combined total of carbon stocks inside the forest and in wood-based products. This can lead to policies to reduce or stop harvesting trees to avoid carbon release. Although 'harvesting' is carefully distinguished from 'deforestation' in other parts of the Guidelines, in terms of the way the carbon is assumed to be released immediately no distinction is made. Avoiding deforestation will prevent the loss of a large carbon reservoir and increased emissions from the subsequent land use. While non-harvest (protection) forestry may be totally appropriate for some objectives, it fails to capture additional benefits for emissions reduction through material and energy substitution.

The type of forest will affect the potential downstream uses and hence the overall GHG benefits of the forestry sector (see Table 1). Protection forests offer little if any net sequestration and no off-site carbon benefits. Sustained yield forests may have lower stocks but higher turnover rates and the biomass harvest offers off-site benefits. Very short rotation energy forestry plantations may have the highest sequestration rate, but lower carbon stocks and a rapid cycle without great opportunities for product substitution.

Forest products

Extracting biomass from the forest for products is equivalent to extending the lifetime of the carbon in the biosphere before it is returned to the atmosphere. Every

unit of carbon in the biosphere, e.g. in forests and wood products, is not in the atmosphere. Therefore the objective is to maintain and enhance these stocks, which means removals must be equal to or more than emissions.

The direct and indirect fossil fuel substitution opportunities offered by wood products are widely recognised. Direct benefits arise from using biomass as a fuel, but indirect benefits can also be gained by substituting wood for more energy- or emissions-intensive materials, e.g. steel, concrete. The atmospheric outcome is maximised if these benefits are additive rather than competitive. For example this could include the manufacture of durable products and extensive reuse and recycling, so that each product replaces a non-renewable material. The carbon is not released to the atmosphere until the biomass is used for energy when there are no available opportunities for reuse and recycling.

Measurement and reporting

The IPCC Guidelines to help Parties report their emissions and removals in their National GHG inventory includes general principles, definitions, calculation procedures, and emissions factors. It is based on preparing an inventory divided into different sectors: energy; industrial processes; agriculture; land use, land use change and forestry (LULUCF); and waste. There are rules on what is reported under each of them, for example:

1. All carbon removed from a forest is reported as an emission of CO₂ in the LULUCF Sector.
2. CO₂ released from biomass (e.g. firewood, bark) burnt for energy is not included in the Energy sector totals (CO₂ from biofuels is noted as a memo item).
3. CH₄ released from biomass burnt for energy is included in the Energy sector.
4. CO₂ released from waste biomass (e.g. wood/paper in landfill) is not included in the Waste Sector.
5. CH₄ emissions from waste biomass are included in the Waste Sector.

Attribution or allocation

The examples above demonstrate incorrect attribution of emissions, i.e. the emissions are not associated with the correct sector let alone the activities that release them. Hence inventories do not accurately report sources and sinks, which can create a distorted picture of where policies need to be targeted to reduce net emissions.

Since all emissions of biomass carbon are allocated

to the grower/producer country, there is no identifiable benefit of extending the life of the carbon in the biosphere. Consumers/countries are not responsible for emissions from imported biomass and hence have no incentive to reduce consumption or encourage reuse and recycling. Under some proposals bioenergy is not only considered emission-free, but is also allocated a credit for avoided fossil fuel emissions.

This allocation system creates the worst possible emission profile for net producers and exporters of primary products. Fortunately for many industrialised countries, most of the biomass production can occur in developing countries, where there are currently no emissions commitments. Countries consuming imported biomaterials and biofuels need have no concern about any associated emissions liabilities. Unfortunately New Zealand relies heavily on exports of primary products and the 'emissions' calculated from stock changes are included in New Zealand national accounts. This also applies to developing countries, and is unlikely to encourage them to adopt emission reduction commitments.

Permanence and additionality

Activities fall into three categories in terms of the atmospheric impacts: those that emit GHGs into the atmosphere (sources), remove GHGs from the atmosphere (sinks), or have no net impact on the atmosphere (static reservoirs). It is the absolute quantity of emissions/removals that is more important to the atmosphere than emissions relative to a counterfactual baseline. However, there was a desire to differentiate between emissions from renewable and non-renewable resources (within current cycles or from geological sources), which resulted in concepts such as permanence and additionality.

Afforestation is considered in some international project mechanisms to be an inferior GHG mitigation activity than others because it is not permanent i.e. it is potentially reversible. The same mechanisms promote using biomass for energy because it is part of a renewable cycle, evaluating its benefit against other energy sources which often means bioenergy is considered as a permanent reduction in emissions from fossil fuels. These projects represent opposite absolute impacts on the atmosphere i.e. afforestation is a sink and combustion is a source. The project accounting system can consider both as 'emissions reductions' but only the bioenergy project would be counted as a permanent reduction in emissions. This could result in an increase in bioenergy use without associated biomass supplies.

Additionality is the concept that activities or projects are evaluated not on the basis of their atmospheric impact, but their impact relative to a counterfactual baseline. For example, a project involving use of gas rather than coal would be evaluated not on the emission from the gas, but on the emissions reduction relative to the baseline (higher emissions per unit of energy from coal).

Policy implications

The forest sector offers New Zealand the opportunity

to increase domestic self-sufficiency and at the same time reduce reliance on non-renewable materials and fuels. Increasing the area of forestry (production and protection) and the efficiency of the forest industries would meet numerous economic, environmental and social objectives. Amongst these would be the reduction in net greenhouse gas emissions.

Creating a simple accounting system will be crucial to achieving atmospheric outcomes. Emission allocation rules in the KP increase the complexity of the accounting system because it no longer mirrors the carbon flows that run through the economy. The complexity has been identified as a reason for slow market uptake and poor industry engagement as well as creating perverse incentives. The inconsistent calculation and allocation rules have also created a system that is considered inequitable. New Zealand can adopt its own inventory and accounting system.

It might be useful to consider developing a national inventory of 'what the atmosphere sees' that would accurately capture forest sector roles. This could facilitate reporting under the UNFCCC and accounting under the KP, by applying the allocation rules or accounting procedures relevant to each agreement. The national carbon balance could be significantly more positive to the atmosphere than current estimates, since carbon sequestered in New Zealand, i.e. around two-thirds of the forest carbon harvested in New Zealand, is exported in various biomaterials.

Correct attribution of emissions would greatly facilitate the identification of real GHG impacts. Deriving actual emissions would be a relatively simple and transparent process for most companies, since it would reflect the material and energy flows that are known to resource users. It could even operate in a similar way to GST, and domestic trading could facilitate reducing net emissions.

In terms of atmospheric impact, the net sink in a forest is equal to the stock change of the forest plus any harvested carbon transferred to another user. In other words, each rotation is acknowledged to remove additional carbon from the atmosphere. A wood processor, bioenergy plant or waste facility would report the emissions that occur, e.g. from biomass combustion or decay (as well as from fossil fuel use), using IPCC guidelines to estimate emissions from these activities. This is likely to promote efficiency of biomass conversion and consumption, including recycling of carbon through multiple product uses as well as the 'useful' release of carbon through its use as a fuel.

Accurate identification of atmospheric exchanges would facilitate the development of appropriate policies and measures that will deliver net emission reductions. Companies in New Zealand might be more accepting of some form of targets if they are evaluated on the basis of their real impact on the atmospheric GHG balance, and given the opportunity to trade with other companies within New Zealand.

Mitigating worries with wildings

Nick Ledgard*

Wilding pines will take over the high country.” This was a comment by a speaker at a High Country Landscape Management Forum held in Queenstown in September 2005. It attracted many nods from the audience. Subsequent discussion led to the insinuation for many at the Forum that all conifers spread and that they are ‘bad news’, not just for the high country but for many other landscapes as well. Unfortunately, although the comment, and the insinuation that many connected to it, was wrong, such thinking is not uncommon in this country. This should be of considerable concern to foresters.

This article addresses why there is such concern about wildings, a common misconception about forestry and wildings, the importance of knowing the real facts and promoting them, how to mitigate wilding spread, and how we as foresters must accept such mitigation as a normal part of ‘everyday’ forest management.

Species and area affected by wildings

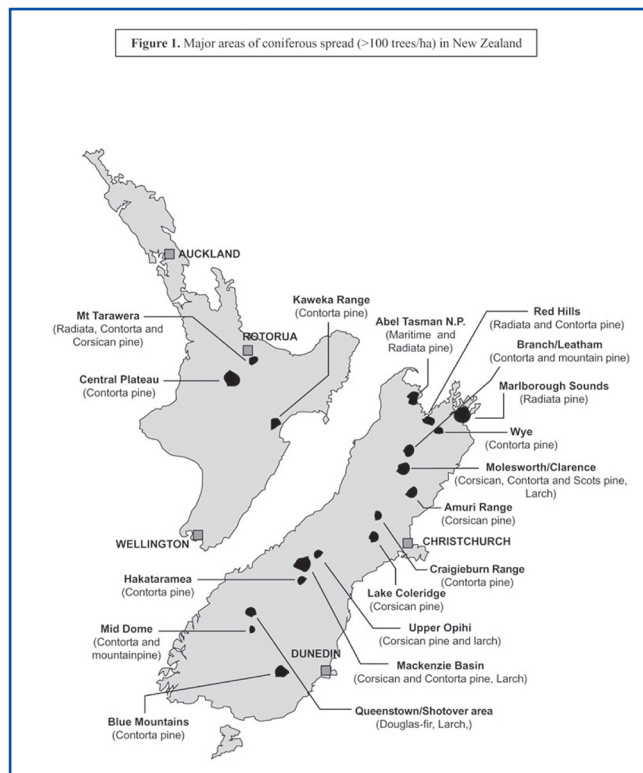
Ten introduced coniferous species are encountered most often as wildings in New Zealand. These are Bishops or muricata pine (*Pinus muricata*), Corsican pine (*P. nigra*), dwarf mountain pine (*P. mugo*), contorta or lodgepole pine (*P. contorta*), maritime pine (*P. pinaster*), ponderosa pine (*P. ponderosa*), radiata pine (*P. radiata*), Scots pine (*P. sylvestris*), Douglas-fir (*Pseudotsuga menziesii*) and European larch (*Larix decidua*).

The main locations where wilding spread affects significant areas at densities >100 trees/hectare, along with the dominant species involved, are shown in Fig. 1 (adapted from Ledgard 2001).

The exact area affected by wildings is difficult to estimate, due to different interpretations of the word ‘affected’. In 2000, I estimated an area of 150,000 ha to have at least 1 wilding/ha (Ledgard 2001), the main component being that affected by contorta pine in the Central Plateau area of the North Island. In 1975, some 30,000 ha had an ‘infrequent’ to ‘dense’ covering of contorta pine on the Plateau (Hunter & Douglas 1975). Although the majority of these wildings have been removed, the present area affected is estimated at over 90,000 ha (J. Mangos, Land Manager, NZ Army, Waiouru), mainly due to the widely scattered presence of lone outlier trees. In the South Island, I wrote of 40-50,000 ha being affected by at least 1 wilding/ha (Ledgard 2001), whereas DOC states in their South Island Wilding Strategy (2001) that ‘the uncontrolled spread of introduced conifers presently threatens over 210,000 ha of land administered by DOC in the South Island’. In DOC’s strategy document the ‘Area under threat’ is defined as ‘the area ... that is likely to be threatened by wilding conifers in 10-15 years if no control is undertaken’. If this definition is extended to land outside the DOC estate, then the area potentially ‘affected’ in the South Island is unlikely to be under 300,000 ha.

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Fig. 1: Major areas of conifer spread (> 100 trees/ha) in New Zealand (adapted from Ledgard, 2001).



More recently, the area affected by wildings (at least one wilding/ha) in Canterbury (total area 2.3 million ha) was estimated at 62,000 ha (Old 2003). On Molesworth Station (in the DOC estate since 2005), which is characterised by extensive open slopes and valleys with little woody vegetation of any stature, I calculated that approximately a third of the total area of 180,000 ha has (or until recently had) an ‘association with wildings’; i.e. a presence of at least 1 wilding / 100 ha (Ledgard, 2006 DOC contract report). Perhaps the second largest area in the South Island is in the Marlborough Sounds, where I estimate around 40,000 ha to be similarly affected.

The major seed sources for the larger areas of ‘historic’ conifer spread (as shown in Fig. 1) can be evenly apportioned into three categories:

- Government erosion control operations mostly undertaken in headwater catchments between the 1950s and 1970s (Kaweka Range in Hawkes Bay, Wye and Branch/Leatham catchments in Marlborough, Craigieburn Range and Hakataramea valley in Canterbury, and Mid Dome in Southland).
- Commercial plantations (Mt Tarawera and Central Plateau in the North Island, Red Hills/Mt Arthur in Nelson, Amuri / Hanmer Ranges in Canterbury, and Blue Mountains in Otago)
- Farm and private plantings (Abel Tasman National Park in Nelson, Marlborough Sounds and Molesworth in Marlborough, Lake Coleridge and Mackenzie Basin in Canterbury, and in the Queenstown area).

Why worry about wildings?

Concern about wilding spread is present in many countries, particularly in the Southern Hemisphere (Richardson & Higgins 1998). In New Zealand, wildings are seen to threaten:

- Landscape values – particularly to disrupt existing open and often treeless landscapes.
- Conservation values – spread can dominate or degrade the habitats of indigenous flora and fauna.
- Existing pastoral uses – grazing species can be shaded out by taller-growing trees.
- Future land use options – wilding dominated land is more expensive than open grassland to convert to other uses such as improved pasture or managed forest.
- Existing hydrology – dense wilding stands covering a significant percentage of a catchment (greater than 20% - in Davie & Fahey 2005) will reduce water yields.

In 2001, the Department of Conservation (DOC) produced a South Island Wilding Strategy (DOC 2001) in which it is stated that wilding conifers are 'the most significant weed threat in many areas'. Over the last decade, the Canterbury (Environment Canterbury), Otago and Southland (Environment Southland) Regional Councils have all featured wildings in their Regional Pest Management Strategies (e.g. Environment Canterbury 2002).

Concern is greatest in the drier zones of the country, where there are large areas of lightly vegetated land and the opportunities for invasion by vigorous pioneering conifers are frequent. It is least in the wetter regions, where the reversion of other woody species (often native) is more vigorous, leaving shorter 'windows of opportunity' for introduced conifer invasion. DOC has compared the cost-effectiveness of a diverse range of conservation projects in the dryland environment around Twizel in the South Island's Mackenzie Basin, with the much wetter Maniapoto area, south-west of Hamilton in the North Island (Stevens 2004). The conclusion was that wildings have comparatively little opportunity to spread in the Maniapoto and are 'a relatively short-term successional weed within seriously disturbed shrub and forest communities' (Stevens 2004). In the Twizel area however, 'wilding conifers have ... substantial opportunities to spread and to change the natural composition, structure and function of native communities'.

Misconception - tendency to extrapolate historic spread cases to present-day forestry

As can be seen from the above, there is certainly cause to be concerned about the risk of wilding invasion, but it is incorrect to extrapolate a key feature associated with existing areas of spread to present-day forestry generally. That feature concerns the species involved. Fig. 1 shows seventeen areas of significant conifer spread. The most common species mentioned is contorta pine. It is the most vigorous spreading conifer in New Zealand (Ledgard & Langer 1999), and is involved in twelve of the seventeen

areas. Its propagation and planting is now forbidden in the Regional Pest Management Strategies of a number of regions (e.g. Environment Canterbury 2002) – hence, no-one is currently planting this species. Similarly, very few people are planting most of the other species featuring in Fig. 1 - namely Scots, maritime and Corsican pine and European larch. The only species commonly planted today are radiata pine and Douglas-fir. Radiata pine can certainly be found as wildings, mainly due to its common occurrence throughout the country, but in terms of natural spreading vigour it is ranked low when compared to the other conifer species named above (Ledgard & Langer 1999; Ledgard 2004). However, the same cannot be said of Douglas-fir – the risk of it spreading is much higher.

Research

Basic knowledge about wilding ecology is essential for understanding and managing spread successfully. The first formal research trial was carried out by Dr Udo Benecke in the mid 1960s, looking at the role of grazing and pasture management in controlling contorta pine seedling establishment (Benecke 1967). The next major phase of research was initiated in the mid 1980s by the author and Lisa Langer (formerly Lisa Crozier). Trials were established to determine the ecology and demography of wilding spread in order to gain a better understanding of the wilding life cycle and the stages of that cycle where control strategies could be implemented most cost-effectively. Life history research has focused on seed production and dissemination, seed bank longevity in the soil, seedling microsite preferences, factors influencing seedling emergence and early survival (plant competition, animal browse, mycorrhizal presence). Recently, this information has been incorporated into predictive models. A more detailed summary of this research is given in 'Wilding conifers – New Zealand history and research background' (Ledgard 2004).

Mitigating spread risk

Research results and experience in the field has highlighted four key areas for mitigating the risk of wilding spread. These are species choice, plantation siting and design, surrounding land management and the use of predictive models.

Species choice

The propensity to spread and spreading vigour varies with species.

The age of significant seed production by the major introduced conifers generally ranges between age 8 and 13 (Ledgard 1988; Ledgard & Langer 1999), although a small proportion of trees will always produce seed a few years earlier than the rest. Contorta and dwarf mountain pine are the earliest coning species, and both of these species will produce seed to well above native tree line (1300-1500 m). The cone production of others, such as Corsican pine and Douglas-fir, drops off with increase in altitude, with little seed produced above 900 m and 1200 m respectively. At 900 m on Molesworth station, Corsican pine cones are hard to find and wildings will not be seen, whereas contorta and Scots pine are

spreading vigorously. Not far way, between 350-700 m asl, Corsican pine has spread extensively from Hanmer Forest. In general, seed production increases where trees are under some stress, often associated with reduced rainfall.

Conifer seed is disseminated by wind, and the distance of seed dispersal varies with species. The lighter the seed, the greater the distance it is likely to travel (Ledgard 2004) – two of the lightest species being contorta pine and Douglas-fir. The dissemination of Douglas-fir seed is also enhanced by the way it displays its cones - hanging down from the tips of branches, as opposed to being held closer to branch (or main) stems, as is the case with the other spreading conifers.

Seedling microsite preferences also vary. The major difference is between Douglas-fir and the pines. The pines can tolerate the more open, exposed sites, whereas Douglas-fir is more shade tolerant, and more able to establish within low-stature bushes and scrub (Cattaneo 2002). However, contrary to what many believe, it will not establish readily under closed canopy forest (Chavasse 1979; Ledgard 2002).

Once established, the attraction of conifers to browsing animals differ. Radiata, ponderosa and contorta pine are the most favoured by animals, whilst Corsican pine is the least (Crozier & Ledgard 1990). Young seedlings are particularly susceptible to browsing by rabbits (Davis *et al.* 1996), so the dramatic drop in rabbit numbers after the arrival of the rabbit calicivirus disease in 1998 led to a rapid increase in wildings.

Douglas-fir deserves special mention when it comes to species choice, especially as it is the most commonly planted species after radiata pine. Up until about 20 years ago, it did not feature as a major spreading species – it was hardly mentioned by Chavasse (1979) in his review of exotic tree species spreading into native forest. However, it is certainly a vigorous spreading species today (Ledgard 2002), probably due to an increase in numbers of readily available mycorrhizal propagules in the environment and a corresponding increase in the number of young seedlings becoming mycorrhizal at an early age (Dickson 2001) – without mycorrhizae they do not usually live more than 2-3 years. Douglas-fir is also more shade tolerant than the pines, which means it may invade open shrublands and canopy gaps in forests more readily.

Plantation location and design

The main determinants of spread relative to plantation siting are slope, aspect and exposure relative to the prevailing winds. Seed is likely to spread furthest from ridgetops and slopes exposed to strong winds. These are known as seed 'take-off' sites. Probably one of the best known is the top of Mid Dome in Southland (1480 m asl), from where contorta pine seed has been blown many kilometres. No spread-prone conifers should be planted on seed take-off sites, particularly if they are upwind of lightly vegetated and/or lightly grazed land.

Good plantation design involves trying to avoid having long edges at right angles to the prevailing wind, especially adjacent to spread-prone land. However, this is often difficult. What is more possible, is the planting of a less

spread-prone species around stand margins. Edge trees are usually closest to spread-prone land and have green cone-bearing crowns down to low levels. Hence, most wildings around plantation edges are likely to have grown from seed disseminated by edge trees. Two rows of less spread-prone radiata or ponderosa pine around the margins of a Douglas-fir plantation will lower the risk of wilding spread from the more spread-prone fir. In this instance, radiata is the better edge tree as it is faster growing. Edge row planting is most effective on flat land – in hilly country, wind eddies are more frequent and can pick up seed from inside the stand.

Surrounding land management

Spread is most likely to occur on undeveloped, lightly vegetated and/or lightly grazed land. It is least likely to occur within closed canopy shrublands or forest, within improved pasture, and on land which is mob-stocked by sheep at least annually (Benecke 1967; Crozier & Ledgard 1990). Gibson (1988) found that sheep were far more effective at controlling wildings than cattle. Even grazing by sheep at very low levels (>0.5 sheep/ha) will significantly reduce wilding establishment (Benecke 1967). Benecke also demonstrated that pasture improvement by use of fertilisers on their own (without grazing) increased vegetation competition to the extent that contorta pine wildings were unable to establish successfully. Davis (1989) explored the option of establishing plantations by direct drilling and found that competition from resident vegetation inhibited establishment unless a herbicide was applied. Recent research has endorsed the strong effect of competition, by showing that the establishment of nine conifer species from seed on unimproved grasslands was reduced by an average of 40% by one application of nitrogen fertiliser (Ledgard, unpublished data).

Decision support systems and predictive models

The major aim of the wilding research has been to gain information which can be used to assist the decision-making of land managers and administrators. To this end, a simple decision support system (DSS) has been produced for calculating spread risk from new plantations (Ledgard 1994; Ledgard & Langer 1999). This can be readily used by foresters and farmers, is available in paper and electronic form (<http://www.forestry.ac.nz/euan/spchc/spchc.htm>), and is advocated by administration agencies dealing with spread-prone land. A similar DSS is being developed for assessing the risk of wilding spread into new areas.

Wilding models will not only assist in determining the life history stages most susceptible to interception, but they can also be used to assess the efficacy of control strategies, such as the removal of trees of different ages and on varying sites. This is important when there are limited resources which must be spent as cost-effectively as possible. The first major progress on a predictive model was made in 2002 (Buckley *et al.* 2005). More recently, the author has collaborated with Heather North of Landcare Research to develop a simulation model (the Ben-Tal Laing model) plus a GIS model for prediction of areas at risk of wilding invasion. In validation runs, the simulation model worked

well for spread in the Craigieburn area, but its use elsewhere will depend largely on the availability of good input data. The GIS model is less data demanding and can be usefully driven with expert knowledge.

Acceptance of wilding spread by foresters

Up until relatively recently, it could be said that most foresters and land managers have failed to acknowledge that the spread of wilding conifers is a natural part of growing trees in New Zealand, and should be accommodated accordingly. Without containment, seedlings will regenerate outside managed areas just as readily as sheep will escape from land which is not properly managed or fenced. Managers of farm animals take this for granted and think nothing of spending time to fix fences (prevent escape) and to recover animals that have strayed off their properties (remove escapees). It is a normal part of their accepted 'everyday' management. It has to be the same with those growing trees. Before any planting commences, plans should consider wilding spread risk and put in place funds and strategies to minimise the risk of unwanted spread. Once trees mature and start producing cones, checks for wildings and their removal before coning, must become a regular activity.

Conclusion

Many introduced conifers grow well in New Zealand. A number regenerate naturally, some more vigorously than others. This is the price we pay for living in a country which has an environment which promotes some of the world's best growth of plantation conifers. Introduced trees have tremendous prospects for enhancing New Zealand's long-term environmental, social and economic well-being, but in order to realise these gains properly, we have to be well aware of the problems. The risk of unwanted wilding spread is one of these and we have to deal with it accordingly.

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