Pesticide use in planted forests in New Zealand

Carol Rolando, Brenda Baillie, Toni Withers, Lindsay Bulman and Loretta Garrett

Abstract

To protect New Zealand's $4.8 billion per annum forest resource from weeds, diseases and pests, forest managers apply pesticides. This includes an estimated 405 tonnes of herbicide (various), followed by significant amounts of fungicide (mainly copper), and even less insecticide (alpha-cypermethrin). These applications are justified on the basis of the need to protect the ongoing productivity of New Zealand's planted forests. Research has significantly influenced how forest growers use pesticides to protect the forest resource from the impacts of weeds, diseases and pests. Over 50% of this country's planted forest area is voluntarily certified under the Forest Stewardship Council and all corporate forests have adopted the New Zealand Forest Owners' Environmental Code of Practice. We review the current use of pesticides in forest management in New Zealand in relation to growers retaining their 'licence to operate' under adopted environmental codes of practice.

Introduction

Planted forests in New Zealand make up 7% of the land area and industries associated with these forests, including the wood processing sector, contribute around 3% to GDP and employ about 21,000 workers directly and many more indirectly (Forest Owners Association, 2014). At about $4.8 billion per annum the forestry sector is New Zealand's third largest export earner, with ambitions to more than double this by 2022 (Woodco, 2014). Protection of this resource from biosecurity threats, and biotic and abiotic risks, is therefore a high priority for forest growers (Forest Owners Association, 2015). Pests, weeds and diseases not only directly reduce the value and productivity of the forest resource, but phytosanitary constraints also have the potential to severely restrict New Zealand log and wood product exports into international markets. Without effective weed control, planted forest productivity would be significantly reduced and growers would not be able to meet either the export volume demand or the consistent quality demands of increasingly discerning wood processors (Richardson, 1993; Rolando et al., 2011a).

Pesticides are used in forests because they generally represent the most cost-effective tool for managing insect pests, diseases and weeds. The two most recent surveys to benchmark pesticide use in the New Zealand forest industry include that conducted by the Ministry for the Environment (Manktelow, et al., 2005) in 2002/2003, followed by a herbicide use survey conducted by Scion in 2012 (Rolando et al., 2013). The earlier study indicated herbicides were the most common pesticide used in forestry, with an estimated 405 tonnes of active ingredient (a.i.) applied in 2002/2003, followed by fungicides, with an estimated 54 tonnes of copper applied (Manktelow et al., 2005). This equated to an annual loading of ~0.27 kg a.i. ha^{-1} yr^{-1}, and was the second lowest in terms of intensity across four sectors (pastoral farming, arable farming, forestry and horticulture), with much higher annual loadings recorded for horticulture and arable farming (13.19 kg a.i. ha^{-1} yr^{-1} and 2.43 kg ha^{-1} yr^{-1}). Similar figures for annual herbicide use in forestry were estimated by Rolando et al. (2013), with the three most intensively used herbicides identified as terbuthylazine, glyphosate and hexazinone. There was no reference to an amount of insecticide used by the forestry sector in the Ministry for the Environment study, except to acknowledge that insecticide (alpha-cypermethrin) was used to manage pests on Eucalypt plantings. The relatively small area of Eucalypt plantations (20,000 ha) means that insecticide use in planted forests is relatively minor. Since that survey, one New Zealand forest company has treated on average 1,500 ha per annum with alpha-cypermethrin to manage the significant defoliator, the Eucalyptus tortoise beetle (*Paropsis charybdis*).

While pesticides are widely accepted as a standard, cost-effective tool for the management of pests, diseases and weeds in planted forests, their continued widespread use is not guaranteed. Globally, there are pressures from regulatory bodies and NGOs to shift away from the use of pesticides towards alternative, non-chemical methods of pest and weed control (FSC, 2015a). Considering that aerial application of pesticide is a heavily regulated activity in the European Union, its continued use in New Zealand should at least be a consideration, if not a concern. For the forest industry, environmental certification, such as that with the Forest Stewardship Council (FSC), already introduced the shift to minimise pesticide use in the 1990s (Fletcher & Hanson, 1999). Further to this, and according to their own set of criteria and standards, the FSC also identify and list highly hazardous pesticides (active ingredients) and require all FSC certified forest growers to modify, or justify, pesticide use to meet these standards. The FSC list of highly hazardous pesticides is actively revised with new knowledge, with the most recently listed active ingredients being picloram and a range of copper compounds (FSC, 2015a). The concept of 'licence to operate' is evolving where there is a requirement for primary sectors not only to ensure (and demonstrate) minimal damage to the environment as a result of primary production, but also that methods used are socially acceptable. In New Zealand, the planted forest sector is proactive in adopting best management practices to reduce environmental impacts, with over 50% of the planted forest area voluntarily FSC certified and with all corporate forests adopting the New Zealand Forest Owners Association Environmental Code of Practice.

Here we take the opportunity to briefly review the use of pesticides in forest management, with a focus on the outcomes of the latest research (herbicide, insecticide and fungicide) conducted to enable growers to sustain their licence to operate.

Herbicide use in planted forests

Decades of research have been dedicated to increasing the efficiency with which herbicides are used for weed control in New Zealand's planted forests (Richardson, 1993; Richardson et al., 1996a; Richardson et al., 1996b; Rolando et al., 2010). Although no longer on the FSC 'highly hazardous' pesticides list, between 2007 and 2015 the widely used active ingredients terbuthylazine and hexazinone were listed as 'highly hazardous' by the FSC and could not be used on FSC certified forest land without a derogation (FSC, 2007, 2015a). At the time, this was a significant issue for growers needing to manage a suite of competitive weeds with the ability to cause complete crop failure if not managed. Consequently, over this period, weeds research focused on finding alternative herbicides to these active ingredients as well as understanding their fate in the environment (Rolando et al., 2011b; Rolando & Watt, 2014; Wang et al., 2010; Watson et al., 2010; Watt et al., 2010; Rolando et al., 2013). This was preceded by an economic assessment of the potential financial impact to the industry of a switch to non-chemical methods of weed control – manual or mechanical (Rolando et al., 2011a). The substantial cost to industry of non-chemical weed control highlighted in that assessment provided some justification for the continued use of herbicides and the need to find alternatives to those listed as highly hazardous.

Monitoring water quality in herbicide fate trials

The research to find alternatives to terbuthylazine and hexazonone was conducted largely on registered herbicides with the aim to determine their ability to control the most competitive weeds common to New Zealand's planted forests (Rolando et al., 2011b; Rolando et al., 2015; Rolando & Watt, 2014; Watt & Rolando, 2014). The research indicated that there were no suitable replacement herbicides for terbuthylazine and hexazinone and that the current operational treatment using these active ingredients was the most effective and low-cost treatment for first-year weed control (Rolando et al., 2015). Terbuthylazine mixed with the active ingredient mesotrione was the most promising alternative tested for first-year weed control, but this only removed hexazinone from the operational mix. Trial results indicated that treatments not including either terbuthylazine or hexazinone generally needed to target specific types of weeds to be effective. Growth losses in excess of 30% were associated with some of these treatments 18 months after application, which was not a particularly promising outcome (Rolando et al., 2015). However this response may shift over time and the trials will need to be re-assessed at a later date. An application of clopyralid, triclopyr and aminopyralid in the spring of the second year after planting was found to be effective against young and emerging scrub weeds, particularly broom and gorse. This outcome indicated that aminopyralid could be used to replace picloram, if no FSC derogation on the continued use of picloram is obtained.

The potential for continued use of herbicides depends, in part, on their use within human health and environmental limits. There was a lack of information about the environmental fate of herbicides used in New Zealand planted forests, which translated to uncertainty about the potential effects on the wider environment. Research has started to address this knowledge gap on herbicide fate in the soil and aquatic environments with the environmental fate of terbuthylazine and hexazinone in 'Pumice and Recent' soils recently evaluated (Garret et al., 2016; Garrett et al., 2015; Baillie et al, 2015, Baillie accepted). Pumice and Recent soils make up 39% of New Zealand's planted forest soils and are considered vulnerable to herbicide movement due

Site for herbicide fate trial on Pumice and Recent soil

to their low carbon concentration, resulting in a low ability to retain some active ingredients in the topsoil. The terrestrial fate of terbuthylazine and hexazinone in a Pumice and Recent soil showed the first two weeks to one month after spray application to pose the greatest potential risk of movement of these herbicides off-site (Garrett et al., accepted; Garrett et al., 2015). After this time the risks are low due to the rapid half-life of the herbicide. Management practices that influence the amount of organic matter on the forest floor can significantly reduce the risk of off-site movement of terbuthylazine and hexazinone.

Research on the aquatic fate of terbuthylazine and hexazinone in a Pumice and Recent soil has shown that the day of herbicide application (24 hours), and rainfall events occurring shortly after, pose the greatest risk to the receiving aquatic environment. These risks were mitigated where 'no-spray' buffers were retained along the channel margins and to a lesser extent where slash residues were present in the stream channel (Baillie, accepted; Baillie et al., 2015). Under operational conditions, and when applied according to the manufacturer's instructions, the downstream risks to human health and receiving aquatic environments were low. This outcome was supported by a catchment-scale model, which was developed to determine the aquatic fate of terbuthylazine and hexazinone over two years in the upper Rangitaiki catchment (118,345 ha; 71% in planted forests) (unpublished data). The model indicated that the concentrations of both these herbicides were below detection limits for most of the monitoring period (2012/2013), posing a very low risk to human health, water quality and the aquatic environment. However field trials have yet to capture extreme rainfall events that could initiate surface erosion shortly after herbicide application, a process that may pose an additional risk to aquatic environments, particularly in steepland forests (Michael et al., 1999).

In 2015, changes to the FSC criteria for rating herbicides as highly hazardous resulted in the removal of terbuthylazine and hexazinone from the FSC list of highly hazardous pesticides (HHP), and the placement of picloram on this list (FSC, 2015a). In terms of the active ingredients terbuthylazine and hexazinone this was a positive outcome for many forest growers. However for those dependent on picloram to manage the scrubweeds such as *C. scoparius* (common broom) and *U. europaeus* (gorse), the search for alternatives will continue. The generally dynamic nature of pesticide regulations globally will result in continued interest in the potential of non-residual herbicides for effective forest weed control. This is partly attributed to the requirement for certified forest growers to continually strive to reduce dependence on the use of herbicides for weed control. In this regard, there is a need for more environmental fate data on herbicides used in planted forests in New Zealand so that their risk to the planted forest environment can be independently evaluated.

Insecticide use in planted forests

Aerial insecticide applications have played a very important part in the eradication campaigns against a number of potentially serious exotic pests of forestry in New Zealand (Hosking et al., 2003; Yamoah et al., 2016). In all these cases applications occurred in urban or semi-rural situations using a variety of insecticides (e.g. Btk, bifenthrin, alpha-cypermethrin), with none actually extending to a requirement for management within commercially-owned planted forests. The most significant insect pest currently affecting planted forests is the tortoise beetle, *Paropsis charybdis*, a Eucalyptus defoliator. To manage this pest, a derogation from FSC has been repeatedly granted to New Zealand Eucalypt growers to use the otherwise prohibited insecticide alpha-cypermethrin. Under derogation, permission is contingent on outbreak conditions only, including continued research to reduce the dependence on insecticides for managing *P. charybdis*.

Spraying is undertaken when field surveys identify significant defoliation and the presence of damaging life stages of *P. charybdis*. To control outbreaks of *P. charybdis* over the last decade, FSC certified forest management companies have aerially sprayed alpha-cypermethrin (0.03 kg a.i. ha^{-1}) over ~1500 ha per annum at low volume (5 L ha^{-1}) in ultra-fine droplets in oil. Availability of aircraft and lack of suitable weather patterns can sometimes inadvertently lead to poorly-timed application and variable control success.

Eggs of *Paropsis charybdis*

Newly-hatched black larvae of the most significant insect pest currently affecting planted Eucalypt forests, the Eucalyptus tortoise beetle, *Paropsis charybdis*

Adult *Paropsis charybdis*

The annual variation in *P. charybdis* population peaks, together with the presence of biological control agents, has exacerbated the difficulties in predicting and responding to peak periods of pest pressure (Murray et al., 2008). Intensive monitoring of all life stages of *P. charybdis*, and the presence of biocontrol agents, is impractical in New Zealand, particularly as it feeds only on the adult flush in the high-crown of very tall trees. This differs significantly from the situation in Tasmania where field scouts are able to monitor for the presence of similar *Paropsine* pests on foliage that is reachable from the ground. Scouting enables management options that are more targeted to population density. In Tasmania, densities above a certain 'damage threshold' justify aerial spraying with broad-spectrum insecticides (Elek & Wardlaw, 2010).

The FSC derogation on alpha-cypermethrin has been extended (between 2013 and 2018) subject to continued research on integrated pest management. This requirement has been met by:

1. The mass-rearing and release of two biological control agents, the southern ladybird *Cleobora mellyi* (Withers & Berndt, 2010) and the egg parasitoid, *Neopolycystus insectifurax* (Murray et al., 2008),
2. Supporting research into potential alternative insecticides (Withers et al., 2013),
3. Investigating a new potential biological control agent for the larval life stage of *P. charybdis* (*Eadya paropsidis*) (Withers et al., 2015), and
4. Supporting research into pest resistance in breeding populations of *E. nitens* through the Specialty Wood Products Partnership (www.mbie.govt.nz/info-services/science-innovation/research-partnerships/current-research-partnerships#11).

Meanwhile non-FSC-certified forest managers growing Eucalypts have been managing outbreaks of *P. charybdis* in their plantations, spraying with alpha-cypermethrin as described above. However there are no records to indicate how often this is occurring or over what areas. If spraying becomes widespread it could interfere with future attempts to establish the new biological control agent *Eadya paropsidis* against *P. charybdis*, as parasitic hymenoptera are known to be highly susceptible to alpha-cypermethrin (Loch, 2005; Pugh, unpublished data). Ensuring sufficient unsprayed refuges are set aside to aid the parasitoid to establish could be a challenge for scientists and growers.

The potential is low that a 'softer' chemical will be registered that will control all damaging life stages of *P. charybdis* while permitting beneficial hymenopteran biocontrol agents to survive (Withers et al., 2013). The active ingredient spinetoram (Dow AgroSciences) shows potential. It is derived from the fermentation of *Saccharopolyspora spinose*, as are other spinosyns, with fermentation followed by chemical modification to create the unique active ingredient in spinetoram. Increasingly, review papers suggest that this insecticide may sometimes have non-lethal but negative impacts upon Hymenopteran biological control agents (Biondi et al., 2012; Khan et al., 2015), although laboratory trials confirmed the predatory ladybird *Cleobora mellyi* was resistant to any effects of this insecticide (Pugh, unpublished data). Despite the increasing cost and complexity of conducting classical biological control in New Zealand, the outlook for long-term pest management of Eucalyptus forests shows an undoubted need to rely upon it.

Fungicide use in planted forests

In the 1950s in the United States, copper fungicides were first shown to provide effective control of dothistroma needle blight. They have been used operationally in this country since the summer of 1966/67, two years after the disease was first confirmed in New Zealand. Stands are sprayed when an average of 10–20% of the total tree crown is affected by the disease. Disease levels are governed by temperature, moisture, age of the host material and amount of inoculum present. The climate in the Central North Island is ideal for disease development and this region is most frequently sprayed. Spraying is not undertaken in most of the South Island except Westland and Nelson, and is infrequently carried out in Wanganui, Taranaki, East Cape and Northland. Stands in the Central North Island are sprayed on average three to four times during the first 15 years of a 30-year rotation, but this may vary considerably depending on the site, silvicultural treatment, weather and a company's threshold for spraying. The variation in these parameters is reflected in the number of hectares treated in the annual copper spraying programme (Figure 1). In the North Island, 66,000 ha have been sprayed each year on average since the mid-1960s, with a low of 2,100 ha in the summer of 1978/79 and a high of 182,000 ha in 2002/2003. Over the last eight years, 40,000 ha have been sprayed on average each year, probably as a result of declining planting reducing the susceptible area.

Through research and advances in aerial spray application technology, the amount of copper applied for operational control of dothistroma needle blight has decreased significantly over time. From 1966 to 1981, 2.08 kg a.i. was applied as copper oxychloride in 50 L water ha^{-1}. From 1982 to 1984 this was reduced to 2.08 kg a.i. in 20 L water ha^{-1}. With the development of micronair technology, the application rate was further reduced in 1984 to 0.86 kg ha^{-1} as cuprous oxide applied in 2 L of spray oil made up to 5 L with water (Bulman et al., 2013). The transition from copper oxychloride to cuprous oxide was made because of price and convenience. The latter is now cheaper to use because the fungicide contains 75% active ingredient, which results in lower handling and application costs. Further, new production methods have reduced the cost relative to 50% a.i. copper oxychloride. Since the 2014/2015 season, a few companies have applied 0.86 kg a.i. ha^{-1} cuprous oxide in 3 L oil, but the economic benefits of this depend on the distance between the loading site and the area to be sprayed.

Based on its aquatic toxicity in the freshwater environment cuprous oxide was placed on the FSC highly hazardous list in 2015 (FSC, 2015a, 2015b). [Note that under FSC Criterion 6.1. a pesticide is considered 'highly hazardous' if it contains any active ingredient that has aquatic toxicity LC50/EC50 <50 µg, using Daphnia as the test organism or other invertebrate or vertebrate aquatic organisms that show greater sensitivity than Daphnia. Acute test duration is up to 96 hours.]

Past research by Fish (1968) on the potential environmental impact of copper fungicides in the aquatic environment when applied to planted forests reported copper in the suspended solid component of the water sample, but found no detectable concentrations of copper in aquatic invertebrates. After aerial application of copper at 1.76 kg a.i. in 50 L water

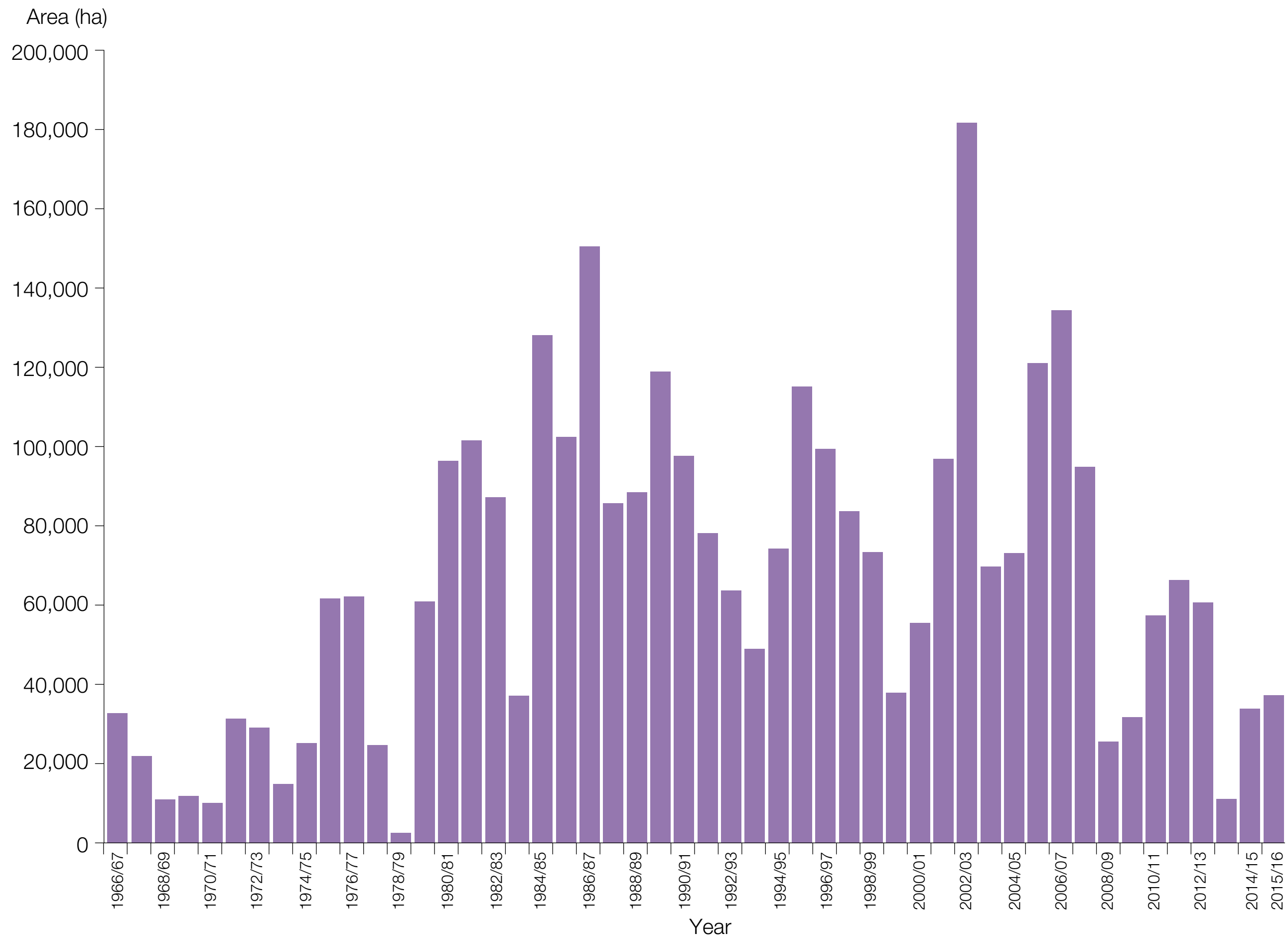

Figure 1: Areas sprayed for dothistroma needle blight control in the North Island using copper fungicides

ha^{-1} at Maimai in Westland, Collier and Hickey (1998) demonstrated the importance of vegetated riparian zones for intercepting spray and thus reducing direct entry of copper into streams. Peak levels of copper in stream water, attained less than one hour after spraying, were approximately ~300 µg (micrograms) L^{-1} where the riparian margin was not vegetated compared with ~50 µg L^{-1} where vegetation was present in the riparian zone.

Given the dependence of the industry on copper for the management of dothistroma needle blight, a research programme was initiated in 2015 to assess the risk to the aquatic environment when copper is applied under current operational conditions. These data are currently being assessed, and the resulting publication will provide further clarification on the aquatic risk posed by operational spraying of copper in the planted forest environment.

In 2008, a study was undertaken to determine if copper builds up in sufficient quantity to cause environmental damage following repeated application. Soil was sampled in stands where copper had been applied five to eight times and in nearby stands that had never been sprayed. Soil and humus from the stands with a history of spraying had significantly higher copper content (4.27 mg kg^{-1}) than the unsprayed stands (2.67 mg kg^{-1}) (Bulman, unpublished data). However this result was of no practical importance because levels were lower than those known to cause environmental damage. In Australia and New Zealand, total copper concentrations exceeding 60 mg kg^{-1} in soil require environmental investigation (ANZECC/NHMRC, 1992). The maximum concentration permitted by the European Community is 140 mg kg^{-1} (CEC, 1986). Furthermore, copper concentrations in unamended New Zealand topsoils vary from 2–120 mg kg^{-1}, with an average value of 17.5 mg kg^{-1} (Wells, 1957). Copper typically accumulates in the upper 150 mm of soil and is bound to organic matter and fine clay fraction (Epstein & Bassein, 2001), reducing the risk of movement into groundwater.

Concluding comments

This review shows the industry's long-term commitment to minimising pesticide use in planted forests, a trend that was initiated independently of, and prior to, the emergence of environmental certification schemes. Research has played a critical role in providing the science to underpin the development of best management practices, thereby assisting forest managers to achieve sustainable use of pesticides and retain their licence to operate. For the industry to maintain its licence to operate, it needs to continue to demonstrate this commitment to various stakeholders through the management of biosecurity threats and biotic risks in the best way possible but, more importantly, within environmental limits. In today's operating environment, this may be increasingly challenging. For example, FSC regularly reviews the criteria for the placement of pesticides on the HHP list, resulting in constant challenges to find suitable and acceptable long-term pest management strategies.

Outside of human toxicity, toxicity to the aquatic environment is often a key parameter that is strictly regulated, as we have already seen with priority pesticides (terbuthylazine, hexazinone and cuprous oxide) used in the forest environment. Since most pesticides are developed elsewhere and for agricultural use, there is often a lack of data on their fate in the planted forest environment and, more specifically, the New Zealand planted forest environment. In the absence of this information the (aquatic) environment toxicity standards are the default for New Zealand, with no data to support or refute subsequent decisions or public enquiries made on the basis of these data. This gap leaves the forest industry vulnerable to decisions or regulations, as these standards may not necessarily reflect the situation within forested catchments. There is value in additional testing to assess the toxicity of pesticides commonly used in planted forests on New Zealand's indigenous aquatic biota, which may be more or less sensitive than the standard species used in laboratory testing worldwide.

With the rapid advancements in novel pesticide products and application technologies, ever-changing certification and regulatory criteria, increasing public awareness around issues regarding pesticide use and a pressure to increase the intensity of wood production, research is likely to continue to play an important role in this area into the foreseeable future.

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All authors of this papers are scientists in the Forest Science team at Scion based in Rotorua. Email: carol.rolando@scionresearch.com.