Section 4: NZDFI Forest Health Research Plan

Background

The NZDFI aims to establish a high quality industry based on drought-tolerant eucalypts that produce naturally ground-durable timber for specific end-uses (Millen 2009). As such, initial species and genotype selection has been, and will continue to be, focused on growth and wood properties (particularly drought tolerance and production of ground-durable timber) targeted to specific growing regions and markets. However, the ability of the selected elite breeds to thrive in the presence of established and future biological threats is fundamental to the success of the program. This document outlines some of the known threats and the research priorities required to minimise those threats such that we are able to produce a high quality, economically and environmentally sustainable product suited to the dry regions of New Zealand.

Biotic threats to New Zealand eucalypt plantations

Like all commercial forestry species, eucalypts are susceptible to insect and pathogen attack which may limit productivity, reduce wood quantity and quality or even cause mortality. The proximity of New Zealand to the native range of *Eucalyptus*, the ever increasing travel and trade between the two countries and similarity in seasonal and environmental conditions are well recognised as factors providing opportunity for insect pests and pathogens to arrive, establish and cause harm to eucalypts grown in New Zealand (Withers 2001). The primary defoliators of plantation eucalypts in Australia, New Zealand and other plantation growing countries, are the paropsine leaf beetles (Coleoptera: Chrysomelidae: Paropsine) (Paine et al. 2011, Elek and Wardlaw 2013). There are over 400 Paropsine species native to Australia where at least 12 are regarded as pests (Simmul and de Little 1999) particularly where plantation eucalypt species are grown outside their native range. In New Zealand 5 eucalypt-feeding paropsines are currently established, including two very recent arrivals, *Paropsisterna beata* and *Paropsisterna variicollis*, the impacts of which are yet to be fully determined. *Paropsis charybdis*, established since 1916 (Thomson 1922, Clark 1930), has historically been a serious impediment to the establishment of a commercial eucalypt industry in New Zealand (Wilcox 1980) and continues to be regarded as our most debilitating eucalypt pest, causing occasionally sever defoliation particularly in the Central North Island (Murphy and Kay 2000). *Trachymela sloanei* and *T. catenata* are regarded as less problematic, although *T. sloanei* is locally abundant in the dryland regions of Gisborne and Hawkes Bay (Pers. Ob.) and should not be underestimated. In addition to the paropsines, at least 24 other eucalypt specialists from Australia cause minor to moderate damage and some occasionally severe localised outbreaks (Withers 2001, Sopow et al. 2012).

New and unknown insect pests and pathogens will also continue to arrive and establish in New Zealand, and many will be unpredictable. In addition to the vast numbers of paropsine beetles noted above there is a diverse fauna of eucalypt-specific defoliating lepidoptera, Hymenoptera and sap sucking psyllids, some of which have already become pests of eucalypt plantations internationally (Paine et al. 2011). Pathogens such a novel *Phytophthora* species and myrtle rust are an ongoing concern following incursions in Australia. Although these threats are important they should not be the cause to abandon the prospect of a successful eucalypt industry in New Zealand, as all commercial plantation species are subject to pests and pathogens to some degree. Even the prospects of radiata pine were at times considered dubious with the Canadian biologist J. J. de Gryse (1955) stating " . . . to ignore the notorious susceptibility of *P. radiata* to insects and fungi, the extreme vulnerability of the extensive monoculture in which it occurs . . . is tantamount to challenging all the laws of Nature” in his report commissioned by the New Zealand Forest Service to assess their forest health program at the time. Currently around 423 insect species are known to feed on the *Pinus* globally including 147 in New Zealand, of which 40 can feed on *P. radiata*. Bain (1981), amongst others, has noted that the assentation’s made by de Gryse have not played out, with the majority of biotic threats being successfully mitigated by intensive plantation management including careful species-site matching, silviculture practices, strong border biosecurity and onsite pest monitoring and management and breeding for pest resistance.

The basis for pest tolerance

Identifying pest tolerance is essential to the genetic improvement of plantation eucalypts in New Zealand if a viable hardwood forest industry is to be sustained. The importance of breeding for resistance, particularly to *P. charybdis*, was recognised in earlier New Zealand eucalypt breeding programs (Wilcox 1980). Recently, Elek and Wardlaw (2013) concluded that developing plantation stock more resistant or tolerant to leaf beetle attack was the highest pest management priority for Australian eucalypt plantations (Table 1). The forest health issues in New Zealand are not dissimilar to those faced in Australia when eucalypt species are grown commercially outside of their native ranges. Elek and Wardlaw (2013) proposed that the best paropsine management approach was to use multiple socially and environmentally acceptable methods with a minimal chemical footprint, an attitude matching the NZDFI sustainable industry ideology.

Table 1: Ranking (by Australian experts in leaf beetle management) of 16 potential management options for paropsine leaf beetles relative to a baseline of broad-spectrum aerial spraying. Ranking is based on 5 criteria (i) effectiveness in reducing larval and adult populations below levels that would be economically damaging; (ii) feasibility or ease of deployment for operational use; (iii) impact on the biotic and abiotic environment; (iv) perceived social acceptability; and (v) perceived cost. Reproduced from Elek & Wardlaw (2013).

	Scores								Ranks	
Management option	Effective Weight = 1	Feasible	Environmental	Sub-total	Social Cost Weight = 0.5		Sub-total	Total	Rank under each category	Overall rank
Baseline ('control' option) Broad-spectrum aerial spraying	5	5	0	10	0	4	2	12	5	10
'Landscape' options										
Tree improvement	3	4	5	12	5	3	4	16	1	1
Conserve natural enemies: overwintering sites	1	5	5	11	3.5	5	4.3	15.3	2	3
Conserve natural enemies: alternative food and hosts	2	4	5	11	5	3	4	15	3	4
Silvicultural management	2	3	5	10	5	3	4	14	4	5
Rear and release natural enemies	2	3	5	10	5	0	2.5	12.5	5	7
Trap trees	1	3	5	9	5	1	3	12	6	10
Pest repellent plants	1	2	4	7	5	2	3.5	10.5	7	13
Classical biological control (in Australia)	2	1	0	3	1	1	1	4	8	17
'Control' options										
Attract-and-kill traps	3	4	5	12	5	2	3.5	15.5	1	2
Lethal trap trees	2.5	4	3.5	10	4	3	3.5	13.5	2	6
Artificial repellents/antifeedants for pests	4	2	4	10	4	1	2.5	12.5	3	7
Softer insecticides	3	4	3	10	2	3	2.5	12.5	3	7
Different application methods for insecticides	4	3	3	10	3	1	2	12	5	10
Artificial attractants for pests	1	4	3	8	3	2	2.5	10.5	7	13
Enhance natural diseases of pest	1	3	2	6	3.5	3	3.3	9.3	8	15
Modify timing of spraying	2	3	2	7	1	3	2	9	9	16

The options were scored for five criteria: from 0 = poor or unacceptable to 5 = excellent. The baseline was ranked under the 'control options' category.

Pest resistance is rarely, if ever, the main selection criteria for the initial improvement of commercial forestry species, although it is regularly incorporated once other key characteristics have been achieved (e.g. *Pinus taeda* and *P. elliottii* for resistance to fusiform rust, *Eucalyptus* spp. for resistance against eucalypt canker in Brazil (Gadgil and Bain 1999)). One of the strengths of the NZDFI program is to include this important factor in the very early stages of the selection process by 'weeding out' the obvious problem breeds then conducting more specific pest tolerance assessment as trials progress.

Within *Eucalyptus* there is a huge degree of variability in insect tolerance to work with, both within and between species. This can result from complex variations in nutritional, physical and chemical characteristics (Ohmart and Edwards 1991, Li 1994). These drive feeding preferences, survival and productivity of insect herbivores. Some insect species are limited by physical factors, such as waxes inhibiting their ability to grasp onto leaves to lay eggs, or by sclerophylly inhibiting larval ability to physically bite into leaves (Ohmart and Edwards 1991, Steinbauer et al. 1998, Steinbauer et al. 2004). As such, many insects are host-specific to either juvenile or adult foliage, or to expanding vs. mature leaves. Preferences driven by foliar chemistry or 'plant secondary metabolites' (e.g. essential oils, phenols (e.g. tannins) and terpenes) are more complex and interact with factors such as nitrogen levels and leaf toughness.

The variation in secondary chemistry between species and provenances can include differences in the presence, quality and relative quantities and ratios of numerous compounds. Few individual compounds have been definitively linked to insect tolerance (Li 1994, Stone and Bacon 1994, Andrew et al. 2007). In general, species in the subgenus *Symphyomyrtus* are considered more susceptible to pests (see Noble 1989 for review). This has been the case in New Zealand with *P. charybdis*. However, even by 1973 *P. charybdis* had been recorded feeding on 59 species, including monocalypts (White 1973), and research has since observed complex variations in preferences and levels of attack even within species (E.g. Steven 1973). Stone et al. (1998) tested the hypothesis that symphyomyrts are more susceptible to attack by alleviating pest pressure with pesticides. They found symphyomyrts did generally outperform monocalypts when defoliation was reduced and suggested selection and breeding of *symphyomyrtus* genotypes exhibiting high levels of natural pest resistance could produce better long-term outcomes. Other authors have observed that although monocalypts tend to be attacked by fewer eucalypt generalists they have their own suite of potentially damaging specialists (see Li 1994 for review).

Factors such as the mix of available species can also have a significant impact on eucalypt herbivores feeding and oviposition choices such that species ignored in the presence of a favoured host may be accepted when that host is absent. *Paropsisterna bimaculata*, for instance, was thought to be specific to *Monocalyptus* until it began to have significant impacts on *E. nitens* grown outside their native range in Tasmanian plantations (Paine et al. 2011). Choice tests with adult beetles have since show that the beetle does not discriminate between *E. regnans* (*monocalyptus*) and *E. nitens* (*symphyomyrtus*) but rather is dependent on leaf morphology and the female beetles ability to grip the leaves during oviposition (Steinbauer et al. 1998).

Their higher performance (better establishment, faster early growth, wider environmental tolerance, more desirable fibre and timber properties) of *Symphyomyrtus* species in the absence of insect pests is one of the main reasons that they are the most commonly grown plantation eucalypts globally (see Stone et al. 1998). Despite the pros and cons of the two main subgenera, it is clear that there is a significant degree of variation in the foliar anatomy and chemistry and consequently levels of insect damage experienced within and between species (Noble 1989, Stone et al. 1998). Therefore, the main focus of selection for pest tolerance within the NZDFI program will be to detect and reduce this variability by genetic selection to ensure only the most insect tolerant of those breeds selected for desirable wood and growth properties are retained in the program.

Advancing pest tolerance research in NZDFI trials

NZDFI's species in the current breeding programme are;

1) A group of the 3 closely related *Symphomyrtus* species *E. bosistoana*, *E. argophloia* and *E. tricarpa*. The latter two are small selections included to provide the option to increase genetic diversity by creating hybrids.

2) *E. quadrangulata* another symphyomyrt

3) *E. globoidea* a monocalypt which although having still good wood properties is less site specific

As the NZDFI species have not previously been grown in commercial plantations information on specific insect and pathogen susceptibility is limited. Of the symphyomyrts, *E. argophlioa* has been found to be a poor host for *Paropsis atomaria*, a common paropsine pest in Australia with a wide host range (Fox and Macauley 1977). *E. tricarpa* has been the subject of several studies showing a link between plant secondary metabolites and resistance to insect herbivores (Andrew et al. 2007, Andrew et al. 2010). Variation in sideroxylonals, a class of foliar chemical antifeedants that deter both mammalian and insect herbivores, has strong plasticity and heritability in *E. tricarpa*, indicating that breeding for high concentrations to confer pest tolerance has a good chance of success (Andrew et al. 2010). However, the same study also found a population x environment interaction, indicating populations could differ in how they react to environmental conditions, and highlighted the need for more multi-site studies to help tease out these interactions. To this end, the established NZDFI breeding and progeny trials provide a timely and essential opportunity to further explore the expression of pest tolerance across a range of environments, such that the beneficial trait can be promoted and variability reduced.

Replication across multiple sites also allows us to assess the susceptibility of multiple species and genotypes to established insect pests across a range of environmental conditions which themselves can directly affect tree growth and insect population cycles. As fast growing, intensively managed vigorous trees are generally less susceptible to insect pests and pathogens (Gadgil and Bain 1999) species-site matching and appropriate silvicultural management is key to minimising biotic impacts when it is not possible to completely remove the threats. This combination of site-species matching and management decisions have effectively eliminated several former pest and pathogen problems in plantations of radiata pine. *Sirex noctilio* (sirex wood wasp) for example was once considered a major pest but is now successfully managed in New Zealand with a combination of biological control and silvicultural methods, including site matching (Bain et al. 2012). Similarly the native lepidopteran *Pseudocoremia sauvis* which historically caused severe defoliation of *Pseudostuga menziesii* under conditions of drought stress and overstocking (Gadgil and Bain 1999) is rarely a problem under present day regimes.

A final, if somewhat macabre, advantage of the NZDFI trials being established across a range of dryland regions in both the North and South Islands will be the ongoing opportunity to detect and immediately assess the impacts of any new incursions and determine the conditions under which any impacts can be alleviated. This has already begun with the recent detection of *Paropsisterna variicollis* (Eucalypts Variegated Beetle - EVB) during regular biosecurity surveillance in Hawkes Bay. At least three NZDFI trial sites are located in the immediate proximity of this incursion. Assessments of the specie's preferences and impacts have already begun in these sites and will continue to provide essential information on the impacts of the new pest without the normal delays that would be incurred if new field trials needed to be established or food plants grown for laboratory research. Like any new arrival, the EVB will not necessarily have the opportunity to exhibit its natural host preferences as seen in its native range given the limited suite of *Eucalyptus* species available to choose from in New Zealand. If preferred species are not present there is a possibility that, assuming environmental conditions are tolerable, a new pest will switch and adapt to the available food supply. As such, within the NZDFI breeding program selection for low susceptibility and high tolerance to pests in general is considered more valuable than selecting for specific resistance to any single know pest species.

Research program

The current NZDFI forest health research plan focus on insect pests rather than pathogens. Although pathogens are extremely important, to-date insects have been the main impediment to eucalypt plantation health. Notwithstanding this focus, pathogens will be given due consideration if new pathogens threats are identified. In particular, the emerging issues of Myrtle rust is 'on the radar' and we will be in a position to implement a program of work on host susceptibility if the pathogen becomes established in New Zealand in the near future.

Research into forest health effectively ties together the other research strands in the NZDFI science program (growth, propagation, wood quality and plantation management). In particular we will seek links between the chemical indicators of timber durability and susceptibility to foliar pests, pest susceptibility and tolerance with respect to species-site matching, and effective silviculture for pest management. Our research will focus primarily on 1) providing support for the selection of elite species and genotypes for further study in the NZDFI program and 2) evidence based recommendations for the monitoring and sustainable management of established pests. We will take an integrated pest management (IPM) approach focusing on reducing risk to the new industry throughout the growing process from selecting the most appropriate pest-tolerant species and genotypes to monitoring and managing pests when they do occur. As noted above, the great advantage of the NZDFI program is the distribution of trials across a range of sites representing variable environmental conditions. By assessing pest impacts across these trials we will be able to identify the most suitable genotypes for future deployment to ensure a viable and high quality durable eucalypt industry both with regard to economic (high productivity) and environmental (low pesticide input into the environment) sustainability.

1. Species selection

Initial NZDFI species selection was based on promising species with high drought tolerance and potential to produce durable heartwood. As part of the process for genetic improvement with regard to forest health we will 'weed out' species and genotypes that are most susceptible (attacked more) to insect pests and where possible select for traits that promote tolerance (ability to withstand or recover quickly from defoliation) to pest impacts.

a) Screening for pest susceptibility

Pest screening will follow a similar process as screening for other traits, such and growth and durability, with a focus on early selection. We will trial and then test the screening process on un-improved and subsequently the improved clonal selections. This will run alongside similar assessment of wood properties and measurement of PSP wherever possible.

Part 1: screen un-improved genotypes for one species (*E. bosistoana*) at one site (Avery's) to develop assessment method.

Part 2: roll out screening process across all 5 species and genotypes in as many sites as possible, targeting trees between 3 and 7 years of age with the aim of identifying the best fit-for-purpose genotypes to grow in each particular site with regard to both the abiotic (environmental) and biotic (established pests) limitations.

Part 3: screen improved selections between ages 3-7 to test selection choices. Repeat screening of initial material to determine the ability of early assessment to represent health and growth later in the rotation.

b) Tools for monitoring pest populations

Monitoring pest populations and impacts can be difficult and time consuming. Historically there has been a reliance on experienced field staff conducting visual assessments based on their knowledge of what a healthy tree should look like. This is a difficult skill to learn and there can be issues in comparing results from different observers. It can also be limited to young trees where the crown is accessible and is difficult to apply comparably to multiple sites at the appropriate time of year (i.e. when insect impacts can be directly observed) without employing multiple, well trained observers. Although this method can be used for the screening of our trials it is not ideal and a faster more quantitative method is required for eventual use by plantation owners for ongoing pest monitoring.

We will assess tools for a quick and robust standardised approach to monitoring tree health with regard to insect attack. Ideally methods should be quantifiable so they can be used to determine intervention thresholds for Integrated Pest Management programs – i.e. if pest abundance is greater than a specific level, pest management should be implemented. Two main approaches will be followed;

1. Test correlations between a single visual percentage estimate of defoliation and more quantitative methods such as the Occupied Leaves per Shoot (OLPS) method used by Forestry Tasmania (Wardlaw et al. 2010) and the Crown Damage Index (CDI) developed by the Australian Bureau of Rural Science for plantation managers (Stone et al. 2003).
2. Test for correlations between the above measures of insect attack and;
    a. Chemical traits determined using foliar NIR which could pick up compounds such as sideroxylonal concentration (reported to give an indication of susceptibility to insect pest attack concentration)
    b. Specific leaf weight (dry leaf weight/leaf area) and laminar thickness (crude measures of toughness (Steinbauer 2001))
    c. Total nitrogen and if possible available nitrogen (following Wallis et al. (2010))
    d. An additional measure will be to assess if there is a correlation between foliar chemical traits and wood traits conferring durability

2. Sustainable Pest Management

As noted above there are currently at least 29 eucalypt specialist insects established in New Zealand and it is likely new species will arrive in the future. Although species selection and appropriate site matching will go a long way to minimising pest problems, we cannot assume pest outbreaks will never occur in the future. An economically and ecologically sustainable approach to the management of these outbreaks is essential, particularly given many future growers of NZDFI eucalypts will wish to maintain Forest Stewardship Council or Organic certification which limits the use of chemical pesticides. Some eucalypts are able to sustain significant defoliation before growth is impacted but this is highly variable and few studies have quantified impacts in the field. For example, while just 10% insect defoliation has been shown to significantly reduced DBH and height growth of 3 year old *E. globulus* (Pinkard et al. 2006), 60% insect defoliation was sustained before observing a significant effect on 2 year old *E. nitens* (Rapley et al. 2009).

This part of the research program aims to provide evidence of the level of defoliation that can be sustained before intervention is required to prevent economic impacts as result of lost productivity. This entails effective monitoring of pests and determination of thresholds above which implementation of pest management is both economically and environmentally justified.

1. Assess species and family response to moderate (c. 50%) and severe (c. 90%) defoliation during spring, summer and spring + summer. This will give an indication of the degree and seasonality of defoliation trees can sustain before growth is substantially retarded compared to undefoliated controls
2. Link pest numbers determined from monitoring methods (above) to pest impacts on growth ascertained in (1). This will aid in the development of a set of monitoring protocols and pest intervention thresholds on which to base pest management decisions
3. Compare growth and recovery of genotypes subject to moderate, severe and seasonal defoliation. This will feed into species selection by effectively screening for pest tolerance (ie ability to withstand and recover from pest attack)

4. Analyse for correlations between pest load and impact and environmental variables (e.g. rainfall, aspect, temperature, exposure etc as set out in site-species matching plan)

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