100 years of the eucalyptus tortoise beetle in New Zealand

Toni Withers and Elise Peters

Abstract

The eucalyptus tortoise beetle, *Paropsis charybdis*, has been one of the most successful insect pests to invade New Zealand. One hundred years have now passed, and yet this pest continues to cause anxiety to forest managers and impact the growth of eucalypt plantations. Research shows there are serious cost implications for plantation managers if they neglect to manage tortoise beetle outbreaks across multiple seasons. Many attempts have been made to control this insect pest with biological control agents imported from its native Australia, with some success.

Scion is hoping to introduce yet another natural enemy in 2018, a braconid parasitoid that targets the larval life stage. The importance of integrating aerial spray technologies with biological control agents to minimise negative impacts on these beneficial insects cannot be under-estimated. We believe a future integrated management strategy will be the key to achieving successful suppression of this pest and ensure the long-term sustainability of *Eucalyptus nitens* as a valuable alternative plantation species for New Zealand.

Arrival and spread

The eucalyptus tortoise beetle, *Paropsis charybdis,* was first located at Coopers Knob on Banks Peninsula in 1916 (Thomson, 1922). Clark (1938) speculated that 'the insect was probably imported in the egg or early larval stages upon young eucalypt plants, although possibly hibernating adults may have entered the country under the bark of imported Australian hardwoods.' All we know for sure is that the pest established quickly in Canterbury. Those founding individuals arrived without any of the natural enemies that regulate their number in Australia.

In New Zealand, the only insects since observed attacking tortoise beetle larvae are some predatory pentatomids (bugs) (Valentine, 1967). So with conditions perfect for its rapid population growth, the eucalyptus tortoise beetle spread steadily through the country, reaching the North Island in 1956 and completing its nationwide establishment by the late 1960s (White, 1973). The beetle can complete at least two generations per annum in our climate. Adults are long lived, and some in captivity have lived for over

E. nitens plantation in the Central North Island showing effects of repeated eucalyptus tortoise beetle damage. Photo: E. Peters, Scion a year (Steven, 1973). Each adult female is capable of laying between 1,500 to 2,000 eggs over a period of a few months (Styles, 1970). This equates to an average daily rate of 20 eggs per day, and with a common 95% to 99% fertility rate (Steven, 1973) it is clear why the pest population can build up so rapidly.

Attempts to control

The first attempts to control the eucalyptus tortoise beetle using biological control were led by government entomologist, A.F. Clark, who was based in the South Island at the Cawthron Institute. Between 1932 and 1935, Clark communicated with CSIRO entomologists in Canberra and attempted to introduce Australian species of egg and larval parasitoids, both tachinid flies and braconid wasps. These species were not reared successfully in the laboratory. Attempts were repeated by scientists based at the New Zealand Forest Research Institute in Rotorua in the 1960s and 1970s, along with New Zealand Forest Products Ltd forestry staff (Bain & Kay, 1989). Despite releasing thousands of tachinids none were ever recovered, and of the *Cleobora mellyi* ladybirds, they were not recovered until much later. We now know that parasitic insects such as tachinid flies are notorious for being difficult to rear in the laboratory, and require that specific environmental conditions be met before they will mate.

The southern ladybird *Cleobora mellyi* was never destined to be the answer for *P. charybdis* control, despite having a huge appetite. We now know it feeds on both the eggs and larvae of tortoise beetles, and also requires hemipterous insects such as aphids and psyllids (little sap-sucking insects) in its diet (Baker et al., 2003; Pugh et al., 2015a). Where psyllids infested large Acacia trees in a sheltered bay in the Marlborough Sounds, the ladybird took hold and was rediscovered there years later. Farm foresters have since been successful at spreading this ladybird throughout New Zealand (Withers & Berndt, 2010).

Success?

It was not until 1988 that some biological control success was achieved. Egg parasitoids imported from Perth, where they were attacking a related tortoise beetle, proved easy to rear and *Enoggera nassaui* was established in New Zealand (Bain & Kay, 1989). All hopes for control lay with this little parasitoid. In fact, it proved remarkably effective and confidence in planting eucalyptus as a specialty crop gradually increased.

Alas, this was not to be a total success story. With *E. nassaui* generally only re-appearing from over-wintering in December, the first spring generation of eucalyptus tortoise beetle largely avoided parasitism (Murphy & Kay, 2000). Forest Research (now Scion) imported new genetic material from the higher altitude Florentine Valley of Tasmania in the hope that this population would be more cold-hardy and start work earlier in the spring (Withers et al., 2011). But success of this cold-hardy strain was never proven and shortly after this the specific natural enemy of *E. nassaui*, a tiny specialist hyperparasitoid *Baeoanusia albifunicle*, invaded New Zealand (Jones & Withers, 2003; Murray & Mansfield, 2015). It was opportune that another egg parasitoid *Neopolycystus insectifurax* was also discovered established around the same time. Entomologists believe the latter was a successful separate invasion as specimens differed from those released in 1987 (Berry, 2003).

Newly-hatched *Paropsis* larvae

Scientists have recently investigated every crevice of the adult *P. charybdis* beetle in Tasmania and found the air holes (tracheae) and beneath the wings (elytra) of the adults are teeming with podapolipid mites. They spread to the younger generation of beetles during mating between older and younger adults. So specific are these hitch-hikers that each species of leaf beetle appears to harbour its own specific species. *Paropsis charybdis* has three: *Chrysomelobia alleni*, *Chrysomelobia intrusus* and *Chrysomelobia pagurus*. Unlikely to kill adults, these annoying creatures may well have a role in reducing the reproductive output of those individuals they inhabit. The New Zealand populations of *P. charybdis* are completely free of these mites, and of course were also freed of all other biological burdens when they invaded. Undoubtedly, this has assisted them in reaching such a problematic pest status (Seeman & Nahrung, 2013). Low genetic diversity arising from what was most likely a very small founder population seems to have had little negative consequences for this highly successful invader.

The situation facing us now is one of variable control. Eucalyptus tortoise beetle adults emerge from over-wintering quiescence on warm days, depending on location. This can be any time from September to November, and they begin to feed as soon as the adult 'flush' eucalyptus foliage appears. Females need to feed for two weeks on this flush to mature their ovaries, before commencing egg laying. This first generation largely escapes egg parasitism.

From December onwards the population build up is variable. Peaks of feeding and activity can be seen from early December right through summer, and are a combination of older beetles who successfully over-wintered and their first generation younger beetles. *Enoggera nassaui* can still undertake control of around one-half to three-quarters of all eggs laid in December and January, but by February the hyperparasite *B. albifunicle* kills most *E. nassaui* infested eggs (Jones & Withers, 2003; Murray et al., 2008; Mansfield et al., 2011). The hyperparasite was expected to have a detrimental impact on the *E. nassaui* populations (Murray & Mansfield, 2015), but it is still persisting (Peters & Withers, unpublished data). Fortunately *Neopolycystus insectifurax* can be very effective and the parasitism of egg batches laid in late summer is very high (Mansfield et al., 2011), but clearly this is not enough.

Aerial spraying

It was not unknown for forest managers in the 1970s to spray DDT to protect *E. nitens* plantations from attack – 'the rate of application at Puketutu Island, Auckland was 1 lb/acre' (equivalent to 1.1 kg/ha) (Baker & de Lautour, 1962). However, it was quickly learnt that one spray was insufficient as the highly mobile beetles would soon re-invade plantations from elsewhere. In recent times, forest companies manage tortoise beetle outbreaks by aerial spraying of a synthetic pyrethroid with the active ingredient alpha-cypermethrin (0.03 kg/ha at low volume 5 L/ha) (Rolando et al., 2016).

This pesticide needs to be kept away from beehives and waterways and a derogation (or special condition) is required for treating Forest Stewardship Council (FSC) certified plantations. This derogation is contingent on outbreak conditions only and continued research to reduce the dependence on insecticides for managing tortoise beetle. Spraying is undertaken when forest managers identify significant defoliation and/or the visible presence of damaging life stages.

Prospective larval biocontrol agent *Eadya paropsidis* stalks eucalyptus tortoise beetle larvae within host range tests. Source: Scion

The unavailability of aircraft and a lack of suitable weather patterns can sometimes lead to poorly-timed applications (Rolando et al., 2016). As has always been the case, eucalyptus tortoise beetles can quickly re-invade plantations from elsewhere, and hence the pattern repeats.

It has proven challenging in New Zealand to quantify *P. charybdis* population density to inform spray decisions (Murphy & Kay, 2000). If this were possible we could develop a consistent management approach. The difficulty arises because the eucalyptus tortoise beetle larvae feed only on the adult flush usually high in the crown of trees. *E. nitens* can exceed 10 m high at five years old. This challenging situation differs greatly from the situation in Tasmania where field scouts are able to undertake monitoring of tortoise beetle populations from the ground. The significant pest species impacting young Tasmania plantations feed on the juvenile foliage at ground level, enabling management options that are more targeted to population density (Elek & Wardlaw, 2010).

What impact does the eucalyptus tortoise beetle have?

So what evidence do we have that eucalyptus tortoise beetle is really responsible for preventing the growth and establishment of palatable blue gums in New Zealand, to the extent that it justifies expensive aerial spraying with a generalist insecticide? Well quite a bit actually.

We know that highly palatable eucalypt species such as *E. camaldulensis* can be very difficult to establish in small lots if left unprotected. Stunted trees will be dripping in *P. charybdis* beetles, who will sit on the trees and eat each new shoot as it is produced. Lack of apical dominance results and height growth is severely limited. Species that are dimorphic and bear waxy juvenile leaves for their first three to five years, such as *E. globulus* and *E. nitens*, can attain greater height before transitioning into the highly palatable adult leaf stage. At this point eucalyptus tortoise beetles colonise the adult crowns and ongoing feeding at the elongating tips can result in a 'witch's broom' appearance during summer time. Repeated defoliation of the crown will lead to the trees slowing height growth and producing juvenile coppice (epicormic) growth from the main stems. In a severe outbreak even this coppice will be colonised by starving adult tortoise beetles.

It is extremely difficult to quantify the impact of eucalyptus tortoise beetle alone on the growth of *E. nitens* in plantations here. This is because of the presence of other insects on the same trees at the same time and pathogens such as leaf spots (Hood et al., 2002), as well as complex genetic and environmental (site) interactions.

A long-term study has recently been published from Tasmania in which *E. nitens* trees were manually defoliated, while also insecticide protected, at different

The eucalypt pest *Paropsis charybdis* (eucalyptus tortoise beetle). Photo: Jon Sullivan, Lincoln University

times and in repeated years. The most significant factors affecting the growth of the trees were timing and frequency of defoliation; the severity of a one-off defoliation had no long-term effect. Trees that received either light or heavy defoliation late in the season for two consecutive years were at least 17% smaller in diameter, and mean annual increment (MAI) in diameter was reduced by at least 21% compared to untreated trees over one rotation. This means they would need to be grown for three to four more years to reach the same stand volume as undefoliated trees at harvest (Elek & Baker, 2017).

This study shows once and for all that there are serious cost implications for plantation managers if they neglect to manage eucalyptus tortoise beetle outbreaks across multiple seasons. Elek and Baker (2017) recommend that to prevent economic losses, a pest management plan should focus on protecting eucalypts from defoliation on 50% or more of current season's adult foliage, especially that happening late in the summer, and in particular preventing defoliation from occurring in the same stands in concurrent years.

This new knowledge will help direct forest managers and researchers to investigate when aerial spraying will be most effective to protect the current season's foliage. Is it spraying the spring generation to prevent the summer generation from being so large? Or is it spraying later in summer to capture both second generation adults and any larvae that have escaped the egg parasitoids? If we can learn to quantify and track impacts within individual stands, it should be possible to avoid the damaging defoliation occurring in concurrent years.

Unfortunately spray trials have revealed that natural enemies, especially parasitoids, are likely to be negatively impacted by aerial spraying of pesticides such as alpha cypermethrin. Alternative pesticides, such as those containing the less toxic active ingredient spinetoram (Withers et al., 2013; Pugh et al., 2015b) are significantly more expensive because of the higher volumes required. For long-term control, however, investing in more expensive products may be a small cost to bear to ensure the environment remains conducive to the presence of beneficial insects.

A sustainable future for growing *E. nitens* in NZ

We know that we cannot continue to rely on aerial spraying with generalist insecticides to continue growing *E. nitens*. Such measures are not sustainable because of the risk of the pest population developing pesticide resistance, as well as increasing public perceptions around the forest industry's 'licence to operate'. Aerial spraying is also not compatible with the increasing value of beehives and their rising presence in rural areas. There is a growing public awareness of the importance of providing diverse pollen and nectar sources for bees, which include recommending eucalypts in planting plans (Trees for Bees, 2009).

Searching for a genetic basis for natural resistance of *E. nitens* to eucalyptus tortoise beetle attack is being explored by the eucalyptus breeding programme under the Specialty Wood Products partnership (www.ffr.co.nz). Working alongside any genetic improvement programme is a new effort to introduce another effective biological control agent for this country, one that targets the larval life stage of *P. charybdis*. Scion and the New Zealand Farm Forestry Association, backed by *E. nitens* growers and the Sustainable Farming Fund, are hoping to introduce *Eadya paropsidis* (Braconidae), a parasitic wasp from Tasmania (Withers et al., 2012; Withers et al., 2015).

This species shows great promise for a few reasons. First, it has a low temperature development threshold suggesting it will be well suited to our *E. nitens* growing areas – predominantly the Central North Island and Southland (Rice & Allen, 2009). Secondly, if successful, this will be the first parasitoid that can both attack and develop within all the instars of the larval life stage, especially the early instars of the spring generation (Rice & Allen, 2009). Currently, this portion of the lifecycle of *P. charybdis* suffers little mortality. The parasitoid has been undergoing careful host range safety testing within Scion's insect quarantine facility, and whether it gains approval for release from the Environmental Protection Authority should be known by the end of 2018.

For this parasitoid to establish and thrive, however, aerial pesticide applications may have to be temporarily curtailed. The necessity of temporally and spatially managing aerial spraying to minimise impacts on both the new and existing beneficial insects, especially the specialist biological control agents, cannot be under-estimated. The authors believe that once we have developed an integrated plantation management plan for *P. charybdis* in *E. nitens* plantations, then the future for eucalypt growing is bright. Finally after 100 years we are close to managing this formidable pest.

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Toni Withers and Elise Peters are in the Forest Protection Group at Scion based in Rotorua. Corresponding author: toni.withers@scionresearch.com.