PAINTED APPLE MOTH:

REASSESSMENT OF POTENTIAL ECONOMIC IMPACTS

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Abstract

1. This paper outlines a reassessment of the potential economic impacts of the painted apple moth in New Zealand in the absence of government intervention to control its spread. Selected impacts on New Zealand's urban, plantation forestry and horticultural sectors over the 20 year period 2002/03 to 2021/22 are estimated to range from $58 million to $356 million (present value in 2001/02). Nationally at least three quarters of these impacts are production losses and spraying costs in plantation forestry. Within the Auckland region these are exceeded by total urban area impacts. Impacts in the Auckland region account for at most 13 per cent of the national total. Additional to the impacts modelled are a number of other possible effects of the painted apple moth, most notably impacts in conservation areas and potential risks to market access.

Introduction

2. An initial basic assessment (Ministry of Agriculture and Forestry, 2000b) estimated the potential economic impacts of the painted apple moth, *Teia anartoides* (formerly *Orgyia anartoides*), to be at least $48 million (present value in 2000) over the first 20 years, as the lower bound of the benefits of eradication in terms of the future impacts averted.

3. This initial assessment is revised and the methodology refined, including to incorporate projected expansions in key sectors and to provide an indication of the range in potential impacts.

Methodology

4. A cost-benefit analysis of eradication of the white-spotted tussock moth, *Orgyia thyellina*, was undertaken by the New Zealand Forest Research Institute (NZFRI) and subsequently modified by the New Zealand Institute of Economic Research (NZIER). Given that the painted apple moth is closely related to the white-spotted tussock moth, the framework adopted by NZFRI and NZIER (Horgan, 1997; NZIER, 1997), adapted for differences, such as in host range, between these two species, was considered to provide a suitable basis for the initial basic assessment of the potential economic impacts of the painted apple moth in New Zealand and is extended in this reassessment.

5. This reassessment models selected impacts of the painted apple moth on:
   - urban households;
   - urban golf courses and school grounds;

- public land in urban areas (streets, parks and reserves);
- plantation forestry (radiata pine); and
- horticulture (apples).

6. Additional to these are a number of other possible impacts of the painted apple moth that are too uncertain at this time to quantify and value (e.g. effects on the conservation sector and potential risks to market access) or thought likely to be relatively small (e.g. effects on soil and watershed conservation and human health).

7. Current prices and control technology are assumed throughout, as is availability of, and approval to use, current treatment products. All values are expressed in real terms (i.e. net of inflation; Statistics New Zealand, 2001b) in 2001/02 New Zealand dollars. In expressing future impacts in terms of their present value in 2001/02, the discount rate is set at ten per cent.

Urban households

8. In Australia the painted apple moth is a common pest of urban garden plants (Elliott *et al*., 1998). Following NZFRI (NZIER, 1997), the impact of the painted apple moth on households in urban areas is modelled in terms of additional annual expenditure on spraying, either to limit defoliation or due to the possible health risks associated with contact with the moth larvae (see p.7). It is thought that households already routinely spraying for existing garden pests would, in most cases, find this sufficient to control for the painted apple moth also. Of other households, only some would choose to treat for the painted apple moth, particularly given the inaccessibility of tree crowns where infestations are likely to be concentrated. Alternatives to spraying, such as physical removal of caterpillars or application of "home remedies", may be used for accessible vegetation. In addition, the painted apple moth may be considered to provide some benefit to gardeners in that its preferred foods include a number of plants considered to be weeds (e.g. brush wattle). Some additional households, however, particularly those with children or pets, given the possible health risks of contact with the moth larvae, may be prompted to take up spraying and products suitable for caterpillar control in home gardens are marketed in both Australia and New Zealand currently (Yates, 2002). Up to the point at which spraying occurs, and for households not undertaking any control for painted apple moth, damage to plantings and possibly reduced use of outdoor areas in the vicinity of heavy concentrations of larvae may reduce the benefits households derive from their gardens.

9. Numbers of occupied dwellings in main, secondary and minor urban areas are obtained from Statistics New Zealand (1996; 2001a). The Auckland region is modelled as encompassing the main urban areas of the Northern, Western, Central and Southern Auckland zones, the secondary urban area of Pukekohe and the minor urban areas of Helensville, Snells Beach, Waiuku, Warkworth and Wellsford. Allowance is made for changing numbers of occupied dwellings to 2051, assumed to be correlated approximately with expansion in household numbers (medium projections from Statistics New Zealand, 1998, with interpolations). For the white-spotted tussock moth, NZFRI adopts a ten per cent increase in the number of private residential properties sprayed (NZIER, 1997). NZIER considers this could be too high. Given that the painted apple moth has a wider host range, infestation of home gardens could be more common for this species. The extent to which households may be willing to tolerate infestations is uncertain, therefore a range in additional household

spraying expenditure is modelled. The increase in the number of properties sprayed is modelled as ranging from four per cent under a low impact scenario to ten per cent under a high impact scenario, with a midpoint of seven per cent under a medium impact scenario. Spraying expenditure by these households is modelled as ranging from a low of $20 per outbreak to a high, following NZFRI (NZIER, 1997), based on spending by US households in response to outbreaks of Asian gypsy moth (Gottschalk, 1990), of $53 per outbreak, with the midpoint adopted as the medium. Although spraying for gypsy moth by US households may have been boosted by publicity surrounding the "Slow the Spread" programme, the gypsy moth produces only one generation to the painted apple moth's four to five. This additional household spraying expenditure is modelled as incurred annually, given the likelihood of reinfestation at the levels of spraying modelled (NZIER, 1997).

Urban golf courses and school grounds

10. Additional annual expenditure on spraying is modelled also for golf courses and school grounds in urban areas, sprayed to limit defoliation or as a precaution against possible risks to human health from contact with the moth larvae. The land area in golf courses and school grounds in main, secondary and minor urban areas is taken from Treeby (1997), based on New Zealand Sports Turf Institute and Ministry of Education data. Using these data, the Auckland region is modelled as comprising the main urban areas of Auckland, Manukau, North Shore and Waitakere Cities, the secondary urban area of Pukekohe, and the minor urban areas of Helensville, Snells Beach, Waiuku, Warkworth and Wellsford. As some routine spraying for existing pests is likely, the increase in area sprayed is modelled as ranging from four per cent under the low impact scenario to ten per cent under the high impact scenario, at an annual cost ranging from $140 to $371 per hectare, as broadly equivalent in area to ten occupied dwellings (NZIER, 1997) with a 30 per cent reduction in unit cost for economies of scale.

11. Costs to other businesses in urban areas are not modelled. Some of these businesses may have professionally maintained gardens or landscaped areas, already subject to routine spraying for existing pests. The average number of trees per commercial or industrial property is very low (Treeby, 1997). On many of these properties, defoliation may be tolerated without incurring any remedial costs or, where severe in the case of isolated trees, result in tree removal without replacement.

Public land in urban areas (streets, parks and reserves)

12. In urban areas the painted apple moth also infests trees on public land. NZFRI models the impact of the white-spotted tussock moth on trees in streets and other public places in terms of the cost of tree removal and replacement where defoliation causes tree mortality (NZIER, 1997). NZFRI identifies removal and replacement as being of considerably lower cost than spraying and thus likely to be the strategy favoured by councils (NZIER, 1997). Mortality due to defoliation by painted apple moth is thought unlikely other than of isolated trees. Defoliation may be tolerated to a considerable degree without incurring any remedial costs, although can still pose significant impacts in terms of reductions in the benefits, including amenity values, derived from urban trees. In the absence of a satisfactory measure of the value of the benefits lost, the impacts of the painted apple moth on trees on public land in urban areas are modelled in terms of expenditure on a low level of removal and replacement,

additional to that undertaken for other reasons (e.g. the principal cause of loss of street trees is not pests and diseases but vandalism), of the most noticeably affected of generally low to medium value trees, plus spraying of a small number of larger or more highly valued trees, which would be very costly to replace, or of severe infestations in prominent locations. Spraying of the latter may, in some cases, be undertaken not so much to limit defoliation but for the presence of the larvae themselves, which, in heavy concentrations, may be thought unsightly or possibly even constitute a nuisance in the immediate vicinity. Presentation of an attractive urban environment may be considered of particular importance in areas significant for tourism, although, for this very reason, street tress and other plantings on public land in such areas may already be subject to high levels of maintenance.

13. Numbers of street trees, including in road reserves, and trees in parks and reserves in main, secondary and minor urban areas are taken from Treeby (1997), based on city council data. The Auckland region modelled is as indicated for land in urban area golf courses and school grounds. NZIER reports that in Auckland City around ten per cent of public amenity trees are of exotic deciduous species susceptible to damage by the white-spotted tussock moth (NZIER, 1997). Given that the painted apple moth "can feed on an extremely wide range of plants" (Elliott *et al*., 1998, p.47) and host species may include some of the tree species most commonly planted by city councils, such as plane (*Platanus*) in central Auckland, the percentage of trees on public land in urban areas of species susceptible to defoliation by the painted apple moth is set at a national average of 40 (although this varies by urban centre).

14. Given uncertainty as to the likely levels of additional replacement and spraying of trees on public land, ranges are modelled. For susceptible species, the rate of tree removal and replacement due to the effects of painted apple moth is set as ranging from 0.2 per cent (one in 500 trees) under the low impact scenario to 0.5 per cent (one in 200 trees) under the high impact scenario. Spraying is modelled for between 0.1 per cent (one in 1,000 trees) under the low impact scenario and 0.25 per cent (one in 400 trees) under the high impact scenario. In each case the midpoint is adopted for the medium impact scenario. NZIER reports that replacement cost can range from $200 for planting and tending trees in park settings to $3,000 for removing and replacing specimen trees in urban streets, but that $800 per tree represents a reasonable average (NZIER, 1997). For the reassessment, this is updated from the initial assessment to $847 in 2001/02 dollars. Spraying expenditure is set at $106 per tree as broadly equivalent to high level spending by two households, given typically four small to medium sized trees per residential site (Treeby, 1997, based on Ministry of Forestry information). Given these costs, over time there may be some substitution of less susceptible for worst affected species.

15. This approach provides very limited representation of the potential impacts of the painted apple moth on this sector. Public trees in urban areas are usually of considerably greater value to the local community than simply the costs of their removal and replacement. Replacement trees are likely to be younger and smaller than, and less endowed with the valued attributes of, the trees they replace. Defoliation of remaining trees may reduce the benefits derived, including amenity values, undermined by a deterioration in tree appearance.

16. No increase in spraying expenditure is modelled for botanical gardens as these are already well tended. Crown land held by urban authorities is commonly in native vegetation as conservation areas and water catchments (see p.7) and, in some cases, includes significant expanses of forest (Treeby, 1997).

Plantation forestry (radiata pine)

17. New Zealand's exotic forests would also be susceptible to infestation by painted apple moth. *Pinus radiata* is a known host, as are *Eucalyptus* and *Acacia*, which are grown in some areas for timber. Nationally, the impacts on plantation forestry are likely to be dominated by the impacts on radiata pine, given that this species comprises around 90 per cent of total plantation forest area (New Zealand Forest Owners Association, 2001). Whilst it is thought unlikely that defoliation of individual trees would be sufficient to cause significant mortality, growth rates could be affected through reduced rates of photosynthesis and transpiration. Moderate to severe defoliation can also predispose trees to attack by other organisms such as wood borers (Elliott *et al*., 1998).

18. The potential costs to plantation forestry of painted apple moth infestations are modelled in terms of combinations of production losses, due to the effect of defoliation on tree growth, and spraying expenditure, to limit defoliation, for radiata pine. For consistency with the regional classification of urban and horticultural sector impacts and rate of spread, the Auckland region is modelled as encompassing Auckland, Manukau, North Shore and Waitakere Cities and Papakura, Franklin and Rodney Districts, which differs from the Auckland wood supply region as defined in the National Exotic Forest Description (Ministry of Agriculture and Forestry, 2002). Continued expansion in total national planted area, by a long-run average of 40,000 hectares per annum (Ministry of Agriculture and Forestry, 2002), is incorporated to 2040 (following Ministry of Agriculture and Forestry, 2000c).

19. Given that the painted apple moth prefers younger trees and defoliation is usually recorded only in younger stands, impacts are modelled for stands aged eight years or less. As a long-run average, around 40 per cent of total national planted area is modelled as being of this age (although there exist significant regional differences in age distribution). Although in Australia beating of older trees yields moth larvae, the effect of the larvae on these trees appears to be negligible (Self, 2000). The likely incidence of the painted apple moth is unknown, given that it is new to New Zealand. Although pine is not one of its preferred foods, the painted apple moth is able to complete its entire life cycle on this host (Forest Research, 1999). Incidence is unlikely to be as low in New Zealand as it is in the painted apple moth's native Australia, where this species has a full range of natural predators such that it is considered a minor pest, affecting typically less than one per cent of individual trees in an infested compartment (Self, 2000). "This moth occasionally causes defoliation of young pines, usually as isolated occurrences scattered throughout compartments." (Self *et al*., 1999, p.3). Given that incidence was the most significant uncertainty in the initial assessment, in this reassessment of the potential economic impacts of the painted apple moth a range in possible incidence is modelled. Annual incidence in radiata pine of susceptible age is set at two per cent (double the incidence experienced in Australia) under the low impact scenario to 25 per cent (on the basis of outbreaks once every four years) under the high impact scenario, with a midpoint of 13.5 per cent incidence under the medium impact scenario. This implies infested areas of between 13,000 and 165,000 hectares per annum.

20. The effect of defoliation is modelled as the loss of, on average, 60 per cent of one year's growth, based on New Zealand research data on growth loss attributable to defoliation following *Cyclaneusma* needle cast (Self, 2000). This is valued in terms of the average value of additional wood grown per annum per hectare (although this covers a very wide range in wood values), which has averaged $1,700 over the past three years (New Zealand Forest Owners Association, 1999; 2000; 2001) and is assumed indicative of long-run real unit value.

This approach clearly involves considerable simplification of the effects of defoliation on tree growth and wood production. Where outbreaks occur in younger stands before pruning, production losses may be reduced by including in the culls the most severely defoliated trees. This reduces the scope for genetic selection in the choice of crop trees, however, and there has been some move away from the practice of pruning. Repeated defoliation may lead to reduced water and mineral uptake which can result in growth losses for up to three years after defoliation.

21. The cost of surveying for painted apple moth infestations and spraying with *Bacillus thuringiensis* (Bt) is modelled as equivalent to $125 per hectare of infested area (although survey costs vary widely according to the size of area surveyed) (Hammond, 2002). Whether and, if so, how often forest owners undertake spraying are modelled as dependent on incidence. The threshold level of damage triggering spraying for control of *Dothistroma pini* is around 15-20 per cent, with damage of 40 per cent prompting two sprays (Hammond, 2002). Given that the effects of Dothistroma are easier to identify by aerial survey, thresholds for spraying for painted apple moth infestations are assumed to be higher. Costs under the low impact scenario are defined to comprise production losses only, with no expenditure on spraying given the low incidence of infestations. Under the medium impact scenario, infested areas are modelled as sprayed once, limiting annual production losses to 30 per cent of what they would be without spraying. Under the high impact scenario, infested areas are modelled as sprayed twice to achieve an equivalent saving in annual production losses.

22. The above represents the impacts on forest owners. No subsequent impacts on logging and processing industries are modelled given that affected trees are still, ultimately, harvested. Where production losses and/or control costs are large, these may have some effect on wood prices, forestry business and land values and investment in the forestry sector. An additional consideration is that the need to spray for painted apple moth to limit production losses may restrict the ability of forestry companies to reduce chemical use in plantation forests to comply with standards for accreditation, as by the Forest Stewardship Council.

23. Additional to impacts on radiata pine are impacts on plantations of *Acacia* and *Eucalyptus*, which are not estimated. Whilst these may be small relative to total national impacts, they could be substantial for the owners of these forests. For example, for infestations in *Acacia* in Northland and *Eucalyptus* in the central North Island, spraying costs, given that spraying may be necessary every year, or production losses, given that the private owners of these plantations may be reluctant to use Bt but unable to obtain regional council approval to use Decis, may be sufficient to drive these operations out of business.

24. Generally a more effective and lower cost way to control forest pests in the long run is through biological control in terms of the cultivation of resistant crop varieties or the introduction of biological control agents such as parasites, predatory insects, pathogenic fungi, bacteria and viruses (Hammond, 1995). This can require substantial investment and take many years to develop to the point of commercial application, however, even where control agents can be found, are suitable for introduction into New Zealand environments and are effective.

Horticulture (apples)

25. NZFRI suggests that, in most cases, the impact of the white-spotted tussock moth on commercial horticultural production would be negligible, given that treatments under existing pest control programmes would generally be sufficient to control also for this moth (NZIER, 1997). This is thought to hold for the painted apple moth also. Increased spraying with Bt may, however, be required in integrated pest management and organic production systems. Widespread, significant reductions in pesticide use have been achieved most notably in the kiwifruit and apple sectors. Kiwifruit is not a preferred food of the painted apple moth. Apple trees are, however. Although the painted apple moth is a defoliating rather than a fruit pest of the latter, its control may be necessary to prevent disruption of picking and risks to market access from contamination of produce.

26. The potential impacts of the painted apple moth on the apple sector are modelled in terms of the increase in spraying costs associated with a reversal in the recent trend towards reduced pesticide use. The apple sector has achieved a 90 per cent reduction in organophosphate use over the past five years, all of which could be jeopardised (Suckling, 2002). On this basis, the spread of the painted apple moth is modelled as increasing Bt use in apple production by a factor of nine from low use currently. The latter is measured in terms of biological and botanical insecticide use in a sample of apple production areas surveyed by Holland and Rahman (1999). The impact on this sector of the spread of the painted apple moth is therefore modelled as additional Bt use of 0.0739 kilograms per hectare per annum averaged across all hectares in apple production (Ministry of Agriculture and Forestry, 2000a), at a cost of $62 per kilogram (Fruitfed Supplies, 2002). Organic produce would continue to qualify as such provided that the maximum doses of Bt prescribed were not exceeded (NZIER, 1997).

27. The spread of the painted apple moth may also constrain pursuit of reduced pesticide use in other sectors of host species, such as brassicas, for which the New Zealand Vegetable and Potato Growers Federation recently launched an integrated pest management programme, and impede continued growth in the adoption of integrated pest management and organic production systems. Some spraying of shelter belts of willow (*Salix*), which has been identified as a food source for the painted apple moth, may also be necessary to reduce the risk of infestation of nearby crops and contamination of produce.

28. Increased use of Bt to control for painted apple moth may provide additional benefits in controlling for other horticultural pests also and enabling some reduction in existing expenditure on other treatment products. Use of Bt may, however, have been reduced to manage the risk of resistance developing in these pests. In addition, reduced pesticide use may be considered to provide benefits to society in the form of reduced risks to the health of operators, consumers, domestic animals and wildlife from pesticide exposure (Mullen *et al*., 1997; Pimentel *et al*., 1993). The benefits forgone with increased use of Bt, however, are likely to be minimal, given that these risks are low (Mumford, 1999).

Other impacts

29. Additional to the impacts modelled are other possible effects of the painted apple moth on:

- soil and watershed conservation;
- conservation areas;

- human health; and
- market access.

30. The initial assessment identified the impacts on soil and watershed conservation and human health as likely to be small. Potential impacts in conservation areas and risks to market access are uncertain.

31. Willow is widely planted for soil and watershed conservation. It is thought unlikely that the painted apple moth would defoliate established plantings to such an extent as to cause significant damage to their root structure sufficient to undermine their ability to contribute to soil and watershed conservation. A number of native species are also now planted for the purpose of watershed conservation, however.

32. A small number of people coming into contact with painted apple moth larvae suffer negative reactions, such as skin rashes and respiratory problems, due to the irritant effects of the larvae's urticating hairs. Symptoms are generally mild, but hospitalisation and fatality can occur in extreme cases with repeated exposure of sensitive individuals. Moderate levels of Asian gypsy moth infestation are associated with 0.2 to one per cent of exposed individuals developing adverse health effects (NZIER, 1997). Given that both the number of people affected and the probability of severe reaction are likely to be low, the total costs, such as medical expenses and labour productivity losses due to absence from work, associated with the effects of the painted apple moth on human health are thought likely to be relatively small. Such possible human health risks may, however, have other impacts in causing changes in behaviour, such as some of the additional household spraying and spraying of school grounds modelled and reduced use of infested recreational areas.

33. Draft findings on host testing to date suggest that, of New Zealand's native species, the painted apple moth favours karaka, kowhai, mangrove and at least six species of *Carmichaelia*, will moult on kauri, ngaio, rangiora and tawapou and will feed but not moult on a range of other native species including beech and podocarps, but will not feed on kamahi, pohutukawa, silver beech and tawa (Department of Conservation, 2002). Significant defoliation of susceptible native species and any change in species composition could affect not only the vegetation of conservation areas, but also the native vertebrate and invertebrate species it supports. Some regeneration may occur following outbreaks, but many indigenous forest ecosystems are already under stress due to the effects of introduced species. Although research completed to date confirms that there would be some impact on the conservation sector, there is considered to be insufficient information available at this time on how the painted apple moth would affect conservation areas and how the Department of Conservation and urban authorities with responsibility for Crown land would attempt to manage these effects, if at all, to attempt any estimation of the impacts on this sector (Department of Conservation, 2002). Under such uncertainty, some degree of precaution may be favoured, particularly in relation to native species of cultural importance to Māori and highly valued by New Zealand society.

34. Nor are potential impacts on market access for New Zealand exports modelled. New Zealand's only export destination currently requiring declaration for painted apple moth is Canada. Given existing inspection procedures for horticultural exports and debarking of log exports to North America, the risks of New Zealand exports harbouring painted apple moth are thought to be low. Although it is possible that egg masses may attach to vehicles in transit to port, NZIER argues this to be of low probability, given that vehicle depots and container

yards are unlikely to be located close to moth populations and provide little food for the larvae when they emerge (NZIER, 1997). It is possible, however, that trading partners free of painted apple moth may alter their declaration requirements and impose restrictions on imports from New Zealand in order to exclude this species. For the white-spotted tussock moth, both NZFRI and NZIER consider the risk of damage to New Zealand's trade prospects to be low (NZIER, 1997). This risk may be similarly low with regard to the painted apple moth. There is, however, some uncertainty as to how New Zealand's export destinations would react, in addition to which there is a risk that phytosanitary concerns could be used, as they have been in the past, as an excuse to erect trade barriers.

Rate of spread

35. For the purpose of the economic impact assessment it is assumed that the painted apple moth is able to establish throughout New Zealand wherever there is suitable vegetation and that regional differences in climate are insufficient to cause significant differences in incidence.

36. Whilst natural dispersal is relatively slow, the role of inadvertent, human-assisted dispersal makes the potential rate of spread of the painted apple moth difficult to determine. Based on the rate of spread assumed for the white-spotted tussock moth (NZIER, 1997), in the initial assessment the painted apple moth was modelled as spreading throughout the Auckland region over ten years from initial impacts in 2001 and spreading throughout the rest of New Zealand over ten years from initial impacts lagged five years behind impacts commencing in the Auckland region. Spread to remote areas, such as parts of the conservation estate, could take longer. Although that female painted apple moths do not fly may impede the rate of spread of this species relative to that of the white-spotted tussock moth, the multiple cycles of the painted apple moth (four to five generations relative to three generations of white-spotted tussock moth) may further it.

37. The rates at which impacts are modelled as developing, with the spread of the painted apple moth, are revised for this reassessment, given that, without further government intervention, existing sites of infestation would be sources of spread to other areas. With the cessation of current control activities, the painted apple moth is modelled as incurring costs to affected sectors in the Auckland region from 2002/03, of full annual magnitude from 2009/10 (i.e. as taking a further eight years to spread throughout this region). Impacts on affected sectors in the rest of New Zealand are modelled as taking ten years to reach full annual magnitude, from three years after impacts commence in the Auckland region (i.e. as developing over the period 2005/06 to 2014/15). Within each of these two regions, impacts are phased in at the rate of a 50 per cent increase in annual impacts each year until reaching full annual magnitude. This rate of spread implies impacts in the Auckland region over a total area of almost 30,000 ha in 2002/03, the first year of impacts on affected sectors in the absence of further government intervention.

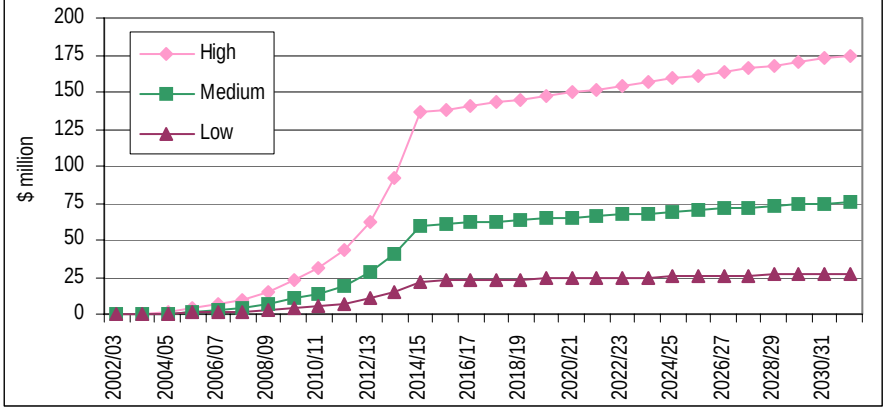
Results

Annual impacts

38. This reassessment estimates that, in the absence of government intervention to control its spread, the painted apple moth would have full annual impacts on New Zealand's urban, plantation forestry and horticultural sectors in 2014/15 of between $22 million and $136 million, according to the severity of impacts in urban areas and plantation forestry.

39. Given the rate of spread modelled and projected expansions in numbers of households and area planted in radiata pine, the estimated annual (June year) impacts over the first 30 years from initial impacts in 2002/03 are as illustrated in Figure 1.

Figure 1: Annual impacts 2002/03 to 2031/32



Present value total impacts

40. The present value[1] total impacts on New Zealand's urban, plantation forestry and horticultural sectors from 2002/03 to selected years are indicated in Table 1.

Table 1: Present value total impacts

Time period: from 2002/03	Present value total impacts ($ million)		
	Low	Medium	High
To 2006/07 (first 5 years)	1.562	3.953	8.361
To 2011/12 (first 10 years)	10.879	28.360	62.009
To 2014/15 (completion of range expansion)	25.642	68.219	152.531
To 2016/17 (first 15 years)	36.938	98.892	222.587
To 2021/22 (first 20 years)	58.347	157.173	355.974
To 2031/32 (first 30 years)	82.007	221.878	504.616
To 2041/42 (first 40 years)	92.274	250.094	569.717
In perpetuity	98.968	268.517	612.282

41. It has been suggested that the length of time until another incursion of painted apple moth, and thus the period for which New Zealand could be expected to remain free of the painted apple moth, if the current incursion were eradicated, is in the range of 20 to 40 years. In the

[1] Discounting reduces all future annual costs or benefits to their present values in a given year, in this case 2001/02, according to their relative timing, to make them directly comparable.

initial assessment of potential economic impacts, the analysis period was limited to 20 years, however, on the grounds that biological control, albeit predominantly in plantation forestry, could be expected to become available within this time (NZIER, 1997), such that the impacts of the painted apple moth thereafter would be much reduced (although any additional costs this might incur, over and above existing research and development expenditure on genetic improvement and biological control agents, are not estimated). In this reassessment, the present value in 2001/02 of the total impacts over the first 20 years, 2002/03 to 2021/22 inclusive, ranges from $58 million under the low impact scenario to $356 million under the high impact scenario. This indicates the impacts averted if eradication could be achieved before 2002/03 and the painted apple moth did not re-establish in New Zealand for 20 years.

42. The distribution of the present value total impacts on New Zealand's urban, plantation forestry and horticultural sectors over these first 20 years is indicated in Table 2. At least three quarters of these impacts are production losses and spraying costs in plantation forestry. The smallest of the impacts modelled is the cost of increased spraying in the horticultural sector. The largest of the impacts in urban areas is replacement and spraying costs for trees on public land under the low and medium impact scenarios, but this is almost matched by household expenditure on spraying gardens under the high impact scenario.

Table 2: Distribution of present value total impacts 2002/03 to 2021/22: New Zealand

Sector	Impacts ($ million) and share of total impacts (%)		
	Low	Medium	High
Urban households	3.449	11.006	22.823
	6%	7%	6%
Urban golf courses and school grounds	0.253	0.809	1.677
	0.43%	0.51%	0.47%
Urban public land (streets, parks and reserves)	9.255	16.197	23.138
	16%	10%	6%
Total urban area impacts	12.957	28.011	47.638
	22%	18%	13%
Plantation forestry (radiata pine)	45.229	129.001	308.175
	78%	82%	87%
Horticulture (apples)	0.161	0.161	0.161
	0.28%	0.10%	0.05%
Total	58.347	157.173	355.974

43. Of the costs associated with impacts on trees on public land in urban areas, tree removal and replacement accounts for 94 per cent, given that this is modelled as favoured over spraying. Of the impacts on plantation forestry, production losses account for 100 per cent under the low impact scenario, 71 per cent under the medium impact scenario and 55 per cent under the high impact scenario, with the balance consisting of spraying costs.

44. The distribution of the present value total impacts on the urban, plantation forestry and horticultural sectors in the Auckland region over these first 20 years is indicated in Table 3.

Under the low impact scenario the largest impact is replacement and spraying costs for trees on public land in urban areas. Under the medium impact scenario this is matched by production losses and spraying costs in plantation forestry. The latter is the largest single impact under the high impact scenario, followed by household spraying expenditure, but remains outweighed by total urban area impacts.

Table 3: Distribution of present value total impacts 2002/03 to 2021/22: Auckland region

Sector	Impacts ($ million) and share of total impacts (%)		
	Low	Medium	High
Urban households	1.626	5.189	10.760
	21%	28%	30%
Urban golf courses and school grounds	0.077	0.245	0.508
	1.00%	1.33%	1.41%
Urban public land (streets, parks and reserves)	3.683	6.446	9.208
	48%	35%	26%
Total urban area impacts	5.386	11.879	20.476
	70%	65%	57%
Plantation forestry (radiata pine)	2.275	6.489	15.502
	30%	35%	43%
Horticulture (apples)	0.005	0.005	0.005
	0.06%	0.03%	0.01%
Total	7.666	18.373	35.983

45. Between 13 per cent (low impact) and ten per cent (high impact) of the present value total New Zealand impacts over this period occur in the Auckland region. Thus by far the largest benefits of eradication of the painted apple moth are in averting impacts beyond the Auckland region. Across all impact scenarios 47 per cent of total New Zealand urban household impacts, 30 per cent impacts on urban golf courses and school grounds, 40 per cent of impacts on trees on public land in urban areas, five per cent of plantation forestry impacts and three per cent of horticultural sector impacts occur within the Auckland region.

46. The present value total impacts over the first 30 years, the first 40 years and in perpetuity have similar distributions to those over the first 20 years, reported above.

47. This is not a complete assessment of possible impacts of the painted apple moth in New Zealand; not included in the above estimates are a number of impacts that are too uncertain at this time to quantify and value (e.g. effects on the conservation sector and potential risks to market access) or thought likely to be relatively small (e.g. effects on soil and watershed conservation and human health).

Sensitivity analysis

48. These impacts have been estimated under considerable uncertainty as to what effects the painted apple moth would have in New Zealand environments and with limited information on how affected sectors would respond. In the initial assessment total impacts were identified as being highly sensitive to the proportion of susceptible plantation forest affected. In the reassessment this and several other key areas of uncertainty are addressed through the modelling of ranges in potential impacts. Sensitivity to a number of further uncertainties is explored. The results are summarised in Table 4.

Table 4: Sensitivity of impact estimates to uncertain coefficient values

Coefficient	Change to coefficient value	Change in present value total impacts over first 20 years		
		Low	Medium	High
Urban public land (streets, parks and reserves)				
Percentage of trees of susceptible species	- 50%	- 8%	- 5%	- 3%
	+ 25%	+ 4%	+ 3%	+ 2%
Replacement cost per tree	+ 50%	+ 7%	+ 5%	+ 3%
Spraying cost per tree	+ 50%	+ 0.47%	+ 0.30%	+ 0.19%
Plantation forestry (radiata pine)				
Maximum susceptible age	- 37.5%	- 35%	- 37%	- 39%
	+ 87.5%	+ 39%	+ 41%	+ 43%
Percentage loss in annual growth	- 33.3%	- 26%	- 19%	- 16%
	+ 66.7%	+ 52%	+ 39%	+ 32%
Percentage of annual production loss occurring under spraying	- 33.3%	no change	- 19%	- 16%
	+ 33.3%	no change	+ 19%	+ 16%
No spraying		no change	+ 112%	+ 72%
Annual expansion in planted area	- 25%	- 5%	- 5%	- 5%
	+ 25%	+ 5%	+ 5%	+ 5%
Horticulture (apples)				
Factor increase in Bt use	+ 100%	+ 0.28%	+ 0.10%	+ 0.05%
Rate of spread				
Spread period outside the Auckland region	+ 2 years	- 22%	- 23%	- 23%
Commencement of impacts on affected sectors	+ 2 years	- 15%	- 15%	- 15%
Discount rate	- 3 %	+ 48%	+ 48%	+ 48%
	+ 2%	- 22%	- 22%	- 22%

49. The impact estimates are most sensitive to the coefficients adopted for plantation forestry, the rate of spread modelled and the discount rate applied.

Plantation forestry

50. If only stands aged five years or less are significantly affected, such that only 22 per cent of total national radiata pine planted area is susceptible to reduced growth, present value total impacts over the first 20 years are reduced by between $20 million (low impact) and $139 million (high impact). If infestations affect stands up to 15 years in age, such that typically 60 per cent of total national planted area is susceptible to reduced growth, total impacts are increased by between $23 million (low impact) and $154 million (high impact).

51. If defoliation causes only a 40 per cent reduction in annual growth, total impacts are reduced by between $15 million (low impact) and $57 million (high impact). If defoliation results in the loss of a full year's growth, total impacts are increased by between $30 million (low impact) and $113 million (high impact).

52. If infestations are identified and treated sooner, such that annual production losses are reduced to only 20 per cent of what they would be without spraying, total impacts are reduced by $31 million under the medium impact scenario and $57 million under the high impact scenario, with no change under the low impact scenario which does not include spraying. If infestations are more difficult to identify, such that it is not possible to treat them before the levels of defoliation reached are sufficient to cause annual production losses of 40 per cent of what they would be without spraying, total impacts under the medium and high impact scenarios are increased by equivalent amounts. Without spraying under the medium and high impact scenarios, production losses are considerably greater, increasing total impacts to $333 million and $613 million respectively, at the incidences modelled.

53. If the total national area planted in radiata pine expands by on average only 30,000 hectares per annum over the next 20 years, total impacts over this period are reduced by between $3 million (low impact) and $19 million (high impact). If planted area expands at the rate of 50,000 hectares per annum, total impacts are increased by equivalent amounts.

Rate of spread

54. A slower rate of spread of the painted apple moth outside the Auckland region, of 12 years to spread throughout the rest of New Zealand, reduces present value total impacts over the first 20 years to $45 million (low impact), $121 million (medium impact) and $274 million (high impact).

55. With impacts on affected sectors deferred by two years, commencing in the Auckland region in 2004/5 and in the rest of New Zealand in 2007/8, present value total impacts over the first 20 years (in this case 2004/5 to 2023/24 inclusive) are reduced by between $9 million (low impact) and $52 million (high impact).

Discount rate

56. At a discount rate of seven per cent, the present value total impacts over the first 20 years are increased to $86 million (low impact), $232 million (medium impact) and $527 million (high impact), in giving increased weight to the larger impacts occurring outside the Auckland region. At a discount rate of 12 per cent, total impacts are reduced to $46 million (low impact), $123 million (medium impact) and $277 million (high impact) and there is a small

increase in the proportion of these occurring in the Auckland region, given that this is where impacts first occur.

Comparison with initial assessment

57. Table 5 compares this reassessment with the initial basic assessment (Ministry of Agriculture and Forestry, 2000b). The lower bound estimate provided by the initial assessment is comparable to the lower end of the range estimated in this reassessment.

Table 5: Initial assessment and reassessment of impacts

	Full annual impact ($ million)		
	Low	Medium	High
Initial assessment[1]	24.161	-	-
Reassessment[2]	21.973	59.591	135.968

[1] At 2000 levels; 2000 dollars.
[2] At 2014/15 levels; 2001/02 dollars.

	Present value total impacts over first 20 years ($ million)		
	Low	Medium	High
Initial assessment[1]	47.644	-	-
Reassessment[2]	58.347	157.173	355.974

[1] 2000 dollars.
[2] 2001/02 dollars.

58. The principal causes of the difference in present value total impacts over the first 20 years between the initial assessment and the low impact scenario of the reassessment are the incorporation in the reassessment of projected expansions in household numbers and radiata pine planted area and two year reductions in the lengths of time remaining until the painted apple moth begins to spread beyond, and completes its spread throughout, the Auckland region. Omitting projected expansions in household numbers and radiata pine planted area reduces total impacts by between 20 per cent and 23 per cent to $46 million (low impact), $123 million (medium impact) and $275 million (high impact). Reinstating a ten year period of spread throughout the Auckland region (albeit for sector impacts commencing in 2002/03) and spread beyond the Auckland region after five years of impacts in the Auckland region reduces total impacts by 26 per cent to $43 million (low impact), $117 million (medium impact) and $264 million (high impact). Together, these reduce estimated total impacts to $34 million (low impact), $90 million (medium impact) and $200 million (high impact).

59. With regard to the range in impacts indicated by the reassessment, the ranges in urban area impacts modelled account for twelve per cent of the difference in total impacts between the low and high impact scenarios. The remainder of this difference is attributable to the range in incidence in plantation forestry, given the effect this has on production losses and spraying costs.

Conclusion

60. In this reassessment of the potential economic impacts of the painted apple moth in the absence of government intervention to control its spread, selected impacts on New Zealand's

urban, plantation forestry and horticultural sectors over the 20 year period 2002/03 to 2021/22 are estimated to range from $58 million to $356 million (present value in 2001/02), according to the severity of impacts in urban areas and plantation forestry.

61. Nationally at least three quarters of the impacts modelled are production losses and spraying costs in plantation forestry. Within the Auckland region these are exceeded by total urban area impacts, the largest of which are replacement and spraying costs for trees on public land under the low and medium impact scenarios and household spraying expenditure under the high impact scenario. Impacts in the Auckland region account for at most 13 per cent of the national total.

62. These estimates are most sensitive to the coefficients adopted for the plantation forestry sector, the rate of spread modelled and the discount rate applied.

63. The principal causes of the difference between the lower bound estimate provided by the initial assessment and the low impact scenario estimate of the reassessment are incorporation in the reassessment of projected expansions in household numbers and radiata pine planted area and an updated rate of spread in modelling impacts on affected sectors.

64. Additional to the impacts modelled are a number of other possible effects of the painted apple moth, most notably impacts on the conservation sector and potential risks to market access.

65. As in the initial assessment, in this reassessment impacts have had to be estimated under considerable uncertainty as to what effects the painted apple moth would have in New Zealand environments and with limited information on how affected sectors would respond. Thus these estimates should be considered approximate only, but provide an indication of the scale of potential impacts.

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