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Standardization of Methyl Bromide use for New Zealand Log Exports

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A report prepared for

Stakeholders in Methyl Bromide Reduction Inc. (STIMBR)

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Both the New Zealand Government (as Party to the Montreal Protocol) and the public are concerned about the increasing use of methyl bromide (MB) to fumigate export pine logs as the trade has grown significantly in recent years. The latest figures show the use of MB has grown from 270 tonnes in 2009 to 406 tonnes in 2010, a 50% increase (New Zealand Ministry for the Environment 2011). The New Zealand increase in MB use is solely due to an increase in log trade to countries that require fumigation (UNEP 2010). Although New Zealand has actively reduced MB used under the critical use exemptions in accordance with the Montreal Protocol, MB use for phytosanitary purposes, especially for exported logs, has increased (UNEP 2010). In 2011, the controls on the use of MB have been tightened by the New Zealand Environmental Protection Agency because of safety concerns that restrict the locations for fumigation under cover. Recapture and destruction of MB is required to be in place by 2020. The 2008 International Plant Protection Convention recommendations for reduction and replacement of methyl bromide for phytosanitary measures include a reassessment of doses to reduce the volume of MB being used. Analysis of fumigation research data for concentration x time products at depth of penetration into pine logs, *Pinus radiata* D. Don, and their correlation to complete mortality of the potential New Zealand pests of quarantine importance, provides evidence that the MB concentrations required by the importing countries could be reduced and still provide adequate quarantine security against any potential pests that may be found in logs exported from New Zealand. The information provided in this report suggest that 73 g/m^3 MB for 16 hours at ≤ 15°C and 49 g/m^3 MB for 16 hours at ≥ 15°C are sufficient to manage the quarantine risk of pests typically present in international trade. For example, these reduced MB rates could deliver nearly 40% reduction in the fumigation schedules required by New Zealand's largest log trading partner, China. China currently requires 120 g/m^3 and 80 g/m^3, at ≤ 15°C and ≥ 15°C for 16 hours, respectively. The reduced MB rates suggested here are conservative and they remain greater than the MB rates required by the fumigation schedules of other countries for New Zealand logs. These optimized rates would greatly reduce the amount of MB released into the atmosphere during aeration, continue to ensure quarantine security against the target pests (UNEP 2010) and, in case of China for example, could save in excess of 150 tonnes of MB per annum given the trend for increasing growth in New Zealand log exports.

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1 Introduction

There are six pests of quarantine importance for all importers of New Zealand logs. They are: the bark-borne burnt pine longhorn (BPL), *Arhopalus ferus* (Mulsant) (= *A*. *tristis* (F.)) (Coleoptera: Cerambycidae) (Hosking 1978a; Brockerhoff and Hosking 2001); black pinebark beetle (BPBB), *Hylastes ater* (Paykull) (Milligan 1978), and the closely related goldenhaired barkbeetle (GBB), *Hylurgus ligniperda* (Fabricius) (Bain 1977) (both Coleoptera: Scolytidae); the wood-borne Sirex woodwasp, *Sirex noctilio* F. (Hymenoptera: Siricidae) (Zondag and Nuttall 1977); huhu, *Prionoplus reticularis* (White) (Coleoptera: Cerambycidae) (Hosking 1978b); and New Zealand drywood termite, *Kalotermes brouni* (Froggatt) (Isoptera: Kalotermitidae) (Milligan 1984). New Zealand is free of pine wood nematode, sawyer beetles from the genus *Monochamus*, and many other quarantine pests that have gained high profile in the international trade of pine logs over the last several decades (UNEP 2010).

This review focuses on the bark-borne pests. GBB predominates in most New Zealand forests and generally makes up over 90% of all bark beetle populations (Bain 1977). The wood-borne huhu and dry wood termite would not be expected to infest well-managed mature logs and inhabit only decaying wood that is not exported (Hosking 1978b; Milligan 1984). *A. ferus*, although occasionally found in logs, is primarily found in *Pinus* spp. dead stumps and trees killed by fire (Hoskings 1978a). Sirex woodwasp only attacks young and/or stressed trees and is unlikely to be present in export quality logs because of measures employed throughout New Zealand forests (Bain et al. 2010; Zondag and Nuttall 1977).

The current treatment used to provide quarantine security against these pests is fumigation with methyl bromide (MB). This is in addition to the offical phytosanitary inspection of exported logs to countries requiring this activity. Some of the major trading partners (e.g. China) also allow debarking to a prescribed standard. A review of all MB schedules for New Zealand logs found that MB dosages (and the respective concentration x time (CT) products) varied greatly depending on the export destination (http://www.biosecurity.govt.nz/commercial-exports/forestry-exports/export-certification-standards).

Offical MB fumigation schedules used to meet phytosanitary regulations consist of a specified MB concentration to be used at the minimum fumigation time and fumigation temperature. The three parameters of concentration, time and temperature are key to every fumigation regardless of other factors, such as whether the fumigation is carried out under a tarpaulin, in a ship’s hold, in a certified chamber, or under vacuum or normal atmospheric pressure (USDA 2011). It has long been established that insect mortality responses to MB can be stated in terms of the MB concentration applied multiplied by the fumigation time (the CT product) (Bond 1984; Monro 1969). Additionally, MB fumigation efficacy responds to direct manipulation of CT products so that treatments for target pests and commodities can be optimised (Bond 1984; Monro 1969).

Continued pressure to reduce MB emissions under the Montreal Protocol (UNEP 2010), the rising cost of MB fumigation, and the 2008 International Plant Protection Convention’s (IPPC) recommendation for a reassessment of doses to reduce the volume of MB being used are significant reasons to identify excessive MB dose rates and seek to have them reduced to reasonable thresholds (UNEP 2008). Considerable reductions in MB use, and also reductions in the resulting release of MB into the atmosphere during aeration, may be possible by providing information to New Zealand’s marketing partners that shows the appropriate dose rates necessary to control the quarantine pests of concern. Currently approximately 1000 tonnes of MB are being replaced by phosphine treatment in transit in the ship’s hold. However, more could be saved by also reducing the application rate for logs that are currently fumigated with MB before loading and then shipped above deck (approximately one third of each ship’s load).

Export of logs from New Zealand to China over the past eight years has increased significantly. Figure 1 shows an increase of 324% since 2004, with most of that increase occurring during the past five years. Export log volumes are expected to increase further by 17% over the next five years (MAF 2011), indicating a concurrent increase in MB usage unless logical regulatory pathways are found to manage phytosanitary risks in trade while effectively reducing MB usage where possible. Figure 2 shows a significant increase in MB use for quarantine and pre-shipment (QPS) purposes over the past decade, while MB use for non-QPS purposes has decreased to zero beginning in 2006.

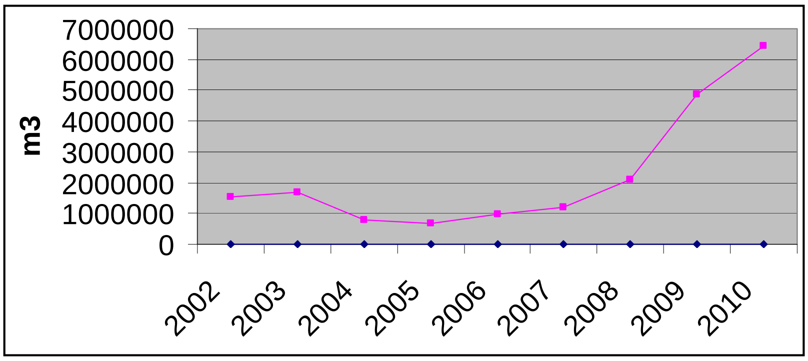

Figure 1. New Zealand log exports to China 2002 to 2010 (MAF 2011).

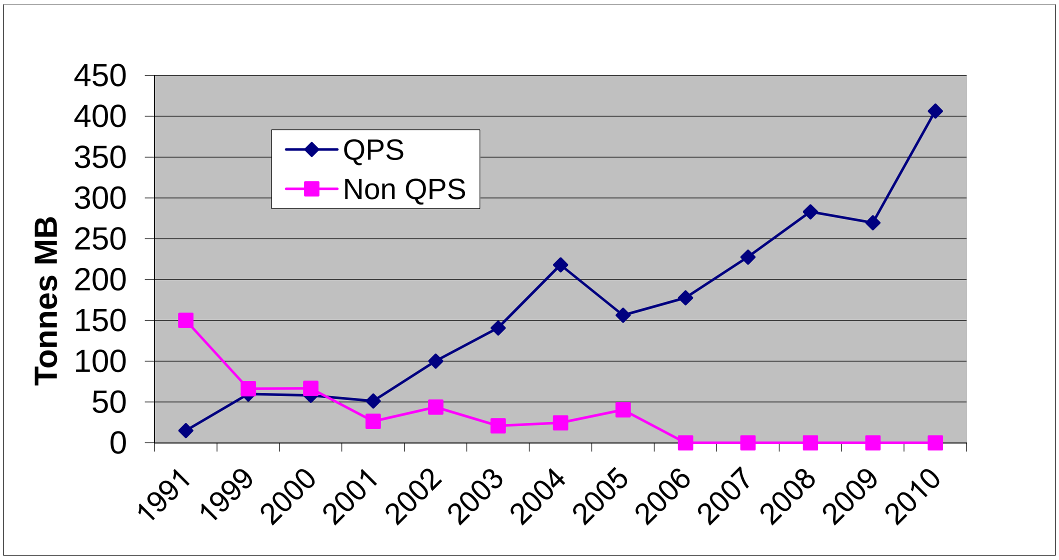

Figure 2. Tonnes of methyl bromide (MB) used by New Zealand for quarantine and pre-shipment (QPS) purposes and non-QPS purposes (New Zealand Ministry for the Environment 2011).

This report follows a review of MB schedules for logs exported from New Zealand (http://www.biosecurity.govt.nz/commercial-exports/forestry-exports/export-certification-standards) that identified a unique variation in MB fumigation schedules required by three of our Asian trading partners. This report identifies an opportunity to seek a reduction of MB dosage rates while assuring our trading partners that quarantine security will be maintained.

Pursuant to the Service Agreement for this project, the review report on MB schedules for export logs, including recommendations on appropriate concentrations for standardizing fumigation schedules, and an identification of the need for new data where appropriate, will be delivered to the Primary Growth Partnership Programme Steering Group.

2 Review of MB schedules for logs exported from New Zealand to some of the main trading partners

Comparison of the requirements for MB fumigation of pine logs from New Zealand (http://www.biosecurity.govt.nz/commercial-exports/forestry-exports/export-certification-standards) of different trading partners shows that they differ significantly. The most significant variation was the pre-shipment MB schedules required by the largest log trading partner, China. Specifically, the China schedules for New Zealand pine logs are: 80 g/m^3 MB for 16 hours at ≥ 15°C, and 120 g/m^3 MB for 16 hours at ≤ 15°C. These MB dose rates and their corresponding CT products (1,280 and 1,920, respectively) are significantly greater than those applied on arrival by New Zealand's other large Asian trading partners, Japan and Korea. Tables 1 and 2 show a comparison of the China MB fumigation schedules with those of Japan and Korea.

Table 1. Methyl bromide (MB) fumigation schedules specified by China at export, and by Japan and Korea at import for fumigation temperatures ≥ 15°C.

Country	MB Rate	Time	Temperature	Applied CT product[a]
China	80.0 g/m^3	16 hours	≥ 15°C	1,280
Japan[b]	48.5 g/m^3	16 hours	≥ 15°C	776
Korea[c]	33.0 g/m^3	24 hours	≥ 15°C	792
	49.5 g/m^3	16 hours[d]		

[a] concentration x time (CT). Theoretical value derived by multiplying the MB rate by the fumigation time.
[b] Japan MAFF PPS 2011.
[c] Yu et al. 1984.
[d] MB rate adjusted to a 16-hour fumigation time that maintains the same theoretical CT product (Bond 1984; Monro 1969).

Table 2. Methyl bromide (MB) fumigation schedules specified by China at export, and by Japan and Korea at import for fumigation temperatures ≤ 15°C.

Country	MB Rate	Time	Temperature	Applied CT product[a]
China	120.0 g/m^3	16 hours	≤ 15°C	1,920
Japan[b]	72.5 g/m^3	16 hours	≤ 15°C	1,160
Korea[c]	49.0 g/m^3	24 hours	≤ 15°C	1,176
	73.5 g/m^3	16 hours[d]		

[a] concentration x time (CT). Theoretical value derived by multiplying the MB rate by the fumigation time.
[b] Japan MAFF PPS 2011.
[c] Yu et al. 1984.
[d] MB rate adjusted to a 16-hour fumigation time that maintains the same theoretical CT product (Bond 1984; Monro 1969).

The Korea schedule uses a 24-hour fumigation time. If we divide the respective CT products by 16 hours (Bond 1984; Monro 1969), the Korea schedules would be 49.5 g/m^3 MB for 16 hours at ≥ 15°C, and 73.5 g/m^3 MB for 16 hours ≤ 15°C (Tables 1 and 2). Additionally, only 1.0 g/m^3 separates the Japan and Korea schedules at both the ≥ 15℃ or ≤ 15℃ fumigations. Hence, there is no difference between the Japan and Korea schedules.

Note that the Japan and Korea schedules at ≥ 15°C (Table 1) represent a significantly lower (39.4% and 38.1% less, respectively) amounts of MB compared with the China schedule. Similarly, the Japan and Korea schedules at ≤ 15°C (Table 2) represent significantly lower (39.6% and 38.7%, respectively) amounts of MB compared with the China schedule. Although there is no difference between the Japan and Korea schedules, there is a difference between the Japan or Korea schedules and the China schedule (Tables 1 and 2). Because all three approved schedules are used to control the same pests of quarantine importance in logs exported from New Zealand, the lowest rate is adequate to provide quarantine security.

3 MB rates for New Zealand log pests of concern

Cross (1992) measured the penetration of MB into *P. radiata* wood and estimated the concentrations found at various depths in the wood for up to one week after the completion of a 24-hour treatment using an extremely high rate of 260 g/m^3 at temperatures between 20-25°C. Cross (1992) was able to plot the accumulated CT products for different thicknesses of green (and dry) wood.

In an earlier study, Cross (1992) determined that the late egg/early larval stage of *P. reticularis* was the most MB-tolerant wood boring and bark species and required a CT product of 100 to 150 $g.h/m^3$. Other species tested, including *A. tristis, H. ater* (the closely related species to *H. ligniperda*, the predominant bark beetle in New Zealand) and a native termite, *K. brouni*, required less than 100 $g.h/m^3$ for reliable kill. Cross (1992) does not report the temperature during the experimental trials to determine these CT values. We have assumed this was 20-25°C as reported for the 1992 fumigant penetration study and when estimating kill rates at lower temperatures a conservative interpretation is used, that is, a temperature of 25°C (see later).

Cross (1992) was explicit in his assumption that the cumulative exposure at any depth was proportional to the initial exposure (applied dose), i.e., no account is taken of gas losses. Using this approach, Cross (1992) estimated the applied CT product necessary to achieve a nominated 'internal' CT product (i.e., the CT product required in the vicinity of the insect to effect reliable kill at any given depth in the wood). Using the same assumption made by Cross (1992), plots were developed for this report for the 'internal CT' target of 150 $g.h/m^3$, which Cross (1992) reported would ensure complete mortality of the target pests for logs. In addition, in this analysis of the rates derived from New Zealand research, we have estimated a rate for use at low temperatures. A second 'internal CT' target of 534 $g.h/m^3$ was estimated as an appropriate value for reliable kill when temperatures were ≤ 15°C. This is based on an assumption that a methyl bromide CT product can theoretically be increased by the product of 12gm^{-3} x16h (or 8gm^{-3} x 24h) for every 5°C drop in temperature below 25°C (FAO 2002, USDA 2011). Ultimately, the plots of CT product versus depth in wood allow for an assessment of application rates that ensure quarantine security while avoiding excessive MB use.

Of the pests of concern likely to be associated with New Zealand pine, *A. ferus* is the most likely to enter into the wood. The maximum depth of *A. ferus* recorded by Bradbury (1998) was 20 mm after 165 days, and represents a worst-case scenario where high numbers of pests have been attracted to fire-damaged trees. Typically logs from New Zealand are exported long before this time frame. The current export phytosanitary system would also prevent any untreated logs being exported.

Using Cross's Figure 4(c) from page 241 (Cross 1992), a transposition of data from the figure can be translated by scaling the graph up or down according to the applied CT product. Reading directly from Figure 4(c) (Cross 1992), the values can be scaled appropriately to produce derived CT products of 150 for MB fumigations of logs at ≥ 15℃ and 534 for MB fumigations of logs ≤ 15℃. The results of Cross (1992) also demonstrate that it is not until a depth into the logs of between 40 and 50 mm that the applied CT needs to exceed the target CT in order to achieve a reliable kill, as shown below in Table 3. Additionally, Table 3 focuses on the CT value at 20 mm depth. Most New Zealand pests of quarantine importance in logs would be found at no more than 20 mm (Bradbury 1998; Cross 1992). Further justification for the requirement of MB fumigation efficacy only to a depth of 20 mm is provided by the use of a debarking process approved in lieu of MB fumigation by a number of countries that import logs from New Zealand (MAFBNZ 2011). The debarking process is considered equivalent to MB fumigation because it removes the outside of the log to a depth of about 20 mm where the pests of quarantine importance would potentially be found, thereby precluding the need for MB fumigation.

Table 3. Scaled values to obtain concentration x time (CT) values in g.h/m^3 required at indicated depth in *Pinus radiata* logs exported from New Zealand to ensure quarantine security at ≥15°C or ≤15°C against pests of quarantine importance. CT values and scaling based on data from Figure 4(c) in Cross (1992).

Depth (mm), x	Scaled values to obtain required CT(x)	
	≥ 15°C; CT(x) = 150	≤ 15°C; CT(x)=534
0	150	534
10	150	534
20	150	534
30	150	534
40	150	534
50	190	678
60	289	1028
70	469	1669
80	771	2746
90	1087	3871
100	1448	5153

The first column in the table (Depth, x) was derived by reading off Figure 4(c) in Cross (1992), and the CT values in g.h/m^3 were obtained by scaling them appropriately to obtain the CT value ranges known to ensure quarantine security against potential New Zealand pests of pine logs (Cross 1992). CT0 = CT applied to the surface, i.e. depth of zero. Column 2 (Table 3) shows the CT(x) = 150 g.h/m^3 scaling for MB fumigation at ≥ 15°C. As previously stated, the scaling shows that the CT(x) values for fumigations at ≥ 15°C do not change (i.e., increase) until depths exceed 40 mm. Column 3 (Table 3) shows the CT(x) = 534 g.h/m^3 scaling for MB fumigations at ≤ 15°C. Again, the data show that the CT(x) values for MB fumigations at ≤ 15°C do not change (i.e., increase) until depths exceed 40 mm. Based on Cross (1992) and Bradbury (1998), the scaled CT values for fumigations at ≥ 15°C or ≤ 15°C (Table 3) are more than adequate to ensure quarantine security against any pests found in logs exported from New Zealand.

The data in columns two and three (Table 3) can be compared with the CT values for MB schedules required by China, Japan and Korea for fumigation ≥ 15°C or ≤ 15°C (Figures 3 and 4).

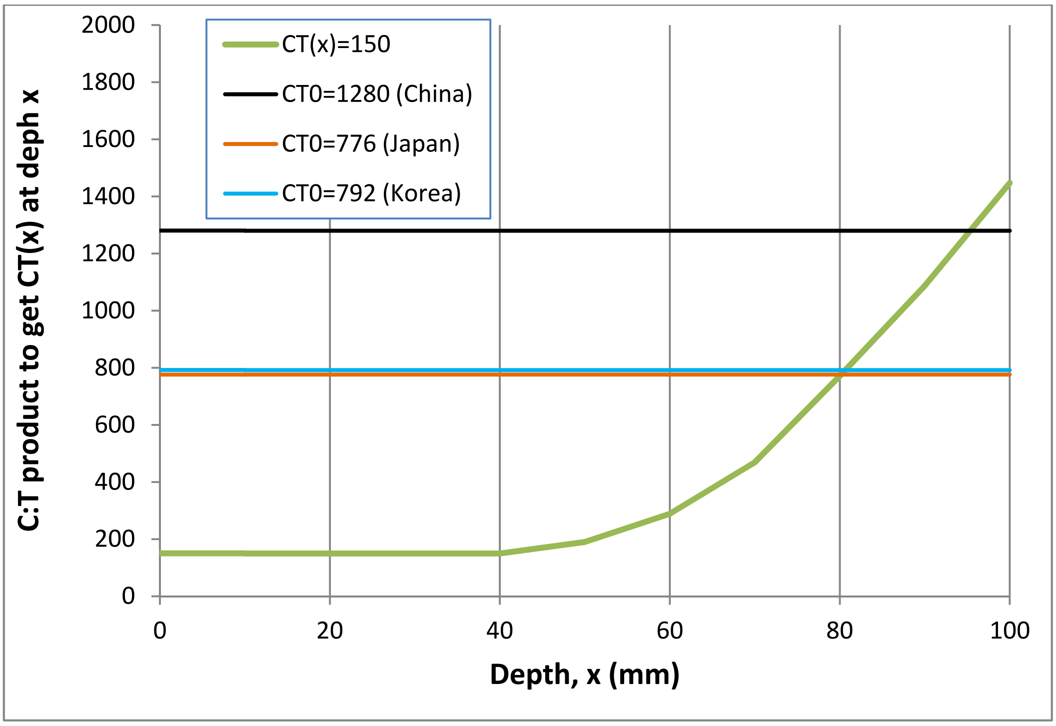

Figure 3. Comparison of China, Japan and Korea methyl bromide concentration x time CT_0 values to a CT product = 150 g.h/m^3 at 0 mm (surface) to 100 mm depths in *Pinus radiata* logs (based on Cross 1998) for fumigation temperatures ≥ 15°C.

The black horizontal line in Figure 3 represents the China schedule using 80 g/m^3 for 16 hours at ≥ 15°C, or a CT product of 1,280 g.h/m^3. The blue and red lines in Figure 3 represent the Japan and Korea schedules and show that there is no difference between the two schedules at ≥ 15°C. The Japan and Korea schedules (Figure 3) represent CT products of 776 and 792 g.h/m^3, respectively, reflecting significantly lower CT products (more than 38% less). The green curve in Figure 3 for CT(x)=150 g.h/m^3 represents the actual CT product required to ensure quarantine security against the pests that may be found in pine logs exported from New Zealand. The data indicate that CT(x)=150 g.h/m^3 will provide quarantine security to a depth of 40 mm minimum, or twice the depth at which the pests would normally be found (Bradbury 1998; Cross 1992). The CT(x)=150 g.h/m^3 line compared with the CT0 lines for Japan and Korea (Figure 3) visually demonstrates that both the Japan and Korea MB fumigation requirements are conservative to a log depth of 60-70 mm and equal the CT(x)=150 g.h/m^3 value at about 80 mm in depth. Therefore, an argument can be made for a considerable reduction in both the Japan and Korea MB dosage requirements, and a substantial reduction in the China MB dosage requirements, to ensure quarantine security against insects of quarantine importance to a depth of 20 mm in logs exported from New Zealand.

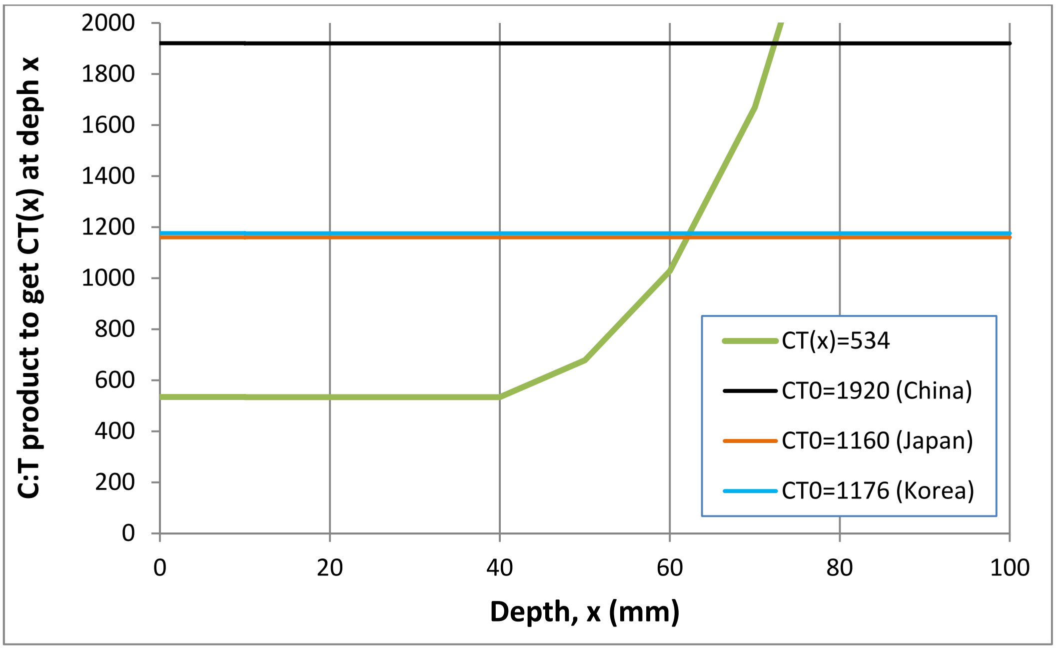

Figure 4. Comparison of China, Japan and Korea methyl bromide concentration x time CT_0 values to a CT product = 150 in g.h/m^3 at 0 mm (surface) to 100 mm depths in *Pinus radiata* logs (based on Cross 1998) for fumigation temperatures ≤ 15°C.

The black horizontal line in Figure 4 represents the China schedule using 120 g/m^3 for 16 hours at ≤ 15°C, or an applied CT product of 1,920 g.h/m^3. The blue and red lines in Figure 3 represent the Japan and Korea schedules and show that there is no difference between the two schedules at ≤ 15°C. The Japan and Korea schedules (Figure 4) represent CT products of 1,160 and 1,176, respectively, again reflecting significantly lower applied CT products (more than 38% less). The green curve in Figure 4 for CT(x)=534 g.h/m^3 represents the CT product estimated to ensure quarantine security against the pests that may be found in pine logs exported from New Zealand. The data indicate that the CT(x)=534 g.h/m^3 will provide quarantine security to a depth of 40 mm minimum, or twice the depth at which the pests could potentially be found (Bradbury 1998; Cross 1992). The CT(x)=534 g.h/m^3 line compared with the CT_0 lines for Japan and Korea (Figure 4) visually demonstrates that both the Japan and Korea MB fumigation requirements are conservative to a log depth of 40-60 mm. Therefore, an argument can be made for a considerable reduction in both the Japan and Korea MB dosage requirements, and a substantial reduction in the China MB dosage requirements, to ensure quarantine security against insects of quarantine importance to a depth of 20 mm in logs exported from New Zealand.

The summary of the rates presented in Tables 1 and 2 indicate that the MB fumigation rate for China could be reduced for fumigations at both ≤ 15°C and ≥ 15°C, to align the significantly lower rates used by Japan and Korea. As all the treatments when applied to New Zealand export logs are targeted at controlling the same group of pests, standarizing the rate to the lowest one would ensure quarantine security while avoiding excessive MB use.

Further reductions in the rates are supported by the research findings of Cross (1992). The data analysis (Cross 1992) and the comparisons of scaled values (Figures 3 and 4) clearly show that the present Japan and Korea protocols are higher than the rates required to achieve reliable kill of New Zealand pests. Based on mathematical interpretations of Table 3 and Figures 3 and 4 the Japan and Korea schedules have been shown to be considerably more severe at depths to 60 mm in logs for fumigations at ≥ 15°C and depths to 40 mm in logs for fumigations at ≤ 15°C (Figs. 3 and 4) than needed to effect reliable kill. The CT values proposed from this study would be up to eight times lower than the currently applied schedules. However, Cross's results and our extrapolation of them rely on a number of assumptions, therefore the results cannot be used directly to support an alternative lower protocol specifically determined for New Zealand pests.

Therefore, instead of using the mathematical interpretation for rate reductions based on Cross's findings, standardization to the Japan and Korea rates of 48.5-49.5 g/m3 for fumigations at ≥ 15℃ and 72.5-73.5 g/m3 for fumigations at ≤ 15℃ would provide more than adequate quarantine security against pests that may be found in logs exported from New Zealand. This standardization procedure would not diminish quarantine security but would provide significant economic benefits and greatly help to reduce the amount of MB released into the atmosphere during aeration.

4 Summary

Analysis of the Cross (1992) data for CT products at a 20 mm depth of penetration required for the pests of concern in New Zealand export logs provided evidence that the MB concentrations currently required could be significantly reduced. This is confirmed when a comparison of the phytosanitary MB fumigations for logs exported from New Zealand showed that, among its trading partners in Asia, some MB concentrations were significantly lower than others for the same fumigation temperature ranges. Moreover, even the lower MB rates used by some trading partners (e.g., Japan and Korea) are still very conservative (Figures 3, 4) and provide more than adequate quarantine security against the pests of concern that may be found in logs exported from New Zealand. Furthermore, the reduction in MB used could be significant, with a potential reduction of over 150 tonnes of MB compared with the amount used in 2010 (Figure 2) and equate to increased reductions in future years should New Zealand log export continue to grow (Fig. 1). These reductions in MB use would greatly assist New Zealand's compliance with both the aims of the Montreal Protocol (UNEP 2008) and the IPPC recommendations for reductions in MB uses for QPS purposes (UNEP 2010).

5 Recommendations

Based on an analysis of the Cross (1992) data, and through direct comparison of the China schedules with the Japan and Korea MB schedules, a conservative recommendation indicates is that the current 80 g/m^3 MB MB rate can be reduced to 49 g/m^3 for fumigations at $\geq$ 15°C, and the 120 g/m^3 MB rate for fumigations at $\leq$ 15°C can be reduced to 73g/m^3 for 16 hours of fumigation. These rates align with the Japan rates, rounded up to the nearest whole number. This recommendation relies on the adequate quarantine security provided by the current Japan rate, and hence our suggested alignment with it, plus the evidence from the study of New Zealand forestry pests which shows that the Japan rate is very conservative. These reductions still provide a reliable phytosanitary control of the pests of quarantine importance present on the export pathway for New Zealand *P. radiata* logs. In the case of a major trading partner, such as China, nearly 40% reduction in MB usage can be achieved and significantly reduce the amount of MB released into the atmosphere during aeration.

6 References

Bain, J. 1977. *Hylurgus* ligniperda (F.) (Coleoptera: Scolytidae). Forest and Timber Insects in New Zealand No. 18. 5 pp.

Bain, J., Sopow, S. L., and Bulman, L. S. 2010. Pest risk assessment for Sirex noctilio in New Zealand Pinus radiata logs exported to India. SCION, New Zealand Forest Research Institute Limited, Rotorua. 45 pp.

Bond, E. J. 1984. Manual of Fumigation for Insect Control, F.A.O. Plant Production and Protection Paper No. 54. UNFAO, Rome. 364 pp.

Bradbury, P.M. 1998. The effects of the burnt pine longhorn beetle and wood- staining fungi on fire damaged *Pinus radiata* in Canterbury. New Zealand Forestry 43: 28-31.

Brockerhoff, E. G., and Hosking, G. P. 2001. Burnt pine longhorn Beetle *Arhopalus tristis* (F.) (=*Arhopalus ferus* (Mulsant)) (Coleoptera: Cerambycidae). Forest and Timber Insects in New Zealand, No. 27. 6 pp.

Cross, D. J. 1992. Penetration of methyl bromide into Pinus radiata wood and its significance for export quarantine. New Zealand J. Forestry Sci. 21(2/3): 235-245

FAO. 2002. International Standards for Phytosanitary Measures No. 15, Guidelines for regulating wood packaging material in international trade, Annex I – Approved measures associated with wood packaging material, methyl bromide. Secretariat of the International Plant Protection Convention, Food and Agriculture Organization of the United Nations, Rome. 21 pp.

Hosking, G. P. 1978a. Burnt pine longhorn, *Arhopalus ferus* (F.) (= *A. tristis* (Mulsant)) (Coleopteran: Cerambycidae). Forest and Timber Insects in New Zealand No. 35. 6 pp.

Hosking, G. P. 1978b. Huhu beetle, *Prionoplus reticularis* White (Coleoptera: Cerambycidae). Forest and Timber Insects in New Zealand No. 27. 7 pp.

Japan MAFF (Ministry of Agriculture, Fisheries and Forestry) PPS (Plant Protection Society). 2011. Import timber quarantine guidelines. Criteria of disinfestation method. http://www.pps.go.jp/law_active/Notification/basis/8/55/html/55.html#14 [Accessed 4 October, 2011; translated from Japanese using Google Chrome translation]

MAF. 2011. Ministry of Agriculture and Forestry, Situation and Outlook for New Zealand Agriculture and Forestry, June 2011. Wellington. 72 pp.

MAFBNZ. 2011. Export Certification Standard - System Overview and Requirements (back reference to MAF Biosecurity New Zealand Export Certification Standard: System Overview & Requirements V1 June 1 2006 in .pdf format) http://www.biosecurity.govt.nz/commercial-exports/plant-exports/standards-system-overview [Accessed 08 April 2011]

Milligan, R. H. 1978. Black pine bark beetle, *Hylastes ater* (Paykull) (Coleoptera: Scolytidae). Forest and Timber Insects in New Zealand No. 29. 6 pp.

Milligan, R. H. 1984. New Zealand Drywood Termite, *Kalotermes brouni* Froggatt (Isoptera: Kalotermitidae). Forest and Timber Insects in New Zealand No. 59. 7 pp.

Monro, H.A.U. 1969. Manual of Fumigation for Insect Control, 2nd. edition. FAO. Agricultural Studies No. 54. Reprinted 1974, St. Paul's Press, Malta for United Nations FAO, Rome. 381 pp.

New Zealand Ministry for the Environment. 2011. Annual Ozone Protection Act Report, Amendment to the Ozone Protection Act, 1996. Wellington. 56 pp.

UNEP. 2008. Replacement of reduction of the use of methyl bromide as a phytosanitary measure adopted as a recommendation for the implementation of the International Plant Protection Convention (IPPC), at the Third Session of the Commission on Phytosanitary Measures (CPM-3) of the IPPC. 7-11 April 2008, Rome. United Nations Environmental Program. UNEP Ozone Secretariat, Nairobi, Kenya. 10 pp.

UNEP. 2010. Montreal Protocol on Substances that Deplete the Ozone Layer. Report of the Methyl Bromide Technical Options Committee, 2010 Assessment. United Nations Environmental Program. UNEP Ozone Secretariat, Nairobi, Kenya. 396 pp.

USDA. 2011. Animal and Plant Health Inspection Service, Plant Protection and Quarantine Treatment Manual, Section 2-2-1, Fumigants. U.S. Dept. Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Washington, DC. http://www.aphis.usda.gov/import_export/plants/manuals/ports/treatment.shtml [Accessed 03 June 2011]

Yu, K. Y., Chung, Y. W., Lee, M. H., and Jae, J. W. 1984. Study on shipboard fumigation of the imported logs. Korea J. Plant Prot. 23: 37-41

Zondag, R., and Nuttall, M. J. 1977. Sirex woodwasp, *Sirex noctilio* (F.) (Hymenoptera: Siricidae). Forest and Timber Insects in New Zealand No. 20. 7 pp.