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Benefit-cost analysis of management options for *Didemnum vexillum* in Shakespeare Bay

Prepared for

Port Marlborough New Zealand Limited

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Prepared for

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by

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Cover Photo: *Didemnum vexillum* smothering Greenshell™ mussels, *Perna canaliculus* underneath the *Steel Mariner* west of Kaipupu Point, Picton. Photo courtesy of Sean Handley (NIWA, Nelson).

EXECUTIVE SUMMARY

The objective of this report is to provide Port Marlborough New Zealand Limited with the outcomes of a benefit-cost analysis and provide recommendations for managing the *Didemnum vexillum* infestation at Shakespeare Bay, Picton.

Four management options are considered for responding to the infestation of *D. vexillum* in Shakespeare Bay.

- Option 1 (Do Nothing) and Option 2 (Monitor and conduct eradication treatment trials) are not attractive.
- The present value of expected impacts on the Greenshell™ mussel industry would be in the order of $807,000 over five years (Table 1).
- Option 3 would involve containing the *D. vexillum* infestation by treating infected recreational vessels (including barges) in 2003, while conducting eradication treatment trials to test methods of killing the species on wharf piles and seabed. An attempted eradication would occur in 2004 with follow-up in 2005 if necessary. Total expected costs would be approximately $173,000, with an estimated 90% probability of success (Table 1). Benefits, i.e. the reduced risk of impacts on the Greenshell™ mussel industry, are estimated at $712,000 over five years in present value terms (taking into account the possibility of failure).
- Option 4 represents more immediate action involving the attempted eradication of *D. vexillum* colonies on recreational vessels, barges, moorings, wharf piles and on the seabed in 2003, while conducting simultaneous trials on other eradication treatment methods, and follow-up in 2004 if necessary on any colonies not fully eradicated. Total expected costs are estimated at about $190,000, with an 85% probability of success, and present value of benefits estimated at $688,000 (Table 1).

Table 1. Summary of estimated benefits and costs over five years, and probabilities of success.

Options available	Expected Impacts*	Expected Benefits*	Expected Costs	Probability of success
Option 1: Do Nothing	$807,000	-	-	-
Option 2: Not estimated	-	-	-	-
Option 3: Contain in 2003, eradicate in 2004	$95,000	$712,000	$173,000	90%
Option 4: Attempt eradication in 2003	$119,000	$688,000	$190,000	85%

* Expected impacts and benefits are present value of five years, using 10% discount rate.

Option 3 is preferred in benefit-cost terms, due to an increased probability of success that comes from testing methods before eradication begins in 2004. This increases the chances of successful treatment, and it also leaves open the possibility that the infestation will die back naturally and the eradication attempt can be put on hold and possibly avoided altogether. Option 4 is expected to cost more because, without the benefit of prior treatment trials, there is a greater likelihood that follow-up treatment would be required in the second year of the eradication attempt.

N.B. Critical success factors

- Recreational vessels that were moored in Shakespeare Bay and inspected on 3 February 2003, but were absent during the 15 July 2003 survey, must be located, inspected and managed appropriately (e.g. anti-fouled if present application is more than, say, six months old).
- The *D. vexillum* infestation on New Zealand King Salmon Limited cages at East Bay must be actively managed and then closely monitored.

If these steps are not taken, then the probability of successful eradication will be considerably lower than indicated in this analysis.

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1.0 INTRODUCTION

On 23 April 2001, a large steel barge, the *Steel Mariner* arrived west of Kaipupu Point, Picton after having been towed from Whatamango Bay and Tauranga, North Island. On 18 December 2001, during a routine biosecurity survey of Shakespeare Bay, Picton, Cawthron divers noticed a colonial ascidian or sea squirt smothering the hull of the *Steel Mariner* and the seabed below.

The Ministry of Fisheries (MFish) contracted a world authority on ascidian taxonomy, Dr Patricia Mather (Queensland Museum, Queensland) to identify the species. Dr Mather believes the ascidian is not recognizable as any of the more than 100 species of the genus known from Australia and Indo-West Pacific waters, nor as any described species from elsewhere in the world. Therefore she named the species *Didemnum vexillum*, and states that there is no evidence to suggest that the species is other than indigenous to New Zealand, although this would not preclude its status as a pest species (Kott 2002).

The New Zealand Mussel Industry Council consider the species to be a serious biosecurity risk to the Greenshell™ mussel industry because of its smothering capabilities, rapid growth rates and preference for artificial structures. On 16 July 2002 a stakeholder meeting decided to trial the use of an underwater vacuum device to remove the bulk of *D. vexillum* from the *Steel Mariner's* hull and the seabed below. The barge was then requested to be removed to the mouth of the Wairau River where the remainder of the colonies would be killed by freshwater. New Zealand Diving and Salvage Limited, Wellington removed approximately 80% of the *D. vexillum* from the *Steel Mariner*, although the removal of the *D. vexillum* from the seabed proved to be more difficult and was not completed.

A delimitation survey undertaken on 13 August 2002 found that despite the attempted containment exercise, the species had already spread and infected 44% of the Waimahara wharf piles in Shakespeare Bay. Furthermore, five small *D. vexillum* colonies were also found on newly refurbished New Zealand King Salmon Limited (NZKSL) cages in Shakespeare Bay that were due to be towed to East Bay, outer Queen Charlotte Sound. NZKSL attempted to prevent the species from being translocated to East Bay by undertaking a thorough in water scrub.

The leasers of the *Steel Mariner*, Heli Harvest Limited received an abatement notice requiring the removal of their barge from the Marlborough Sounds by no later than 20 December, 2002 because their Resource Consent on moor the *Steel Mariner* west of Kaipupu Point, Picton expired on 1 December, 2002. Heli Harvest Limited applied to Marlborough District Council (MDC) for a new Resource Consent to enable the barge to remain in its present position, however this was refused on the grounds that a) the barge possessed an undesirable organism that was a biosecurity risk to the Greenshell™ mussel industry, and b) the barge was in poor condition and unlikely to be repaired. The MDC therefore applied to the Environment Court for Enforcement Orders under Section 316 of the Resource Management Act 1991, for the *Steel Mariner* to be removed from the coastal marine area of the MDC. An Environmental Court Hearing held in Christchurch on 16 April 2003 ordered that the *D. vexillum* be removed from the *Steel Mariner*, and the *Steel Mariner* was removed from the Marlborough Sounds and scuttled in an approved dumping area in Cook Strait before 31 August 2003.

Considering the *Steel Mariner* is to be removed from the Marlborough Sounds, Port Marlborough New Zealand Limited (PMNZL) were interested to know the extent of spread of *D. vexillum*, and feasibility of eradicating the species in the Marlborough Sounds. PMNZL contracted Cawthron to undertake a thorough delimitation survey of Shakespeare Bay and East Bay on 15 July 2003. The survey revealed -

- Despite in water cleaning of the infected NZKSL cages in Shakespeare Bay, *D. vexillum* colonies had successfully been translocated to East Bay.
- *D. vexillum* colonies on the *Steel Mariner* have grown back because the barge was not relocated to the mouth of the Wairau River due to it posing a navigational hazard.
- *D. vexillum* colonies on the seabed underneath the *Steel Mariner* were still plentiful.
- Well established *D. vexillum* colonies were found on McManaway's mooring chain/buoys and on an artificial structure on the seabed in between the *Steel Mariner* and Waimahara wharf.
- 99% of the Waimahara wharf piles were found infected with *D. vexillum*.
- *D. vexillum* colonies have established on rocks underneath Waimahara wharf.
- Four of the 14 recreational vessels in Shakespeare Bay were found infected with *D. vexillum.*

Given these results, PMNZL then contracted Cawthron to undertake a benefit-cost analysis and provide recommendations for managing the *D. vexillum* infestation at Shakespeare Bay, Picton.

2.0 BENEFIT-COST ANALYSIS

This analysis presents four options for responding to the infestation of *D. vexillum* in Shakespeare Bay. Estimated costs are given for each measure although in some cases certain measures might not be required. However, "total expected costs" for an option reflect the probabilities of successful treatment and other uncertain outcomes, including the possibility that some measures would not be required. The "total expected costs" are therefore an average of the range of possible costs of each option, weighted by the likelihood of each separate scenario. *Actual total costs for the entire response will be higher or lower depending on whether these adverse outcomes occur, i.e. which scenario eventuates.*

Key assumptions used to derive calculations and probabilities are numbered with superscripts (e.g.,[1]) throughout the document and their corresponding explanation supplied in Section 3.1.

2.1 Option 1: Do Nothing

This option provides a counter-factual as a baseline to compare the benefits and costs of other options. For this analysis, the following assumptions and calculations were made regarding the likely outcomes if no measures were taken to control the infestation of *D. vexillum*:

- There is 50% chance that the organism will spread throughout much of the Marlborough Sounds if no measures are taken, reaching maximum extent within five years[1];
- If this spread occurs, within five years about 10% of Greenshell™ mussel lines would be impacted to the point of either requiring treatment or being a complete loss[2];
- Loss of 10% of production would equate to over \$12 million per year, but the affected lines could be treated for an estimated \$1.14 million per year, so the latter figure is used as the potential cost of impacts on mussel farming[3] (Appendix 1A and B).
- Given the 50% chance that the organism will or will not spread, the fact that any impacts would occur gradually, and discounting future costs by 10% per year, it is estimated that the present value of expected impacts on mussel farming over five years would be in the order of \$807,000 (Appendix 2).

2.2 Option 2: Monitor spread and conduct eradication treatment trials

This option entails monitoring the spread of *D. vexillum* and conducting eradication treatment trials to determine the most effective method of eradicating the organism from recreational vessels, barges, wharf piles and the seabed. Measures to contain or eradicate the infestation would be undertaken in 2004. This option is not attractive as it presents an unacceptably high risk that the organism will spread further and control options will become more expensive and less effective. The benefits of this option have not been estimated because to do so would be moderately complicated i.e. the risk of spread via untreated artificial structures would probably outweigh the advantages of waiting while treatment trials are conducted.

2.3 Option 3: Contain spread, conduct eradication treatment trials and attempt eradication in 2004

This option involves the containment of *D. vexillum* within Shakespeare Bay by treating recreational vessels in 2003, while conducting eradication treatment trials on wharf piles and seabed colonies followed by an attempted eradication in 2004, with follow-up treatments in 2005 if required. There is some chance that the organism will die back like it has recently in Whangamata and Tauranga Harbours, in which case only further monitoring would be required. However, there is also a possibility of the organism spreading beyond Shakespeare Bay such that eradication would be more complicated or even impossible if a new infestation goes undetected for a considerable period (Refer to Appendix 3 for decision tree diagram). Key measures are as follows:

- **The *Steel Mariner* barge** has recently (4-6 August, 2003) undergone a *D. vexillum* biomass reduction whereby 90% of the biomass was removed from its hull in preparation for its tow out to Cook Strait where it will be scuttled. It is understood that the lessees (Heli Harvest Limited) and/or owner of the *Steel Mariner* (Gemeni Barge Company Limited) will pay the estimated cost of $50,000. This cost is therefore not included in the estimated costs of the options presented here. It has been considered that there is roughly a 10% residual risk of remaining *D. vexillum* colonies being dislodged during transit and successfully establishing a new infestation within the Queen Charlotte Sound, or that other infestations already exist outside Shakespeare Bay[4] (Appendix 4).
- **All recreational vessels** that have been moored in Shakespeare Bay after 1 October 2002 for more than 24 hours must be located, inspected and managed appropriately (e.g. anti-fouled unless the anti-fouling is less than 6 months old and in excellent condition)[5]. Estimated cost = $12,000 (Appendix 1B). Probability of success = 95% (Appendix 4) if all vessels are located.
- **All barges** that have been in Shakespeare Bay since 1 October 2002 must be located, inspected and managed appropriately (e.g. anti-fouled unless the anti-fouling is less than 18 months old and in good condition)[6]. Estimated cost = $20,000 for anti-fouling 2 barges (Appendix 1B). Probability of success = 95% (Appendix 4).
- **Conduct eradication treatment trials** i.e. freshwater, chlorine, vinegar, heat, suffocation for eradicating *D. vexillum* from wharf piles and the seabed[7]. Estimated cost = $34,000 (Appendix 1B).
- **Continue 6-monthly monitoring** for any new infestations in and around Shakespeare Bay[8]. Estimated cost = $20,000 for two years (Appendix 1B).
- **Treat Waimahara wharf piles** in 2004 in attempt to eradicate *D. vexillum*[9]. Estimated cost = $40,000 (Appendix 1B). Probability of success = 95% (Appendix 4).
- **Treat all mooring lines** i.e. remove from the water and treat in 2004 in Shakespeare Bay[10]. Estimated cost = $5,000 (Appendix 1B). Probability of success = 99% (Appendix 4).
- **Treat seabed under *Steel Mariner*** in 2004 in attempt to eradicate organism[11]. Estimated cost = $10,000 (Appendix 1B). Probability of success = 95% (Appendix 4).

- **Treat seabed under Waimahara wharf** in 2004, in attempt to eradicate the organism[12]. Estimated cost = $10,000 (Appendix 1B). Probability of success = 90% (Appendix 4).
- **Follow-up treatments in 2005**: allow $55,000[13].
- **Total expected costs** are approximately $173,000 over 2-3 years (above costs are reduced by the probability that some measures would not be required) (Appendix 2).
- **The probability of successful eradication** is estimated to be about 90% (note: this figure was estimating using a statistical assumption that is not strictly correct, and the true probability of successful eradication may be somewhat lower; refer Section 2.0: Key Assumptions and Appendix 4).
- Given the above measures and the possibility of failure, it is estimated that the expected impacts on the Greenshell™ mussel industry over five years would be reduced from $807,000 to $95,000, i.e. **net benefits are estimated at about $712,000**. This includes discounting of future impacts using a 10% annual interest rate (Appendix 2).

2.4 Option 4: Attempt eradication in 2003 and follow-up in 2004

This option is similar to Option 3 except that eradication would be attempted in 2003 instead of 2004. It is recommended that treatment trials on wharf piles and seabed colonies still be undertaken (e.g. on surrogate *Didemnum* sp. in Port Nelson) so that findings can be used in follow-up treatments in Shakespeare Bay in 2004. The estimated probability of a successful eradication in 2003 is only 50%, hence some follow-up treatments must be allowed for in 2004. However, this option does minimize the risk that the organism will spread outside of Shakespeare Bay during 2003 (Refer to Appendix 5 for decision tree diagram). Key measures are as follows:

- **Measures for recreational vessels and barges** would be undertaken as per Option 3[6&7]. Estimated cost = $32,000 (plus $50,000 for *Steel Mariner*, but not included).
- **Conduct treatment trials** of alternative methods for treating colonies on wharf piles and seabed[8]. Estimated cost = $34,000.
- **Continue 6-monthly monitoring** for any new infestations in and around Shakespeare Bay for two years[9]. Estimated cost = $20,000.
- **Treat wharf piles, mooring lines and seabed** in attempt to eradicate organism. Estimated cost: $65,000[10,11&12]. Probability of success = wharf piles: 90%; mooring lines: 95%; seabed under barge: 90% first year, 95% second year; seabed under wharf: 70% first year, 90% second year (Appendix 3).
- **Follow-up treatments in 2004**: allow $55,000[13].
- **Total expected costs** are approximately $190,000 over two years (Appendix 2).
- **The probability of successful eradication** is estimated to be about 85% in 2004 (Refer Section 2.0: Key Assumptions and Appendix 4).
- Given the above measures and the possibility of failure, it is estimated that the expected impacts on the Greenshell™ mussel industry over five years would be reduced from $807,000 to $119,000, i.e. **net benefits are estimated at about $688,000**. This includes discounting of future impacts using a 10% annual interest rate (Appendix 2).
- If a third year of eradication treatments were included, this would raise the cost even more, but would also raise the probability of success. This option would then have the highest chance of success but also the highest cost. With time for further analysis, estimates could be provided for expected impacts, costs, benefits and probability of success.

3.0 KEY ASSUMPTIONS

This analysis is based on a number of assumptions and estimates of probabilities and costs. These are shown in the following tables (Table 2 and 3). In addition, the following assumptions were made:

- If *D. vexillum* were to spread unchecked, it is assumed that it would reach maximum spread and densities within five years and then probably vary from year to year. As for the rate of spread, it is assumed that spread in the first year (2003) would be only 5% of maximum extent, then 10% in the year 2, 25% in year 3, 50% in year 4, and reach maximum extent (100%) by the year 5 (2007).
- The risk of *D. vexillum* being re-introduced to the Marlborough Sounds from Whangamata and Tauranga, or from some unknown location i.e. within or outside New Zealand, is assumed to be negligible. The infestations in northern New Zealand have died back for unknown reasons (David Groot, *pers. comm.*), hence are not considered to pose a significant risk at this point in time. The possibility of re-introduction cannot be completely dismissed, but this has not been accounted for it in this analysis.
- It is assumed that infected NZKSL cages currently residing in Shakespeare Bay and at the farms in East Bay will be managed appropriately and that residual risk of spread from these sources will therefore be minimal.
- Options 3 and 4 both provide for follow-up treatment if eradication is not completely successful the first year. This has been taken into account in estimating the overall probability of successful eradication, but doing so in a statistically rigorous manner involves both more subjective judgment and more complicated calculations than time has allowed. For the purpose of this analysis, we have assumed that the probability of successful treatment in the second year is statistically independent of (i.e. not related to) the probability of success in the first year. This is not strictly correct, because lack of success in the first year would typically suggest a somewhat lower probability of success on the second attempt than previously assumed. On the other hand, one can also learn from experience and adapt the treatment in the second year, so this would tend to raise the probability of success. In practice, it is difficult to know which of these two factors will dominate, but the overall probability of success may be somewhat lower over two years than indicated in this analysis.

3.1 Further Assumptions (superscripts)

The following assumptions relate to numbered superscripts in the description of Options 1 – 4 in Section 1.0.

[1] The species has illustrated its ability to colonize various artificial structures in Shakespeare Bay (i.e. recreational vessels, barges and NZKSL cages), all of which are then capable of translocating the species throughout the Marlborough Sounds. Spread is likely to occur as 'stepping stone' events over several years given that the larvae are only competent of settlement between 10 minutes and a few hours after being liberated from a colony (Olson 1983; Morgan 1995; Lambert 2001; Kott 2002 and Mather 2002). However the species is capable of asexual reproduction i.e. budding enables the species to spread via fragmentation from de-fouling or even de-ballasting activities. Fortunately, currents in the Shakespeare Bay area are weak and are away from Picton Harbour, thus reducing the risk of the species naturally dispersing and establishing in Picton Harbour (New Zealand Charts 1999 and Paul Barter, *pers. comm.*).

[2] Observations of the species smothering behaviour, e.g. of mussels underneath the *Steel Mariner*, on ropes hanging from the *Steel Mariner* and wharf piles, illustrates the species' potential impact on the Greenshell™ mussel industry. However, the difficulty is estimating the likely percentage of

Greenshell™ mussel lines that could be impacted, and more importantly, the percentage impact per mussel line? In light of the impacts other ascidians, i.e. *Ciona intestinalis* and *Styela clava*, have had on mussel aquaculture industries around the world, it was estimated that *D. vexillum* would impact approximately 10% of Greenshell™ mussel lines in the Marlborough Sounds, with 75% or more of an impacted line being smothered (Paul Lupi, *pers. comm*.). This impact would then necessitate some sort of treatment. However, there would also probably be additional lines that were impacted to a lesser degree, and therefore not warrant treatment. The resulting production losses have not been taken into account in this analysis; therefore the expected impacts of the "Do Nothing" scenario are probably understated.

Table 2. Summary of key probabilities

Activity	Probability	
D. vexillum spreads to pest densities in Marlborough Sounds	50%	
Percentage of mussel long lines impacted	10%	
Containment		
D. vexillum spreads beyond Shakespeare Bay	10%	
Detected at an early stage	50%	
Main infestation in Shakespeare Bay dies back	25%	
Bloom again in 2005 or 2006	50%	
Spread via *Steel Mariner* in transit	10%	
Eradication - colonies eliminated on:	**2003**	**2004**
Moorings	99%	
Vessels i.e. recreational vessels, barges.	95%	99%
Wharf piles	90%	95%
Seabed under *Steel Mariner*	90%	95%
Seabed under Waimahara wharf	70%	90%

Table 3. Summary of cost estimates

Item	Cost
Annual monitoring costs	10,000
Treatment trials for seabed and wharf piles	34,000
Recreational vessels e.g. 20 ± 2	12,000
Cost per vessel	500
Finding "missing in action" yachts	2,000
Logging barges	20,000
Cost per vessel (includes towing to Nelson Slipway)	10,000
Treat mooring lines	5,000
Treat wharf piles	40,000
Treat seabed under wharf	10,000
Treat seabed under barge	10,000
Annual cost to treat 1 m of longline	1

[3] These estimates were supplied by Paul Lupi, Chief Executive of the New Zealand Mussel Industry Council (see Appendix 1A and B for calculations).

[4] Cawthron Institute and Commercial Diving Consultants Limited, Picton successfully removed an estimated 90% of *D. vexillum* wet biomass weight from the *Steel Mariner* on the 4–6 August 2003. Therefore, an estimated 10% of *D. vexillum* still remains on the *Steel Mariner*, some of which is likely to be removed during the expected 4-5 knot tow through the Queen Charlotte Sound. Given defouled colonies have successfully colonized the seabed underneath the *Steel Mariner* west of Kaipupu Point, there is the potential for the *Steel Mariner* to seed the Queen Charlotte Sound. However, it is requested that the *Steel Mariner* be towed up the middle of the Sound, whereby it is hoped that defouled colonies will settle in deep water where the substrate of mud and silt is unsuitable establishment of the species. We put the residual risk of such establishment at 10%, which also includes the possibility that there are already other undetected *D. vexillum* infestations outside Shakespeare Bay (since it might not be possible in future to distinguish whether an infestation was pre-existing or the result of towing the barge).

[5] Eight recreational vessels that were moored in Shakespeare Bay in February 2003 are presently missing (see Section 3.1 also). Given that five recreational vessels are currently infected with *D. vexillum*, this illustrates the need to ascertain the status of these “missing in action” vessels. Furthermore, despite the 24 moorings being privately owned, other vessels may have also visited Shakespeare Bay between 1 October and 1 May (i.e. approximate breeding season of *D. vexillum*) and should be inspected and managed appropriately. Effective anti-fouling paint is the best line of defence to prevent the *D. vexillum* colonizing vessels, as this species is an epibiotic organism i.e. prefers to attach to other organisms. Therefore only those recreational vessels possessing anti-fouling paint less than 3 months old and in excellent condition should be exempt from being slipped and anti-fouled.

[6] There are at least two barges that regularly visit Waimahara wharf (Peter McManaway, *pers. comm.*). These barges are generally used to transport sand, stones and logs between Waimahara wharf, Wellington and throughout the Marlborough Sounds. There is a danger of these barges being colonized and spreading *D. vexillum* throughout the Marlborough Sounds, particularly if they possess old or ineffective anti-fouling paint. These barges are slipped and re-painted in Nelson every two years, therefore it is recommended that these barges be slipped and anti-fouled before this summer if they possess anti-fouling paint that has been in service for 18 months or more. We understand that it costs approximately $5,000 to tow the barges to from Picton to Nelson/return and a further $5,000 to cover slipway costs (Peter McManaway, *pers. comm.*). However it should be pointed out that despite the effectiveness of anti-fouling paints on barges, the paint is often damaged as a consequence of the loading/unloading process, hence providing a non-toxic surface for fouling organisms to colonize which *D. vexillum* can then smother. Therefore, these barges may require some on-going monitoring. An inspection of the *Waimarie 1* barge on 15 July 2003 revealed that attempts to remove *D. vexillum in situ* has proven successful.

[7] There are no proven techniques currently available for eradicating *D. vexillum*. However, several physical and chemical methods have been used to manage the incursion of unwanted marine organisms around the world (see McEnnulty et al. 2001 and Stuart 2002). It is proposed to trial the effectiveness of freshwater, chlorine, vinegar, heat and suffocation on killing *D. vexillum* on the natural substrate and on wharf piles. This would involve some initial laboratory trials to ascertain appropriate treatment concentrations/strength and exposure times, followed by field trials for validation. These various treatments would be measured/assessed according to time, cost and effectiveness.

[8] Six-monthly monitoring would involve undertaking a similar protocol to previous delimitation surveys of the Shakespeare Bay area (see Coutts 2002a, b; Coutts 2003 and Forrest 2003).

[9] There are 172 of the 173 Waimahara wharf piles infected with *D. vexillum*. There are 139 concrete piles 600 diameter ranging from 2 to 16 m deep and 34 metal RSJ piles at 16 m depth (see Coutts 2002b). A smothering technique i.e. wrapping wharf piles with 50µm polypropylene plastic is currently being trialed to kill *D. vexillum* colonies on the Waimahara wharf piles. This technique has the advantage that it is a "set and forget" technique that relies on an anoxic environment, in which naturally occurring production of ammonia and nitrates will kill the colonies over time. Then once the colonies are destroyed, a clean up operation is needed to remove and collect all the plastic material. The expense with this technique is the diving time, as materials are extremely cheap i.e. $2,000 to wrap 173 wharf piles.

[10] There are 24 privately owned moorings in Shakespeare Bay (Mike Baker *pers. comm.*). Approximately seven of these moorings are presently infected with *D. vexillum*. It is proposed that all moorings be re-inspected, including the blocks, and all infected mooring lines and blocks be removed from the water, water blasted on land and returned five days later. Mooring lines that are not infected would not be treated, because the operation would be conducted at a time when all colonies would be visible.

[11] The treatment of *D. vexillum* colonies on the seabed underneath the *Steel Mariner* is challenging, in that small colonies are distributed within an approximate 40 x 80 m area. The probability of success is estimated at 95%. Several methods could be used to treat the *D. vexillum* colonies. Colonies could be smothered by depositing dredging material within the area. Alternatively, polypropylene plastic could be used to smother the colonies i.e. set and forget or a large scoop or scallop dredge with a fine collection bag could be used to systematically collect the colonies within the contaminated area. Follow-up treatment would need to be considered.

[12] The treatment of *D. vexillum* colonies on the rocks underneath the Waimahara wharf is even more challenging, because the seabed is sloping and consists of large boulders, both of which complicate smothering techniques. Therefore the probability of success is only 90%. It is proposed that divers remove as much of the infestation as possible by hand followed by smothering the colonies with dredging material.

[13] Follow-up eradication measures are likely to require repeating treatments for mooring lines, vessels and seabed, at a total cost of $25,000. For wharf piles, if plastic wrap were used, then only those with new infestations would need to be re-treated (for other piles, removal of the plastic wrap would remove any undetected larval infestations.) An estimate of $20,000 has therefore been allowed (one-half the cost of the initial treatment) for the second treatment of wharf piles. Actual cost could be more or less than this depending the treatment used (plastic wrap or some other treatment) and the extent of the re-infestation. Finally, a further year of monitoring would be required, at $10,000.

4.0 OTHER OPTIONS

The option of on-going containment rather than attempting eradication was considered informally, but it was concluded that it would require very stringent measures on vessel movements in and out of Shakespeare Bay on a more or less permanent basis. These would be expensive and, in the long run, prone to failure as it will be difficult to maintain vigilance year after year. However, if eradication were to fail, some containment measures might be justified in order to delay impacts on the Greenshell™ mussel industry.

5.0 DISCUSSION

It must be stressed that this analysis is solely reliant upon the authors' informed guesses of probabilities (i.e. about the probability of *D. vexillum* spreading or dying back, the extent of impacts if it spreads, and the probability that treatments will succeed, among other things) and upon cost estimates supplied by various stakeholders. Given the urgency of this analysis, these estimates are the 'best approximations possible' in the limited timeframe. Some of these estimates and assumptions would most likely change if more time was available and would probably alter the results of this analysis.

With that caveat, Options 3 and 4 both appear to have substantial net benefits. Option 3 is preferred i.e. it has lower expected costs and higher expected benefits. This is due to the increased probability of success that comes from containing spread in 2003, but waiting until 2004 to begin eradication. This enables trials to be conducted, thereby increasing the chances of successful treatment, and it leaves open the possibility that the infestation will die back naturally and the eradication attempt can be put on hold and possibly avoided altogether.

Option 3 also entails a risk that leaving the infestation in place will lead to spread beyond Shakespeare Bay. This is considered a relatively low risk, given that a) the prominent currents in the area are weak and are away from Picton, b) outside Shakespeare Bay, there is a lack of artificial structures/shaded areas preferred by the species and c) if any such spread is detected early it could probably be treated successfully. This analysis indicates that there is a strong case for an attempt to eradicate *D. vexillum* from Shakespeare Bay due to the potential impacts on the Greenshell™ mussel industry, even though there is a chance that the attempt will not succeed.

If Option 4 were to allow for a third year of eradication treatments, this would raise the cost even more, but would also raise the probability of success. This option would then have the highest chance of success but also the highest cost. Further analysis would be required to provide estimates for this approach.

This analysis considered only the impacts on the Greenshell™ mussel industry given that NZKS regularly replace/clean their cages and the species is unlikely to survive on intertidal oyster cages. It is acknowledged that there may be other values at risk from the organism, be they ecological, aesthetic or cultural, however these were outside the scope of this analysis at this point in time. The severity of these other impacts may depend on whether the organism is a nonindigenous or introduced species to New Zealand, which has yet to be determined. In any event, if other values are at risk from the organism and are included in future analyses, then this is likely to strengthen the case for action.

It is important to note that the "expected impacts" in the analysis may appear somewhat lower than one might otherwise expect, given the estimate that the cost of treating 10% of the mussel lines would be in the order of $1.14 million per year within five years. The results for the "Do Nothing" option indicate "expected impacts" of $807,000 over five years. This is less than the $1.14 million for three reasons:

1) Costs are reduced by 50% due to the probability that it will not happen.

2) Spread is assumed to occur gradually (starting at 5% impact and roughly doubling every 2 yrs), so costs in the early years are quite low.

3) Costs are discounted by 10% per year for the time value of money, which means e.g. that costs for year 5 are cut roughly in half again. (The 10% discount rate is rather arbitrary. It is assumed that commercial operators face a reasonably high cost of capital, but in today's interest rate environment a lower rate might be appropriate. Using a 6% rate instead would raise the expected impacts of doing nothing to $907,000 from $807,000).

It is important to note that, although the estimates of expected impacts were discounted, the costs of management that occur in later years were not because it was initially thought that most costs would occur this year or next. In retrospect, this probably should have been done because some of costs would not occur until the 3rd or even 4th year.

5.1 Critical success factors

The following factors will not guarantee success, but they must be undertaken if the probability of success is not going to be reduced significantly below that indicated above.

5.1.1 Recreational vessels

A total of 15 recreational vessels were inspected for *D. vexillum* in Shakespeare Bay on 26 September 2002. A further inspection of 22 recreational vessels was undertaken on 3 February 2003. No *D. vexillum* colonies were witnessed during these two surveys. However, an inspection of 14 vessels on 15 July 2003 revealed that five vessels are infected with *D. vexillum*. Unfortunately, four known vessels i.e. *Sky Rocket*, *Braveheart*, *Tera* and *Aligvando* and four unknown/un-named vessels were present during February's survey but missing during July's survey. One or more of these vessels could be infected and at risk of spreading the organism during the coming summer.

The Picton Harbourmaster has been contacted regarding the whereabouts of these vessels and believes they would be extremely difficult to track. Mike Baker of Commercial Diving Consultants Limited, Picton has the contract to maintain most of these moorings and has contact details for most of the privately owned moorings. The question remains, whose responsibility is it to chase these "missing in action" vessels?

5.1.2 NZKSL cages

Several attempts have been made to contact NZKSL about whether they have managed the *D. vexillum* infestation on their cages at East Bay. It is understood that they have not taken any action to date, however they would like Cawthron Institute to visit their facility at East Bay to discuss management options for treating the infestation.

5.1.3 Approvals required to remove D. vexillum from the marine environment?

According to Keith Heather (Marlborough District Council) Resource Consent may be required depending on the eradication techniques proposed. Otherwise Resource Content is not required for attempting to eradicate a marine species, be it native, cryptogenic or introduced in New Zealand at the point in time. The issue has also been raised with Chad Hewitt (Ministry of Fisheries, Chief Technical Officer, Marine Biosecurity) who is presently exploring whether any biosecurity or fisheries approvals are required. The analysis of options in Section 1.0 above does not take into the account the costs or possible delays if any such approvals are required.

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Appendix 1

Values at risk

Mussel Production in Marlborough Sounds	Units
Annual production - tonnes	60,000
Marketed weight factor	0.47
Market price US$/lb	1.2
Pounds/kg	2.2
US$/NZ$	0.58
Total value of production NZ$'000	128,359,

Appendix 2

Risk reduction costs and on-going management costs

Activity	Units	Source of information
Costs to manage effects of infestations on mussel farms		
cost per metre of mussel line	1	Estimates supplied by Paul Lupi, MIC
No of production longlines	3280	˝
No of spat catching longlines	0	˝
Metres of crop line per longline	3500	˝
total length of mussel lines (km)	11.48	˝
% of lines requiring treatment	10%	˝
Estimated treatment costs - @$1/m	1148000	˝
Est. costs - $'000	1148	
Monitoring costs x $1000 - 2 yrs	20	Estimates supplied by Cawthron
Semi-annual surveys x 1 yr	10	˝
Semi-annual surveys x 2 yrs	20	˝
Treatment trials x $1000	34	Estimates supplied by Cawthron Institute
Trial 4x options in Port Nelson	34	˝
Trial 4x options in Shakespeare Bay	34	˝
Containment measures x $1000	**32**	
Remove barge to Cook Strait	?	*Excluded from analysis*
Anti-foul recreational vessels	10	Estimates supplied Peter McManaway
No. of vessels to treat	20	˝
Cost per vessel	0.5	˝
Anti-foul logging barges	20	˝
No. of vessels to treat	2	˝
Cost per vessel	10	˝
Find MIA vessels	2	Guess, need to confirm
Treat NZKS cages	?	*Excluded from analysis*
Eradication (1st try) x $1000	**95**	In addition to containment measures
Treat mooring lines	5	Estimates supplied by diving companies
Treat wharf piles	50	˝
Treat seabed under wharf	10	˝
Treat seabed under barge	10	˝
Monitoring for two years	20	Estimates supplied by Cawthron Institute
Eradication (2nd try) x $1000	**55**	In addition to containment measures
Treat mooring lines	5	
Treat wharf piles	20	
Treat seabed under wharf	10	
Treat seabed under barge	10	
Monitoring for additional year	10	

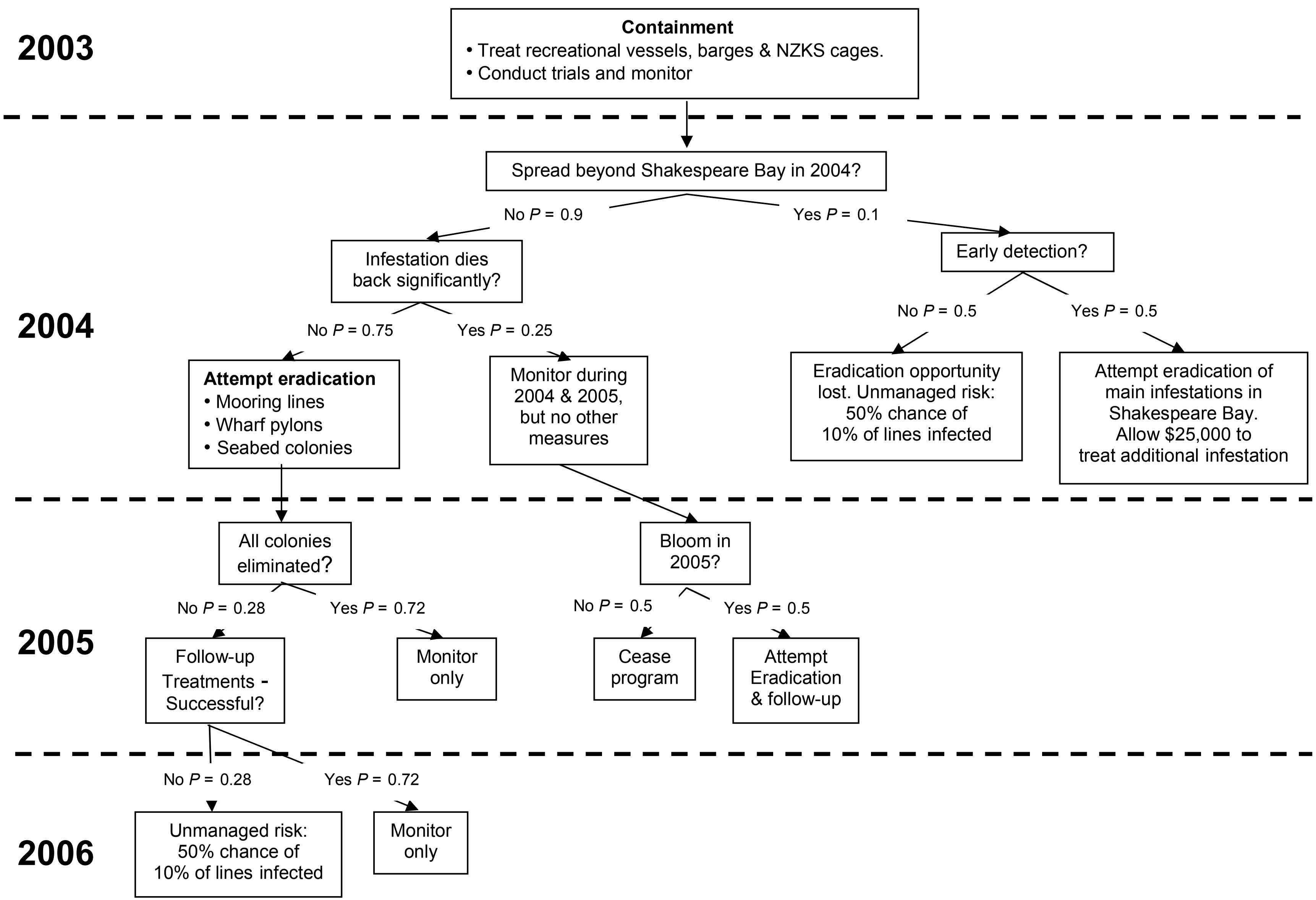
Appendix 3

Benefit-cost analysis for various management options

MANAGEMENT OPTIONS	DETAILS	P/pd2	Impact	V$ @risk $'000	Yr 1 $'000	Yr 5 $'000	PV(1-5) $'000
Option 1: Do Nothing							
Expected impacts - unmanaged risk							
	Cost of full impact	0.5	0.1	127600		6380	
	Cost of impact - treated lines	0.5	0.1	1148		574	807
Option 2: Monitor spread and conduct trials							
Expected impacts - unmanaged risk						574	
Expected impacts - reduced risk						?	?
	Only sensible if going to attempt eradication in 2004, then:						
	Rm = Prob.spread*higherPfail*Ru + [1-Pspread]*Pfail*Ru						
Costs	Monitoring				54		
	Treatment trials				20		
	Eradication costs in 2004?				34		
Benefits?? Reduction in risk??							
Option 3: Contain and conduct trials; attempt eradication in 2004							
Expected impacts - unmanaged risk						574	807
Expected impacts - reduced risk							
	Pfail1 * Pfail2 * unmanaged risk	Appendix 3					95
Benefits = risk reduction							712
Costs	Monitoring				173		
	Treatment trials						
	Containment	Appendix 3					
	Eradication 2004						
Net benefit = Risk reduction - costs							
Benefit/Cost ratio							
Option 4: Attempt eradication							
Expected impacts - unmanaged risk							
Expected impacts - reduced risk							
	Pfail1 * Pfail2 * unmanaged risk	0.52	0.28		4	85	119
Benefits = risk reduction						489	688
Eradication Costs					190		
	Treatment trials				34		
	Containment				32		
	Eradication measures				95		
	Pfail(1st try) * cost of 2nd try	0.52	55		29		
Net benefit = Risk reduction - costs							499
Benefit/Cost ratio		Given Probability of success				2.6	3.6

Appendix 4

Decision-tree for management Option 3


2003
Containment
• Treat recreational vessels, barges & NZKS cages.
• Conduct trials and monitor
2004
Spread beyond Shakespeare Bay in 2004?
No P = 0.9
Yes P = 0.1
Infestation dies back significantly?
Early detection?
No P = 0.75
Yes P = 0.25
No P = 0.5
Yes P = 0.5
Attempt eradication
• Mooring lines
• Wharf pylons
• Seabed colonies
Monitor during 2004 & 2005, but no other measures
Eradication opportunity lost. Unmanaged risk: 50% chance of 10% of lines infected
Attempt eradication of main infestations in Shakespeare Bay. Allow $25,000 to treat additional infestation
2005
All colonies eliminated?
Bloom in 2005?
No P = 0.28
Yes P = 0.72
No P = 0.5
Yes P = 0.5
Follow-up Treatments - Successful?
Monitor only
Cease program
Attempt Eradication & follow-up
2006
No P = 0.28
Yes P = 0.72
Unmanaged risk: 50% chance of 10% of lines infected
Monitor only

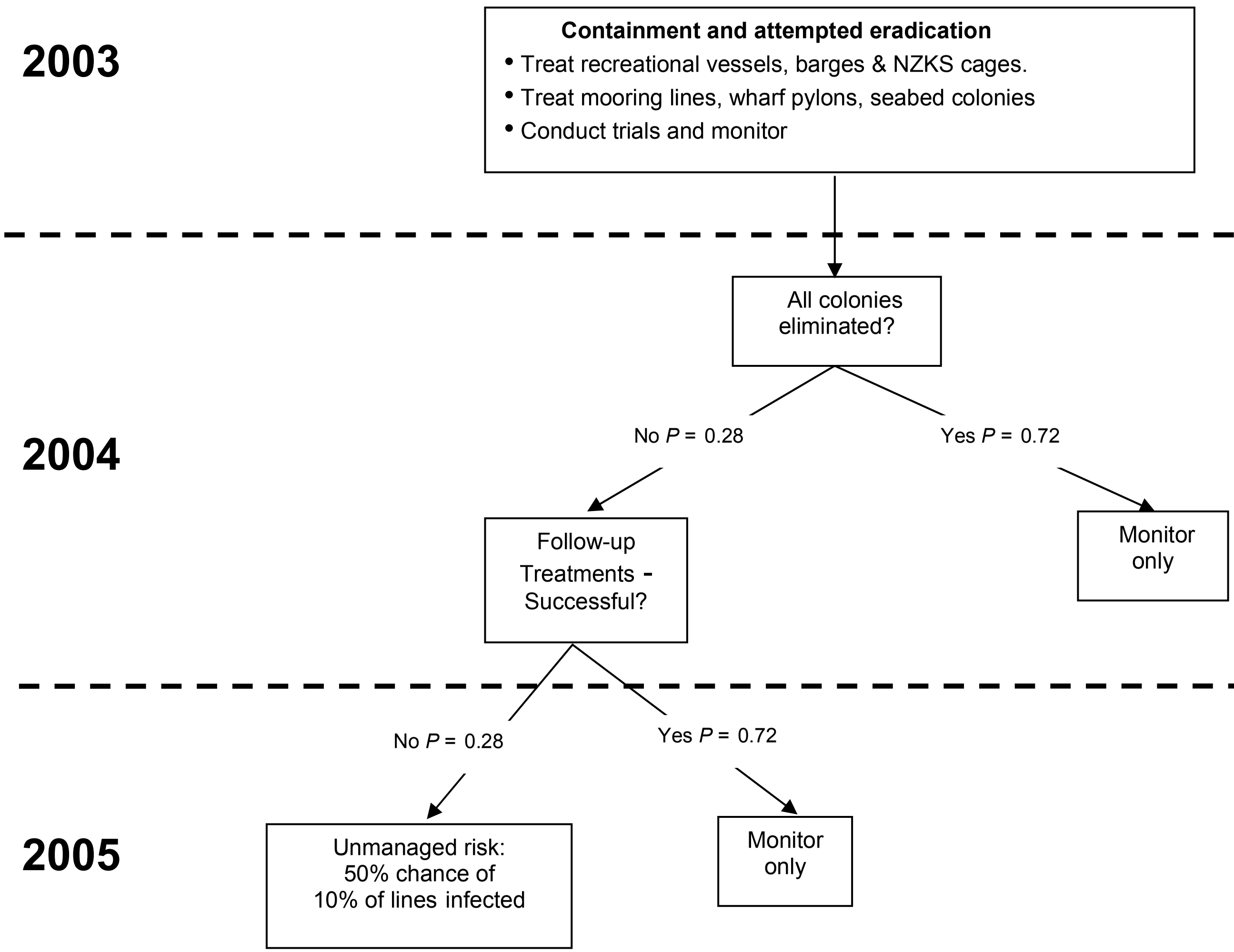
Appendix 5

Probabilities and other parameters for risk assessment

Management option	Option 3		Option 4	
Probability of eradication	**1st try 2004**	**2nd try 2005**	**1st try 2003**	**2nd try 2004**
moorings	0.99	0.99	0.99	0.99
vessels	0.99	0.99	0.95	0.99
piles	0.95	0.95	0.9	0.95
seabed-wharf	0.9	0.9	0.7	0.9
barge-residual risk	0.9	0.9	0.9	0.9
seabed-barge	0.95	0.95	0.9	0.95
combined P	0.72	0.72	0.48	0.72
P over 2 tries		0.92		0.85
Discount rate	10%			

Appendix 6

Decision-tree for management Option 4


2003
Containment and attempted eradication
• Treat recreational vessels, barges & NZKS cages.
• Treat mooring lines, wharf pylons, seabed colonies
• Conduct trials and monitor
2004
All colonies eliminated?
No P = 0.28
Yes P = 0.72
Follow-up Treatments - Successful?
Monitor only
2005
No P = 0.28
Yes P = 0.72
Unmanaged risk: 50% chance of 10% of lines infected
Monitor only