Cawthron Report No. 925

An updated benefit-cost analysis of management options for *Didemnum vexillum* in Queen Charlotte Sound

Prepared for

Marlborough District Council

July 2004

An updated benefit-cost analysis of management options for *Didemnum vexillum* in Queen Charlotte Sound

Prepared for

Marlborough District Council

by

Ashley D. M. Coutts

Cawthron Institute
98 Halifax Street East
Private Bag 2
NELSON
NEW ZEALAND

Phone: +64-3-548 2319
Fax: +64-3-546 9464
Email: ashley.coutts@cawthron.org.nz

&

Jim Sinner

Senior Fellow
Ecologic Foundation
27 Victoria Heights
NELSON
NEW ZEALAND

Phone: +64-3-548 8778
Fax: +64-3-548 8385
Email: jim@ecologic.org.nz

Cover Photo: *Didemnum vexillum* collected from the *Steel Mariner* prior to her removal from the Marlborough Sounds and sinking in Cook Strait on 31 August, 2003 (Photo credit: Ashley Coutts; 6 August, 2003).

EXECUTIVE SUMMARY

In July 2003, Cawthron Institute was contracted by Port Marlborough New Zealand Limited (PMNZL) to undertake a benefit-cost analysis and provide recommendations for managing the *Didemnum vexillum* infestation in Shakespeare Bay, Picton. Four options were presented, and after discussion with stakeholders, PMNZL elected to attempt eradication immediately.

Most eradication measures were completed in August and September of 2003. Subsequent monitoring suggested that most of these were effective. However, the treatment of the colonies on the seabed underneath Waimahara wharf in Shakespeare Bay was not completed until late December, and it appears that these colonies released larvae before being treated. As a result, a survey in June 2004 showed that structures and vessels in Shakespeare Bay have been re-infected. In addition, an infected barge was probably responsible for infecting two other barges and neighbouring structures at Ahitarakihi Bay, outer Queen Charlotte Sounds. Furthermore, a lack of effective treatment measures at the New Zealand Kind Salmon Limited (NZKSL) farm, East Bay during 2003 has resulted in these colonies spreading within the farm.

At a meeting in July 2004, stakeholders requested that the options presented in 2003, and the benefit-cost analysis, be updated. This report describes the results of that further analysis. Four options are again presented:

- Option 1 - Do Nothing
- Option 2 - Monitor spread and gather more information on potential impacts and control options
- Option 3 - Contain spread on an on-going basis
- Option 4 - Attempt eradication in 2004 and follow-up in 2005.

Option 1 is the baseline case, against which the other options are compared. It assumes that, if nothing is done, there is a 50% likelihood that *D. vexillum* will spread to mussel farms throughout the Marlborough Sounds within 5 years, and that if this occurs, 10% of mussel lines would be impacted to the extent of requiring on-going treatment costs of $1/metre/year. Annual costs would reach $574,000 within five years, and total expected costs over five years (i.e., reduced by discounting and the probability that impacts will not in fact occur) are estimated at $1.16 million.

Option 2 presents an unacceptably high risk that the organism will spread further and control options will become more expensive and less effective. Benefits and costs have therefore not been estimated for this option. Options 3 and 4 both appear to have net benefits, even though both have less than a 50% chance of success.

Option 3 would seek to contain the existing infestation to permanent structures in Shakespeare Bay and East Bay. It entails treating and permanently relocating all recreational vessels from Shakespeare Bay, treating and monitoring barges, and implementing an on-going containment program for the NZKSL farm in East Bay. Monitoring would be done to detect any new spread, and there would be an attempt to eradicate any new infestations detected in their early stages. The program would cease if infestations spread beyond the two bays and could not be eradicated or the species diminished by natural means. For Options 3 and 4, the Benefit:Cost ratios represent "expected" benefits and costs. For instance, for Option 3, the expected benefits are estimated to be $669,000 over five years, compared to costs of $256,000, for a Benefit:Cost ratio of 2.6. First year costs would be $63,000. Option 3 has an estimated 54% chance of uncontrolled spread (i.e., failure) within 5 years, but benefits would be gained during this time by delaying the potential/predicted impacts on the Greenshell™ mussel industry.

Option 4 would aim to eradicate *D. vexillum* from both Shakespeare Bay and East Bay, as well as the minor infestation in Ahitarakihi Bay, with a series of measures to be undertaken in August and September 2004. Follow-up treatments would be conducted in 2005, but if these were unsuccessful it is assumed the program would be cancelled. For Option 4, the expected benefits in reduction of potential/predicted impacts are estimated at $430,000 over five years, compared to expected costs of $143,000. First year costs would be $114,000. The Benefit:Cost ratio for Option 4 is 3.0. For this option, there is also 54% chance of failure, with consequent impacts estimated at $1.16 million, and a 46% chance of success, with no impacts.

Benefits of Option 3 are higher than Option 4 because the probability of containment in any given year is higher than the probability of successful eradication, but Option 3 also has higher costs because the containment programme would continue indefinitely, until it eventually failed.

Critical success factors for Option 3 would involve:

- Removal, treatment and permanent relocation of recreational vessels from Shakespeare Bay, and an on-going prohibition on recreational vessels entering the Bay between September and May every year.
- Rigorous implementation of a containment program for the NZKSL farm at East Bay.

Critical success factors for Option 4 would involve:

- All eradication measures, at Shakespeare Bay, East Bay and Ahitarakihi Bay, must be completed prior to 1 October 2004, and that follow-up treatments next year will be completed by 1 October 2005.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

CoP	Code of Practice
MDC	Marlborough District Council
NZKSL	New Zealand King Salmon Limited
NZMIC	New Zealand Mussel Industry Council
PMNZL	Port Marlborough New Zealand Limited

Report reviewed by:

Dr Michael Taylor (Biosecurity Research Manager, Cawthron Institute)

Approved for release by:

Dr Michael Taylor (Biosecurity Research Manager, Cawthron Institute)

1.0 INTRODUCTION

In July 2003, Cawthron Institute was contracted by Port Marlborough New Zealand Limited (PMNZL) to undertake a benefit-cost analysis and provide recommendations for managing the *Didemnum vexillum* infestation in Shakespeare Bay, Picton (Sinner and Coutts 2003). Four options were presented –

- Option 1 - Do Nothing
- Option 2 - Monitor spread and conduct eradication treatment trials
- Option 3 - Contain spread, conduct eradication treatment trials and attempt eradication in 2004
- Option 4 - Attempt eradication in 2003 and follow-up in 2004.

Option 3 was recommended as being the preferred option in benefit-cost terms, due to an increased probability of success (i.e., estimated to be 90%) that comes from testing treatment methods before attempting an eradication in 2004. This was considered to increase the chances of achieving a successful eradication, and it allowed for the possibility that the infestation may die back naturally and the eradication attempt can be put on hold and possibly avoided altogether. However, the consensus amongst stakeholders was to adopt Option 4, with an estimated 85% probability of success, because the risk of the species spreading outside of Shakespeare Bay during 2003 was considered to be too high.

An attempted eradication commenced in early August 2003 involving –

- The removal of the bulk of *D. vexillum* from the *Steel Mariner,*
- The removal of the *Steel Mariner* from the Queen Charlotte Sound and scuttling it in an approved dumping area in Cook Strait.
- The dumping of indigenous dredging material to smother *D. vexillum* on the seabed area underneath the *Steel Mariner*.
- The use of plastic wrapping to smother *D. vexillum* on wharf piles at Waimahara wharf.
- The adoption of a smothering technique to treat *D. vexillum* on the seabed underneath Waimahara wharf.
- The removal and treatment of all infected vessels (i.e., recreational vessels and barges) throughout Queen Charlotte Sound.
- The removal and treatment of all infected moorings in Shakespeare Bay.
- Continued 6-monthly monitoring for any new infestations in and around Shakespeare Bay for two years.

A targeted delimitation survey (i.e., priority was given to inspecting artificial structures known to be or are likely to be infected with *D. vexillum* in Queen Charlotte Sound) was undertaken by Cawthron on 10 July, 2004 to assess the success of the attempted eradication. The survey revealed that, despite some successful treatments, the attempted eradication had failed overall. Various delimitation surveys over the past 10 months revealed that –

- Approximately 90% of *D. vexillum* was successfully removed from the *Steel Mariner* prior to its removal and sinking in Cook Strait on 31 August 2003.
- The indigenous dredging material was 100% effective at smothering and killing *D. vexillum* on the seabed underneath the *Steel Mariner*.

- *D. vexillum* had re-infected the outside of 155 of the 178 (87%) plastic wrappings used to treat the Waimahara wharf piles.
- The filter fabric used to treat *D. vexillum* colonies on the seabed underneath Waimahara wharf failed to completely eradicate the species.
- Four barges (i.e., *Karitea, Onewaka, Mac III*, and *Sea-Tow No. 8*) and three of the 17 recreational vessels in Shakespeare Bay are infected with *D. vexillum*.
- *D. vexillum* was detected on six of the 22 recreational vessel moorings closest to Waimahara wharf in Shakespeare Bay.
- *D. vexillum* was not detected on the Queen Charlotte College mussel lines within Shakespeare Bay.
- *D. vexillum* was not detected on or in the vicinity of the treated *Noreti* vessel at Endeavour Inlet.
- *D. vexillum* was not detected on or in the vicinity of the treated *Lady Joan* vessel at Linkwater.
- Newly established *D. vexillum* colonies were detected on artificial structures (i.e., mussel buoys and ropes) at Ahitarakihi Bay.
- *D. vexillum* had grown and spread within the New Zealand King Salmon Limited (NZKSL) cages at East Bay.
- *D. vexillum* was not detected on Greenshell™ mussel lines to the south of the NZKSL farm at East Bay.

In light of the above results, a stakeholder meeting was held at PMNZL, Picton on 21 July 2004 to discuss options for managing *D. vexillum* in Queen Charlotte Sound. Stakeholders agreed that the Marlborough District Council (MDC) should contract Cawthron to undertake an updated benefit-cost analysis to provide options for managing the *D. vexillum* infestations throughout Queen Charlotte Sound.

2.0 BENEFIT-COST ANALYSIS

This analysis updates the benefit-cost analysis of four options for responding to the infestations of *D. vexillum* throughout Queen Charlotte Sound undertaken by Sinner and Coutts (2003). "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 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 per metre, or a total of $1.14 million per year, so the latter figure is used as the potential cost of impacts on mussel farming[3] (Appendix 1 and 2).
- Given the 50% chance that the organism will spread, and the fact that any impacts would occur gradually, it is estimated that impacts on mussel farming would reach $574,000 per year within five years (2009/2010). Discounting future costs by 10% per year, the present value of expected impacts, cumulative over five years, would be in the order of $1.16 million (Appendix 3).

2.2 Option 2: Monitor and gather more information

This option entails monitoring the spread of *D. vexillum* throughout the Queen Charlotte Sounds while further information is gathered on potential impacts and control options. 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. The risk of spread via untreated artificial structures would probably outweigh the advantages of waiting while further information is gathered.

2.3 Option 3: Contain spread and monitor

This option involves the containment of *D. vexillum* within Shakespeare Bay and East Bay by treating all infected vessels in 2004 and continuing the program indefinitely, as long as it remains effective. The fact that the species has bloomed in Shakespeare Bay for the past three consecutive seasons (i.e., 2001/02, 2002/03, and 2003/04) suggests that the species is likely to continue to thrive. Furthermore, the species has also clearly demonstrated its ability to spread outside Shakespeare Bay via anthropogenic mechanisms. Therefore, unless containment measures are effective and on-going, there is a strong possibility of the organism spreading beyond both Shakespeare Bay and East Bay. Containment measures can reduce this possibility, but not eliminate it. If spread occurs, detection within the first season is essential if eradication of new infestations is to have a reasonable chance of success (Refer to Appendix 4 for decision tree diagram).

Under this option, colonies on permanent structures in Shakespeare Bay and East Bay would be left unmanaged, and the risk of spread would be reduced by treating all vessels and equipment that might enable the species to spread outside these two bays. Key containment measures requiring urgent attention prior to 1 October 2004 are as follows:

- **Three infected recreational vessels** in Shakespeare Bay that are currently infected with *D. vexillum* should have the colonies removed, collected *in situ*, and disposed of at an appropriate landfill[4]. Estimated cost = $1,500 (Appendix 2 and 4).
- **"Missing-in-action" vessels** that may have visited Shakespeare Bay between 1 October, 2003 and 1 May, 2004, but were absent during June's delimitation survey must be identified, inspected and treated as required[5]. Estimated cost = $2,000 (Appendix 2 and 4).
- **The *Karitea* barge** presently in Shakespeare Bay should be re-treated *in situ* with the plastic wrapping and chlorine method. The barge should then be immediately removed from Shakespeare Bay[6]. Estimated cost = $2,000 (Appendix 2 and 4).
- **The *Onewaka* barge** presently moored in Shakespeare Bay should be treated *in situ* via plastic wrapping and chlorine, and then towed and slipped in Nelson for new anti-fouling. Estimated cost = $20,000[7] (Appendix 2 and 4).

- **The *Mac III* barge** also presently moored in Shakespeare Bay should be treated *in situ* via wrapping and chlorine and then towed to Picton for anti-fouling at McManaway's slipway. Estimated cost = $5,000[8] (Appendix 2 and 4).
- **The *Sea-Tow No. 8* barge** at the entrance to Shakespeare Bay should have all colonies removed *in situ* and then relocated[9]. Estimated cost = $1,500 (Appendix 2 and 4).
- **Permanent relocation of all recreational vessels from Shakespeare Bay.** With permanent colonies of *D. vexillum* in Shakespeare Bay, the risk of spread via recreational vessels is considered to be unacceptably high[10].
- **Implement an on-going containment program at the NZKSL farm at East Bay** that minimizes the natural and artificial spread of the species outside their farm[11]. Estimated cost = $10,000 per year (Appendix 2 and 4).
- **Removal of infected ropes and mussel buoys at Ahitarakihi Bay[12].** Estimated cost: $1,000 (Appendix 2 and 4).
- **Follow-up treatments of vessels etc[13].** Estimated cost = $10,000 (Appendix 2 and 4).
- **Continue 6-monthly monitoring** for any new infestations in and around Shakespeare Bay and East Bay each year, indefinitely (until the containment fails or the species dies off naturally and the program is cancelled)[14]. Estimated cost = $10,000.
- **Total expected costs** are approximately $256,000 over five years (above costs are reduced by discounting at 10% and by the probability that some measures would not be required every year) (Appendix 2 and 3).
- **The probability of successful containment** is estimated to be about 75% in any given year (i.e., there is a 25% probability of spread beyond Shakespeare Bay and East Bay each year). There is an estimated 54% likelihood that containment would fail within five years, but during that time some benefits would have been gained by delaying the impacts of *D. vexillum* on mussel farms.
- 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 $1.164 million to $495,000 **(i.e., benefits are estimated at about $669,000 versus expected costs of $256,000)**. This includes discounting of future impacts using a 10% annual interest rate (Appendix 3).

2.4 Option 4: Attempt eradication in 2004 and follow-up in 2005

This option involves an attempted eradication of *D. vexillum* in Shakespeare and East Bay prior to October 2004, and follow-up treatments in 2005.

- **Treatment measures for recreational vessels and barges** would be undertaken as per Option 3[4-9]. Estimated cost = $32,000 (Appendix 2). Probability of success = 91% (Appendix 5).
- **The removal and treatment of all infected mooring lines** in Shakespeare Bay[15]. Estimated cost $3,000 (Appendix 2). Probability of success = 99% (Appendix 5).
- **Treat Waimahara wharf piles** by re-wrapping plastic over the infected wrappings on the piles prior to August 2004[16]. Estimated cost: $10,000 (Appendix 2). Probability of success = 90% (Appendix 5).
- **Treatment of seabed underneath Waimahara wharf** may involve the dumping of indigenous dredge spoil on top of the filter fabric to smother the organism. Estimated cost: $20,000[17] (Appendix 2). Probability of success = 75% (Appendix 5).

- **Removal of infected ropes and mussel buoys at Ahitarakihi Bay[12].** Estimated cost: $1,000 (Appendix 2). Probability of success = 99% (Appendix 5).
- **Treatment of the NZKSL cages at East Bay[18].** Estimated cost: $17,500 first year (Appendix 2); repeat could be required the following year. Probability of success = 41% first year, 66% after two years (Appendix 5).
- **Continue 6-monthly monitoring** for any new infestations in and around Shakespeare Bay and East Bay for two years[14]. Estimated cost = $20,000 (Appendix 2).
- **Follow-up treatments in 2005[19]**. Estimated cost = $33,000 (Appendix 2).
- **Total expected costs** are approximately $143,000 over two years (Appendix 2).
- **The probability of successful eradication** (Shakespeare Bay and East Bay combined) is estimated to be about 25% in 2004 and 29% if follow-up treatments are undertaken in 2005, giving a 46% combined probability of success over the two years (Refer Section 3.0: Key Assumptions and Appendix 5).
- 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 $1.164 million to $734,000 **(i.e., benefits are estimated at about $430,000 verses expected costs of $143,000**). This includes discounting of future impacts using a 10% annual interest rate (Appendix 3).
- If a third year of eradication treatments were included, this would raise the cost even more, but would also raise the probability of success. 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 1 and 2). In addition, the following assumptions are 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 (2004) 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 (2008/2009).
- The risk of *D. vexillum* being re-introduced to the Marlborough Sounds from Whangamata and Tauranga, or from some unknown location (e.g., within or outside New Zealand), remains a possibility. However, vessel traffic from these ports to the Marlborough Sounds is limited, and in any case there is little that can be done to manage this risk, so this has not been accounted for in this analysis.
- Cawthron 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 remained on the *Steel Mariner*, some of which could have been naturally defouled during the tow through Queen Charlotte Sound to Cook Strait where it was scuttled on 31 August, 2003. Given defouled colonies have successfully colonized the seabed underneath the *Steel Mariner* and Waimahara wharf (Coutts 2002; Ashley Coutts *pers. obs.*), there is the possibility that some defouled colonies from the *Steel Mariner* may have survived. There is also a 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). This residual risk is probably small, but cannot be quantified, and has therefore not been included in the analysis.

- Option 3 calls for on-going containment, and Option 4 provides 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 containment (Option 3) and eradication (Option 4), 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.

Table 1 Summary of key probabilities

Activity	Probability	
D. vexillum spreads to pest densities in Marlborough Sounds	50%	
Percentage of mussel long lines impacted	10%	
Containment and monitoring		
D. vexillum spreads beyond Shakespeare and East Bay	25%	
Detected at an early stage	50%	
Successful eradication of spread detected early	75%	
Probability of uncontrolled spread within five years	**54%**	
Attempted eradication - colonies eliminated at/on:	**2004**	**2005**
Shakespeare Bay		
Recreational vessels in Shakespeare Bay	99%	99%
Waimahara wharf piles	90%	90%
Seabed underneath Waimahara wharf	75%	85%
Karitea barge	99%	99%
Onewaka barge	99%	99%
Mac III barge	99%	99%
Sea-Tow No. 8 barge	99%	99%
Combined probability of success at Shakespeare Bay	**61%**	**69%**
Combined probability over two years		**88%**
NZKSL farm at East Bay		
Pontoons	75%	75%
Predator nets	75%	75%
Salmon nets	90%	90%
Ropes and anchors	50%	50%
Combined probability of success at East Bay	**41%**	**41%**
Combined probability over two years		**66%**
Ahitarakihi Bay	99%	99%
Overall probability of successful eradication at all three bays	**25%**	**28%**
Combined probability over two years		**46%**

Table 2 Summary of cost estimates

Item	Cost
Annual monitoring costs	10,000
Recreational vessels	
Resident vessels (3 @ $500 each)	1,500
Finding "missing in action" yachts	2,000
Logging barges (4 @ various costs)	28,500
Treat mooring lines	3,000
Treat wharf piles	10,000
Treat seabed under wharf	20,000
Annual cost to treat 1 m of longline	1

3.1 Further assumptions (superscripts)

The following assumptions relate to numbered superscripts in the description of Options 1–4 in Section 2.0.

[1] Since *D. vexillum* was first detected in Shakespeare Bay 3.5 years ago, the species has clearly demonstrated its ability to spread both naturally (i.e., via larvae and fragmentation) and artificially (i.e., via the translocation of vessels and artificial structures). The ability of the species to spread naturally throughout the Marlborough Sounds is considered comparatively less than its ability to disperse artificially via anthropogenic vectors. This is because the competency period of the larvae is from 10 minutes to a few of hours (Olson 1983; Morgan 1995; Lambert 2001; Kott 2002 and Mather 2002), and the water currents throughout the Marlborough Sounds are also relatively weak (New Zealand Charts 1999). Sinner and Coutts (2003) successfully predicted that the species would spread from Shakespeare Bay utilizing a combination of both natural and artificial means as 'stepping stone' events. For instance, in the summer of 2001/02, larvae released from the *Steel Mariner* were responsible for contaminating wharf piles at Waimahara wharf. In the summer of 2002/03 larvae released from these colonies were responsible for infecting neighboring recreational vessels, barges and aquaculture equipment. In the same summer, an infected NZKSL salmon cage resident in Shakespeare Bay was then responsible for translocating the species to a salmon farm at East Bay within 200 metres of a Greenshell™ mussel farm. If the species continues to spread to nearby mussel farms, the species has the potential to be dispersed further throughout the Marlborough Sounds via the movement or exchange of aquaculture equipment. Therefore, in light of the above information, the assumption is made that the species has a 50% chance of spreading throughout the Marlborough Sounds via these 'stepping stone' events within five years.

[2] Observations have been made of the species smothering behaviour of mussels underneath the *Steel Mariner*, on ropes hanging from the *Steel Mariner* and on wharf piles. The species appears to have an amazing asexual growth rate and it is capable of smothering market sized Greenshell™ mussels within 14 days (in the middle of summer), and then mussels are unable to obtain the required food needed to grow, hence mussels have been witnessed several months later loosing condition and even dying as a consequence (Ashley Coutts *pers. obs*.). This is the only information available to date to suggest that the species may have an impact on the Greenshell™ mussel industry. While it is acknowledged that this limited information makes it difficult to ascertain whether this species is likely to become a pest to the Greenshell™ mussel industry, the potential clearly exists. However, the difficulty is estimating the likely percentage of Greenshell™ mussel lines that could be impacted, and more importantly, the level of impact on a mussel line? Considering that other ascidians such as *Ciona intestinalis* and *Styela clava* have had considerable impacts on mussel aquaculture industries around the world, it is 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*., July 2003). This impact would then necessitate some sort of treatment such as utilising the New Zealand Mussel Industry Council (NZMIC) *Ciona* treatment unit (see Appendix 2 for cost calculations). However, there would also probably be additional lines impacted to a lesser degree, and therefore would 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.

[3] If 10% of mussel lines in the Marlborough Sounds were impacted by up to 75% from the smothering effects of *D. vexillum*, then it is estimated that the cost of treatment to avoid production loss would be less than the loss of production in the absence of treatment. The second assumption that is made is, once this species successfully colonizes a mussel farm, it is likely to persist despite re-seeding and mussel harvesting operations because infected mussel buoys, backbones and even neighbouring farms or structures may provide subsequent inoculations. Furthermore, considering the species is capable of further dispersal via fragmentation, such de-fouling operations could acerbate the problem further. Unless all farmers coordinate to remove and treat all their infected structures, there is little hope of eradicating the species. Furthermore, it is unlikely that the species will have the same impacts amongst all mussel farms, hence those farms that are less impacted maybe unwilling incur the costs of treating their own farm for the benefit of others. One of the only developed treatment options currently available for killing sea squirts on mussel lines is the NZMIC *Ciona* treatment unit. This unit is very effective at killing *Ciona intestinalis* and even colonial sea squirts such as *Aplidium* sp. on mussel lines (Kevin Heasman *pers. comm*.). However, de-fouling and fragmentation would need to be seriously considered. Therefore, the cost of treating infected mussel lines are based on the utilization of this treatment technique and these estimates were supplied by Paul Lupi, Chief Executive of the NZMIC in July 2003 (see Appendix 1 and 2 for former calculations).

[4] Three of the 17 recreational vessels moored in Shakespeare Bay were found to be infected with newly settled *D. vexillum* colonies during the delimitation survey on 10 June, 2004. While most of the 17 vessels were slipped and anti-fouled during last years attempted eradication program, some newly established colonies were found within dry-docking support strips on the bottom of the three vessels where old anti-fouling paint exists. Given these colonies are newly established, they could be safely removed *in situ* using a putty-scraper and the colonies disposed of in an appropriate landfill. However, these vessels would need to be inspected on a regular basis during summer to ensure they are not re-infected.

[5] There is a possibility that there are some "missing-in-action" vessels that may have visited Shakespeare Bay between 1 October, 2003 and 1 May, 2004, but were absent during June's delimitation survey may also exist. These vessels must be identified, inspected and treated as required. For instance, five of the "missing-in-action" recreational vessels that had visited Shakespeare Bay between 1 October, 2002 and 1 May, 2003 (i.e., approximate breeding season of *D. vexillum*), were eventually tracked down and inspected during last years attempted eradication program. Interestingly, three of these vessels (60%) had migrated throughout Queen Charlotte Sound and were found to be infected with *D. vexillum*. Effective anti-fouling paint is the best line of defence to prevent *D. vexillum* colonizing vessels, as this species is an epibiotic organism (i.e., prefers to attach to other organisms). It should also be stressed that the anti-fouling paint on recreational vessels operating in temperate waters is only effective at preventing the accumulation of fouling for approximately 12-18 months at best (Oliver Floerl *pers. comm.*). Therefore, if the containment option for this benefit-cost analysis is chosen as the most suitable management option, then these recreational vessels will require slipping and anti-fouling again this summer or undergo constant inspections prior to their departure.

[6] The *Karitea* barge was found to be infected with *D. vexillum* on 22 December, 2003 at Te Ipapakereru Bay, outer Queen Charlotte Sounds. It is possible that this barge was infected with *D. vexillum* during its visit to Shakespeare Bay sometime in 2001 (Peter McManaway *pers. comm.*), although *D. vexillum* was very much in its infancy in Shakespeare Bay at this time. However, a more likely scenario is the *Karitea* was infected during the past 12 months while assisting with the ski-wire logging operations at Ahitarakihi Bay. This is because the *Onewaka* barge (which was infected with *D. vexillum* during its residency period in Shakespeare Bay over the summer of 2002/03) was also involved in the logging operations at Ahitarakihi Bay, and spent considerable time during these 12 months alongside the *Karitea*. The *Karitea* was towed into Shakespeare Bay on 24 December, 2003 and positioned alongside Waimahara wharf. On 29 December, 2003 two divers wrapped the bottom of the barge in a large sheet of black polyethylene plastic. All edges were secured to the barge and then two 20 litres buckets of granulated chlorine was mixed with freshwater and pored between the plastic and the barge. All fouling material, including *D. vexillum* was killed within 48 hours, hence the wrapping and defouled material was removed on 31 December, 2003. Unfortunately, the *Karitea* has remained in Shakespeare Bay owing to concerns about it seaworthiness, hence the vessel has become re-infected and will require the same *in situ* wrapping and chemical treatment before this vessel can depart Shakespeare Bay. Slipping and anti-fouling would be the preferred management measure thereafter, although there is some doubt as to whether the structural integrity of the barge is sufficient to support its own weight out of the water.

[7] The *Onewaka* barge was infected with *D. vexillum* during its residency period in Shakespeare Bay over the summer of 2002/03. This barge was beached on the western shore of Shakespeare Bay on high tide on 24 December, 2003 in an attempt to kill the *D. vexillum*. The barge remained beached at this location for approximately two weeks, which desiccated the colonies on the landward side. However, some *D. vexillum* survived on the submerged side of the *Onewaka*, hence this barge which currently resides at McManaway's mooring in Shakespeare Bay is still infected and requires *in situ* wrapping and chemical treatment. Given that this barge is a frequent visitor to Shakespeare Bay, this vessel should be slipped and anti-fouled. Owing to the size of the barge, it would need to be towed to the nearest slipway (i.e., Nelson) for slipping and anti-fouling. Towing costs from Picton to Nelson are approximately $4,000, slippage fees approximately $7,500, and cleaning and anti-fouling approximately $8,500 (Peter McManaway *pers. comm.*).

[8] The *Mac III* barge that has resided next to the *Onewaka* at McManaway's mooring for the past five months was probably infected by colonies on the *Onewaka*. This barge should also undergo *in situ* wrapping and chemical treatment. This barge is also a frequent visitor to Shakespeare Bay, and therefore should be slipped and anti-fouled. This barge could be accommodated at McManaway's slipway in Picton for cleaning and anti-fouling. The cost of this process is likely to be around $5,000 (Peter McManaway *pers. comm.*).

[9] The *Sea-Tow No. 8* barge arrived in Picton on 23 November, 2003 and has since remained anchored at the entrance to Shakespeare Bay. Inspection of this vessel soon after its arrival revealed that the hull was free of any significant fouling. However, given the barges inactivity for the past seven months, the anti-fouling paint system has started to fail, allowing mussels such as *Perna canaliculus* and *Mytilus galloprovincialis* to establish on the hull. Eleven well established *D. vexillum* colonies were found attached to the mussels on the bottom of the barge during June's delimitation survey. This suggests that liberated larvae from colonies on the Waimahara wharf some 700 metres away were probably responsible for infecting this barge. Considering the vessel is only fouled with mussels, and the colonies are only attached to the mussels, the vessel could be cleaned by divers *in situ* ensuring that all mussels and colonies are collected and disposed of in an appropriate landfill. This cost would approximately be $1,500. The vessel should then be relocated or be slipped and anti-fouled if the vessel intends to remain in Shakespeare Bay for any extended period. The likely cost of towing this vessel to Nelson for slipping and anti-fouling is likely to be

around $40,000 (Dick Mogridge *pers. comm.*). Therefore, it is recommended the barge be cleaned *in situ* and relocated.

[10] Recreational vessels have clearly illustrated their potential to artificially disperse *D. vexillum* from Shakespeare Bay (refer to superscript No. 5). Various management measures to prevent the artificial spread of *D. vexillum* from Shakespeare Bay via recreational vessels were considered. For example, one option might be to adopt a voluntary "Code of Practice" (CoP) that requires stakeholders to consistently and honestly maintain fouling free hulls. However, experience has shown that such voluntary measures are often neglected by stakeholders and eventually fail. A more successful management option might be for PMNZL and/or MDC to enforce an on-going CoP, but such measures are expensive and still prone to failure. Therefore, if containment is to be successful, the most effective management measure would be for all recreational vessels to be removed and relocated from Shakespeare Bay. In addition to relocating resident vessels, there would need to be a prohibition on all recreational vessels entering the Bay between October and May. Banning these vessels from Shakespeare Bay will impose costs on vessel owners, and on the PMNZL and/or MDC for enforcement, although these costs have not been estimated.

[11] A containment program should be adopted at the NZKSL farm at East Bay, to minimize the artificial spread of the species outside their farm. The program might involve divers removing and collecting all visible colonies *in situ* several times a year, thus reducing the potential larval innoculum pressure. Furthermore, all submerged artificial structures from this farm should not be relocated to other areas without some type of treatment (e.g., the structure air-dried for 48 hours to ensure desiccation of any *D. vexillum* present).

[12] Larvae released from the infected *Onewaka* or *Karitea* barges during the summer of 2003/04 were most likely responsible for infecting nearby ropes and mussel buoys at Ahitarakihi Bay. Considering there are only newly settled colonies of *D. vexillum* on these structures, these structures could be easily removed from the water and remain on land for a minimum of two days to desiccate the species. It is recommended this situation is dealt with under the containment option considering it is cost-effective to do so and then limits the *D. vexillum* infestations to Shakespeare Bay and East Bay.

[13] There is a possibility that some treatments may be unsuccessful in 2004, and may require follow-up treatment in 2005. A cost of $10,000 is allowed (i.e., two large barges requiring treatment, each costing approximately $5,000).

[14] Both the containment and attempted eradication options will require targeted delimitation surveys (i.e., similar to previous surveys) throughout Queen Charlotte Sound every six months for two years to assess the success of the relevant programs. If *D. vexillum* is found to escape from Shakespeare Bay and/or East Bay, or the species dies off due to natural causes, then the relevant program will require immediate re-assessment.

[15] There are 24 privately owned moorings in Shakespeare Bay (Mike Baker *pers. comm.*). The recent delimitation survey on 10 June, 2004 revealed that six of these moorings are presently infected with *D. vexillum*. All infected mooring lines should be treated using the same methods adopted during the attempted eradication last year (i.e., mooring lines and blocks removed from the water, water blasted on land and returned two days later).

[16] All 178 wharf piles at Waimahara wharf were successfully wrapped with 50μm polypropylene plastic during the attempted eradication program in August 2003. While the plastic wrappings were successful at killing *D. vexillum* on both concrete and metal RSJ piles, unfortunately the colonies on the seabed proved too difficult to manage and were responsible for infecting 155 of the 178 wrappings. Therefore, it is recommended that all 178 wharf piles be re-wrapped using similar methods. The cost of the wrapping operation may be reduced considerably second time around

given the knowledge and experienced acquired from the previous attempt (see Appendix 2 for estimated costs).

[17] The treatment of *D. vexillum* colonies on the seabed underneath Waimahara wharf proved to be very challenging during the attempted eradication in 2003. A variety of treatment methods were trailed (e.g., dumping of dredge spoil, lime, concrete, vinegar, petrogen torch and filter fabric), although the only method considered worthy of attention was the use of the filter fabric. Unfortunately the filter fabric only reduced the biomass of *D. vexillum* on the rocks underneath the wharf. Gaps between the filter fabric (i.e., between the wharf piles) enabled the release of larvae from the seabed colonies which re-infect the wharf piles. It has been suggested that stockpiled dredge spoil could be used to dump on top of the filter fabric to potentially smother and kill any settled colonies on the surface of the filter fabric as well as sealing the colonies underneath the fabric and eventually suffocating them. Although this treatment could be achieved for under $12,000, an extra $8,000 has been included to allow for any unforeseen challenges.

[18] An attempted eradication program of *D. vexillum* at the NZKSL farm at East Bay would require divers removing and collecting all fouling material from the bottoms of all infected pontoons. This defouled material must be disposed of at an appropriate landfill site, as this species is cable of dispersing via fragmentation. Divers would then need to monitor these pontoons regularly for any regrowth. Predator nets, anchor ropes, warps etc would also need to be inspected and any *D. vexillum* removed, collected, land filled and monitored. Internal salmon holding nets are likely to possess only newly settled colonies given that they are routinely replaced on average every 2-3 weeks. However, any colonies encountered during changeovers should be removed and land filled. Given the complexity of a salmon farm (i.e., possess multiple submerged artificial structures that are capable of being infected), the probability of success of an attempted eradication is therefore estimated at only 75%.

[19] Follow-up eradication measures are likely to involve repeating treatments for mooring lines, vessels, wharf piles and seabed, at a total cost of $33,000. For wharf piles, 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 $10,000 has therefore been allowed (one-third the cost of the initial attempted eradication in 2003) for the second treatment of wharf piles. Actual cost could be more or less than this depending on the extent of the re-infestation. Finally, a further year of monitoring would be required, at $10,000.

4.0 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, the likelihood of early detection of new infestations, 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 time and budget constraints of this analysis, these estimates are the 'best approximations possible' in the limited timeframe made available. Some of these estimates and assumptions would most likely change if more time was available and would probably alter the results of this analysis.

A source of considerable uncertainty in this analysis is the assumptions and probabilities regarding the species' origin and pest potential, particularly its potential impacts on the Greenshell™ mussel industry. Ascidian taxonomists from all over the world are still debating the identity and origin of *D. vexillum*. Over the past three years, there have been many attempts (e.g. genetic sequencing) to determine the likely origin of *D. vexillum*, but all have failed. To date, Kott (2002) is the only person to publish any findings on this species. Kott comments "although the species is undescribed, there is no evidence to suggest that the species is other than indigenous, although this would not preclude its status as a pest species". However, irrespective of the species origin, the most important question relevant to this analysis is whether *D. vexillum* poses a significant threat to the Greenshell™ mussel industry?

The species has displayed a smothering behaviour of *Perna canaliculus* mussels underneath the *Steel Mariner*, on ropes hanging from the *Steel Mariner* and on wharf piles at Waimahara wharf. The species appears to have an unusually high asexual growth and it is capable of smothering market sized Greenshell™ mussels within 14 days (in the middle of summer). Mussels are then unable to obtain the required food needed to grow, and mussels have been witnessed several months after an infestation losing condition and even dying as a consequence of smothering by *D. vexillum*. This is the only information available to date regarding the species' potential impact on the Greenshell™ mussel industry.

Assuming that *D. vexillum* is a real threat to the Greenshell™ mussel industry, difficulty arises when estimating the likely percentage of Greenshell™ mussel lines that could be impacted, and more importantly, the level of impact on a mussel line. Considering that other ascidians such as *Ciona intestinalis* and *Styela clava* have had considerable impacts on mussel aquaculture industries around the world, it is 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. This impact would then necessitate some sort of treatment such as utilising the NZMIC *Ciona* treatment unit. However, there would also probably be additional lines that were impacted to a lesser degree, and therefore not warrant treatment, but this analysis assumes an impact on 10% of lines.

The benefit-cost analysis revealed that Options 3 and 4 both appear to have net benefits. Option 3 has a Benefit:Cost ratio of 2.6, while for Option 4 the ratio is 3.0. For both options, there is only about a 50% probability of success, so these ratios represent "expected" costs and benefits. For example, for Option 4, there is a 54% chance of failure, with consequent impacts of $1.16 million, and a 46% chance of success, with no impacts, so the expected benefits in reduction of impacts are estimated at $430,000 over five years, compared to expected costs of $143,000. For Option 3, the expected benefits are estimated to be $669,000 over five years, compared to costs of $256,000. Benefits for Option 3 are higher than Option 4 because the probability of containment in any given year is higher than the probability of successful eradication, but Option 3 also has higher costs because the containment program would continue indefinitely, until it eventually failed. Option 3 has an estimated 54% chance of uncontrolled spread (i.e., failure) within 5 years, but benefits would be gained during this time by delaying the impacts on the mussel industry. If eradication fails, the program could shift to containment, although this possibility has not been analyzed.

This analysis considered only the impacts on the Greenshell™ mussel industry given that NZKSL 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. The severity of these other impacts may depend on whether the organism is a non-indigenous or introduced species to New Zealand, which has yet to be conclusively determined. In any event, if other values are at risk from the organism, this would strengthen the case for action.

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 cumulative "expected impacts" of $1.16 million over five years. This is only slightly more than the 5th year impact of $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 (i.e., starting at 5% impact and roughly doubling every 2 years), so impacts in the early years are quite low.

3) Costs and impacts are discounted by 10% per year for the time value of money, which means that for example, that costs for year 5 are cut roughly in half again (i.e., 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 $1.33 million from $1.16 million over five years).

4.1 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. Any failure to achieve a critical success factor is likely to cause the entire program to fail.

4.1.1 Removal of recreational vessels from Shakespeare Bay

Option 3 requires removing all recreational vessels from Shakespeare Bay and prohibiting them from re-entering. Past experience with both resident vessels and occasional visitors demonstrates that recreational vessels are difficult to keep clean and hence pose a significant risk of transferring *D. vexillum* to new locations. Option 3 assumes that this can be achieved and enforced on an on-going basis.

4.1.2 Completion of treatments prior to 1 October 2004 and 2005

Option 3 requires that infected vessels and barges be treated expeditiously and effectively, and that the containment program for managing the infestation at NZKSL cages at East Bay be implemented rigorously on an on-going basis. Option 4 requires that all eradication measures, at Shakespeare Bay, Ahitarakihi Bay, and East Bay be completed prior to 1 October 2004, and that follow-up treatments next year will be completed by 1 October 2005.

5.0 ACKNOWLEDGEMENTS

Firstly, we would like to thank Keith Heather, Marlborough District Council for supporting us to undertake this important piece of research. We would also like to thank the following people who provided important cost estimates for the analysis: Dick Mogridge (Sea-Tow Marine/Fleet Superintendent, Auckland), Mark Gillard (New Zealand King Salmon Limited, Nelson), Paul Lupi and Rebecca Clarkson (New Zealand Mussel Industry Council, Blenheim), Peter McManaway (McManaway Marine Limited, Picton), and Wayne Barnett (Port Marlborough New Zealand Limited, Picton). Finally, thank you to Michael Taylor (Biosecurity Research Manager, Cawthron Institute, Nelson) for reviewing this report before release.

6.0 REFERENCES

Coutts, A.D.M. 2002. A biosecurity investigation of a barge in the Marlborough Sounds. Prepared for Heli Harvest Limited. *Cawthron Report No. 744*. 25p plus appendices.

Kott, P. 2002. A complex didemnid ascidian from Whangamata, New Zealand. *Journal of the Marine and Biological Association of the United Kingdom* **82**: 625-628.

Lambert, G. 2001. A global overview of ascidian introductions and their possible impact on the endemic fauna. In: Sawada, H.; Yokosawa, H.; Lambert, C.C. (Eds) *The Biology of Ascidians*. Springer-Verlag, Hong Kong. 249-257.

Mather, P. 2002. Identification of a didemnid? Ascidian from Whangamata Harbour. *Ministry of Fisheries Report. ZBS2001-08.* 11p.

Morgan, S.G. 1995. The timing of larval release. In: McEdward, L (Ed). *Ecology of Marine Invertebrate Larvae*. CRC Press. 157-191.

New Zealand Charts. 1999. Marlborough Sounds. Chart No. 615.

Olson, R.R. 1983. Ascidian-Prochloron symbiosis: the role of larval photoadaptations in midday larvae release and settlement. *Biology Bulletin* **165**: 221-240.

Sinner, J., Coutts, A. D. M. 2003. Benefit-cost analysis of management options for *Didemnum vexillum* in Shakespeare Bay. Prepared for Port Marlborough New Zealand Limited. *Cawthron Report No. 924.* 14p plus appendices.

Appendix 1

Values at risk

Mussel Production in Marlborough Sounds	Units
Annual production - tonnes	60000
Marketed weight factor	0.47
Market price US$/lb @30 June, 2004 (Rebecca Clarkson NZMIC *pers. comm.*).	1.5
Pounds/kg	2.2
US$/NZ$	0.63
Total value of production NZ$	147.714million

Appendix 2

Risk reduction costs and on-going management costs

Activity	Units	Source of information
Costs to manage infestations on mussel farms x $1000	**1148**	
cost per metre of mussel line	1	Estimates supplied by Paul Lupi, NZMIC
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	״
Containment measures x $1000	**74**	
Clean three recreational vessels	1.5	Estimates supplied by Cawthron
Locate and treat any "missing-in-action" vessels	2	Estimates supplied by PMNZL
Treat the *Karitea* barge	2	Estimates supplied by Peter M[c]Manaway
Treat the *Onewaka* barge	20	״
Treat the *Mac III* barge	5	״
Treat the *Sea-Tow No. 8* barge	1.5	Estimates supplied by Cawthron Institute
Treatment of artificial structures at Ahitarakihi Bay	1	״
Follow-up treatments	20	״
Eradication (1st try) x $1000	**70.5**	In addition to containment measures
Treat mooring lines	3	Estimates supplied by PMNZL
Treat wharf piles	10	Estimates supplied by Cawthron
Treat seabed under wharf	20	״
Management of NZKS at East Bay	17.5	״
Monitoring for two years	20	״
Eradication (2nd try) x $1000	**33**	In addition to containment measures*
Treat mooring lines	3	Estimates supplied by Cawthron
Treat wharf piles	10	״
Treat seabed under wharf	10	״
Monitoring for additional year	10	״

* Except that *Onewaka* barge does not need to be anti-fouled again.

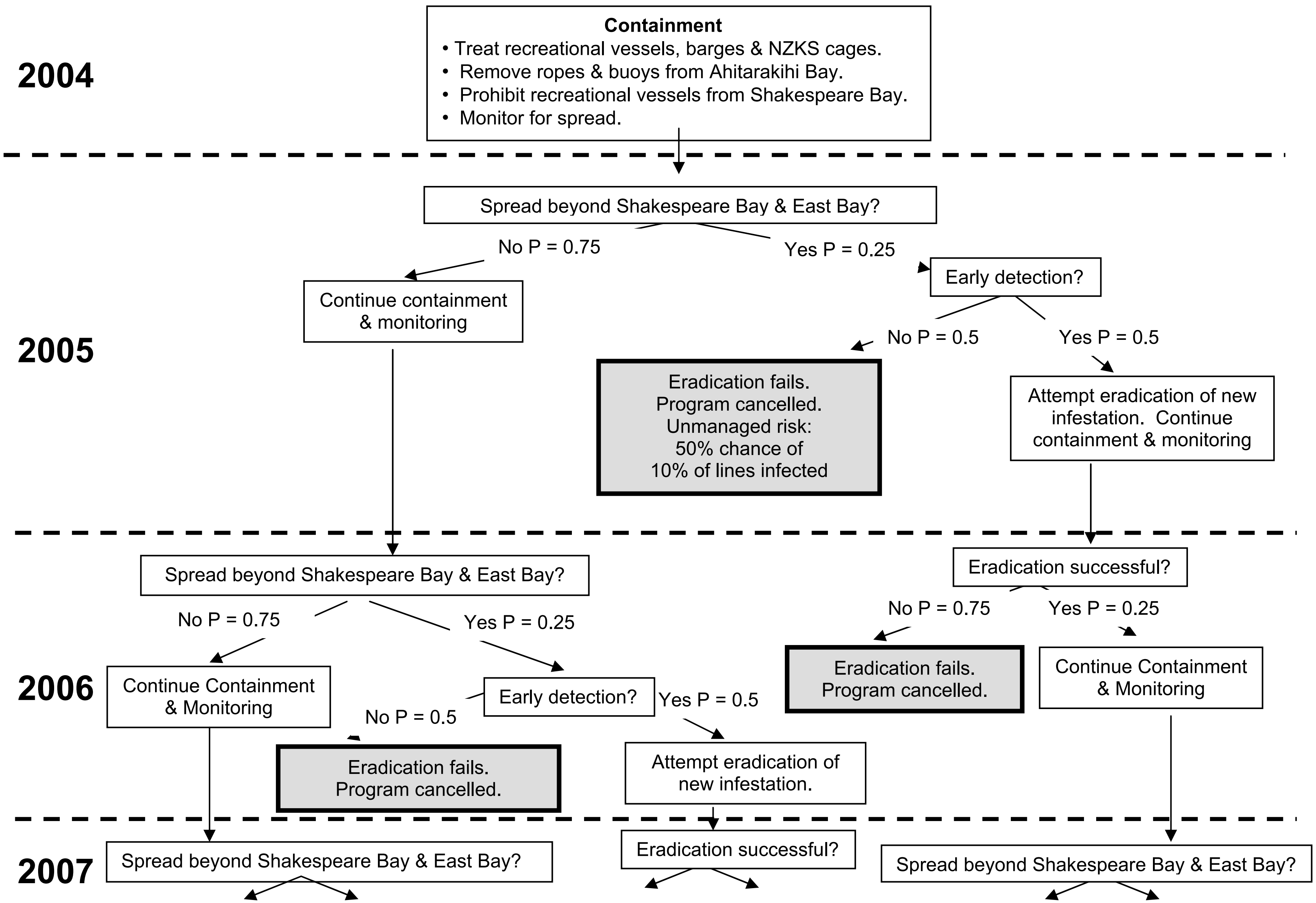
Appendix 3

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	147700		7386	
	Cost of impact - treated lines	0.5	0.1	1148		574	1164
Option 2: Monitor spread and conduct trials							
Expected impacts - unmanaged risk	Option 2 is not attractive due to risk of uncontrolled spread.					574	
Expected impacts - reduced risk	Benefits and costs have not been estimated.					?	?
Option 3: Contain and monitor							
Expected impacts - unmanaged risk						574	1164
Expected impacts - reduced risk							
		Appendix 4					495
Benefits = risk reduction							669
Costs	Containment and Monitoring	Appendix 4			63		256
Net benefit = Risk reduction - costs							413
Benefit/Cost ratio							**2.6**
Option 4: Attempt eradication							
Expected impacts - unmanaged risk							**1164**
Expected impacts - reduced risk							**734**
Benefits = risk reduction						489	430
Eradication Costs	Containment, Eradication and Monitoring				114		143
Net benefit = Risk reduction - costs							287
Benefit/Cost ratio							3.0

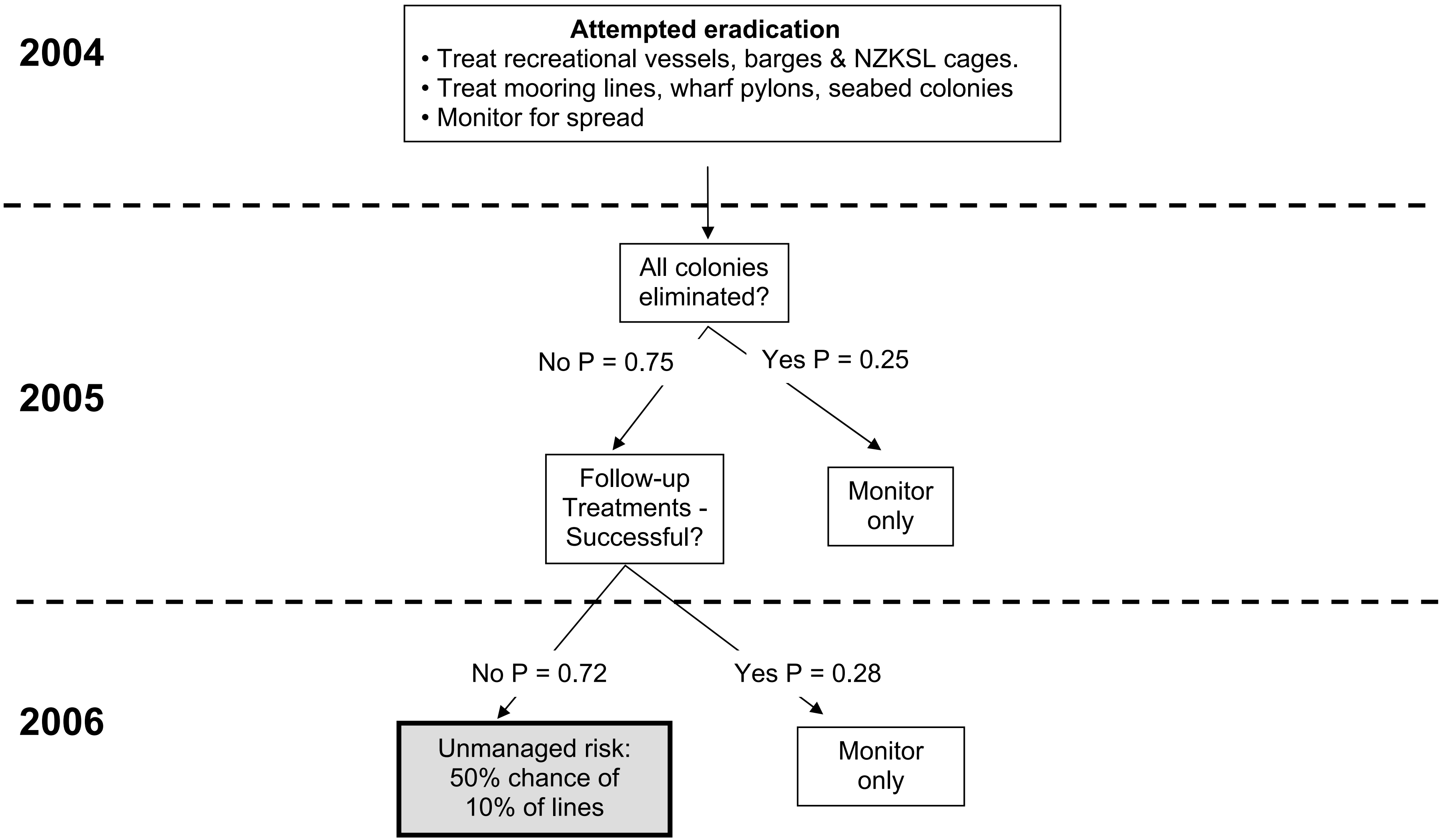
Appendix 4

Decision-tree for management Option 3


2004
Containment
• Treat recreational vessels, barges & NZKS cages.
• Remove ropes & buoys from Ahitarakihi Bay.
• Prohibit recreational vessels from Shakespeare Bay.
• Monitor for spread.
2005
Spread beyond Shakespeare Bay & East Bay?
No P = 0.75
Yes P = 0.25
Continue containment & monitoring
Early detection?
No P = 0.5
Yes P = 0.5
Eradication fails. Program cancelled. Unmanaged risk: 50% chance of 10% of lines infected
Attempt eradication of new infestation. Continue containment & monitoring
2006
Spread beyond Shakespeare Bay & East Bay?
No P = 0.75
Yes P = 0.25
Continue Containment & Monitoring
Early detection?
No P = 0.5
Yes P = 0.5
Eradication fails. Program cancelled.
Attempt eradication of new infestation.
Eradication successful?
No P = 0.75
Yes P = 0.25
Eradication fails. Program cancelled.
Continue Containment & Monitoring
2007
Spread beyond Shakespeare Bay & East Bay?
Eradication successful?
Spread beyond Shakespeare Bay & East Bay?

Appendix 5

Decision-tree for management Option 4


2004
Attempted eradication
• Treat recreational vessels, barges & NZKSL cages.
• Treat mooring lines, wharf pylons, seabed colonies
• Monitor for spread
2005
All colonies eliminated?
No P = 0.75
Yes P = 0.25
Follow-up Treatments - Successful?
Monitor only
2006
No P = 0.72
Yes P = 0.28
Unmanaged risk: 50% chance of 10% of lines
Monitor only