Biosecurity New Zealand
Tiakitanga Pūtaiao Aotearoa

Technical Advisory Report

Summary of TAG submissions received in November 2021, and the discussions had at the TAG meeting on 8 December 2021, and their final recommendations.

Caulerpa Great Barrier Island 2021 Response

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Response Controller: Kieran Patchell

Authors: Response Planning Function
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1 Executive summary

Caulerpa brachypus and *Caulerpa parvifolia* are unwanted organisms first detected in New Zealand in Blind Bay, Aotea Great Barrier Island (GBI) in July 2021. Following two rounds of targeted surveillance by the National Institute for Water and Atmospheric Research (NIWA), exotic *Caulerpa* was discovered in three areas. Extensive coverage was detected in Blind Bay, with smaller detections in Tryphena and Whangaparapara Harbours.

A Controlled Area Notice (CAN) to limit the human-mediated spread of exotic *Caulerpa* was issued over the affected areas and a rāhui was issued by Aotea mana whenua at the same time covering the same areas.

A proposal was made to assemble a Technical Advisory Group (TAG) to provide independent, expert scientific and technical advice on methods/tools (particularly where these methods may be new or emerging) to manage exotic *Caulerpa* at Aotea GBI. TAG members were presented with a set of eight questions.

In December 2021, NIWA was commissioned to carry out treatment work in Tryphena and Whangaparapara Harbours. However, when the site inspections were carried out prior to treatment, significant growth of exotic *Caulerpa* had occurred in both harbours compared to what was documented during the September 2021 delimiting survey.

The TAG discussions were conducted in the context of the exotic *Caulerpa* being unwanted organisms in New Zealand, with a known distribution that is highly localised. The understanding of the TAG was that the highest priorities were the ongoing containment or slowing the spread of exotic *Caulerpa* to minimise its impacts and prevent it from spreading to high-risk locations outside of GBI, such as the Hauraki Gulf.

1.1 Conclusions and recommendations

- The scale of the incursion is far beyond that at which successful eradication has ever been achieved in marine environments internationally.
- Eradication within each infected area is also not possible with the current set of tools available.
- It is extremely difficult to define the extent of the entire population on GBI. Therefore, it is highly likely some will be missed, if the treatment used is non-selective (kills everything) the bare substrate will be ideal habitat for exotic *Caulerpa* recolonisation
- At small scale coarse salt appears to be the most practical and cost-effective method for local elimination and suppression currently available.
- The best we can aim for with the current tools is suppression and containment.
- The most effective treatment programme will likely have to combine a range of treatment options.
- Exotic *Caulerpa* will require a long-term management plan to limit further spread.
- Research is required to develop/expand/adapt tools that can work at larger scales in the aquatic environment and that are targeted to specific organism types (e.g., seaweed).
- Ecological research, in addition to tool development research, is required to determine the environmental tolerances and impacts of exotic *Caulerpa* in a New Zealand context.

There was a prevailing theme of an inability to achieve eradication and the need for research and wider surveillance seen through all the submissions and the discussion during the meeting.

2 Introduction

2.1 Purpose of this document

Biosecurity New Zealand (BNZ) identified the need for a TAG to provide innovative and technical advice on tools to manage exotic *Caulerpa* at Aotea GBI. This document reports on the submissions made by each TAG member, the discussions had at the TAG meeting on 8 December 2021, and their final recommendations.

The questions presented to the TAG members and their recommendations are also included.

2.2 Background

On 5 July 2021, BNZ was notified of a suspected exotic *Caulerpa* species found in Blind Bay, Aotea GBI. Testing of samples taken by the National Institute of Water and Atmospheric Research (NIWA) confirmed the species as new-to-New Zealand, *Caulerpa brachypus*. A biosecurity response was initiated by BNZ with support from mana whenua, Auckland Council (AC), and Department of Conservation (DOC). On 2 November 2021 genome sequencing showed the presence of *Caulerpa parvifolia* in addition to *C. brachypus.*

The two species are almost identical in morphology; therefore, the response approach is unaffected. Both species were given Unwanted Organism status by the Chief Technical Officer (CTO) of MPI.

Two rounds of surveillance were undertaken by NIWA in August and September 2021. Results demonstrated extensive occurrence throughout Blind Bay, one patch in Tryphena Harbour, and 65 small patches through Whangaparapara Harbour. Other areas searched, where exotic *Caulerpa* was not detected, included Katherine Bay and Port Fitzroy (including mussel farms).

On 3 December 2021, NIWA returned to Aotea GBI to undertake treatment within Tryphena and Whangaparapara harbours. Upon inspection, significant growth was observed in both harbours compared to what was documented during the September 2021 delimiting survey. Exotic *Caulerpa* increased from 10 m^2 to 1750 m^2 and from 0.01 m^2 to 1840 m^2 at Whangaparapara and Tryphena harbours, respectively.

There is estimated to be approximately 88 hectares within Blind Bay with partial seabed cover. This is based on what we know about five ‘meadow’ areas. A conservative estimate of the total area of exotic *Caulerpa* in Blind Bay would be approximately 44 hectares.

A Controlled Area Notice (CAN) to limit the human-mediated spread of exotic *Caulerpa* was issued over Blind Bay and Tryphena Harbour on 20 September 2021 and was extended to cover Whangaparapara Harbour on 16 October 2021. Concurrently, Aotea mana whenua placed a rāhui over the same areas to coincide with the CAN. The CAN and rāhui will be in place until at least 30 June 2022.

The CAN restricts the removal of any marine organisms from all three areas and requires a permit issued by MPI to allow any anchoring activity within these areas.

MPI runs a Marine High-risk Site Surveillance (MHRSS) programme at 12 ports and marinas across Aotearoa. The two species of exotic *Caulerpa* have not previously been detected at any of these sites, including during the most recent survey conducted in Whangarei in December 2021. The next survey is scheduled for January to March 2022 in the Waitemata Harbour and Opua.

In October 2021, the Response Governance Group endorsed the decision for a phase-based approach to this incursion, and a short-term "phase 1" strategic plan was created and approved by Governance in November 2021.

3 Purpose of the Technical Advisory Group (TAG)

In October 2021, it was requested by the *Caulerpa* Governance that a *Caulerpa* Technical Advisory Group (TAG) be established.

3.1 The purpose of the *Caulerpa* TAG

- Provide independent, expert scientific and technical advice on tools/methods to manage (supress, contain, control, eliminate) exotic *Caulerpa* at Aotea GBI
- Provide advice for similar issues in the future, as requested by the TAG coordinator
- Seek technical advice or information (where necessary) from third parties in preparation for supplying advice and recommendations.

The TAG coordinator is the delegated contact point between the TAG and the *Caulerpa* Response Incident Management Team (IMT).

3.2 The intended scope of the *Caulerpa* TAG

- Act as an advisory body and does not have decision making powers
- Consider the *Caulerpa* response programme goals, objectives, and surveillance results
- Provide advice to the TAG co-ordinator in relation to similar issues in the future
- Provide innovative, scientific, and technical advice in writing, in response to the information requested by the TAG co-ordinator
- Make recommendations to BNZ with the understanding that BNZ will not be bound to act on or follow those recommendations.

3.3 TAG meeting processes and objectives

The TAG is comprised of nine subject matter experts in marine biosecurity, mātauranga Māori, algae, *Caulerpa* management, and marine natural products chemistry (appendix 1).

Activities of the TAG:

- TAG members were provided with a range of relevant reference material including response background, a table of potential treatment methods, and the NIWA delimiting results images and footage.

- Members were provided with a set of questions but were permitted to expand or change these questions based on their discussions.
- Some TAG members made written submissions to the TAG coordinator addressing these questions.
- Due to COVID restrictions, all meetings and discussions were held virtually through Microsoft Teams.

See section 5 for the TAG's responses to the set questions.

All submissions were shared amongst the TAG members for their consideration prior to the meeting. The first meeting was held on Wednesday, 8 December 2021 and was facilitated by the Response Manager, Kieran Patchell.

4 Discussion and recommendations

4.1 Situations update discussion

To open the meeting the TAG was provided with a verbal response update from then-Response Controller, David Yard. Discussions were therefore conducted with the updated knowledge of increased spread through all three infested areas and the treatment trials undertaken.

Exotic *Caulerpa* have been detected growing on living scallops and infesting areas with known scallop beds that hold importance to the Aotea mana whenua and the community. It is not currently known to what extent exotic *Caulerpa* may impact scallops or commercial scallop beds if it spreads to mainland New Zealand. As the growth has been detected on living scallops this could be determined as an additional method of spread.

As of January 2022, there have been no delimiting surveys outside of Aotea directed by the *Caulerpa* Response. However, early in the response, NIWA were in the middle of conducting a nationwide scallop stock assessment with no reported detection of exotic *Caulerpa.* The stock assessment is carried out by the same dive team responsible for marine biosecurity surveillance and therefore are experienced in identifying pest species. In addition to the NIWA stock assessment there are existing long-term marine pest species surveillance programmes which are expected to have detected exotic *Caulerpa* if it is present due to its fast growth and ability to cover a range of substrates.

While these programmes have not detected exotic *Caulerpa* at additional locations, that alone cannot be considered evidence of its absence. Additional surveillance in areas frequented by recreational vessels is necessary as these areas have a high likelihood of human-mediated spread. Additionally, these should be relatively sheltered areas with low wave action, which are an ideal environment for exotic *Caulerpa* to establish.

There is always the possibility of undetected small patches in searched areas due to the limitations of visual search methods (e.g., water visibility).

In Blind Bay it was observed that two of the 11 plots revisited in December 2021 had minor reduction in size compared to the August 2021 visit. The cause of this reduction is unknown, and the TAG mentioned it could be worth getting samples of exotic *Caulerpa* from these locations to assess if it was caused by a pathogen.

During discussions, the TAG was reminded of the current response objectives.

- (1) reduce the risk of transmission of exotic *Caulerpa,* through movement controls and treatment to reduce propagule pressure, and
- (2) ensure the mana of all parties is maintained throughout.

4.2 Mātauranga Māori

Blind Bay, Whangaparapara Harbour, and Tryphena Harbour are historical food baskets that have been harvested for thousands of years by Aotea mana whenua. Should the long-term ecological integrity of these areas change, there is likely to be an adverse effect on mana whenua. There is an expectation for some short-term negative impacts, however, the important assurances needed by mana whenua is that there is a positive return to the natural ecology in the long-term.

Complete eradication with minimal impact on mauri and taonga species most closely aligns with the principals Te Ao Māori and Kaitiakitanga.

Meaningful discussion is required to determine the tikanga for this rohe. Working collaboratively with mana whenua through meaningful engagement and planning will enable an important exchange of local knowledge and mātauranga Māori. Active participation, partnership, and protection of local mana whenua in exotic *Caulerpa* management should occur. Engaging with local whānau to identify expertise and capacity would support in enhancing relationships with mana whenua.

Upholding tikanga Māori helps to facilitate long-term working relationships, ownership, and responsibility for local kaitiaki. It is important to acknowledge tapu of place and process; tūrangawaewae, belonging and identity; manaakitanga, of taonga and people; mātauranga of past, present, and future; and proactive inter-generational kaitiakitanga.

5 Addressing the Questions

5.1 Are there any tools/treatments that have not been considered that can be implemented in the short-term (months) that are superior to the treatments in the provided table? (Consider efficacy, scale of treatment (square meters to hectares), non-target species impacts, logistical and operational feasibility).

The TAG were provided a summary of nine treatment techniques identified in the individual submissions. There was discussion on each technique which is described below and summarised in table 1. The important factor in their discussion was to consider the techniques ability, or not, to scale up.

Table 1: Summary of the treatment methods suggested by the TAG and discussed above

Treatment Technique	Could it work?	Has it worked previously?	Is it scalable to the hectare scale?	Recommended immediate next steps
Coarse salt	In some situations, yes	Yes	• Logistically very difficult to apply at the required rate and environmentally damaging at scale. • May not be effective on rocky/uneven substrate. • Health and Safety considerations will limit utility at hectare scale. • Resource consent required if using at hectare scale? • Efficacy at max depth unknown	• Monitor the success of the salt treatments currently being undertaken in the bay noting specific variables and parameters to determine if scalability is feasible. • Coarse salt would be a straightforward known approach to quickly apply to a new incursion in another area. • Tarps and mats could be rolled onto the sea floor mechanically rather than unfolded by hand to increase productivity.
Sodium hypochlorite	In some situations, yes	Yes – in a smaller area with a uniform substrate.	• Unlikely - Scalability to the hectare level is logistically extremely difficult to potentially impossible. • Would require a resource consent. • Health and Safety considerations will limit utility at hectare scale.	• No immediate action.
Dredge spoil	Possibly	Yes, on filter feeders, however not proven effective against *Caulerpa* species.	• Application is logistically difficult, sourcing uncontaminated (chemical- and pest-free) dredge spoil is likely to be an issue. • Unlikely to be effective on rocky/uneven substrate. • Will have serious environmental and social impacts due to increased sedimentation and non-target species mortality. • Would require a resource consent.	• Potential research for inclusion in a suite of tools for marine pest management. • Research to further understand the environmental and social impact of the treatment tool.
UV-C light	Possibly	No evidence with *Caulerpa*.	• Unlikely for an eradication objective. Reduction of biomass, possible. • Efficacy of treatment on visible marine macro-algae is unknown and is not likely to kill stolons that grow under the sediment.	• Research to further understand the environmental and social impact of the treatment tool. • Conduct trials to determine efficacy of the treatment on exotic *Caulerpa*

Treatment Technique	Could it work?	Has it worked previously?	Is it scalable to the hectare scale?	Recommended immediate next steps
			• Application at scale would be difficult. • Impacts on other macro-algae species likely • Impacts on large bivalve species is unknown • Will potentially require a resource consent.	• Response should follow up with the Lake Tahoe researchers to get more of their data.
Augmentative biocontrol	Unknown	No evidence for *Caulerpa*.	• Unlikely for an eradication objective.	• No immediate action • Potential for some ecological research that could assist in understanding how exotic *Caulerpa* will behave in a New Zealand context. This could include work assessing any presence of natural predators.
Invasive species displacement	Unlikely	Some evidence that exotic *Caulerpa* co-exists with native species in some situations.	• Will not achieve eradication.	• No immediate action • Potential for some ecological research that could assist in understanding how exotic *Caulerpa* will behave in a New Zealand context. This could include how exotic *Caulerpa* interacts with native species and the presence/absence of natural pathogens.
Heat treatment	In some situations, yes	Has been trialled on exotic *Caulerpa* overseas, difficult to achieve 100 % mortality.	• Unlikely for an eradication objective. • Application at scale would be difficult. • Likely to require a resource consent.	• Potential research into its efficacy in treating exotic *Caulerpa* on a natural substrate. • If successful it could be included in a suite of tools for marine pest management.
Matting on the bottom	Unlikely	Has been trialled overseas, difficult to achieve 100 % mortality.	• Unlikely for an eradication objective. • Application at scale would be difficult.	• Potential research into its efficacy in treating exotic *Caulerpa* on its own without an added chemical • If successful it could be included in a suite of tools for marine pest management.
Copper-impregnated mesh netting	Unlikely	Copper is used to treat micro-algae, not applicable for macro-algae.	No	• No immediate action

5.1.1 Coarse Salt

Description

This method has been trialled in Tryphena and Whangaparapara harbours. Salt was applied directly to the exotic *Caulerpa* by divers using a hose/chute connected to the vessel.

The salted areas were then covered with hessian mats followed by a polythene sheeting. The salt took 24 hours to dissolve completely. NIWA took rhizome samples before and after application and have reported seeing some deterioration in the health of exotic *Caulerpa*.

This method requires follow-up monitoring visits which are scheduled one month, two months, and three months post-treatment. As there is extensive growth within the bays, fragments of exotic *Caulerpa* may settle on the treated areas and regrow. This would not represent a failure of the treatment.

We need to accept there will be some non-target species covered in salt which will also likely die when using this method. For example, exotic *Caulerpa* has been found growing on live scallops, therefore any scallops found in the treatment area were removed and disposed of on shore.

The automation of salt application would make it quicker and potentially cheaper. This would require a barge to transport the amount of salt required to be delivered down a chute with stakes along the substrata to assess the depth of delivery.

Benefits and challenges

This method has previously been successful in NSW, Australia. However, it needs to be applied at the correct rate of 50 kg/m^2. With the estimated 88 hectares of partial cover in Blind Bay, which is still growing, we would require at least 22,000 tonnes of salt for one treatment event. This comes with logistical difficulty of how to apply such an extensive quantity.

The efficacy of this treatment is dependent on the substrate and depth (i.e., best applied on soft flat sediments in low current environments).

This treatment also is non-selective, and any marine organisms present in exotic *Caulerpa* beds would also likely perish.

Salt dissolves into the sediment and treats the exotic *Caulerpa* stolons below the surface, and efficacy is dependent on correct application rates and sufficient sediment for the salt to dissolve into. This treatment is not suited to rocky outcrops.

There are health and safety requirements to be considered surrounding repetitive dives during a 24-hour period and therefore several dive teams would be necessary.

Scalability

Salt treatment is good on a small scale, and for treatment of smaller patches, it would be a straightforward approach to quickly apply to a small incursion in a new area (e.g., mainland New Zealand marina).

It is not suitable for all types of substrate and would be a huge operation to apply at a large scale. Larger scale salt treatment could be applied using autonomous underwater vehicles

(AUV) using a grid system which could apply treatments 24 hours a day. This however requires further research and assessment.

There is agreement that this treatment would not be successful on its own and needs to be accompanied by other methods.

5.1.2 Sodium hypochlorite

Description

This method involves a tarpaulin-type cover with a piping system built in. Sodium hypochlorite is pumped underneath the tarp until the target concentration is achieved and this concentration is monitored until a residual concentration remains after a pre-determined time.

It has been shown to be effective in California over approximately 1 hectare of soft sediment in a low current environment (enclosed marina).

Benefits and Challenges

The incursion and subsequent eradication in California had several advantages that aided this outcome. The incursion was present over a flat, muddy, silty seafloor without any rocky substrate in a low energy enclosed environment. There are challenges maintaining a watertight seal and preventing tears when placing tarpaulins over rocky substrate, especially in areas that have currents present.

Using sodium hypochlorite in a marine environment requires a very large dosage, because usually 50% is consumed by the organic matter within minutes. Even if it is proven effective elsewhere, research to calculate chemical dosage is needed. Factors such as doubling applications to maintain a sufficient concentration, applications at different depths and seasonal temperatures variations need to be explored.

There is a limited supply of available sodium hypochlorite.

A resources consent is required prior to application of this method.

Scalability

Unable to be scaled up to the current size of the current infestation on Aotea GBI.

There are some similarities with coarse salt treatment for small populations or new incursions with some evidence of success. This chemical treatment would likely have more significant negative effects on mauri and the local ecology than coarse salt (a natural mineral).

5.1.3 Dredge Spoil

Description

This method involves smothering the exotic *Caulerpa* beds with dredge spoil. It was previously used in NZ on a filter-feeding colonial sea squirt at depths of 5 to 18m.

Efficacy of this treatment method is reliant on the spoil being applied at quantities at least 300 mm thick. This is required to sufficiently smother the exotic *Caulerpa* and remain in place long enough to prevent its reestablishment. However, there is no research being done on the survivability of the stolon, so the minimum application amount could vary from 200 mm to 500 mm.

Benefits and Challenges

The spoil needed could potentially be procured in large quantities through the Ports of Auckland who are currently applying for capital dredging. This could provide a ready and accessible supply source. The spoil would need to be assessed for harmful contaminants as well as other existing marine pests in the area, such as Mediterranean fan worm.

Ports of Auckland currently dispose of the dredge spoil at the Cuvier Dump site approximately 75 km east-southeast of Aotea GBI. If this source is not available for use, then consent would be required for dredging clean material from somewhere nearby. This would require the modification/disruption of two locations.

This method would result in a significant amount of environmental and ecological damage to the treatment areas. It would cause significant sedimentation and may result in long-term changes to the local environment.

This method is likely to be met with resistance from the community and local mana whenua in terms of collateral impacts and habitat change. The impacts are arguably acceptable against a scenario of regional or national spread and irreversible adverse effects of exotic *Caulerpa.*

However as exotic *Caulerpa* has been found out to at least the 30-metre depth contour it is likely that not all populations will be identified, allowing fragments from these surviving populations to recolonise the dredge spoil which would be ideal habitat for exotic *Caulerpa* in the absence of other species. This could result in higher densities of exotic *Caulerpa* than before the treatment occurred due to the lack of competition for habitat from other species.

Scalability

Dredge spoil has previously been successful at a local scale (approximately 320 m^2) for *Didemnum vexillum.* However, other research found that 35% of *C. taxifolia* survived 17 days of burial and began to recover when uncovered. Complete and permanent burial may be effective but likely only achievable in some situations (i.e., not high current environments).

Further research is required to determine the minimum thickness and duration of cover. It is likely that thousands of cubic meters are required which makes it logistically difficult to transport and apply at large scale.

5.1.1 UV-C Light Treatments for biomass reduction

Description

UV-C light treatment requires a relatively simple setup with a series of UV-C lamps attached to a treatment vessel, which is then deployed to the sea floor. The treatment chamber has five walls (i.e., four sides and a top) and is set approximately 15 cm above the bottom.

This method was used in Lake Tahoe, California, and resulted in algal mortality after approximately 15 days, following 5 to 15 minutes of treatment.

The UV-C light array used in Lake Tahoe was designed to minimise damage outside of the chamber walls which do not allow UV-C light outside the immediate treatment area, minimising the environmental impacts.

Benefits and challenges

Quick acting with results seen after 15 minutes of treatment, in Lake Tahoe there was 100% mortality after 15 days.

UV-C light may have limited impact on some species in the area (i.e., scallops) but other important marine vegetation would likely also be killed (native seaweeds).

Prior laboratory testing concluded that UV-C light has little penetrating power through sediment with almost all light blocked at a depth of 1.5 mm of test media. The field assumption is that the UV-C rays will be stopped at the surface of the seabed sediments with virtually no penetration occurring. This may not kill exotic *Caulerpa* stolons and requires further research.

Scalability

Application at scale would be challenging, if efficacy is proven it could be possible after development of the technology and equipment.

As efficacy of the treatment is unproven for exotic *Caulerpa* more research is required before recommending this option for field deployment.

A first step could be to request the Lake Tahoe team for access to raw data that was not necessarily published in reports, followed by a small-scale efficacy trial.

5.1.2 Augmentative Biocontrol

Description

This technique involves the introduction of another native species to predate exotic *Caulerpa.* This is seen as a way to control or reduce biomass in the early stages of an incursion.

Any pathogens that could be impacting the growth of exotic *Caulerpa* could also be investigated as part of any future research.

Benefits and challenges

Exotic *Caulerpa* species are known to be toxic to predating species. The ‘black urchin’ (*Centrostephanus* sp.) may be able to tolerate it but there is no evidence for this.

Kina cannot access certain areas, such as the intertidal zone (between high and low tide) and depths > 15 m and will only supress exotic *Caulerpa* in the early stages of establishment. Kina as an augmentative biocontrol will not result in elimination but could be a useful biomass reduction tool. However, there is no evidence that kina grazes exotic *Caulerpa* in New Zealand.

Scalability

This method is not scalable to the hectare level.

In 2011, after conducting an efficacy trial, an incursion in Fiordland saw the translocation of approximately 30-35,000 Kina to an area approximately 470 m^2 to clear native canopy species in the areas that were masking *Undaria*. At the seeding rate of 30 - 50/m2, kina were found to be very effective at removing most, or all the native canopy species in the areas that they were translocated into.

5.1.3 Invasive species displacement

Description

This method involves introducing/restoring seagrass beds to increase competition for available space and nutrients. In previous studies, exotic *Caulerpa* densities were lower in some situations where seagrass was present.

Overseas trials have incorporated native seagrass seeds into hessian mat and bag fibres to restore previous meadows. Therefore, this could be used in conjunction with the hessian mat treatment described in the following sections.

Benefits and challenges

Benefits include the added habitat for juvenile fish, sediment stabilisation, and seagrass carbon sequestration.

This method provides an opportunity for community and local iwi involvement.

Exotic *Caulerpa* would re-establish on top of the matting.

Scalability

The collection of seagrass seed is laboursome and acquiring enough seed to scale up across hectares would be logistically challenging and successful establishment of new seagrass habitat would be dependent on the amount of habitat available.

As seagrasses are usually limited to shallow waters, this method is not scalable to deeper waters over 7 metres.

Growth of new seagrass meadows will not lead to the eradication of exotic *Caulerpa*. But may help with reducing the available habitat for exotic *Caulerpa* and help maintain the ecological integrity of the areas where exotic *Caulerpa* is established.

5.1.4 Heat Treatments

Description

This method was previously successful in the eradication of *Undaria* from the hull of a sunken trawler in the Chatham Islands.

New Zealand Diving and Salvage Ltd treated the vessel using two methods:

1. Plywood boxes 60 mm in depth were constructed with foam seals on the open side to provide a seal against the hull. Elements inside the boxes heated the enclosed seawater to a target temperature of 70 degrees Celsius. A diesel generator powered the elements from a surface support vessel.

Two temperature-measuring units were placed inside the box and were read from the surface to monitor the water temperature. A vent at the top of each box allowed expanding water and steam to overflow into a filter bag to contain any dislodged material.

2. Divers used a Petrogen flame torch to treat the areas of the hull where the boxes were not practical due to bent or curved plating. The flame torch was also required for inaccessible areas of the vessel such as near the seafloor and for areas with heavy fouling.

Benefits and Challenges

The *Undaria* treatment area was smaller and on a different substrate (boat hull) to what we are dealing with on GBI. This treatment is manoeuvrable, but research is required to determine efficacy on different/natural substrates. It was used to get into the crevices of the sunken trawler to treat the *Undaria* across the whole vessel.

This technique requires electricity, and in the Chatham Islands example a diesel generator was used. It is quite labour-intensive if divers are required. An automated technique where the box system could follow a grid across the sea floor could reduce the amount of labour required although this has never been achieved in practice and would require further investigation.

The heat treatment would kill all organisms present in the treatment area.

Scalability

It is difficult to maintain a good seal between the treatment substratum and the shroud, which would experience heat loss to the point of not achieving an effective target temperature. Therefore, this method is not scalable to the level required for the current exotic *Caulerpa* incursion. This tool could be considered as part of a research programme for small scale treatment.

5.1.5 Lining seafloor with matting (i.e., harakeke or hessian)

Description

This technique lines the seafloor with a matting material to prevent photosynthesis of exotic *Caulerpa*. Harakeke, hessian, and tarpaulins could be deployed. Hessian mats can contain seagrass seeds to aid in the establishment of new beds.

The use of harakeke mats to stop freshwater invasive weeds is currently being trialled in the Rotorua Te Arawa Lakes at small scale, up to 50 m^2.

Benefits and challenges

Both harakeke and hessian are natural materials which will biodegrade.

Coverings used in overseas trails have not been successful at killing 100 % of exotic *Caulerpa.*

The use of harakeke is a direct community involvement opportunity regarding the production of the mats and follow up monitoring within snorkelling depths. It could become a community tool to use for quick response to shallow incursions.

Bottom lining using hessian matting has been used in lakes to suppress invasive plants while allowing native plants to grow through due to the residing native seed bank in the sediment. However, research suggests it is not very effective in marine environments unless combined with chlorine or salt treatment under the barrier, which would not allow for the growth of native plants through the mat covering.

Scalability

It is unable to be scaled to the required extent and would not kill 100 % of the covered Caulerpa.

5.1.6 Copper-impregnated mesh netting

Description

This technique involves covering the exotic *Caulerpa* with a mesh netting, similar to hessian, impregnated with copper sulphate. The copper sulphate dissolves on the sea floor while in contact with the algae.

Benefits and challenges

Copper sulphate is widely used algicide in water treatment for single celled microalgae. It is unlikely to kill macroalgae when used at environmentally acceptable concentrations. It is likely to kill non-target species.

Resource consent would be required prior to application in the marine environment.

Scalability

It is not practical to use this at the scale required due to uncertainty around efficacy and non-target species impacts.

5.2 What key information do we need to collect to measure success of the short-term treatment? Or how do we measure success?

5.2.1 Quality assurance

The level of assurance relies on identifying all populations of exotic *Caulerpa* and ensuring treatment methods kill all exotic *Caulpera* present, including the buried stolon.

5.2.2 Treatment site monitoring

Incursion sites

Regular surveys of the treatment areas for any signs of regrowth at regular intervals such as 1 month, 3 months, and 6 months after treatment. TAG members suggested using a combination of manual and autonomous methods.

Survey the incursion areas prior to treatments and at intervals post-treatment to see how native assemblages re-establish in the treated areas.

Environmental monitoring to record any short- or long-term effects to non-target species or changes to the environment. Pre-treatment surveys would also have to occur to establish an ecological baseline.

5.2.3 CAN compliance monitoring

Top side risks

Conduct a vessel survey collecting and monitoring data on percentage of contamination of topside risks such as fishing equipment, anchors, recreational craft, etc. This could be one aspect of assessing compliance with the CAN and drive continual improvement to minimise the likelihood of spread of exotic *Caulerpa*.

5.2.4 Surveillance

Active

Wider surveillance (e.g., Hauraki Gulf) outside of locations already regularly surveyed to increase the likelihood of detecting new populations at low densities that will be easier to manage.

Surveillance could incorporate a combination of methods such as manual dives, underwater remote operated vehicles and intertidal searches to facilitate wider survey coverage.

The likelihood of detection for each method needs to be considered as it will vary for each method.

General / Passive surveillance

Continue the public awareness campaign to ensure that unusual or suspect seaweed is report to the 0800 Pest and Disease hotline.

5.2.5 Monitoring of existing populations

Long-term monitoring of populations should occur to gain insights into how exotic *Caulerpa* behaves in a New Zealand context.

5.2.6 Lab environment test

Testing of the environmental tolerances of exotic *Caulerpa* would be beneficial to understand it's likely habitat suitability. Lab testing of treatment efficacy could also be undertaken.

5.3 In the medium- to long-term, what tools/treatments or approaches could work at the hectare scale (i.e., bay or harbour wide) that would warrant further investigation or research?

Many of the methods discussed in this report require further research to determine their efficacy, non-target species and social-cultural impacts, cost, and operational feasibility.

5.3.1 UV-C light for biomass reduction

This method would benefit from research for its use on exotic *Caulerpa* as well as any future aquatic macroalgae incursions.

However, UV-C light will not penetrate below the sediment surface and therefore the stolons will not be treated with this method. It will need to be used in collaboration with another method such as salt.

5.3.2 Dredge Spoil

Provided that sourcing enough spoil through the Auckland Council is achievable, and application is not an issue, this could be a cost-effective method.

The matter of efficacy will need to be addressed by conducting burial experiments. Any spoil used will need to be tested for level of contaminants.

Dredge spoil could be used in conjunction with salt application or another treatment.

However, the environmental and cultural-social impacts would need to be assessed to ensure this is a worthwhile approach.

5.3.3 Robotics

Monitoring/surveillance

Potential for technological solutions from KiwiNet. Richard Green, from the University of Canterbury, has been working in the field of robotics for biosecurity to scan vessels for biofouling as means to reduce manual diver inspections.

This work was focused on cameras adapted for turbid environments which may have potential for mapping and monitoring exotic *Caulerpa* beds.

Alternatively, Intelligent Vision Systems Lab at the University of Auckland in collaboration with Marine Sciences are adapting existing 3D mapping solutions in the estuary environment. Work is aiming to create technology and applications to enable mapping of large sections of the marine environment.

Work is already underway on automated identification of marine invasive species and marine environmental health assessment and monitoring. Efficacy would depend on whether exotic *Caulerpa* morphological features make it easily distinguishable from other macroalgae species.

Treatment application

There could be potential to develop or adapt robotics for treatment application. For example, a controlled targeted vacuum system for automated removal, coupled with a robotic system to deploy the salt treatment.

Automated delivery of salt, heat, or chemical treatments using a grid system could be used to apply treatments up to 24 hours a day. Boat-based self-charging ROV's could be programmed to cover defined areas and deliver treatments once sites are mapped and site plans created.

This approach could be further researched to assess technical and operational feasibility.

5.4 What are the key bottlenecks for applying treatment at the hectare scale?

5.4.1 Biological traits

- The ability for exotic *Caulerpa* to disperse by fragments, potentially over scales of kms during storm wave disturbance.
- High apparent invasiveness in multiple types of habitats.
- Its current present distribution across 10s of hectares around GBI.
- The presence of exotic *Caulerpa* stolons under the sediment not being visible and therefore missed when conducting surveillance or monitoring. Also, many treatments only work on visible portions of the individuals.

5.4.2 Environment

- Multiple habitats requiring treatment, individuals able to grow in deep water, and challenges in treatment in an open/uncontained system.
- Water depth of known incursion (approximately 30 m) limits the feasibility of treatments and quality assurance for treatment efficacy and determining the location of all populations.

5.4.3 Weather

- Most suggested treatments require a period of calm weather. Any storm or swell activity would disrupt operations.

5.4.4 Logistics

- Access and transportation of the materials needed for treatment.
- Permitting required for the use of some chemicals in the marine environment.
- Health and Safety implications of attempting to treat all exotic *Caulerpa* within its current known distribution (e.g., in deep water habitats requiring long durations underwater to apply treatments).

5.4.5 Resource availability

- Availability of the personnel with the necessary skills and knowledge to undertake treatments accurately.
- Availability or development of the technology required to undertake some of the recommended research including autonomous underwater vehicles (AUV)
- Costly and technically challenging to survey all the substrate within each of the three bays and entrances where exotic *Caulerpa* is currently distributed. This would need to be completed many times to monitor effectiveness of any operational work
- Cost of procuring and sourcing the required quantity of materials needed such as salt.

5.5 Are there any ‘blue sky’ tools/treatments on the horizon that are worth considering in the medium- to long-term (1-5 years)?

There is not currently a system wide tool, general consensus with research, adaptation of current tools available or tools in development, that will treat exotic *Caulerpa* at GBI or future marine incursions at this scale (10s of hectares).

Some ‘blue sky’ tools could require EPA approval which can take years to achieve even before any research can commence.

Section 5.3 covers some novel treatment methods worth considering for research.

5.6 To what scale can the tool/treatments be applied and what are the non-target species impacts?

5.6.1 Scale

The scalability of each proposed treatment is discussed in section 5.1 and summarised in table 1.

5.6.2 Non-target impacts

The worst-case scenario assumption is that the treatment will be “scorched earth” and kill non-target species in the short- to medium-term. Provided the treatment does not involve significant concentrations of toxicants that are persistent in the long-term. It could be argued that scorched earth is acceptable relative to the potential irreversible and regional scale of impacts from exotic *Caulerpa.* This assumes that exotic *Caulerpa* could be eradicated.

Several methods have evidence to suggest that native species assemblages will recover quickly, after approximately 6 months.

However, there are some methods with moderate to severe impacts to non-target species and these will need heavy consideration and input from mana whenua and the GBI community:

- Smothering with dredge spoil would cause significant sedimentation and may result in long-term changes to the local environment.
- Copper sulphate can cause collateral damage, including mass fish die-offs.

5.7 What is the reinvasion risk of exotic *Caulerpa* to treated areas if non-targeted methods are used or if undetected colonies exist, and over what time scale is this likely to occur?

5.7.1 Aspects to reinvasion that could be considered:

- Exotic *Caulerpa* regrowth ***within*** the treated areas due to ineffective treatment:
    - Emergence of exotic *Caulerpa* in treated areas, but where it survived due to buried stolons or visible individuals not being rendered non-viable.

  - This can be mitigated if the treatment is correctly applied, and robust quality assurance processes are followed.

- Exotic *Caulerpa* recolonisation from ***outside*** the treated areas via fragments from undetected or untreated populations due to:
  - The presence of already established populations in close proximity to the treated areas, and
  - Longer-distance vessel-mediated reintroduction of exotic *Caulerpa* from other areas where it has already established but remains undetected.

5.7.2 Time scale

Reinvasion of treated areas is highly likely to occur within a short timeframe (within a year). To minimise or prevent reinvasion the following would need to be met:

- Chosen treatment method effectiveness per unit area is 100%.
- There has been accurate, full delimitation of the incursion zone (i.e., we know where all populations are).
- The entire incursion zone can be treated to the maximum plausible establishment depth (i.e., treat the entirety of Blind Bay out to 30 m and potentially deeper).

5.8 What is the potential outcome of the tool/treatment i.e., local elimination, suppression, eradication, and over what time scale? Also, how do we measure success?

Measurements of success are also discussed in section 5.2.

Due to the ability of exotic *Caulerpa* to spread via fragmentation, suppression is the most likely outcome with potential for pockets of small-scale elimination.

If the assumption that GBI is the first and only location of exotic *Caulerpa* incursion is in fact true, then suppression/containment is possible if it hasn't already spread further, or this is not the first site of establishment in New Zealand waters.

Eradication is unlikely for several reasons—the scale of the incursion is far beyond that at which successful eradication has ever been achieved in marine environments internationally. In addition to the sheer scale, this species' situation has some specific considerations that would make eradication challenging even at a far smaller scale. These considerations have been discussed in section 5.4 – bottlenecks.

Any elimination or eradication success will greatly depend on the detection and treatment of all exotic *Caulerpa.*

Prior to any operational work the objectives, non-target impacts, operational feasibility, cost, and cultural and social impacts need to be fully assessed.

6 Conclusions and recommendations

The scale of the incursion is far beyond that at which successful eradication has ever been achieved in marine environments internationally.

The eradication of this species from the recorded locations is not possible due to the many reasons discussed in this report (fragmentation, depths, established population size, tools that are non-selective, etc.). While it may be possible to use a combination of treatments which result in short-term or small-scale control, the spatial extent of the established populations, and combined with the species ability to spread via fragmentation, will result in recolonisation of treated areas by exotic *Caulerpa*.

We do not have sufficient understanding or confidence that both *Caulerpa brachypus* and *C. parvifolia* are confined to the present locations. It is strongly suspected the species is more widespread, albeit in low abundances which may not be detectable at this point in time. While this doesn't necessarily mean that the species will thrive in these other locations due to differing habitats, environmental conditions, etc., the risk of re-infection in years to come will remain.

Coarse salt seems to be the most efficacious, practical, and cost-effective treatment method followed by chemicals pumped underneath a watertight cover such as a tarpaulin.

6.1.1 Research

Many of the different treatment techniques discussed in this report require further research to understand more about their effectiveness, non-target species impacts, operational feasibility, cost, and cultural and social impacts.

While coarse salt seems to be the most appropriate and cost-effective tool for managing this incursion in the short-term, there will need to be a long-term programme for the management of the species to meet any long-term management goals.

The tools recommended and discussed by the TAG members are a great place to start in terms of researching new tools. Invaluable knowledge would be gained to inform future responses in similar habitats.

It is worth noting here, although not discussed during the TAG meeting, there is an existing research programme underway that was initiated when this exotic *Caulerpa* incursion was first detected.

The four-year research programme, funded by Readiness and Response Services, will assist in the development of marine treatments for pathways management and incursion response.

6.1.2 Recommendations

- Continue the use of coarse salt applications for small-scale suppression and containment.
- Invest in pathways management for topside risks including public engagement and communication.
- Increase the number of swing moorings within the CAN areas to reduce the likelihood of vessels anchoring.

- Research is required to develop/expand/adapt tools that can work at larger scales in the aquatic environment and that are targeted to specific organism types (e.g., seaweed).
- Ecological research is required to determine the environmental tolerances and impacts of exotic *Caulerpa* in a New Zealand context.

7 Appendices

Appendix 1: TAG members

Name	Organisation	Area of expertise
s9(2)(a)	s9(2)(a)	Biofouling solutions, lateral thinking, marine biosecurity 20+ years.
s9(2)(a)		Marine biosecurity/science, PhD student, mātauranga māori, Asian paddle crab innovation, crayfish studies and innovation focussed.
s9(2)(a)	s9(2)(a)	Applied Marine and Freshwater Monitoring Solutions: • Subsurface biosecurity surveillance • Water quality monitoring • Ecological impact assessments • Iwi consultant
s9(2)(a)	s9(2)(a)	Tikanga Maori Advisor/Guidance.
s9(2)(a)		Experience of *Caulerpa* infestations in USA, Australia, and Europe. 40+ years' experience with boating, diving, fishing, and sailing in NZ. Experienced business professional that brings extensive experience in governance along with hands-on experience with many forms of water treatment gained as GM of Davey Water Products.
s9(2)(a)	s9(2)(a)	30 years multidisciplinary experience in aquatic and environmental sciences, with specialist expertise in marine biosecurity, biofouling and pest management. Contributed to the development and testing of marine pest response tools and been part of marine national or regional advisory groups.

s9(2)(a) [redacted]	s9(2)(a) [redacted]	Research and innovation with coastal science and technical expertise. Algal expertise for reproductive cycles and growth, amongst other fields. Marine natural products chemistry, and algal bioactives.
s9(2)(a) [redacted]	s9(2)(a) [redacted]	PhD on factors influencing the establishments and phenology of *Undaria* in the Hauraki Gulf. 20+ years' experience in marine and terrestrial biosecurity and conservation – particularly in the Coromandel region.
s9(2)(a) [redacted]	s9(2)(a) [redacted]	Innovative science and technical expertise, commercialisation proposals.

Appendix 2: References

UV-C Light Plant Control Pilot Project – Final Monitoring Report (2018) - https://tahoercd.org/wp-content/uploads/2019/02/UV_Plant_Control_Pilot_2018_Monitoring_FINAL.pdf

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Zubia, M., Draisma, S. G., Morrissey, K. L., Varela-Álvarez, E., & De Clerck, O. (2019). Concise review of the genus *Caulerpa* J.V. Lamouroux. *Journal of Applied Phycology*, *32*(1), 23–39 https://link.springer.com/article/10.1007%2Fs10811-019-01868-9

Appendix 3: Supporting information

s9(2)(g)(i) [redacted]

s9(2)(g)(i) [redacted]

Treatments for Marine Pathways Management and Incursion Response. Current Knowledge and Research Priorities s9(2)(g)(i) [redacted]