Biosecurity New Zealand

Tiakitanga Pūtaiao Aotearoa

Exotic *Caulerpa* Suction Dredge Technical Advisory Group Report

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Prepared for Caulerpa Response
by Suction Dredge Technical Advisory Group

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Te Kāwanatanga o Aotearoa
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Manatū Ahu Matua

Contents

1 Karakia

Kia hora te Marino,	May peace be widespread,
Kia whakapapa pounamu te moana,	May the seas be like greenstone,
Hei huarahi mā tātou te rangi nei,	A pathway for us all today,
Aroha atu, aroha mai	Let us show respect for each other,
Tātou i ā tātou katoa	For one another,
Hui ē! Tāiki ē!	Bind us all together.

Ngā mihi Rangatira ki a tātou katoa.

Kia tū hei toka tū moana, hei kaitiaki mō to tātou moana.

Kia kaha, kia māia, kia manawanui

Tēnā koutou, tēnā koutou, tēnā tātou katoa.

Karakia is a traditional Māori prayer or incantation performed to invoke spiritual guidance and protection. Karakia is a crucial component in achieving successful outcomes. It is an important practice that acknowledges Māori's kin relationship with the land and the sea.

2 Executive summary

Exotic caulerpa has been detected at three sites in Aotearoa. Currently, no treatment protocols have been demonstrated to be effective to eradicate the scale of infestation seen in Aotearoa. Biosecurity responders and communities are assessing the feasibility of different tools to identify a scalable and effective means for achieving eradication, local elimination, or control, while taking the environmental impacts into account.

Suction dredging could be a useful tool in a seaweed pest management strategy, but it should be trialled first to understand how effective it is, the area it can be used on, how consistent it is, cost, logistics, impacts on other species and habitat, impact on the Mauri of the ecosystem, and the extent of follow-up needed. The vessels, equipment, procedures, and personnel capability are available in Aotearoa to conduct a trial soon.

This Technical Advisory Group (TAG) recommends trialling suction dredging at the earliest opportunity to test its effectiveness and efficiency at removing caulerpa in Aotearoa on a large scale (≥ 1 hectare). The trial would answer specific questions that can inform a broader response strategy. Methods should be established ahead of time to ensure the fate of above-surface, surface, and subsurface biomass[1] of exotic caulerpa is understood.

[1] Above-surface biomass is the fronds of attached seaweed that can waft in the water above the seafloor; surface biomass is seaweed that is tightly attached to the seafloor; subsurface biomass is the parts of the seaweed that grows below the seafloor, e.g. in sand and silt.

The trial should also consider and incorporate the kaupapa and values of Mātauranga Māori.

Suction dredging has been used for pest removal in aquatic ecosystems around the world, but it is a relatively new marine biosecurity tool. Suction dredging offers more efficiency than hand removal for caulerpa biomass removal. In addition, suction dredging is potentially more selective at reducing bycatch than chemical and/or mats and tarps. Suction dredging is resource-intensive and has high setup costs, but once it is set up, it may be cost-effective over larger scales. Like all methods, it has impacts on native species. It may affect physical habitat more than other methods.

The costs and impacts (positive and negative) must be communicated effectively to mana whenua, hau kāinga, ahi-kā-roa and other affected communities. Engagement with all communities should be prioritised to maintain well-coordinated support for this broader incursion response. Where possible, communities should be enabled to assist with on-the-ground management actions or monitoring, including oversight of or involvement in a suction dredge trial.

2.1 Conclusions and recommendations

a) Suction dredging should be trialled immediately to acquire more information on the Aotearoa context and to inform a broader exotic caulerpa management strategy.
b) Suction dredging could be one of many useful tools to manage exotic caulerpa in Aotearoa, but a trial is essential to understand its utility here.
c) Suction dredging is likely to be effective at reducing the biomass of large infestations of exotic caulerpa.
d) It is likely that suction dredging would not achieve total removal of exotic caulerpa. If the aim of a biosecurity response is local elimination or eradication of exotic caulerpa, suction dredging may need to be combined with other methods, such as mats or hand removal.
e) Exotic caulerpa management is multiyear, and it is important to take an intergenerational view of ecological restoration.
f) Two suction dredging trials are recommended: one on the mainland and one in a remote location.

The trial must have full scientific oversight, as a poorly designed trial could jeopardise both this response to caulerpa and future responses to other marine invaders.

The trial should include full follow-up assessment and monitoring of the site. The knowledge and experience gained from the trial could be immediately used for any other more extensive control, elimination or eradication operations. The trial should include several days of active dredging (minimum five continuous days or more) over a large area (at least one hectare) at two different locations: one offshore and one on the mainland. The trial will include site scoping and boundary setting, pre-treatment measurements, during treatment monitoring, and at least three rounds of post-treatment measurements.

A well-designed trial will provide data that addresses uncertainties about suction dredging to inform a key decision point on how to proceed (i.e., a stop/go decision point on further use of suction dredging).

3 Introduction

3.1 Purpose of this document

The purpose of this report is to provide advice for the Caulerpa Governance Groups to enable them to make informed decisions.

Biosecurity New Zealand asked a group of technical experts for advice on the utility of suction dredging in the Aotearoa caulerpa response. This document summarises the advice Biosecurity New Zealand received from the group.

3.2 Background

On 5 July 2021, the National Institute of Water and Atmospheric Research (NIWA) notified Biosecurity New Zealand of a *Caulerpa* species that appeared exotic to Aotearoa on Aotea/Great Barrier Island. The species was identified as *Caulerpa brachypus* on 22 July 2021. A second exotic species of *Caulerpa* was found in September 2021 and identified as *Caulerpa parvifolia* in November 2021. In March 2022, *Caulerpa parvifolia* was found at Ahuahu/Great Mercury Island. In May 2023, both *Caulerpa* species were found near Te Rāwhiti.

In 2021 and 2022, NIWA conducted delimiting dive surveys. They estimated that the area of caulerpa at that time was roughly 48 hectares at all sites at Aotea and roughly 3.2 hectares at Ahuahu[2]. We do not have recent data for these sites, and the caulerpa could now be much larger. Surveillance has also been conducted at high-risk locations around the Hauraki Gulf, Northland, and Coromandel. During the 2023 cyclone, ~50 tonnes of caulerpa washed ashore in Blind Bay at Aotea. In 2023, Biosecurity New Zealand estimated that the caulerpa in Te Rāwhiti was spread over around 200 hectares, but the distribution here was very patchy, with some areas being densely populated and some sparsely populated. The density of caulerpa across all sites varies. For more on the current locations and maps, see "App. 1 Locations of caulerpa in Aotearoa".

Both *Caulerpa brachypus* and *Caulerpa parvifolia* are classified as unwanted organisms under the Biosecurity Act 1993. They are collectively known as exotic caulerpa. The seaweeds and the impacts they may have in Aotearoa are not yet fully understood. Some seaweeds in the *Caulerpa* genus can grow rapidly from small fragments (as small as 5 mm in some species). Overseas, other invasive *Caulerpa* species have formed large meadows that exclude other species and impact on organism diversity, habitats, and fisheries. It is possible that the two exotic *Caulerpa* species in Aotearoa may have similar impacts here. For more information on caulerpa seaweeds, see "App. 2 Caulerpa species and relevance to control methods (Graeme Inglis & Irene Middleton)".

A previous technical advisory group (TAG) met several times in 2021 to provide independent, expert scientific and technical advice on methods and tools (particularly new or emerging methods) to manage exotic caulerpa at Aotea. This group did not investigate suction dredging. The report on the 2021 TAG is available on request.

[2] 44 ha Blind Bay (August 2021); 2.3 ha Tryphena Harbour (March 2022); 1.6 ha Whangaparapara (May 2022); 3.2 ha Ahuahu Great Mercury Island (March 2022)

Suction dredging has been used in biosecurity responses for caulerpa in Spain (Grau et al., 1996), Croatia (Žuljević & Antolic, 2002), California (SCCAT, 2021; Woodfield, 2023) and Australia (Creese et al., 2004), for other seaweed in Hawaiʻi and for *Undaria pinnatifida* in Fiordland in Aotearoa.

In this document, 'suction dredging' and 'dredging' refer to diver-controlled suction dredging. It does not refer to the suction dredging with heavy machinery or purpose-built ships that is used to build large infrastructure such as canals.

Suction dredging to remove seaweed involves using a mechanical pump with a hose or a pick-up pipe to suck the seaweed off the seabed with its runners (stolons) and roots (rhizoids). It can be used to remove just the seaweed that is on the surface of the seabed, or the seaweed that is both on and below the seabed (including runners, roots and seaweed buried under sand). When it is used to remove subsurface seaweed, the dredge lifts a section of the sediment the seaweed is growing in. The dredge is controlled by a diver, who moves the pickup hose across the seabed to target the seaweed and clear obstacles from the nozzle, such as rocks or shellfish. The pick-up pipe for this type of suction dredging usually has a narrow inlet to restrict the entry of fish. The material that the pump sucks up then goes into a collection bag, usually on a barge or boat. Various methods can separate the seaweed from some of the sand. In one method, the dredged material goes into a bag made of fine mesh (1–2 mm), which allows water, sand, and small particles to drain out. In other methods, the nozzles are fitted with drum filters. Wedge wire is another way to separate sand from seaweed.

3.3 Purpose of the Suction Dredge TAG

The technical advisory group are 11 subject matter experts in marine biosecurity, mātauranga Māori, algae, caulerpa management, and marine natural products chemistry.

Name	Organisation	Area of expertise
Arie Spyksma	Independent	Marine community ecology
Barry Scott	Massey University	Biology, genetics and conservation
Craig Thorburn	Craig Thorburn Consulting Ltd	International connections
Ian Davidson	Cawthron Institute	Marine science, field operations logistics
Hone Martin	Ngātiwai	Mātauranga Māori
Irene Middleton	NIWA	Marine science, benthic enviro impacts
Kaeden Leonard	Northland Regional Council	Consents, Biosecurity Act, regional plans, district plans
Rob Campbell	Managing Director, Bay Underwater Services	Dredging technology
Rodney Ngawaka	Aotea Manawhenua	Mātauranga Māori
Scott Godwin	Auckland Council	Consents, Biosecurity Act, regional plans, district plans
Tom Daly	EnviroKiwi	Disposal and logistics Beach and landfill

The purpose of the group is to:

a) Advise whether suction dredging might be a useful tool for eradication, local elimination, or suppression (biomass reduction for the purpose of slowing the spread)
b) Advise under what situations suction dredging could be suitable for the reduction of biomass
c) Take into consideration the extent of infestation, practicality, cost, environmental impacts, disposal options and Mātauranga considerations, the impact of not taking any actions, and the remote nature of current infestations
d) Identify the issues and risks that need to be resolved at the front and at the end of the suction dredging pipe (e.g., disposing of suction dredge biomass and spoil)
e) Compare the above factors to other known caulerpa treatment methods, such as coarse salt, or combinations of treatment methods
f) Advise whether suction dredging could be an alternative or complementary to salt treatment for local elimination of small new infestations
g) Advise on the scale of investment required for the options considered (broad scope, not detailed costings)
h) Identify questions that may be addressed by a suction dredge pilot based on the advice on the feasibility, scope, location, and potential cost, and the circumstances that would make a pilot feasible.

3.4 Scope of the Suction Dredge TAG

The group acts as an advisory body and does not have decision-making powers. The group advised Biosecurity New Zealand on whether suction dredging should be explored further for Aotearoa and compared it to other methods.

This advice has been provided to the Caulerpa Response Governance Groups for Ahuahu, Aotea and Te Rāwhiti and is being publicly released.

The group considered the goals of the Caulerpa Response Programme and the programme's objectives[3] and surveillance results, including the transition from the response stage to long-term management.

Members were asked to advise on:

- All relevant overseas literature and experience with suction dredging techniques and technologies, including discussions with other researchers and teams;
- Whether the levels of in-situ fragmentation (of caulerpa) are manageable and what technologies or methods are available to mitigate fragmentation risk;
- The efficacy of suction dredging on different benthic substrates and whether alternative approaches to removal can be used in conjunction with suction dredging to enhance success;
- The environmental impacts of suction dredging on benthic and terrestrial environments and any associated mitigation techniques or technologies;

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[3] 1. Slow the spread of exotica *Caulerpa* around Aotea, Ahuahu and Aotearoa;
2. Minimise the potential impacts to the environment, communities, and visitors of Aotea/Great Barrier Island, Ahuahu/Great Mercury Island, and wider Aotearoa New Zealand; and
3. Enhance the mana of mana whenua (ahi-kā-roa) and all partners in the response.

- All regulatory requirements for suction dredging and subsequent containment, transport and disposal;
- All logistics and resources required for establishing a suction dredge pilot with preferred pilot locations;
- Potential ongoing management needs and costs.

3.5 Process of the Suction Dredge TAG

The group divided the issues they were asked to address into key questions, which they then categorised into three workstreams. Under Workstream 1, the feasibility of using suction dredging to remove caulerpa in Aotearoa. Under Workstream 2, they compared suction dredging with other methods of control and analysed the scale of investment needed. Under Workstream 3, they documented key issues that Biosecurity New Zealand should consider if it develops a trial. During all workstreams, the group identified knowledge gaps, many of which can be filled by field-based trials.

The group met online in a series of five hui on 2 June, 9 June, 15 June, 22 June, and 30 June. During these hui, the group discussed these issues and reported on their findings. They wrote individual responses to the questions they had developed and exchanged further information through email. Biosecurity New Zealand helped to summarise their advice for this report.

The group reached consensus on most matters. Remaining differences of opinion are largely a matter of degree. Some experts feel more strongly than others about the value and utility of suction dredging as a biosecurity response tool. Some experts wish to better highlight the scientific uncertainty and knowledge gaps and prefer to approach with more caution.

During the hui and in email exchanges, the group investigated the design of a pilot that Biosecurity New Zealand might use by drawing on the results of the first two workstreams. This goes slightly beyond the scope of the group but is included as appendices (App. 3 Recommended performance specifications; App. 4 Resource consents).

4 Findings

4.1 Mātauranga Māori

From the perspective of Mātauranga Māori, the protection of the Mauri, the life force or energy inherent in all living things, is indeed highly respected. Any threat to the Mauri is considered a serious offence and requires immediate action in accordance with tikanga Māori principles.

The Rāhui, which involves implementing temporary restrictions or prohibitions on an area, allows for healing and regeneration, and it serves as a powerful tool for the protection and preservation of all living organisms, particularly kaimoana, which is essential for the survival of Māori whānau. Therefore, it is important to consider the most appropriate method for removing unwanted exotic seaweed from the seabed.

In the context of Māori practices, it is worth noting that the specialised suction dredging method is a key tool that aligns with the principles of tikanga Māori, which emphasise the holistic and sustainable relationship between people and the environment.

If specialised suction dredging is to be considered as a tool for removing exotic seaweed, it will be necessary to ensure that it minimises harm to the Mauri and the overall ecosystem. This should involve engaging with local hapū and incorporating their knowledge and expertise to assess the potential impacts of specialised suction dredging and develop appropriate guidelines for its use. Additionally, it would be important to conduct thorough environmental assessments and monitoring to evaluate the short-term and long-term effects of specialised suction dredging on the seabed, including its impact on other marine life and habitats.

Ultimately, any decision regarding the use of specialised suction dredging or any other method should be made in collaboration with Māori communities and in accordance with their cultural values, tikanga Māori principles, and the goal of protecting and preserving the Mauri of the seabed and its ecosystems.

4.2 Feasibility of suction dredging exotic caulerpa in Aotearoa

The group expects that diver-controlled suction dredging may be effective at reducing the biomass of large infestations of exotic caulerpa. It is likely that suction dredging would not achieve total removal. Regardless of the strategy chosen, if suction dredging is used, it is only one step in the process and additional methods or tools may also be needed to assist with seaweed removal, along with intensive surveying.

However, the group strongly recommends a trial first to answer questions about:

- Efficacy and consistency of suction dredging over large scales (>1 ha)
- Usefulness on different seafloor, sediment types and caulerpa density
- The amount of space covered per unit of time and associated amount of caulerpa removed
- The ability to remove above-surface, surface, or subsurface biomass
- Our ability to manage the risk of spreading caulerpa fragments created by the suction dredge or during travel from a dredge site to landfill
- The impact of suction dredging on the Mauri and ecology
- The ability of the Mauri and ecology to recover
- Logistics of operating in a variety of sites (including offshore islands)
- Costs

Diver-controlled suction dredging is likely most useful for:

- Depths less than 30 metres (it is hard for divers to work deeper)
- Areas with relatively flat and homogeneous seafloors[4]
- Areas that are distant from high-value species
- Large areas (due to the setup costs involved).

To read about the sediments involved in Aotearoa's caulerpa infestations, see "App. 1.2 Substrate where caulerpa has been found in Aotearoa".

Suction dredging can also be used in other situations that do not meet these criteria, such as deeper than 30 m, complex reef systems, smaller infestations, or areas with high-value

[4] Suction dredging can be used on both soft and hard substrates, and both flat and sloping areas, but it may be hard to use it on seafloor areas that have mixed terrain, such as where sand is interspersed with boulders.

taonga. Subsurface suction dredging may also be less suitable for muddy sediments, as the mud can worsen visibility issues and clog equipment. In these situations, the method may become less efficient, and more problem-solving will be needed to solve challenges. Some solutions could be moving taonga species to other areas temporarily and returning them after operations; having a larger dive team to swap out more frequently at greater depths; filtering out sediment at the nozzle end; or finding new ways to remove the caulerpa runners and roots on a reef system. These operational constraints create higher costs.

Known operational constraints and limitations include:

- Managing fragmentation that the dredge creates
- Visibility for divers and cameras
- Limiting bycatch and impact on the Mauri of the seabed
- Separating caulerpa from other material
- Transporting and disposing of caulerpa in a biosecure way.

Small fragments of caulerpa can grow into new weeds, and caulerpa seaweeds can naturally spread without human involvement when broken up by storms, currents or sea creatures. In a suction dredge operation, the dredge breaks caulerpa into fragments, which it then sucks up. Because any of these fragments can regrow and form a new weed, dredging operations will need to manage and minimise the risk of fragments being missed or carried away on the water or by divers to locations where they can start a new infestation of caulerpa. There is a concern that dredging may make the problem worse in some situations. This could be by creating new fragments; unintentionally spreading the caulerpa to new areas; degrading the area and weakening the Mauri to a point where there is lower resilience and the area becomes vulnerable to new infestations; or causing stress to reproductively mature shellfish, which may then release planktonic stages out of season.

Another issue is maintaining visibility for divers. The dredge and divers can stir up a lot of sediment and reduce visibility for divers. It is also an issue for cameras trying to document and monitor the work. Divers control the nozzle end of the dredge to target Caulerpa. They also clear blockages and move obstacles such as shellfish out of the way. Divers need around one metre of visibility to work, and poor visibility can reduce ability to detect caulerpa on the seafloor, reduce the selectiveness of this tool, and hamper divers in their work.

The approach used should measure and attempt to mitigate environmental damage. It is important to avoid bycatch of kaimoana and taonga species as much as possible. However, even very small organisms such as worms and amphipods are part of the ecosystem and contribute to the Mauri and health of an area. The approach should limit bycatch of all organisms that are not caulerpa as much as possible. The impact of suction dredging on habitats should also be carefully evaluated because physical changes to habitat are certain in some areas (take up and removal of sediment).

Several pieces of legislation apply to suction dredging operations and are documented in "App. 5 Legislation". Operations must also obtain resource consents. See "App. 4 Resource consents" for specific requirements for resource consents from Northland Regional Council, Auckland Council and Waikato Council.

Some of the caulerpa incursions are in remote locations, and the operation will need to overcome logistical constraints for transporting the gear and team to the site, providing for the needs of the team in the remote locations, and transporting and disposing of caulerpa afterwards.

Suction dredge operations will need a biosecurity plan to minimise the risk of moving caulerpa to marine habitats outside of the dredge site. This should include a whole-of-operations plan from deployment to the end of a dredging period. Important points to consider include on-site decontamination of divers and equipment, rapid inspection of underwater components of vessels that are about to depart a dredge site, and containment of all caulerpa fragments in collection bags on board vessels. It is imperative that no new caulerpa outbreaks occur along the route of travel by a suction dredge team, especially at the ports/docks where collection bags are transferred from vessels to onshore facilities or trucks.

A trial will give us more information on how to resolve these issues. For more on this, see "App. 3 Recommended performance specifications" and "App. 6 Overseas experience with suction dredging".

4.3 Comparison of suction dredging and other methods of control

Different methods of caulerpa control should be considered complementary of each other. Several methods may be needed in different contexts of caulerpa distribution.

To date, programmes to control and eradicate caulerpa have most commonly used mats (either natural fibre mats such as uwhi or hessian or plastic mats such as tarpaulins), chemicals (salt or chlorine), hand removal and suction dredging.

Mats work by depriving the seaweed of the light that it needs to grow. If they are well-sealed, they also deprive it of oxygen. Mats do not need a high level of expertise to install, but they are less useful in areas where boats anchor or there is high disturbance. They need to be fastened to the seabed in a way that withstands sea currents and weather conditions, and they need to remain in place for a long period of time, typically more than six months or a year. In that sense, multi-month covering is usually only suited to low-energy environments (calm water, low or no current). They also need a way to release gas as the material underneath them decomposes, so that they do not billow and lift up from the seafloor. Mats kill the target seaweed and most other creatures that are under them. Uwhi decay into the environment and may not need to be removed later (depending on how they are fastened). Tarpaulins need to be removed later.

There is uncertainty about how effective mats are at killing caulerpa on their own. In California, tarpaulins were used with chlorine, sometimes placed on the seabed as pellets under the mats and sometimes injected through port holes in the mats after installing them. Having chemicals under the mats speeds up the process of death and decay and gave the Californian teams more assurance of efficacy. Adding chemicals could mean the mats do not need to stay in place for as long (hours/days/weeks) as they do without chemicals.

Chlorine and salt work similarly. Salt has been used to treat caulerpa on its own in Australia. In seawater, salt and chlorine quickly become diluted, so placing mats over chemicals helps to maintain the chemicals at a higher concentration. In Aotearoa, salt was used under mats in a trial and was very effective at killing caulerpa. Salt has the potential to kill everything beneath it, but salt and chlorine do not accumulate or persist in the environment. In the salt-and-mat trials in Aotearoa, there was near-full recovery of seafloor species after three months. However, salt is logistically bulky so becomes less practical over large areas of many hectares.

Hand removal involves divers removing the seaweed by hand. The caulerpa is removed from the sea and is disposed of on land. It must be disposed in a biosecure manner to manage the risk of fragments accidentally re-entering the sea. Divers removing caulerpa need high attention to detail and must be able to rigorously cover precise gridded lines across the infestation site.

Suction dredging works like a vacuum cleaner and sucks the seaweed out of the sea. Suction dredging has high setup costs, but once it is set up, the cost stabilises. This means it may be more economical to scale up than other control methods, as methods with consumables such as chemicals simply increase in cost as they are scaled up. The teams involved in suction dredging need a higher level of technical experience and training than teams applying other methods.

Mats and chemicals all kill caulerpa where it is in the environment and leave it to decay. With suction dredging, the caulerpa is removed from the sea to be disposed of on land. As with hand removal caulerpa must be contained, transported, and disposed of in a biosecure way to avoid accidentally releasing live fragments to new sites. With subsurface dredging, a lot of sediment is also be removed. The sediment needs to be separated from the seaweed or disposed of with the seaweed. Suction dredging may be more selective than mats and chemicals for avoiding bycatch, but still has some impacts. Although the diver can control the dredge nozzle to target caulerpa, the dredge will also pick up everything below the nozzle.

All methods involve surveillance dives and monitoring for regrowth over several years as a matter of best practice. The limited experiences with caulerpa management so far indicate that the native environment can recover after all the treatment methods. Some methods may enable faster recovery than others. From a Mātauranga Māori perspective, the preferred method is one with the least impact on non-target species and the one that restores the Mauri of the site.

The pros and cons of other methods for general marine invaders are documented in the 2021 Biosecurity New Zealand technical paper *Treatments for Marine Pathways Management and Incursion Response* (Cahill et al., 2021). Members of the technical advisory group assessed suction dredging using the criteria in that paper in "App. 7 Suction dredging assessed using the criteria for treatments of marine invasive species from Cahill et al. (2021)".

4.4 Matters to consider for a suction dredge trial

The key goal of a trial is testing the effectiveness and efficiency of suction dredging at removing caulerpa in Aotearoa on a large scale (hectares).

The purpose of a trial is to gather information on the role suction dredging can have in the long-term approach to caulerpa management in Aotearoa and the ecological impacts of suction dredging.

A side benefit of the trial will be reduced caulerpa at the trial sites.

The technical advisory group recommends running one trial at the mainland and one offshore to test the logistics of operating under these two very different situations, with the goal of establishing the effectiveness of the method across Aotearoa more broadly.

The trial should include site scoping and boundary setting, pre-treatment measurements, several days of active dredging, during treatment monitoring, and at least three rounds of post-treatment measurements. These follow-up operations would measure the amount of caulerpa missed during dredging, the degree of caulerpa regrowth, and changes in the seabed, native flora, and fauna, as well as monitoring any reinfestation. A newly cleared area will be particularly susceptible to reinfestation by caulerpa migrating from other infested areas.

The follow-up operations could also include testing complementary methods such as hand removal and small mats and their effectiveness in removing caulerpa. This would again inform the broader response. Testing complementary methods would significantly increase the cost, time and complexity of a trial.

A trial will inform decisions on the feasibility of using suction dredging to control caulerpa in Aotearoa. It will answer questions on short-term issues relating to:

- Effectiveness, consistency, usefulness in:
    - Different substrates/habitat types (rocky, coarse sediment, fine/muddy sediment)
    - Different depths
    - Different scales (small infestations 10s of m^2 to 1,000s of m^2 and large infestations >1 ha)
    - Different densities of caulerpa
    - Different levels of wave exposure
- The ability to remove above-surface, surface, or subsurface caulerpa biomass
- Visibility for divers
- Impact on surface and subsurface organisms, the Mauri and ecology
- Level of dredge bycatch
- Mitigating bycatch
- Managing fragmentation
- Feasibility of separating material once it has been dredged up
- Disposing of caulerpa and other dredged material
- Logistics of working in a variety of sites (including offshore islands).

If the trial also tests complementary methods, it will answer questions on:

- Efficacy of mats such as uwhi or tarpaulin when used on their own
- Impact of mats on sediment structure, the Mauri and ecology
- Usefulness of reducing biomass before using mats or chemicals
- Ability of other methods to complement suction dredging.

It could also inform us about medium- to long-term issues, such as:

- Effectiveness of initial removal efforts at suppressing or eradicating caulerpa in the different settings of the trial
- Rate of exotic caulerpa regrowth or reinfestation
- Costs of initial dredge operations (and follow-up work) for different settings

- Recovery of surface and subsurface organisms, and Mauri after dredging.

We estimate the overall cost of a full trial to be $500,000 per site. This will vary based on logistical difficulties associated with each location and the scope of work. This is a rough estimate, and a trial still needs to be fully costed, as it involves multiple steps. This estimate includes a five-day deployment for dredging (at least ~$65,000) and very detailed scientific measurements that must be conducted with stringent scientific oversight.

One of the key points being tested during a trial will be the logistics and biosecurity of disposing of dredged material. Another key point will be developing tight performance specifications for use in future operations.

A suction dredge trial could be completed within three months. The duration is largely determined by the endpoints for post-dredge measurements.

If the first phase of the trial shows that dredging is effective, suction dredging could then be rolled out to reduce biomass in other areas, while taking the environmental impacts into account. If testing for local elimination or eradication, the follow-up phases, which test the dredge's efficacy at removing all caulerpa fragments from an area, are a longer-term project and are likely to last a year or more to confirm complete absence of caulerpa.

Any investment in long-term management should anticipate a multiyear project.

5 Discussion

5.1 General comments

Suction dredging is potentially a very useful primary method of removing caulerpa, but it needs to be tested in Aotearoa with the goal of determining its effectiveness and efficiency. We are recommending a mainland and offshore site because the logistical challenges might be different, and there is a public willingness to undertake trials. The technical advisory group expects that suction dredging will need to be combined with secondary methods of removal such as mats or chemicals if local elimination or eradication are the goals of a broader response.

The trial should consist of a primary treatment phase with at least three follow-up dive surveys to determine the effectiveness of the method. A trial could also consider testing additional methods such as hand removal to inform a more general incursion response, but added steps will prolong a trial and increase costs. While the group recommends trialling two locations, one on the mainland and one offshore, the group was not in total agreement on this. Regardless of the sites chosen, there should be strong engagement with mana whenua, ahi-kā-roa and the local community throughout the trial, and if possible, the trial should enable them to assist.

The purpose of the trial is to test this technology based on conditions and current caulerpa distributions in Aotearoa. While it has been used overseas (Creese et al., 2004; Grau et al., 1996; Woodfield, 2023; Žuljević & Antolic, 2002), our ocean environments are physically and biologically very different from the locations it has been used in elsewhere. Information acquired in the trial will show how useful this technology might be for a more general incursion response where operations will need to be scaled. The first phase will address the knowledge gaps about logistics, costs and rate of removal. It will also give us new knowledge about operations on the seabed, barge and onshore. The subsequent phases will address knowledge gaps about the rate of regrowth and the ability of the sites to recover. Other knowledge gaps that the trial could fill are outlined earlier in the sections 4.2 "Feasibility of suction dredging exotic caulerpa in Aotearoa" and 4.4 "Matters to consider for a suction dredge trial".

The efficacy of any control method is only as a good as the operator. Quality assurance of dredge operations will need active oversight and management. As mentioned in section 4.2, a key issue during the trial will be understanding how much caulerpa is missed or left behind. Managing fragmentation caused by the dredge and possibly the divers will play a role in this. Fragmentation of caulerpa will be restricted by divers controlling the nozzle from the outer to inner perimeter of the dredge site, by nozzle design, and by the suction pressure applied. GPS tracking and maps of operations will ensure transparency of information associated with potential caulerpa fragmentation at a dredge site. It is difficult to record video in poor visibility caused by subsurface dredging, but fitting the divers or equipment with cameras may also give further reassurance and data about the quality of operations. One mitigation could be to systematically treat areas divided into grids and then return to the gridded areas to dredge a second time after the sediment has settled.

Suction dredging will not be suitable if secondary infestation from fragmentation remains a high risk and cannot be mitigated. It is essential that the suction dredging is only used when the benefits outweigh the impacts and the risk of further spread. Secondary control measures are probably necessary to limit fragmentation spread.

A key issue during the subsequent phases will be managing the risk of reinfestation. Removing caulerpa from a habitat can create an empty space that is perfect for reinfestation. If the removal effort is not maintained, the area will be reinfested.

A poorly designed or poorly implemented trial will harm the broader caulerpa response as well as future responses to invasive marine species. It is important to make attempts to remove or kill invasive marine species to ensure progress in marine invader management and overcome a sense of defeatism that is common in this field. It is also important to ensure false positive or false negative conclusions are avoided after a trial because these can lead to wasted resources or longer-term assumptions that are incorrect.

5.2 Suction dredging as a primary method of treatment

Diver-operated suction dredging has been used effectively as a primary method of treatment at Newport in California in combination with follow-up methods to put this site on a pathway to eradication. It has also been used in Croatia and Spain and has been trialled in Australia. At other sites in California, the primary treatment was tarpaulin mats with chlorine injections and hypochlorite pellets (SCCAT, 2021), with suction dredging used as a secondary treatment around the edges. We do not yet know if mats, which exclude light and prevent photosynthesis, are effective when used on their own. Salt has also been used as a primary treatment in Australia (Creese et al., 2002) and Aotearoa at small scale.

All primary methods of removal require intensive follow-up surveillance and treatment. Most strategies for larger scale incursions will need more than one method if the goal is eradication. For eradication, this follow-up must also continue over several years.

Testing suction dredging in Aotearoa will inform us of the effectiveness of this technology as a primary treatment and, if it proves useful, the scale it could be used at for long-term management. Any decisions on using suction dredging in a long-term management strategy must weigh up benefits of using this technology over the risk of exacerbation (section 4.2) and the impacts of doing nothing, discussed below.

5.3 Beyond the trial

We do not yet know the long-term impact that exotic caulerpa will have in Aotearoa. Based on its current trajectory here and invasion history elsewhere, it seems wise to control the spread as best we can to provide time to answer some of those unknowns and to inform a more general incursion response.

There is currently little in-depth and up-to-date information on treating infestations of exotic caulerpa, let alone at the large scales of infestations we have here. A trial will contribute not just to our own knowledge but world knowledge. Because the trial will actively remove caulerpa in the chosen sites, it will also buy the country time to work on further innovation, assess the impacts of the incursion, and develop a better-informed biosecurity response. Involving local communities in the trial will increase both capacity and capability around incursion sites. Local communities should be involved with a long-term strategy in mind.

The pros and cons of different management options are outlined in the table below.

Control method	Pros	Cons
No action	• No management cost • No expertise • No permits or consents needed • No monitoring needed • Does not require Biosecurity Act permits	• Expected to have high environmental damage • May have high cost to aquaculture • May substantially change ecosystem • High impact on kaimoana and taonga species • Promotes caulerpa spread
Hand removal	• Lowest environmental impact	• Laborious and slow • Not scalable • Need to handle collected caulerpa underwater • Need to dispose of collected caulerpa • Requires Biosecurity Act permits • Needs follow-up monitoring
Natural mats (uwhi or hessian)	• Potential to kills caulerpa onsite • Less expertise to apply than dredge team • No need to dispose of dead caulerpa • Mats do not need to be removed (biodegradeable) • Does not require Biosecurity Act permits	• Application and efficacy largely untested (needs trialling) • Mats must be in place for long durations (not quick, mats need monitoring) • Some regrowth may occur on top of mats • Requires low-energy environment (slow sea currents) to stay in place for the whole time • Needs follow-up monitoring

Control method	Pros	Cons
Tarpaulin mats	• Potential to kill caulerpa onsite • Less expertise to apply than dredge team • No need to dispose of dead caulerpa • More durable than natural mats • Does not require Biosecurity Act permits • Can be applied to large areas (successful international examples of multiple plots summing up to ~4 ha)	• Higher non-target biology impacts than removal methods (kills most organisms under the mat) • Creates anoxic environment under the mats • Mats must be in place for long durations (not quick, mats need monitoring) • Mats need to be removed later • Requires suitable sea currents to stay in place for the required time • Efficacy unknown; needs trial • Needs follow-up monitoring • Unsuccessful if too buoyant
Suction dredging	• Reduces biomass quickly • No underwater handling of collected caulerpa (for quicker removal process) • Can be applied over hectares • Possible to reduce or manage bycatch (of non-target organisms) during operations	• Requires team with technical expertise • Does not kill caulerpa onsite (requires handling and disposal of collected material, and potential for regrowth) • Creates fragments, which need to be managed • Higher physical habitat impacts (than hand removal or chemical). Alters sediment structure and removes infauna • Need to transport and dispose of dredged caulerpa and other material • Efficacy uncertain; Needs trial • Requires Biosecurity Act permits • Requires resource consent • Will need to be done regularly if used for control
Mats+salt	• Faster than mats on their own • Treating areas relatively rapidly allows reuse of mats (moving mats around systematically) • Greater assurance of efficacy • Low likelihood of physical habitat impacts • Less technical expertise to apply than dredge team • Does not require Biosecurity Act permits	• Logistically bulky as the spatial scale increases • Higher non-target biology impacts than removal methods (kills most organisms under the mat) • Tarpaulin mats create anoxic environment and need to offgas • Tarpaulin mats need to be removed later • Mats require a suitable sea currents and weather conditions to physically stay in place for the required amount of time • Requires resource consent • Need follow-up monitoring

Control method	Pros	Cons
Mats+chlorine	• Faster than mats on their own • Greater assurance of efficacy • Less expertise to apply than dredge team • Does not require Biosecurity Act permits • Already has resource consent for use in Northland from NRC	• Higher non-target biology impacts than removal methods (kills most organisms under the mat) • Dosage can be challenging but concentration can be monitored in real time • Chlorine is highly soluble in seawater • Tarpaulin mats create anoxic environment and need to offgas • Tarpaulin mats need to be removed later • Mats require suitable sea currents to stay in place for the whole time • Needs follow-up monitoring • Requires resource consent
Dredging+mats	• Expected to have the lowest environmental impact for a large area • Can be applied over hectares	• Requires high expertise for dredging phase • Need to dispose of dredged material • Need to manage fragments during dredging • Efficacy unknown; needs trial • Requires Biosecurity Act permits • Requires resource consent • Needs follow-up monitoring
Dredging+mats +chemical	• Greatest assurance of efficacy • Can be applied over hectares	• Kills everything under the mat • Requires high expertise for dredging phase • Need to dispose of dredged material • Need to manage fragments during dredging • Needs trial • Requires Biosecurity Act permits • Requires resource consent • Needs follow-up monitoring

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Appendices

To help develop their conclusions, the group also produced several supporting documents.

App. 1 Locations of caulerpa in Aotearoa

App. 1.1 Area of caulerpa, excluding Te Rāwhiti detection

Location	Est. pop. size	Date estimated
Whangaparapara Harbour, Aotea/Great Barrier Island	15,557 m^2	May 2022
Tryphena Harbour, Aotea/Great Barrier Island	22,700 m^2	March 2022
Western Bay of Ahuahu/Great Mercury Island	~32,380 m^2	March 2022
Blind Bay, Aotea/Great Barrier Island	440,000 m^2	August 2021

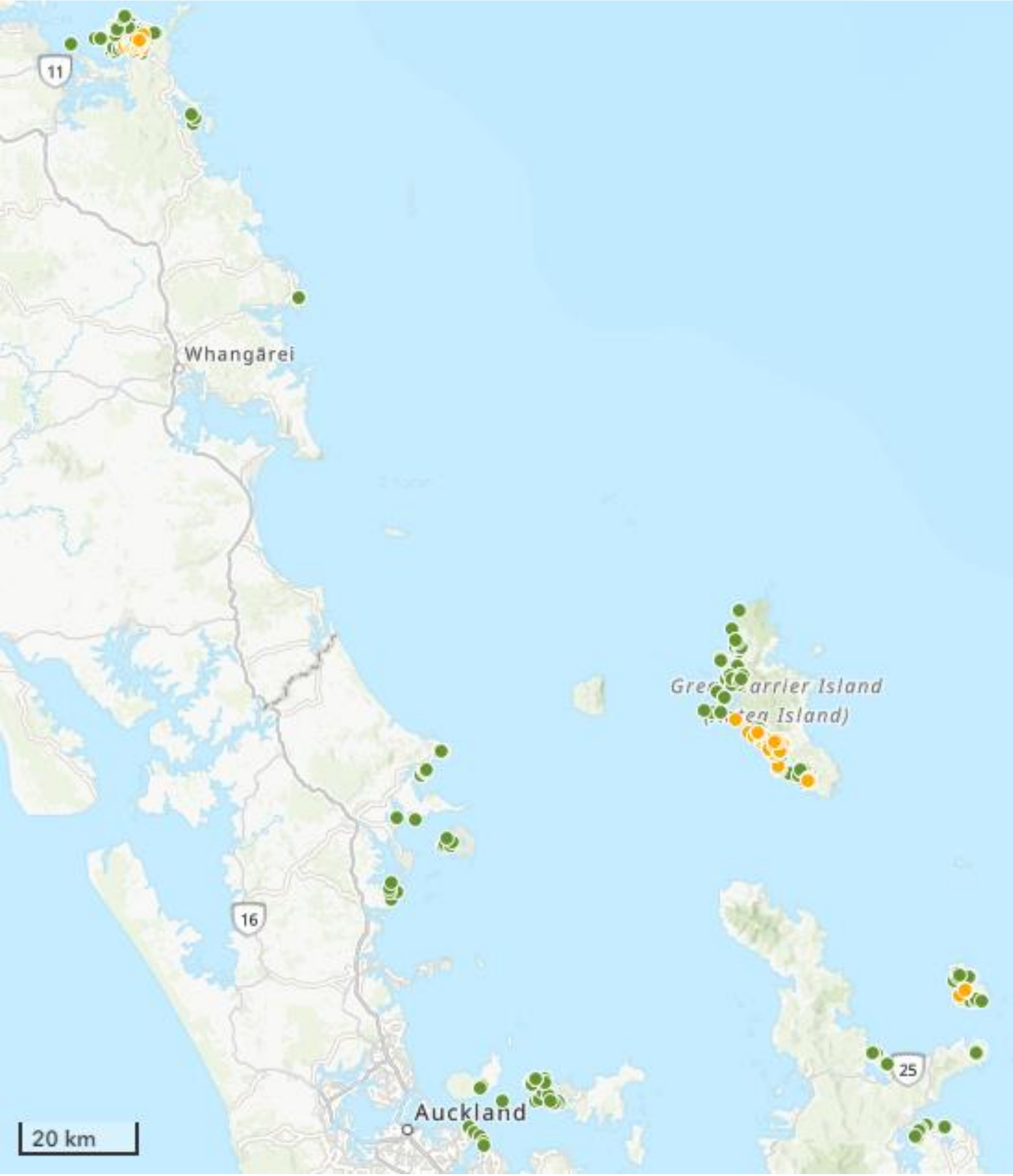
Note: Divers are not inspecting all the time, so the above table is the most recent information received by Biosecurity New Zealand.

App. 1.2 Substrate where caulerpa has been found in Aotearoa

Ahuahu	Aotea	Te Rāwhiti
Sandy gravel	Sandy mud	Sandy mud
Sand	Muddy sand	Muddy sand
Shelly gravel	Sand	Sand
Reef	Sandy gravel	Sandy gravel
Algae bed	Shelly gravel	Reef
	Reef	Algae beds
	Mud	Seagrass
	Algae beds	Horse mussels
	Seagrass	
	Scallop beds	
	Dog cockles	

App. 1.3 Map of Aotearoa detections (June 2023)

Survey results: ● (orange) = caulerpa present, ● (green) = absent



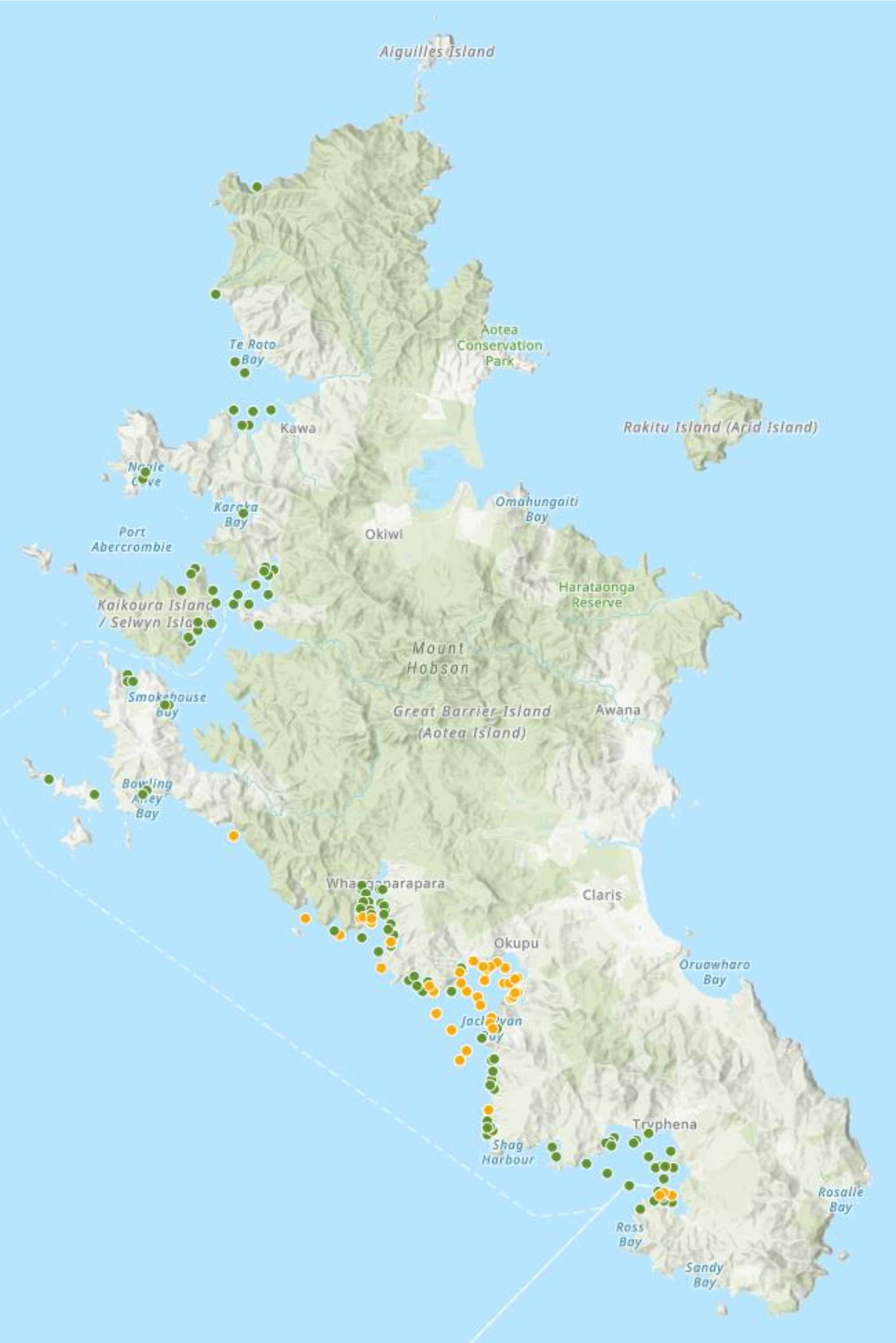
App. 1.4 Map of Bay of Islands detections (June 2023)

Survey results: ○ (orange) = caulerpa present, ● (green) = absent

App. 1.5 Map of Aotea/Great Barrier Island detections (June 2023)

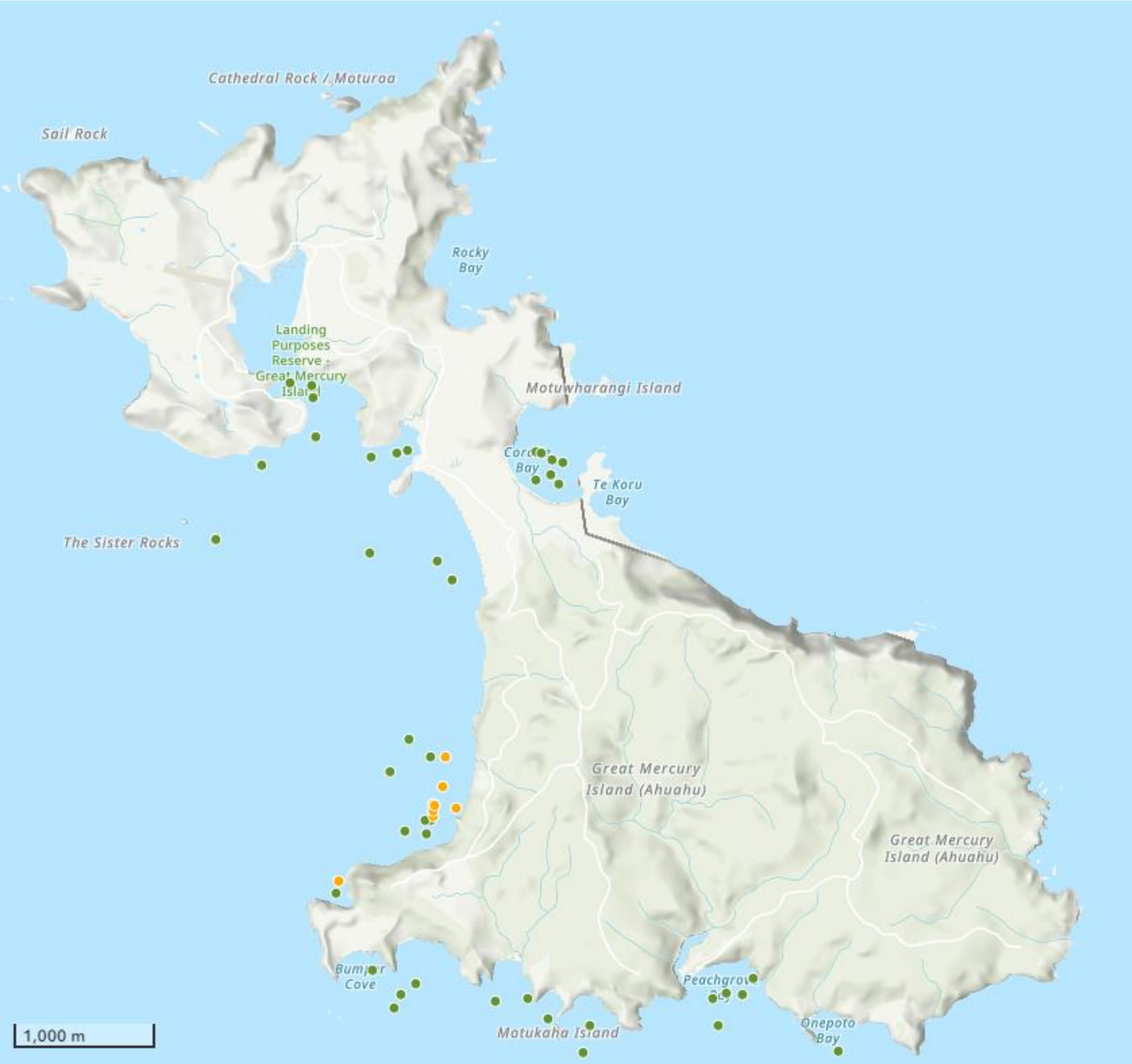
C. brachypus and *C. parvifolia* grow very rapidly in the marine environments of Aotea. The initial infested areas expanded from 0.01 m² to 1,840 m² in Tryphena and from 10 m² to 1,750 m² in Whangaparapara in the three-month period (September to December 2021) after the bays were first surveyed.

Survey results: ● (orange) = caulerpa present, ● (green) = absent



App. 1.6 Map of Ahuahu/Great Mercury Island detections (June 2023)

Survey results: ● (orange) = caulerpa present, ● (green) = absent



App. 2 *Caulerpa* species and relevance to control methods (Graeme Inglis & Irene Middleton)

App. 2.1 How species of *Caulerpa* differ

Caulerpa is one of the most widespread and diverse green macroalgal groups worldwide. Currently, more than 100 species or variants are recognised[1]. Southeast Asia, Australia, and the Caribbean are known regions with high diversity and endemicity of *Caulerpa* species. The genus exhibits a wide range of different morphologies, but the general growth form comprises a horizontal-growing stolon (or rhizome) with erect photosynthetic fronds (assimilators) and fine, colourless, rhizoids that anchor the alga in sediments or stick it to hard surfaces (Figure 1)[2]. In some species, the rhizoids also appear to have a role in nutrient uptake[3]. The form of the frond varies among species. They can be leaf-like (ligulate), or they may have a central axis known as a rachis (Figure 1) with lateral branchlets known as ramuli. The ramuli exhibit different forms across the species (e.g., terete, turbinate, clavate, peltate, falcate, vesiculate) and can have different arrangements on the rachis (Figure 1). For example, the ramuli may be arranged opposite each other (distichous), be irregular with no distinct arrangement (vesiculate) or be whorled (verticillate).

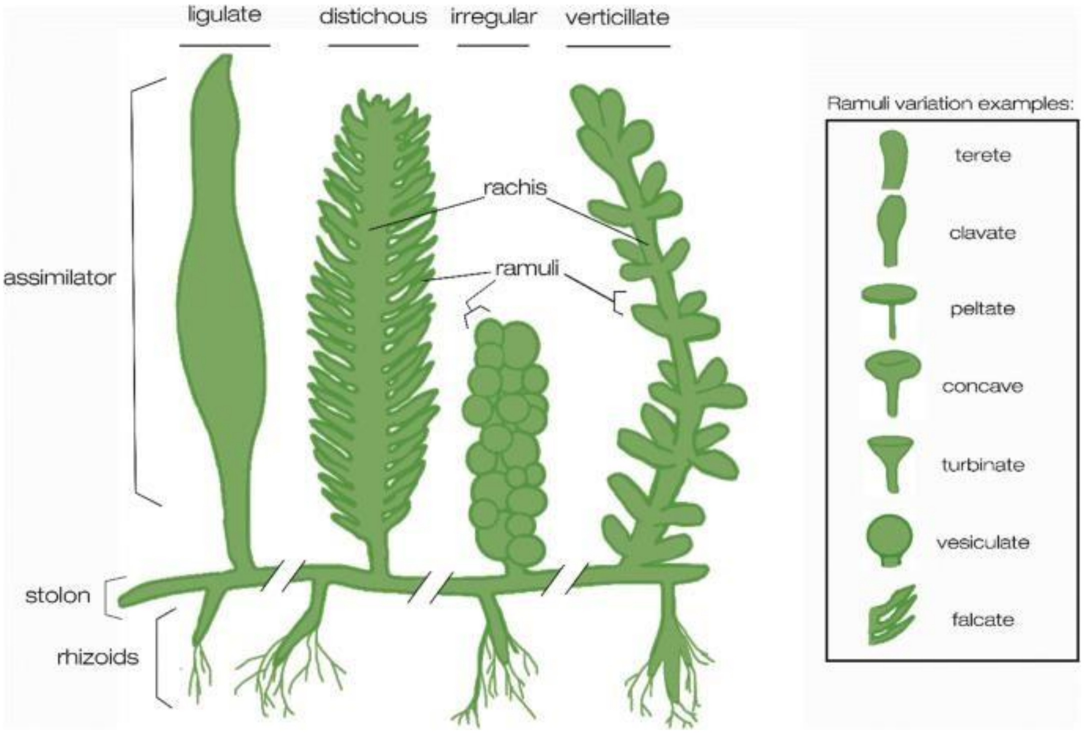


Figure 1. Schematic diagram showing the general morphology of species in the genus Caulerpa (source: Zubia, et al.[1]). Different forms of assimilator are shown next to each other for comparison. These different forms are normally present on different species.

Some *Caulerpa* species can themselves display remarkably high levels of variability in their morphology. This seems to be related to the environmental conditions they occur in, such as the substrata they are growing on, light intensity, and water motion[4]. This morphological plasticity means that there has been a lot of taxonomic confusion within the genus.

App. 2.2 Species of *Caulerpa* in New Zealand

Nine species of *Caulerpa* have been recorded from New Zealand and are considered native to our waters[5]. These include:

- *Caulerpa articulata* Harvey 1855 (images)
- *Caulerpa brownii* (C.Agardh) Endlicher 1843 (images)
- *Caulerpa fastigiata* Montagne 1837 (images)
- *Caulerpa flexilis* J.V.Lamouroux ex C.Agardh 1823 (images)
- *Caulerpa geminata* Harvey 1855 (images)
- *Caulerpa longifolia* C.Agardh 1823 (images)
- *Caulerpa racemosa* (Forsskål) J.Agardh 1873 (images)
- *Caulerpa sertularioides* (S.G.Gmelin) M.Howe 1905 (images)
- *Caulerpa webbiana* Montagne 1837 (images)

Three of these species—*C. articulata*, *C. flexilis*, and *C. geminata*—occur in the North Island and as far south as the top of the South Island. *C. brownii* occurs throughout both main islands and is present at the Chathams, Rakiura and the Snares Islands[5]. The other species are less common. Scattered records of *C. fastigiata* have been recorded from the Three Kings Islands to Hawkes Bay. *C. longifolia, C. racemosa*, *C. setularioides* and *C. webbiana* have only been recorded from New Zealand's northern offshore islands, the Three Kings and Kermadecs[6].

App. 2.3 Exotic *Caulerpa*

Caulerpa brachypus and *C. parvifolia* are the only exotic C*aulerpa* species to have been recorded from marine environments in mainland New Zealand. However, eight species have been recorded as intentional or unintentional introductions within the marine aquarium trade[7], some as recently as 2020[8]. None of the eight species are native to mainland New Zealand, and none have been found outside of aquaria. These were:

- *Caulerpa chemnitzia* (Esper) J.V.Lamouroux
- Caulerpa cylindracea Sonder
- Caulerpa lentillifera J. Agardh
- *Caulerpa nummularia* Harvey ex J. Agardh
- *Caulerpa racemosa* (Forsskål) J.Agardh 1873
- *Caulerpa serrulata* (Forsskål) J.Agardh
- *Caulerpa sertularioides* (S.G.Gmelin) M.Howe 1905
- Caulerpa taxifolia C.Agardh 1817

App. 2.4 Relevance of differences between species for controls

App. 2.4.1 Fragmentation

Fragmentation is an important way in which *Caulerpa* clones expand and disperse. There are, however, quite marked differences among species in their propensity to produce fragments and in the ability of fragments to regrow. Smith and Walters[9] compared the survival and growth of fragments of different sizes taken from three species of *Caulerpa* with different morphologies and habitats. *C. taxifolia* has feather-like, flattened fronds that grow between 3–15 cm tall, *C. prolifera* has leaf-like fronds (much like *C. brachypus* and *C. parvifolia*) that range from 3–15 cm tall, and *C. verticillata* has fronds up to 3 cm high with very fine, whirled ramuli that form dense low turfs on sand covered rocks or corals. Although the basal structures (stolons and rhizoids) of the three species have the same general morphology, they differ in robustness. Stolons of *C. taxifolia* can be up to 4 mm in diameter, while those of *C. verticillata* are much finer, around 0.12 mm diameter. Smith and Walters[9] showed that *C. taxifolia* can regrow stolons and rhizoids (the structures needed to reattach to the sea floor) from fragments of the frond and stolon. In contrast, *C. prolifera* only regrew basal structures from fragments that contained a section of stolon[9].

There is limited information about the ability of *C. brachypus* to regenerate from fragments and the distances that fragments can be transported. In *C. taxifolia* and *C. prolifera*, fragments of the stolon as small as 5 mm can survive, attach, and grow in aquaria. In natural environments, short-term survivorship of fragments is typically size-dependent. Larger fragments grow faster and produce more rhizoids enabling secure attachment[10]. In dynamic marine environments, fragments may need to be deposited in quiescent environments or entrapped by other structures (microalgal turfs, seagrasses, rocks, corals, etc) to allow the rhizoids to attach.

The species may also exhibit different strategies for fragmentation. *C. taxifolia* is more likely to shed fragments of frond than *C. prolifera*. These are more buoyant than the basal structures. Fragmentation of *C. prolifera* is more likely to occur from disturbances that uproot the basal structures. The large, drifting mats of *C. brachypus* that were ripped up on Aotea by Cyclone Gabrielle provide an indication of how this can occur.

App. 2.4.2 Toxicity

Caulerpa species contain a variety of biologically active chemicals (secondary metabolites), that can be toxic or distasteful and which act as deterrents to herbivores or microorganisms[11]. Much of the biological activity is attributable to a compound called caulerpenyne. Caulerpenyne is an important component of wound repair in *Caulerpa*. It allows these algae to quickly plug any rupture to the outer cell wall to prevent the loss of cytoplasm[12]. The concentrations of caulerpenyne can vary considerably among different species and even among different stands of the same *Caulerpa* species.

For example, concentrations of caulerpenyne are 35–80 times greater in *C. taxifolia* than in *C. racemosa* and vary seasonally with the growth of the alga and herbivore pressure[13]. Some species, notably *C. lentillifera* and *C. racemosa* (commonly referred to as sea grapes or green caviar), have comparatively low concentrations of caulerpenyne and are eaten by humans throughout the Indo-Pacific.

App. 2.5 Knowledge gaps

Species-specific knowledge for *Caulerpa brachypus* and *Caulerpa parvifolia* fragmentation rates, the dispersal potential of fragments and the ability of fragments to regrow is limited. Understanding the success and distribution patterns of fragments is important for effective management and surveillance activities. Furthermore, there is little data on the caulerpenyne concentrations of *C. brachypus* and *C. parvifolia*, likely due to the fact they are not the most common invasive species in the genus. Given that concentrations of secondary metabolites such as caulerpenyne can be highly variable[13], literature on secondary metabolites in these species from overseas may not be applicable or comparable to the New Zealand populations. If grazing and augmentative biocontrol are going to be considered for management, the concentrations of secondary metabolites such as caulerpenyne may impact success.

Caulerpa species are highly adaptive and have wide thermal and environmental tolerances[14]. However, some species undergo seasonal reductions in biomass during colder months[15]. These seasonal reductions in biomass have not yet been observed in infestations of *Caulerpa brachypus* and *Caulerpa parvifolia* in New Zealand. The growth rate and temperature tolerances of *Caulerpa brachypus* and *Caulerpa parvifolia* in New Zealand are currently not well understood. However, lab-based trials are underway to determine the environmental tolerances of these species. With changing ocean climates and increased heat wave occurrences, understanding the optimal and critical temperatures for growth and survival of *Caulerpa brachypus* and *Caulerpa parvifolia* will be crucial for long-term management.

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App. 3 Recommended performance specifications

A biosecurity response involving suction dredging should have tight performance specifications. The technical advisory group proposes that the specifications require:

- Relevant approvals (regulatory, consultations with mana whenua and communities) (see sections 0 "Relevant legislation" and 7.3 "Resource consents")
- Mitigation for fragmentation (closed circuit filtration system, monitor of dive operations, camera on divers, active downstream sampling)
- Confidence that the biosecurity risk of spreading caulerpa during operations is managed
- Rigid reinforced plastic suction hose
- Biodegradable non-mineral oil hydraulic pump
- Selective nozzle head
- Minimised depth of substrate removal
- Less than 50 m distance from suction head to pump
- Clearly described methodology for capturing and separating pump discharge components
- Containment structures with lower environmental impact, if being used for disposal
- Strength of all manufactured elements to exceed the maximum pressure able to be generated by the hydraulic pump
- Spill, equipment failure response plans

There should also be a specification for the material selected for containment once we know the smallest fragment size from which the two exotic species can regrow. The exact size should be confirmed by trial. The proposal should also be able to address concerns of failure and should cover health and safety (see "App. 3 Legislation").

A trial will need some preliminary documents:

- Methodology: written brief and some performance specifications covering site establishment and material handling from front end of dredge to back end, including disposal
- Equipment list
- A quality assurance plan (standard operating procedures and how these are managed to ensure qulaity and consistency)
- General health and safety plan, safe work method statement
- Environmental impact safety plan and biosecurity plan documenting how further spread will be mitigated and describing environmental impacts

App. 3.1 Operational considerations

All the operations can be carried out on a boat that is not physically connected to land, including the diving operations and suction dredge pipe. Straight, heavy machinery dredging does not select what is sucked up the nozzle. Diver-controlled dredging allows control of the nozzle and oversight of caulerpa fragments going up the nozzle but involves a high level of diver expertise. There are different ways to separate the caulerpa from sand, including pumping into dewatering bags with fine mesh bottoms, using drum filters at the nozzle end, or wedge-wire screens.

Suction dredging has been used as both a primary and secondary phase tool in California. At one site, they removed caulerpa by dredging and then followed this with hand removal and hypochlorite pellets. At another site, they removed caulerpa with mats and chlorine injections. Large biomass of caulerpa can be removed by suction-dredging first with the remaining caulerpa (e.g. under the sediment) removed by hand or treated with mats, with or without chemicals. Treatment could be done layer by layer. Treatments and approaches should be dredging or mats with chlorine (as in California) first. The key is to stay flexible and adapt the approach as needed for the specific site. The combination of treatments at one site may not be the best combination for the next site. Monitoring progress will be key to better understand the effectiveness of the operations.

App. 3.2 Suitable locations

Trials could be run on block areas of 1 to 2 ha, heavily infested by caulerpa. It is probably not helpful to choose a plot that is ideal for suction dredging. Some challenges of seafloor composition, topography, caulerpa patchiness, or other factors will be useful as a proper test of the approach.

Site selection for a trial must be a subpopulation and entire local area of a caulerpa incursion (not part of a bay, for example, but a whole bay). The treatment area must be isolated from nearby occurrences of caulerpa to prevent reimmigration.

Remote areas are resource-heavy locations for fieldwork, both in terms of getting gear to the remote areas and providing for the needs of the team while they are there. Consideration should be given to planning how to resource the suction-dredging activity and efficacy monitoring at remote locations.

App. 3.3 Requirements for a successful trial

- Determine the goal of the trial: local elimination or biomass reduction? If the treatment involves clearing an area within a larger exotic caulerpa infestation, regrowth will occur rapidly, and this is not analogous to treating a novel infestation, whereas this would be relevant if the goal was biomass reduction.
- Have robust scientific oversight, and have scientists working very closely with dredge operators to ensure that the approach is robust, consistent and remains scientifically valid across the entire scope of the trial.
- Determine a baseline measure of current diversity and environmental status of the area to compare before and after treatment.
- Address any tikanga, tapu, taonga species and values for the area.
- Obtain resource consent and identify suitable spoil disposal methods before treatment occurs.
- Identify an area to be treated, cost it up, and measure the time required and resources during treatment.
- Track the resources, costs and time of the treatment during the treatment to track the costs and timing against the proposal.
- Have an efficacy and environmental impact monitoring protocol in place before, during and after the treatment.
- Run suction dredging and salt treatment trials in the same location on the same area at the same time to test the efficacy, impacts and costs of both treatments.
- Test the method on a range of different habitats, caulerpa densities and depths to understand the limitations of the tool.
- Monitor the site and adjacent area for reinfestation of exotic caulerpa both within the treated area and adjacent habitat.

App. 4 Resource consents

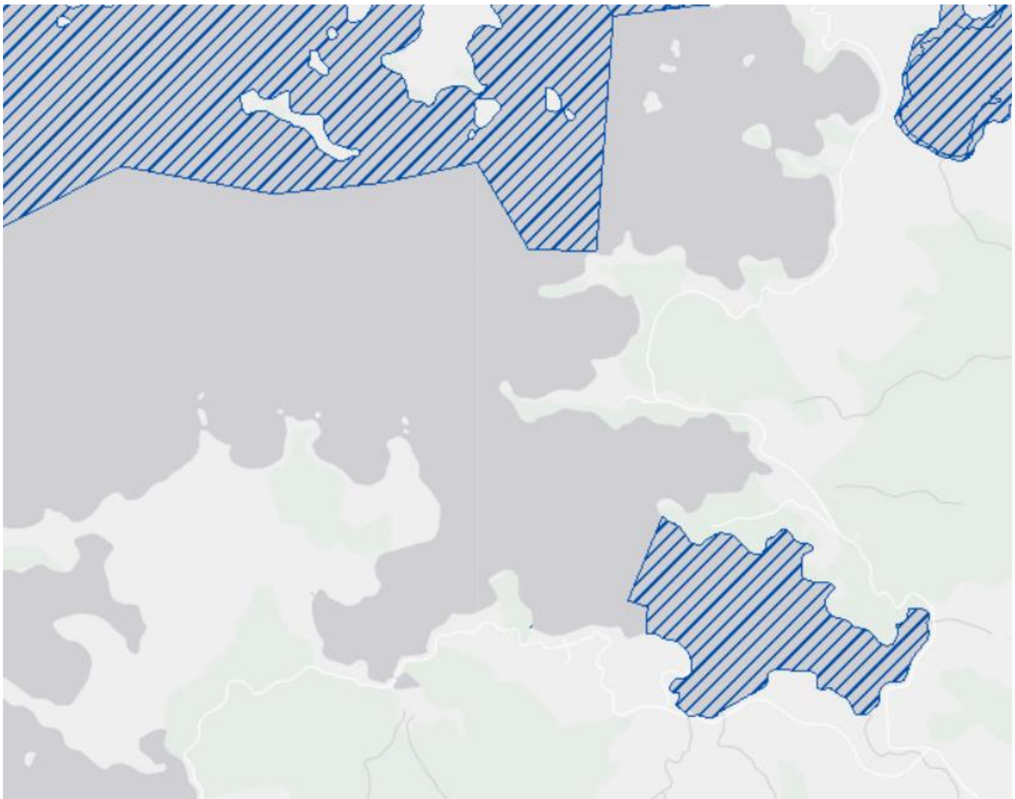
Resource consents require an Assessment of Environmental Effects (AEE) to accompany the consent application. As a minimum, the AEE must include:

- description of the proposal
- description of the site and locality – including site plan
- description of the possible environmental effects of the activity
- description of effects on tangata whenua and their taonga
- description of ways in which adverse environmental effects can be avoided, remedied, or mitigated
- names of people affected, including tangata whenua, by the proposal
- record of any consultation you've undertaken, including with affected parties (if any)
- discussion of any monitoring of environmental effects that might be required
- any relevant objectives, policies, or rules in the Regional Plans
- any relevant objectives and policies in an Iwi/Hapu Environmental Management Plan that covers the location of your application.

App. 4.1 Northland: Resource consent required through Northland Regional Council (NRC)

Proposed suction dredging in Northland would fall under C.1.5.12 of the Proposed Regional Plan as a **discretionary activity, as long as the activity is not in a mapped significant ecological area** (shaded below).

(Note any works in the shaded area are subject to a Section 104D Gateway test.)



Based on survey work carried out by NIWA and Northland Regional Council to date (2.06.2023 Caulerpa Maps), all identified *Caulerpa* locations in Omakiwi Cove fall outside mapped significant ecological areas (SEAs), with the exception of the two most north-eastern locations (where seaweed were identified).

Consent application has a 20-day maximum turnover, during which the council allows Iwi/Hapu to respond.

In the instance of Bay of Islands, Ngāti Kuta, Patukeha, Ngāti Wai and Ngāpuhi need to be consulted. A notice of support from these iwi/hapu before applying for consent would expediate the application significantly.

As of July 2023, Northland Regional Council has an existing resource consent to use mats and chlorine. The council is in the process of amending the consent to include salt and remove any limitations to the size of the mats that can be used.

App. 4.2 Auckland: Resource consent required through Auckland Council

Advice from Resource Consents at Auckland Council

- All current outbreak areas on Aotea fall within the General Marine Zone except the eastern side of Tryphena Harbour, which is within an SEA M1 & M2.
- All current outbreak areas fall within the Aotea Outstanding Natural Landscape Overlay (ONL)
- Parts of Whangaparapara Harbour and coast to north fall within Outstanding Natural Character Overlays (ONC)

This type of small-scale suction dredging is not covered by ‘dredging’ in the Auckland Council rules, because it is not being used to deepen channels for maritime navigation. Instead it is covered by ‘disturbance activities’.

Rules triggered by using suction dredge to remove caulerpa:

Rule F2.19.14(A32) Coastal Marine Area Disturbance not otherwise provided for

F2.19.4 (A32) is a permitted activity in GMZ, SEA, ONL and ONC areas provided it meets the following criteria:

1) Any visible disturbance to the substrate of the coastal marine area must be remedied or restored within 48 hours of the completion of the works if within SEA, ONC, ONF Overlay and within seven days within all other marine areas.
2) There must be an emergency spill plan in place to address the unforeseen release of contaminants from equipment which may result in spills being used for the activity.
3) There must be no discharge of chemical herbicides in the coastal marine area, other than as provided for in an approved pest management strategy.
4) All equipment and materials must be removed from the foreshore and seabed on the completion of works or activities.
5) Any disturbance associated with control or eradication of any exotic or introduced plant or animal species must be: (a) in accordance with an approved pest management plan prepared under the Biosecurity Act 1993; and (b) written advice must be given to the Council at least 10 working days prior to the work starting.

(6) Non-compliance with F2.21.5.3(1), (2), (3), (4) or (5) is a non-complying activity.

A suction dredge trial is likely to run into issues complying with Criteria 1 given the large-scale visible disturbance that trialling would create. This would mean that Rule F2.19.4

(A37) is triggered and the activity becomes non-compliant, but a resource consent can still be applied for.

Rule F2.19.7 (A70) Discharge not otherwise provided for in the Plan

F2.19.7 (A70) is a discretionary activity everywhere other than Whangaparapara and the coastline to the north, where it is a non-compliant activity and must meet the following standards:

1) The discharge must not, after reasonable mixing, give rise to any or all of the following effects:
    a. the production of any conspicuous oil or grease films, scums or foams, or floatable or suspended materials;
    b. any conspicuous change in the colour or visual clarity water in the coastal marine area;
    c. any emission of objectionable odour; and
    d. any significant adverse effects on aquatic life.

App. 4.3 Waikato: Resource consent required through Waikato Regional Council

Mercury Islands are classified as an Area of Significance Conservation Value. Rules will be assessed in relation to impact to this additional overlay.

Rules triggered by using suction dredging to remove caulerpa:

Rule 16.2.2 Removal or Eradication of Exotic Plant Species

- Considered a controlled activity provide it meets the following Standards and Terms:
- The exotic plant species is spreading, or is colonising, or is destroying existing plant communities or destroying the habitat of existing fauna.
- The exotic plant species is restricting the natural movements of sediment, water or biota.
- No contaminants shall be discharged to water or land from the vehicle.
- WRC has control over size of eradication area, method used for eradication, monitoring requirements, timing of works.

Rule 16.6.12 or 16.6.12 Disturbance to the Foreshore or Seabed

- Rule depending on if the dredging exceeds any of the following:
- in quantities of 50,000 cubic metres or less; or
- extracted from areas of less than 4 hectares; or
- which extends less than 1,000 metres over the foreshore or seabed.
- Seabed disturbance under Rule 16.6.12 and 16.6.13 is a Discretionary activates provide they meet the following standards and terms
- For 16.6.12:
    - There shall be no disturbance to high density shellfish breeding beds, areas vegetated by mangroves, eel grass or saltmarsh, bird nesting areas during nesting season, fish spawning grounds or any area identified as waahi tapu.

- For 16.6.12
  - There shall be no disturbance to shellfish beds, vegetated areas, bird nesting areas during nesting season, fish spawning grounds or any area identified as waahi tapu.

If these standards are not met, it becomes a non-compliant activity.

App. 5 Legislation

Caulerpa is an unwanted organism, and section 52 of the Biosecurity Act requires a permit to move unwanted organisms. Private landowners who may wish to have caulerpa composted on their land will also need a permit. If dredging encourages or causes propagation, it is likely to require permission from a chief technical officer under section 53 of the Biosecurity Act. If dredging is prohibited by the controlled area notices that are currently in place, it would need permission from an inspector or authorised person under section 134(1)(b)) of the Biosecurity Act. Permits can take up to 20 working days to be processed.

Suction dredging requires a coastal permit (resource consent) under the Resource Management Act 1991. Relevant sections are 9 and 12–15. Obtaining a permit requires an assessment of environmental effects, with consideration of any regional plans or iwi/hapu environmental management plans that are in place in the areas affected. Permits can take up to 20 days to be processed if no additional information is needed. Emergency resource consent is unlikely to apply to this situation, as it has been a long time between initial detection and the preventive measures being proposed.

If the dredging involves dumping waste or other matter in the “coastal marine area” (foreshore, seabed, and coastal water between the outer limits of the territorial sea and the mean high water springs), the Resource Management (Marine Pollution) Regulations 1998 may be relevant.

There are a few marine reserves in the Bay of Islands. Under the Marine Reserves Act 1971, nothing can be taken or removed from a marine reserve. Biosecurity New Zealand would require authorisation from the Director-General of Conservation to take exotic caulerpa from a marine reserve.

Treaty of Waitangi obligations (including consultation) should also be considered. The organisation may need to assess what principles are involved. This includes the positive duty of the Crown and Māori to act in good faith, fairly, reasonably and honourably towards each other and the positive duty of the Crown to protect Māori property interests and taonga, including te moana. The Treaty of Waitangi will be especially important if suction dredging is likely to disturb the seabed in a way that kills other organisms. Biosecurity New Zealand should also check whether it has obligations to iwi under any deeds of settlement (and settlement acts and accompanying accords) with any affected iwi, whether in relation to te moana, biosecurity, or both.

Under the Marine and Coastal Area (Takutai Moana) Act 2011, a response using suction dredging must also consider what customary interests may be affected.

Biosecurity New Zealand should also assess the impact of suction dredging on communities, businesses, iwi and other parties more broadly and the extent to which these parties should be consulted.

If the area is in the territorial sea, the response should also look at the activity in the context of the New Zealand Coastal Policy Statement.

There will be health and safety duties and obligations under the Health and Safety at Work Act 2015.

If the dredging takes place in Aotearoa's exclusive economic zone or continental shelf, there may be restrictions under the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012. This act includes restrictions on activities that are likely to have an adverse effect on the seabed/subsoil or marine species and their habitat.

If harmful substances are being discharged from seacraft into the sea or seabed in the EEZ or continental shelf, there may be restrictions under the Maritime Transport Act 1994.

App. 6 Overseas experience with suction dredging

App. 6.1 Lessons from California

In California, recent work in China Cove has cleared 200 m^2 of caulerpa over 1.2 ha of sandy substrate. Although still within a relatively sheltered area, the site bathymetry was sloping, and tarps were deemed unsuitable. Initial suction dredging was followed by hand removal over a multi-year period. Algae material and dredge spoils (to a depth of ~10 cm) were deposited on land for disposal. Following dredge work, surveillance diving was used to detect and remove remnant seaweed and fragments. This work is still ongoing.

Suction dredging is included in the current Newport Bay *Caulerpa prolifera* Rapid Response Plan and is listed as a tool on the California Department of Fish and Wildlife website as a primary response supported by CDFW, along with partners on the Southern California Caulerpa Action Team from the Santa Ana Regional Water Quality Control Board, State Water Resources Control Board, California Coastal Commission, NOAA's National Marine Fisheries Service, U.S. Fish and Wildlife Service https://wildlife.ca.gov/Conservation/Invasives/Species/Caulerpa.

The use of tarpaulins in combination with chlorine treatment was the phase one method used by the Californian response team to eliminate *C. taxifolia* from the two Southern Californian lagoons, Agua Hedionda Lagoon near San Diego and Huntington Harbor. Eradication at those two sites required rigorous and regular surveillance of the site. Divers also removed regrowth by hand or placed hypochlorite tablets on the regrowth. Removing caulerpa by hand is labour-intensive but has been shown to be a very effective method and should not be underestimated as a tool for eradication.

According to Rachel Woodfield and Robert Mooney from the Californian team, the human factor was very important in achieving eradication success at the two Californian sites and for the current operation at Newport (see the webinar on these operations). In California, they planted artificial caulerpa at various points to check that the surveillance divers were finding all caulerpa.

The California team also highlighted that while their preferred method was using a tarpaulin mat with hypochlorite tablets, the topology and hydrology of the more recent site at Newport was not suitable for this. They therefore went with hydraulic dredging for the first phase of removal. As with the two earlier sites, they are currently following up with regular surveillance and manual treatment (hand removal and hypochlorite tablets) using divers working along clearly marked physical and GPS grids. They are confident the final outcome at Newport will again be eradication.

The Californian experience tells us we need to be nimble and flexible in our approach to caulerpa removal depending on the nature of the incursion and the geophysical and biological features of the site. It should be noted that the two *Caulerpa* species in Aotearoa are different species, and the sites here are very different. The incursions are also much larger in area. Using the knowledge and experience of the Californian response will be very helpful, but we should be prepared to adapt and change our approach based on the knowledge we acquire from the pilot study.

App. 6.2 Other overseas experience

Most management of caulerpa has been targeted at eradication. There is limited current information in many areas on the long-term success of pursuing eradication. In Australia and Croatia, management was largely abandoned after the situation became too costly to continue.

In Spain (early 90s), the spread of *Caulerpa taxifolia* from a 2-ha site was successfully contained through a combination of suction dredge and manual hand removal. Annual treatments were required. There is no recent information on whether this was successful long term or if suction dredging was used over the whole area.

In Croatia between 1996–1997, caulerpa was removed to a sediment depth of 10 cm via suction dredge from a main infected area covering 1.6 ha near Krk Island. Of this area, 1,300 m² was high density. The main area remained free of Caulerpa up until late 2001. However, it is unclear whether there has been any establishment since that time. Smaller colonies were also cleared within the same area but quickly recolonised due to missed fragments remaining in the substrate.

Also in Croatia, a second infestation in Stari Grad Bay was addressed through a combination of suction dredge and plastic foil. The initial infestation when control measures were started in 1997 was 11 ha and was considered too large to eradicate, so effort focussed on containing this patch by eradicating colonies around its perimeter through the use of a suction dredge and smothering under black plastic. Smaller colonies in other parts of the bay totalling less than 100 m² were also treated this way. The approach was undertaken for five years, over which time the main area expanded to 39 ha, suggesting control was ineffective. For the smaller colonies, the combination of repeat suction dredge and covering was successful at suppressing the area of infestations and in some cases resulted in elimination. It is unclear what the long-term success of this project has been.

In Australia, an infested area of coarse sand totalling 760 m² was effectively cleared by suction dredge in 2001. However, a second area in much muddier substrate could not be cleared due to continual clogging of the geotextile bags attached to the suction dredge. It is the TAG’s understanding that suction dredge clearances are no longer undertaken due to the significant spread of caulerpa since this time.

There is also anecdotal evidence from South Australia that suction dredging has been used to remove surface biomass to suppress growth and slow spread. In this situation, the suction dredging is being used for control only. Without any empirical data on the success/outcomes of this approach, it is hard to say how applicable this approach would be for New Zealand, and it will likely depend on the management strategy chosen.

Regardless, more information is needed, and it would be extremely valuable to trial suction dredging to reduce biomass for control only and before attempting eradication with other approaches.

App. 6.3 Other methods of control used overseas

Other approaches such as tarping an area with or without the application of chlorine or using salt have been successfully applied to areas up to ~4 ha (though not as a continuous area) and have been successful with a single application. Tarping has been used on areas measuring hundreds to thousands of square meters in Croatia and California. Large scale attempts in Australia were unsuccessful because the material used was too buoyant. In California tarping was used to contain chlorine that was applied under the tarp. Salt has been applied in Australia over a 4 ha area, including 2-3 continuous ha within Lake Macquarie. This required 1100 tonnes of salt and the requirements of vast quantities of salt could be a major limitation for this approach.

App. 7 Suction dredging assessed using the criteria for treatments of marine invasive species from Cahill et al. (2021)

Criteria	Suction dredge considerations and issues to address
Efficacy	Removes a lot of biomass. Trial will give more information on efficacy. For example, if one hectare has 100% cover with mixed sandy and rocky seafloor, will we have >90% or >95% or >99% removal based on pre- and post-dredge surveys? Does the dredge *remove* all caulerpa from the seafloor that is directly under the nozzle? If so, this would suggest all propagules of the invader are susceptible to the method. If not, suction dredging may only be useful for biomass reduction or in conjunction with other treatment options. A pilot trial could answer this to some extent (albeit only for the context of the trial area). Does the dredge *capture* all of the removed caulerpa under the nozzle? This may not need to occur at 100% efficacy, but a high rate of efficacy would reduce the number of passes needed for each affected area. The method does not kill caulerpa. Damaged seaweed is likely to regrow. Capture *and* removal are required for elimination or eradication strategies. An Allee effect cannot be applied to caulerpa because of its growth and reproductive biology. We need 100% removal to locally eliminate or eradicate. (Luck could occur if a sufficiently small remnant population is left after treatment, but this would not be sufficient in a strategy beyond the goal of biomass reduction).
Safety	Health & safety requirements can be met using this approach. There are some risks for divers and surface support personnel around vessel operations and equipment usage, but these can be mitigated with appropriate procedures and safety equipment. It is likely that contractors could readily provide the information and certifications to proceed. Physical impacts may include sedimentation and temporary water quality (clarity) issues. These are likely to be acceptable or manageable. Likewise, inadvertent physical damage to infrastructure or marine spaces by vessel ops is low risk and manageable. Environmental risks include damage to habitats and impacts to non-target organisms. Some of these are unavoidable and necessary to proceed with this method. Ecological and cultural considerations will have to be evaluated and a pilot trial may be able to provide some answers to uncertain issues.
Biosecurity	On-site failure to capture all fragments (during treatment) of caulerpa underwater may not be a significant biosecurity risk for spreading the seaweed but may contribute to underperformance of suppression, elimination, or eradication goals.

Criteria	Suction dredge considerations and issues to address
	Excessive non-capture of underwater fragmented caulerpa may pose a risk of spread (but is unlikely and probably measurable). Above water filtration (1 mm mesh) of dredge effluent must be reasonably effective at capturing caulerpa because excessive release of plant fragments may undermine the method significantly (and potentially contribute to plumes of dispersal that are worse than a do-nothing scenario). Can 1-mm-wide fragments of caulerpa persist and regrow? Can measure post-mesh effluent to rule out any issues. The life cycle of caulerpa may need more evaluation to ensure the timing of suction dredging does not coincide with the plant's potential periods of spore release, which could undermine removal efforts or increase spread risks (check this – life cycle issues may already be resolved here). Decontamination of divers, dive gear, and some equipment prior to their re-entry to other sites is imperative to prevent spread. Anchors and any equipment that touches the sea floor require special attention. Vessel fouling is unlikely to be a transfer risk, but vessel niche areas could be quickly checked for seaweed entanglement prior to departure from the site. All captured material in bulk bags on the barge must not return to the sea once the barge is underway after working at an infested site. Deck wash containment and treatment, or decontamination prior to overboard, is also required to minimise the likelihood of caulerpa spreading to new sites.
Quality control	Quality control can only be implemented with surveys and monitoring before, during and after the dredging. It is challenging to measure removal or capture during dredging. Cameras or diver data collection can have some usefulness but require sufficient visibility. Additional dive personnel during operations can complicate H&S. If key questions of efficacy can be answered at the small scale (susceptibility of the organism under the nozzle) and large scale (percent cover removed), then strong quality assurance policies can be drafted and implemented to ensure consistent levels of efficacy are achieved for every deployment.
Compliance	Consents are needed for any activity that affects or removes material from the seafloor, manages an invader, and collects/removes species from the marine environment. Discharges to the sea also require consents, as does appropriate permitting for landfill disposal. Permits may be needed to transfer unwanted organisms under certain circumstances (Biosecurity Act). We have supporting documents regarding applicable laws and consent procedures. Fisheries New Zealand has recently created a new special permit category for collecting marine life in biosecurity scenarios. Consents can be obtained for suction dredging for caulerpa in Aotearoa.