Estimates material on Biosecurity

Out of Scope

Spend on Caulerpa

Biosecurity New Zealand, in partnership with mana whenua, local authorities and DoC, has been responding to two exotic caulerpa seaweed species since July 2021, at Great Barrier Island, Great Mercury Island, Te Rāwhiti Inlet in the Bay of Islands, Iris Shoal near Kawau Island, and at Waiheke Island.

A total of $10.8 million has been committed or spent to date by the Ministry for Primary Industries to fund work to understand the behaviour and distribution of exotic caulerpa, to trial treatments and removal methods, and to prevent spread through legal controls and public education.

Committed a total of $5.8 million (excl accelerated programme)

Area	Total Time	Weight delivered to treatment site	Total Cleared Area	Method
Aotea	19.4 hours	17 tonnes	1200m^2	Suction dredging (diver assisted)
Waiheke	8 days	3.157 tonnes	540m^2	Suction dredging (diver assisted)
Kawau, Iris Shoal	6 days	26.9 kg	1,212 m^2	Hand removal
Te Rāwhiti	Monitoring data to be confirmed	Approx.100 tonnes mass (includes substrate, % of exotic caulerpa unknown)	1998m2	Suction dredging (mechanical)

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Exotic Caulerpa Accelerated Programme ($5mil)

Removal Projects

Project	Total Time	Caulerpa density and habitat	Total Cleared Area	Method
Omakiwi Cove removal trial	TBC	High to very high density, sandy substrate	17,430m2	Suction dredging (mechanical with sand separating trommel)
Iris Shoal diver operated suction dredging	15 Days	Low Density, sandy sediment	12,700m2	Suction dredging (diver assisted)
Aotea perimeter management	8 days	Low to medium density, hard rocky substrate	2600m2	Suction dredging (diver assisted)

Other Projects

Area	Objective
Waiheke Island	Establish a rapid, cost effective, culturally sensitive approach for large-scale seafloor surveys using automated technology – including remote and towed cameras.
Ahuahu Great mercury Island	Surveillance will determine the extent of the infestation in preparation for a local elimination programme depending on the survey outcome.
National Advisory Group	Stakeholder input into future management strategy and decision making – first meeting 12 June 2024.
Enhanced public awareness	public information campaign boosted during the programme with increased signage and printed material in priority regions, radio and digital activity

The response is actively developing a transition pathway to a long-term management programme that will be nationally coordinated and locally delivered including providing toolboxes for treatment, surveillance, and behaviour change.

Out of Scope

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Ngāti Rehua Ngātiwai ki Aotea Iwi Trust Board

Ngāti Rehua-Ngātiwai ki Aotea Trust Board
PO Box 5
Port Fitzroy
Aotea 0960

25 May 2024

Tēnā tātou Ministers

Request for Establishment Funding and Urgent Control Works for Exotic Caulerpa at Aotea

I am writing to you to introduce the Aotea Caulerpa Response Team (ACRT) and to formally request funding for its work. ACRT is a mana whenua led partnership with the community. Our purpose is to stop the spread of exotic Caulerpa in our waters, remove existing masses and set up for long term, cost-effective control based on Aotea. The group is co-Chaired by Ngāti Rehua Ngātiwai ki Aotea trustee Fletcher Beazley and Chris Ollivier, Deputy Chair of the Aotea Great Barrier Local Board.

The accompanying proposal to this letter outlines our proposed approach and prioritises in-water removal action in our harbours over winter, and establishing Aotea based teams to control Caulerpa cost-effectively in the future. This work has the full support of the Ngāti Rehua Ngātiwai ki Aotea Trust Board.

We request a kanohi ki te kanohi meeting with you as soon as possible to discuss the proposal and emphasise to you the urgency of the situation. A delegation will come from Aotea to Wellington for this meeting, if necessary, but we stand ready to meet you here on Aotea or in Auckland if that is your preference.

Context for this request and funding proposal

In winter of 2021 Caulerpa was first discovered on the Aotea (Great Barrier Island) coastline at Okupu, then at Tryphena and Whangaparapara. Since that date it has spread in small and large patches from the southern end of the island to the most northern tip - approximately 40km of coastline. At present three out of four safe anchoring harbours are closed off for anchoring fishing, diving, and there is no take of all shellfish, kina and crayfish. This restriction has been put on all Barrier residents (approximately 1,000 permanently here) as well as visitors and boaties visiting the island.

Pre-2021 Aotea would be visited by approximately 800 to 1,000 boaties every holiday season. The community understood that the restrictions were put in place because of the fear this devastating weed would spread not only to other areas of coastline of Great Barrier but the eastern coast of the North Island. The support for the restrictions from the locals has been overwhelming and this summer was enforced by our own on-water ambassadors, funded by MPI, with more than 170 known breaches - mainly by non-locals.

With this acceptance of restrictions, there was also the understanding that solutions to control and remove Caulerpa were on the near horizon and the investment to support this would be put in place. This has not happened. What limited funds that were available through MPI went towards research, trials and monitoring. We acknowledge Auckland Council's support in utilising the minimal funding that has been made available to Aotea.

Three years on from the first report of Caulerpa here, there are still no funds to support us to stop it spreading, or to open up our harbours, let alone consider elimination. Of the $5million Accelerator Programme, Great Barrier Is only receiving $200,000.

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Decisions made by your officials in 2021 and 2022 not to use proven dredge tools to eliminate Caulerpa from Tryphena and Whangaparapara early in its growth, and not to reduce the Okupu masses have led *directly* to the spread of Caulerpa. It has spread not only along 40kms of our coasts, and closed our harbours, but also to the Mokohinau Islands and likely other sites too.

At Port Fitzroy, only the proactivity of this community ensured that surveys were conducted to allow the harbour to be open over the summer of 2023/4. We continue to work hard alongside Auckland Council to keep this harbour free from Caulerpa as the only safe haven for boaties to anchor.

The impact to the Great Barrier Island residents has been devastating. Locals have lost their freedom on the water, tourism and visitor numbers are at a low ebb, there has been a devastating slump in business confidence, and charter vessels, local commercial fishers, and hospitality and retail business owners have taken a big hit.

Government must take this seriously

Because of the failure of MPI's response Aotea is suffering the impacts and they will get even worse if the procrastination around fit for purpose financial support to implement an immediate control and long-term elimination plan continues. Great Barrier Island has always been the largest affected area in NZ. We feel that we have been marginalised and the fear is that Aotea will be a source for the spread of Caulerpa to the whole eastern coast of the northern half of the North Island.

Although we have proposed funding to support immediate control measures, we may need up to $100 million over the next 5 to 10 years to seriously hit it hard and make sure it does not reestablish.

As Iwi/Hapū we see this as a very serious matter. We are very disappointed in the lack of understanding and support from the Crown. Our long-term Ahu Moana monitoring research inside the CAN shows that our native fish can't live with Caulerpa, and neither can we. You could liken Caulerpa infested areas to a barren desert on the seabed. For us this is not except able, and I believe it shouldn't be acceptable to the present Government. We do not understand why MPI have fed us pennies for three years and that is not acceptable either. We just want it gone and we are ready to do the work to make that happen.

We look forward to your response and to meeting you to discuss a way forward.

Nāku, noa nā

Chair
Ngāti Rehua-Ngātiwai ki Aotea Trust Board
Call 0211750135

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AOTEA CAULERPA RESPONSE TEAM PROPOSAL

FOR AOTEA PROJECT ESTABLISHMENT AND URGENT CONTROL WORKS

May 2024

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BACKGROUND AND AOTEA CONTEXT

Ngāti Rehua Ngātiwai ki Aotea
Iwi Trust Board

- Caulerpa was detected on Aotea almost three years ago and has spread along the west coast, from Sandy Bay south of Tryphena to Miner's Head, and now at the Mokohinau Islands to our north.
- *Caulerpa brachypus* (present at Aotea and Omakiwi) is far more invasive and costly to control than *Caulerpa parvifolia* (Waiheke/Kawau/Ahuahu).
- The economic impact of *Caulerpa brachypus* spreading across the Hauraki Gulf to the mainland of Auckland, Coromandel, Bay of Plenty and Northland has not yet been quantified but will be significant due to the impact on shellfish, fish stocks, kōura and tourism which has already been observed on Aotea.
- *Caulerpa brachypus* has to be contained on Aotea to protect Aotea and the rest of Te Ika a Maui. Recent finds at the Mokohinau Islands and at Rākino prove this risk is high.
- The most cost-effective approach to achieve this is to build an Aotea-based exotic caulerpa control capability and operate the response locally.
- A Ngāti Rehua Ngātiwai ki Aotea led team has been established to guide this work and to establish the project on Aotea. Ngāti Rehua Ngātiwai ki Aotea by right of customary take are mana whenua to the Mokohinau Islands.
- Our vision for the long term is to efficiently control and remove exotic caulerpa around Aotea to limit its impact, stopping the spread to other communities and to untouched areas of our coast.
- This document outlines the proposed project structure, goals and year one funding requirements.

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Ngāti Rehua Ngātiwai ki Aotea Iwi Trust Board

AOTEA CAULERPA RESPONSE PROJECT STRUCTURE

Ngāti Rehua Ngātiwai ki Aotea Trust

Steering Committee

Appointed by and reporting to Ngāti Rehua Ngātiwai ki Aotea Trust, with four mana whenua and four community representatives (including at least one Local Board member) and reducing to a 3x3 model over time

Overseeing operations and providing support to the Operational Team and the Trust guided by tikanga

Operations

Project Lead and Coordinator: *key contact point, project plan, funding, team management, MPI & Auckland Council liaison*

Communications Officer: *whānau and community education, engagement, visitor communications with agencies*

Surveillance Team: *divers, transport, ROVs, NIWA liaison, Ahu Moana liaison*

Caulerpa Removal Crew: *expert local team for removal and treatment of sites, MPI and AC liaison*

Mapping and Evaluation: *GIS, mapping of sites, recording monitoring data, reports from the public*

Agency Liaison & Enablement

MPI Representative

Auckland Council Representative(s)

DOC Representative

Non-agency Support

Other iwi/community response projects

Californian expert team

Te Wero Nui

Marine scientists

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HOW AOTEA WILL FIGHT CAULERPA & STOP THE SPREAD

Ngāti Rehua Ngātiwai ki Aotea Iwi Trust Board

01

CONTROL THE EDGES

With dredges and mats

02

PATROL THE COAST

To locate new spots and eradicate them whilst small

03

FOCUS ON HARBOURS

Provide short term moorings whilst removing it from harbours to allow the island's economy to operate and the community to fish

04

MASS REDUCTION

Begin exotic caulerpa mass reduction to reduce current spread using dredge tools tested at Omakiwi, and others as they become available

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YEAR 1 PROJECT TEAM REQUIREMENTS

Ngāti Rehua Ngātiwai ki Aotea Iwi Trust Board

ITEM	INCLUSIONS	ESTIMATED COST
Project Lead/Coordinator	Annual contract	$160,000
Finance, administration, H&S and governance support	Annual contract	$80,000
Engagement & Comms Specialist	Annual contract	$40,000
Operational set up (ROVs, GIS, equipment, training)	Estimated cost for two drones, GIS system, training, licensing and other operational kit	$70,000
Detailed ongoing surveillance and removal (vessel, dive and snorkel crews, mana whenua observers)	See 100-day operational plan on following slide	$2,225,000
	TOTAL COST YEAR 1	$2,575,000

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100-DAY PLAN REMOVAL REQUIREMENTS

What we need to fight caulerpa depends on tools, disposal options & the number/size of target areas

Ngāti Rehua Ngātiwai ki Aotea Iwi Trust Board

ITEM	INCLUSIONS	ESTIMATED COST
Surveillance crews and boats to monitor key sites	At least two contracted boats with associated crew, two ROVs	$5,000 per day
Removal crews – spot removal around the perimeter and key sites (multiple methods)	At least one contracted boat with divers, crew	$3,000 per day
	TOTAL FOR 75 DAYS	$600,000
Dredge-capable boat, barge and dredge tools	Based on off-island contracted rates [1]	$50,000 per day
Disposal capability (where not killed in place)	Further research is needed [2]	$15,000 per day
	TOTAL FOR 25 DAYS	$1,625,000

[1] For Aotea, locally-based resources are key to reducing set up costs and maximising people's availability to work within weather windows

[2] Dredge & disposal capability assets to be determined after Omakiwi dredge and Aotea perimeter projects conclude, but will include dredge vessel, dredge, barge, diver support vessel etc.

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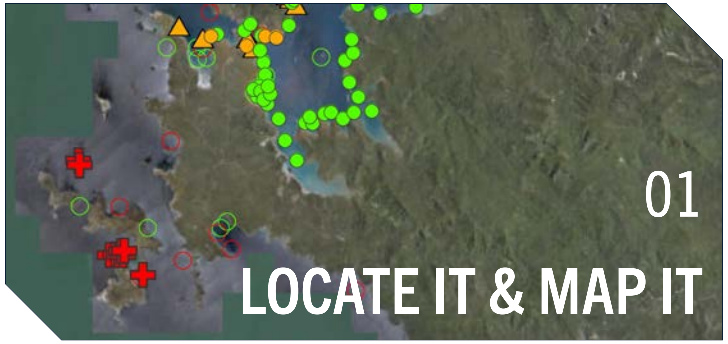
THREE GOALS FOR 2024/25

Ngāti Rehua Ngātiwai ki Aotea Iwi Trust Board



Conduct planned surveillance and GIS mapping of high risk and high value sites

Clear priorities – where to look and why
Trained ROV crews and boats
Post-treatment monitoring of sites
GIS to capture and share data to agreed protocols
Cultural mapping and biodiversity indicators
Aerial surveillance (TBC)
Public reports (e.g., Port Abercrombie, Sandy Bay, Tryphena)

Secure and put into use the best available tools to kill and/or remove it from priority sites

Permits and consents for operations
Trained crews (H&S, dive qualifications, tool use)
Right tool for the size and location and density of caulerpa: benthic mats (e.g., wool), suction from the sea floor (vacuum/dredge), UV light, hand removal)
Disposal processes if removed
Effective and efficient use of resources

Establish Aotea project, build capacity and knowledge, work with new technologies as they emerge

Establish governance, secure funding stream and permits and build operational team
Engage with the community in each harbour/locale
Understand the growth cycle/seasonality: temperature, sediment/water clarity and depth effects; substrate preferences (sandy, reefs, etc.); current/wave effects and spread; human spread; reproduction/biology; effects on (local) ecosystems & marine life

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OPERATING PRINCIPLES

Ngāti Rehua Ngātiwai ki Aotea Iwi Trust Board

- Least-cost sourcing (i.e. not loaded costs from contractors based off-island)
- Maximise availability – flexible, Aotea-based, weather responsive crews that are adaptive to new information
- Work with existing qualified vessel owners who are island-based where available; or lease and base temporarily on Aotea
- Ensure fit for purpose H&S – for marine environment; diving operations (responsibility is with contractors)
- Effectively leverage external experience, tools/technology knowledge and offers of assistance

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WINTER 2024 WORK PROGRAMME

Winter provides an opportunity to delimit spread at the north/east & manage new outbreaks whilst small

Ngāti Rehua Ngātiwai ki Aotea Iwi Trust Board

WORKSTREAM	MAY	JUNE	JULY	AUGUST TO NOVEMBER
SURVEILLANCE	Secure ROV for training purposes Training & trials Identify local boats and skippers for roster	Pilot of local surveillance at Whangaparapara Deploy volunteer divers to Whangaparapara Identify and plan to cover at risk areas	Stand up operational GIS system Survey east coast anchorages Detailed surveillance of Tryphena in advance of dredge deployment	Support Whangaparapara and Tryphena removal sites as required North and east coast surveillance continues Adopt new tools if available
REMOVAL & CONTROL	Complete northern perimeter control project (AC & MPI) Explore mat treatment options and sites Partnering with Ngāti Paoa/others	Procure mats and assess available tools Plan and begin Whangaparapara removal (tools TBC following detailed surveillance)	Plan Tryphena dredge control operation Monitor Whangaparapara site Options for further sites (e.g. Schooner Bay, Miner's Head)	Tryphena dredge operation Build case for island-based dredge team Sea trial of UVC treatment Spot removal of new finds
PROJECT SET-UP	Establish governance processes Present funding request and proposal to MPI (Minister) Secure establishment funding	Prepare project plan – 6-month & HSEW Recruit Project Lead Establish project base and operational processes	Evaluate - Whangaparapara & perimeter Revise business case and project plan Secure long-term funding Continue establishment activities	Further plan and budget revisions as operations continue
SUPPORTING ACTIVITIES	On-water compliance – options after end of April Moorings request to harbourmaster Community engagement	Secure whole of island removal consent (s52) Review of CAN and restrictions Community engagement	Support updated restrictions with on-water monitoring Bottom contact fishing method restriction options inside 40m contour	Review pathways and research needs Community engagement Plan for managing summer boat traffic

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LONG TERM FUNDING OF AT LEAST $15-20 MILLION IS REQUIRED FOR LEAST-COST CAULERPA CONTROL ON AOTEA

OUR PURPOSE

To limit the spread of exotic caulerpa around Aotea and reduce the risk that boats will spread it to the mainland - cost effectively & efficiently as possible

OUR VISION

A locally operated, long-term control capability:

- Surveillance programme and crews to patrol clean coasts and monitor treated sites.
- *Rapid-response crew to cover new finds early in their growth.*
- *Maintenance of Caulerpa-free harbours to allow free movement of vessels.*
- *A dredge team – diver directed and remote tools with supporting barge.*
- *Long term scientific monitoring of exotic caulerpa biology and ecological interactions.*

BENEFITS FOR ALL OF NEW ZEALAND

- *Aotea is ground zero for NZ's worst ever marine pest and without control here other investments are put at risk.*
- *Displaces scallops, crayfish, mussels and other species such as seabirds, rays and dolphins that depend on inshore ecosystems.*
- *Other sites will benefit as Aotea builds experience on multiple substrates – optimising rapid detection, control & removal operations in a range of conditions*

Ngāti Rehua
Ngātiwai ki Aotea
Iwi Trust Board

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Ngāti Rehua
Ngātiwai ki Aotea
Iwi Trust Board

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Northland REGIONAL COUNCIL
Te Kaunihera ā rohe o Te Taitokerau

Caulerpa i Pewhairangi | Caulerpa in the Bay of Islands

The cost of inaction

12 June 2024

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1. Papamuri | Introduction – Caulerpa

In the middle of 2021, divers discovered colonies of two exotic species of seaweed – Caulerpa brachypus and Caulerpa parvifolia – growing in the waters around Aotea/Great Barrier Island. Earlier this year, scientists discovered that the same Caulerpa species had spread to the Bay of Islands. Though biosecurity experts are actively working to contain the outbreaks, eradicating the seaweed will likely take years.

As far as the Economics Team at the Northland Regional Council know, no countries modelled the economic impacts of Caulerpa outbreaks. However, ecologists across multiple Mediterranean countries have spent decades tracking the spread of Caulerpa taxifolia, a similar organism that began to colonise large parts of the region in the 1970s. Notably, across much of Europe, efforts designed to control the spread of Caulerpa taxifolia were largely ineffective, creating an ecological disaster and providing us with the data we need to estimate the cost of failing to contain the spread of Caulerpa in the Bay of Islands.

In this report, we first estimate the likely growth path of Caulerpa in the Bay of Islands and then use this growth path to estimate the costs, both tangible and intangible, of failing to contain the outbreak. Our analysis assumes that the Caulerpa species found in the Bay of Islands exhibit similar growth characteristics to Caulerpa taxifolia.

Caulerpa taxifolia outbreak in the Mediterranean

A Natural History

When Prince Albert I of Monaco opened the country's Oceanographic Museum in a grand and imposing building nestled along its Mediterranean coast, he intended for it to serve as a monument to the marine sciences, designed to educate visitors, advance the field, and protect the region's delicate ecosystem. Just months after he opened the museum in 1911, Albert began touring European capitals and boasting about it to the scientific community, describing his new institution as a "palace worthy of intellectual humility," during a speech in Madrid.

To this day, guests that visit the Oceanographic Museum can spend hours wandering through vast halls lined with thousands of carefully protected aquatic creatures, learning about the natural world as they gaze out at the sea. A few times each year, the museum even hosts dignitaries, activists, and corporate leaders for conferences about marine conservation.

But a little over four decades ago, the museum renovated its displays and sparked an ecological crisis that continues to affect much of the Mediterranean Sea. In the late 1970s, visitor counts at the museum were dropping and its staff were looking for ways to improve the quality of their exhibits. Within a few short years, under the leadership of the French explorer Jacques-Yves Cousteau, they had developed a simple plan.

In place of the corals that decorated their aquaria, the museum's decorators decided to start growing beds of vivid green, imported seaweed that swayed underwater throughout the year, hoping to enhance the vibrancy of their displays.

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At the time, oceanographers actively supported the idea, with some going as far as to recommend that they use Caulerpa taxifolia, a seaweed species native to Australia that was known for its ability to thrive across a range of conditions, in their exhibits. Soon after, the museum began its renovations, completing them by the end of 1982. And at first, their plan appeared to work. Visitors embraced the updated displays and the Caulerpa beds didn't appear to affect other organisms in the museum's self-contained aquaria.

It was only years later, in 1984, that oceanographers began to worry. Early in the year, diving enthusiasts exploring the waters around Monaco discovered a small patch of seaweed growing just outside the museum and started tracking its growth.

At first, some experts suspected that the patch would wither in the Mediterranean's frigid winter waters. In his 1999 book, Killer Algae, the French scientist Alexandre Meinesz recounted that Dominique Bezard, the museum's aquaria director, seemed to think that "the Caulerpa prairie seemed sparser in the winter." But after observing the seaweed over multiple years and seasons, scientists began to realise that, in the wild, the features of Caulerpa taxifolia that had made it attractive to aquarium decorators were enabling it to spread out across the sea.

Each time they checked in on the patch, observed found that it had grown and inched towards parts of the sea that native seaweed and fauna occupied. By 1989, divers in France had discovered Caulerpa taxifolia colonies growing near Nice and Toulon; two years later, it had spread to Spain and Italy; and by the end of the decade, scientists estimated that the Caulerpa taxifolia had grown to cover over 13000 hectares of the Mediterranean seabed.

Though some European governments did attempt to control the spread of Caulerpa taxifolia, their campaigns were largely unsuccessful. In a small number of cases, governments even appeared to successfully eradicate the seaweed, only for observers to return weeks later and find it reoccupying the seabed. Today, large portions of the Mediterranean seabed remain covered in dense forests of seaweed, harming the region's economy, level of biodiversity, and aquatic populations.

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Growth Rate

In this section, we model the growth rate of Caulerpa taxifolia across four European regions, France/Monaco, Croatia, Italy, and Spain over an eleven-year period between 1989 and 2000. Our models suggest that the growth rate of Caulerpa taxifolia in the Mediterranean was dependent on the temperature of the sea.

Model:

To understand the growth rate of Caulerpa taxifolia, we fit a model describing its logged spread to data collected from four regions bordering the Mediterranean between 1989 and 2000.

$$E(Ln(Coverage)) = \alpha + (\beta_1 * Time) + (\beta_2 * Time * Temperature) + (\beta_3 * France/Monaco) + (\beta_4 * Italy) + (\beta_5 * Spain)$$

This model explained 94.49% of the variation in the spread of Caulerpa, indicating that our model fit the data quite well. Further, the errors associated with the model varied randomly around a mean of zero, across every nation.

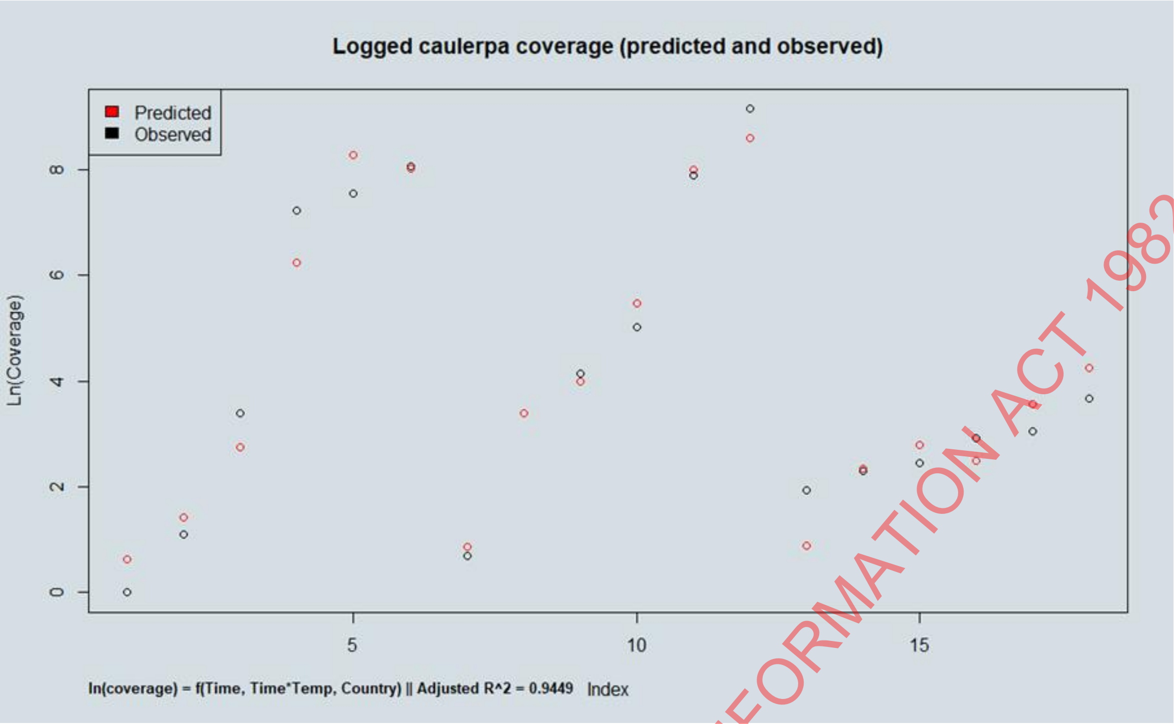

*Figure 1: Predicted and observed logged Caulerpa coverage, using the model: ln(Coverage) = f(Time, Time*Temperature, Country)*

Estimated Effects:

Model Term	Estimated Effect
Intercept	0.8836
Time	1.8336
Time * Temperature	-1.6597
France / Monaco	-0.2468
Italy	2.3492
Spain	-2.2660

The significance of the terms France/Monaco, Italy, and Spain can be explained by the likely lag between when Caulerpa taxifolia first began to spread and when divers first observed its spread in each of the respective regions.

All the terms in this model, with the exception of France/Monaco, are statistically significant. Our model's estimated effects imply that France/Monaco and Croatia detected their Caulerpa invasions at the same stage as each other, later in the invasion than Spain, and earlier in the invasion than Italy.

Alternate Model:

$$E(Ln(Coverage)) = \alpha + (\beta_1 * Time) + (\beta_2 * Time * Temperature)$$

This model explained 67.48% of the variation in the spread of Caulerpa, indicating that our model fit the data quite poorly. However, we should note that most of the errors in the model were

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associated with clear, and remarkably stable, country effects, indicating that our estimates of the effects of Time and Time/Temperature are relevant.

The errors associated with Spain varied around a mean of approximately two; the errors associated with Italy varied around a mean of negative two; and the errors associated with France/Monaco and Croatia varied around a mean of zero.

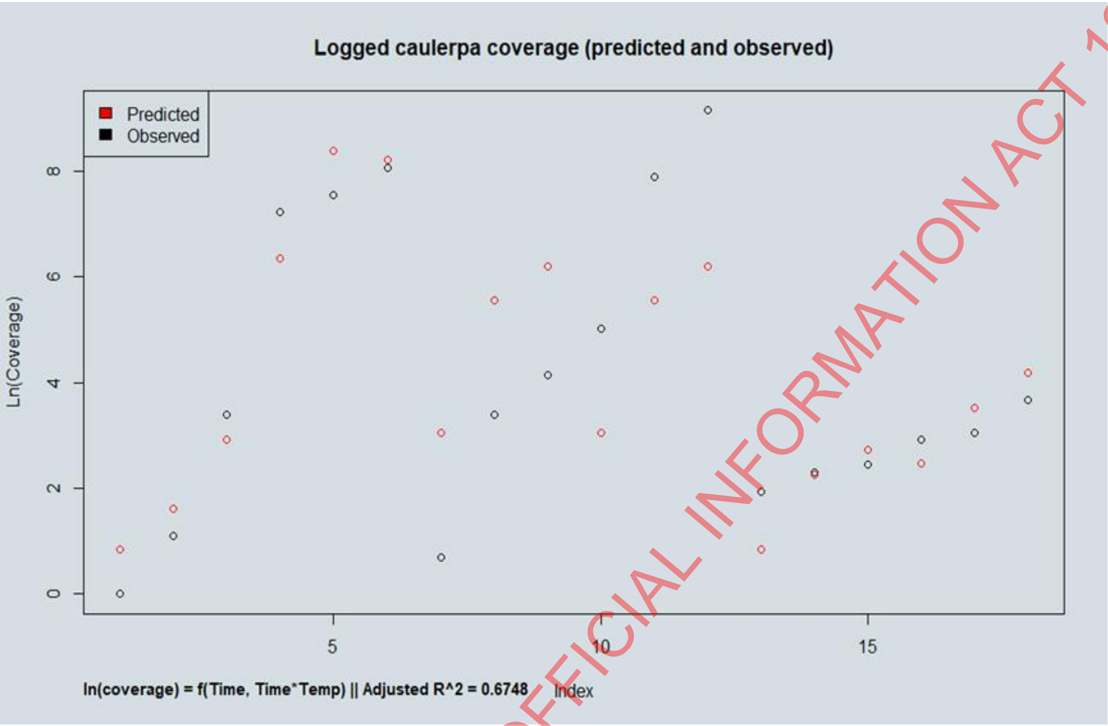

*Figure 2: Figure 1: Predicted and observed logged Caulerpa coverage, using the model: ln(Coverage) = f(Time, Time*Temperature)*

Alternate Model Estimated Effects:

Model Term	Estimate
Intercept	0.8436
Time	1.7910
Time * Temperature	-1.6013

Data Sources

Variable	Data Source
Time	Appendix 2; Killer Algae by Alexandre Meinesz | Meinesz, A. (2001). *Killer Algae*. University of Chicago Press
Temperature	NASA's Combined Land-Surface Air and Sea-Surface Water Temperature Anomalies (Land-Ocean Temperature Index, L-OTI) Datasets; Zonal mean for the region encompassing the Mediterranean Sea.

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Coverage	- Meinesz, A., Belsher, T., Thibaut, T. et al. The Introduced Green Alga Caulerpa Taxifolia Continues to Spread in the Mediterranean. Biological Invasions 3, 201–210 (2001). - Zuljevic, A., & Antolic, B. (2002). Appearance and eradication of Caulerpa taxifolia in Croatia. International Caulerpa Taxifolia Conference Proceedings. - Meinesz, A. (2001). *Killer Algae*. University of Chicago Press; a book about the spread of Caulerpa in the Mediterranean, written by one of the main researchers involved in responding to the outbreak.

Limitations:

Our original model fit six terms to eighteen data points, elevating the risk that it was overfit. On the other hand, our alternate model, which fits three terms to eighteen data points, is highly unlikely to be overfit.

For this reason, the similarity between the estimated effects of Time and Time/Temperature on ln(Coverage) in our original and alternate models suggests that we can trust our original model.

Term	Estimate (Alternate)	Estimate (Original)
Time	1.7910	1.8336
Time * Temperature	-1.6013	-1.6597

Beyond this, its worth mentioning that mean zonal anomalies are relatively crude and imprecise measures of temperature.

Implied Growth Rate:

Both our original and alternate growth models imply that the rate of Caulerpa taxifolia growth in an area is dependent on the average combined land-surface air and sea-surface temperature anomalies in that area.

Using our original model, we can estimate the logged growth rate of Caulerpa in a given area using the equation:

$$E(r) = \frac{dE\big(Ln(Coverage)\big)}{dTime}$$

Using our original model:

$$E(r) = \frac{dE\big(Ln(Coverage)\big)}{dTime}$$

$$\Leftrightarrow E(r) = 1.8336 - (1.6597 * Temperature)$$

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2. **Te whakatau tata i te tipu me te horapa o Caulerpa ki Aotearoa**| Estimating Caulerpa growth and spread in New Zealand

Growth

Between 2010 and 2022, the annual mean average zonal combined land-air and sea-surface temperature anomaly for the region encompassing the Bay of Islands was 0.697692. Assuming that this continues over the next thirty years and that the Caulerpa species found in the region behave similarly to how Caulerpa taxifolia behaved in the Mediterranean, we can calculate an expected average annual logged growth rate of Caulerpa in the Bay of Islands using our expected growth rate equation.

$$E(r) = 1.8336 - (1.6597 * 0.697692) = 0.67564$$

Spread

We can now plug our expected growth rate into the standard logistic population growth function to find the expected coverage of Caulerpa over time:

$$E(Coverage) = \frac{K}{1 + \left(\frac{K - C_0}{C_0}\right) e^{-E(r)*t}};$$

$where\ E(r) = Expected\ logged\ growth\ rate, C0 = inital\ coverage, t = time,$
$K = maximum\ coverage$

Based on a depth map produced by Toitu Te Whenua Land Research New Zealand (LINZ) and conversations with the Northland Regional Council's biosecurity team, we estimate the maximum possible coverage of Caulerpa in the Bay of Islands is 20,086 hectares (Figure 3). This is the area within the Bay of Islands that are shallower than 30m.

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Figure 3: The area of the Bay of Islands that is likely to be occupied by Caulerpa.

When divers discovered Caulerpa growing in the Bay of Islands, the seaweed occupied 10 ha of the area's seabed. For this reason, we assume that the initial coverage of Caulerpa was 10 ha.

Under these assumptions, we can now produce a graph and table displaying the expected coverage of Caulerpa over the first thirty-five years of its invasion.

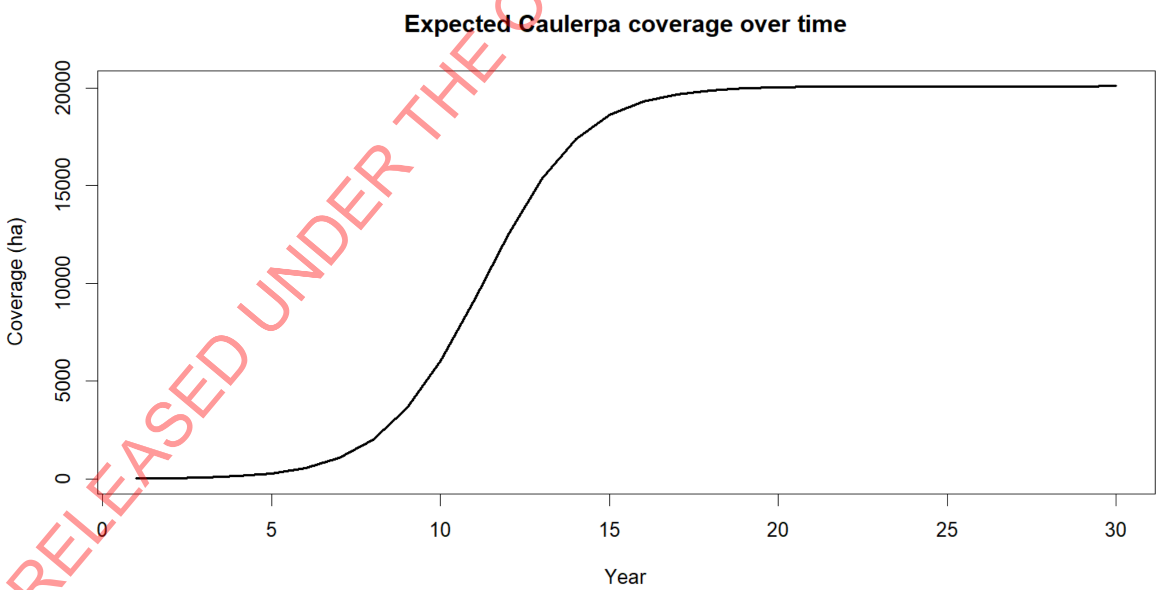

Figure 4: Expected growth path of Caulerpa in the Bay of Islands

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Time	Caulerpa Coverage (ha., 2s.f)
1	19
5	290
10	6000
15	19,000
25	~20,000
30	~20,080

Notably, within the next fifteen years, we believe that Caulerpa is likely to occupy 95% of the area that it can likely occupy.

Limitations

While completing this analysis, we spoke to a population ecologist who pointed that the Mediterranean Sea is an atrophic environment – one with a low level of phosphorus – while the Bay of Islands is a trophic environment. The ecologist suggested that this could result in Caulerpa growing more rapidly in the Bay of Islands than it did in the Mediterranean Sea.

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3. Ko nga utu o Caulerpa | Caulerpa Costs

Tangible Costs

The spread of Caulerpa in the Bay of Island has the potential to impact multiple industries across Northland, through declines in the average biomass of aquatic organisms and the potential decrease in the region's relative appeal to tourists and boaters.

In this section of the report, we specifically consider five types of tangible costs likely to be associated with an uncontrolled Caulerpa outbreak:

- Reduction in the level of GDP generated by firms in the Fishing and Aquaculture sector.
- Reduction in the level of GDP generated by firms in the Accommodation and Food Services sector.
- Reduction in the level of GDP generated by firms in the Transport Equipment Manufacturing sector.
- Reduction in the recreational value of the Bay of Islands.

Our analysis does not consider the broader consumption and employment effects that may follow a drop in GDP.

For each sector:

$$Cost_t = \frac{Caulerpa_t}{Caulerpa_{Max}} * Cost_{Max};$$

$$PV(Cost)_t = Cost_t * \frac{1}{(1+0.05)^t},$$

$where \ \ Cost_{Max} = E(impact) * GDP,$
$Caulerpa_t = Caulerpa \ coverage \ at \ time, t$
$Caulerpa_{Max} = Maximum \ Caulerpa \ coverage \ in \ the \ Bay \ of \ Islands$

Cumulative cost over x years:

$$\mathrm{PV}(Cost) = \sum_{t=1}^{x} PV(Cost_t)$$

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Fishing and Aquaculture

Across the Bay of Islands, firms operating in the fishing and aquaculture sector generate $4.2 million of GDP per year (Five-year average 2018-2023 in valued in 2023-dollar terms, Infometrics regional economic Profile for Northland).

Soon after Caulerpa taxifolia began to spread across France, marine biologists observed that the mean biomass of fish in areas occupied by Caulerpa declined by approximately fifty-seven percent at depths of between two and ten metres, and by approximately forty-two percent at depths of between ten and thirty metres.

The analysis assumes that Caulerpa growth in the Bay of Islands has a similar impact on the region's fish stock as that in the Mediterranean.

- Lower Bound: At maximum coverage, Caulerpa reduces fishing and aquaculture output by 42%.
- Upper Bound: At maximum coverage, Caulerpa reduces fishing and aquaculture output by 57%.

Cumulative Time Period (years)	Cumulative PV – Lower Bound ($)	Cumulative PV – Upper Bound ($)
10	795,000	1,089,000
20	7,790,000	10,600,000
30	12,900,000	17,600,000

Over a 30-year period, it is estimated that the cost of "doing nothing" to prevent the spread of Caulerpa in terms of its impact on the fishing and aquaculture industry in the Bay of Islands to be $13 - $18 million.

Accommodation and Food Services

Across the Bay of Islands, firms in the accommodation and food services industry generate $57.6 million of GDP per year. The analysis assumes that:

- Caulerpa growth uniformly affects spending on Accommodation and Food Services across the Bay of Islands
- Lower bound: At maximum coverage, Caulerpa reduces spending on Accommodation and Food Services by 5%
- Lower bound: At maximum coverage, Caulerpa reduces spending on Accommodation and Food Services by 15%

Cumulative Time Period (years)	Cumulative PV – Lower Bound ($)	Cumulative PV – Upper Bound ($)
10	1,290,000	3,880,000
20	12,700,000	38,000,000
30	21,000,000	63,100,000

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Over a 30-year period, it is estimated that the cost of "doing nothing" to prevent the spread of Caulerpa in terms of its impact on the accommodation and food services industry in the Bay of Islands to be $21 - $63 million.

Transport Equipment Manufacturing

In the process of developing this analysis, multiple environmental economists and ecologists pointed out that an uncontrolled Caulerpa outbreak in the Bay of Islands could cause foreign ports to restrict the movement of ships that visit the area. Even without official restrictions, there is also a likelihood that private vessels owners may seek out other ports to carry-out ship/boat repair services rather than use businesses located in the Bay of Islands. This could severely impact the local transport equipment manufacturing sector.

Across the Bay of Islands, firms in the transport equipment manufacturing sector generate $3.4 million of GDP per year. The analysis assumes that:

- Reputational damage and foreign berth restrictions kick in once Caulerpa occupies 5% of the Bay of Islands.
- Lower bound – at maximum coverage, Caulerpa reduces transport equipment manufacturing activity by 10%
- Upper bound – at maximum coverage, Caulerpa reduces transport equipment manufacturing activity by 30%

Cumulative Time Period (years)	Cumulative PV – Lower Bound ($)	Cumulative PV – Upper Bound ($)
10	137,000	410,000
20	1,470,000	4,410,000
30	2,460,000	7,370,000

Over a 30-year period, it is estimated that the cost of "doing nothing" to prevent the spread of Caulerpa in terms of its impact on the transport equipment manufacturing industry in the Bay of Islands to be $2.5 - $7.3 million.

Recreational Benefits

To estimate the recreation loss associated with the spread of Caulerpa, we first assessed the recreational value of relevant coastal marine environments (CMEs) in the Bay of Islands. Due to a lack of information about the recreational value of CMEs in the area, we estimated these values using research conducted around the Nelson and Tasman Bays (Cole, Clark, and Patterson, 2018).

Using this method, we estimated that the areas of the Bay of Islands likely to be affected by a Caulerpa outbreak generate $5.34 million in recreational value each year.

Notably, this is likely a very conservative estimate of the recreational value of the area, given its uniqueness and quality, relative to other bays.

From here, we assumed that:

- Lower bound: The Caulerpa occupation decreases the recreational value of the Bay of Islands by 10% per year.

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- Upper bound: The Caulerpa occupation decreases the recreational value of the Bay of Islands by 25% per year.

Cumulative Time Period (years)	Cumulative PV Cost – Lower Bound ($)	Cumulative PV Cost – Upper Bound ($)
10	240,000	599,000
20	2,350,000	5,870,000
30	3,900,000	9,760,000

Over a 30-year period, it is estimated that the cost of "doing nothing" to prevent the spread of Caulerpa in terms of its impact on recreational activity in the Bay of Islands to be $4 - $10 million.

Total Cost:

Overall, we estimate that the tangible costs of an uncontrolled Caulerpa outbreak in the Bay of Islands are likely to range between $40 million and $98 million over the next thirty years.

Cumulative Time Period (years)	Cumulative PV Cost – Lower Bound ($m)	Cumulative PV Cost – Upper Bound ($m)
10	2.5	6.0
20	24.3	58.9
30	40.3	97.8

Limitations

Due to the absence of economic data about the impact of Caulerpa taxifolia on the aquaculture, seafood processing, accommodation and food services, and transport equipment manufacturing sectors of other nations, much of the analysis in this section of the report is, necessarily, speculative and rooted in the considered judgement of its authors – neither of whom have a background in the marine sciences – as opposed to any robust empirical analysis.

For this reason, our estimates of the tangible costs associated with the spread of Caulerpa in the Bay of Islands should be viewed with a great deal of caution and considered alongside other relevant pieces of information. We believe that our estimates are likely to be conservative.

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Sensitivity Analysis

Given that our baseline growth rate and impact estimates are likely to be conservative, we also calculated the cumulative thirty-year costs associated with the outbreak under less restrictive assumptions. If Caulerpa grows 50% faster than assumed, and that the impact on economic activity is 50% greater anticipated, the total cost of "doing nothing" to prevent the spread of Caulerpa in the Bay of Islands will be between $82-$200 million over a 30-year period.

Scenario	Total cost over a 30-year period Lower Bound ($m)	Total cost over a 30-year period Upper Bound ($m)
Baseline	40.3	97.8
Growth rate is 50% higher than we expect	55.0	133.4
Impacts are 50% more severe than we expect	60.5	146.7
Growth rate is 50% higher than we expect, and impacts are 50% more severe than we expect.	82.5	200.1

Intangible Costs

Beyond the enumerable economic costs associated with the growth of Caulerpa, the growth of exotic seaweed is likely to affect the biodiversity of the Bay of Islands and the ability of tangata whenue to collect kai moana.

Biodiversity

Across much of the Mediterranean Sea, dense and vibrant patches of Caulerpa taxifolia occupy spaces that had previously housed a wide range of fauna. At its peak, the seaweed grew throughout the year, displacing seasonal fauna and absorbing the region's nutrients, turning parts of the Mediterranean seabed into a dense forest of Caulerpa. In some parts of the sea, biodiversity measures fell by as much as thirty percent.

Unlike other marine plants, Caulerpa taxifolia also produced a potent toxin that prevented other organisms from consuming it, adding it to its relative growth advantages in the region and reducing the number and range of indigenous fish that could survive in the area. Notably, the Caulerpa species detected in the Bay of Islands do not appear to produce this toxin.

Indigenous Values

The uncontrolled spread of Caulerpa is likely to negatively affect tangata whenua. In June of 2023, representatives of Patuheka and Ngāti Kuha jointly instituted a rāhui in the Bay of Islands. Speaking to RNZ, one of the representatives noted that "[if Caulerpa spreads] there will be no kaimoana for future generations." However, we have not fully examined the impacts of Caulerpa on tangata whenua.

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4. Te Reo | Conclusion

If we assume that the behaviour of Caulerpa brachypus and Caulerpa parvifolia in the Bay of Islands are likely to be broadly similar to the behaviour of Caulerpa taxifolia in the Mediterranean Sea, the uncontrolled spread of the seaweed could, potentially, cost the region's economy millions of dollars, damage its recreational and cultural value, and severely depress its level of biodiversity.

Based on the assumption outlined above, Caulerpa colonies could cost the Bay of Islands' economy between $40 -$98 million, in present value terms, over the next thirty years. However, that could reach up to $200 million, if are assumptions are loosened.

Though we cannot be certain that our estimates of the costs associated with the spread of Caulerpa taxifolia are highly accurate, it appears highly likely that, in the absence of meaningful and assertive control programmes, the seaweed could have a devastating effect on the region.

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