Addressing invasive caulerpa in New Zealand

Modelling the benefits of alternative mitigation options using the natural capital valuation approach

NZIER report to Martin Jenkins

3 December 2024

About NZIER

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Our expert team is based in Auckland and Wellington and operates across all sectors of the New Zealand economy. They combine their sector knowledge with the application of robust economic logic, models and data and understanding of the linkages between government and business to help our clients and tackle complex issues.

Authorship

This paper was prepared at NZIER by Ting Huang and Roshen Kulwant.

It was quality approved by Michael Bealing.

A technical reference group comprising representatives from iwi, regional councils and Biosecurity New Zealand provided critical review and input on the modelling parameters, assumptions and initial results.

The assistance of Sarah Spring, Christina Leung, Peter Clough and the technical reference group is gratefully acknowledged.

How to cite this document:

NZIER. 2024. Addressing invasive caulerpa in New Zealand. Modelling the benefits of alternative mitigation options using the natural capital valuation approach. A report for Martin Jenkins.

Registered office: Level 13, Public Trust Tower, 22–28 Willeston St | PO Box 3479, Wellington 6140
Auckland office: Level 4, 70 Shortland St, Auckland
Tel 0800 220 090 or +64 4 472 1880 | econ@nzier.org.nz | www.nzier.org.nz

Key points

Purpose of this report

Martin Jenkins commissioned NZIER to undertake economic modelling to support the assessment of options to fight invasive caulerpa, as part of a business case commissioned by Pou Rahui iwi in partnership with regional councils.[1] This modelling considers the economic impact of these options on the current and potential future impacted areas in New Zealand. In particular, our task was to build on the approach and methodology developed in our previous *Valuing the Hauraki Gulf* report and estimate the benefits of a range of alternative mitigation options relative to a 'do minimum' that assumes Controlled Area Notices (CANs) continue to be the main form of intervention.

Our modelling approach

The study area of this work covers an area of approximately 810,540 hectares in the marine environment from Cape Reinga in Northland to East Cape in Gisborne District. Biosecurity New Zealand has identified this study area as the potential distribution of area suitable for invasive caulerpa to reside in New Zealand.[2]

We are still developing our collective knowledge and understanding of caulerpa, its habitable environments, how it spreads and its impacts on New Zealand's native biodiversity and ecosystems. As a result, we are not yet in a position where we can estimate the possible trajectories by which caulerpa could spread to any degree of certainty. Given this significant knowledge gap, our approach makes use of relatively simplified scenarios for how caulerpa could spread, assuming either a high, medium or low rate of spread (or infestation). These scenarios make use of the modelling approach developed by Northland Regional Council, based on the observed pattern of spread in the Mediterranean, albeit with the more toxic species of *Caulerpa Taxifolia*.

We utilised the ecosystem services and natural capital valuation approach from the *Valuing the Hauraki Gulf* (NZIER 2023). The ecosystem services framework links ecosystem conditions to natural functions and services of value to people. We focused on three different categories of ecosystem services that benefit people:

- **Provisioning services** such as the supply of wild food (e.g. fishing, aquaculture)
- **Cultural services** such as benefits of access to the natural environmental amenity for recreational activities and/or cultural connection to the environment
- **Regulating and supporting services** such as water quality, biodiversity, carbon sequestration.

The natural capital valuation approach estimates the values of ecosystem systems services through three steps. First is the estimation of the annual values of the outputs from ecosystem services. The costs of inputs and returns from all other capital are then deducted to calculate the annual economic rents attributable to nature. The flows of expected economic rents are then projected over a certain time horizon and discounted at a discount

[1] Iwi represented are Ngāti Pāoa, Ngāti Tamaterā, Ngāi Tai ki Tāmaki and Ngāti Hei, partnering with and supported by Northland Regional Council, Auckland Council, Waikato Regional Council, Thames-Coromandel District Council and Hauraki District Council.

[2] Based on what we know currently about the temperature and depth at which caulerpa can grow in New Zealand.

rate to estimate the asset value of natural capital. We used a discount rate of 2 percent as per the Treasury's guideline for non-commercial proposals.[3]

To model the benefits of alternative mitigation options relative to the do minimum counterfactual, we estimated the values of ecosystems for when there is no invasion of invasive caulerpa. For the different mitigation options (including do minimum), our model captures the impacts of each option through deterioration in the environmental qualities, restrictions on activities to limit spread and the associated additional costs of compliance. Any combination of these three reduces the annual and rent values of the ecosystem services in the study area, which flow through to reduced asset value of the natural capital compared to if there was no invasion of invasive caulerpa.

Modelling scenarios for inclusion

Our model assumes that the proportion of the study area covered by CANs on areas infested with invasive caulerpa will be the same as the rate of Caulerpa infestation assumed for that option. This means that the rate of caulerpa infestation forms the foundation of our modelling.

Given the lack of science to inform how the rate of caulerpa infestation could look like with the interventions under each of the five mitigation options, we proceed with a scenario-based approach to model the different options as below:

- Option 1: do minimum, reliance on CANs and local action – high infestation scenario
- Option 2: Focus on exclusion in high value areas only – high infestation scenario
- Option 3: Dual focus on containing the spread in heavily infested sites and exclusion in high value areas – high infestation scenario
- Option 4a: Strengthened marine biosecurity framework that supports suppression and local elimination – medium infestation scenario
- Option 4b: Strengthened marine biosecurity framework with an ambition to remove the threat – low infestation scenario
- Option 5: Restrict access and movement to support eradication – low infestation scenario.

Option 1 represents the high caulerpa infestation scenario, which we will define as the counterfactual for assessing the relative benefits of the other mitigation options. Our model assumes that impacts on commercial and recreational activities and regulating and supporting ecosystem services under each option change proportionately to the rate of caulerpa infestation.

About $9.4 billion (or 14 percent) of the study area's natural capital asset value can be lost over 30 years if CANs remain the main intervention to address the risk of invasive caulerpa

Compared to if there is no invasion of invasive caulerpa, our model estimated that implementing Option 1, which relies on using CANs as the main intervention to address invasive caulerpa, could result in a loss of about $9.4 billion (a 14 percent reduction from $66.1 billion) in the study area's natural capital asset value over 30 years.

[3] https://www.treasury.govt.nz/information-and-services/state-sector-leadership/guidance/reporting-financial/discount-rates

Across the different types of ecosystem services, the value of recreational use is mostly impacted, with a loss of $8.6 billion (or a 16 percent loss against the value without caulerpa). This reflects the importance of the unique environmental values and natural amenity of the study area to support regular recreational use by the resident population and visitors. As a high rate of caulerpa infestation persists, a higher proportion of the study area will require restrictions to mitigate further spread, leading to a greater loss of recreational value due to the reduced recreational activities and higher compliance costs for the remaining recreational activities that can still take place.

The loss to the value of biodiversity is the second largest, with an estimated loss of $419 million over 30 years. This result is consistent with the existing science from international literature, which suggests invasive caulerpa's considerable negative effects on biodiversity in the affected marine environment.

Successful implementation of alternative mitigation responses can mitigate a range of $0.9 billion to $2.9 billion of the natural capital asset value that would otherwise be lost

While our modelling shows that the study area's natural capital asset value will be lower across all options compared to if there was no invasion of caulerpa, successful implementation of the alternative responses proposed under the business case can mitigate a considerable amount of the natural capital asset that would otherwise be lost with the do minimum high infestation scenario. In particular:

- Implementation of exclusion or containment strategies that are less likely to mitigate the spread of caulerpa but seek to manage its impacts within high value areas or existing infested areas can mitigate up to $0.9 billion (or up to 10 percent) of the loss in the natural capital assets
- Successful Implementation of a strengthened marine biosecurity system that leads to a medium or low infestation outcome can mitigate $2.5 billion to $2.9 billion (or 27 percent to 30 percent) of the loss in the natural capital assets
- Adopting an option that significantly restricts access and movement to pursue a low infestation outcome can mitigate $2.5 billion (27 percent) of the loss in natural capital asset values.

The benefits of implementing alternative mitigation options, especially Options 4a, 4b or 5, reflect their lower caulerpa infestation outcomes. The combination of increased treatments, surveillance, enforcement, research and education means that the spread of invasive caulerpa can be slowed and prevented earlier than with minimal intervention effort. Therefore, a higher proportion of the study area can remain free of invasive caulerpa so that more risk to the study area's environmental qualities, especially the risk to biodiversity, can be mitigated, and more activities will be unaffected overall.

While imposing stringent restrictions on access and movement until eradication is complete (i.e. Option 5) can still achieve a low infestation outcome, this response results in a lower benefit than the response under Option 4b, which can achieve a similar low infestation outcome with fewer restrictions imposed on activities. The difference in the modelled benefits between these two options reflects the additional economic loss associated with imposing a much higher level of restrictions for achieving a similar infestation outcome.

Headline results from our modelling are set out in Table 1 below.

Table 1 Headline modelling results

2024 dollars

	Estimated loss under Option 1 ($m)	Mitigated loss in asset value relative to Option 1 ($m)				
		High infestation		Medium infestation	Low infestation	
		Option 2	Option 3	Option 4a	Option 4b	Option 5
Total asset value	**$9,397.7**	**$0**	**$931.4**	**$2,515.0**	**$2,863.4**	**$2,532.6**

Source: NZIER

Concluding remarks

Our economic modelling presented in this report is limited to the information available about the environmental qualities and activities in our study area, as well as the existing science and research for understanding the likely spread of invasive caulerpa and its impacts on marine ecosystems in New Zealand. Forming assumptions for the potential rate of infestation and impacts on environmental qualities such as water quality, biodiversity, and carbon sequestration has been proven to be a very challenging task given the lack of science to inform a range of possible impacts for New Zealand. This highlights the urgency for further research to establish a more robust scientific evidence base for New Zealand, which will better inform the development of strategies to mitigate the risk of invasive caulerpa in New Zealand.

While it was not within the scope of our work to attempt to monetise the cultural impacts for mana whenua, we acknowledge that all options present significant impacts from a te ao Māori perspective, particularly for environment management and cultural values related to kaitiakitanga, manaakitanga, mahinga kai and rangatiratanga.

Overall, this modelling exercise provides a useful starting point for assessing the relative impacts of mitigation strategies, which can be repeated and improved as more scientific evidence and knowledge becomes available.

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1 Purpose of our work

Martin Jenkins commissioned NZIER to undertake economic modelling to support the assessment of options to fight invasive caulerpa as part of a business case commissioned by Pou Rahui iwi in partnership with regional councils.[4] This modelling considers the economic impact of those options on the current and potential future impacted areas in New Zealand. In particular, our task was to build on the approach and methodology developed in our previous *Valuing the Hauraki Gulf* report (NZIER 2023) and estimate the benefits of a range of alternative mitigation options relative to a 'do minimum' that assumes Controlled Area Notices (CANs) continue to be the main form of intervention.

1.1 The context

Two exotic invasive species of caulerpa algae, *Caulerpa brachypus* and C. *parvifolia*, were first detected in New Zealand in Aotea Great Barrier in 2021. They are known for their ability to form large, dense meadows that smother sea-floor habitats, displacing indigenous species and impacting marine ecosystems. The two caulerpa species found showed similar characteristics to the highly invasive *Caulerpa taxifolia,* which has caused significant ecological damage overseas. In September 2021, *Caulerpa brachypus* and C. *parvifolia* were listed as Unwanted Organisms under the Biosecurity Act (National Institute of Water and Atmospheric Research 2022).

In December 2021, Biosecurity New Zealand convened its Strategic Technical Advisory Group (Strategic TAG) discussion to provide recommendations on what can be done for the long-term management of invasive caulerpa in New Zealand (Biosecurity New Zealand 2022). Over time, the Strategic TAG has been looking at five possible strategies: do nothing, containment, suppression, local elimination, and eradication. Several trial studies have been undertaken to explore the treatment options available (Biosecurity New Zealand 2024d).

To date, the known extent of caulerpa infestation covers an area in excess of 1,700 hectares (Biosecurity New Zealand 2024d), with infested sites found in Aotea Great Barrier Island, Ahuahu Great Mercury Island, Te Rāwhiti, Bay of Islands, Kawau Island, Waiheke Island, Mokohīnau Islands, Rākino Islands, Coromandel Peninsula, and Omaha Cove, Leigh Harbour (Biosecurity New Zealand 2024b; 2024d). Earlier this year, the Strategic TAG concluded that it would not be feasible to eradicate in the medium term (3–5 years) with the tools currently available and the current size of incursion in New Zealand (Biosecurity New Zealand 2024c). Acknowledging the potential for significant impacts, caulerpa can have on the ecology and mauri of New Zealand's marine ecosystems, Biosecurity New Zealand has been implementing CANs under Section 131 of the Biosecurity Act 1993 to reduce the human-mediated spread of invasive caulerpa to other locations. Currently, two CANs are covering high-risk zones such as Aotea, Ahuahu (Zones 1 & 2) and Te Rāwhiti (Zone 3).[5]

4 Iwi represented are Ngāti Pāoa, Ngāti Tamaterā, Ngāi Tai ki Tāmaki and Ngāti Hei, partnering with and supported by Northland Regional Council, Auckland Council, Waikato Regional Council, Thames-Coromandel District Council and Hauraki District Council.

5 The new CANs' restrictions and requirements came into force on 25 October 2024 (Biosecurity New Zealand 2024a).

It has been broadly agreed that caulerpa could have the potential to spread from Cape Reigna to East Cape if left untreated. Recognising this, Biosecurity New Zealand has established the National Caulerpa Advisory Group in 2024, with the role of providing independent advice to:

- guide its tole in the ongoing management of invasive caulerpa
- oversee the development of a strategy and approach to the ongoing response to caulerpa
- support a more integrated, coordinated focus on the ongoing management of caulerpa.

1.2 Objectives and scope

As noted above, Martin Jenkins is developing an indicative business case on behalf of Pou Rāhui iwi and regional council partners on options to overcome the threat caulerpa poses. To provide the key input for informing this business case, we were tasked with estimating the benefits of a range of alternative mitigation options relative to a counterfactual scenario reflecting 'do minimum'. Specifically, NZIER was commissioned to undertake economic modelling, building on the ecosystem services and natural capital valuation approach developed in our previous work on *Valuing the Hauraki Gulf* (NZIER 2023), to estimate the impacts on values derived from commercial, social and recreational uses and environmental qualities of the current and potential impacted areas, which goes beyond the Hauraki Gulf.

The scope of this work includes the following:

- A focus on the marine environment from Cape Reigna to East Cape
- Update the key parameters of the *Valuing the Hauraki Gulf* report
- Estimate the values of ecosystem services without invasion of caulerpa
- Quantify the values of ecosystem services at risk due to caulerpa infestation under a counterfactual scenario reflecting 'do minimum' compared to if there is no caulerpa invasion, including a 30-year outlook
- Model the benefits of alternative mitigation options relative to the counterfactual scenario and identify the trajectory over a 30-year period
- Sensitivity analysis of the modelled benefits.

Assessment of the implementation costs of the different mitigation options (including the counterfactual scenario) is out of the scope of this work.

1.3 Structure of this report

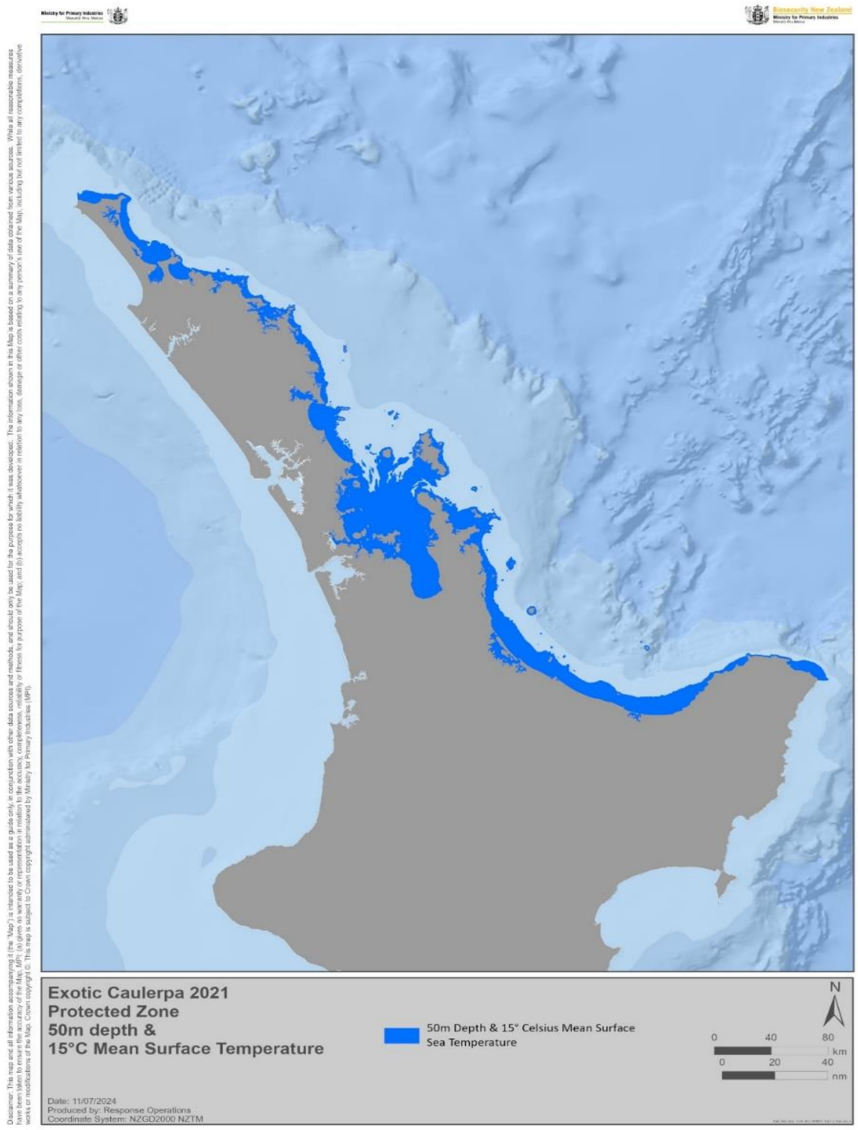
The report begins with a description of the study area, the underlying frameworks and our modelling approach.

2 Our approach

2.1 Study area

Based on global experience with caulerpa incursions and information on sea water temperature and depth ranges of locations discovered with caulerpa, it has been suggested that invasive caulerpa is likely to reside in marine environments within 50 metres deep and with a mean surface temperature of 15 degrees Celsius.[6] Correlating this to NIWA's bathymetry data and the sea surface data on Stats NZ, Biosecurity New Zealand has predicted the likely habitable range of invasive caulerpa in New Zealand, as indicated by the navy-blue shaded area in the map shown in Figure 1 below.

Figure 1 Extent of the area caulerpa could likely reside in New Zealand



Source: Biosecurity New Zealand

6 Insights from discussions with marine ecologists from the technical reference group.

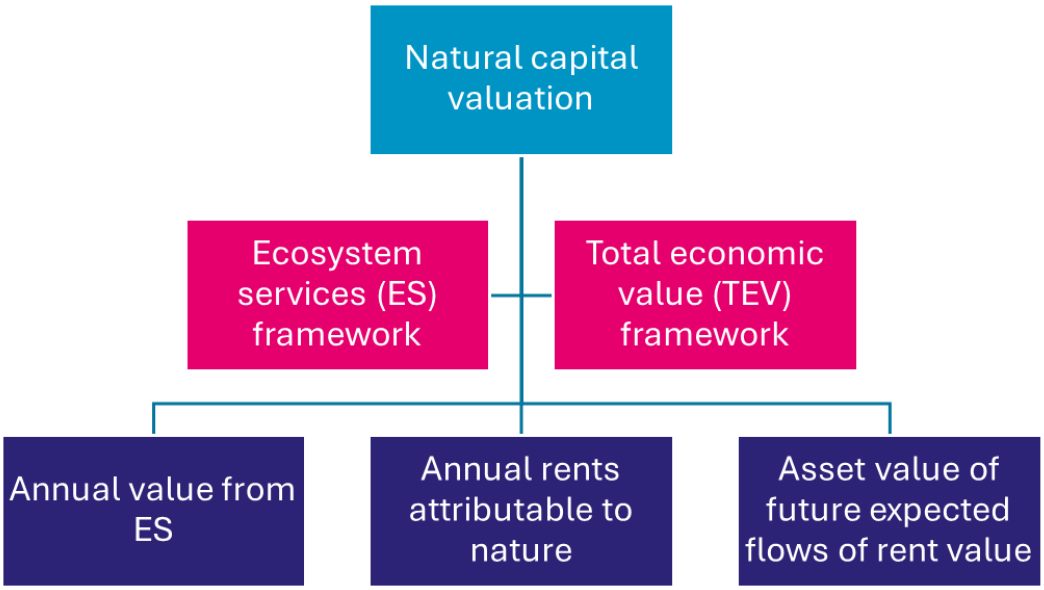
The map suggests that, based on the metrics of water depths and mean surface temperature, the area potentially at risk of being infested with caulerpa is in proximity to the coastline of the marine environment between Cape Reigna and East Cape. According to Biosecurity New Zealand, who created this map, this area covers approximately 810,540 hectares.

As confirmed at the technical reference group workshop consisting of marine biosecurity and ecology experts from regional councils and the University of Waikato, this area is defined as the study area for the business case and our economic modelling.

2.2 Frameworks

Figure 2 is a simplified illustration of the frameworks and approaches used in *Valuing the Hauraki Gulf*.

Figure 2 Frameworks and approaches in *Valuing the Hauraki Gulf*



Source: NZIER

The two key frameworks underpinning *Valuing the Hauraki Gulf* are Total Economic Value (TEV) and ecosystem services. The ecosystem services framework links ecosystem conditions to natural functions and services of value to people, and the TEV framework enabled us to incorporate both the market and non-market values in our valuation of the ecosystem services that flow from Hauraki Gulf's natural capital. Our valuation focused on four different categories of ecosystem services that nature provides for humans:

- **Provisioning services** such as the supply of wild food (e.g. fishing, aquaculture).
- **Cultural services** such as benefits of access to the natural environmental amenity for recreational activities and/or cultural connection to the environment.

- **Regulating and supporting services** such as water quality, biodiversity, and carbon sequestration.

The values of those ecosystem services are then estimated using the natural capital valuation approach, which constitutes three distinct components:

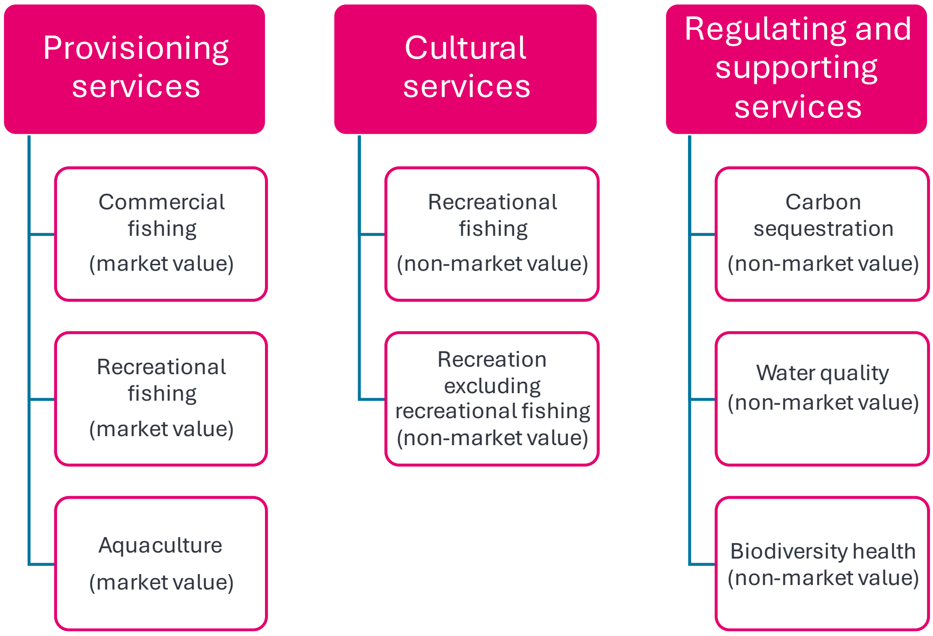
- Annual value from ecosystem services, which is a value of service outputs
- Economic rents attributable to nature, which is the residual value after deducting returns to all other capital from the output value
- Asset value, which is the capitalised value of future expected flows of economic rent from environmental sources over a projection period.

2.3 Our modelling approach

Prior to this economic modelling work, NZIER (2024) completed a basic assessment for the Hauraki Gulf Forum on which ecosystem services of the Hauraki Gulf could be exposed to the two exotic species of caulerpa.[7] The assessment used the findings of our *Valuing the Hauraki Gulf* work as a benchmark for the annual value of the ecosystem services linked to the Gulf and drew on the limited local and international research in an effort to understand the potential value at risk.

Figure 3 lists the ecosystem services included in our modelling for which we were able to quantify and monetise. These are based on the findings from NZIER's recent basic assessment of Hauraki Gulf's ecosystem services at risk and discussions at the technical reference group workshops on the ecosystem services in the study area that are more likely to be at risk due to infestation of caulerpa.

Figure 3 Ecosystem services values for inclusion

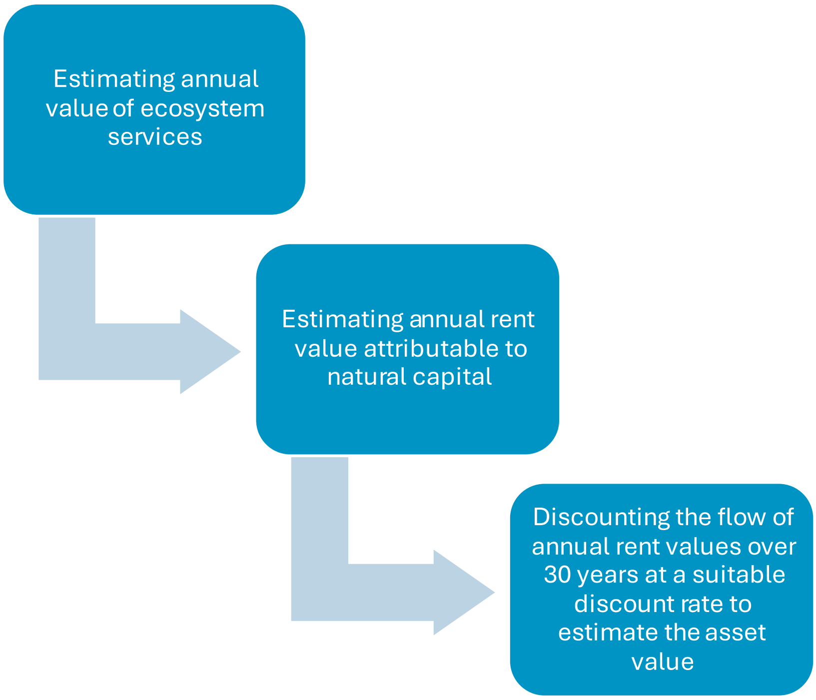


Source: NZIER

7 Available at https://gulfjournal.org.nz/wp-content/uploads/2024/08/NZIER-assessment-of-the-potential-impacts-of-exotic-Caulerpa.pdf

The overarching approach of our modelling is natural capital valuation. So, to be able to model the impacts of caulerpa with a counterfactual scenario reflecting 'do minimum' and the impacts mitigated (or avoided) with alternative mitigation options, the values of ecosystem services of natural capital need to be estimated for the case without caulerpa and each modelling scenario. Figure 4 illustrates three key steps involved in natural capital valuation.

Figure 4 Key modelling steps under a natural capital valuation approach



Source: NZIER

Our model captures the main channels through which ecosystem services in the study area can be impacted under the counterfactual and alternative mitigation scenarios. These are:

- Restrictions on activities, which reduce the service output from the natural capital
- Additional costs of compliance, which increases the cost of inputs for users of the affected environment
- Deterioration in environmental qualities.

Any combination of the above will reduce the annual and rent values derived from the natural capital of the affected environment, which will flow through to reduced asset value of the natural capital compared to if there was no caulerpa.

As agreed with Martin Jenkins, we use a discount rate of 2 percent to project the 30-year asset value of the study area's natural capital in our modelling. While in *Valuing the Hauraki Gulf,* we used a discount rate of 9 percent as in Stat NZ's Environmental Economic Accounts (SEEA); using a 2 percent discount rate is in line with the latest Treasury guidance on the public sector discount rates for non-commercial proposals over a 30-year period.[8] We

[8] https://www.treasury.govt.nz/information-and-services/state-sector-leadership/guidance/reporting-financial/discount-rates

undertake sensitivity testing on our modelling results with alternative discount rates at 5 percent, 8 percent and SEEA's 9 percent.

Before modelling the scenarios, we start with establishing the value of ecosystem services without invasion of caulerpa in the study area. This involves updating the key parameters in the *Valuing the Hauraki Gulf* report and overlaying them with relevant input data and information about the study area and the demographics in the surrounding districts.

3 Value of ecosystem services in the absence of caulerpa

In *Valuing the Hauraki Gulf*, we drew heavily on information pertaining to the Hauraki Gulf and its adjoining settlements to inform inputs for estimating the current value of ecosystem services. We used a combination of:

- Biophysical indicators about the state of the environment
- Data from the Hauraki Gulf Survey (Horizon Research 2021) on residents' recreational activities in the Gulf and their attitudes to the Gulf
- The value-transfer method, in which we drew on New Zealand studies applicable to the Hauraki Gulf environment to inform on the unit values.

We follow a similar approach for this work to establish the values that reflect the ecosystem services in the study area without invasion of caulerpa.

3.1 Aquaculture

Aquaculture in our study area is mainly comprised of mussel and Pacific oyster farming. According to the 2023 Aquaculture sector overview (Aquaculture New Zealand 2024), 92,967 tonnes of mussels and 1,546 tonnes of Pacific oysters were harvested across the aquaculture farms in New Zealand, which generated a total revenue of about $443 million in 2023.

The 2023 Aquaculture sector overview suggests that mussel farms in Coromandel, Bay of Plenty and Auckland together contributed a quarter of the mussel production in terms of the harvest greenweight, and 95 percent of the oyster production was by oyster farms in Auckland, Northland, Coromandel/ Bay of Plenty. The Clean Hull Plan proposal, which was shared with NZIER in confidence, suggests that approximately 31 percent of the national mussel farming and 97 percent of the oyster farming are in the study area. Averaging those percentage figures between the 2023 sector overview and the Clean Hull Plan proposal, we calculate that the study area accounts for 28 percent of the national mussel farming production and 96 percent of the national oyster farming production.

Pro-rata, these percentages to the total revenue from the national mussels and oysters' production as recorded in Aquaculture New Zealand's 2023 sector overview, we estimate an annual value of $143.2 million (2024 dollars) for aquaculture in the study area.

3.2 Commercial fishing

To estimate commercial fishing impacts, we applied port prices[9] to the quantity of fish that is caught and landed each year from within the study area. Data on commercial fishing activity was provided to us by Fisheries NZ at the MPI, including:

- The average percentage of each fish stock caught within the study area across the October 2007–September 2022 period by statistical area and fishing method groups
- The total landings of fish stocks for the 2022/23 October and 2023/24 April fishing years
- Port prices for the 2023/24 October and April fishing years.

Combining these datasets, we estimate that commercial fishing activity within the study area is valued at $47.9 million. It is important to note that not all fish stocks or species had a corresponding port price, for which we did not estimate a proxy port price.

3.3 Recreational fishing

The National Panel Survey of Marine Recreational Fishers 2022/23 by Fisheries NZ (Heinemann and Gray 2024) estimated that nearly 52 percent of New Zealand's recreational fishing activity occurred in FMA1, which covers most of our study area.

The National Panel Survey also provides estimates on the total number of fish caught by recreational fishers in each FMA and weight conversions for each species. We applied the number of fish caught in FMA1 by recreational fishers to the average export price[10] per unit. This gives us a total market value of $51.6 million for recreationally caught fish in FMA1.

We use export prices in our analysis as this is the closest proxy we have for prices recreational anglers would pay if they instead were to buy the equivalent amounts of fish. It should be noted that not all species had a corresponding weighting factor or export price. Where this is the case, we opted to omit these species from our estimates as we do not believe this will materially affect the size and scale of our results.

The market value of recreational fishing activity reflects the value of the food provisioning services sourced from the wild fish species in the study area's marine ecosystem. There is also a non-market value component as a cultural service in the sense that recreational fishers utilise wild fish species and fishable waters for their activities. This can be measured by the willingness to pay for particular recreational fishing events estimated by Wheeler and Damania (2001), who conducted a contingent valuation survey study of recreational fishers in New Zealand and estimated the marginal willingness to pay (MWTP) and average willingness to pay (AWTP) for recreational fishing catch for several species based on revealed preferences for spending on fishing trips.

Table 2 below shows our estimates of the non-market value of recreational fishing for the study area by multiplying the AWTP (in 2024 dollars)[11] estimates in Wheeler and Damania (2001) with the total recreational catch by species in FMA1 from the 2022/23 National

9 MPI surveys licenced fish receivers annually to calculate port prices. The port price reflects the average price per kilogram of unprocessed fish (greenweight) paid at the dock or their best estimate of what the price would have been in an arm's length sale.

10 Export prices were gathered from Seafood New Zealand's July 2024 export datasets.

11 Adjusted to 2024 values using the Reserve Banks's inflation calculator (https://www.rbnz.govt.nz/monetary-policy/about-monetary-policy/inflation-calculator).

Panel Survey. The total non-market value for recreational fishing in the study area is about $166.7 million.

Table 2 Estimated non-market value for recreational fishing in the study area

2024 dollars

Species	Catch greenweight (kg)	AWTP $/kg	Total value
Snapper	2,149,861	$55.73	$119,813,541
Kingfish	240,114	$53.35	$12,810,593
Blue Cod	843	$65.28	$55,015
Kahawai	370,911	$86.73	$32,167,658
Rock Lobster - Spiny/Red	14,527	$130.85	$1,900,802
Total			**$166,747,610**

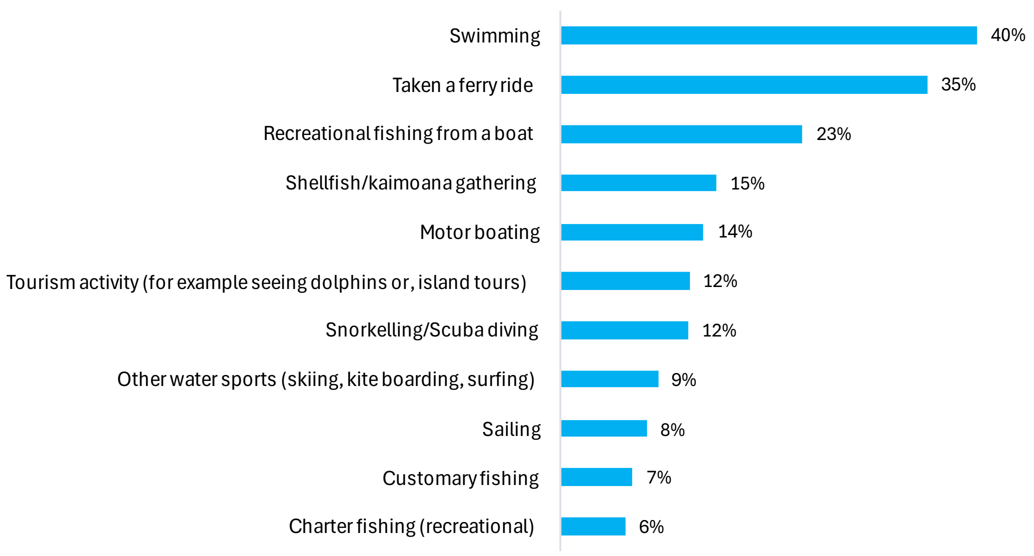
Source: NZIER estimates based on Heinemann and Gray (2024) and Wheeler and Damania (2001)

3.4 Recreation (ex. recreational fishing)

The marine and coastal environment of the study area also provides the setting for a range of recreational activities other than recreational fishing. In the Hauraki Gulf Survey undertaken in 2021 (Horizon Research 2021), 70 percent of respondents from the surrounding districts took activities in the Hauraki Gulf (excluding commercial fishing), and 29 percent participated in recreational fishing (either from a boat or charter fishing). Figure 5 shows the percentages of respondents who participated in activities in the Hauraki Gulf.

Figure 5 Activities in the Hauraki Gulf

% of respondents



Note: These are not mutually exclusive, as respondents were allowed to select more than one activity.

Source: Horizon Research (2021)

While those responses were not mutually exclusive, we have applied weightings to them to exclude recreational fishing in our calculation of the value of the broader recreational use of the study area. This is to avoid potential double counting of the recreational value that could have already been captured in the non-market value of recreational fishing (see section 3.3). Our weighting analysis suggests a 9:91 ratio between the proportion of Hauraki Gulf users for recreational fishing and other recreational activities. Hence, on this basis, we take out this 9 percent of users to exclude recreational fishing from our calculation of the broader recreational value.

In the absence of data about the recreation use for parts of the study area outside the Hauraki Gulf, we apply the proportion of recreational users in the Hauraki Gulf Survey to the total residential population in the study area. We estimate a total of 1.76 million recreational users for non-recreational fishing activities in the study area, based on Stats NZ's population estimates for the year ended June 2023 for the surrounding regions and districts.[12]

Estimation of the value of the study area for recreational use also requires information on the frequency of recreational visits and activities and the value of each activity. We have followed the same approach as we applied in the *Valuing the Hauraki Gulf*.

Firstly, Active NZ survey by Sport New Zealand (2024) suggests that, between 2017 and 2023, an average of 35 percent of respondents across Auckland, Northland, Waikato, Bay of Plenty and Gisborne had participated in water-based activities (excluding marine fishing) in the previous seven days. Using this as a proxy for the level of recreational use in the study area, then the average user would use the study area for recreational activities 18.2 times per year.

Secondly, a Covec (2013) study estimated that a recreational visit to water in New Zealand is between $41.4 and $162.9 in 2024 dollars, with a central estimate of $74.8. Multiplying this central estimate by the estimated number of recreational users and average frequency of use per year gives a value of $2,386.8 million per year for the study area's recreational value. This estimated value translates to an average per person spend of around $16.4 per week for the residential population surrounding the study area.

While the estimated recreation value may seem large, this should not be viewed as the study area's economic contribution to the recreation/tourism industry. Rather, it reflects the value or benefits to the resident population in the surrounding districts from using the study area's coastal and marine environment for their regular recreational needs. The districts adjoining the study area make up over half of New Zealand's total resident population.

3.5 Water quality and biodiversity

We have followed the same approach used in *Valuing the Hauraki Gulf* to estimate the non-use values of water quality and biodiversity for the study area. Our calculation uses the following three key inputs:

- State of the environment quality as informed by the relevant indicators
- The proportion of respondents in the 2021 Hauraki Gulf survey who rated the environmental health of the Gulf

12 These include Auckland and Northland regions and Gisborne District, and most of Waikato and Bay of Plenty regions.

- Estimates of average willingness to pay for improving coastal and marine environment per household per year from Batstone and Sinner (2010).

3.5.1 Current state and trends in water quality and biodiversity health

In *Valuing the Hauraki Gulf*, we drew on Auckland Council and Waikato Regional Council's environmental reporting on marine ecological health in terms of sedimentation, metal contamination and benthic biodiversity for monitoring sites across the Hauraki Gulf. These two regional councils have been undertaking this as a part of the State of the Environment reporting, which also fed into the State of Our Gulf 2023.

In terms of water quality measures, trends in Auckland indicate that the state of sedimentation and metal contamination was predominantly fair; the levels of sedimentation and metal contamination were higher at the Waitematā Harbour (Drylie 2021). Sites in the Firth of Thames and Tairua Harbour range from fair to good, with the southern Firth of Thames more prone to sediments (Jones 2021). Regarding ecological health in terms of biodiversity, the Traits-based Index (TBI) data indicated 36 percent of monitored sites across the Hauraki Gulf had good benthic biodiversity health, and the remaining sites had either intermediate (36 percent) or poor (28 percent) biodiversity health.

Table 3 summarises the sources we found on reporting the state of water quality and biodiversity health for those parts of the study area outside the Hauraki Gulf.

Table 3 Water quality and biodiversity data for areas outside the Hauraki Gulf

	Data source	Summary
Northland	Northland coastal water quality: results from 2018-2020 (Griffiths 2021) Estuary macrofauna health score (Land Air Water Aotearoa 2023)	Less than half of the sites achieved the water quality standards for metal contamination, while most sites met standards for nutrient concentration. The site in Ruakākā had good macrofauna health, whereas Kerikeri had poor macrofauna health.
Bay of Plenty	Tauranga Harbour ecological state assessment (Crawshaw, Park, and Fox 2022) Ōhowa Harbour State of the Environment (Bevan 2018)	The ecological health of Tauranga Harbour is good in terms of sedimentation, metal contamination and ecological communities. The majority of the sediment quality in Ōhiwa Harbour's estuary monitoring sites was in a moderate to poor state, with moderately high nutrient levels, while levels of metal contamination were low. The benthic macrofauna health was good to moderate.
Gisborne District (East Cape)	State of Our Environment 2020 (Gisborne District Council 2021)	Measures of nutrients and other sediments indicate a low level of sedimentation for sites in the coastal catchment around East Cape. Heavy metals are generally highest in estuaries around the urban area (which does not include East Cape). The Macroinvertebrates Community Index suggest good aquatic ecosystem health in the coastal catchment sites near East Cape.

Source: Griffiths (2021), Land Air Water Aotearoa (2023), Crawshaw et al. (2022), Bevan (2018) and Gisborne District Council (2021)

3.5.2 Calculating the annual values for water quality and biodiversity health

Similar to in *Valuing the Hauraki Gulf,* we drew on the New Zealand-based study by Batstone and Sinner (2010), which estimated the willingness to pay values per household per year for improving water quality and ecological health in coastal and marine environments. We have calculated the unit values as below.

Table 4 Unit values for calculating water quality and biodiversity values

Per household per year, 2024 dollars

Improvement in environment	Water quality	Ecological health (a proxy for biodiversity)
Poor to medium	$131.0	134.1
Medium to high	$217.6	$177.0

Source: NZIER estimates based on Batstone and Sinner (2010)

Drawing on the environmental reporting information on water quality and biodiversity health (as described in section 3.5.1), the average willingness to pay per household per year ranges from $174.3 to $217.6 for water quality improvements and $164.3 to $177.0 for biodiversity improvements.

In the Hauraki Gulf Survey, 82 percent of the respondents rated environmental health. Applying this to the number of households in districts surrounding our study area suggested by the 2023 Census, this would equate to a total of 715,729 households, which the willingness to pay values for water quality and biodiversity applies to the study area's adjoining resident population. Our calculations give an annual value of $126.8 million for water quality and $118.4 million per year for biodiversity in the study area.

3.6 Carbon sequestration

In *Valuing the Hauraki Gulf,* our estimate of the carbon sequestration value was based on the known extent of mangroves (4,578 hectares), saltmarshes (460 hectares) and seagrasses (773 hectares) that were known to exist on the Hauraki Gulf coast as estimated by EnviroStrat (2022). In searching for data on the extent of the vegetation outside the Hauraki Gulf in our study area, we found additional documentation by Northland Regional Council and Bay of Plenty Regional Council, as shown in Table 5.

Table 5 Known extent of mangroves, saltmarshes and seagrasses in Northland and Bay of Plenty

Hectares

Vegetation	Northland	Bay of Plenty
Mangroves	8,827.6	
Saltmarshes	2,077.5	
Seagrasses		3,804

Source: Northland Regional Council (2024) and Crawshaw and Park (2024)

The EnviroStrat paper also included estimates of carbon storage potential per hectare of mangroves, saltmarshes and seagrasses, based on international literature. We apply these figures to multiply by the unit carbon price and the known extent of vegetation with carbon sequestration potential in the study area. The New Zealand Emissions Trading Scheme at the start of 2023 suggests a unit carbon price of $69 per tonne of carbon equivalent. The Energy Efficiency and Conservation Authority's (EECA) Greenhouse Gas Cost Assessment Tool[13] suggests a shadow carbon price of $81 per tonne of carbon equivalent for the 2023 year. We use this as the unit carbon price for calculating the value of carbon sequestration, given that it better reflects the climate targets New Zealand is committed to. This gives an estimated annual value of $10.1 million of carbon sequestration from the study area's ecosystems.

Table 6 Estimated annual value of carbon sequestration in the study area

$m, 2024 dollars

Vegetation	Carbon sequestration potential (tCO_2-e per year)	Value of carbon sequestration ($m)
Mangroves	84,723	$6.9
Saltmarshes	20,224	$1.6
Seagrasses	20,137	$1.6
Total		**$10.1**

Source: NZIER calculations

3.7 Acknowledging te ao Māori impacts

The marine ecosystem is highly pertinent in terms of te ao Māori. Te ao Māori is a holistic worldview that emphasises the interconnections between nature and people, which does not necessarily make the distinction between the living and the non-living in the way that Western science does. This means that iwi and Māori in settlements adjoining our study area may place different values on aspects of the marine environment than the general resident population.

The State of Our Gulf 2023 (Hauraki Gulf Forum 2023) lists the four significant Māori uara (values) relevant to the marine environment, which are:

- Kaitiakitanga, which refers that tangata whenua are guardians of both the land and waterways in their rohe to ensure the continued good health and abundance of resources
- Manaakitanga, which refers to expressing kindness and respect for others, emphasising responsibility and reciprocity (e.g. being able to cater for or host others)
- Mahinga kai, or food gathering places, which in the marine environment include traditional fishing grounds, diving spots and shellfish gathering places
- Rangatiratanga, which in the environment management context means the right of tangata whenua to participate in meaningful decision-making about the environment in which they hold mana whenua.

13 https://www.eeca.govt.nz/assets/EECA-Resources/Product-regulations/NDIGHG-Cost-Assessment-Tool-Sep-2024.xlsx

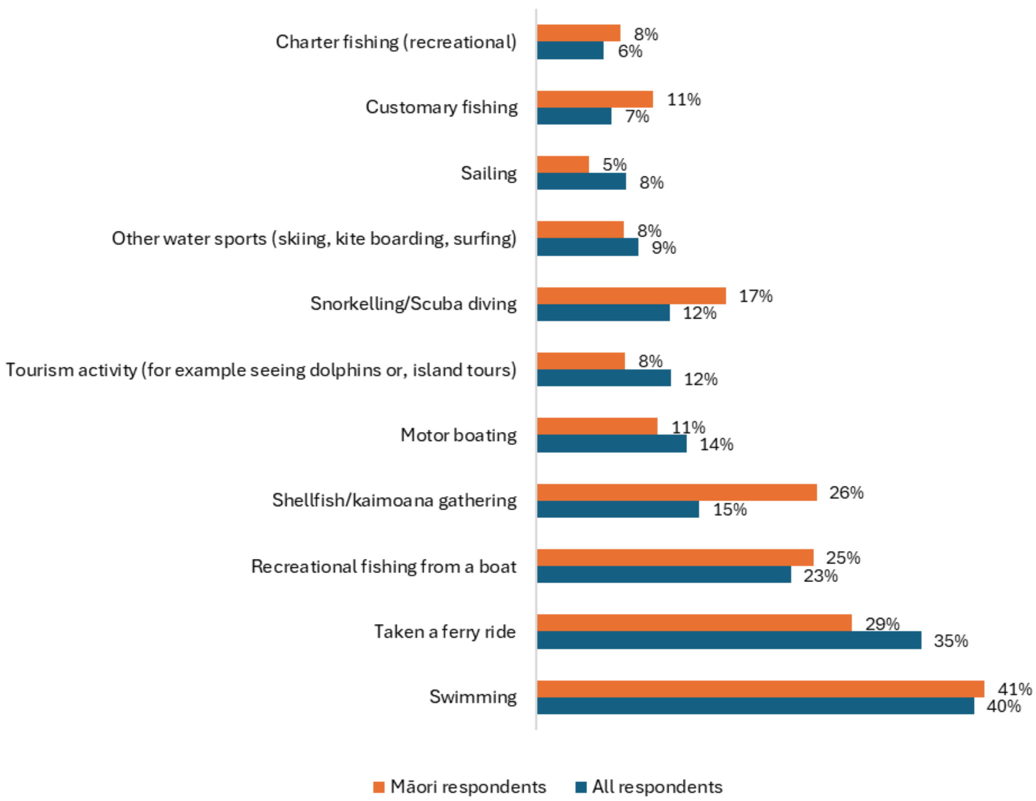
The values above are embedded in iwi management plans for Te Moana, for example, the joint Tauranga Moana iwi Management Plan 2016-2026 for Ngāti Ranginui, Ngāi Te Rangi and Ngāti Pūkenga (Tauranga City Council 2016). Responses from Māori respondents in the 2021 Hauraki Gulf Survey also suggest that they use the Gulf more for customary fishing and food gathering practices than the rest of the respondents (see Figure 6), and they view the Gulf more important for the manaakitanga, mahinga kai, mauri, connection and culture (see Figure 7).

The Our Marine Environment 2022 report (Ministry for the Environment and Stats NZ 2022) highlighted that the traditional knowledge practices and tikanga of Māori can be impacted by changes in the marine ecosystem, as they can:

- limit the ability to practice manaakitanga or undertake kaitiakitanga practices
- result in losses for future generations and transmission of mātauranga Māori
- mean that Mahinga kai practices associated with gathering kai moana at risk.

Figure 6 Māori respondents use the Hauraki Gulf more for customary and food gathering than all other respondents

% of respondents

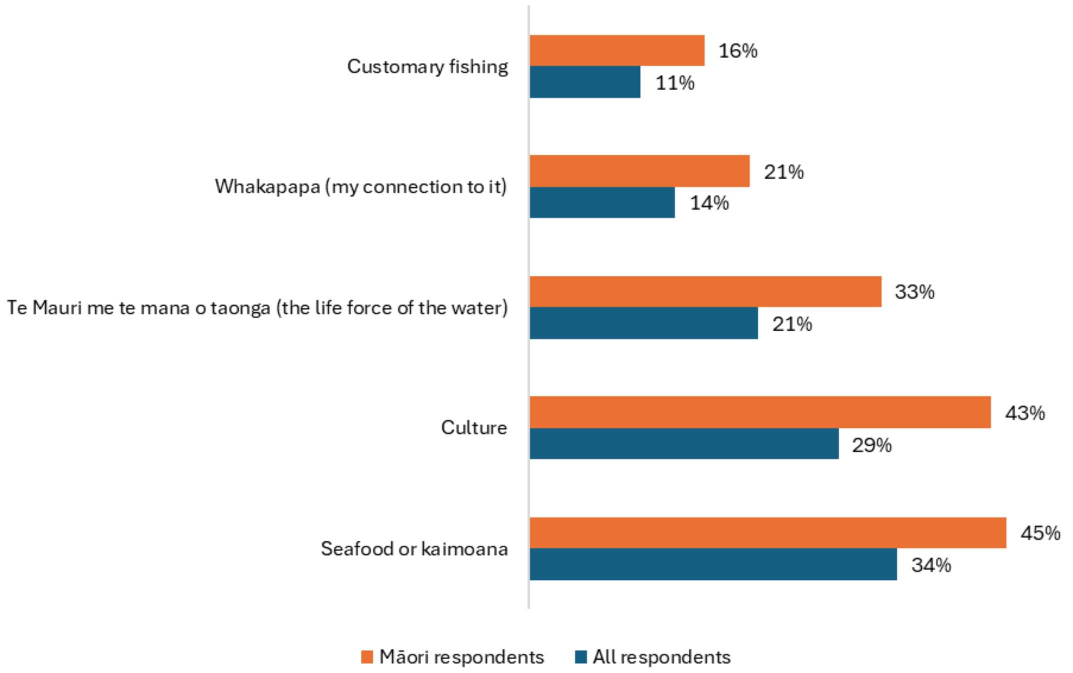


Note: These are not mutually exclusive, as respondents were allowed to select more than one answer.

Source: Horizon Research (2021)

Figure 7 The value Māori respondents place on the Hauraki Gulf differs from the rest of the respondents

% of respondents



Note: These are not mutually exclusive, as respondents were allowed to select more than one answer.

Source: Horizon Research (2021)

Under the restrictions in the current CANs, customary food gathering can still happen in Aotea and Ahuahu (Zones 1 & 2) but not in Te Rāwhiti (Zone 3). In acknowledging that the CAN restrictions could impact customary fishing to some extent, we looked at Fisheries NZ's reporting on customary catch to understand the value of customary fishing in the absence of caulerpa invasion. However, the quality of the data does not enable us to quantify this accurately, given that the quantities of catch approved and harvested have not been recorded with a consistent unit.

We also acknowledge that the broader Māori cultural value derived from the natural environment amenity in the study area will likely be impacted due to the negative effects caulerpa could have on the mauri of Te Moana. However, as highlighted in the State of Our Gulf 2023 (Hauraki Gulf Forum 2023), developing measures in relation to the key values of importance to tangata whenua for Te Moana is still a work in progress in New Zealand. Therefore, we have not quantified and monetised the study area's cultural value to the surrounding iwi population as an item of the study area's cultural services, and we have not included this in our economic modelling in sections 4 to 6 of this report.

Nonetheless, we can still identify the size of the iwi population residing in the study area's surrounding districts, which could then be used for determining the size of the potential Māori population that their cultural values could be affected by invasion of caulerpa and CAN restrictions. From the 2023 Census, just over 2.6 million residents living in districts surrounding the study area had iwi affiliations. We also note that large parts of the study area are home to a higher proportion of Māori than the national average,[14] and there are a number of Māori-owned fisheries and aquaculture businesses in the area that could be disproportionately impacted by caulerpa.

We considered making use of the latest Treasury's CBAx database (New Zealand Treasury 2024), which provides a unit value for 'cultural capability and belonging' per person per year ($4,112). This is a figure monetised based on the New Zealand General Social Survey measure of life satisfaction from the ability to reflect people's own culture as an element of people's housing outcomes (Smith and Davies 2020). A simplistic approach could be to multiply this value by the population identifying as Māori in the study area's surrounding districts as identified above. However, this is unlikely to provide a true measure given that this unit value provided in the CBAx does not distinguish between Māori and the general New Zealand population. More importantly, this value was derived from the context of housing outcomes, which is irrelevant to the marine environment.

3.8 Summary of values

Table 7 summarises estimates of the annual output values from the study area's ecosystem services, annual economic rents, and 30-year asset value attributable to the natural capital of the study area. These are viewed as the values of the natural capital's ecosystem services when there is no invasion of caulerpa in the study area, which forms the base for our modelling presented in sections 4 to 6 of this report.

It should be noted that annual rents are smaller than the annual value from service outputs for commercial activities such as aquaculture and commercial fishing. This is because rents are calculated from each sector's output minus all costs of obtaining that output from labour, fixed capital formation, and rate of return from investments in the sector. The natural capital asset value is obtained by projecting the annual rent over 30 years and discounting it at 2 percent. For recreational activities and regulating and supporting ecosystem services, their annual values are used as the economic rents.

Table 7 Estimated value of the study area's natural capital – without caulerpa

2024 dollars

Ecosystem service	Annual value ($m/yr)	Annual rent ($m/yr)	30-year asset value ($m)
Provisioning services	***$244.7***	***$83.5***	***$1,906.9***
Aquaculture	$143.2	$14.3	$325.9
Commercial fishing	$47.9	$15.6	$356.5
Recreational fishing	$53.6	$53.6	$1,224.5
Cultural services	***$2,553.6***	***$2,553.6***	***$58,335.0***
Recreation (ex. recreational fishing)	$2,386.8	$2,386.83	$54,525.7
Recreational fishing	$166.7	$166.7	$3,809.2
Regulating & support services	***$255.4***	***$255.4***	***$5,833.5***
Water quality	$126.8	$126.8	$2,897.1

14 Including the Northland Region, South Waikato District in the Waikato Region, Rotorua, Whakatane and Ōpōtiki Districts in the Bay of Plenty Region and Gisborne District

Ecosystem service	Annual value ($m/yr)	Annual rent ($m/yr)	30-year asset value ($m)
Biodiversity	$118.4	$118.4	$2,705.0
Carbon sequestration	$10.1	$10.1	$231.5
Total value attributable to natural capital	***$3,053.6***	**$2,892.4**	**$66,075.4**

Source: NZIER

An important caveat to highlight is that we estimated those values presented in Table 7 based on the data and information we could source at the time of this work. They can be improved as new information becomes available in future.

4 Modelling the scenarios

The rest of this report presents our economic modelling. This section describes the scenarios we modelled, including the key parameters and assumptions.

4.1 The proposed options for addressing invasive caulerpa

Table 8 outlines the proposed five options for addressing invasive caulerpa in the study area. Martin Jenkins has developed these under the direction and oversight of the Pou Whakarae (governance group) for the wider business case work. The options consist of the following:

- Option 1: do minimum, with reliance on CANs and local action
- Option 2: focus on exclusion in high-value areas only
- Option 3: Dual focus on containing the spread in heavily infested sites and exclusion in high value areas
- Option 4a: Strengthened marine biosecurity framework that supports suppression and local elimination
- Option 4b: Strengthened marine biosecurity framework with an ambition to remove the threat
- Option 5: Restrict access and movement until invasive caulerpa is eradicated completely.

Please note that the do minimum option, Option 1, aligns with the strategy that Biosecurity New Zealand has been implementing for managing the risk of caulerpa infestation. The mitigation strategies under the alternative options, Options 2 to 5, encompass exclusion, containment, suppression and local elimination and eradication. While these options also involve the use of CANs on infested areas, the degrees of surveillance and monitoring, enforcement, treatments, science and research, education and management of infestation pathways also increase progressively. In particular, Options 3 to 5 also impose preventive CANs with varying degrees of restrictions on movement and anchoring and compliance of gear and cleaning requirements for activities taking place in the study area.

Table 8 Proposed options for addressing caulerpa over the next 30 years

Working titles	Option 1 Do minimum, rely on CANs and local action	Option 2 Focus on exclusion in high-value areas only	Option 3 Dual focus on containing the spread in heavily infested sites and exclusion in high value areas	Option 4a Strengthened marine biosecurity response that supports suppression and local elimination	Option 4b Strengthened marine biosecurity response with an ambition to remove the threat	Option 5 Significantly restrict access and movement to support eradication
Description	• Reactive approach that uses CANs as the primary intervention. • Existing CANs and rāhui continue, and new CANs imposed as new outbreaks identified. • Treatments delivered locally with no national action plan in place to achieve coordination. Assume under this option that funding for treatments would be redirected to other pests by year 10 • Delivered within existing baselines with no increases in enforcement, education, monitoring, and R&D.	• Option 1 plus: • Enhanced surveillance at high-value areas • Some increase in treatment of new incursions focused on high value areas.	• Option 2 plus preventative CANs put in place over high-value areas. • Modest increases in enforcement and education, as well as investment in public moorings • Monitoring and surveillance of affected areas and high-value areas. • Some ad-hoc investment in science primarily through grants and existing research programmes. • More strategic approach to the application of treatments.	• Multi-regional CAN from North to East Cape, replaced by a pathways management plan eventually. • Larger increases in enforcement and education, plus investment in more public moorings. • Increase in monitoring and surveillance at high-risk and high value areas. • Treatment applied to new incursions to eliminate and to existing populations where it is worthwhile and has a greater net benefit. • Innovation fund established to support R&D. • Co-ordinated science strategy. • Option of introducing a levy.	• Option 4a plus: • Further increases in enforcement and education. • Increase in monitoring and surveillance to include areas where caulerpa has been eliminated. • Further increase in innovation funding. • Significant increase in treatment expenditure to remove caulerpa over time. • Option of introducing a levy.	• CANs over all infested areas and preventative CANs have significant restrictions on access and movement within those areas. • Further increases in enforcement, monitoring and surveillance, and education. • Further increase in investment into new technology and in science to better understand caulerpa and its impact. • Option of introducing a levy.

Working titles	Option 1 Do minimum, rely on CANs and local action	Option 2 Focus on exclusion in high-value areas only	Option 3 Dual focus on containing the spread in heavily infested sites and exclusion in high value areas	Option 4a Strengthened marine biosecurity response that supports suppression and local elimination	Option 4b Strengthened marine biosecurity response with an ambition to remove the threat	Option 5 Significantly restrict access and movement to support eradication
What regulatory interventions would be used?	• Unwanted organism. • CANs and rāhui continue. • New CANs and rāhui imposed as needed.	• Same as Option 1.	• Same as Option 1 with the addition of preventative CANs.	• Larger CAN put in place from North to East Cape. • New CANs and rāhui imposed as new outbreaks identified. • “Nested” CANs protecting higher risk areas with more targeted enforcement could occur. • Pathways management plan implemented as a priority	• Same as Option 4a	• CANs over all existing affected areas and preventative CANs have significant restrictions on access and movement within those areas. • Pathways management plan implemented as a priority
How would regulatory interventions be enforced?	• Baseline enforcement.	• Same as Option 1.	• Modest increase in enforcement at affected sites and high-value areas.	• Further increase in enforcement.	• Further increase in enforcement.	• Further increase in enforcement.
How would high-risk and high-value sites be protected?	• No protection of high-risk, high-value sites.	• Increase in targeted surveillance at high value sites.	• Preventative CANs over high-value sites. • Additional increase in targeted surveillance at high-value sites. • Some investment in public moorings at popular anchorages.	• Preventative CANs over high-risk and high-value sites with stringent requirements confined to some particular areas. • Further increase in targeted surveillance at high-value sites. • Additional investment in public moorings at popular anchorages.	• Same as Option 4a.	• Larger number of high value sites identified. Requirements under all existing CANs strengthened to minimise the risk of spread. • Preventative CANs over high-risk and high-value sites also strengthened to address possible vectors of spread.
How would surveillance and monitoring be conducted?	• No increase in surveillance.	• As above.	• Increase in surveillance at affected areas to better.	• Comprehensive monitoring and surveillance of affected areas, high-risk, and high-	• Further increase in monitoring and surveillance to include ongoing and frequent	• Further increase in monitoring and

Working titles	Option 1 Do minimum, rely on CANs and local action	Option 2 Focus on exclusion in high-value areas only	Option 3 Dual focus on containing the spread in heavily infested sites and exclusion in high value areas	Option 4a Strengthened marine biosecurity response that supports suppression and local elimination	Option 4b Strengthened marine biosecurity response with an ambition to remove the threat	Option 5 Significantly restrict access and movement to support eradication
		• No increase in surveillance at affected areas	understand boundaries of existing infestations.	value areas to ensure majority of new outbreaks are identified early enough to eliminate.	monitoring at sites where caulerpa has been removed.	surveillance over and above Option 4b.
Would there be any investment in R&D for new tools?	• No additional funding support from government. • Some private funding support for treatment.	• Same as Option 1.	• Same as Option 1.	• Innovation fund to be established to support the development of new treatment tools and likely to result in efficiencies over time.	• Greater funding towards innovation fund to accelerate promising new technologies.	• Further increase in funding towards innovation fund.
What treatment tools would be available and how would treatments be delivered?	• Treatment delivered locally, driven by iwi and community groups. • Limited to existing tools.	• Same as Option 1 • Some increase in treatment of new incursions focused on high value areas.	• More strategic approach to delivering treatment - mix of locally driven application and a nationally coordinated action plan. • Treatment applied to new incursions and to existing populations where it is worthwhile and has a greater net benefit.	• Strategic approach to treatments is same as Option 3. • Treatment applied to new incursions and to existing populations where it is worthwhile and has a greater net benefit. • Treatments applied to new incursions focused on local elimination.	• Treatments applied strategically as under Options 3 and 4a • Treatments applied to both new incursions and existing populations with the ambition being to remove the threat of caulerpa over time.	• Treatment application same as Option 4b. • Additional investment into new technologies may result in faster development of new tools.
What would the information campaign involve?	• Existing information and awareness campaign at affected areas continues.	• Same as Option 1.	• Modest increase in funding to support more widespread campaign.	• Additional increase in funding to support more widespread campaign.	• Additional increase in funding	• Additional increase in funding
Would there be investment in science?	• No additional funding to support scientific research.	• Same as Option 1.	• Some ad hoc investment from existing grants and research programmes.	• Delivery of science strategy to address to knowledge gaps.	• Same as Option 4a.	• Same as Option 4a.

Working titles	Option 1 Do minimum, rely on CANs and local action	Option 2 Focus on exclusion in high-value areas only	Option 3 Dual focus on containing the spread in heavily infested sites and exclusion in high value areas	Option 4a Strengthened marine biosecurity response that supports suppression and local elimination	Option 4b Strengthened marine biosecurity response with an ambition to remove the threat	Option 5 Significantly restrict access and movement to support eradication
What measures would be put in place at existing infested areas?	• Ahuahu: CAN remains, no further intervention beyond local efforts. • Aotea Great Barrier: CAN remains, some dredging conducted at perimeter, local management efforts continue and are funded privately. • Te Rāwhiti: CAN remains, no further intervention beyond local efforts. • Waiheke Island: CAN put in place as next priority area. • Kawau Island: CAN put in place over time.	Same as Option 1.	• Ahuahu: Treatment applied at perimeter and in sparsely populated infestations. • Aotea Great Barrier: Perimeter management, detection and suppression of new outbreaks. • Te Rāwhiti: Perimeter management, detection and suppression of new outbreaks. • Waiheke Island: Perimeter management, detection and suppression of new outbreaks. • Kawau Island: Treatment applied at perimeter and in sparsely populated infestations.	• Across all existing infested areas: – Treatment applied at perimeter and in sparsely populated infestations. – Treatments applied in more dense infestations to reduce density.	• Across all existing infested areas: – Treatment applied at perimeter and in sparsely and densely populated infestations. – Treatments applied in more dense infestations to reduce density. – Eradication of infestations achieved over time.	• Across all existing infested areas: – Access is restricted to enable eradication at infested areas. – Following eradication, access and use continues to be managed through use of preventative CANs.

Source: Martin Jenkins

4.2 Scenarios for inclusion

As discussed in our modelling approach in section 2.3, ecosystem services in the study area can be impacted through restrictions on activities, additional compliance costs, and deterioration of environmental qualities. This means that the extent of these effects depends on the extent of areas affected by invasive caulerpa. Therefore, we use the rate of caulerpa infestation to develop the hypothetic scenarios for our modelling.

We are still developing our collective knowledge and understanding of caulerpa, its habitable environments, how it spreads and its impacts on New Zealand's native biodiversity and ecosystems. As a result, we are not yet in a position where we can estimate the possible trajectories by which caulerpa could spread to any degree of certainty. Given this significant knowledge gap, our approach makes use of relatively simplified scenarios for how caulerpa could spread, assuming either a high, medium or low rate of spread (or infestation). These scenarios make use of the modelling approach developed by Northland Regional Council (Govind 2024), based on the observed pattern of spread in the Mediterranean, albeit with the more toxic species of *Caulerpa Taxifolia*. The following defines what we consider as high, medium and low infestation scenarios:

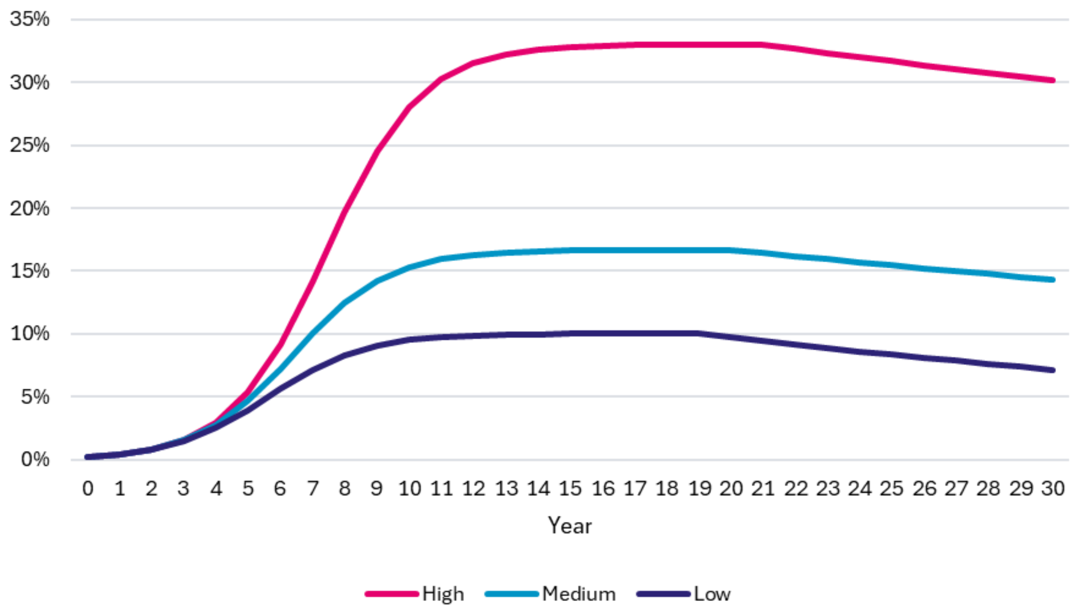
- a third of the study area under a high caulerpa infestation scenario
- a sixth of the study area under a medium caulerpa infestation scenario
- 10 percent of the study area under a caulerpa infestation scenario.

Based on these definitions, Martin Jenkins projected the probable size of the study area infested with invasive caulerpa over a 30-year period, in terms of hectares, by replicating the method demonstrated in Govind (2024). We then converted these projections in terms of the proportion of the study area infested. Figure 8 shows the forecast rate of caulerpa infestation under scenarios of high, medium and low infestation.

The path of a caulerpa infestation in all infestation scenarios portrays some characteristics of an ecological hysteresis. This concept refers to the case that when there is a phase shift in the community structure in the marine system, it can provide alternative stable states which allow the persistence of the invasion, and the system manifests little capacity to recover (Valentine, Magierowski, and Johnson 2007). Ling et al. (2015) demonstrated evidence of this ecological hysteresis from sea urchin overgrazing. A similar path could be envisioned for caulerpa invasion after it causes a change in the biodiversity and habitat structure of the marine ecosystem.

Figure 8 Forecast rate of caulerpa infestation

% of the study area infested with caulerpa



Source: NZIER calculations based on hectare figures provided by Martin Jenkins

Given the lack of science to inform how the rate of caulerpa infestation could look like with the interventions under each of the five mitigation options, we proceed with a scenario-based approach to model the different options as below:

- Option 1: do minimum, reliance on CANs and local action – high infestation scenario
- Option 2: Focus on exclusion in high value areas only – high infestation scenario
- Option 3: Dual focus on containing the spread in heavily infested sites and exclusion in high value areas – high infestation scenario
- Option 4a: Strengthened marine biosecurity framework that supports suppression and local elimination – medium infestation scenario
- Option 4b: Strengthened marine biosecurity framework with an ambition to remove the threat – low infestation scenario
- Option 5: Restrict access and movement to support eradication – low infestation scenario.

Our modelling defines Option 1 as the counterfactual scenario, in which we compare the impacts of invasive caulerpa on the values of the study area's ecosystem services under each alternative option. By adopting this scenario-based approach, results from our modelling can show the range of possible benefits results from implementing each of the alternative options under varying infestation outcomes.

4.3 Key parameters and assumptions

Our model assumes that the parameters of the impacts on commercial and recreational activities and regulating and supporting ecosystem services move proportionately to the rate of caulerpa infestation. We describe these in more detail below.

4.3.1 Impacts to fishing

Imposing CANs in local areas has an immediate impact on the ability to undertake fishing activities.

Table 9 below shows a breakdown of the current commercial fishing activities within the study area using methods that we assume would be restricted under CANs. These sum up to 84 percent of the total port price value and 83 percent of the total greenweight.

Table 9 Commercial activities in the study area by method

	Port price value ($m)	Greenweight (tonnes)
Restricted methods	$40.4	6,532
Non-restricted methods	$7.5	1,378
Total study area	**$47.9**	**7,910**

Source: Fisheries NZ

For those commercial fishing activities that can still happen, there will be a compliance cost for cleaning gear and equipment. The cost-benefit analysis for the Clean Hull Plan (CHP) proposal suggested an additional cost of $31 million per year for cleaning commercial vessels to meet biofouling standards for moving. Pro-rata this at the proportion of commercial vessels used for fishing, we estimate the additional cleaning cost for commercial fishing would be $3.5 million per year under Options 4a, 4b and 5, in which there is a preventive CAN imposing gear and equipment cleaning requirements across the entire study area. Under Options 1 to 3, this additional compliance cost will be proportional to the proportion of non-restricted commercial fishing activities.

According to the National Panel Survey, about 3 percent of all fishing events across New Zealand used methods that may be restricted by the CANs across various platforms. Applying these ratios to the events in FMA1 by platform, we estimate that 19,300 fishing events could be restricted under the CANs in infested areas.

We assume that the remaining number of fishing events can still happen under the CANs but incur some compliance costs from having to clean their gear. We estimate this additional compliance activity to come at the cost of $8 per 15 minutes of compliance activity based on the Treasury's CBAx[15] impact factor.

15 https://www.treasury.govt.nz/publications/guide/cbax-spreadsheet-model

Table 10 Recreational fishing activities in FMA1 by fishing platform

Fishing platform	Events (n)	Events using methods allowed under CANS	Events using methods restricted under CANS
Trailer motorboat	290,248	279,413	10,835
Larger boat/launch	85,980	83,370	2,610
Trailer yacht	1,078	1,078	0
Larger yacht/keeler	11,130	11,130	0
Kayak/rowboat	19,787	18,865	922
Off land	160,704	155,775	4,929
Other	7,805	7,805	0
Total	**576,732**	**557,435**	**19,297**

Source: Heinemann and Gray (2024)

4.3.2 Impacts to aquaculture

The implications for aquaculture are more uncertain. Insights from our discussions with Aquaculture NZ suggest that anchoring restrictions of CANs could limit vessels moving in and out of marine farms. However, they viewed that the overall impact of caulerpa infestation on the aquaculture industry in our study area could potentially be small, given that most aquaculture farms are located in the mid-water column, not close to the seabed.

There has been some evidence in New Zealand of caulerpa detected in shallower waters, such as in Omakiwi Cove (Davidson et al. 2024). More generally, the Regulatory Impact Statement for Aquaculture Biosecurity Programme in 2023 by MPI (2023) highlighted that the aquaculture sector is generally at risk of marine biosecurity incursions. MPI's earlier estimates on the impact of introduced species on aquaculture production suggest an average impact of a 7 percent reduction in production per hectare of marine farmers, with a range of 5 to 35 percent (Branson 2012). The average impact of the introduction of styela clava, the marine pest which the aquaculture industry has been putting a significant effort into managing in recent years, was estimated at a 5 percent reduction in production per hectare.

In the absence of other better information sources, we assume that the percentage loss in aquaculture production relative to the annual value of aquaculture shown in Table 7 ($143.2 million) will be 5 percent per year under a high caulerpa infestation scenario, 3.3 percent per year under a medium infestation scenario and 1.7 percent per year under a low infestation scenario.

We also assume an additional cost of compliance in terms of equipment cleaning for the remaining aquaculture production, in the same way as for commercial fishing, as described in section 4.3.1 previously.

4.3.3 Impacts on recreation

Under all five options, restrictions to recreational use (excluding recreational fishing) will be limited to vessels that would anchor in infested areas with CAN restrictions, which are mostly tour or sightseeing boats. Other activities like swimming, canoeing, diving, etc., are permitted with compliance of cleaning gear and equipment.

Based on our weighting analysis of those activities in the 2021 Hauraki Gulf Survey (refer to Figure 5), we estimate that about a quarter of recreational activities in activities in the Hauraki Gulf would involve the use of tour or sightseeing boats. For Options 1 to 2, we multiply the proportion of the study area infested with caulerpa by the proportion of total recreational activities using tours or sightseeing boats we implied from the Hauraki Gulf Survey. Under Options 3, 4a and 4b, the varying provision of public mooring at popular locations without needing to anchor means that some use of tour and sightseeing vessels is allowed. For Option 3, we assume a third of this activity can still happen in infested areas covered by CAN restrictions and two-thirds for Options 4a and 4b. We had discussed with Martin Jenkins what the preventive CANs under Option 5 mean for tours and sightseeing, and we had reached an agreement to assume that a third of this activity can still happen under Option 5.

For the remaining recreational activities that can still happen, we again assume an additional unit cost of $8 per 15-minute compliance for cleaning gear and equipment. This is an average over and above the cleaning that recreational users would take anyway in the absence of CANs (e.g. taking an extra 15 minutes to check if there is any caulerpa seaweed on their gear). Under Options 4a, 4b and 5, this unit cost will apply uniformly to all recreational use, given that the preventive CANs will be imposed across the whole study area to require compliance with gear and equipment cleaning. For Options 1 to 3, the additional compliance costs will be proportionate to the proportion of recreational activities that can still happen.

4.3.4 Impacts on regulating and supporting services

There is a very limited scientific base to inform us on the potential impact of caulerpa on water quality, biodiversity and carbon sequestration of New Zealand’s marine.

NZIER’s (2024) basic assessment of caulerpa for the Hauraki Gulf forum undertook a literature review and found evidence indicating that invasion of caulerpa is associated with a decrease in the biodiversity of the marine ecosystem.

Parreira et al. (2021) showed that when caulerpa replaces seagrass, the observed level of biodiversity decreases from high to medium density. Insights from the science advisor in the technical reference group also reinforced these findings. The native seaweed habitat in the shallow subtidal provides a nursery for grazing invertebrates (kina, gastropods, etc.), crayfish, paua, and a host of fish species, including juvenile stages of more deep-water species. An international study by Harmelin et al. (1999) on the Mediterranean Sea, which was severely infested by the toxic *Caulerpa Taxifolia* found a 42 to 57 percent decrease in fish biomass, a 23 to 31 percent decrease in species richness and a 31 to 36 percent loss in mean density, over a 6-year period.

However, the impact on biodiversity in New Zealand’s marine environment is still unknown, which requires further research. In acknowledging the uncertainty around this and the international evidence of caulerpa’s impact on biodiversity, for all five options, we pro-rata the assumptions on percentage cumulative loss to the biodiversity value at two-thirds of the rate of infestation. This approach has been agreed with the technical reference group.

The potential impact of caulerpa on water quality and carbon sequestration is unknown. A 2023 field study by NIWA (Middleton 2023) at Aotea Great Barrier Island collected samples to test sediment and water chemistry, but the majority of these still require analysis. There is some international evidence suggesting the correlation between algae outbreaks and nutrient limitations in waters (Nelson, Neill, and D'Archino 2015). In particular, the case study of the Ulva *spp* outbreak in New Zealand suggests that during El Niño conditions, when nutrient-rich deep waters upwelled offshore and entered the harbour, the Ulva blooms were particularly severe. The State of Our Gulf 2023 noted that piles of invasive caulerpa, up to 1m high, covered the shoreline of Blind Bay invasive in the aftermath of Cyclone Gabrielle. Drawing on this observation, the technical reference group also raised that invasive caulerpa could have some negative effect to coastal water quality in extreme storm events.

In terms of carbon sequestration, caulerpa as a plant could contribute to carbon sequestration. However, there is also some literature suggesting that caulerpa releases carbon at a higher rate than native seagrass habitats, and it stores carbon at a lower rate (Ruiz-Halpern, Vaquer-Sunyer, and Duarte 2014). If there is considerable loss in the diversity in the native seagrass habitat due to invasion of caulerpa, then there could be a potential net loss in carbon sequestration. This could then flow through to the increased carbon flux that is passed on to other elements of the food chain, including fish.

The existing science base is still very limited in giving us a clear idea of how invasive caulerpa could impact water quality and carbon sequestration in New Zealand's marine ecosystem. However, there is some information in the international literature suggesting some correlation. Thus, at this stage, to be conservative, we acknowledge the possibility of some impact of invasive caulerpa on water quality and carbon sequestration of our study area, given some of the literature suggesting the correlation between the presence of invasive caulerpa and nutrient levels, trapped sediment and carbon flux. For each option, we pro-rata the assumptions on the percentage decrease in water quality at 10 percent of the rate of infestation and carbon sequestration at 5 percent of the rate of infestation. The technical reference group considered this approach appropriate.

Table 11 summarises our model parameters and assumptions described above on impacts to the study area's ecosystem services for each option.

Table 11 Assumptions of impacts to the study area's ecosystem services – cf. no caulerpa invasion

<table>
<thead>
<tr><th>Parameters</th><th>Option 1</th><th>Option 2</th><th>Option 3</th><th>Option 4a</th><th>Option 4b</th><th>Option 5</th></tr>
</thead>
<tbody>
<tr><td>Percentage loss in aquaculture production</td><td colspan="3">5 percent per year</td><td>3.3 percent per year</td><td colspan="2">1.7 percent per year</td></tr>
<tr><td>Additional compliance costs to aquaculture</td><td colspan="3">$3.5 million/year × remaining aquaculture production</td><td colspan="3">$3.5 million/year</td></tr>
<tr><td>Commercial fishing activities restricted</td><td colspan="6">Proportion of commercial fishing using bottom-contacting methods × proportion of the study area infested</td></tr>
<tr><td>Compliance costs to commercial fishing</td><td colspan="3">$3.5 million/year × remaining commercial fishing activities</td><td colspan="3">$3.5 million/year</td></tr>
<tr><td>Recreational fishing activities restricted</td><td colspan="6">Proportion of recreational fishing using bottom-contacting methods × proportion of the study area infested</td></tr>
<tr><td>Compliance cost to recreational fishing</td><td colspan="3">$8 per 15-minute compliance
× remaining recreational fishing activities</td><td colspan="3">$8 per 15-minute compliance × all recreational fishing activities</td></tr>
<tr><td>Recreational use restricted</td><td colspan="2">All tourism/sightseeing activities in infested areas</td><td>2/3 of tourism/sightseeing activities in infested areas</td><td colspan="2">1/3 of tourism/sightseeing activities in infested areas</td><td>2/3 of tourism/sightseeing activities in infested areas</td></tr>
<tr><td>Compliance cost to recreational use</td><td colspan="3">$8 per 15-minute compliance × remaining recreational use</td><td colspan="3">$8 per 15-minute compliance × all recreational use</td></tr>
<tr><td>Percentage decrease in water quality</td><td colspan="6">Pro-rata at 10% of the rate of infestation</td></tr>
<tr><td>Percentage decrease in carbon sequestration</td><td colspan="6">Pro-rata at 5% of the rate of infestation</td></tr>
<tr><td>Percentage decrease in biodiversity</td><td colspan="6">Pro-rata at 2/3 of the rate of infestation</td></tr>
</tbody>
</table>

Source: NZIER

5 Results

This section presents the results of our economic modelling. We start with our results for our counterfactual scenario, Option 1, representing the do minimum under a high infestation scenario.

5.1 Estimated impacts of Option 1 (i.e. do minimum under a high infestation scenario) compared to no caulerpa invasion

Table 12 presents our model's estimates of the potential loss in the study area's value of natural capital due to caulerpa under Option 1, which represents do minimum under a high infestation scenario. We do this by comparing the values of the study area's ecosystem services under this scenario with those values in the case when there is no invasion of caulerpa.

Table 12 Comparing the study area's natural capital value between no caulerpa invasion and under do minimum

2024 dollars

Ecosystem service	30-year asset value ($m)		Loss in asset value relative to no caulerpa	
	No caulerpa	Option 1	$m	%
Provisioning services	***$1,906.9***	***$1,755.4***	***$151.5***	***7.9%***
Aquaculture	$325.9	$302.0	$23.9	7.3%
Commercial fishing	$356.5	$238.4	$118.1	33.1%
Recreational fishing	$1,224.5	$1,214.9	$9.5	0.8%
Cultural services	***$58,335.0***	***$49,576.2***	***$8,758.7***	***15.0%***
Recreation (ex. recreational fishing)	$54,525.7	$45,897.7	$8,628.0	15.8%
Recreational fishing	$3,809.2	$3,678.5	$130.7	3.4%
Regulating & supporting services	***$5,833.5***	***$5,344.2***	***$489.4***	***8.4%***
Water quality	$2,897.1	$2,829.7	$67.4	2.3%
Biodiversity	$2,705.0	$2,285.6	$419.3	15.5%
Carbon sequestration	$231.5	$228.8	$2.7	1.2%
Total asset value of natural capital	**$66,075.4**	**$56,675.7**	**$9,399.6**	**14.2%**

Note: the asset values are calculated by discounting the rent values at a 2% discount rate over 30 years.

Source: NZIER

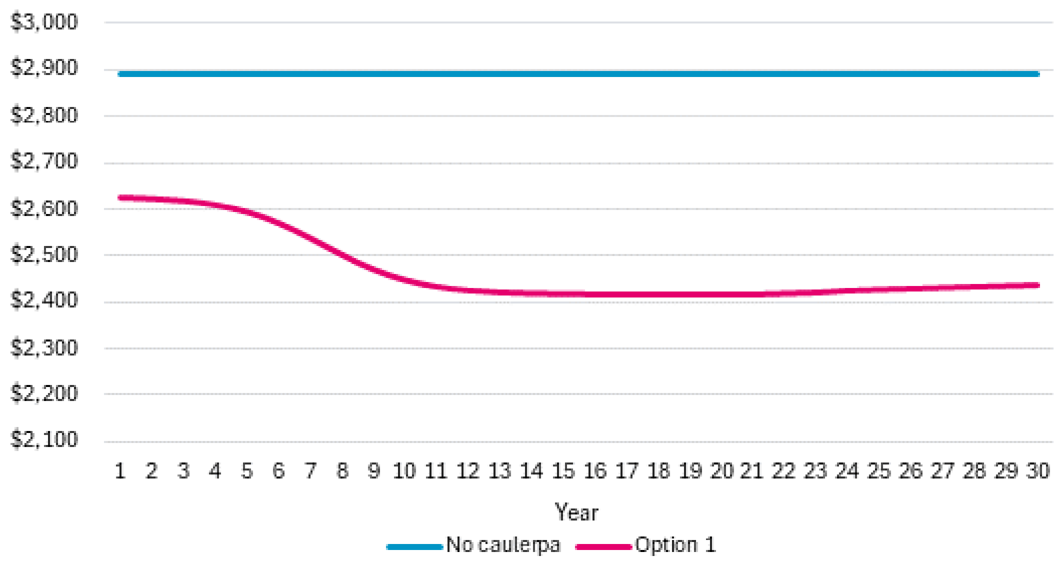
Our modelling results suggest that relative to the case when there is no invasion of caulerpa, implementing the do minimum option (Option 1) could result in a potential loss of about 14 percent (approx. $9.4 billion) in the study area's natural capital asset value over 30 years. Looking across the different types of ecosystem services, the value attributable to recreational use is mostly impacted, with a 16 percent ($8.6 billion) reduction from no caulerpa invasion over 30 years. This reflects the importance of the study area as a natural environment amenity for regular recreation use by the surrounding resident population and visitors. If a high rate of caulerpa infestation persists, a higher proportion of the study area will require restrictions to mitigate further spread, leading to a greater loss of recreational value due to the reduced recreational activities and higher compliance costs for the remaining recreational activities that can still happen in the study area.

The loss to the value of biodiversity is the second largest, amounting to a loss of $419 million (16 percent) from if there was no invasion of caulerpa. Even with conservative assumptions on the extent of the ecological impact, our modelling results suggest invasive caulerpa would have considerable negative impacts on biodiversity in the affected marine environment. This is consistent with the expected impacts based on the international experience.

Figure 9 compares the 30-year outlook of annual economic rent attributable to the study area's natural capital under Option 1 with the annual rent value if there was no invasion of caulerpa. The difference in rent values increases rapidly in the first 10 years of the projection period, reflecting the rapid spread of invasive caulerpa in the study area during this period.

Figure 9 30-year outlook of annual rent value, Option 1 vs no caulerpa

$million, 2024 dollars

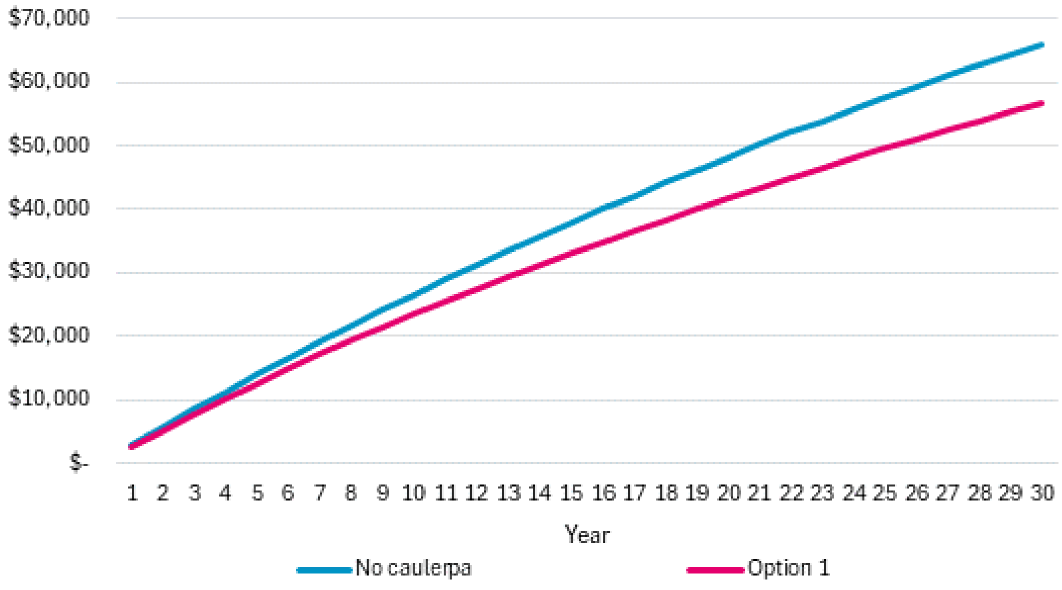


Source: NZIER

By discounting the annual economic rents using a 2 percent discount rate, Figure 10 projects the 30-year outlook of the study area's natural capital asset value under Option 1 and when there is no invasion of caulerpa. The projected trajectories point to a widening of the gap in natural capital asset value over time as high infestation persists.

Figure 10 30-year outlook of natural capital asset value, Option 1 vs no caulerpa

$million, 2024 dollars



Source: NZIER

5.2 Benefits of alternative mitigation options relative to Option 1

We model the relative benefits of implementing the alternative mitigation options as the mitigated (or avoided) loss to the values of ecosystem services relative to Option 1, representing the high caulerpa infestation scenario with the do minimum. The results presented in Table 13 can be interpreted as below:

- Option 2 mitigates zero (or minimal) of the natural capital value that would otherwise be lost by implementing Option 1 under a high infestation outcome over 30 years
- Option 3 mitigates $0.9 billion of the natural capital value that would otherwise be lost by implementing Option 1 under a high infestation outcome over 30 years
- Option 4a mitigates $2.5 billion of the natural capital value that would otherwise be lost by implementing Option 1 under a medium infestation outcome over 30 years
- Option 4b mitigates $2.9 billion of the natural capital value that would otherwise be lost by implementing Option 1 under a low infestation outcome over 30 years
- Option 5 mitigates $2.5 billion of the natural capital value that would otherwise be lost by implementing Option 1 under a low infestation outcome over 30 years.

Table 13 Estimated benefits of alternative mitigation options relative to Option 1

2024 dollars

Ecosystem service	Estimated loss under Option 1 relative to no caulerpa ($m)	Mitigated loss relative to Option 1 ($m)				
		High infestation		Medium infestation	Low infestation	
		Option 2	Option 3	Option 4a	Option 4b	Option 5
Provisioning services	***$151.5***	***$0***	***$0***	***$25.7***	***$47.8***	***$47.8***
Aquaculture	$23.9	$0	$0	$5.0	$10.5	$10.5
Commercial fishing	$118.1	$0	$0	$16.2	$30.8	$30.8
Recreational fishing	$9.5	$0	$0	$4.5	$6.5	$6.5
Cultural services	***$8,758.7***	***$0***	***$931.4***	***$2,258.2***	***$2,482.7***	***$2,151.9***
Recreation (ex. recreational fishing)	$8,628.0	$0	$931.4	$2,245.0	$2,463.3	$2,132.5
Recreational fishing	$130.7	$0	$0	$13.2	$19.4	$19.4
Regulating & support services	***$489.4***	***$0***	***$0***	***$231.7***	***$334.2***	***$334.2***
Water quality	$67.4	$0	$0	$31.9	$46.0	$46.0
Biodiversity	$419.3	$0	$0	$198.6	$286.3	$286.3
Carbon sequestration	$2.7	$0	$0	$1.3	$1.8	$1.8
Total asset value of natural capital	**$9,399.6**	**$0**	**$931.4**	**$2,515.7**	**$2,864.7**	**$2,533.9**

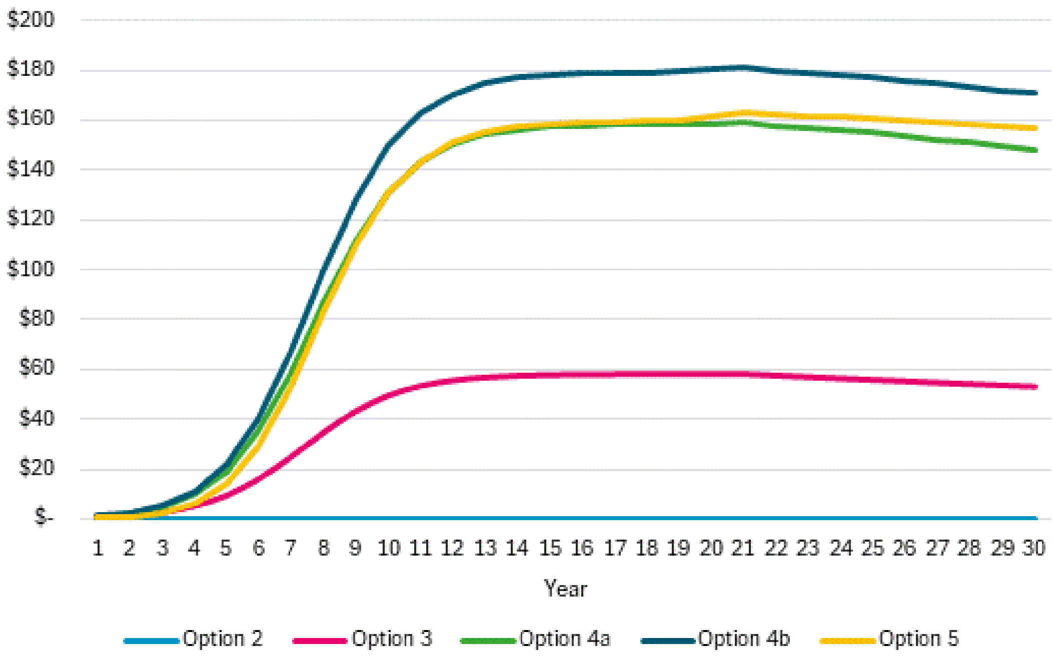
Note: the asset values are calculated by discounting the rent values at a 2% discount rate over 30 years

Source: NZIER

Figure 11 and Figure 12 project the 30-year outlook of the mitigated loss in annual rent and mitigated loss in asset value of the natural capital for each alternative mitigation option relative to Option 1.

Figure 11 30-year outlook of mitigated loss in annual rent relative to Option 1

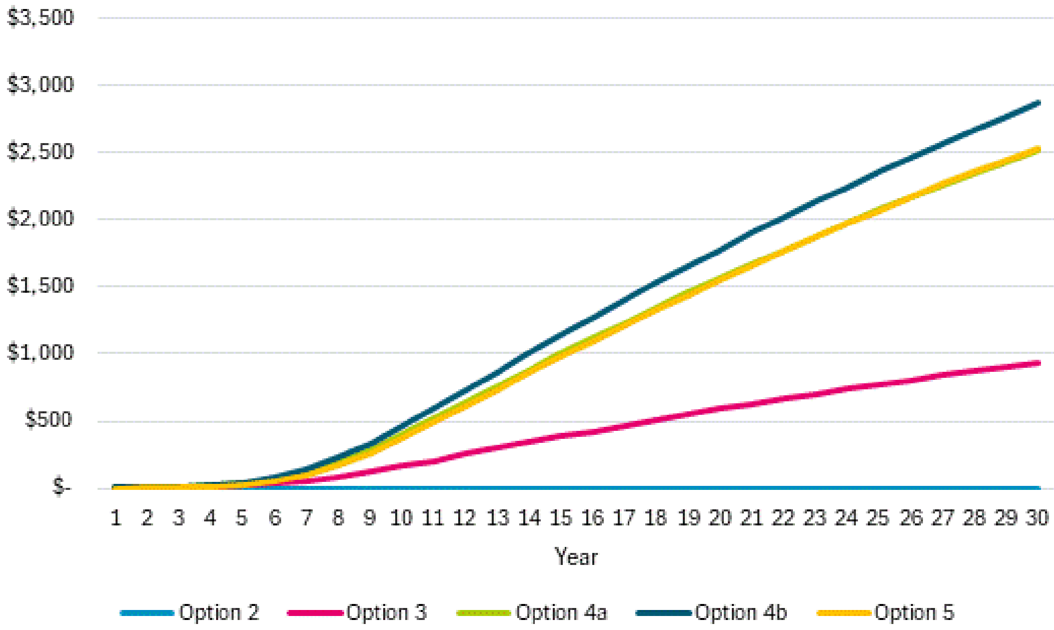
$million, 2024 dollars



Source: NZIER

Figure 12 30-year outlook of mitigated loss in natural capital asset value relative to Option 1

$million, 2024 dollars



Source: NZIER

While our modelling shows that the study area's natural capital asset value will be lower across all options compared to if there was no invasion of caulerpa, successful implementation of the alternative responses proposed under the business case can mitigate a considerable amount of the natural capital asset that would otherwise be lost with the do minimum high infestation scenario. In particular:

- Implementation of exclusion or containment strategies that are less likely to mitigate the spread of Caulerpa but seek to manage its impacts within high value areas or existing infested areas can mitigate up to $0.9 billion (or up to 10 percent) of the loss in the natural capital assets
- Successful Implementation of a strengthened marine biosecurity system that leads to a medium or low infestation outcome can mitigate $2.5 billion to $2.9 billion (or 27 percent to 30 percent) of the loss in the natural capital assets
- Adopting an option that significantly restricts access and movement to pursue a low infestation outcome can mitigate $2.5 billion (27 percent) of the loss in natural capital asset values.

The benefits of implementing alternative mitigation options, especially Options 4a, 4b or 5, reflect their lower caulerpa infestation outcomes. The combination of increased treatments, surveillance, enforcement, research and education means that the spread of invasive caulerpa can be slowed and prevented earlier than the minimal intervention effort under Option 1. Therefore, a higher proportion of the study area can remain free of invasive caulerpa, so that more risk to the study area's environmental qualities, especially the risk to biodiversity, can be mitigated, and more activities will be unaffected overall.

Our results also suggest that Options 4a, 4b and 5 are more effective than Option 3 in addressing the risk of invasive caulerpa. These three options impose a strengthened marine biosecurity response with greater surveillance, enforcement, education, investment in science and innovation, and greater national and regional support for delivering a coordinated marine biosecurity response.

While imposing stringent restrictions on access and movement until eradication is complete (i.e. Option 5) can still achieve a low infestation outcome, this response results in a lower benefit than the response under Option 4b, which can achieve a similar low infestation outcome with fewer restrictions imposed on activities. The difference in the modelled benefits between these two options reflects the additional economic loss associated with imposing a much higher level of restrictions when a similar infestation outcome can be achieved.

6 Sensitivity analysis

This section presents a set of sensitivity analyses undertaken to test the impact of changes in some of our model parameters.

6.1 Alternative assumptions on recreation values

The recreation services of the study area make up most of the total natural capital value, and our modelling suggests that the ecosystem services are also most impacted by the interventions of addressing caulerpa across all five options. Thus, we have undertaken sensitivity analysis to test how our modelling results will change when we apply lower assumptions to the following parameters of recreational values:

- Resident population base in surrounding districts, excluding the Hauraki Gulf
- Unit WTP (willingness to pay) value per visit for recreation.

Results of this sensitivity analysis shown in Table 14 to Table 17 suggest that the results are much more sensitive to the assumption of value per recreational visit than to the assumption around the resident population base in the study area's surrounding districts outside the Hauraki Gulf. However, recreational values remained the most significant component in our model output when assumptions on either of those two parameters were lowered.

Table 14 Modelling results with original assumptions on recreational values

Ecosystem service	Asset value – no Caulerpa ($m)	Estimated loss under Option 1 ($m)	Mitigated loss in asset value relative to Option 1 ($m)				
			High infestation		Medium infestation	Low infestation	
			Option 2	Option 3	Option 4a	Option 4b	Option 5
Recreation	$54,525.7	$8,628.0	$0	$931.4	$2,245.0	$2,463.3	$2,132.5
Total asset value	**$66,075.4**	**$9,399.6**	**$0**	**$931.4**	**$2,515.7**	**$2,864.7**	**$2,533.9**

Source: NZIER

Table 15 Modelling results when reducing the resident population base for the other surrounding districts by 25%

Ecosystem service	Asset value – no Caulerpa ($m)	Estimated loss under Option 1 ($m)	Mitigated loss in asset value relative to Option 1 ($m)				
			High infestation		Medium infestation	Low infestation	
			Option 2	Option 3	Option 4a	Option 4b	Option 5
Recreation	$53,286.0	$8,431.9	$0.0	$910.2	$2,193.9	$2,407.3	$2,084.0
Total asset value	**$64,835.7**	**$9,203.5**	**$0.0**	**$910.2**	**$2,464.6**	**$2,808.7**	**$2,485.4**

Source: NZIER

Table 16 Modelling results when reducing the resident population base for the other surrounding districts by half

Ecosystem service	Asset value – no Caulerpa ($m)	Estimated loss under Option 1 ($m)	Mitigated loss in asset value relative to Option 1 ($m)				
			High infestation		Medium infestation	Low infestation	
			Option 2	Option 3	Option 4a	Option 4b	Option 5
Recreation	$52,046.3	$8,235.7	$0.0	$889.0	$2,142.9	$2,351.3	$2,035.5
Total asset value	**$63,596.0**	**$9,007.3**	**$0.0**	**$889.0**	**$2,413.6**	**$2,752.7**	**$2,436.9**

Source: NZIER

Table 17 Modelling results when applying the lower bound unit WTP value of $41.4 per recreational visit

Ecosystem service	Asset value – no Caulerpa ($m)	Estimated loss under Option 1 ($m)	Mitigated loss in asset value relative to Option 1 ($m)				
			High infestation		Medium infestation	Low infestation	
			Option 2	Option 3	Option 4a	Option 4b	Option 5
Recreation	$30,183.5	$7,231.2	$0.0	$465.7	$1,093.3	$1,214.1	$1,031.0
Total asset value	**$41,733.2**	**$8,002.8**	**$0.0**	**$465.7**	**$1,364.0**	**$1,615.5**	**$1,432.4**

Source: NZIER

6.2 Alternative assumptions of caulerpa's impact on water quality

Water quality presents the largest component in the value of regulating and supporting services in our modelling. With the uncertainty around to what extent water quality could be negatively impacted by invasive caulerpa, we have agreed with the technical reference group to test how our modelling results could undertake sensitivity analysis with alternative assumptions on water quality impact.

Results on the estimated loss in the value of water quality under Option 1 and the loss mitigated by the alternative options increase proportionately to the increase in assumptions on water quality impacts (see Table 18 to Table 20).

Table 18 Modelling results with original assumption on water quality impacts

Ecosystem service	Asset value – no Caulerpa ($m)	Estimated loss under Option 1 ($m)	Mitigated loss in asset value relative to Option 1 ($m)				
			High infestation		Medium infestation	Low infestation	
			Option 2	Option 3	Option 4a	Option 4b	Option 5
Water quality	$2,897.1	$67.4	$0.0	$0.0	$31.9	$46.0	$46.0
Total asset value	**$66,075.4**	**$9,399.6**	**$0.0**	**$931.4**	**$2,515.7**	**$2,864.7**	**$2,533.9**

Source: NZIER

Table 19 Modelling results when pro-rata water quality impact from caulerpa at 20% of the rate of infestation

Ecosystem service	Asset value – no Caulerpa ($m)	Estimated loss under Option 1 ($m)	Mitigated loss in asset value relative to Option 1 ($m)				
			High infestation		Medium infestation	Low infestation	
			Option 2	Option 3	Option 4a	Option 4b	Option 5
Water quality	$2,897.1	$134.7	$0.0	$0.0	$63.8	$92.0	$92.0
Total asset value	**$66,075.4**	**$9,467.0**	**$0.0**	**$931.4**	**$2,547.6**	**$2,910.7**	**$2,579.9**

Source: NZIER

Table 20 Modelling results when pro-rata water quality impact from caulerpa at 30% of the rate of infestation

Ecosystem service	Asset value – no Caulerpa ($m)	Estimated loss under Option 1 ($m)	Mitigated loss in asset value relative to Option 1 ($m)				
			High infestation		Medium infestation	Low infestation	
			Option 2	Option 3	Option 4a	Option 4b	Option 5
Water quality	$2,897.1	$202.1	$0.0	$0.0	$95.7	$138.0	$138.0
Total asset value	**$66,075.4**	**$9,534.4**	**$0.0**	**$931.4**	**$2,579.5**	**$2,956.7**	**$2,625.9**

Source: NZIER

6.3 Alternative discount rates

We have also undertaken a more traditional sensitivity analysis of alternative discount rates. The alternative discount rate as per Treasury's guideline for non-commercial proposals for sensitivity analysis is 8 percent. We have also tested with a 5 percent discount rate and the 9 percent discount rate as per Stats NZ's Environmental Economic Account.

Results in Table 21 suggest that while the natural capital asset value when there is no caulerpa invasion decreases as a higher discount rate is applied, the estimated loss in asset value under Option 1 and estimated benefits of alternation options also decrease as the discount rate increases. With an 8 percent discount rate, the estimated loss to natural capital asset would be 51 percent lower, and the estimated benefits of Options 3 to 5 would be about 60 percent lower than if a 2 percent discount rate was applied.

Table 21 Modelling results with alternative discount rates

Ecosystem service	Asset value – no Caulerpa ($m)	Estimated loss under Option 1 ($m)	Mitigated loss in asset value relative to Option 1 ($m)				
			High infestation		Medium infestation	Low infestation	
			Option 2	Option 3	Option 4a	Option 4b	Option 5
2%	$66,075.4	$9,399.6	$0.0	$931.4	$2,515.7	$2,864.7	$2,533.9
5%	$46,686.6	$6,378.6	$0.0	$585.1	$1,567.2	$1,783.9	$1,566.7
8%	$35,167.1	$4,608.5	$0.0	$386.5	$1,025.5	$1,167.0	$1,017.0
9%	$32,390.1	$4,186.9	$0.0	$340.0	$899.3	$1,023.3	$889.3

Source: NZIER

7 Conclusion

This report has prepared an economic modelling of the impacts of implementing different mitigation strategies in managing caulerpa infestation in the currently impacted and at-risk areas in New Zealand (i.e. Cape Reigna to East Cape). Our model builds on the approach and method developed in our previous work on *Valuing the Hauraki Gulf,* which assesses the impacts on the values of the ecosystem services of the natural capital under the implementation of the strategies encompassing do minimum to slow the spread, exclusion or containment, suppression and localised elimination and long-term eradication.

Results from our modelling suggest a $9.4 billion loss in the asset value of the study area's natural capital over a 30-year period with implementing a do minimum strategy, which only focuses on CANs as the main intervention albeit with limited investment in other tools such as monitoring and enforcement (i.e. Option 1). Compared to this counterfactual, exclusion or containment strategies seeking to manage the impact of invasive caulerpa within high value areas or existing infested areas can mitigate up to $0.9 billion of the natural capital assets that would otherwise be lost under do minimum over 30 years. Options such as imposing a strengthened marine biosecurity system to support suppression and local elimination or the ambition to remove the threat can mitigate $2.5 billion to $2.9 billion of the natural capital asset that would otherwise be lost if a lower infestation outcome is achieved. While imposing significant restrictions on access and movement to pursue a low infestation outcome can still mitigate $2.5 billion of the loss in natural capital asset values, there is also some economic loss associated with such restrictions.

Our economic modelling presented in this report is limited to the information available about the environmental qualities and activities in our study area, as well as the existing science and research for understanding the likely spread of invasive caulerpa and its impacts on marine ecosystems in New Zealand. Forming assumptions for the potential rate of infestation and impacts on environmental qualities such as water quality, biodiversity, and carbon sequestration has been proven to be a very challenging task given the lack of science to inform a range of possible impacts for New Zealand. This highlights the urgency for further research to establish a more robust scientific evidence base for New Zealand, which will better inform the development of strategies to mitigate the risk of invasive caulerpa in New Zealand.

We also acknowledge that there are significant implications for te ao Māori, especially the four key Māori cultural values relevant to environment management in relation to kaitiakitanga, manaakitanga, mahinga kai and rangatiratanga. However, we were not able to quantify those impacts given the scarce research around measuring the key values of importance for Te Moana, which is still a work in progress in New Zealand.

Overall, this modelling exercise provides a useful starting point for assessing the relative impacts of mitigation strategies, which can be repeated and improved as more scientific evidence and knowledge becomes available.

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Appendix A Supplementary tables

Table 22 Comparing the 30-year natural capital asset value under alternative mitigations with no caulerpa invasion

$million, 2024 dollars

Ecosystem service	No caulerpa	High infestation		Medium infestation	Low infestation	
		Option 2	Option 3	Option 4a	Option 4b	Option 5
Provisioning services	***$1,906.9***	***$1,755.4***	***$1,755.4***	***$1,781.1***	***$1,803.2***	***$1,803.2***
Aquaculture	$325.9	$302.0	$302.0	$307.0	$312.5	$312.5
Commercial fishing	$356.5	$238.4	$238.4	$254.6	$269.2	$269.2
Recreational fishing	$1,224.5	$1,214.9	$1,214.9	$1,219.4	$1,221.4	$1,221.4
Cultural services	***$58,335.0***	***$49,576.2***	***$50,507.6***	***$51,834.4***	***$52,058.9***	***$51,728.2***
Recreation (ex. recreational fishing)	$54,525.7	$45,897.7	$46,829.1	$48,142.7	$48,361.0	$48,030.2
Recreational fishing	$3,809.2	$3,678.5	$3,678.5	$3,691.8	$3,698.0	$3,698.0
Regulating & support services	***$5,833.5***	***$5,344.2***	***$5,344.2***	***$5,575.9***	***$5,678.3***	***$5,678.3***
Water quality	$2,897.1	$2,829.7	$2,829.7	$2,861.6	$2,875.7	$2,875.7
Biodiversity	$2,705.0	$2,285.6	$2,285.6	$2,484.2	$2,572.0	$2,572.0
Carbon sequestration	$231.5	$228.8	$228.8	$230.0	$230.6	$230.6
Total asset value of natural capital	**$66,075.4**	**$56,675.7**	**57,607.1**	**$59,191.4**	**$59,540.4**	**$59,209.6**

Note: the asset values are calculated by discounting the rent values at a 2% discount rate over 30 years

Source: NZIER