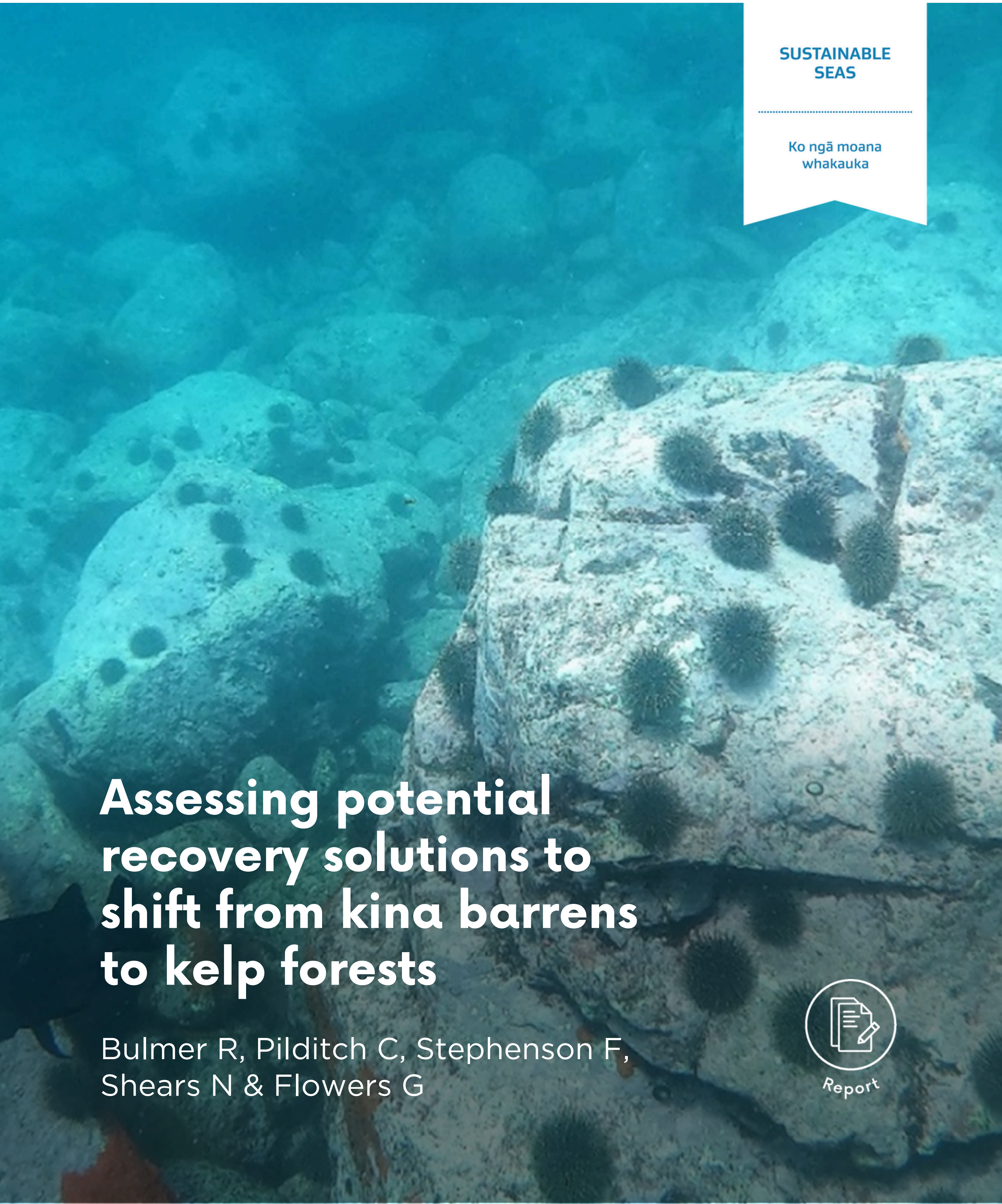
National Science Challenges

SUSTAINABLE SEAS

Ko ngā moana whakauka



Assessing potential recovery solutions to shift from kina barrens to kelp forests

Bulmer R, Pilditch C, Stephenson F, Shears N & Flowers G

Report

Report for Sustainable Seas National Science Challenge project *Assessing potential recovery solutions for kina barrens (IFI3)*

Authors

Richard Bulmer, Conrad Pilditch, Fabrice Stephenson, Nick Shears, Georgina Flowers

Date of publication

June 2024

About the Sustainable Seas National Science Challenge

Our vision is for Aotearoa New Zealand to have healthy marine ecosystems that provide value for all New Zealanders. We have 75 research projects that bring together around 250 scientists, social scientists, economists, and experts in mātauranga Māori and policy from across Aotearoa New Zealand. We are one of 11 National Science Challenges, funded by the Ministry of Business, Innovation & Employment.

www.sustainableseaschallenge.co.nz

Cover image: Kina barren by Nick Shears.

Acknowledgements

We would like to acknowledge and thank the input of all workshop attendees for graciously sharing their knowledge, which was used to generate the model and associated report, and for providing feedback on the report.

Contents

Executive summary

Kelp forests are highly productive ecosystems that provide habitat and food for many ecologically and commercially important fish and invertebrate species. However, habitat shifts from kelp forests to kina barrens are increasingly recognised as an issue affecting coastal reefs in Aotearoa New Zealand. Management actions that address the problem using existing information are urgently needed.

The purpose of this project was to:

- share knowledge between Fisheries New Zealand (FNZ), Tangata Whenua representatives, and Sustainable Seas researchers about the causes of kina barrens in Northland, New Zealand
- identify and explore management actions that could address the issue.

Two workshops were held to share understanding of the drivers of kina barrens and potential management solutions to recover kelp (workshops included four Sustainable Seas marine ecosystem researchers, three Fisheries New Zealand (FNZ) science staff, and four Tangata Whenua representatives). A probabilistic Bayesian Network model was developed as part of this process to summarise this knowledge to further help inform management decision-making, including furthering FNZ's goal to mitigate the impacts of barrens.

A key result of this project was consensus between all workshop attendees about the ecological drivers of kina barrens and the need to restore the abundance of large predators (including snapper and crayfish) to recover kelp forests long term. The emerging science and mātauranga held by Tangata Whenua representatives was aligned, as was agreement regarding the increase in kina barrens in recent years and the general decline of the snapper and crayfish fisheries. Workshop attendees also agreed that, to address the issue, fisheries closures or bespoke management actions at a local scale, which involve Māori, would be required.

The model building process was useful to focus discussions and share knowledge, and to synthesise key information that was used to run scenarios to generate further discussion and explore potential management outcomes. By including some of the cultural values identified by Tangata Whenua, the model illustrated how differences in the method of management approach (via rāhui/mātaitai vs. via crown led closure) had significant implications for iwi/hapū. In addition, the relationship between FNZ and Tangata Whenua was discussed, and suggestions made to improve this relationship in the future. This included FNZ and the government honouring their obligations under the Treaty of Waitangi by empowering Tangata Whenua to take a greater leadership role in research outputs and management decision-making for their rohe.

Opportunities to improve the utility of the model were also discussed, which included:

1. updating the model to be able to look into different management options (e.g., changes to total allowable catch, management targets, customary harvest occurring in marine protected areas, and local closures)
2. incorporating ecosystem health both within and outside the modelled area (i.e., to assess flow on/spillover effects of management actions at different scales)
3. ongoing training/expert advice on the use and refinement of the model
4. collating and collecting additional data to fill gaps in our understanding of kina barrens and potential management solutions, noting that data gaps should not be considered a barrier to management action.

Emerging research, supported by workshop attendees, demonstrates that management actions that increase the abundance of large predators (in addition to potential kina culling) are the most promising approaches to reducing kina barrens and restoring kelp forests. The overarching message from the workshops was that lack of data should not be used as a reason for delaying management action to address the kina barren issue. By implementing informed management actions now, despite uncertainty in exact outcomes, the impacts of precautionary measures on kelp recovery and associated biodiversity will be valuable for informing and refining future management actions. Continued investment in co-developing management strategies with iwi / hapū, community, and other stakeholders is key to supporting restorative action and restoration success.

Introduction

Kelp forests are highly productive environments / ecosystems that provide habitat and food for many ecologically and commercially important fish and invertebrate species (Eger et al., 2023). However, habitat shifts from kelp forests to kina barrens are increasingly recognised as an issue throughout Aotearoa New Zealand (Figure 1)(Wing et al. 2022, Kerr et al. 2024). Kina barrens are areas where kina (*Evechinus chloroticus,* also commonly referred as urchins) grazing causes the substratum to have little or no macroalgae and is dominated by bare rock or encrusting algae (Shears and Babcock 2003). Barrens have been shown to occur once kina densities exceed critical thresholds (i.e. ~2.5 m^{-2}, Ling et al. 2015), and once these thresholds are exceeded and kina barrens are established, they are difficult to reverse. Kina need to be reduced to <1 per m^2 to reverse the barren and recover kelp-dominated habitat (Shears and Babcock 2003). Alongside declines in kelp and other macroalgal communities, kina barrens dramatically change rocky reef communities, including declines in other reef organisms, with significant consequences for the ecological functioning of the areas and the ability of the areas to support sustainable fisheries. While an over-abundance of kina due to a lack of kina predators is thought to be the main driver of barrens in northeastern New Zealand, other factors can also drive the loss of kelp and the creation of barrens, such as coastal darkening, sedimentation, and warming temperatures (Blain et al. 2021), and these vary regionally.

Many factors influence kina abundance and where kina barrens occur. The abundance of kina barrens is notably lower in long-term marine reserves (Peleg et al. 2023, Kerr et al. 2024). For example, in marine reserves in northeastern New Zealand, kina barrens covered < 2 % of shallow reef areas (Kerr et al. 2024). Meanwhile, in non-protected/fished areas, kina barrens cover 7-49 % of shallow reefs (Kerr et al. 2024). Kina barrens occur in our most pristine reef ecosystems and are found in specific depth zones (e.g., from 2 to 10 m (Shears and Babcock 2003, Shears and Babcock 2004)), restricted from deeper waters by a combination of biological and physical processes. Kina barrens are more extensive on moderately wave-exposed reefs and are not observed in areas with high turbidity (Kerr *et al.,* 2024). Their extents expand and contract over time, and they have expanded in many locations since the 1950's (Wing et al. 2022, Kerr et al. 2024). For example, in Mimiwhangata 'marine park' where recreational fishing can occur, 49% of shallow reef are now kina barrens, yet no barrens were present in the 1950s (Kerr et al. 2024). A 2 km^2 area of kina barren can contain approximately 10 million kina, demonstrating the scale of the management problem when kina barrens become established.

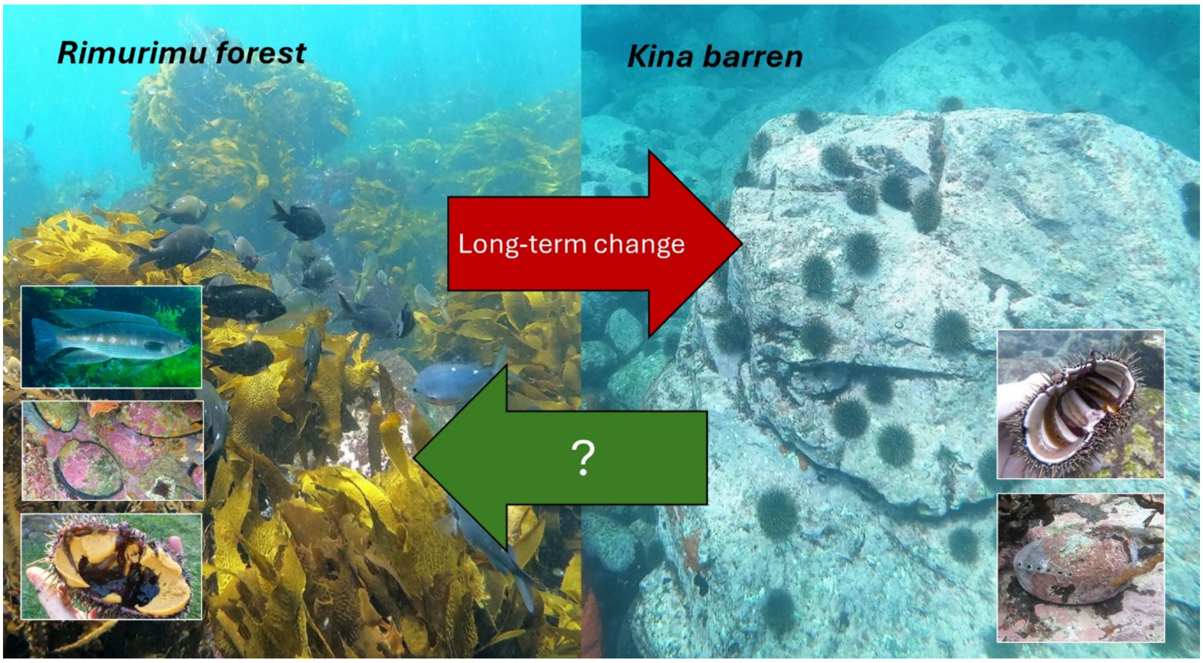


Figure 1: Kelp (*Rimurimu*) forest with abundant fish and other reef species (left). Kina barren devoid of macroalgae as a result of grazing by kina (right). Source: Nick Shears

The loss of large predators has been identified as the primary cause of kina barrens in northeastern New Zealand, in particular the loss of large reef predators such as snapper (tāmure) *Pagrus auratus* and spiny lobster / crayfish (kōura) *Jasus edwardsii*. Snapper biomass within the SNA1 fishery has declined from over 350 thousand tons in the 1900s to less than 100 thousand tons by 2020 (Snapper Stock Status | NIWA). The decline in the abundance of large snapper is significant as larger snapper eat larger kina (J Marinovich (PhD candidate; *unpublished data*)), and larger kina also have greater grazing capacity (Stevenson et al. 2016). In many kina barren locations, large declines in large crayfish abundance have also been observed (Eddy et al. 2015). The reduced population of large predators (snapper and crayfish) has resulted in these species no longer playing an effective role in controlling the abundance of kina in many locations.

Management actions that address the problem using existing information are urgently needed. Marine reserves such as the Leigh marine reserve, where predators are protected from fishing pressure, have been shown to be an effective ecological tool for restoring kelp forests and reducing kina barrens at regional scales (Babcock et al. 2010, Peleg et al. 2023). Customary management approaches (e.g. rotational harvest or harvesting based on local scale population abundance / health) has also been used to successfully manage the abundance of key predators as well as kina numbers throughout Northland for many hundreds of years (Reti, *pers. Comm*). The appropriate management action taken to restore kelp forests will depend on the ecosystem and stressor status of the reef (Figure 2). In reefs that are showing early signs of degradation (i.e. increasing kina abundances and signs of kelp loss), a management action that reduces stressors (e.g., fishing pressure) may be sufficient to recover the reef to a healthier state. However, once kina barrens have established, in addition to reducing stressors, more active interventions may be required (e.g., kina removal; Figure 2).

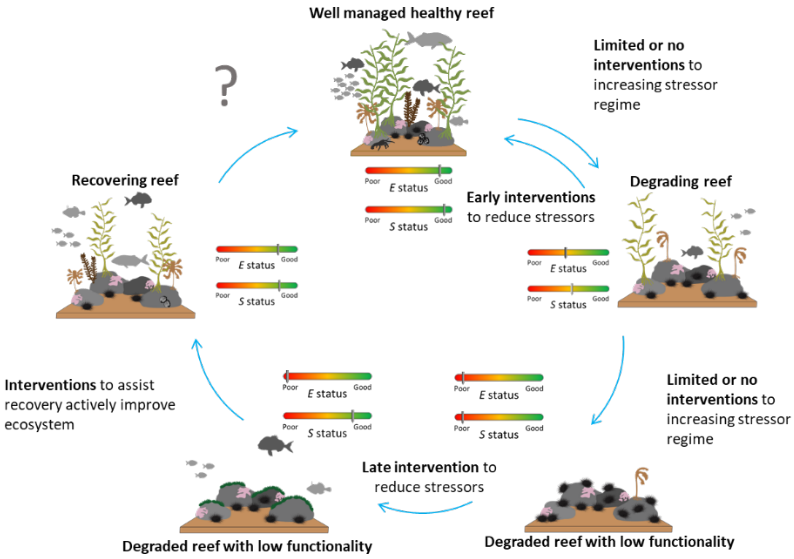


Figure 2: Conceptual diagram demonstrating how the appropriate intervention lever depends on the state of the ecosystem (E) and the state of the stressor (S) (sourced from Gladstone-Gallagher et al. (2024)). E and S range from good, healthy and desirable (green end of scale), to poor and undesirable (red end of scale).

Experiments have shown that kina removal of areas 1-2 ha (to <1 kina per m^2) have been successful in recovering kelp forests (Miller et al. 2024). The kina culling is costly, requiring approximately 50 diver hours per ha to reduce densities to <1 kina per m^2 (Miller and Shears 2023, Miller et al. 2024). Rapid recovery of kelp cover (and other macroalgal species) over the two years post kina barren removal was observed (four-fold increase in cover) (Miller et al. 2024). In parallel, the kina roe condition for the remaining kina in the areas was found to improve (Miller 2023). However, by year three, without any further culling of kina, kina numbers and barrens were observed to be increasing within the removal areas (Shears, pers comm). This may have resulted from re-invasion of kina from outside the removal area and growth and recruitment of kina within the removal area. The increase is facilitated by low numbers of kina predators (snapper and crayfish) in removal areas where fishing continues (Miller et al. 2024). This suggests that kina removal is not a management solution on its own, but can be used as part of a wider restoration strategy that rebuilds predator numbers. Miller et al. (2022) provides a useful summary of restoration methods, costs, outcomes, and benefits, identifying that predator enhancement (e.g., via the establishment of marine reserves or other fisheries management actions such as rāhui or mātaitai reserves and area specific limits and controls) is the only proposed solution to restore kelp forests and associated ecosystem benefits that would be enduring (Figure 3).

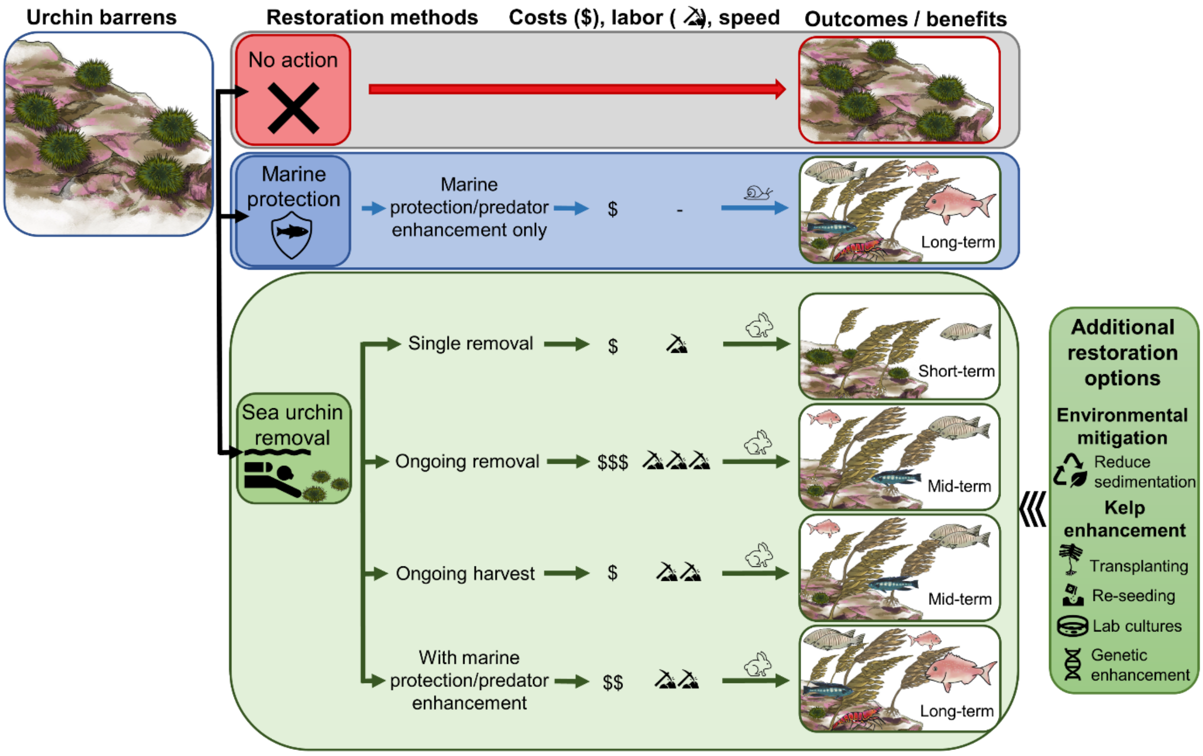


Figure 3: Approaches to restoration of kelp forests in urchin / kina barrens (no action, marine protection and sea urchin/kina removal), the costs labour and speed of the restoration approach, and the likely restorative outcome (sourced from Miller et al. 2022).

Requirements / scope

A major topic that Fisheries New Zealand (FNZ) is being pressed to address, by industry, iwi, non-governmental organisations, and community groups, is the occurrence of kina barrens in several parts of the country. A workshop was held by FNZ in March 2023 with key experts and stakeholders to establish the current state of knowledge on the topic of kina barrens and to identify research priorities to support management action. The workshop identified that addressing the issue of kina barrens was urgent and would require a suite of options involving spatial management, reduced harvest of kina predators, and targeted removal of kina from some areas (Doheny et al. 2023). Continuous engagement with Tangata Whenua on the appropriate level and clear communication with stakeholders and other organisations was also identified as key requirements to develop an effective approach.

Workshop feedback highlighted that taking an ecosystem-based approach to fisheries management would require the development of tools to support stakeholder discussions about potential management strategies such as ecosystem models (Doheny et al. 2023). The purpose of this project was to share knowledge between FNZ, Tangata Whenua representatives, and Sustainable Seas researchers of the causes of kina barrens and to identify some of the possible management actions that could be applied to address the issue. Based on the collective knowledge, a network model showing the connections between nature and people was to be developed that FNZ can use to move forward in their goal to increase kelp recovery.

As part of the project, Sustainable Seas and FNZ had the following objectives.

Sustainable Seas aims:

1. To produce a preliminary model that FNZ can use to move forward in its goal to increase kelp recovery.

2. To support decision-making practices that are more inclusive, multi-sectorial and account for the effects from cumulative and multiple activities.

3. To use knowledge from the Challenge (science and mātauranga Māori) in decision-making to improve ecological health and influences Aotearoa New Zealand's marine management practice and policy.

4. The relationship of Māori with Te Ao Tūroa – the wisdom and guidance of atua and tūpuna – is understood and informs approaches to marine governance, decision-making and practice.

5. Decision-making processes explicitly identify and address both risk and knowledge uncertainty in a way that reduces risks to ecological, social, cultural and economic wellbeing.

Fisheries New Zealand aims:

1. To work with iwi to develop measures to support a healthy ecosystem. To achieve this by exploring:
    a. customary knowledge about local ecosystems
    b. preferred management options for kina barrens
    c. how to support regional involvement in response to a large-scale issue
    d. what tools can be used to help work out the best approach.

Methodology

The key outputs and milestones of this work were:

- Workshop 1 with iwi and stakeholders to create a connections map: held 16th February 2024
- Sustainable Seas preliminary model creation: completed March 2024
- Workshop 2 with iwi and stakeholders to explore model and scenarios: held 16th April 2024
- Produce a report summarising the model outputs, including assumptions and limitations and hand over model: by end June 2024.

Workshops 1 and 2 were held with members of the project team (four Sustainable Seas marine ecosystem researchers, three Fisheries New Zealand science staff, and four Tangata Whenua representatives). Tangata Whenua represented iwi / hapū from Northland, New Zealand (including Ngāti Wai), with a focus on the east coast, which was the focal point of discussions and the subsequent model build. Workshop 1 was held in person in Whangaruru, Northland. Workshop 2 was held online. Notes were recorded throughout the workshops and summarised as short anonymous summaries (see results section) to inform the report and associated model.

During Workshop 1, the aims and objectives of the research were discussed by participants, who also shared their respective knowledge of the state and drivers of the kina barrens throughout Northland and Aotearoa, as well as potential management solutions.

To empower involvement of all workshop participants, a semi-structured method of expert elicitation was used to help guide discussions and explore key knowledge, which included:

1. Where do we want to be and what does that mean for this area? To determine what the management aspiration is for the area.
2. How did it used to be and how is it now? To determine the current state and to discuss why it is like this.
3. Why has the ecosystem changed and what is impacting it now? To help determine what is driving the occurrence of kina barrens through time.
4. How have these changes impacted the hapū? To help determine the wider cultural and social impacts of kina barrens.
5. What management actions can we take to improve its ecosystem health and what actions can we take to make it worse?

During Workshop 2, lessons learnt from the prior workshop were discussed, as well as how the Sustainable Seas team transferred these lessons to build the preliminary model. Example scenarios of the model were run, and management actions were further explored and discussed.

For both workshops, the intention to use the information gathered to generate an associated model and report, as defined above, was discussed, with summaries of the workshops used to inform the model building process sent to participants for input and to cross check that they reflected what was discussed.

Model generation

The Bayesian Network model was created using Genie software (version4.0.2304.0, BayesFusion LLC). Briefly, the model structure was depicted in a directed acyclical graph (DAG), where causal relationships (links) between the variables (nodes) are shown as arrows. In a broad way, the model aimed to explore the link between, cultural harvesting, recreational fishing or commercial fishing, and the abundance of snapper and crayfish, which in turn was used to explore the likelihood of kina barrens and a subset of social-cultural-ecological implications. Additionally, the effect of active interventions such as kina removal was also included to explore how, in combination with hypothetical changes in fishing, this could affect the likelihood of kina barrens.

The preliminary model structure was developed based on participant conversations during Workshop 1, with the model focal area being the eastern coast of Northland. The underpinning relationships between nodes (defined as Bayesian Networks) as conditional probability tables (CPTs), was determined based on empirical research (where available) or expert knowledge as is normally done for these kinds of models (Supplementary Table 1). For some elements of the model limited empirical data was available to inform the relationships. For example, the relative impact of cultural harvesting, recreational fishing, or commercial fishing was uncertain. In these instances, we treated their impact on large crayfish and snapper as equal, however we acknowledge some of these limitations in the Discussion section of this report.

Five hypothetical scenarios were generated to explore the consequences of a range of management scenarios of interest:

1. Baseline. No areas closed to snapper or crayfish harvest and current-day levels of cultural harvesting, recreational fishing, or commercial fishing are assumed occur.
2. Fisheries closures are implemented for 70% of the rohe / target area.
3. Rāhui / Mātaitai is implemented for 70% of the rohe / target area.
4. Rāhui / Mātaitai is implemented for 70% of the rohe / target area plus kina removal is put in place as an active management action
5. Restored ecosystem. Assumes that there has been 5-10 years’ worth of recovery due to management action, which has resulted in a significant decline in kina barrens and increase in snapper and crayfish.

Results

Workshop 1 summary

Over 20 pages of notes were collected based on conversations during Workshop 1. The following is a two-page summary of the key messages, which have been used to inform the model and associated scenarios. This two-page summary was shared with workshop participants to ensure that the key messages were accurately collated. Note that text below in quotation marks are not word-for-word quotes but summarise key messages / stories from the workshop participants.

The cause of kina barrens and the implications on hapū

- Kina barrens occur due to a lack of large predators (snapper and crayfish) to keep kina numbers in check.
- Cause of lack of large predators attributed to commercial and recreational fishing practices, in addition to changes in customary fishing practices in response to fisheries regulations and socioeconomic pressures and migration.
- CRITICAL to bring back large predators for long term recovery.
- Huge loss of abundance observed since the 70's *'When you hear the stories of the old days of people getting crays they would measure them with their [dive] bottle but we don't get that, we use our arm. As a youngster I saw a lot, but I don't see that now. We aspire for it to be like it was'.*
- Once kina barrens have become established not many kina are needed to maintain the barren (less than one kina per m^2 is needed to allow kelp to come back).
- Control the kina (<1 per m^2) = recover the kelp.
- Kina removal can result in rapid kelp recovery within the first two years BUT if large predators haven't come back then kina barrens take over again by year three.
- Every time hapū members are stopped from collecting kai it hurts them. Many hapū members have low socio-economic status so without kai we are impacted. This is an impact felt every day. *'For most hapū/returning whanau that come here, getting kina/kaimoana is one of the basic things we can supply but that's getting harder and harder. Traditionally, our marae would gather from the sea. Being able to Manaaki is a goal. We are known for that so when we have no kaimoana for our guests it is scary.'*

What management actions can we take to improve its health?

- Tangata Whenua have long term plans for the moana (e.g. 1000-year plans) to recover the abundance of the area (the moana vibrating with life, trees back, birds back, te reo Māori spoken, students sort after, and healthy people). They have recently secured funding (Māori led) to support ongoing monitoring, kina removal, potential fishing closures, establishment of hatcheries for taonga species recovery. This can be used as an example of the way forward.
- Rāhui and mātaitai can be used to modify fishing behaviours but for mātaitai it still needs to be approved by the Crown, which takes mana away from Tangata Whenua.
- We need holistic thinking. These issues need addressing in multiple ways.
- Management needs to be at a rohe / tribal area scale rather than a Snapper / Cray 1 scale, with local rules and guidelines.
- For Tangata Whenua, need to support a return to the old ways of customary harvest (e.g. rotational harvest, harvesting based on what is best for the kaimoana in that area - not what's allowed based on the rules and regulations, kina removals etc).

- Fishing rules and regulations need to be based on what's best for the ecosystem in that area. E.g. *'20 years ago, FNZ came to the marae, we told them we were throwing back the big ones for breeding purposes, but they told us that leaving the big snapper for reproduction was a fallacy. We were told that the sperm and egg count were not that great in the older fish, it gets worse with size. After being told this information and the rules changed, we started taking the bigger fish. However, we were not told of the importance of the big fish for the reef.'*
- Tangata Whenua representatives expressed that commercial fishing needs to be stopped. Recreational limits need to be lowered (other than for kina which needs to increase). Some areas need temporary closures and then phased re-openings with new rules e.g. *'If a snorkeler can get there then the bottles shouldn't be there, if a small rowboat can get there the commercial fisherman shouldn't be there. Boundaries need to be put out there for different practices'.* Real penalties for breaking the rules are also needed. Once you put someone up as an example of what not to do it can have a real effect.
- Tangata Whenua representatives expressed that the commercial fishing is not benefitting local hapū. *'Māori own 50 % of the commercial fishing industry but we know that Māori aren't receiving more than 1 % of the profit. Therefore, there are no benefits to them. We have no commercial fisherman and see none of the money. It doesn't make sense to us to ask the people to continue to fish because nothing comes back to us.'*
- Differences in the perception of commercial fishing impacts between FNZ and Tangata Whenua representatives may in part be to a mismatch in the scale of the fishing area, the spatial location of the fish stocks and overall effort (e.g., Snapper 2, Cray 1). The impacts are at a finer spatial scale so might be being felt even if the larger regional pressure is relatively low.
- Better information and education is needed. Rules / regulations vary so much from area to area and people always push it right to the line.
- Harsher penalties are needed if rules to recover the moana are broken.

A different way forward is needed

- *'Historically, we haven't changed. There has been no change in how we solve a problem. In the past, government agencies come to hapū to get information about a problem, and they go away and nothing changes. When are we going to do something different that results in a positive change for our people? We want to write up our own korero to give to the minister, but we are not paid / funded to write up our korero, so it is not getting to the minister. What has been done in the past doesn't work and has got to change. There are things that we would love to say but we can't because of the interpretation that would happen in order for it to be presented to the minister.'*

Model

A preliminary conceptual map of the key drivers of kina barrens and the associated ecological and cultural interconnections was developed based on key messages from Workshop 1. The relationships between nodes were estimated using a combination of empirical evidence and expert opinion from the workshop participants (Figure 4, Supplementary Table 1).

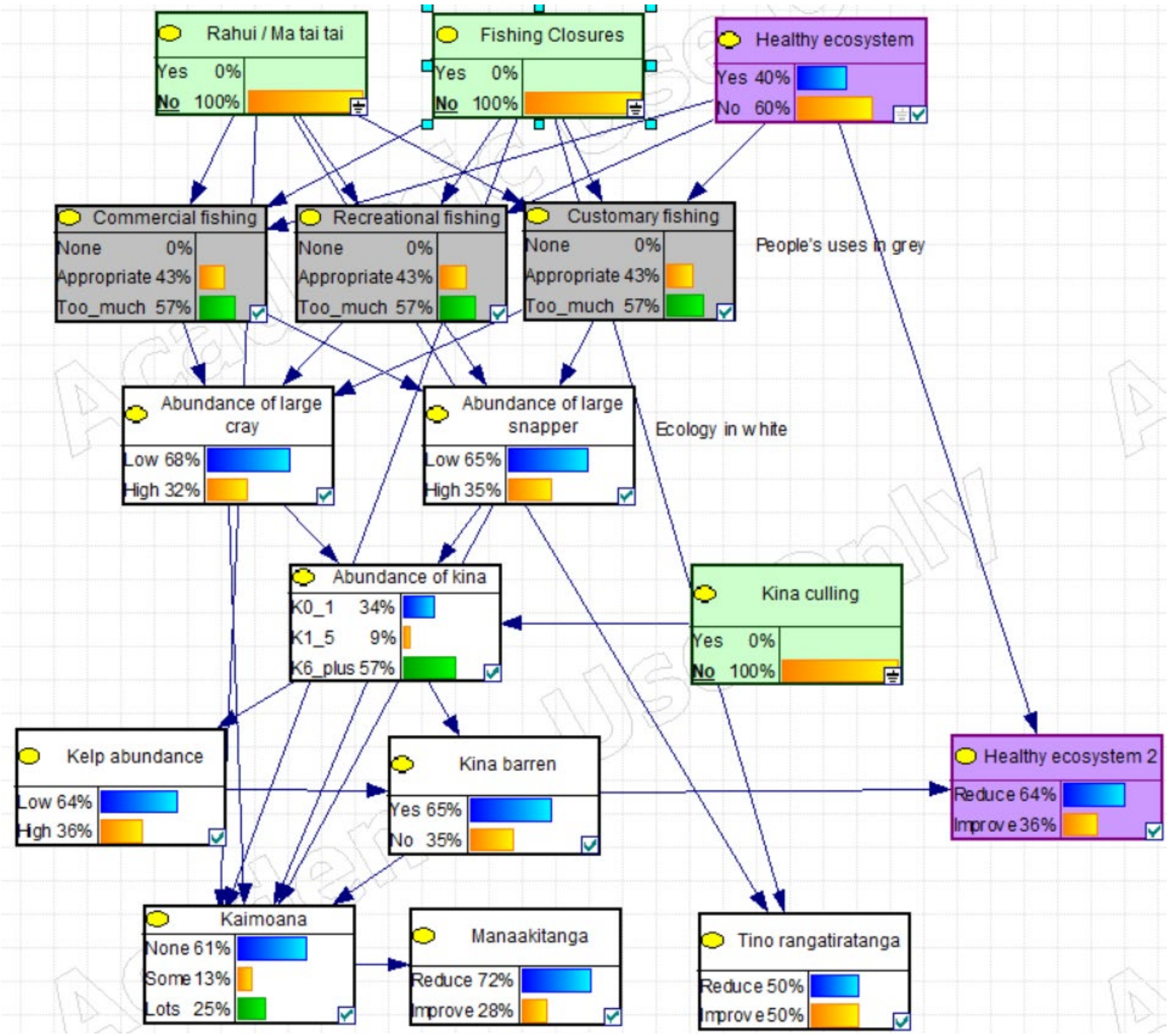


Figure 4: Preliminary model of the key drivers of kina barrens and associated ecological and cultural interconnections (ecological and cultural components = white boxes, people's uses = grey boxes, management techniques = green boxes, ecosystem health = purple boxes).

As there was broad agreement on the ecological drivers of kina barrens, it was possible to leverage existing empirical evidence to inform the relationships between individual components of the model (as summarised in the Introduction and in Supplementary Table 1). Where there was greater uncertainty in the relationships between elements of the model, for example the relative impact different fishing types (commercial, recreational, customary) on large snapper and crayfish, their impacts were duplicated. These limitations were discussed further at Workshop 2 and in the discussion of this report.

The model was comprised on management components (at the top in green), which included whether the area was under rāhui / mātaitai reserve or fishing closure, and whether kina removal has occurred as a management action. The model also included a prediction about the current state of the system, whether the ecological state of the wider area was mostly in a healthy or poor state (and therefore more capable of supporting a sustainable fishery). Fishing impacts were separated into commercial, recreational and customary, and classified on a scale from none (not present), appropriate (supporting a sustainable fishery), and too much (resulting in a decline in snapper and crayfish abundance). The kina abundance was driven by the abundance of snapper and crayfish, with greater kina numbers increasing the likelihood of kina barrens and decreasing the abundance of kelp.

Elements that relate to cultural values, which were discussed during Workshop 1, were also included in the model, to enable some of the cultural consequences of management scenarios to be explored. Kaimoana was differentiated from being purely driven by the abundance of snapper, crayfish, and kina, to also being driven by the management approach. For example, a management approach that prevented cultural harvest may increase snapper and crayfish stocks but may decrease the amount of kaimoana available for harvest. Manaakitanga was included and conceptualised as an ability for hapū to provide for guests through an abundance of sustainable kaimoana. A tino rangatiratanga element was included, which was conceptualised as relating to the ability and empowerment of the hapū to govern over the rohe moana (e.g. negatively impacted for instance if the crown imposed a fisheries closure rather than this being led by hapū initiative via a rāhui or mātaitai reserve). At the bottom right of the model, a second healthy ecosystem node was created, relating to whether the ecosystem was getting better or worse after the management actions.

A series of management scenarios were then run to explore potential consequences, which were presented at Workshop 2 and briefly described here. It is important to note that the scenarios are designed to explore shared understandings of the system, and to inform potential management decisions, but are not designed to be predictive (i.e., it would not be appropriate to use the model to attempt to quantity the precise outcomes of management actions, e.g, if x% of the fishery is closed then kina barrens will reduce to y%).

Model scenarios

Scenario 1: Baseline present-day conditions

Results (probabilities of each state) for Bayesian Network model set for Scenario 1 is shown in Figure 5. For example, there is 65% chance of snapper abundance being 'low' and a 35% of being 'high' in this scenario.

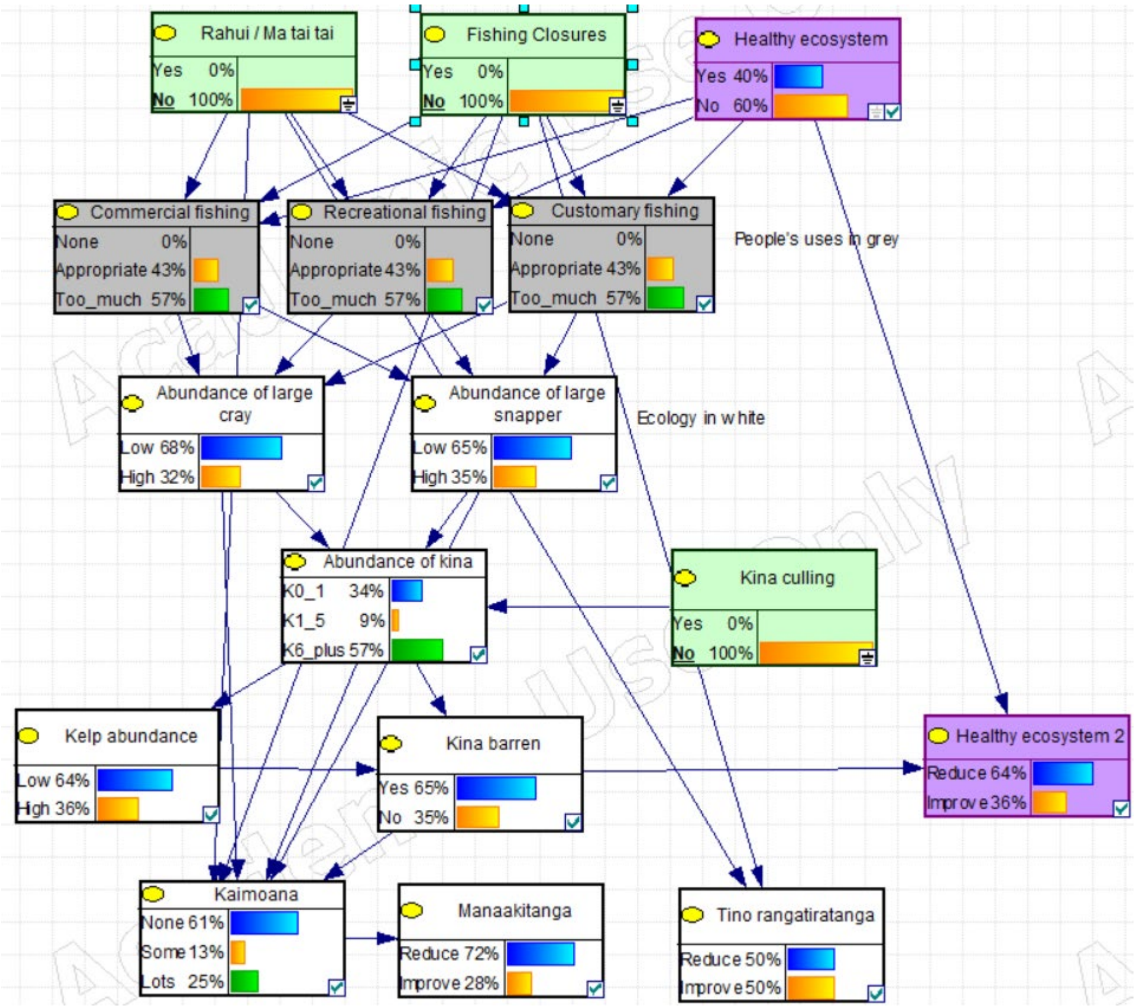


Figure 5: Baseline model of the key drivers of kina barrens and associated ecological and cultural interconnections under 'present-day conditions' with current-day levels of cultural harvesting, recreational fishing, or commercial fishing are assumed occur (ecological and cultural components = white boxes, people's uses = grey boxes, management techniques = green boxes, ecosystem health = purple boxes). See Supplementary Table 1 for box definitions and descriptions.

Key results from this baseline scenario model include the following.

- No areas are closed to snapper or cray harvest.
- The ecosystem health is degraded in more areas than it is healthy.
- Fishing effort is, on balance, too much.
- The abundance of large crays and snapper is, on balance, too low.
- The abundance of kina is too high and therefore the abundance of kelp is low and kina barrens is high.
- There is some kaimoana but many areas are degraded, and because the kaimoana is less abundant, the ability to manaaki is reducing.
- Ultimately, the ecosystem health is in decline.

Scenario 2: Fisheries closure for 70% of the rohe / target area

Results (probabilities of each state) for Bayesian Network model set for Scenario 2 is shown in Figure 6. The scenario assumes 70% of the rohe/area is closed to fishing and this is kept in place for 10-15 years.

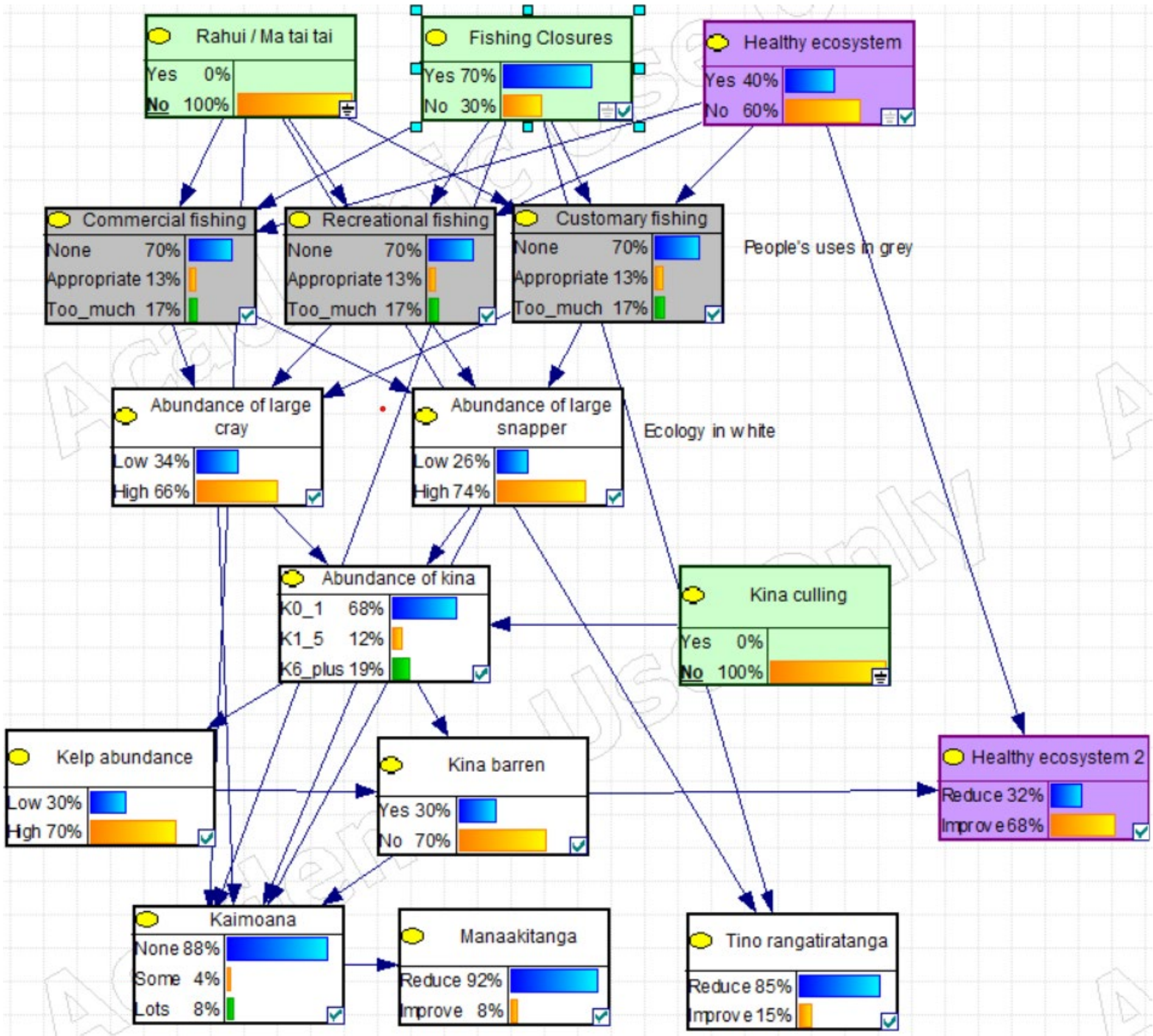


Figure 6: Model of the key drivers of kina barrens and associated ecological and cultural interconnections with fisheries closure for 70 % of the rohe / target area (ecological and cultural components = white boxes, people's uses = grey boxes, management techniques = green boxes, ecosystem health = purple boxes).

Key results:

- The ecosystem health is degraded in more areas than it is healthy.
- Fishing effort is low.
- The abundance of large crays and snapper has improved and on balance is high.
- The abundance of kina is low and therefore the abundance of kelp is high and kina barrens is low.
- Because the fishery is 70% closed, the kaimoana is low and the ability to manaaki has reduced.
- In addition, because the management mechanism is via a top-down Crown-led fisheries closure, tino rangatiratanga has been reduced.
- Ultimately, ecosystem health is improving.

Scenario 3: Rāhui / mātaitai closure for 70% of the rohe / target area

Results (probabilities of each state) for Bayesian Network model set for Scenario 3 is shown in Figure 7. The scenario assumes 70% of the rohe / area is closed to fishing via a rāhui / mātaitai closure and this is kept in place for 10-15 years.

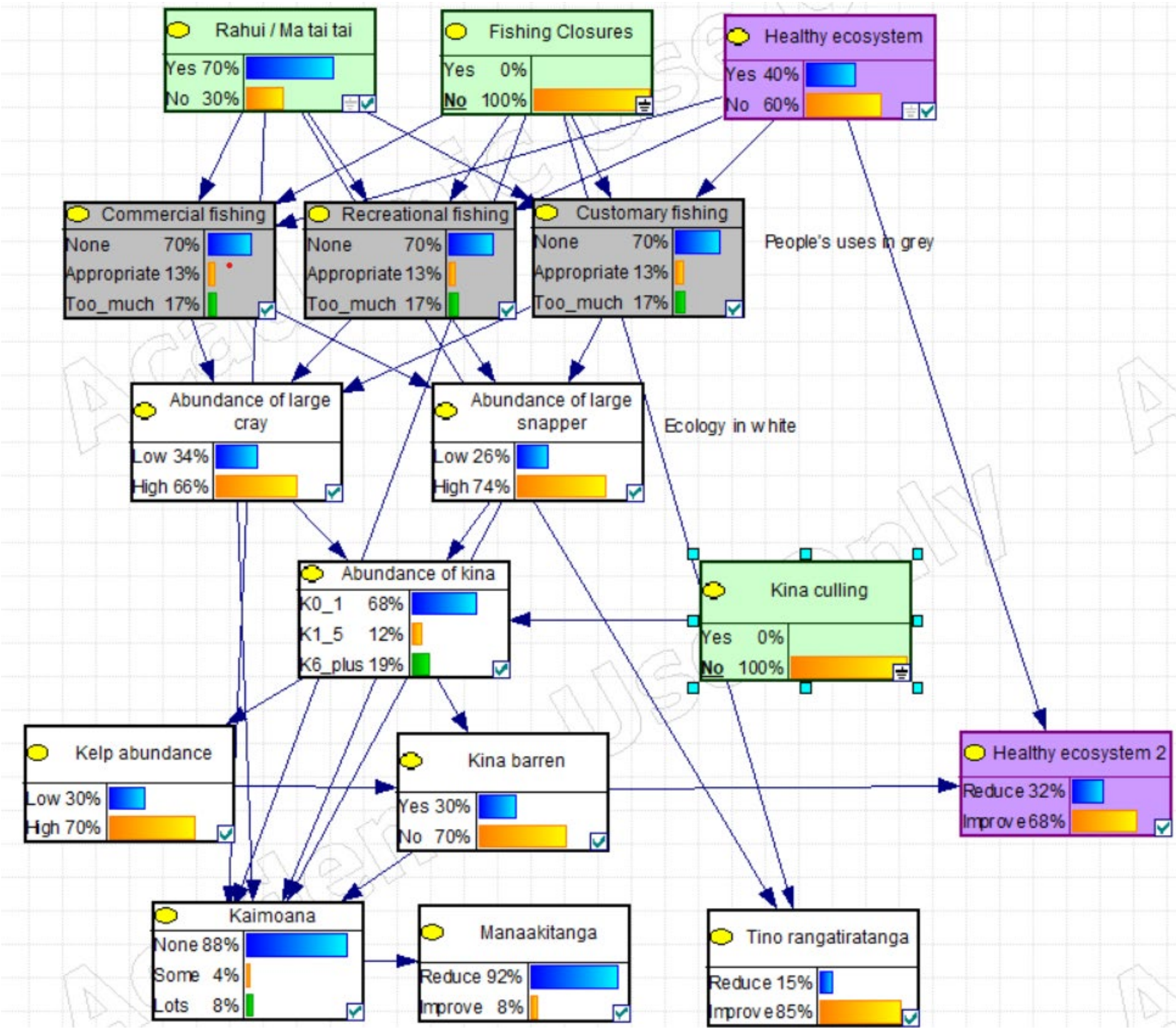


Figure 7: Model of the key drivers of kina barrens and associated ecological and cultural interconnections with rāhui/mātaitai closure for 70 % of the rohe/target area (ecological and cultural components = white boxes, people's uses = grey boxes, management techniques = green boxes, ecosystem health = purple boxes).

Key results:

- Same outcome as Scenario 2; however, because the fisheries closure is being led by iwi / hapū via a rāhui / mātaitai closure mechanism, tino rangatiratanga is improving.

Scenario 4: Rāhui / mātaitai closure for 70% of the rohe / target area plus kina culling as a management action

Results (probabilities of each state) for Bayesian Network model set for Scenario 4 is shown in Figure 8. The scenario assumes 70% of the rohe / area is closed to fishing via a rāhui / mātaitai closure and kina culling occurs as a management action. This is kept in place for 10-15 years.

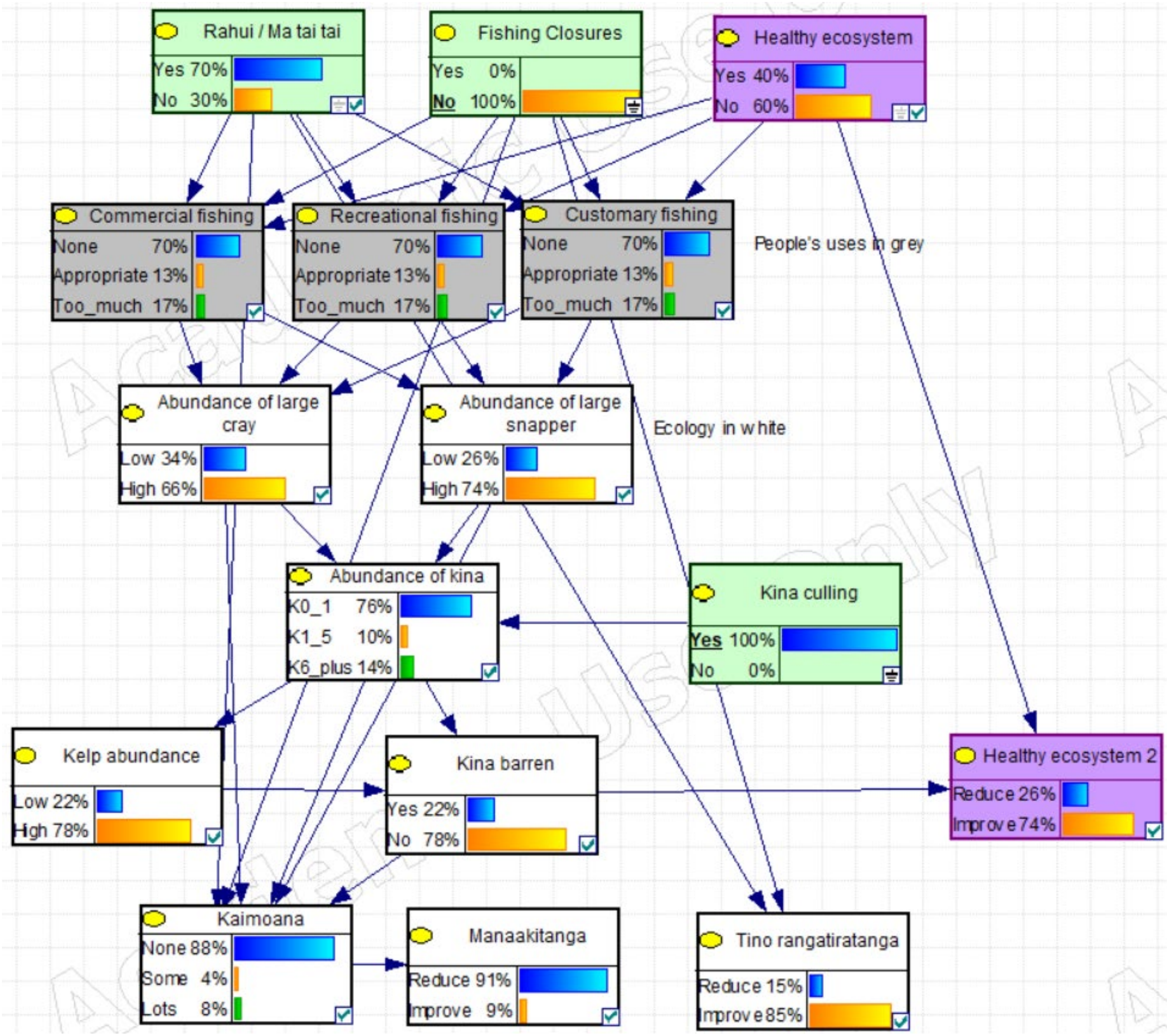


Figure 8: Model of the key drivers of kina barrens and associated ecological and cultural interconnections with rāhui / mātaitai closure for 70 % of the rohe / target area and kina culling occurring as a management action (ecological and cultural components = white boxes, people's uses = grey boxes, management techniques = green boxes, ecosystem health = purple boxes).

Key results:

- Same outcome as Scenario 3; however, because of the kina culling there is a further decline in kina and associated decline in kina barrens, plus a further improvement in the ecosystem.

Scenario 5 (restored ecosystem)

Results (probabilities of each state) for Bayesian Network model set for Scenario 5 is shown in Figure 9. The scenario assumes that there has been 10-15 years' worth of recovery due to successful management action, which has resulted in a significant decline in kina barrens and an increase in snapper and crayfish.

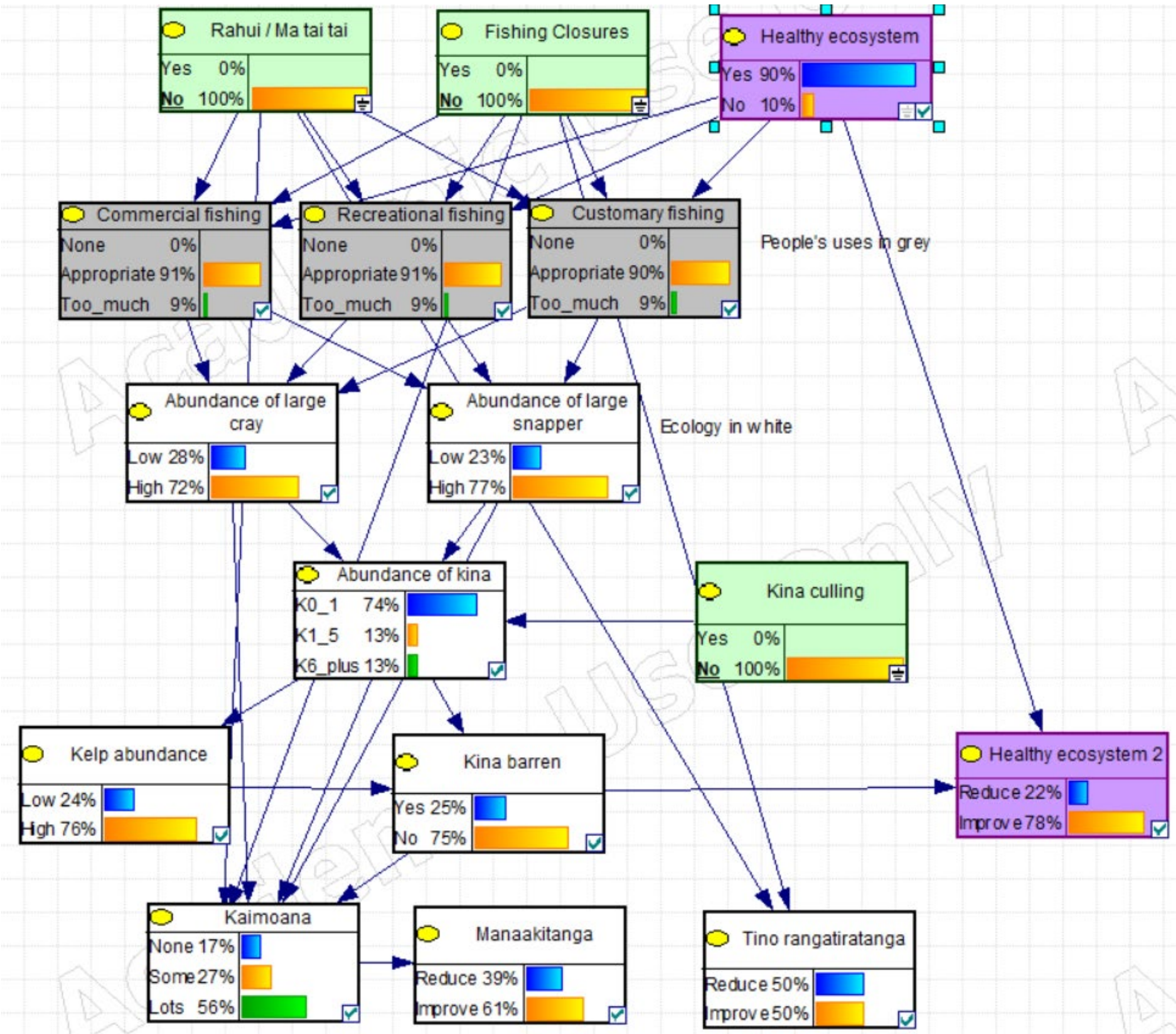


Figure 9: Model of the key drivers of kina barrens and associated ecological and cultural interconnections for an ecosystem that has been restored following management actions that have resulted in a significant decline in kina barrens and increase in snapper and crayfish (ecological and cultural components = white boxes, people's uses = grey boxes, management techniques = green boxes, ecosystem health = purple boxes).

Key results:

- The ecosystem now starts in a healthy state; therefore, it is able to support sustainable levels of fishing without reducing the predators to the point that kina barrens return.
- Kaimoana has increased substantially, and this has meant that the ability to manaaki has also substantially increased.
- Meanwhile, the system is staying, on balance, healthy, even after the reintroduction of some harvesting at appropriate levels.

Workshop 2 summary

During workshop 2, the model was presented and the model building process and key elements and relationships were discussed. Seven pages of notes were collected based on conversations during workshop 2. The following is a short summary of some of the key messages, which have been used to inform the discussion of this report.

- It was noted that the model provides a snapshot of our conversations. For example, it focusses on present day, but does not consider what may have been in the past. Before commercial take, and pre-European colonisation, the populations of snapper were much more abundant and may have supported much greater take than they could today.
- The usefulness of the model depends on the scale in which the model is looking to be applied. The model is currently designed at a general scale that could be applied at a rohe scale, but opportunities exist for this to be refined to more appropriately reflect the outcomes expected for an area of interest.
- After running through the five hypothetical scenarios, workshop participants highlighted that future changes which enabled the model to be able to investigate the impact of different management options would be valuable for informing management decisions (e.g., changes to total allowable catch, management targets, and customary harvest occurring in marine protected areas).
- It was noted that FNZ tend to manage at larger scales, but the interest and impact of fishing may be felt more at the local level and unevenly across the fishery.
- The incorporation of management targets was seen as an opportunity, which allowed for a combination of spatial closures and more regular fisheries management.
- The importance of detailing the node definitions and their interactions in the report was highlighted by workshop participants.
- There was agreement that being able to incorporate the ecosystem health both within and outside a protected area would be useful.
- Workshop participants highlighted that it would be valuable for the report to include limitations of the model and proposed next steps for if the model was to be progressed further.

Discussion

Two workshops were held to share understanding of the drivers of kina barrens and potential management solutions to recover kelp. A probabilistic Bayesian Network model was developed as part of this process to summarise this knowledge to further help inform management decision making. Workshops and associated model building processes were designed to include multiple viewpoints of the participants, informed by Sustainable Seas Challenge research and research outside of the Challenge. The collective knowledge from workshop participants, including Tangata Whenua, regarding the local ecosystem and management solutions was fundamental in the design of the associated model. In addition, the relationship between FNZ and Tangata Whenua was discussed, and suggestions made to improve this relationship in the future. This included FNZ and the government honouring their obligations under the Treaty of Waitangi by empowering Tangata Whenua to take a greater leadership role in research outputs and management decision making for their rohe.

A key result of this project was consensus between all workshop attendees about the ecological drivers of kina barrens and the need to restore the abundance of large predators (including snapper and crayfish) to recover kelp forests long term, in addition to managing other key stressors to kelp ecosystems such as sedimentation and climate change. The emerging science and mātauranga held by Tangata Whenua representatives was aligned, as there was agreement regarding the historical increase in kina barrens coinciding with the general decline of the large snapper and crayfish.

Customary knowledge around the history of the fishery and drivers of the decline was explored during the workshops. While the conversation only touched the surface of customary knowledge in the area, aspects of these conversations were reflected in the model building process, through the addition of components such as kaimoana (which differed from snapper / crayfish/ kina abundance as it also accounted for the ability of hapū and iwi to harvest), manaakitanga (which related to the ability of the hapū to host guests through the provision of kaimoana), and tino rangatiratanga (relating the ability of iwi/hapū to make management decisions over the rohe, rather than these be imposed based on the Crown). These additions enabled different kinds of fishery closure and management mechanisms to be explored, and at a basic level revealed how differences in the management types could result in similar ecological outcomes but entirely different cultural consequences. Different management types explored here would be implemented and enforced via very different policies and legislations some of which will also have implications for the speed at which these can be implemented, the duration over which they are implemented and how easily they can be adapted should new evidence indicate the necessity to do so.

While there was general agreement regarding the ecological relationships driving kina barrens, other aspects had greater uncertainty between workshop attendees. For example, Tangata Whenua expressed that commercial fishing was a key factor maintaining snapper and crayfish at low abundance in their rohe, yet FNZ researchers pointed out that while this was a key factor in historical declines, currently commercial fishing for crayfish in the area was low and other impacts including recreational fishing would need to be addressed to allow for recovery. One potential explanation may be that FNZ tends to manage at larger scales, but the interest and impact of fishing may be felt more at the local level and unevenly across the fishery. This dynamic is explored in Sustainable Seas research on scale dependences and its influence on ecosystem-based management (EBM), which highlights that a major barrier to implementing EBM is the 'mismatch' in space (national vs. local / regional) and / or time (short vs. long-term thinking). Mismatches in jurisdictional boundaries also create barriers, which may be further complicated by institutional fragmentation and siloed agencies. Knowledge on scale can aid EBM by identifying meaningful spatial scales for operation (e.g. for restoration) and a better consideration of context. Both environmental and cultural disciplines highlighted that a better understanding of cumulative stressor effects across scales using Western science and mātauranga Māori can aid EBM." (Ellis et al. 2022).

The model building process was useful to focus discussions and share knowledge, and to synthesise key information, which was used to run scenarios to generate further discussion and explore potential management outcomes, including helping to bring multiple perspectives and values together to address a management issue. As mentioned earlier, it is important to note that the model was not designed to give precise predictions of outcomes of management actions (e.g, if x% of the fishery is closed then kina barrens will reduce to y and ecosystem health will increase to z).

Opportunities to improve the model to address future management needs were discussed, which would increase the utility of the model for informing management decisions moving forward. These opportunities included:

1. updating the model to be able to explore additional management options (e.g., changes to total allowable catch, management targets, customary harvest occurring in marine protected areas, local closures)
2. incorporating ecosystem health both within and outside the modelled area (i.e., to assess flow-on / spillover effects of management actions at different scales)
3. providing ongoing training/expert advice on the use and refinement of the model
4. collation and collection of additional data to fill gaps in our understanding between the model components and to improve the predictive capacity of the model (e.g. Parsons et al. 2021).

Some key data gaps in our understanding of the management actions that may impact the model included:

- quantifying the magnitude and relative consequences of commercial, recreational, and customary harvesting on the ecosystem at appropriate scales
- quantifying the predator densities and scale required to prevent kina barrens
- improving the model to include other stressors (sedimentation, connectivity to other kelp habitats to provide recruits etc, climate change), which are known to drive the loss of kelp and the creation of barrens.

While data gaps were identified during this project, data gaps or uncertainty in the exact outcomes of management actions should not be considered as a barrier to implementing management actions. Instead, workshop participants were clear that management action to address the kina barren issue needs to happen now. Research demonstrates that management actions that increase the abundance of large predators (in addition to potential kina culling) results in a decline in kina barrens and a recovery of kelp forests.

By implementing informed management actions now, despite uncertainty in exact outcomes, kelp reefs and associated biodiversity can be recovered. Lessons learnt by implementing recovery actions now will be valuable for informing and refining future management actions. Continued investment in co-developing management strategies with iwi / hapū, community and other stakeholders is key to supporting restorative action and restorative success.

References

Babcock, R. C., N. T. Shears, A. C. Alcala, N. S. Barrett, G. J. Edgar, K. D. Lafferty, T. R. McClanahan, and G. R. Russ. 2010. Decadal trends in marine reserves reveal differential rates of change in direct and indirect effects. Proceedings of the National Academy of Sciences **107**:18256-18261.

Doheny, B., J. P. Davis, and B. Miller. 2023. Fishery-induced trophic cascades and sea urchin barrens in New Zealand: a review and discussion for management. New Zealand Aquatic Environment and Biodiversity Report No. 324. 110 p. .

Gladstone-Gallagher, R. V., J. E. Hewitt, J. M. L. Low, C. A. Pilditch, F. Stephenson, S. F. Thrush, and J. I. Ellis. 2024. Coupling marine ecosystem state with environmental management and conservation: A risk-based approach. Biological Conservation **292**:110516.

Kerr, V. C., R. V. Grace, and N. T. Shears. 2024. Estimating the extent of urchin barrens and kelp forest loss in northeastern Aotearoa, New Zealand. New Zealand Journal of Marine and Freshwater Research:1-22.

Miller, K. I. 2023. Evaluating large-scale sea urchin removal as a potential tool for restoring kelp forests. The University of Auckland, Auckland, New Zealand.

Miller, K. I., C. A. Balemi, D. R. Bell, C. O. Blain, P. E. Caiger, B. J. Hanns, S. E. Kulins, O. Peleg, A. J. P. Spyksma, and N. T. Shears. 2024. Large-scale one-off sea urchin removal promotes rapid kelp recovery in urchin barrens. Restoration Ecology **32**:e14060.

Miller, K. I., C. O. Blain, and N. T. Shears. 2022. Sea urchin removal as a tool for macroalgal restoration: A review on removing “the spiny enemies”. Frontiers in Marine Science **9**:831001.

Miller, K. I., and N. T. Shears. 2023. The efficiency and effectiveness of different sea urchin removal methods for kelp forest restoration. Restoration Ecology **31**:e13754.

Peleg, O., C. Blain, and N. Shears. 2023. Long-term marine protection enhances kelp forest ecosystem stability. Ecological Applications:e2895.

Shears, N. T., and R. C. Babcock. 2003. Continuing trophic cascade effects after 25 years of no-take marine reserve protection. Marine Ecology Progress Series **246**:1-16.

Shears, N. T., and R. C. Babcock. 2004. Community composition and structure of shallow subtidal reefs in northeastern New Zealand. New Zealand Department of Conservation, New Zealand.

Stevenson, C. F., K. W. Demes, and A. K. Salomon. 2016. Accounting for size-specific predation improves our ability to predict the strength of a trophic cascade. Ecology and Evolution **6**:1041-1053.

Wing, S. R., N. T. Shears, L. W. Tait, and D. R. Schiel. 2022. The legacies of land clearance and trophic downgrading accumulate to affect structure and function of kelp forests. Ecosphere **13**:e4303.

Supplementary materials

Supplementary Table 1: Model node (component) definitions and relationships. Timeframe: Outcome after 10-15 years. Geographic area: Rohe scale.

Node name	Description	Child node	Relationship	Direction	References
Rahui/Mataitai	Management action: Closure of fishing with phased reopening/bespoke fishing rules planned in the future as determined by hapū/iwi	Commercial fishing	Implementation of Rāhui / Mātaitai (state = 'yes') means commercial fishing will not occur in the study area (commercial fishing = 'none')	-	
		Recreational fishing	Implementation of Rāhui / Mātaitai (state = 'yes') means recreational fishing will not occur in the study area (recreational fishing = 'none')	-	
		Customary fishing	Implementation of Rāhui / Mātaitai (state = 'yes') means customary fishing will not occur in the study area (customary fishing = 'none')	-	
		Tino Rangatiratanga	Implementation of Rāhui / Mātaitai (state = 'yes') means that tino rangatiratanga will improve	+	
Fishing Closures	Hypothetical fishery closure for Snapper and spiny rock lobster/crayfish	Commercial fishing	Implementation of Fishing closures (state = 'yes') means commercial fishing will not occur in the study area (commercial fishing = 'none')	-	
		Recreational fishing	Implementation of Fishing closures (state = 'yes') means recreational fishing will not occur in the study area (recreational fishing = 'none')	-	

Node name	Description	Child node	Relationship	Direction	References
		Customary fishing	Implementation of Fishing closures (state = 'yes') means customary fishing will not occur in the study area (customary fishing = 'none')	-	
		Tino Rangatiratanga	Implementation of Fishing closures (state = 'yes') means that tino rangatiratanga will reduce	-	
Healthy ecosystem	Abundant and healthy ecosystem including other species	Commercial fishing	Abundant and healthy ecosystem including other kaimoana means that appropriate levels of fishing (commercial, recreational and customary) are possible	+	
		Recreational fishing	Abundant and healthy ecosystem including other kaimoana means that appropriate levels of fishing (commercial, recreational and customary) are possible	+	
		Customary fishing	Abundant and healthy ecosystem including other kaimoana means that appropriate levels of fishing (commercial, recreational and customary) are possible	+	
Commercial fishing	Commercial fishing carried out using longlines, pots (traps) and trawls, expressed as the annual catch of species X and Y from the Hauraki Gulf as at the 2013 assessment	Large Cray	Commercial fishing targeting cray (potting) can reduce local populations	-	
		Large Snapper	Commercial fishing targeting snapper (trawling and longlines) can reduce local populations	-	

Node name	Description	Child node	Relationship	Direction	References
Recreational fishing	Fishing carried out for non-commercial purposes, expressed as the annual catch of species X and Y from the Hauraki Gulf as at the 2013 assessment.	Large Cray	Recreational fishing targeting cray (potting) can reduce local populations	-	
		Large Snapper	Recreational fishing targeting snapper (predominantly longlines) can reduce local populations	-	
		Kina			
Customary fishing	Fishing carried out for non-commercial purposes by hapū/iwi, expressed as the annual catch of species X and Y	Large Cray	Customary fishing targeting cray (potting) can reduce local populations	-	
		Large Snapper	Customary fishing targeting snapper (predominantly longlines) can reduce local populations	-	
		Kina			
Abundance of large cray	Crayfish (*Jasus edwardsii*)	Kina	High abundance of large cray can reduce the density of kina (by predating the smaller size kina) and maintain it at low levels	-	
		Kaimoana	Increase in cray abundance means more are available as food for whanau, hapū, iwi	+	

Node name	Description	Child node	Relationship	Direction	References
Abundance of large snapper	Snapper (*Chrysophrys auratus*) where individual fish are > 30 cm fork length (c. 19 years old +).	Kina	High abundance of large snapper can reduce the density of kina (by predating the smaller size kina) and maintain it at low levels	-	* Predation is highest on juvenile urchins (Shears & Babcock, 2002) - reducing the reimergence of kina if cray densities are high * When predators (Snapper & Lobster) are present (ie., in a reserve) a bimodal size distribution of sea urchins occurs and only large sea urchins (≥ 80 mm) exhibit an exposed lifestyle (Peleg et al. 2023) - i.e., removal of urchins at this stage can remove these and help maintain low populations naturally moving forward (or when the urchins die from natural causes).
		Kaimoana	Increase in snapper abundance means more are available as food for whanau, hapū, iwi	+	
Abundance of kina	Adult kina/sea urchin (*Evechinus chloroticus*) density (number per m^2) c. greater than 180 days old	Kina barren	~1 exposed sea urchin/kina per m^2 is required to maintain barrens (Shears & Babcock, 2003)	+	~1 exposed sea urchin/kina per m^2 is required to maintain barrens (Shears & Babcock, 2003). Urchin densities > ~6 m^2 sufficient to allow the formation of barrens (Ayling, 1981 (as referenced by Shears & Babcock, 2003)).
		Kelp	Urchin densities > ~6 m^2 sufficient to allow the formation of barrens (Ayling, 1981 (as referenced by Shears & Babcock, 2003))	-	

Node name	Description	Child node	Relationship	Direction	References
Kina culling	Management action:	Kina	Kina culling can reduce local kina abundance to <1 m^2 over areas of similar size to study area (1 ha) (Miller et al. Shears PhD)	-	
Kelp abundance	Sites were classified as a kelp forest if they were dominated by large brown macroalgae (mean ≥ 4 adult plants m^2), and the mean adult *E. radiata* density was higher than that of adult fucoids.	Kina barren	If kelp is low and kina are moderate - high, then there can be formation of barrens. Barrens only cease if kina <1 m^2	-	
Kina barren	Sites with low large brown macroalgal density (mean < 4 adult plants m^2), and high mean encrusting cover (combined cover of bare rock, CCA and other encrusting algae > 50 %) were classified as an urchin barren (Peleg et al. 2023)	Kaimoana	Increased kina barrens means less food for whanau, both in terms of good quality kina, but also other kaimoana - i.e., as measured by 'healthy ecosystem 2'	-	
		Healthy ecosystem 2	Kina barrens means that other kaimoana species are not in high abundance and ecosystems are not healthy	+	

The following node definitions are in the context of the kina barrens model but have deeper meanings than described

Node name	Description	Child node	Relationship	Direction	References
Kaimoana	Sea food (including Kōura/crayfish, tāmure/snapper, kina but also other food species), available for whanau, hapū, iwi and community		If snapper, crayfish and kina are abundant and the fishery is open, kaimoana is abundant		
Manaakitanga	Expressing kindness and respect for others, emphasising responsibility and reciprocity via the provision of kaimoana to guests		If kaimoana is abundant, Manaakitanga is improved		
Tino Rangatiratanga	Ability to govern/manage the rohe moana, linked to self-determination, sovereignty, independence, autonomy.		If fisheries closure is through a crown led action rather than through rāhui / mātaitai then tino rangatiratanga is reduced		
Healthy ecosystem 2	Abundant and healthy ecosystem including other kaimoana		If kina barrens are low, the health of the ecosystem is improved		