SUSTAINABLE SEAS

Ko ngā moana whakauka

National SCIENCE Challenges

A. PROJECT TITLE

Overnight tipping points from a cataclysmic event: impacts, recovery and constraints on rocky reef ecosystems

B. PROJECT TEAM

Project Leader:	Investigators:
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C. ABSTRACT

The unprecedented loss of habitat-forming algae and their associated understory flora and fauna following the Kaikōura earthquakes has significant implications for nutrient cycling, primary productivity and overall functioning of nearshore ecosystems on one of the most productive coastal zones in New Zealand. The elasticity of kelp ecosystems following these massive events may be very slow and modification of sediment dynamics associated with land-use changes, erosion and underwater sediment slips may promote the monopolisation of space by turfing algae at the expense of habitat-forming kelp. These events provide an opportunity to examine the role of biological changes (canopy-subcanopy and herbivore-recruit interactions), physical shifts (both of habitat and decreased buffering of physical forces by canopies), and interactions between the two (e.g., increased sediment retention within turf-algae) on the potential tipping points affecting kelp dominated ecosystems.

Habitat-forming algae have suffered declines in nearshore marine environments worldwide, the causes of which often relate to changes in water quality and overexploited fisheries. In rocky reef ecosystems these changes appear as tipping points where ecological states shift abruptly from habitat-forming algae to low-lying, turfing algae, resulting in alteration of food-webs and loss of ecosystem functioning (i.e., reduced primary production and loss of habitat). However, the trajectory of ecological change inevitably involves a combination of physical, physiological and ecological mechanisms, which are difficult to assess in combination. Our research will examine vital ecosystem functions as key habitat-forming species recover across gradients of disturbance and turbidity to assess biological thresholds resulting in tipping points.

In New Zealand the recovery of habitat-forming algae can be very slow[4], with well understood negative feedback loops driven by recruitment disruption by sediment and turfing algae[11]. Habitat-

forming species can, on the other hand, produce positive-feedback cycles for canopy replenishment by reducing the light intensity to the subcanopy, and exerting physical force on the subcanopy maintaining bare reef for recruits. This poses significant challenges to the recovery of extensive reef areas now devoid of kelp and dominated by turfing and ephemeral species capable of excluding canopy-forming species.

We will assess changes to light delivery associated with reduced buffering of sediment resuspension by large algal canopies across a regional turbidity gradient. In particularly we will use novel flux apparatus to measure benthic metabolism of habitat-forming algae combined with recently developed PAM fluorometry apparatus (custom Walz© Monitoring PAM fluorometer) and protocols[1] to assess the long-term health and resilience of key-species in impacted areas. This will enable us to determine the long-term resilience of plants thrust into shallow water in the low and immediate subtidal, as well as determine the potential mechanisms affecting canopy expansion, colonisation and survival. Specifically we will:

1. Quantify the consequences of kelp loss on carbon fixation and export
2. Assess inter- and intra-regional gradients in water clarity and implications for kelp bed resilience and recovery.
3. Estimate critical tipping point thresholds associated with compromised buffering by canopies.
4. Develop an early warning indicators of incipient tipping points transferable to rocky reef, kelp dominated ecosystems.

D. RELEVANCE TO CHALLENGE OBJECTIVE

Kelp beds contribute significant services to marine ecosystems, including habitat provision, carbon fixation, and nutrient transport. They directly and indirectly support numerous cultural, commercial, and recreational fisheries and form an iconic part of the Kaikōura landscape, a region important to New Zealand tourism. These habitat-engineers therefore provide a focal point for nearshore ecosystem based management (EBM), where protection of the habitat ensures the long-term sustainability of other resources.

We will use the Kaikōura earthquakes as a natural experiment to examine the conditions under which resilience is compromised, indicating an approaching tipping point. This will provide the first step in setting thresholds for sustainable management of kelp beds throughout New Zealand. This research will provide early warning metrics of compromised resilience of kelp ecosystems, forming guidelines for EBM of New Zealand nearshore rocky reef ecosystems, which are both highly valued, and highly impacted by a range of terrestrial, and marine industries.

E. INTRODUCTION

Globally, kelp beds are in decline in nearshore coastal areas due to a range of anthropogenic stressors, with cascading effects on associated fisheries[2]. Areas of rocky reef formerly dominated by large habitat-forming kelp are increasingly shifting to ecological states dominated by turfing/ephemeral algae[3]. These changes reverberate through food-webs with reduced primary production[4] and loss of habitat[5]. While the factors forcing this ecological transition are not fully understood, a range of bottom up (altered nutrient and sediment regimes) and top down (trophic cascades) drivers are frequently cited[6,7]. However, the trajectory of ecological change inevitably involves a combination of physiological and physical (bottom-up), and ecological mechanisms (top-down and bottom up), which have rarely been assessed in combination.

While reduction in water quality parameters or changes in trophic dynamics can cause a transition of ecological states (e.g., tipping points), kelp communities in exposed coastal marine ecosystems are susceptible to physical perturbations that remove the canopy species periodically[8]. Recovery of canopies following these frequent perturbations is highly dependent on the growth and survival of recruits and juvenile plants[9]. These early life-history stages, however, are far more prone to changes in competitive dynamics and reduced water quality parameters than adult canopies. In fucoid algae, which dominate the shallow regions of the Kaikōura coastline, sediments and dominance by turfing algae greatly affect the attachment and survival of early life-history stages[10,11]. The loss of adult canopies and their associated communities greatly increases the chances that turf-forming species will colonise and occupy space, potentially reducing the ability of fucoids to establish viable populations. The presence of adult canopies can potentially buffer sediment resuspension and accumulation, reduce light availability to turfing algae[12], reduce fish predation on vulnerable life-history stages[13] and physically remove turfing algae through whiplash effects[14], all of which promote the long-term persistence of kelp beds.

Predicting ecological transitions is extremely difficult, but a slowing of recovery following small perturbations, a phenomenon known as 'critical slowing down' has been recognised as a key indicator of incipient regime shifts[6]. The gradient of perturbations caused by the variation in vertical uplift across the Kaikōura region provides an ideal natural experiment to assess the potential early-warning indicators of regime shifts related to critical patch size dynamics, water quality parameters, and interactions between the two, specifically sediment and turfing algae dynamics.

We will assess the conditions relating to the temporary or permanent transition from kelp beds to turfing algae and the potential for habitat rehabilitation where conditions are favourable for kelp persistence. The recent shifts in rocky reef ecosystems as a result of the November 14th earthquake in Kaikōura provide an unprecedented opportunity to examine how varying scales of kelp loss affect the ability of kelp and their associated communities to recover across gradients of water quality parameters, particularly the quality of the light environment. Critical physiological (irradiance and nutrients) and biological (community structure) thresholds for recovery will elucidate the fundamental requirements for resilient rocky reef ecosystems and help assess critical biological and environmental constraints for management of kelp forest ecosystems.

F. AIMS

This research will determine resilience and recovery relating to tipping points following wide-scale loss of habitat-forming algae and develop early-warning metrics for impending regime shifts. We will examine the physiological thresholds of light availability in kelp beds resulting in long-term transitions to turf dominated communities. This research will inform habitat rehabilitation and management practices related to the Kaikōura earthquakes. We will use the Kaikōura region to develop a framework for assessing the vulnerability of kelp forest ecosystems throughout New Zealand.

The resilience framework will identify critical thresholds relating to kelp bed size (and the related buffering services provided by adult canopies), water quality parameters (light quality and quantity) and physical processes (sediment resuspension, increased reef erosion) essential for long-term kelp bed health. In particular, we will determine the physical, ecological and physiological characteristics which lead to the persistence of turfing algae at the expense of canopy-forming species. We will develop both early warning metrics of incipient tipping points and thresholds of environmental and biological parameters potentially leading to these tipping points. Pinpointing the ecological and environmental thresholds of tipping points across gradients will be invaluable for establishing guidelines for ecosystem based management of kelp-dominated rocky-reef ecosystems throughout New Zealand.

G. PROPOSED RESEARCH

This research will assess the bottlenecks to recovery of habitat-forming species associated with ecological and environmental gradients. This will involve the establishment of a gradient of water clarity across the wider Kaikōura region, and gradients of canopy loss within the wider turbidity gradient. The research will fall into four major categories; 1) tipping points in recovery; 2) in situ environmental monitoring; 3) changes in ecosystem services; and 4) tipping point predictors and threshold frameworks.

1. *Tipping points in recovery*

With habitat mapping expected to form a major part of MPI funded research related to the Kaikōura earthquakes, we will align with intertidal and subtidal habitat mapping carried out by University of Canterbury and the Cawthron Institute. We will use quarterly aerial drone imagery captured as part of this research to measure the trajectory of patch recovery and assess critical thresholds of patch size for habitat recovery. This work will be completed with participation of students in 'Māori and Indigenous Studies' at the University of Canterbury.

In aligning with this work we will seek out transitions of kelp disturbance outside of the most heavily impacted areas. We will track the propagule settlement and establishment, and the environmental and biological parameters that support re-establishment of canopy-forming macroalgae. Rate of recovery from disturbance or resilience has been observed as a critical indicator of tipping points[6], and we will explore the rate of recovery related to presence of varying sizes of remnant populations (particularly bull kelp, *Durvillaea antarctica*, *Durvillaea willana,* and *Durvillaea poha*) and regional gradients of turbidity. We will measure the density and photosynthetic parameters (PAM and photorespirometry) of juvenile and adult plants, and subcanopy communities. In particular, the role of algal blooms (*Ulva* sp) compared to encrusting and articulated coralline algae in supporting or inhibiting recruitment and establishment of canopy-forming macroalgae.

Specifically this experiment will establish gradients of canopy loss (i.e., three locations, severely impacts, moderately impacted and minimally impacted), in three regions with varying sediment loads from local and distant sources. This will involve; 1) long-term turbidity monitoring and discrete environmental parameter measurement in each of three regions (Figure 1), see section 2 below (*Environmental parameter monitoring*), 2) assessment of photosynthetic health (PAM fluorometry) of canopy-forming and sub-canopy kelp, 3) assessment of recovering communities, particularly kelp and fucoid recruits, encrusting and ephemeral macroalage and grazing fauna. This will be done in the low intertidal zone and where possible in the immediate subtidal zone to no greater than 6m depth.

Furthermore, in areas where canopy-forming macroalgae remain, we will assess the buffering role of kelp beds on rates of sediment resuspension and accumulation in turfing algae and the consequences to recruit establishment and survival. This internal kelp bed gradient will enable us to determine some of the key characteristics of the positive feedback loops that help to maintain the resilience of kelp beds.

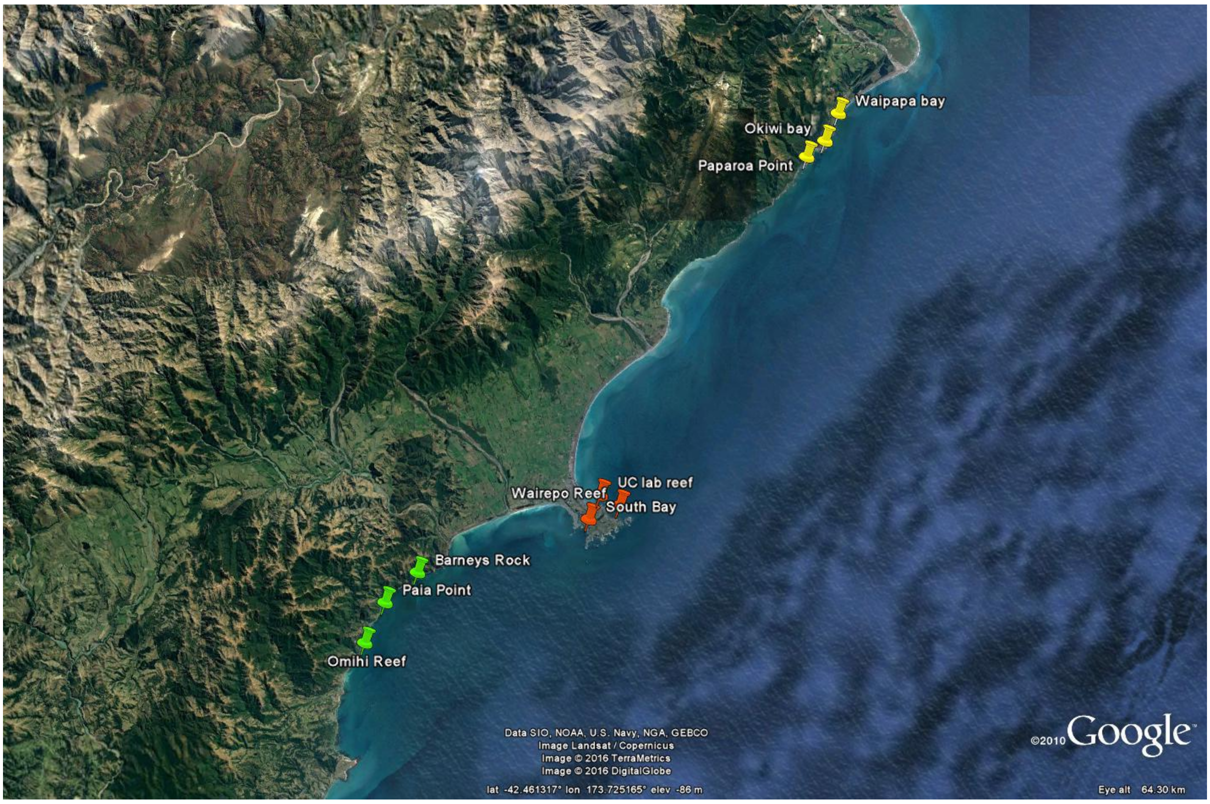

Figure 1. Approximate study site locations in the southern impacted region (green symbols), Kaikōura Peninsula (orange symbols) and northern impacted area (yellow symbols).

2. *Environmental parameter monitoring*

   Following setting of study sites across a gradient of uplift, PAR (Odyssey integrating PAR logger) sensors will be installed within subtidal rocky reefs and onshore to determine the attenuation of light through the water column. This data will provide an *in situ* measure of incident energy for photosynthesis across gradients of uplift within regions where buffering of sediment resuspension from adult canopies has potentially been compromised. This will also provide an indication of wider gradients of turbidity where sites may be more heavily influenced by turbidity associated within riverine inputs or changes to coastal erosion caused by earthquake related slips. Long-term PAR measurements will enable us to estimate the effect of canopy-buffering on the intensity, duration and frequency of light variation allowing the calculation of dynamic energy budget models. We will also examine other water-quality parameters across the monitoring sites, particularly O_2, nutrients, and spectral light dynamics using discrete measurements.

   The incident PAR data will provide the basis for modelling and extrapolating primary productivity dynamics of assemblages over various scenarios of light delivery and community primary productivity capacity. However, the main purpose for PAR measurement will be to examine the physical and physiological parameters that reduce the resilience of kelp bed communities and therefore threaten their long-term sustainability.

3. *Changes to ecosystem services*
   Shifts in other important ecosystem services will be measured in conjunction with metrics of habitat-provision (as identified in work-stream '1'). These metrics will include measurements of integrated whole-community primary productivity across shore height gradients using a novel apparatus designed to measure diurnal cycles of carbon fixation. These have been specifically designed to measure whole community photosynthesis continuously for long periods of time (1-3 days) by periodically replacing the enclosed water volume and continuously measuring oxygen flux to estimate photosynthesis during sunlight hours and respiration during the night.

   These measurements will be completed at peninsula sites where benthic NPP pre-earthquake is known across shore height gradients[15]. Furthermore, the changes to exposure time of these extensive and productive[15] reef platforms has the potential to greatly affect whole reef primary productivity and space availability for harvested species (i.e., karengo, *Porphyra* spp.). These measurements will be done over time to measure the recovery of photosynthetic potential, but also to estimate the turnover and transport of biomass associated with different successional stages of macroalgal communities. Benthic metabolism measurements will be done at multiple shore heights.

   In particular we will examine the effects of patch size of remaining canopy-forming algae on the photosynthetic health of canopy and subcanopy species (including recruits of canopy forming species) to assess the patch requirements for self-sufficient populations. PAM fluorometry will be done in mid-shore communities, low-shore communities and subtidal communities. These measurements will identify: a) the long-term health of habitat-forming plants, b) the long-term health of subcanopy algae beneath canopies of varying density and outside of canopies, and c) the short and long-term health of ephemeral/turfing species. Using previous data collected on these reef platforms we will also assess the changes in ecosystem services caused by loss of canopy-forming algae. In particular, we will calculate the carbon production and turnover of biomass of pre- and post-earthquake systems.

4. *Tipping point predictors and threshold frameworks*
   We will use the knowledge of species-specific critical light requirements (gained in the wider tipping points programme in *Sustainable Seas*), variation in incident PAR and evidence of patch size dynamics to develop a frameworks for determining tipping point thresholds and early warning indicators of approaching thresholds. We will assess the potential for rehabilitation techniques and protocols, but will first seek to establish areas where recovery is likely or where special management may be required to ensure this recovery. This information may be used to engage rehabilitation efforts with help and/or blessings of local iwi and hapū or provide input into decisions on establishment or maintenance of management practices.

   We hope to achieve this through engagement of local community representatives (Te Runanga O Kaikōura) and establish plans for long-term mentoring of students through the School of Biological sciences and Indigenous and Maori studies courses at the University of Canterbury.

We will provide an oversight of our proposed research at an upcoming meeting of Te Korowai (August 14), to establish further communications with local iwi, hapū and community groups. We hope to establish and maintain meaningful contacts with this group to facilitate engagement with the wider community to pass on our findings and possibly encourage future rehabilitation efforts. Furthermore, we will utilise NIWA's Maori Science group Te Kuwaha (particularly Christchurch based Mandy Home) and University of Canterbury's John Pirker to ensure our findings are transferred and relationships with the communities affected by the Kaikōura earthquakes are maintained.

Through these relationships we will also provide (and fund) a workshop to local community members interested in the research we are performing and what we are observing. We will provide updates regularly to local iwi and hapū through Te Korowai and will run a workshop at the end of the project to trial rehabilitation of specific canopy forming plants or to show potential management methods. The funding of these workshops has been identified in the budgeting of this proposal.

H. RESEARCH ROLES

Researcher	Organisation	Contribution
Leigh Tait	*NIWA*	*Project lead: Leading flux and PAM measurements, PAR measurement and project management.*
David Schiel	*University of Canterbury*	*Oversee intertidal community composition and primary productivity sampling and experimental design. Provide oversight and alignment with other earthquake related activities*
John Pirker	*University of Canterbury*	*Contribute to intertidal habitat sampling of kelp beds and invertebrate communities, including provision of aerial drone imagery. Liaise with local iwi in sampling and outreach initiatives*

I. LINKAGES AND DEPENDENCIES

Examining physical and biological thresholds of kelp forest ecosystems is a key component of the Dynamic Seas programme. Kelp are a classic representation of habitat engineers and can provide a focal point for ecosystem based management. By maintaining the kelp canopy and species within, the myriad values and services that feed into on-shore (terrestrial) cross-shore (sand shores) and off-shore foodwebs (Kaikōura canyon) are maintained. Where possible we will provide samples to Prof. Steve Wing for the "Ecosystem Connectivity" component of the challenge, to estimate the contribution and potential changes to surrounding ecosystems.

Current research in the Tipping Points programme aims to identify tipping points associated with thresholds of light requirements, but varying scales of kelp canopy loss provide an opportunity to better understand biological tipping points, where varying degrees of canopy loss can affect the resilience and recovery of kelp beds[11]. While the current research in the tipping points programme is focused on the fundamental light requirements of habitat-forming kelp and fucoid species, this research will enable these findings to be placed into an ecological context where positive feedback loops supporting the persistence of kelp canopies, and negative feedback loops supporting the persistence of turfing algae may modulate recovery dynamics.

Collection of *in situ* irradiance during the proposed research will provide a valuable data-set for the wider Tipping Points programme which will enable complex energy budget modelling of dominant canopy-forming species, their photosynthetic outputs and their realised and fundamental niches of light requirements. Irradiance collected at multiple sites across local and coast-wide gradients of turbidity will help determine the relative importance of physiological requirements (incident light), altered ecological interactions (canopy/subcanopy interactions), and altered physical effects (sediment dynamics) on the recovery and resilience of habitat-forming kelp.

Measurements of ecosystem function (carbon fixation and photosynthetic efficiency), will also inform consequences of canopy loss on the relative flux of impacted and non-impacted communities, relating directly to work-stream (2) of Ecosystem connectivity (Dynamic Seas). High turnover and potentially high NPP of ephemeral species now dominating impacted areas has the potential to greatly shift nutrient cycling compared to the high NPP, low turnover kelp beds. Identification of the connection between surrounding ecosystems (i.e., the Kaikōura canyons) and nearshore kelp beds through the “Ecosystem Connectivity” programme will benefit from an increased understanding of the total carbon output of nearshore kelp beds and alterations to this output caused by the earthquakes.

This research will feed into the Valuable Seas programme by quantifying key ecosystem services (e.g., carbon fixation, nutrient export, habitat provision, and physical buffering) provided by rocky reef ecosystems and the changes to these services over local and coast-wide scales. Outputs of this research may also provide key parametrisation (i.e., carbon and nutrient production/turnover) of ecosystem models (the Ecosystem Model programme within “Managed Seas”). Furthermore, developing early warning indicators of critical tipping points will provide thresholds for development of spatially explicit decision support tools for ecosystem based management (“Managed Seas”).

J. RISK AND MITIGATION

There are risks associated with travel to and from Kaikōura with land-slips still being removed by contractors. Future earthquakes may also exacerbate these slips and affect completion of fieldwork. This represents the main risk to completion of the intertidal sampling which can be completed in a variety of weather conditions. This risk will be managed by frequent checking of road conditions (NZTA website) and weather conditions (i.e., particularly forecast heavy rainfall). While there is likely significant time between submission of this proposal and commencement of field-work, there is the potential that northern sampling locations (i.e., Waipapa Bay) may be difficult to access resulting in excessive travel costs. In these circumstances we will look to make budgetary savings on other aspects of the work to enable the surveying of these sites which have been most heavily impacted by reef uplift. Furthermore, we will look to run fieldwork from two NIWA offices, with NIWA Christchurch used as a base to access southern Kaikōura sites (including the Kaikōura Peninsula) and the NIWA Nelson office will be used to access the northern Kaikōura sites (i.e., Waipapa Bay).

Subtidal sampling can be greatly affected by weather conditions, particularly along exposed coastlines such as Kaikōura. This risk will be managed by scheduling research to weather windows covering multiple weeks, during which time field teams will be mobilised quickly upon receiving favourable weather forecasts. Subtidal sampling campaigns will also be limited to summer/autumn months where calm conditions and clear water are more common. The NIWA dive teams include Roberta D’Archino and Leigh Tait who have completed and lead SCUBA research throughout New Zealand and are well versed in subtidal sampling of exposed coastlines. The weather risk will be further managed by an experimental design which has study sites of varying directions of wind/wave exposure, so that diving logistics can be flexible to sample different locations as conditions suit.

We note that the northern and southern Kaikōura regions may be difficult to access by boat due to loss of boat launching ramps. Access to southern regions will be mitigated by launching boats at the Kaikōura Peninsula (South Bay), but northern regions are more distant, and more exposed to adverse conditions. We will look for alternative options for sampling these locations if the use of small boats is not practical. This may include the use of larger vessels such as the NIWA research vessel Ikatere based in Wellington.

The habitat rehabilitation aspect of the proposed research will rely heavily on engagement with local iwi, and will require a high level of participation to be successful. This represents significant risk if local communities are unable to participate. We will mitigate this risk by early engagement with Te Runanga o Kaikōura, provision of funding to support the time of the local community and delaying of rehabilitation efforts till towards the end of the project to ensure communities have had sufficient time to deal with more pressing issues associated with the Kaikōura earthquakes.

K. ALIGNED FUNDING AND CO-FUNDING

A range of research initiatives are being funded by MPI as a result of the Kaikōura earthquakes. In particular MPI is funding a range of short-term research programmes involving multiple organisations to assess the changes to important biogenic habitats and important cultural, commercial and recreational fisheries, with the aim of providing critical knowledge for decision-making. Of particular relevance to this study is an examination of changes to rocky reef habitat, habitat-forming macroalgae, and marine fisheries (particularly pāua). This research proposal will relate directly to assessments of the scale of habitat change and we will align with this research for shared benefits. In particular, we will collaborate with drone-based habitat mapping initiatives already under way (Dr. John Pirker, University of Canterbury) to greatly increase our understanding of patch dynamics, but will also add small-scale resolution to this work by assessing critical photo-physiological metrics of canopy and subcanopy recovery in discrete areas. Much of the planned MPI funded research is expected to occur within one year of the earthquakes, and where possible we will look to extend monitoring beyond this time-frame.

Where this research will be different from the MPI research is in the measurement of changes to light attenuation associated with altered ecological buffering, reef erosion and sediment regimes (associated with slips). Flux measurements of ecosystem functioning, and measurements of photosynthetic health using PAM fluorometry, will also identify changes to ecosystem functioning not included within the MPI funded research.

L. VISION MĀTAURANGA (VM)

The Kaikōura earthquakes have resulted in significant challenges to Māori communities that go well beyond changes to the marine environment. Changes to key harvesting areas and species have the potential to dramatically affect the traditional kai moana harvesting practices. Besides the impacts to the pāua fishery, the loss of rimurapa (*Durvillaea antarctica*) across large stretches of coastline has consequences that go beyond the importance of the species alone (which is traditionally used for cooking, food preservation and crafting). This species is an important habitat provider for myriad culturally harvested species, but is also a key contributor to nutrient flux.

Our research will address the consequences of habitat loss, but will also assess the potential for community lead habitat-rehabilitation.

Local iwi initiatives of pāua relocation highlight the benefit of Māori knowledge, resources and people and such participation is essential to succeed in habitat rehabilitation. The engagement of local iwi for rehabilitation projects has the potential to result in novel and innovative methods of plant re-establishment which could be used under different circumstances. Such rehabilitation measures could include transfer of whole attached adult plants, juvenile recruits, or could involve the use of drift kelp transplants (temporary or permanent) to promote mass gamete release.

We have engaged Te Runanga O Kaikōura during the creation of this proposal to assess their needs and the willingness for participation (***see attached letter of support***). We will engage through Te Runanga o Kaikōura throughout the project, including knowledge transfer sessions supported by the proposal. The key outcome of the research is to provide Te Runanga O Kaikōura with guidance and support for establishing their own programmes of habitat rehabilitation. We will also engage students in Māori and indigenous studies at the University of Canterbury to continue monitoring and rehabilitation research beyond the life of this proposed research.

M. CONSENTS AND APPROVAL

The proposed research focuses on non-destructive sampling of macroalgal communities (i.e., PAM fluorometry), but small-scale plot harvesting may be required to standardise primary productivity measurements by community biomass. Macroalgae harvesting is covered under current permits that NIWA and UC have through MPI, including dispensation for algal collection given the coast wide ban on seaweed harvesting. However, we will concentrate on non-destructive methods (i.e., PAM fluorometry). In the case that these restrictions are still in place at the onset of this research, we will seek an allowance to harvest very small amounts of macroalgae through both MPI and local iwi representatives. If required, destructive sampling of macroalgae will be associated with Milestone 2.1 (Jan-Feb 2018). This allows sufficient time to apply for exceptions for harvesting algae and consult with local and national authorities. No harvesting will be done within any marine protected area.

The proposed research will not require harvesting of any invertebrate, vertebrate species, and will only quantify numbers of these species using non-destructive methods.

N. REFERENCES

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