IN THE MATTER OF the Proposed East Coast Beach Vehicle Bylaw

MEMORANDUM OF MARLBOROUGH DISTRICT COUNCIL

Introduction

1. Marlborough District Council (MDC) staff have been instructed under Minute 4, 4(4)(f) issued by Commissioners dated 26 November 2021 to provide a report on:

   (i) Whether the Bylaw may include a licensing requirement for persons that wish to obtain access by motor vehicle to the subject beach areas. We understand that Tauranga City Council operates a licensing system for some beach access, and we ask that Council staff report back on the feasibility and validity of such an approach.

   (ii) What is an appropriate definition of "quad bike", and vehicles under 1000cc? Does Council have a duty under HSE legislation (or otherwise) to require that vehicles seeking access to the subject areas are warranted and registered?

   (iii) Whether we can recommend restrictions on vehicle access from Wharenui south to the MDC district boundary. Is this within the notified parameters of the proposed bylaw?

   (iv) Whether we can recommend signage and fenced areas at certain pinch-points for access and/or areas of high biodiversity or dune restoration areas (if vehicle access is granted). Is this within the notified parameters of the proposed bylaw? (We are aware that we cannot through a bylaw introduce a requirement for Council to incur expenditure, therefore this can only be a recommendation.)

   (v) Whether Council has additional information available relating to presence of rare and threatened flora and fauna at Awatere river mouth and Waima (Ure) River mouth.

   (vi) Whether Council has additional information available relating to effects of motor vehicles on biodiversity within the intertidal zone.

   (vii) Draft contour maps that identify 200 m, 300 m, 400 m, 500 m, 1 km no-drive areas at Awatere River mouth, Waima (Ure) River mouth, and adjacent to the DOC reserve at Marfells Beach.

2. Responses below are provided by Sarah Edmonds (MDC Strategic Planner), with input and information from Council Officers, NZTA and University of Canterbury Scientists.

Whether the Bylaw may include a licensing requirement for persons that wish to obtain access by motor vehicle to the subject beach areas. We understand that Tauranga City Council operates a licensing system for some beach access, and we ask that Council staff report back on the feasibility and validity of such an approach.

3. A copy of the Tauranga City Council Beaches Bylaw 2018, Speed Limits Bylaw 2009 and application form (including conditions of use) from the Tauranga City Council (TCC) website are included in Appendices 1-3 in this memorandum.

4. The following is a summary of provisions in the TCC Bylaw for vehicles, horses and longlines on beaches.

All-terrain vehicles (ATVs) and horses are allowed on our beaches, but only in certain areas. Longline/kontiki fishing devices can be used anywhere along the beach, but summer restrictions apply.

<u>Vehicles</u>

Vehicles are generally not permitted to drive on the beach, however there are some exceptions:

All-terrain vehicles (ATVs) that display a council permit may be driven on the beach for recreational fishing purposes only. The beach access point is located between 105 and 107 Karewa Parade, Papamoa. An ATV can only be driven east of the access point towards/from the Kaituna River. The ATV must be registered and display a current licence label, as well as be in a safe and road worthy condition.

ATVs do not have priority on the beach – they must be driven in a careful manner with consideration to all beach users. They must not be driven on the dunes. The speed limit is 20 km/h.

A police, fire, ambulance, government service, surf life saving or council vehicle may be driven on the beach. They have priority of use for authorised, justifiable or operational matters.

All other vehicles are not permitted to drive on the beach, including outside of the permitted boat ramp access areas of the beach.

<u>Horses</u>

As a general rule you can ride your horse on the beach. However there are some places where you cannot ride, drive or lead a horse on the beach:

- Any beach at Mauao (the mountain).
- The main Mt Maunganui Beach from Moturiki Island (Leisure Island) to, and including, the base of Mauao.
- Any beach at Moturiki Island (Leisure Island).
- Pilot Bay Beach from the base of Mauao to Salisbury Wharf.
- Any beach within 100 metres directly in front of and adjoining any land at mean high water springs classified as Marae Community Zone (as identified in the Tauranga District Plan and shown on the maps in Schedule 2), unless the horse is at a walking pace.

Council may, by resolution, define further beaches where horses are prohibited.

Access by horses and their riders to those coastal beaches where horses are permitted, must be via a Council-controlled vehicle access or any other access designated for that purpose.

You must remove any horse manure and dispose of it in a hygienic manner.

For a map of the areas where you can ride a horse on the beach please see the map in Schedule one of the Beaches Bylaw.

Longline/kontiki fishing devices

Longline/kontiki fishing devices can be used anywhere along the beach, so long as they aren't within 300 m of any flagged lifeguard area. Additional restrictions apply over the summer period.

If an ATV is used to transport the device onto the beach, the above ATV rules also apply.

Summer restrictions:

Between the hours of 10.00 am and 5.00 pm from 15 December to 15 February each year, longline/kontiki fishing devices (regardless of deployment) cannot be used on the beach.

5. Sarah Edmonds contacted officers at TCC. They advised that they introduced a permit system as there was a need expressed by the fishers in the community to retain access to the beach using quad bikes to go fishing. A permit system allows TCC to ensure ATV users are aware of the conditions of use to ensure they operate in a safe manner in conjunction with other users of the beach and can still access the beach for fishing. Applicants comply with the requirement for a permit as they want to be able to use their ATV's to access the beach for fishing. Generally the fishers are on the beach early in the morning (7.00 am) and are gone by 9.00 am. The longline restrictions in the TCC Bylaw reduce the numbers of ATV's using the beach over the summer period.
6. A key difference is the environment. Papamoa Beach adjoins an urban area. Approximately 500-600 metres of the 7km where ATV's can travel is past housing. There are nuisance issues and with a growing population the popularity of the beach for recreation activities increases safety concerns.
7. TCC is a Territorial Authority (TA). The Bylaw has been made under the LGA 2002 for the purposes of public safety and managing nuisance. Generally TA's control the beach above Mean High Water Mark (MHWM), with Regional Councils controlling the area below MHWM out to the 12 nautical mile limit. Unusually, three of the TA's in the Bay of Plenty Region (including TCC) are able to control the beach to the Mean Low Water Mark (MLWM) through a Gazette Notice.
8. With regards to enforcement, NZ Police, TCC, DOC and MPI work collaboratively. They rely on good signage and self-regulation, i.e. other users/capable guardians teaching and advising the requirements to other beach users. Education and public awareness campaigns were used in early stages of commencement. TCC has never prosecuted anyone, to take a case is too onerous, instead a stepped approach using a verbal warning, followed by a letter then the issuing of an infringement notice if necessary.

MDC Officer Comments

9. A permit system has been considered for this Bylaw and is a valid approach to manage vehicle use on the beach. Such a system provides the opportunity to educate users on the conditions of use of a vehicle in the beach environment.
10. The proximity of the east coast from Blenheim (35 km) does create a challenge for MDC and NZ Police to respond to any complaints and carry out enforcement. TCC's experience is that the powers under the LGA are not as effective as an infringement notice issued by NZ Police. A question to answer is who is going to carry out the enforcement of vehicles on the east coast beaches? Any system put in place would need to reflect the communities by-in to a permit system and will most likely rely on self-regulation.
11. The Mean High Water Mark (MHWM) and Mean Low Water Mark (MLWM) have not been surveyed so defining a route would rely on a robust description of the route vehicles could travel as accurate mapping above and below MHWM is currently not possible.
12. MDC does ask the question of who pays; ratepayers or users? And what fee would be tolerable to users and would this be sufficient to cover costs? Other MDC processes are subject to a user pays environment with the setting of fees. In a user pays environment, any fee would need to cover the administrative and enforcement costs to run and maintain a licensing system. MDC does have experience of implementing and managing licensing

systems. The implementation of a new system would require budget to be allocated through the Annual Plan process and resourcing to be provided for.

What is an appropriate definition of "quad bike", and vehicles under 1000cc?

13. Definition of a "quad bike" from the Waka Kotahi - NZ Transport Agency (NZTA), website:

All-terrain vehicles (ATVs) are vehicles that are principally designed for off-road use.

They have three or more wheels, an engine capacity exceeding 50 ml and a gross weight of less than 1,000 kg (which is the greater of the on-road weight with load and accessories OR the gross laden weight set by the manufacturer).

ATVs include most quad bikes, smaller 'side by sides' and amphibious vehicles. They do not include 'utes' or light trucks, even if modified for off-road travel – these are originally constructed for road use and are too heavy to meet the definition.

14. Further information can be found in Appendix 4 in this memorandum.

Does Council have a duty under HSE legislation (or otherwise) to require that vehicles seeking access to the subject areas are warranted and registered?

15. Guidance is provided from the Waka Kotahi - NZ Transport Agency (NZTA) website. You can use ATVs on public roads under certain conditions.

You must:

- register and license the ATV;
- hold a current New Zealand driver licence;
- wear an approved safety helmet when riding them on the road (except farmers travelling slower than 30 km/h, from one part of their farm to another or to an adjoining farm);
- maintain a current Warrant of Fitness (except if used as a farm vehicle).

ATVs that will never be used on any road don't have to be registered or licensed.

16. What is a road?

Roads are not only streets and highways, but any place the public has access to – including bridges, culverts, beaches, riverbeds, reserve lands, wharves and road shoulders.
This doesn't mean you have a right to use these areas, but if you do – the rules relating to registration, licensing and general driver behaviour apply.

The full definition of a road from the Waka Kotahi website is as follows:

Statutory definitions of 'road'

Enforcement of the law and the use of motor vehicles

The definition of **road** that is used for law enforcement purposes, including the enforcement of requirements relating to the use of motor vehicles, has been widened from the traditional view of what is a road.

This statutory definition covers places to which the public have access - whether of right or not. For an example, read the definition of 'road' in the Land Transport Act 1998(external link) (on the Public Access to Legislation Project website). Take particular note of paragraph (d) and the words 'A place to which the public have access, whether as of right or not'.

Another feature, not seen often overseas, is the specific inclusion of a beach as a road. This allows local authorities to set speed limits on beaches, and also allows the New Zealand Police to enforce traffic laws, such as registration requirements, that apply to the on-road use of motor vehicles.

The definition aims to ensure that the public are protected from the misuse of motor vehicles, even in areas where we would not ordinarily expect to find motor vehicles. It is important to note that the definition does not give a **right of access** to any area covered by it, but rather ensures that the Act, and others like it, applies regardless of any public rights of access and use.

Because of the wide scope of the definition, the courts have developed a number of principles that they apply when considering whether a place is a road. These include that:

- 'public' means the public in general, and not just a section of the public
- it is not enough that the place is physically open to the public - they must be shown to be actually using it.

This assessment is made by the courts on a case-by-case basis and is dependant on the facts of each case. Therefore, it is not possible to give a simple 'yes' or 'no' in answer to the question, 'Is this place a road?'

Public roads

There is another statutory approach to the definition of road that is used in New Zealand. It is found used in Acts that provide for the funding, construction and traffic management powers of central and local government agencies. A good example is the definition in the Local Government Act 1974(external link). This definition refers to areas clearly taken for use as roads by the general public. In common law terms, these are public roads or highways, which the public are permitted to access and use. (See also Use of motor vehicles on roads below).

Common law definition of 'road'

The common law that we inherited from England used a very simple test to determine what is a road: essentially, there had to be a 'right of way' or 'right of passage' granted to the public by the land owner. It didn't matter whether the land was publicly or privately owned - it was the **permission for public use** that counted.

Roads were classed as footpaths, bridleways or bridle paths, or carriageways, depending on the type of use permitted. A footpath was limited to pedestrians only, with animals added if it was a bridleway, and wheeled vehicles only allowed on a carriageway. The basic right that could be exercised on a road was that of travelling from one place to another. Obstructing or interfering with someone else's rights to the use of the road was a criminal offence.

Use of motor vehicles on roads

While the common law courts developed detailed rules about the rights of people on foot, riding animals or driving animal-drawn vehicles to use roads, they never had to deal with motor vehicles. In a 1981 case (*Brader v Ministry of Transport* [1981] 1 NZLR 73 at 78, 84), the New Zealand Court of Appeal rejected a claim that the law gave individuals an absolute right to use motor vehicles, stating that the 'liberty to drive' is not a natural right and that even the provisions in the legislation imposed restrictions and obligations, rather than granting rights. The court commented further in 1994 (*R v Jefferies* [1994] 1 NZLR 290, at 296) that there is no traditional approach of the common law to motor vehicles.

Common law terms

Street and **way** are terms used interchangeably with road. Another is **highway** - this is simply a road or street dedicated for public use, normally between two localities or towns, and is often referred to as a **public highway** or **public road**.

Whether we can recommend restrictions on vehicle access from Wharenui south to the MDC district boundary. Is this within the notified parameters of the proposed bylaw?

17. The focus area of the Technical Report is between the Awatere River mouth south to the Waima/Ure River mouth.

18. In drafting the proposed bylaw all public access points to the focus area were considered. This included the two vehicle access points at the Waima River and Wharanui.

19. The area south of the Waima (Ure) River has not been the subject to the same level of investigation as the focus area. Retaining vehicle use south of the Waima (Ure) River has been proposed to offset the restrictions being imposed to the north of the Waima River. A speed restriction is sought for public safety as this area is known for vehicles to travel at speed.

Whether we can recommend signage and fenced areas at certain pinch-points for access and/or areas of high biodiversity or dune restoration areas (if vehicle access is granted). Is this within the notified parameters of the proposed bylaw? (We are aware that we cannot through a bylaw introduce a requirement for Council to incur expenditure, therefore this can only be a recommendation.)

20. Signs were always regarded as necessary to educate the public regardless of the outcome of the proposed Bylaw. This option is signalled in the Statement of Proposal as a method that could be used alone or in conjunction with a Bylaw.

21. Given the extensive nature of the dune systems along the east coast, it is considered impractical and too expensive to fence the entire length of dune systems.

22. Any consideration of budget necessary for signs and fencing would need to go through Council's Annual Plan process.

23. The installation of signs and fencing for the East Coast could be a shared cost with other agencies, such as the Department of Conservation and/or Ministry for Primary Industries.

Whether Council has additional information available relating to presence of rare and threatened flora and fauna at Awatere River mouth and Waima (Ure) River mouth.

24. We refer the panel to the information submitted by Andrew John from Forest and Bird Royal Protection Society. This information is available on Council's website.

25. We also attach two Significant Natural Areas (SNA) reports, one for the Waima (Ure) River mouth and a second report for the Awatere River mouth. The full reports are in Appendix 5.

Whether Council has additional information available relating to effects of motor vehicles on biodiversity within the intertidal zone.

26. Shane Orchard from University of Canterbury has shared two recently published reports which are attached in Appendix 6.

- Cataclysmic Disturbances to an Intertidal Ecosystem: Loss of Ecological Infrastructure Slows Recovery of Biogenic Habitats and Diversity.
- Threshold effects of relative sea-level change in intertidal ecosystems: empirical evidence from earthquake-induced uplift on a rocky coast.

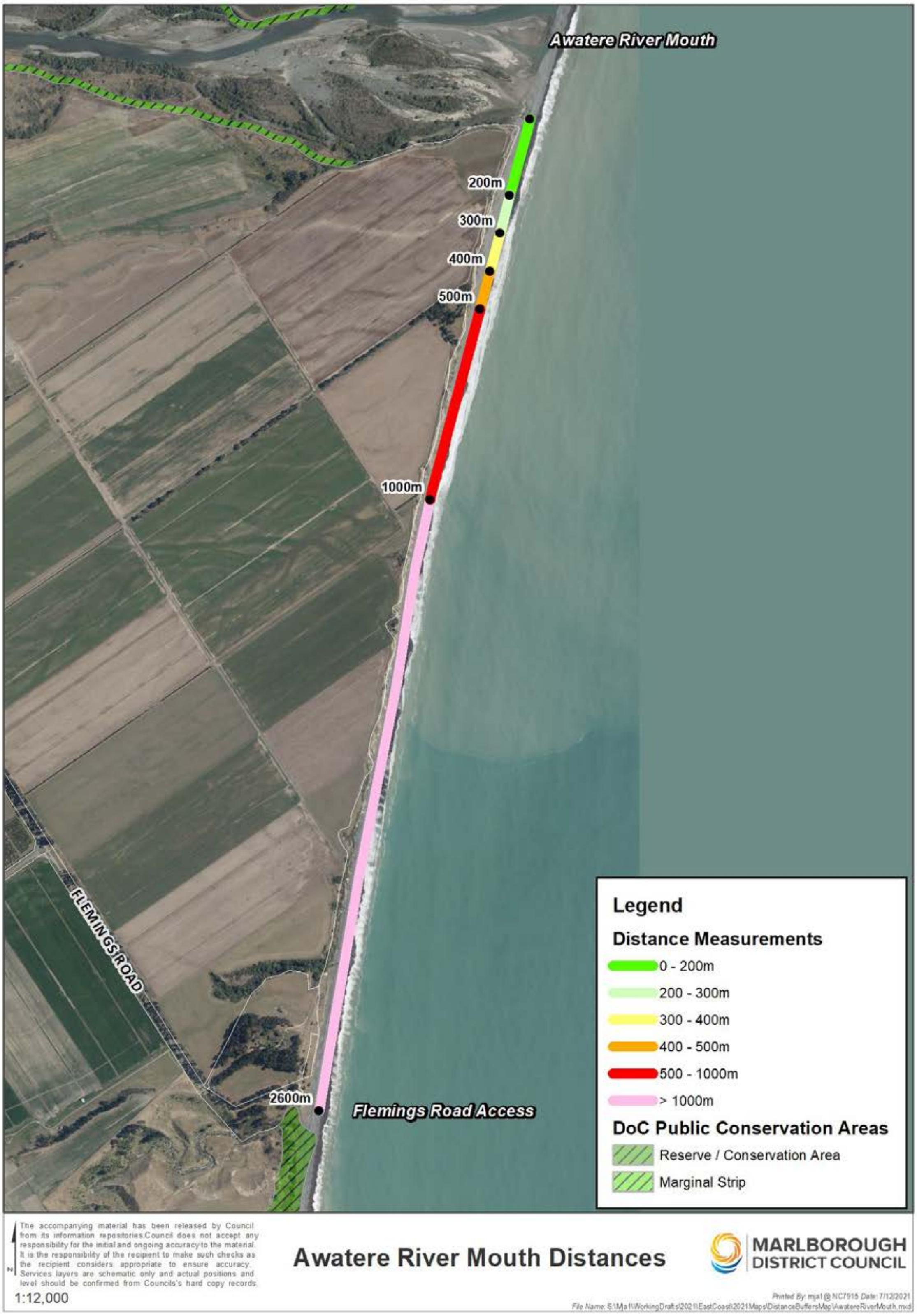
27. MDC's Coastal Scientist Oliver Wade makes the following comments:

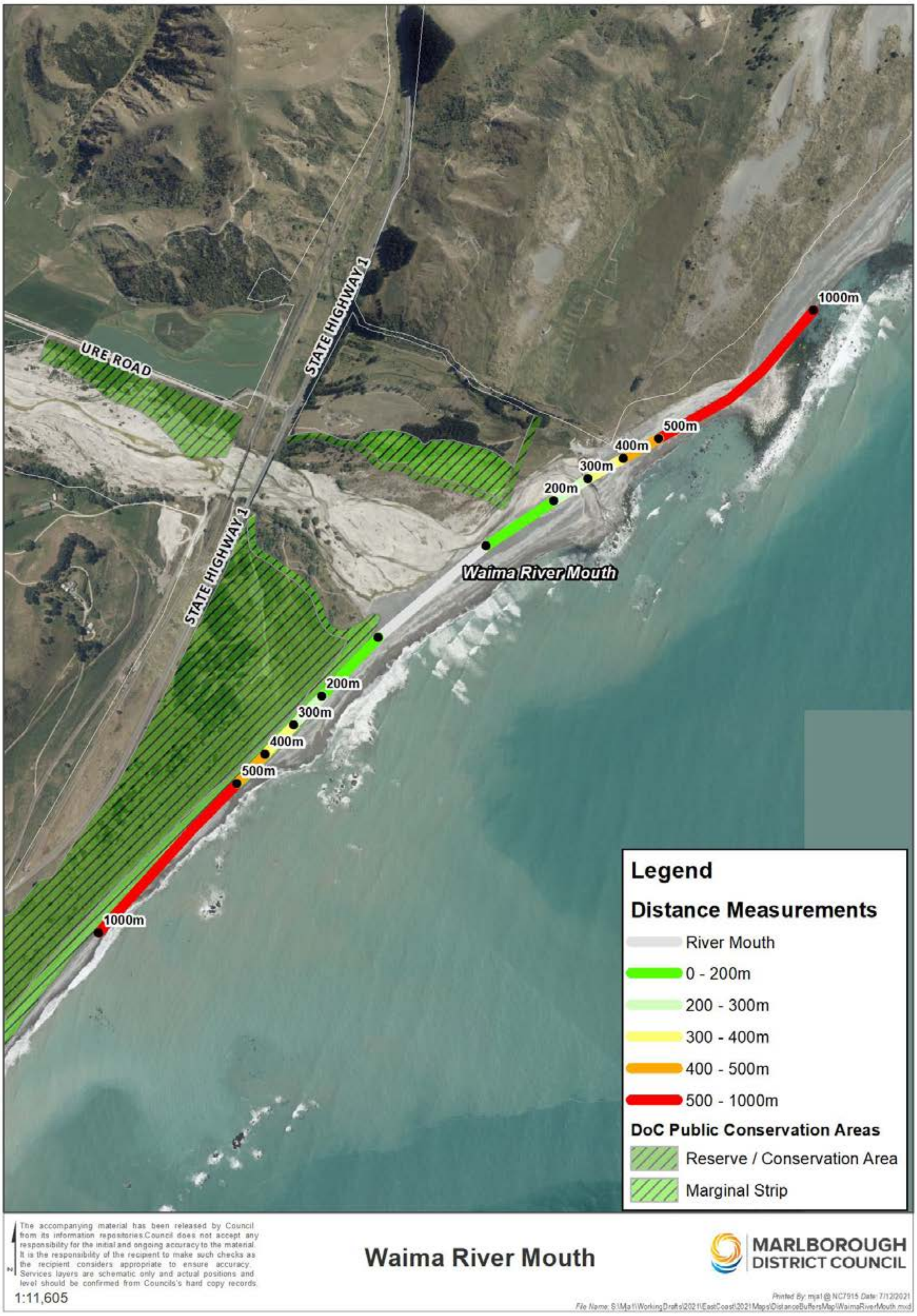
Most of the focus to date on vehicle access to the foreshore around Cape Campbell has focussed on vehicles remaining below MHWS. Whilst this makes sense in terms of limiting disturbance to roosting and nesting birds, coastal vegetation and hauled out marine mammals above the high tide mark, it does not consider the impact of vehicle traffic on intertidal marine biodiversity.

This coastline experienced a remarkable upheaval during the 2016 earthquake from which it is still recovering. Large swathes of subtidal reef became intertidal reefs in a matter of minutes. This uplift was deleterious for many of the organisms living in these areas. These new intertidal reefs are slowly being colonised by new species suited to this harsh intertidal environment. Vehicle traffic can be very harmful to species that colonise these areas, mainly through crushing. Especially the juveniles of species as they have recently colonised areas. Further, intertidal reefs also provide for feeding habitat for many bird species and haulout and nursery areas for marine mammals. Any passage of vehicles over the intertidal reefs in this area will inhibit the recovery of marine biodiversity on these reefs.

As such it is hard to envisage what zone on this coast would provide for the passage of vehicles (cars or ATVs) that would not be harmful in some way to the animals and plants that live below MHWS on this coastline.

Draft contour maps that identify 200 m, 300 m, 400 m, 500 m, 1 km no-drive areas at Awatere river mouth, Waima (Ure) river mouth, and adjacent to the DOC reserve at Marfells Beach.

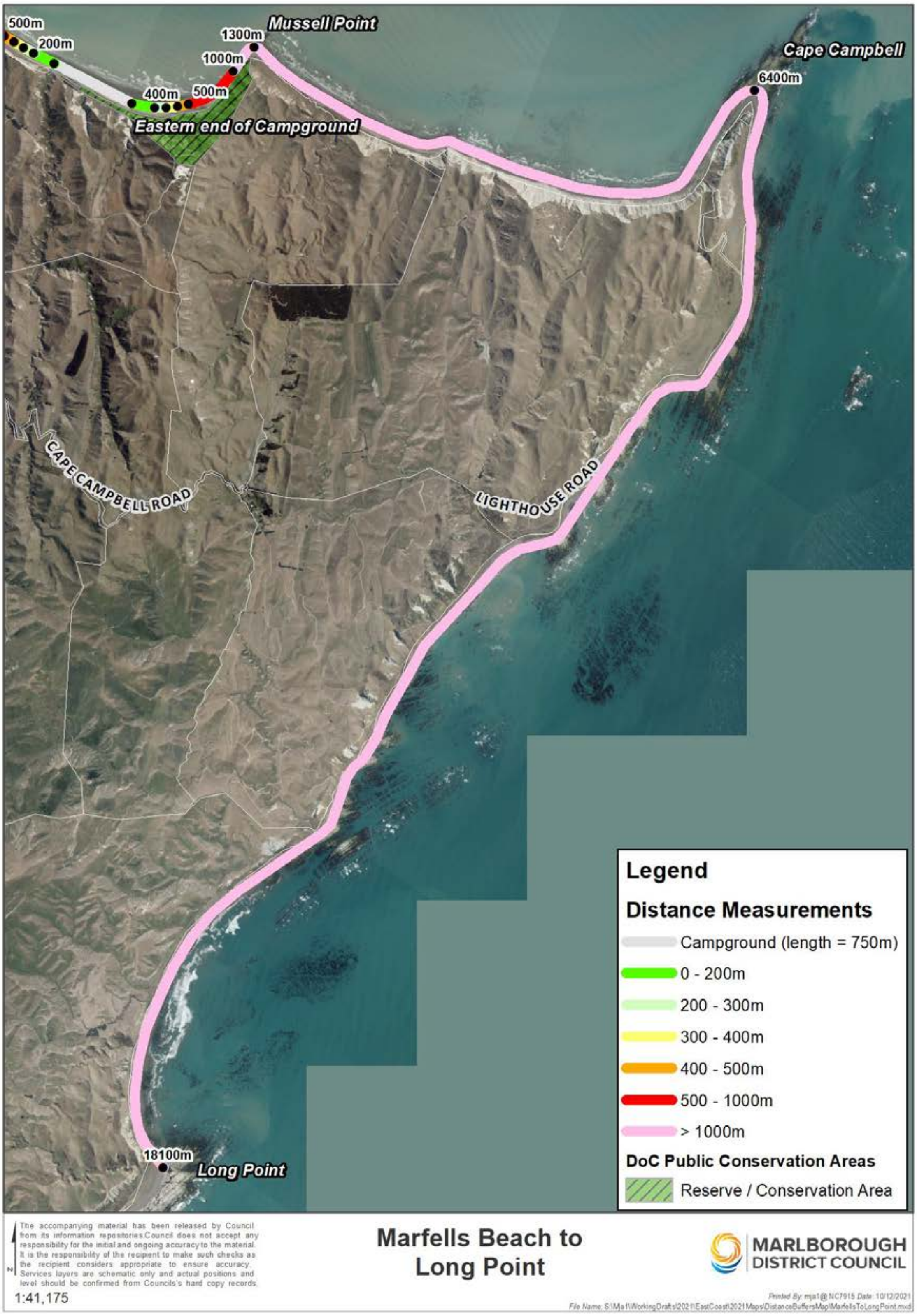




URE ROAD
STATE HIGHWAY 1
STATE HIGHWAY 1
Waima River Mouth
1000m
500m
400m
300m
200m
200m
300m
400m
500m
1000m
Legend
Distance Measurements
River Mouth
0 - 200m
200 - 300m
300 - 400m
400 - 500m
500 - 1000m
DoC Public Conservation Areas
Reserve / Conservation Area
Marginal Strip
The accompanying material has been released by Council from its information repositories.Council does not accept any responsibility for the initial and ongoing accuracy to the material. It is the responsibility of the recipient to make such checks as the recipient considers appropriate to ensure accuracy. Services layers are schematic only and actual positions and level should be confirmed from Councils's hard copy records.
N
1:11,605
Waima River Mouth
MARLBOROUGH
DISTRICT COUNCIL
Printed By: mja1@NC7915 Date: 7/12/2021
File Name: S:\Mja1\WorkingDrafts\2021\EastCoast\2021Maps\DistanceBuffersMap\WaimaRiverMouth.mxd


Saltworks
2000m
1000m
500m
400m
300m
200m
Western End of Campground
MARFELLS BEACH ROAD
Legend
Distance Measurements
Campground (length = 750m)
0 - 200m
200 - 300m
300 - 400m
400 - 500m
500 - 1000m
> 1000m
DoC Public Conservation Areas
Reserve / Conservation Area
1:9,500
Marfells Beach West
MARLBOROUGH DISTRICT COUNCIL


Legend
Distance Measurements
Campground (length = 750m)
0 - 200m
200 - 300m
300 - 400m
400 - 500m
500 - 1000m
> 1000m
DoC Public Conservation Areas
Reserve / Conservation Area
Mussell Point
1300m
1000m
500m
400m
300m
200m
Eastern end of Campground
Marfells Beach Recreation Reserve
1:6,500
Marfells Beach East
MARLBOROUGH DISTRICT COUNCIL



500m
200m
1300m
Mussell Point
1000m
400m
500m
Eastern end of Campground
Cape Campbell
6400m
CAPE CAMPBELL ROAD
LIGHTHOUSE ROAD
18100m
Long Point
Legend
Distance Measurements
Campground (length = 750m)
0 - 200m
200 - 300m
300 - 400m
400 - 500m
500 - 1000m
> 1000m
DoC Public Conservation Areas
Reserve / Conservation Area
The accompanying material has been released by Council from its information repositories.Council does not accept any responsibility for the initial and ongoing accuracy to the material. It is the responsibility of the recipient to make such checks as the recipient considers appropriate to ensure accuracy. Services layers are schematic only and actual positions and level should be confirmed from Councils's hard copy records.
N
1:41,175
Marfells Beach to Long Point
MARLBOROUGH DISTRICT COUNCIL
Printed By: mja1@NC7915 Date: 10/12/2021
File Name: S:\Mja1\WorkingDrafts\2021\EastCoast\2021Maps\DistanceBuffersMap\MarfellsToLongPoint.mxd

Dated: 15 December 2021

Sarah Edmonds
Marlborough District Council

Appendix 1: Tauranga City Council Beaches Bylaw 2018

BEACHES BYLAW 2018

Tauranga City

First adopted	2004	**Minute reference**	M04/105.3
Revisions/amendments	16 December 2007 1 December 2008 17 August 2010	**Minute references**	M07/101.4 M08/137.01 M10/61.12
Review date	This bylaw to be reviewed ten years after date of adoption.		
Engagement required	Special Consultative Procedure		
Associated documents	Street Use and Public Places Bylaw Dog Control Bylaw 2008 Speed Limit Bylaw 2009		
Relevant legislation	This bylaw was made under Local Government Act 2002.		

1. TITLE

1.1 This bylaw is the Beaches Bylaw 2018.

2. COMMENCEMENT

2.1 This bylaw comes into force on 1 December 2018.

3. APPLICATION

3.1 This bylaw applies to Tauranga.

4. PURPOSE

4.1 The purpose of this bylaw is to enable the safe, recreational use of Tauranga beaches.

4.2 This bylaw is to manage public safety and nuisance issues arising from use of Tauranga beaches.

4.3 Bay of Plenty Regional Council rules to ensure protection of the foreshore and seabed, or to manage air quality, may apply to vehicles on beaches or the lighting of fires.

5. DEFINITIONS

5.1 For the purposes of this bylaw the following definitions apply:

Term	Definition
Act	Refers to the Local Government Act 2002.
All-terrain Vehicles (ATVs)	Means vehicle (with or without motorcycle controls and equipment) that:— (a) is principally designed for off-road use; and (b) has 3 or more wheels; and (c) has an engine capacity exceeding 50 ml; and (d) has a gross weight of less than 1 000 kg.
Approved	Approved in writing by the Council, either by resolution of the Council or by any authorised officer of the Council.
Authorised Officer	Refers to any officer of the Council or any other person authorised under the Local Government Act 2002 and authorised by the Council to administer and enforce its bylaws.
Bathing	Refers to swimming and sunbathing.
Beach	Refers to any land in Tauranga adjacent to any seacoast or lakeside which is part of the foreshore, or is land contiguous to and used in connection with the foreshore, and to which the public has a right of access. For the purposes of this bylaw, the beach includes the foreshore which is the parts of the bed, shore or banks of tidal water between mean high water springs and mean low water springs.
Bylaw	Refers to the Tauranga City Council Beaches Bylaw 2018.
Coastal beach	Refers to any beach from, and including, Mauao, Mt Maunganui Main Beach to the Kaituna River.
Council	Refers to Tauranga City Council - the elected member body representing Tauranga.
Craft	Refers to any ship, boat or other machine or vessel used or able to be used by any person on, or in, the sea.
Dune	Refers to areas of undulating contour above mean high water springs, where there is a marked change in landform from a gently sloping beach to rolling sand hills or where a line of vegetation cover starts. The area can be considered 'wild and undeveloped'. The landward extent of sand dunes can be characterised at a point where the soil type changes and sand dune vegetation is less dominant.
License	Refers to a permit or other authority from the Council.
Longline fishing off the beach	Refers to fishing from the beach using long lines fitted with multiple hooks regardless of device (for example kontiki, kite, drone) used to deploy the line.

Term	Definition
Marae community zone	(Either rural or urban) is as contained in the Tauranga City Plan.
Motorcycle	Shall have the same meaning as defined in the Land Transport Act 1998 (or subsequent amendment).
Offence	Includes any act or omission in relation to this bylaw or any part thereof for which any person is liable to prosecution.
Owner	Of any property, or as applied to any land, building, or premises, means any person for the time being entitled to receive the rent of such property, land, building, or premises, and where any such person is absent from New Zealand, shall include their attorney or agent, or any other person acting for them or on their behalf.
Person	Includes a corporation sole and also a body of persons, whether corporate or unincorporated.
Sign	Means any display or device whether or not placed on land or affixed to a building, stationary vehicle or structure, intended to attract attention for the purposes of directing, identifying, and informing, or advertising, and which is visible from a public place.
Structure	Is any permanent or temporary works which are not part of the natural beach environment.
Vehicle	Shall have the same meaning as defined in the Land Transport Act 1998 or subsequent amendments.
Wharf	Is a permanent or floating waterfront structure which is purpose designed for the berthing of marine vessels and includes every wharf, quay, jetty, pier, pontoon or other structure under the control of the Council from which passengers or goods may be taken on board or landed from any vessel or boat.

6. VEHICLES

6.1 No person shall on any part of the beach, except as allowed in Sections 6.2, 6.3 or 6.4:

(1) Drive any land yacht, all-terrain vehicle or other vehicle in a manner which is or might be dangerous, or which causes or might cause inconvenience to any person in the area.

(2) Bring or ride any motorcycle thereon.

(3) Bring or drive any vehicle thereon except to launch a craft or remove it from the water 50 metres either side of a boat ramp, boat launching facility, or from the vehicle access points at Harrison's Cut, Pāpāmoa Domain, and Taylor's Reserve.

(4) Leave any trailer thereon other than boat trailers during launching or retrieving of boats only.

6.2 All-terrain vehicles may be driven on the beach for recreational fishing purposes with the permission of Council provided they use the vehicle access point between 105 and 107 Karewa Parade. All-terrain vehicles shall only be ridden on the beach east of Karewa Parade (to or from the Kaituna River).

6.3 Vehicles must be driven in accordance with the Speed Limit Bylaw 2009 (or subsequent amendments), and to ensure the safety and consideration of others in the area.

6.4 Vehicles may be driven on the beach for the purposes of setting up and running of events on the beach, but only if permitted by the Council and in accordance with that permission.

6.5 All vehicles should be driven below the high tide line (except when unsafe to do so) and must not be driven on the dunes.

6.6 Nothing in this paragraph shall apply to any police vehicle, fire appliance, ambulance, government service, surf life saving or Council vehicles or other vehicle authorised by Council to drive on the beach.

7. CRAFT

7.1 Craft may be moored, secured, anchored or left on the beach but Council may require them to be removed if they are deemed to be causing a safety or nuisance issue, or impacting on the wider public enjoyment of the beach.

8. HIRING OF CRAFT

8.1 The Council may permit the use of any defined part of the beach for the hiring, storing, launching, and recovery of particular types of waterborne craft made available for public hire.

8.2 All persons carrying out one or more of the activities outlined in section 8.1, or using the beach for any commercial activity, must have a license to do so.

8.3 Any such permission may include an administration fee and such conditions as may be desirable in the interests of the safety and convenience of the public, including that of bathers in particular.

9. LONGLINE FISHING

9.1 Longline fishing off the beach (regardless of method of deployment) is not permitted between the hours of 10:00am and 5:00pm from 15 December to 15 February.

9.2 Fishing is not permitted within 300 metres of any flagged lifeguard area.

10. HORSES ON BEACHES

10.1 No person may ride, drive or lead a horse on the following beaches as shown on the map at schedule one:

- Any beach at Mauao
- The main Mt Maunganui beach from Moturiki to, and including, the base of Mauao
- Any beach at Moturiki
- Waikorire (Pilot Bay) from the base of Mauao to Salisbury Wharf

- Any beach within 100 metres directly in front of and adjoining any land at mean high water springs classified as Marae Community Zone (as identified in the Tauranga City Plan and shown on the maps in schedule two), unless the horse is at a walking pace.

10.2 Council may, by resolution, define further beaches where horses are prohibited.

10.3 Access by horses with their riders to those coastal beaches where horses are permitted, must be via a Council-controlled vehicle access or any other access designated for that purpose.

10.4 Any person in control of a horse on the beach must remove any faeces deposited by their horse and dispose of it in a hygienic manner away from the beach.

11. REMOVAL OF MATERIAL

11.1 No person shall remove, for commercial, landscaping or building purposes, any stone, shingle, sand, boulders, silt, mud, shell or other material from any part of the beach or foreshore except pursuant to a licence issued by the Council or if otherwise authorised by law.

12. PROTECTIVE WORKS

12.1 No person shall interfere with or remove any portion of any protective works, groynes or other structures erected on the beach or foreshore for the control of sand or shingle or for the prevention of erosion.

13. LIFESAVING EQUIPMENT

13.1 No person shall interfere with or remove, destroy or damage any sign, navigation structure or aid, or any lifebuoy or lifesaving apparatus erected or maintained on the beach or on any wharf, jetty or landing place thereon.

14. STRUCTURES

14.1 No person shall commence, make or construct any work, or place any pile or other structure whatsoever in, on, over, through or across the beach without first having obtained a licence from the Council.

14.2 No person shall maintain or continue to use, or permit to remain on any part of the beach any structure without being the holder of a current licence to do so.

14.3 Every applicant for a licence to erect a structure or to maintain an existing structure on the beach or to renew a previous licence shall with the application pay the processing fee and provide the information required.

14.4 Any licence may be cancelled for any breach of any relevant clause of this Bylaw.

14.5 The licence holder shall at all times keep the structure in good repair, appearance and condition and if necessary the Council may order the licence holder to undertake remedial works to its satisfaction.

14.6 No licence holder shall make charges for the use of a structure unless they are first approved by the Council or unless the licence is granted for commercial use.

Explanatory note: *Temporary sun protection structures and children's sandcastles are not defined as structures for the purpose of this bylaw.*

15. PROHIBITION OF BATHING

15.1 The Council may, for the purposes of public health and safety, prohibit bathing on any beach or any portion of the beach under its control.

15.2 The Council may, for this purpose, erect signs defining the limits within which bathing shall be confined.

16 BERTHS

16.1 No owner or person in charge of any vessel or boat shall, except in case of emergency, cause, or allow such vessel or boat to occupy a berth alongside any wharf or to lie off a wharf with a line or mooring attached thereto, unless such vessel or boat shall first have been licensed by the Council to occupy such berth. This section shall not apply to any wharf determined by Council to be a public wharf in accordance with section 16.3.

16.2 The person in charge of any vessel or boat occupying a berth must adhere to all stated safety signage.

16.3 Council may, by resolution, determine any wharf, or part thereof to be a public wharf for the specific purpose of casual picking up and setting down of passengers from private vessels or boats. Permission is not specifically required to use these berths for these purposes.

16.4 Nothing in clauses 16.1, 16.2, and 16.3 shall override conditions relating to public access set under a resource consent.

17. AIRCRAFT

17.1 No person shall (except in case of emergency) land or attempt to land on the beach, or become airborne or waterborne from the beach, or ride along the beach, any motorised aircraft (excluding drones), without the permission of Council. In all cases, the person must ensure that all other statutory requirements are also complied with.

17.2 Recreational non-motorised aircraft may land on, take off from and ride along the beach except when it is dangerous or might cause inconvenience to any person in the area. In all cases, the person must ensure that all other statutory requirements are also complied with.

18 FIRES

18.1 Fires may be lit between the hours of 5am and 10pm. All fires must be below the high tide mark, be less than one metre in diameter and must be under supervision at all times. The person lighting the fire must ensure that the materials being burnt are wholly combustible, that there is some form of extinguishment available, and the fire is fully extinguished with water before leaving the beach. All litter and debris must be removed.

Explanatory note: *Fire and Emergency New Zealand have legislative authority to prohibit fires in open air and prohibit or restrict other activities if fire conditions exist or is necessary for fire control regardless of provisions in this bylaw.*

19. OFFENCES AND PENALTIES

19.1 Every person who breaches the terms of this Bylaw commits an offence. And further, every person commits a breach under this Bylaw who:

i. Fails, refuses or neglects to comply with any notice duly given to that person under this Bylaw;

ii. Obstructs or hinders any Authorised Officer of the Council or other Council appointed person in performing any duty or in exercising any power under this Bylaw.

19.2 The infringement fee for a breach of clause 6, except for a parking offence, is $150.

19.3 Subject to any provision to the contrary, any person guilty of an offence against this Bylaw shall be subject to the penalties set out in Section 242(4) of the Local Government Act 2002, and is liable on summary conviction to a fine not exceeding $20,000.

20. LICENCES

20.1 The form of any application for and grant of any permission, licence or approval required under this Bylaw will be determined by the Council.

20.2 The Council may attach to any permission, approval or licence any terms or conditions as it thinks fit.

20.3 No application for a licence from the Council, and no payment of or receipt for any fee paid in connection with such application or licence, shall confer any right, authority or immunity on the person making such application or payment.

20.4 Suspending or Revoking Licences

(a) The Council may revoke or suspend a licence granted under this bylaw if it reasonably believes the licence holder:

i. has acted or is acting in breach of the licence; or

ii. is unfit in any way to hold such a licence.

(b) The Council may require the licence holder to attend a hearing to explain why the licence should not be revoked or suspended. The Council may revoke or suspend the licence at its discretion. If either;

i. the licence holder does not attend the hearing; or

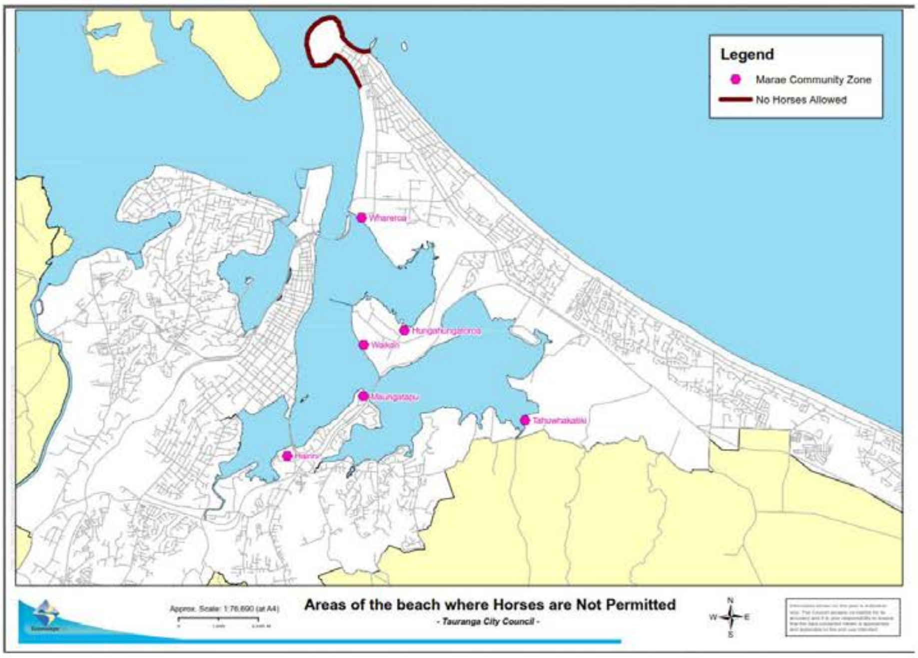
ii. if after the hearing the Council is satisfied the licence holder has been in breach of the licence or is unfit to hold the licence.

(c) The Council may suspend any licence granted under this bylaw for a period not exceeding 72 hours during the staging of any special event, by giving the licence holder 10 days' notice in writing. The Council may suspend any such licence for the purposes of protecting the public from nuisance or for protecting, promoting or maintaining public health and safety.

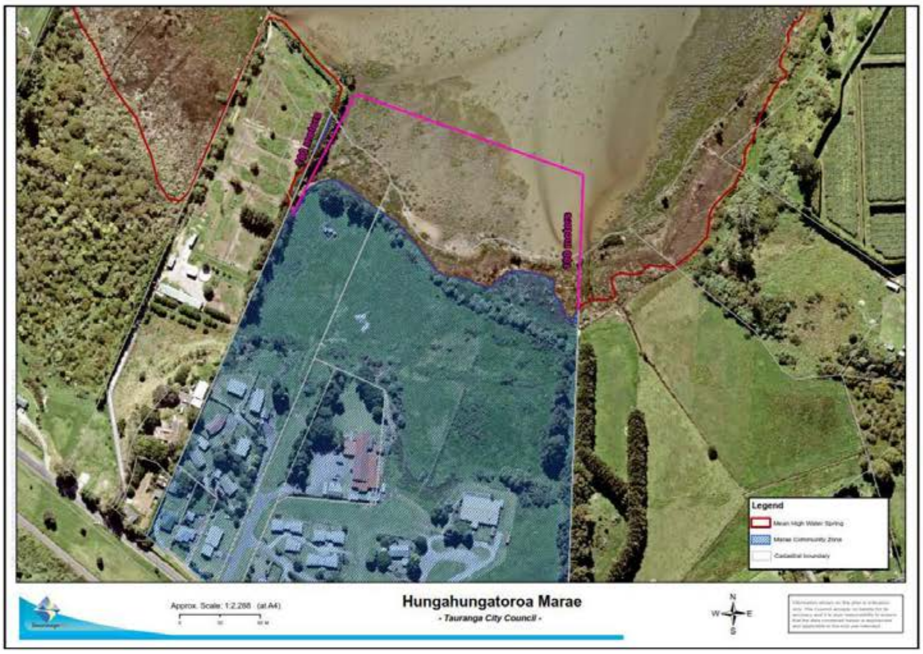
21. DISPENSING POWERS

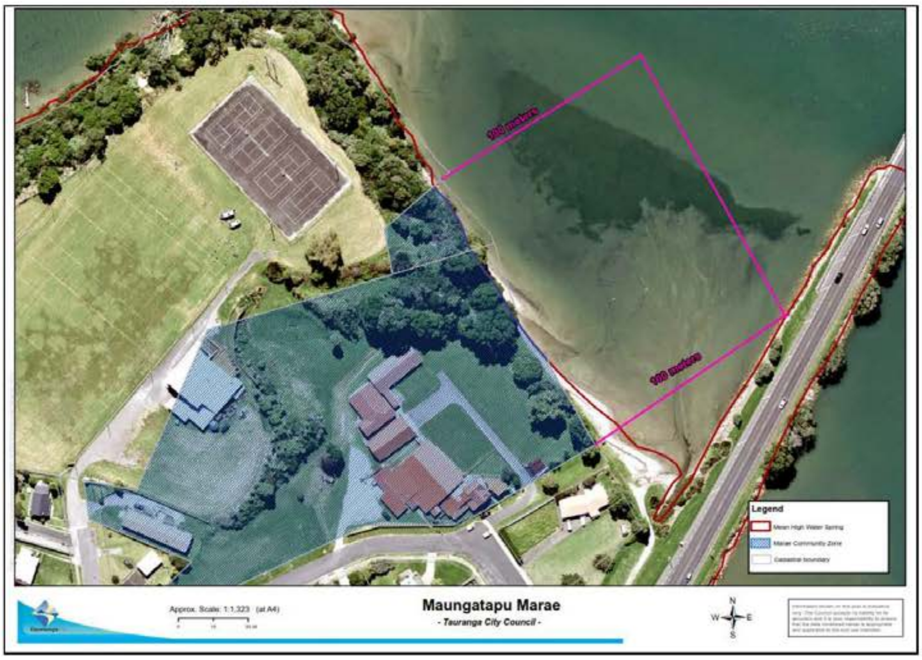
21.1 The Council may waive full compliance with any provision of this Bylaw in a case where the Council is of the opinion that full compliance would needlessly cause harm, loss, or inconvenience to any person or business without any corresponding benefit to the community. The Council may in its discretion pose conditions of any such waiver.

Schedule one: Horses on beaches



Schedule two: Marae community zones




Legend
Maungatapu Marae
- Tauranga City Council -
Approx. Scale: 1:1,323 (at A4)
N
W
E
S


Legend
Tahuwhakatiki Marae
- Tauranga City Council -
Approx. Scale: 1:2,876 (at A4)
N
W
E
S


100 meters
100 meters
Legend
Mean High Water Spring
Marae Community Zone
Cadastral boundary
Approx. Scale: 1:2,404 (at A4)
Waikari Marae
- Tauranga City Council -
N
W
E
S


100 meters
100 meters
Legend
Mean High Water Spring
Marae Community Zone
Cadastral boundary
Approx. Scale: 1:1,612 (at A4)
Whareroa Marae
- Tauranga City Council -
N
W
E
S

Tauranga City

Tauranga City Council

SPEED LIMIT BYLAW 2009

This bylaw is made pursuant to Section 684(1) (13) of the Local Government Act 1974, Section 145 of the Local Government Act 2002 and the Land Transport Rule: Setting of Speed Limits 2003 and their subsequent amendments.

1. Scope and Purpose

This bylaw allows Tauranga City Council to set speed limits by resolution, on all roads under its ownership and/or control, and in other designated locations as specified in the Bylaw.

The speed limits described in the schedules to this bylaw come into force on the date this bylaw is effective from, or on such other date specified in the schedules.

2. Interpretation

In this bylaw:

Council means the Tauranga City Council or any officer authorised to exercise the authority of the Council.

Road has the same meaning as in the Land Transport Act 1998, but does not include any State Highways in the city. It does include the beach as defined in Tauranga City Council's Beaches Bylaw 2007.

Speed Limit has the same meaning as in the Land Transport Rule: Setting of Speed Limits 2003.

Urban Traffic Area has the same meaning as in the Land Transport Rule: Setting of Speed Limits 2003.

Vehicle has the same meaning as in Section2 (1) of the Land Transport Act 1998.

3. Speed Limit of 20km/h

3.1 The roads or areas described in Schedule 1 or as shown on Map 1 are declared to have a speed limit of 20 km/h.

3.2 This speed limit on beaches shall not apply to any vehicle authorised by Council to drive on the beach when it is operating in its official capacity.

3.3 The Council may, by resolution, add to or delete from Schedule 1.

4. Speed Limit of 30km/h

4.1 The roads or areas described in Schedule 2 or as shown on Map 2 are declared to have a speed limit of 30 km/h.

4.2 The Council may, by resolution, add to or delete from Schedule 2.

5. Speed Limit of 40km/h

5.1 The roads or areas described in Schedule 3 or as shown on Map 3 are declared to have a speed limit of 20 km/h.

5.2 The Council may, by resolution, add to or delete from Schedule 3.

6. Speed Limit of 50km/h

6.1 The roads or areas described in Schedule 4 or as shown on Map 4 are declared to have a speed limit of 50 km/h and are within the urban traffic area.

6.2 The beaches described in Schedule 4 or as shown on Map 4 are declared to have a speed limit of 50 km/h.

6.3 This speed limit on beaches shall not apply to any vehicle authorised by Council to drive on the beach when it is operating in its official capacity.

6.4 The Council may, by resolution, add to or delete from Schedule 4.

7. Speed Limit of 60km/h

7.1 The roads or areas described in Schedule 5 or as shown on Map 5 are declared to have a speed limit of 60 km/h.

7.2 The Council may, by resolution, add to or delete from Schedule 5.

8. Speed Limit of 70km/h

8.1 The roads or areas described in Schedule 6 or as shown on Map 6 are declared to have a speed limit of 70 km/h.

8.2 The Council may, by resolution, add to or delete from Schedule 6.

9. Speed Limit of 80km/h

9.1 The roads or areas described in Schedule 7 or as shown on Map 7 are declared to have a speed limit of 80 km/h.

9.2 The Council may, by resolution, add to or delete from Schedule 7.

10. Speed Limit of 90km/h

10.1 The roads or areas described in Schedule 8 or as shown on Map 8 are declared to have a speed limit of 90 km/h.

10.2 The Council may, by resolution, add to or delete from Schedule 8.

11. Speed Limit of 100km/h

11.1 The roads or areas described in Schedule 9 or as shown on Map 9 are declared to have a speed limit of 100 km/h.

11.2 The Council may, by resolution, add to or delete from Schedule 9.

12. Holiday Speed Limit

12.1 The roads or areas described in Schedule 10 or as shown on map 10 are declared to have a variable speed limit.

12.2 The Council may, by resolution, add to or delete from Schedule 10.

13. Variable Speed Limit

13.1 The roads or areas described in Schedule 11 or as shown on map 11 are declared to have a variable speed limit.

13.2 The Council may, by resolution, add to or delete from Schedule 11.

14. Minimum Speed Limit

14.1 The roads or areas described in Schedule 12 or as shown on map 12 are declared to have a minimum speed limit.

14.2 The Council may, by resolution, add to or delete from Schedule 12.

15. Other Speed Limits

15.1 The Council may, by resolution, make or alter speed limits for roads in any of the following designated locations:

- A car park
- An educational or scientific facility
- A health facility
- A residential facility
- A camping ground
- A sports facility or other recreational area
- A botanical garden
- A port or wharf area
- An airport
- A beach
- A cemetery
- A facility owned by the New Zealand Defence Force
- Any other location approved by the Director of the New Zealand Transport Agency
- Any other location in which authority has been given e.g. supermarket

15.2 The speed limits declared on all roads or areas in Clauses 3 – 15 of this bylaw are shown on map 13.

16. Consultation

If the Council chooses to create, amend or alter any bylaw speed limit by way of resolution under clauses 3 - 15 of this bylaw, the consultation process in Section 7.1 of the Land Transport Rule: Setting of Speed Limits 2003 must be followed.

17. Offences and Breaches

Every person breaches this Bylaw and commits an offence who:

1. Does, or allows anything to be done, which is contrary to this Bylaw or any part of it or

2. Fails to do, or allows anything to remain undone, which ought to be done by him or her within the time and in the manner required by this Bylaw or any part of it or

3. Does anything which this Bylaw prohibits; or

4. Fails to comply with any notice given to him or her under this Bylaw or any part of it or any condition of a licence granted by the Council; or

5. Obstructs or hinders any Council officer or other Council appointed person in performing any duty or in exercising any power under this Bylaw.

18. Notices

The Council may give notice to any person in breach of this Bylaw to carry out any remedial action in order to comply with the Bylaw and every such notice shall state the time within which the remedial action is to be carried out, and may be extended from time to time.

19. Penalties

Subject to anything to the contrary, every person who commits an offence against this Bylaw shall be subject to the penalties set out in The Land Transport Act 1998, the Land Transport (Road User) Rule 2004 and the Land Transport (Offences and Penalties) Regulations 1999.

20. Dispensing Powers

The Council may waive full compliance with any provision of this Bylaw in a case where the Council is of the opinion that full compliance would needlessly cause harm, loss or inconvenience to any person or business without any corresponding benefit to the community. The Council may in its discretion impose conditions of any such waiver.

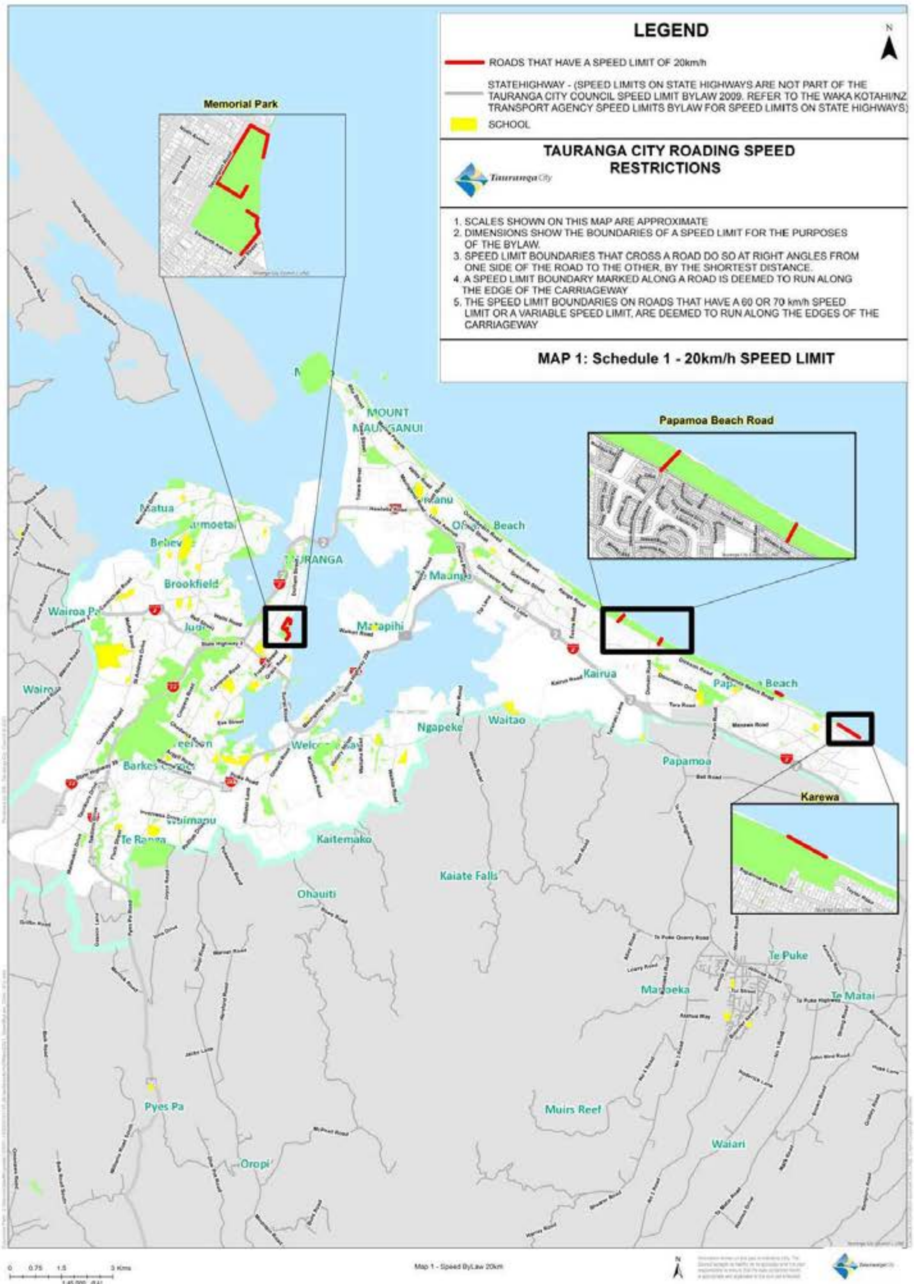
21. Commencement

This bylaw comes into force on 1 October 2009.

Schedule 1: Roads that have a Speed Limit of 20 km/h

The roads or areas described in this schedule, and as shown on Map 1, are declared to have a speed limit of 20km/h.

Description	Date Effective From	Legal Instrument	Previous Legal Instrument
At Fraser Street. North of the intersection with Eleventh Avenue, generally northward to the end.	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
At Seventh Avenue. East of its intersection with Devonport Road, generally eastward to the end.	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
The coastal beach from the vehicle access point between 105 and 107 Karewa Parade up to the end of the residential area.	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
The designated boat ramps and the beach 100 metres either side of the designated boat ramps at Taylors Reserve, Papamoa Domain and Harrisons Cut.	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a



LEGEND
N
ROADS THAT HAVE A SPEED LIMIT OF 20km/h
STATEHIGHWAY - (SPEED LIMITS ON STATE HIGHWAYS ARE NOT PART OF THE TAURANGA CITY COUNCIL SPEED LIMIT BYLAW 2009. REFER TO THE WAKA KOTAHI/NZ TRANSPORT AGENCY SPEED LIMITS BYLAW FOR SPEED LIMITS ON STATE HIGHWAYS)
SCHOOL
TAURANGA CITY ROADING SPEED RESTRICTIONS
Tauranga City
1. SCALES SHOWN ON THIS MAP ARE APPROXIMATE
2. DIMENSIONS SHOW THE BOUNDARIES OF A SPEED LIMIT FOR THE PURPOSES OF THE BYLAW.
3. SPEED LIMIT BOUNDARIES THAT CROSS A ROAD DO SO AT RIGHT ANGLES FROM ONE SIDE OF THE ROAD TO THE OTHER, BY THE SHORTEST DISTANCE.
4. A SPEED LIMIT BOUNDARY MARKED ALONG A ROAD IS DEEMED TO RUN ALONG THE EDGE OF THE CARRIAGEWAY
5. THE SPEED LIMIT BOUNDARIES ON ROADS THAT HAVE A 60 OR 70 km/h SPEED LIMIT OR A VARIABLE SPEED LIMIT, ARE DEEMED TO RUN ALONG THE EDGES OF THE CARRIAGEWAY
MAP 1: Schedule 1 - 20km/h SPEED LIMIT
Memorial Park
Papamoa Beach Road
Karewa
MOUNT
Brookfield
Matapihi
Kairua
Ngapeke
Waitao
Papamoa
Kaitemako
Kaiate Falls
Ohauiti
Te Puke
Te Matai
Te Ranga
Pyes Pa
Oropi
Muirs Reef
Waiari
Map 1 - Speed ByLaw 20km

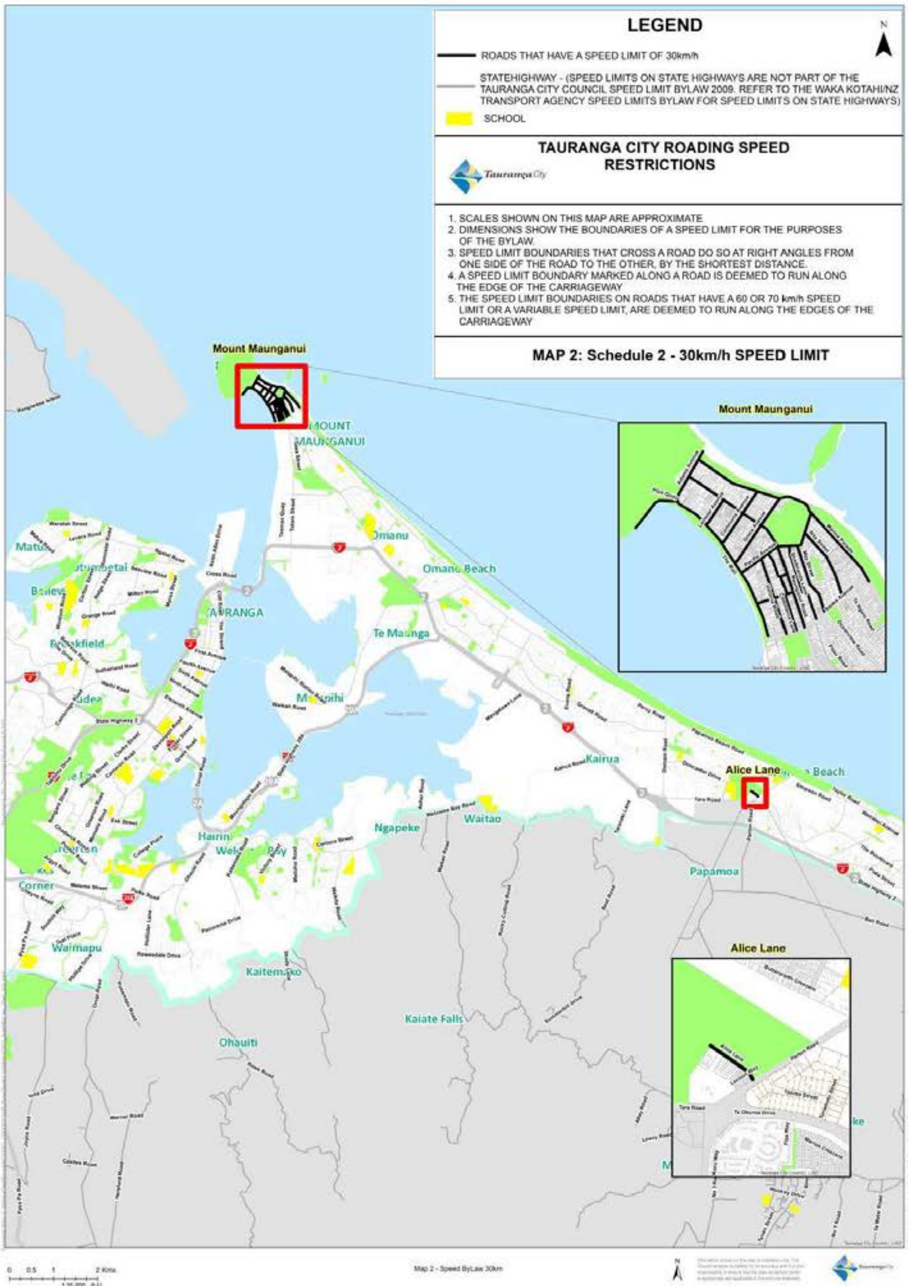
Schedule 2: Roads that have a Speed Limit of 30 km/h

Council resolution dated 21 September 2010 and Minute Number M10/72.13
Council resolution dated 20 June 2011 and Minute Number M11/41.8

The roads or areas described in this schedule, and as shown on Map 2, are declared to have a speed limit of 30km/h.

Description	Date Effective From	Legal Instrument	Previous Legal Instrument
Adams Avenue - Between its intersection with the northern side of Maunganui Road and its intersection with Marine Parade	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
Adams Avenue – from its intersection with The Mall to its intersection with Maunganui Road	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Alice Lane – from its intersection with Parton Road, north-westward for its entire length	11/10/2010	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Commons Avenue – for its entire length.	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Grace Avenue – for its entire length.	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Leinster Avenue – for its entire length.	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
May Street – for its entire length.	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Marine Parade - Between its intersection with Adams Avenue and its intersection with the northern side of Banks Avenue.	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
Maunganui Road – from its intersection with Salisbury Avenue / Banks Avenue to its intersection with Adams Avenue.	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009

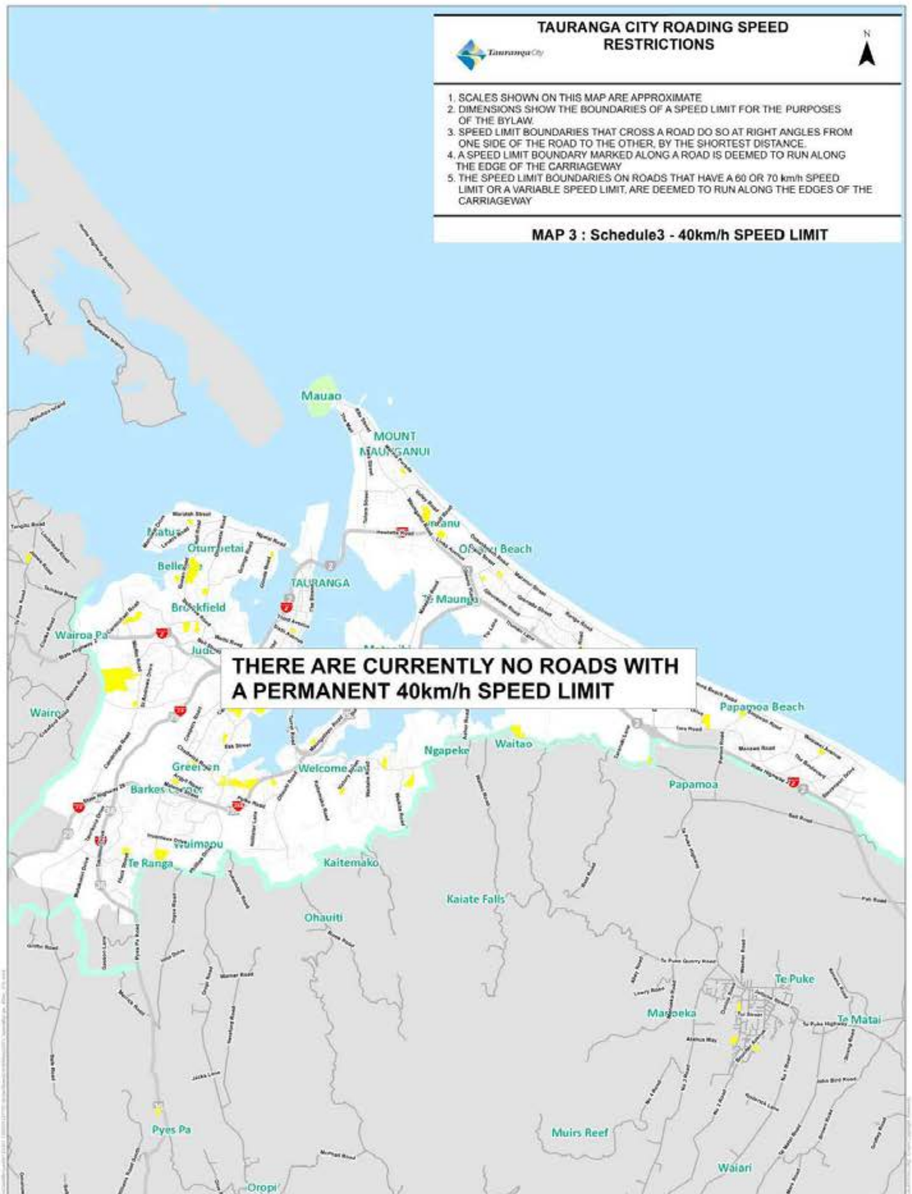
Description	Date Effective From	Legal Instrument	Previous Legal Instrument
Pacific Avenue – for its entire length.	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Pilot Quay – for its entire length.	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Prince Avenue –for its entire length.	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Rita Street – for its entire length.	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
The Mall – for its entire length.	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Victoria Road – for its entire length.	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009


LEGEND
ROADS THAT HAVE A SPEED LIMIT OF 30km/h
STATEHIGHWAY - (SPEED LIMITS ON STATE HIGHWAYS ARE NOT PART OF THE TAURANGA CITY COUNCIL SPEED LIMIT BYLAW 2009. REFER TO THE WAKA KOTAHI/NZ TRANSPORT AGENCY SPEED LIMITS BYLAW FOR SPEED LIMITS ON STATE HIGHWAYS)
SCHOOL
TAURANGA CITY ROADING SPEED RESTRICTIONS
1. SCALES SHOWN ON THIS MAP ARE APPROXIMATE
2. DIMENSIONS SHOW THE BOUNDARIES OF A SPEED LIMIT FOR THE PURPOSES OF THE BYLAW.
3. SPEED LIMIT BOUNDARIES THAT CROSS A ROAD DO SO AT RIGHT ANGLES FROM ONE SIDE OF THE ROAD TO THE OTHER, BY THE SHORTEST DISTANCE.
4. A SPEED LIMIT BOUNDARY MARKED ALONG A ROAD IS DEEMED TO RUN ALONG THE EDGE OF THE CARRIAGEWAY
5. THE SPEED LIMIT BOUNDARIES ON ROADS THAT HAVE A 60 OR 70 km/h SPEED LIMIT OR A VARIABLE SPEED LIMIT, ARE DEEMED TO RUN ALONG THE EDGES OF THE CARRIAGEWAY
MAP 2: Schedule 2 - 30km/h SPEED LIMIT
Mount Maunganui
MOUNT MAUNGANUI
Omanu
Omanu Beach
TAURANGA
Te Maunga
Matapihi
Kairua
Alice Lane
Waitao
Ngapeke
Papamoa
Welcome Bay
Kaitemako
Kaiate Falls
Ohauiti
Welcome Bay
Map 2 - Speed ByLaw 30km

Schedule 3: Roads that have a Speed Limit of 40 km/h

The roads or areas described in this schedule, and as shown on Map 3, are declared to have a speed limit of 40km/h.

Description	Date Effective From	Legal Instrument	Previous Legal Instrument


TAURANGA CITY ROADING SPEED RESTRICTIONS
1. SCALES SHOWN ON THIS MAP ARE APPROXIMATE
2. DIMENSIONS SHOW THE BOUNDARIES OF A SPEED LIMIT FOR THE PURPOSES OF THE BYLAW.
3. SPEED LIMIT BOUNDARIES THAT CROSS A ROAD DO SO AT RIGHT ANGLES FROM ONE SIDE OF THE ROAD TO THE OTHER, BY THE SHORTEST DISTANCE.
4. A SPEED LIMIT BOUNDARY MARKED ALONG A ROAD IS DEEMED TO RUN ALONG THE EDGE OF THE CARRIAGEWAY
5. THE SPEED LIMIT BOUNDARIES ON ROADS THAT HAVE A 60 OR 70 km/h SPEED LIMIT OR A VARIABLE SPEED LIMIT, ARE DEEMED TO RUN ALONG THE EDGES OF THE CARRIAGEWAY
MAP 3 : Schedule3 - 40km/h SPEED LIMIT
THERE ARE CURRENTLY NO ROADS WITH A PERMANENT 40km/h SPEED LIMIT
Mauao
MOUNT MAUNGANUI
TAURANGA
Papamoa Beach
Papamoa
Ngapeke
Waitao
Kaitemako
Ohauiti
Kaiate Falls
Te Puke
Te Matai
Muirs Reef
Waiari
Pyes Pa
Oropi
Te Ranga
Brookfield
Wairoa Pa
Map 3 - Speed ByLaw 40km

Schedule 4: Urban Traffic Areas - Roads that have a Speed Limit of 50 km/h

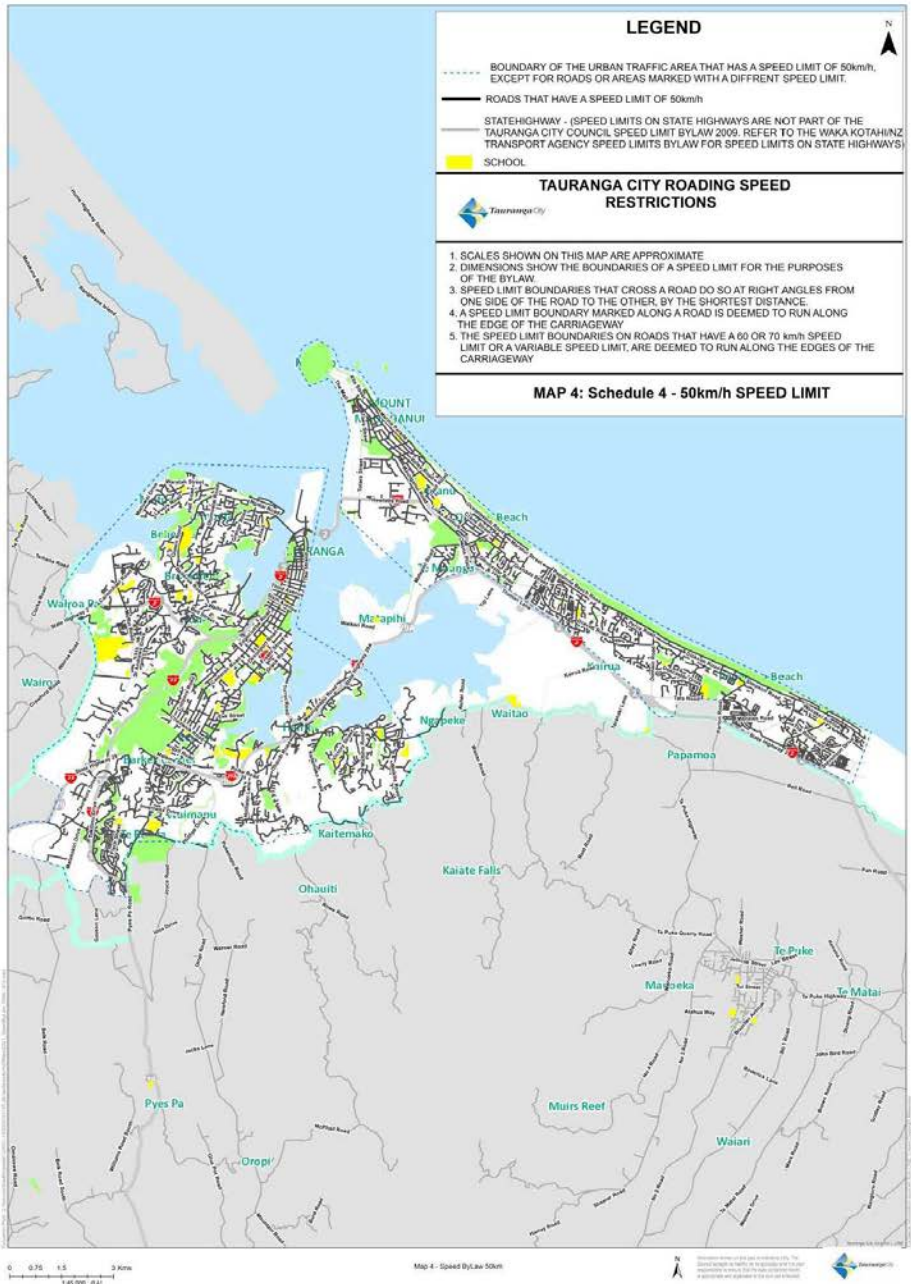
Council resolution dated 17 April 2018 and Minute Number M18/30.6
Council resolution CO5/21/5 dated 12 April 2021

The roads or areas described in this schedule, and as shown on Map 4, are declared to be urban traffic area and to have a speed limit of 50km/h except for those roads or areas that are:

(a) described as having a different speed limit in the appropriate schedule of this bylaw; or

(b) shown on a map as having a different speed limit, as referenced in the appropriate schedule of this bylaw.

Description	Date Effective From	Legal Instrument	Previous Legal Instrument
All the roads within the area marked on Map 4	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
The coastal beach from the end of the residential area to the Kaituna River.	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a


LEGEND
N
BOUNDARY OF THE URBAN TRAFFIC AREA THAT HAS A SPEED LIMIT OF 50km/h, EXCEPT FOR ROADS OR AREAS MARKED WITH A DIFFRENT SPEED LIMIT.
ROADS THAT HAVE A SPEED LIMIT OF 50km/h
STATEHIGHWAY - (SPEED LIMITS ON STATE HIGHWAYS ARE NOT PART OF THE TAURANGA CITY COUNCIL SPEED LIMIT BYLAW 2009. REFER TO THE WAKA KOTAHI/NZ TRANSPORT AGENCY SPEED LIMITS BYLAW FOR SPEED LIMITS ON STATE HIGHWAYS)
SCHOOL
TAURANGA CITY ROADING SPEED RESTRICTIONS
1. SCALES SHOWN ON THIS MAP ARE APPROXIMATE
2. DIMENSIONS SHOW THE BOUNDARIES OF A SPEED LIMIT FOR THE PURPOSES OF THE BYLAW.
3. SPEED LIMIT BOUNDARIES THAT CROSS A ROAD DO SO AT RIGHT ANGLES FROM ONE SIDE OF THE ROAD TO THE OTHER, BY THE SHORTEST DISTANCE.
4. A SPEED LIMIT BOUNDARY MARKED ALONG A ROAD IS DEEMED TO RUN ALONG THE EDGE OF THE CARRIAGEWAY
5. THE SPEED LIMIT BOUNDARIES ON ROADS THAT HAVE A 60 OR 70 km/h SPEED LIMIT OR A VARIABLE SPEED LIMIT, ARE DEEMED TO RUN ALONG THE EDGES OF THE CARRIAGEWAY
MAP 4: Schedule 4 - 50km/h SPEED LIMIT
Matapihi
Waitao
Papamoa
Kaitemako
Kaiate Falls
Ohauiti
Te Puke
Te Matai
Pyes Pa
Muirs Reef
Waiari
Oropi
Map 4 - Speed ByLaw 50km

Schedule 5: Roads that have a Speed Limit of 60 km/h

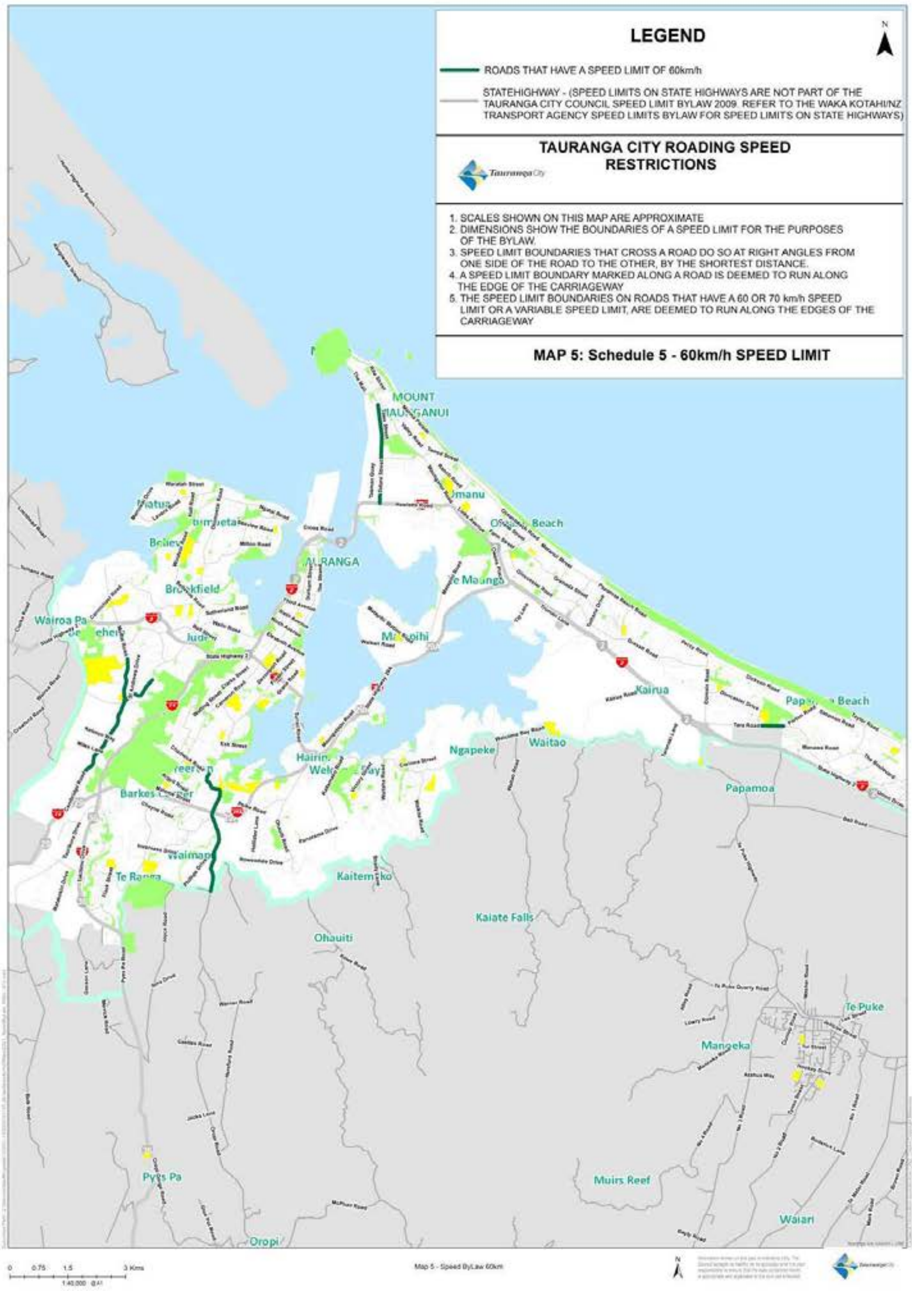
Council resolution dated 21 September 2010 and Minute Number M10/72.13
Council resolution dated 20 June 2011 and Minute Number M11/41.8
Council resolution dated 18 March 2013 and Minute Number M13/12.11
Council resolution dated 17 December 2013 and Minute Number M13/75.5
Council resolution dated 17 April 2018 and Minute Number M18/30.6
Council resolution dated 5 March 2019 and Minute Number M19/11.10
Council resolution CO5/21/5 dated 12 April 2021

The roads or areas described in this schedule, and as shown on Map 5, are declared to have a speed limit of 60km/h.

Description	Date Effective From	Legal Instrument	Previous Legal Instrument
Cambridge Road – from a point approximately 120 metres south of its intersection with Moffat Road, northwards then north-eastwards for a distance of approximately 960 metres	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Cambridge Road – from a point approximately 120 metres south of its intersection with Moffat Road, southwards to its intersection with State Highway 29.	27/01/2014	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Hairini off-ramp – from a point approximately 105 metres northwest from the centre of the Maungatapu roundabout, north-westwards to the intersection with Welcome Bay Link Road.	30/03/2019	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Hairini on-ramp – from a point approximately 105 metres northwest from the centre of the Maungatapu roundabout, north-westwards to the intersection with Welcome Bay Link Road.	30/03/2019	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Hairini Street – from a point approximately 30 metres north of the intersection with Tamahika Street northwards to its intersection with the Hairini on-ramp.	30/03/2019	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Hungahungatoroa Road – for its entire length.	30/05/2018	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Hoskins Road – for its entire length.	30/05/2018	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009

Description	Date Effective From	Legal Instrument	Previous Legal Instrument
Matapihi Road – from a point approximately 140 metres south of the south side of Bayfair Drive, for its entire length.	30/05/2018	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Matapihi Station Road – for its entire length.	30/05/2018	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Moffat Road – from its intersection with Cambridge Road northwards to a point approximately 75 metres south of the southern side of Beaumaris Boulevard.	22/01/2010	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Oropi Road – from a point approximately 100 metres south of the southern side of Maleme Street, generally in a northern direction to a point approximately 160 metres south of the southern side of Chadwick Road.	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Oropi Road – from its intersection with the south side of State Highway 29, southwards to its intersection with Wood Road.	12/04/2021	Tauranga City Council Speed Limit Bylaw 2009	NA
Puwhariki Road – for its entire length.	30/05/2018	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Pyes Pa Road - From its intersection with State Highway 29 to a point approximately 200 metres north of Joyce Road.	12/04/2021	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Tara Road - From its intersection with Doncaster Drive to its intersection with Parton Road. Includes the roundabout intersection at Doncaster Drive.	12/04/2021	Tauranga City Council Speed Limit Bylaw 2009	NA
Totara Street – from its intersection with Hewlett's Road to its intersection with Rata Street	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Turret Road – from a point approximately 10 metres north of the northern abutment of the Hairini Bridge, southwards to its intersection with Welcome Bay Link Road.	30/03/2019	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009

Description	Date Effective From	Legal Instrument	Previous Legal Instrument
Waikari Road – for its entire length.	30/05/2018	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Welcome Bay Road – From a point approximately 100 metres west of the western side of Arawata Avenue, eastwards for a distance of approximately 700 metres	12/04/2021	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Welcome Bay Link Road – its entire length, between Welcome Bay Road and Turret Road.	30/03/2019	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Welcome Bay Road – from a point approximately 60 metres west of the western side of Waitaha Road, generally in a westerly direction to its intersection with Welcome Bay Link Road/Hammond Street.	12/04/2021	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009

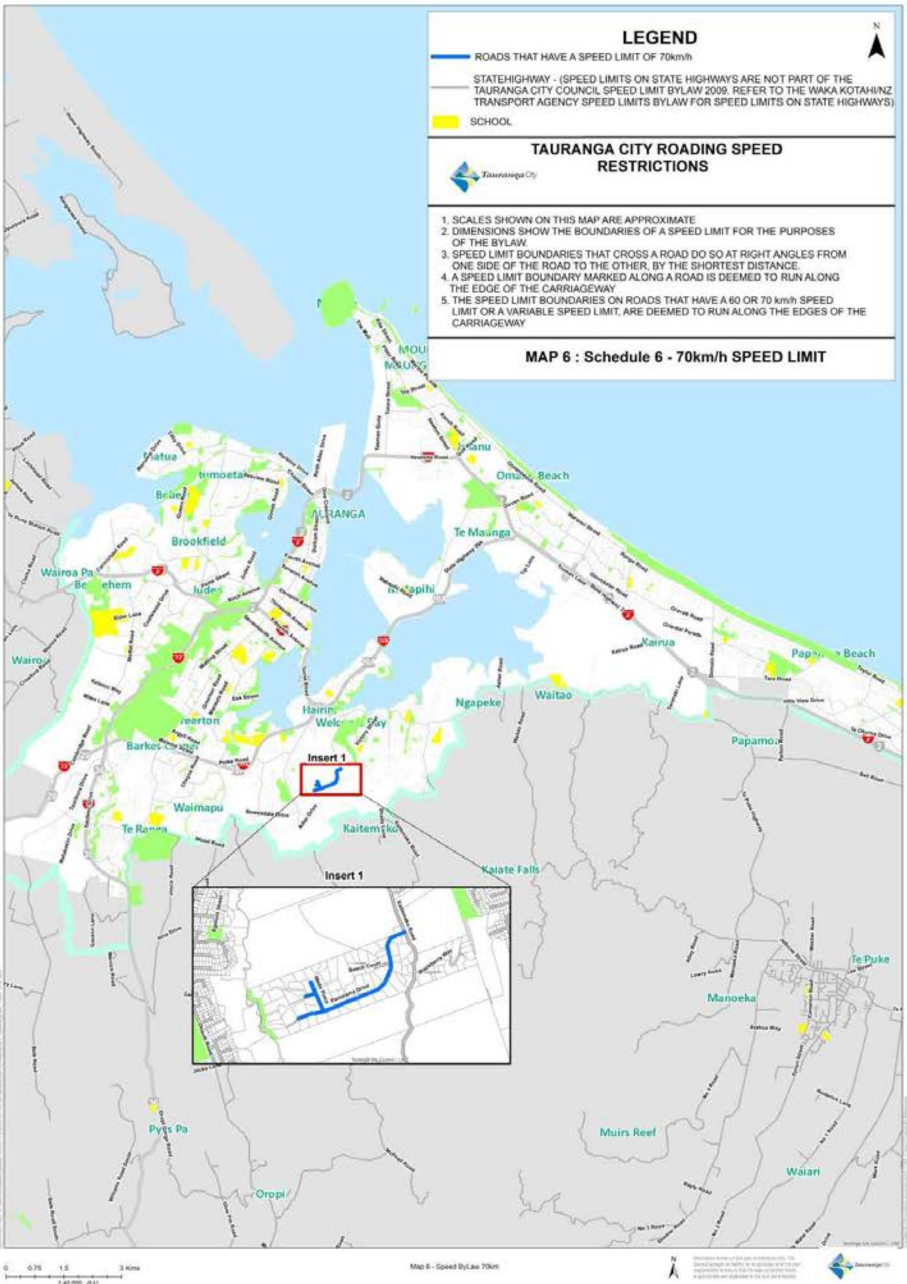

LEGEND
ROADS THAT HAVE A SPEED LIMIT OF 60km/h
STATEHIGHWAY - (SPEED LIMITS ON STATE HIGHWAYS ARE NOT PART OF THE TAURANGA CITY COUNCIL SPEED LIMIT BYLAW 2009. REFER TO THE WAKA KOTAHI/NZ TRANSPORT AGENCY SPEED LIMITS BYLAW FOR SPEED LIMITS ON STATE HIGHWAYS)
TAURANGA CITY ROADING SPEED RESTRICTIONS
1. SCALES SHOWN ON THIS MAP ARE APPROXIMATE
2. DIMENSIONS SHOW THE BOUNDARIES OF A SPEED LIMIT FOR THE PURPOSES OF THE BYLAW.
3. SPEED LIMIT BOUNDARIES THAT CROSS A ROAD DO SO AT RIGHT ANGLES FROM ONE SIDE OF THE ROAD TO THE OTHER, BY THE SHORTEST DISTANCE.
4. A SPEED LIMIT BOUNDARY MARKED ALONG A ROAD IS DEEMED TO RUN ALONG THE EDGE OF THE CARRIAGEWAY
5. THE SPEED LIMIT BOUNDARIES ON ROADS THAT HAVE A 60 OR 70 km/h SPEED LIMIT OR A VARIABLE SPEED LIMIT, ARE DEEMED TO RUN ALONG THE EDGES OF THE CARRIAGEWAY
MAP 5: Schedule 5 - 60km/h SPEED LIMIT
MOUNT MAUNGANUI
Omanu
Otumoetai
Brookfield
Bethlehem
Wairoa Pa
Te Maunga
Kairua
Papamoa
Ngapeke
Waitao
Kaitemako
Te Ranga
Barkes Corner
Ohauiti
Kaiate Falls
Te Puke
Mangeka
Pyes Pa
Muirs Reef
Waiari
Oropi
Map 5 - Speed ByLaw 60km

Schedule 6: Roads that have a Speed Limit of 70 km/h

Council resolution dated 20 June 2011 and Minute Number M11/41.8
Council resolution dated 18 March 2013 and Minute Number M13/12.11
Council resolution dated 17 April 2018 and Minute Number M18/30.6
Council resolution CO5/21/5 dated 12 April 2021

The roads or areas described in this schedule, and as shown on Map 6, are declared to have a speed limit of 70km/h

Description	Date Effective From	Legal Instrument	Previous Legal Instrument
Beech Court – For its entire length	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
Hoskins Road – For its entire length	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
Kaitemako Road – From a point approximately 300 metres south of the southern side of Panoroma Drive northwards to a point approximately 240 metres south of the southern side of Te Arawa Place	12/04/2021	Tauranga City Council Speed Limit Bylaw 2009	n/a
Ohauiti Road – from a point approximately 20 metres south of the southern kerbline of Kaimai View Drive, southwards to a point approximately 105 metres south of the southern kerbline of Adler Drive.	12/04/2021	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Panorama Drive – From its intersection with Kaitemako Road for its entire length	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
Puwhariki Road – For its entire length	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
Waikari Road – For its entire length	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
Wade Place - For its entire length	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a


LEGEND
ROADS THAT HAVE A SPEED LIMIT OF 70km/h
STATEHIGHWAY - (SPEED LIMITS ON STATE HIGHWAYS ARE NOT PART OF THE TAURANGA CITY COUNCIL SPEED LIMIT BYLAW 2009. REFER TO THE WAKA KOTAHI/NZ TRANSPORT AGENCY SPEED LIMITS BYLAW FOR SPEED LIMITS ON STATE HIGHWAYS)
SCHOOL
TAURANGA CITY ROADING SPEED RESTRICTIONS
1. SCALES SHOWN ON THIS MAP ARE APPROXIMATE
2. DIMENSIONS SHOW THE BOUNDARIES OF A SPEED LIMIT FOR THE PURPOSES OF THE BYLAW.
3. SPEED LIMIT BOUNDARIES THAT CROSS A ROAD DO SO AT RIGHT ANGLES FROM ONE SIDE OF THE ROAD TO THE OTHER, BY THE SHORTEST DISTANCE.
4. A SPEED LIMIT BOUNDARY MARKED ALONG A ROAD IS DEEMED TO RUN ALONG THE EDGE OF THE CARRIAGEWAY
5. THE SPEED LIMIT BOUNDARIES ON ROADS THAT HAVE A 60 OR 70 km/h SPEED LIMIT OR A VARIABLE SPEED LIMIT, ARE DEEMED TO RUN ALONG THE EDGES OF THE CARRIAGEWAY
MAP 6 : Schedule 6 - 70km/h SPEED LIMIT
Brookfield
Te Maunga
Omanu Beach
Papamoa
Waitao
Ngapeke
Kairua
Waimapu
Te Puke
Manoeka
Muirs Reef
Oropi
Waiari
Insert 1
Map 6 - Speed ByLaw 70km

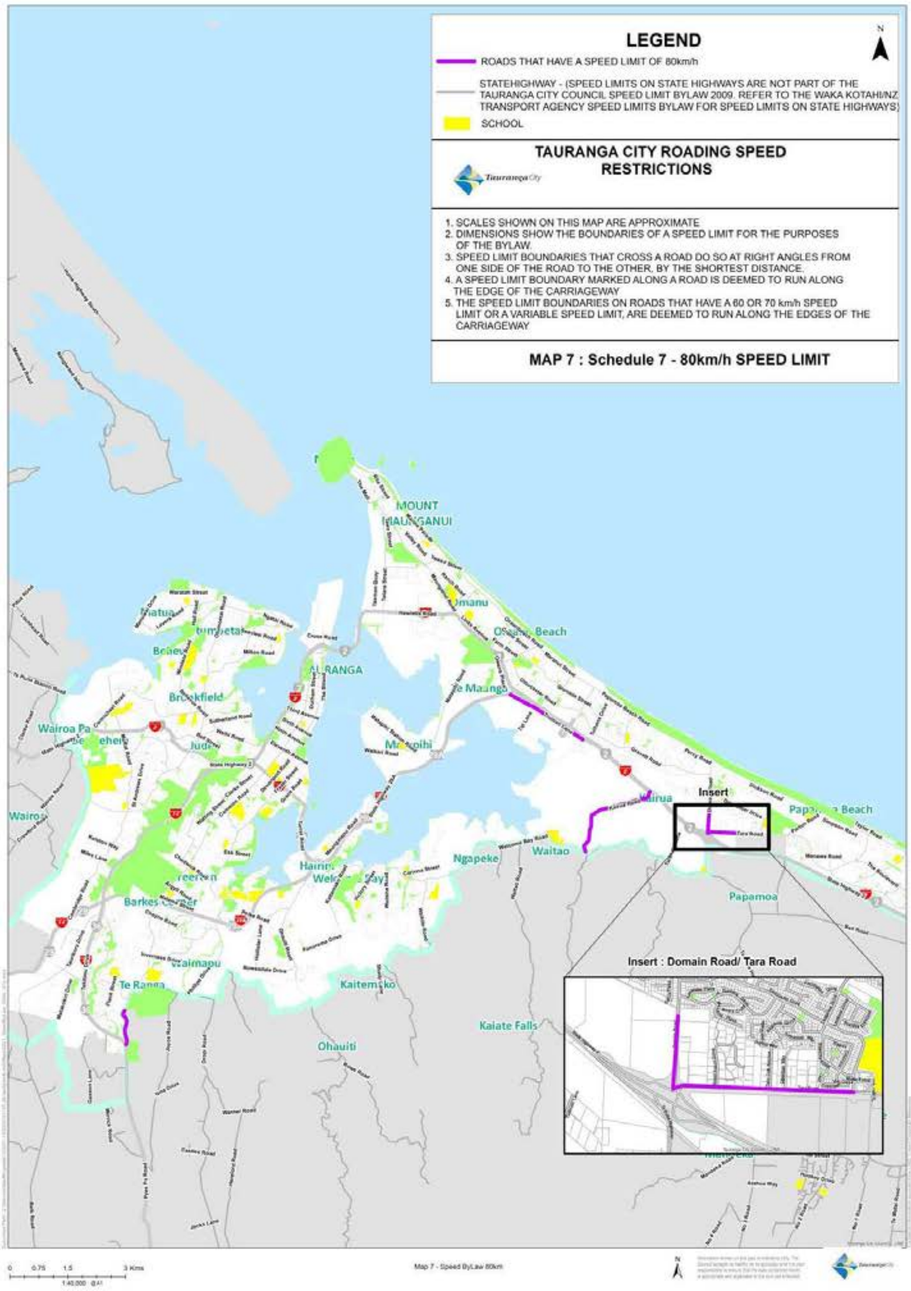
Schedule 7: Roads that have a Speed Limit of 80 km/h

Council resolution dated 22 January 2009 and Minute Number M09/105.7
Council resolution dated 21 September 2010 and Minute Number M10/72.13
Council resolution dated 20 June 2011 and Minute Number M11/41.8
Council resolution dated 18 March 2013 and Minute Number M13/12.11
Council resolution dated 17 December 2013 and Minute Number M13/75.5
Council resolution dated 17 April 2018 and Minute Number M18/30.6
Council resolution CO5/21/5 dated 12 April 2021

The roads or areas described in this schedule, and as shown on Map 7, are declared to have a speed limit of 80km/h

Description	Date Effective From	Legal Instrument	Previous Legal Instrument
Domain Road from a point approximately 968 metres south of the southern side of Gravatt Road, southwards to its intersection with State Highway 2, a distance of approximately 750 metres	11/10/2010	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Kairua Road – from a point approximately 70 metres south-west of the south-west side of State Highway 2, generally in a western and southern direction to a point approximately 30 metres north of the north side of Welcome Bay Road	11/10/2010	Tauranga City Council Speed Limit Bylaw 2009	Tauranga City Council Speed Limit Bylaw 2009
Kaitemako Road – from a point approximately 300 meters south of the southern side of Panaroma Drive, southwards to its boundary with Western Bay of Plenty District.	After 12/04/2021, once limit signs are amended.	Tauranga City Council Speed Limit Bylaw 2009	NA
Ohauiti Road – From a point approximately 105 metres south of the south side of Adler Drive, southwards to boundary with Western Bay of Plenty District	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
Pyes Pa Road – From a point approximately 200 metres north of Joyce Road, southwards to its intersection with State Highway 36 (Takitimu Drive)	29/04/2013	Tauranga City Council Speed Limit Bylaw 2009	n/a

Description	Date Effective From	Legal Instrument	Previous Legal Instrument
Tara Road - From its intersection with Domain Road to its intersection with Doncaster Drive.	12/04/2021	Tauranga City Council Speed Limit Bylaw 2009	n/a
Truman Road - Full length.	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a


LEGEND
ROADS THAT HAVE A SPEED LIMIT OF 80km/h
STATEHIGHWAY - (SPEED LIMITS ON STATE HIGHWAYS ARE NOT PART OF THE TAURANGA CITY COUNCIL SPEED LIMIT BYLAW 2009. REFER TO THE WAKA KOTAHI/NZ TRANSPORT AGENCY SPEED LIMITS BYLAW FOR SPEED LIMITS ON STATE HIGHWAYS)
SCHOOL
TAURANGA CITY ROADING SPEED RESTRICTIONS
1. SCALES SHOWN ON THIS MAP ARE APPROXIMATE
2. DIMENSIONS SHOW THE BOUNDARIES OF A SPEED LIMIT FOR THE PURPOSES OF THE BYLAW.
3. SPEED LIMIT BOUNDARIES THAT CROSS A ROAD DO SO AT RIGHT ANGLES FROM ONE SIDE OF THE ROAD TO THE OTHER, BY THE SHORTEST DISTANCE.
4. A SPEED LIMIT BOUNDARY MARKED ALONG A ROAD IS DEEMED TO RUN ALONG THE EDGE OF THE CARRIAGEWAY
5. THE SPEED LIMIT BOUNDARIES ON ROADS THAT HAVE A 60 OR 70 km/h SPEED LIMIT OR A VARIABLE SPEED LIMIT, ARE DEEMED TO RUN ALONG THE EDGES OF THE CARRIAGEWAY
MAP 7 : Schedule 7 - 80km/h SPEED LIMIT
MOUNT MAUNGANUI
Omanu
Te Maunga
Matapihi
Wairoa Pa
Brookfield
Papamoa
Insert
Insert : Domain Road/ Tara Road
Ngapeke
Waitao
Te Ranga
Kaitemako
Kaiate Falls
Ohauiti
Map 7 - Speed ByLaw 80km

Schedule 8: Roads that have a Speed Limit of 90 km/h

Council resolution dated 22 January 2009 and Minute Number M09/105.7

The roads or areas described in this schedule, and as shown on Map 8, are declared to have a speed limit of 90km/h

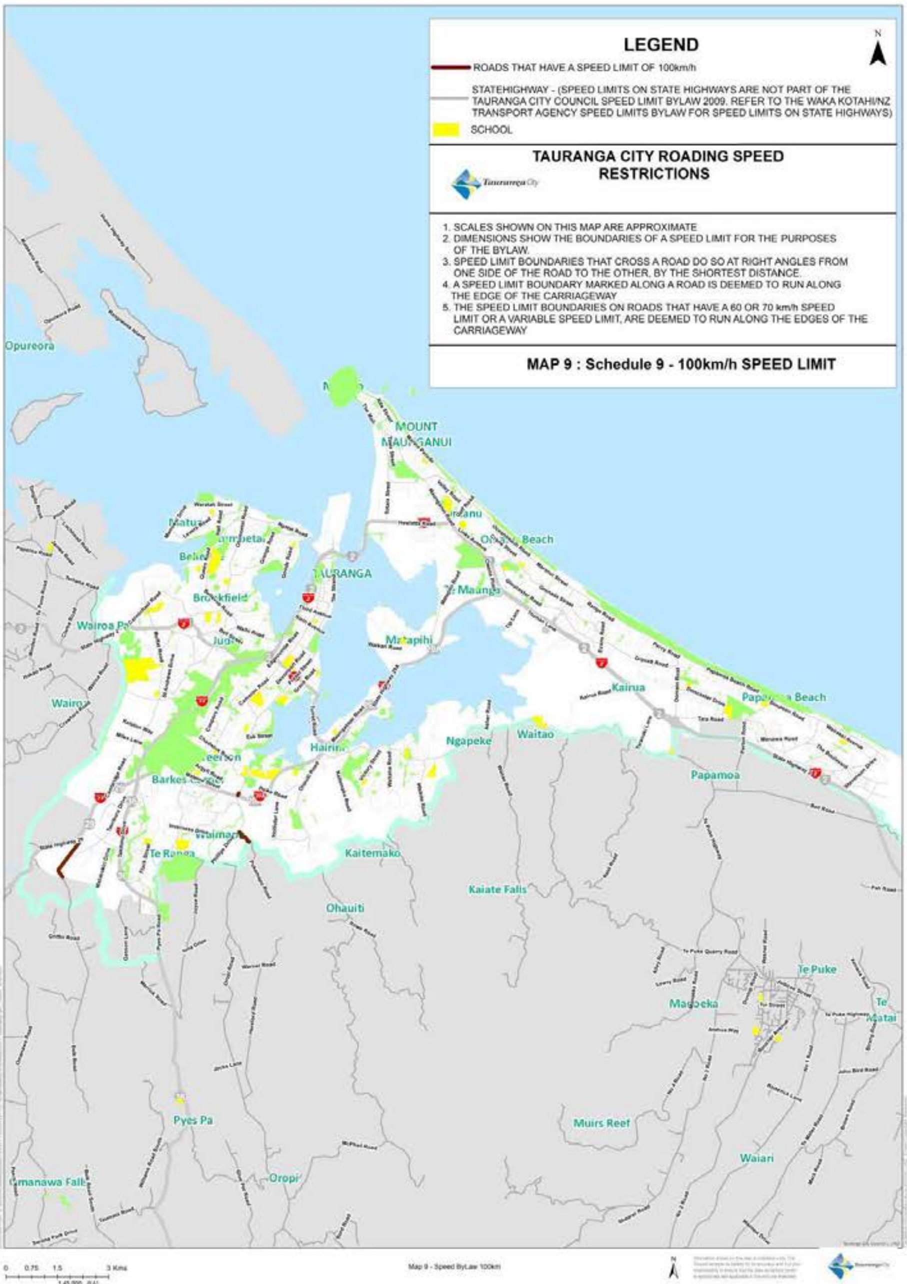
Description	Date Effective From	Legal Instrument	Previous Legal Instrument

Schedule 9: Roads that have a Speed Limit of 100 km/h

Council resolution dated 20 June 2011 and Minute Number M11/41.8
Council resolution dated 18 March 2013 and Minute Number M13/12.11
Council resolution CO5/21/5 dated 12 April 2021

The roads or areas described in this schedule, and as shown on Map 9, are declared to have a speed limit of 100km/h

Description	Date Effective From	Legal Instrument	Previous Legal Instrument
Gargan Road - For its entire length	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
Kennedy Road – For its entire length	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
Oropi Road – from its intersection with State Highway 29, northwards for a distance of approximately 150 metres	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
Parton Road – From a point approximately 200 metres south of the southern boundary of Tara Road, southwards to its boundary with Western Bay of Plenty District.	29/04/2013	Tauranga City Council Speed Limit Bylaw 2009	n/a
Pukemapu Road – From its intersection with Oropi Road, south-eastwards to its boundary with Western Bay of Plenty District	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
Takitimu Drive (Route K) – From a point approximately 500 metres north of the intersection of State Highway 29, northwards to its intersection with State Highway 2	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
Waioroi Place – For its entire length	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a
Wintrebre Lane – For its entire length	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a


LEGEND
ROADS THAT HAVE A SPEED LIMIT OF 100km/h
STATEHIGHWAY - (SPEED LIMITS ON STATE HIGHWAYS ARE NOT PART OF THE TAURANGA CITY COUNCIL SPEED LIMIT BYLAW 2009. REFER TO THE WAKA KOTAHI/NZ TRANSPORT AGENCY SPEED LIMITS BYLAW FOR SPEED LIMITS ON STATE HIGHWAYS)
SCHOOL
TAURANGA CITY ROADING SPEED RESTRICTIONS
1. SCALES SHOWN ON THIS MAP ARE APPROXIMATE
2. DIMENSIONS SHOW THE BOUNDARIES OF A SPEED LIMIT FOR THE PURPOSES OF THE BYLAW.
3. SPEED LIMIT BOUNDARIES THAT CROSS A ROAD DO SO AT RIGHT ANGLES FROM ONE SIDE OF THE ROAD TO THE OTHER, BY THE SHORTEST DISTANCE.
4. A SPEED LIMIT BOUNDARY MARKED ALONG A ROAD IS DEEMED TO RUN ALONG THE EDGE OF THE CARRIAGEWAY
5. THE SPEED LIMIT BOUNDARIES ON ROADS THAT HAVE A 60 OR 70 km/h SPEED LIMIT OR A VARIABLE SPEED LIMIT, ARE DEEMED TO RUN ALONG THE EDGES OF THE CARRIAGEWAY
MAP 9 : Schedule 9 - 100km/h SPEED LIMIT
Opureora
MOUNT
Kairua
Ngapeke
Waitao
Papamoa
Kaitemako
Kaiate Falls
Ohauiti
Te Puke
Pyes Pa
Muirs Reef
Waiari
Map 9 - Speed ByLaw 100km

Schedule 10: Roads that have a Holiday Speed Limit

The roads or areas described in this schedule, and as shown on Map 10, are declared to have a holiday speed limit

Description	Date Effective From	Legal Instrument	Previous Legal Instrument

Schedule 11: Roads that have a Variable Speed Limit

Council resolution dated 21 September 2010 and Minute Number M10/72.13
Council resolution dated 20 June 2011 and Minute Number M11/41.8
Council resolution CO5/21/5 dated 12 April 2021

The roads or areas described in this schedule, and as shown on Map 11, are declared to have a variable speed limit

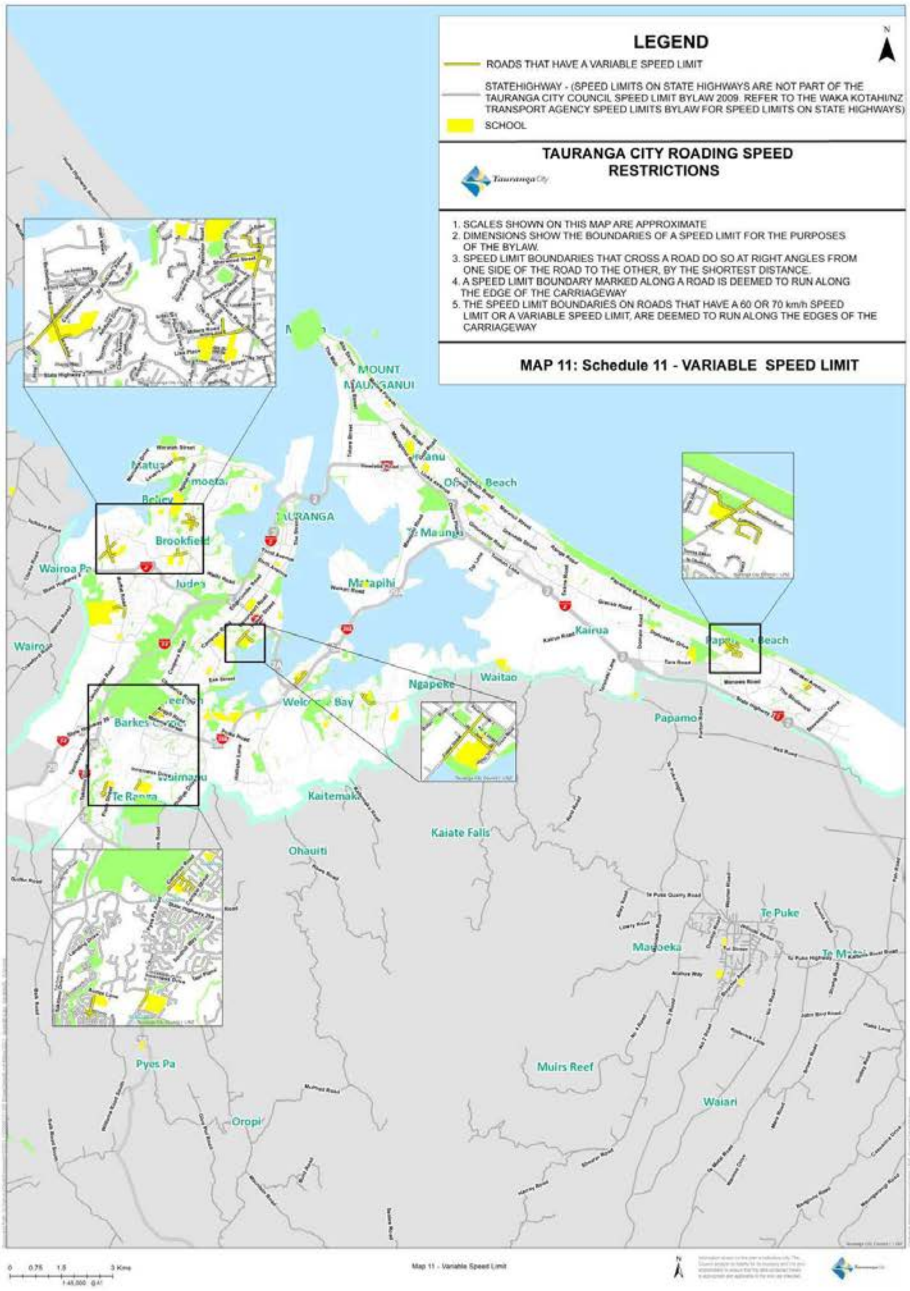
Description	Date Effective From	Legal Instrument	Previous Legal Instrument
40km/h Variable Speed School Zones: Effective on days when the school is operating: • from 35 minutes before school starts until the time school starts, and • from the time school finishes until 20 minutes after school finishes; and • for 10 minutes at any other time when at least 50 children are crossing the road. At all other times the speed limit in these school zones is the permanent speed limit for the road as declared in this bylaw.	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009 NZ Gazette 2 June 2005, No 86, pg 2051	n/a
Aquinas College • Pyes pa Road, from a point 200m north of Joyce Road to 35m north of Freeburn Road.	**After 12/04/21 when signs are posted to indicate a variable limit.**	Tauranga City Council Speed Limit Bylaw 2009	n/a
Bethlehem College • Moffat Road – from a point approximately 250 metres south of the southern side of Elder Lane then northwards for a distance of approximately 450 metres. • Elder Lane – for its entire length.	25/10/2011	Tauranga City Council Speed Limit Bylaw 2009	n/a

Description	Date Effective From	Legal Instrument	Previous Legal Instrument
Bethlehem Primary School • Bethlehem Road – From a point approximately 150 metres north of the north-western side of Carmichael Road, southwards for a distance of approximately 470 metres • Carmichael Road – From a point approximately 160 metres north-east of the east side of Bethlehem Road, south-westwards for a distance of approximately 520 metres • Westmoreland Rise – From its intersection with the eastern side of Bethlehem Road eastwards for a distance of approximately 35 metres	11/10/2010	Tauranga City Council Speed Limit Bylaw 2009 NZ Gazette 2 June 2005, No 86, pg 2051	n/a
Brookfield Primary School • Millers Road – From a point approximately 33 metres west of the south-western side of Bellevue Road, westwards for a distance of approximately 380 metres • Warwick Place – From its intersection with the northern side of Millers Road, northwards for a distance of approximately 40 metres	1/08/2011	Tauranga City Council Speed Limit Bylaw 2009	n/a
Golden Sands School • Golden Sands Drive from 200m east of Kapuka Street to 20m south of Wairakei Avenue	**After 12/04/21 when signs are posted to indicate a variable limit.**	Tauranga City Council Speed Limit Bylaw 2009	n/a

Description	Date Effective From	Legal Instrument	Previous Legal Instrument
Greenpark Primary School • Cameron Road – From a point approximately 50 metres north-east of the north-east side of Maleme Street, north-eastwards for a distance of approximately 370 metres • Argyll Road – From its intersection with Cameron Road, south-eastwards for a distance of approximately 300 metres • Lumsden Street – For its entire length • Sinclair Street – For its entire length • Seaforth Grove – For its entire length	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009 NZ Gazette 2 June 2005, No 86, pg 2051	n/a
Matua School • Levers Road from a point 25m south-west of Sylvania Drive to 30m east of Woods Avenue	**After 12/04/21 when signs are posted to indicate a variable limit.**	Tauranga City Council Speed Limit Bylaw 2009	n/a
Maungatapu Primary School • Maungatapu Road – From a point approximately 40 metres north-east of its intersection with State Highway 29, north-eastwards for a distance of approximately 550 metres • Ririnui Place – From its intersection with the north-western side of Maungatapu Road, north-westwards for a distance of approximately 45 metres • Sunset Crescent – From its intersection with north-western side of Maungatapu Road, north-westwards for a distance of approximately 40 metres	11/10/2010	Tauranga City Council Speed Limit Bylaw 2009 NZ Gazette 2 June 2005, No 86, pg 2051	n/a

Description	Date Effective From	Legal Instrument	Previous Legal Instrument
Otumoetai Primary School • Otumoetai Road – From a point approximately 15 metres south of the southern side of Brookfield Terrace, northwards for a distance of approximately 425 metres • Sherwood Street – From its intersection with Otumoetai Road, westwards for a distance of approximately 300 metres • Claremont Terrace – For its entire length • Lydbrook Place – For its entire length	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009 NZ Gazette 2 June 2005, No 86, pg 2051	n/a
Papamoa Primary School • Parton Road – from a point approximately 270 metres south-west of the southern side of Dickson Road then north-eastwards to its intersection with Papamoa Beach Road, a distance of approximately 450 metres • Dickson Road – from its intersection with Parton Road, north-westwards for a distance of approximately 300 metres • Simpson Road – from its intersection with Parton Road, south-eastwards for a distance of approximately 100 metres • Enterprise Drive – for its entire length • Market Place – for its entire length	25/10/2011	Tauranga City Council Speed Limit Bylaw 2009	n/a
Taumata School • Kennedy Road between the western end of Mortlake Heights and Flack Street; • Mortlake Heights from 15m west of Audax Lane to Kennedy Road; • Te Ranga Memorial Drive from Kennedy Road to Turnbridge Street	**After 12/04/21 when signs are posted to indicate a variable limit.**	Tauranga City Council Speed Limit Bylaw 2009	n/a
Tauranga Intermediate School • Fraser Street, from a point 100m north of Brook Street to Seventeenth Avenue; • Eighteenth Avenue, from Fraser Street to Grace Road; Grace Road, from Eighteenth Avenue to Kaka Street.	09/08/2021	Tauranga City Council Speed Limit Bylaw 2009	n/a

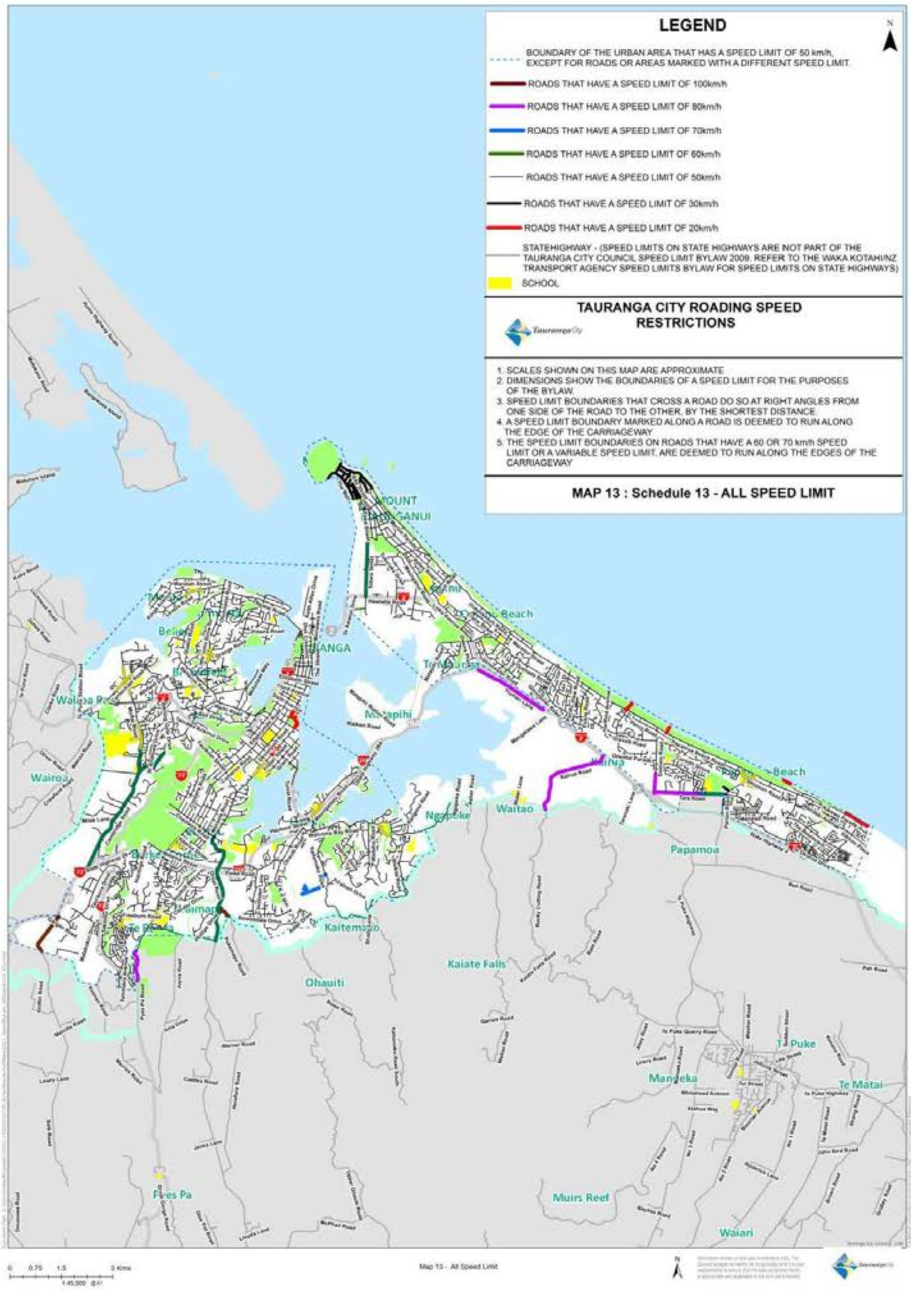
Description	Date Effective From	Legal Instrument	Previous Legal Instrument
Welcome Bay Primary School • Welcome Bay Road – From a point approximately 15 metres west of the western side of Oteki Park Drive, westwards then northwards for a distance of approximately 470 metres • Pennington Place – For its entire length	1/10 /2009	Tauranga City Council Speed Limit Bylaw 2009	n/a


LEGEND
ROADS THAT HAVE A VARIABLE SPEED LIMIT
STATEHIGHWAY - (SPEED LIMITS ON STATE HIGHWAYS ARE NOT PART OF THE TAURANGA CITY COUNCIL SPEED LIMIT BYLAW 2009. REFER TO THE WAKA KOTAHI/NZ TRANSPORT AGENCY SPEED LIMITS BYLAW FOR SPEED LIMITS ON STATE HIGHWAYS)
SCHOOL
TAURANGA CITY ROADING SPEED RESTRICTIONS
1. SCALES SHOWN ON THIS MAP ARE APPROXIMATE
2. DIMENSIONS SHOW THE BOUNDARIES OF A SPEED LIMIT FOR THE PURPOSES OF THE BYLAW.
3. SPEED LIMIT BOUNDARIES THAT CROSS A ROAD DO SO AT RIGHT ANGLES FROM ONE SIDE OF THE ROAD TO THE OTHER, BY THE SHORTEST DISTANCE.
4. A SPEED LIMIT BOUNDARY MARKED ALONG A ROAD IS DEEMED TO RUN ALONG THE EDGE OF THE CARRIAGEWAY
5. THE SPEED LIMIT BOUNDARIES ON ROADS THAT HAVE A 60 OR 70 km/h SPEED LIMIT OR A VARIABLE SPEED LIMIT, ARE DEEMED TO RUN ALONG THE EDGES OF THE CARRIAGEWAY
MAP 11: Schedule 11 - VARIABLE SPEED LIMIT
MOUNT MAUNGANUI
TAURANGA
Brookfield
Judea
Matapihi
Kairua
Ngapeke
Waitao
Papamoa
Welcome Bay
Kaitemako
Kaiate Falls
Ohauiti
Te Puke
Pyes Pa
Oropi
Muirs Reef
Waiari
Map 11 - Variable Speed Limit

Schedule 12: Roads that have a Minimum Speed Limit

The roads or areas described in this schedule, and as shown on Map 12, are declared to have a minimum speed limit

Description	Date effective from	Legal Instrument	Previous Legal Instrument


LEGEND
BOUNDARY OF THE URBAN AREA THAT HAS A SPEED LIMIT OF 50 km/h, EXCEPT FOR ROADS OR AREAS MARKED WITH A DIFFERENT SPEED LIMIT.
ROADS THAT HAVE A SPEED LIMIT OF 100km/h
ROADS THAT HAVE A SPEED LIMIT OF 80km/h
ROADS THAT HAVE A SPEED LIMIT OF 70km/h
ROADS THAT HAVE A SPEED LIMIT OF 60km/h
ROADS THAT HAVE A SPEED LIMIT OF 50km/h
ROADS THAT HAVE A SPEED LIMIT OF 30km/h
ROADS THAT HAVE A SPEED LIMIT OF 20km/h
STATEHIGHWAY - (SPEED LIMITS ON STATE HIGHWAYS ARE NOT PART OF THE TAURANGA CITY COUNCIL SPEED LIMIT BYLAW 2009. REFER TO THE WAKA KOTAHI/NZ TRANSPORT AGENCY SPEED LIMITS BYLAW FOR SPEED LIMITS ON STATE HIGHWAYS)
SCHOOL
TAURANGA CITY ROADING SPEED RESTRICTIONS
1. SCALES SHOWN ON THIS MAP ARE APPROXIMATE.
2. DIMENSIONS SHOW THE BOUNDARIES OF A SPEED LIMIT FOR THE PURPOSES OF THE BYLAW.
3. SPEED LIMIT BOUNDARIES THAT CROSS A ROAD DO SO AT RIGHT ANGLES FROM ONE SIDE OF THE ROAD TO THE OTHER, BY THE SHORTEST DISTANCE.
4. A SPEED LIMIT BOUNDARY MARKED ALONG A ROAD IS DEEMED TO RUN ALONG THE EDGE OF THE CARRIAGEWAY
5. THE SPEED LIMIT BOUNDARIES ON ROADS THAT HAVE A 60 OR 70 km/h SPEED LIMIT OR A VARIABLE SPEED LIMIT, ARE DEEMED TO RUN ALONG THE EDGES OF THE CARRIAGEWAY
MAP 13 : Schedule 13 - ALL SPEED LIMIT
MOUNT MAUNGANUI
Papamoa
Waitao
Kaitemako
Ohauiti
Kaiate Falls
Te Puke
Te Matai
Muirs Reef
Waiari
Pyes Pa
Map 13 - All Speed Limit

Appendix 3: Tauranga City Council Bylaw 2018 – Application Form for a Permit

Application for a permit to use an all-terrain vehicle on Pāpāmoa Beach

Tauranga City

Applicant details

Full name of applicant: ……………………………………………………………………………………………

Address: ………

……

Phone day: ……………………………………… Phone mobile: ………………………………………

Email address: ……………………………………………………………………………………………………

Vehicle registration number: ………………………………………………

I confirm this vehicle is a (please tick):

- ☐ Three wheeled ATV
- ☐ Four wheeled ATV
- ☐ ATV with more than four wheels

Only registered and licenced all-terrain vehicles (ATVs) are permitted to drive on Pāpāmoa Beach between 105 Karewa Parade and Kaituna River.

The beach access point is between 105 and 107 Karewa Parade. The speed limit is 20km/h.

ATV permits are not transferrable and do not authorise ATVs to be driven on any other beach in Tauranga.

A copy of your current NZTA licence label exempt class A (EA) or exempt class B (EB) must be attached to this application.

Conditions of use

I have read and understood the conditions of use as outlined on the back of this application. I agree to comply with these conditions.

Signed: …………………………………………………… Date: ……………………………………………

Fee: $40.00

Applications and payments can be made in person at the Customer Service Centre at 91 Willow Street or at Pāpāmoa Library Tuesdays and Thursdays from 2 September, 2021.

Applications can be e-mailed to ATV.Applications@tauranga.govt.nz along with proof of payment and vehicle licencing.

Payments can be made via bank transfer to ANZ 06 0433 0213474. Please reference the payment with 'ATV Licence' and your first initial and surname.

(Office use only)	Alpha code: ATP
Receipt number: ………………………	Licence number: …………………………
Authorised by: ………………………	Contact ID: …………………………

Tauranga City Council Private Bag 12022, Tauranga 3143, New Zealand +64 7 577 7000 info@tauranga.govt.nz www.tauranga.govt.nz

All-terrain vehicles on Pāpāmoa Beach

The beach is included in the definition of a 'road' in the Land Transport Act 1998

Conditions of use

Authorisation permits are subject to complying with the following conditions:

- the all-terrain vehicle (ATV) shall be principally designed for off-road use and have three or more wheels, an engine capacity exceeding 50ml and a gross weight of less than 1000kg
- the ATV must be registered and display a current licence label, including being in a safe and road worthy condition
- ATV drivers must hold a current New Zealand drivers licence
- the ATV permit must be prominently displayed on the ATV
- ATVs may only be driven on the beach for recreational fishing purposes, east of the access point to the Kaituna River (including to/from the Kaituna River) - the beach access point is located between **105 and 107 Karewa Parade, Pāpāmoa**
- ATV drivers and passengers must comply with the Beaches Bylaw 2007 and subsequent Beaches Bylaw 2018 - the Beaches Bylaw 2018 commences on 1 December 2018
- ATV drivers must comply with provisions in accordance with the Land Transport Act 1998 and Speed Limit Bylaw 2009 (and/or subsequent amendments) - the speed limit on the beach is **20km/h**
- ATVs do not have priority of use on the beach, and must be driven in a careful manner with courteous consideration to all beach users
- ATV drivers and passengers must wear approved safety helmets
- the authorised ATV permit holder, if allowing other persons to drive the ATV, must ensure the intended driver is lawfully eligible to drive and is made aware of the conditions of use
- ATV permits are issued by council, based on the information provided by the applicant - if information provided is inaccurate, the permit may be deemed invalid by council or police
- an ATV permit does not guarantee the ATV access to the beach
- ATVs should be driven and used in a reasonable manner that preserves the beaches natural environment, wildlife habitats including dotterel nesting areas and must not be driven on the dunes
- these conditions of use can be reasonably amended by council at any time
- all ATV permits issued for the yearly period after 30 September 2021, will expire on **30 September 2022.**

Please ensure you are familiar with the conditions of use. Should you not comply with any of the conditions, or any justified complaint be received and upheld by council, your authorisation will be reviewed and consideration given to the cancellation of your ATV permit.

Appendix 4: Quad Bikes and ATVs

The following information is from the NZTA website: www.nzta.govt.nz/vehicles/vehicle-types/quad-bikes-and-atvs/

What is an ATV?

All-terrain vehicles (ATVs) are vehicles that are principally designed for off-road use.

They have three or more wheels, an engine capacity exceeding 50ml and a gross weight of less than 1000kg (which is the greater of the on-road weight with load and accessories OR the gross laden weight set by the manufacturer).

ATVs include most quad bikes, smaller 'side by sides' and amphibious vehicles. They do not include 'utes' or light trucks, even if modified for off-road travel – these are originally constructed for road use and are too heavy to meet the definition.

Where you can use an ATV

You can use ATVs on public roads under certain conditions. You must:

- register and license the ATV
- hold a current New Zealand driver licence
- wear an approved safety helmet when riding them on the road (except farmers travelling slower than 30km/h, from one part of their farm to another or to an adjoining farm)
- maintain a current warrant of fitness (except if used as a farm vehicle).

What is a road?

Roads are not only streets and highways, but any place the public has access to – including bridges, culverts, beaches, riverbeds, reserve lands, wharves and road shoulders. This doesn't mean you have a right to use these areas, but if you do – the rules relating to registration, licensing and general driver behaviour apply.

Read the full definition of a road

Take safety seriously

- ATVs are a significant cause of work-related fatalities in New Zealand.
- Take particular care if you're towing a trailer.
- Children under 12 years of age should not drive an ATV.

Using your ATV on a farm

Some requirements for ATVs vary when used on the farm. For example, you can use different safety helmets, as collisions on farms are likely to occur at lower speeds than on the road.

Learn more about the requirements and safe farm use practices from Quad bike safety(external link) on the Worksafe NZ website.

Helmets and other safety equipment

About a quarter of all injuries sustained in ATV crashes are to the head, yet very few riders wear helmets. Wearing an approved helmet is the best way to prevent serious head injury.

The Land Transport (Road User) Rule 2004 states that if an ATV is being used on a road and there are no seatbelts fitted (most side by sides have seatbelts and roll over protection), the rider or driver and passengers have to wear an approved helmet. The rule provides an exception to the requirement to wear a helmet for farmers if they're travelling slower than 30km/h, from one part of their farm to another or to an adjoining farm.

For off-road use, there's a design standard specifically for ATV helmets (NZS 8600:2002) and purpose-built ATV helmets are available. An ATV helmet should provide enough protection if you're travelling under 30km/h. If you're going to be riding faster than this, you need a more substantial helmet (such as a motorcycle helmet).

When quad bikes are being used for work purposes (on or off-road), the Health and Safety in Employment Act 1992 also applies. The Ministry of Business, Innovation and Employment advises that wearing a helmet is a practicable step under this act.

The Transport Agency also strongly recommends that you wear other safety equipment, such as strong footwear, gloves, protective pants and eye protection.

ATVs on sealed roads

ATVs behave very differently on sealed roads from other vehicles. They're off-road vehicles, and aren't designed to be ridden on hard surfaces. Most ATVs have wide, low-pressure tyres – ideal for minimising damage to crops, but not good for road handling.

Many ATVs are four-wheel-drive vehicles (4WDs). 4WDs have different steering characteristics on and off the road. Unless they undergo major modification, it is strongly recommended that you don't travel faster than 30km/h on sealed roads.

Rider training

While you can ride an ATV on the road if you have a learner motorcycle licence, many motorcycle techniques are unsafe when used on an ATV. Most ATV accidents are caused by rider error.

The best way to learn the skills necessary to ride an ATV safely and avoid accidents is to attend a specialised training course. These courses are offered by a number of organisations, including motorcycle clubs.

More information on the ACC website(external link)

Make sure you read the owner's manual of your ATV before attempting to ride it.

Children and ATVs

Full size ATVs are heavy, powerful machines and many injuries occur when child riders lose control. Fatal ATV accidents in New Zealand have involved riders as young as six years old.

Full-sized ATVs carry labels from the manufacturer specifying that no one under 16 years of age rides the ATV.

Several factors prevent a child from riding an ATV with the same control as an adult. ATVs demand an active riding technique, where rider movement, strength and weight shifting are necessary to ensure stability and control. Children often lack the strength or weight to effectively handle an ATV. Some have trouble reaching the controls. In addition, children don't have the motor skills, coordination and perception necessary to safely operate an ATV of any size.

Carrying passengers on ATVs

Some quad bikes are equipped with large seats to allow the rider to shift weight to control the vehicle – not to carry other people. Passengers restrict the rider's mobility and add weight, making it harder to control and more prone to tipping over.

Passengers should only be carried on ATVs that have been specifically designed for this purpose. These ATVs come fitted with a special passenger seat.

Towing with an ATV

You need to take special care when towing trailers and other equipment with ATVs. Refer to the owner's manual to find the safe ratio between the maximum weight of a load and the unladen weight of the ATV.

Towing an ATV

You must not tow an ATV unless it is mechanically disabled (unable to be ridden).

ATV registration and licensing requirements

Do ATVs have to be registered and licensed?

You should first consider how you will use your ATV. The way you will use it will fall into one of the categories below. Each category has different registration and licensing requirements, and different rules governing the ATV's use.

1. No road use

ATVs that will never be used on any road don't have to be registered or licensed.

2. Exempt class A (EA) and exempt class B (EB)

ATVs used on a road must be registered and licensed.

Most ATVs fit within exempt class A. They are exempt from registration fees and the vehicle licence portions of the licensing fee. You still have to pay for other fees such as a (reduced) ACC levy and administration fees for obtaining a licence label.

An ATV used by a farmer can be licensed as exempt class B. These vehicles pay a licensing fee but are exempt from the payment of some levies and charges such as ACC levies and can apply for refunds of fuel excise. They are restricted to travel related to a farm or going from one farm to another that is owned and managed by the same person.

Do ATVs have to be licensed continuously?

No. All vehicles, including ATVs, must be licensed while in use on roads. However, unlike most vehicles, ATVs aren't required to be licensed continuously. Their vehicle licences date from the day the fee is paid, not the date due.

If you don't pay your ATV's licence fee for two years, its registration will be cancelled. If there's any chance you'll want to use the ATV on the road again, we recommend you get an exemption from licensing before this happens. (Getting a vehicle registered again after its registration has been cancelled is expensive.)

More information about vehicle licensing (rego)

Fuel excise duty refunds

ATVs owned by farmers or farm managers are 'exempt vehicles' for the purposes of fuel excise (the tax that is paid for petrol, LPG, and CNG used in vehicles).

More information about fuel excise duty refunds

Commercial use

If an ATV is used in a commercial service, either hired out or used to carry passengers for a fee, you may need to obtain a Transport Service Licence. This only applies if that service is provided on a road.

More information about transport service licences

Amphibious ATVs

If you operate amphibious ATVs and intend to use the machines over water, you must also have a safety plan approved by Maritime New Zealand.

Meeting legal requirements

ATVs aren't subject to a warrant of fitness (WoF) inspection when they are used in the following conditions but must be safe to operate and meet relevant legal technical requirements.

You don't need a WoF for your ATV if you are only:

- moving from the place you live to a road that is not a public highway when the distance travelled is less than 3km
- using your ATV in connection with the ATV's servicing or repair, or
- using the ATV as an agricultural vehicle for agricultural purposes.

Driver licensing requirements

You must have an appropriate driver licence to ride or drive an ATV on the road. ATVs can be ridden or driven on a class 1 (car) or class 6 (motorcycle) licence.

Other off-road vehicles

The vehicles are similiar to ATVs, but cannot be registered or used on the road:

- vehicles of the type used by councils for gardening or property maintenance, including three- and four-wheeled vehicles that are classified overseas as motorcycles but do not qualify here
- mobile machines used at airports on runways and airport land
- small rugged vehicles used on farms that do not meet the standards requirements for class NA goods vehicles and also do not meet the frontal-impact requirements for passenger cars.

Appendix 5: Significant Natural Area Reports – Waima (Ure River) River Mouth and Awatere River Mouth

4. Grassmere Ecological District

The terms 'District' and 'Region' used in the text below refer to the Grassmere Ecological District and the Wairau Ecological Region respectively.

4.1 NATURAL CHARACTER

4.1.1 Location and Setting

Grassmere Ecological District (see Map 1) is the smallest of the five Districts in the Wairau Ecological Region, covering an area of 18470 ha. It lies in the east of the Region and adjoins Kekerengu Ecological District in Kaikoura Ecological Region, the most eastern part of the South Island.

The north-western boundary is defined by the edge of the Awatere River plain where it meets the edge of the Wither Hills. A contour of approximately 150m defines the boundary to the south west (there are no defining landforms to follow). The foot of the coastal hills east of Ward define its south-eastern margin, whilst its eastern boundary is formed by the Clifford Bay coastline.

4.1.2 Relief and Drainage

The District is low lying, running from sea level in the east to 293 m in the north-west. All the stream and river courses run in a generally parallel south-west to north-east orientation. The lowest reaches of the Awatere River pass through the District to the sea, although it drains very little of the area. Drainage is largely confined to a number of winter-borne streams, notably the Blind/Otuwhero River system, and Starborough Creek, although their headwaters fall outside the District to the south-west.

4.1.3 Geology

(Ref: New Zealand Geological Survey 1964, 1975).

Large areas of the central and southern portions of the District are of Tertiary origin, being composed of massive sandy mudstones and massive concretionary sandy mudstones with sandstone bands and shellbeds. There are also localised areas of mudstone and sandstone grading into basal conglomerate and grit. However, significant areas are overlain by Quaternary terminal moraine and glacial outwash deposits from a range of glacial periods. The northern portion of the District is composed entirely of these Quaternary deposits. Tertiary sediments also surface as a long thin band along the coast, north of the Blind River. The area of land between Lake Grassmere and the sea is derived from post-glacial swamp and lagoon deposits.

4.1.4 Geopreservation Sites

Three sites of significance are listed in the Nelson/Marlborough geopreservation inventory (Hayward *et al*., 1999). Two are of national importance: 'Starborough Creek Pliocene fossils' as an example of a well exposed section through fossil-bearing Pliocene sedimentary rocks; and 'Blind River Miocene-Pliocene fossil sequence' for their excellent exposures of fossil-bearing Miocene and Pliocene sedimentary rocks. The Blind River mouth Pliocene fossils' are of regional importance as an excellent exposure of fossil-bearing Pliocene rocks.

4.1.5 Soils

(Ref: McEwen, 1987; Soil Bureau, 1968)

Fourteen soil sets are represented in the District, six of them being yellow-grey earths that dominate the area. The most extensive of these is the Flaxbourne Hill soil set that is particularly associated with the Tertiary mudstones and sandstones based in the centre of the District. Also widespread is the Sedgemere soil set, similarly derived. A number of other soil sets, namely Seddon, Wither and Seaview, are derived from greywacke loess, and occupy much of the terraces and rolling land immediately south of the Awatere River. North of the Awatere River, Dashwood soils dominate the terraces, derived from mixed alluvium. Immediately adjacent to the Awatere River and Blind River courses are recent soils – Waimakariri and Eyre-Paparua soil sets, derived from greywacke alluvium and stony or sandy loess. Around the margins of Lake Grassmere are a range of gleyed soils derived from greywacke alluvium – gley soils (Temuka soil set), gley-recent soils (Taitapu soil set), and saline gley-recent soils (Motukarara soil set). The dunes that separate the lake from the sea are yellow-brown sands of the Taumutu soil set. Other than around the lake margin soils are very well drained, droughty in summer and generally of moderate to high fertility.

4.1.6 Climate

(Ref: Leathwick *et al*., 2002; McEwen, 1987).

In broad terms, the District experiences mild to warm temperatures, high to very high solar radiation, and high vapour pressure and annual water deficits. Annual water deficit is greater than 400mm. The District is the driest in the Ecological Region, with less than 700mm of rain per annum. Summers are very warm and very dry. Temperatures are moderate in winter.

4.1.7 Land Systems and Bioclimatic Zones

Bioclimatic zones have proven very difficult to delineate because of the vast areas of land that are essentially bereft of native vegetation and the highly modified nature of the surviving remnants. Coastal, semi-coastal, and lowland zones are present. No plant species recorded within the District show a geographical cut-off in their distributions that could be used as indicative of where these respective zones might begin and end. Nevertheless, a broad estimate of bioclimatic zones of the Region has been attempted, and is illustrated in Map 2 and discussed in the Introduction, Chapter 1.3.7.

Land Systems are units of land where broadly similar areas of geology and soils produce recurring patterns of vegetation and landform. In this report Land Environments of New Zealand (LENZ) classifications (Leathwick *et al.*, 2003) are used as a surrogate for land systems. LENZ is a classification system of New Zealand's landscapes using a comprehensive set of climate, landform and soil variables chosen for their roles in driving geographic variation in broad biological patterns. An analysis of the Ecological Districts, protected natural areas (PNA's) and recommended areas for protection (RAP's) in relation to the Land Environments is presented in the Discussion (Chapter 8), and the locations of these are illustrated in Map 16.

4.1.8 Vegetation

4.1.8.1 Vegetation history

Prior to human arrival, the District was largely forested. Subsequent deforestation, in common with most eastern South Island districts, has been attributed to Polynesian fires (McGlone, 1983, 1989). The original tree cover has been described as being largely of mahoe – titoki - ngaio coastal hardwood forest with small areas of matai – hinau - mahoe forest, manuka - kanuka scrub and fescue - silver tussock grassland (McEwen, 1987). However there is no apparent reason why lowland totara would not also have been a dominant component of the former tree cover, with matai perhaps dominant on less fertile land. Totara, matai, titoki and hinau (*Elaeocarpus dentatus*) are no longer present in natural areas in the District, such has been the loss of forest cover. Moist riparian areas and swamps along low-lying land would have provided habitat for kahikatea. Silver tussock may naturally have been confined to coastal slopes and slips, its later widespread presence inland being fire-induced.

In Grassmere Ecological District, the fires of 6-800 years ago resulted in a complete loss of forest by the time of European settlement. Frederick Weld's diary of 1846 (quoted in Kennington, 1978) is the earliest surviving description of the area:

"We... stood on a low range of grassy hills with...Kaiparatehau lagoon [Lake Grassmere] *...stretched out before us. As we descended to its banks we surprised a great quantity of ducks on the low lands that immediately surround it and I shot several while the others endeavoured to boil our camp kettle by means of docks and toetoe stalks as not a vestige of wood was to be seen... Leaving Kaiparatehau behind us, from the next ridge we saw a brook which we thought to be bushed but when we reached it at nightfall the timber was found to consist of nothing but a few miserable manuka shrubs. Just before encamping we saw two wild dogs beating like setters for quail...I ascended the next range to the north... and looking* [sic] *down on the magnificent expanse of undulating grass lands."*

Weld also gives us a unique and tantalising glimpse into the nature of the pre-European grasslands. Describing the country around the lower reaches of the Flaxbourne River just over into the adjoining Kekerengu Ecological District he relates, *'This* [country] *consists of plains and gently undulating hills, all covered solely with grass and anise* [presumably *Gingidia montana*]...*This style of country...rich in grass, milk thistle* [presumably *Sonchus oleraceus*] *and wild cabbage* [species?] ... *The general aspect of the country is open, not a bush except flax to be seen, neither is there any fern...The pasturage, as I have said before is composed of grass and anise, the former is of a short and apparently nutritious description, with some tufts of a coarser species."*

These descriptions reveal a complete lack of species such as bracken, tauhinu, coastal shrub daisy, *Coprosma* spp., matagouri and pohuehue which are such a current feature of grazed grasslands in this area where they are not heavily controlled.

4.1.8.2 Recent vegetation change

Lake Grassmere was formerly a freshwater lake (and prior to that an estuary up until 1800 years ago) until its freshwater values were destroyed by the development of the saltworks in the 1940's. Due to water abstraction, the ephemeral Blind River and its tributaries now runs dry for much longer periods of the year with an inevitable concomitant decline in wetland values.

4.1.8.3 Current vegetation

Grassmere Ecological District is heavily modified with almost all of its natural values now lost. Beach margins and coastal gullies harbour much of what remains, including areas of dune, scrub, and very small forest remnants. Saltmarsh turfs exist along the eastern margins of Lake Grassmere, as sea water now flows into it as a result of the saltworks development. A number of gorged tributaries of the Awatere River shelter small forest and treeland remnants. Several areas of 'grey shrublands' persist on hill slopes. Small pools and wet ground persist along some stream courses all year round, but otherwise there are no freshwater wetlands. Estuarine conditions exist at the mouth of the Blind River and Awatere River. The Awatere River margins are very weedy but there are localised areas of sandy gravels with native herbfield components.

4.1.8.4 Vegetation pattern and types

The following broad vegetation types are distinguished according to predominant canopy species and, to some extent, by landform where this marks a significant change in vegetation composition. Some vegetation types are included to highlight their unusual nature and are therefore narrowly defined, whilst the more common types may encompass quite a broad range of similar vegetation. The grouping of ecological units into vegetation types was done by hand sorting of the ecological unit field cards – see Methods 2.4.

The principle species which typify a vegetation type are described below, within broad tiers, to give an indication of the characteristic structure. The ground tier is comprised of species below 30cm, while the shrub tier lies between 30cm and 2m. The understorey may be of variable height between the canopy and shrub tier. Abundant species include those whose mean cover of the described tier is greater than 25%; common species range between 10-25%; minor species 5-10%; infrequent/scattered/ occasional species 1-5%, while species whose cover is less than 1% are termed scarce.

Type 1: Broadleaved forest, treeland, shrubland and scrub

Type 1a: Ngaio forest, treeland and scrub

Ngaio forms a dominant forest and scrub canopy only very locally. Inland, along a stream gorge cut through moraine and glacial outwash deposits, very small (< 0.1ha) stands of treeland exist, with infrequent *Muehlenbeckia australis* and cabbage tree. *Coprosma crassifolia*, mahoe and akiraho are infrequent understorey and shrub tier associates. *Hebe stenophylla*, barberry, karamu and elder are present but scarce in the shrub tier. *Rytidosperma* sp. is infrequent and *Pellaea rotundifolia* and *Asplenium flabellifolium* are present but scarce in the ground tier.

On coastal mudstone and sandstone gully slopes, ngaio forms a very small (< 0.5ha) area of low forest and scrub at one site. Akiraho, five finger, mahoe, cabbage tree, manuka and tutu *(Coriaria arborea)* are scarce associates in the canopy. Boxthorn is infrequent in the shrub tier. Yorkshire fog, *Linum monogynum*, *Bromus diandrus*, *Rytidosperma racemosum*, and *Muehlenbeckia australis* are common to minor ground tier species, where *Polystichum richardii* and harestail grass are infrequent. Along the rear of the adjacent beach on gentle colluvial slopes, ngaio forms an open treeland over rank grass of *Bromus diandrus*, cocksfoot, and *Rytidosperma racemosum*, and common shrubs of pohuehue. *Einadia triandra*, *Haloragis erectus*, *Melicytus* "Waipapa", *Acaena anserinifolia*, and *Disphyma australe* are present but scarce.

Type 1b: Ngaio-mahoe forest and shrubland

Several short coastal gullies spread along Clifford Bay support ngaio-mahoe forest and shrubland locally, with varying dominance of the two species. Radiata pine (*Pinus radiata*) is common at one site. Cabbage tree is a scarce associate in the canopy. Lianes can be common in the canopy, with *Rubus squarrosus*, *Calystegia tugoriorum*, and *Muehlenbeckia australis*. Minor understorey associates include rangiora and karamu, with infrequent akiraho, *Carmichaelia australis*, and five finger. Mapou, *Coprosma repens* (probably naturalised), cabbage tree and boxthorn are present but scarce. The shrub tier is sparse, other than bracken locally, with any of the previously mentioned species potentially present. *Polystichum richardii*, *Adiantum cunninghamii*, *Melicytus* "Waipapa", *Bromus diandrus* and Yorkshire fog are infrequent ground tier species, with *Einadia allanii*, *Microsorum pustulatum*, *Uncinia leptostachya*, *Asplenium appendiculatum*, *Blechnum chambersii*, *Pellaea rotundifolia*, *Asplenium flabellifolium*, *Sonchus oleraceus*, catsear, Scotch thistle, *Luzula* sp., *Acaena anserinifolia*, and *Haloragus erectus* present but scarce. Where a more open mahoe-ngaio shrubland occurs, *Rubus squarrosus* is present, with open grassland of *Bromus wildenowii*, cocksfoot, and *Tetragona trigyna* common. This habitat forms a mosaic with an open shrubland of pohuehue, *Carmichaelia australis*, *Melicytus* "Waipapa", and *Rubus squarrosus*.

Type 1c: Mahoe forest

Mahoe forest occurs in very small (1ha) areas at two sites, on a terrace riser and a gully side slope on moraine and glacial outwash deposits. Akiraho, ngaio, cabbage tree, and *Muehlenbeckia australis* are infrequent canopy associates. Lower tiers vary between the two sites, with understories that include ongaonga (*Urtica ferox*), *Solanum aviculare*, *Parsonsia heterophylla*, *Calystegia tugoriorum*, *Rubus squarrosus*, *R. schmidelioides*, *Coprosma crassifolia*, barberry, five finger, and elder. Shrub tier species include *Fuchsia* *perscandens, Asplenium bulbiferum* and *Pneumatopteris pennigera.* The ground tier is almost barren with occasional low fern species including *Blechnum chambersii, Asplenium appendiculatum, A. flabellifolium* and *Polystichum richardii*.

Type 1d: Akiraho forest and scrub

Three sites support akiraho forest or tall scrub, though all areas are small (< 8ha). All are on terminal moraine and glacial outwash deposits, on gully side slope and lower hill slope. There is a broad similarity of species present between coastal and inland sites, though some species, such as muritai broom (*Carmichaelia muritai*), *Linum monogynum, Tetragona trigyna* and boxthorn were not recorded inland. Ngaio and five finger are infrequent canopy associates, with kowhai scarce. Understorey species include infrequent kohuhu, and *Rubus squarrosus*. Shrub tiers are sparse generally, although one site had much regenerating akiraho due to exclusion of stock. Matagouri can be a minor component while *Melicytus* "Waipapa", pohuehue, *Carmichaelia australis*, and regenerating canopy species are infrequent. Ground tiers are quite barren, with occasional ferns such as *Polystichum richardii, Asplenium flabellifolium, A. hookerianum, Pellaea rotundifolia, Microsorum pustulatum*, and *Pyrrosia eleagnifolia. Craspedia* "Marfells", *Poa imbecilla, Clematis forsteri*, and exotic grasses are present but scarce.

One small area of colluvial terrace akiraho - kowhai forest also occurs inland. *Coprosma crassifolia* is common in the understorey tier, with ngaio scarce. The shrub tier includes mahoe, elder, barberry, and *Solanum aviculare*.

Type 1e: Mixed coastal shrubland

A long narrow band of shrubland runs along the coast in the north of the District above and below the low beach edge cliffs. Harakeke, karamu, pohuehue, and boxthorn are common, with minor shining karamu. Infrequent to scarce associates include coastal shrub daisy, ngaio, marram, silver tussock, knobby clubrush, tall fescue, *Haloragus erectus, Linum monogynum, Samolus repens, Selliera radicans*, sea rush, and a suite of exotic herbs.

At the head of one coastal gully, there is a mixed dense shrubland of manuka, coastal shrub daisy, *Hebe stenophylla*, pohuehue and *Rubus squarrosus*, with infrequent *Carmichaelia australis. Coprosma propinqua* is scarce. Lower tiers are sparse, with infrequent cocksfoot, *Melicytus "Waipapa"*, and a suite of occasional species, including many of the typical coastal ferns as in type 1d, *Dichondra repens*, and a range of exotic herbs and grasses.

Type 2: Small-leaved xeric shrubland

Type 2a: Coastal matagouri and pohuehue shrubland

Rear dune areas in the south of Clifford Bay typically support prostrate shrubland associations of matagouri and pohuehue. Common associates are marram, knobby clubrush, harestail grass, viper's bugloss, *Bromus diandrus, B. commutatus, B. willdenowii*, and *Rytidosperma racemosum*. Infrequent to scarce species include wild carrot, *Vicia* sp., silver tussock, shore bindweed, *Melicytus* "Waipapa" and briar.

Type 2b: Coastal shrub-daisy shrubland

A very small (< 0.25ha) area of mature open coastal shrub daisy occurs between Lake Grassmere and the coastal dunes. The often rank lower tiers are of marram, oioi, and goatsbeard (*Tragopogon porrifolius*). *Rytidosperma racemosum* and harestail grass are infrequent associates.

Type 2c: Mixed inland shrubland

At least six sites, mostly on hill slopes or gully sides away from the coast hold open to dense shrublands and shrub-grasslands. The shrubs are usually dominated by matagouri and/or pohuehue. *Rubus schmidelioides*, *Coprosma crassifolia*, coastal shrub daisy and *Melicytus* "Waipapa" are common, as is harakeke locally, along ephemerally wet gully bottoms. Briar and blackberry are often minor associates while bracken, tauhinu, barberry and *Clematis quadribracteolata* are present but scarce. Grassland components are rank with sweet vernal grass, *Rytidosperma* spp., *Bromus* spp., and *Lolium perenne*. A suite of occasional exotic herbs occur.

Type 3: Saltmarsh ribbonwood scrub

Two ephemeral stream mouths support areas of saltmarsh ribbonwood scrub and shrubland. Sea rush is common, with minor *Bromus commutatus*, wild carrot, pohuehue, *Atriplex hastata*, glasswort, *Plantago coronopus* and *Bromus* sp. Also present are creeping bent, knobby clubrush, *Bolboschoenus caldwellii*, tall fescue, *Lactuca virosa*, silver tussock, briar, *Leptinella dioica*, and *Selliera radicans*.

Type 4: Shrub-rockland

Gorge and riparian cliff faces of conglomerate and moraine/glacial outwash deposits may support woody vegetation locally, where the substrate is sufficiently stable. Marlborough rock daisy and *Heliohebe hulkeana* are locally common and *Hebe stenophylla* is a minor component. One site supports abundant *Hebe stricta*. A range of occasional species are present, including European broom, gorse, briar, foxglove, viper's bugloss, *Convolvulus waitaha*, catsear, *Epilobium cinereum*, wild carrot, *Verbascum nigrum*, sheep's sorrel, *Senecio quadridentatus*, *Pseudognaphalium luteo-album*, *Leontodon hispidus*, and exotic grass species.

Type 5: Silver tussock grassland

Silver tussock grassland is confined to a few very small (< 0.1ha) patches on upper side slopes of one coastal gorge, where mudstone has slipped and stabilised. Minor associates are *Senecio hauwai* and cocksfoot, with occasional tauhinu, akiraho, sweet vernal grass, manuka, *Elymus* sp., matagouri, black medick, *Lagenifera pumila*, and *Microseris scapigera*.

Type 6: Non-woody duneland associations

Type 6a: Marram-spinifex grassland

Marram dominates much of the dunelands above the foreshore of Clifford Bay, with spinifex sometimes co-dominant. Associated species diversity and abundance increases away from the foreshore. Harestail grass is abundant, *Bromus diandrus* minor, with occasional to scarce *Bromus sterilis*, wild carrot, black medick, goatsbeard, lesser broomrape, catsear, *Senecio elegans*, viper's bugloss, knobby clubrush, *Vicia* sp., and *Calystegia soldanella*.

Type 6b: Spinifex grassland

Spinifex dominates the extreme foredune and dune crests locally where it has not been overcome by marram colonisation. On the littoral margin there are few associates, with infrequent *Senecio elegans* and *Calystegia soldanella* and scarce catsear and harestail grass. Dune crests are more diverse, with infrequent associates as above as well as *Rauolia* aff. *hookeri* "coast", silver tussock and *Carduus edulis*, and scarce *Bromus diandrus* and lesser broomrape.

Type 6c: Knobby clubrush-harestail grass sedge-grassland

This association is widespread along the Clifford Bay coast, in hollows and flats behind the foredune, and on the rear dune where one is present. Knobby clubrush and harestail grass are invariably numerous, with locally abundant *Raoulia* aff. *hookeri* "coast", bracken, *Rytidosperma racemosum* and viper's bugloss. Locally common to minor are sweet vernal grass, *Vicia* sp., *Bromus diandrus*, and, in one area, pingao *(Desmoschoenus spiralis*). Infrequent species include black medick, *Calystegia soldonella*, matagouri, catsear, *Carduus edulis*, *Senecio elegans* and silver tussock.

Type 6d: Sand-sedge sandfield

Areas of flat sands intrude occasionally between dune hummocks, swept by high seas. They have sand sedge scattered through them locally. Shore bindweed is common while horned poppy (*Glaucium flavum*), harestail grass and *Bromus diandrus* are also associates.

Type 7: Glasswort saltmarsh

Very extensive glasswort saltmarsh vegetation occurs around the deep margins of Lake Grassmere and locally at the mouth of Blind River. *Parapholis incurva* and *P. stricta* are co-dominant locally and often abundant. Common to minor associates include sea rush, *Selliera radicans*, *Samolus repens*, *Plantago coronopus*, *Atriples hastata*, *Einadia triandra*, and at one site, *Chenopodium glaucum*. *Hordeum marinum*, *Cotula coronopus*, and knobby clubrush occur occasionally, with *Spergularia media*, silver beet (*Beta vulgaris*), *Leptinella dioica*, and *Puccinellia stricta* present but scarce.

Mimulus repens, *Atriplex hastata* and glasswort form an open herb turf on the bottom of an ephemeral lagoon at the mouth of the Blind River that is inundated only by the highest tides, and by flooding.

Low sea cliffs in the north of the District support a very small area (< 0.01ha) of dense *Samolus repens* herbfield, with occasional *Sonchus oleraceus*, *Lobelia anceps*, *Carex flagellifera*, *Disphyma australe* among other herbs, where water seeps down the cliffs.

Type 8: Native iceplant herb-rockland

Native iceplant (*Disphyma australe*) dominates a community on steep, dry coastal faces of Tertiary sandstone/mudstone at one site on the Clifford Bay coast. *Rytidosperma racemosum* is an abundant associate with minor *Linum monogynum* and infrequent cocksfoot and *Rytidosperma* sp.. Scarce associates include tauhinu, boxthorn, akiraho, silver tussock, *Acaena anserinifolia*, sweet vernal grass, *Lolium perenne* and *Bromus diandrus*.

Type 9: Rushland

Type 9a: Saline rushland

Several narrow strips of sea rush occur along the margins of Lake Grassmere between saltmarsh and pasture, and toward the mouth of the ephemeral Station Creek. Typically, where conditions are less saline, creeping bent and sweet vernal grass are common. Where saltmarsh is present glasswort, *Samolus repens* and *Selliera radicans* are common, and *Plantago coronopus*, *Atriplex hastata*, *Apium prostratum* and *Chenopodium glaucum* may be present. *Polypogon monspeliensis* is common at Station Creek.

Type 9b: Freshwater rushland

Very minor areas (< 0.1ha) of *Juncus gregiflorus* rushland occur on the dry margins of Blind River, while jointed rushland is present in its ephemeral bed. The latter species forms small, dense swards with abundant creeping bent, marsh foxtail (*Alopecurus geniculatus*), and common *Eleocharis acuta* and *Myosotis laxa*. *Juncus gregiflorus* occurs with creeping bent, *Eleocharis acuta*, white clover, and locally, *Juncus krausii*. *Carex virgata* and *C. flagellifera* are scare associates.

Type 10: Sedgeland

At one small (< 0.1ha) wet site in a field margin, *Schoenoplectus tabernaemontani* forms a dominant sward with creeping bent an abundant associate, and three square and Yorkshire fog common. Soft rush, jointed rush, *Eleocharis acuta*, and cocksfoot grass are infrequent associates.

A very small (< 0.01ha) narrow margin of three square sedgeland occurs around the margin of a brackish lagoon at the mouth of Blind River. *Bolboschoenus caldwellii* and *Selliera radicans* are common associates.

Type 11: Raupo reedland

Small (< 0.1ha) areas of raupo occur along Blind River where water ponds during the long periods when there is no flow. Marginal areas commonly support three square, creeping bent, jointed rush, watercress, with minor *Juncus gregiflorus*, harakeke, and exotic herbs.

Type 12: Harakeke flaxland

Harakeke is very localised in the District, never forming the dense stands that are so characteristic of the species. It occurs in and around one ephemeral stream bed, a wetland area dominated by monkey musk and on a small river terrace and lower hill slope at the mouth of Blind River. All are very small (< 0.2ha) sites. Wet ground associates include watercress, creeping bent, sea rush, with scarce occurrence of other *Juncus* species. Where drier and coastal, harakeke and bracken are co-dominant with rare knobby clubrush, boxthorn, coastal shrub daisy, saltmarsh ribbonwood, briar, pohuehue and tall fescue.

Type 13: Aquatic herbfield

Ponded sections of the ephemeral Blind River support aquatic herbfield where the water is deep enough to exclude other vegetation. *Potamogeton cheesemanii*, and *Myriophyllum propinquum* may dominate with minor *Azolla filiculoides*, *Lemna minor* and *Ranunculus trichophyllus*.

Type 14: River gravelfield

Localised areas of the Awatere riverbed gravels support sparse mat-forming *Muehlenbeckia axillaris* and *Raoulia australis*, sometimes in association with tutu and predominantly exotic grasses and herbs. Such areas are confined to semi-stable gravels that are too recently formed or too flood prone to have allowed gorse to develop.

Type 15: Bracken fernland

Bracken fernland is largely confined to a coastal site, near the mouth of Station Creek, where it forms a fern-grassland on a south-facing gully slope close to the sea. Small areas (< 0.2ha) of bracken are also evident very locally, on rear dunes along the coast just south of this site.

Type 16: Exotic forest, treeland, scrub and shrubland

Localised willow forest and treeland, and gorse shrublands occurs along the Awatere River margins, with predominantly exotic associates. European broom forms small areas of dense shrublands and scrub in parts of Nina Brook and Mt. Adde Stream. The former also has thickets of hawthorn and barberry in its very lowest reaches. Boxthorn forms extensive shrublands along much of the coastal slopes of Clifford Bay.

Type 17: Exotic grassland

Marram tussocklands are a component of the dune vegetation of Clifford Bay. Freshwater margins, and damp pasture are often choked with tall fescue, Yorkshire fog and creeping bent. Tall fescue is often dominant along damp, brackish wetland margins. Exotic pasture grasses dominate most drier grassland areas. These are largely of *Lolium perenne*, browntop, sweet vernal grass, *Bromus* species and Yorkshire fog.

4.1.9 Flora

A checklist of all plant species that have been recorded in Grassmere Ecological District can be found in Appendix 1. This is not a complete list as the PNA survey is a rapid technique that does not allow for detailed species survey. Only one prior plant survey within the Ecological District has been done (by A.P.Druce of the Marfells coast), and this has been incorporated into the list in Appendix 1.

4.1.9.1 Threatened and notable plant species

The national threatened species list (de Lange *et al.*, 2004) includes 10 species of plants known from Grassmere Ecological District. Threat categories are defined in Appendix 3.

TABLE 3: THREATENED VASCULAR PLANT SPECIES OF GRASSMERE ECOLOGICAL DISTRICT.

THREAT CATEGORY	SPECIES	COMMON NAME	DISTRIBUTION IN DISTRICT	THREATS LOCALLY
Acutely threatened, nationally critical	*Carmichaelia muritai*	Coastal tree broom	One protected population.	Lack of recruitment.
Acutely threatened, nationally vulnerable	*Muehlenbeckia astonii*		Several plants known.	Lack of recruitment through weed competition.
Chronically threatened, serious decline	*Carmichaelia vexillata*		One population.	Mammal browse.
	Euphorbia glauca	New Zealand sea spurge/shore spurge	One population.	Habitat loss.
Chronically threatened, gradual decline	*Austrofestuca littoralis*	Sand tussock	Local at Marfells Beach.	Marram encroachment; damage from off road vehicles.
	Desmoschoenus spiralis	Pingao	Scattered along the Clifford Bay coast.	Marram encroachment.
	Eryngium aff. *vesiculosum*	Sea holly	Large patch between Lake Grassmere and the sea.	Unknown.
	Raoulia aff. *hookeri* "coast"	A mat daisy	Rare along the coast.	Trampling/vehicle use along foreshores.
At risk, sparse	*Mimulus repens*	Native musk	Mouth of Blind River.	Unknown.
	Muehlenbeckia ephedroides	Leafless pohuehue	One inland record.	Unknown.
At risk, range restricted	*Senecio hauwai*		Locally common along the Clifford Bay coast.	Unknown.

4.1.9.2 *Distribution limits*

No vascular plant species are known to reach their distributional limit in the District.

4.1.9.3 *Weeds*

The most significant ecological weed in the District is marram. The dune systems often contain dense stands of this species to the exclusion of native dune plants such as pingao, sand tussock, and spinifex. Rear dune areas are often dominated by harestail grass and a suite of other exotic herbs and grasses. Gorse, broom, barberry, blackberry, and old man's beard are absent from nearly all areas of natural significance, with only Nina Brook gorge having a significant woody weed problem among the sites surveyed. Briar is present, but generally only as a small component of shrubland areas. Boxthorn often dominates coastal slopes.

4.1.10 Palaeofauna

As throughout mainland New Zealand, the native birdlife has declined catastrophically since humans arrived. In the Wairau Ecological Region, only Blenheim and Grassmere Ecological Districts have any archaeological or documented evidence of their former avifauna. Excavations at Maori midden sites and natural deposits on the Lake Grassmere foreshore have revealed the remains of 88 native avian taxa, many of which are now extinct (Worthy, 1998).

4.1.11 Fauna

A checklist of fauna recorded in the District, excluding invertebrates, is given in Appendix 2.

4.1.11.1 *Birds*

Eight of the native bird species recorded in the District are on the national threatened species list (Hitchmough, 2002). Threat categories are defined in Appendix 3.

TABLE 4: THREATENED BIRD SPECIES RECORDED IN GRASSMERE ECOLOGICAL DISTRICT

THREAT STATUS	SPECIES	COMMON NAME	DISTRIBUTION WITHIN THE DISTRICT	LIKELY THREATS LOCALLY
Chronically threatened, serious decline	*Larus bulleri*	Black-billed gull	Present on the Awatere River and at Lake Grassmere, although nesting sites tend to be further upstream, outside the District.	Water abstraction effecting braids. Weed growth effecting gravel nest areas. Nest predation from cats, mustelids and hedgehogs. Human disturbance.
	Sterna albostriata	Black-fronted tern/Tarapiroe	Lake Grassmere is nationally important as a feeding/roosting site. Nests on the lower Awatere River.	As above.
	Anas superciliosa	Grey duck/Parera	Occurs on all water bodies throughout the District.	Hybridisation with the introduced mallard duck.
Chronically threatened, gradual decline	*Charadrius bicintus bicintus*	Banded dotterel/Tuturiwhatu	Occurs in regionally significant numbers along the Awatere River, the lower reaches of which run through the District.	As for black-billed gull.
	Sterna striata striata	White-fronted tern/Tara	Breeds erratically at Lake Grassmere.	Nest disturbance.
	Falco novaeseelandiae "Eastern"	Eastern falcon/Karearea	Scattered in very low numbers through the District.	Not determined.
At risk, sparse	*Phalacrocorax carbo*	Black shag/Kawau	Present along the coast and the Awatere River.	(Historically persecuted.)
	Phalacrocorax varius	Pied shag/Karuhiruhi	Occurs in regionally significant numbers at Lake Grassmere; present along the coast.	(Historically persecuted.)

No formal bird survey was attempted during the course of the fieldwork, and what follows has been collated from the literature and from our cursory observations only.

Other than at Lake Grassmere, wetland and water birds are scarce throughout the District, occurring at discrete and often small and widely separated wetlands in an otherwise arid landscape. Native species include grey duck/mallard, grey teal, shoveler, paradise shelduck and pukeko.

Lake Grassmere deserves special mention as an exceptional site for birdlife (Sagar, 1996). It is a major feeding and roosting site for large numbers of waders such as bar-tailed godwit, pied stilt, South Island pied oystercatcher and knot, and many species of migrant and vagrant waders have been noted. Seasonally the area also supports large numbers of waterfowl especially grey teal, grey duck/mallard and the introduced black swan. White-fronted tern has bred here.

Native forest and shrublands are very nearly absent from the District, and the few native bird species recorded from them include bellbird, grey warbler, silvereye and fantail. The survey season was too late to note the presence of cuckoo species. Introduced species commonly encountered in such areas were greenfinch, goldfinch, chaffinch, redpoll, Californian quail, sparrow and starling. Dunnock, blackbird and songthrush were occasional, though no doubt under-recorded due to the lateness of the season. Kahu and welcome swallow were often present in open habitats.

The birdlife of the Awatere River is well documented (Hallas, 2003). Within the District there are large numbers of breeding banded dotterel (chronically threatened, gradual decline), and small numbers of breeding black-fronted tern (chronically threatened, serious decline), and pied stilt. Five percent of the South Island population of black-fronted dotterel breed along the mid to lower reaches of the Awatere River. South Island pied oystercatcher and black-billed gull (chronically threatened, serious decline) frequent the river, but breed mainly outside the District, upriver. Black shag (at risk, sparse), little shag, and kingfisher are also present. Backwaters support grey teal and grey duck/mallard. Welcome swallows frequent the open riverbed and spur-winged plover and paradise shelduck the margins, braids and adjacent alluvial pastoral flats. Caspian tern and white-faced heron occur occasionally along the Awatere riverbed.

4.1.11.2 Reptiles and frogs

No specific searches were made for lizards during the course of the survey. There are records of common gecko (*Hoplodactylus maculatus*) in the District (Whitaker and Gaze, 1999). During the course of our fieldwork we also identified common skink (*Oligosoma nigriplantare polychroma*) under coastal driftwood on the Clifford Bay coast.

4.1.11.3 Freshwater fish

Fourteen species of native freshwater fish have been recorded in the District (Allibone, 1995) (Appendix 2). There are, however, large knowledge gaps in the distribution and abundance of freshwater fish species in the District. Of the species recorded the long-finned eel is listed as "chronically threatened, gradual decline" in the national threatened species list (Hitchmough, 2002). Banded kokopu is regionally uncommon.

Two species are non-diadromous (non-migratory) – northern galaxias and upland bully. Such species are of particular significance as non-diadromous species may be genetically isolated within their catchments, and may differ from other populations. The true taxonomic status of these populations in relation to others of the species is however currently unknown, although the northern galaxias may well be a species in its own right, distinct from *Galaxias vulgaris* elsewhere (Martin Rutledge pers. comm.).

The Awatere River catchment, the lowest reaches of which flow through the District, is considered to be of regional importance for freshwater fish and habitat diversity (Allibone, 1995). The catchment is huge and the main river stem that lies in the District is critical for allowing the passage of diadromous species between the tributaries and the sea. It is very important for torrent fish (*Chaemarrichthys fosteri*) containing probably the best population in the Region (Martin Rutledge pers. comm.). The Otuwhero (Blind) River catchment drains much of the District. Its flow is ephemeral, although deep pools remain year round. Banded kokopu have been recorded in parts of the upper catchment. Both eel species are present, which support a part of the Marlborough commercial eel fishery. Water abstraction has, however, greatly reduced the seasonal duration of flow, which will have impacted heavily on the ecology of the river system.

Lake Grassmere was a freshwater lake up until the 1940's when it was developed for salt manufacture. The freshwater wetland values were entirely destroyed in this process.

4.1.11.4 Invertebrates

There is no documented information on the invertebrate fauna of the Grassmere Ecological District.

4.1.11.5 Introduced mammals

With so much of the District developed under semi-intensive agriculture, the mammal fauna is restricted to smaller species. Likely species include house mouse, ship rat, Norway rat, hedgehog, feral cat, hare, rabbit, stoat, weasel, ferret, and brush-tailed possum. Feral pig, goat and deer are almost certainly absent, as there is no suitable habitat.

4.2 EXISTING PROTECTED AREAS

4.2.1 Introduction

Protected natural areas (PNA's) cover 0.3% of the Grassmere Ecological District. The three sites, which lie along the Clifford Bay coastline are protected as reserves administered by the Department of Conservation. A breakdown of the Land Environments in which these occur is given in Chapter 8 – Discussion.

Descriptions for protected natural areas are given below. Note that the ecological units are more narrowly defined than the broader vegetation types (which are amalgamations of related ecological units) described in Chapter 4.1.8.4. These broader vegetation types are listed below by number only, for each of the sites described.

The principle species which typify an ecological unit are described below within broad tiers to give an indication of the characteristic structure. The ground tier is comprised of species below 30cm, while the shrub tier lies between 30cm and 2m. The understorey may be of variable height between the canopy and shrub tier. Abundant species include those whose mean cover of the described tier is greater than 25%; common species range between 10-25%; minor species 5-10%; infrequent/scattered/ occasional species 1-5%, while species whose cover is less than 1% are termed scarce.

'District' and 'Region' below refer to the Grassmere Ecological District and Wairau Ecological Region respectively.

National threat categories for species given below are from Hitchmough, 2002 and de Lange *et al.*, 2004.

4.3 RECOMMENDED AREAS FOR PROTECTION

4.3.1 Introduction

Thirteen recommended areas for protection (RAP's) cover 8.9% of the Grassmere Ecological District. A breakdown of the Land Environments in which these occur is given in Chapter 8 – Discussion.

Descriptions for recommended areas for protection are given below. Note that the ecological units are more narrowly defined than the broader vegetation types (which are amalgamations of related ecological units) described in Chapter 4.1.8.4. These broader vegetation types are listed below by number only, for each of the sites described.

The principle species which typify an ecological unit are described below within broad tiers to give an indication of the characteristic structure. The ground tier is comprised of species below 30cm, while the shrub tier lies between 30cm and 2m. The understorey may be of variable height between the canopy and shrub tier. Abundant species include those whose mean cover of the described tier is greater than 25%; common species range between 10-25%; minor species 5-10%; infrequent/scattered/ occasional species 1-5%, while species whose cover is less than 1% are termed scarce.

'District' and 'Region' below refer to the Grassmere Ecological District and Wairau Ecological Region respectively.

National threat categories for species given below are from Hitchmough, 2002 and de Lange *et al.*, 2004.

4.3.2 Recommended Areas for Protection

RAP G13 – Awatere River *(Maps 8 & 12, P 35 & 43)*

This river passes through both Grassmere and Flaxbourne Ecological Districts, with a RAP designation covering the whole length of this section. The description below is for the Grassmere Ecological District section only.

Grid Reference Centre	NZMS 260
Area	c600ha
Altitude	0-90m
Tenure	Crown Riverbed (Marlborough District Council)
Vegetation Type	10, 19, 20
Study Area Number	G3
Bioclimatic Zone	Coastal, semi-coastal, lowland

Ecological Units		**% Cover**
Mixed herb-grass-gravel-sandfield on alluvium	)	
Gorse and/or broom shrubland	)	Not determined
Willow spp. forest on riparian margins	)	

Landforms

The Awatere River is the second largest river and braided river system in the Ecological Region, and in Marlborough. The very lowest reaches of the river pass through the District, falling from 90m at the point where it enters the District, to the sea. Much of its length is braided, but the river is narrowly confined by steep to vertical, rapidly eroding slopes, so that the braids are not well-developed. The river runs through post-glacial alluvium and Quaternary terminal moraine/glacial outwash deposits, which overlie the now exposed Tertiary mudstone/sandstone.

Vegetation and Flora

The river is largely confined to narrow braid channels except when in flood, so that there are wide expanses of sandy gravel margins and islands. Where flood scouring is periodic or where the braid course has recently changed, these areas may be sparsely vegetated, with native species present locally. There may be prostrate mats of *Raoulia australis* and *Muehlenbeckia axillaris*, with *Epilobium komarovianum*, *E. microphyllum*, and thickets of tutu. The exotic species tend to become more frequent nearer the banks. These include sweet vernal grass, European broom, gorse, lotus, *Medicago nigra*, Californian stinkweed, Scotch thistle, creeping thistle, *Verbena bonariensis*, white clover, woolly mullein, sheep's sorrel, *Picris echioides*, foxglove, viper's bugloss, *Senecio quadridentatus*, narrow leaved plantain, haresfoot clover, *Conyza albida*, *Hypericum perforatum* and wild carrot.

Locally, riparian margins may be dominated by mature crack and grey willow forest where there is sufficient alluvium between the active riverbed and the collapsing cliffs. These damper areas are otherwise dominated by other exotic plants, notably tall fescue and blackberry. Backwater margins where there is sufficient light may hold monkey musk, jointed rush, *Veronica anagallis-aquatica*, *Cyperus eragrostis*, water pepper and creeping buttercup, and, more locally, three square, and *Myriophyllum propinquum*. Locally, drier areas of river margin are covered in dense stands of gorse and broom where changes in river flow have resulted in less flood scouring of former open gravel beds.

The estuary is not large for a river of this size. It is actively scoured across much of its surface between banks, but there are also areas of very diverse exotic herbs and grasses on sands, gravels and margins. Native species are generally scarce here and include *Lachnagrostis filiformis*, three square, *Cyperus ustulatus*, *Atriplex hastata*, raupo, *Cotula coronopifolia*, *Einadia triandra*, *Apium prostratum*, *Isolepis cernua*, harakeke, *Disphyma australe*, *Eleocharis acuta*, sea rush, *Schoenoplectus tabernaemontani*, *Raoulia australis*, *Epilobium komarovianum*, knobby clubrush and tauhinu.

Fauna

(Ref: Hallas, 2003 for river-dependant birds. Counts in brackets are from a 1997 survey.)

The Awatere River is regionally important as a site for nesting river-dependant birds.

Within the District there are good numbers of breeding banded dotterel (116 birds), and small numbers of breeding black-fronted tern (18 birds) and pied stilt (11 birds). Five percent of the South Island population of black-fronted dotterel breed along the mid to lower reaches of the Awatere, most of which do so within the District. South Island pied oystercatcher and black-billed gull frequent the river, but breed mainly upriver outside the District. Black shag, little shag, and kingfisher are also present. Backwaters support numbers of grey teal and grey duck/mallard. Welcome swallows frequent the open riverbed, and spur-winged plover and paradise shelduck the margins, braids and adjacent alluvial pastoral flats. Caspian tern and white-faced heron are occasional along the Awatere riverbed.

The Awatere River catchment, the lowest reaches of which flow through the District, is considered to be of regional importance for freshwater fish and habitat diversity (Allibone, 1995). The catchment is huge and the main river stem that lies in the District is critical for allowing the passage of diadromous (migratory) species between the tributaries and the sea. It is very important for torrent fish (*Chaemarrichthys fosteri*) with probably the best population in the Region (Martin Rutledge pers. comm.).

Selection Criteria

- The Awatere River is the largest river in the District and the second largest braided river system in the Region. Natural erosion and deposition processes continue largely unmodified by direct human interference.
- The lower Awatere River is of significance for river dependant birds, with regionally important breeding populations of banded dotterel (chronically threatened, gradual decline) and black-fronted dotterel. Black-fronted tern (chronically threatened, serious decline) also breed in small numbers within the District.
- The main stem of the river is important not only for resident fish, but also as a corridor for migratory species that move between the tributary streams and the sea to spawn. Fourteen species of native fish have been recorded from the District, many of which occur in the lower Awatere River. The torrent fish population is at least regionally important. Long-finned eel (chronically threatened, gradual decline) are present.
- This is the only site in the District where native plant communities associated with braided riverbeds occur.

Secondary Criteria

The river is a significant landscape feature in the District.

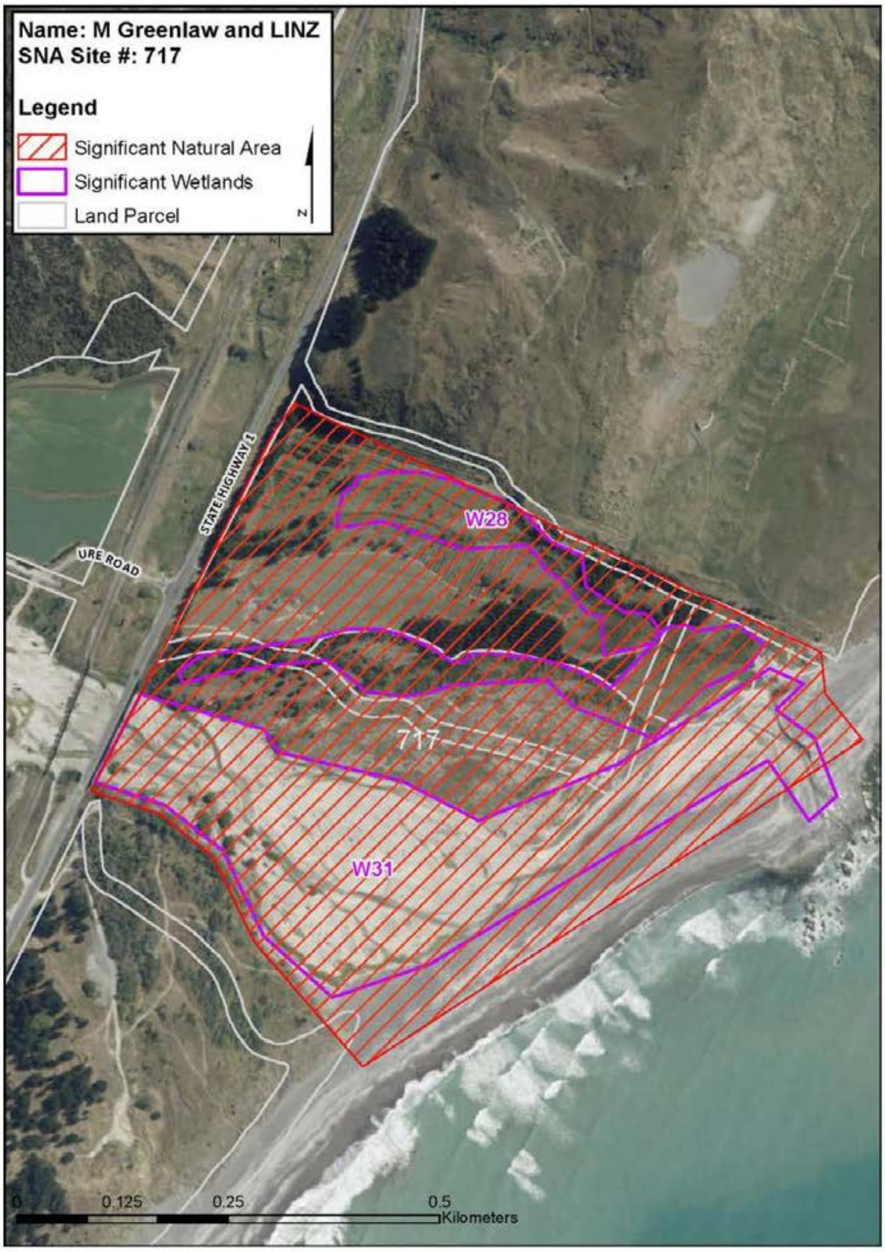
Threats, Modifications and Management Suggestions

Introduced predators, weed growth on gravel nest sites and human disturbance threaten all the river-dependant nesting bird species. Any future water abstraction could potentially impact on river-dependant breeding birds, by changing flows that might impact upon feeding grounds and nesting sites. Unfortunately, precise breeding numbers and population trends are not known for this river, nor are the precise threats known at this site. Information on the current status, population trends and threats is needed.

The establishment and continued spread of weeds threatens the small remnant indigenous vegetation cover.

Reduction in water quality from adjacent and upstream land use, development of the riparian margin, stock pollution, and low flows due to irrigation abstraction are recognised threats (Marlborough District Council, 1998) and may be impacting on natural values. Sediment loads are also likely to have increased with the historic loss of forest cover in the catchment and more recently the conversion of increasingly large areas of land to viticulture, where the soil is kept permanently tilled or sprayed and exposed to the elements. Water take from the river is a concern with regard to residual flows during drier periods.

ECOLOGICAL SIGNIFICANCE ASSESSMENT REPORT
Kekerengu – Site SNA717



1

MARLBOROUGH DISTRICT
ECOLOGICAL SIGNIFICANCE ASSESSMENT REPORT

Property Number: 182975
Name: Waima River Mouth
Landowner(s)/Occupier(s): M Greenlaw, LINZ, NZTA
Ecological District: Kekerengu
Surveyed by: Geoff Walls & Mike Aviss
Date: 30 September 2020
Number of Significant Sites: 1

THE SETTING

The Kekerengu Ecological District, the northern-most of three districts in the Kaikoura Ecological Region, is a zone of low coastal hills composed of sedimentary rocks (sandstone, limestone and mudstone), loess and recent river and coastal deposits. It has a dramatic coastline exposed to south and east, with an abrupt directional change at Cape Campbell. It is a very dry area with hot summers and strong winds channelled by Cook Strait. The original vegetation was probably predominantly forest but now consists of regenerating forest, shrublands and silver tussock grassland, all within a pastoral land use.

The northern zone of the Kekerengu ecological district is defined by the Flaxbourne River in the south, and Lakes Grassmere (Grassmere Ecological District) and Elterwater in the west. Both lakes are significant, Grassmere being a coastal lagoon managed for salt production, Elterwater being an internal drainage basin, one of few examples in New Zealand. Both features may reflect the dry climate, around 600 millimetres per year. The district is hill country. The highest points are on the Limestone Ridge (350 metres) and London Hill (322 metres) in the south, Mt Misery (Ref. Grassmere, 282 metres) centrally, and Trig A (243 metres) in the north. The deeply incised streams flow mostly to the north in the western part of the area, but to the east along the eastern coast. One of the latter, Boo Boo Stream, is misnamed from pupu, meaning spring, for there is a permanent, rock-encased spring near the head of one of its tributaries on Flaxbourne Station.

The area is geologically complex. In general terms an older Mesozoic core is bordered on both sides by a younger Tertiary flank. The youngest strata (Pliocene and Miocene marine deposits) form very unconsolidated mudstone ('papa') and gravel which erode into steep, bare cliffs along the northern coast. Inland there is a sequence west to east of Jurassic to Upper Cretaceous sandstone (greywacke) which accounts for most of the high points. The dominant geological feature, which runs the length of the area, is a limestone ridge of Lower Tertiary age. The various geological bands are separated by north-south fault-lines. Windblown loess soils form a surface layer in places. The geological complexity underlies landscape and habitat diversity. The landforms are particularly scenic, sometimes forming gentle smooth terrain, sometimes eroding to form a 'badlands' terrain.

Although most of the land was probably once forest covered, none of the original forest remains. Being a summer dry area there may have been a mosaic of forest, shrubland and grassland. Totara logs have been uncovered in valleys near Cape Campbell (pers. comm., Robbie Peter, Cape Campbell Station). Samples have been collected and await identification. A dryland forest of totara (with matai in the sheltered valleys), kanuka and kowhai, with akiraho and broadleaf on the rocky slopes, may have dominated. Shrublands of prostrate kowhai occurred on inland rocks, takutai (*Olearia solandri)* was abundant in coastal areas, along with matagouri and Shrubby tororaro (*Muehlenbeckia astonii)* may have occurred in many open sites, and silver tussocks would have been scattered throughout. The nearest beech trees in the ecological district are located on Tar Barrel Station, just north of the Waima River mouth. It seems likely that some beech would have grown in the moister parts of the area on the old sandstone.

The limestone masses are inherently unstable, and have eroded into cliffs, steep outcrops, precipitous gullies and mobile screes. For that reason, they have developed a suite of plants found nowhere else. They include various daisies and small fleshy herbs. Plants normally found in the mountains, such as big speargrasses, also occur on the limestone, in places very near the coast.

People have lived in the district for centuries. The first settlers were Maori, who were probably based primarily near the coast and around large wetlands, but who made regular forays into the hinterland. Plantations of karaka trees, dune middens, garden sites and earthworks such as pa terraces are the most tangible signs of those former inhabitants. There are other less obvious signs, some of which are contained in oral history. Maori fires though substantially changed the natural pattern of vegetation and replaced the forest and much of the shrubland with silver tussock. In many places this tussock would have been so dense that woody species would have been excluded. Since European settlement and farming began 150 years ago the silver tussock cover has been thinned and shrubs have been able to regenerate. The dominant vegetation pattern today reflects the degree to which this colonisation has been permitted to proceed within the farming regime. Tauhinu (*Ozothamnus leptophyllus*), takutai (*Olearia solandri)*, porcupine shrub (*Melicytus "Waipapa"*), manuka (*Leptospermum scoparium*), matagouri (*Discaria toumatou*) and native broom (*Carmichaelia australis*) are the most widespread shrubs in the current vegetation pattern, capable of growing on all terrains but especially on slopes with a southern aspect.

SIGNIFICANT ECOLOGICAL SITES

The whole area defined on the location map is deemed to be ecologically significant.

Site 717: Waima River Mouth; NZTM E1692500 N5360400, 38 hectares.

Waima River Mouth

Landform

The site is the leading portion of the braided floodplain of a dynamic river that carries high quantities of limestone debris associated with frequent severe tectonic activity. It is entirely coastal, and subject to massive changes from storm sea surge, king tides, high rainfall events and human activities. It includes uplifted beach gravel (mostly argillite and igneous rocks from the inland mountains) that has been transported along the coast by long-shore drift. At the river mouth are two estuarine areas, an elongated gravel "island" and some sand dunes. The river makes its way through these with apparent trepidation, because it has yet to settle after the massive earthquake sequence in November 2016. In the northern part of the site is an elongated wetland (Greenlaw Wetland). It has been identified separately by MDC as a Significant Wetland.

Vegetation

The wetland has some small areas of raupo and a scattering of rushes and sedges, some of which are native species. Other naturally-occurring native plants include harakeke, cabbage tree, karamu (*Coprosma robusta*), mingimingi (*C. propinqua*), karamu x mingimingi hybrids, takutai (*Olearia solandri*) and some young kowhai (*Sophora longicarinata,* a local species). Much of the wetland is covered in willows. The owners have planted manuka, harakeke and a range of "exotic natives", species native to NZ but not the ecological district. These include pohutukawa, karo (*Pittosporum crassifolium*) and *P. ralphii*, all of which have the potential to proliferate and spread widely. Plantations of exotic conifers occupy about one-fifth of the SNA site's area and more or less encircle the wetland.

The rest of the site is in two parts. The middle of the site is a broad area of floodplain that has been elevated above the currently active floodplain. It is clad in low-growing plants: native mat daisies (mainly Raoulia australis. Pimelea prostrata, Muehlenbeckia axillaris and some grasses) and exotic grasses and herbs, of which stonecrop (Sedum acre), a small highly invasive succulent, is most abundant. There are scattered matagouri bushes, the occasional dwarfed ngaio and clumps of introduced iceplant.

The other part, occupying the south and east of the site, is almost devoid of vegetation. It is the stretch of active floodplain that meets the sea and the river's outlet itself. The floodplain is almost entirely limestone material washed from the hill country.

Flora

While no nationally threatened plant species were found during the survey, there was at least one that is classified as At Risk - Declining: coastal mat daisy Raoulia aff. hookeri "coast". Sand tussock (Poa billardierei) and swamp nettle (Urtica perconfusa), also At Risk - Declining, were not found but both could be present. Coastal gravel-field vegetation dominated by native mat daisies (Raoulia australis and R. "coast") and prostrate native daphne (Pimelea prostrata) is nationally rare.

Fauna

The site is of high significance to coastal birds. Black-billed gull (Nationally Critical), black-fronted tern (Nationally Endangered), Caspian tern (Nationally Vulnerable), white-fronted tern (At Risk – Declining), wrybill (Nationally Vulnerable), banded dotterel (Nationally Vulnerable), black-fronted dotterel (At Risk - Naturally Uncommon), red-billed gull (At Risk – Declining) variable oystercatcher (Recovering) and New Zealand pipit (At Risk – Declining) all feed, breed and rest there. Other coastal birds, including shags, penguins, oystercatchers, stilts and southern black backed gulls, also depend on the site. Native wetland birds present include grey teal, shoveler ducks, paradise shelduck, pukeko, kingfisher, white faced heron, harrier and welcome swallow. Fernbird, spotless crake, banded rail and marsh crake could possibly occur too. Bush birds present include bellbird, fantail, silvereye and riroriro. Native fish, including nationally threatened species, are in the catchment and are likely to make use of the stream and wetland. Koura (crawlies, freshwater crayfish) are also in the catchment so are probably in the wetland. Geckos, skinks, katipo, sand scarab and shore earwig are probably all present in the strand zone. Seals undoubtedly visit the site and either haul out to rest or explore the river mouth.

Other features

The locality has a very rich human heritage. It was probably occupied soon after the first settlers arrived from East Polynesia. The site shows evidence of pre-European occupation and has no doubt been an attractive place to camp seasonally, live permanently or stop at while travelling up or down the coast, not just for the first settlers, but for all people.

ECOSYSTEMS REPRESENTED AT THE SITE	
Ecosystem type	**% area of site**
Lowland freshwater wetland	15
Estuarine wetland	5
River-mouth floodplain, active, limestone	30
River-side floodplain, uplifted, inactive, limestone	20
Gravel beach and dunes, uplifted	8
Gravel beach and dunes, active, newly forming	8
Sand dune system	2
Exotic conifer plantations	9
Dwellings and gardens	3

Assessment of ecological significance

***(a) Representativeness**: does the site represent a good example of one of the characteristic types of native vegetation in the district?*

The site is highly representative of the coastal ecosystems at the mouths of the many rivers that carry high tectonic debris loads and flow abruptly to the sea in the ecological district.

***(b) Rarity**: are there rare species or communities?*

Coastal wetlands and dunes are nationally and regionally rare. Those on limestone are more special still. The site is important to many rare birds, other rare fauna (lizards, fish, invertebrates) and some rare plants and unusual plant communities.

***(c) Diversity and pattern**: is there a notable range of species and habitats?*

The site has considerable species and habitat diversity for its size.

***(d) Distinctiveness/special ecological characteristics**: are there any features which make the site stand out locally, regionally or nationally?*

The limestone substrate is regionally distinctive. The degree of recent tectonic uplift is nationally significant. The gravel-fields are classified as nationally rare, yet are almost completely trashed repeatedly by people driving off-road for recreation.

(e) *Size and shape*: *how do size and shape influence character and viability?*

The site is considerable and compact.

(f) *Connectivity*: *what is the degree of ecological connections with surrounding areas?*

The site is aquatically connected to the whole catchment and the ocean. It is an integral part of a wild coast. Other native vegetation is nearby.

Sustainability: *does the site possess the resilience to maintain its ecological integrity and processes?*

The site is currently in marginal ecological condition. The coastal birds are seriously disrupted in breeding, feeding and resting by the recreational vehicle activity. The highly distinctive shore gravel mat daisy-daphne vegetation is being destroyed as it recovers by the vehicles. There are several weeds and exotic predators on the scene. Sustainability then is about changing management tack from hands off to hands on ecological restoration and custodianship.

Tabulated ranking of the above criteria using the scale: L = Low M = Medium H = High

Criterion	Ranking
Representativeness	H
Rarity	H
Diversity and pattern	M-H
Distinctiveness/special ecological characteristics	H
Size and shape	M-H
Connectivity	H
Sustainability	M-H
Overall ecological significance	**H-**

Ranking for National Biodiversity Priorities

A site that triggers any of the four priorities is significant nationally.

Priorities	Yes/No
1. Land environment with less than 20% indigenous vegetation cover left (LENZ Level IV)	**Yes**
2. Indigenous vegetation or habitat for indigenous fauna associated with sand dunes or wetlands.	**Yes**
3. Indigenous vegetation or habitat for indigenous fauna associated with originally rare ecosystem types (not covered above; see list)	**No**
4. Habitat of acutely and chronically threatened indigenous species	**Yes**

Suggestions for future management

Waima River Mouth

The most urgent management intervention required is protection of the breeding and migrating coastal birds that use the many shallow braids, channels, backwaters, pools and shingle banks. That will involve stopping the use of the site as a recreational vehicle playground. It will take community buy-in and may need some form of wardening or surveillance and enforcement. A first step might be provision of easy public vehicle access to the site and a good walking track loop, designed to avoid disruption to the breeding and feeding birds. Alternative places for the recreational vehicles, without the high ecological values, could be provided. Good public information about the site would help too.

In the wetland, weeds are compromising its natural integrity. Willows are having the biggest impact, but at the same time provide useful habitat for some native birds. The willows could be removed in stages so that the wetland forest habitat did not all disappear at once. Pockets of young willows and other weeds should be destroyed so that they don't become rampant.

Weeds that threaten the ecological integrity of the raised floodplain include old man's beard, sweet briar, buddleia, cotoneaster (2 species), various former garden plants, introduced iceplant and introduced herbs and grasses. The gravel-fields as yet have very little plant cover, just a scattering of horned poppy, iceplant and a few mat daisies that have escaped the vehicle onslaught. The horned poppy is not considered a threat at this stage, but the iceplant is.

Boosting the native planting on the wetland margins with appropriate native species would provide more diversity and act as a buffer. The obvious plants to use are: harakeke/lowland flax, cabbage tree, lowland ribbonwood, saltmarsh ribbonwood, narrow-leaved lacebark, ngaio, kowhai, broadleaf, kahikatea, takutai, shrubby tororaro and totara. Kanuka and manuka could also be used in places. It would also be an appropriate site to plant coastal tree broom (*Carmichaelia muritai*), endemic to the ecological district, with a very limited known range and classified as Nationally Endangered.

The marram grass on the dunes and raised gravel beach surfaces could be progressively replaced with spinifex and pingao, sand tussock, sand coprosma and sand daphne. Shore milkweed could be used to make a special feature. Ngaio is naturally colonising these surfaces, suggesting that pockets of ngaio forest could be established there.

Predator control would make the site safer for native birds, lizards and invertebrates.

The residents are committed to an ethic of nurturing nature. They are doing some good planting, but their knowledge of the ecology of the South Marlborough coast and of native plants appears limited at present. They are intelligent thoughtful friendly people – potentially perfect custodians.

APPENDIX

Photographs of representative and/or special features.

Below: Panorama at eastern estuarine area and the river outlet (4 photos). Note tyre marks.

8

9

Below: A 6 photo panorama of the northern estuarine area, the river outlet, a gravel "island", active floodplain, raised "inactive" floodplain and the outlet of the Greenlaw Wetland.

10

11

Below: Photos of the Greenlaw Wetland.

12

Below: Photos of the active riverbed and the adjacent raised floodplain on the southern side of the Greenlaw property. (4 photos, 180degrees)

14

Below: Vegetation of the raised "inactive" floodplain: matagouri, *Pimelia* and *Raulia*.

15

Above: *Meuhlenbeckia axillaris* **Below:** *Sophora longicarinata*, the local limestone kowhai.

16

Above: Raulia hookeri “coast”. **Below:** Sand scarab beetles live under driftwood.

17

Below: Panorama of 7 pics on the western side near where the river enters the lagoon.

18

19

20

Below: Excellent wading bird habitat at the lagoon but note the tyre marks in the waterway.

21

Above and below: many threatened birds use the site, including banded and black fronted dotterels, black- and red-billed gulls and Caspian and white fronted terns.

23

frontiers in Ecology and Evolution

ORIGINAL RESEARCH
published: 19 November 2021
doi: 10.3389/fevo.2021.767548

Cataclysmic Disturbances to an Intertidal Ecosystem: Loss of Ecological Infrastructure Slows Recovery of Biogenic Habitats and Diversity

David R. Schiel[1], Shawn Gerrity[1], Shane Orchard[1], Tommaso Alestra[1], Robyn A. Dunmore[2], Thomas Falconer[1], Mads S. Thomsen[1] and Leigh W. Tait[3]*

[1] Marine Ecology Research Group, School of Biological Science, University of Canterbury, Christchurch, New Zealand, [2] Cawthron Institute, Nelson, New Zealand, [3] National Institute of Water and Atmospheric Research, Christchurch, New Zealand

OPEN ACCESS

Edited by:
Yun-wei Dong,
Xiamen University, China

Reviewed by:
Maura Geraldine Chapman,
The University of Sydney, Australia
Nelson Valdivia,
Universidad Austral de Chile, Chile
Megan Tyrrell,
Waquoit Bay National Estuarine Research Reserve, United States

***Correspondence:**
David R. Schiel
david.schiel@canterbury.ac.nz

Specialty section:
This article was submitted to Biogeography and Macroecology, a section of the journal Frontiers in Ecology and Evolution

Received: 31 August 2021
Accepted: 28 October 2021
Published: 19 November 2021

Citation:
Schiel DR, Gerrity S, Orchard S, Alestra T, Dunmore RA, Falconer T, Thomsen MS and Tait LW (2021) Cataclysmic Disturbances to an Intertidal Ecosystem: Loss of Ecological Infrastructure Slows Recovery of Biogenic Habitats and Diversity. Front. Ecol. Evol. 9:767548. doi: 10.3389/fevo.2021.767548

Understanding the resilience and recovery processes of coastal marine ecosystems is of increasing importance in the face of increasing disturbances and stressors. Large-scale, catastrophic events can re-set the structure and functioning of ecosystems, and potentially lead to different stable states. Such an event occurred in south-eastern New Zealand when a Mw 7.8 earthquake lifted the coastline by up to 6 m. This caused widespread mortality of intertidal algal and invertebrate communities over 130 km of coast. This study involved structured and detailed sampling of three intertidal zones at 16 sites nested into four degree of uplift (none, 0.4–1, 1.5–2.5, and 4.5–6 m). Recovery of large brown algal assemblages, the canopy species of which were almost entirely fucoids, were devastated by the uplift, and recovery after 4 years was generally poor except at sites with < 1 m of uplift. The physical infrastructural changes to reefs were severe, with intertidal emersion temperatures frequently above 35°C and up to 50°C, which was lethal to remnant populations and recruiting algae. Erosion of the reefs composed of soft sedimentary rocks was severe. Shifting sand and gravel covered some lower reef areas during storms, and the nearshore light environment was frequently below compensation points for algal production, especially for the largest fucoid *Durvillaea antarctica/poha*. Low uplift sites recovered much of their pre-earthquake assemblages, but only in the low tidal zone. The mid and high tidal zones of all uplifted sites remained depauperate. Fucoids recruited well in the low zone of low uplift sites but then were affected by a severe heat wave a year after the earthquake that reduced their cover. This was followed by a great increase in fleshy red algae, which then precluded recruitment of large brown algae. The interactions of species' life histories and the altered physical and ecological infrastructure on which they rely are instructive for attempts to lessen manageable stressors in coastal environments and help future-proof against the effects of compounded impacts.

Keywords: earthquake, intertidal, communities, resilience, recovery, fucoid, algae, invertebrate

INTRODUCTION

There has been renewed interest in large and usually infrequent disturbances. As the pace of change in climatic extremes has increased, there is an increasingly urgent need to better understand processes underlying the persistence, resistance, resilience, adaptive capacity and recovery from events such as catastrophic fires, heat waves, hurricanes, and floods across all of earth's ecosystems (Lubchenco and Karl, 2012). Such understanding is a fundamental requirement for the design of effective management (Dale et al., 1998; Chambers et al., 2019). The basic concept involves attention to the vulnerabilities and resilience of ecosystems and communities. Holling's (1973) initial definition of resilience was a measure of the ability of systems to absorb changes of state and driving variables, and yet still persist, and stability as the ability of a system to return to an equilibrium state after a temporary disturbance. Many definitions and the implications of component processes and thresholds have been a focus of subsequent discussions (e.g., Walker et al., 2004; Brand and Jax, 2007). The severity or intensity, frequency or return time, and scale of disturbances have been repeatedly highlighted as features that underpin the robustness of ecosystems and their ability to resist and recover from disturbance (e.g., Levin and Lubchenco, 2008). Large disturbances can re-set the "successional clock," leaving a residual assemblage that provides a legacy on which subsequent patterns build (Paine et al., 1998). Falk et al. (2019) state that resilience responses are emergent properties from the component processes of persistence, recovery and re-organization. Recovery is influenced by the spatial and temporal scale of initial impacts, as well as the interactions and requirements of key species in the post-disturbance environment. Depending on all of these factors, an ecosystem may or may not return to its former state.

Many recovery outcomes depend on the extent to which the fundamental ecological "infrastructure" has been altered by a disturbance. The concept of "ecosystems as infrastructure" has been discussed since the 1980s and has many definitions and uses involving the elements of inter-related systems providing goods and services to humans (Fulmer, 2009; da Silva and Wheeler, 2017). The concept can be extended, however, to include inter-relationships between species, and the provision of conditions conducive to the survival and persistence of the ecosystems themselves. These "goods and services" of their own making underpin the health and resilience of many characteristic ecosystems, particularly those that have become adapted to survive and thrive in harsh environments.

In the case of intertidal marine systems, much of the biophysical infrastructure on which species and communities build is affected by a wide range of stressors operating over many spatial and temporal scales. The litany of stressors is long and includes eutrophication, marine heat waves, overfishing, invasive species, storms and wave events, coastal development, and sediment from intensive land use, among others (e.g., Schiel, 2009), and additional step-change events (e.g., Orchard et al., 2021). Each of these is known to affect coastal ecosystems through impacts on vulnerable species, ecological structure, and diversity, thereby altering ecological functions and services. Although highly context-dependent because of varying species' life history traits, life spans and ecological niches, natural recovery is compromised by the degree of change in the physical conditions on which they rely and to which they have adapted (e.g., Bekkby et al., 2020). On nearshore rocky reefs, such changes may involve increased air or sea temperatures (Schiel et al., 2004; Cavanaugh et al., 2019; Smale et al., 2019; Thomsen et al., 2019), smothering by sediments (Airoldi, 2003; Schiel, 2006), a compromised light environment in the water column (Tait et al., 2021), human access and direct impacts on reef communities (Povey and Keough, 1991; Schiel and Taylor, 1999; Van De Werfhorst and Pearse, 2007), and altered wave forces (Denny, 1985; Gaylord and Denny, 1997; Schiel et al., 2016), all of which can affect the fundamental requirements of benthic species to attach, survive and thrive.

These issues came to the fore when a large earthquake struck the northeast coast of the South Island of New Zealand (NZ) in November 2016. The Mw 7.8 Kaikôura earthquake event was one of the most complex ever recorded (Hamling et al., 2017; Holden et al., 2017; Shi et al., 2017; Xu et al., 2018). Although originating inland, the stress release activated a large number of faults in a northeasterly direction affecting extensive areas of land and sea (Clark et al., 2017; Hamling et al., 2017; Gusman et al., 2018). Vertical displacement affected over 130 km of coastline in a highly variable manner but predominantly in the direction of uplift (Clark et al., 2017; Orchard et al., 2021). Impacts on anthropogenic infrastructure included severe damage to road and rail networks that run close to the sea in this area (Kaiser et al., 2017). Major changes to relative sea-levels, associated with displacement, caused long-lasting effects in comparison to the tidal range of c.2 m. Broad-scale land and seascape changes included the generation of over 170 ha of new terrestrial land and extensive remodeling of intertidal ecosystems (Orchard et al., 2021). Environmental impacts included widespread mortality of algae, invertebrates and fish along virtually the entire coastline, which effectively reset the nearshore ecosystem (Schiel et al., 2019). Some remnant populations remained in areas of lesser uplift but the natural stage was mostly a blank slate for the ecological communities to re-assemble (Orchard et al., 2021). Ecological resilience was greatly tested, with "recovery" to the former state being far from certain because of the loss of connectivity between remaining patches of key habitat-formers such as large algal species. Previous small-scale experiments in which dominant algal canopies had been removed showed that it took up to 8 years for canopies to re-develop and associated communities to re-assemble, even though clearances of $< 10\ m^2$ were surrounded by reproductively active adults (Lilley and Schiel, 2006; Schiel and Lilley, 2011).

Initial post-earthquake surveys showed that some species of large brown algae, almost all of them fucoids, were functionally extinct along many areas of the uplifted coast, so there were few local sources of propagules to re-colonize affected areas (Schiel et al., 2019; Thomsen et al., 2019). It was anticipated, therefore, that re-establishment of algal assemblages would take many years, and that there would likely be a successional sequence as canopies re-formed and understory species that relied on facilitative effects of canopy cover eventually became established (Schiel and Lilley, 2007). There was also ongoing disturbance from post-earthquake shifting of gravels and sand that buried some reefs, while erosion effects were prominent at others (Orchard et al., 2021). Invertebrate populations suffered high mortality with most limpets, and turbinid and trochid gastropods dying relatively soon after the earthquake. Of particular importance economically was the great mortality of NZ black-foot abalone, *Haliotis iris* (Gerrity et al., 2020). Tens of thousands of individuals were propelled upwards beyond the tidal influence where they suffered severe heat stress and died (picture in Schiel et al., 2019). Their recruitment habitats among small rocks in the lowest intertidal and upper subtidal zone were also uplifted along much of the coast, causing concerns about future recruitment rates.

The earthquake, therefore, provided a novel opportunity to test recovery dynamics of a severe and rare large-scale disturbance on a coastal marine system. Other similar studies, primarily from earthquake-prone Chile (e.g., Castilla, 1988; Castilla et al., 2010; Jaramillo et al., 2012; Ortega et al., 2014) and Japan (Sato and Chiba, 2016; Muraoka et al., 2017) have shown multi-year effects on the recovery of both soft shore and rocky reef communities.

The initial hypothesis of our study was that the intertidal zone would eventually shift downward to re-establish on newly available boulders and reefs pushed up from the subtidal zone. We set out to test this with intensive, field-based quantitative surveys done annually for 4 years after the earthquake. To relate recovery dynamics and trajectories to physical changes, we monitored temperatures at many sites, gauged erosion and break-up of the soft sedimentary rocks and substrate accretion effects, and monitored the nearshore light environment. We evaluated changes across tidal zones relative to the initial community structure, which was known from surveys and prior data. We also tested to what extent recovery was related to the degree of uplift, as a gauge of the degree of initial disturbance and relative sea-level change. The results facilitate an evaluation of the recovery dynamics and resilience of this complex reef system.

MATERIALS AND METHODS

Sites and Design

The Mw 7.8 earthquake struck just after midnight, at low tide on 14 November 2016, near the start of austral summer. The coastal zone was lifted by up to c. 6 m around Waipapa Bay, over 2 m near Cape Campbell in the north, < 1 m on Kaikôura Peninsula, and around 1.7 m at Omihi further south with a considerable degree of variation between sites in localized areas (Orchard et al., 2021; **Figure 1**). Coastal cliffs fell over the main coastal highway in many places, blocking access from the north and south, and roads remained closed for over a year. The coast is sparsely populated except around the town of Kaikôura, which is a major tourism destination, and access to coastal sites was difficult. There were few detailed data for intertidal and subtidal communities along this coast except for sites to the north and south, which have been surveyed annually for > 20 y (Schiel, 2011, 2019). Nevertheless, we were able to access sites via air within a week of the earthquake to begin structured surveys of the former intertidal zone over the following few weeks when most species were readily identifiable, even down to small understory species. From these data we established the pre-earthquake condition of most of our sites, which serves as a reference for recovery over the past four years. The extensive rocky shore habitats of this coast support a rich diversity of intertidal and shallow subtidal marine species including habitat-dominating seaweeds, understory species, rock lobsters, New Zealand abalone (pâua) and other invertebrates (Lilley and Schiel, 2006; Schiel, 2006; Gerrity et al., 2020). Physical habitats include a wide variety of substrate types and topographies including near-horizontal platforms and extensive boulder fields, interspersed with dynamic mixed sand-gravel and sandy beaches.

Intertidal Community Surveys

Intertidal surveys were done at eight locations. Replicate sites (usually two) within each location were separated by at least 500 m. Sites and locations were selected to encompass the length of the earthquake-affected coastline and represent different levels of uplift. These were: control (no uplift); low uplift (0.5–1.4 m); medium uplift (1.5–2.5 m); high uplift (4–5.5 m, **Figure 1**). Many were areas of particular ecological, cultural, or commercial importance. Note that there were no unaffected sites to the north that could serve as "controls" due to the predominance of sandy beaches in this area. Rocky reefs and boulders occupy around a third of the earthquake-affected coastline (Gerrity et al., 2020; Orchard et al., 2021). Around 2 km of coastline experienced uplift beyond 4 m.

Surveys were done along 30 m permanent transects, one each within three intertidal zones (low, mid, and high) that are associated with characteristic flora and fauna and have been the subject of many years of surveys and experimental studies on South Island shores (Schiel, 2011). We tried to sample on the lowest tides, generally 0–0.2 above Lowest Astronomical Tide (LAT), with the tidal range being 2 m (Land Information New Zealand, 2018). Tidal heights for the three zones varied by wave exposure but were generally around 0–0.5 m, 0.6–1.2 m, and > 1.2 m above LAT. Initial sampling was completed immediately after the earthquake in the former high, mid and low zones. Most of the uplifted organisms died and disappeared within several weeks. Subsequent "post-earthquake" surveys were done in the newly formed equivalent zones, and these comprise the time series on which recovery trajectories are based. Algae and invertebrates were identified to species level when feasible or to the finest possible taxonomic resolution. Their abundances were recorded in ten 1 m^2 quadrats located randomly along the 30 m transect in each tidal zone. Abundances were expressed as% cover for sessile organisms and as counts for mobile animals (mostly gastropods).

Intertidal community structure was analyzed statistically using a distance-based permutational analysis (PERMANOVA), testing for differences on the final sampling date among uplift groups and sites within them (Uplift- fixed, 4 levels: Control, low, medium, high, and Site- random, nested within Uplift, 16 levels). Data were square-root transformed to de-emphasize the influence of abundant taxa, and analyses were based on Bray-Curtis similarities. For the Bray-Curtis similarity matrices, a dummy variable of 0.01 was used so that double zero data

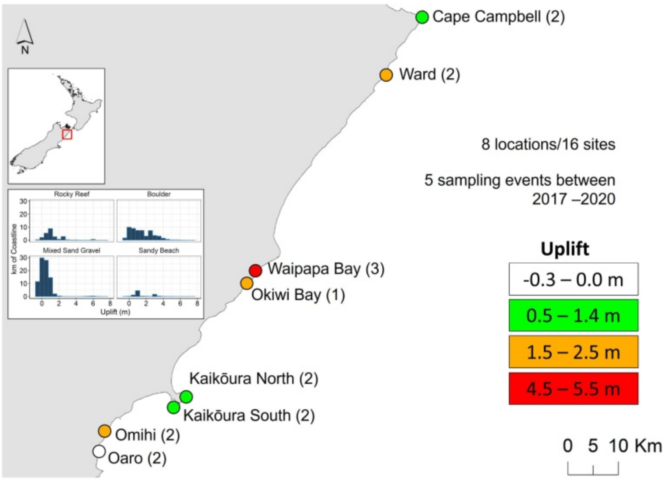


FIGURE 1 | The sites used for repeated monitoring were within 8 "locations," across c.130 km of coastline. The numbers in brackets indicate the number of sites per location. Uplift categories are indicated. Inset shows the km of coastline within different substratum categories (from Orchard et al., 2021). Sampling was done only in "rocky reef" and "boulder" habitats.

were treated as 100% similar. SIMPER was used to identify taxa contributing to dissimilarity between communities (PRIMER, Clarke and Gorley, 2015). The results included here mainly relate to broad taxonomic groups (i.e., groups of species sharing common morphological and life-history traits: canopy-forming large brown algae, lower lying fleshy red algae, and limpets) and not to individual species. PERMANOVA was also used to test uplift and site effects on the full community in the last survey. Principal Coordinate Analysis was used for multidimensional scaling graphs.

The relationship between the degree of uplift and the% cover of large brown algae was tested using an exponential decay model with log-data. The relationship in abundance trends of large brown and fleshy red algae was further explored using a mixed-effects linear regression model including the cover of large brown algae as the response variable and that of fleshy red algae as a fixed effect. Sites were treated as random effects to account for the geographical heterogeneity of the surveys and to partition among- and within-site variability. A random intercept model was used and conditional and marginal pseudo-coefficients of determination were calculated to account for the proportion of variance explained by the fixed factor alone and the proportion of variance explained by both the fixed and random factors (so it accounts for site-by-site differences in addition to the effect of the fixed factor). To address the large variability in the data, a quantile regression model was also developed to test whether the relationship between these algal classes remained stable across the entire range of the data set. One site (Waipapa Bay 1) was excluded from analyses because large brown and fleshy red algae were absent.

Temperature and Light

HOBO temperature data loggers were placed in the low, medium and high tidal zones of each site, and maintained over the study. These were used to assess thermal conditions over the study, and were placed in areas adjacent to our survey transects. Some loggers failed (as is typical) so data sets are not always complete. Each logger was attached to a cage on the reef, so they were not in touch with the reef itself. This provided an accurate assessment of near-reef temperatures of air and water as the tide came in, but not of the surface temperatures of the rocks themselves on which organisms settled.

To gauge the light environment, PAR (photosynthetically active radiation) loggers (Odyssey®, Dataflow Systems Ltd) were deployed in the shallow subtidal zone, and above maximum high water at four locations 16 months post-earthquake (February 2018). These loggers were set to record integrated irradiance every 10 min and were downloaded and cleaned every 2 months for 1 year. Antifouling paint was applied to the top of the sensors (avoiding the sensor) and very little fouling of the sensors was observed over the course of the deployments. Using PAR data collected in the subtidal and at the surface, the daily PFD (photo flux density) was calculated. With daily PFD from the surface and at depth (average depth of the subtidal sensor accounting for tidal flux) the diffuse attenuation coefficient [Kd (PAR), hereafter referred to as Kd] was calculated daily. The daily Kd, the surface PFD and the compensating irradiance of *Durvillaea antarctica/poha* (Tait et al., 2015) were used to calculate the maximum habitable depth threshold for this important foundation species (see Tait, 2019). We then examined the proportion of days for which maximum habitat depth thresholds were shallower than 10 m (as an indication of light levels which may affect productivity of this species) and shallower than 5 m (as an indication of light levels which threaten growth, reproduction and survival).

RESULTS

The most obvious change to the habitats after the earthquake involved widespread algal mortality on the uplifted reefs. For example, Wairepo Reef (Kaikôura) is one of the most studied reefs in NZ and was noted for its lush beds of the desiccation-resistant fucoid alga *Hormosira banksii* (**Table 1**) across large stretches of the reef platform. Numerous experimental studies showed the high diversity of its understory, comprised of over 100 species, many of which relied on the moist canopy cover of *Hormosira* (e.g., Lilley and Schiel, 2006). This reef was lifted by c 0.9 m (Orchard et al., 2021). Temperatures spiked quickly after the earthquake, reaching well over 30°C on many daytime low tides for the next month (**Figure 2A**). Water still covered this reef at high tide, but emersion times increased to 4–4.5 h in the semi-diurnal tidal cycle. Virtually all algae disappeared from this extensive series of platforms over several weeks (Schiel et al., 2019). This pattern of high temperatures in the new mid and low tidal zones persisted in subsequent summers. From winter 2018 to mid-summer 2019, for example, the temperatures in these tidal zones frequently exceeded 35°C for protracted periods from December onward (**Figure 2B**). Any large algae that had recruited over the cooler months could be seen to be desiccating and then dying. This was especially evident in the summer of 2017–18 (**Figure 3A**) when a severe marine heat wave affected the coast of southern NZ, and in conjunction with very low tides and hot air temperatures caused mass mortality of intertidal seaweeds along the east coast of the South Island (Thomsen et al., 2019). Experimental data showed that when a canopy of *Hormosira* was artificially placed onto a reef, temperatures below the canopy never reached a lethal level over the hottest part of summer (2018–19), indicating the potential facilitative effects of a canopy, should one become established, on species below (**Figure 3B**).

One of the formerly dominant species in the low tidal zone along the exposed coast was *Durvillaea antarctica/poha* (these two species occupy the same habitats and are generally indistinguishable in the field; Fraser et al., 2009, 2012). *Durvillaea* species have a massive holdfast, thick stipe, and long leathery blades that both dampen the swell (Hay and South, 1979) and affect the understory species' composition (Santelices et al., 1980; Westermeier et al., 1994). *Durvillaea* had high mortality on virtually all reefs due to uplift and desiccation, and population recovery has been slow. The analysis of the maximum habitable depth threshold for *Durvillaea* showed that some of the most uplifted sites were frequently light-limited (**Figure 4A**). For example, Waipapa Bay sites experienced > 5 m of uplift that was followed by numerous high-sediment events during rainfall because of the erosion of earthquake-damaged hills in nearby catchments, and the light environment was frequently below its compensation point (**Figure 4A**). An initial cover of bull kelp of around 55% at these sites has remained at zero after 4 years. There was some recovery of *Durvillaea* at Omihi (from around 30% cover pre-earthquake to around 15% cover after 4 years), a site of around 1.7 m of uplift. This site frequently experienced

TABLE 1 | Key habitat-forming large brown algae in the study area.

Species	Zone	Repro season	Life span (year)	Notes related to earthquake effects
Durvillaea antarctica/poha	Very low intertidal	Winter	>10	Abundant at most sites pre-EQ; virtually disappeared post-EQ and poor recovery; grows to 10 m long as adults, with great biomass (>20 kg)
Durvillaea willana	Shallow subtidal	Winter	>10	Greatly affected by EQ; occasionally found in lowest tidal zone; fronds grow to several m; great biomass (>20 kg per individual)
Carpophyllum maschalocarpum	Low intertidal band	Spring-summer	Prob v long-lived	Very tough, dense intertwined holdfasts; fronds up to 40 cm; high initial mortality in some sites, but recovered well in sites it previously occupied
Cystophora torulosa	Lower-mid intertidal	Spring-summer	c. 7	Common and abundant pre-EQ; high initial mortality; recovery observed in some places
Cystophora retroflexa	Lower-mid intertidal	Spring-summer	c. 7	Not as abundant as *C. torulosa*, tends to occur slightly lower on shore; high initial mortality, some recovery observed
Cystophora scalaris	Low intertidal	Spring-summer	c. 7	Least abundant of the *Cystophora* spp.; mostly found in tide pools and found only in a few sites in any abundance post-EQ
Hormosira banksii	Mid intertidal	Year round	c. 7	This species was ubiquitous in the mid-intertidal zone of rocky reefs; provides extensive cover on reef platforms, biomass up to 6 kg/m^2 wet wt. Extensive post-EQ mortality and little recovery despite being the most desiccation-resistant fucoid.
Marginariella boryana	Subtidal	Spring-summer	???	Mainly a subtidal species that occurs occasionally in the lowest tidal zone on exposed shores; high initial mortality post-EQ, but recovered slightly in some places
Lessonia variegata	Subtidal	Winter	???, but probably long-lived	A laminarian species; mainly subtidal that occurs occasionally in the lowest tidal zone on exposed shores; high initial mortality post-EQ, but recovered slightly in some places

Only species with > 1% cover at any time are shown. Estimates of reproductive periodicity and life span are derived mostly from long-term experimental studies of the authors. ??? = unknown.

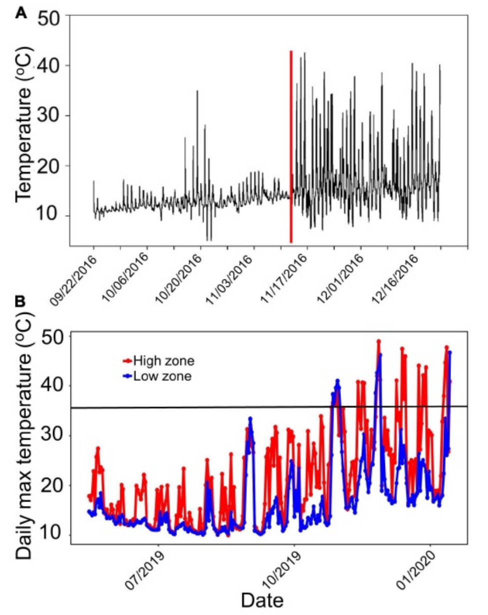


FIGURE 2 | (A) Temperatures within the mid-tide *Hormosira* zone of Wairepo Reef, Kaikoura, before, during and after the earthquake on 14 November 2016; vertical line indicates timing of the earthquake. **(B)** Maximum daily temperatures for the upper mid (red) and lower mid tidal zones at Wairepo Reef, Kaikoura from 2018 to 2019. Inset line indicates approximate lethal temperature for fucoid algae exposed for c 4 h at low tide.

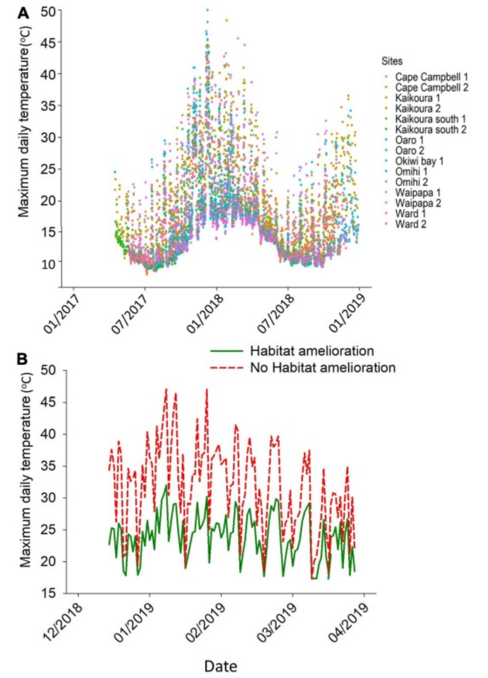


FIGURE 3 | (A) Color-fade graph of low shore temperatures across all sites from January 2017 to 2019. Note the numerous periods for most sites when temperatures exceed 40°C during the summer of 2018. **(B)** Effects of canopy facilitation of understory temperatures, above and below experimental canopy of *Hormosira banksii* on a lower mid tidal zone site.

a compromised light environment below the depth threshold. Furthermore, a moderate rainfall event in April 2018 caused an immediate and dramatic reduction in light availability for all sites monitored, the effects of which lasted for several weeks, especially at Waipapa (**Figure 4B**). Across the full time series, the Waipapa sites experienced very shallow maximum habitable depth thresholds 30% of the time, while the two least uplifted sites had sufficient light > 70% of the time (**Figure 4C**).

Four years post-earthquake, algal cover varied significantly between tidal zones, across uplift levels, and at sites within uplift levels. There was very limited recovery of algae in the high and mid tidal zones of uplifted reefs, with < 10% cover of encrusting coralline and ephemeral green algae, so the focus here is on the abundance of key taxa in the low tidal zones of sites across uplift levels. In the low zone, there were significant differences between uplift levels [Pseudo-$F_{(3,\ 12)}$ = 2.56, $p < 0.01$] and sites within uplift levels [Pseudo-$F_{(12,\ 144)}$ = 9.31, $p < 0.01$]. The abundance of large brown algae generally decreased with increasing uplift across the control and uplift groups (**Figure 5**). One prominent feature was the decline in brown algal cover at 12–16 months at all sites and uplift levels, which coincided with a marine heat wave and high air temperatures combined with calm sea conditions over several days. Large brown algal cover at the Oaro control sites recovered over the next 2 years (**Figure 5A**). Similarly, the large brown algae cover of low uplift sites mostly recovered to pre-earthquake levels by 4 years, although there was considerable variation among sites (**Figure 5B**). Medium uplift sites remained below their pre-earthquake cover, except for one site at Omihi (**Figure 5C**). The high uplift sites around Waipapa, which formerly had around 70% cover of large brown algae (mostly *Durvillaea* spp.) had < 20% cover after 4 years, with one site having no brown algal cover at all (**Figure 5D**). The large brown algae species found on uplifted recovering reefs were primarily *Carpophyllum maschalocarpum* and *Cystophora* spp., with some *Marginariella boryana* and a small cover of the kelp *Lessonia variegata* at a couple of sites (cf. **Table 1**). Overall, the low-uplift and control sites had the highest average large brown algal cover (c. 60%), followed by the medium-uplift (38%), and the high-uplift sites (8%).

Fleshy red algae were the other dominant group of habitat-defining seaweeds along the coast, and they were generally not as affected by the heat wave in the summer of 2017–18 as were

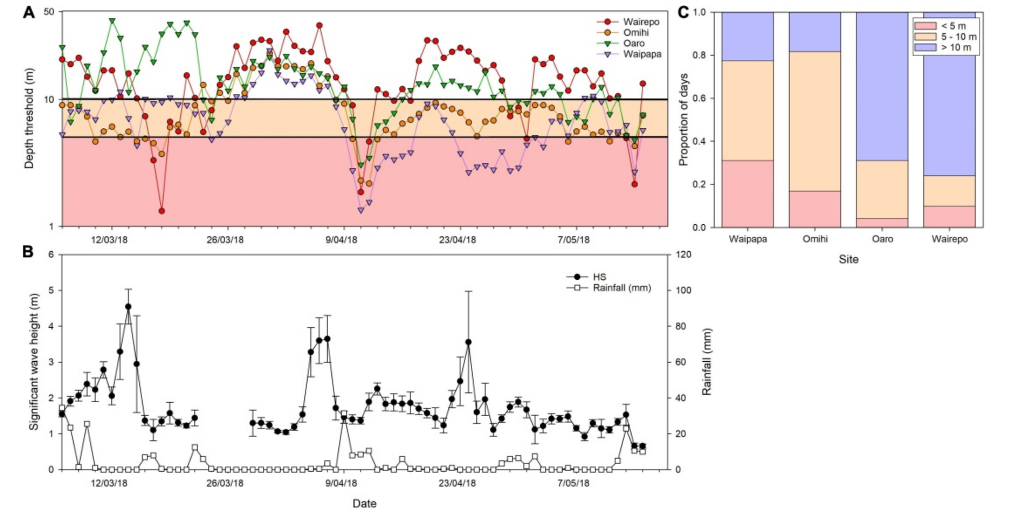


FIGURE 4 | (A) Maximum depth threshold for *Durvillaea antarctica/poha* (as estimated by compensating irradiance) based on measured PAR at multiple sites, **(B)** associated timing of wave events and rainfall, and **(C)** the proportion of days where the light availability depth threshold for *Durvillaea antarctica/poha* is below 10 and 5 m. Depth threshold **(A)** is log transformed.

large brown algae (**Figure 6**). After 4 years, there were significant differences between uplift levels [Pseudo-$F_{(3, 12)} = 1.82$, $p < 0.05$] and sites within uplift levels [Pseudo-$F_{(12, 144)} = 11.10$, $p < 0.01$]. At the control sites, red algae fluctuated over the years and had a slightly lower cover (–10%, **Table 2**) after 4 years than at the start of the study (**Figure 6A**). Red algae in low uplift sites generally had the same cover throughout the study and seemed to be little affected by the earthquake (**Figure 6B** and **Table 2**). However, medium uplift sites showed increases of 25% in cover (across all sites, **Table 2**) over the 4 years (**Figure 6C**), and high uplift sites showed overall increases of 22% in red algal cover over the years in comparison to pre-earthquake conditions (**Figure 6D**). The high-uplift areas had the greatest variation among sites. The taxa of fleshy red algae primarily responsible for these patterns were *Gelidium microphyllum*, *Pterocladia lucida*, *Ceramium* spp., *Gigartina chapmanii*, *Chondria macrocarpa*, *Polysiphonia* spp., *Echinothamnion* spp., and *Champia* sp.

Two prominent features of the recovery process were the relationships between uplift and percentage cover of large brown algae, and between the percentage cover of brown and fleshy red algae. There was an exponential fall-off in brown algal cover with degree of uplift ($Y = 75.5\ e^{-0.499X}$; $r^2 = 0.89$, **Figure 7A**) after 4 years. Regression analyses highlighted a negative relationship between the cover of large brown algae and fleshy red algae. This relationship accounted for 10% of the variability in the abundance of large brown algae in the mixed-effects linear regression, whereas the whole model (accounting also for site-by-site differences) accounted for 36% of the variability. Quantile regression analyses confirmed the presence of a strong negative relationship between the two groups across five different quantiles (q10 slope –0.25, $p < 0.001$; q25 slope –0.35, $P < 0.001$; Q50 slope –0.41, $p < 0.001$; q75 slope –0.44, $p < 0.001$; q90 slope –0.4, $p < 0.01$, **Figure 7B**). These relationships contribute to the observed percentage gains and losses of red and brown algae across tidal zones in the different uplift levels (**Table 2**).

Limpets are the dominant grazers at all study sites and were typically abundant from the mid tidal zone upwards. At 6 months post-quake, control and low uplift sites had the greatest densities of limpets (c. 30 m^{-2}) but after 4 years had the fewest (< 20 m^{-2}; **Figure 8A**). The medium and high uplift sites showed increases in limpets over the 4 years. In particular, the medium uplift sites

TABLE 2 | Overall changes in percentage cover of major taxonomic groups between abundances pre-earthquake (November 2016) and 4 years later (Nov–Dec 2020).

			Tidal zone		
			Low	**Mid**	**High**
Uplift level	**Control**	Brown algae	−10%	+1%	0%
		Red algae	−17%	–4%	+2%
	Low	Brown algae	+4%	−28%	−13%
		Red algae	+5%	0%	+2%
	Medium	Brown algae	−20%	−48%	−10%
		Red algae	+24%	−14%	–9%
	High	Brown algae	−58%	−19%	−1%
		Red algae	+22%	–9%	−1%

Data are compiled across all sites within each uplift category.

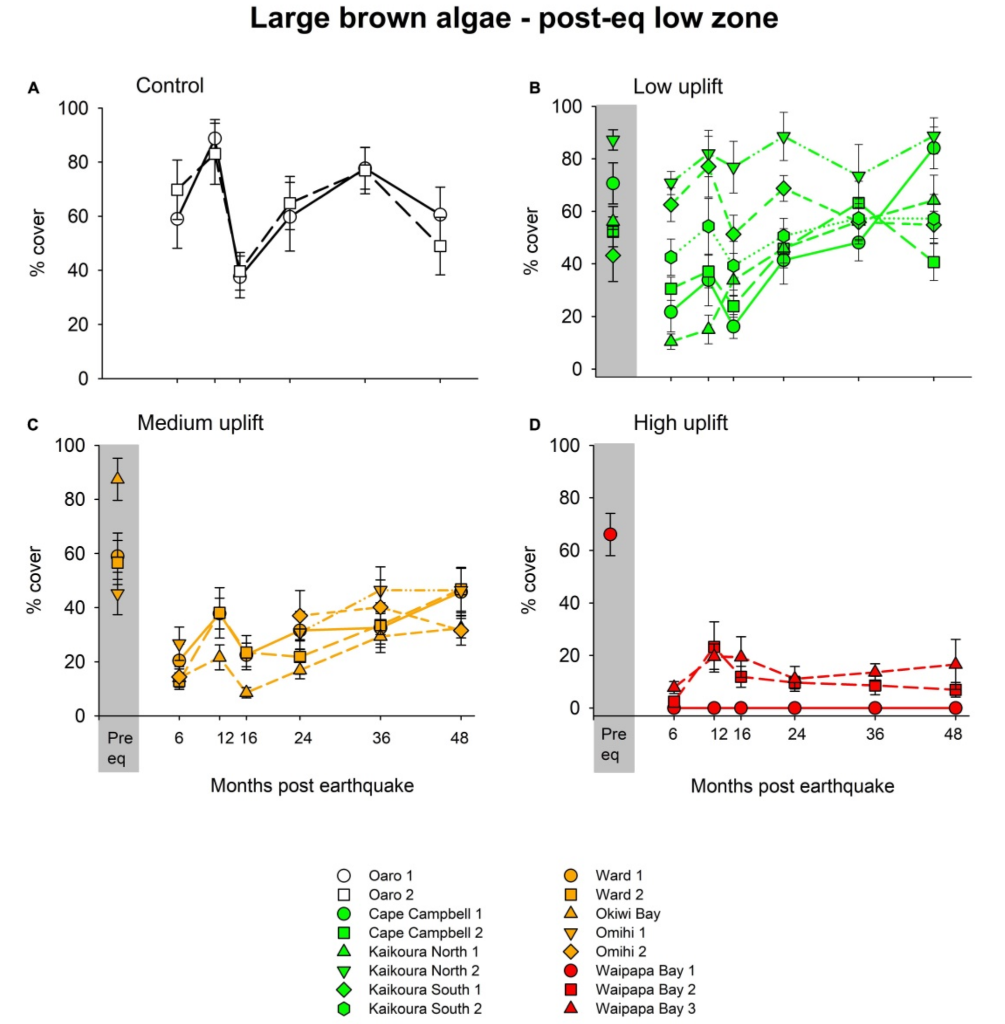


FIGURE 5 | The percentage cover (± SE) of large brown algae at each site within control **(A)**, low **(B)**, medium **(C)** and high **(D)** uplift areas. Note the decline at 12 months, due to a severe heat wave. For the sites sampled in November 2016, the average abundance of large brown algae in the pre-earthquake low zone is displayed in the gray panels.

had an average of 60 limpets m^{-2}, but this was driven mainly by one of the sites (Okiwi Bay) within this uplift level that had 216 limpets m^{-2}. There was therefore a significant difference in sites within uplift levels [Pseudo $F_{(12, 144)} = 2.99$, $p < 0.01$], but not among uplift levels [Pseudo $F_{(3, 12)} = 2.66$, $p = 0.10$]. The limpets were mostly *Cellana* species, but also included *Notoacmea* and pulmonate limpets (*Siphonaria*). The decline in limpet numbers in the control and low-uplift sites did not reflect a widespread decline in the abundance of all limpet species, but was due to the absence of large clusters of *Siphonaria* spp. Another gastropod, the commercially valuable pâua (abalone, *Haliotis iris*) recruited well in all post-earthquake years, with numbers accumulating through to year 4 (**Figure 8B**). This was related to recovering juvenile habitat of small boulder-fields in the lowest

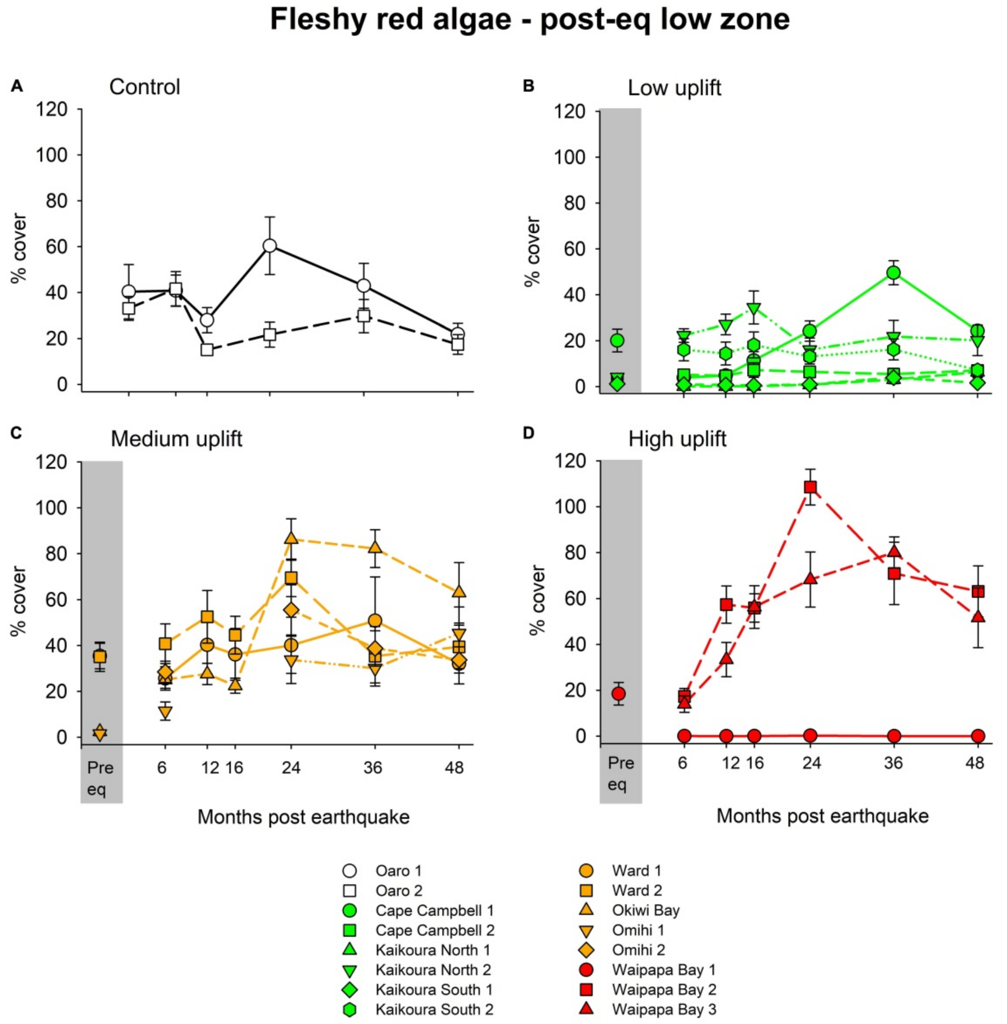


FIGURE 6 | The percentage cover (± SE) of fleshy red algae at each site within control **(A)**, low **(B)**, medium **(C)** and high **(D)** uplift areas. Note the decline at 12 months, due to a severe heat wave. For the sites sampled in November 2016, the average abundance of large brown algae in the pre-earthquake low zone is displayed in the gray panels.

tidal zone, and accumulating numbers of reproductive adults in most shallow rocky habitats (Gerrity et al., 2020).

Taken together, there remained large differences in community structure between sites and uplift levels within tidal zones at 4 years post-quake (**Figure 9**). Multivariate analysis showed uplift had a significant effect on intertidal community composition in the post-earthquake high tidal zone [Uplift: Pseudo-$F_{(3, 12)} = 2.42$, $p < 0.05$] as did sites within uplift levels [Pseudo-$F_{(12, 144)} = 4.96$, $p < 0.01$; **Figure 4A**]. In particular, the control and the low-uplift groups differed from the medium-uplift group because of higher covers of ephemeral green (*Ulva* spp.) and red algae (*Pyropia* spp.). However, this was a reflection of occasional blooms in the abundance of ephemeral algae rather than a real earthquake legacy. Long-lasting earthquake

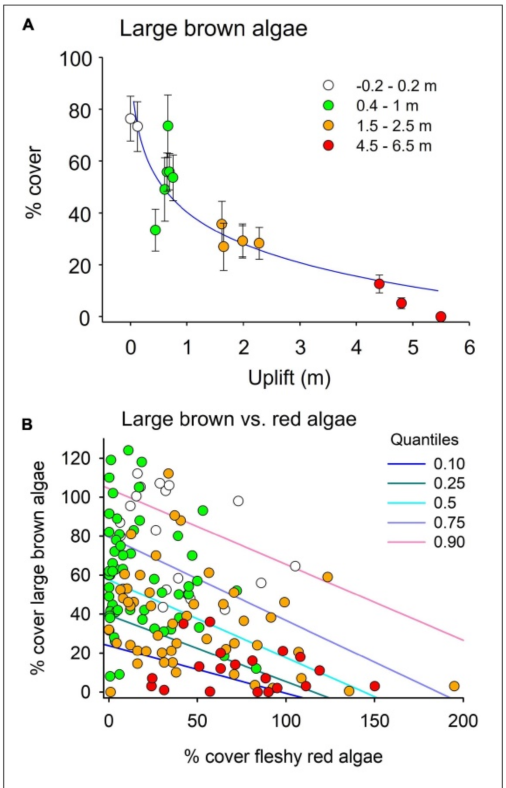


FIGURE 7 | (A) The relationship between percentage cover (± SE) of large brown algae across degrees of uplift. **(B)** Relationship between the abundance of large brown and fleshy red algae 3 years after the earthquake estimated through a quantile regression model. Regression lines are displayed for significant relationships. Symbol colors indicate different levels of uplift (white = no uplift, green = low uplift, yellow = medium uplift, red = high uplift). Data from the high-uplift site of Waipapa Bay 1, where both large brown and fleshy red algae were not present, were not included in this analysis.

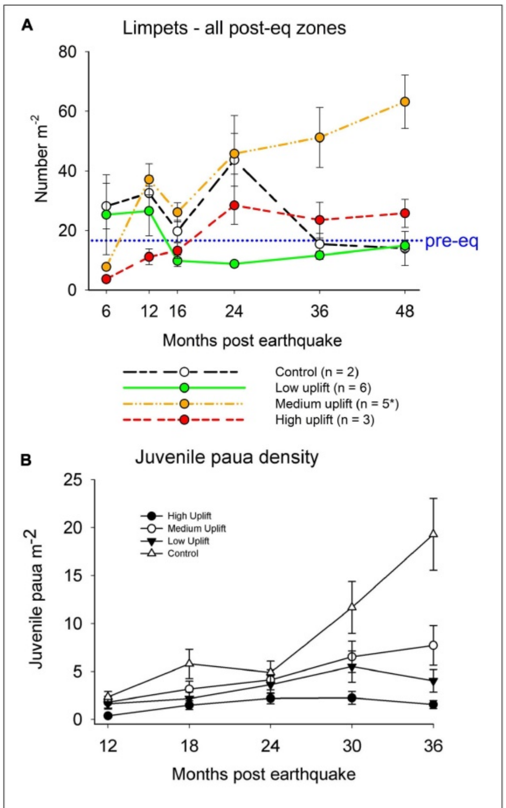


FIGURE 8 | | (A) Time series of the mean number (± SE) of limpets per m^2 across uplift levels. The dotted blue line indicates the average abundance of limpets across sites sampled in November 2016. **(B)** The abundance of juvenile (<80 mm shell length) and adult (> 80 mm) pāua (*Haliotis iris*) in the low intertidal zone of study sites in different degrees of uplift over 3 years post-earthquake.

effects were especially evident in mid zone, where abundant algal communities occurred only at control sites (**Figure 9B**). This led to a significant effect of uplift [Pseudo-$F_{(2, 8)}$ = 2.62, $p < 0.01$], but there was also a significant site effect [Pseudo-$F_{(8, 99)}$ = 9.37, $p < 0.01$]. In the low zone, the composition of benthic communities was different in the low-uplift group (where large brown algae, particularly *Carpophyllum maschalocarpum*, had recovered) compared to the medium- and high-uplift groups [which were characterized by high percentage cover of red algae; Uplift: Pseudo-$F_{(3, 12)}$ = 2.43, $P < 0.01$, **Figure 9C**]. No other uplift group differed from the others but there was significant variability in the structure of benthic communities among sites within each uplift group [Pseudo-$F_{(12, 144)}$ = 7.66, $P < 0.01$, **Figure 9C**].

DISCUSSION

This study has been instructive in understanding the dynamics of recovery from a major disturbance event involving species, communities and the infrastructure on which they build and depend. It was unusual, if not completely novel, to witness such extensive damage to a coastal ecosystem. Rocky reef communities that had been dynamic but intact in structure and function over many decades in the face of periodic storm and wave impacts (Schiel, 2011, 2019) were obliterated by a major event that occurred over a matter of minutes (Clark et al., 2017). The horizontal distance between the former and post-earthquake high tide marks reached c. 200 m in areas of major uplift. It was somewhat disconcerting to see entire shallow coastal assemblages high and dry out of tidal influence. This, however, provided the

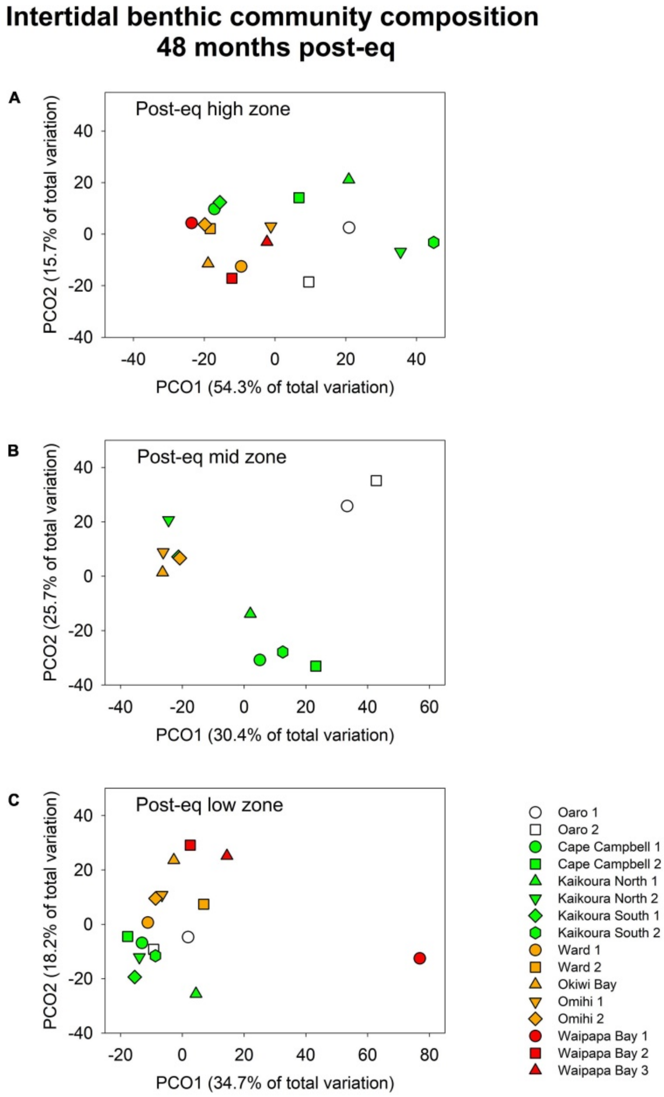


FIGURE 9 | Principal coordinates analysis (PCO) plots showing differences in the composition of benthic communities in the post-earthquake high **(A)**, mid **(B)** and low zone **(C)** across sites with different degrees of uplift 48 months after the earthquake. The symbols represent the centroid of each site and the colors the different levels of uplift (white = no uplift, green = low uplift, yellow = medium uplift, red = high uplift). Sites are ordered north to south within each uplift group. Only the high and the low zone were sampled at high-uplift sites.

opportunity to assess pre-earthquake communities quantitatively that were previously difficult to access and therefore rarely studied in detail.

At most sites, uplifted reef platforms were not compensated by new rocky substrates uplifted from the subtidal zone; this led to a new configuration of low and mid tidal zones that are now near-vertical in places. This morphological change was important in recovery because there was a much smaller tidally influenced zone in which communities could re-assemble. A surprise that unfolded within a month post-earthquake was the loss of speciose algal communities, which had been the focus of decades of studies, in the mid and upper tidal zones of extensive reef platforms, even though they still had tidal coverage. Furthermore, recovery of the low tidal zone was substantially set back by the severe heat wave a year after the earthquake, the timing of which coincided with the replacement of large brown algae by a suite of tough, fleshy red algae. The density and longevity of the latter have precluded settlement of large brown algae in the period since the heat wave. Intertidal platforms and boulders, composed of Paleocene limestone overlain by Oligocene gray mudstones (Kirk, 1977), have also eroded at annual rates > 35 mm at several sites post-quake (Schiel et al., 2019) compared to a long-term average of 1.13 mm yr^{-1} (Kirk, 1977; Stephenson and Kirk, 1998).

Studies from Chile have shown that recovery from coastal uplift can take several years. For example, Castilla (1988) found that uplift of 0.4–0.6 m caused extensive mortality of the laminarian alga *Lessonia nigrescens*, which had formed a conspicuous band on the low shore. As understory species also died, the areas they occupied became covered in barnacles, and *Lessonia* populations were still recovering 3 years after the earthquake. In 2010, a mega-earthquake of Mw 8.8 caused coastal lifting up to 3.1 m (Castilla et al., 2010). Similar to our study, there was widespread mortality of intertidal organisms after being exposed to solar radiation and elevated temperatures, especially *Durvillaea antarctica* and red algae which became bleached and desiccated. Jaramillo et al. (2012) also documented broad-scale impacts of this earthquake and found, as in our study, that the ecological impacts varied strongly with magnitude and direction of land-level change across different shore types and with the mobility of characteristic biota. Because of structural changes to the intertidal zones, the likelihood of recovery to a former state was unclear.

One of the novel features of recovery of the shores in southern NZ is the role of mostly long-lived fucoid algae that are the dominant habitat-formers. These generally have short dispersal distances of propagules, often a matter of meters, and rely on drifting, reproductively active adults for long distance dispersal (Schiel, 2011). Because of the patchy nature of post-earthquake fucoid populations, connectivity to previously occupied areas was compromised and mostly relied on drifting adults for recolonization. This is illustrated by one of the hardest hit taxa, *Durvillaea*. Chilean studies have shown that drift *Durvillaea antarctica* can be abundant onshore (Tala et al., 2019) and it is known that this species can drift extensively in southern seas (Waters, 2008). However, the deposition of drifting fucoids at distant inshore sites is probabilistically low over short time periods (Hawes et al., 2017). Additionally, *Durvillaea* is dioecious, so male and female fronds must arrive inshore together, and this needs to coincide with their relatively short reproductive season (c. 8 weeks) in winter. Few drift *Durvillaea* have been seen at our study sites since the earthquake. As well, its sporelings are known to be highly vulnerable to heat stress (Hay, 1979), and in at least some sites of former abundance the water clarity is so poor that effective growth would be compromised.

Similar impediments to establishment are faced by other fucoids. For example, *Hormosira banksii* is the most desiccation-resistant fucoid because of its mucilage-filled fronds (Brown, 1987). However, the reduced period of tidal immersion, erosion of reefs and increases in fine sediments can all compromise effective recruitment (Alestra and Schiel, 2015). This is coupled with low-tide temperatures frequently exceeding 35°C during summer, killing off the sparse annual recruitment in the lower mid-tide zone and effectively turning this perennial and formerly dominating species into an ephemeral one. This species has declining productivity beyond 25°C (Tait and Schiel, 2013), and its canopy interacts synergistically with other fucoids, such as *Cystophora torulosa* and *Carpophyllum maschalocarpum*, to increase per-area primary productivity (Tait and Schiel, 2011, 2013), which is similar to fucoids elsewhere (Colvard et al., 2014). By comparison to the low-shore fucoids, fleshy red algae seem to be more resistant to heat stress and can remain productive and recover from desiccation at temperatures above 30°C (Smith and Berry, 1986).

In contrast to algae, broadcast-spawning invertebrates recovered quickly, as would be expected. In the first 6 months post-earthquake, the mid and lower intertidal zone was bright green along much of the coast from a massive bloom of mostly *Ulva* spp. As grazers recruited, such blooms became more patchy and ephemeral. One surprise, however, was the recovery of pâua (abalone, *Haliotis iris*) populations in the low intertidal—subtidal margins. Despite the initial loss of recruitment habitat in the lower zone, there was good recruitment in each year following the earthquake (Gerrity et al., 2020). Adult pâua were lifted into this zone from uplifted subtidal reefs and also migrated there from deeper areas, and there was a ban imposed on recreational and commercial fishing along the coast. The combined result was an abundance of shallow pâua populations at levels not seen in decades.

Resilience and recovery clearly need to be considered within the context of species' life histories, life spans, their interactions with each other, and prevailing conditions, which can involve long time trajectories. In this study, recovery has been influenced by a combination of altered topography, increased temperatures at the reef surface, erosion of rocky substrata, sedimentation from earthquake-damaged catchments, a compromised light environment in nearshore waters, and human-induced stressors from increased coastal access around headlands. These processes are acting on a pattern of widespread initial mortality that occurred even at lesser uplifted sites, and are consistent with major re-assembly processes being driven by relatively small increments of relative sea-level change (Orchard et al., 2021). The variable patterns of recovery we have observed reflect the influence of complex site-specific combinations of stressors that are mostly hindering the re-establishment of supportive ecological infrastructure. Exceptions, however, include the recovery of large brown algae at several of the low uplift (<1 m) sites which likely reflects the influence of surviving population remnants, and the expansion of fleshy red algal cover at others in absence of the recovery of brown algae. In relation to the degree of uplift, there are confounding factors among sites from the rate of weathering characteristic of softer substrata that predominate at them. The associated erosion effects are a likely cause of slow recovery on these reefs and exhibit further interactions with turbidity and alterations to the light environment that we recorded in these areas.

It may turn out that there are multiple stable states depending on the level of uplift and its interactions with other factors. These complex interactions affect how communities re-align themselves over longer time periods but notably exert their most pervasive effects through the key habitat-forming species that generate the ecological infrastructure and supportive conditions upon which others depend. Scheffer et al. (2001) point out that state shifts in ecosystems can be reflected more by biological than physical factors because biotic feedbacks can stabilize communities in different ways, and that such shifts may be triggered by catastrophic physical events. So far, our time scales for recovery have not coincided with those needed for stabilization of the most earthquake-affected ecological infrastructure, notably that provided by the large brown fucoid species characteristic of this coast.

Much of the resilience and ecological infrastructure literature addresses nature's goods and services, and potential management interventions to maintain them (da Silva and Wheeler, 2017; Chambers et al., 2019). It would initially seem that there would be few management strategies for ecosystem recovery that could be effective in the face of cataclysmic earthquake impacts followed by a major heatwave. And yet manageable stressors and potentially effective pathways to facilitate recovery trajectories can be identified. For example, there is a current legislative initiative to restrict vehicular traffic on the recovering beaches and tidal platforms around Cape Campbell in the north of the study area. The coast-wide closure of the pāua fishery also resulted in an unanticipated and quick rebound of pāua stocks, which led to current proposals favoring the reduction of commercial and recreational fisheries, and an adoption of a more adaptive and resilience-based management strategy. Additionally, there were lightly affected areas representing ecological "safe havens" along the coast at locations such as Oaro, where traditional management practices of restricted fishing have been overseen by customary Māori tikanga (practices). These highlight the value of multiple protected areas along coastlines which, perhaps by chance and good fortune, can act as insurance policies to provide sources of reproductive propagules to aid the recovery of key habitat-forming species. These examples illustrate that a focus on the protection of ecological infrastructure is a tractable objective for the facilitation of disaster recovery. It can be promoted by the strategy of addressing manageable stressors such as sediment loss and overharvesting, and is indeed essential for the return of desirable states in the aftermath of natural disasters.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

DS wrote the manuscript and led the research program. SG and TA led the field team and collected much of the data. TA and TF did data analyses. RD led subtidal research and helped set up the program and did initial surveys. SO led community liaison and did the analyses of physical changes to the coastline. MT analyzed heat wave effects. LT did photophysiology and light studies. All authors contributed to the article and approved the submitted version.

FUNDING

This research was funded by the MBIE contract UOCX1704 and the Ministry of Primary Industries grant KAI2016-05. Aligned funding was by the Sustainable Seas National Science Challenge (CO1X1901).

ACKNOWLEDGMENTS

We thank Dr. John Pirker for iwi liaison, Jason Ruawai and Te Runanga o Kaikoura for input and support throughout the study, Dr. Sharyn Goldstien for helping with logistics and involvement in the hectic days following the earthquake, NCTIR for granting us access to field sites during the extensive period or cliff stabilization and road closure, Dr. Rich Ford of MPI for support throughout the program, Dr. Mike Hickford for help with logistics, Dan Crossett who helped with field work in parts of the program not reported here, and many others who helped at times with field work and other support.

REFERENCES

Airoldi, L. (2003). The effects of sedimentation on rocky coast assemblages. *Oceanogr. Mar. Biol. Annu. Rev.* 41, 169–171.

Alestra, T., and Schiel, D. R. (2015). Impacts of local and global stressors in intertidal habitats: influence of altered nutrient, sediment and temperature levels on the early life history of three habitat-forming macroalgae. *J. Exp. Mar. Biol. Ecol.* 468, 29–36. doi: 10.1016/j.jembe.2015.03.017

Bekkby, T., Papadopoulou, N., Fiorentino, D., McOwen, C. J., Rinde, E., Boström, C., et al. (2020). Habitat features and their influence on the restoration potential of marine habitats in Europe. *Front. Mar. Sci.* 7:184. doi: 10.3389/fmars.2020.00184

Brand, F. S., and Jax, K. (2007). Focusing the meaning(s) of resilience: resilience as a descriptive concept and a boundary object. *Ecol. Soc.* 12:23. doi: 10.5751/ES-02029-120123

Brown, M. (1987). Effects of desiccation on photosynthesis of intertidal algae from a southern New Zealand shore. *Bot. Mar.* 30, 121–128. doi: 10.1515/botm.1987.30.2.121

Castilla, J. C. (1988). Earthquake-caused coastal uplift and its effects on rocky intertidal kelp communities. *Science* 242, 440–443. doi: 10.1126/science.242.4877.440

Castilla, J. C., Manríquez, P. H., and Camaño, A. (2010). Effects of rocky shore coseismic uplift and the 2010 Chilean mega-earthquake on intertidal biomarker species. *Mar. Ecol. Prog. Ser.* 418, 17–23. doi: 10.3354/meps08830

Cavanaugh, K. C., Reed, D. C., Bell, T. W., Castorani, M. C. N., and Beas-Luna, R. (2019). Spatial variability in the resistance and resilience of giant kelp in southern and baja california to a multiyear heatwave. *Front. Mar. Sci.* 6:413. doi: 10.3389/fmars.2019.00413

Chambers, J. C., Allen, C. R., and Cushman, S. A. (2019). Operationalizing ecological resilience concepts for managing species and ecosystems at risk. *Front. Ecol. Evol.* 7:241. doi: 10.3389/fevo.2019.00241

Clark, K. J., Nissen, E. K., Howarth, J. D., Hamling, I. J., Mountjoy, J. J., Ries, W. F., et al. (2017). Highly variable coastal deformation in the 2016 MW7.8 Kaikōura earthquake reflects rupture complexity along a transpressional plate boundary. *Earth Planet. Sci. Lett.* 474, 334–344. doi: 10.1016/j.epsl.2017.06.048

Clarke, K. R., and Gorley, R. N. (2015). *PRIMER v7: User Manual/Tutorial*. Plymouth: PRIMER-E.

Colvard, N. B., Carrington, E., and Helmuth, B. (2014). Temperature-dependent photosynthesis in the intertidal alga *Fucus gardneri* and sensitivity to ongoing climate change. *J. Exp. Mar. Biol. Ecol.* 458, 6–12. doi: 10.1016/j.jembe.2014.05.001

da Silva, J. M. C., and Wheeler, E. (2017). Ecosystems as infrastructure. *Perspect. Ecol. Conserv.* 15, 32–35. doi: 10.1016/j.pecon.2016.11.005

Dale, V. H., Lugo, A. E., MacMahon, J. A., and Pickett, S. T. A. (1998). Ecosystem management in the context of large, infrequent disturbances. *Ecosystems* 1, 546–557. doi: 10.1007/s100219900050

Denny, M. W. (1985). Wave forces on intertidal organisms: a case study 1. *Limnol. Oceanogr.* 30, 1171–1187. doi: 10.4319/lo.1985.30.6.1171

Falk, D. A., Watts, A. C., and Thode, A. E. (2019). Scaling ecological resilience. *Front. Ecol. Evol.* 7:275. doi: 10.3389/fevo.2019.00275

Fraser, C. I., Hay, C. H., Spencer, H. G., and Waters, J. M. (2009). Genetic and morphological analyses of the southern bull kelp *Durvillaea antarctica* (phaeophyceae: durvillaeales) in New Zealand reveal cryptic species. *J. Phycol.* 45, 436–443. doi: 10.1111/j.1529-8817.2009.00658.x

Fraser, C. I., Spencer, H. G., and Waters, J. M. (2012). Durvillaea poha sp. nov. (fucales, phaeophyceae): a buoyant southern bull-kelp species endemic to New Zealand. *Phycologia* 51, 151–156. doi: 10.2216/11-47.1

Fulmer, J. E. (2009). *What in the World is Infrastructure?*. London: Infrastructure Investor.

Gaylord, B., and Denny, M. (1997). Flow and flexibility. I. effects of size, shape and stiffness in determining wave forces on the stipitate kelps eisenia arborea and pterygophora californica. *J. Exp. Biol.* 200, 3141–3164. doi: 10.1242/jeb.200.24.3141

Gerrity, S., Alestra, T., Fischman, H. S., and Schiel, D. R. (2020). Earthquake effects on abalone habitats and populations in southern New Zealand. *Mar. Ecol. Prog. Ser.* 656, 153–161. doi: 10.3354/meps13458

Gusman, A. R., Satake, K., Gunawan, E., Hamling, I., and Power, W. (2018). Contribution from Multiple Fault Ruptures to Tsunami Generation During the 2016 Kaikoura Earthquake. *Pure Appl. Geophys.* 175, 2557–2574. doi: 10.1007/s00024-018-1949-z

Hamling, I. J., Hreinsdóttir, S., Clark, K., Elliott, J., Liang, C., Fielding, E., et al. (2017). Complex multifault rupture during the 2016 Mw 7.8 Kaikōura earthquake, New Zealand. *Science* 356:eaam7194. doi: 10.1126/science.aam7194

Hawes, N. A., Taylor, D. I., and Schiel, D. R. (2017). Transport of drifting fucoid algae: nearshore transport and potential for long distance dispersal. *J. Exp. Mar. Biol. Ecol.* 490, 34–41. doi: 10.1016/j.jembe.2017.02.001

Hay, C. H. (1979). Some factors affecting the upper limit of the southern bull kelp *Durvillaea antarctica* (Chamisso) hariot on two New Zealand shores. *J. R. Soc. N.Z.* 9, 279–287. doi: 10.1080/03036758.1979.10419408

Hay, C. H., and South, G. R. (1979). Experimental ecology with particular reference to proposed commercial harvesting of *Durvillaea* (Phaeophyta, Durvilleales) in New Zealand. *Bot. Mar.* 22, 431–436. doi: 10.1515/botm.1979.22.7.431

Holden, C., Kaneko, Y., D'Anastasio, E., Benites, R., Fry, B., and Hamling, I. J. (2017). The 2016 Kaikōura Earthquake revealed by kinematic source inversion and seismic wavefield simulations: slow rupture propagation on a geometrically complex crustal fault network. *Geophys. Res. Lett.* 44, 11,320–11,328. doi: 10.1002/2017GL075301

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annu. Rev. Ecol. Syst.* 4, 1–23. doi: 10.1146/annurev.es.04.110173.000245

Jaramillo, E., Dugan, J. E., Hubbard, D. M., Melnick, D., Manzano, M., Duarte, C., et al. (2012). Ecological implications of extreme events: footprints of the 2010 earthquake along the chilean coast. *PLoS One* 7:e35348. doi: 10.1371/journal.pone.0035348

Kaiser, A., Balfour, N., Fry, B., Holden, C., Litchfield, N., Gerstenberger, M., et al. (2017). The 2016 Kaikōura, New Zealand, earthquake: preliminary seismological report. *Seismol. Res. Lett.* 88, 727–739. doi: 10.1785/0220170018

Kirk, R. M. (1977). Rates and forms of erosion on intertidal platforms at Kaikoura Peninsula, South Island, New Zealand. *N.Z. J. Geol. Geophys.* 20, 571–613. doi: 10.1080/00288306.1977.10427603

Land Information New Zealand (2018). *New Zealand Nautical Almanac, 2018/2019 edition, NZ 204*. Wellington: Land Information New Zealand.

Levin, S. A., and Lubchenco, J. (2008). Resilience, robustness, and marine ecosystem-based management. *Bioscience* 58, 27–32. doi: 10.1641/b580107

Lilley, S. A., and Schiel, D. R. (2006). Community effects following the deletion of a habitat-forming alga from rocky marine shores. *Oecologia* 148, 672–681. doi: 10.1007/s00442-006-0411-6

Lubchenco, J., and Karl, T. R. (2012). Predicting and managing extreme weather events. *Phys. Today* 65:31. doi: 10.1063/PT.3.1475

Muraoka, D., Tamaki, H., Takami, H., Kurita, Y., and Kawamura, T. (2017). Effects of the 2011 Great East Japan earthquake and tsunami on two kelp bed communities on the Sanriku coast. *Fish Oceanogr.* 26, 128–140. doi: 10.1111/fog.12198

Orchard, S., Fischman, H. S., Gerrity, S., Alestra, T., Dunmore, R., and Schiel, D. R. (2021). Threshold effects of relative sea-level change in intertidal ecosystems: empirical evidence from earthquake-induced uplift on a rocky coast. *Geohazards* 2, 302–320.

Ortega, K. J., Sáez, C. A., and Macaya, E. C. (2014). Changes in invertebrate assemblages inhabiting *Lessonia spicata* (Phaeophyceae) holdfasts after the 2010 earthquake-mediated coastal uplift in Chile. *Rev. Biol. Mar. Oceanogr.* 49, 129–134. doi: 10.4067/S0718-19572014000100014

Paine, R. T., Tegner, M. J., and Johnson, E. A. (1998). Compounded perturbations yield ecological surprises. *Ecosystems* 1, 535–545. doi: 10.1007/s100219900049

Povey, A., and Keough, M. J. (1991). Effects of trampling on plant and animal populations on rocky shores. *Oikos* 61, 355–368. doi: 10.2307/3545243

Santelices, B., Castilla, J. C., Cancino, J., and Schmiede, P. (1980). Comparative ecology of *Lessonia nigrescens* and *Durvillaea* antarctica (phaeophyta) in central Chile. *Mar. Biol.* 59, 119–132. doi: 10.1007/BF00405461

Sato, S., and Chiba, T. (2016). Structural changes in molluscan community over a 15-year period before and after the 2011 great east Japan earthquake and subsequent tsunami around Matsushima Bay, miyagi prefecture, northeastern Japan. *PLoS One* 11:e0168206. doi: 10.1371/journal.pone.0168206

Scheffer, M., Carpenter, S., Foley, J. A., Folke, C., and Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature* 413, 591–596. doi: 10.1038/35098000

Schiel, D. R. (2006). Rivets or bolts? When single species count in the function of temperate rocky reef communities. *J. Exp. Mar. Biol. Ecol.* 338, 233–252. doi: 10.1016/j.jembe.2006.06.023

Schiel, D. R. (2009). "Multiple stressors and disturbances," in *Marine Hard Bottom Communities*, ed. M. Wahl (Berlin: Springer), 281–294.

Schiel, D. R. (2011). Biogeographic patterns and long-term changes on New Zealand coastal reefs: non-trophic cascades from diffuse and local impacts. *J. Exp. Mar. Biol. Ecol.* 400, 33–51. doi: 10.1016/j.jembe.2011.02.026

Schiel, D. R. (2019). Experimental analyses of diversity partitioning in southern hemisphere algal communities. *Oecologia* 190, 179–193.

Schiel, D. R., Alestra, T., Gerrity, S., Orchard, S., Dunmore, R., Pirker, J., et al. (2019). The Kaikōura earthquake in southern New Zealand: loss of connectivity of marine communities and the necessity of a cross-ecosystem perspective. *Aquat. Conserv. Mar. Freshwat. Ecosyst.* 29, 1520–1534. doi: 10.1002/aqc.3122

Schiel, D. R., and Lilley, S. A. (2007). Gradients of disturbance to an algal canopy and the modification of an intertidal community. *Mar. Ecol. Prog. Ser.* 339, 1–11. doi: 10.3354/meps339001

Schiel, D. R., and Lilley, S. A. (2011). Impacts and negative feedbacks in community recovery over eight years following removal of habitat-forming macroalgae. *J. Exp. Mar. Biol. Ecol.* 407, 108–115. doi: 10.1016/j.jembe.2011.07.004

Schiel, D. R., Lilley, S. A., South, P. M., and Coggins, J. H. (2016). Decadal changes in sea surface temperature, wave forces and intertidal structure in New Zealand. *Mar. Ecol. Prog. Ser.* 548, 77–95. doi: 10.3354/meps11671

Schiel, D. R., Steinbeck, J. R., and Foster, M. S. (2004). Ten years of induced ocean warming causes comprehensive changes in marine benthic communities. *Ecology* 85, 1833–1839. doi: 10.1890/03-3107

Schiel, D. R., and Taylor, D. I. (1999). Effects of trampling on a rocky intertidal algal assemblage in southern New Zealand. *J. Exp. Mar. Biol. Ecol.* 235, 213–235. doi: 10.1016/S0022-0981(98)00170-1

Shi, X., Wang, Y., Liu-Zeng, J., Weldon, R., Wei, S., Wang, T., et al. (2017). How complex is the 2016 Mw 7.8 Kaikoura earthquake, South Island, New Zealand. *Sci. Bull.* 62, 309–311. doi: 10.1073/pnas.1916770116

Smale, D. A., Wernberg, T., Oliver, E. C., Thomsen, M., Harvey, B. P., Straub, S. C., et al. (2019). Marine heatwaves threaten global biodiversity and the provision of ecosystem services. *Nat. Clim. Change* 9, 306–312. doi: 10.1038/s41558-019-0412-1

Smith, C. M., and Berry, J. A. (1986). Recovery of photosynthesis after exposure of intertidal algae to osmotic and temperature stresses: comparative studies of species with differing distributional limits. *Oecologia* 70, 6–12. doi: 10.1007/BF00377105

Stephenson, W. J., and Kirk, R. M. (1998). Rates and patterns of erosion on intertidal shore platforms, Kaikoura Peninsula, South Island, New Zealand. *Earth Surf. Process. Landf.* 23, 1071–1085. doi: 10.1002/(SICI)1096-9837(199812)23:12<1071::AID-ESP922<3.0.CO;2-U

Tait, L. W. (2019). Giant kelp forests at critical light thresholds show compromised ecological resilience to environmental and biological drivers. *Estuar. Coast. Shelf Sci.* 219, 231–241. doi: 10.1016/j.ecss.2019.02.026

Tait, L. W., and Schiel, D. R. (2011). Dynamics of productivity in naturally structured macroalgal assemblages: importance of canopy structure on light-use efficiency. *Mar. Ecol. Prog. Ser.* 421, 97–107. doi: 10.3354/meps08909

Tait, L. W., and Schiel, D. R. (2013). Impacts of temperature on primary productivity and respiration in naturally structured macroalgal assemblages. *PLoS One* 8:e74413. doi: 10.1371/journal.pone.0074413

Tait, L. W., South, P. M., Lilley, S. A., Thomsen, M. S., and Schiel, D. R. (2015). Assemblage and understory carbon production of native and invasive canopy-forming macroalgae. *J. Exp. Mar. Biol. Ecol.* 469, 10–17. doi: 10.1016/j.jembe.2015.04.007

Tait, L. W., Thoral, F., Pinkerton, M. H., Thomsen, M. S., and Schiel, D. R. (2021). Loss of giant kelp, macrocystis pyrifera, driven by marine heatwaves and exacerbated by poor water clarity in New Zealand. *Front. Mar. Sci.* 8:721087. doi: 10.3389/fmars.2021.721087

Tala, F., López, B. A., Velásquez, M., Jeldres, R., Macaya, E. C., Mansilla, A., et al. (2019). Long-term persistence of the floating bull kelp *Durvillaea antarctica* from the South-East Pacific: potential contribution to local and transoceanic connectivity. *Mar. Environ. Res.* 149, 67–79. doi: 10.1016/j.marenvres.2019.05.013

Thomsen, M. S., Mondardini, L., Alestra, T., Gerrity, S., Tait, L., South, P. M., et al. (2019). Local extinction of bull kelp (*Durvillaea spp.*) due to a marine heatwave. *Front. Mar. Sci.* 6:84. doi: 10.3389/fmars.2019.00084

Van De Werfhorst, L. C., and Pearse, J. S. (2007). Trampling in the rocky intertidal of central California: a follow-up study. *Bull. Mar. Sci.* 81, 245–254.

Walker, B., Holling, C. S., Carpenter, S. R., and Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecol. Soc.* 9:5. doi: 10.5751/ES-00650-090205

Waters, J. M. (2008). Driven by the west wind drift? A synthesis of southern temperate marine biogeography, with new directions for dispersalism. *J. Biogeogr.* 35, 417–427. doi: 10.1111/j.1365-2699.2007.01724.x

Westermeier, R., Müller, D. G., Gómez, I., Rivera, P., and Wenzel, H. (1994). Population biology of *Durvillaea* antarctica and *Lessonia nigrescens* (Phaeophyta) on the rocky shores of southern Chile. *Mar. Ecol. Prog. Ser.* 110, 187–194. doi: 10.3354/meps110187

Xu, W., Feng, G., Meng, L., Zhang, A., Ampuero, J. P., Bürgmann, R., et al. (2018). Transpressional rupture cascade of the 2016 Mw 7.8 Kaikoura earthquake, New Zealand. *J. Geophys. Res. Solid Earth* 123, 2396–2409. doi: 10.1002/2017JB015168

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

GeoHazards

Article

Threshold Effects of Relative Sea-Level Change in Intertidal Ecosystems: Empirical Evidence from Earthquake-Induced Uplift on a Rocky Coast

Shane Orchard [1,2,*], Hallie S. Fischman [1], Shawn Gerrity [1], Tommaso Alestra [1], Robyn Dunmore [3] and David R. Schiel [1]

1 Marine Ecology Research Group, University of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand; halliefischman@ufl.edu (H.S.F.); shawn.gerrity@canterbury.ac.nz (S.G.); tommaso.alestra@canterbury.ac.nz (T.A.); david.schiel@canterbury.ac.nz (D.R.S.)
2 School of Earth and Environment, University of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand
3 Cawthron Institute, 98 Halifax Street, Nelson 7010, New Zealand; robyn.dunmore@cawthron.org.nz
* Correspondence: s.orchard@waterlink.nz

Abstract: Widespread mortality of intertidal biota was observed following the 7.8 Mw Kaikōura earthquake in November 2016. To understand drivers of change and recovery in nearshore ecosystems, we quantified the variation in relative sea-level changes caused by tectonic uplift and evaluated their relationships with ecological impacts with a view to establishing the minimum threshold and overall extent of the major effects on rocky shores. Vertical displacement of contiguous 50 m shoreline sections was assessed using comparable LiDAR data to address initial and potential ongoing change across a 100 km study area. Co-seismic uplift accounted for the majority of relative sea-level change at most locations. Only small changes were detected beyond the initial earthquake event, but they included the weathering of reef platforms and accumulation of mobile gravels that continue to shape the coast. Intertidal vegetation losses were evident in equivalent intertidal zones at all uplifted sites despite considerable variation in the vertical displacement they experienced. Nine of ten uplifted sites suffered severe (>80%) loss in habitat-forming algae and included the lowest uplift values (0.6 m). These results show a functional threshold of c.1/4 of the tidal range above which major impacts were sustained. Evidently, compensatory recovery has not occurred—but more notably, previously subtidal algae that were uplifted into the low intertidal zone where they ought to persist (but did not) suggests additional post-disturbance adversities that have contributed to the overall effect. Continuing research will investigate differences in recovery trajectories across the affected area to identify factors and processes that will lead to the regeneration of ecosystems and resources.

Keywords: natural hazards; seismic displacement; post-disaster planning; hydro-ecology; relative sea-level; tipping points; impact assessment; multiple stressors; social-ecological system; New Zealand

check for updates

Citation: Orchard, S.; Fischman, H.S.; Gerrity, S.; Alestra, T.; Dunmore, R.; Schiel, D.R. Threshold Effects of Relative Sea-Level Change in Intertidal Ecosystems: Empirical Evidence from Earthquake-Induced Uplift on a Rocky Coast. *GeoHazards* **2021**, 2, 302–320. https://doi.org/10.3390/geohazards2040016

Academic Editor: Robert Kayen

Received: 9 August 2021
Accepted: 24 September 2021
Published: 29 September 2021

1. Introduction

Relative sea-level trends are pervasive drivers of change in nearshore coastal systems due to the multitude of social and ecological relationships that are structured by the position of land in relation to the sea [1]. Enduring sea-level changes present a specific set of challenges that differ from those associated with periodic extreme events. For example, they are more likely to force long-term adjustments to the spatial configuration of coastal landscapes upon which both periodic extreme events and regular hydrological fluctuations interact [2]. Land-mass displacement mechanisms play a critical role in determining relative sea-level trends and include crustal movements associated with tectonic plates and isostatic responses to stress redistribution associated with glacial de-loading [3,4]. Land surface elevation changes may also result from shallow sources of uplift and subsidence such as the movement of hydrocarbons and groundwater, decay of organic material and compaction of sediments [5–7].

Rapid changes in relative sea-levels can result in widespread disturbance to the antecedent pattern of development in both natural and anthropogenic environments. While various degrees of resistance or resilience to these changes are a feature of social–ecological systems, there are also tipping points beyond which major losses are sustained [8–10]. These thresholds are therefore of fundamental interest for the study of disaster risk reduction and disaster recovery processes to improve strategic planning and preparedness for further change. The potential for rapid displacement events is a serious consideration in seismically active regions that include vast tracts of coastline in territories close to subduction zones in the Pacific Ocean [11]. In addition to the direct impacts of hydrological changes, the cumulative effects of land mass movements have important consequences for the development of climate-change adaptation strategies [12,13]. Depending on the direction of motion, they may potentially mitigate or exacerbate eustatic sea-level rise effects and drive additional interactions with erosion and sedimentation processes [14–16].

There are few contemporary studies of the impact of co-seismic displacement events on coastal communities, but they have undoubtedly been a regular occurrence over geological time periods. The available studies have documented massive changes in the structure and function of coastal ecosystems with associated impacts on the persistence and condition of natural resources, including shellfish and finfish fisheries, coastal forests, blue-carbon ecosystems, and coastal land. Recent examples include a 2007 earthquake in the Solomon Islands that caused subsidence leading to major changes in the spatial extent of mangroves and coastal wetlands [17]. In New Zealand, the 2010–2011 Canterbury earthquakes caused both subsidence and uplift in coastal waterways as a consequence of tilt effects associated with fault-line movements [18]. Ground-surface deformation caused widespread damage to residential properties in low-lying areas, and exacerbated flood risk in areas of subsidence leading to a managed retreat initiative [19–21]. Hydrological changes also caused the loss of coastal wetlands and shorebird habitat in areas of relative sea-level rise as characteristic ecosystems moved landward [2,12,22]. In uplifted areas, impacts included shifts in the salt water intrusion characteristics of lowland waterways leading to the downstream migration of coastal zonation patterns and key habitats [23,24].

In the 2010 8.8 Mw Chilean earthquake, coastal uplift was associated with severe losses of low intertidal sand beach habitat and gains in upper- and mid-intertidal habitat [25,26]. These impacts were influenced by the magnitude and direction of vertical displacement, interactions with substrate types, and the mobility of characteristic biota [25]. Similar circumstances are found in the present study, which investigates impacts of the 2016 7.8 Mw Kaikōura earthquake on the east coast of New Zealand. The associated fault ruptures were among the most complex ever recorded [27–29] and manifested as a highly variable pattern of ground-level displacement but mostly in the direction of uplift [30]. These physical impacts led to widespread reassembly of ecological communities on rocky shorelines [31–33]. Associated social and economic effects included new landscape configurations altering access to the coast, and the closure of commercial fisheries and recreational harvesting of seaweeds and shellfish [34,35].

Objectives

In the aftermath of the earthquake we began a research programme to determine the severity of impacts and investigate prospects for recovery. In this study, our major objectives were (a) to quantify relative sea-level changes caused by the earthquake as close as possible to our post-earthquake study sites in the new intertidal environment, and (b) to estimate the severity of impacts on major habitat-forming macroalgal, particularly large brown kelp and fucoid algae (phaeophyceae) that provide habitat, are highly productive, support a large biomass, and define ecosystem structure on the rocky shores of this coast [36]. Challenges for this assessment included the availability of elevation data within the landforms and ecosystem types of interest, particularly in the new intertidal areas that were previously submerged and therefore outside of the spatial extent of aerial and satellite-based altimetry surveys. There was also a need to include the evaluation of tilt effects that could lead to ground-level displacement gradients across the shore profile, and the potential for continued displacement subsequent to the main seismic event.

Despite being an investigative study of a natural event, we identified several intriguing hypotheses, including the expectation that the short dispersal distances of reproductive large brown algae [37,38] would limit recruitment into areas of newly available habitat, reducing the potential for recovery of impacted population and/or slowing recovery rates. Interactions with other stressors (e.g., erosion, compromised light environment) in the post-quake environment were also expected to limit the potential for recovery through rapid post-quake recruitment and potentially reduce the survival of individuals that were uplifted to new and more physically stressful vertical positions within the tidal range. We expected that testing these hypotheses would manifest as net losses in habitat-forming algae for equivalent pre- and post-quake tidal zones, which are the focus of this study.

Note that these expectations contrast with an alternative hypothesis in which characteristic habitats remain intact due to the survival of key species and/or rapid recovery from recruitment, with the overall intertidal zone simply shifting along the coastal profile in response to new sea levels. In considering the implications, the latter is associated with few negative impacts or quick recovery through seeding from nearby reproductive individuals that survived initial impacts. In contrast, the former are indicative of widespread ecosystem collapse with associated social and economic impacts, such as prolonged fishery closures and other ecosystem service losses.

2. Materials and Methods

2.1. Study Area

The study area is a contiguous 100 km section of coastline stretching from Oaro to Waipapa Bay on the east coast of the South Island of New Zealand. Kaikōura is a small town (population c.2500) located at the base of the Kaikōura Peninsula, a prominent feature on this wave-exposed coast (Figure 1). The coastal environment of this area is renowned for its rocky shore habitats that support a rich diversity of intertidal and shallow subtidal marine species, including habitat-dominating seaweeds, understory species, rock lobsters, New Zealand abalone (pāua), and other invertebrates [33,39]. The area features a wide variety of substrate types and topographies, including near-horizontal platforms and extensive rock and boulder fields, interspersed with dynamic mixed sand-gravel and sandy beaches. Much of the coast is sparsely populated and the single highway along it was severely damaged and closed for over a year. As a result, access to study sites had many logistical constraints, especially in the early phases of the study.

2.2. Data

Our overall approach took advantage of the availability of light detection and ranging (LiDAR) datasets that included three post-quake LiDAR acquisitions and a comparable pre-quake dataset (Table 1). The two immediate post-quake datasets (covering different spatial extents) were combined and all data re-projected to a common reference system and aligned to facilitate vertical displacement analyses based on differencing of 1×1 m digital elevation models (DEM). To evaluate temporal effects, we compared differences derived from the pre-quake (July 2012) to immediate post-quake (December 2016) period, and the immediate post-quake to 18-months post-quake (June 2018) LiDAR datasets. Confounding factors from ground-level changes between the July 2012 LiDAR acquisition and the earthquake event have been reviewed in previous studies [30], and the most significant seismic event in that period was associated with the Cook Strait earthquake sequence of up to Mw 6.6 that produced only small vertical displacements (<5 mm) in the Kaikōura region [40]. The potential for further post-seismic movement has been also assessed in previous work using interferometric synthetic aperture radar (InSAR) and GPS data that showed considerable further displacement effects at many sites in the upper South Island and much farther afield in the lower North Island [41,42]. Other sources of variance affecting differencing analyses include erosion and accretion effects that are difficult to account for in the before–after earthquake comparison. However, we made use of high resolution (0.1 m) RGB imagery captured during the aerial LiDAR acquisition to identify deposition from rockfall, unstable surfaces such as riverbeds, and anthropogenic modifications such as earthworks associated with earthquake recovery activities on the road and rail corridor. These areas were manually delineated where visible in the aerial imagery and the DEMs masked to remove these features from the analysis.

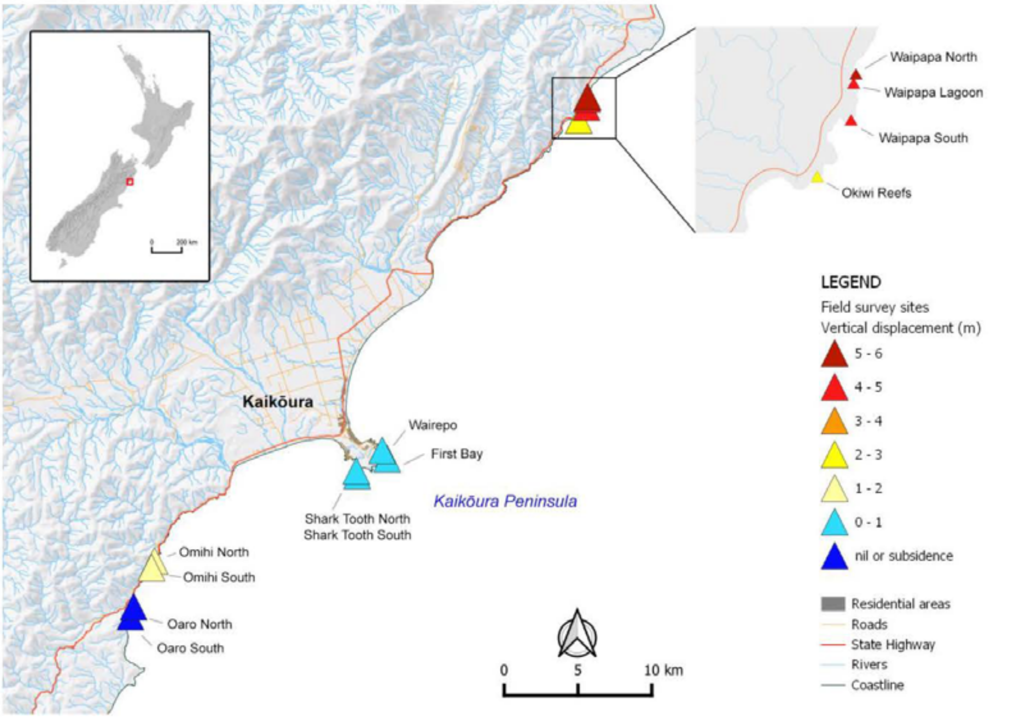


Figure 1. Location of the study area on the east coast of the South Island of New Zealand.

Table 1. LiDAR data specifications.

Timing in Earthquake Sequence	LiDAR Acquisition Date	Supplier	Commissioning Agency	Accuracy Specification (m)	
				Vertical	Horizontal
pre-earthquake	Jul 2012	Aerial Surveys Ltd.	Environment Canterbury	unknown †	unknown †
immediate post-quake	Nov 2016	AAM NZ Ltd.	New Zealand Transport Agency	±0.10	±0.50
Immediate post-quake	Dec 2016–Jan 2017	New Zealand Aerial Mapping	Land Information New Zealand	±0.10	±0.50
18 months post-quake	Jun 2018	AAM NZ Ltd.	Land Information New Zealand	±0.10	±0.50

† 2012 LiDAR data were originally provided in New Zealand Vertical Datum (NZVD) 2009 but were reprocessed by Aerial Surveys Ltd. to NZVD2016 and subjected to control checks.

2.3. Vertical Displacement

To assess spatio–temporal variability in vertical displacement at the coast, we constructed an assessment baseline using the first contiguous 0.1 m contour common to all datasets, which was located at the approximate position of the 2012 (pre-quake) mean high water springs (MHWS). A set of analysis windows was constructed landward of this baseline to facilitate the closest possible approximation of ground-level change within new intertidal areas (generally located seaward of this line), which are a key focus for recovery and impact assessments (Figure 2A). Tilt effects were assessed independently (see below) to verify the transferability of these measurement to the new intertidal zone. At Waipapa, a sizeable portion of the intertidal zone was lifted higher than surrounding areas to landward as the result of block-faulting on the western strand of the Papatea Fault (Figure 3A). Fortunately, outcrops of relatively tall flat-topped rocks are a characteristic of this area and were captured in both pre- and post-earthquake LiDAR data. This enabled the calculation of uplift values for the uplifted block to be calculated using manually constructed analysis windows (Figure 2B).

Ground-level changes were computed by differencing the DEMs after applying slope constraints (see below) and summarised using zonal analysis of returns within each of the analysis polygons. Vertical displacements recorded in national geodetic updates to the Land Information New Zealand (LINZ) survey benchmark network were also catalogued for comparison to the values obtained. To assess the interactions between vertical displacement and substrate, four substrate types (rocky reef, boulder, mixed sand–gravel and sandy beach) were mapped at the position of the new (post-quake) MHWS corresponding to the 0.5 m NZVD contour using 2018 aerial imagery and ground-truthing in the field. Each analysis window was classified according to substrate type in the adjacent coastal environment by intersecting the substrate map with its associated shore-perpendicular transect (Figure 2).

2.4. Tilt and Horizontal Displacement Effects

To test for tilt effects in the vicinity of the coast, three sets of analysis windows (each $n = 2000$) were constructed with different landward extents (50 m, 200 m and 500 m) oriented perpendicular to each 50 m segment of the baseline (Figure 2). Horizontal ground displacement effects that confound the measurement of vertical displacement using overlapping DEMs were controlled by restricting the analysis domain to nearly flat ground (Figure 3). Two separate slope thresholds (less than 2 and 5 degrees, respectively) were calculated by slope analysis of the DEMs and applied as masks to the differencing analysis.

Results from the above analyses were used to provide sensitivity tests of tilt and horizontal displacement effects on the vertical differencing assessment. One way ANOVAs were used to test for significant differences in vertical displacement for the independent variables of orthogonal distance from the coast (tilt effects) and slope constraints (horizontal displacement effects). Linear regressions were also used to further test for biases across the range of uplift values found within the sampling domain for each of the above comparisons.

2.5. Field Surveys

Quadrat-based field surveys were used to assess biological impacts within the intertidal area at 12 sites (Table 2). In these surveys, transects of 30–50 m were laid out horizontally along the shore at different tidal heights (see below) representing equivalent mid and low intertidal zones, respectively, and ten 1 m^2 quadrats sampled from each zone and the percentage cover or abundance of key species recorded, including all visible algae and invertebrates. These sites were selected to provide both geographical coverage and representation of a range of uplift values across the extensive study area. Their locations also reflect a paired sampling strategy whereby six pairs of sites were located in areas of similar uplift. The most southern sites were located at Oaro, which had experienced negligible uplift and therefore functioned as a control (Table 2). The remaining sites included two sites at Omihi, four sites on Kaikōura Peninsula, and four sites in higher uplift zones in the north of the study area (Figure 1). All of these sites are rocky shorelines that were previously dominated by large brown algae with a similar composition of rocky reef substrate types (e.g., reef and boulder) in pre- and post-earthquake intertidal areas.

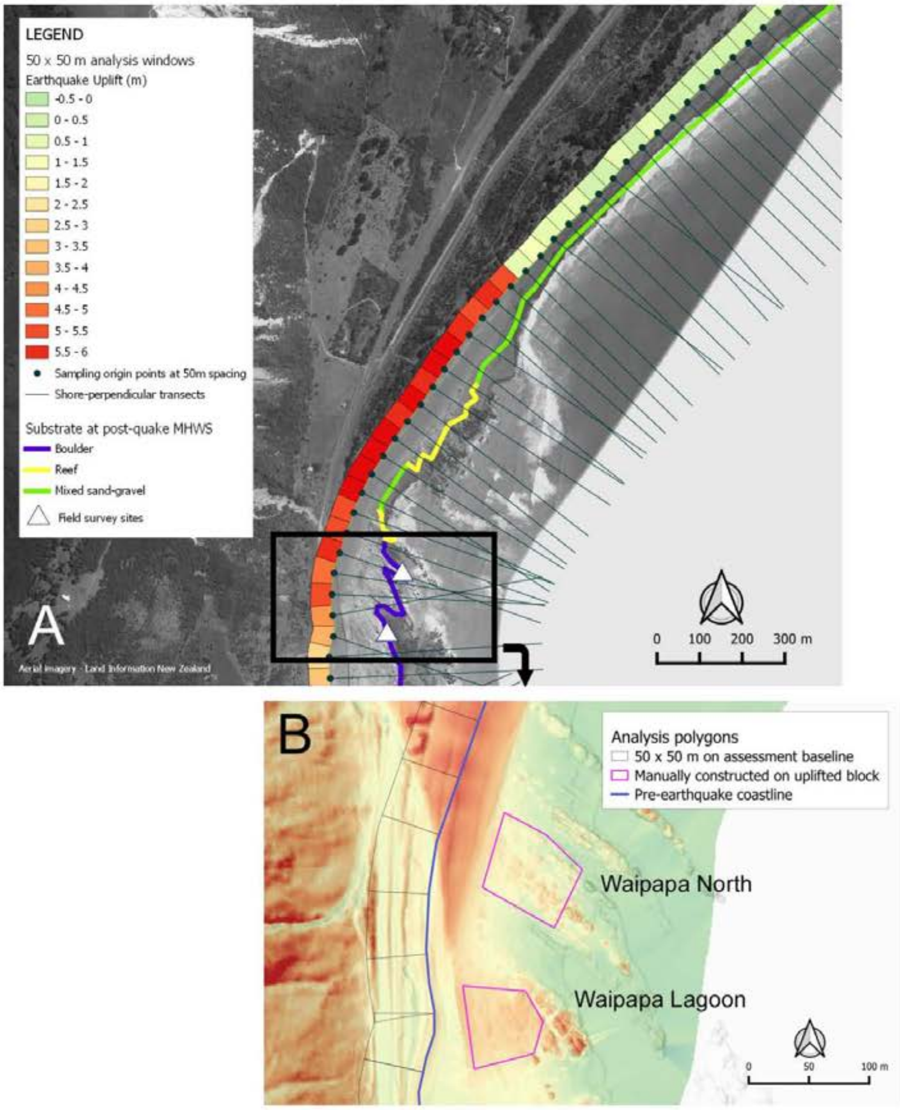


Figure 2. (**A**) Sampling setup for differencing analysis of 1 × 1 m digital elevation models derived from LiDAR data showing sampling origin points at 50 m spacing on an assessment baseline located at the approximate position of the pre-earthquake mean high water springs. 50 × 50 m analysis windows landward of this line are within the spatial extent of all LiDAR datasets. Shore-perpendicular transects extending seaward were used to associate each analysis window with the dominant substrate type in the adjacent intertidal area. Two of the field survey sites (Waipapa North and Waipapa Lagoon) are located in the inset. (**B**) Manually constrained analysis windows used to assess uplift at the Waipapa sites where block-faulting

uplifted intertidal areas higher than was recorded in the analysis windows to landward on the assessment baseline. The underlying image is a difference model with the same uplift scale as (A) for the pre-quake—immediate post-quake period.

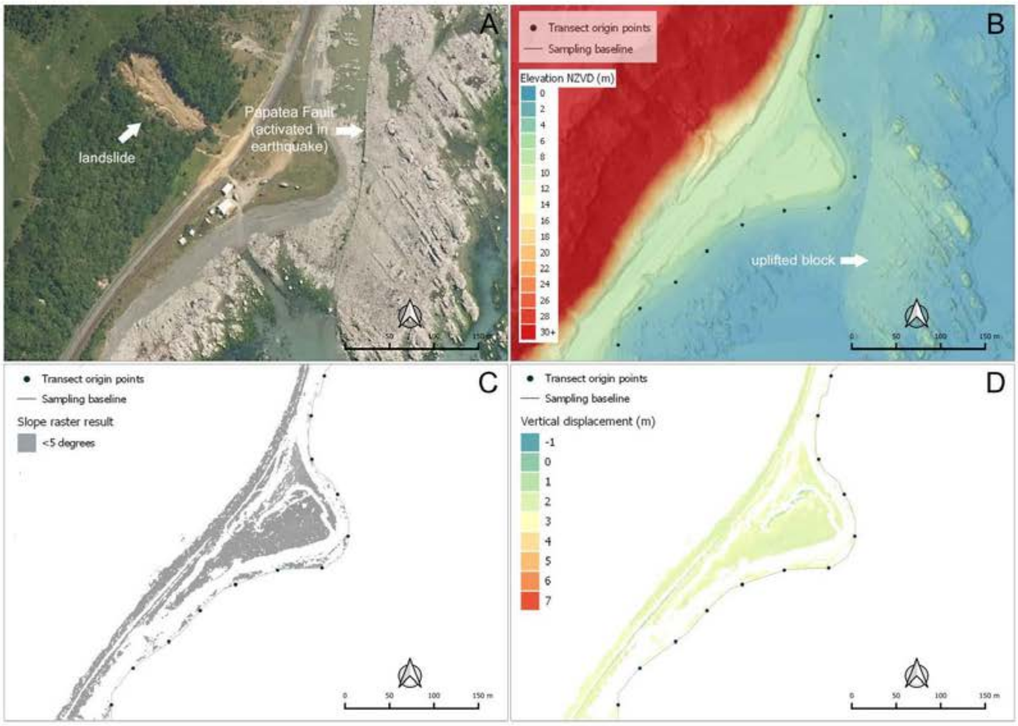


Figure 3. Workflow for differencing analyses. (**A**) Aerial image captured concurrent with LiDAR data showing examples of surface deformation features associated with the earthquake. The acquisition date was November 2016 (immediate post-quake). (**B**) 1×1 m digital elevation model constructed from LiDAR data at the same date. (**C**) Example of slope mask used to constrain the analysis domain to slopes <5 degrees. (**D**) Example of differencing result for July 2012 and December 2016 ground heights, with the former subtracted from the latter.

The first round of surveys was completed immediately after the earthquake and assessed the pre-earthquake intertidal zone in which the majority of species were still identifiable for at least two months after the earthquake before 'burning off' in the post-earthquake configurations. It is important to note that these initial surveys and selection of sites were completed in extremely arduous circumstances in a high-hazard environment with the sites being accessed by combinations of helicopter and on foot. Coastal roads were impassable due to massive landslides and ongoing rockfall hazard. The strategic priority for these surveys was obtaining quantitative data representative of pre-quake intertidal conditions from each general locality, followed by the establishment of additional study sites where possible. In three locations (Waipapa, Omihi and Sharks Tooth) only single sites could be surveyed, but these represent the only pre-quake information available (Table 2). Subsequent survey rounds were completed annually at all sites, and these sampled the new post-earthquake intertidal area. As a consequence of variable uplift, there is also variability in the degree of overlap between the intertidal zone in its pre- and post-earthquake configuration between sites. Due to variable mortality rates, species that persisted could be recorded in the post-quake survey areas albeit in a different region of the intertidal zone, and the overall composition of those zones was in a state of constant readjustment. To address these aspects, our analysis has a specific focus on the cover and abundance of key species in equivalent intertidal zones in their pre- and post-earthquake quake configurations. Post-quake data represent the mean values recorded across all quadrats for each of three surveys completed in the period 2017–2018, which are compared to their pre-quake equivalents. This provides the most intuitive and practical means for empirical evaluation of impacts that are attributable to the earthquake.

Table 2. Characteristics of study sites showing their pre-earthquake algal cover. The mean percentage cover of four algal classes (brown, red, corallines, green) was recorded (species by species and then grouped) in 1 m^2 quadrats sampled at random positions throughout the algal-dominated mid and low intertidal zones. The total cover value can sum to > 100% due to layering and overlapping of algal species.

Site	Coordinates (WGS84)		Pre-Earthquake Mean Percentage Cover (%)					
	X	Y	Brown	Red	Coralline	Green	Total Algae	Bare Ground
Oaro South	173.5054366	−42.5226367	40	26	63	2.1	131	14
Oaro North	173.5080324	−42.5165183	44	28	55	6.8	134	16
Shark Tooth North *	173.6914398	−42.4356525	22	4.7	53	0.5	80	20
Shark Tooth South	173.690683	−42.4328186	22	4.7	53	0.5	80	20
First Bay	173.7159516	−42.4251374	66	3.6	78	0.1	148	7
Wairepo	173.7119037	−42.4200986	56	2.2	39	0.0	97	3
Omihi North	173.5250354	−42.4885951	41	11	71	0.1	123	7
Omihi South *	173.5225126	−42.4926815	41	11	71	0.1	123	7
Ōkiwi North	173.8709615	−42.2174891	77	8.9	60	0.3	147	1
Waipapa South *	173.877159	−42.2096143	49	15	73	0.3	138	10
Waipapa Lagoon	173.8775657	−42.2045148	49	15	73	0.3	138	10
Waipapa North *	173.8779818	−42.2032321	49	15	73	0.3	138	10

* algal cover estimated from nearby sites.

Cover changes in habitat-forming macroalgae were calculated in terms of percentage gain or loss in canopy cover from their pre-earthquake values. Data were collected for each species, but the major classes were grouped to give an assessment of major functional changes. In this assessment, our main focus was large brown algae that include the major habitat-forming foundation species of this coastal area. Large brown species consisted of fucoids, including the large southern bull kelp *Durvillaea* spp., the sea wrack *Carpophyllum maschalocarpum*, and *Cystophora* spp. in the low tidal zone and bladder alga *Hormosira banksii* that formed extensive beds in the mid-tidal zone of some sites. The high-tide zone has no large algae and was omitted from this analysis.

Earthquake impacts were classified as severe (>80% loss), high (51–80%), moderate (21–80%), or low (1–20%), and a fifth class (nil or gain) was used to show increases versus pre-quake values. Uplift values derived from the analysis window closest to the field survey site were used to identify relationships with biological impacts. The extent of major losses in habitat-forming algae across the whole coast was estimated by identifying the minimum relative sea-level change associated with high or severe impacts as observed at the field study sites. The length of coastline with relative sea-level changes exceeding this threshold was calculated at 50 m intervals for substrates supporting these communities (rocky reef and boulder) across the 100 km study area.

2.6. Assumptions and Limitations

Key assumptions in this approach include the representativeness of the pre-quake values obtained since they may be prone to confounding effects, such as seasonal fluctuations, that can affect estimates of ephemeral algal species, such as the green algae *Ulva* spp. These limitations are addressed by the use of the impact classification system that places the observed gains and losses into broad categories that summarise the predominant pattern. All of the pre-earthquake percentage cover scores were also checked against long-term records of similar quadrat-based surveys completed by our research group in the vicinity of the sites chosen for this assessment. At most sites these include multi-year studies using similar quadrat techniques and sampling arrangements [36]. It is important to note that the identification of appropriate control sites (Oaro North and South) required non-impacted locations close to the earthquake-affected area with similar substrate compositions and pre-quake taxa. As with other studies based on a Before-After-Control-Impact (BACI) approach, limitations of such control sites include their inability to provide true replicates of the treatment effect of interest (e.g., relative sea-level change). There remains some degree of variability between sites despite best efforts to control for this in the site selection process [43,44].

3. Results

3.1. Sensitivity Analyses

Tilt assessments showed that landward extension of the analysis windows had little effect on the uplift values obtained (Figure 4). Regressions of all combinations of analysis window size showed consistent results, with R^2 values of 0.983, 0.982, and 0.996 for 50 m vs. 200 m, 50 m vs. 500 m, and 200 m vs. 500 m, respectively. One-way ANOVAs showed no significant difference between the uplift values obtained ($F_{2,3987} = 0.022$, $p = 0.978$). These results validated use of the finest-scale assessment window (50 × 50 m) for subsequent analyses. Sensitivity analyses for the control of horizontal displacement effects showed no significant difference between the two- and five-degree slope constraints for the 50 × 50 m analysis windows (one way ANOVA: $F_{1,2652} = 0.001$, $p = 0.916$). A regression of these results also showed a high correlation at all uplift values ($R^2 = 0.996$, see Supplementary Material Figure S1).

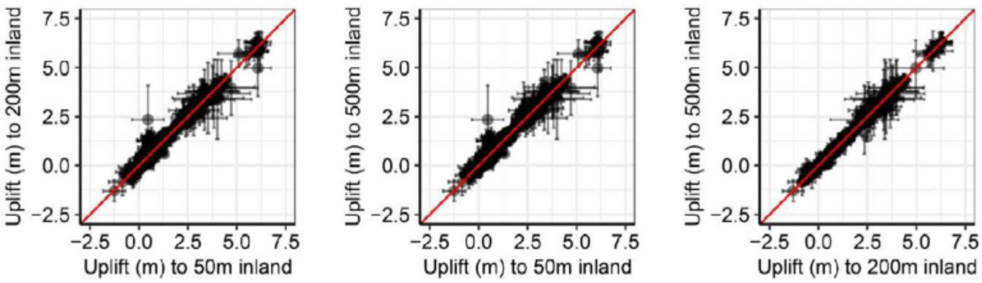


Figure 4. Regressions of uplift values obtained from all combinations of the three analysis window sizes (50 × 50 m, 50 × 200 m, 50 × 500 m) that differ in their landward dimension perpendicular to the coastline.

3.2. Degree of Uplift

Assessment of the two post-quake time periods showed that the majority of vertical displacement was co-seismic and associated with the 16 November earthquake event (Figure 5A,B). Ground level displacements in the period between December 2016 and June 2018 were generally site-specific and lacking in distinct coast-wide trends. Field observations and aerial photography suggest that the ground-level differences between these LiDAR acquisition dates result primarily from erosion and accretion effects of erodable substrates. These include significant discharges of material from adjacent hill-country that was fuelled by numerous landslides along the coast and nearby mountain ranges. An uplift assessment using the most recent (post-quake) LiDAR data enabled the generation of a complete dataset for all sections of the 100 km study area (Figure 5C). Vertical displacement at the coastline varies from subsidence of nearly 2 m to uplift of over 7 m as measured within the 50 × 50 m analysis units. Several prominent spatial patterns are evident, with negligible uplift at Oaro situated at the south end of the study area, an area of very high uplift near Waipapa Bay and variable degrees of uplift elsewhere (Figure 5C).

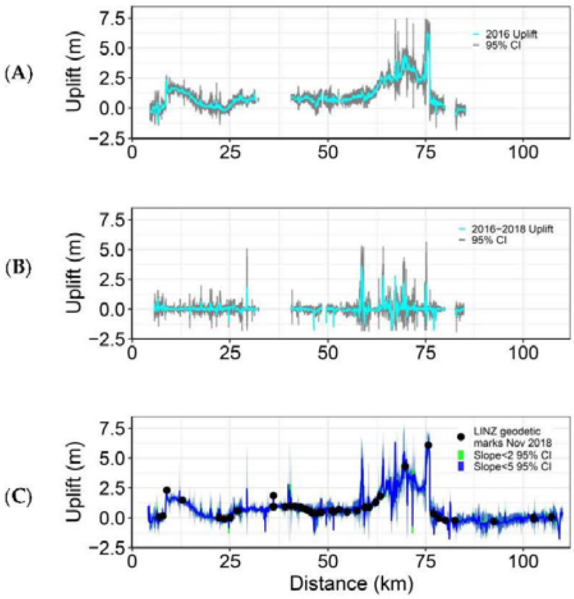


Figure 5. Vertical displacement of the Kaikōura coast calculated for two time periods (**A**) 2012–2016 and (**B**) 2012–2018 using independent differencing analyses and a 5-degree slope constraint to control for horizontal displacement effects. The LiDAR datasets have comparable resolution but slightly different coverage. The gap in coverage at c. 35 km on the X axis is the Kaikōura Peninsula. This area was outside of the LiDAR acquisition extent in the immediate post-quake dataset (December 2016), but was included in the June 2018 acquisition, enabling the analysis of 2012 to 2018 ground-level changes for the entire study area. (**C**) Estimated vertical displacement of the entire coastline between July 2012 and June 2018. Vertical displacements recorded in national geodetic updates to the Land Information New Zealand (LINZ) survey benchmark network to November 2018 are also shown for comparison.

3.3. Interaction between Uplift and Substrate Type

Substrate mapping showed that the length of coastline represented by substrate type was 14.7 km for rocky reef, 26.7 km for boulder fields, 54.3 km for mixed sand-gravel, and 4.4 km for sandy beaches. Evaluation of the interaction between these substrate types and vertical elevation change using the most recent data showed that the majority of boulder and rocky reef habitat was uplifted by various degrees in the 0–4 m range (Figure 6). A small section of rocky reef that was lifted c. 6 m can also be seen in this plot, which represents the high uplift area at Waipapa. Uplift also affected the mixed sand–gravel and sandy beach environments to various degrees. Modest degrees of subsidence affected small sections of coastline within all four of these substrate types, with most of these areas being located at the far north and south of the study area (as seen in Figure 5).

3.4. Ecological Impacts

Post-earthquake measurements show that algal mortality was severe (>80% loss) in at least one algal class at nine of the 12 study sites. High mortality (>50%) was absent at only two sites, both of which were located at Oaro and were the only study sites characterised by an absence of uplift, thereby functioning as controls. Vertical displacement at the field survey sites ranged from 0.3 m of subsidence at Oaro South to 5.5 m of uplift at Waipapa North based on the most recent data (Figure 7).

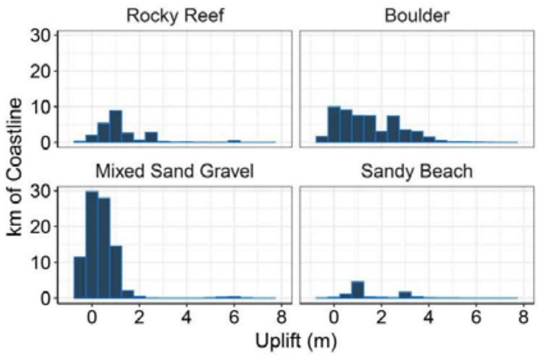


Figure 6. Histograms of the degree of uplift experienced within a classification of four substrate types found on the Kaikōura coast for the period July 2012–June 2018. Calculations used a 50 × 50 m analysis window and a 5-degree slope constraint to control for horizontal displacement effects.

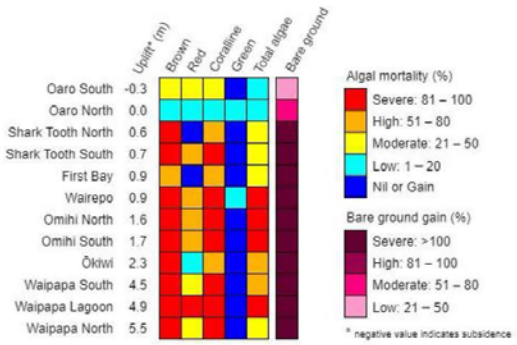


Figure 7. Summary of earthquake-induced mortality by major intertidal taxa and associated bare ground changes for 12 sites that experienced various degrees of uplift on the Kaikōura coast. Colours represent the severity of changes in percentage cover from pre-earthquake values as measured in post-earthquake field surveys within the equivalent intertidal zone with the highest severity recorded over three surveys presented here.

Large brown algae suffered the greatest mortality across all uplifted areas, regardless of degree of uplift. However, coralline algae also suffered high or severe mortality at all uplifted sites. These are low-stature base algae that form the primary cover of rocky substrates through much of the mid and low intertidal zones. Fleshy red algae showed highly variable site-specific contributions to post-quake cover, with some sites experiencing gains relative to pre-quake levels in the equivalent tidal zone and no obvious relationship to uplift overall (Figure 7). However, green algae increased at nearly all sites. Ephemeral species such as the sea lettuce *Ulva* bloomed extensively in the post-quake mid and low tidal zones, likely facilitated by the initial loss of competing algal species and the extensive mortality of intertidal grazers such as limpets and pāua (abalone) at uplifted sites, but also the extremely warm conditions that prevailed in the 2016–2017 summer. Bare ground increased at all sites from pre-earthquake values of 1–20%, consistent with the pattern of total algal cover change. At some sites including the controls at Oaro but notably at Waipapa lagoon, the increase in unvegetated substrate was partly due to sand and gravel deposition onto rocky shores.

Within the above overall pattern there were many site- and zone-specific nuances in terms of impacts across the coastline. For example, it was immediately apparent that large brown algae suffered high mortality at most sites, but these were not necessarily the same species. For example, the low zone of the highest uplift sites around Waipapa was mostly dominated by the large southern bull kelp, *Durvillaea* spp., prior to the earthquake, but this disappeared completely from these sites post-quake (Figure 8A). Red algal species comprise much of the diversity of this coastline. These expanded quickly in the low tidal zone, primarily because they can regenerate from remnant patches and also can reproduce, recruit and grow faster than most of the large brown algae that had died. Coralline algae are tough calcareous species that form an extensive primary cover of rock surfaces. As they desiccated and died, the soft sedimentary rocks they were on usually eroded rapidly and disintegrated [45], contributing to gravel deposition and sediment loads in nearshore waters along the coast (Figure 8B). Some of the worst affected areas include reefs on Kaikōura Peninsula such as Wairepo. This one of the longest studied coastal sites in New Zealand [39] and has an extensive intertidal platform. It was covered in the mid-tidal zone by the bladder alga *Hormosira,* which suffered severe mortality from reduced tidal inundation and increased temperatures despite the relatively small degree of uplift (Figure 8C,D).

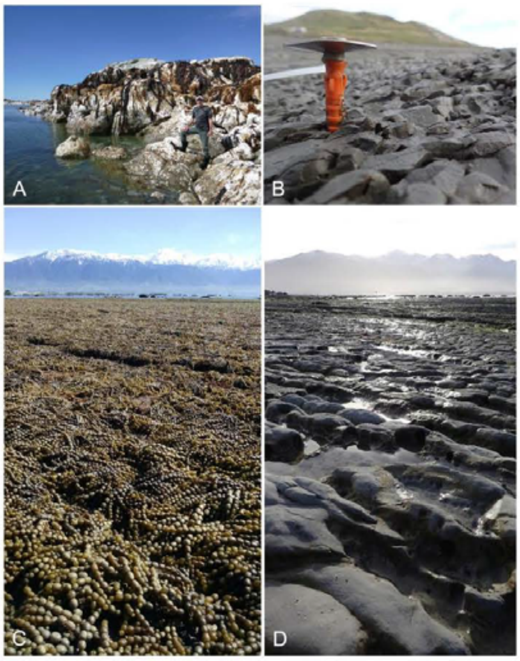


Figure 8. Impacts of uplift on the Kaikōura coast. (**A**) Waipapa Lagoon site on high tide in the post-quake landscape. Dead and dying bull kelp (*Durvillaea* spp.) and other brown seaweeds can be seen. The pre-quake high tide mark is at the top of the large rocks, a displacement of nearly 5 m. (**B**) Reef erosion at Wairepo six months after the earthquake. The washer was flush with the rock surface when installed immediately post-quake. (**C**,**D**) A graphic illustration of the severity of impacts on habitat-forming algae at Wairepo. Despite experiencing only modest uplift, nearly all seaweeds including *Hormosira* (in foreground) perished soon after the earthquake.

3.5. Threshold Value for Relative Sea-Change Associated with High Mortality

These results show that uplift values of 0.6 m or higher were consistently associated with high mortality in habitat-forming brown algae and also coralline algae. Despite widespread increases in green algal cover and some increases in reds, the combined canopy cover of all algal classes was also reduced by nearly 50% or more at all uplifted sites. This equates to massive losses in biomass in equivalent tidal zones as a consequence of the earthquake and reflects both losses in pre-quake populations and the failure of compensatory recovery in the post-quake environment. It can be noted that the absence of study sites in the uplift range 0.1–0.5 m is a limitation for identifying the true 'threshold' value for relative sea-change associated with high mortality on rocky shores. Despite this, the empirical evidence strongly suggests that these effects occurred with uplift of 0.6 m or more, and this value is adopted to estimate the extent of high or severe mortality for the whole coast. Although we cannot fully answer the question of a potentially lower threshold, only a small proportion of the coastline experienced uplift in the 0.1–0.5 m range, and very little of this area has rocky reef or boulder substrata. Therefore, our estimate of the extent of impacts would be relatively unaffected by assuming a slightly lower threshold for relative sea-change.

3.6. Extent of Impacts across 100 km of Coast

Using a threshold value of 0.6 m, we estimate that high or severe mortality of habitat-forming species has occurred over 87% of the rocky reef and 72% of the boulder habitat in the study area. The length of coastline involved is 19.4 km for rocky reef and 12.9 km for boulder habitat. In combination, major impacts have affected over 30 km of coastline that previously supported highly productive and diverse marine communities in these intertidal habitats. Note that the coastline considered in these calculations includes the Oaro control sites and adjacent areas. Nearly all of the remaining coastline exceeded the 0.6 m threshold value for high or severe mortality in habitat-forming brown algae and coralline algae. Furthermore, there are also rocky coast areas at least 30 km to the north that are not represented in this study (due to lack of LIDAR surveys), which were similarly affected [31].

4. Discussion

This study illustrates important considerations and methodological solutions for producing reliable estimates of relative sea-level change at ecologically relevant scales across a large study area. Inherent in this are crucial decisions on the selection of data that best meet these objectives, which typically requires a compromise between the scale and extent of potentially useful data sources. In this case, the zonation pattern and topography of the intertidal zone drove the ecological components of interest for which a relatively fine scale (i.e., tens of metres) is needed to resolve physical environmental changes of consequence. In contrast, the size of the overall study area is huge in comparison because of the sheer extent of the natural disaster event. The need, therefore, is for data with high resolution and large spatial coverage, an ideal that is somewhat of a holy grail.

Along with other options for ground-level change analysis using satellite altimetry platforms [46], airborne LiDAR provides an attractive data acquisition solution because it can incorporate concurrent high resolution aerial imagery (e.g., 0.2 m resolution in this case). As exemplified here, this imagery can be very useful for identifying and delineating the position of mobile landforms such as rivermouths that are problematic for differencing analyses. While direct field observations are also important to gain an understanding of these features, the combined approach produces an efficient workflow for these manual tasks in the analysis. Other aspects of note in this study include the use of largely terrestrial data to estimate geographical changes in the nearby marine environment. The rationale for this approach relates to the advantages of LiDAR data in meeting sampling objectives (large spatial extent and high resolution), which are virtually impossible to reproduce at this scale using any other method. This exemplifies the challenges of geographical surveys of the coastal interface in which the study area is exposed to periodic inundation and where water depths are too shallow and wave-exposed for use of sonar survey platforms [47].

Our approach also exemplifies the use of sensitivity analyses as a tool for validating methodological solutions for potentially confounding factors. We applied a nearly flat-ground slope constraint to the differencing analysis, but we tested more than one slope threshold to verify its efficacy. The highly correlated results suggest that a slope constraint of 5 degrees is sufficient for these purposes in a relatively high relief study area, although this may differ in other analysis contexts due to other combinations of ground sampling dimensions and sampling window size. Reducing the slope threshold will generally reduce the number of data points available for the analysis. In our case, however, the 2-degree slope constraint did not result in the complete loss of data in any of the analysis windows, and the mean uplift values obtained were very similar (Supplementary Material Figure S1).

Sensitivity analyses were also used to test for tilt effects as a confounding factor in the direction of interest (perpendicular to the coastline). These analyses provided a very useful test of assumptions around the transferability of vertical displacement estimates to nearby locations across the shore profile, thereby addressing the main objective of supporting intertidal ecological sampling. Within the overall workflow, these tests complement, but cannot completely replace, the manual inspection of DEMs, differencing results and aerial imagery to detect geographical irregularities that influence the interpretation of results at key locations. This is exemplified by the block faulting effects on the Papatea Fault that are visible in all three of the above data sources, but could be easily missed without the benefit of field observations (Figure 8). In this case they directly affected our area of interest in the new intertidal zone configuration and required manually constrained sampling domains for the estimation of vertical displacement at those locations (Figure 2). Overall, these aspects show that the combined methodological approach of (a) using adjacent 'terrestrial' data to estimate large-scale change in the nearby intertidal zone, and (b) sensitivity analyses for confounding factors provides a computationally efficient approach for the estimation of vertical displacement and associated relative sea-level changes in a difficult sampling environment.

4.1. Contribution of Temporal Changes

Along with the above approaches for estimating co-seismic displacement effects on relative sea levels at intertidal locations, the potential for ongoing change must be addressed and considered. To provide an initial indication of potential changes at the whole-coast scale, we used the available LiDAR data to test for further post-seismic vertical displacement to 18 months post-earthquake, which is also an important time period in the context of disaster recovery. The decomposition of ground-level changes between the co-seismic and post-seismic periods showed that the majority of vertical displacement was associated with the 16 November earthquake event. This is consistent with other studies that have shown post-seismic afterslip effects associated with the Kaikōura earthquake [41,42], for which the main locations exhibiting vertical motion are located farther north (i.e., outside of our study area). Although there has been some degree of horizontal afterslip within our study area, these effects are largely obscured by the use of slope constraints in our analysis. Importantly, however, our results for the post-seismic period show there have been considerable gains and losses in ground elevation at numerous sites along the coastline, even though highly mobile landforms such as rivermouths and earthquake-damaged areas such as road corridors were removed from the analysis. These effects indicate the contribution of important ongoing topographical changes that involve both accretion and erosion. Both processes continue to affect the new intertidal zone in a highly variable manner.

Field observations showed that these dynamics included extensive gravel depositions that covered areas of former reef and boulder fields at several locations. Additionally, many of these rocky areas are experiencing significant erosion from accelerated weathering in their uplifted positions, which is particularly prominent on mudstone platforms. At these sites, changes to the wetting and the additional drying time caused by uplift has exacerbated tension cracking, essentially shattering the upper few centimetres of the substrate surface. This shattered material is then quickly eroded away by wind and wave action, and is repeated in successful cycles. These reefs typically erode at 1–2 mm annually [45,48], but lost up to 30 mm within 6 months post-earthquake [31]. At many sites, these accelerated erosion effects have been ongoing since the initial uplift event, suggesting that they may continue until new wave-cut platforms have lowered sufficiently to provide wetting times that promote substrate stabilisation, consistent with established theory [49,50]. By extension, these same conditions may be required to support the eventual recovery of characteristic algal species at densities comparable to their former abundance because many of the rocky surfaces are too unstable for effective recruitment of large algae. Both of the above phenomena have obvious relevance for the re-establishment of biogenic algal cover and are significant additional stressors.

4.2. Impact Thresholds and Contributing Factors

Our analyses indicate that the threshold of major impacts is in the vicinity of a quarter of the tidal range (approximately 2 m) for the characteristic habitat-forming algal communities in this area. The four least-uplifted of our sampling sites outside of Oaro (which function as 'control' sites) provide a direct test of relative sea-level changes in the 0.6 m–0.9 m range. Changes in tidal cover at these sites were evidently beyond the adaptive threshold of the algal communities they previously supported, causing widespread mortality in the intertidal zone (Figure 8C,D). This interpretation is consistent with the general zonational pattern of these habitat-forming species. However, the empirical data also show that compensatory recovery has not occurred in the equivalent post-quake tidal zone and it is the combination of the two processes that are responsible for the net impact as assessed in this study. This finding is consistent with our central hypothesis in which a lag effect would occur in consideration of likely recruitment rates and that would manifest as net losses in the short term. However, the severity of these losses was even greater than expected. This primarily relates to conditions in the new post-quake intertidal area, in which only sparse habitat-forming algae were recorded and despite the fact that many individual algae were also uplifted into that zone from populations that were previously subtidal. This highlights the fragility of the post-quake environment and indicates the need for further research on the nature of contributing factors and potential timelines for appreciable recovery to occur.

Once populations of large algae are removed, recovery can be slow where reproductive adults become widely separated due to connectivity effects between suitable habitat for re-colonisation and the remaining recruitment sources [32]. A wide range of processes are likely hindering recovery in the post-earthquake landscape, including the now widely dispersed adult populations, the relatively short distance of propagule dispersal (usually only tens of meters), and limited ability of drifting detached reproductive algae to reach sites [37]. This emphasises the importance of the remaining remnant populations of reproductive adults. Our observations indicate that many of these individuals may have experienced, and may continue to be experiencing, heightened vulnerability due to interactions between relative sea-level changes and other processes. In particular, there is mounting evidence to suggest that previously stable subtidal substrates have become unstable and are now weathering faster as a consequence of vertical displacement into areas of higher wave energy. This hypothesis might explain the initial loss of algae affixed to such substrates that would otherwise appear to have remained with a suitable tidal zone for the species, and the same effects may be hindering the re-establishment of new recruits in these areas.

4.3. Stressors and Recovery Prospects

Related post-earthquake studies on the large southern bull kelp, *Durvillaea* spp., which occupies the intertidal–subtidal fringe on wave-exposed shores, show that it is particularly susceptible to desiccation with prolonged exposure, especially when wave splash is low and temperatures are high during low tide [51]. Other large brown algae such as *Carpophyllum maschalocarpum* and *Cystophora* spp. also occur in the lowest margins of the intertidal zone and typically die back to the lowest portion of the tidal zone if tides are exceptionally low, wave splash is small, and air temperatures are high. Losses were also observed in the formerly extensive mid-intertidal beds of the fucoid *Hormosira*. This is the most desiccation-tolerant of the fucoid species (the large brown algae of the intertidal zone) and typically recovers quickly [52], even after prolonged exposure at low tides. For example, the 0.9 m of uplift experienced by the Wairepo reef platform resulted in wetting times of 2–2.5 h of the 5 h of pre-earthquake daily high tide inundation in the semi-diurnal tidal cycle. Despite remaining within the tidal zone, desiccation stress from air temperatures often exceeding 40 °C above the reef surface and elevated water temperatures as tides covered the reefs to only shallow depths, proved too harsh for *Hormosira* to persist. In most places it died off over a period of 6 weeks post-earthquake. This species facilitates productivity and very high diversity by shading other species below its canopy, and its near-total loss was catastrophic for local diversity.

Interactions between the degree of uplift and topography of the shore platform are highlighted in the above processes and provide a further layer of complexity that underpins the pattern of loss. As the *Hormosira* example shows, relatively small changes in intertidal position can affect water temperatures and susceptibility to desiccation that may represent a tipping point leading to complete loss of the pre-existing population. Furthermore, these losses can involve extensive areas where the intertidal topography is relatively flat, as is a feature of many reef platforms on the Kaikōura coast. These topographical aspects are additional to the coastal erosion and deposition effects discussed above, which can also be catastrophic for both remnant algae of uplifted surfaces and newly established recruits. Fine silts are also abundant in the post-earthquake environment and add further stresses associated with the smothering of rocky substrates and occlusion of nearshore waters, leading to reduced light transmission and impacts on photosynthesis.

5. Conclusions

This work has been an important milestone in relating ecological damage along an extensive stretch of coastline to vertical displacement caused by one of the major seismic events in modern times. This is the first study to quantify relative sea-level changes at the position of the new intertidal environment and the first to estimate the extent of earthquake impacts on major habitat-forming algal species that are characteristic of the Kaikōura region. In doing so, we demonstrated a practical workflow for translating high-resolution data from nearby terrestrial areas to adjacent data-poor intertidal areas that includes sensitivity analyses to assess validity.

Our assessment of major impacts associated with the relative sea-level change reflects losses of habitat-forming macroalgae in the equivalent pre-quake and post-quake intertidal zones compounded by a lack of recruitment into the latter. Our whole-coast estimate of c. 90% mortality of large algae on a percentage cover basis provides some indication of the tenuous starting point upon which future recovery depends. The intensity and frequency of hydro-ecological changes and continuing interactions between stressors are key influences on recovery processes that will have legacy effects for many years to come in this coastal area, and similarly in other natural disaster contexts. Against this broad-scale backdrop it will be important to follow the fate of the remnant populations in addition to the establishment of new recruits. Both remain vulnerable to the effects of additional stressors, including those already observable and potentially for additional extreme events, particularly heat waves, in future years.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/geohazards2040016/s1, Figure S1: Regressions of uplift values for 2-degree and 5-degree slope constraints for the three analysis window sizes that differed in their landward dimension perpendicular to the coastline. Figure S2: Vertical displacement of the Kaikōura coast for the period July 2012–June 2018 within three analysis window sizes (50 × 50 m, 50 × 200 m, 50 × 500 m) differing in their landward dimension. These calculations used a 5-degree slope constraint to control for horizontal displacement effects. Figure S3: Density plot of the degree of uplift experienced within a classification of four substrate types found on the Kaikōura coast for the period July 2012–June 2018. Calculations used a 50 × 50 m analysis window and a 5-degree slope constraint to control for horizontal displacement effects. Table S1: Post-earthquake algal cover expressed as the percentage of pre-earthquake values for 12 sites on the Kaikōura coast. Data show the minimum values recorded over three post-quake sampling campaigns during the period to 18-months post-quake in which algal mortality was occurring at variable rates. The average percentage cover of four algal classes (brown, red, corallines, green) was recorded (species by species and then grouped) in 1 m^2 quadrats sampled at random positions throughout the algal-dominated mid- and low intertidal zones. The total cover value can sum to > 100% due to layering and overlapping of algal species.

Author Contributions: Conceptualization, S.O., D.R.S.; methodology, S.O., D.R.S.; formal analysis, S.O., H.S.F., D.R.S.; investigation, S.O., T.A., S.G., R.D.; resources, D.R.S.; data curation, S.O., H.S.F.; writing—original draft preparation, S.O.; writing—review and editing, S.O., D.R.S.; visualization, S.O., H.S.F.; funding acquisition, S.O., D.R.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Ministry of Business Innovation and Employment (MBIE) Endeavour Fund (UOCX1704), with additional support from the Ministry for Primary Industries (MPI) (KAI2016-05) and the Sustainable Seas National Science Challenge (UOA20203).

Institutional Review Board Statement: Ethical review was not required for this study.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article or supplementary material. LiDAR datasets are available from Land Information New Zealand or the commissioning agency (Table 1).

Acknowledgments: We thank our funders, and staff at the University of Canterbury, particularly Ian Wright and Sharyn Goldstein, and others at the National Institute of Water and Atmospheric Research (NIWA) for assisting with initial post-disaster survey work and gaining access to sites. Thanks to Stephanie Mangan, Thomas Falconer, Dave Taylor and Paul South for assisting with field surveys or data preparation, and John Pirker for iwi liaison in support of this work.

Conflicts of Interest: The authors declare no conflict of interest. The sponsors had no role in the design, execution, interpretation, or writing of the study.

References

1. Cahoon, D.R. Estimating relative sea-level rise and submergence potential at a coastal wetland. *Estuaries Coasts* **2015**, *38*, 1077–1084. [CrossRef]
2. Orchard, S.; Hughey, K.F.D.; Measures, R.; Schiel, D.R. Coastal tectonics and habitat squeeze: Response of a tidal lagoon to co-seismic sea-level change. *Nat. Hazards* **2020**, *103*, 3609–3631. [CrossRef]
3. Shugar, D.H.; Walker, I.J.; Lian, O.B.; Eamer, J.B.R.; Neudorf, C.; McLaren, D.; Fedje, D. Post-glacial sea-level change along the Pacific coast of North America. *Quat. Sci. Rev.* **2014**, *97*, 170–192. [CrossRef]
4. Stammer, D.; Cazenave, A.; Ponte, R.M.; Tamisiea, M.E. Causes for contemporary regional sea level changes. *Annu. Rev. Mar. Sci.* **2013**, *5*, 21–46. [CrossRef] [PubMed]
5. Cahoon, D.R.; Reed, D.J.; Day, J.W. Estimating shallow subsidence in microtidal salt marshes of the southeastern United States: Kaye and Barghoorn revisited. *Mar. Geol.* **1995**, *128*, 1–9. [CrossRef]
6. Rybczyk, J.M.; Cahoon, D.R. Estimating the potential for submergence for two wetlands in the Mississippi River Delta. *Estuaries* **2002**, *25*, 985–998. [CrossRef]
7. Woodroffe, C.D.; Rogers, K.; McKee, K.L.; Lovelock, C.E.; Mendelssohn, I.A.; Saintilan, N. Mangrove sedimentation and response to relative sea-level rise. *Annu. Rev. Mar. Sci.* **2016**, *8*, 243–266. [CrossRef]
8. Berkes, F.; Colding, J.; Folke, C. *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2003.
9. Holling, C.S. Resilience and stability of ecological systems. *Annu. Rev. Ecol. Syst.* **1973**, *4*, 1–23. [CrossRef]
10. Martinez, M.L.; Taramelli, A.; Silva, R. Resistance and resilience: Facing the multidimensional challenges in coastal areas. *J. Coast. Res.* **2017**, *77*, 1–6. [CrossRef]
11. Bilek, S.L.; Lay, T. Subduction zone megathrust earthquakes. *Geosphere* **2018**, *14*, 1468–1500. [CrossRef]
12. Orchard, S.; Schiel, D.R. Enabling nature-based solutions to climate change on a peri-urban sandspit in Christchurch, New Zealand. *Reg. Environ. Chang.* **2021**, *21*, 66. [CrossRef]

13. Saunders, M.I.; Albert, S.; Roelfsema, C.M.; Leon, J.X.; Woodroffe, C.D.; Phinn, S.R.; Mumby, P.J. Tectonic subsidence provides insight into possible coral reef futures under rapid sea-level rise. *Coral Reefs* **2016**, *35*, 155–167. [CrossRef]
14. Church, J.A.; Clark, P.U.; Cazenave, A.; Gregory, J.M.; Jevrejeva, S.; Levermann, A.; Merrifield, M.A.; Milne, G.A.; Nerem, R.S.; Nunn, P.D.; et al. Sea level change. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2013.
15. Nicholls, R.J.; Cazenave, A. Sea-level rise and its impact on coastal zones. *Science* **2010**, *328*, 1517–1520. [CrossRef]
16. Simms, A.R.; Anderson, J.B.; DeWitt, R.; Lambeck, K.; Purcell, A. Quantifying rates of coastal subsidence since the last interglacial and the role of sediment loading. *Glob. Planet. Chang.* **2013**, *111*, 296–308. [CrossRef]
17. Albert, S.; Saunders, M.I.; Roelfsema, C.M.; Leon, J.X.; Johnstone, E.; Mackenzie, J.R.; Hoegh-Guldberg, O.; Grinham, A.R.; Phinn, S.R.; Duke, N.C.; et al. Winners and losers as mangrove, coral and seagrass ecosystems respond to sea-level rise in Solomon Islands. *Environ. Res. Lett.* **2017**, *12*, 94009. [CrossRef]
18. Quigley, M.C.; Hughes, M.W.; Bradley, B.A.; van Ballegooy, S.; Reid, C.; Morgenroth, J.; Horton, T.; Duffy, B.; Pettinga, J.R. The 2010–2011 Canterbury Earthquake Sequence: Environmental effects, seismic triggering thresholds and geologic legacy. *Tectonophysics* **2016**, *672–673*, 228–274. [CrossRef]
19. Hughes, M.W.; Quigley, M.C.; van Ballegooy, S.; Deam, B.L.; Bradley, B.A.; Hart, D.E.; Measures, R. The sinking city: Earthquakes increase flood hazard in Christchurch, New Zealand. *GSA Today* **2015**, *25*, 4–10. [CrossRef]
20. Orchard, S. *Floodplain Restoration principles for the Avon-Ōtākaro Red Zone: Case Studies and Recommendations*; Avon Ōtākaro Network (Publisher): Christchurch, New Zealand, 2017; p. 40.
21. Potter, S.H.; Becker, J.S.; Johnston, D.M.; Rossiter, K.P. An overview of the impacts of the 2010–2011 Canterbury earthquakes. *Int. J. Disaster Risk Reduct.* **2015**, *14*, 6–14. [CrossRef]
22. Orchard, S.; Hughey, K.F.D.; Schiel, D.R. Risk factors for the conservation of saltmarsh vegetation and blue carbon revealed by earthquake-induced sea-level rise. *Sci. Total Environ.* **2020**, *746*, 141241. [CrossRef]
23. Orchard, S.; Hickford, M.J.H. Protected Area Effectiveness for Fish Spawning Habitat in Relation to Earthquake-Induced Landscape Change. In *Sustainable Bioresource Management: Climate Change Mitigation and Natural Resource Conservation*; Maiti, R., Rodríguez, H.G., Kumari, C.A., Mandal, D., Sarkar, N.C., Eds.; Apple Academic Press: Waretown, NJ, USA, 2020; p. 526. Available online: https://www.routledge.com/Sustainable-Bioresource-Management-Climate-Change-Mitigation-and-Natural/Maiti-Gonzalez-Rodriguez-Kumari-Mandal/p/book/9780429284229 (accessed on 1 September 2021).
24. Orchard, S.; Hickford, M.J.H.; Schiel, D.R. Earthquake-induced habitat migration in a riparian spawning fish has implications for conservation management. *Aquat. Conserv. Mar. Freshwat. Ecosyst.* **2018**, *28*, 702–712. [CrossRef]
25. Jaramillo, E.; Dugan, J.E.; Hubbard, D.M.; Melnick, D.; Manzano, M.; Duarte, C.; Campos, C.; Sanchez, R. Ecological implications of extreme events: Footprints of the 2010 earthquake along the Chilean coast. *PLoS ONE* **2012**, *7*, e35348. [CrossRef]
26. Rodil, I.F.; Jaramillo, E.; Hubbard, D.M.; Dugan, J.E.; Melnick, D.; Velasquez, C. Responses of dune plant communities to continental uplift from a major earthquake: Sudden releases from coastal squeeze. *PLoS ONE* **2015**, *10*, e0124334. [CrossRef]
27. Holden, C.; Kaneko, Y.; D'Anastasio, E.; Benites, R.; Fry, B.; Hamling, I.J. The 2016 Kaikōura Earthquake revealed by kinematic source inversion and seismic wavefield simulations: Slow rupture propagation on a geometrically complex crustal fault network. *Geophys. Res. Lett.* **2017**, *44*, 11320–11328. [CrossRef]
28. Xu, W.; Feng, G.; Meng, L.; Zhang, A.; Ampuero, J.P.; Bürgmann, R.; Fang, L. Transpressional rupture cascade of the 2016 Mw 7.8 Kaikoura Earthquake, New Zealand. *J. Geophys. Res. Solid Earth* **2018**, *123*, 2396–2409. [CrossRef]
29. Hamling, I.J.; Hreinsdóttir, S.; Clark, K.; Elliott, J.; Liang, C.; Fielding, E.; Litchfield, N.; Villamor, P.; Wallace, L.; Wright, T.J.; et al. Complex multifault rupture during the 2016 Mw 7.8 Kaikoura earthquake, New Zealand. *Science* **2017**, *356*, eaam719. [CrossRef] [PubMed]
30. Clark, K.J.; Nissen, E.K.; Howarth, J.D.; Hamling, I.J.; Mountjoy, J.J.; Ries, W.F.; Jones, K.; Goldstien, S.; Cochran, U.A.; Villamor, P.; et al. Highly variable coastal deformation in the 2016 MW7.8 Kaikōura earthquake reflects rupture complexity along a transpressional plate boundary. *Earth Planet. Sci. Lett.* **2017**, *474*, 334–344. [CrossRef]
31. Alestra, T.; Gerrity, S.; Dunmore, R.A.; Crossett, D.; Orchard, S.; Schiel, D.R. *Rocky Reef Impacts of the 2016 Kaikōura Earthquake: Extended Monitoring of Nearshore Habitats and Communities to 3.5 Years. New Zealand Aquatic Environment and Biodiversity Report No. 253*; Ministry for Primary Industries: Wellington, New Zealand, 2021; p. 46.
32. Schiel, D.R.; Alestra, T.; Gerrity, S.; Orchard, S.; Dunmore, R.; Pirker, J.; Lilley, S.; Tait, L.; Hickford, M.; Thomsen, M. The Kaikōura earthquake in southern New Zealand: Loss of connectivity of marine communities and the necessity of a cross-ecosystem perspective. *Aquat. Conserv. Mar. Freshwat. Ecosyst.* **2019**, *29*, 1520–1534. [CrossRef]
33. Tait, L.W.; Orchard, S.; Schiel, D.R. Missing the forest and the trees: Utility, limits and caveats for drone imaging of coastal marine ecosystems. *Remote. Sens.* **2021**, *13*, 3136. [CrossRef]
34. Gerrity, S.; Alestra, T.; Fischman, H.S.; Schiel, D.R. Earthquake effects on abalone habitats and populations in southern New Zealand. *Mar. Ecol. Prog. Ser.* **2020**, *656*, 153–161. [CrossRef]
35. Orchard, S.; Falconer, T.; Fischman, H.; Schiel, D.R. *Beach Dynamics and Recreational Access Changes on an Earthquake-Uplifted Coast*; Marlborough District Council: Blenheim, New Zealand, 2020; p. 42. Available online: https://hdl.handle.net/10092/101043 (accessed on 1 September 2021).

36. Schiel, D.R. Biogeographic patterns and long-term changes on New Zealand coastal reefs: Non-trophic cascades from diffuse and local impacts. *J. Exp. Mar. Biol. Ecol.* **2011**, *400*, 33–51. [CrossRef]
37. Hawes, N.A.; Taylor, D.I.; Schiel, D.R. Transport of drifting fucoid algae: Nearshore transport and potential for long distance dispersal. *J. Exp. Mar. Biol. Ecol.* **2017**, *490*, 34–41. [CrossRef]
38. Schiel, D.R.; Foster, M.S. The population biology of large brown seaweeds: Ecological consequences of multiphase life histories in dynamic coastal environments. *Annu. Rev. Ecol. Evol. Syst.* **2006**, *37*, 343–372. [CrossRef]
39. Lilley, S.A.; Schiel, D.R. Community effects following the deletion of a habitat-forming alga from rocky marine shores. *Oecologia* **2006**, *148*, 672–681. [CrossRef] [PubMed]
40. Hamling, I.J.; D'Anastasio, E.; Wallace, L.M.; Ellis, S.; Motagh, M.; Samsonov, S.; Palmer, N.; Hreinsdóttir, S. Crustal deformation and stress transfer during a propagating earthquake sequence: The 2013 Cook Strait sequence, central New Zealand. *J. Geophys. Res. Solid Earth* **2014**, *119*, 6080–6092. [CrossRef]
41. Jiang, Z.; Huang, D.; Yuan, L.; Hassan, A.; Zhang, L.; Yang, Z. Coseismic and postseismic deformation associated with the 2016 Mw 7.8 Kaikoura earthquake, New Zealand: Fault movement investigation and seismic hazard analysis. *Earth Planets Space* **2018**, *70*, 1–14. [CrossRef]
42. Wallace, L.M.; Hreinsdóttir, S.; Ellis, S.; Hamling, I.; D'Anastasio, E.; Denys, P. Triggered slow slip and afterslip on the Southern Hikurangi Subduction Zone following the Kaikōura Earthquake. *Geophys. Res. Lett.* **2018**, *45*, 4710–4718. [CrossRef]
43. Stewart-Oaten, A.; Murdoch, W.W.; Parker, K.R. Environmental Impact Assessment: "Pseudoreplication" in Time? *Ecology* **1986**, *67*, 929–940. [CrossRef]
44. Underwood, A.J. Beyond BACI: The detection of environmental impacts on populations in the real, but variable, world. *J. Exp. Mar. Biol. Ecol.* **1992**, *161*, 145–178. [CrossRef]
45. Stephenson, W.J.; Kirk, R.M. Rates and patterns of erosion on inter-tidal shore platforms, Kaikoura Peninsula, South Island, New Zealand. *Earth Surf. Process. Landf.* **1998**, *23*, 1071–1085. [CrossRef]
46. Fu, L.-L.; Cazenave, A. *Satellite Altimetry and Earth Sciences*; Academic Press: Cambridge, MA, USA, 2001; p. 463.
47. Mayer, L.A. Frontiers in seafloor mapping and visualization. *Mar. Geophys. Res.* **2006**, *27*, 7–17. [CrossRef]
48. Stephenson, W.J.; Kirk, R.M.; Hemmingsen, M.A. Forty three years of micro-erosion meter monitoring of erosion rates on shore platforms at Kaikōura Peninsula, South Island, New Zealand. *Geomorphology* **2019**, *344*, 1–9. [CrossRef]
49. Edwards, A.B. Wave action in shore platform formation. *Geol. Mag.* **2009**, *88*, 41–49. [CrossRef]
50. Stephenson, W.J.; Kirk, R.M. Development of shore platforms on Kaikoura Peninsula, South Island, New Zealand: II: The role of subaerial weathering. *Geomorphology* **2000**, *32*, 43–56. [CrossRef]
51. Thomsen, M.S.; Mondardini, L.; Thoral, F.; Gerber, D.; Montie, S.; South, P.M.; Schiel, D.R. Cascading impacts of earthquakes and extreme heatwaves have destroyed populations of an iconic marine foundation species. *Divers. Distrib.* **2021**, *00*, 1–15.
52. Brown, M.T. Effects of desiccation on photosynthesis of intertidal algae from a southern New Zealand shore. *Bot. Mar.* **1987**, *30*, 121–128. [CrossRef]