Kaikōura earthquake: Summary of impacts and changes in nearshore marine communities

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Introduction

The M_w 7.8 Kaikōura earthquake of November 2016 is commonly described as unprecedented. That is certainly the case for its impacts on the nearshore ecosystem in New Zealand. Over 100 kilometres of coastline was lifted by up to six metres. The upheaval happened within a few minutes at night on an incoming tide when mobile species such as fish and lobster come inshore to feed.

The newly exposed reefs therefore gave a high, and mostly dry, snapshot of rocky reef communities. The marine community composition of many of the affected areas was not known in detail because the prevailing swell and turbid water conditions along the northeastern coastline of the South Island made it difficult to survey. Some areas, however, particularly at Cape Campbell in the north and Kaikōura in the south, had been meticulously monitored two to four times annually since 1992[1]. With the upheaval, there was therefore a unique opportunity to gauge what was there, quantitatively sample the communities present and, in some cases, compare changes to long-term data.

Our group (the Marine Ecology Research Group, University of Canterbury, and the Cawthron Institute) was out on those shores within a week of the earthquake, and along with scientists from NIWA, have spent over 2000 person-hours in the field since then. There was some background knowledge about earthquake impacts on the coastal zone because large earthquakes have occurred from time to time in other countries, especially Japan and Chile. In Japan, for example, minor subsidence (< 1 m) resulted in poor recovery of sessile invertebrates over three years[2]. However, most of what we know about marine impacts from earthquakes comes from Chile, where a series of large quakes over the past several decades have caused both uplift and subsidence of the coastal zone[3, 4].

The major lessons learned from these places is that large algal beds are greatly disrupted, mortalities of algae and associated organisms are high, and recovery takes many years, even if appropriate physical habitats are still available. Usually, large invertebrates like grazing snails suffer high mortality and their loss has consequences on ecological relationships such as grazing of algal material. Although all parts of the nearshore ecosystem are disrupted in these types of events, it is generally the disruptions to rocky reef communities that cause most concern. This is because rocky reefs support the most diverse benthic (bottom-dwelling) communities and coastal habitats.

This includes canopy-forming large seaweeds, such as kelps and fucoids, a diverse array of understory species, particularly red algae, and myriad species associated with algal beds that rely on them for food, shelter and settlement sites. Numerous invertebrate such as small isopods, amphipods and gastropods live and feed on algal fronds or the detritus that comes from them. Larger species such as abalone (pāua), large snails and coastal fishes feed either on algal material or on the small animals in algal beds. The two major concerns for these communities relating to the earthquake are therefore the loss of physical habitat – how much rocky reef remains and whether new reef was created – and the loss of biogenic habitat – the seaweeds themselves that provide three-dimensional structure for other species. Both of these types of habitat were severely disrupted along the coastline of the northeastern South Island, with consequent impacts on fisheries such as pāua, cultural values relating to taonga (treasured) species, and ecosystem health. Here we briefly describe the impacts on coastal reefs and some of the changes we have seen over the past year.

Science plan and methodologies

The only way to know what was going to be lost from the earthquake was to get out to as many field sites as soon as possible after the earthquake and count and measure the species and habitats that were uplifted or newly accessible. As indicated elsewhere in this publication, access to coastal sites was a challenge, and so we concentrated on rocky intertidal areas. The coast was categorised into three uplift zones from small (near Kaikōura, 0 - c.1 m), larger (around Ward and Cape Campbell in the north, up to 2 m) and largest (around Waipapa, north of Kaikōura, up to 6 m). Within each of these zones we did structured surveys at several sites using transects from the upper limit of exposed organisms to the lowest level at low tide. Transects of 30 to 50 m were laid out horizontally along the shore at different tidal heights and then at least ten 1 m^2 quadrats were sampled along each transect for all species, including algae and invertebrates. The majority of species were identifiable for at least two months after the earthquake.

As part of a wider programme funded by the Ministry of Primary Industries, we targeted sampling of pāua and their habitats. Reproductive dynamics of pāua, key algal and invertebrates species were assessed to determine if there were sub-lethal effects on them related to the earthquake. Through community interactions, the fate of pāua that had been transplanted from newly exposed areas to subtidal habitats ~~were~~ assessed. One commonly asked question was: 'wouldn't the marine communities simply realign themselves down the new tidal gradient'? This would only happen, however, if there was intertidal and subtidal rock in these new zones. To determine this, we did subtidal surveys for rocky reefs and associated organisms along many sites. Of particular concern to us was the potential loss of recruitment habitat for pāua, the larvae of which settle from the plankton into very specific habitats featuring small rocks and boulders inshore.

Description of results to date

Compilation and analysis of our large database covering dozens of sites allow a comprehensive view of changes to the nearshore ecosystem in the different degrees of uplift zones and their initial recovery trajectories. Here we describe them broadly.

Witnessing intertidal and subtidal habitats, with all of their organisms suddenly exposed, remains one of the most astounding things any of us ecologists have seen. We were able to walk through what were formally subtidal habitats in many areas and see the full array of physical habitats and species that were present. There was massive mortality of seaweeds along virtually the entire coastline. The large habitat-forming algae, with plants up to several metres long, including bull kelp and other strap-like fucoid algae were festooned over rocks and quickly drying in the sun.

*Figure 1: Uplifted reef north of Kaikōura near Waipapa. The vertical algae hanging from the rock on the left is bull-kelp (*Durvillaea poha*), which normally occurs at the intertidal-subtidal margin. Plants are about 2 m long. Below them are newly exposed smaller boulders. The dark algae are fucoids which can reach up to about a metre long. The white on the rocks is mostly bleached calcareous algae, which generally forms a primary cover on rocks and boulders from the low intertidal zone downwards. Photo was taken about a month after the earthquake (Photo: D Schiel).*

Thousands of pāua, often greater than the 125 mm legal size, were exposed among boulders at many sites along the coast. Mortalities were high, often numbering thousands at particular sites, but many stranded pāua were relocated into the subtidal environment by local communities, commercial pāua divers, local iwi, and fisheries officers. The fate of these translocated individuals is not entirely clear, but they surely would have died had they been left on the

Figure 2: The uplift occurred just after midnight on an incoming tide, when mobile marine animals like crayfish and butterfish were actively feeding around submerged reefs. In some areas the speed and suddenness of the uplift was evident in the large number of these animals that were found stranded. Some areas of high uplift, such as Waipapa Bay (pictured), had hundreds of crayfish and fish left permanently above the waterline. Slower moving and sessile animals such as pāua, kina, and mussels had even less chance of escaping back to water (Photo: Marine Ecology Research Group).

newly exposed reefs. Coastal fishes were dead and scattered throughout the uplifted areas, particularly at the more severely affected sites around Waipapa to the north of Kaikōura. These included butterfish (*Odax pullus*) and coastal labrids (*Notolabrus fucicola* and *N. celidotus*). At Waipapa, thousands of lobsters, mostly juveniles, were dead, as were the many species of rocky reef snails, such as the turbinid gastropods (e.g., cat's eye snail *Lunella smaragdus* and Cook's turban *Cookia sulcata*).

In the high intertidal zone, virtually all of the limpets died. These are some of the most important grazing gastropods on coastal reefs. In areas around Kaikōura, thousands of limpets were eaten by seagulls, which apparently had one of the best reproductive years in over a decade because of the high, limpet-fuelled nutrition suddenly available.

While the full panoply of rocky shore communities was

Figure 3: Sea of green. Fast settling and generally ephemeral green seaweeds, often called sea-lettuce, settled throughout the middle and lower intertidal zone beginning about three months after the earthquake and lasting till around December 2017. Their longevity was aided by the massive loss and general absence of grazing invertebrates on reefs along much of the earthquake coast (Photo: ~~S Gerrity~~).

evident, death and decomposition were the major features, and the most overpowering sense was the smell associated with the wide-scale destruction. One consequence was that water quality was compromised in tide pools and in the new low intertidal zone, where dissolved oxygen was at or below the minimum level to sustain life.

Ecologically, several main factors stand out. One is that the very large bull-kelps *Durvillaea antarctica* and *D. poha*, which can reach several metres long and are dominant on wave-exposed shores on the South Island, are now largely missing. Grazing invertebrates have remained absent or in very low numbers on the rocks and boulders of the new intertidal zone, except on the cooler sides of rocks and within crevices. Fast-settling ephemeral algae such as sea lettuce (*Ulva* spp.) bloomed along most of the intertidal zone of the coast, forming a wide belt of emerald green that persisted into December 2017.

Presumably, the longevity of this green algae was aided by the lack of grazing invertebrates. On our much-studied reefs of Kaikōura, some of New Zealand's most diverse algal communities and their associated organisms simply disappeared from large stretches of reef. Interestingly, these reefs had relatively little upheaval, probably around 0.7 m. They are still mostly covered with water at high tide, but the water depth is only a few centimetres and now experiences extreme temperatures. Sensors put out before and after the earthquakes showed that lethal temperatures over 40°C were frequently reached, especially over the summer months.

The consequences were not only the loss of seaweeds initially, but the inability of the perennial seaweeds to recruit into such harsh conditions. There was some recruitment of perennial seaweeds at the lowest reef margins, but large portions of the formerly lush reefs are covered with shiny brown ephemeral algae.

One major concern is the loss of habitat for pāua settlement and recruitment. Sites such as Omihi, south of Kaikōura, had known juvenile pāua habitat down to a depth of around one to two metres. Much of this habitat was left high and dry after the earthquake. We have continued sampling for juvenile pāua to determine whether some survived the earthquake and whether the 2016 reproductive period had produced successful recruitment in 2017. We have found some 'hot-spots' for pāua recruitment and our efforts continue to identity key areas of appropriate settlement habitat to help gauge the likely long-term impacts on the pāua fishery along the earthquake coast.

The massive loss of seaweeds and invertebrates has almost surely disrupted the coastal food web. Recent studies by Otago University, for example, have shown that large algae such as kelps provide much of the food that supports mobile organisms in the coastal ecosystem, such as fishes. This is because fish feed on a wide range of invertebrates, which feed on kelp and other algae. One way to detect these shifts and ecosystem connections is through stable isotope analysis, which is currently being pursued.

There is obviously much to be done to understand how the ecosystem will re-assort itself. The northeast coast of the South Island is normally highly exposed to waves. The sea bottom is predominately sand and gravel, and sediment deposition can be high. This is most likely exacerbated by the continual erosion of cliffs along much of the Kaikōura coast. As well, the deterioration of the reef system itself is ongoing and severe in places. Most of the boulders and reefs are soft sedimentary rock, which is thoroughly dried out and has become unstable and is eroding greatly. Resultant fine-grain sediments have accumulated in the low intertidal zone where in many places they have smothered rock surfaces. Fine sediments can also remain in the water column and alter the quantity and spectral quality of light

Figure 4: Before (left) and after (right) comparison of the rocky reef at Kaikōura that has been studied for over 25 years. This had been one of the highest diversity reefs in New Zealand until the earthquake. It is now devoid of macroalgae except at its lowest margins (Photos: L. Tait).

Figure 5: Research associate Shawn Gerrity turns over small boulders in the search for surviving juvenile pāua . Much of the habitat of this species was uplifted (Photo: D Schiel).

necessary for benthic algae to grow. As yet, we do not know the full extent of subtidal rocky reef along the coastline and whether there is even the capability of the marine organisms to re-align themselves downwards ~~into~~ deeper reefs. Multi-beam surveys currently being done in some key areas of this coastline, as well as our own subtidal surveys, will help clarify this.

Obviously, there is much that remains to be known about the recovery dynamics of this coastal zone. The human element is also of particular concern. Prior to the earthquake, many of these areas had isolated embayments and beaches that were relatively inaccessible, except at very low tides. Such areas served as haul-out places for seals, nesting sites for coastal birds and refuges from harvesting because of general inaccessibility. Many of these areas are now readily accessible at all stages of the tide. For example, it is now possible to drive around the coastline to Cape Campbell in the northeast of the South Island, an area that was formerly hard to visit, except through farmland. This has brought new pressures to the coastline including tourism and its associated people and vehicular pressure, access for fishing, particularly for highly desirable inshore organisms like pāua and lobsters, and potentially elevated levels of illegal fishing (e.g., undersized or over-limit catches, and for pāua, which is prohibited from being fished commercially and recreationally).

In our estimate, recovery of this ecosystem will take many years. In the meantime we will have to face and solve new management issues associated with the reconfigured coastline and the marine environment.

References

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