

Kōura

In the 2016 survey, kōura were only observed within the deep zone at the Snout and Crombie (one individual at each location), whereas all seven kōura counted in 2010 were from the mid depth zone at the Crombie (Figure 5).

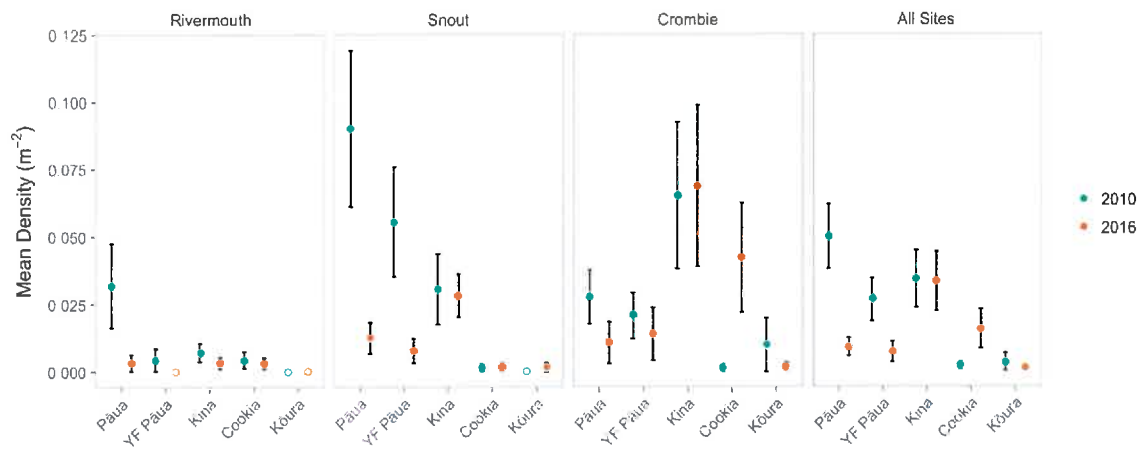


Figure 4: Average density \pm standard error of blackfoot pāua (pāua, *Haliotis iris*), yellow foot pāua (YF Pāua, *Haliotis australis*), Kina (*Evechinus chloroticus*), Cookia (*Cookia sulcata*) and Koura (*Jasus edwardsii*) within the three survey locations (River Mouth, Snout and Crombie) and averaged for all sites for the 2010 (green dots) and 2016 (orange dots) surveys. Note hollow dots indicate zero (no creatures found).

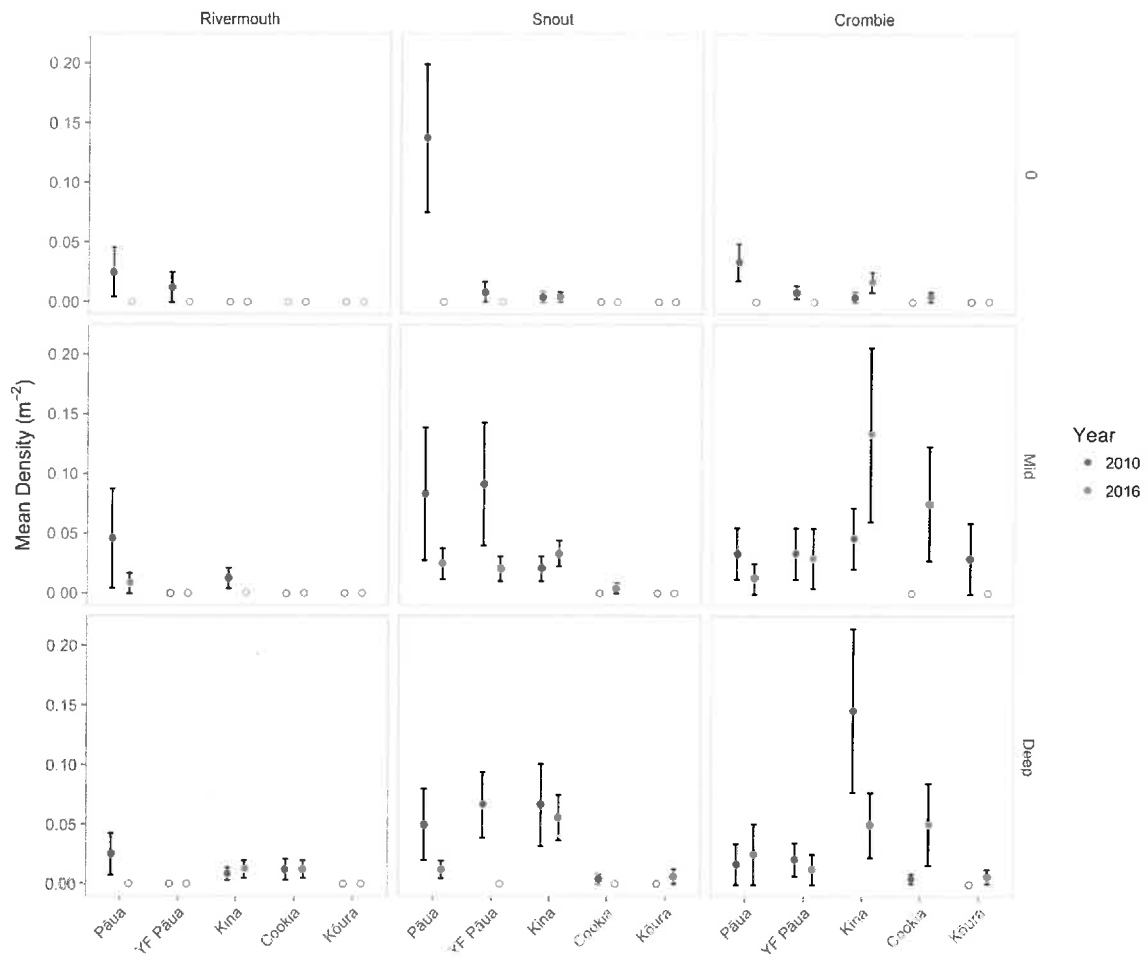


Figure 5: Average density \pm standard error of blackfoot pāua (pāua, *Haliotis iris*), yellow foot pāua (YF Pāua, *Haliotis australis*), Kina (*Evechinus chloroticus*), Cookia (*Cookia sulcata*) and Koura (*Jasus edwardsii*) at three depths (0 m, Mid = 0.1 – 2 m and Deep = 0.5 – 4 m depth) within the three study locations during 2010 (green dots) and 2016 (orange dots). Note hollow dots indicate zero (no creatures found)..

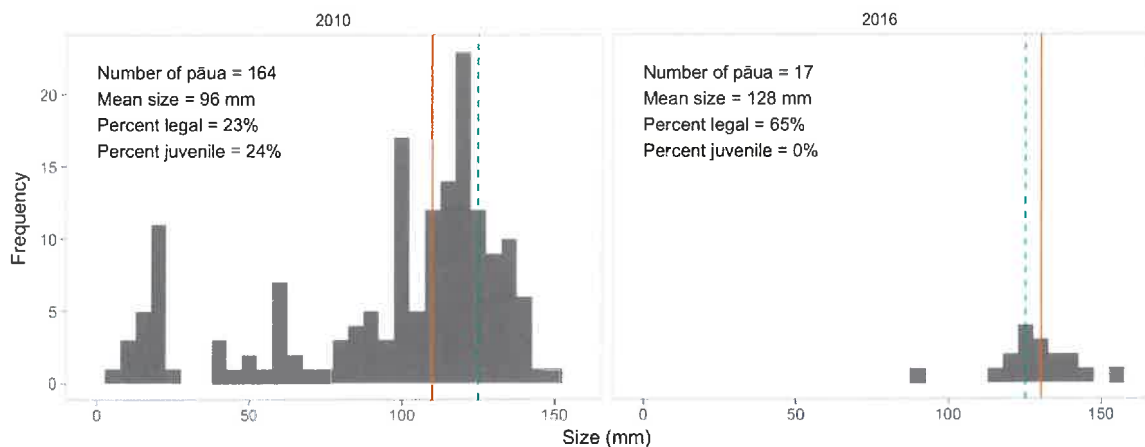


Figure 6: Size frequency distribution of pāua within Waitutu survey areas for 2010 (left-hand panel) and 2016 (right-hand panel). The green dashed line represents the median size and the orange line represents the minimum legal size of pāua (125 mm).

Habitat Characteristics

Macroalgae

A total of 50 macroalgal species or species assemblages were encountered during this survey (Appendix 1), with 30 species observed within quadrats (Appendix 2). Turf forming assemblages were the principal algal cover at all sites and depths followed by CCA species (Figure 7). The percentage cover of CCA species did not vary with depth ($p_{\text{perm}} = 0.086$), however Turf and Low-turf forming species increased with depth ($p_{\text{perm}} = 0.003$ and $p_{\text{perm}} = 0.001$, respectively) and the coverage of *Cystophora* spp. peaked at the mid depth ($p_{\text{perm}} = 0.008$). Between the 2010 and 2016 surveys, the average cover of CCA increased ($p_{\text{perm}} = 0.001$), while turf forming species declined ($p_{\text{perm}} = 0.003$, Figure 7).

Benthic Substrate

Reef structure was the dominant benthic substrate within the Waitutu survey area, ranging between $44\% \pm 9$ p.p. and $74\% \pm 9$ p.p. cover (Figure 7). Boulder habitat

was the second most common benthic substrate, with cover ranging between $26\% \pm 9$ p.p. and $48\% \pm 8$ p.p. (Figure 7). There was no statistically significant difference over time, or between sites and depths in either of these two primary substrate types (Figure 7, $p_{\text{perm}} > 0.37$ for all), however the percentage coverage of sand increased with depth ($p_{\text{perm}} = 0.004$, but was relatively stable through time, $p_{\text{perm}} = 0.54$). In 2010 the only location that fine sediment was recorded was at the Crombie (within the deep depth strata) and at very low levels $0.3\% \pm 0.3$ p.p. In contrast, fine sediment was recorded at all locations and depth strata and as high as $19\% \pm 8.7$ p.p. during the 2016 survey (Figure 7) resulting in a statistically significant increase in coverage between the 2010 and 2016 surveys ($p_{\text{perm}} = 0.001$).

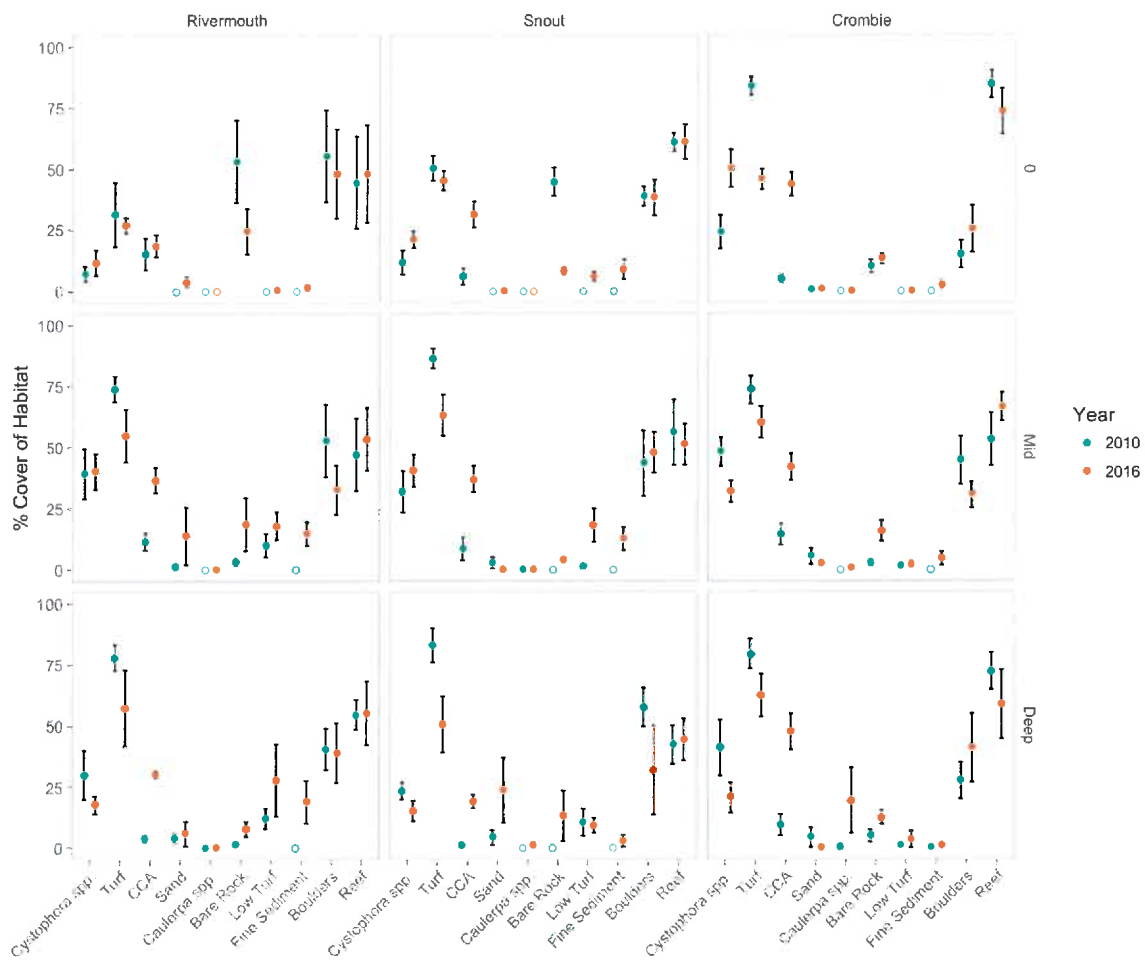


Figure 7: Average percent cover \pm standard error of the primary habitat forming macroalgae and substrate across three depth strata (0 m, Mid = 0.1 – 2 m and Deep = 0.5 – 4 m depth) within the three study locations during 2010 (green dots) and 2016 (orange dots). Note hollow dots indicate zero.

Discussion

The original baseline survey conducted in December 2010 established that the density of blackfoot and yellow foot pāua (from now on collectively termed pāua) was considerably lower than the lowest densities observed in other customary protected areas within the Ngāi Tahu takiwā (Hepburn and Richards 2012). During the five years since the 2010 baseline survey, the density of pāua within the Waitutu survey area has further decreased by approximately 82% and 73% for blackfoot and yellow foot pāua respectively.

This survey revealed that average density of blackfoot pāua within the Waitutu survey locations was extremely low (between 0.003 and 0.014 pāua m⁻²). The low density of pāua found within Waitutu Mātaitai and the 'control' site (Crombie) is concerning due to the free spawning reproductive strategy of this species. For abalone species, densities of less than 1 m⁻² in randomly placed quadrats have been related to limited fertilisation success, known as a population Allee effect (e.g., Quinn et al. 1993, Babcock and Keesing 1999, Miner et al. 2006). Therefore, it is likely the observed low densities within the Waitutu survey area may lead to reduced recruitment of juveniles. It is possible that the pāua population is now at such a low density that 'natural' recruitment is unlikely to be able to restore the fishery to a level that can be sustainably harvested. An option that could be considered by the Waitutu Mātaitai Management Committee is some form of reseeding into the mātaitai to enhance the recovery of this taonga species. For example, restocking with hatchery raised juveniles (or spat) that are the offspring of brood stock taken from within the Waitutu area.

Although the 2010 survey included juvenile pāua measured by turning over rocks ('rock flipping') and the 2016 did not, this is not in itself an explanation for the lower densities observed in 2016. Generally, blackfoot pāua emerge from cryptic habitats at 80 – 85 mm in shell length, which takes approximately four to five years post settlement (McShane and Naylor 1995). The 2010 survey found approximately 24% of the population was below 80 mm, whereas no blackfoot pāua in the 2016 survey were in that size class (see Figure 6). Importantly, however, when pāua smaller than 80 mm are removed from the 2010 dataset, there remains a large reduction in the density of blackfoot pāua that is unable to be attributed to the different survey methodologies.

A possible explanation is that some environmental change occurred between the surveys that negatively influenced the pāua population. The higher levels of fine sediment observed during the 2016 survey provide some evidence that sediment input (e.g. terrestrial sediment inputs from slips) or movement might be responsible (see Figure 7). Fine sediment can adversely impact juvenile pāua populations (Chew et al. 2013), as well as inhibit larval settlement (Onitsuka et al. 2008). Furthermore, changes in habitat structure, especially burial by sand, can reduce the survival of pāua (Schiel 1993). The River Mouth and Snout survey locations had more sand (an increase from approximately 1% to 6%) in the 2016 survey. Although this is a relatively minor increase, when combined with the amount of fine sediment, it amounts to approximately 17% and 15% of the habitat on average, at the River Mouth and Snout respectively. Additionally, sites at the Crombie had the lowest cover of sand and fine sediment (where average cover of sand actually decreased from the 2010 survey) which coincided with the smallest reduction in pāua density.

In contrast to pāua, the overall density of Cookia increased between the two surveys (although this difference was not statistically significant). The density of Kina did not change between surveys. Within the Waitutu survey area the distribution of Cookia and Kina overlap with pāua (see Figure 5), and as such there is some indication that the decrease in pāua density may not simply be a result of the impact of environmental change on the wider kaimoana population as a whole, but rather something that is related specifically to pāua (for example, harvesting).

Another possible explanation for the reduction in pāua density could be the impact of large storms disturbing the pāua population (Naylor and McShane 2001, Takami et al. 2013). Occurrences of this disturbance along the Otago / Southland coastline have been reported recently, where the Ministry for Primary Industries (MPI) stated that the situation appeared to be a natural event related to flooding with freshwater (Otago Daily Times 2016, Stuff 2016). This phenomenon was observed on the beach near the Wairaurahiri River mouth after a large storm and heavy rainfall several months before the 2016 survey commenced (J. Groters and P. Baldwin personal communication 2016).

Overall, it is likely that a combination of all these factors has contributed to the decline in the pāua populations observed within the survey area. In areas of low pāua density, such as Waitutu, it is difficult to separate effects of environmental change or harvesting and it is impossible to say, from these data alone, which explanation is more likely. The patchy distribution of pāua populations at local scales requires high sampling replication to detect changes in density, especially when densities of pāua are low (McShane 1995, Keesing and Baker 1998). Utilising other indicators of change in pāua stock, such as population size structure, is one way to

address the issues surrounding density estimates for pāua. However as there were only 17 blackfoot pāua measured in 2016 we are unable to employ this technique at this time. The survey methods used here are most powerful when they are replicated through time (ideally more than three times). However, it seems unlikely that waiting for ≈ 5 years for a third survey of these sites will yield substantively more information about pāua density. It is clear that pāua density at traditional customary fishing depths within the Waitutu mātaimai are easily among the lowest within the nine CPA within the Ngāi Tahu network that have been surveyed using comparable methods and it is unlikely these stocks will recover without active intervention (e.g. reseeded).

Conclusions

The unintentional addition of a 'control' site (Crombie) due to the alteration of the proposed Waitutu Mātaimai boundary provides the Waitutu Mātaimai Management Committee an opportunity to trace the progress of management interventions for the pāua fishery.

The data and methods provided in this report should not be used in a vacuum because local knowledge and mātauranga provides the broader context that extends further into the past. All available knowledge, alongside the aspirations of the Waitutu Mātaimai Tangata Tiaki and their Rūnanga, can and should be used as a basis for decision making. Continuing scientific support is available for Tangata Tiaki / Kaitiaki to help them direct future monitoring to build on the monitoring provided by this work and to track the status the fishery and habitats within the Waitutu Mātaimai in the future.

References

- Babcock, R. and Keesing, J. 1999. Fertilization biology of the abalone *Haliotis laevis*: Laboratory and field studies. *Canadian Journal of Fisheries and Aquatic Sciences*. 56:1668–1678.
- Chew, C.A., Hepburn, C.D. and Stephenson, W. 2013. Low-level sedimentation modifies behaviour in juvenile *Haliotis iris* and may affect their vulnerability to predation. *Marine Biology*. 160:1213–21.
- Hepburn, C.D. and Richards, D.K. 2012. Baseline survey of the proposed Waitutu Mātaitai reserve 2010. University of Otago He Kōhinga Rangahau No. 12.
- Keesing, J.K. and Baker, J.L. 1998. The benefits of catch and effort data at a fine spatial scale in the South Australian abalone (*Haliotis laevis* and *H. rubra*) fishery. *Canadian Special Publication of Fisheries and Aquatic Sciences*. 179–86.
- Kingsford, M. and Battershill, C. (Eds.) 1998. Studying temperate marine environments: a handbook for ecologists. Canterbury University Press, Christchurch, N.Z. 335 pp.
- McShane, P. 1995. Estimating the abundance of abalone: the importance of patch size. *Marine and Freshwater Research*. 46:657–62.
- McShane, P.E. and Naylor, J.R. 1995. Small-scale spatial variation in growth, size at maturity, and yield- and egg-per-recruit relations in the New Zealand abalone *Haliotis iris*. *New Zealand Journal of Marine and Freshwater Research*. 29:603–12.
- Miner, C.M., Altstatt, J.M., Raimondi, P.T. and Minchinton, T.E. 2006. Recruitment failure and shifts in community structure following mass mortality limit recovery prospects of black abalone. *Marine Ecology Progress Series*. 327:107–117.
- Morton, J.E. and Hayward, B.W. 2004. Seashore ecology of New Zealand and the Pacific. Bateman, Auckland, N.Z. 504 pp.
- Morton, J.E. and Miller, M.C. 1973. The New Zealand sea shore. Collins.
- Naylor, J.R. and McShane, P.E. 2001. Mortality of post-settlement abalone *Haliotis iris* caused by conspecific adults and wave exposure. *New Zealand Journal of Marine and Freshwater Research*. 35:363–9.
- Onitsuka, T., Kawamura, T., Ohashi, S., Iwanaga, S., Horii, T. and Watanabe, Y. 2008. Effects of sediments on larval settlement of abalone *Haliotis diversicolor*. *Journal of Experimental Marine Biology and Ecology*. 365:53–8.
- Otago Daily Times 2016. Paua washed up on beach by fresh water, wind. Available At: <https://www.odt.co.nz/regions/south-otago/paua-washed-beach-fresh-water-wind> (last accessed August 2, 2017).
- Quinn, J.F., Wing, S.R. and Botsford, L.W. 1993. Harvest Refugia in Marine Invertebrate Fisheries: Models and Applications to the Red Sea Urchin, *Strongylocentrotus franciscanus*. *American Zoologist*. 33:537–50.

- Schiel, D.R. 1993. Experimental evaluation of commercial-scale enhancement of abalone *Haliotis iris* populations in New Zealand. *Marine ecology progress series*. 167–181.
- Stuff 2016. Natural event likely to have caused paua washup in the Catlins. Available At: <http://www.stuff.co.nz/environment/76428496/natural-event-likely-to-have-caused-paua-washup-in-the-catlins> (last accessed August 2, 2017).
- Subritzky, P. 2013. The identification of juvenile *Haliotis iris* habitat within the East Otago Taiāpure. University of Otago.
- Takami, H., Won, N.-I. and Kawamura, T. 2013. Impacts of the 2011 mega-earthquake and tsunami on abalone *Haliotis discus hannai* and sea urchin *Strongylocentrotus nudus* populations at Oshika Peninsula, Miyagi, Japan: *Mega-earthquake and tsunami effect on abalone and sea urchin. Fisheries Oceanography*. 22:113–20.
- Wang, Y., Naumann, U., Wright, S.T. and Warton, D.I. 2012. mvabund - an R package for model-based analysis of multivariate abundance data. *Methods in Ecology and Evolution*. 3:471–4.

Appendix 1

Supplementary Table 1: Primary producer species (grouped by phylum) encountered within the Waitutu survey locations during the January 2016 survey. Note this is not intended to be a comprehensive list of all the macroalgal species present at this location.

| Phylum | Common name | Species |
|--------------------------------|------------------------------------|----------------------------------|
| Rhodophyta (Red algae) | ACA | Mix of species |
| | | <i>Adamsiella</i> sp. |
| | | <i>Anotrichium crinitum</i> |
| | | <i>Apophlaea lyallii</i> |
| | | <i>Asparagopsis armata</i> |
| | CCA | <i>Bostrychia arbuscula</i> |
| | | Mix of species |
| | | <i>Chondria macrocarpa</i> |
| | | <i>Cladhymeria oblongifolia</i> |
| | | <i>Craspedocarpus erosus</i> |
| | | <i>Gigartina clavifera</i> |
| | | <i>Hildenbrandia</i> spp. |
| | | <i>Hymenena affinis</i> |
| | | <i>Hymenena durvillei</i> |
| | | <i>Pachymenia lusoria</i> |
| | | <i>Peyssonnelia</i> spp. |
| | | <i>Plocamium angustum</i> |
| | | <i>Plocamium cirrhosum</i> |
| | | <i>Plocamium microcladioides</i> |
| | | <i>Polysiphonia</i> spp. |
| <i>Sarcothalia livida</i> | | |
| <i>Schizoseris griffithsia</i> | | |
| Chlorophyta (Green algae) | Green Crust | <i>Bryopsis</i> spp. |
| | | <i>Caulerpa brownii</i> |
| | | <i>Chaetomorpha coliformis</i> |
| | | <i>Cladophora herpestica</i> |
| | | <i>Cladophora feredayi</i> |
| | | <i>Codium convolutum</i> |
| | | <i>Codium dimorphum</i> |
| | | <i>Codium fragile</i> |
| | | Mix of species |
| | | <i>Ulva</i> spp. |
| Brown Crust | Mix of species | |
| | <i>Carpophyllum flexuosum</i> | |
| | <i>Carpophyllum maschalocarpum</i> | |
| | <i>Colpommnia claytoniae</i> | |
| | <i>Cystophora platylobium</i> | |

Heterokontophyta
(Brown algae)

Cystophora retroflexa
Cystophora scalaris
Cystophora torulosa
Dictyota kunthii
Desmarestia ligulata
Ecklonia radiata
Halopteris spp.
Homosira banksii
Papenfussiella lutea
Splachnidium rugosum
Scytosiphon lomentaria
Tinocladia novae-zelandiae
Zonaria turneriana

Appendix 2

Supplementary Table 2: Primary producer taxa and groups with mean cover ranked from most common to least across all survey locations.

| Species / variable | Mean cover (%) |
|-----------------------------------|-----------------------|
| CCA | 34 |
| ACA | 28 |
| <i>Cystophora retroflexa</i> | 24 |
| Mixed Reds | 22 |
| Empty Space | 13 |
| <i>Zonaria turneriana</i> | 9 |
| SOO | 8 |
| Brown Crust | 5 |
| <i>Cystophora scalaris</i> | 3 |
| <i>Dictyota kunthii</i> | 3 |
| <i>Caulerpa brownii</i> | 2 |
| <i>Bostrychia arbuscula</i> | 2 |
| <i>Cystophora torulosa</i> | 2 |
| <i>Ulva</i> spp. | 1 |
| <i>Hormosira banksii</i> | 1 |
| <i>Desmarestea ligulata</i> | 1 |
| <i>Papenfussiella lutea</i> | < 1 |
| <i>Colpomenia</i> spp. | < 1 |
| <i>Scytosiphon lomentaria</i> | < 1 |
| <i>Tinocladia novae-zelandiae</i> | < 1 |
| <i>Chaetomorpha coliformis</i> | < 1 |
| <i>Plocamium</i> spp. | < 1 |
| <i>Cladophora feredayi</i> | < 1 |
| <i>Halopteris</i> spp. | < 1 |
| <i>Splachnidium rugosum</i> | < 1 |
| <i>Apophlaea</i> spp. | < 1 |
| <i>Codium</i> spp. | < 1 |
| Green Crust | < 1 |
| <i>Carpophyllum flexuosum</i> | < 1 |
| <i>Ecklonia radiata</i> | < 1 |
| <i>Bryopsis</i> spp. | < 1 |

