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The lost kelp forest: A multi-disciplinary approach to understand change of *Macrocystis pyrifera* habitat in Otago, New Zealand

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Introduction

Macrocystis pyrifera (Bladder/Giant kelp; Rimurimu) typically grows on hard rocky reef substrates (Young et al., 2015). The large canopies created by *M. pyrifera* form kelp forests and they are considered to be ecosystem engineers (Miller et al., 2018). The canopies have the ability to reduce wave energy within the forest, which is important for larval settlement and habitat refugia (Miller et al., 2018).

The forests provide important nutrients to the surrounding waters as they break down as well as a direct food resource to grazers (Miller et al., 2018). Kelp forests also have the ability to reduce coastal erosion by reducing wave energy (Hurd et al., 1997), and they provide a buffer against ocean acidification through carbon dioxide uptake (Hepburn et al., 2011).

Globally, kelp forests provide many services to humans such as supporting fisheries, direct harvest, tourism, science, and potentially carbon uptake, and these services are estimated to be worth NZ$3.6 million per km per year (Filbee-Dexter and Wernberg, 2018).

In New Zealand, *M. pyrifera* is found ranging from Marlborough and Wellington in the north to the Sub-Antarctic Islands in the south (Desmond, 2016). Kelp forests support ecologically, culturally, and commercially important species such as *Haliotis iris* (pāua), *Jasus edwardsii* (southern rock lobster), *Parapercis colias* (blue cod), *Evechinus chloroticus* (kina), and *Odax pullus* (greenbone) (Desmond, 2016). In Otago, there has been an anecdotal decline in the density and distribution of these ecologically important kelp beds post-industrialisation.

Kelp forest decline

Nineteen semi-structured interviews were undertaken to determine changes in the distribution and density of *M. pyrifera* and to identify potential drivers of decline within the living memory of local experts. The pool of experts was made up of commercial and recreational fishermen, kaumātua, scientists, a skipper, a dive instructor, and a university technician. From the interviews, it is evident there has been a clear loss of kelp forests and a decline in density along the southern coastline from approximately the 1970s-1980s (see Figure 1). There has also likely been a decline in density and distribution along the northern coastline occurring around the 1980s-1990s (see Figure 1), however this is not as clear, likely due to shifting baselines amongst interviewees (Pauly, 1995).

Interviewees indicated that 'river runoff', primarily attributed to sediment increases in waterways, was the most likely driver of the loss of kelp forests along the Otago coast. Sedimentation is known to reduce kelp cover as a result of hard substrate occlusion preventing attachment, decreasing light availability for photosynthesis, and smothering smaller life stages (Young et al., 2015; Miller et al., 2018; Hurd et al., 1997).

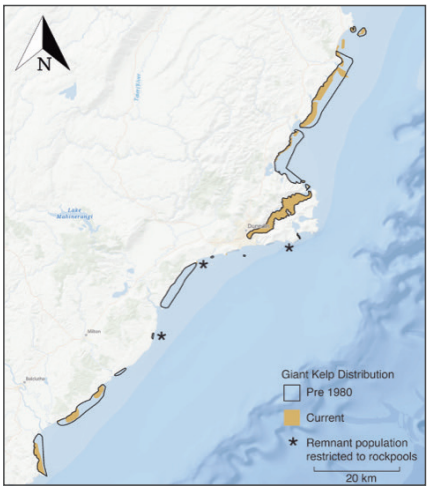

Figure 1: Macrocystis pyrifera distribution along coastal Otago from Katiki Point to Nugget Point showing the pre-1980 distribution and post-1980 decline (Image: Madeline Glover, Matthew Desmond and Chris Hepburn).

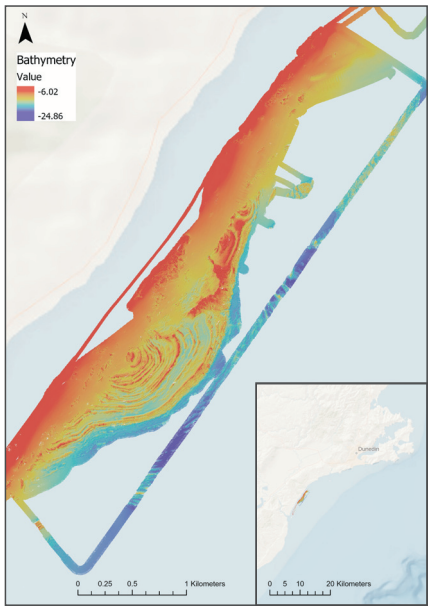

Figure 2: Reef structures found in the 2019 survey of the southern Otago coast between Taieri Island (46°03'27.2"S 170°13'02.5"E) and Bruce Rocks (45°58'37.7"S 170°18'12.3"E).

Remaining habitat

A significant loss of kelp was identified by interviewees along the Taieri-Brighton coast so this area was further investigated through multibeam and camera drop surveys. These surveys aimed to both validate the interviewees and determine what habitat remains in the area. A multibeam survey was undertaken using a R2 Sonic 2026 multibeam. The survey covered a 9.9 km stretch of coastline between Taieri Island and Brighton and identified two concentric reef structures (0.2 km^2 and 0.9 km^2) (see Figure 2). The reef structures are in the area described by interviewees and are in the correct depth band (Tait, 2019) with hard structures (Young et al., 2015) to support *M. pyrifera* growth, supporting the interviewees.

A drop camera survey of the reef structures was undertaken with 88 video camera drops being completed. The camera drop survey was compared to a previous survey of the East Otago Taiāpure, where it is known that *M. pyrifera* is still present. The camera drop

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survey of the Taieri reef structures supported the multibeam survey that there was sufficient hard structure to support *M. pyrifera*. The hard structure at the southern site was identified as predominantly consolidated reef as opposed to mainly boulders and cobbles in the East Otago Taiāpure. The algal compositions at the two sites were significantly different. In the East Otago Taiāpure there was a more heterogeneous mix of understory corallines and canopy brown seaweeds, whereas the Taieri Island site was a homogenous mix of coralline, rhodophytes, and *Caulerpa brownii* (see Figure 3).

Potential drivers

Globally, kelp forest distribution has been changing, with some increasing but the majority decreasing (Wernberg et al., 2019). There is seldom one driver of loss in an area, rather multiple stressors that cause a decline (Wahl et al., 2015). There are trends of increased coastal nutrients, increased sediment, warming ocean temperatures, global expansion of herbivorous organisms, harvesting, and invasive species that are creating unfavourable conditions for *M. pyrifera*, altering both distribution and density.

Interviewees indicated that increased sediment was the most likely cause for the decline observed in kelp forests along the Otago coast. Given the information available from this research it is likely that there were multiple stressors that caused the loss and lack of re-establishment of *M. pyrifera* at this site. The primary driver is likely increased fine sediment from the Taieri River post-industrialisation from land conversion. Increased sediment in waterways is an issue across much of New Zealand as a result of conversion of native plantations to urban, agricultural and forestry uses (Galbraith and Burns, 2007). There continues to be frequent large inundation of sediment from the Taieri River to the Otago coast (see Figure 4) that would likely continue to occlude reef structures and alter the light environment for macroalgal growth (Tait, 2019).

It is possible that alongside increases in sediment from the Taieri River, other factors have contributed to the loss and lack of re-establishment. During the late 1970s there was an alteration of ENSO cycling due to upwelling that caused a prolongment of the eastward shift of the El Niño phase of the cycle (Wang and An, 2002). The alteration of the cycle would have resulted in fewer storms and big seas along the Otago coast. Storms and big seas can cause the removal of sediment along the Otago coast and as a result there could have been a compounding accumulation of sediment as a result of increased sediment and lack of removal (Carter and Carter, 1986). Since the 1970s it is possible that there has been a recruitment limitation issue that has disallowed the re-establishment of *M. pyrifera* (Raimondi et al., 2004).

Future work

The thesis this article is based on achieved the initial stages of a 'bottom-up' or ecosystem-based understanding of a habitat. The identification of the structures, substrate composition, and algal community has allowed initial insights into changes that may have occurred at this site. To further understand this environment, and if it is ecologically viable as a site for future regeneration of *M. pyrifera*, it would be essential to further investigate the biotic and abiotic parameters. Other tolerance factors that would be important to further investigate would include, but not be limited to, the suspended sediment environment, wave action, light, and temperature. It is important to understand how the factors fluctuate and how this will then, in turn, alter the ability of *M. pyrifera* to carry out its biological functioning. In understanding how these environmental parameters are acting and interacting with the habitat it would also be essential to understand how, long term, these factors may change. If sustainable regeneration were to occur it needs to be put into a long-term goal, understanding the durability of the species under changing climatic conditions.

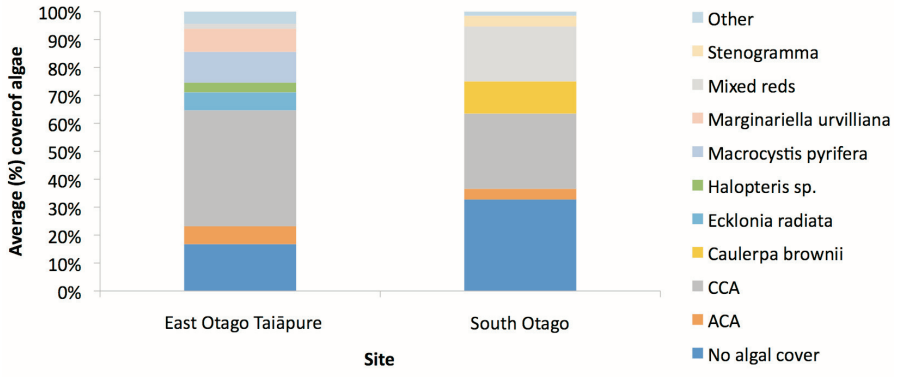

Figure 3: Average percentage cover of substrate types at East Otago Taiāpure (n=36) and South Otago (n=88) from drop camera surveys.

Figure 4: Screenshots from an aerial flyover of the Taieri River in flood in 2018 – (a) confluence of the Taieri River and the southern Otago coastline, and (b) Sediment plume along the Taieri-Brighton coastline (Images: Taieri River flyover, Blokenshed, 2019).

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