Using local knowledge to understand and manage ecosystem-related decline in fisheries productivity

A case study of seagrass decline in Corner Inlet, Victoria

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In submitting this report, the researcher has agreed to FRDC publishing this material in its edited form.

23rd May 2016
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Dear John,

Re: A case study of seagrass decline in Corner Inlet

Thank-you for providing the West Gippsland Catchment Management Authority with a draft final copy of the *"Using local knowledge to understand and manage ecosystem-related decline in fisheries production- A case study of seagrass decline in Corner Inlet'* report. The WGCMA has valued the opportunity to be involved with this research over the past 3 years, as it has assisted in addressing a number of key knowledge gaps, whilst developing and strengthening our partnership with the commercial fishing industry, as well the University of Melbourne and the Fisheries Research Development Corporation.

Corner Inlet supports outstanding environmental values that have been recognised through its listing as a wetland of international importance under the Ramsar Convention. The size and diversity of habitats across Corner Inlet (e.g. seagrass, mud and sand flats, mangroves, saltmarsh, and permanent shallow marine water) support many aquatic and semi-aquatic plant and animal populations. In particular, the seagrass ecosystem is a driver of marine ecology and has a critical role in carbon sequestration, providing habitat and food for fauna including fish and migratory and resident wader birds. As such, seagrass plays a critical role in the viability of the Corner Inlet commercial fishery.

With national parks, waterways, farmland and coast, the land surrounding Corner Inlet is also a place of natural beauty, productivity and internationally recognised environmental values. However, as identified in the Corner Inlet Water Quality Improvement Plan (WGCMA, 2013), poor water quality in Corner Inlet (as a result nutrient and sediment run-off from the catchment) threatens the condition and extent of seagrass meadows.

The WGCMA, in partnership with the local community, landholders, industry and government agencies (national, state and local) are committed to improving the quality of water entering the Corner Inlet Ramsar site in order to protect its unique and significant values. The WQIP provides a long-term, on-ground works program to achieve measurable reductions in the level of nutrient and sediment entering Corner Inlet form the surrounding catchment. The outcomes of FDRC funded project will support the implementation of the WQIP through:

- Provision of a robust, cost effective and easily repeatable method for mapping the extent of seagrass across Corner Inlet. Previous attempts to understand the historical extent of seagrass decline have been hampered by the use of different mapping methods and interpretations. The work undertaken by this project has assisted greatly in understanding historical fluctuations in seagrass through the use of local knowledge from Corner inlet fisherman. Further, the project has created a 2013 seagrass extent map that combines modern GIS techniques with the knowledge of the fishermen. The technique developed by the project is repeatable, and provides an opportunity for mapping seagrass across the 30-year life of the WQIP to assess if the on-ground catchment works having an impact on seagrass.

- Having established a clear link between catchment nutrients/sediment, algal blooms and seagrass decline. Prior to this project, there was limited documentation on the type and extent of algal blooms in Corner Inlet. The project has identified two types of blooms, one which appears to be fuelled by nutrients coming from the natural breakdown of seagrass and has been occurring for many decades, and the other fuelled by nutrients originating in the catchment and which is increasing in impact over the past decade. This information is important in informing the on-going nutrient/sediment reduction work in the catchment and the associated monitoring requirements.

- Water quality monitoring of streams draining to Corner Inlet undertaken through the project has confirmed the findings of the WQIP- that high nutrient and sediment loads are entering the Inlet from the north and NW, and the western tributaries have high concentrations of nutrients. This information will support the WGCMA and partners in targeting limited financial resources to undertake on-ground nutrient/sediment reduction works in these priority sub-catchments.

- As stated previously, strong partnerships are the key to achieving change in Corner Inlet. The work over the past 3 years through the project has fostered a strong partnership with the local commercial fishing industry, and we look forward to continuing this into the future. Further, the information generated through the project (e.g. seagrass map, water quality information and interested generated through field days and presentations) will assist the WGCMA to strengthen the community engagement programs ran in Corner Inlet.

We look forward to seeing the final report and hope to continue working with the FRDC and University of Melbourne staff into the future.

Yours sincerely

Martin Fuller
Chief Executive Officer
West Gippsland CMA

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Acknowledgments

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The commitment of the West Gippsland Catchment Management authority was integral to the success of this project. We would especially like to thank Tracey Jones for her ongoing support and dedication to Corner Inlet, and to Michelle Dickson, who was vital in getting the project off the ground.

The Landcare groups provided strong links to the farming community and we thank them for giving us the opportunity to convey the messages of seagrass decline and threats to habitat. In particular we would like to thank Jenny O'Sullivan and Kate Williams at South Gippsland Landcare and Sam Monks at Yarram Landcare.

The Corner Inlet Connections group was an important forum for discussion and dissemination of ideas.

The involvement of Dairy Australia added a strong link to the farming industry and we thank Gillian Hayman for the many discussions and her involvement in the Farmer-fisher day.

We would like to thank A/Prof Perran Cook, Ryan Woodland and Weiwen Wong from Monash University for advice and guidance in the algal N-isotope experiment.

Dr Tim Smith was integral in the seagrass restoration experiment and we hope to see further development of this initiative.

We also thank Peter Crockett for algal identification, Jillian Staton for assistance developing engagement guidelines, Tina Hines at the Monash Water Studies Centre for running water quality tests and Simon Sharp of CAPIM for GIS assistance.

Abbreviations

Corner Inlet Fisheries Habitat Association (CIFHA)

Corner Inlet Water Quality Improvement Plan (CIWQIP)

West Gippsland Catchment Management Authority (WGCMA)

Executive Summary

What the report is about

This project is the first in Australia to comprehensively engage fisher's local knowledge to understand and address external, catchment-related threats to fisheries productivity. The project, led by researchers at the University of Melbourne, collaborated with the Corner Inlet commercial fishing industry to document, understand, communicate and address declines in fish habitat that threatens productivity. Declines in seagrass, the key fish habitat, was intrinsically linked with the activities in the broader region through catchment runoff and addition of excess nutrients and sediments from land. We successfully raised the regional and management profile of the fishery, its importance to the economy and culture, and increased the awareness of threats to the fishery. Most importantly, and in collaboration with local catchment managers and the farming industry, we engineered and have begun to implement attitude and practice changes that will undoubtedly benefit the fishery in the long term.

We present in this report an analysis of seagrass decline and its threat to coastal fisheries, with a detailed case study of the issues specifically facing Corner Inlet and its fishery. We document seagrass decline in Corner Inlet between 1965 and 2013, and identify algal blooms and turbidity as key threats. We outline a unique methodology of valuing and using the local environmental knowledge of fishers to understand environmental change to help inform threats and guide management action. Finally, we provide a set of guidelines for engaging coastal fishing communities in catchment management, and hope to see this approach applied successfully across fisheries at risk from catchment-related inputs.

Background

Throughout Australia there is a need to address external, often environmental or land-based threats to fishery productivity. The loss of seagrass, a key fish habitat, is an issue in many coastal fisheries that relies of seagrass associated species. This project was undertaken in response to the decline in seagrass in Corner Inlet that threatens productivity in the commercial and recreational fisheries. There was little capacity of the fishery to influence decision-making in the regional catchment. Hence we saw a need to integrate the fishing industry into the catchment management framework, communicate their challenges and advocate for improved water quality and responsible land practices.

Seagrass decline in Corner Inlet had been loosely documented but not empirically demonstrated. Without this definitive evidence, managers were not successful in advocating for catchment improvements that could improve water quality and stabilize seagrass cover. We identified a deep knowledge and understanding of the local ecosystem in the fishing community, and saw the potential for this to be used to interpret historical information and document seagrass change. Through communicating the local knowledge of fishers, we saw the potential to both provide evidence of seagrass decline and as a line of direct engagement with catchment managers and landholders to address external threats to the fishery.

Aims/objectives

This project aims to ensure that the local fishing industry plays an integral part of the environmental decision making process in the catchment, and more broadly display how commercial fishers can add value to such a process. Our initial objectives were to understand and document the change in the seagrass system by using fisher's local knowledge, to create a current map of seagrass distribution, to review and investigate threats to seagrass such as algal blooms and chemicals, and to engage with the wider catchment, both landowners and managers, to communicate the concerns of fishers. During the project we received additional funding to trial the active restoration of seagrass meadows in areas of recent loss, and to develop a methodology for future large-scale rehabilitation.

Methodology

We undertook a unique methodology that engaged with the local environmental knowledge of commercial fishers to understand ecosystem change and threats to seagrass. Fishers were interviewed one-on-one and asked to convey their observations around seagrass, algal blooms, ecosystem variability and threats to seagrass. Fishers were also integral in the seagrass mapping process, which combines the use of satellite imagery and GIS software with spatial observations and species identification from local knowledge. Similarly, we used a unique method to document the frequency, extent and duration of algal blooms from fisher's observations.

We used the outcomes of the local knowledge methods to guide further scientific exploration of ecosystem change and seagrass threats. We examined the nitrogen isotope signatures of algal blooms, and compared these to signatures acquired from the seagrass system and local catchment inputs. Chemical threats were assessed, before a broader assessment of all threats to seagrass was conducted to ensure targeting of the most important risks to fishery productivity.

We engaged with managers and landusers in the catchment in a variety of different ways, including public presentations, one-on-one meetings, workshops and collaborative events. Most prominent was the Far-fisher day, where dialogue and understanding was fostered through reciprocal visits to fishing grounds and to farm paddocks.

Seagrass restoration was trialled using ramet (growth shoot) transplants and seeding. We undertook the trials in the Yanakie Basin area and followed the results for six months.

Key findings

We found the current cover of subtidal seagrass is the lowest in the past 48 yrs (85.3km^2) and has declined at a rate of 0.5km^2 yr^{-1}. There were species-specific differences, where the current cover of *Z. nigricaulis* is the lowest in living memory and it is completely absent from the deeper muddy basins historically dominated by the species. There was a massive loss of *Z. nigricaulis* between 2011 and 2013, which coincides with the aftermath of the La Nina and drought-breaking floods of 2010 and 2011. Natural 5-10 yr cyclical fluctuations in *Z. nigricaulis* have caused significant variation in seagrass maps made in different decades. There has likely been a long term decline in *P. australis* from the southern and northern shores and high banks, although the areas were subsequently colonised by *Z. nigricaulis.*

Filamentous algal blooms are an important but previously unrecognized threat to seagrass in Corner Inlet. There are two types of filamentous bloom, a 'brown' bloom dominated by *Feldmannia irregularis* that occurs almost every autumn and a 'green' bloom of the red algae *Stylonema alsidii* occasionally in mid-summer. Blooms lasted on average 6 weeks and covered 61% of the seagrass in Corner Inlet. Most areas of reported seagrass decline (NW corner, Agnes/Toora, Golden Creek basin, Red Bluff, Yanakie) were always covered during blooms. The brown bloom has occurred annually for over 60 years and nitrogen was mostly sourced from the seagrass system. It is probable that the natural decomposition of *P. australis* blades in autumn provides a large nitrogen source for the bloom. The green bloom is a more recent phenomenon, increasing in frequency and severity in the past 10 years. The majority of nutrients are sourced from the catchment.

Reduction in light as a result of algal blooms and turbidity pose the greatest threat to seagrass in Corner Inlet. Sediment from the catchment entering the Inlet likely contributes significantly to turbidity, although resuspension of sediment from wind and waves will also play an important role. Nutrients from the catchment play a significant role in fuelling green algal blooms. Levels of nutrients and sediment were high in all rivers and creeks entering the Inlet from the north and west, and all samples were above the EPA 75th percentile for total nitrogen and total phosphorous. Old Hat and Poor Fellow Me creeks both had consistently very high concentrations of nutrients. The threat of heavy metals, hydrocarbons and most agricultural chemicals to seagrass is low in Corner Inlet. Spraying of phenoxy acid herbicides in the intertidal zone by helicopter presents an unknown but concerning risk. Physical disturbance of seagrass beds could pose a high risk if large scale dredging works are carried out in the future.

Conditions were not conducive to small scale seagrass restoration in the Yanakie basin, as physical disturbance from strong easterly winds uprooted growth shoot transplants. Seed bags successfully dropped seeds into the sediment, but produced few viable seedlings. A seedbank could be established through large scale seed bag deployments, which may lie dormant until conditions are conducive for growth.

Implications for relevant stakeholders

The project has raised the public and management profile of the Corner Inlet fishery, its sustainability and the threats to productivity. The role of the fishing industry in the regional community and economy was strengthened through outreach of the research team but importantly by the fishers themselves. The validation of the majority of the hypotheses posed by local fisher's knowledge raises the profile of the industry in providing relevant and real advice. Already fishers are represented on key management groups such as Corner Inlet Connections, and we hope that this will spread to other regional bodies

Already, key components of the report are being utilized by catchment managers. The 2013 seagrass map will be used a baseline from which managers will benchmark seagrass cover and the effectiveness of their management initiatives. The observation of a definitive decline in seagrass cover answers the uncertainty around this issue which has prevented adequate action in the past. Furthermore, the link between catchment nutrients, algal blooms and seagrass decline provides the first strong evidence that the activities in the catchment are contributing to habitat loss and productivity costs to the fishery. The momentum created by this project, along with the strong case for addressing habitat decline, lays a strong platform for the catchment-wide improvement of land practices and water quality

Recommendations

Catchment management recommendations

1. The Corner Inlet Water Quality Improvement Plan (CIWQIP) be fully funded to carry out the initiatives and works planned until 2033, focusing on best management practices for farms and waterway management such as gully and streambank rehabilitation

2. Develop a strategy to engage, educate and motivate the landowners who are currently disengaged and provide financial incentives to make environmental improvements

3. Convert shoreline farming paddocks into natural saltmarsh and swamp. Purchase of land or finding alternative economic benefit from these areas (e.g. samphire harvest) may be required

4. Investigate the contribution of other major land uses, particularly forestry operations to water quality issues in Corner Inlet

Regulatory recommendations

1. Legislative changes to the *Victorian Fisheries Act* that empower Fisheries Victoria to identify and manage aquatic and marine habitat important for recreational and commercial fisheries.

2. Strengthening regulation around farm runoff, and consider establishment of market based approaches such as nutrient trading schemes

3. Review the continued extension of Crown Land leases on the edges of Victorian waterways and provide funds for fencing all Crown Land waterway frontages

Research and monitoring recommendations

1. Ongoing nutrient and sediment monitoring of the Corner Inlet waterways to determine effectiveness of the CIWQIP and inform ongoing adaptive management. Include intermittent testing of herbicides

2. Seagrass mapping be carried out every 3-5 years using the local knowledge technique outlined in this project

3. Research into the exposure of seagrass to phenoxy-acid herbicides after aerial intertidal spraying, and consequent effects

4. Inlet-wide monitoring of turbidity levels using light loggers to investigate effects of water way sediment loads and resuspension

5. Monitor the green summer blooms and determine if they are linked to seagrass loss. Identify the sources of catchment nutrients fuelling green algal blooms.

6. Further development of seagrass restoration techniques using seed dispersal of both *Z. nigricaulis* and *P. australis*

Keywords

Algal blooms, catchment inputs, catchment management, collaborative management, ecosystem services, fisher’s ecological knowledge, habitat loss, seagrass decline, seagrass restoration, habitat mapping, fishery productivity, Corner Inlet, Victoria

Introduction

Threats to productivity in coastal fisheries

Throughout Australia's coastal fisheries, there is a growing need to address external, often land-based threats to fishery sustainability (Kearney and Farebrother 2015). The importance of environmental drivers in fisheries productivity is well established (Garcia and Rosenberg 2010, Fu et al. 2012) and can be a greater determinant of stock size than fishing pressure (Wilson et al. 2010). Productivity in coastal fisheries is often determined by local processes such as catchment inputs (Caddy 2000, Paerl 2006) and habitat availability (Dayton et al.1995, Jackson et al. 2001). Habitat loss is considered one of the greatest threats to coastal ecosystems (Crain et al. 2009) and fisheries managers are starting to include the protection of fishery-habitat into management frameworks (Rosenberg et al. 2000). However more often, external threats to fisheries habitat are often dismissed, poorly understood, or deemed too difficult to address under traditional management frameworks.

Recent developments across Australia toward a more collaborative management of the coastal environment have the potential to benefit fisheries by arresting productivity declines. On the Great Barrier Reef, a key threat is poor water quality driven by runoff from land catchments (Kroon et al. 2012). Major government initiatives such as the Reef Plan, Reef Rescue and Reef Protection package, have encouraged the collaborative engagement of catchment users in reducing runoff, with some success (Brodie et al. 2012). Oyster farmers on the NSW South coast have also undertaken collaborative catchment management initiatives, engaging with the dairy industry to encourage improvement in the water quality that affects their productivity (Gietzelt et al. 2014). Such a collaborative approach requires the co-operation of fishers, researchers, landowners and catchment managers to share understanding of the system and decide on management actions targeted to be both realistic and effective.

This project aimed to develop a catchment-wide collaborative management approach to addressing decline in seagrass habitat in Corner Inlet, Victoria and the consequent effects on fishery productivity and the livelihood of the fishers. Previous work had identified issues related to water quality and catchment runoff; but there was little integration of the fishing industry into broader discussions, and little knowledge of the impact of catchment-related habitat declines and their effects on the fishing industry.

Corner Inlet fishery

Corner Inlet in eastern Victoria (Figure 1) was identified as a prime opportunity to develop and implement such a collaborative approach to address fishery declines and ensure long term sustainability. The 150 year old Corner Inlet fishery is an important component of the economy, culture and history of South Gippsland, with a long history of engagement with the regional community. Fisher-led organisations such as the Corner Inlet Fisheries Habitat association (CIFHA) have been active in raising concerns about the seagrass decline, creating public awareness around the sustainability of the fishery and creating drive for better habitat management. Local NRM organisations such as the West Gippsland Catchment Management Authority (WGCMA) and Landcare were already active in engaging landowners to improve riverine and estuarine water quality. This work was further supported through the development of the Corner Inlet Water Quality Improvement Plan (CIWQIP) in 2013 (Dickson et al. 2013), which highlighted the need for broad scale NRM initiatives (erosion control, riparian restoration and support for adoption of agricultural Best Management Practices). Significant management and knowledge gaps remained however, particularly around a lack of engagement with commercial fishers and poor understanding of the nature of the threats to the key fisheries habitat, seagrass.

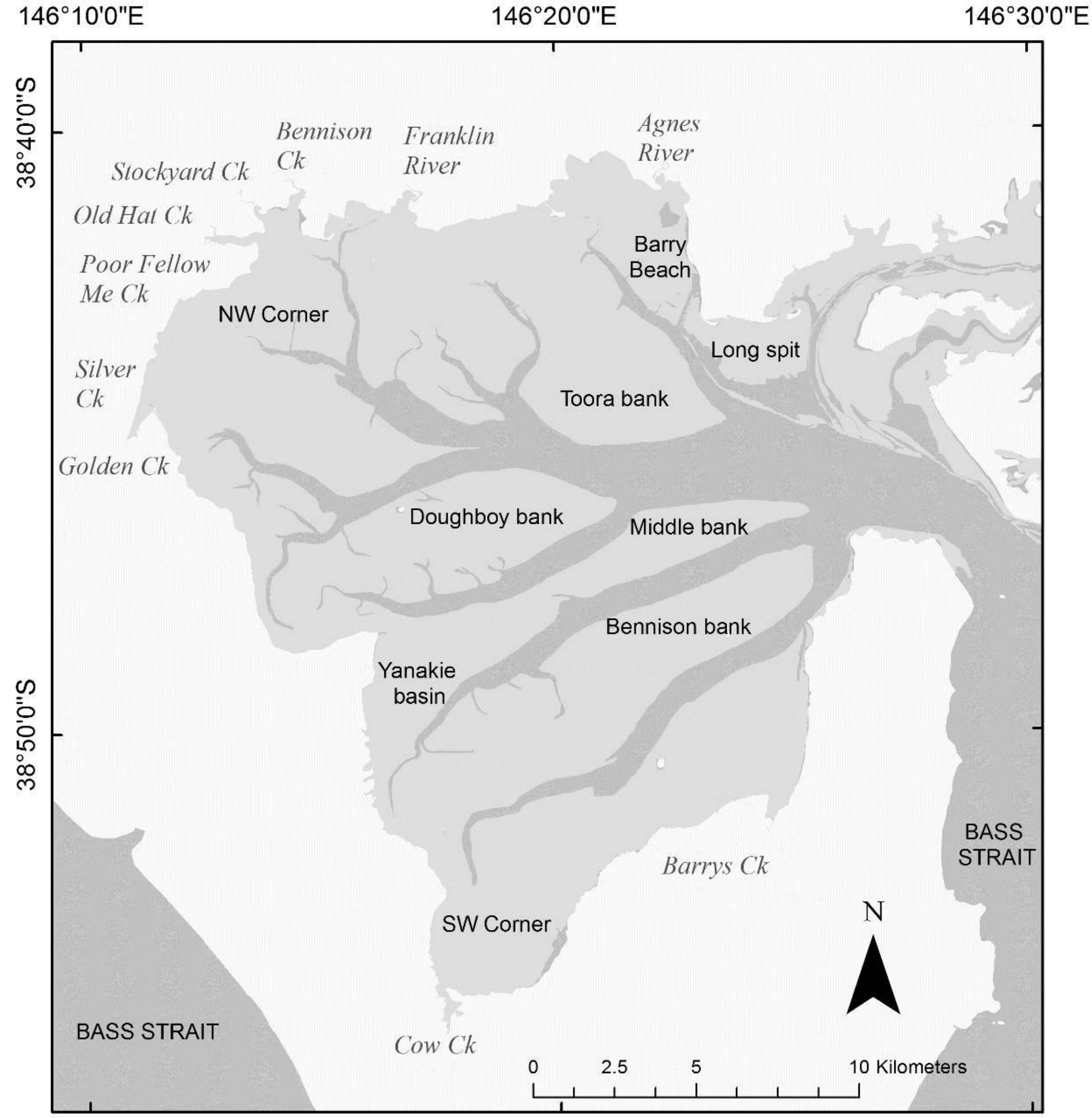


Figure 1. Map of Corner Inlet, showing locations of main banks and basins, and waterways

The Corner Inlet-Nooramunga fishery is a limited entry, 18 licenses fishery with an average annual fishery production of 345t over five years between 2007/8 and 2011/12; and is worth around $2.6 million (Victorian Department of Primary Industries 2012). The key species in order of value are King George whiting, rock flathead, calamari and garfish, which are targeted by either haul seines or set mesh nets. Each of these top four species is dependent on seagrass habitat for part, if not most, of their life cycle (Hindell 2006). The seagrass ecosystem (seagrass, epiphytes and related invertebrates) has been shown to contribute up to 90% of the total nutrition of key target species (Hindell et al. 2009). The three most important species in the fishery have been independently assessed as sustainable in 2012 by the Sustainable Australian Seafood Assessment Program, although the assessment noted that catchment activities posed a likely threat to long term fisheries productivity and potentially to fishery sustainability. Simply put, these key species that comprise 75% of the value of the fishery would not be present without a healthy seagrass ecosystem.

Seagrass decline

Seagrass ecosystems are important drivers of productivity in many coastal fisheries (Jackson et al. 2001), acting as critical habitat for many key species (Beck et al. 2001). Seagrass is, however, significantly threatened from expanding human populations, catchment alterations and coastline development (Orth et al. 2006, Ralph et al. 2010). Globally, seagrass has declined by 29% since 1879 and the rate of this loss is accelerating (Waycott et al. 2009). With an estimated value of $19,000 ha-1 yr-1 in ecosystem services such as nutrient cycling (Costanza et al. 1997), and a net worth in fisheries productivity of up to $230,000 ha-1 yr-1 (Blandon and zu Ermgassen 2014), these losses can cause significant impact on the productivity of coastal ecosystems (Beck et al. 2001) and the viability of related industries such as fishing and tourism.

Australia has followed this trend of widespread seagrass decline in coastal waters (Walker and McComb 1992). Like many global examples, Australian seagrass decline is often observed in areas with significant modification of the surrounding catchment – 58% loss of *Posidonia australis* in Botany Bay (Larkum and West 1990), 77% decline of mainly *Posidonia* species in Cockburn Sound (Kendrick et al. 2002), 24% decline in *Halophila* in Hervey Bay (Preen et al. 1995) and a 70-85% decline in *Zostera* in Western Port (Bulthuis 1983). Extensive seagrass decline have also been documented in Moreton Bay (Kirkman 1978), along the Adelaide coastline (5000 ha; Westphalen et al. 2005) and in NSW estuaries (1300ha in Tuggerah Lakes, 700 ha in Lake Macquarie; in Walker and McComb 1992).

While there is ample evidence for global seagrass decline, it is important to note that observations of seagrass expansion or recovery are often overlooked (Walker et al. 2010), and this has occurred both in fast growing tropical species (*Halodule* species – Robbins 1997) and in slow growing temperate species (*Posidonia coriacea* – Kendrick et al. 2000, and *P. australis* - Meehan and West 2000). This is an important and encouraging point to consider for scientists, managers and stakeholders; if the pressures that are causing the decline in seagrass are removed or alleviated, there is good evidence to suggest that seagrass will recover. Hence success in managing seagrass-dependent fisheries must at least in part lie in reducing these external pressures on fisheries productivity.

Seagrass decline in Corner Inlet

Corner Inlet supports large seagrass meadows on shallow banks in < 5m water depth and on intertidal mud flats. The seagrass meadows also mostly lie in the Corner Inlet and Nooramunga Coastal Park and are a RAMSAR listed significant habitat for migrating birds. The dominant species are broad-leaf seagrass (*Posidonia australis*), fine-leaf seagrass (*Zostera nigricaulis*), whiting-grass or paddle-weed (*Halophila australis*) and the intertidal swan-grass *Zostera muelleri*. The former three species are sub-tidal, although they can cope with occasional exposure at a very low tide if water is pooled at the base of the blades (Kirkman 2013). *Z. muelleri* is exclusively an intertidal species in Corner Inlet, although it persists subtidally at Port Albert.

The seagrass ecosystem supports the commercial fishery and hence any sustained decline in seagrass is likely to significantly affect the fishery. Most important for the commercial fishery are *P. australis* and *Z. nigricaulis*, and understanding the dynamics of the two species is key to deciphering the patterns of seagrass change in Corner Inlet. The two species each have a very different biology and ecology: *P. australis* has a large rhizome mat and associated energy stores, but is slow to colonise new areas (West and Larkum 1979), while *Z. nigricaulis* is fast growing, has few energy stores and colonises new areas more quickly. Hence we would expect change in these species to be happening on different temporal scales, where both the loss and regrowth of *P. australis* is likely to be much slower than that of *Z. nigricaulis*.

There have been eight seagrass mapping studies (not including the present study) carried out in Corner Inlet in the past fifty years. Unfortunately, few have used comparative methodology and only two cover all areas of Corner Inlet, so that it is extremely difficult to compare studies and accurately quantify seagrass change over the 50 years of monitoring (Kirkman 2013). Techniques range from early tracing of aerial photos with little ground-truthing (Poore 1978, Morgan 1986) and early use of GIS generated maps from aerial photos (Roob et al. 1998), to more recent sophisticated remote sensing and LIDAR (Light Detecting and Ranging) analysis from satellite imagery (Monk et al. 2011, Pope et al. 2013). Seagrass species identification has been quite poor for the range of maps, with early maps from Poore (1978) and Morgan (1986) classifying all subtidal seagrass as *P. australis.* Roob et al. (1998) report *Zostera* as the dominant subtidal species, which is refuted by later maps (Monk et al. 2011) and field observations.

The most widely used estimate of seagrass cover in Corner Inlet is 149 km^2, which is taken from the mapping work of Roob et al. (1998), the only study to map seagrass across the entire Inlet. Most studies of seagrass in Corner Inlet state that there has been a decline of seagrass beds in some areas, most prominently the north-west (Poore 1978, Morgan 1986, Hindell et al. 2009). Roob et al. (1998) attempted to quantify some of the natural variability in seagrass cover, and noted cycles in seagrass coverage: the general trend over time was good coverage in the 1960s and 1970s; a decline in the late 1970's followed by stages of regrowth to return to a healthy coverage by 1998. Hindell et al. (2009) and Ball et al. (2010) add to this a period of decline from 1998 to 2005 and regrowth from 2006 to 2007. A coarse scale map produced from Landsat imagery in 1989 (Allen 1994) and a 2007 map produced from fisher's observations (CIFHA 2008) confirm these trends. The period of decline during the late 1970s and 1980s corresponded to a 40% reduction in the yield of the fishery, although this was also influenced by fisher's moving offshore to more profitable fishing grounds (Roob et al 1998). Whilst the estimated total seagrass coverage of the inlet has fluctuated, there is evidence of overall declines, particularly between 1975 and 1984 (Morgan 1986). To date there has been no attempt to compare across the 50 years of mapping, there is little understanding of which species are involved in the decline, how the declines fit into natural environmentally driven cycles, and whether anthropogenic factors are involved.

This project aimed to improve understanding of these fluctuations by using fishermen's local knowledge to better interpret the mapping studies. Many of the fishermen in Corner Inlet have been involved in the fishery over this 50 year period and could hence fill some of the gaps in our knowledge of the past and how it relates to present conditions. Importantly, this project has created a seagrass map that combines modern GIS techniques with the knowledge of the fishermen

Engaging fisher's local knowledge

The knowledge of local communities that work with and depend upon natural systems can provide unique insights into ecological processes and their relationships with human activities. This local knowledge can provide information for management that may be difficult or cost-prohibitive to obtain using scientific measurement and monitoring methods (Anadon et al. 2009). For these reasons, the use of local knowledge has been widely promoted over the past two decades as an important next step in informing natural resource management and conservation measures (Huntington 1998, Johannes et al. 2000, Folke 2004, Gilmour et al. 2013). Unfortunately the documentation of local knowledge and its uptake into management has been slow at best (Anadon et al. 2009), hindered by a combination of inflexibility of decision making systems, lack of scientific rigour, limited confidence in data, unfamiliarity with social science methods by ecologists and managers, reluctance of local communities to share truthful information and different motivations and values of communities and scientists (Huntington 2000). Continued refinement of local knowledge techniques, particularly in fisheries (e.g. Garret et al. 2012, Zukowski et al. 2013, MacDonald et al. 2014) highlights the growing importance of the local knowledge process as an important information gathering and engagement tool. The current debate over the use of local knowledge is summarized by Silver and Campbell (2005, p.273) "It is not so much the idea of participation that is contested, but what participation entails. Debate continues regarding the why, where, how and who of participation".

Most of the studies involving fishermen's local knowledge have informed biological and ecological understanding of individual species (e.g. breeding cycles, migration, growth rates) or ecosystem linkages (food webs, seasonality, river flows or currents) (see Valbo-Jorgensen and Poulsen 2000, Silvano and Valbo-Jorgensen 2008, Silver and Campbell 2005, Ruddle and Davis 2011). Management decisions, however, are mostly made by different authorities in a separate process. For example, Prigent et al (2008) created conceptual models from fishermen's local knowledge, which were used as a reference state for the ecosystem, but this did not directly inform management decisions: these were not based on the fishermen's observations or perceived needs. Few marine scientists and managers have attempted to integrate local knowledge into a more formal process of decision making (but see Day et al. 2010), and this appears to be the next step in the process of taking advantage of the experience and ecological understanding of local fishing communities.

Most successful uses of local knowledge occur in countries with less-developed scientific fisheries management programs than Australia (Valbo-Jorgensen and Poulsen 2000, Silvano and Valbo-Jorgensen 2008, Silver and Campbell 2008). In countries with develop fisheries research, such as Australia, much of the biological information that might be gathered through local knowledge elsewhere has instead been the domain of biologists and ecologists. Australia has built good scientific knowledge of most of our commercial fish species and to a lesser extent their ecosystems, often through researchers working in conjunction with fishers. It is appropriate therefore that the current use of local knowledge in Australia focuses on aspects of the fishery and ecosystem that are not easily measured or monitored by one-off research projects (e.g. biology, physiology) or regular government compilation of data (e.g. catch and effort, climate, water quality). Instead, local knowledge may be best employed in Australian fisheries to directly inform local management practices that conserve the health of the aquatic system that support fisheries productivity.

Documenting ecosystem change outside of natural ecological variability can assist in targeting management practices to improve aquatic health. Long term scientific datasets on ecosystem or habitat condition are very rare in marine and aquatic environments (Wolfe et al. 1987, Magurran et al. 2010). Local knowledge has the potential to fill these data gaps by characterising natural ecological cycles, documenting ecosystem change and identifying areas of degradation. This information can be used to alert managers of problems, guide the spatial application of management initiatives or improve scientific studies investigating the causes of degradation.

Local knowledge may be especially useful in many of Australia's coastal or bay and inlet fisheries, where ecosystem health and fisheries productivity are strongly influenced by external sources such as land based activities and climate. Environmental factors such as nutrient inputs, chemical pollution, sediment and freshwater flow, all of which can influence fish dependent habitat and primary productivity, often make traditional management indicators unreliable. In such circumstances, where fishing pressure may not be the dominant driver of fish abundance, there arises a need to effectively manage the external influences to ensure sustainability.

The extensive local knowledge of Corner Inlet fishermen provides an important opportunity to engage fishermen with catchment management initiatives aiming to improve aquatic health and maintain fisheries productivity. Fisheries Victoria has already taken small steps to incorporate indicators generated by local knowledge into stock assessment in Corner Inlet. This project set out to engage with the local knowledge of fishermen to better understand the Corner Inlet ecosystem, natural cycles of variability, habitat changes and threats to fishery productivity. In aligning local knowledge observations with other lines of evidence, we aimed to document seagrass decline and provide managers with directions on addressing the external threats to the fishery.

Threats to seagrass

Seagrasses are threatened by both natural and man-made processes, and it is often a combination of multiple stressors which lead to large declines in seagrass extent (Orth et al. 2006). Natural physical disturbances such as cyclones or storm surge have led to losses of seagrass beds (Walker et al. 2010), but such stressors are often coupled with corresponding pressure from anthropogenic sources, such as large freshwater discharges that bring sediment and pollutants from the catchment (e.g. Hervey Bay; Preen et al. 1995). Although direct physical removal can occur through dredging and land reclamation activities, most anthropogenic stressors to seagrass are related to declining water quality, caused by intensive urban or rural landuse. Furthermore, modifications to river systems and the removal of swamps, saltmarsh and mangroves from estuarine systems can channel runoff more quickly to seagrass beds, concentrating the impacts of freshwater runoff and reducing the natural settlement of sediment and breakdown of nutrients and pollutants.

Human induced changes to water quality over seagrass beds are most often the result of freshwater runoff from land, which may be elevated in nutrients, sediment, or anthropogenic chemicals. Eutrophication through input of high nutrient loads from the catchment is considered to have the most widespread impact on seagrass beds (Ralph et al. 2010). Excess nutrients promote the growth of phytoplankton and epiphytic macroalgae which block light and reduce oxygen availability to the seagrass (Short et al. 1995). High levels of nutrients have been identified as the cause of seagrass declines in North Carolina (Burkholder et al. 1994), and in Spain (Brun et al. 2002). Increased nutrient loads are often associated with high sedimentation, which can both reduce light through turbidity and bury seagrass (Short and Wyllie-Echeverria 1996). High sediment loads have been implicated in seagrass decline in the Gulf of Carpentaria (Longstaff and Dennison 1999) and in the Philippines (Duarte et al. 1997). Most often however, it is a combination of high nutrients and sediment that are implicated in seagrass loss, e.g. Chesapeake Bay (Moore and Wetzel 2000) and the Adelaide coastline (Bryars et al. 2006).

Algal blooms are a key threat to seagrass worldwide (Bricker et al. 2008, Thomsen et al. 2012). Nutrient enrichment of estuarine and coastal waters, mostly through urban and agricultural runoff, can provide conditions conducive to fast growing algal species that compete with seagrass for light and oxygen (Valiela et al. 1997, McGlathery 2001). Overabundant algae caused by nutrient enrichment are directly linked to seagrass losses (Balthuis and Woerkerling 1983, Short et al. 1995, Cummins et al. 2004), and have been documented in areas such as Cockburn sound in Western Australia (Silberstein et al. 1986), Waquoit Bay in Massachusetts (Hauxwell et al. 2001) and Mondego estuary in Portugal (Cordoso et al. 1994).

Algal blooms drive declines in seagrass mostly through reducing light availability (Short et al. 1995), although oxygen limitation and ammonia and hydrogen sulphide toxicity are also important factors (Burkholder et al. 2007). Filamentous mat forming algae, the type which is common in Corner Inlet, have the greatest impact on seagrass because of their greater biomass and horizontal growth direction (Thomsen et al. 2012). By blanketing or smothering seagrass, low levels of light and oxygen, and high concentrations of ammonia and sulphide are created near the sediment surface where the sensitive seagrass meristem occurs (Thomsen et al. 2012). However, high rates of water movement and tidal flow may alleviate the impacts of light reduction and biochemical changes (Hessing-Lewis et al. 2015).

Reduced salinity and anthropogenic chemicals are not generally considered to be responsible for observed widespread declines in seagrass (Short and Wylie-Echevierra 1996, Orth et al. 2006, Bryars et al. 2006). But there is a general lack of understanding of the impacts of many toxicants, and anthropogenic chemicals and toxicants are considered likely to have significant localised impacts on seagrass around urban areas and intensively farmed catchments (Lewis and Devereux 2009).

Improving water quality in Corner Inlet

The WGCMA released a catchment-wide strategy and implementation document in 2013 aimed at identifying and addressing threats to the natural values of Corner Inlet. The document, *The Corner Inlet Water Quality Improvement Plan* (CIWQIP), had four key objectives: 1. Understand the Corner Inlet Catchment, 2. Provide clear and achievable management advice, 3. Raising awareness and taking action and 4. Involving community and stakeholders (Dickson et al. 2013). Whilst the document was not able to establish strong links between water quality and seagrass decline, it acknowledges the high loads of nutrients and sediment entering the Inlet and proposes targets of 15% reductions in total nitrogen and phosphorous loads and a 10% reduction in suspended sediment loads by 2033. These are encouraging targets for those concerned with addressing the decline of seagrass, although most of the initiatives set out to achieve these ($8.95 million per year for direct works over 20 years, with additional funds required for monitoring) are not yet funded.

Reducing nutrient loads in Corner Inlet may lead to a significant reduction in the frequency and extent of epiphyte loads on seagrass and algal blooms in the Inlet. Whilst epiphytes are not considered a major issue in Corner Inlet compared to other areas (Hindell et al. 2009), fishers have reported large and frequent filamentous algal blooms. Algal blooms in Corner Inlet are not documented in the scientific literature, and appear only as potential threats or anecdotal reports in management reports such as the Corner Inlet Environmental Audit (Molloy et al. 2005) and the CIWQIP (WCGCMA 2013). Local commercial fishermen however, report frequent and widespread algal blooms, often referred to as “slub”. Two forms of slub are reported: a brown type found in autumn and spring and a green type found in summer.

The focus of the CIWQIP is on the threats of sediments and nutrients to the seagrass system, which previous studies have identified as the most likely threats (Molloy et al. 2005, Hindell et al. 2009). However, the CIWQIP did not examine agricultural chemical use in the catchment as a threat to the seagrass system. The use of chemicals such as herbicides are a likely threat to seagrass in the catchment, as identified in Hervey Bay (McMahon et al. 2005) and internationally (Lewis and Devereux 2009). The absence of herbicides in water and sediments in the 1970s (Poore 1978) is cited as a reason not to consider agricultural chemicals as a threat in Corner Inlet (Molloy et al. 2005). This study however, was conducted over 35 years ago and we believe this is an important knowledge gap that has not been addressed in other studies. Therefore we saw an opportunity to fill this research gap in the CIWQIP by reviewing chemical use in the catchment to identify possible threatening substances, and provide alternatives where possible.
We saw a clear opportunity for the fishing community to become involved with raising the profile of seagrass and encourage land practices that will meet these water quality targets. Fishers were initially not involved in the drafting of the CIWQIP and we aimed to integrate the industry into the collaborative catchment management framework led by the WGCMA.

Seagrass restoration

A practical next step in understanding and addressing seagrass decline in Corner Inlet is the active restoration of areas that have experienced loss. Under natural conditions, seagrass ecosystems are generally thought to recover naturally from disturbance by relying on underground rhizomes and seed banks once the stress from the disturbance has abated (Schaffelke et al. 2005; Waycott et al. 2005). But in some situations a more active restoration approach is required, such as where seagrasses and their seed banks have been physically removed or damaged, or where long-term light deprivation has exhausted the reserves of stored energy and seed.

Seagrass restoration has been practised in the US, and Europe and WA for over three decades, but most projects have been faced with difficult challenges and have had low success rates (Fonseca et al. 1998; van Katwijk et al. 2009, Cunha et al. 2012, van Katwijk et al. 2016). Success of restoration will depend on a variety of factors such as appropriate site selection, favourable environmental conditions, and cost-effective methods, suitability of donor populations and clear objectives and expectations (Fonseca et al. 1998, Campbell 2002). Most importantly, success requires the absence of the conditions that caused the seagrass to be lost in the first place, such as poor water quality or physical disturbance.

Seagrass restoration has used three main techniques to re-establish beds: transplant of whole plants in "sods" with sediment attached (Thorhaug 1986), the planting of growth shoots (Seddon 2004), and the assisted dispersal of seed (Marion and Orth 2010). The three techniques vary in their logistical challenges and their success rate. While sod transplants and growth shoots attached to heavy frame structures are often the most successful techniques, such transplants require large amount of time and resources and hence only small areas are generally restored, or at great cost (van Katwijk et al. 2016). Seed dispersal, on the other hand, has the potential to restore very large areas at a cheaper cost, but it can have a very low success rate (Busch et al. 2010). The most appropriate technique will depend on the life history and biology of the seagrass species and the environmental conditions faced at the restoration site.

Opportunities exist in Corner Inlet to trial techniques of seagrass restoration for both key species. Such efforts will aim to both evaluate whether restoration is feasible right now and also to refine methods for future work when environmental conditions favour seagrass regrowth.

Objectives

OBJECTIVE ONE – Use fishermen's local knowledge to create maps of current seagrass distribution and document past ecosystem states and historical fluctuations in seagrass cover in Corner Inlet

OBJECTIVE TWO - Produce a report on potential chemical threats to seagrass in Corner Inlet; identify knowledge gaps and needs for further research

OBJECTIVE THREE – Link the key threats to seagrass in Corner Inlet with historical seagrass loss, focusing on the role of nutrients in driving algal blooms

OBJECTIVE FOUR – Convey the local knowledge of the system and threats through a series of workshops involving local management agencies and landowners

OBJECTIVE FIVE – Review of mapping and engagement process, investigating the feasibility of ongoing seagrass monitoring and creating general guidelines for future collaborative management

OBJECTIVE SIX - Assess the feasibility of seagrass restoration in Corner Inlet through scientific field trials and make recommendations on future steps to restore seagrass

Note on objectives:

Objective three was substantially altered during the study, as approved by the FRDC. The initial objective was to "Create a conceptual model of the aquatic system, incorporating threats to seagrass and fisheries productivity, by integrating scientific research with fishermen's local knowledge". During the project it became clear that the utility of a Corner-Inlet specific conceptual model was limited, given that similar models do exist for seagrass systems elsewhere and indeed simple ones exist for Corner Inlet. Instead, we identified algal blooms as a real and undocumented threat to the system, and saw great benefit in understanding the extent, duration and sources of these blooms in order to provide management recommendations.

The wording of other objectives was altered slightly, but with little overall effect on the outcome of the project. E.g. objective two initially referred only to "agricultural chemicals" which was later broadened to "chemical threats".

Method

Seagrass mapping

Seagrass mapping process 2013

We aimed to produce a cost-effective and accurate map of sub-tidal seagrass cover in Corner Inlet for 2013. We also wanted to overcome some of the drawbacks of previous mapping projects, such as poor species accuracy (e.g. 1998 Fisheries map) or high cost (e.g. 2009 Parks Victoria map). To achieve this, we combined modern GIS analysis of satellite imagery with the fisher's local knowledge of seagrass cover and species composition.

We purchased commercially available high resolution (50cm pixels) 2013 satellite imagery covering the whole of the Corner Inlet basin west of Long spit and Singapore Pt. At the time no single satellite run had acquired recent images of the entire Inlet, we hence used two separate Geoeye™ image sets, one covering the northern half (13th Feb 2013) and one covering the southern half (31st May 2013). Both images were ideal for our purposes due to 0% cloud cover, off-nadir < 12° and were supplied georeferenced. The southern image was taken at a lower tide and it was easier to identify exact edge boundaries of seagrass beds, whereas we encountered some difficulties in accurately mapping the edges of deeper channels using the northern images. We used ArcMap v10.2 for all further analysis of the images.

The imagery was divided into twelve approximate 8 x 6 km sections and printed onto A1 laminated paper at a scale of 1:10000. A researcher then undertook in-depth one-on-one interviews with two experienced (>30yrs) fishermen and systematically worked through the photos, asking the fisherman to identify and outline with a marker pen the seagrass beds on these maps, and to note the species composition and any historical or recent changes to these beds. The interviews with fishermen were repeated for one-quarter of the map to examine accuracy of memory, and there were no boundary or species composition differences between the two interviews. Where there was disagreement or uncertainty amongst fishermen as to the extent or species identity of a seagrass bed, we repeated the interview process with two additional fishermen for these locations only. If further uncertainty existed, we undertook ground-truthing by accompanying fishermen to the locations during their fishing operations.

The satellite imagery was initially analysed using ArcMap's Image classification tool "Maximum likelihood classification", starting with training samples based on known seagrass beds and species types. Whilst initially helpful to understand the broad distribution of seagrass, there were evident differences between the areas identified and those marked by fishermen on the hard-copy maps. Inaccuracies with the image classification method are attributed to the broad range of colour values for different seagrass species and their level of tidal exposure. In particular, the southern maps were taken in May, when the *P. australis* meadows were in their annual dieback stage. Different degrees of blade dieback amongst beds create very different colour intensities and were hence difficult to classify. Beds were therefore hand drawn using the "Create polygon" feature, guided by the fishermen's maps, the image classification polygons, and the visual display of the images. Species classification for each seagrass polygon was based on fisher's observations.

Both targeted and non-targeted ground-truthing was carried out by researchers in conjunction with other field collections (e.g. algal sample collection, see below) and observations of fishing activities. In total 265 ground truthing marks were collected over seven days between August 2013 and March 2016. Marks collected in 2015 and 2016 were used only to ground truth *P.australis,* given the dynamic nature of *Zostera* beds. Ground-truthing revealed that very sparse areas of *P. australis* (approx. < 2 plants m^{-2}), and areas dominated by ascidians and *Caulocystis,* were not identified using our methods, as they did not appear as significantly darkened areas on the images. Whilst fishers identified these often as sparse kelp or ascidian grounds, seagrass densities are very low and these areas were hence not classified as beds. Mixed *P. australis* and *Z. nigricaulis* beds were also identified, mostly toward the shallow centre of the large banks, the western end of Golden Creek channel and Long spit. Ground-truthing revealed that these beds were all dominated (> 80%) by one seagrass type and hence they received a single classification. Increasing the accuracy of mapping these mixed beds would require further development of methods.

Historical seagrass comparison

We calculated subtidal seagrass change using seven maps spanning 48 years: four recent maps that were available as GIS layers, and three older maps only available as illustrations. The illustration were scanned as high resolution picture files then georeferenced with a spline function using 20 evenly spaced control points from key features such as points, creek mouths and islands. Seagrass polygons were hand drawn over the illustrated bed using the ‘Create polygon’ feature. All maps were created in, or projected to, WGS1984 UTM Zone 55S. The seven maps were:

- 1965 hand drawn map taken from Poore (1978) that covers the entire Inlet. The map was created from B&W aerial photos and all seagrasses were grouped into a single class, *P. australis*. It does not appear to map intertidal *Zostera muelleri* (swangrass). Limited ground-truthing.

- 1975-6 hand drawn map taken from Morgan (1986). Covers the majority of the inlet apart from the SW Corner and Yanakie basin. The map was created from colour aerial photos and seagrass grouped into a single class, *P. australis*. Does not appear to map intertidal *Z. muelleri*. No ground truthing carried out.

- 1983-4 hand drawn map taken from Morgan (1986) created using aerial photos. The map covers the majority of the inlet apart from a thin strip running west to east across the centre. Seagrass is labelled as a single species *Posidonia australis* although it is evident from other map comparisons and local knowledge that it instead covers all subtidal seagrass which includes both *P.australis* and *Zostera nigricaulis.* Intertidal *Z. muelleri* (swangrass) is explicitly not mapped. No ground truthing carried out.

- 1998 map created by Fisheries Victoria that covers the entire Inlet (Roob et al. 1998). The map was created from colour aerial photography, where seagrass bed boundaries were first marked on hard copies and then digitised. Ground-truthing was carried out using towed video transects and direct observation, although how this was then applied to the entire Inlet is unclear from the report. Despite the authors claiming a 90% confidence level in classification, it is evident that extensive areas of seagrass are misclassified, particularly large areas of *P.australis* classified erroneously as *Zostera.* Some intertidal *Zostera* is also mapped, and these areas (identified from the 2013 map and local knowledge) were removed from the map for historical comparisons. Local knowledge also guided the removal of seagrass beds mapped in deep channels where seagrass does not grow.

- 2009 and 2011 maps created by Deakin University and Parks Victoria that covers only central and northern Corner Inlet (Monk et al. 2010, Pope et al. 2013). Maps were created from digital satellite imagery (ALOS and RAPIDEYE satellite imagery respectively) and seagrass type assigned by remote sensing using known spectral signatures of the major habitats. Ground-truthing was carried out and used to train and appraise the classification process. 73% classification accuracy was obtained. This was confirmed by local knowledge identifying some errors in classification, mostly around *Zostera* or mixed beds being classified as *Posidonia*.

- 2013 map created by the current FRDC project covering the entire inlet using digital satellite imagery and local knowledge. Seagrass beds were first identified using GIS image classification techniques (trained maximum likelihood classification), and then the outlines hand corrected using the local knowledge of commercial fishermen. Seagrass type was split into three categories (*P. australis*, *Z. nigricaulis*, and mud flats/sparse *Z. muelleri*) and classified based on local knowledge and extensive ground-truthing.

Two additional maps were created during this period: a 1987 coarse scale map based on Landsat imagery (Allen 1994) and a hand drawn map created from local fishers' knowledge (CIFHA 2008). These were not used for our historical comparisons due to their unique methods and difficulty in obtaining high quality copies.

Our historical comparison compared only estimates of the subtidal seagrasses *Posidonia australis* and *Zostera nigricaulis.* Intertidal *Z. muelleri* was not compared due to its highly dynamic nature, seasonal growth and lack of consistency in its mapping. To remove mapped *Z. muelleri* from our comparisons, we identified the shallow intertidal banks on which it grows using the 2013 map; and then deleted mapped seagrass in these areas on all maps. Deletions were made predominantly around the northern and south-eastern shorelines, and on the high lumps in the north-west and central Inlet. All subtidal seagrasses were then put into a single category "seagrass", which removes issues around poor species classification in early maps.

We used the 1965, 1975, 1984, 1998 and 2013 maps for a whole-of inlet comparison of seagrass cover. The 1975 and 1984 maps were incomplete and estimates for the missing areas were taken from the prior seagrass maps (i.e. 1975 area calculation used the 1965 map; the 1984 area calculation used the 1975 map). The proportions of total seagrass area derived from previous maps were 6.8 and 8.7% for each map respectively. The 2009 and 2011 maps only covered half the Inlet and were hence excluded from the comparison.

Along with whole-of-inlet comparisons, we also analysed seagrass change in sub-regions of the inlet. Different sediment, tide and wave conditions across the Inlet create specific habitats favourable to the growth of either *P. australis* or *Z. nigricaulis.* To understand better the species-specific dynamics over time, we identified key areas from local knowledge which historically supported predominately a single species and estimated change in seagrass cover in these areas. We identified six basins historically dominated by *Z. nigricaulis*: Foster beach basin, Golden Creek basin, Red bluff, Doughboy Hollow, Yanakie basin and SW corner, and five key areas dominated by *P.australis*: Toora channel bank between Blackney's gutter and Jimmy's gutter, Franklin channel bank between Black Beacon and Powder gutters, the eastern point of Doughboy bank, eastern point of Middle bank ('Slocombs') and the eastern point of Bennison bank. We also identified six areas that were reported to have undergone declines in *P. australis* (see results for Local knowledge below). Only three areas of each type (basin, bank, and area of reported decline) were covered by all seven seagrass maps; all in the central or northern sections of the Inlet (Figure 2, for full map of all 16 sites see Appendix D). These nine areas were isolated in all seven maps using the clip feature in ArcMap and the total seagrass area calculated and compared.

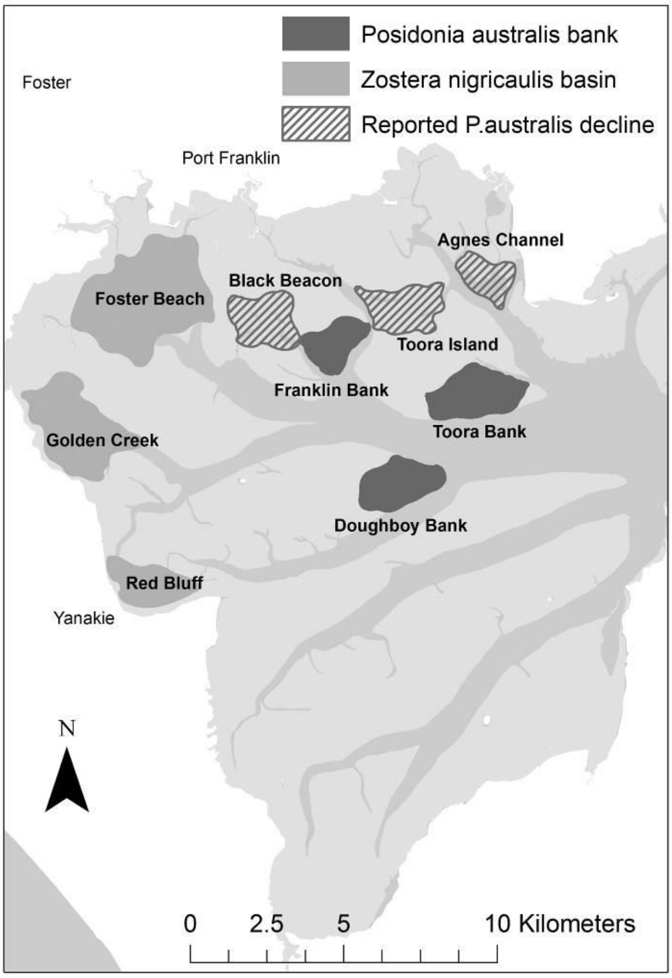


Figure 2. The three *Posidonia australis* banks, three *Zostera nigricaulis* basins and three areas of reported *P. australis* decline used to understand species-specific change in seagrass cover over 48 years of mapping.

Local knowledge

We conducted interviews with six current and two retired Corner Inlet fishermen, who collectively have over two centuries of active fishing experience in Corner Inlet. Given that the selection of "experts" is key to successfully obtaining local knowledge (Davis and Wagner 2003); we interviewed fishers with a minimum of ten years' experience in the Corner Inlet fishery. The interview process consisted of three parts: a formal semi-structured interview, a mapping process, and informal reports around algal blooms (Table 1). The interviews were approved by the University of Melbourne Human Ethics Committee (#1341015.1) and all participants were provided with a Plain Language Statement and provided written consent.

Formal interviews were semi-structured and aimed to elicit discussion around a few key areas of environmental observations: historical seagrass change and natural dynamics, historical change to water quality and environmental conditions, algal blooms, and the importance of seagrass to key fish species. Semi-structured interviews allow the participants as well as the researcher to guide the interview, making it a very effective tool to elicit local knowledge (Huntington 1998).

Secondly, we asked fishermen to create maps of seagrass change and algal bloom coverage by drawing with a marker pen on the 2013 seagrass map of the inlet. The use of maps can open further discussion not covered in formal interviews (Huntington 1998), and this method has been successful in mapping migration patterns and distribution of fish (Valbo-Jorgensen and Poulsen 2000). We undertook in-depth seagrass mapping interviews with two >30 year experienced fishermen, and this is described in the "Seagrass mapping" section of the methods below.

Thirdly, we undertook short informal interviews with fishermen during algal blooms, which are further described in the "Algal bloom" section of the methods below.

Researchers were clear in outlining what questions would be asked and what the information would be used for. We communicated that the focus of questions was to obtain environmental history and observations of ecosystem change, and not upon fishing practices or fish stocks. Similarly, the purpose of results was clearly stated as attempting to address seagrass habitat decline and not to inform fisheries regulation. Participation in surveys and interviews aimed at the latter outcome can face challenges in obtaining truthful answers and can limit participation (Silver and Campbell 2005), often due to a general distrust of and estrangement from the fisheries management process (Garret et al. 2012). Nevertheless, fishers generally provided extensive information in the interviews on the state of fish stocks and their relationship with fisheries management. This data was not further explored within the constraints of this project, but reveals an abundant source of fisheries information that many fishermen were willing to share.

Over 16 hours of interview recordings were transcribed and coded using key subject areas (seagrass change, algal blooms, ecosystem change, water quality, fishing, fish species), sub-areas (e.g. for algal blooms this was bloom type, and for this seagrass change this was specific species) and location within the Inlet. We qualitatively analysed the interview transcripts in NViVo v.10, collating responses under key subject areas. We structured our analysis around obtaining observations, rather than value judgements, from the fishermen and identifying where consistency and inconsistencies occur. Where consistency occurred, we developed a series of hypotheses around the key subject areas for further testing.

We evaluated the hypotheses by examining other sources of information about Corner Inlet and attempted to triangulate multiple lines of evidence. Testing of local knowledge hypotheses with external data is a widely used technique for understanding fisheries ecology, with examples from Canada and Vietnam (Ruddle and Davis 2011), Brazil (Silvano and Valbo-Jorgensen 2008), the English Channel (Rochet et al. 2008) and locally on the Murray River (Zukowski et al. 2013). The data sources we considered were: previous seagrass maps of Corner Inlet (see "seagrass mapping" section above), published scientific studies on Corner Inlet ecology, Fisheries Victoria reports, and broader reviews of Corner Inlet ecology or fisheries (e.g. Molloy et al. 2005, Dickson et al. 2013).

Where multiple data sources strongly supported the local knowledge hypothesis, we considered this hypothesis 'Confirmed'. Where some moderately supporting and no conflicting evidence was available we considered the hypothesis as 'Likely'. Where no supporting or conflicting evidence was available we considered the hypothesis 'Unknown'. Where external evidence was contradictory, we considered the hypothesis 'Unlikely'

Table 1. Key questions and areas of discussion used to elicit environmental observations from commercial fishermen in Corner Inlet. Three interview types were used: a formal one-on-one semi-structured interview, a formal one-on-one seagrass mapping exercise, and informal discussions during algal blooms.

Method	Seagrass observations	Ecosystem change	Algal blooms	Threats to seagrass
Formal interview	• Current state of seagrass cover in Corner Inlet • Historical seagrass cover and rate of change • Conditions and areas most conducive to seagrass growth • Natural cycles of growth and change • Change at channel edges and intertidal areas	• Relationship between seagrass and fish species • Relationship between seagrass change and productivity • Observed change to other components of the seagrass ecosystem • Changes to water quality	• Type of algal blooms • Timing and general extent of blooms • History and frequency of blooms • Environmental and weather conditions related to blooms • Effects of blooms on fish and fishing practices • Effects of blooms on seagrass	• Observations around water quality (focus on turbidity) • Historical change in catchment flows • Erosion or deposition on seagrass banks • Observations of herbicide spraying • Impacts of past dredging
Formal Mapping	• Current distribution of seagrass • Past distribution of seagrass • Key areas for seagrass species and their natural cycles • Change in seagrass density	• Areas of different sediment type • Prevailing wind and wave action • Extent of tidal flushing	• Indicate areas generally affected by algal blooms	• Indicate areas of poor water quality • Identify catchment input sources (rivers, creeks etc.)
Algal bloom reporting		• Current weather and environmental conditions	• Current location of algal blooms • Type of bloom • Clear areas without blooms	

Algal blooms

Algal bloom mapping

We engaged the local knowledge of fishermen to create maps of algal blooms in Corner Inlet from January 2013 until March 2016. A researcher engaged regularly with the fishermen via phone or in person and enquired about the location, duration and type of algal blooms they had recently observed. When an algal bloom had been recently observed, the fishermen marked the locations where the algal bloom was observed to be present and absent on a map of the Inlet. For all major blooms, multiple fishermen (n > 3) were interviewed to confirm reports and also to cover different areas of the Inlet. An algal bloom was considered significant when the fishermen could not work their nets (because the nets clogged with algae), which from observation was when the algae covered >30% of the seagrass. In many cases the cover was 100% over large beds (Figure 3). The bloom was considered over when cover dropped below 30%.

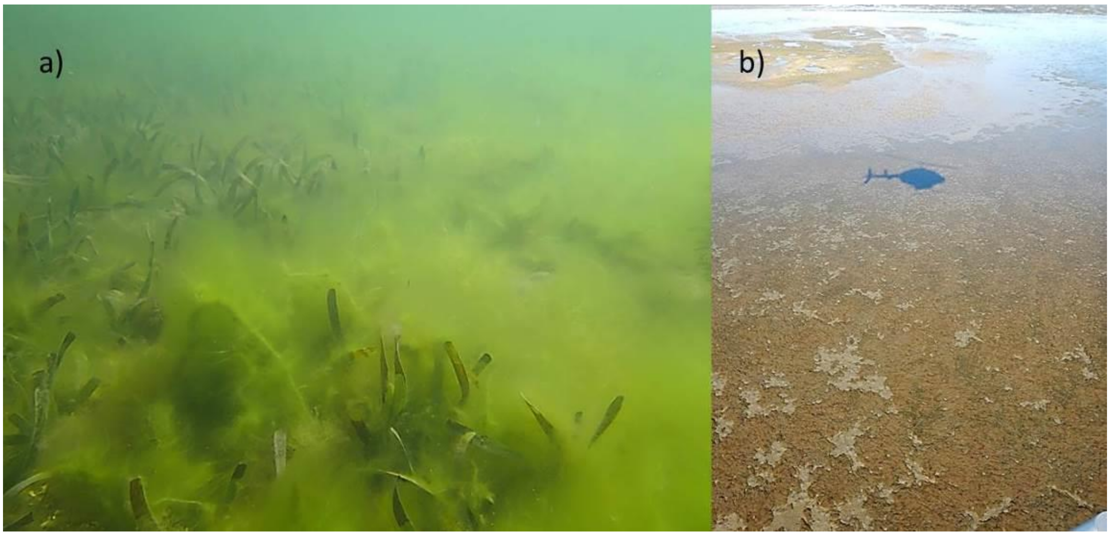


Figure 3. a) Bloom of red algae *Stylonema alsidii* over a *P. australis* bed, and b) aerial shot of a *Feldmannia irregularis* bloom over seagrass beds in NW Corner Inlet

From maps we calculated the approximate amount of time during summer and autumn that seagrass beds in different locations were affected by algal blooms. We then compared the predicted impact from light reduction to known light thresholds of seagrass growth and survival.

Algal identification

Fourteen algal bloom specimens were collected for species identification between January 2013 and winter 2015. We collected nine brown "slub" samples from mostly autumn and winter and eleven green algal samples from summer from various locations in Corner Inlet. Samples were either frozen or stored in 80% ethanol before identification by a marine algal expert.

Nitrogen isotope signatures

In order to better understand the flow of nutrients through the estuarine food web, and specifically the source of nutrients that create the filamentous algae blooms, we undertook a study of the nitrogen isotope signatures. Nitrogen isotopes are used extensively to understand the flow of nitrogen through food webs (Cabana and Rasmussen 1994), and identify anthropogenic additions of nitrogen (Cabana and Rasmussen 1996). The most widely used technique to identify sources of nitrogen from water and aquatic samples is through comparison of stable isotopes of nitrogen ($\delta^{15}N$) and oxygen ($\delta^{18}O$) in nitrates (NO_3^-, Xue et al. 2009). Isotopic composition of NO_3^- is different amongst sources such as atmospheric N^2, soil chemical fertilizers, manure and sewage. Synthetic fertilizers are low in enriched N, soil and groundwater moderately enriched, whilst animal manures are the most enriched (Figure 4a). Manure and sewage have low enriched O, synthetic fertilizers are moderately enriched, and precipitation is highly enriched (Figure 4b).

We firstly characterized the stable isotope signatures of NO_3^- of waterways draining into Corner Inlet by taking water samples after moderate-high rainfall events (>10mm in 24h). Samples were taken from 8 waterways on 3 occasions during the summer and autumn of 2015 (see waterways on Figure 1). Two samples were also obtained from the Foster sewage treatment ponds which discharge in the NW of the Inlet. Water samples were filtered using a 0.45 micron filter, frozen immediately and sent to the Colorado Plateau Analytical Laboratory at Northern Arizona University for analysis. We used a mean signature for each waterway to obtain an overall catchment $\delta^{15}N$. Individual waterway signatures were weighted according to their estimated total nitrogen input into the inlet, obtained from the Corner Inlet Water Quality Improvement Plan (Dickson et al. 2013).

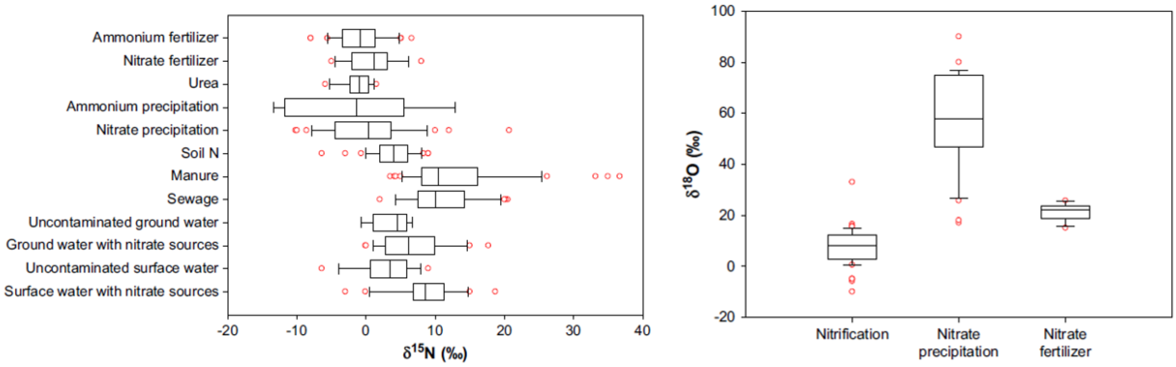


Figure 4. Box plots of the range of reported values from different sources (and sinks) for a) stable isotopes of nitrogen ($\delta^{15}N$) and b) oxygen ($\delta^{18}O$) in nitrates (NO_3). Source: Xue et al. 2009

Stable isotopes of nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) are used to characterise nutrient flows in marine plant and animal tissue (LePoint et al. 2004). We characterized the stable nitrogen and carbon isotope signature of primary producers in the system by analyzing samples of the seagrasses *P. australis, Z. nigricaulis*, the macroalgae *Caulocystis* sp., the filamentous brown algae *Feldmannia irregularis* and the red filamentous algae *Stylonema alsidii.* Samples of all but the red algae were collected from 20 locations broadly distributed around Corner Inlet during a brown algal bloom on 1st May 2015. The red algae were collected during a bloom on 13th February 2016. All samples were frozen and analysed for stable isotopes of nitrogen ($\delta^{15}N$) and carbon ($\delta^{14}C$) at the Water Studies Centre, Monash University.

We calculated a $\delta^{15}N$ signature for the seagrass system by taking the mean of the seagrass and macroalgal signatures. To assess the nitrogen contribution of the catchment or seagrass systems to the two filamentous algal blooms, we used a two component mixing equation (Eberts et al. 2013), using the catchment and seagrass signatures as the two end members and the algal signature as the mixed sample. We did not use a marine signature in our models because nitrogen contribution to the system is likely small, and there was no evidence that uncharacteristically large amounts of nitrogen were entering the system at the time of the algal blooms

Threats to seagrass

It is apparent that the threat to fishery productivity caused by a decline in seagrass cover and quality needs to be addressed in Corner Inlet. The causes for this decline appear complex. The West Gippsland CMA has initiated a Water Quality Improvement Plan to address nutrients and sediment runoff, but this project is needed to adequately counter these and other threats to the seagrass system.

Chemical threats

We conducted an in-depth review of chemical threats to seagrass and a risk analysis of chemical threats in Corner Inlet. We present here the risk assessment of chemicals in Corner Inlet, based on a generic *likelihood-consequence* risk assessment model based on the US EPA model (EPA 1998) and Standard ANZS 1999. For full details of methods see the standalone report in Appendix D.

Water quality

We took water quality measurements from the creeks and rivers flowing into the Corner Inlet basin opportunistically on four occasions during 2014-2015. Samples were taken at the downstream end to obtain samples representative of the whole catchment; and taken on a low tide to ensure only freshwater was sampled. Water was collected in clean 60ml Nalgene bottles, placed on ice and taken for analysis at Monash University Water Studies Centre within 48hrs. The three sets of 2014 samples were analysed for total suspended solids, total nitrogen and total phosphorous. These were chosen to give a broad understanding of N and P loads, and to be comparable to EPA water quality guidelines. The single set of 2015 samples (also used to characterise N signatures, see Algal Bloom section) were analysed for ammonia (NH_3), nitrites/nitrates (NO_x) and free reactive phosphorous (FRP) to help provide a more detailed understanding of the nutrient types in the waterways, and to make the data comparable to those collected by Hindell et al. (2009). Two rounds of estuarine water sampling were carried out in the first half of 2015, at sites previously sampled by Hindell et al. (2009), and analysed for NH_3, NO_x and FRP.

Assessment of seagrass threats in Corner Inlet

We took the established list of potential threats to seagrass compiled in the CIWQIP (Dickson et al. 2013) and reviewed them in light of data from this study. We used outcomes of seagrass mapping, local knowledges, algal bloom mapping, chemical threat assessment and water quality results to assess the relevance and importance of each threat to seagrass decline in Corner Inlet. The threats are ranked in order of importance and to provide guidance on further research and management of seagrass decline.

Collaborative catchment management

Engagement took many forms in this project. Alongside developing one-on-one relationships with members of the fishing community, many strong connections were established as a part of broader communication and engagement initiative in the region. Much time was invested in developing rapport with the users and managers of the catchment: farmers, farming industry bodies, and local and state government managers. The key aim was to effectively communicate the challenges fishermen were facing around seagrass decline and how the collaboration of the whole catchment community is required to address it. We aimed more broadly to embed the fishing industry into the catchment management and decision making process and ensure their voice was heard.

We focussed on a number of key messages: 1) the fundamental connection between land and sea, 2) fishers and farmers both being primary industries, and the seagrass is the ‘pasture’ for fishermen, 3) difficulty in managing pasture is affected by upstream activities, 4) the importance of regional interconnectedness (e.g. farmers buy fish and fishers buy milk) and 5) the marine environment is the shared responsibility of all members of the public.

To properly target management actions and verify their effectiveness, the first-hand knowledge of fishers was needed to identify areas of seagrass loss and areas currently under threat. This project facilitated direct lines of communication and thus a collaborative approach by fishers, farmers, researchers, councils and catchment and fishery managers to understand the linkages, so as to implement ecosystem-based management. Further, we provide a model as to how such collaborative approaches may be best carried out in other Australian coastal fisheries.

Engagement guidelines

In order to best communicate the learnings of our broader engagement process, we produced a document of "Engagement guidelines for fostering collaborative relationships in coastal fishing communities" (see Appendix E). We communicate step-by-step the journey of collaboration in Corner Inlet and provide key points of advice to enable successful community engagement in fishing communities throughout Australia. The target audience is the fishing industry and fisheries managers who want to address catchment-related declines in coastal fishery productivity.

Farmer-fisher day

We held an extremely successful collaborative field day on May 8th 2015 in Port Franklin that brought together over 40 fishers, farmers, scientists and land managers around the issue of seagrass decline. We wanted to create a collaborative dialogue and ensure the interaction between fishers and farmers was not one-sided and characterised by finger-pointing and blame. In collaboration with the WGCMA and Landcare, we gave fishers and farmers the opportunity to explain their industry and its challenges on their own turf. Fisher took farmers out on the Inlet on their boats to view seagrass meadows, explaining their fishing practice and the importance of their seagrass pastures. Farmers then hosted fishers on their farms to explain their practices and the importance of their grassland pastures. The overall aim was to increase the level of connection between the fishing industry and other catchment users. For the fishers the aim was to increase awareness of the sustainability of the fishing industry, the importance of seagrass and the importance of improving land practices to address seagrass decline. For the farmers the aim was to increase awareness of the practices they use to reduce nutrient loss from farms and improve productivity, and the issues they face.

There were many positive outcomes from the day, including creating and strengthening relationships between fishers and farmers, reciprocal communication about the challenges of fishing and farming, and developing a common will to address seagrass declines in Corner Inlet. An evaluation sheet was completed by 29 attendees, which documented change in awareness and key messages learned from the experience.

We created two key media outputs from the farmer-fisher day: a case study fact sheet (Appendix F) and a short video in collaboration with South Gippsland Landcare and the WGCMA. The video is available at: https://vimeo.com/130063251 and available for download.

Seagrass restoration

Rationale and site selection

We trialled two techniques of seagrass restoration in the Yanakie basin (Figure 1), an important area of the fishery which is now devoid of seagrass and mostly unproductive for targeted fish species (Figure 5). We chose the species *Zostera nigricaulis* for restoration because it has undergone a significant decline in recent years and due to promising recent work carried out in Port Phillip by Jenkins' team, who have successfully germinated *Z. nigricaulis* seeds (Jenkins and Keough 2015). Our seagrass mapping and analysis of fishermen's local knowledge during this project has revealed that *Z. nigricaulis* has been lost from all the deeper muddy basins in Corner Inlet. This form of *Z. nigricaulis* was long bladed and referred to as "Yanakie" or "Basin" fineleaf by the fishermen. Currently, *Z. nigricaulis* exists inside the inlet only in the upper subtidal regions along shorelines, is very thin and short-bladed, and unlike the description of the *Z. nigricaulis* that grew in the basins. We hypothesize therefore that the Corner Inlet basin has lost the locally adapted form of Z. *nigricaulis* that grows in the deeper muddy basins, and hence the reintroduction of this variant may "kick-start" the natural restoration process. This variant was sourced from sites in Nooramunga (Figure 5)

Seagrass *Zostera nigricaulis* covered the majority of the Yanakie basin in maps created in 1965, 1998, 1984 and 2007, and was lost in the early 2010s coinciding with a major La Nina event and major flooding events. We therefore know that seagrass has grown at Yanakie in proliferation very recently and conditions are unlikely to have changed significantly enough to prevent the assisted recolonization. We conducted the experiment at two trial locations within the Yanakie basin, one along the Yanakie shoreline and a site further into the basin, both 1-2m deep (Figure 5).

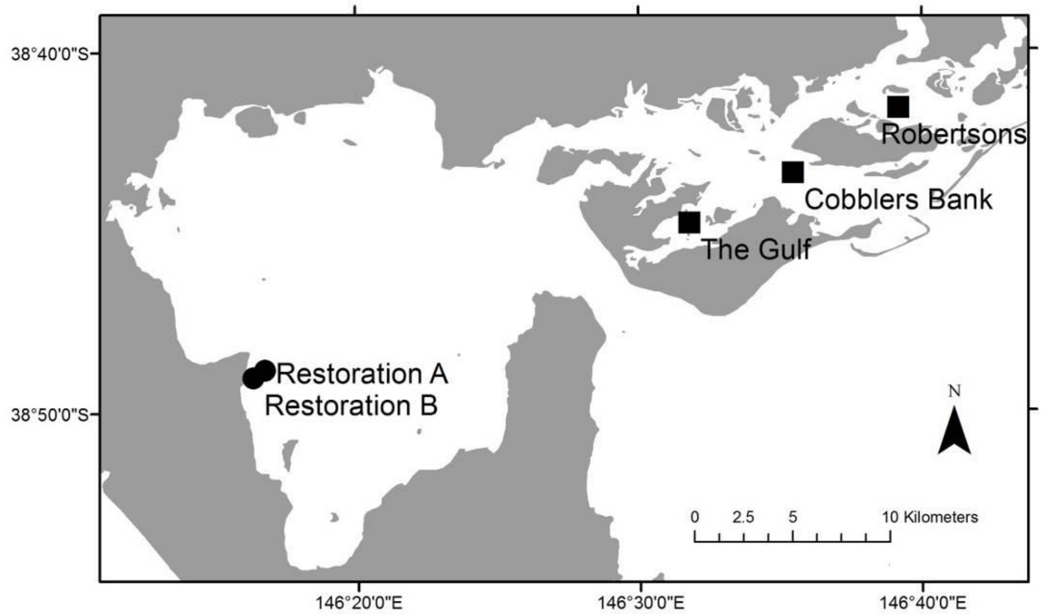


Figure 5. Location of restoration sites (circles) and donor sites (squares) in Corner Inlet – Nooramunga.

The three locations in Nooramunga where the seagrass was sourced were 20-30km to the east of Yanakie (Figure 5). We chose these areas because the seagrass grew in subtidal areas of similar sediment type, following our hypothesis that the deeper, permanently subtidal form of *Z. nigricaulis* was absent in the Corner Inlet basin (Figure 6a). Whilst we did not identify a complete match of site characteristics between source and donor locations (Table 2), we did see close matches to the Gulf, Cobblers Bank and Robertsons sites in Nooramunga.

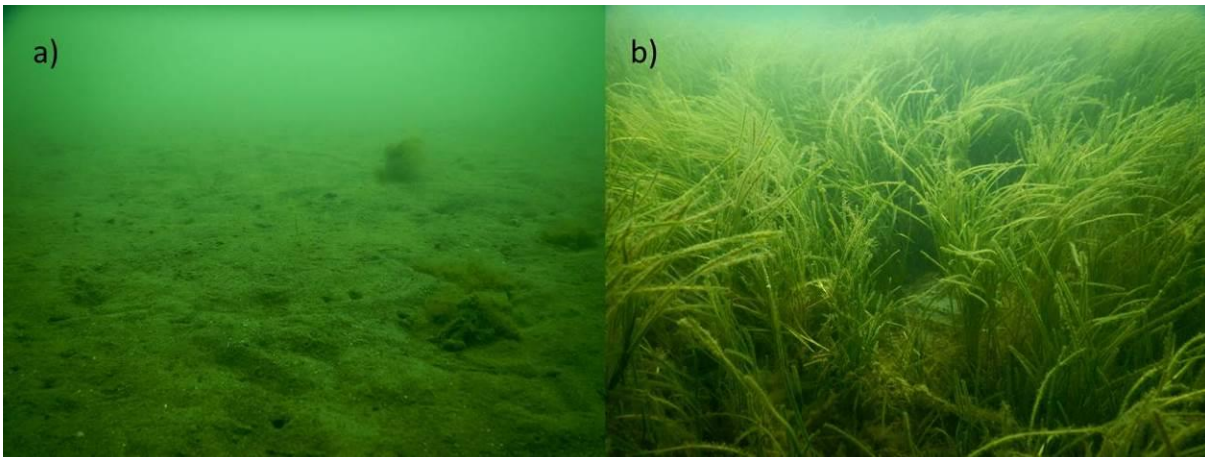


Figure 6. Underwater conditions at a) the Yanakie restoration site, a soft sediment environment with sparse invertebrates and algae, and b) the Gulf donor seagrass site, dominated by dense long-bladed *Zostera nigricaulis*.

Table 2. Comparison of environmental conditions at the three donor sites and the restoration site. These donor sites were chosen because three of the five criteria were met, and were logistically accessible. Note that eight sites were initially evaluated and none met all five conditions.

	Similar to Yanakie restoration site?				
Donor site	Depth (1-2m)	Sediment (muddy)	Tidal flow (moderate)	Seagrass type (long-blades)	Wind/wave exposure
The Gulf	No	Yes	Yes	Yes	No
Cobblers Bank	Yes	Yes	No	Yes	No
Robertson's bank	No	Yes	Yes	No	Yes

Restoration techniques

Ramets of *Z. nigricaulis* were transplanted successfully on 23rd October 2015 to two restoration sites in the Yanakie Basin, 1-2m deep. Ramets are growth shoots produced off the main stem that are designed to unattach and disperse to colonise new locations (Cambridge et al. 1983, Thomson et al. 2015). Ramets are easily recognisable by their fleshy yellow rhizome, which contrasts strongly to the wiry black stem of the blades (Figure 7a). Four 2m x 2m plots were deployed at each site, each with 6 rows of 10 ramets (seedlings) planted into the sediment and pinned in place with bamboo forks (Figure 7b). Half the plots were planted shallow (partial ramet and shoots visible on the sediment) and the other half deep (ramet completely buried, only shoots visible). In total 240 ramets were planted per restoration site, for a total of 480 ramets.

Figure 7. a) *Zostera nigricaulis* ramets growing off the black wiry main stem, and b) ramets pinned in place on the sediment by bamboo forks. Note that this photo shows the ramets before the yellow fleshy rhizome was pinned partially or fully beneath the surface of the sediment, depending on treatment.

Ramet collections were carried out with assistance of Corner Inlet commercial fishermen who provided boat support and crew for the day (Figure 8).

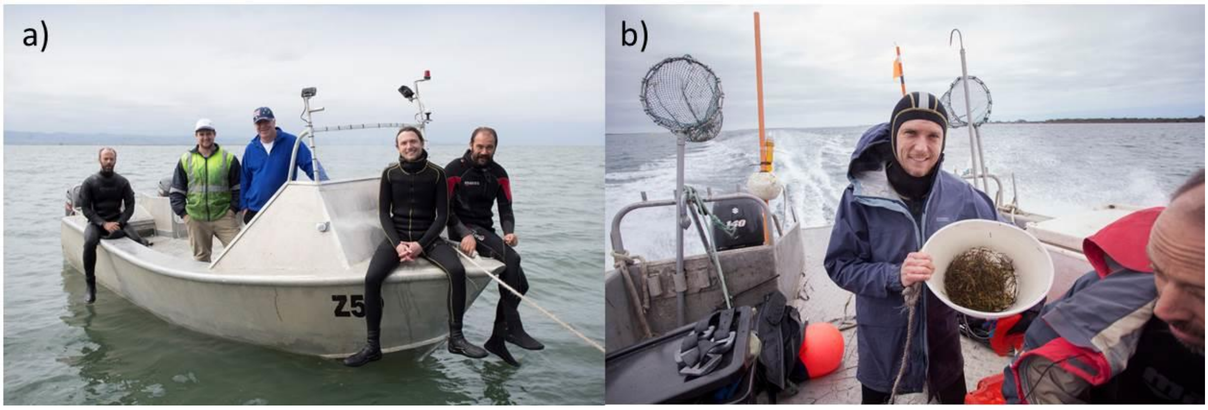


Figure 8. a) Corner Inlet seagrass restoration team, left to right: Dean Chamberlain (Melbourne Uni), Luke Anetta (fisherman), Bruce Collis (fisherman), John Ford (Melbourne University) and Tim Smith (Deakin University). b) Principle investigator John Ford displays a bucket of *Zostera nigricaulis* ramets ready for transplanting.

Seed bags were deployed on 9th December 2015 at the restoration sites. Three plots were deployed at each site (total six plots) and each plot consisted of three mesh bags of seagrass attached to star pickets at each end to form a triangle (Figure 9). Each bag has approximately 3-4kg (wet weight) of seagrass plants with flowers and seeds collected by hand from the donor sites. Seeds ripen within the bags; the seagrass decays and drops the seeds onto the surrounding sediment (Figure 10). At restoration site A, all three plots were sourced from a single donor site, The Gulf (same donor site as ramet transplants). At restoration site B, the three plots were sourced from different donor locations (The Gulf, Cobbler's Bank and Robertsons Bank) to compare the viability of seed from different locations.

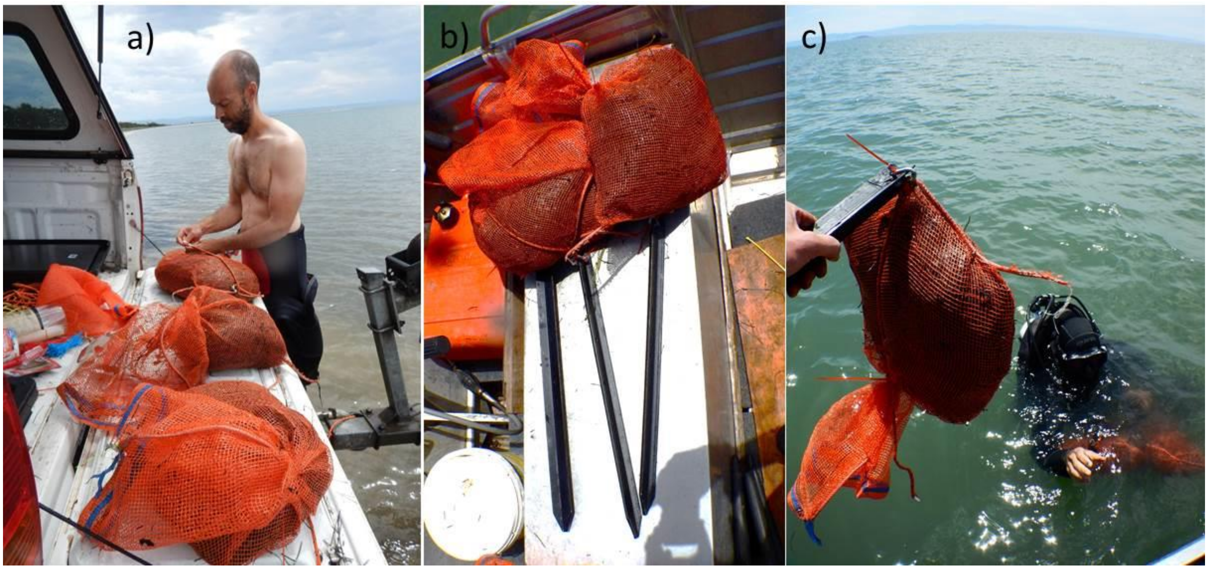


Figure 9. Seed bag deployment. a) Dean Chamberlain secures onion bags full of *Zostera nigricaulis* with ripening seed, b) three bags attached to star pickets which will be secured in a triangle shaped array, and c) bag is passed to a diver for deployment.

Figure 10. *Z. nigricaulis* seeds before ripening and dispersal

Sediment toxicants

Sediment samples were taken from restoration sites and all donor sites to examine any differences in sediment chemistry. Specifically we were interested in possible contaminants which may inhibit seagrass restoration such as heavy metals, petrochemicals and herbicides. Three samples of the top 5cm of sediment were collected by sterile gloved hand from each of the donor sites (The Gulf, Cobbler's Bank and Robertson's Bank) and the two restoration sites in Yanakie Basin. The three samples were combined in a clean, acid washed bucket and placed in clean jars for analysis. The sediment was sent to ALS laboratories and assessed for: particle size, heavy metal concentration (Ag, As, Cd, Cr, Cu, Hg, Pb, Ni, Sb, Zn), organic carbon, total hydrocarbon fractions, herbicides (including phenoxy acids and triazines), pesticides and fungicides (see Appendix G for a complete list).

Monitoring

Ramet transplants: Divers on SCUBA surveyed the ramet transplants approximately one (19th Nov 2015), three (25th Jan 2016) and five months (30th Mar 2016) after deployment. At each plot, divers counted the number of surviving ramets, the number of shoots, length of those shoots, and the number of bamboo forks along the six lines of each plot. Hence the unit of replication for most variables was the number per line, with six lines per plot. The number of bamboo forks were surveyed as a possible indicator of disturbance on the plots, e.g. high loss of both ramets and forks is likely attributable to physical disturbance. Statistical comparisons were made of the effects of restoration site (site A or B) and depth of planting (deep and shallow) and their statistical interaction on four response variable: number of remaining ramets, shoot number, shoot length and remaining forks (2-way ANOVA).

Seed bags: The six seed-bag plots (three at each restoration site) were surveyed on 30th March 2016, 16 weeks after deployment. We predicted that it may take this amount of time for the seeds to ripen, fall and germinate. We conducted visual searches for *Z. nigricaulis* seedlings on SCUBA in the 1m radius around the bags, and then ran two 10m survey lines in the directions of the prevailing winds (westerly transect for easterly winds, north-easterly transect for south-westerly winds), because previous work has shown seed dispersal related to wind direction (Pickerell et al. 2005). We counted all seedlings on a 1m swathe along these transects. We collected sediment samples (15cm diameter corer, top 5cm of sediment) which we passed through a 2mm sieve to remove larger shell and organic matter, and then a 500 micron sieve to identify any dropped but ungerminated seeds. We collected 4 samples in the 1m radius surrounding the bags, and samples at the 5m and 10m marks along the two transects.

Results

Seagrass mapping

2013 Seagrass map

We mapped 85.3km^2 of subtidal seagrass *P. australis* and *Z. nigricaulis* in the Corner Inlet Basin for 2013 (Figure 11). *P. australis* was the dominant seagrass in Corner Inlet, covering 70.3km^2. *P. australis* was distributed widely across the Inlet, but dominated the larger banks closer to the ocean entrance (Bennison, Middle, Doughboy, Toora and Long Spit), creating almost total cover in the shallows between channels. There was very little cover of *P. australis* in the Northwest and Southwest or along any shoreline. *Z. nigricaulis* beds covered 15km^2, mostly confined to the western and southern shorelines, and sparse beds on the Northern shoreline. Some of the more shallow areas of main banks supported *Z. nigricaulis*, presumably where tidal exposure prevented the establishment of *P. australis*. We also mapped 35km^2 of intertidal mud flats which support sparse seasonal cover of *Z. muelleri;* however these areas were not used in any further comparison.

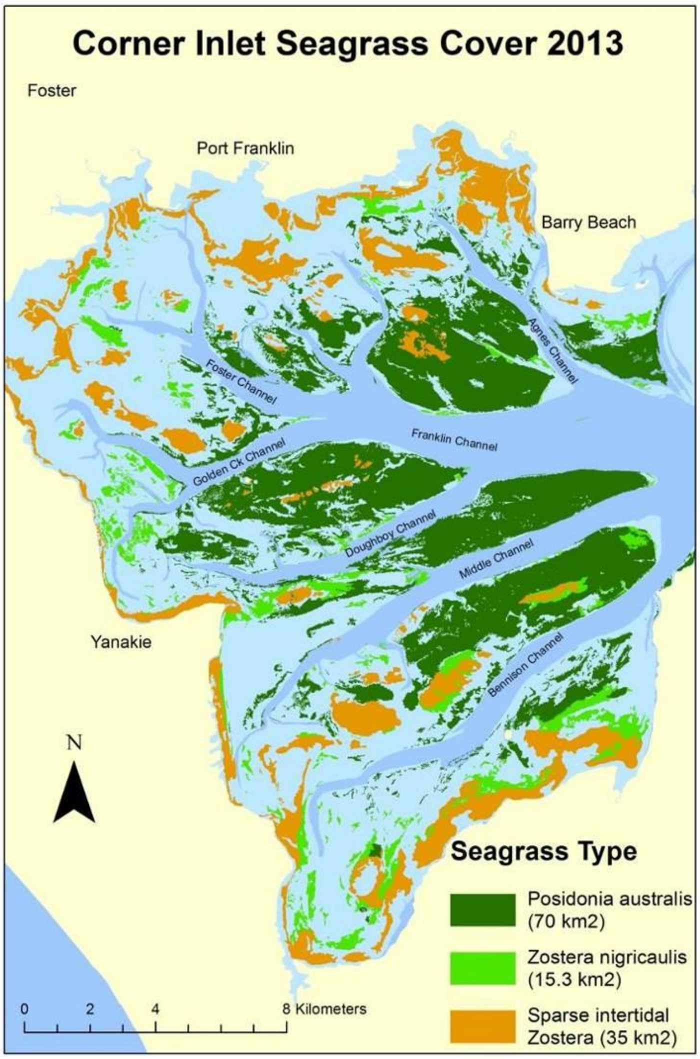


Figure 11. Seagrass cover in Corner Inlet 2013. Note that the “Sparse intertidal Zostera” classification maps the locations of intertidal mudflats which intermittently support beds of Zostera muelleri, and is not an indication of seagrass cover for this species.

Historical seagrass change

Total area of subtidal seagrass in the Corner Inlet Basin fluctuated between 85.3 km^2 and 117.3 km^2 over the 48 years covered by the seagrass mapping, with an average cover of 109.1 km^2 (Table 3). The most recent map in 2013 displays the lowest cover of seagrass; 19% less (19.6 km^2) than the average and a 27% decline (32 km^2) from 1975, the year of highest cover. Direct comparison of the maps reveals many areas of both seagrass growth and decline between the mapping periods, mostly the appearance, disappearance and migration of small seagrass beds closer to the coastline. Many of the apparent fluctuations in the larger beds on the central banks may be errors associated with the digitising and geo-referencing of hand drawn maps, and in comparing maps created with different techniques and source data. The fluctuations in the beds along the coastline however, are likely associated with rapid changes in the cover of *Z. nigricaulis*, which can quickly colonise and spread (see result of local knowledge below).

Table 3. Total subtidal seagrass change in Corner Inlet 1965-2013

Year	Total area of seagrass (km^2)	Deviation from average (km^2)	Change from previous map (km^2)	Rate of change (km^2 $year^{-1}$)
1965	110.4	-0.5		-
1975	117.3	+12.4	+6.9	+0.7
1984	98.8	-6.1	-18.5	-2.1
1998	112.5	+7.6	+13.7	+1.0
2013	85.3	-19.6	-27.2	-1.8
Average	104.9			±1.4

The slope of the linear fit of seagrass cover on year (Figure 12) was not significantly different to zero (Linear regression, df = 4, p = 0.17, R^2 = 0.48), although power was low, with only five data points (power = 0.24) and hence negative results should be interpreted with caution. The slope was negative, indicating a decline in cover between 1965 and 2013, where a linear fit of year explained 48% of the variation in cover between 1965 and 2013.

The declining trend of seagrass cover over time is one reported by fishermen in their local knowledge, and has been noted since the 1970s (Poore 1978). However, change in seagrass mapping techniques may be at least partially responsible for this apparent decline. More recent techniques used high quality imagery and GIS could more accurately define bed boundaries, and patchy beds can now be mapped to the 0.5m scale. Past mapping was hand drawn from photos, and hence patchy beds may have been represented as a solid shape rather than a detailed network of smaller patches. The extent to which this may be a methodological artefact creating an apparent decline is unknown, but it important to note that local knowledge reports that the patchiness of beds has also increased over time, and hence the increasing patchiness may also be a true reflection of seagrass cover.

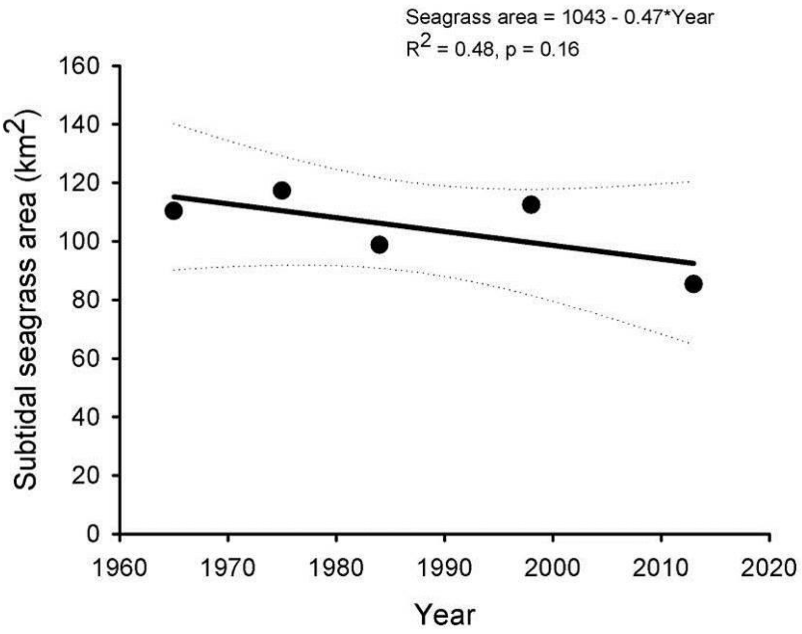


Figure 12. Linear fit of total seagrass cover in Corner Inlet on year. Data points represent mapping studies, solid line is best linear fit and dotted lines are 95% confidence intervals. The slope was not significantly different from zero (p = 0.15).

The increase in seagrass cover between 1965 and 1975, and the subsequent decline from 1975 to 1984, occurred predominantly close to the northern and southern shorelines, and the higher regions of central banks (Poore 1978, Morgan 1986). These areas (such as the Sugarbasin, Foster Beach and Golden Creek basin) are identified by local knowledge as historical *Zostera nigricaulis* regions with naturally fluctuating cover of seagrass. Hence 1975 likely represents a high point on the natural *Z. nigricaulis* cycle, and 1984 a low point. The increase of cover from 1984 to 1998 is mostly in similar regions, but also shows growth on some of the main *P. australis* banks. Decline from 1998 to 2013 again reveals similar areas of change along the northern and southern shorelines, but also new areas of decline in the Yanakie Basin and the Franklin river channel. To better understand the role of the different species of seagrass in the long-term decline, we investigated change in three sets of regions: *P. australis* banks, *Z. nigricaulis* basins and in mixed seagrass areas where *P. australis* is reported to have declined.

Historical change in P. australis banks

The seagrass cover on three large banks of *Posidonia australis* (Franklin, Doughboy and Toora) was mostly stable over the past 48 years (Figure 13). Comparison of maps revealed that most variability is related to the seagrass changes on the deeper channel edges and at the central shallow “high bank” regions, which may both represent changes in *Zostera* cover in marginal deep channel and intertidal areas.

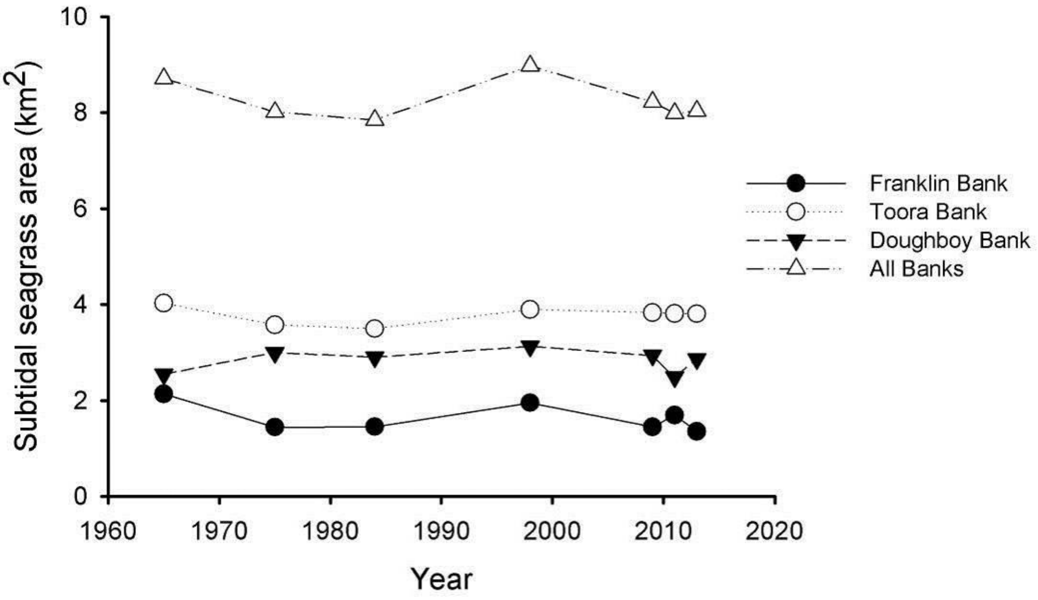


Figure 13. Historical change in seagrass cover on *P. australis* banks in Corner Inlet between 1985 and 2013.

Historical change in Z. nigricaulis basins

The seagrass cover in the *Z. nigricaulis* basins showed large fluctuations between survey years (Figure 14). Total cover peaked in 1975, and again in 2009, before falling to a historical low in 2013. 2013 total cover was 64% lower than the historical average, but in the Golden Creek basin cover was 83% below average. Changes in cover were somewhat synchronous across the three basins, apart from Red Bluff which had highest cover in 2009. Clear findings are: 1) *Z. nigricaulis* beds undergo cyclical fluctuations in cover, 2) presently *Z. nigricaulis* cover is at a historical low, and 3) there has been massive loss of *Z. nigricaulis* between 2011 and 2013.

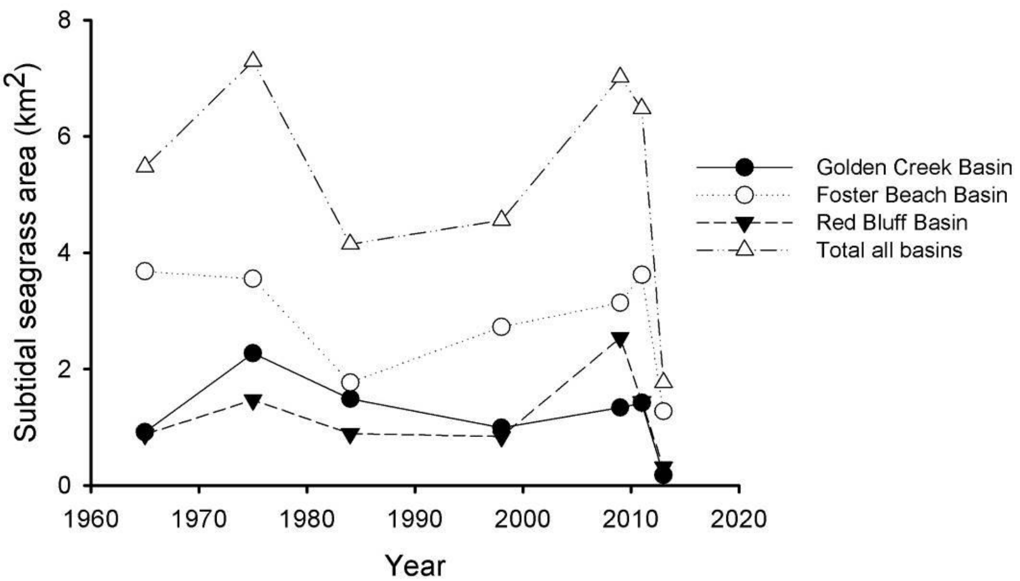


Figure 14. Change in seagrass cover in three *Z. nigricaulis* basins from 1965 to 2013

Historical change in reported areas of P. australis decline

The historical seagrass cover was highly variable in areas of northern Corner Inlet where local knowledge reported declines of *P. australis* (Figure 15). All areas show a slight declining trend over time, but we detected no significant linear relationships due to high variability, particularly in the past 15 years. The Agnes and Toora areas showed a slow decline from 1965 until 1984, then a large jump in cover to their highest point in 1998. The Black Beacon shows consistent decline until a huge spike in cover between 2009 and 2011, then an equally large decline in the two years 2013. Such rapid change in all cases is likely related to the growth of *Zostera* species in these areas, providing evidence for a shift in species composition over time from *Posidonia* to *Zostera.* However, there is little evidence of an overall seagrass decline in these regions.

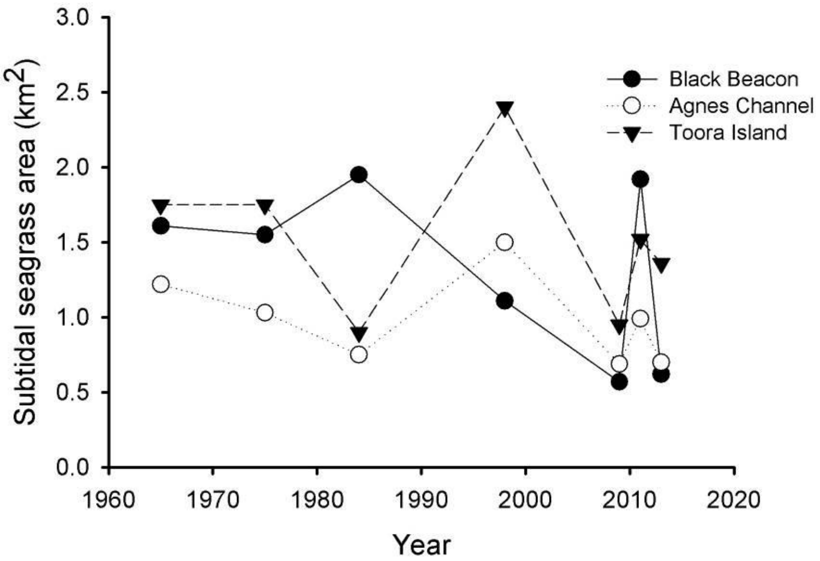


Figure 15. Change in seagrass cover in three areas of reported *P. australis* decline, between 1965 and 2013.

Further historical comparisons of seagrass cover in banks and basins in Corner Inlet are included in Appendix C.

Local knowledge

Local knowledge hypotheses

We developed twenty hypotheses from local fisher's knowledge in one of three categories: seagrass change, algal blooms, and ecosystem/threats (Table 4). Ten of these hypotheses were confirmed with strong external evidence sources, seven were considered likely and three were considered unknown as we could find no evidence to support or contradict them.

We confirmed five important seagrass hypotheses which provide a much clearer understanding of seagrass change in Corner Inlet than previous studies: 1. There has been an overall seagrass decline in Corner Inlet between 1965 and 2013, 2. the cover of *P. australis* is stable on central banks, 3. *Z. nigricaulis* was at its lowest extent on record in 2013, 4. *Z. nigricaulis* is currently absent from many of the muddy basins where it has historically grown, and 5. There was a major decline in *Z. nigricaulis* between 2011 and 2013. There was moderate support for many of the hypotheses related to change in specific species or in specific areas of Inlet, but these could not be confirmed due to the confusion and/or absence of seagrass species identification in historical maps. Declines of *P.australis* in the northern and southern regions of the Inlet are considered likely, and we also consider likely the replacement of *P. australis* beds with *Z. nigricaulis* prior to 2013.

Two local knowledge observations were key to understanding the historical fluctuations in seagrass. Firstly, the identification of specific areas of the Inlet that have historically supported a single seagrass species allowed species-specific dynamics to be analysed. Secondly, the hypothesis that areas of slow *P. australis* decline were replaced with *Z. nigricaulis* provided an important alternate way to view historical seagrass maps. The opportunistic growth of *Z. nigricaulis* may have masked a *P. australis* decline occurring slowly over decades, as reported by local knowledge as far back as the 1970s (Poore 1978). Indeed, not until the significant loss of *Z. nigricaulis* between 2011-13 was the true extent of this decline revealed. The fact that Poore (1978) and Morgan (1986) only reported on and mapped *P. australis* suggests that this species was so dominant in the subtidal that other species were not considered. We currently lack the evidence to confirm or reject this hypothesis. Analysis of sediment cores that provide a history of recent seagrass growth, as outlined by Kirkman (2013), could provide this evidence.

We confirmed three basic hypotheses around algal blooms, which until this study were not documented in any Corner Inlet literature. Firstly, we conformed that there are two major types of algal bloom in Corner Inlet, a brown bloom occurring in autumn and a green bloom occurring in summer. These blooms are similar in area, covering over 40% of the seagrass in the Inlet (but not the central banks) and lasting around 2 months. These hypotheses are further explored in the Algal Bloom Threats section.

We confirmed two general ecosystem observations that will assist in evaluating threats to seagrass in Corner Inlet. Firstly, large sediment plumes are created by the flow of the Franklin and Agnes Rivers after heavy rain. Secondly, herbicide spraying occurs in the intertidal areas of Corner Inlet close to seagrass beds. We found likely support for ongoing poor water clarity in the NW of Corner Inlet and the major decline of the crab *Nectocarcinus integrifons* (a major component of the diet of Rock Flathead [Klumpp and Nichols 1983]) around the same time as the decline in *Z. nigricaulis*.

Table 4. Twenty hypotheses derived from fisherman's local knowledge and their assessment against mapping, literature and observational evidence

a) Seagrass hypotheses

Number	Hypothesis	Mapping evidence	Literature evidence	Field observations	Assessment
S1	Total seagrass cover has declined in the past 30-40 yrs	Total seagrass cover trend is negative and currently at lowest mapped point in 48yrs (see Table 3 and Figures21-15, Appendix C)	Conclusions of likely seagrass decline in: Morgan (1986), Hindell et al. (2009) and Kirkman (2013)	Ground-truthing confirmed absence of seagrass in areas of suspected long-term decline: NW corner, Franklin and Toora banks and southern Bennison channel	CONFIRMED
S2	*P. australis* cover has declined most in the north and north-west of the Inlet	Mapping evidence shows downward trends (Figure 15) but not conclusive	Declines reported in Morgan (1986) but species composition unknown, and Hindell et al. (2009) reports likely *P. australis* decline	Observations of some sparse *P. australis* beds in these areas with low shoot density and blade lengths	LIKELY
S3	*P. australis* cover has declined significantly south of Bennison channel	Mapping evidence shows a significant downward trend in cover (Appendix C). Species composition unknown	No reference to declines in these areas	Area supports small patches of sparse *P. australis* with low shoot density and blade lengths	LIKELY
S4	*P. australis* cover is generally stable on the large banks	Mapping evidence shows stability on main banks (Figure 13 and Appendix C)	References to stability of cover on these banks from Poore (1978), Morgan (1986) and Kirkman (2013).	Banks currently support large areas of medium to high density *P. australis*	CONFIRMED
S5	The areas of *P. australis* loss over decades was often replaced by *Z. nigricaulis*, masking the decline	Mapping evidence inconclusive, although initial stability the rapid change in cover in some areas may indicate a change from a *P. australis* system to a *Z. nigricaulis* system. Also some evidence of an increasing rate of change in total cover (Fig 15), possibly linked to increase dominance of *Z. nigricaulis*	Hindell et al. (2009) documents a decrease in medium-dense seagrass (thought to be *P. australis)* and a corresponding increase in sparse seagrass (*Z. nigricaulis*) between 1998 and 2005. The initial three maps (65, 75 and 84) did not consider the cover of *Z. nigricaulis* important enough to map, suggesting that *P. australis* was more dominant	Currently very little *Z. nigricaulis* cover and hence difficult to ascertain	LIKELY
S6	*Z. nigricaulis* cover is currently lowest in memory	Mapping shows that the main *Z. nigricaulis* basins are at their lowest historical levels (Fig 14 and Appendix C)	N/a	Field observations confirm near absence of *Z. nigricaulis* in Yanakie basin, Red Bluff and Doughboy Hollow	CONFIRMED

Number	Hypothesis	Mapping evidence	Literature evidence	Field observations	Assessment
S7	*Z. nigricaulis* is absent from key muddy basins (e.g. Yanakie and Doughboy Hollow) and currently confined to shallows on the shores and high banks	Mapping shows that the main *Z. nigricaulis* basins are at their lowest historical levels (Fig 14 and Appendix C) and cover is mostly along coastline and high banks	N/a	Field observations confirm that *Z. nigricaulis* is currently distributed in the shallow sublittoral region only	CONFIRMED
S8	*Nigricaulis* had a major decline after the Prom fires and the floods (2009-2011)	Comparison of 2009, 2011 and 2013 maps reveal a major decline in cover for the northern half of the inlet between 2011 and 2013	N/a	N/a	CONFIRMED
S9	*Z. nigricaulis* cover fluctuates in muddy basins, often on 5-10yr growth cycles, and often in sync	Large variability in seagrass cover in basins (Fig.14), although without more frequent data it is difficult to determine length of cycles. Appears to be some level of synchrony.	No direct references to *Z. nigricaulis* cycles in literature, but known to be a dynamic species able to recolonise quickly (Hindell et al. 2009)	Observations of rapid changes to *Z. nigricaulis* beds during the length of this study (3yrs)	LIKELY
b) Algal blooms					
A1	A brown algal bloom occurs almost every year in Autumn when the water cools down	Algal blooms maps show a brown bloom every Autumn 2013-2015 (Table 5)	No Mention of algal blooms until CIWQIP, which was informed by the researchers on this project	Observations of brown algal blooms in Autumn 2013-2015, around water temperatures of 16-17 degrees	LIKELY
A2	Brown algal bloom cover is variable, but generally affects 50-75% of the Inlet and lasts 1-2 months	Algal bloom maps show variable cover of 42-68% of seagrass covered and lasting for an average of seven weeks (Table 5)	No previous mention of algal blooms	Observations of brown algal blooms in Autumn 2013-2015 confirm mapping information	CONFIRMED
A3	Brown algal blooms have occurred for 60+yrs	N/a	No previous mention of algal blooms	N/a	?
A4	Green algal blooms occur occasionally in Summer when the water is around 20 degrees	Algal bloom mapping shows blooms in January and February of 2013, 2014 and 2016 (Fig.16)	No water temperature data for Corner Inlet	Blooms occurred after summer hot periods (often days of 35°C +) and water temp > 20°C	CONFIRMED
A5	Green blooms have been becoming more frequent and covering a larger area in past decade	Algal bloom maps only cover past three years	No previous mention of algal blooms	N/a	?

Number	Hypothesis	Mapping evidence	Literature evidence	Field observations	Assessment
A6	Blooms don't cover the large *P. australis* banks towards the entrance	Algal bloom mapping shows no algal bloom occurred on the end of the larger banks between 2013 and 2016	No previous mention of algal blooms	Fishing activities often constrained to the ocean-end of the larger banks during blooms	CONFIRMED
c) Ecosystem and threats					
E1	Major decline in red rock crab *Nectocarcinus integrifons* since 2009-10	N/a	No previous studies quantifying macroinvertebrates, but this crab was shown to be a major component in fish diet in Klump et al. 1984	Observations of fishing activities showed very few (<2/shot) crabs caught. Preliminary surveys did not locate any crabs in seagrass (Barrow 2015)	LIKELY
E2	Decline in leatherjackets since 2010-11	N/a	No publically available data on leatherjacket catch or bycatch	Observations of fishing activity showed few leatherjackets being caught	?
E3	Water clarity is very poor along the NW coast most of the time	N/a	Hindell et al (2009) observed the highest turbidity levels in the north of the Inlet. NW creeks contribute one third of sediment load to Corner Inlet and this area has a higher water residence time (Dickson et al. 2013)	Observations of high turbidity in areas around TiTree Island, Black Swamp and Red Bluff on multiple trips between 2013-2015. At no time was vertical water clarity >30cm	LIKELY
E4	Large sediment plumes flow from the Franklin and Agnes Rivers after heavy rain	N/a	Water quality results from Hindell et al. (2009) show high nutrients loads linked to Franklin and Agnes rivers. CIWQIP predicts large sediment inputs from these rivers, particularly after heavy rain	Observations of poor visibility and turbid water in Franklin and Agnes channels after rain	CONFIRMED
E5	Herbicide is sprayed in the intertidal zone near seagrass beds	N/a	Parks Victoria and WGCMA work plan for spraying invasive *Spartina* includes spraying herbicide in intertidal areas by helicopter in summer and autumn. Not carried out in 2014-15 summer	N/a	CONFIRMED

Algal blooms

Algal bloom mapping

We identified six major algal blooms in Corner Inlet between January 2013 and March 2016. A brown algal bloom was observed every autumn, beginning in either April or May, lasting for between 4 and 10 weeks at full extent and covered on average 53% of the seagrass beds in Corner Inlet (Figure 16). Three green algal blooms (actually a red algae, see below) were observed in January and February of 2013, 2014 and 2016. Blooms lasted an average of 6 weeks at their full extent and covered an average of 61% of seagrass beds in Corner Inlet (Table 5).

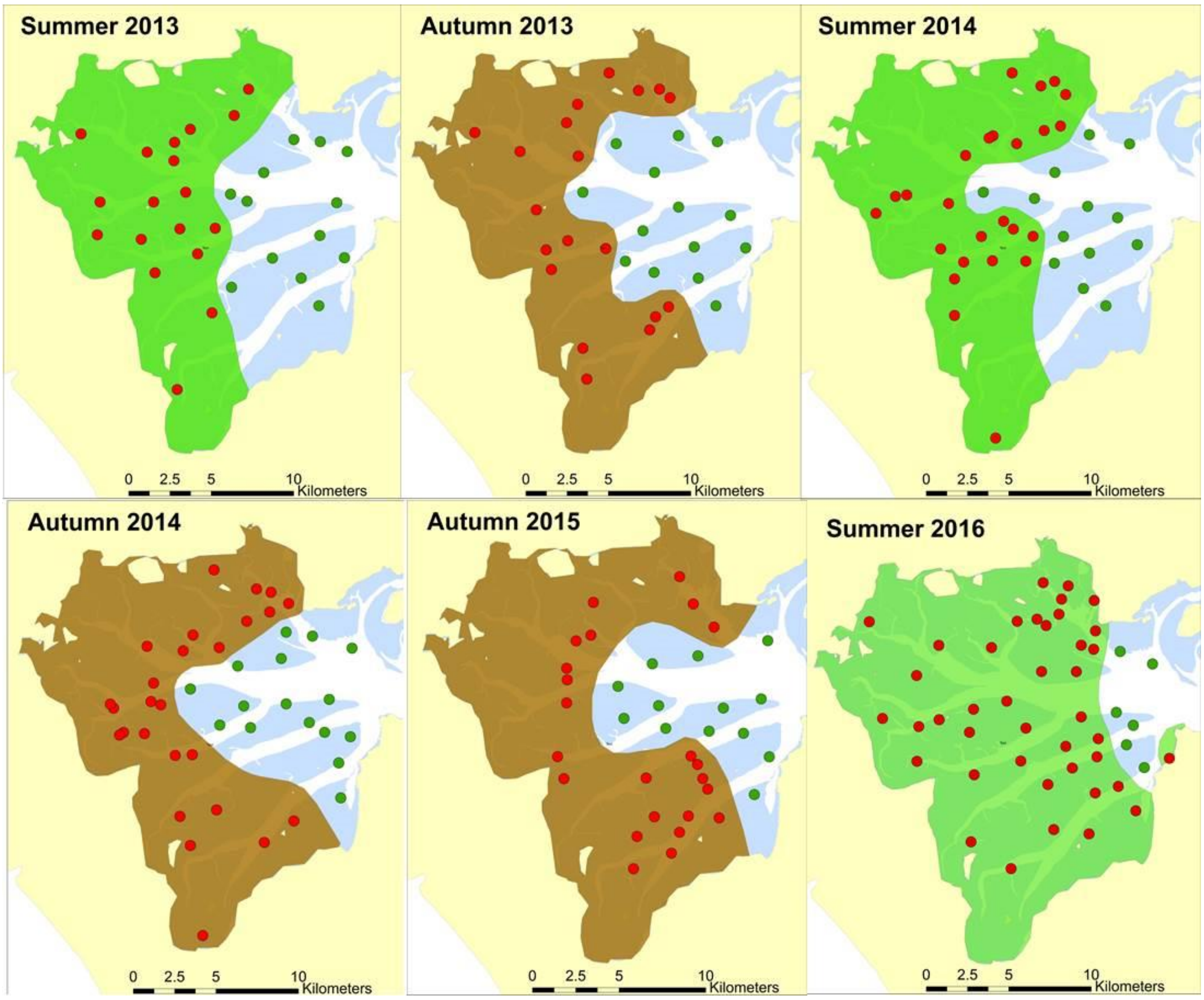


Figure 16. Extent of algal blooms in Corner Inlet recorded between January 2013 and March 2016. Red dots are confirmed sightings of algal blooms from local knowledge during the two weeks when the bloom was at its fullest extent. Green dots are confirmed non-occurrence of algal blooms during that period.

All of the areas that have experienced significant seagrass decline (NW corner, Northern shoreline, Yanakie basin, SW corner) were consistently affected by algal blooms. Over the 158 weeks of the study, algal blooms covered these areas for 42 weeks or 27% of the total time. The large *P. australis* banks, which have maintained their seagrass cover, were mostly unaffected by the algal blooms (except for the 2016 green bloom).

Table 5. Occurrence, duration and extent of algal blooms in Corner Inlet 2013-2016

Start of bloom	Duration (weeks)	Type	Seagrass coverage (%)
Jan 2013	6	Green	46
April 2014	10	Brown	42
Feb 2013	8	Green	51
March 2014	8	Brown	50
April 2015	4	Brown	67
Feb 2016	6	Green	88

Algal identification

The identification of algal bloom samples was very consistent, with the slub brown algae identified almost exclusively as *Feldmannia irregularis,* and the green bloom as the red algal species *Stylonema alsidii* (Table 6). *F. irregularis* is a filamentous brown alga widespread in temperate waters of Australia. It is thought to have originated in the Mediterranean but is now cryptogenic with a global distribution (Hewitt et al. 2003). *S. alsidii* is filamentous red algae that can appear green in shallow water and has a similarly cryptogenic and widespread distribution. Both are also present in nearby Port Phillip Bay (Hewitt et al. 2003). One sample of brown algae from the 2013 autumn bloom also contained *Hincksia sordida*, a known nuisance algae from sub-tropical waters of east coast Australia (Lovelock et al. 2008). One summer 2013 sample of green algae also contained a *Cladophora* species, a very common green filamentous alga in fresh and salt water.

Table 6. Species identification of filamentous algae collected during algal blooms in Corner Inlet 2013-2015

	Bloom	Collection date	Collection location	Species
Brown algae "slub"	Aut-13	18/04/2013	Toora Is	*Hinksia sordida*
	Aut-14	5/06/2014	Doughboy Is	*Feldmannia irregularis*
		15/06/2014	Doughboy Spit	*Feldmannia irregularis*
	Aut-15	24/02/2015	Franklin channel	*Feldmannia irregularis*
		17/04/2015	Duck Pt	*Feldmannia irregularis*
		21/04/2015	Ti Tree Is	*Feldmannia irregularis*
		1/05/2015	Redboy gutter	*Feldmannia irregularis*
		14/06/2015	Lousy Bite	*Feldmannia irregularis*
		14/06/2015	West Spit	*Feldmannia irregularis*
Green algae	Sum-13	21/01/2013	Doughboy Is	*Cladophora* spp.
		28/1/2013	Franklin channel	*Stylonema alsidii*
		14/02/2013	Toora Is	*Stylonema alsidii*
	Sum-14	19/03/2014	Barry Beach	*Stylonema alsidii*
	Sum-15	24/02/2015	Doughboy spit	*Stylonema alsidii*
	Sum-16	13/02/2016	Various	*Stylonema alsidii*

Catchment Isotope signature

The Corner Inlet catchment had a mean $\delta^{15}N$ signature of 6.8. The $\delta^{15}N$ signatures of the streams and rivers entering Corner Inlet from the north and west were typical of agricultural catchments, ranging between 4 and 8 (Figure 17). Bennison Creek consistently had very high $\delta^{15}N$, likely an indication of mostly manure sources of nitrogen. The sewage samples were typically enriched, between 9 and 11. The Wilson's promontory creeks were typical of forested catchments with very low $\delta^{15}N$. Some of the Western tributaries – Old Hat, Poor Fellow Me and Silver Creeks – were twice sampled with negative $\delta^{15}N$ between -5 and 0. Further water analysis revealed very high levels of ammonia and very low levels of nitrates, possibly indicative of fresh manure inputs. Because the $\delta^{15}N$ was analysed on nitrates only, these readings are unreliable because of the small proportion of total nitrogen analysed, and the possibility of preferential uptake of the lighter species of nitrogen by bacteria when converting into nitrates.

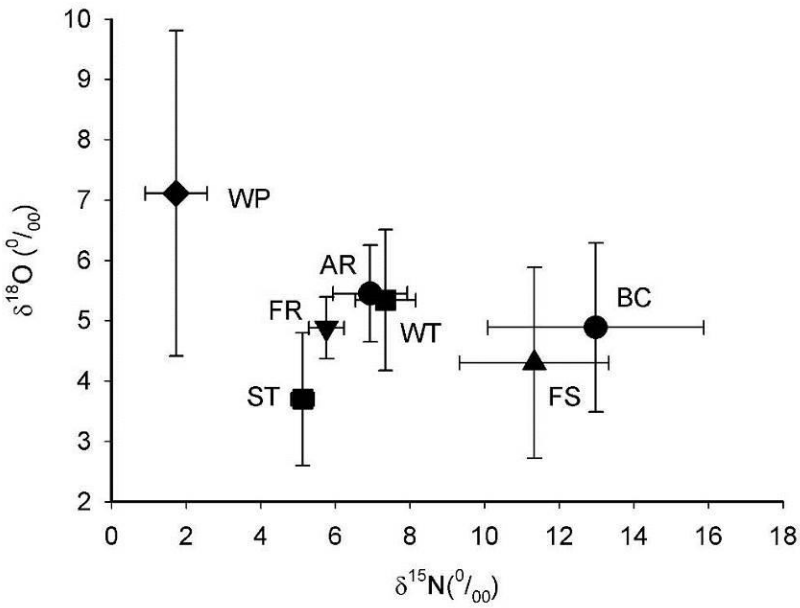


Figure 17. $\delta^{15}N$ and $\delta^{18}O$ signatures of streams and rivers entering Corner Inlet sampled on four occasions during summer and autumn 2015.

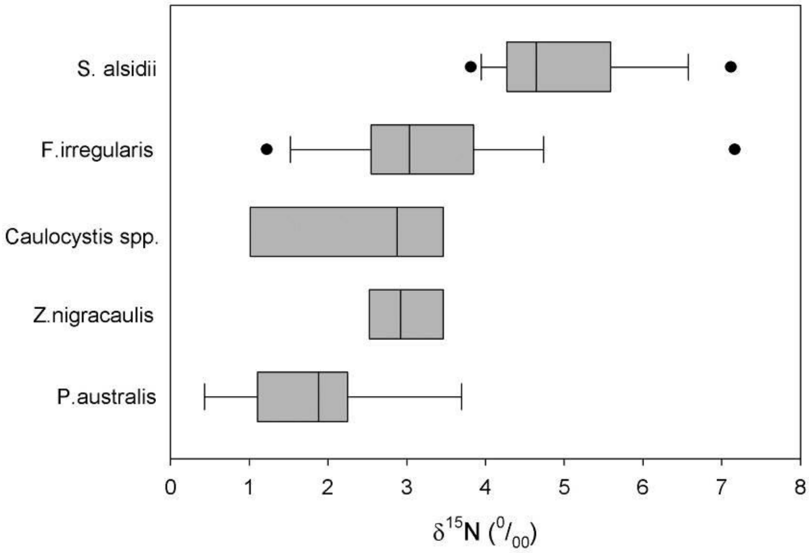
Bars represent standard error around the mean. WP: Wilsons Promontory creeks, ST: Stockyard Creek. FR: Franklin River, AR: Agnes River, WT: Western Tributaries, FS: Foster sewage pond, BC: Bennison Creek.

Seagrass and algal isotope signatures

The $\delta^{15}N$ of the seagrass system had a mean $\delta^{15}N$ signature of 2.38, a very low enrichment value for estuarine systems (Figure 18a). *P. australis* values were lower (mean 1.8) than previous values recorded in Corner Inlet (mean 3.2, Hindell et al. 2009). *Z. nigricaulis* values (mean 2.9) were similar to those recorded by Hindell et al (2009). Brown slub *F. irregularis* had similarly low enrichment (mean 3.2) with most values overlapping with seagrass system values. However the red alga *S. alsidii* was more enriched (mean 5.0) suggesting nitrogen sources from outside the seagrass system.

Whilst it is difficult to assign the sources of N to any particular source, the generally low enrichment of the primary producers in the seagrass system strongly suggests their source to be local nitrogen fixation. This local fixation is most likely sulphate reducing bacteria associated with seagrass roots and also cyanobacteria. Interestingly, the brown *F. irregularis* is also poorly enriched, suggesting they also derive their N from local N fixation in the seagrass system. There is also no evidence for an offset between *F. irregularis* and seagrass, suggesting this macroalgae are not receiving their N from nutrient runoff (lower macroalgal signature would indicate a synthetic fertiliser source, and a higher signature a manure source). The red algae *S. alsidii* showed an enriched signature and likely contribution on N from the catchment (see below).

There was little overlap in the $\delta^{13}C$ signatures among species (Fig 16b), with the algal species showing the greatest depletion and the seagrass species the least. Values for *P. australis* (mean = -9.0) are slightly more depleted than those recorded by Hindell et al. (2009) (mean = -7.9) and Nichols et al. (1986) (mean = -7.2).



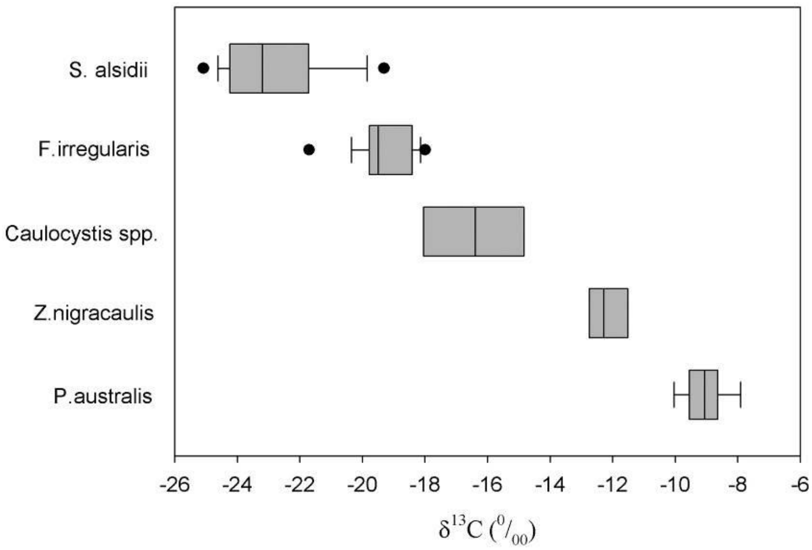


Figure 18. Boxplots of mean and 95% confidence intervals of a) $\delta^{15}N$ and b) $\delta^{13}C$ from tissue of two seagrass (*Posidonia australis* and *Zostera nigricaulis*), one macroalgae (*Caulocystis* species) and two filamentous algae (*Feldmannia irregularis* and *Stylonema alsidii*) species from Corner Inlet.

Source contribution of nitrogen to algal blooms

The two filamentous algal species differed in their source contributions of nitrogen. The brown algae *F. irregularis* sourced 82% of nitrogen from the seagrass system and only 18% from the catchment. The green algae *S. alsidii* instead sourced the majority (60%) of nitrogen from the catchment and 40% from the seagrass system.

A possible scenario of N uptake by the slub *F. irregularis* is via the decomposition of *P. australis* blades during the autumn months. The slub blooms correspond every year to the dieback of the *P.australis* plants, which have an annual cycle of blade growth in spring and summer, a dieback in Autumn and dormant in Winter. The overlap in $\delta^{15}N$ signatures make this a plausible scenario, and the observation of consistent yearly blooms at the same time of year suggest a combination of nutrient availability and drop in temperature are the trigger for these blooms.

The specific catchment source of nitrogen fuelling the green algal blooms is presently unclear. While water temperature is the most likely trigger of the bloom (> 20°C), the nutrients must be present within the system to create such rapid and extensive growth. There was little runoff immediately before and during the 2016 bloom, suggesting that the input may not be directly from the waterways. Yanakie on the west coast received 71.2mm in January, including 44.4mm in the 48h period 31st January to 1st February, which would likely trigger runoff in these areas, but only 43.9mm of rain was recorded in January at the Toora station (between the Agnes and Franklin Rivers), although a peak of 27.4mm fell on February 1st. Unfortunately flow records do not exist for Corner Inlet and hence we do not know the amount of runoff that occurred in this period and whether it could be sufficient to fuel the bloom.

Better understanding of the N sources may be gained through analysis of conditions in summer 2015, when a green algal bloom did not occur. The mean maximum January temperature in Yanakie (23.6°C) was very similar to 2016 (23.7°C), suggesting temperature was not a factor. Total rainfall in January 2015 was lower at Yanakie (39mm) and higher at Toora (65mm) than in 2016, however there were no single rain days in 2015 of >14mm and no 48h period of >15mm. At these low levels there may have been no runoff from the catchment into streams and rivers; however analysis of the 2013 and 2014 rainfall shows rainfall patterns very similar to 2015. One difference between the summer of 2015 and years in which we observed green blooms was a much reduced herbicide spraying program for invasive *Spartina* in the intertidal regions of Corner Inlet. No aerial spraying was conducted that summer, which has been ongoing for about a decade until that point. The length of the aerial spraying program also coincides with local knowledge reports of an increase in frequency and extent in the past decade.

We have therefore narrowed the possibilities down to three plausible scenarios: 1) Rainfall between Jan 31st and Feb 1st mobilised large amounts of nutrients from the catchment into Corner Inlet, 2) there was a build-up of nitrogen in the seagrass system during Spring and Summer and the algae bloomed when the temperature rose, or 3) extensive weed spraying around the shorelines of Corner Inlet during December and January caused large amounts of nitrogen to enter the waterway through breakdown of targeted vegetation.

Chemical threats to seagrass

Risk assessments are presented separately for heavy metals, herbicides, petrochemicals and other toxicants (Tables 6a-d). There are no identified extreme, high or medium risk threats from chemical toxicants to seagrass in Corner Inlet. There are two threats however, that have unknown risks and are provisionally considered to be high (phenoxy acid herbicides) and low (fire retardants). In such cases of unknown risks provisionally classified medium and above, further information is required before a definite risk level can be assigned.

Table 7. Risk assessment of chemical toxicant threats to seagrass in Corner Inlet, Victoria, based on experimental evidence of detrimental effects on seagrass, and known levels and exposure to these toxicants in Corner Inlet. Note that for some chemicals, two concentration thresholds are assessed; these represent sub-lethal and lethal effect concentrations.

a) Heavy metals

HEAVY METAL	RELEVANT CONCENTRATION (mg L^{-1})	CONSEQUENCES	LIKELIHOOD	RATING
Cd	0.1	4. MINOR Evidence of cell damage and reduced photosynthesis and growth rates at concentration greater than 0.1, however no effects detected in the field.	D. UNLIKELY Max recorded from Hindell (2009) was <0.001 mg L^{-1}	LOW
Cr	10	UNKNOWN One study shows cellular damage at 10mg L-1	D. UNLIKELY Max recorded from Hindell (2009) was <0.001 mg L-^{1}	LOW
Cu	0.1	4. MINOR Reduction in photosynthetic activity in both lab and field at 0.1 mg L-1	D. UNLIKELY Max recorded from Hindell (2009) was 0.0015 mg L-^{1}	LOW
Ni	0.5	UNKNOWN One study shows cellular damage at 0.5mg L-1	D. UNLIKELY Max recorded from Hindell (2009) was <0.001 mg L-1	LOW
Pb	50	4. MINOR Reduced nitrogen fixation and growth at >50 mg L-1	D. UNLIKELY Max recorded from Hindell (2009) was <0.001 mg L-1	LOW
Zn	0.1	4. MINOR Reduction in photosynthesis at > 0.1 mg L-1	D. UNLIKELY Max recorded from Hindell (2009) was 0.01 mg L-1	LOW

b) Herbicides

HERBICIDE	RELEVANT CONCENTRATION (µg L^{-1})	CONSEQUENCES	LIKELIHOOD	RATING
Atrazine	0.1	4. MINOR Reduces photosynthesis, respiration and metabolism from 0.1 µg L^{-1}.	D. UNLIKELY All below detection (< 0.1 µg L^{-1}) from Hindell et al. (2009)	LOW
	100	3. SERIOUS Growth and survival affected at 100 µg L^{-1}.	E. RARE Concentration would require direct spraying of estuarine areas, which does not occur	LOW
Diuron	0.1	4. MINOR Reduces photosynthesis from 0.1 µg L^{-1}, growth from 3.2 µg L^{-1}	D. UNLIKELY Not analysed in Hindell et al (2009) or in catchment. Very low use of diuron in the catchment (Rose et al. 2010)	LOW

	200	3. SERIOUS Productivity and survival affected at 200 µg L^{-1}	E. RARE Concentration would require direct spraying of estuarine areas, which does not occur	LOW
Phenoxy acids		UNKNOWN No lab studies that appropriately examine the effects of phenoxy acids. Some evidence of negligible effects in field	B. LIKELY No testing for phenoxy acids. Potential exposure to high concentrations of fluazifop after aerial spraying. 2,4-D one of main herbicides used in catchment (Rose et al. 2010)	UNKNOWN (HIGH)
Glyphosate		5. INSIGNIFICANT No effects on seagrass in both lab and field studies	UNKNOWN No testing for glyphosate. One of the main herbicides used in the catchment (Rose et al. 2010)	UNKNOWN (LOW)

c) Petrochemicals

CHEMICAL	RELEVANT CONCENTRATION (ml L^{-1})	CONSEQUENCES	LIKELIHOOD	RATING
Oil and dispersants	>0.1	4. MINOR Reduction of photosynthesis at levels > 0.1 ml L^{-1}, some mortality > 75 ml L-1 for intertidal species. Recovery after sub-lethal effects in lab and field	D. UNLIKELY No hydrocarbon spill documented however with boat traffic and oil operation it is conceivable. Major spill could come from Bass Strait	LOW
Drilling fluid	n/a	5. INSIGNIFCANT No effects on seagrass in both lab and field studies	E RARE No drilling occurring with the catchment and waters	LOW

d) Other chemicals

CHEMICAL	RELEVANT CONCENTRATION (ml L^{-1})	CONSEQUENCES	LIKELIHOOD	RATING
Insecticides	n/a	5. INSIGNIFCANT No documented effects on seagrass in both lab and field studies	D. UNLIKELY All below detection limits (Hindell et al. 2009, Rose et al. 2010)	LOW
Fungicides	n/a	5. INSIGNIFCANT No documented effects on seagrass in both lab and field studies	D. UNLIKELY Most below detection limits (Hindell et al. 2009, Rose et al. 2010)	LOW
Fire retardants	n/a	UNKNOWN No studies investigating the effects of fire retardants on seagrass	D. UNLIKELY Phos-chek only used during active fire periods, unknown what concentration reaches seagrass	UNKNOWN (LOW)

Water quality

Catchment water quality varied amongst waterways and between sampling periods (see Appendix H for full dataset). Wet sampling periods showed higher nutrient concentrations, but lower TSS concentrations. Two creeks in the north-west of the Inlet, Poor Fellow Me and Old Hat, had consistently the highest N and P concentrations, and were second and third highest average TSS (Figure 19). These results reflect the pattern of high nutrient concentrations in these two waterways detected during Waterwatch monitoring from 1997 to 2006 (Vella 2006). Stockyard Creek had the highest average TSS, but this was mostly a result of a very high reading in the dry weather sample.

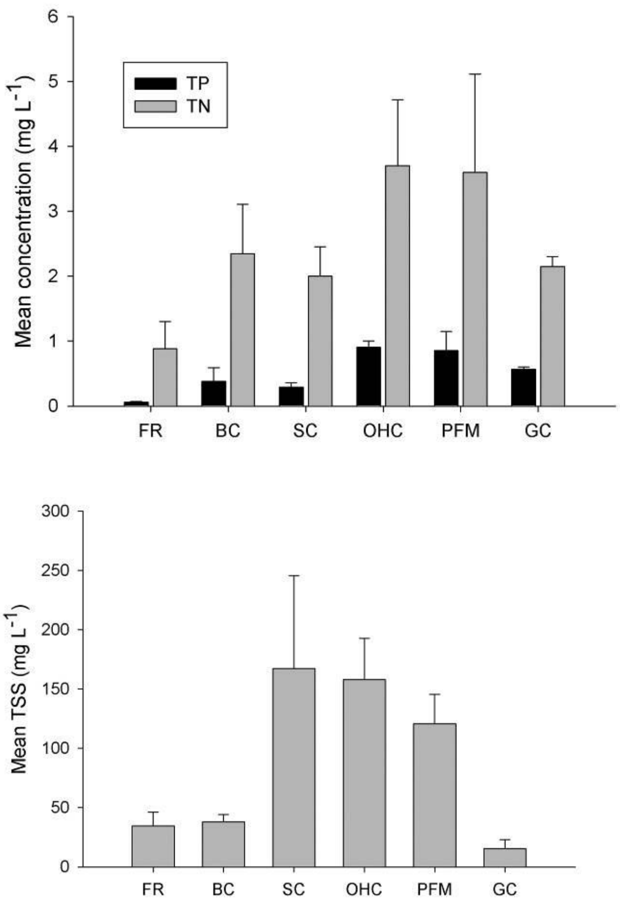


Figure 19. Mean concentrations of a) Total phosphorous (TP) and total nitrogen (TP), and b) Total suspended sediment (TSS) in six waterways in the Corner Inlet Catchment. Waterways were sampled on three occasions in 2014. The EPA 75th percentiles for TP and TN are 0.045 and 0.6 mg L^{-1} respectively, and all samples were consistently above these values. FR = Franklin River, BC = Benison Ck, SC = Stockyard Ck, OHC = Old Hat Ck, PFM = Poor Fellow Me Ck, and GC = Golden Ck.

All measurements of TN and TP from creeks and streams were above the EPA 75th percentile values for Coastal Plains (Tiller and Newell 2003). Whilst ideally comparisons to EPA guidelines would have at least 10 samples, these results strengthen the CIWQIP findings of large nutrient loads in catchments NW of the Inlet. Our TP results are consistently higher than those obtained over 10yrs of Waterwatch sampling (Vella 2006), but the spatial patterns are similar. With the exception of the Franklin River site, all current samples were taken much further downriver than the Waterwatch sites and could explain the higher concentrations.

Estuarine water quality samples were reasonably consistent amongst sites and between sampling periods (see Appendix H for full dataset). Values were generally low, although the Franklin channel had the highest nutrient concentrations (Figure 20). Except for FRP at the Franklin Channel site, all samples were below the EPA objectives for estuarine water quality. Values were in the lower ranges of those observed by Hindell et al. (2009).

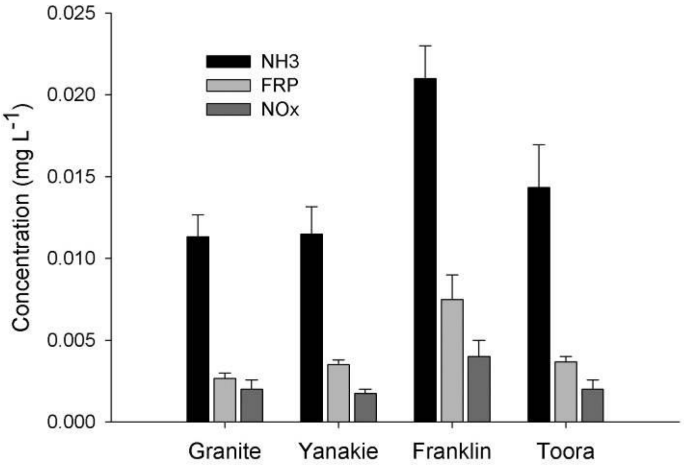


Figure 20. Mean nutrient concentrations in three estuarine sampling locations in Corner Inlet, taken one three occasions in 2015. NH_3 = ammonia, FRP = free reactive phosphorous, NO_x = nitrites and nitrates. The EPA objectives are 0.03, 0.005 and 0.03 mg L^{-1} respectively. All sites were below these objectives except for phosphorous at Franklin channel.

Assessment of threats to seagrass in Corner Inlet

We identified algal blooms and turbidity as equally the two most important threats to seagrass in Corner Inlet. We have documented the wide spread and frequent algal blooms, which can shade seagrass for up to five months a year. Turbidity is not monitored but anecdotal reports, field observations and strong relationships between areas of poor water clarity and seagrass loss highlight turbidity as a very important threat. Further work into understanding and managing these two threats are strongly recommended. Herbicide spraying is an unknown threat and we strongly recommend further research into understanding seagrass exposure in the field, and the role of vegetation breakdown in fuelling algal blooms. The remaining three threats are low priority, although if major dredging work were to be carried out in Corner Inlet, very careful management is required to minimise effects on seagrass.

Table 8. Assessment of threats to seagrass in Corner Inlet. List of threats taken from CIWQIP and assessed in light of findings from our study. We ranked threats in order of importance for future research and management (ranking in parentheses)

Threat	Mechanism	Causes	Evidence	Next steps
Algal blooms (=1st)	Reduced light and oxygen	Elevated nutrients, predominantly nitrogen in estuarine environments (Woodland et al. 2015). Blooms triggered by temperature change	Mapping revealed 1-2 major blooms a year, covering 42-88% of seagrass over 4-10 weeks.	Continue to reduce N loads from catchment. Investigate *Spartina* breakdown as a source of N. Focus on understanding effects (e.g. light reduction) and reducing incidence of green blooms.
Turbidity (=1st)	Reduced light	Catchment sediment inputs via creeks and river and re-suspension of bare sediments through wind and waves	Substantial anecdotal evidence but no monitoring of turbidity. Relationship between seagrass loss and reported high turbidity.	Continue to reduce sediment loads from catchment. Monitor light levels over seagrass beds and areas of recent loss.
Toxicants (3rd)	Reduce photosynthesis or disrupt biochemical pathways	Catchment inputs, herbicide spraying, coastal and urban development, oil spills	No evidence of seagrass loss attributable to toxicants. However herbicide spraying in the intertidal is an unknown risk.	Field trials of the effects of intertidal herbicide spraying. Move to use of seagrass-friendly herbicides.
Physical disturbance (4th)	Direct removal or damage	Dredging, boat anchors, storms	No evidence of recent impact, although any future dredging works related to port development has potential for major impacts	Carefully manage future dredging, both to minimise direct seagrass loss and impacts of turbidity
Desiccation (5th)	Heat stress	Sedimentation of banks, changing climate increasing number of very hot days	Loss has occurred from channel edges, not high banks. However *P. australis* possibly replaced in high banks by *Z. nigricaulis*	Monitoring of the upper boundaries of *P. australis* on high banks
Erosion and infilling (6th)	Burial or substrate removal	Catchment inputs, dredging, storms, natural processes	No erosion or infilling reported on seagrass beds in Corner Inlet	Focus attention on Nooramunga, which has had reported erosion and infilling affecting seagrass banks

Collaborative catchment management

Engagement guidelines

We produced a set of engagement guidelines available in Appendix E as a stand-alone document: *Engagement guidelines: fostering collaborative relationships in coastal fishing communities.* These guidelines aim to assist the formation and development of collaborative relationships between fishers and land users that will:

- lead to a mutual understanding of the impacts of land use on the marine environment, the sustainability of the local fishery and the sustainability of the land users' businesses;
- encourage land users to identify and adopt management practices targeted at protecting and restoring the marine environment;
- ensure that fishers' observations and concerns are integrated into the community's decision-making framework.

Farmer-fisher day

We produced a case study of the Farmer-fisher day held in May 2015, which is available as Appendix F. The document covers the motivation, preparation, process and outcomes of the engagement events. Interest in the field day was extremely high but numbers were limited to the carrying capacity of the fishing boats. Thirty beef and dairy farmers and six fishermen were among the participants who went out onto the Inlet, while several more farmers and fishermen enjoyed the lunch and a visit to a nearby dairy farm.

The day was highly successful, with important information and idea exchange happening at the initial discussions at the town hall (Figure 21) information and on the boat and farm visits (Figure 22). The key to the field day's success was the reciprocal sharing of knowledge in the workplaces each group knew best – in the fishing boat and on the farm. The methodology adopted by organisers created a better understanding of the links between land practices and coastal health, and developed a mutual respect of each group as food producers, natural resource managers and business operators. The field day has laid important steps in establishing an ongoing relationship between farmers and fishers. Future challenges involve engaging a wider audience of less environmentally-aware farmers, and providing evidence that best management practices are having a positive impact on the health of the Inlet.

Figure 21. Images from the discussion in Franklin Town hall

Figure 22. Images from the farm visit and fishing boat trip

Results of participant feedback

We observed increases in perceived awareness about out key messages of the farmer fisher day: the sustainability of the corner inlet fisher, the importance of seagrass and the actions farmers are taking to improve soil and fertiliser runoff (Table 9).

Table 9. Survey responses for Farmer-fisher day

Survey question		Average score (out of 10)
Please indicate your level of awareness of the environmental sustainability of the Corner Inlet Fishery.	Before the event	5.2
	After the event	7.6
Please indicate your level of awareness of the importance of seagrass for sustainable fisheries?	Before the event	5.3
	After the event	8.4

Engagement with the fishing industry

The engagement with industry was continuous throughout the project. Obtaining local knowledge required an ongoing relationship of trust and mutual respect. The connection to the fishing industry remains and we are working on finding funding for furthering a number of the project recommendations.

Progress Advisory Committee Meeting

We held a Progress and Advisory meeting at Port Franklin Hall on 11th August 2014, which was well attended by commercial fishermen and local stakeholders. The purpose was to relate the purpose and progress of the project to date, and to clarify directions for the remainder of the project. A delegate from the FRDC, Crispian Ashby, was in attendance. We had a very productive meeting and covered much ground. In brief, we have decided on three specific directions for the project beyond the current seagrass and algal bloom mapping that will provide important information for the water quality improvement work of the WGCMA.

Engagement with community

Landcare community events

Project PI John Ford was a guest speaker at two Landcare community events. The first was the Jack and Albert River Restoration (JARR) Discovery Day in Port Albert, organised by the Yarram Landcare Group. The PI provided information to local landowners and landcare members on the project, the threats to seagrass and the livelihoods of local fishermen, and things people could do on their properties to reduce those threats. The second event was organised by the South Gippsland Landcare Group and held at Port Welshpool. The group toured shoreline seagrass meadows, mangroves and saltmarshes, while experts discussed the importance of these habitats.

Farmer-fisher day

The farmer-fisher day was successful in bringing together farmers and fishers to raise awareness of threats to seagrass. The event is described in detail above.

Meetings with Dairy Australia

Project team members John Ford and Rob Day met with local representatives of Dairy Australia on a number of occasions. The industry made it clear that they would need to see strong evidence linking their practices to seagrass loss in order for them to engage in the project. It was clear, however, that substantial efforts are being made to better manage nutrient and sediment runoff from dairy farms and this will be appropriately acknowledged by the project team in the future. Dairy Australia was generous with their time and resources and was a very important part of the farmer-fisher day.

Key outcomes of these meetings were a better understanding of the: 1. the level of information/evidence required to engage the dairy industry and acknowledge downstream effects of their practices, and 2. The incentives required to engage individuals farmers collaboratively on a project that does not immediately benefit them.

Engagement with management

Presentations to Corner Inlet Connections

The project PI John Ford is an active member of the Corner Inlet Connections Working Group and attended all meetings held during the life of the project. We presented the final results of our study to the group in March 2016, who is very interested in further work on seagrass mapping and determining the source of catchment nutrients fuelling algal blooms. We also presented to this group at the beginning of the project in early 2014 to raise awareness of seagrass issues.

Corner Inlet Connections is an established partnership between state government agencies, local councils, regional water managers, the WGCMA, farming industry groups, forestry industry, landowners and the community. The partnership is committed to maintaining and improving the environmental, agricultural and economic sustainability of the inlet and its surrounds. The inclusion of the fishing industry in this group is a real win for the project and the local fishing industry.

Presentation to the Corner Inlet Catchment Working Group

Project investigator John Ford presented to the Corner Inlet Catchment Working Group on 16th December 2015. The group oversees the catchment management of Corner Inlet and is responsible for creating and implementing the Water Quality Improvement Plan. Present were representatives from the West Gippsland CMA, the Federal government Dept. of Environment (much of the work is funded federally through Caring for Country and RAMSAR grants amongst others), Landcare, Parks Victoria and Dairy Australia. We presented the broad project results: documenting the loss of seagrass, the value of fisher's knowledge, the threat of algal blooms, chemical threats to seagrass, sources of nutrients and advice on catchment management targets. The working group was particularly interested in how the Corner Inlet Water Quality Improvement Plan could improved/updated to get better outcomes for seagrass and fishermen.

Corner Inlet RAMSAR Assessment Group

The PI participated in the Corner Inlet RAMSAR assessment group, which met a number of times in the start of 2014 to identify conservation goals for the next 3 years for the Corner Inlet RAMSAR site (which incorporates all the area commercially fished). The PI was representing the fishermen's interest and provided expert knowledge on seagrass and its threats in the Inlet. While seagrass was not chosen as a priority due to the progress of the WGCMA's Water Quality Improvement Plan, mangroves and saltmarsh were chosen, which represents a good outcome for fishermen. Saltmarsh in particular has been significantly degraded in the inlet and no longer serves a key role in fish habitat that it once did. Conservation and restoration work in this area will certainly benefit fishery productivity, sustainability and profitability in the long term.

Seagrass Restoration

Sediment analysis

Results: No contaminant was detected at levels of concern or triggering ANZECC (2000) guidelines (Table 10). Concentrations of petroleum hydrocarbons were elevated at some sites, particularly in the C15-C28 range. No detectable trace of any pesticide, herbicide or fungicide was found. Sediment was mostly composed of sand particles (0.06 – 2mm), and further analysis revealed that over 90% of this was very fine sand between 75 and 300 µm. Restoration B and The Gulf also had significant components of both clay (<2µm) and silt (2-60µm).

Ramet transplants

An average of 22.5% of ramets survived after the first month, which was an anticipated but high early loss rate. Ramet survival continued to decline over time and only 1.3%, or 6 individual ramets, were alive after 5 months (Figure 23). We observed initial significant differences in the survival of ramets planted at different depths (ANOVA $_{df=20}$ F=4.27, p=0.02, Tukey's post-hoc tests), where deep planted ramets (29% ± 3.8se) survived almost twice as well as those shallow planted (15.8% ± 3.6se), and significantly higher retention of bamboo forks were also observed (ANOVA $_{df=20}$ F=3.47, p=0.03) in deep plantings (51% ± 5.7se) compared to shallow plantings (29% ± 5.8se). However no effects of plot or sampling depth were detected after 3 or 5 months due to the extremely low survival observed across all treatments.

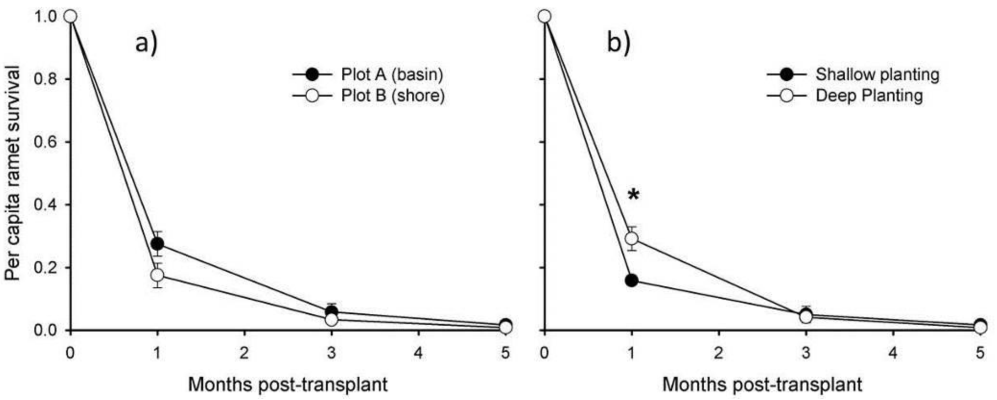


Figure 23. Survival of transplanted *Zostera nigricaulis* ramets over five months, plotted by a) restoration plot and b) depth of planting. Bars are standard error.

There were significant differences in the planting depth after one month (α=0.05, indicated by an asterix), were the deeper plantings showed significantly greater survival than the shallow planting treatment. We also observed significantly higher bamboo fork retention (used to secure the ramets) in the deep plantings after one month. No statistical differences were observed between plots, or planting treatments at the three and five month stages.

Table 10: Analysis of contaminants in sediment samples. See Appendix G for list of chemicals tested. “bd” refers to below detection limit.

Analysis	Detection limit	ANZECC trigger	Restore A	Restore B	The Gulf	Cobbler’s Bank	Robertson’s Bank
Particle size (%)							
Clay (<2µm)	-	-	9	15	12	2	2
Silt (2-60µm)	-	-	6	12	18	2	1
Sand (60µm-2.00mm)	-	-	85	70	64	96	97
Gravel (>2mm)	-	-	<1	3	6	<1	<1
Extractable metals (1M HCl, mg/kg)							
Antimony	1	2	<1.0	<1.0	<1.0	<1.0	<1.0
Arsenic	1	20	1.2	4.2	3.6	<1.0	1.6
Cadmium	0.1	1.5	<0.1	<0.1	<0.1	<0.1	<0.1
Chromium	1	80	1.9	3.7	3.4	<1.0	1.1
Copper	1	65	<1.0	<1.0	<1.0	<1.0	<1.0
Lead	1	50	1.6	2.9	2.4	<1.0	<1.0
Nickel	1	21	<1.0	<1.0	<1.0	<1.0	<1.0
Silver	1	1	<1.0	<1.0	<1.0	<1.0	<1.0
Zinc	1	200	2.2	4.6	4.2	<1.0	1.1
Mercury	1	2	<1.0	<1.0	<1.0	<1.0	<1.0
Total organic carbon (%)		-	0.73	0.99	0.78	0.2	0.16
Total petroleum hydrocarbons (mg/kg)							
C10 -C14 Fraction	3	-	<3	<3	<3	<3	<3
C15 -C28 Fraction	3	-	8	10	23	30	21
C29 -C36 Fraction	5	-	8	5	8	<5	<5
C10 -C36 (sum)	3	-	16	15	31	30	21
Various herbicides	varies	-	bd	bd	bd	bd	bd
Various pesticides	varies	-	bd	bd	bd	bd	bd
Various fungicides	varies	-	bd	bd	bd	bd	bd

At the five month sampling, we observed greater abundances of *Posidonia australis* seedlings in our plots (n = 9) than the restoration target species. These naturally established seedlings (Figure 24) were growing in areas where past abundances were low, and is a very encouraging sign for future growth and confirms suitable conditions for seagrass growth in Yanakie basin.

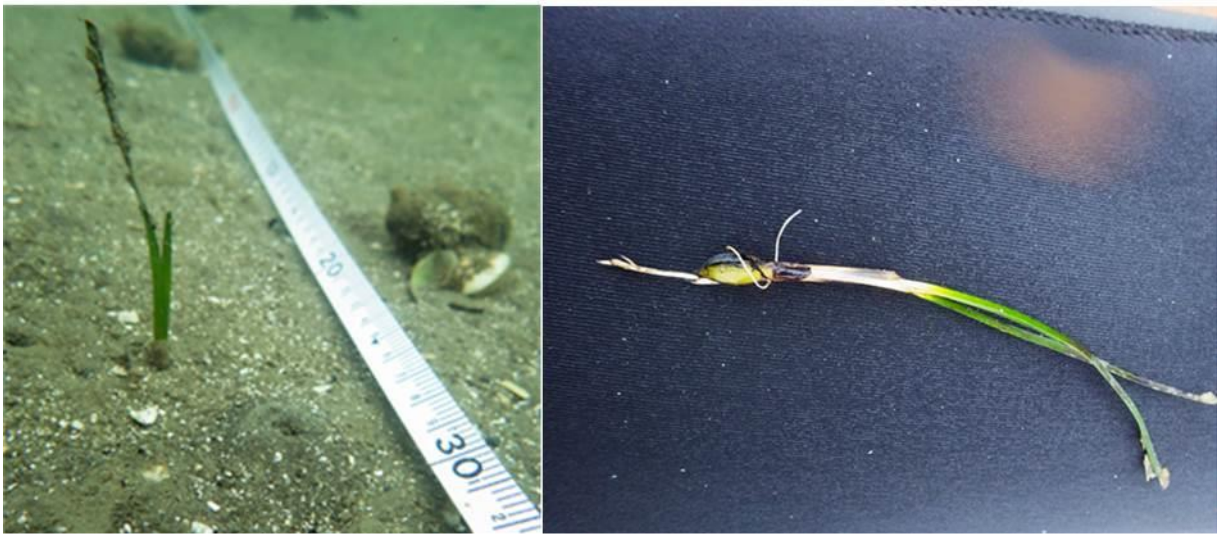


Figure 24. *Posidonia australis* seedlings, a) observed in Yanakie basin at 1m depth and b) uprooted with seed still visible. Blades were approximately 10cm long.

Seed bags

Only two *Z. nigricaulis* seedlings were observed in our seed bag plots four months after deployment. One was observed immediately beneath the seed bags at Restoration site B (shore) from the Robertson's source population. The other was observed at Restoration site A, 5m along the westerly transect from a Gulf seed-bag treatment. Whilst this number is extremely low, this is possibly the first time that *Z. nigricaulis* seedlings have been observed in their natural environment, proving the first evidence that seed supplementation can work for this species.

Interestingly, we also observed two *Z. nigricaulis* plants on sediment beneath bags that had established through ramets and not seeds. The seed bags contained seagrass plants, often with ramets attached, and hence inadvertent ramet transplant provides another mechanism for restoration using the seed-bag technique.

We observed fallen seeds in the sediment near all plots, the density decreasing with distance from the seedbags (Figure 25). We estimate that an average of 125 seeds were present in the 1m radius around the bags, an adequate number to support small scale regrowth of *z. nigricaulis* if germination is successful. We also observed many seed fragments in the cores next to seedbags, indicating that seeds had either already germinated and subsequently not survived, or seeds were not viable and have decomposed.

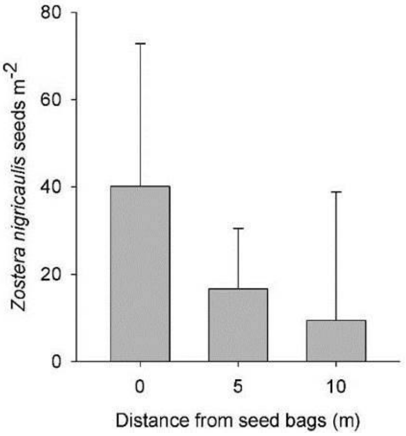


Figure 25. Abundance of *Zostera nigricaulis* seeds found in sediment cores within 0-1m, at 5m and at 10m from the seed bags, four months post-deployment. Bars are standard error.

Discussion

The project successfully met all of its six objectives. Combining local knowledge, scientific experiments and observations, alongside practical engagement and extension, we have increased the scientific and public understanding of ecosystem-related fishery decline in Corner Inlet. The project makes many important management and research recommendations to assist in arresting the decline of fisheries productivity.

Objective One – Seagrass and local knowledge

We successfully used local knowledge to create a map of seagrass distribution, document past ecosystem states and historical fluctuations in seagrass cover. Our methodology of combining local knowledge hypotheses with scientific, mapping and field observations was robust, effective and cheaper than many more technical processes. It enabled an informed assessment of environmental change and threats to fisheries productivity.

Whilst we cannot make direct comparisons of the costs and accuracy of different mapping techniques, this could be explored in future mapping opportunities. Now that our technique is proven, it can be adopted in other coastal fisheries as a cost-effective way to map habitat that engages and respects the knowledge of local fishing communities. It also opens lines of communication and engagement between the fishing community and the managers who ultimately use these maps to inform their decisions. We recommend the ongoing use of our technique in Corner Inlet, and its extension to other fisheries which hold in-depth local knowledge and concern for fish habitat.

Our results provide conclusive evidence of historical seagrass decline in Corner Inlet, along with the alarming observation that the current extent of seagrass is the lowest in the past 48 years. The majority of the seagrass loss was identified as subtidal *Z. nigricaulis*, with a lesser decline in *Posidonia australis.* Unfortunately the historical maps do not have the accuracy to determine species-specific declines, but the use of local knowledge of fishermen has enabled us to broadly understand these dynamics. The massive, Inlet-wide loss *Z. nigricaulis* between 2011 and 2013, and its current absence in key historical regions of abundance (e.g. Yanakie basin, Doughboy hollow, Red Bluff) is outside of the natural 5-10yr cycles of fluctuation identified and is a major cause for concern. There is also strong evidence of a multi-decadal *P. australis* decline in the northern and southern regions that was masked by an increase in *Z. nigricaulis* in the areas of loss. Only since the widespread loss of *Z. nigricaulis* is this loss now apparent.

Objective Two: Chemical threats to seagrass

We fulfilled this objective through the creation of the standalone report “Chemical threats to seagrass in Corner Inlet” (Appendix D). The report reviews current scientific information around the risk of chemicals and toxicant to seagrass, and secondly reviews this in light of the known or suspected levels of use and exposure in Corner Inlet. We identified knowledge gaps in our understanding of three important toxicants: the herbicides in the phenoxy acid and glyphosate groups, and fire retardants used to supress bushfires. The risks of glyphosates and fire retardants were considered provisionally low, but the frequent exposure of seagrass to phenoxy acids in intertidal weed spraying highlights this unknown as a priority for further research.

Objective Three: Link key threats to historical loss, focusing on algal blooms

We addressed this objective in three ways: an in-depth investigation the emerging threat of algal blooms, monitoring water quality of streams running into the Inlet, and then combining all information available to assess all potential threats to seagrass in Corner Inlet.

Algal blooms arose as a key threat to seagrass through the local knowledge of fishers, as before this project there was no documented reports of blooms in Corner Inlet. We found that algal blooms occurred every year, often multiple times, covered very large areas and lasted many weeks. These blooms are likely to have a major impact on the light available to seagrass during this time, reducing photosynthesis and energy production. We identified two types of blooms, one which appears to be fuelled by nutrients coming from the natural breakdown of seagrass and has been occurring for many decades, and the other fuelled by nutrients originating in the catchment and which is increasing in impact over the past decade. It is unclear what the specific nutrient pathway is from land to coast and this requires further investigation. Regardless of source, however, these blooms pose a key threat to seagrass and fisheries productivity in Corner Inlet.

Secondly, we monitored water quality of streams draining into Corner Inlet and identified high concentrations of nutrients and sediments in most waterways. Strikingly, all samples (including both wet and dry periods) were above the EPA 75th percentile for coastal streams, meaning they are enriched compared to the majority of streams of this type. Two creeks in the northwest, Old Hat and Poor Fellow Me, were particularly of concern. Therefore we confirm the findings of the CIWQIP that high nutrient and sediment loads are entering the Inlet from the north and NW, and the western tributaries have high concentrations of nutrients. Water quality is an important but understudied threat to seagrass in Corner Inlet, with no estuarine monitoring of nutrients or turbidity. Field observation and local knowledge detailing high turbidity in many of the shoreline areas of Corner Inlet should be further investigated.

Finally, we combined out local knowledge, scientific and literature results to rank the threats to seagrass in Corner Inlet. Algal blooms and turbidity we ranked equally important as the highest threats to seagrass in Corner Inlet, and should be the focus of further research and management. Toxicants, physical disturbance, desiccation and erosion were ranked in that order of importance. Further research is recommended for some of these lower priority threats.

Objective Four: Convey local knowledge and threats to managers and landowners

We completed objective four through conveying the threats to seagrass and fisheries productivity through a series of events, workshops, public presentations, one on one conversations and information material. We acknowledged that different audiences would respond best to different forms of engagement, and hence we adopted this diverse strategy of information dissemination.

Our most important event was the farmer-fisher day, where the reciprocal visits of farmers and fishers to seagrass beds and a dairy farm enabled strong discussion and understanding of the respective industries and their issues. Feedback showed an increased awareness of farmers about the problems faced by fishers around the decline of seagrass, and what can be done to address that decline. Fishers also showed an increased awareness around the many positive strategies in place to address water quality issues on farm.

Project researchers provided presentations on the importance of seagrass to Landcare groups in both South Gippsland and the Yarram areas. Other public presentations and numerous local radio interviews and newspaper articles also spread the message of how to address the threats to fisheries habitat (see “Project coverage” below).

Finally the local knowledge and results of this study were communicated directly to managers in a series of presentations, discussion and working groups. Most important were presentations to the water and farm engagement teams in the WGCMA, and the Corner Inlet Connections group.

Milestone Five: review mapping and engagement process

The process of mapping and engagement were a success. We produced accurate and cost effective seagrass maps that engaged the local knowledge of fishers. The use of local knowledge was a highly effective way to recreate the environmental history of Corner Inlet and develop hypotheses around seagrass decline and threats. Half of the hypotheses were confirmed from external evidence and no hypothesis was disproven with contradictory evidence. Triangulating the multiple sources of evidence allowed a number of different types of data and observations to be considered together in a simple ‘weight of evidence approach’ that is becoming more widely used when evaluating complex environmental problems (Linkov et al. 2009).

Fishers were ideal candidates for communicating local environmental knowledge due to their often daily and long term immersion in the environment, and the importance of the state of the environment to their livelihoods. These factors created a deep understanding of the natural variability of the system and was key in helping identify change that was outside of natural cycles. For example, the observations of natural cyclical variability in *Z. nigricaulis* basins enabled a much improved synthesis of historical seagrass area, and also was key in validating the unusual and unprecedented decline in *Z. nigricaulis* from 2011-2013. In particular the observations that the Yanakie basin has never been devoid of seagrass in the last 50 yrs (confirmed by mapping) has highlighted the severity of the current problem.

To assist in addressing similar fisheries affected by external environmental threats to productivity, we produced a stand-alone document that reviews our engagement process and provides a step-by-step guide to engaging fishing communities in the wider catchment management process. We hope that this document can be widely adopted and adapted across Australia's coastal, habitat-dependent fisheries.

This process of engaging landowners and farmers was a successful start, but the process is slow and requires a substantial investment of time and patience to listen and be part of a wider process with multiple goals. Most importantly, we learned that the key difficulty lies in reaching, informing and encouraging change in landowners and farmers that are disengaged from the issue. We observed many highly motivated and environmentally aware farmers who are making many changes to improve water quality and the habitat for fishers. But further engagement and different methods are required to reach and motivate those with very little interest in the issue. One-on-one conversations with farmers and encouraging farmers to raise these issues with their peers appeared the most successful way to do this, but may not be sufficient. For many landowners the changes to land management needed to improve water quality may be simply financially out of reach, and hence continued and enhanced funding of groups like the WGCMA is vitally important to provide grants for these activities. The whole community would profit from such targeted and thus cost-effective funding.

Whilst we have developed an effective method for mapping seagrass using fisher's local knowledge, there is currently no commitment for its ongoing funding. The WGCMA, the primary users of seagrass maps to aid in their catchment and RAMSAR management, have stated that this technique a viable cost effective option for ongoing periodic mapping. The technique, however, relies heavily on two factors: 1) the availability of off-the-shelf satellite imagery to keep costs down (<20% the cost of chartered aerial photography or satellite imagery), and 2) strong relationships with the fishing community to engage with the local knowledge. Whilst the project team could replicate the current process smoothly, a third party without an established relationship with the fishing community could find this challenging. As there is a need to establish a replicable methodology that is comparative over time, this aspect requires further development in co-operation with the WGCMA.

Objective Six: Assess feasibility of seagrass restoration

The seagrass restoration trial yielded disappointing short-term results, but provides important guidance for future attempts. Restoration is unlikely to be successful in the Yanakie basin using the techniques we trialled, unless there is the potential for a much greater scale of activity. Only small numbers of plants need to survive the early months to establish meadows over time, and in some cases restoration only requires sufficient plants to be present so that they can take advantage of favourable environmental conditions when they arrive. A recent review has observed the scale of the project is the strongest determinant of success in the long term – larger projects have proportionally more success (van Katwijk et al. 2016).

The low survival observed over the first month was not unexpected and follows the trend of many small-scale seagrass restoration attempts globally (van Katwijk et al. 2016). The source of early low ramet survival appears to be physical disturbance, as we also had a corresponding low recovery of bamboo forks. In the two weeks following transplant, 30-40kt easterlies blew for several days in Corner Inlet, resulting in large wind waves and significant disturbance of the Yanakie Basin. The effects were clearly demonstrated in the amount of seagrass wrack that appeared on the westerly shore, which was impressive given the area is mostly devoid of seagrass.

The causes of ramet mortality in later months in unknown. Black dead seagrass stems were still visible after 5 months, often held in place with the bamboo forks, and hence physical disturbance was not the only factor. Better understanding of the sediment and light requirements of different populations of *Z. nigricaulis* may better inform the causes of this mortality. Ramet transplant, however, was not predicted to be a viable option for large scale restoration, and was chosen primarily to determine whether seagrass from the donor site would grow in the Yanakie basin. Given the low success rate of ramets from the Gulf site, other sites should be considered in the future.

Our results show that the seed bag technique in its current form is not a viable option for restoration in Corner Inlet. The main barrier appears to be successful germination and early survival of seedlings, not the delivery of seed. Improvements in collection and deployment efficiencies, and locating suitable donor sites, could create a viable scale up technique for larger scale seagrass restoration.

Conclusion

We successfully engaged with the local knowledge of fishers to understand ecosystem-related decline in fisheries productivity and to assist the catchment management process to start addressing key threats. We have provided a framework for creating similarly successful outcomes in coastal fisheries that has a number of key elements:

- Engaging and documenting ecosystem change from local knowledge
- Mapping fisheries habitat by combining local knowledge with contemporary techniques
- Identifying and assessing threats to fisheries habitat and productivity
- Engaging with and motivating the wider community to create positive change
- Embedding the fishing community in the catchment management process

This process was successful in raising the regional profile of both the fishing industry and the importance of maintaining a healthy environment for fisheries productivity.

Key results around understanding seagrass decline, and the severity of different threats have provided critical advice for catchment managers and provide important context for fisheries assessments and evaluation. We make a series of recommendations on further research and management, some of which have already been acted upon. We are confident that our strong relationships with the WGCMA, Corner Inlet Connections and the other regional management bodies will result in many or most of these recommendations being pursued and executed.

The key findings and outcomes of the project were:

Seagrass Loss

- The total cover of subtidal seagrass has declined in Corner Inlet over 48 years at a rate of 0.5km^2 yr^{-1}
- Current (2013) subtidal seagrass cover is the lowest in the past 48 yrs (85.3km^2)
- The current cover of *Z. nigricaulis* is the lowest in living memory and it is completely absent from the deeper muddy basins historically dominated by the species
- There was a massive loss of *Z. nigricaulis* between 2011 and 2013, which coincides with the aftermath of the La Nina and drought-breaking floods of 2010 and 2011
- Natural 5-10yr cyclical fluctuations in *Z. nigricaulis* have caused significant variation in seagrass maps made in different decades
- 27.2km^2 of seagrass was lost between 1998 and 2013, the majority of this *Z. nigricaulis*
- There has likely been a long term decline in *P.australis* from the southern and northern shores and high banks, although the areas were subsequently colonised by *Z. nigricaulis*

Algal Blooms

- Filamentous algal blooms are an important but previously unrecognized threat to seagrass in Corner Inlet
- There are two types of filamentous bloom, a ‘brown’ bloom dominated by *Feldmannia irregularis* that occurs almost every autumn and a ‘green’ bloom of the red algae *Stylonema alsidii* occasionally in mid-summer.

- Blooms lasted on average 6 weeks and covered 61% of the seagrass in Corner Inlet\
- All blooms covered similar areas of the Inlet, where there was always total cover near the shorelines and little to no coverage near the ocean entrance.
- Most areas of reported seagrass decline (NW corner, Agnes/Toora, Golden Creek basin, Red Bluff, Yanakie) were always covered during blooms.
- The brown bloom has occurred annually for over 60 years and nitrogen was mostly sourced from the seagrass system. It is probable that the natural decomposition of *P. australis* blades in autumn provides a large nitrogen source for the bloom.
- The green bloom is a more recent phenomenon, increasing in frequency and severity in the past 10 years. The majority of nutrients are sourced from the catchment.

Chemical threats to seagrass

- Man-made chemicals, particularly herbicides, are a threat to seagrass globally.
- The threat of heavy metals, hydrocarbons and most agricultural chemicals is low.
- The main herbicide used in Corner Inlet, glyphosate, presents a low risk to seagrass, although local studies are lacking.
- Spraying of phenoxy acid herbicides in the intertidal zone by helicopter presents an unknown but alarming risk to seagrass. Unlike agricultural runoff, direct nearby spraying is much more likely to subject seagrass to lethal or damaging concentrations of herbicide.

Assessment of threats to seagrass in Corner Inlet

- Reduction in light as a result of algal blooms and turbidity pose the greatest threat to seagrass in Corner Inlet
- Sediment from the catchment entering the Inlet likely contributes significantly to turbidity, although resuspension of sediment from wind and waves will also play an important role.
- Nutrients from the catchment play a significant role in fuelling green algal blooms.
- Levels of nutrients and sediment were high in all rivers and creeks entering the Inlet from the north and west, and all samples were above the EPA 75th percentile for TN and TP
- Old Hat and Poor Fellow Me creeks both had consistently very high concentrations of nutrients
- Physical disturbance of seagrass beds could pose a high risk if large scale dredging works are carried out in the future

Seagrass restoration

- Conditions were not conducive to small scale seagrass restoration in the Yanakie basin.
- Physical disturbance from strong easterly winds uprooted growth shoot transplants.
- Seed bags successfully dropped seeds into the sediment, but produced few viable seedlings.
- A seedbank could be established through large scale seed bag deployments, which may lie dormant until conditions are conducive for growth.

Implications

Public awareness

The project has undoubtedly raised the public and management profile of the Corner Inlet fishery, its sustainability and the threats to productivity. We believe that the role of the fishing industry in the regional community and economy was strengthened through outreach of the research team but importantly by the fishers themselves. Engagement and media coverage has also grown the awareness around the importance of seagrass in coastal waters and how each member of the public can play a role in protecting these ecosystems.

Whilst these changes are not quantifiable in a broad sense without extensive surveys, we have evidence that farmers had increased awareness and willingness to protect seagrass after the farmer-fisher day. We saw similar results from the Landcare field days and feedback from media coverage. Indeed, overhearing locals having an intense discussion about the importance of seagrass at the local pub was strong encouragement that this message is taken seriously and spread within people's wider circles.

Management implications

Already, key components of the report are being utilized by catchment managers. The 2013 seagrass map will be used a baseline from which the CIWQIP will benchmark seagrass cover and the effectiveness of their management initiatives. The observation of a definitive decline in seagrass cover answers the uncertainty around this issue which has prevented adequate action in the past. Furthermore, the link between catchment nutrients, algal blooms and seagrass decline provides the first strong evidence that the activities in the catchment are contributing to habitat loss and productivity costs to the fishery.

The validation of the majority of the hypotheses posed by local fisher's knowledge raises the profile of the industry in providing relevant and real advice. Already fishers are represented on key management groups such as Corner Inlet Connections, and we hope that this will spread to other regional bodies. Challenges remain in adequate resourcing of fishers to attend meetings and finding willing representatives.

Addressing seagrass decline

We propose that if effective measures are taken to improve water quality, the fishery is likely to see benefits of continued or increased yields through maintaining or enhancing fisheries productivity. This is a long term goal and requires the cooperation and commitment of government, catchment managers, farming industry groups, individual landowners and the fishing community. The CIWQIP outlines a pathway to roll out land management practices, reduce sediment and nutrient loads and make water quality improvements. The funding of these improvements is not committed and this is a critical stumbling block to making tangible differences to seagrass habitat and fisheries productivity.

The momentum created by this project, along with the strong case for addressing habitat decline, lays a strong platform for the catchment-wide improvement of land practices and water quality.

The absence of a water quality monitoring program in Corner Inlet is a challenge to quantifying any water-quality gains made through the actions of this project. Similarly, observing actual seagrass regrowth resulting from improvements may takes years or decades to manifest. Hence this project must be only the beginning of ongoing action and momentum to improve the health of Corner Inlet. We begin this process by documenting the problem and its likely causes, raising the profile of the fishery habitat and leave a lasting legacy of engagement and education in the region.

Recommendations and Further Development.

The key goal of this project is to understand and facilitate the environmental conditions required for the re-establishment of seagrass to boost fisheries productivity. Evidence suggests that these environmental conditions will not return in some areas of Corner Inlet without significant changes to catchment practices and proactive work on behalf of the fishing and agricultural industry. Hence we provide here a series of recommendations to address a broad range of necessary actions and knowledge gaps that require investigation. Note that these recommendations are specific to Corner Inlet, although most would also be relevant to the adjoining Nooramunga system.

Catchment management recommendations

1) The Corner Inlet Water Quality Improvement Plan (CIWQIP) be fully funded to carry out the initiatives and works planned until 2033

2) As per the CIWQIP, Continued funding of Best Management Practices for farms around Corner Inlet, targeted at properties in the west and north-west of the catchment.

3) As per the CIWQIP, continued funding of traditional waterway management activities, including gully and streambank rehabilitation

4) Develop a strategy to engage, educate and motivate the landowners who are currently disengaged with issues of water quality and environmental improvement

5) Provide financial incentives for currently disengaged landowners to make environmental improvements. This can involve possible payments to landholders based on lost opportunity costs to production or to offset profit losses

6) Further investigate the feasibility of converting shoreline farming paddocks into natural saltmarsh and swamp. Purchase of land or finding alternative economic benefit from these areas (e.g. samphire harvest) may be required

7) Investigate the contribution of other major land uses, particularly forestry operations (covering 21% of catchment) to water quality issues in Corner Inlet. Focus on use of herbicides and sediment runoff after logging

Regulatory recommendations

1) Legislative changes to the *Victorian Fisheries Act* that empower Fisheries Victoria to identify and manage aquatic and marine habitat important for recreational and commercial fisheries.

2) Strengthening regulation around farm runoff, and consider establishment of market based approaches such as nutrient trading schemes

3) Review the continued extension of Crown Land leases on the edges of Victorian waterways and provide funds for fencing all Crown Land waterway frontages

Research and monitoring recommendations

1) Ongoing nutrient and sediment monitoring of the Corner Inlet waterways to determine effectiveness of the CIWQIP and inform ongoing adaptive management. Include intermittent testing of herbicides

2) Seagrass mapping be carried out every 3-5 years using the local knowledge technique outlined in this project

3) Research into the exposure of seagrass to phenoxy-acid herbicides after aerial intertidal spraying, and consequent effects

4) Inlet-wide monitoring of turbidity levels using light loggers to investigate effects of water way sediment loads and resuspension

5) Monitor the green summer blooms and determine if they are linked to seagrass loss. Identify the sources of catchment nutrients fuelling green algal blooms.

6) Further development of seagrass restoration techniques using seed dispersal of both *Z. nigricaulis* and *P. australis*

Extension and Adoption

Extension was a key component of this project from the outset. Many of our objectives and goals simply cannot have been met without dedicated and consistent communication with the fishing industry, catchment managers, landowners, farming industry groups and government. We have contributed to three public events, five catchment management meetings or workshops, published two media releases, carried out five radio interviews and at least seven print or newspaper articles during the two and half years of the project.

Adoption of project outputs and recommendations

- Project results around seagrass decline and threats to fishery productivity were used to inform the Fisheries Victoria 2016 Corner Inlet Stock Assessment and subsequent management decisions
- Recommendations around further research into the effects of phenoxy acid herbicides on seagrass were adopted by the WGCMA and Parks Victoria. Funding was provided for researchers at RMIT to carry out acute toxicity studies in the lab. These found that the main herbicide used in intertidal spraying had serious effects on seagrass, and established sub-lethal and lethal exposures. A field trial to determine the actual exposure to seagrass after spraying is being carried out in May 2016 and involves researchers from this project
- The 2013 seagrass map created in this project will be used as a baseline for measuring the CIWQIP
- Project researchers are currently in discussion with the WGCMA about establishing a turbidity monitoring plan in Corner Inlet to investigate this threat to seagrass
- Project researchers are currently in discussion with the WGCMA about establishing an ongoing seagrass mapping plan for Corner Inlet. Funding permitted, this will be initiated as soon as off-the-shelf satellite imagery is available

Project coverage

Print articles

- South Gippsland Times 27/05/2014
- Corner Inlet Connections newsletter October 2014

Farmer-fisher day coverage:

- Foster Mirror 12/05/15
- Sentinel Times 12/05/15
- Gippsland “Coast” magazine June 2015
- Dairy Direct magazine June 2015
- Landcare Connections Autumn 2015
- FRDC “Fish” magazine Spring 2015

Radio interviews

- ABC Rural August 2014

- ABC Gippsland September 2014
- ABC Gippsland May 2015 x2
- ABC Gippsland May 2016

Project materials developed

Appendix D – Chemical toxicant threats to seagrass (Report)

Appendix E – Engagement Guidelines for fishing communities in catchment management

Appendix F – Farmer-fisher day case study

Appendix I – Project fact sheet

Appendices

Appendix A: List of personnel

Appendix B: Reference list

Appendix C: Historical seagrass change at additional sites in southern Corner Inlet

Appendix D: Chemical toxicant threats to seagrass (Report)

Appendix E: Engagement guidelines for fishing communities in catchment management

Appendix F: Farmer-fisher day case study

Appendix G: Results of chemical analysis of sediment samples

Appendix H: Results of nutrient and suspended sediment analysis of catchment and estuarine water samples

Appendix I: FRDC Project 2013-021 Fact sheet

Appendix J: GIS map layers

Appendix A – List of personnel

Named Investigators

Primary Investigator:

- Dr John Ford, School of Biosciences, Melbourne University

Chief Investigators:

- Associate Professor Robert Day, School of Biosciences, Melbourne University
- Associate Professor Kate Barclay, School of International Studies, University of Technology Sydney

Co-Investigators:

- Gary Cripps, Environmental Officer, Corner Inlet Fisheries Habitat Association
- Neville Clarke, Secretary, Victorian Bay and Inlet Fisheries Association
- Tracey Jones, Water Program Coordinator, West Gippsland CMA
- Dr Andrew Longmore, Centre for Aquatic Pollution Identification and Management, Melbourne University

Research Investigators

- Dr Tim Smith, School of Life Sciences, Deakin University
- Associate Professor Perran Cook, School of Chemistry, Monash University

Consultants

- Jillian Staton, Freelance writer
- Pete Crockett, Algal expert
- Mick Green, Drift Media

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Appendix C

Historical seagrass comparisons of additional sites in Southern Corner Inlet

In addition to the areas of historical seagrass cover analysed in the main repot, we also compared cover over time for an additional seven sites. These sites were not included in the main report because they were not included in every seagrass map. The 1975 map was missing the SW of the Inlet, the 1984 map was missing a thin strip running east to west across the centre of the Inlet, and the 2009 and 2011 maps did not cover the southern half of the Inlet.

We compare three additional *Zostera nigricaulis* basins, two additional *Posidonia australis* banks and two additional areas of reported long term seagrass decline (Figure C1).

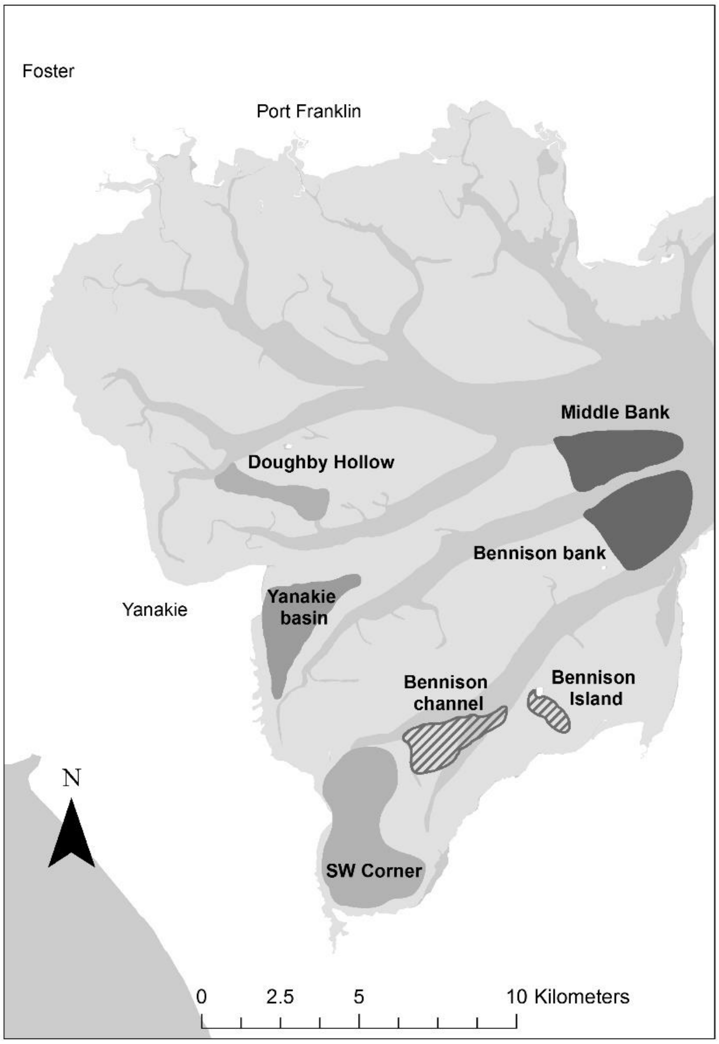

Figure C1. Three additional *Zostera nigricaulis* basins, two additional *Posidonia australis* banks and two additional areas of reported long term seagrass decline

The patterns of change observed were very similar to the areas compared in the main report. The *Z. nirgicaulis* basins showed high variability and a sharp decline in the last 15 years (Figure C2). The

Doughboy Hollow site showed little variation before 1998 but a recent decline.

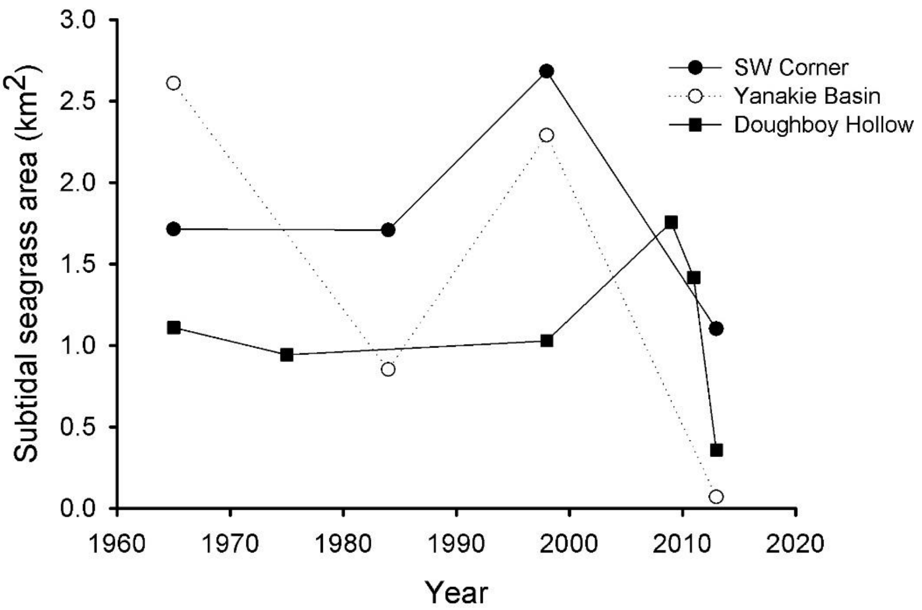

Figure C2. Historical change in seagrass cover in three *Z. nigricaulis* basins

The Posidonia banks were mostly stable (Figure C3), although Bennison bank showed a slight increase in cover over time. The change was mostly around the high banks, suggesting that this may be growth of *Z. nigricaulis* in these areas.

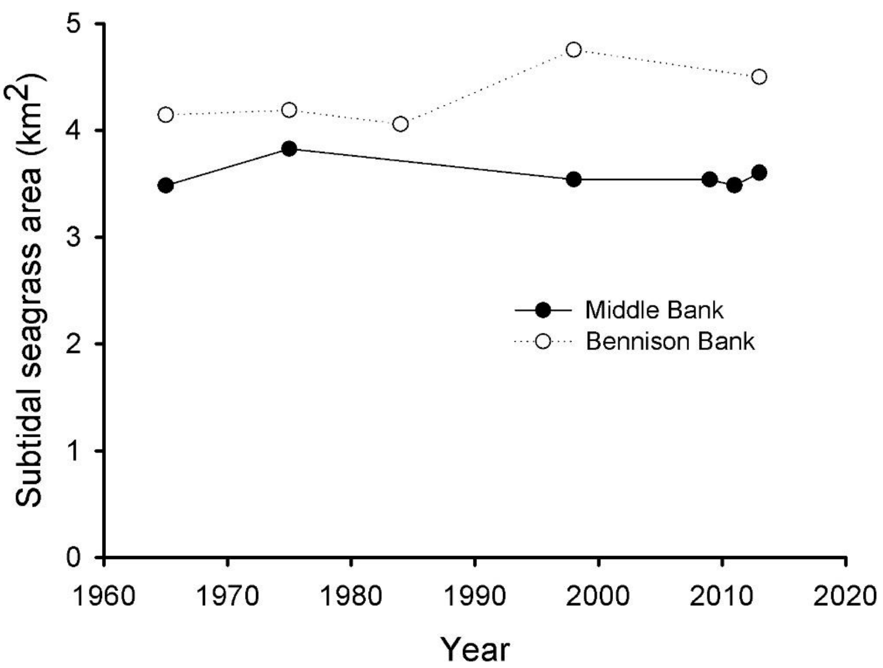

Figure C3. Historical change in seagrass cover at two *P. australis* banks

The areas of reported decline showed a mixed result (Figure C4), where there was a very large decline in cover in the Bennison channel area since 1998, however the Bennison Island area remained constant. The Bennison channel area may have had a shift from *P. australis* to *Z. nigricaulis* over time, which then declined significantly since 2011 like most other basins.

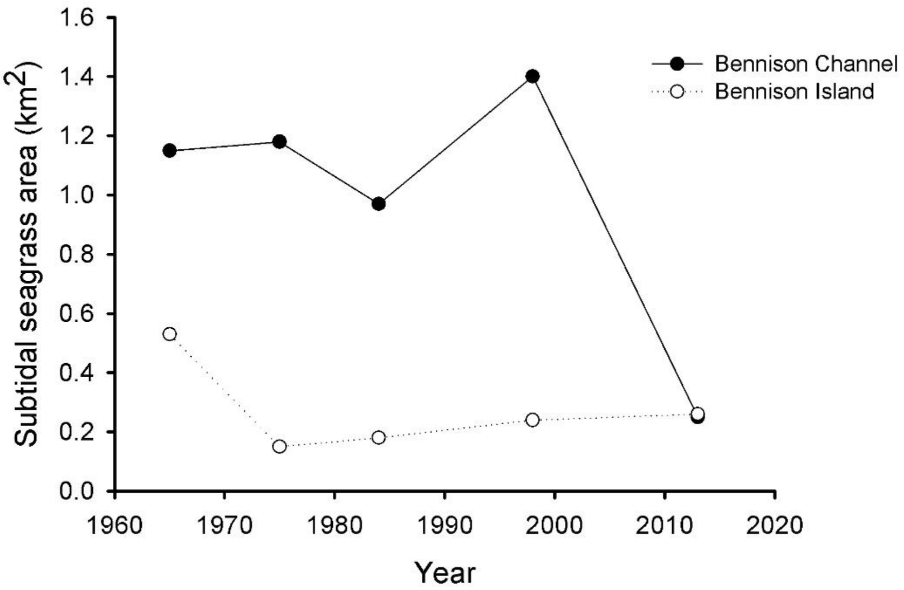

Figure C4. Historical change in seagrass cover in two reported areas of seagrass loss

Appendix D

Report: “Chemical toxicant threats to seagrass”

A review of the chemical toxicant threats to seagrass in Corner Inlet, Victoria

Report compiled for the West Gippsland Catchment Management Authority as part of Fisheries Research Development Corporation Project 13/021.

Corner Inlet looking toward Wilsons Promontory

John Ford, School of Biosciences, Melbourne

June 2014

FRDC FISHERIES RESEARCH & DEVELOPMENT CORPORATION

West Gippsland Catchment Management Authority

The FRDC project 2013/021 "*Using local knowledge to understand linkages between ecosystem processes, seagrass change and fisheries productivity to improve ecosystem-based management*" is supported by funding from the Fisheries Research Development Corporation (FRDC) on behalf of the Australian Government. The West Gippsland Catchment Management Authority is a third party funding contributor and project partner.

Report should be cited as:

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Thanks go to Dr Andrew Longmore from the Centre for Aquatic Pollution Identification and Management for his expert review of the report.

Contents

EXECUTIVE SUMMARY

Seagrass ecosystems are in decline globally, principally due to human induced change to estuarine and coastal water quality. Urban stormwater runoff, industrial discharge, land clearing and inputs from catchment activities such as farming and forestry have elevated levels of nutrients, turbidity, sedimentation and toxicants over many seagrass beds. Corner Inlet, while not experiencing the large declines of seagrass observed in nearby Western Port, has nevertheless had a decline in seagrass cover over the past few decades. It is currently not certain what the major driver of this decline has been, however increased nutrient and sediment runoff from the catchment is the most likely mechanism. Nevertheless, the threat and impact of chemical toxicants on seagrass in Corner Inlet has not been thoroughly investigated before this study. This report addresses this knowledge gap by evaluating the potential threat of chemical toxicants (heavy metals, herbicides, petrochemicals, other pesticides and fire retardants) to seagrass in Corner Inlet.

Chemical toxicants are considered important site-specific factors in the decline of some localised seagrass beds, but are not thought to be a major driver of total seagrass decline worldwide. Nevertheless, investigation of potential localised lethal and sub-lethal threats in Corner Inlet is an important step in narrowing down our understanding of causes of seagrass decline locally. A review of lab and field studies revealed substantial work on the short term effects of heavy metals, crude oil and a small number of herbicides. Longer term effects were less often addressed, particularly for chronic exposure to herbicides. However most importantly, there exist complete knowledge gaps on the effects of many commonly used herbicides such as phenoxy acids and urea based chemicals.

Most heavy metals have only minor effects on seagrass, and frequent exposure to high concentrations would be required to have any lasting effect on seagrass beds. Oil spills can have acute short term impacts on intertidal seagrass (or subtidal seagrass when oil is dispersed); however field studies have shown fast recovery from such impacts. Herbicides are toxic to seagrass in concentrations 1000 times lower than metals or herbicides, and some field observations have infrequently recorded these low, sub-lethal concentrations around seagrass. Seagrass is extremely unlikely to be exposed to lethal concentrations of herbicides unless they were directly sprayed. Herbicides considered most toxic to seagrass are atrazine, diuron and hexazinone, while glyphosate and MCPA are considered least toxic.

Risk assessment of toxicant threats in Corner Inlet revealed no medium, high or extreme risk to seagrass. However, two important high to medium risk knowledge gaps were identified. Firstly, there is no information on the direct toxicity of fluazifop-p, the active ingredient in the herbicide Fusilade, which is used in the intertidal zone of Corner Inlet to control the invasive weed *Spartina*. There is high likelihood of exposure to high concentrations of Fusilade through aerial spraying operations carried out in the intertidal zone adjacent to beds of *Zostera muelleri*. Therefore the effect of Fusilade is deemed to be unknown with an interim risk rating as high. Secondly, the toxicity and exposure of seagrass to fire retardants is also an important unknown risk that requires further attention. The fire retardant Phos-chek has been used during bushfire periods in the southern end of the Inlet but it is not known what concentrations seagrass was exposed to, and whether there were secondary indirect effects of algal blooms and eutrophication.

Recommendations

1. **Research into the effects of Fusilade on seagrass (*High priority)***

Experimental trials are required to determine the level of toxicity of fluazifop-p on seagrasses in Corner Inlet. Priority is to run trials on *Zostera muelleri,* as this is the seagrass most likely to come into contact with high concentrations in the intertidal zone. Trials with *Posidonia australis* are also recommended as it forms the majority of seagrass in the Inlet and does not recover rapidly from disturbance. First stage should examine the lethal dose in controlled lab experiments. The second stage should examine sub-lethal effects over longer periods. If found to be toxic, field studies should examine the concentrations in the field after aerial spraying and assess the short and long term effects on seagrass.

2. **Trials of alternative control methods of *Spartina* *(Dependent on outcome of above)***

Currently spraying of Fusilade is the most cost effective way of controlling *Spartina*. However, taking into account the potential costs to seagrass and related decline in fisheries and aquatic productivity, there may be more cost effective methods available. Trials should investigate the substitution of herbicides with those known to have negligible effects on seagrass, or using mechanical non-chemical methods such as steam treatments and heavy duty techniques of smothering.

3. **Baseline monitoring of selected herbicides in Corner Inlet *(Medium priority)***

While studies have quantified levels of atrazine herbicides in water above seagrass, post storm event sampling of other herbicides in use in the catchment is recommended. In particular phenoxy acids (e.g. 2,4-D) and urea based herbicides (e.g. metsulfuron-methyl) should be tested, to determine concentrations in the Inlet and seagrass exposure periods.

4. **Investigation into the effects of fire retardants on seagrass *(Low priority)***

Experimental trials and field observations are required to better understand the effects of Phos-chek or other fire retardants on seagrass. Firstly, lab trials should be conducted on the toxicity of Phos-chek to seagrass, similar to those described for Fusilade above. Opportunistic sampling should be carried out of nutrients in water above seagrass, and monitoring of algal bloom growth, after spraying of Phos-chek for operational purposes.

AIM OF THE REPORT

This report aims to identify and assess the threat of anthropogenic chemicals and toxicants to seagrass in Corner Inlet, Victoria, Australia. It is designed to be an accessible reference for managers and stakeholders when considering the potential impacts of chemicals on the Corner Inlet marine system, and should help guide any necessary management actions or further research.

The report was compiled for the West Gippsland Catchment Management Authority by Dr John Ford from the School of Biosciences, Melbourne University, as part of the FRDC funded project "Using local knowledge to understand linkages between ecosystem processes, seagrass change and fisheries productivity to improve ecosystem based management" (FRDC Project 13/021).

SEAGRASS DECLINE: EXTENT AND CAUSES

Seagrass decline in a global context

Seagrass ecosystems are significantly threatened from expanding human populations, catchment alterations and coastline development (Orth et al. 2006, Ralph et al. 2010). Globally, seagrass has declined by 29% since 1879 and the rate of this loss is accelerating (Waycott et al. 2009). With an estimated value of \$19,000 ha^{-1} yr^{-1} in ecosystem services such as nutrient cycling (Costanza et al. 1997), and a net worth in fisheries productivity of up to \$230,000 ha^{-1} yr^{-1} (Blandon and zu Ermgassen 2014), these losses can cause significant impact on the productivity of coastal ecosystems (Beck et al. 2001) and viability of related industries such as fishing and tourism.

Australia has followed this trend of widespread seagrass decline in coastal waters (Walker and McComb 1992). Like many global examples, Australian seagrass decline is often observed in areas with significant modification of the surrounding catchment – 58% loss of *Posidonia australis* in Botany Bay (Larkum and West 1990), 77% decline of mainly *Posidonia* species in Cockburn Sound (Kendrick et al. 2002), 24% decline in *Halophila* in Hervey Bay (Preen et al. 1995) and a 70-85% decline in *Zostera* in Western Port (Bulthuis 1983). Extensive seagrass decline have also been documented in Moreton Bay (Kirkman 1978), Adelaide coastline (5000 ha; Westphalen et al. 2005) and NSW estuaries (1300ha in Tuggerah Lakes, 700 ha in Lake Macquarie; in Walker and McCoomb 1992).

While there is ample evidence for global seagrass decline, it is important to note that observations of seagrass expansion or recovery are often overlooked (Walker et al. 2010), and has occurred in fast growing tropical species (*Halodule* species – Robbins 1997) and slow growing temperate species (*Posidonia coriacea* – Kendrick et al. 2000, *P. australis* - Meehan and West 2000). This is an important and encouraging point to consider for scientists, managers and stakeholders; if the pressures that are causing the decline in seagrass are removed or alleviated, there is good evidence to suggest that seagrass will recover.

Seagrass decline in Corner Inlet

Corner Inlet supports large seagrass meadows on shallow banks < 5m water depth and intertidal mud flats. The dominant species are broad-leaf *Posidonia australis*, fine-leaf *Zostera nigricaulis* (and possibly other *Zostera* species), and the swan-grass *Zostera muelleri.* The broad-leaf and fine-leaf are predominantly sub-tidal species that are not often exposed, while the swan-grass is an intertidal species almost always exposed at low water. The seagrass ecosystem supports a commercial fishery that has been in operation for 150 years which targets key seagrass associated species such as King George whiting, rock flathead, garfish and calamari. Seagrass, epiphytes growing on it and resident invertebrates contribute up to 90% of the total nutrition of key fisheries target (Hindell 2006), and hence any sustained decline in seagrass is likely to significantly affect the fishery. The seagrass meadows also fall into the Corner Inlet and Nooramunga Coastal Park and are a Ramsar listed significant habitat for migrating birds.

The most widely used estimate of seagrass cover in Corner Inlet is 149 km^2, which is taken from the 1998 mapping work of Roob et al. (1998). However, more recent mapping carried out by the author of this study estimates 2013 seagrass cover at 120 km^2. The dominant seagrass in 2013 was broad-leaf *P. australis* which covered 73 km^2, followed by swan-grass at 40km^2, and fine-leaf *Z. nigracaulis* at only 7km^2. There have been a series of exercises undertaken to map seagrass in Corner Inlet, however only the two studies referred to above have covered the entire inlet with reliable methodology. Numerous attempts to track the fluctuations in seagrass extent in Corner Inlet, ranging from early sketches and anecdotal evidence (Poore 1978, Morgan 1986) to the most recent use of sophisticated ALOS (Advanced Land Observation Satellite) and LIDAR (Light Detecting and Ranging) data (Monk et al. 2011), have been generally inconclusive. For further information on these studies, see Kirkman (2013).

By synthesizing the findings of the above mapping studies with historical observations of commercial fishermen, there has been significant loss of broad-leaf seagrass in the north west of Corner Inlet, and smaller losses in other areas. This decline appeared to occur most quickly during the 1970-1980s (Poore 1978, Morgan 1986), but has continued at a slower pace since (Hindell et al. 2009). Fine-leaf by contrast is very dynamic and the Inlet has reportedly undergone a number of "boom and bust" cycles over the past few decades (N. Clark, G. Cripps pers comm.). Iin 2014 there was very little fine-leaf seagrass in the Inlet, and this is confirmed by comparisons of 2013 maps with those of Roob et al. (1998) and Hindell et al. (2009). A full description of these dynamics and the likely areas and extent of seagrass declines will be produced as a component of the wider FRDC project.

Threats to seagrass

Seagrasses are threatened by both natural and man-made processes, and it is often a combination of multiple stressors which lead to large decline in seagrass extent (Orth et al. 2006). Natural physical disturbances such as cyclones or storm surge have led to losses of seagrass beds (Walker et al. 2010), however such stressors are often coupled with corresponding pressure from anthropogenic sources, such as large freshwater discharges that bring sediment and pollutants from the catchment (e.g. Hervey Bay; Preen et al. 1995). Although direct physical removal can occur through dredging and land reclamation activities, most anthropogenic stressors to seagrass are related to declining water quality, caused by intensive urban or rural landuse. Furthermore, modifications to river systems and the removal of swamp, saltmarsh and mangroves from estuarine systems can channel runoff more quickly to seagrass beds, concentrating the impacts of freshwater runoff and reducing the natural breakdown and settlement of sediment, nutrients and pollutants.

Human induced changes to water quality over seagrass beds are most often the result of freshwater runoff from land which may be elevated in nutrients, sediment, or anthropogenic chemicals. Eutrophication through input of high nutrient loads from the catchment is considered to have the most widespread impact on seagrass beds (Ralph et al. 2010). Excess nutrients promote the growth of phytoplankton and epiphytic macroalgae which block light and reduce oxygen availability to the seagrass (Short et al. 1995). High levels of nutrients have been identified as the cause of seagrass declines in North Carolina (Burkholder et al. 1994), and in Spain (Brun et al. 2002). Increased nutrient loads are often associated with high sedimentation, which can both reduce light through turbidity and bury seagrass (Short and Wyllie-Echeverria 1996). High sediment loads have been implicated in seagrass decline in Gulf of Carpentaria (Longstaff and Dennison 1999) and in the Phillipines (Duarte et al. 1997). However, most often it is a combination of high nutrients and sediment that are implicated in seagrass loss, e.g. Chesapeake Bay (Moore and Wetzel 2000) and Adelaide coastline (Bryars et al. 2006).

The effects of reduced salinity and anthropogenic chemicals are not generally considered to be responsible for observed widespread declines in seagrass (Short and Wylie-Echevierra 1996, Orth et al. 2006, Bryars et al. 2006). However, there is a general lack of understanding around the impacts of many toxicants, and anthropogenic chemicals and toxicants are considered likely to have significant localised impacts on seagrass around urban areas and intensively farmed catchments (Lewis and Devereux 2009). Given this uncertainty, I will therefore review the current knowledge around chemical and toxicant effects on seagrass, identify threats relevant to Corner Inlet, and calculate their risk to seagrass beds.

CHEMICAL TOXICANT THREATS TO SEAGRASS

Toxicant and chemical threats to seagrass can be broken down into three main groups that are known to cause adverse impacts: heavy metals, herbicides and petrochemicals. There exist also a number of other toxicants with unknown effects on the seagrass such as insecticides, fungicides and fire retardants. The threat of toxicants is spatially variable and related to catchment use, the frequency and intensity of pulse storm events, and environmental factors that drive bio-availability and dilution (Westphalen et al. 2005). While toxicants are not generally considered a major factor in global seagrass decline (Waycott et al. 2009), their sub-lethal impacts may be working synergistically with other stressors, particularly as pulses of toxicants are associated with storm events that also bring increased turbidity, nutrients and freshwater flows (Haynes et al. 2000b). I will review the current knowledge of all these groups of toxicants, noting that although synthetic fertilizers are anthropogenic chemicals, they will not be examined in this report as their main impact is considered to be the promotion of algal growth and eutrophication, not toxicity to seagrass.

Heavy Metals

Many heavy metals can be toxic to seagrass in sufficiently high concentrations and exposures (Ralph et al. 2010). Most metals disrupt the function of photosynthesis, the effects of which are often reversible (Ward 1987, Prange and Dennison 2000), although impacts are species specific and highly dependent on exposure period and concentration (Westphalen et al. 2005). It is very important to note there are no field observations of mortality through heavy metal exposure. Instead, heavy metal exposure would be considered a sub-lethal impact in most circumstances and only of concern when exposure is intense and chronic.

Results from controlled lab studies have described a variety of negative impacts on seagrass survival, growth, photosynthesis and respiration (Westphalen et al. 2005). However, the complex and dynamic conditions experienced by seagrass in the natural environment (i.e. salinity, pH, water temp, redox potential, organic matter and metal concentrations) reduce the exposure and bioavailability of metals compared to lab studies (Ralph et al. 2010). Few field studies have therefore demonstrated consistent negative impacts of heavy metals of seagrass (Macinnis-Ng and Ralph 2002), despite reasonably efficient uptake of metals into seagrass tissues (Sanchiz et al. 2001). Recent observational field studies have linked metal concentrations in seagrass tissue and root with high levels of metals in the environment (Marín-Guirao et al. 2005, Ambo-Rappe et al. 2007), however there is little evidence for broad-scale effects of high metal contamination (Ambo-Rappe et al. 2008). Therefore assessing toxicity based solely on metal concentrations in the water or sediment does not provide an accurate indication of impact (Ralph et al. 2010). Furthermore, difficulties in identifying the source of heavy metal contamination can limit the effectiveness of management measures put in place to reduce exposure.

A summary of all peer reviewed and accessible lab and field studies investigating the effects of heavy metals on seagrass is presented in Table 1. Cadmium and copper are considered to have the most acute impact on seagrasses, although there are observations of only minor negative effects of copper in the field, and none for cadmium. The specific metals are reviewed below.

Cadmium

Cell damage and reduced photosynthesis observed in concentration > 0.1 mg L^{-1} (Lyngby and Brix 1984, Malea 1994, Ralph and Burchett 1998a, Malea et al. 2013b) much less than observed concentrations for metals other than copper. No effects observed in the field (Macinnis-Ng and Ralph 2002).

Chromium

Only a single study into the effects of chromium; observed cell death at 10 mg L^{-1} (Malea et al. 2013a).

Copper

Reduction in photosynthesis and in some cases leaf growth in lab trials at concentrations > 0.1 mg L^{-1} (Prange and Dennison 2000, Macinnis-Ng and Ralph 2002, Ambo-Rappe et al. 2011, Malea et al. 2013a). Small but significant reductions in photosynthesis detected in the field, however the result was inconsistent across sites, suggesting local conditions affected the bioavailability (Macinnis-Ng and Ralph 2004).

Nickel

Only a single study into the effects of nickel; observed cell death at 0.5 mg L^{-1} (Malea et al. 2013a).

Lead

Lead is considered to have very little effect on seagrasses generally (Ralph and Burchett 1998a, Malea 1994), as reduction to growth has only been recorded at high doses > 50 mg L^{-1} (Ambo-Rappe et al. 2011). However a recent lab study has identified cell death at low concentrations (> 0.1 mg L^{-1}) over a two week exposure period (Malea et al. 2014). No effects detected in the field (Macinnis-Ng and Ralph 2002).

Zinc

Zinc toxicity has only been studied in the field, with some reduction in photosynthesis measured at concentrations higher than 0.1mg L^{-1} (Macinnis-Ng and Ralph 2002), but otherwise no effects on survival and growth (Macinnis-Ng and Ralph 2004).

Table 1. Review of lab and field studies examining the effects of heavy metals on seagrass

Metal	Type	Species	Dose(s) ($mg\ L^{-1}$ except where stated)	Exposure	Lowest observed effect concentration ($mg\ L^{-1}$)	Response	Source
Cd	Lab	*Halophila stipulacea*	0.1, 1.1 $\mu g\ L^{-1}$ 0.1, 1.1, 11	16 d	0.1	Cellular damage at concentrations ≥ 0.1124 $mg\ L^{-1}$.	Malea (1994)
	Lab	*Zostera marina*	0.01124, 0.0562, 0.562, 5.62	19 d	0.562	Growth rate inhibited for ≥ 0.562 and 5.62 $mg\ L^{-1}$.	Lyngby and Brix (1984)
	Lab	*Halophila ovalis*	1, 5, 10	4 d	1	Slight reduction in photosynthetic efficiency in all treatments proportional to dose.	Ralph and Burchett (1998a)
	Field	*Zostera capricorni*	0.1, 1	10 h	n/a	None	Macinnis-Ng and Ralph (2002)
	Lab	*Cymodocea nodosa*	0.5, 5, 10, 20, 40	13 d	0.5	Microtubule depolymerization and cell death proportional to strength of dose	Malea et al. (2013b)
Cr	Lab	*Cymodocea nodosa*	0.5, 5, 10, 20, 40	13 d	10	Microtubule depolymerization and cell death proportional to strength of dose	Malea et al. (2013a)
Cu	Field	*Zostera capricorni*	0.1, 1	10 h	0.1	Reduction in photosynthetic efficiency proportional to dose.	Macinnis-Ng and Ralph (2002)
	Lab	*Halophila ovalis*	1, 5, 10	4 d	1	Reduction in photosynthetic efficiency in proportion to does.	Ralph and Burchett (1998a)
	Lab	*Halophila spinulosa*	1	12 d	1	Leaf senescence after 24 hours.	Prange and Dennison (2000)
	Lab	*Halophila ovalis*	1	12 d	1	Reduction in photosynthetic efficiency	Prange and Dennison (2000)
	Lab	*Halodule univervis*	1	12 d	1	Reduction in photosynthetic efficiency, although not significant	Prange and Dennison (2000)
	Lab	*Zostera capricorni*	1	12 d	1	Reduction in photosynthetic efficiency	Prange and Dennison (2000)
	Lab	*Cymodocea serrulata*	1	12 d	n/a	None	Prange and Dennison (2000)
	Lab	*Zostera marina*	0.635, 3.177 $\mu g\ L^{-1}$ 0.3177, 3.177	19 d	0.3177	Growth rate inhibited ≥ 0.3177 $mg\ L^{-1}$ with response proportional to dose.	Malea (1994)
	Field	*Zostera capricorni*	0.1, 1	10 h	0.1	Reduction in photosynthetic efficiency proportional to dose.	Macinnis-Ng and Ralph (2004)
	Lab	*Halophila ovalis*	0.5, 2, 4	51 d	0.5	Reduced growth proportional to dose. Significant changes to leaf shape at 2ppm	Ambo-Rappe et al. (2011)
	Lab	*Cymodocea nodosa*	0.5, 5, 10, 20, 40	13 d	0.5	Microtubule depolymerization and cell death, onset proportional to strength of dose	Malea et al. (2013a)
Ni	Lab	*Cymodocea nodosa*	0.5, 5, 10, 20, 40	13 d	0.5	Microtubule depolymerization and cell death proportional to strength of dose	Malea et al. (2013a)
Pb	Lab	*Zostera marina*	10, 100	24 h	100	Reduced nitrogen fixation at 100 $mg\ L^{-1}$	Brackup and Capone (1985)
	Lab	*Zostera marina*	0.02, 0.1036, 1.036, 10.36	19 d	n/a	None	Malea (1994)
	Lab	*Halophila ovalis*	1, 5, 10	4 d	n/a	None	Ralph and Burchett (1998a)
	Field	*Zostera capricorni*	0.1, 1	10 h	n/a	Slight reduction in photosynthetic efficiency but highly variable.	Macinnis-Ng and Ralph (2002)
	Lab	*Halophila ovalis*	10, 50	51 d	50	Reduced growth only at 50 $mg\ L^{-1}$. No change to leaf shape	Ambo-Rappe et al. (2011)
	Lab	*Cymodocea nodosa*	0.1, 0.25, 0.5, 5, 10, 20, 40	13 d	0.1	Microtubule depolymerization and cell death proportional to strength of dose	(Malea et al. 2014)
Zn	Field	*Zostera capricorni*	0.1, 1	10 h	0.1	Variable reduction in photosynthetic efficiency proportional to dose.	Mcinnis-Ng and Ralph (2002)
	Field	*Zostera capricorni*	0.1, 1	10 h	n/a	None	Macinnis-Ng and Ralph (2004)

Herbicides

Herbicides are considered site-specific, localised threats to seagrass and are thought to have played only a minor role in the major global decline of seagrass (Waycott et al. 2009). However, this conclusion is challenged given the small amount of research available on chronic effects (Lewis and Deveraux 2009). Indeed, it is the sub-lethal effects of herbicides (reduced photosynthesis, metabolism and growth) that are considered a significant threat to seagrass (Ralph et al. 2010). Most at risk are seagrasses exposed to frequent pulses of freshwater runoff from catchments with high herbicide usage (McMahon et al. 2005, Westphalen et al. 2005). Herbicides may be an important additional impact during storm events, which also elevate levels of turbidity, increase nutrients and sedimentation, lower salinity, and may bring other toxicants from the catchment.

There is a wide range of herbicides found in estuarine and marine environments, which are spill-over from use in farming, forestry, noxious weed control, and are also leached from biocides used on ship hulls (Ralph et al. 2010). Each herbicides targets different types or groups of plants, have different active pathways of toxicity and hence the type of impact (e.g. on mortality, growth, photosynthesis, respiration) will vary with both herbicide and seagrass type. Of most concern to seagrass are herbicides that directly target monocotyledons (grasses, including seagrasses), are readily uptaken into seagrass tissue, and have long residence time in water or sediment.

The most intensively studied herbicides are atrazine and diuron because of their widespread use, the former being the most widely used herbicide in the USA (Jablonowski et al. 2011). Both are PSII, or photosynthesis, inhibitors used mostly in cropping (e.g. corn farming in USA – Correll and Wu 1982, sugar farming in QLD – Haynes et al. 2000b). Accordingly, most toxicity studies have measured photosynthesis inhibition, even when testing the effects of herbicides that act on other toxicity pathways (e.g. Wahedally et al. 2012). Herbicides such as glyphosate and some phenoxy acids do not actively inhibit photosynthesis and therefore require more appropriate tests to determine sub-lethal effects.

Herbicide concentrations lethal to seagrass (e.g. atrazine > 100µg L^{-1}) are generally not observed in the environment unless the seagrass is directly sprayed. Even in these rare cases, dilution and breakdown of herbicides can often be rapid and therefore exposure times very short. Concentrations required for sub-lethal effects (e.g. > 0.1 µg L^{-1} for atrazine and diuron) are detected after flood events in some locations where there is heavy use in the catchment (e.g. 10 µg L^{-1} diuron in coastal QLD waters; Haynes et al. 2000a). However, there is evidence that seagrass recovers quickly after sub-lethal exposure (Haynes et al 2000b, Macinnis-Ng and Ralph 2003a), and more experimental focus is required on the effects of realistic, frequent pulse exposure over long periods (Ralph et al. 2010).

A summary of all peer reviewed and accessible lab and field studies investigating the effects of herbicides on seagrass in presented in Table 2. The known impacts of each herbicide are presented below, however note that there is no information on the effects to seagrass for many herbicides currently in use.

Atrazine

One of the most widely used herbicides and considered along with diuron to be the highest risk to seagrass, as it is a non-specific, environmentally persistent photosynthesis inhibitor (Westphalen et al. 2005). Studies have shown clear negative effects on seagrass that vary with species, concentration and exposure. The lowest observed effect concentration was 0.1 µg L^{-1} in a study by Delistraty and Hershner (1984) that observed significant reduction in metabolism in *Zostera marina*. The lowest concentration observed for photosynthesis inhibition was 1 µg L^{-1} in *Z. marina,* and Flores et al. (2013) observed a 50% photosynthesis inhibition at 13.4 µg L^{-1} in *Z. muelleri*.

Diuron

Another widely used agricultural urea-based herbicide, diuron is considered the most important toxicant threat to Queensland coastal seagrass systems (McMahon et al. 2005, Flores et al. 2013). All studies have demonstrated some effect of diuron on seagrass, most in the inhibition of photosynthesis (Westphalen et al. 2005). The lowest observed effect concentration for photosynthesis inhibition for *Z. capricorni* and *Halophila ovalis* was 0.1 µg L^{-1} (Haynes et al. 2000b), and 50% inhibition recorded at relatively low concentrations; 2.41 and 2.47 µg L^{-1} for *Z. muelleri* and *Halodule uninervis* respectively (Flores et al. 2013).

Cybutryne

Cybutryne (also known as Irgarol) is a triazine herbicide/algacide used primarily for antifouling on ship hulls, and its direct contact with marine and estuarine waters makes it a toxicant of concern for seagrass (Macinnis-Ng and Ralph 2003a). Like atrazine and diuron, it is a photosynthesis inhibitor and all studies have detected an effect of cybutryne. The lowest observed effect concentration for photosynthesis inhibition for *Z. marina* was 0.5 µg L^{-1} (Scarlett et al. 1999, Chesworth et al. 2004), but higher for *Z. capricorni* at 10 µg L^{-1} in both the lab and field (Macinnis-Ng and Ralph 2003a).

Tebuthiuron

Tebuthiuron is a urea-based general-use herbicide used in agriculture. Only one study has examined its effects on seagrass, which observed a 50% inhibition in photosynthesis at moderate concentrations of 29 µg L^{-1} (Flores et al. 2013).

Hexazinone

Hexazinone is a triazine agricultural herbicide that acts as a non-selective photosynthesis inhibitor. Only one study has examined its effects on seagrass, which observed a 50% inhibition in photosynthesis at low concentrations of 4-6 µg L^{-1} (Flores et al. 2013).

Glyphosate

Glyphosate (also known as Roundup) is one of the most widely used herbicides, used in both agriculture and home gardens to kill broadleaf and grass weeds. It is a glycine based herbicide and acts as an enzyme inhibitor, effective only on actively growing plants. Glyphosate has been shown to have no negative impacts on seagrass either in the lab and the field (Major et al. 2004).

Fluazifop-p

Fluazifop-p (also known as Fusilade) is a phenoxy-acid class herbicide that targets grasses, used primarily in cropping and grass weed control. It works as an enzyme inhibitor that prevents lipid synthesis, weakens cell membranes and causes eventual cell death. The only lab study of the effects of fluazifop on seagrass measured photosynthesis and found no effect at any concentration (Wahedally et al. 2012). However, fluazifop does not target the photosynthetic function and other sub-lethal effects may have gone undetected. The only field study compared seagrass density between sprayed and unsprayed plots of *Z. muelleri*, and found no difference after 6 months (Palmer et al. 1996). However, short term effects were not reported and there is no recognition of the possible baseline differences in density amongst plots prior to treatment.

2,4-D

2,4-D is a widely used phenoxy-acid class herbicide that targets mainly broad leafed plants (dicotyledons), and is hence used mainly on cereal crops, pasture, lawns, and verges and has some application in forestry. It is a synthetic hormone, causing uncontrolled growth in plants which eventually wither and die. The only lab study of the effects of 2,4-D on seagrass measured photosynthesis and found no effect at any concentration (Wahedally et al. 2012). However, 2,4-D does not target the photosynthetic function and other sub-lethal effects may have gone undetected.

Bentazone

Bentazone is a thiadiazine herbicide specifically targeting certain dicotyledons, acting primarily as a photosynthesis inhibitor. The only study to test the effects of bentazone on seagrass found little to no effect (Nielsen and Dahllöf 2007).

MCPA

MCPA is a phenoxy-acid class herbicide that targets dicotyledons for use in cereal crops and pasture. Similar to 2,4-D it is a synthetic auxin hormone that promotes plant natural functions to extremes. The only study to test the effects of bentazone on seagrass found no effect (Nielsen and Dahllöf 2007).

Table 2. Review of the effects of herbicides on seagrass

Herbicide	Type	Species	Dose(s) (μg L-1)	Exposure	Lowest observed effect concentration (μg L^{-1})	Response	Source
Atrazine	Lab	Thalassia testudinum	100, 500, 1000	88 h	100	Reduced oxygen uptake proportional to dose. EC50 was 320 μg L^{-1}	Walsh et al. (1982)
	Lab	Zostera marina	75 and 650	48 d	650	75 μg L^{-1} stimulated photosynthesis, while 650 μg L^{-1} inhibited.	Correll and Wu (1982)
	Lab	Zostera marina	10, 100	6 h	10	Reduced metabolism (ATP and adenalytes) proportional to dose. Net productivity decreased at 100 μg L^{-1}	Delistraty and Hersher (1984)
			0.1, 1, 10, 100, 1000	21d	0.1	Reduced metabolism proportional to dose. 50% mortality and growth inhibition at 100 μg L^{-1}	
	Lab	Halodule wrightii	30000	23 d	30000	Reduction in survival of ramets, production of new ramets, above ground biomass and growth.	Mitchell (1987)
	Lab	Halophila ovalis	10, 100, 1000	96 h	10	Reduction in photosynthetic efficiency proportional to dose.	Ralph (2000)
	Field & Lab	Zostera capricorni	10, 100	10 h	10	Reduction in photosynthetic efficiency proportional to dose	Macinnis-Ng and Ralph (2003)
	Lab	Zostera marina	1,10,100	28 d	1	Photosynthesis reduced at 1 μg L^{-1}. Growth and survival reduced at 100 μg L^{-1}, Mass and photosynthesis reduced in 10 and 100 μg L^{-1}	Gao et al. (2011)
	Lab	Zostera muelleri Halodule uninervis	0.1 - 1000	72 h	1.17 2.11	Inhibition of chlorophyll fluorescence by 50% at 13.4 μg L^{-1} Inhibition of chlorophyll fluorescence by 50% at 18.2 μg L^{-1}	Flores et al. (2013)
Diuron	Lab	Cymodocea serrulata Halophila ovalis Zostera capricorni	0.1, 1, 10, 100	5 d	10 0.1 0.1	Reduction in photosynthetic efficiency in ≥ 10 μg L^{-1}. Reduction in photosynthetic efficiency proportional to dose. Reduction in photosynthetic efficiency proportional to dose.	Haynes et al. (2000b)
	Field & Lab	Zostera capricorni	10, 100	10 h	10	Reduction in photosynthetic efficiency proportional to dose.	Macinnis-Ng and Ralph (2003)
	Lab	Zostera marina	0.5, 1, 2.5, 5, 10, 25	10 d	1	Reduction in photosynthetic efficiency ≥ 1 μg L^{-1} proportional to dose. Significant reduction in growth at 3.2 μg L^{-1}	Chesworth et al. (2004)
	Lab	Zostera marina	150, 200	14d	200	Reduction in leaf mass, width, length and productivity only at 200 μg L^{-1}	Rodgers (2010)
	Lab	Zostera muelleri Halodule uninervis	0.1 - 1000	72 h	0.49 0.47	Inhibition of chlorophyll fluorescence by 50% at 2.47 μg L^{-1} Inhibition of chlorophyll fluorescence by 50% at 2.41 μg L^{-1}	Flores et al. (2013)
	Lab	Thalassodendron ciliatum	1, 10, 100	72 h	1	Reduction in photosynthetic efficiency proportional to dose. Inhibition of chlorophyll fluorescence by 50% at 10 μg L^{-1}	Wahedally et al. (2012)
Cybutryne	Lab	Zostera marina	0.5, 1, 2.5, 5, 10, 25	10 d	0.5 (10 for growth)	Reduction in photosynthetic efficiency proportional to dose.	Scarlett et al. (1999)
	Field & Lab	Zostera capricorni	10, 100	10 h	10	Reduction in photosynthetic efficiency proportional to dose.	Macinnis-Ng and Ralph (2003)
	Lab	Zostera capricorni	100	10 h	100	Reduction in effective quantum yield	Macinnis-Ng and Ralph (2004)
	Lab	Zostera marina	0.5, 1, 2.5, 5, 10, 25	10 d	0.5	Reduction in photosynthetic efficiency proportional to dose. Significant reduction in growth at 1 μg L^{-1}	Chesworth et al. (2004)
Tebuthiuron	Lab	Zostera muelleri Halodule uninervis	0.1 - 1000	72 h	4.79 3.87	Inhibition of chlorophyll fluorescence by 50% at 29.1 μg L^{-1} Inhibition of chlorophyll fluorescence by 50% at 29.7 μg L^{-1}	Flores et al. (2013)
Hexazinone,	Lab	Zostera muelleri Halodule uninervis	0.1 - 1000	72 h	0.67 1.27	Inhibition of chlorophyll fluorescence by 50% at 4.4 μg L^{-1} Inhibition of chlorophyll fluorescence by 50% at 6.87 μg L^{-1}	Flores et al. (2013)
Glyphosate	Lab	Halophila ovalis	1, 10, 100	96 h	n/a	None	Ralph (2000)
	Field	Zostera japonica	Direct spraying	1 year	n/a	No effects of glyphosate spraying on seagrass after 1 year	Major et al. (2004)
	Lab	Zostera marina	0.1, 1, 10, 100	72 h	n/a	No effect, some stimulation	Nielsen and Dahloff (2007)
Fluazifop	Field	Zostera muelleri	Direct spraying	5 months	n/a	No effect on seagrass density	Palmer et al. (1996)
	Lab	Thalassodendron ciliatum	10, 100, 1000	72 h	n/a	No effect on chlorophyll fluorescence	Wahedally et al. (2012)
2-4-D	Lab	Thalassodendron ciliatum	10, 100, 1000	72 h	n/a	No effect on chlorophyll fluorescence	Wahedally et al. (2012)

Petrochemicals

Seagrasses are threatened by petrochemicals from two main sources; chronic low level exposure from urban runoff and intense high level exposure from oil spills and industrial accidents (Ralph et al. 2010). Chronic effects are little studied and considered a localised threat around urban areas and ports. Most research into the effects of petrochemicals on seagrasses have followed major oil spills such as the Exxon Valdez in Alaska and the Gulf war oil spill in the Persian Gulf, and field monitoring has observed little long term impact of oil spills (Kenworthy et al. 1993, Dean et al. 1998). While lab studies demonstrate that petrochemicals cause acute impact, including mortality, when in direct contact with seagrass (Hatcher and Larkum 1982, Baca and Getter 1984, Thorhaug et al. 1986, Ralph and Burchett 1998b), recovery rates of remaining plants after exposure is rapid (Macinnis-Ng and Ralph 2003b), which can explain this longer term absence of an effect. Like studies of many toxicants, lab experiments are considered to overestimate the effects of petrochemicals that would be experienced in the field (Ralph et al. 2010).

Intertidal seagrasses are considered the most at risk from petrochemical spills, as both refined and unrefined chemicals remain on the surface of the water and coat intertidal areas as the tide recedes (Durako et al. 1993). Oil can be absorbed by the tissues and cause toxic effects (Zieman et al. 1984), or can coat and smother blades, reducing light and killing sensitive parts such as flowers (Howard et al. 1989, Dean et al. 1998). Subtidal seagrass is only at risk if dispersants are used to clean up spills, which disperse the oil by allowing it to effectively dissolve into the water column. Many dispersants are toxic to seagrass (Baca and Getter 1984, Thorhaug et al. 1986, Ralph and Burchett 1998b), although combined oil and dispersant are found to be both more (Hatcher and Larkum 1982, Thorhaug et al. 1986) and less (MacInnis-Ng and Ralph 2003) toxic than either component separately. It has been suggested that if removal of spills is necessary, rapid mechanical removal will have less impact on existing subtidal seagrass than chemical dispersal (Hatcher and Larkum 1982).

It is important to consider petrochemical threats in conjunction with other stressors, as an oil spill combined with an epiphyte bloom that often follow oil spills could be a major threat (Ralph et al. 2010). Furthermore, if a spill coincides with a major storm event, seagrass may be already stressed by toxicant exposure or reduced light through high turbidity.

A summary of all peer reviewed and accessible lab and field studies investigating the effects of petrochemicals on seagrass in presented in Table 3. Drilling fluid is also considered in some studies, stemming from concerns around shallow water drilling operations, however no effect of drilling fluid was observed (Allen Price II et al. 1986, Morton et al. 1986, Weber et al. 1992). In summary, seagrasses can generally recover rapidly from oil spills, however they are still considered an important threat in seagrass areas which experience multiple stressors and where resilience is low.

Table 3. Review of the effects of petrochemicals on seagrass

Petrochemical	Type	Species	Dose(s) (ml L^{-1} unless stated)	Exposure	Lowest observed effect concentration (ml L^{-1})	Response	Source
Dispersed oil	Lab	Posidonia australis	0.01, 0.121, 0.363	7 d	0.01	No effect on leaf growth or mortality. Short term reduction in photosynthesis and increase in respiration. Oil treatments recovered over 40d, dispersed oil treatments did not	Hatcher and Larkum (1982)
Oil Dispersants	Lab	Thalassia testudinum	various	4 d	n/a	LC50 202 mg L-1 LC50 200 mg L-1	Baca and Getter (1984) Baca and Getter (1984)
Oil	Lab	Thalassia testudinum Syringodium filiforme Halodule wrightii	125, 500	5 and 100 h	125	LD50 at 125ml/L for 100h. Mortality only at 100h exposure but for all concentrations LD50 at 75ml/L for 100h. Mortality at 5h exposure for highest concentration LD50 at 75ml/L for 100h. Mortality only at 100h exposure but for all concentrations	Thorhaug et al. (1986)
Dispersants	Lab	Thalassia testudinum Syringodium filiforme Halodule wrightii	12.5, 50	5 and 100 h	12.5	No significant effect on growth rates but significant cause of mortality Significant effect on mortality and growth Significant effect on mortality and growth	
Drilling fluid	Lab	Thalassia testudinum	190	42 d	none	No effect on seagrass chlorophyll levels. Significant effect on decomposition rates	Morton et al. (1986)
Dispersed oil	Lab	Thalassia testudinum Syringodium filiforme Halodule wrightii	75 oil/7.5 dispersant, 125/12.5	5 and 100 h	75/7.5	Mortality in all treatments with three dispersants. Variability in seagrass type and dispersant type, up to 100% mortality	Thorhaug and Marcus (1987)
Drilling fluid	Field Lab	Thalassia testudinum	111 133	84 d	none	No effect on biomass either in lab or field	Weber et al. (1992)
Crude oil	Lab	Halophila ovalis, Halophila stipulacea, Halodule uninervis	10	18 h	none	No clear effect on photosynthesis or respiration rate	Durako et al. (1993)
Crude oil	Field	Halophila ovalis, Halophila stipulacea, Halodule uninervis	Oiled/non-oiled	Oil spill	none	No significant effects of oil on density or biomass after one year	Kenworthy et al. (1993)
Crude oil	Field	Zostera marina	70 - 4000 ng g-1 (in sediment)	Oil spill	4000ng g-1	Small reduction in flowering and blade and shoot density in first year, however no significant effect thereafter	Dean et al. (1998)
Crude oil	Lab	Halophila ovalis	2.5, 5, 10	5 - 96 h	2.5	No effect of oil on chlorophyll levels, but effect on quantum yield.	Ralph and Burchett (1998b)
Dispersants			0.25, 0.5, 1		0.25	Dispersant caused a similar effect to mixed dispersant and oil. Reduced chlorophyll and quantum yield.	
Dispersed oil			2.5/0.25, 5/0.5, 10/1		2.5/0.25	No effect on chlorophyll levels, but effect on quantum yield. Some recovery	
Crude oil	Lab	Zostera capricorni	10, 25	10 h	10	Decline in quantum yield with little recovery	Mcinnis-Ng and Ralph (2003b)
Dispersants			0.2, 0.5		0.2	Decline in quantum yield with continued decline in recovery period	
Dispersed oil			10/0.2, 25/0.5		n/a	No effect on quantum yield	
Crude oil	Field		10, 25		25	Initial impacts on chlorophyll and quantum yield at 25 however recovery occurred quickly, even during the exposure period	
Dispersants			0.2, 0.5		n/a	No effect on quantum yield	

AUDIT OF TOXICANT THREATS TO SEAGRASS IN CORNER INLET

This section aims to collate the current knowledge and assess risk of chemical threats to seagrass in Corner Inlet. Firstly, the review will cover the known levels and sources of toxicants in Corner Inlet waters and sediments and identify important knowledge gaps. Secondly, by combining knowledge of toxicant effect thresholds from experimental observations (see previous section) with this data specific to Corner Inlet, we undertake a risk assessment of chemical toxicant threats to seagrass in Corner Inlet.

Heavy Metals

Heavy metals have not been consistently recorded in water or sediment at levels of concern in Corner Inlet. There have been two studies that quantified the levels of heavy metals in Corner Inlet and both dismissed heavy metals as causes for seagrass declines (Poore 1978, Hindell et al. 2009). Poore (1978) tested metal concentrations in seagrass, sediment and in mussels (bioindicators of heavy metals) and did not detect elevated levels of any metal. The two more toxic heavy metals, copper and cadmium, were detected at their highest concentration at levels 10 times less than the acceptable limit. Hindell et al. (2009) tested for heavy metals in both water and sediment at six locations in 2005 and 2006. Most samples were below detection limits, and ANZECC guidelines were exceeded only twice for sediment (elevated lead) and once for water (slightly elevated copper).

Given these low recordings, and without any obvious catchment source of heavy metals (e.g. industrial waste, mining), the threat of heavy metals to seagrass in Corner Inlet appears very low.

Herbicides

As a predominantly agricultural catchment, it is inevitable that herbicides will be reaching Corner Inlet during storm and flood events. However the type of herbicide, the concentrations which seagrasses are exposed to, and the duration of this exposure is all critical to determining the threat level. Cropping, which generally uses a broader range and higher applications of herbicides, is not a major land use in the Corner Inlet catchment. Instead, potential sources of herbicides are dairy farming, beef cattle farming, plantation forestry and weed control on roadsides and public land. Unfortunately the results of a 2009 government commissioned study assessing herbicide use and concentrations in waterways are not publically available and could not be used to inform this assessment. Most herbicides used in the catchment are likely to be heavily diluted during storm and flood events and exposure to seagrass in such a highly tidal system would be short. This is supported by the two studies that tested for herbicides in water around seagrass beds (Poore 1978, Hindell et al. 2009), as all herbicides tested were below detection limit in all samples. It is important to note that only selected herbicides were tested for; e.g. Hindell et al. (2009) only tested for triazine class herbicides such as atrazine and hexazinone, and did not sample other potential threats such as diuron, phenoxy acids (2,4-D and fluazifop) and metsulfuron methyl.

The type and extent of use of herbicides in forestry operations in the upper catchment is unknown and difficult to estimate. Common uses of herbicide may be in preparation to plant seedlings (often targeting grasses) and to reduce competition during the first few years of growth (often targeting broadleaf trees and shrubs). Application of herbicides over large areas of forest in a short time period may present a hazard to seagrass when followed by heavy rain which rapidly transports the herbicide into the Inlet. Further engagement with the forestry industry is recommended to reduce the current uncertainty around their herbicide use.

Direct spraying of herbicides to control weeds in the intertidal zone presents a much more plausible threat to seagrass than agricultural use of herbicides. In particular, the aerial spraying of Spartina grass in the intertidal zones presents a direct mechanism for high concentrations of herbicides to come into contact with seagrass more substantial periods (6 hrs between tidal cycles). The spraying of fluazifop, a phenoxy acid specifically targeting grasses, is a potential localised threat to intertidal seagrass (*Zostera muelleri*) in Corner Inlet. The only study to assess the effects of fluazifop was carried out in Corner Inlet, and reports no difference in seagrass density between sprayed and unsprayed plots after 6 months (Palmer et al. 1996). However, it is not clear whether there were differences in density between treatments before spraying, and whether there was any significant change in density pre- and post- spraying in the treated plots. Most importantly, there is no information of the actual toxicity of fluazifop to any seagrass, and hence it is unknown whether *Zostera* or *Posidonia* species experience either lethal or sub-lethal effects and at what concentration.

In summary, the tidal nature of Corner Inlet makes it likely that subtidal seagrasses will not be exposed to significant levels and durations of herbicides from the catchment. Herbicide spraying for weed control in the intertidal zone presents a more plausible but localised threat, however little information is available to assess the potential effect to seagrass.

Petrochemicals

The chance of a major oil spill in Corner Inlet is low given the lack of a major local source of oil, however it is possible that an oil spill in Bass Strait could affect seagrass if carried toward shore. Corner Inlet does not have any major oil pipelines, nor is it a receiving port for crude oil from the Bass Strait rigs. The Barry Beach terminal, adjacent to some significant *Posidonia* beds at Long Spit, receives supply boats for the rigs but no tankers. However, small oil spills have been reported on occasion (Poore 1978) and diesel and drilling fluid spills remain a potential hazard during unloading/loading and refuelling. Further investigation of the refuelling protocol, boom deployment and emergency response at Barry Beach is warranted, however there is no suggestion that these are presently inadequate. In the event of a large oil spill, intertidal *Z. muelleri* would likely be most affected, however recovery is likely if it an isolated incident. Chronic low level exposure is unlikely to be a significant impact due to the nature of the catchment as agricultural and not urban or industrial.

Only one study has assessed the levels of petrochemicals in Corner Inlet (Poore 1978), and found very low levels of hydrocarbons present in the sediment (max 1 $\mu g\ L^{-1}$), well below those concentrations known to have an effect on seagrass. Levels of poly-aromatic hydrocarbons in Corner Inlet are documented in (Maher and Aislabie 1992), and Corner Inlet described as a low-pollution environment where the majority of hydrocarbons are the result of bushfires and not human activity.

In summary, the chance of major petrochemical impacts is low and in isolation seagrass is likely to recover from any impacts

Insecticides and fungicides

Only one study has measured the concentrations of pesticides and fungicides in Corner Inlet and all samples were below detection limits (Hindell et al. 2009). Given that these chemicals are not designed to harm plants, they are not in widespread use in the catchment due to little cropping agriculture; the threat to seagrass is likely to be very low. There is, however, an unknown level of use in forestry in the upper catchment.

Fire retardants

Fire retardants have been sprayed over large areas of the Wilsons Promontory National Park when bushfires are active, most recently in 2001 and 2009. The chemical used was Phos-chek, which is an ammonium phosphate based mix of chemicals used to prevent the combustion of plant tissue. It also acts as a post-fire fertilizer, releasing large amounts of available nitrogen and phosphorus into soils and water. The application of such retardants is questioned in the Australian environment because of their negative effects on native plants and promotion of weed growth (Adams and Simmons 1999, Bell et al. 2005). However fire retardants, including Phos-check, are known to be toxic to freshwater fish (Giménez et al. 2004), and aquatic environments are considered much more at risk than terrestrial environments (Kalabokidis 2000).

There is no information on the toxicity of fire retardants such as Phos-chek on seagrass. It is unknown whether significant concentrations reach seagrass beds and how long they persist. Of most concern is the potential for fire retardants to significantly elevate nutrient levels in estuarine waters in the southern end of Corner Inlet adjacent to Wilson's Promontory National Park, causing algal growth and eutrophication around seagrass beds. Elevated nutrients are also likely to coincide with increased turbidity from the sediment transported from bare hillsides, adding further stress to seagrass beds.

RISK ASSESSMENT OF TOXICANTS TO SEAGRASS IN CORNER INLET

There are a variety of risk assessment approaches for the use of chemicals in the environment (Allinson et al. 2007, Lee-Steere 2009), however we adopt a generic *likelihood-consequence* risk assessment model based on the US EPA model (EPA 1998) and Standard ANZS 1999 (Table 4). In applying a structured semi-quantitative approach to ranking risks to seagrass, we saw the need to include an unknown category due to the lack of information available on many chemical threats.

Table 4. Generic risk matrix used to assess toxicant threats to seagrass in Corner Inlet (adapted from ANZS 1999). L = low risk, M = medium risk, H = high risk, E = extreme risk, U = unknown

	Consequences					
Likelihood	Catastrophic 1	Major 2	Moderate 3	Minor 4	Insignificant 5	Unknown
A (Almost certain)	**E**	**E**	**H**	**H**	**M**	**U (H)**
B (Likely)	**E**	**E**	**H**	**M**	**L**	**U (H)**
C (Possible)	**E**	**H**	**M**	**M**	**L**	**U (M)**
D (Unlikely)	**H**	**M**	**M**	**L**	**L**	**U (L)**
E (Rare)	**H**	**M**	**L**	**L**	**L**	**U (L)**
(Unknown)	**U (H)**	**U (H)**	**U (M)**	**U (L)**	**U (L)**	**U**

We have adapted the model to incorporate the specific desirable endpoints relevant to environmental outcomes for Corner Inlet seagrass; i.e. maintenance of current levels of seagrass abundance and condition. The definitions used in the risk analysis table are presented in Table 5.

Table 5. Definitions used to assess the risk of threats to seagrass in Corner Inlet. Trigger levels refer to the lowest observed effect concentrations for each toxicant, presented in Tables 1-3.

Likelihood	**Consequence**
A: ALMOST CERTAIN Almost continuous exposure to concentrations consistently exceeding trigger levels	1. CATASTROPHIC Permanent loss of large areas of seagrass
B: LIKELY Regular exposure to concentrations above trigger level	2. MAJOR Serious but potentially reversible damage to large areas of seagrass
C: POSSIBLE Infrequent exposure to concentrations exceeding trigger levels	3. MODERATE Serious but reversible small scale effects on seagrass
D: UNLIKELY Concentrations have never exceeded trigger levels, however this remains a possibility due to use of toxicant in catchment	4. MINOR Decline in seagrass condition but no mortality or physical damage
E: RARE Measured concentrations have never exceeded trigger levels and not considered possible given lack of sources in the catchment	5. INSIGNIFICANT Potential observable effects on condition; no fitness consequences
UNKNOWN	UNKNOWN

Risk assessment outcomes

Risk assessments are presented separately for heavy metals, herbicides, petrochemicals and other toxicants (Tables 6a-d). There are no identified extreme, high or medium risk threats from chemical toxicants to seagrass in Corner Inlet. However, there are three threats that have unknown risks, one provisionally considered to be high (phenoxy acid herbicides) and two low (glyphosate and fire retardants). In such cases of unknown risks provisionally classified medium and above, further information is required before a definite risk level can be assigned.

Table 6. Risk assessment of chemical toxicant threats to seagrass in Corner Inlet, Victoria, based on experimental evidence of detrimental effects on seagrass, and known levels and exposure to these toxicants in Corner Inlet. Note that for some chemicals, two concentration thresholds are assessed; these represent sub-lethal and lethal effect concentrations.

a) Heavy metals

HEAVY METAL	RELEVANT CONCENTRATION (mg L^{-1})	CONSEQUENCES	LIKELIHOOD	RATING
Cd	0.1	4. MINOR Evidence of cell damage and reduced photosynthesis and growth rates at concentration greater than 0.1, however no effects detected in the field.	D. UNLIKELY Max recorded from Hindell (2009) was <0.001 mg L^{-1}	LOW
Cr	10	UNKNOWN One study shows cellular damage at 10mg L-1	D. UNLIKELY Max recorded from Hindell (2009) was <0.001 mg $L\text{-}^{1}$	LOW
Cu	0.1	4. MINOR Reduction in photosynthetic activity in both lab and field at 0.1 mg L-1	D. UNLIKELY Max recorded from Hindell (2009) was 0.0015 mg $L\text{-}^{1}$	LOW
Ni	0.5	UNKNOWN One study shows cellular damage at 0.5mg L-1	D. UNLIKELY Max recorded from Hindell (2009) was <0.001 mg L-1	LOW
Pb	50	4. MINOR Reduced nitrogen fixation and growth at >50 mg L-1	D. UNLIKELY Max recorded from Hindell (2009) was <0.001 mg L-1	LOW
Zn	0.1	4. MINOR Reduction in photosynthesis at > 0.1 mg L-1	D. UNLIKELY Max recorded from Hindell (2009) was 0.01 mg L-1	LOW

b) Herbicides

HERBICIDE	RELEVANT CONCENTRATION (µg L^{-1})	CONSEQUENCES	LIKELIHOOD	RATING
Atrazine	0.1	4. MINOR Reduces photosynthesis, respiration and metabolism from 0.1 µg L^{-1}.	D. UNLIKELY All below detection (< 0.1 µg L^{-1}) from Hindell et al. (2009)	LOW
	100	3. SERIOUS Growth and survival affected at 100 µg L^{-1}.	E. RARE These concentration would require almost direct spraying of estuarine areas, which does not happen in the catchment	LOW
Diuron	0.1	4. MINOR Reduces photosynthesis from 0.1 µg L^{-1}, growth from 3.2 µg L^{-1}	D. UNLIKELY Not analysed in Hindell et al (2009) or in catchment. Very low use of diuron in the catchment	LOW
	200	3. SERIOUS Productivity and survival affected at 200 µg L^{-1}	E. RARE These concentration would require almost direct spraying	LOW

			of estuarine areas, which does not happen in the catchment	
Phenoxy acids		UNKNOWN No lab studies that appropriately examine the effects of phenoxy acids. Some evidence of negligible effects in field	B. LIKELY No testing for phenoxy acids. Exposure to high concentrations of fluazifop after aerial spraying. 2-4-D one of main herbicides used in catchment (Rose et al. 2010)	UNKNOWN (HIGH)
Glyphosate		5. INSIGNIFICANT No effects on seagrass in both lab and field studies	UNKNOWN No testing for glyphosate. One of the main herbicides used in the catchment (Rose et al. 2010)	UNKNOWN (LOW)

c) Petrochemicals

CHEMICAL	RELEVANT CONCENTRATION (ml L^{-1})	CONSEQUENCES	LIKELIHOOD	RATING
Oil and dispersants	>0.1	4. MINOR Reduction of photosynthesis at levels > 0.1 ml L^{-1}, some mortality > 75 ml L-1 for intertidal species. Recovery after sub-lethal effects in lab and field	D. UNLIKELY No hydrocarbon spill documented however with boat traffic and oil operation it is conceivable. Major spill could come from Bass Strait	LOW
Drilling fluid	n/a	5. INSIGNIFCANT No effects on seagrass in both lab and field studies	E RARE No drilling occurring with the catchment and waters	LOW

d) Other chemicals

CHEMICAL	RELEVANT CONCENTRATION (ml L^{-1})	CONSEQUENCES	LIKELIHOOD	RATING
Insecticides	n/a	5. INSIGNIFCANT No documented effects on seagrass in both lab and field studies	D. UNLIKELY All below detection limits (Hindell et al. 2009, Rose et al. 2010)	LOW
Fungicides	n/a	5. INSIGNIFCANT No documented effects on seagrass in both lab and field studies	D. UNLIKELY Most below detection limits (Hindell et al. 2009, Rose et al. 2010)	LOW
Fire retardants	n/a	UNKNOWN No studies investigating the effects of fire retardants on seagrass	D. UNLIKELY Phos-chek only used during active fire periods, unknown what concentration reaches seagrass	UNKNOWN (LOW)

DISCUSSION

Similar to other investigations around the globe (Bryars et al. 2006, Waycott et al. 2009, Ralph et al. 2010), chemical toxicants present broadly only a low risk to seagrass in Corner Inlet. However, as these studies and others have rightly noted (e.g. Lewis and Deveraux 2009), there are many localised threats to seagrass where specific toxicants come into contact with seagrass in high concentrations or for long exposure times. We identified two such possible cases in Corner Inlet, although it is not possible to make a proper assessment of the risks of these chemicals due to a lack of knowledge, principally around their effect of seagrass but also about concentrations in water and sediment. These knowledge gaps require further attention, and in the case of fluazifop-p (Fusilade) the interim risk is deemed to be high.

The decline in seagrass in Corner Inlet is most likely related to a combination of stressors, the most prominent being algal blooms and turbidity (Hindell et al. 2009). If seagrass beds are already under significant stress from these pressures, the addition of localised but intense toxicant exposure could be the additional factor required for significant degradation of these beds. While the damage caused by toxicant threats such as intertidal weed spraying are likely to be confined to areas immediately surrounding the sprayed area, these area could be significant in size if aerial spraying is employed.

It is entirely possible that neither of the identified potential toxicant threats to seagrass in Corner Inlet have any detrimental effect on seagrass. However until there is firm evidence of this, the threats must be treated with caution and action initiated on filling these knowledge gaps.

RECOMMENDATIONS

Research into the effects of fluazifop on seagrass

Experimental trials are required to determine the level of toxicity of fluazifop to seagrasses in Corner Inlet. Priority is to run trials on *Zostera muelleri,* as this is the seagrass most likely to come into contact with high concentrations in the intertidal zone. Trials with *Posidonia australis* are also recommended as it forms the majority of seagrass in the Inlet and does not recover rapidly from disturbance.

1. First stage trials should examine the lethal dose of fluazifop (and associated additives) to seagrass in controlled laboratory experiments.

2. Second stage trials should examine the sub-lethal effects of environmentally relevant concentrations (i.e. that observed in waters and sediment around seagrass) of fluazifop over a number of weeks. Where no lethal or sub-lethal effects are identified, fluazifop should be eliminated as a potential threat to seagrass and further trials are not warranted.

3. Third stage trials should observe the effects of aerial fluazifop spraying on intertidal *Zostera muelleri* and nearby *Posidonia australis* (if relevant). Field trials should measure the density and growth of seagrass in treated and control plots, both pre and post spraying and make appropriate comparisons. Trials should also investigate the breakdown and dispersion of the active chemicals through a series of water and sediment samples taken at different times after the spraying.

Trials of alternative control methods of Spartina

The aerial spraying of Fusilade is considered the most cost effective method of *Spartina* control in many areas of Australia (Hedge et al. 2010), including intertidal areas of Corner Inlet. However, there needs to be consideration of the potential costs to seagrass and related decline in fisheries and aquatic productivity, and hence there may be more effective methods available. These could involve the substitution of herbicides, or using mechanical non-chemical methods.

Some methods include the following:

- Hand removal is generally considered too labour intensive (Shaw 1999), and smothering with plastic sheeting is successful at a small scale (Bishop 1996), but difficult in strongly tidal areas such as Corner Inlet. However, smothering with heavy duty landscape fabric anchored with large spikes has been successful in the US (Pickering 2010) and may be an option worth exploring.
- Steam treatment had similar effect to initial herbicide spraying but more trials are required to evaluate longer term effectiveness (Shaw and Gosling 1996).
- Use of glyphosate could be an acceptable herbicide alternative and is the only herbicide approved for use on *Spartina* in the US (Shaw 1999). However trials show it is not as effective as other chemicals such as Gallant and Fusilade (Pritchard 1996), and control can take a number of years to be effective (Patten and O'Casey 2010).

- Use of the herbicide Gallant (haloxyfop) has been extremely successful in New Zealand (Miller 2010), with few observed negative effects on the environment. However, similar to Fusilade there is no experimental information on toxicity to seagrass.

Depending on the results from initial toxicity trials of Fusilade, some of the above techniques should be trialled if Fusilade proves toxic to seagrass and is considered a significant threat.

Baseline monitoring of selected herbicides in Corner Inlet

While Hindell et al. (2009) quantified levels of atrazine herbicides in water above seagrass, post storm event sampling of other herbicides in use in the catchment is recommended. In particular phenoxy acids (e.g. 2,4-D) and urea based herbicides (e.g. metsulfuron-methyl) should be tested, to determine concentrations in the Inlet and seagrass exposure periods.

Investigation into the effects of fire retardants on seagrass

The direct and indirect effects of fire retardants such as Phos-chek on seagrass are currently unknown. Filling this information gap could be attempted in two stages:

1. Lab trials on the toxicity of Phos-chek to seagrass, similar to those proposed for Fusilade above
2. Opportunistic sampling of nutrients in water above seagrass, and monitoring of algal bloom growth, after spraying of Phos-chek for operational purposes.

Minor Recommendations

1. Further assess the type and extent of herbicide use in forestry operations in the upper Corner Inlet catchment to better understand risks to seagrass
2. Investigate the refuelling and emergency spill response protocols at Barry Beach terminal

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Appendix E

Engagement guidelines for fishing communities in catchment management

ENSURING THE LONG TERM SUSTAINABILITY OF AUSTRALIA'S SMALL SCALE COASTAL FISHERIES

ENGAGEMENT GUIDELINES

FOSTERING COLLABORATIVE RELATIONSHIPS in COASTAL FISHING COMMUNITIES

There is a growing need to address external, often land-based, threats to the sustainability of Australia's coastal fisheries. Shoreline development, vegetation loss and poor water quality from catchment runoff all threaten the coastal habitat and fisheries' productivity.

Encouraging collaborative management of the broader coastal environment, including the catchment, has the potential to benefit fisheries by addressing these threats and arresting productivity declines. A collaborative approach requires fishers' and land users' cooperation to share understanding of, and responsibility for, the coastal ecosystem, and to decide on targeted management actions that are both realistic and effective.

These guidelines aim to assist the formation and development of collaborative relationships between fishers and land users that will:

- lead to a mutual understanding of the impacts of land use on the marine environment, the sustainability of the local fishery and the sustainability of the land users' businesses;
- encourage land users to identify and adopt management practices targeted at protecting and restoring the marine environment;
- ensure that fishers' observations and concerns are integrated into the community's decision-making framework.

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FISHERIES RESEARCH & DEVELOPMENT CORPORATION

All photos courtesy Robert Kenyon, Drift Media, except bottom right (Jenny O'Sullivan)

The guidelines are based on a process that has been used by representatives of the Corner Inlet fishery in south-east Victoria to communicate fishers' concerns about declining seagrass meadows to the community. Research indicates that likely causes of the decline are sediment and nutrients entering the catchment from urban areas, local farming and forestry businesses.

The fishers recently organised an event that brought fishers, farmers and other members of the community together to discuss the issue from both the fishers' and the farmers' perspectives. Feedback from participants revealed increased awareness and understanding about the issue from both groups, and a willingness to engage in the future.

Remember:

- understand the size and extent of your circle of influence. Work from the inside out.
- be realistic about your goals. The decline of the coastal marine environment has occurred over many decades; likewise, its restoration is likely to require an equally long period.
- be satisfied with small wins. It will take many small steps to reach your goal.

1. Identify and understand the issue that you want resolved

Invest time and resources in:

- gathering reliable evidence that demonstrates that you have a legitimate environmental concern;
- gathering reliable evidence that identifies potential causes of that concern. (Look for evidence from similar areas if information is lacking for your system);
- establishing links with reputable bodies or organisations that can suggest and initiate potential solutions to that concern.

Over a period of eight years, the Corner Inlet fishers (and more recently, researchers from the University of Melbourne) have been mapping the size and location of seagrass meadows in the inlet. These maps provide visual proof of the fact and extent of the decline of the seagrass meadows. The fishers and researchers have also being collecting and analysing water samples from the inlet and its tributaries to measure and identify the sources of excess nutrient and sediment loads.

2. Know your players and your playing field

To engage the most effective people within your community, you need to be able to identify:

- the size and extent of the catchment;
- the major land users within the catchment;
- the industry bodies/ organisations representing the major land users eg regional dairy, beef, wool, sugar cane, forestry companies, fisheries;
- the natural resource managers operating in the catchment eg catchment management authority, water authority, parks and wildlife;
- governmental agencies operating in the catchment eg the council, Department of agriculture, environment, fisheries etc
- not for profit organisations with an environmental focus, eg Landcare, Coastcare, community action groups;
- other stakeholders eg foreshore committees of management, tourist bureau.
- Engaging early with your regional catchment management authority will assist in identifying:
- major stakeholders and existing networks;
- existing initiatives that may align with the issue you want to bring to the table;
- partnership and funding opportunities.

3. Identify an advocate (find a champion)

When considering potential advocates who will speak and act on behalf of the fishers, think laterally as the best candidate may not necessarily be a fisher. Your advocate needs to be committed for the long term, and able to interact and even negotiate with a wide range of people.

The Corner Inlet fishery's advocate is a researcher; other advocates could include a Landcare or Coastcare member, celebrity chef, community leader.

4. Establish your credentials

The community is more likely to acknowledge the fishers' concerns if the fishers can demonstrate that they operate legitimately and transparently, and fish responsibly and sustainably.

The Corner Inlet fishers have a recognised code of practice to ensure that the area is not overfished *or degraded, and have independent sustainability accreditation through the Sustainable Australian Seafood Assessment Program. They are always ready to explain and demonstrate their practices.*

5. Know your value to the community

Identify and, if possible, quantify the value(s) that the fishers contribute to the community, and the potential loss to the community if the fishery was to cease.

Value can include:

- economic: eg direct and indirect employment, wages/profit spent within the community, tourism;
- food and sustenance: eg fresh fish and seafood;
- cultural & historical.

6. Identify other motivating factors

Highlight the potential benefits of the outcomes you are seeking that go beyond the fishing community, i.e. that will be shared by the broader community, such as:

- aesthetic benefits;
- increased land values;
- improved recreation (fishing, swimming, bird watching)
- increased bird and wild life;
- protection of a shared natural resource;
- improved water quality.

7. Reach out and listen

Begin a dialogue with each of the ‘players’ identified in section 2, bearing in mind:

- reciprocity (if you want them to listen to you, you must also listen to them);
- empathy (if you want them to acknowledge your concerns, you must also acknowledge theirs);
- do not start by laying blame. Almost certainly no-one will be acting with bad intentions, and everyone will react defensively if accused of something. Instead, explain your problem;
- do not shame people into action. Instead, focus on building awareness of when lapses can or do occur, and the help that is available to prevent or deal with those lapses;
- people are often more comfortable and receptive if they are in their own environment (ie consider ‘sitting at their table’ rather than asking them to sit at yours);
- seek to identify similarities between the fishers and the people you are engaging with;
- approach each dialogue with an open mind;
- be content with small gains;
- be persistent;
- be creative with your interactions so that people will sit up and take notice.

The Corner Inlet fishers’ advocate offered to speak for just three or four minutes about the issues concerning fishers at field days and workshops run for local farmers by Landcare and GippsDairy. As well as being able to ‘get his message out’, these events gave him a deeper insight into the issues that local farmers perceived as being important to their businesses and provided a relaxed environment to meet several of the ‘players’ identified in step 2.

8. Planning for active engagement between fishers and other groups in the community

To design your own event to bring fishers and other groups of the community together you need:

- clarity about your goals and what you want to achieve. Do you want to initiate new relationships, or consolidate existing relationships? Identify solutions to the problem? Develop action plans to resolve the problem?
- to identify your target audience;
- creativity: you want people to sit up and take notice of your event;
- awareness about the restraints or commitments (eg time, economic, social) that may prevent your target audience from participating;
- making the most of the contacts and networks you have already made to publicise your event;
- the support of local media (remember to budget for advertising) and potentially the use of social media to publicise your event.

The Corner Inlet fishers wanted to meet with farmers to raise awareness of the impacts that sediment and nutrient loads have on seagrass in the inlet, and to establish collaborative relationships to carry out restorative works in the future.

The target audience was farmers managing land in the catchment, although representatives from other industries and agencies were also invited.

Organisers wanted to design an event that would be interactive, educational and social, involve both anecdotal and scientific evidence about the decline of seagrass meadows, and encourage a mutual understanding between the two groups. A boat trip and seafood lunch at the local hall (both hosted by the fishers), followed by a paddock walk on a nearby dairy farm, ticked all the boxes.

The event was scheduled on a Friday, and ran from 11am to 2.30pm to fit in with morning and evening milking, and the tides. Speakers included researchers from Melbourne University and a representative of the regional dairy body, the fishers and a local dairy farmer. The event was publicised through the local Landcare network, the regional dairy body, local newspapers and radio. Numbers for the boat trip were limited to the vessels' carrying capacity, but extra spaces were available at the lunch and paddock walk.

9. On the day - the keys to success

Maximise your outcomes by:

- reminding participants to listen and to be respectful;
- avoiding blame and accusation;
- keeping to advertised times;
- posing questions to encourage discussion eg do you have ideas about this issue? What do you perceive as the main problems here? Does anyone have a view on a solution?
- highlighting the similarities between the different groups to create empathy and mutual understanding;
- recording the event (photos, video);
- obtaining participants' feedback at the end of the event (rate this event; what did you get out of this event, what could have been done better; are you interested in further action etc).

The Corner Inlet event was designed to highlight the similarities between the fishers and the farmers. Both groups were referred to as primary producers, and discussions focused on the importance of high quality pasture within their businesses. Each group was encouraged to describe their management practices, profit drivers and threats to their business: in the fishers' case, while out on the boat, and in the farmers' case, while in the paddock.

Written feedback obtained at the event indicated that both groups had a better understanding of each others' businesses and environmental concerns. The farmers were more aware of the problem of declining seagrass meadows, while the fishers realised that many farmers are already working to reduce nutrient and sediment loads. Both groups indicated they were willing to work together in the future.

10. After the event

Maintain momentum and make the most of your outcomes by:

- analysing the event (what worked, what didn't etc);
- analysing the feedback;
- recording contact details;
- publicising your success (newspapers, radio, social media);
- following up with participants, particularly any who had questions and/or indicated an interest in further action.

The Corner Inlet fishers arranged for a video to be made of the day which has been released on social media: https://vimeo.com/130063251. A press release was also distributed to traditional media outlets including local newspapers and industry publications: [http://www.wgcma.vic.gov.au/news/latest-news/farmers-and-fishers-of-corner-inlet.](http://www.wgcma.vic.gov.au/news/latest-news/farmers-and-fishers-of-corner-inlet)

Quotes from feedback:

"The question over seagrass diminishment is a community, as well as an industry, issue."

"Everyone is trying to work after the sea and the land, and now we need to work with each other."

"We now have an improved understanding of seagrass management and the need for collaboration between primary industry sectors."

Appendix F

Farmer-fisher day case study

Seagrass pasture day in Corner Inlet

Bringing farmers and fishers together to create opportunities for engagement, communication and future collaboration

FRDC FISHERIES RESEARCH & DEVELOPMENT CORPORATION

THE UNIVERSITY OF MELBOURNE

GippsDairy

Dairy Australia

Your Levy at Work

SOUTH GIPPSLAND LANDCARE NETWORK

Seagrass, which supports healthy marine ecosystems and by extension, viable commercial fisheries, is under threat globally from excessive nutrient and sediment loads.

Land-based activities which contribute to excessive nutrient and sediment loads entering coastal waters include farming, forestry and urban development.

Establishing collaborative relationships between land and sea managers is the first step in identifying and impementing realistic solutions to resolve the problem of declining seagrass pastures.

With this goal in mind, commercial fishermen, researchers from Melbourne University, and local farmers met recently to share their perspectives on the decline of seagrass within Corner Inlet.

Representatives of the dairy industry, local water catchment authorities and Landcare also attended the seagrass pasture day which included a boat trip into the Inlet, a seafood lunch and a visit to a local dairy farm.

This case study outlines the process adopted by organisers, which can be replicated as part of collaborative engagement projects in other catchments.

Photo: Jenny O'Sullivan

The seagrass pasture day highlighted the similarities between the fishermen and the farmers as primary producers, natural resource managers and business operators.

A common theme was the importance of large amounts of quality pasture to the profitability of their businesses. The difference, of course, was that unlike the farmers, the fishermen have little or no control over the management of their seagrass pasture.

Scientists are working with fishermen to develop an environmental history of Corner Inlet. This process includes using local knowledge to create detailed maps of seagrass meadows. Identifying the sources of nutrients that threaten seagrass meadows is the next important step in arresting the decline of the seagrass meadows.

Keys to success

The first key to the seagrass pasture day's success was inviting each group into the other's workplace.

On the fishing boat, farmers saw firsthand the scarcity of the seagrass, and were able to connect with the fishermen's concerns. On farm, the fishermen realised that practices to reduce sediment and nutrient run-off are in fact being implemented by many farming businesses.

Other factors which contributed to the seagrass pasture day's success include professional facilitation and the presentation of straightforward, scientific data evidencing the decline of seagrass cover and the potential causes of that decline. Discussions were friendly, balanced and respectful and many participants indicated that they were a positive step towards further collaboration.

Photo: Jenny O'Sullivan

Background

The seagrass pasture day was held as part of a project that is using local knowledge to conserve seagrass and maintain a productive fishery in Corner Inlet.The project's goals include increasing awareness, and facilitating communication and identifying solutions that can be cooperatively supported by the regional community.

The target audience for this event was farmers managing land within the catchment. Organisers linked in with regional dairy industry body, GippsDairy, and the Landcare network to engage participants. Representatives from the water and catchment management authorities were also invited to attend.

Interest was high but numbers for the trip onto the Inlet were limited to the boats' carrying capacity. Thirty farmers and six fishermen were among the participants who went out onto the Inlet, while several more farmers and fishermen enjoyed the lunch and a visit to a nearby dairy farm.

Local fishermen and scientists are working towards restoring Corner Inlet's lost seagrass meadows through a combination of seagrass transplant and seed broadcasting. These techniques have not previously been trialled in Victoria.

Process

The seagrass pasture day was designed to be a low-key event that would encourage reciprocal sharing of local knowledge and experience, develop a mutual understanding of the different industries and raise awareness of the links between land practices and coastal health.

The event began at 10am at a local hall. After tea and coffee, participants were seated in a horseshoe shape and asked to introduce themselves and explain their reasons for attending. Researcher, John Ford, spoke about the importance of seagrass to the fishing industry, likening it to the pasture that farmers rely on for their income, and the impacts of its decline on fishermen.

John demonstrated how the quality of water entering the catchment varies, by showing participants samples of water taken from three different creeks that morning. Participants were clearly surprised at how poor the water quality was in one of the creeks. They were also surprised at the impact that seagrass has on water quality, via a demonstration involving three tanks containing seawater. The water in the tank containing seagrass was noticeably clearer than either the tank containing algae or the tank containing zero plant matter.

John explained briefly that global research indicates that seagrass decline is caused by excessive loads of nutrients and sediments entering coastal waters. While natural processes are responsible for some nutrient and sediment loads, he described some of the activities associated with farming that can exacerbate the problem. These include grazing on or near waterways and drainage lines, excessive clearing and fertiliser use.

Participants then boarded the fishing boats which were piloted by two fishermen for an hour and a half tour of the Inlet. As well as showing participants the lack of seagrass cover, the fishermen described their business, their day to day activities, and the efforts of the industry to self-regulate and be recognised as environmentally sustainable by the independent Sustainable Australian Seafood Assessment Program.

Discussions on board each boat were vigorous, friendly and informative, with many farmers commenting that they had learned a lot about the industry and the care that fishermen are taking to ensure Corner Inlet's fishery remains sustainable.

The tour was followed by a seafood lunch prepared by the fishermen's wives which offered further opportunities to socialise. Gillian Hayman from GippsDairy then spoke about the practices that dairy farmers undertake to reduce sediment and nutrient run-off from their land.

The seagrass pasture day finished at the property of Dan and Cindy Knee. This time, the fishermen ventured onto a working dairy farm to learn about producing good quality pasture, and the steps the Knees take to keep nutrients and sediments on-farm and out of the waterways. These include rotational pasture management to maximise ground cover, fencing and revegetation of streams, gullies and rivers as well as fertiliser planning (Fert$mart) to ensure nutrients are applied at the right time, rate and place.

The fishermen expressed surprise that there is genuine concern amongst farmers about the impacts of run-off in the Inlet, and at the efforts that many are already making to reduce that run-off. One current fisherman (a former dairy farmer) pointed out that the increasing intensification of dairy farming means that it is critical that the high standard of practice demonstrated at the Knees' property is replicated around the Inlet.

The general sentiment at the end of the event was that the seagrass pasture day had opened up avenues of communication and had paved the way for further cooperation in the future.

Unless captioned, all images courtesy of Robert Kenyon - Drift Media
Case study written & prepared by Jillian Staton, The Write Woman

Challenges

Many participants expressed frustration that although farmers have been making significant efforts to reduce run-off over the years, improvements are not yet being seen in the Inlet. In fact, the situation has worsened, with seagrass cover at an historical low.

Most of the farmers who participated in the field day are active in Landcare and/or have already implemented strategies to reduce run-off. A major challenge is engaging with farmers who have not yet reached the standard of practice demonstrated on the Knees' dairy farm, and supporting them to make the transition.

A related challenge is finding ways to engage farmers in the beef and sheep sectors which are not guided by a strong, regionally-focused industry body.

Appendix G

Results of chemical analysis of sediment samples

EP202A: Phenoxyacetic Acid Herbicides by LCMS

CHEMICAL			LOR	GULF	REST-A	REST-B	COBB	ROB
CHLOROPHENOXY ACETIC ACID	122-88-3	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
2.4-DB	94-82-6	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
DICAMBA	1918-00-9	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
MECOPROP	93-65-2	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
MCPA	94-74-6	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
2.4-DP	120-36-5	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
2.4-D	94-75-7	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
TRICLOPYR	55335-06-3	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
2.4.5-TP (SILVEX)	93-72-1	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
2.4.5-T	93-76-5	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
MCPB	94-81-5	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
PICLORAM	########	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
CLOPYRALID	1702-17-6	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
FLUROXYPYR	69377-81-7	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02

EP234A: OP Pesticides

CHEMICAL			LOR	GULF	REST-A	REST-B	COBB	ROB
AZINPHOS-ETHYL	2642-71-9	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
AZINPHOS-METHYL	86-50-0	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
CHLORFENVINPHOS	470-90-6	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
COUMAPHOS	56-72-4	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
DIAZINON	333-41-5	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
DIMETHOATE	60-51-5	mg/kg	0.004	<0.004	<0.004	<0.004	<0.004	<0.004
DISULFOTON	298-04-4	mg/kg	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
ETHOPROPHOS	13194-48-4	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
FENAMIPHOS	22224-92-6	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
FENITROTHION	122-14-5	mg/kg	0.5	<0.5	<0.5	<0.5	<0.5	<0.5

FENSULFOTHION	115-90-2	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
FENTHION	55-38-9	mg/kg	0.01	<0.010	<0.010	<0.010	<0.010	<0.010
MALATHION	121-75-5	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
MEVINPHOS	7786-34-7	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
MONOCROTOPHOS	6923-22-4	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
OMETHOATE	1113-02-6	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
PARATHION	56-38-2	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PARATHION-METHYL	298-00-0	mg/kg	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
PHORATE	298-02-2	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
PIRIMIPHOS-METHYL	29232-93-7	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
SULFOTEP	3689-24-5	mg/kg	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
TETRACHLORVINPHOS	22248-79-9	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
TRIAZOPHOS	24017-47-8	mg/kg	0.001	<0.001	<0.001	<0.001	<0.001	<0.001

EP234B: Thiocarbamates and Carbamates

CHEMICAL			**LOR**	**GULF**	**REST-A**	**REST-B**	**COBB**	**ROB**
ALDICARB	116-06-3	mg/kg	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
BENDIOCARB	22781-23-3	mg/kg	1	<1	<1	<1	<1	<1
BENOMYL	17804-35-2	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
CARBARYL	63-25-2	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
CARBOFURAN	1563-66-2	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
3-HYDROXY CARBOFURAN	16655-82-6	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
METHIOCARB	2032-65-7	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
METHOMYL	16752-77-5	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
MOLINATE	2212-67-1	mg/kg	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
OXAMYL	23135-22-0	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
THIOBENCARB	28249-77-6	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
THIODICARB	59669-26-0	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002

EP234E: Conazole and Aminopyrimidine Fungicides

CHEMICAL			LOR	GULF	REST-A	REST-B	COBB	ROB
CYPROCONAZOLE	94361-06-5	mg/kg	0.004	<0.004	<0.004	<0.004	<0.004	<0.004
FLUSILAZOLE	85509-19-9	mg/kg	0.004	<0.004	<0.004	<0.004	<0.004	<0.004
HEXACONAZOLE	79983-71-4	mg/kg	0.004	<0.004	<0.004	<0.004	<0.004	<0.004
PACLOBUTRAZOLE	76738-62-0	mg/kg	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PROPICONAZOLE	60207-90-1	mg/kg	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
TEBUCONAZOLE	107534-96-3	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
CYPRODINIL	121552-61-2	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
PYRIMETHANIL	53112-28-0	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005

EP234F: Phenylurea Uracil and Sulfonylurea Herbicides

CHEMICAL			LOR	GULF	REST-A	REST-B	COBB	ROB
DIURON	330-54-1	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
FLUOMETURON	2164-17-2	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
TEBUTHIURON	34014-18-1	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
BROMACIL	314-40-9	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005

EP234H: Triazine Herbicides

CHEMICAL			LOR	GULF	REST-A	REST-B	COBB	ROB
AMETRYN	834-12-8	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
ATRAZINE	1912-24-9	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
CYANAZINE	21725-46-2	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
PROMETRYN	7287-19-6	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
PROPAZINE	139-40-2	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
SIMAZINE	122-34-9	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
TERBUTHYLAZINE	5915-41-3	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
TERBUTRYN	886-50-0	mg/kg	0.1	<0.1	<0.1	<0.1	<0.1	<0.1

EP234I: Miscellaneous (ESI Positive Mode) Pesticides

CHEMICAL			LOR	GULF	REST-A	REST-B	COBB	ROB
FENARIMOL	60168-88-9	mg/kg	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
IRGAROL	28159-98-0	mg/kg	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
METOLACHLOR	51218-45-2	mg/kg	0.002	<0.002	<0.002	<0.002	<0.002	<0.002

Appendix H

Results of nutrient and suspended sediment analysis of catchment and estuarine water samples

Site	Date	Dry/wet	TSS (mg/L)	TP (mg/L)	TN (mg/L)	NH3 (mg/L)	FRP (mg/L)	Nox (mg/L)
Poor Fellow Me	5/01/2014	wet	170	1.1	3.2	-	-	-
Golden	5/01/2014	wet	23	0.60	2.0	-	-	-
Old Hat	5/01/2014	wet	154	1.0	5.0	-	-	-
Stockyard	5/01/2014	wet	62	0.19	1.5	-	-	-
Bennison	5/01/2014	wet	50	0.80	2.9	-	-	-
Stockyard	4/04/2014	dry	320	0.42	1.6	-	-	-
Bennison	4/04/2014	dry	30	0.15	0.84	-	-	-
Franklin	4/04/2014	dry	23	0.06	0.47	-	-	-
Poor Fellow Me	4/04/2014	dry	92	0.27	1.2	-	-	-
Old Hat	4/04/2014	dry	220	0.72	1.7	-	-	-
Stockyard	30/06/2014	wet	120	0.26	2.9	-	-	-
Golden	30/06/2014	wet	7.5	0.53	2.3	-	-	-
Bennison	30/06/2014	wet	34	0.19	3.3	-	-	-
Poor Fellow Me	30/06/2014	wet	100	1.2	6.4	-	-	-
Old Hat	30/06/2014	wet	100	1.0	4.4	-	-	-
Franklin	30/06/2014	wet	46	0.06	1.3	-	-	-
Agnes	21/04/2015	wet	-	-	-	0.021	0.01	0.43
Stockyard	21/04/2015	wet	-	-	-	0.076	0.02	0.13
Franklin	21/04/2015	wet	-	-	-	0.041	0.015	0.16
Toora	21/04/2015	wet	-	-	-	0.01	0.025	0.018
Poor Fellow Me	21/04/2015	wet	-	-	-	0.43	0.33	0.095
Old Hat	21/04/2015	wet	-	-	-	0.39	0.37	0.11
Bennison	21/04/2015	wet	-	-	-	0.059	0.071	0.2
Silver	14/05/2015	wet	-	-	-	0.13	0.06	0.29
Franklin	14/05/2015	wet	-	-	-	0.044	0.011	1.5
Golden	14/05/2015	wet	-	-	-	0.061	0.14	0.74
E-Yanakie	17/04/2015	estuarine	-	-	-	0.014	0.003	0.002
E-Yanakie	17/04/2015	estuarine	-	-	-	0.011	0.004	0.002
E-Franklin	17/04/2015	estuarine	-	-	-	0.014	0.003	0.002
E-Franklin	17/04/2015	estuarine	-	-	-	0.019	0.006	0.003
E-Granite	17/04/2015	estuarine	-	-	-	0.014	0.002	0.002
E-Granite	17/04/2015	estuarine	-	-	-	0.010	0.003	0.003
E-Toora	17/04/2015	estuarine	-	-	-	0.014	0.003	0.002
E-Toora	17/04/2015	estuarine	-	-	-	0.019	0.004	0.003
E-Toora	1/05/2015	estuarine	-	-	-	0.01	0.004	0.001
E-Franklin	1/05/2015	estuarine	-	-	-	0.023	0.009	0.005
E-Granite	1/05/2015	estuarine	-	-	-	0.01	0.003	0.001

E-Yanakie	1/05/2015	estuarine	-	-	-	0.007	0.004	0.001

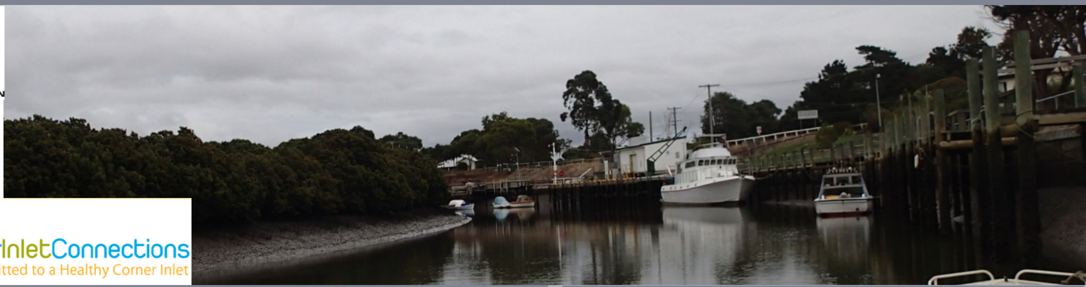
Appendix I

FRDC Project 2013-021 Fact sheet

Harnessing local knowledge for fisheries sustainability

Research collaboration between Corner Inlet fishers, Melbourne University and the West Gippsland CMA (2013-2015)

FRDC FISHERIES RESEARCH & DEVELOPMENT CORPORATION
THE UNIVERSITY OF MELBOURNE
West Gippsland Catchment Management Authority
CornerInletConnections Committed to a Healthy Corner Inlet



A collaborative approach to estuarine and catchment management

The land and sea are intrinsically connected. Healthy and well managed streams, bushland, farms and gardens all contribute to a clean and productive coastal marine system. Understanding where best to target land management to achieve good outcomes is often challenging, but by bringing together communities from both land and water we are aiming to improve the health of local coastal waters. Local Corner inlet fishers will provide their local observations of change to the coastal system, which will help in targeting efforts to improve water quality and ensure the preservation of seagrass beds and fisheries productivity.

"Fishermen are the natural stewards of these areas – they spend every working day out there observing what's going on. It is logical to listen to fishers experiences and observations, as they can notice changes that we could never pick up in a short scientific survey" **Dr John Ford, lead investigator, University of Melbourne.**

Healthy broadleaf seagrass *Posidonia australis*

"For the last 25 - 30 years, the broadleaf and fineleaf seagrasses, along with the kelp, have slowly been dying off. The dieback started from shore areas and now extends out into the Inlet for up to 3-4 kms in some places". **Gary Cripps, Port Franklin fishermen**

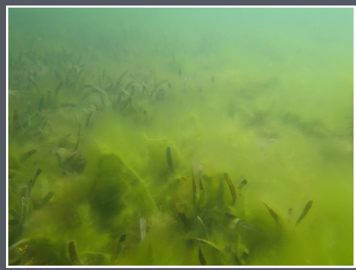
The Corner Inlet Nooramunga fishery

Corner Inlet and Nooramunga support productive and sustainable commercial and recreational fisheries. The commercial fishery is reliant on the health of seagrass beds for its most important species: King George whiting, rock flathead, garfish and calamari. Reported seagrass declines linked to poor water quality and algal blooms have affected the fishery over the past few decades. Fishermen are now taking a proactive approach of co-operation and knowledge sharing to ensure a sustainable future.

"We require more documented evidence to link water quality conditions and seagrass health. This project will help us collect evidence of the changes that occur in the marine ecosystems over the seasons based on the observations and knowledge of the Corner Inlet fishers" **Michelle Dickson, West Gippsland CMA**

Possible threats to seagrass

- Algal blooms starve seagrass of light, nutrients and oxygen
- Sediment reduces light and buries seagrass
- Erosion and infilling of channels and banks
- Chemicals and pollution from land
- Physical removal by dredging, boat anchors and props
- Storm activity and changing climate

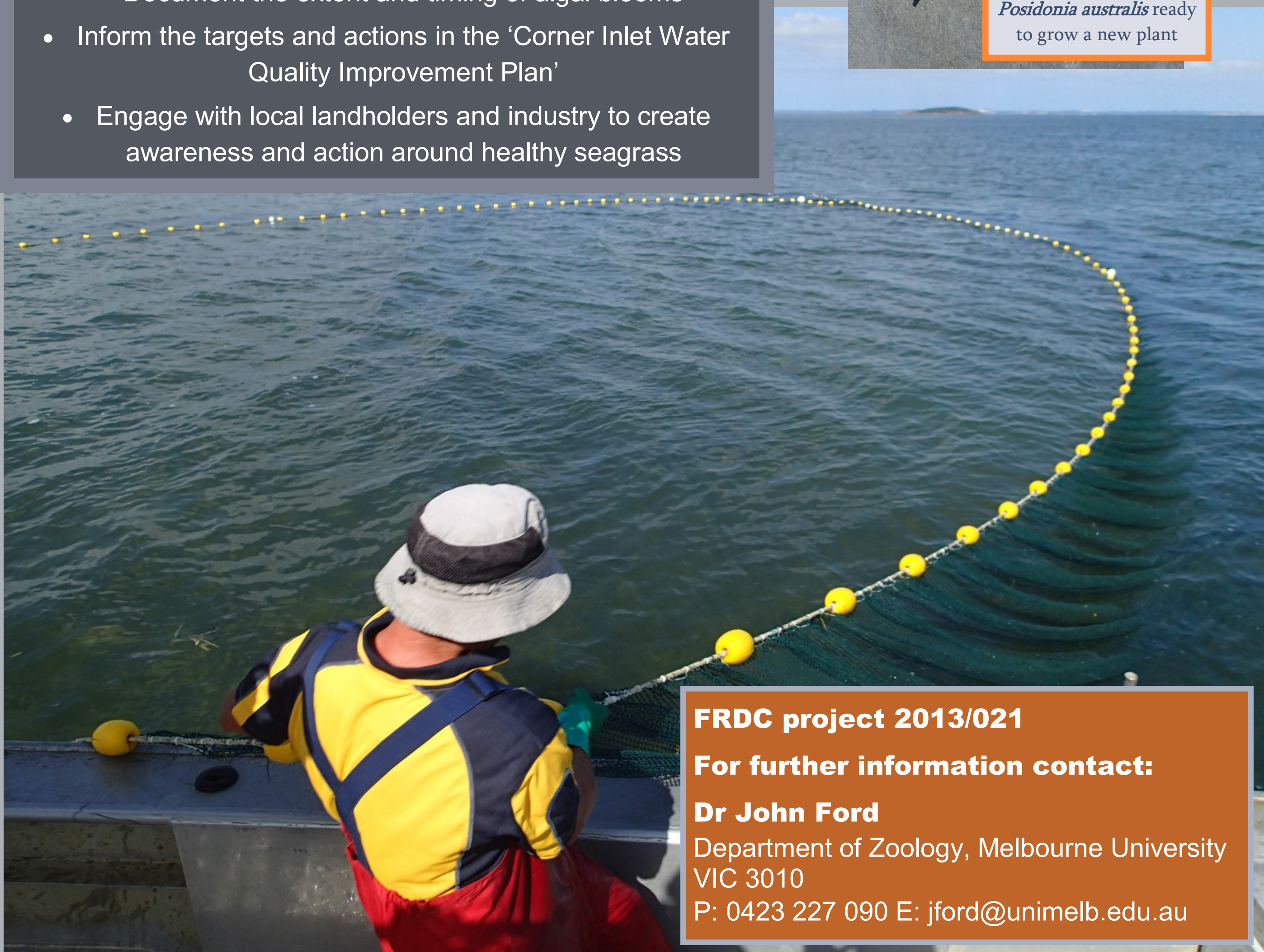


Clean *Posidonia* (left) and overgrowth by green algae (right)

What we intend to do

- Map seagrass beds from fishers' knowledge
- Characterise areas of seagrass decline and link them back to possible threats to target management action
- Document the extent and timing of algal blooms
- Inform the targets and actions in the 'Corner Inlet Water Quality Improvement Plan'
- Engage with local landholders and industry to create awareness and action around healthy seagrass

Seed of the seagrass *Posidonia australis* ready to grow a new plant



FRDC project 2013/021

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Appendix J

GIS map layers of the 2013 seagrass cover are available for downloads as shapefiles from the FRDC website.