# Understanding broad scale impacts of salmonid farming on rocky reef communities

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# Executive Summary

### What the report is about

The strategic growth of the Tasmanian Salmonid Industry is contingent upon ecologically sustainable development. Current Tasmanian production is not meeting domestic demand, and the industry is in the process of expanding farming operations to meet strategic growth targets. While local scale impacts are well understood, the extent of broad scale environmental impacts from finfish farming needs to be better understood, especially in relation to nutrient emissions and their potential ecosystem effects on macro-algal community assemblages on rocky reefs. This report describes the results of analyses and surveys designed to examine patterns of change and characterise reef assemblages in south eastern Tasmania, where there is increasing concern as the salmonid aquaculture sector expands into more exposed waterways that overlap with traditional wild fishing sectors (such as abalone and rock lobster). The first part of the study used the existing Marine Protected Area (MPA) monitoring dataset to examine patterns of change in macroalgal communities in south eastern Tasmania between 1992 and 2015. The second component of the study included a field survey of rocky reefs, incorporating the MPA sites, along with additional sites chosen to better represent industry expansion into new growth areas. The study used a collaborative approach, with field work and data analysis carried out by Aquenal and Marine Solutions. Scientific support and supply of the MPA dataset was provided by IMAS.

This report describes the approach and results of the time series analysis and reef characterisation. Complexities associated with reef assessment and options for future monitoring are also addressed.

### Background

Extensive monitoring of salmonid farms has been undertaken and is based on rigorous and broad-ranging research and monitoring that has been ongoing for over 20 years. The success of this integrated research framework has been enhanced through very strong links between government, industry and researchers. Robust regulatory controls have been used to manage benthic impacts from salmon farming activities, and through the adoption of adaptive management strategies, organic loading effects from marine farming operations have been effectively managed using the environmental monitoring framework administered by the Tasmanian Government. The salmon industry funded Broadscale Environmental Monitoring Program (BEMP) for the D'Entrecasteaux Channel region (which commenced in 2009) has further enhanced the understanding of impacts to include the detection of broad scale impacts to water quality and sediment health. The only marine habitats not subject to broad scale assessment of potential impacts from salmon farming are rocky reef communities. As the Tasmanian salmon industry expands, both in terms of production and growing areas, commercial and recreational fishing groups are concerned that their targeted fishing grounds, which are predominantly based around rocky reef systems, may be impacted by nutrient emissions released through marine farming activities. This study aims to characterise reef community health in south eastern Tasmanian waters.

### Aims/objectives

The primary objective of this study was to provide an immediate response to characterising reef community health prior to the development of new growing areas in south eastern Tasmanian waters. Three specific objectives formed the basis of the study, including:

1 Undertake analysis of subtidal macroalgal community survey data since the inception of the monitoring program in 1992 at the Ninepin point and Tinderbox Marine Protected Areas

2 Characterise macroalgal community assemblages within south eastern Tasmanian waters to determine potential broad scale impacts from salmon farm developments in south eastern Tasmanian waters.

3 Communicate the status and health of rocky reef communities (based on objective 2) to broad industry and recreational stakeholder groups

### Methodology

The first component of the study involved a time series analysis of macroalgal community structure using the Tasmanian MPA dataset. The scope of the analyses included areas adjacent to marine farming activities (i.e. Ninepin Point and Tinderbox), along with sites remote from salmonid farming in the vicinity of the Maria Island MPA. The focus of the analysis was to investigate patterns of change in macroalgal community structure that may be attributable to elevated nutrients associated with salmonid farming activities. The analysis included different structural elements of the macroalgal community, including examination of canopy-forming, understorey and encrusting algal species. A particular focus for the analysis was trends in abundance of algal species known to respond to elevated nutrients (‘nutrient indicator species’).

A diving survey was also carried out to characterise reef assemblages in 2015 as part of the second component of the study, using the same methodologies applied in MPA surveys (i.e. ‘Edgar-Barrett method). The survey included the MPA monitoring sites (allowing the time series analysis in the first component of the study to include the most up to date data), along with new sites located in areas that reflect industry expansion in south eastern Tasmania. Analysis of the 2015 dataset was mainly concerned with documenting abundance of the same algal groups and nutrient indicator species used in the time series analysis. Multivariate analysis allowed comparison of macroalgal community structure between the new sites added in 2015 and the existing MPA monitoring sites.

### Results/key findings

Analysis of data from MPA monitoring sites for the period 1992-2015 showed no consistent patterns of broad-scale change in macroalgal community structure over time. While key functional groups and dominant taxa showed some variability, these tended to be fluctuations rather than directional change.

Abundance of nutrient indicator species was low and variable over the 1992-2015 period and there was no evidence of an increasing trend over time. There were occasional peaks in abundance of nutrient indicator species, but these were not consistent within each region or between years. It is notable that the frequency and magnitude of peaks in abundance of nutrient indicator species were observed at the Maria Island sites which are remote from salmonid farming operations (> 50 km).

One of the few changes identified in the time series analysis was at one of the Tinderbox sites (Central Tinderbox). At Central Tinderbox, there has been a considerable increase in cover of *Caulerpa* spp. (particularly *C. trifaria*) since 2004. Prior to 2004, *Caulerpa* spp. abundance at this site averaged < 10%, before an increasing trend that reached a maximum of 65% in 2007. Since 2007, *Caulerpa* spp. cover has been maintained at around 40%. Reasons behind this change remain speculative, but there is no documented evidence in the scientific literature to suggest that *Caulerpa* spp. respond to increases in nutrient levels. One possible explanation relates to changes in sand or sediment deposition at this site, since *Caulerpa* species tend to flourish on the reef/sand edge.

The results of the current study were largely consistent with the findings of Crawford et al (2006), who undertook a similar analysis based on annual MPA surveys from 1992-2002. A more recent IMAS study in the D’Entrecasteaux and Huon in 2008 demonstrated changes in abundance of nutrient indicator species consistent with salmonid farming impacts. However, comparisons between the 2008 and current study were limited by differences in the timing and spatial distribution of study sites. Rather than the gradient approach used in the IMAS study, the current study was designed to examine broad scale impacts and most sites were located at considerable distance from fish farms. Differences in survey timing also limit meaningful comparisons with the IMAS study. Nutrient indicator and ephemeral species are typically highly seasonal, and more likely to be encountered in the summer months when the IMAS study was undertaken. It is therefore likely that the low abundance of ephemeral and opportunistic algal species observed in the current survey may at least partially be explained by the autumn timing of the 2015 survey.

**Implications for relevant stakeholders**

This study has provided an improved understanding of patterns of change on rocky reef communities in southeast Tasmania. The study provides an important contribution to continuation of the long term MPA dataset that can be used to assess broad scale changes to rocky reef communities in southeast Tasmania. Incorporation of new reef monitoring sites adjacent to recent or planned salmonid farm expansions also complements the MPA monitoring program, providing an important baseline and improved suite of assemblage types that can be used to investigate potential impacts of salmonid farming activities.

The current study also provides important insights into many of the issues surrounding effective monitoring of potential nutrient related impacts on macroalgal communities. For future monitoring activities, consideration should be given to broadening the spatial and temporal scope of the monitoring program, and developing a more targeted approach to tracking the abundance of nutrient indicator species.

**Recommendations and further development**

One of the main limitations associated with the current study relates to the restricted spatial and temporal scope of reef monitoring. In particular, timing surveys to coincide with expected periods of ephemeral algal growth would improve understanding of potential nutrient related impacts on macroalgal communities. Incorporating additional sites in closer proximity to salmonid farming operations would also greatly assist interpretation of potential salmonid farming impacts.

One potential option to more cost effectively increase the spatial and temporal scope of algal monitoring activities would be to develop a more targeted survey method that focuses on the algal taxa that are recognised as indicators of nutrient enrichment (e.g. opportunistic green algae as identified in the current study). A rapid survey of nutrient indicator species could potentially involve assessment of algal epiphytes colonising the dominant canopy-forming algae at each site, with potential for inclusion of multiple depth ranges and different canopy-forming species.

Development of a rapid assessment method, whereby sites could be surveyed within a dive time of < 1 hour (compared to 4-5 hours using the method employed in the current study) has the potential to dramatically increase the spatial coverage of algal monitoring activities for a given budget. Assuming that an effective rapid assessment method can be defined, a sensible future monitoring approach would be to implement a targeted algal survey on a more frequent basis (e.g. 6 monthly), with the more detailed 'Edgar-Barrett' surveys conducted over longer time scales (e.g. every 3-5 years). While a targeted algal survey method will increase cost effectiveness of algal monitoring, including the 'Edgar Barrett' method in future monitoring activities is still considered vital. Proliferation of nutrient indicator species may eventually lead to structural change in macroalgal communities and detection of such changes necessitates the more detailed macroalgal assessment provided by the 'Edgar Barrett' method. There is also considerable value in using the 'Edgar Barrett' method to monitor the long-term MPA sites for the purpose of identifying broad scale changes in reef communities.

**Keywords**

**Salmonid Aquaculture, rocky reef assemblages, macroalgae, macroalgal assemblages, nutrients, nuisance algae, broad scale impacts, environmental management**

# Introduction

The Tasmanian salmonid aquaculture sector is currently worth around $660 M, of which export values comprises around $30 M. The industry has set a sales target of $1 billion in value by 2030 and industry sales are currently growing by > $1.0m per week. Current Tasmanian production is not meeting domestic demand, and to meet strategic growth targets, the extent of broad scale environmental impacts from finfish farming needs to be better understood, especially in relation to nutrient emissions, and their potential ecosystem effects on macroalgal community assemblages on rocky reefs. This issue is particularly topical within the current or recently completed marine farming development plan amendments throughout south east Tasmanian waters, as the salmonid aquaculture sector seeks to expands into more exposed waterways that overlap with traditional wild fishing sectors (such as abalone and rock lobster).

Despite extensive consultation with wild fishing sectors and community groups, there remains concern from the wild fishing sector (particularly abalone fishers) that these recent proposals or approved amendments to Tasmanian Marine Farming Development Plans could lead to changes in ecosystem structure and function, particularly in relation to reef community assemblages. This research will provide important underpinning information on variability in broad scale rocky reef conditions that will be used to refine the more extensive reef interactions research program planned as part of FRDC 2015-024 "Managing ecosystem interactions across differing environments: building flexibility and risk assurance into environmental management strategies". This latter project has been framed to specifically address key concerns of industry (both aquaculture and fisheries), regulators and other stakeholder groups, and directly complements the current study. The research team for the current project will have direct and ongoing involvement in FRDC project 2015-024 via the projects scientific advisory group and as observers on the project steering committee.

Crawford et al. (2006) undertook an analysis of changes in abundance of the seven most abundant macroalgal species for annual surveys (1992-2002) at the Ninepin Point and Tinderbox MPAs. This study was aimed at assessing whether broad scale impacts of effluent from marine farming activities could be detected at rocky reef communities. Whilst the studies of Crawford et al. (2006) found no apparent patterns of changes in macroalgal community composition over the 10 year time period, the Tasmanian salmonid industry has grown and matured since the Crawford et al. (2006) study was undertaken, hence updating this information would prove useful in demonstrating the sustainable nature of salmon production in south east Tasmanian waters. In addition, the opportunity of increased areas of salmonid farming in more exposed waters provides a once off opportunity to gather baseline information, and a time series of information throughout the first production cycle of an expanded lease.

The monitoring of salmon farms in Tasmania is more comprehensive than that in most other parts of the world and is based on rigorous and broad-ranging research and monitoring that has been ongoing for over 20 years. The success of this integrated research framework has been enhanced through very strong links between government, industry and researchers. Robust regulatory controls have been used to manage benthic impacts from salmon farming activities. Through the adoption of adaptive management strategies, organic loading effects from marine farming operations have been effectively managed using the environmental monitoring framework administered by the Tasmanian Government. The salmon industry funded Broadscale Environmental Monitoring Program (BEMP) for the D'Entrecasteaux Channel and Huon River region (which commenced in 2009) has further enhanced the understanding of impacts to include the detection of broad scale impacts to water quality and sediment health. The only marine habitats not subject to broad scale assessment of potential impacts from salmon farming are rocky reef communities. As the Tasmanian salmon industry expands, both in terms of production and growing areas, commercial and recreational fishing groups are concerned that their targeted fishing grounds, which are predominantly based around rocky reef systems, may be impacted by nutrient emissions released through marine farming activities. This project seeks to provide an immediate response to characterising reef community health prior to the development of new growing areas in south eastern Tasmanian waters.

# Objectives

The primary objective of this study was to provide an immediate response to characterising reef community health prior to the development of new growing areas in south eastern Tasmanian waters. Three specific objectives formed the basis of the study, including:

1 Undertake analysis of subtidal macroalgal community survey data (1992-2014) at the Ninepin point and Tinderbox Marine Protected Areas

2 Characterise macroalgal community assemblages within south eastern Tasmanian waters to determine potential broad scale impacts from salmon farm developments.

3 Communicate the status and health of rocky reef communities (based on objective 2) to broad industry and recreational stakeholder groups

Minor changes to the objectives outlined above were made during the study. For objective 1, the scope of the analysis was extended to include data collected in 2015 as part of objective 2. Including the 2015 data allowed for the most up to date assessment of reef health across the area of interest. The scope of the analysis was also extended to include the Maria Island Marine Protected Area. Inclusion of this region was viewed as way of increasing understanding of temporal changes in macroalgal communities. Overall, the changes outlined above provided a more robust assessment of macroalgal community structure through time.

It should be noted that the current study examined evidence for broad scale changes in algal assemblages, rather than measuring potential local or fine scale impacts associated with salmon farming in southern Tasmania. The emphasis on broad scale monitoring largely reflected the spatial arrangement of the long-term monitoring sites that were the focus of survey activities.

# Methods

## 1. Community composition of macroalgae on subtidal rocky reefs through time

To understand changes in the community composition of macroalgae on subtidal rocky reefs through time in south east Tasmania, the first component of this project aimed to largely repeat the analysis of Crawford et al (2006). This involved examining trends in algal abundance using data collected as part of Marine Protected Area (MPA) monitoring program. Three MPA's located at Tinderbox, Ninepin Point, and Maria Island have been regularly surveyed by IMAS since 1992 (see Table 1).

**Table 1 Chronology of monitoring events at Ninepin Point, Tinderbox and Maria Island Marine Protected Areas since 1992.**

| Year | Season | Ninepin | Tinderbox | Maria Island | | Year | Season | Ninepin | Tinderbox | Maria Island |
|---|---|---|---|---|---|---|---|---|---|---|
| 1992 | Autumn | ✓ | ✓ | ✓ | | 2004 | Autumn | ✓ | ✓ | ✓ |
| | Spring | ✓ | ✓ | ✓ | | | Spring | x | x | x |
| 1993 | Autumn | ✓ | ✓ | ✓ | | 2005 | Autumn | ✓ | ✓ | ✓ |
| | Spring | ✓ | ✓ | ✓ | | | Spring | x | x | x |
| 1994 | Autumn | ✓ | ✓ | x | | 2006 | Autumn | ✓ | ✓ | ✓ |
| | Spring | x | x | x | | | Spring | x | x | ✓ |
| 1995 | Autumn | ✓ | ✓ | ✓ | | 2007 | Autumn | ✓ | ✓ | ✓ |
| | Spring | x | x | x | | | Spring | x | x | x |
| 1996 | Autumn | ✓ | ✓ | ✓ | | 2008 | Autumn | ✓ | ✓ | ✓ |
| | Spring | x | x | x | | | Spring | x | x | x |
| 1997 | Autumn | ✓ | ✓ | ✓ | | 2009 | Autumn | ✓ | ✓ | ✓ |
| | Spring | ✓ | ✓ | ✓ | | | Spring | x | x | x |
| 1998 | Autumn | x | x | ✓ | | 2010 | Autumn | ✓ | ✓ | ✓ |
| | Spring | x | x | x | | | Spring | x | x | x |
| 1999 | Autumn | ✓ | ✓ | ✓ | | 2011 | Autumn | ✓ | ✓ | ✓ |
| | Spring | x | ✓ | ✓ | | | Spring | x | x | x |
| 2000 | Autumn | ✓ | ✓ | ✓ | | 2012 | Autumn | ✓ | ✓ | ✓ |
| | Spring | x | x | ✓ | | | Spring | x | x | x |
| 2001 | Autumn | ✓ | ✓ | ✓ | | 2013 | Autumn | ✓ | ✓ | ✓ |
| | Spring | x | ✓ | ✓ | | | Spring | x | x | x |
| 2002 | Autumn | ✓ | ✓ | ✓ | | 2014 | Autumn | ✓ | ✓ | ✓ |
| | Spring | x | x | x | | | Spring | x | x | x |
| 2003 | Autumn | x | x | | | 2015 | Autumn | ✓ | ✓ | ✓ |
| | Spring | x | x | | | | Spring | x | x | |

As part of the MPA monitoring program, community composition of macroalgae has been recorded in the reserve areas and at external control sites. The location of MPA sites in the three survey regions is shown in Figures 1-3. At Tinderbox, four sites have been regularly surveyed since 1992 (*Central Tinderbox, Piersons Point, Lucas Point, Dennes Point*) while at Ninepin Point three sites have been regularly surveyed over the same period (*Central Ninepin, Charlottes Cove, Huon Island*). Additional sites at Tinderbox (*Blackmans Bay*) and Ninepin Point (*Arch Rock*) were added to the survey program in 2010 following changes to marine reserve boundaries. At Maria Island, 12 core sites have been surveyed since 1992 (*Darlington North, Magistrates Point North, Magistrates Point South, Painted Cliffs North, Painted Cliffs South, Return Point, Green Bluff, Ile du Nord, Okehampton Bay, Point Home Lookout, Point Lesueur, Spring Beach*). In all three regions there have been surveys of other sites on a less frequent basis, these sites were not included in the time series analysis. It should be noted that data from the Maria Island MPA surveys was not analysed in the 2006 study, but was included in the current study to provide a more robust assessment of temporal changes in macroalgal communities.

As part of the MPA monitoring program macroalgal cover has been assessed along four contiguous 50 m transects laid out along the 5 m depth contour (see Edgar and Barrett 1999). Percentage cover of algal species has been estimated in 0.25 $m^2$ quadrats positioned every 10 m along the transect line, i.e. 5 quadrats per 50 m transect. The quadrat is divided into a grid of 7 x 7 perpendicular wires, giving 50 points (including one corner). Cover is estimated by counting the number of times each species occurs directly under the 50 points on the quadrat (1.25 $m^2$ for each of the 50 m sections of transect line).

For the time series analysis, the data was restricted to the autumn sampling event. This provided for the most meaningful time series analysis since the spring survey events have been sporadically undertaken and are not consistent across each region (see Table 1).

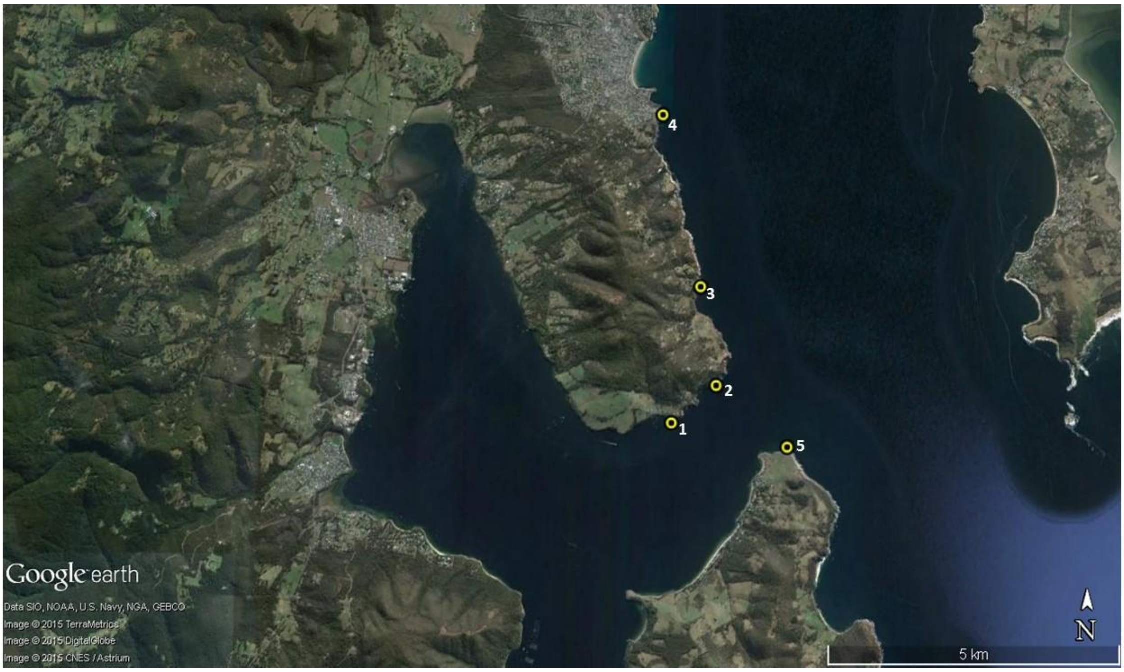


**Figure 1 MPA survey sites at Tinderbox: Central Tinderbox (1), Piersons Point (2), Lucas Point (3), Blackmans Bay (4), Dennes Point (5).**


**Figure 2 MPA survey sites at Ninepin Point: Central Ninepin (1), Charlottes Cove (2), Huon Island (3), Arch Rock (4).**


**Figure 3 MPA survey sites at Maria Island: Spring Beach (1), Point Home Lookout (2), Okehampton Bay (3), Ile du Nord (4), Darlington North (5), Magistrates Point North (6), Magistrates Point South (7), Painted Cliffs North (8), Painted Cliffs South (9), Return Point (10), Point Leseur (11), Green Bluff (12).**

## Data Analysis

Univariate data analysis

For each sampling period at each site, percentage cover data was averaged across all transects at individual sites to obtain an average abundance at each site. The abundance at each site was then averaged across each region to obtain overall macroalgal cover (i.e. Tinderbox, Ninepin Point, and Maria Island). This data was used to graphically depict percentage macroalgal cover for each year from 1992 up until and including 2015.

Time series plots were initially depicted graphically according to functional groups. Functional groups included canopy-forming species (predominately perennial brown algal species), understorey red algae, understorey green algae and understorey brown algae. Species or taxa that occurred abundantly across the three regions were also depicted graphically (e.g. *Ecklonia radiata*, *Carpoglossum confluens*). *Sargassum* spp. and *Cystophora* spp. were combined into a single grouping – this particular group was considered of interest since they tend to be accumulate relatively high levels of sediment within the algal canopy. Crustose coralline algae were included since it is an abundant growth form that plays an important ecological role, particularly in relation to the settlement of marine invertebrates (e.g. abalone). It should be noted that quantification of encrusting understorey algae and invertebrates has not been carried out since the inception of the MPA monitoring program, having been initiated in 2005.

Images of selected functional groups and taxa observed in the survey that were the focus of univariate analyses are shown in Figure 4.

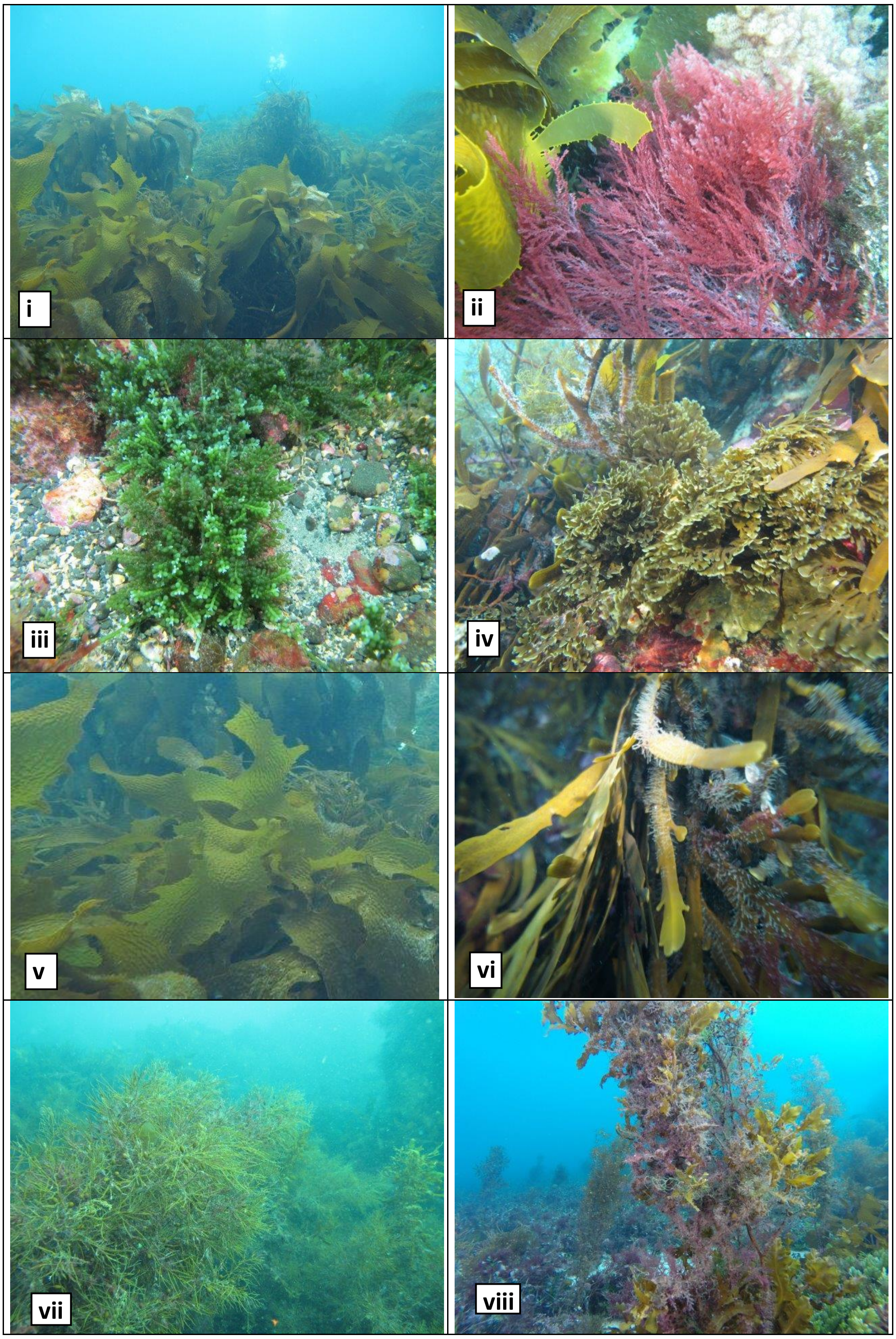


**Figure 4 Images of selected of functional groups and taxa observed in the survey that were the focus of univariate analyses including (i) canopy-forming algae; (ii) understorey red algae; (iii) understorey green algae; (iv) understorey brown algae; (v) *Ecklonia radiata*; (vi) *Carpoglossum confluens*; (vii) *Cystophora retroflexa*; and (viii*)* *Sargassum fallax*.**

Algal species known to respond specifically to elevated nutrients with rapid growth were also examined in particular detail (collectively described as ‘nutrient indicator’ species). Species and groups considered included *Chaetomorpha billardieri* (green tangleweed), *Chaetomorpha* spp. and *Cladophora* spp. The broad groupings of ‘filamentous algae’ and ‘opportunistic green algae’ were also examined. . ‘Opportunistic green algae’ included *Chaetomorpha* spp., *Cladophora* spp., *Ulva* spp. and unidentified filamentous green algae (see Figure 5).

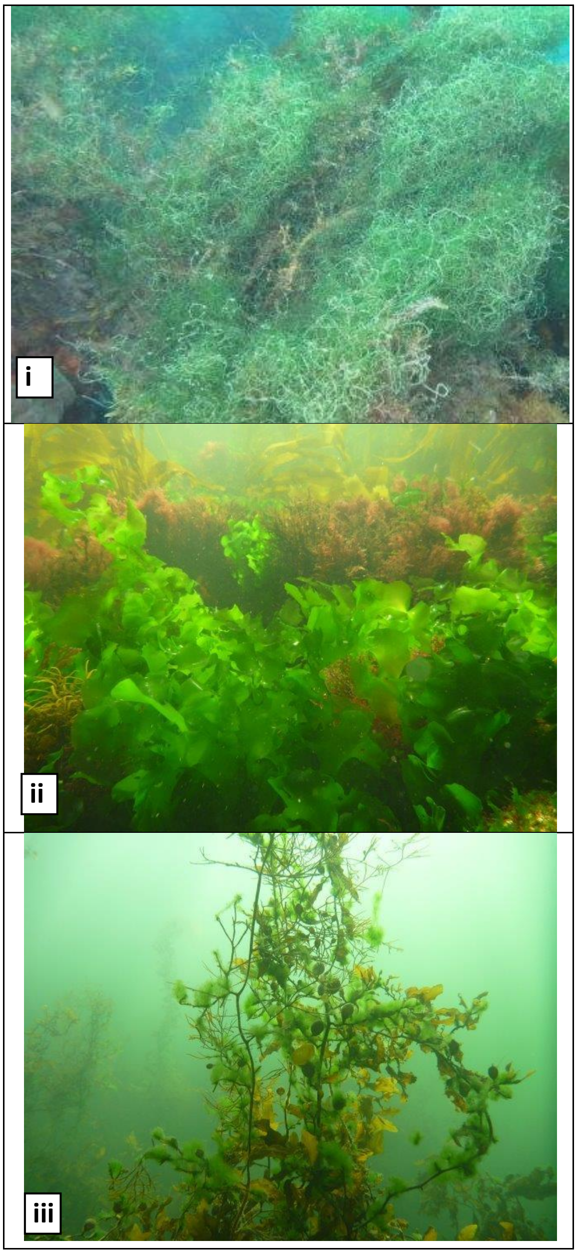


**Figure 5 Imagery showing examples of selected nutrient indicator species observed during the current survey including (i) *Chaetomorpha billardieri*; (ii) *Ulva* sp.; and (iii) filamentous green algae.**

NP-PERMANOVA was used to undertake univariate analyses for the indicators described above, incorporating the factors Year, Region, and 'Site (Region)' as a nested term. For the NP-PERMANOVA, analysis was restricted to data collected from three time periods. This included the start of the monitoring program in 1992, ten years after commencement of the monitoring program in 2002 and the most recent 2015 assessment. The NP-PERMANOVA was based on a similarity matrix calculated for single variables using Euclidean distance. F-values generated using this procedure are identical to those produced using ANOVA, however, the probability values associated with F-tests differ slightly because they are calculated by permutation rather than using assumptions of homogeneous and normal variance structure (Anderson et al., 2008).

Multivariate data analysis

To describe community patterns through time and assess the significance of differences, nonmetric multi-dimensional scaling (MDS) and nonparametric PERMANOVA were used, respectively. These analyses were based on Bray–Curtis similarity matrices derived from percentage cover data after a fourth root transformation to reduce the influence of dominant species. Differences in macroalgal cover over time were tested using PERMANOVA for data collected in 1992, 2002 and 2015. To identify species most responsible for any observed differences in community structure over time, SIMPER analysis was also conducted. For the SIMPER analysis, macroalgal cover was compared between the time periods 1992-1997 and 2010-2015, with the primary focus to examine if there were consistencies between sites and regions in terms of changing patterns of abundance of particular algal species over time. All analyses were undertaken using the PRIMER 6.0 software.

## 2. Characterising reef communities in southeast Tasmanian waters

To characterise reef communities from Actaeon Island in the south, to Maria Island off the east coast of Tasmania, field-based dive surveys were undertaken at 26 locations (Table 2; Figures 6-8). Survey sites were chosen on the basis that:

- They are existing MPA's located within the D'Entrecasteaux Channel region and represent sites that possess high natural marine values that are subject to little physical disturbance (i.e. fishing), or;

- They are sites part of a long term monitoring studies (undertaken by IMAS) in the D'Entrecasteaux Channel that have been surveyed since 1992, or;

- They are new sites that are relatively close to marine farm lease areas, or are currently under investigation, or where ecological baseline information is required to characterise reef communities prior to the development of new farming areas.

Each survey site was initially scoped with a depth sounder to determine reef depth and extent. The 26 sites were surveyed during autumn in 2015, to exclude any seasonal variations in macroalgal abundance.

As macroalgal community composition was expected to vary with depth, reefs were sampled along two depth contours (either 2 m and 5 m, or 5 m and 10 m, depending on the nature of the reef structure and level of exposure to significant wave heights). Each site within a location was located using a GPS, and marked with a surface buoy. A total of six transects were surveyed at each site, incorporating a 200 m transect along the 5 m contour and a 100 m transect at either the 2 m or 10 m contour, depending on the site. Each transect was divided into 50 m segments (i.e. two at 2 m or 10 m and four at 5 m depth).

An underwater visual census was conducted along each transect using a modified 'Edgar-Barrett' method (e.g. Edgar and Barrett 1999) to characterise reef communities. This methodology has been widely used for reef surveys in southern Australia and allows standardised collection of data for the repeated census of a set of sites within locations. This survey method utilises three census techniques to record descriptive information on reef communities at different spatial scales:

1. Fish abundance and size was surveyed in 5 m wide blocks, either side of the transect line by a diver swimming parallel to the transect line

2. Mobile invertebrates and cryptic fish were surveyed in a 1 m block by a diver swimming adjacent to the transect line

3. The abundance of macroalgal species and sessile invertebrates was recorded by placing 0.25 $m^2$ quadrats at 10 m intervals along the transect line (i.e. 5 quadrats each transect) and quantifying the percentage cover of these species.

Although abundance of fish and invertebrates was recorded, the focus of the current study was patterns of macroalgal cover. Abundance of fish and invertebrates was not analysed, but has been incorporated into the IMAS MPA database.

In addition to these survey methods, underwater video footage was taken at each survey site as an archive of reef condition. Video footage was captured at the 5 m depth contour transect at each site using a digital

SLR camera housed in an underwater housing, whereby the diver swam approximately 1 m off the bottom keeping the transect line in view.

**Table 2 Site names, GPS locations and depth contours sampled at each of the 26 sites surveyed as part of the current 2015 study.**

| Region | Date | Site | Distance from nearest salmonid farm | Depths (m) | GPS coordinates (WGS 84) | |
|---|---|---|---|---|---|---|
| | | | | | Latitude | Longitude |
| Tinderbox MPA | 21/05/2015 | Dennes Point | 3.6 km | 5 and 2 | -43.06273 | 147.35709 |
| | 20/05/2015 | Blackmans Bay South | 7.5 km | 5 and 2 | -43.01180 | 147.33106 |
| | 20/05/2015 | Lucas Point | 4.5 km | 5 and 2 | -43.03834 | 147.33894 |
| | 19/05/2015 | Piersons Point | 2.7 km | 5 and 2 | -43.05339 | 147.34210 |
| | 21/05/2015 | Central Tinderbox | 1.7 km | 5 and 2 | -43.05907 | 147.33253 |
| Storm Bay | 18/06/2015 | North Passage Point (new) | 0.4 km | 5 and 2 | -43.10058 | 147.70619 |
| | 18/06/2015 | Apex Point (new) | 1.2 km | 5 and 2 | -43.1077 | 147.71741 |
| | 16/06/2015 | Variety Bay S2 (new) | 6.5 km | 5 and 2 | -43.1928 | 147.41196 |
| | 16/06/2015 | Variety Bay South | 5.2 km | 5 and 2 | -43.2044 | 147.41701 |
| Ninepin MPA | 28/05/2015 | Charlotte Cove Light | 2.3 km | 5 and 2 | -43.27292 | 147.14343 |
| | 28/05/2015 | Huon Island | 2.5 km | 5 and 2 | -43.29383 | 147.14182 |
| | 27/05/2015 | Central, Ninepin | 4.5 km | 5 and 2 | -43.28450 | 147.16739 |
| | 27/05/2015 | Arch Rock | 6 km | 5 and 2 | -43.2877 | 147.17924 |
| Channel sites | 29/05/2015 | Redcliffs (new) | 0.8 km | 5 and 2 | -43.32578 | 147.07229 |
| | 29/05/2015 | Lady Bay (new) | 8 km | 5 and 2 | -43.40952 | 147.02329 |
| | 3/07/2015 | Zuidpool Rock | 2.5 km | 5 and 10 | -43.32533 | 147.16840 |
| | 5/06/2015 | Actaeon Island site 1 | 17 km | 5 and 10 | -43.52525 | 146.99609 |
| | 5/06/2015 | Actaeon Island site 2 (new) | 18 km | 5 and 10 | -43.53484 | 146.99289 |
| | 22/05/2015 | Eastern Partridge (new) | 2.5 km | 5 and 2 | -43.396 | 147.10629 |
| | 22/05/2015 | Butlers Point (new) | 0.2 km | 5 and 2 | -43.41662 | 147.12280 |
| | 4/06/2015 | Western Partridge (new) | 3 km | 5 and 2 | -43.39711 | 147.09627 |
| | 4/06/2015 | Little Penguin Point | 3.5 km | 5 and 2 | -43.35424 | 147.17931 |
| Maria Island* | 7/07/2015 | Point Home | >50 km | 5 | -42.55305 | 147.94814 |
| | 7/07/2015 | Okehampton Bay | >50 km | 5 | -42.52398 | 147.96925 |
| | 7/07/2015 | Magistrates Point (North) | >50 km | 5 | -42.58268 | 148.05460 |
| | 7/07/2015 | Painted Cliffs (South) | >50 km | 5 | -42.60250 | 148.04628 |

*Video transects only, IMAS carried out field surveys

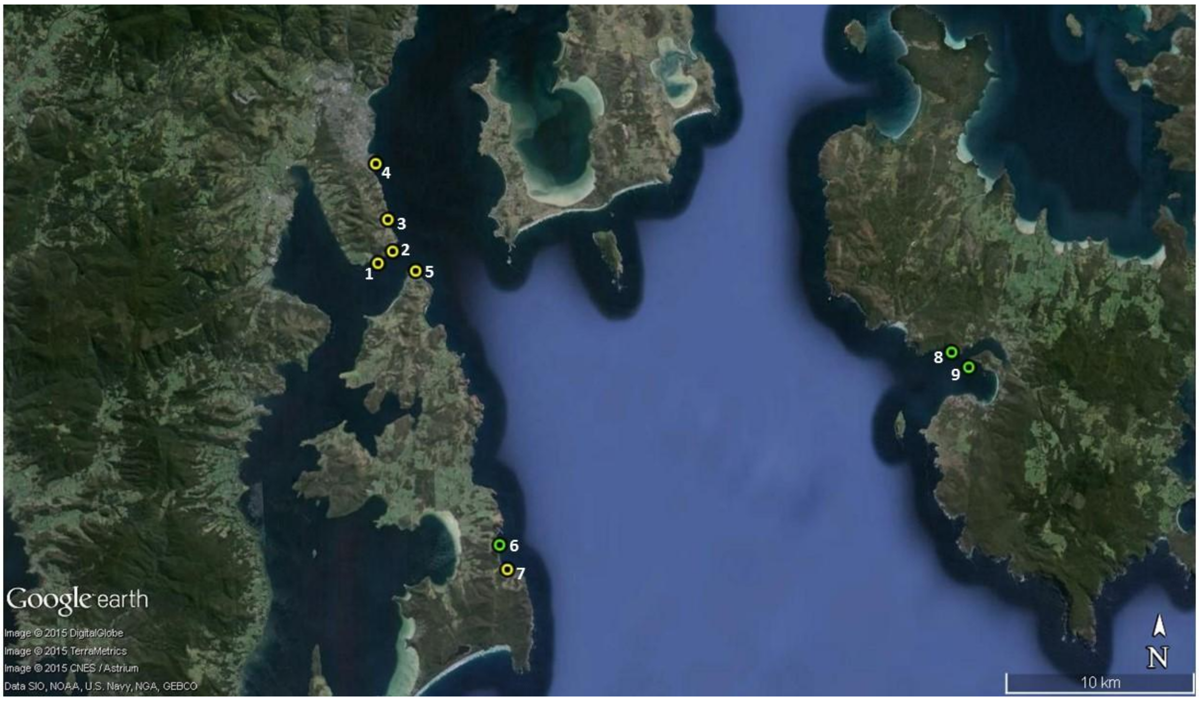


**Figure 6 Tinderbox MPA and Storm Bay survey sites, 2015. Yellow symbols represent long term IMAS monitoring sites, while new sites added in 2015 are indicated by green symbols. Site names: Central Tinderbox (1), Piersons Point (2), Lucas Point (3), Blackmans Bay (4), Dennes Point (5), Variety Bay S2 (6), Variety Bay South (7), North Passage (8), Apex Point (9).**


**Figure 7 Ninepin Point MPA and Channel survey sites, 2015. Yellow symbols represent long term IMAS monitoring sites, while new sites added in 2015 are indicated by green symbols. Site names Central Ninepin (1), Charlottes Cove (2), Huon Island (3), Arch Rock (4), Little Penguin Point (5), Zuidpool Rock (6), Redcliffs (7), Partridge Island East (8), Partridge Island West (9), Lady Bay (10), Butlers Point (11), Actaeon Island (12), Actaeon Island S2 (13).**


**Figure 8 Maria Island MPA survey sites, 2015. Site names: Point Home (1), Okehampton Bay (2), Magistrates Point North (3), Painted Cliffs South (4).**

## Data Analysis – reef characterisation

The same functional groups and taxa used in the time series analysis were depicted graphically to allow comparison of key algal groups between sites and regions. This included comparison of algal taxa that are potential indicators of nutrient enrichment (e.g. *Chaetomorpha* spp., *Cladophora* spp.).

Sites were characterised in relation to the generalised scheme devised for Tasmanian algal assemblages detailed by Edgar (1984). This scheme describes algal community structure in relation to the two main physical determinants of reef structure, wave exposure and depth (Figure 9). To illustrate differences in macroalgal community structure between sites, nonmetric multi-dimensional scaling (MDS) was also used. This analysis was based on a Bray–Curtis similarity matrix derived from percentage cover data after a fourth root transformation to reduce the influence of dominant species. The MDS analyses provided a useful means of comparing the MPA sites with those surveyed for the first time as part of the current project. Note that only a subset of the core Maria Island monitoring sites were examined in the MDS analyses, since the large number of sites prohibited meaningful graphical representation.

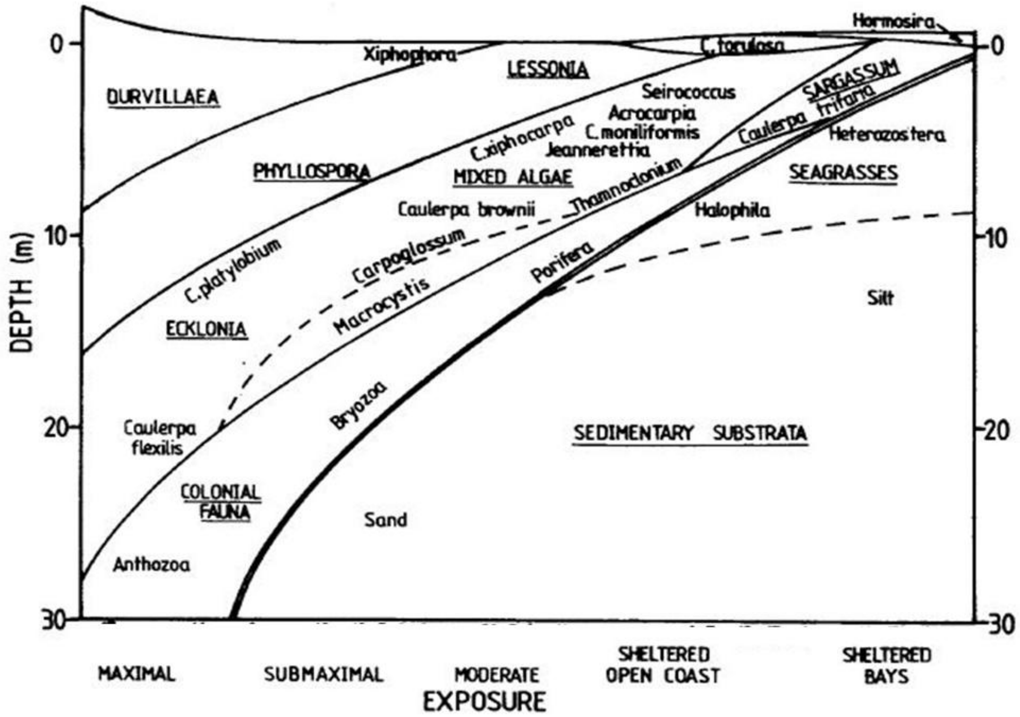


**Figure 9 Generalised scheme detailing the distribution of benthic assemblages on Tasmanian reefs (reproduced from Edgar 1984)**

Additional assessment of reef health involved assessment of epiphytic growth, since the level of epiphytes (particularly algal epiphytes) was considered a potential indicator of organic enrichment. Assessment of epiphytic growth was undertaken using the video transect footage. While the ‘Edgar-Barrett’ methodology quantifies all algal species (including those capable of epiphytic growth), it does not make the distinction between sessile and epiphytic growth forms, so it was deemed most practical to use video footage for this aspect of the study.

Video footage was used to assess invertebrate, algal epiphytic algal growth at 10 m intervals along each transect. Epiphytic growth was assessed on a qualitative scale from 1 to 5, whereby:

1. Very low epiphytic growth, virtually clean plant;
2. Low, minimal epiphytic growth;
3. Medium, obvious epiphytic growth;
4. High, most of plant covered;
5. Very high, plant completely covered.

# Results

## 1. Community composition of macroalgae on subtidal rocky reefs through time

*Functional groups*

At the functional group level, there were considerable fluctuations in abundance over time for each of the groups considered (Figure 10). Average cover of perennial canopy-forming algae across the three regions has varied between 22 and 100% across the study period, with cover generally lower in the Ninepin Point region compared to Tinderbox and Maria Island. Since 2013 there has been a declining trend of canopy-forming algal cover, however, levels in 2015 are within the range of values observed across the sampling period.

Understorey red algae at Tinderbox and Maria Island has shown minor variation in abundance since 1992. In the Ninepin Point region, where understorey algae represent a more significant proportion of the algal community, considerable variation in cover was evident. Variation between sites appears to have been higher in the period 2006 - 2014. Between 2014 and 2015 there also appears to be a decrease in cover of red understorey species. Whilst there has been considerable variation in red understorey algal cover over time at Ninepin Point, the levels recorded in 2015 are within the range of values observed across the monitoring program.

Trends in understorey green algal cover were not consistent between regions. In the Ninepin Point and Maria Island regions, levels of understorey green algal cover have been comparable and generally averaged < 10% over the duration of the study. At Tinderbox, an increasing trend has been apparent. In the period 1992-2002, understorey green algal cover averaged < 4%, before gradually increasing to a maximum of 21% average cover in 2007. Since 2007 higher levels of understorey green algal cover have been maintained, with an average of 16% recorded over the 2007-2015 period. Further investigation of this trend at Tinderbox showed that the patterns were driven by an increase in cover of *Caulerpa* species that has occurred at the Central Tinderbox site (Figure 11).

Abundance of understorey brown algae was generally low across the three survey regions, averaging 3%. There were no strong patterns spatial or temporal patterns in understorey brown algal cover, with considerable variability between regions and survey periods (Figure 10).

Results of univariate PERMANOVA analysis for the different functional groups provided additional insights into patterns of macroalgal abundance (Table 3). A significant 'Year*Site (Region)' interaction term was evident for canopy-forming brown algae, understorey green algae and understorey brown algae, indicative of differences between sites that varied depending on the year concerned. Highly significant 'Site (Region)' probability values were also evident for all functional groups, indicative of strong differences in abundance of each functional group between sites with each region (Table 3). Variance components estimates provided further understanding of patterns of variation, with most variation attributable to 'Region', 'Site (Region)' and the error term. The contribution to overall variation from Year, Region*Year and Year*Site (Region) was very low. This indicates that the relative contribution of temporal effects to overall variation in macroalgal assemblages was low (Table 3).

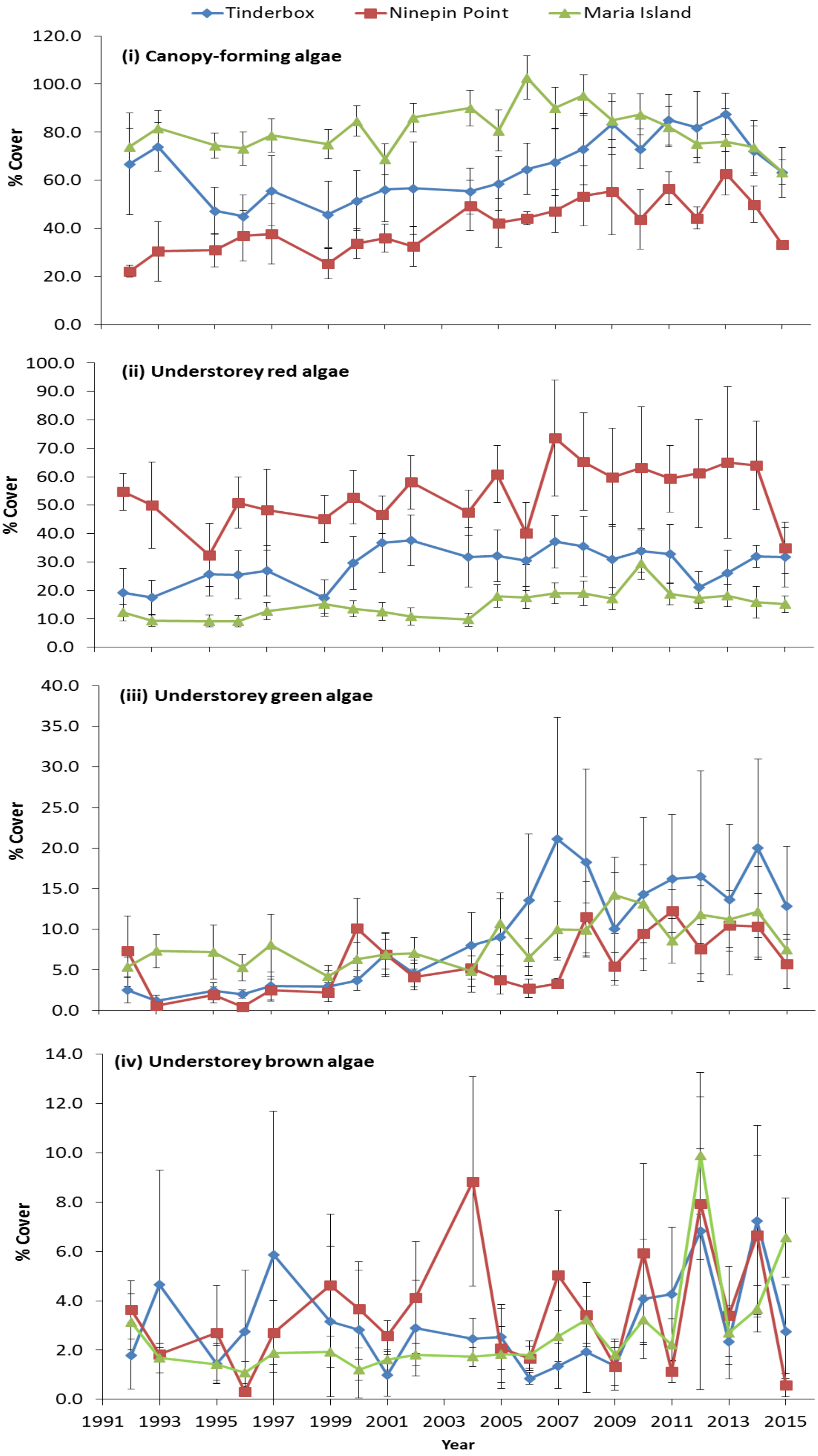


**Figure 10 Time series plots depicting abundance of functional groups, 1992-2015. Data represent mean (± SE) across replicate sites within each region (Tinderbox, n=4; Ninepin Point, n = 3; Maria Island, n = 12).**

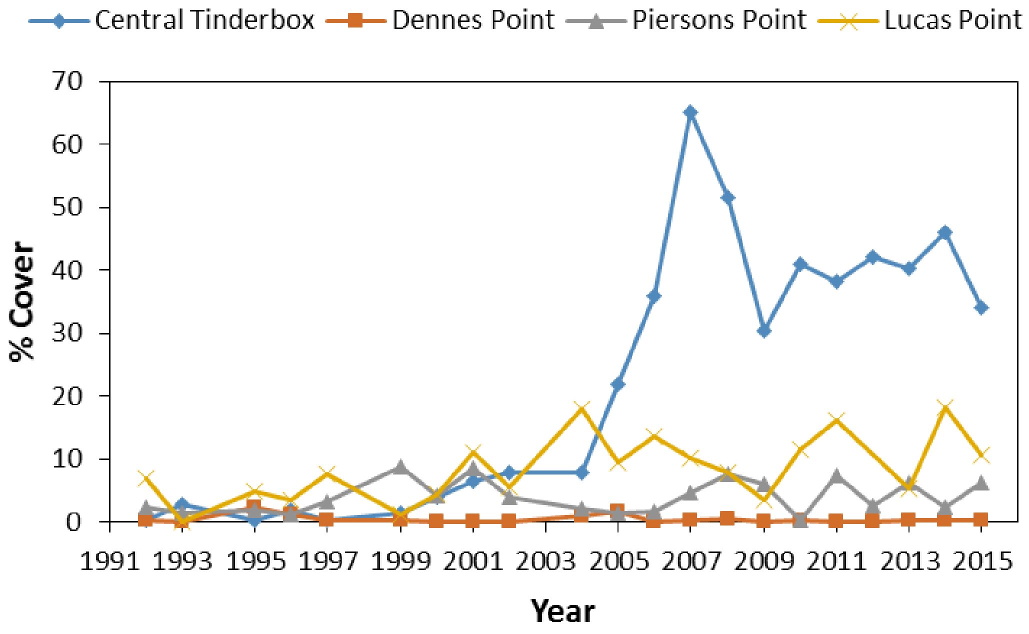


**Figure 11 Time series plot of *Caulerpa* spp. at Tinderbox**

*Abundant Taxa*

Whilst considerable fluctuations were evident, there were no strong consistent patterns over time in relation to the dominant algal species considered (i.e. *Ecklonia radiata*, *Cystophora* spp. + *Sargassum* spp., *Carpoglossum confluens*, crustose coralline algae; see Figure 12). While there were no consistent patterns, one notable result was observed for the combined *Cystophora* spp. + *Sargassum* spp. category. Levels of this grouping were relatively stable for the Tinderbox and Ninepin Point regions, but showed considerable temporal variation at Maria Island. At Maria Island, average levels of this particular grouping declined from 27% in 1992 to 11% in 1999. Since 1999 levels again increased back to an average cover of 32%, in 2006 before another declining trend, with 2015 levels (14%) comparable to 1999 (Figure 12).

Results of univariate PERMANOVA analysis for *Ecklonia radiata*, *Cystophora* spp. + *Sargassum* spp. and *Carpoglossum confluens* were generally consistent with patterns described above for functional groups. As demonstrated by variance components analysis, the 'Site (Region)' term for these taxa was highly significant and was the dominant contributor to overall variation, particularly for *Ecklonia radiata* and *Cystophora* spp. + *Sargassum* spp. (Table 3).

*Nutrient indicator algal species*

Cover of nutrient indicator species was generally very low (Figure 13). 'Opportunistic green algae' averaged 0.5 % across all survey periods and regions. During some survey years there were occasional increases in opportunistic green algal abundance, but the magnitude of these increases was relatively low, with a maximum average value of 3% recorded for Maria Island in 1997 and 2009. As contributing components of the green algal category, *Chaetomorpha* spp. species displayed low cover and similar patterns of the opportunistic green algal category (Figure 13). Abundance of filamentous algae has also been low and variable over the study period, averaging 2% across all years and regions. In the most recent 2015 survey, average cover of filamentous algae measured < 1%. The low and variable nature of nutrient indicator species was evident in the PERMANOVA analysis, with 'Year*Site (Region)' the only significant term for the opportunistic green algal category. The main feature of the PERMANOVA analysis for indicator species was the overwhelming contribution of the error term to overall variation, as revealed by variance components analysis (Table 3). This indicates that the majority of the variation was attributable to differences between different replicate transects.

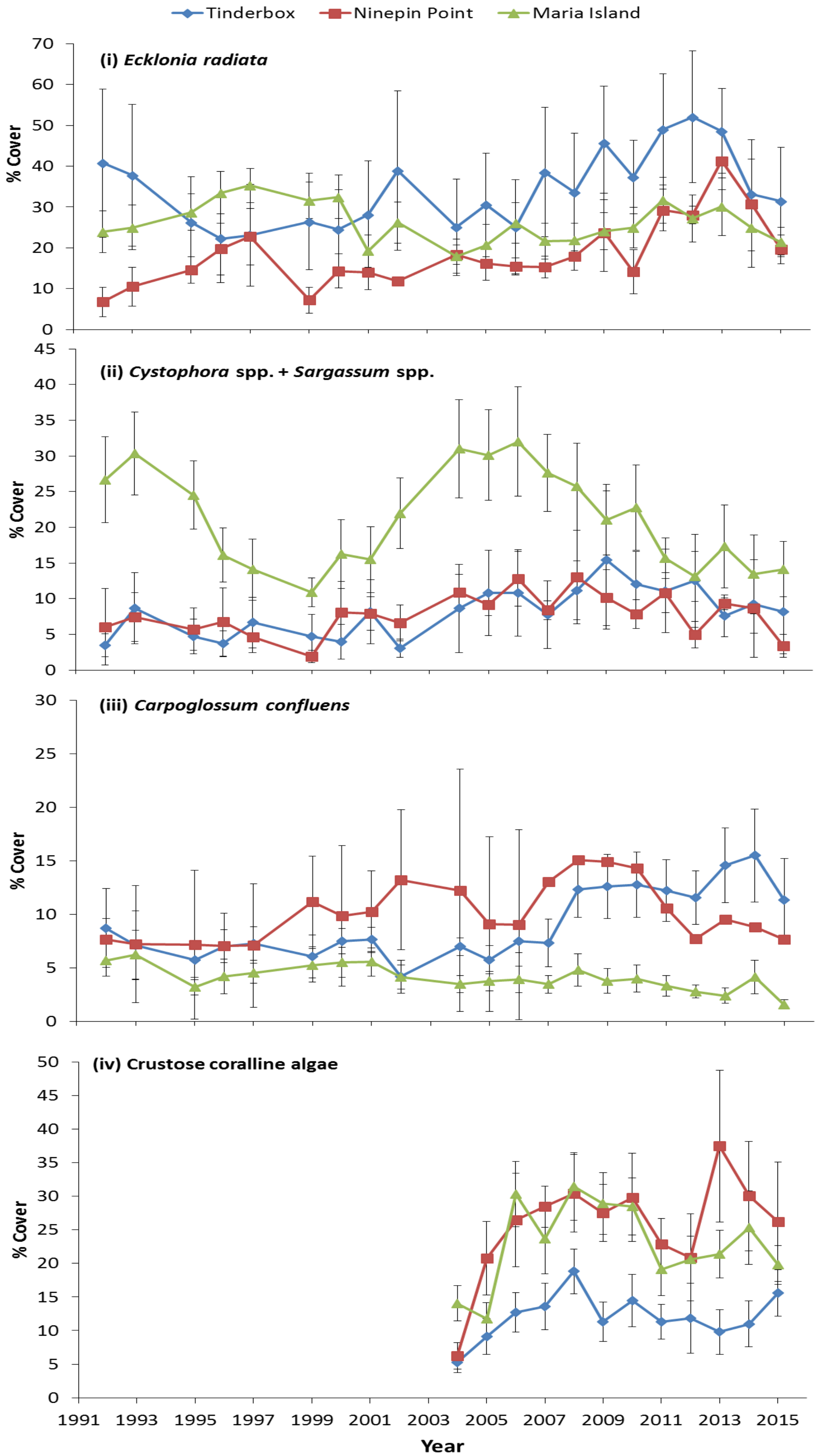


**Figure 12 Time series plots depicting abundance of abundant taxa, 1992-2015. Data represent mean (± SE) across replicate sites within each region (Tinderbox, n=4; Ninepin Point, n = 3; Maria Island, n = 12).**

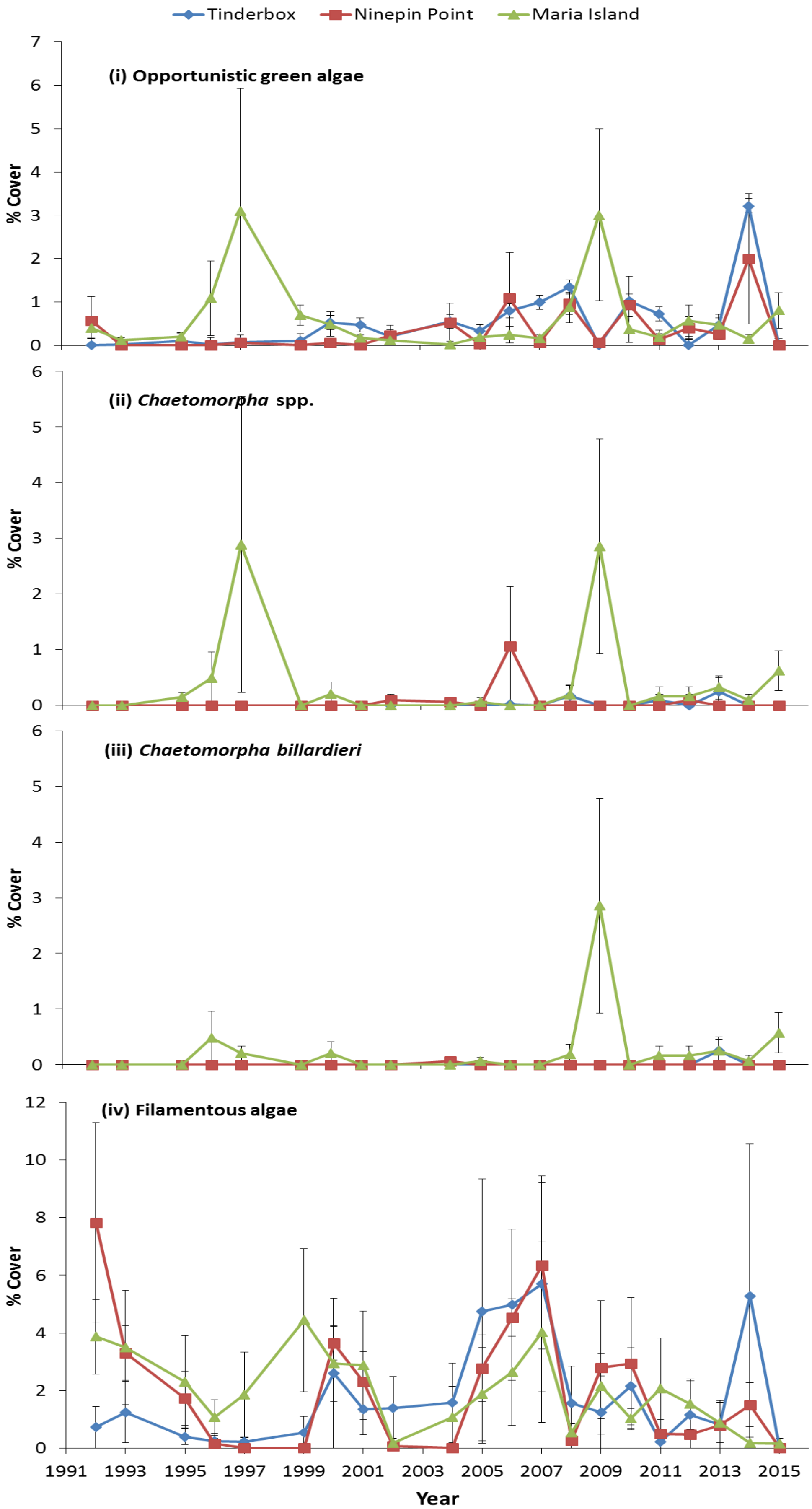


**Figure 13 Time series plots depicting abundance of nutrient indicator species, 1992-2015. Data represent mean (± SE) across replicate sites within each region (Tinderbox, n=4; Ninepin Point, n = 3; Maria Island, n = 12).**

**Table 3 Results of univariate PERMANOVA for functional groups, abundant taxa and nutrient indicator algal species. Analysis was based on three survey years including 1992, 2002 and 2015. df, degrees of freedom; MS, mean square; P (perm), probability as estimated by permutation; variation (%), estimates of components of variation, expressed as a percentage of total variation.**

| Source of Variation | df | Response | Canopy-forming brown algae | Understory red algae | Understory green algae | Understory brown algae | *Ecklonia radiata* | Cystophora spp. + *Sargassum* spp. | *Carpoglossum confluens* | Opportunistic green algae | *Chaetomorpha* spp. | *Chateomorpha billardieri* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Region | 2 | MS | 29556 | 14374 | 13.117 | 1826 | 6274.2 | 5394.7 | 652.64 | 2.6742 | 0.5 | 0.97447 |
| | | F | 5.2358 | 9.7829 | 0.039618 | 6.653 | 1.5117 | 2.2084 | 4.9118 | 1.3412 | 0.35778 | 0.68695 |
| | | P (perm) | **0.02** | **0.008** | 0.958 | **0.007** | 0.244 | 0.103 | **0.018** | 0.29 | 0.51 | 0.434 |
| | | Variation (%) | 30.9513 | 37.31958 | 0 | 28.42549 | 5.730096 | 12.54508 | 11.93715 | 0.529124 | 0 | 0 |
| Year | 2 | MS | 391.65 | 5250.1 | 225.31 | 81.691 | 54.889 | 136.09 | 3.6943 | 0.27514 | 0.335 | 0.66125 |
| | | F | 0.21809 | 4.1149 | 1.3336 | 2.4204 | 0.11615 | 0.3196 | 0.017063 | 0.11715 | 0.44664 | 0.64636 |
| | | P (perm) | 0.797 | 0.048 | 0.305 | 0.141 | 0.906 | 0.766 | 0.991 | 0.911 | 0.728 | 0.587 |
| | | Variation (%) | 0 | 12.90753 | 1.190816 | 0.999334 | 0 | 0 | 0 | 0 | 0 | 0 |
| Region*Year | 4 | MS | 1951.9 | 1418.2 | 178.69 | 29.621 | 477.46 | 453.2 | 231.8 | 2.2672 | 0.67053 | 0.97447 |
| | | F | 3.7218 | 12.172 | 1.9938 | 0.4396 | 1.1036 | 2.2333 | 2.5177 | 0.75283 | 0.4798 | 0.68695 |
| | | P (perm) | **0.012** | **0.001** | 0.136 | 0.772 | 0.371 | 0.097 | 0.068 | 0.54 | 0.67 | 0.592 |
| | | Variation (%) | 5.540471 | 11.29408 | 5.239592 | 0 | 0.360177 | 3.19423 | 9.57748 | 0 | 0 | 0 |
| Site (Region) | 16 | MS | 5645 | 1469.3 | 331.1 | 274.46 | 4150.4 | 2442.8 | 132.87 | 1.9939 | 1.3975 | 1.4185 |
| | | F | 18.118 | 14.446 | 7.7222 | 7.6751 | 23.121 | 22.39 | 3.9376 | 1.1169 | 1.0576 | 1.0354 |
| | | P (perm) | **0.001** | **0.001** | **0.001** | **0.001** | **0.001** | **0.001** | **0.001** | 0.32 | 0.435 | 0.413 |
| | | Variation (%) | 34.87514 | 19.99263 | 28.57959 | 22.09638 | 54.17397 | 50.10304 | 11.52074 | 0.81986 | 0.470862 | 0.291453 |
| Year*Site (Region) | 32 | MS | 524.46 | 116.51 | 89.622 | 67.381 | 432.63 | 202.93 | 92.067 | 3.0116 | 1.3975 | 1.4185 |
| | | F | 1.6834 | 1.1456 | 2.0903 | 1.8842 | 2.4101 | 1.86 | 2.7284 | 1.6869 | 1.0576 | 1.0354 |
| | | P (perm) | **0.027** | 0.259 | **0.002** | **0.007** | **0.001** | **0.008** | **0.001** | **0.027** | 0.388 | 0.421 |
| | | Variation (%) | 4.18282 | 0.648884 | 13.93255 | 8.77193 | 10.34692 | 6.053581 | 20.12659 | 14.45801 | 1.41257 | 0.874366 |
| Error | 171 | MS | 311.56 | 101.71 | 42.876 | 35.76 | 179.51 | 109.1 | 33.744 | 1.7853 | 1.3214 | 1.3701 |
| | | Variation (%) | 24.45027 | 17.83729 | 51.05744 | 39.70686 | 29.38884 | 28.10407 | 46.83804 | 84.193 | 98.11657 | 98.83418 |

*Community level analyses*

At Tinderbox MDS analyses showed that the algal community composition has been relatively stable since 1992 at Dennes Point, Lucas Point and Piersons Point (Figure 14). At Central Tinderbox, however, there have been considerable shifts in algal community structure since 1992. SIMPER analysis showed that the main differences when comparing the 1992-1997 and 2010-2015 datasets were driven by variation in abundance of *Caulerpa trifaria* and *Caulerpa longifolia* (Table 4). This pattern was consistent with trends identified in the time series analyses for *Caulerpa* spp. described in results section 1 above. At Blackmans Bay there appears to have been a shift in community structure between 2014 and 2015, however, given that this site has only been surveyed since 2010 it is more difficult to provide meaningful interpretation of temporal change.

At Ninepin Point there was some annual variability in macroalgal community structure; however, there was no clear directional trend over time (Figure 15). In 2015 the community composition was generally within the range observed in previous years.

For the four Maria Island sites considered, macroalgal community structure was generally consistent for Magistrates Point North, Painted Cliffs South and Okehampton (Figure 16). More variation was evident at Point Home, with substantial changes in community structure evident. Algal community structure at Point Home appears to have shifted between 2002 and 2004, with further shifts apparent until 2010. Since 2010, community structure appears to have stabilised. Using SIMPER analysis to compare the time period 1992-1997 with 2010-2015, the major changes appear to have been an overall decrease in algal cover (particularly canopy forming species) and an increase in cover of barnacles (Table 4). These changes are likely to be due to overgrazing by the high densities of sea urchins (*Heliocidaris erythrogramma*) that are found at this site.

Comparisons of difference in species composition between the 1992-1997 and 2010-2015 periods using SIMPER analysis also provided an indication of long term change (Table 4). Overall, there were very few consistent patterns in terms of the individual taxa between 1992-1997 and 2010-2015, with species contributing to change varying between regions and also between sites with each region. Although there were occasional exceptions (e.g. Caulerpa trifaria at Central Tinderbox), many of the taxa contributing to differences between 1992-1997 and 2010-2015 were species recorded at low cover levels during one time period but not recorded in the other time period.

When community comparisons were made between the years 1992, 2002 and 2015 using PERMANOVA analysis, a significant 'Year*Site (Region)' interaction term was evident (Table 5). This was consistent with the patterns described in the MDS analyses, highlighting that significant community differences were evident between sites, although there were depended upon the year concerned. Variance components analyses indicated that most of the variation was attributable to differences between sites (i.e. Site nested within Region; 27.3%) and differences between replicate transects (i.e. error term; 27.6%).

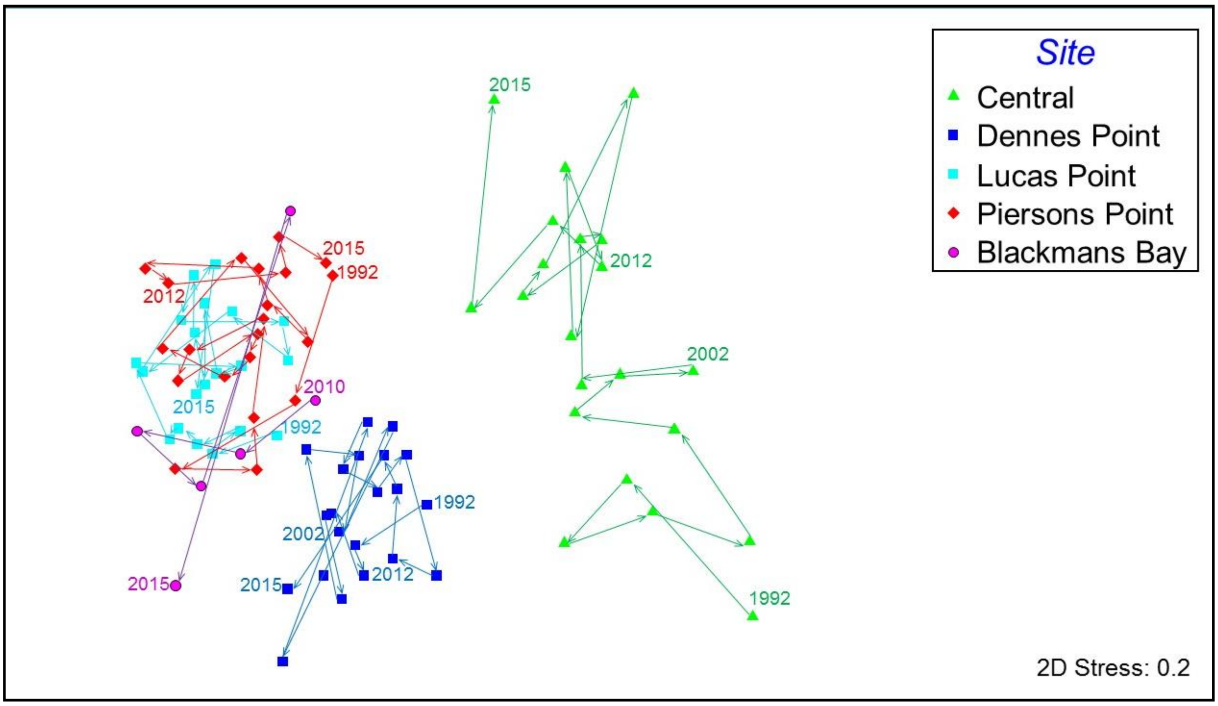


**Figure 14 MDS plot showing patterns of macroalgal community structure at Tinderbox MPA monitoring locations, 1992-2015.**

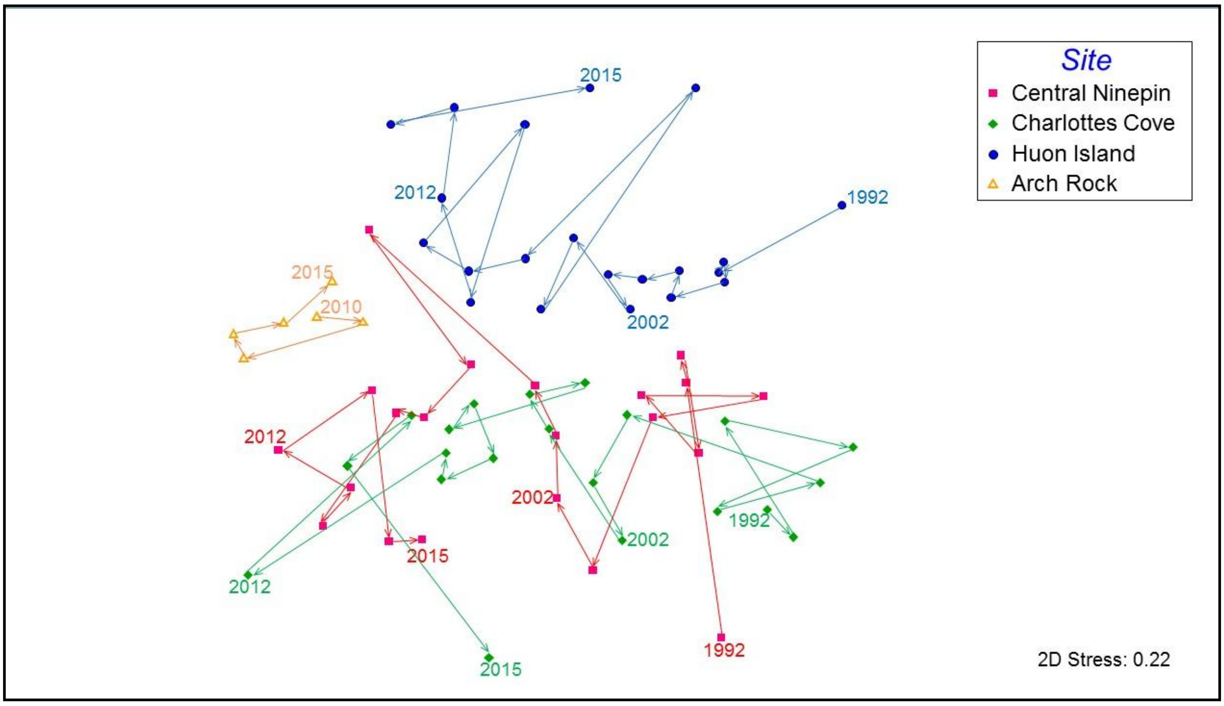


**Figure 15 MDS plot showing patterns of macroalgal community structure at Ninepin Point MPA monitoring locations, 1992-2015.**

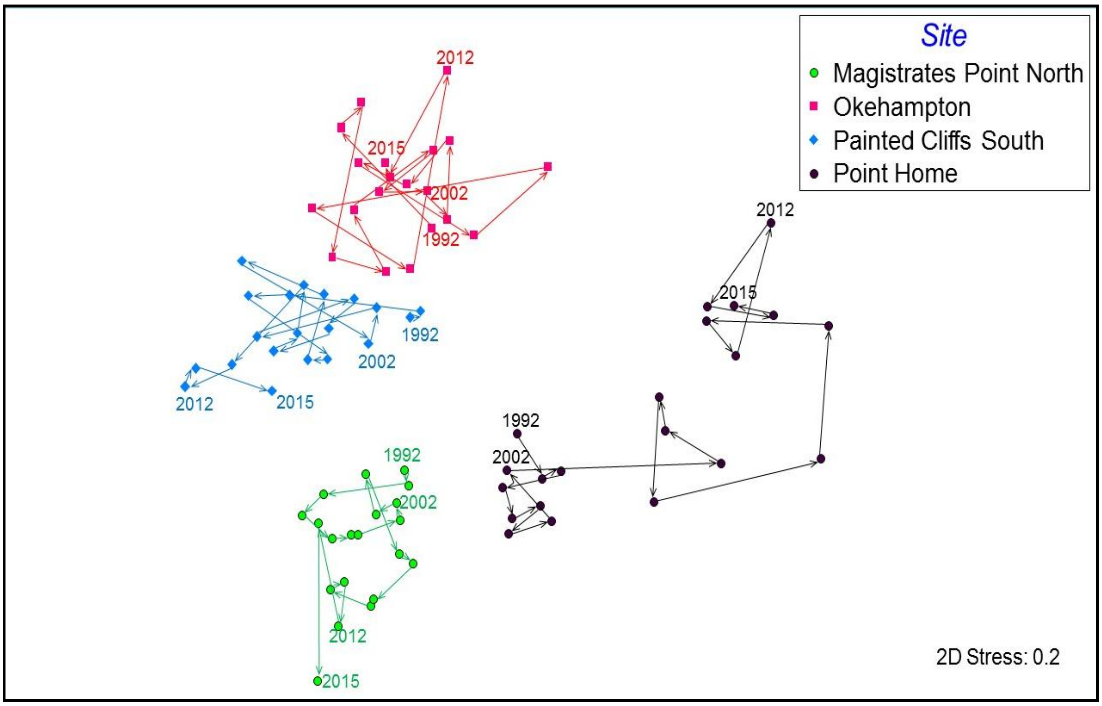


**Figure 16 MDS plot showing patterns of macroalgal community structure at Maria Island MPA monitoring locations, 1992-2015.**

**Table 4 SIMPER analysis identifying individual species or guilds responsible for the differences in community structure between 1992-1997 and 2010-2015. The column '% Contribution' quantifies the breakdown of the contributions from each species to the difference in community structure based on Bray–Curtis similarity matrices derived from percentage cover data after a fourth root transformation to reduce the influence of dominant species. The top five species accounting for differences between 1992-1997 and 2010-2015 are included for each site.**

| Region | Site | Species | Average abundance (%) | | Average Dissimilarity | % Contribution | Cumulative % |
|---|---|---|---|---|---|---|---|
| | | | 1992-1997 | 2010-2015 | | | |
| Tinderbox MPA | Central Tinderbox | *Caulerpa trifaria* | 1.03 | 27.29 | 3.3 | 5.59 | 5.59 |
| | | *Ecklonia radiata* | 14 | 35.69 | 3.15 | 5.34 | 10.93 |
| | | *Erythropodium hicksoni* | 0 | 7.57 | 2.35 | 3.98 | 14.91 |
| | | *Caulerpa longifolia* | 0.1 | 7.13 | 2.2 | 3.73 | 18.64 |
| | | *Plocamium angustum* | 0.95 | 1.01 | 1.68 | 2.85 | 21.48 |
| | Dennes Point | *Sargassum fallax* | 0 | 2.68 | 2.11 | 4.66 | 4.66 |
| | | *Carpoglossum confluens* | 1.54 | 18.93 | 1.84 | 4.07 | 8.73 |
| | | *Halopteris paniculata* | 0 | 2.12 | 1.76 | 3.89 | 12.61 |
| | | *Callophyllis lambertii* | 4.28 | 0 | 1.62 | 3.57 | 16.18 |
| | | *Caulerpa trifaria* | 0.7 | 0 | 1.42 | 3.15 | 19.33 |
| | Lucas Point | *Delisea* spp. | 1.68 | 0 | 1.61 | 4.18 | 4.18 |
| | | Unidentified algae (filamentous/foliose red) | 3.1 | 0.32 | 1.32 | 3.43 | 7.61 |
| | | Unidentified bryozoans (soft) | 0 | 1.04 | 1.22 | 3.18 | 10.79 |
| | | *Caulerpa trifaria* | 0.72 | 5.28 | 1.12 | 2.92 | 13.71 |
| | | *Dictyopteris muelleri* | 0 | 1.36 | 1.06 | 2.77 | 16.48 |
| | Piersons Point | Unidentified bryozoans (soft) | 0 | 6.2 | 2.36 | 5.22 | 5.22 |
| | | *Ptilonia australasica* | 0 | 1.13 | 1.77 | 3.92 | 9.15 |
| | | *Sargassum fallax* | 0.02 | 2.08 | 1.65 | 3.66 | 12.81 |
| | | *Unidentified hydroid* | 0 | 1.88 | 1.51 | 3.34 | 16.15 |
| | | *Lessonia corrugata* | 2.92 | 0.53 | 1.41 | 3.12 | 19.27 |
| Ninepin MPA | Central Ninepin | *Nitospinosa tasmanica* | 0 | 9.7 | 2.33 | 4.23 | 4.23 |
| | | Unidentified bryozoans (soft) | 0 | 3.13 | 1.73 | 3.14 | 7.36 |
| | | *Myriogramme gunniana* | 0.62 | 5.95 | 1.57 | 2.85 | 10.21 |
| | | *Halopteris paniculata* | 0 | 1.23 | 1.37 | 2.49 | 12.7 |
| | | *Caulerpa trifaria* | 2.62 | 4.98 | 1.35 | 2.45 | 15.14 |
| | Charlottes Cove | *Nitospinosa tasmanica* | 0 | 9.22 | 2.16 | 3.77 | 3.77 |
| | | *Seirococcus axillaris* | 0 | 1.45 | 1.58 | 2.75 | 6.52 |
| | | *Sargassum fallax* | 0.17 | 3.1 | 1.5 | 2.63 | 9.15 |
| | | *Rhodymenia sonderi* | 0 | 2.98 | 1.36 | 2.38 | 11.53 |
| | | Unidentified algae (structural corallines) | 0 | 1.05 | 1.28 | 2.24 | 13.77 |
| | Huon Island | *Phyllospora comosa* | 0.53 | 3.85 | 1.67 | 3.13 | 3.13 |
| | | Unidentified algae (filamentous/foliose red) | 7.5 | 0.62 | 1.65 | 3.09 | 6.22 |
| | | *Acrocarpia paniculata* | 3.37 | 1.2 | 1.36 | 2.54 | 8.76 |
| | | Unidentified algae (structural corallines) | 0 | 1.05 | 1.33 | 2.49 | 11.25 |
| | | *Perithalia caudata* | 3 | 0.32 | 1.33 | 2.48 | 13.73 |

**Table 4 (continued)**

| Region | Site | Species | Average abundance (%) | | Average Dissimilarity | % Contribution | Cumulative % |
|---|---|---|---|---|---|---|---|
| | | | 1992-1997 | 2010-2015 | | | |
| Maria Island | Magistrates Point (North) | Unidentified bryozoans (soft) | 0 | 7.26 | 2.62 | 5.71 | 5.71 |
| | | *Rhodymenia sonderi* | 0 | 5.88 | 2.42 | 5.27 | 10.97 |
| | | *Phyllospora comosa* | 6.8 | 45 | 1.61 | 3.5 | 14.48 |
| | | *Homoeostrichus olsenii* | 5.68 | 1.28 | 1.53 | 3.33 | 17.81 |
| | | *Lobophora variegata* | 2.9 | 4.94 | 1.51 | 3.29 | 21.1 |
| | Okehampton | *Echinothamnion hystrix* | 0 | 2.36 | 1.65 | 3.53 | 3.53 |
| | | *Sargassum sonderi* | 0 | 6.72 | 1.61 | 3.44 | 6.97 |
| | | *Caulocystis cephalornithos* | 3.06 | 1.66 | 1.59 | 3.39 | 10.36 |
| | | *Haliptilon roseum* | 0 | 0.72 | 1.56 | 3.33 | 13.69 |
| | | *Phyllospora comosa* | 1.1 | 2.14 | 1.4 | 3 | 16.69 |
| | Painted Cliffs South | Unidentified bryozoans (soft) | 0 | 4.34 | 2.18 | 4.62 | 4.62 |
| | | *Cystophora moniliformis* | 0.62 | 0 | 1.29 | 2.74 | 7.35 |
| | | *Sargassum fallax* | 1.74 | 6.06 | 1.21 | 2.57 | 9.92 |
| | | *Hypnea ramentacea* | 0 | 1.8 | 1.19 | 2.52 | 12.44 |
| | | *Lobophora variegata* | 0 | 0.68 | 1.14 | 2.41 | 14.85 |
| | Point Home | *Unidentified barnacles* | 4.06 | 14.87 | 4.5 | 7.41 | 7.41 |
| | | *Cystophora retroflexa* | 11.6 | 1.52 | 3.7 | 6.08 | 13.49 |
| | | Gravel | 1.39 | 2.7 | 2.57 | 4.23 | 17.72 |
| | | Unidentified bryozoans (soft) | 0.11 | 1.23 | 2.36 | 3.89 | 21.61 |
| | | *Chaetomorpha billardieri* | 1.18 | 1.93 | 2.19 | 3.6 | 25.21 |

**Table 5 Results of multivariate PERMANOVA for percentage cover of macroalgae. Factors: Region (3 regions, random factor); Year (three years 1992, 2002 and 2015; fixed factor); Site nested within Region (random factor). df, degrees of freedom; MS, mean square; P (perm), probability as estimated by permutation; variation, estimates of components of variation.**

| Source | df | MS | F | P(perm) | Variation | Variation (%) |
|---|---|---|---|---|---|---|
| Region | 2 | 42615 | 3.8784 | **0.001** | 522 | 16.8 |
| Year | 2 | 19091 | 2.5307 | **0.003** | 214 | 6.9 |
| Region*Year | 4 | 8185.7 | 3.5354 | **0.001** | 290 | 9.4 |
| Site (Region) | 16 | 10988 | 12.871 | **0.001** | 845 | 27.3 |
| Year*Site(Region) | 32 | 2315.3 | 2.7121 | **0.001** | 365 | 11.8 |
| Error | 171 | 853.69 | | | 854 | 27.6 |
| Total | 227 | | | | | |

## 2. Characterising reef communities in southeast Tasmanian waters

*Functional groups*

Canopy-forming algae were abundant at all sites in 2015, averaging 61 % across all sites for the 5 m depth contour and 72 % along the 2 m depth contour (Figure 17). There was no strong pattern between regions, with considerable variation evident between sites within each region surveyed. Cover of canopy-forming algae for the sites added to the monitoring program in 2015 were within the range of values measured at the existing monitoring sites (Figure 17).

Understorey red algal abundance averaged 12% across all sites for the 5 m depth contour and 15% along the 2 m depth contour. At most sites understory red algal abundance was low; however there were several sites where exceptionally high understorey red algal abundance was apparent. Understorey red algal abundance was particularly high at Actaeon Island (5 m depth contour, average cover 56 %), Piersons Point (5 m depth contour, average cover 51%) and Charlottes Cove (5 m depth contour, average cover 27 %).

Understorey green algal abundance was generally low (< 20%) at most sites for both the 5 m and 2 m depth contours (Figure 17). Considerable variation was evident between sites within each region, with no consistent patterns at the regional level (Figure 17). Green understorey algal cover was exceptionally high at the Central Tinderbox site, where an average cover of 34% was recorded (Figure 17).

Patterns of abundance of understorey brown algae were complex, with considerable variation between regions and sites within each region. The most striking pattern was the higher abundance of understorey brown algae measured at Maria Island at 5 m depth, where cover averaged 12%, compared to 2% for all remaining sites. Within the Maria Island sites there was also considerable variation evident, with understorey brown algal cover tending to be higher at the more sheltered sites (e.g. Painted Cliffs, Darlington), when compared with those subject to higher levels of oceanic swell (e.g. Point Home Lookout, Point Leseur).

Differences in relation to depth were also apparent at some sites for understorey brown algae, with some sites recording slightly higher levels along the shallower 2 m depth contour (e.g. Butlers Point; average cover 0.3% at 5 m, 16% at 2 m)

*Abundant Taxa*

Few consistent patterns were evident when the abundant algal taxa were considered, with considerable variation between sites within each region for *Ecklonia radiata*, *Sargassum* spp. + *Cystophora* spp. and *Carpoglossum confluens*. One of the more prominent patterns was the variation in abundance of the *Sargassum* spp. + *Cystophora* spp. group, with most sites recording low levels but occasional sites recording very high levels (Figure 18). This pattern is most likely attributable to variation in wave exposure. For example, sites, the highest abundance of this particular group was measured at Butlers Point and Partridge Island East, which were the two most sheltered sites within the Ninepin and Channel region (Figure 18).

Levels of crustose coralline algae were generally high in all regions, with an average of 38% in 5 m and 42% in 2 m. whilst there was considerable variation between regions, crustose coralline algal levels tended to be highest at the more wave exposed sites (e.g. Actaeon Island S2, Lady Bay, Variety Bay S2, see Figure 18).

*Nutrient indicator algal species*

Abundance of nutrient indicator species was very low across all regions and individual sites (Figure 19). Coverage of the combined grouping ‘opportunistic green algae’ averaged < 0.5% at 5 m and < 2% at 2 m depth (Figure 19). There were no strong patterns between regions, although within some regions differences between depths were evident. For example, at the Tinderbox sites, there were minor variations in relation to depth, with slightly higher levels recorded from the 2 m depth strata (Figure 19). This pattern was largely driven by the presence of small patches of *Ulva* spp. that tended to occur in the shallows at all Tinderbox sites.

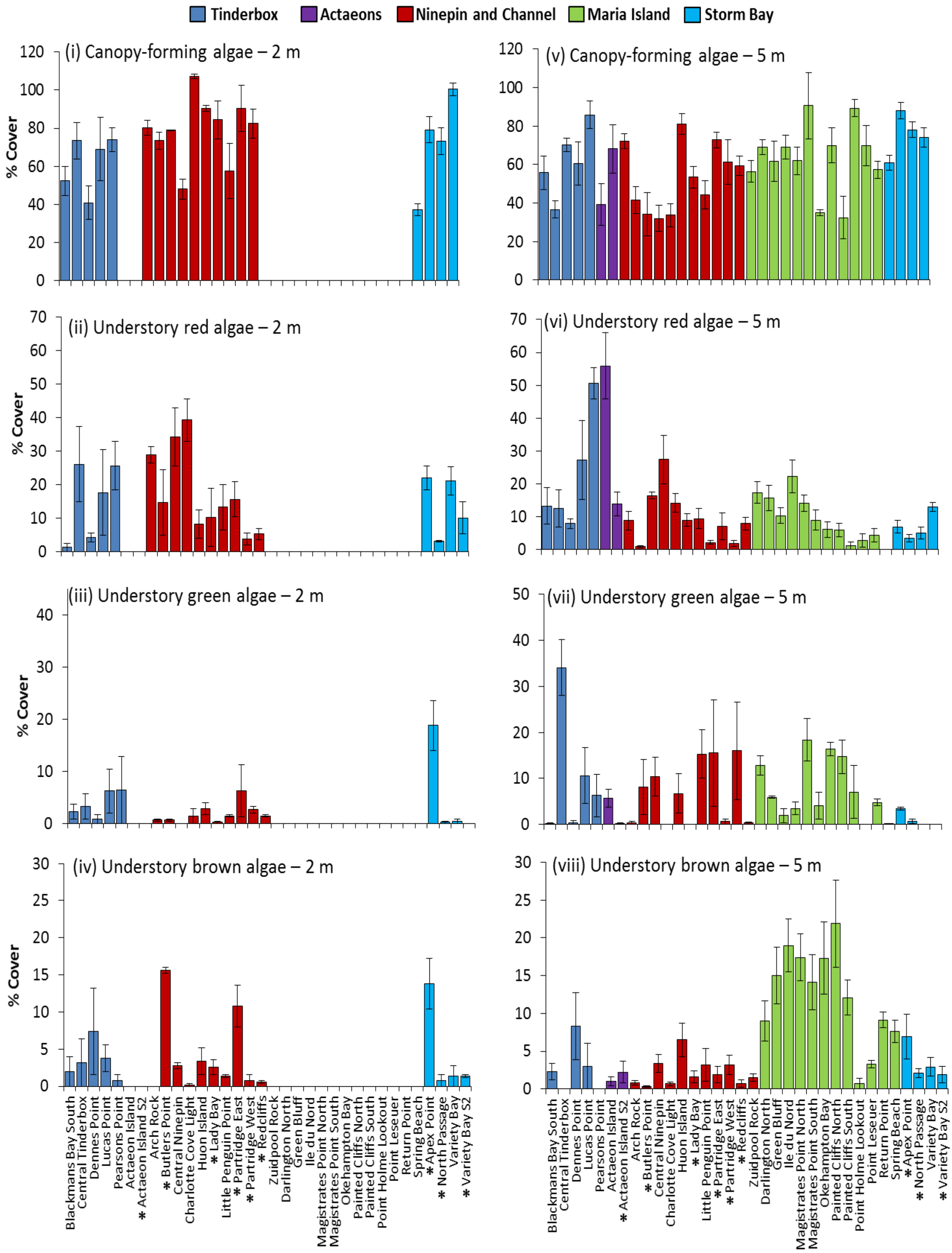


**Figure 17 Abundance of functional groups based on 2015 survey data. Date represent mean (± SE) across four replicate 50 m transects. Note – no data were collected for Maria Island, Actaeon Island and Zuidpool Rock for the 2 m depth contour.**

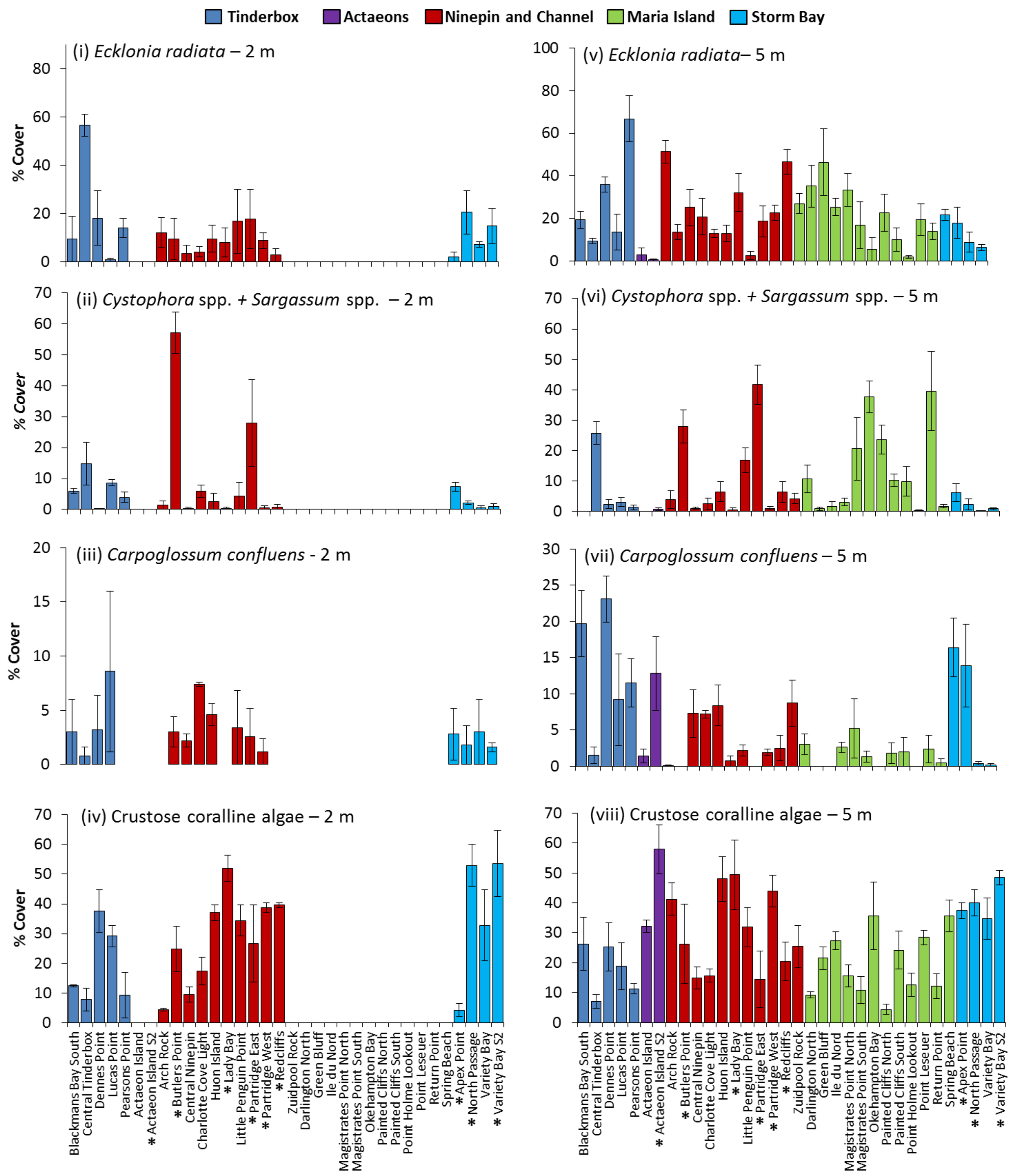


**Figure 18 Abundance of abundant taxa based on 2015 survey data. Date represent mean (± SE) across four replicate 50 m transects. Note – no data were collected for Maria Island, Actaeon Island and Zuidpool Rock for the 2 m depth contour.**

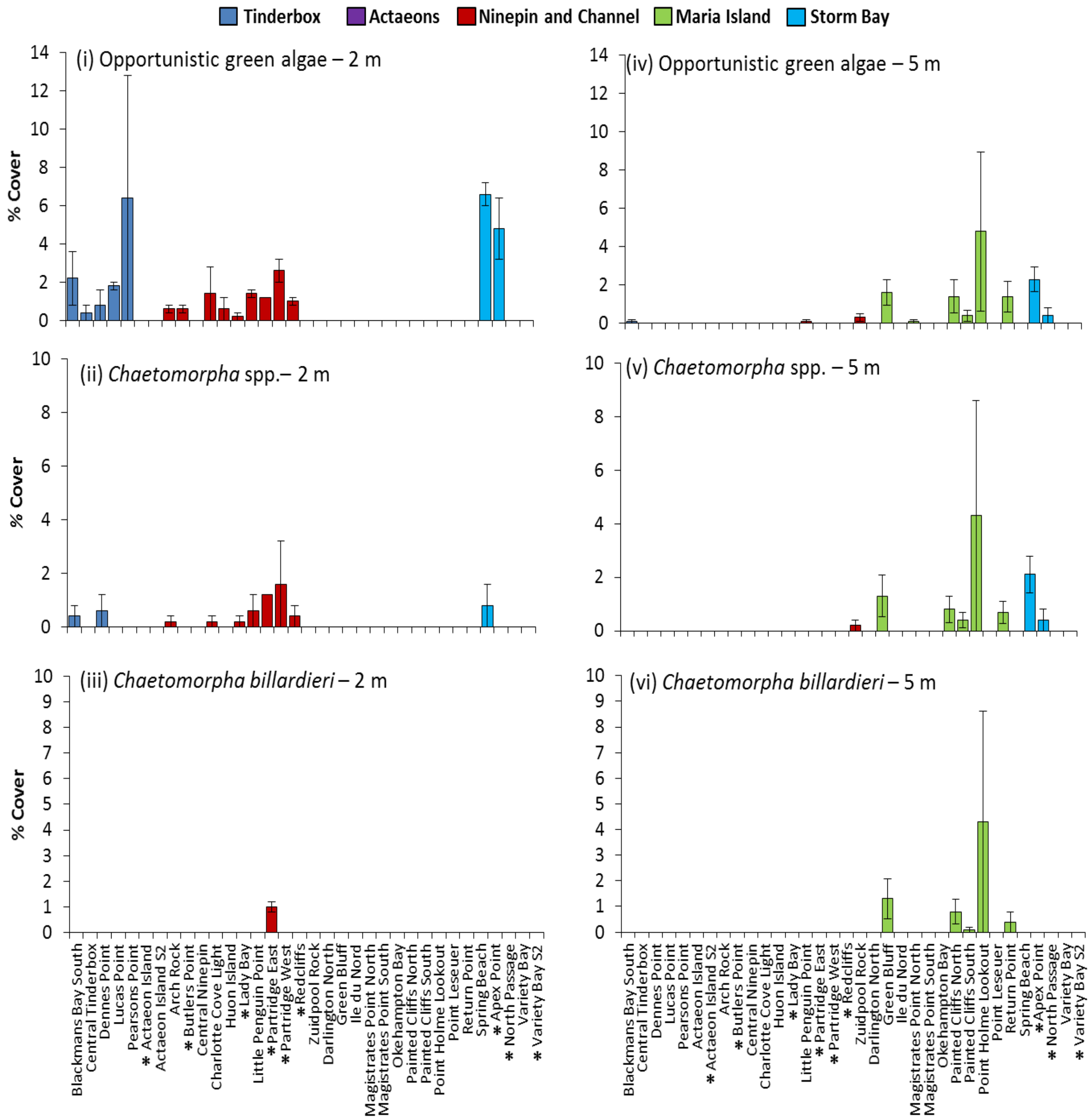


**Figure 19 Abundance of nutrient indicator taxa based on 2015 survey data. Date represent mean (± SE) across four replicate 50 m transects. Note – no data were collected for Maria Island, Actaeon Island and Zuidpool Rock for the 2 m depth contour.**

*Epiphyte coverage – video assessment*

Additional assessment of reef health during the 2015 survey involved assessment of epiphyte coverage based on analysis of video transects. Opportunistic green algal epiphyte cover was generally very low (Figure 20). Point Home in the Maria Island region recorded the highest average score of 2.4. Other sites where opportunistic green algal epiphytes were recorded at low levels included Arch Rock, Butlers Point, Partridge East, Redcliffs and Zuidpool Rock. For the remaining and vast majority of sites the lowest qualitative assessment score of one was assigned (i.e. 1 = very low epiphytic growth, virtually clean plant; Figure 20). Examples of opportunistic green algal epiphytes observed during the survey are shown in Figure 21.

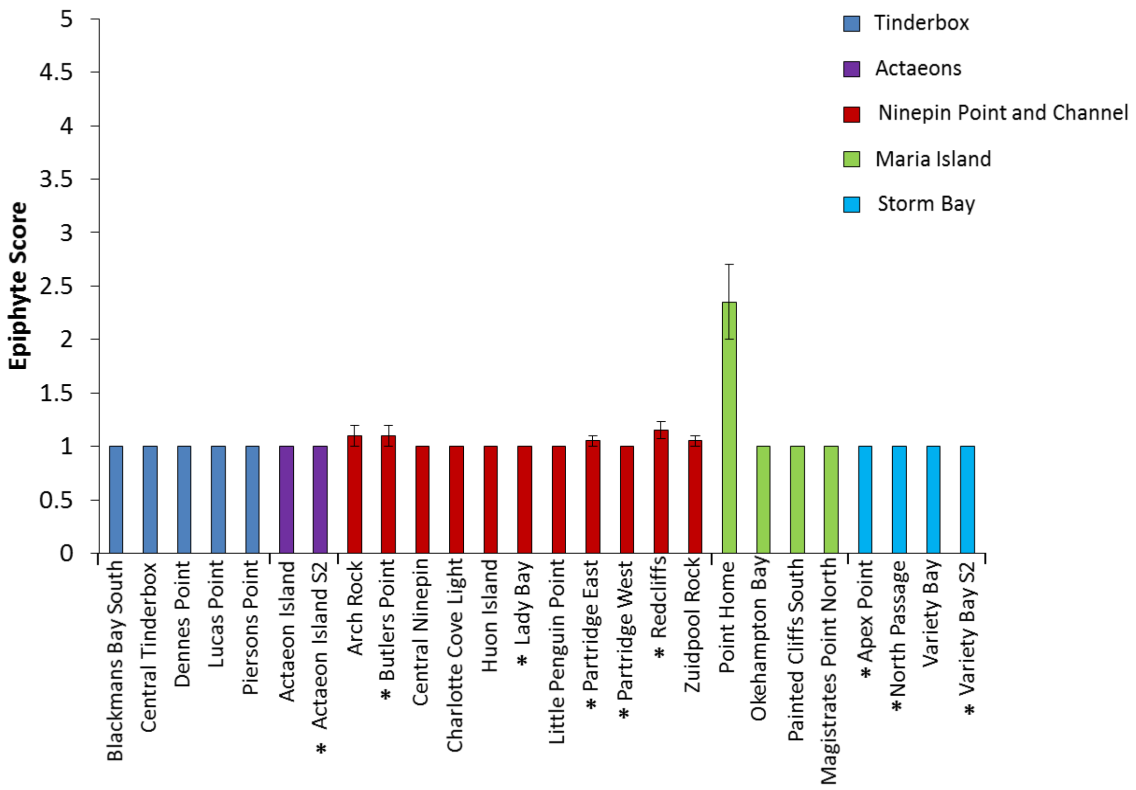


**Figure 20 Results of qualitative assessment of opportunistic green algal epiphytes, based on video footage collected at each site along the 5 m depth contour. Results represent mean (± SE) of four replicate transects at each site. Sites surveyed for the first time in 2015 are denoted by a *.**

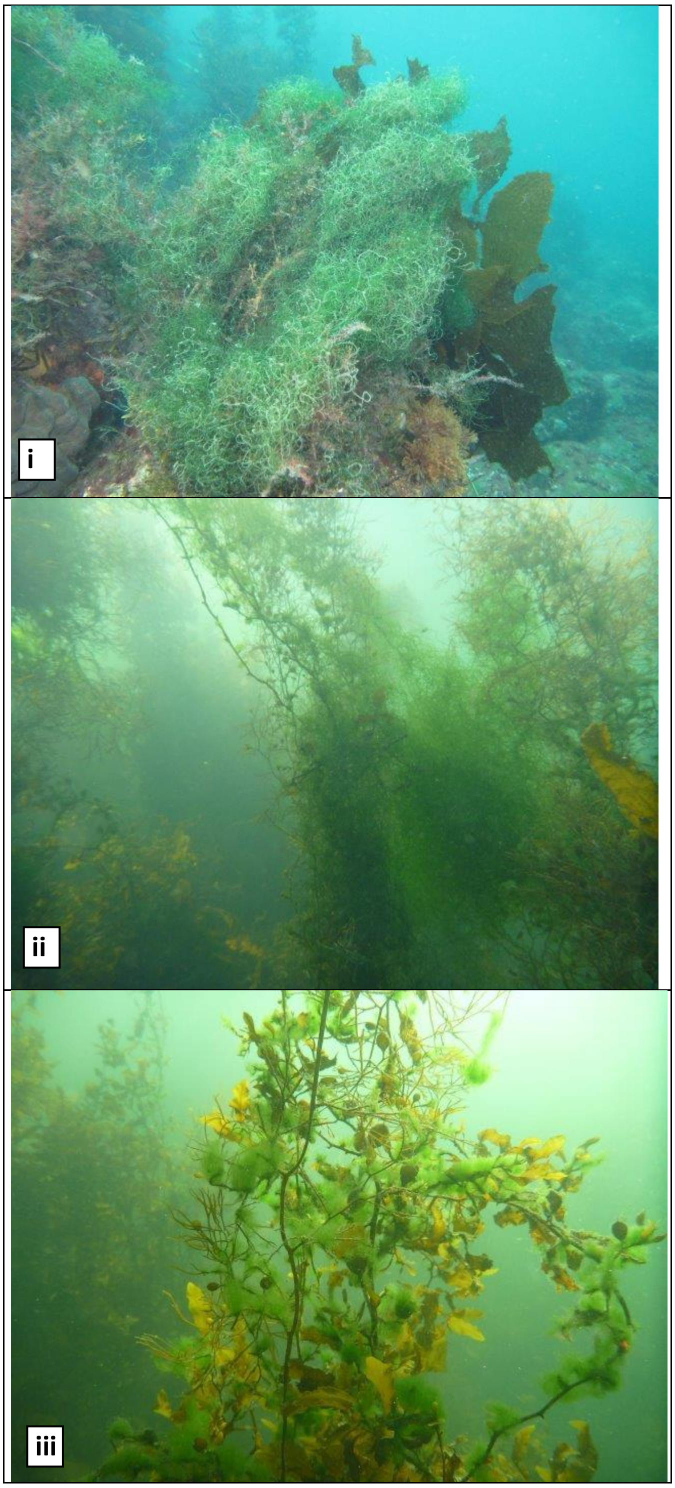


**Figure 21 Opportunistic green algal epiphytes including: (i) *Chaetomorpha billardieri* at Point Home; Maria Island region (ii) *Chaetomorpha billardieri* at Butlers Point; Channel region; and (3) filamentous green algae at Butlers Point, Channel region.**

Site characterisation: Community level analyses

*Community level analysis and site characterisation*

MDS analysis of sites sampled in 2015 showed clear separation of sites (Figure 22). Differences between sites appear to be driven by regional differences in algal assemblages, with grouping also closely tied with wave exposure Overall, communities tended to be dominated by large brown algal species (e.g. *Ecklonia*, *Phyllospora*), with varying abundance and diversity of understorey species. The broad assemblage types 'mixed algae' and '*Phyllospora'* (Edgar 1984) were the most common assemblages observed (Figure 22; Table 6). Consistent with the classification outlined in Edgar (1984), more sheltered habitats tended to be dominated by *Sargassum* and *Cystophora* species (e.g. Partridge Island East; Table 6).

The MDS analysis also provides a useful means of illustrating how the sites added in 2015 compare with the existing monitoring sites (Figure 22). A distinct 'Storm Bay and lower Channel' grouping was identified in the MDS which was mostly comprised of new sites added in the 2015 survey. These sites were located in more wave exposed areas, and were chosen to reflect the movement of salmonid farms to these more exposed locations. The output from the MDS analyses shows that this assemblage type is now well represented in the suite of monitoring sites. The other community type that was not previously represented in the MPA monitoring sites was sheltered bays. This gap was addressed in the current study through the inclusion of Butlers Point and Partridge East in the 2015 survey, and these sites formed a distinct community type in the MDS analysis.

A summary of the classification of the sites according to Edgar (1984) is provided in Table 6, while representative images of different habitat types are provided in Figure 23.

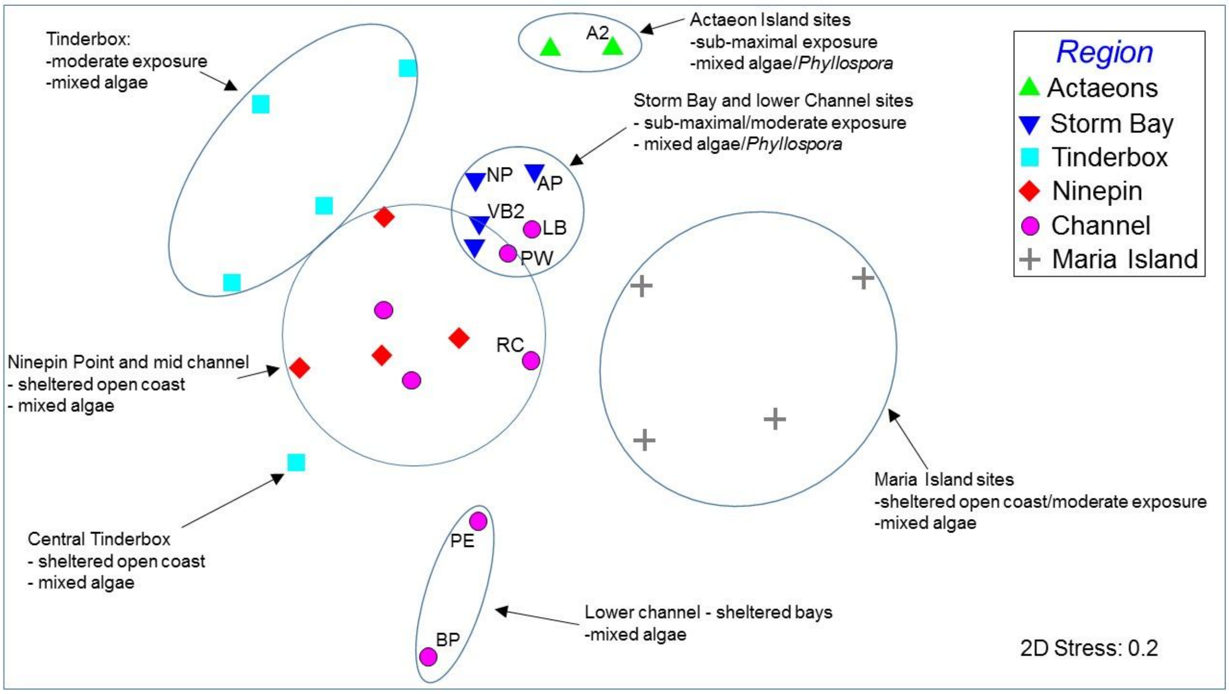


**Figure 22 MDS plot showing patterns of macroalgal community structure at 5 m depth, based on the 2015 survey data. Sites added in 2015 are labelled (A2 = Actaeon Island S2, AP=Apex Point, BP=Butlers point, LB=Lady Bay, NP=North Passage, PE=Partridge Island East, PW=Partridge Island West, RC=Redcliffs, VB2=Variety Bay S2).**

**Table 6 Overall site characterisation according to the generalised scheme for Tasmanian reefs (Edgar 1984)**

| Region | Site | Depths (m) | Wave exposure (Edgar 1984) | Broad Assemblage 5 m (Edgar 1984) | 5 m assemblage dominant species |
|---|---|---|---|---|---|
| Ninepin MPA | Charlotte Cove Light | 5 and 2 | Sheltered open coast | Mixed algae | *Ecklonia/Acrocarpia/Sargassum/*under storey red algae/*Macrocystis* |
| | Huon Island | 5 and 2 | Sheltered open coast | Mixed algae | *Ecklonia/Sargassum/Caulerpa/* understorey red algae |
| | Central, Ninepin | 5 and 2 | Sheltered open coast | Mixed algae | *Ecklonia/Sargassum/* understorey red algae |
| | Arch Rock | 5 and 2 | Sheltered open coast | Mixed algae | *Ecklonia/Acrocarpia/Sargassum/ Phyllospora* |
| Tinderbox MPA | Dennes Point | 5 and 2 | Moderate exposure | Mixed algae | *Ecklonia/Acrocarpia/ Carpoglossum* |
| | Blackmans Bay South | 5 and 2 | Moderate exposure | Mixed algae | *Ecklonia/Acrocarpia* |
| | Lucas Point | 5 and 2 | Moderate exposure | Mixed algae | *Ecklonia/Acrocarpia/ Lessonia/Macrocystis* |
| | Piersons Point | 5 and 2 | Moderate exposure | Mixed algae | *Ecklonia/Acrocarpia/Macrocystis* |
| | Central Tinderbox | 5 and 2 | Sheltered open coast | Mixed algae | *Ecklonia/Sargassum/Caulerpa* |
| Channel sites | Redcliffs (new) | 5 and 2 | Moderate exposure | Mixed algae | *Phyllospora/Ecklonia/Sargassum/ Cystophora/Caulerpa* |
| | Lady Bay (new) | 5 and 2 | Moderate exposure | Phyllospora | *Phyllospora* |
| | Zuidpool Rock | 5 and 10 | Sheltered open coast | Mixed algae | *Ecklonia/Sargassum* |
| | Actaeon Island site 1 | 5 and 10 | Sub-maximal exposure | Mixed algae | Understorey red algae/ *Acrocarpia/Phyllospora* |
| | Actaeon Island site 2 (new) | 5 and 10 | Sub-maximal exposure | Phyllospora | *Phyllospora* |
| | Eastern Partridge (new) | 5 and 2 | Sheltered bay | Mixed algae | *Sargassum/Caulerpa/Ecklonia* |
| | Butlers Point (new) | 5 and 2 | Sheltered bay | Mixed algae | *Sargassum/Caulerpa/Ecklonia* |
| | Western Partridge (new) | 5 and 2 | Moderate exposure | Phyllospora | *Phyllospora/Ecklonia* |
| | Little Penguin (Ventenant Pt) | 5 and 2 | Sheltered open coast | Mixed algae | *Sargassum/Ecklonia/Caulerpa* |
| Storm Bay | North Passage Point (new) | 5 and 2 | Moderate exposure | Phyllospora | *Phyllospora/Ecklonia/Lessonia/ Macrocystis* |
| | Apex Point (new) | 5 and 2 | Moderate exposure | Mixed algae | *Ecklonia/Carpoglossum/Sargassum/ understorey red algae* |
| | Variety Bay (new) | 5 and 2 | Sub-maximal exposure | Phyllospora | *Phyllospora* |
| | Variety Bay South | 5 and 2 | Sub-maximal exposure | Phyllospora | *Phyllospora* |
| Maria Island* | Point Home | 5 | Moderate exposure | Mixed algae | *Urchin barren* |
| | Okehampton Bay | 5 | Moderate exposure | Mixed algae | *Ecklonia/Cystophora/Seirococcus* |
| | Magistrates Point (North) | 5 | Sheltered open coast | Mixed algae | *Ecklonia/Phyllospora* |
| | Painted Cliffs (South) | 5 | Sheltered open coast | Mixed algae | Mixed *Ecklonia/Sargassum/ Cystophora* |

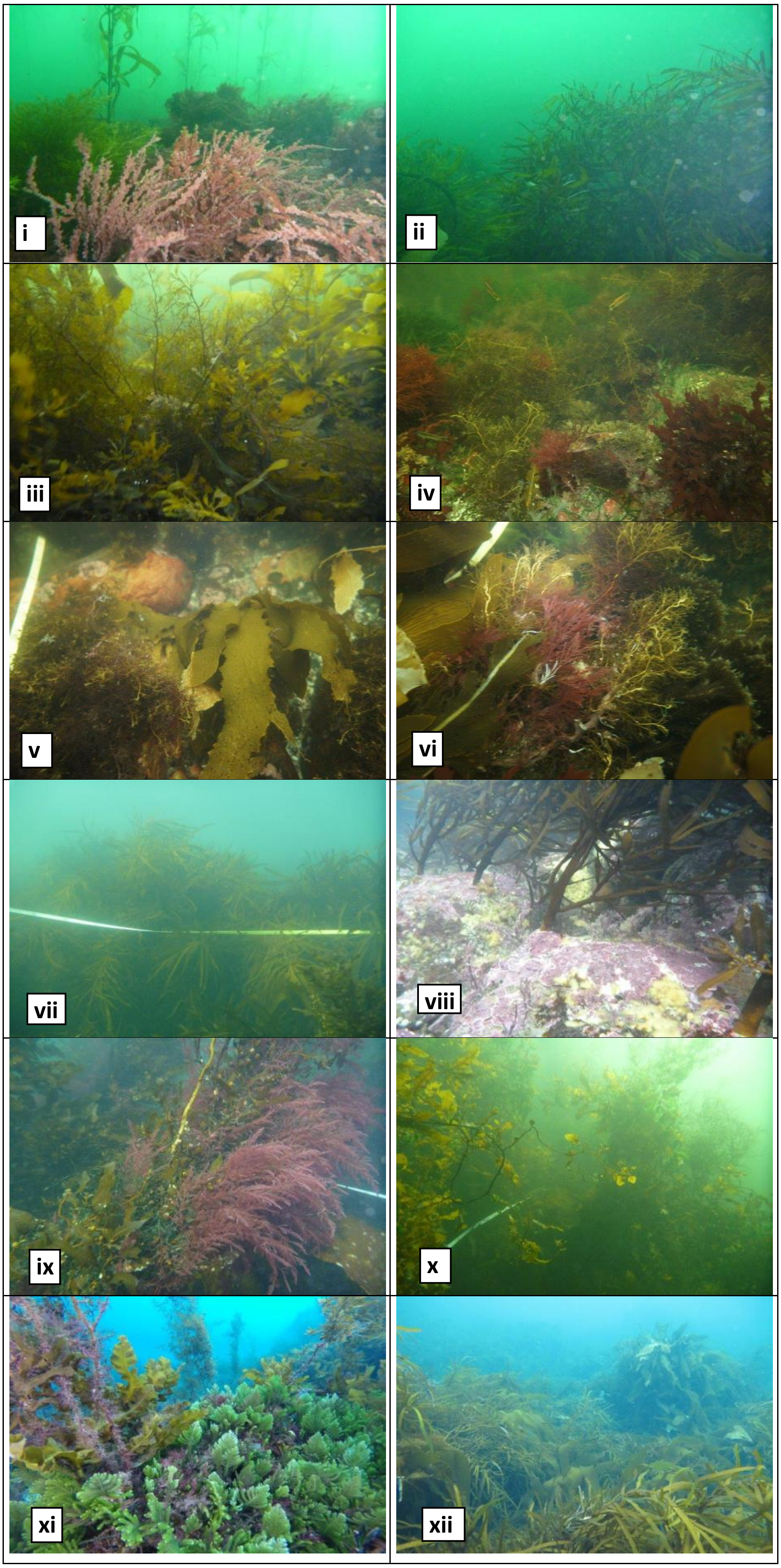


**Figure 23. Imagery depicting typical features of different assemblage types observed during the survey: (i) Actaeon Island mixed algae; (ii) Actaeon Island Phyllospora; (iii, iv) Ninepin Point mixed algae; (v, vi) Tinderbox mixed algae; (vii, viii) Storm Bay and Channel; (ix, x) Channel sheltered bay, mixed algae; (xi, xii) Maria Island mixed algae.**

# Discussion and conclusions

*Time series trends*

Analysis of data from MPA monitoring sites for the period 1992-2015 showed no consistent patterns of broad-scale change in macroalgal community structure over time. While key functional groups and dominant taxa showed some variability, these tended to be fluctuations rather than directional change.

Abundance of nutrient indicator species was low and variable over the 1992-2015 period, and there was no evidence of an increasing trend over time. There were occasional peaks in abundance of nutrient indicator species, but these were not consistent within each region or between years. It is notable that the frequency and magnitude of peaks in abundance of nutrient indicator species were observed at the Maria Island sites which are remote from salmonid farming operations (> 50 km).

One of the few changes identified in the time series analysis was at Central Tinderbox. At this site, there has been a considerable increase in cover of *Caulerpa* spp. (particularly *C. trifaria*) since 2004. Prior to 2004, *Caulerpa* spp. abundance at this site averaged < 10%, before an increasing trend that reached a maximum of 65% in 2007. Since 2007, *Caulerpa* spp. cover has been maintained at around 40%. Reasons behind this change remain speculative, but there is no documented evidence in the scientific literature to suggest that *Caulerpa* spp. respond to increases in nutrient levels. One possible explanation relates to changes in sand or sediment deposition at this site, since *Caulerpa* species tend to flourish on the reef/sand edge. It is notable that changes were also identified at Central Tinderbox in the previous 2003 assessment (Crawford et al. 2006), when an increase in abundance of *Undaria pinnatifida* was detected at this particular site. Given that *U. pinnatifida* tends to establish in disturbed habitats (Valentine and Johnson 2003), the increase in cover of *Caulerpa* spp. might reflect a response to sediment scour disturbance on the reef edge, although grazing effects by sea urchins (*Heliocidaris eryththrogramma*) are another potential source of disturbance at this site.

Analysis of macroalgal community structure using multivariate analysis was largely consistent with the patterns described above for individual taxa and functional groups. While variation in community composition was apparent, there was no strong directional change and individual sites tended to consistently form relatively discrete groups in MDS analyses. SIMPER analysis provided further evidence of a lack of consistent change in algal communities. Where community differences were apparent, these were largely driven by taxa recorded at low cover levels during one survey period but not recorded in the other period. The main exceptions to this pattern were at Central Tinderbox (attributable to changes in *Caulerpa* spp. abundance) and Point Home (attributable to sea urchin grazing).

It is also possible that some of the community level differences identified could be explained by difficulties in accurately identifying particular algal groups *in-situ*. For example, some red algal species are difficult to identify *in-situ*, and there is some risk that mis-identifications could occur between years, particularly when surveys are undertaken by different personnel. This may explain the prominence of the 'Unidentified algae (filamentous/foliose red)' category in the SIMPER analysis that was evident at several sites.

Based on outputs from univariate and multivariate analyses, one of the main consistent trends was of significant variation between sites within each region. Investigating the underlying reasons behind such differences was beyond the scope of the current study, but is likely to be a result of the complex interplay between physical and biological factors in structuring algal communities (Dayton 1985; Schiel and Foster 1986; Connell 2007). The apparent variation in macroalgal community structure in south eastern Tasmania, in particular, is not unexpected, given the spectrum of physical factors that are known to vary over small spatial scales in this region. For example, over relatively small spatial scales there is considerable variation in key factors influencing algal distribution including rock type, wave exposure, background nutrients, sedimentation, light attenuation (e.g. tannin from riverine inputs) and grazing intensity. Although the current study did not demonstrate effects of elevated nutrients on macroalgal assemblages, it highlights the complexities underlying macroalgal community structure in this system. Any future assessment of elevated nutrients therefore needs to consider nutrients as one factor amongst a range of other structuring forces, necessitating careful interpretation of monitoring results.

*Site characterisation and reef health in 2015*

Using a range of univariate, multivariate and qualitative analyses, the sites surveyed in 2015 were characterised. The monitoring sites included existing MPA monitoring sites and additional sites chosen to reflect recent or planned developments of salmonid farming in the region. Based on the data collected during the autumn 2015 survey, there was no overall indication of reduced health of macroalgal communities. One of the main indicators of elevated nutrients, opportunistic green algae, was recorded in low numbers across all sites, and was equally abundant at Maria Island sites compared with the Tinderbox/Ninepin Point areas.

Abundance of macroalgae as assessed via functional groupings and abundant taxa also provided no indication of reduced community health. Crustose coralline algae, which is known as an important habitat for recruitment of invertebrates including abalone (Shepherd & Turner 1985, Daume et al. 1999), was a prominent component of the understorey community at most sites surveyed.

Multidimensional scaling (MDS) provided a useful way of depicting the variation between survey sites in 2015. This analysis showed clear separation of groupings that could be broadly linked to wave exposure and the generalised scheme of Tasmania algal assemblages devised by Edgar (1984). Importantly, this analysis showed that the addition of new sites provided important coverage of two habitat types that were not well represented in the existing MPA dataset. These habitat types included sheltered bay mixed algal communities and mixed algal communities on moderately and sub-maximally exposed coasts. Inclusion of these community types complemented the MPA monitoring dataset and improved their representation amongst the suite of available monitoring sites.

*Comparison with previous studies*

The results of the current study were consistent with the findings of Crawford et al (2006), which found no consistent evidence of changes in macroalgal assemblages attributable to salmonid farms.

A more recent study by IMAS in 2008 in the D'Entrecasteaux and Huon, however, demonstrated changes consistent with salmonid farming impacts (Oh et al. 2015). Using a gradient approach, Oh et al. (2015) examined macroalgal community structure at four fixed distances from salmonid farms (100 m, 400 m, 1 km, 2 km and 5 km). The study showed that macroalgal assemblages differed significantly between sites immediately adjacent (100 m) to fish farms and reference sites at 5 km distance, with sites at 400 m and 1 km exhibiting intermediate characteristics. The main impacts included increased cover of nutrient indicator species including *Chaetomorpha* spp. near fish farms at wave-exposed sites and increased cover of filamentous green algae near sheltered farms. While impacts on opportunistic species were demonstrated, cover of canopy-forming brown algae appeared unaffected by fish farm impacts (Oh et al. 2015). Overall, the results of Oh et al. (2015) suggested nutrient enrichment from fish farms affected particular components of subtidal reef communities to a variable distance, and at scales of hundreds of metres, but rarely kilometres. These findings were consistent with previous assessments of algal enrichment from salmonid farm impacts in other parts of the world, where algal enrichment has been demonstrated to occur on a scale of hundreds of metres (Dalsgaard and Krause-Jensen, 2006; Sanderson et al. 2008).

The apparent discrepancy between the results of the current study and those of Oh et al. (2015), predominately in relation to opportunistic green algal abundance, most likely lies with the spatial distribution of survey sites and differences in survey timing. Rather than the gradient approach used in the Oh et al. (2015) study, the current study was designed to examine broad scale impacts and most sites were located at considerable distance from fish farms (see Table 2). There was no practical scope to use a gradient approach to analysis in the current study, since the vast majority of sites were at least 2 km from fish farms.

Differences in survey timing also limit meaningful comparisons between the current study and Oh et al. (2015). Nutrient indicator and ephemeral species are typically highly seasonal (e.g. Nelson et al. 2015, Teichberg et al. 2009), and more likely to be encountered in the summer months when the Oh et al. (2015) study was undertaken. It is therefore likely that the low abundance of ephemeral and opportunistic algal species observed in the current survey may at least partially be explained by the autumn timing of the current survey.

Another point of discussion relates to the possibility raised by Oh et al. (2015) that impacts may have already occurred throughout the whole farming region, including distant sites (i.e. > 5 km from farms). Based on the results of the current study and lack of consistent changes since 1992, it appears that this scenario is unlikely.

*Potential improvements and limitations of survey design and methodology*

Since the majority of MPA surveys have been conducted in autumn, this timing provided the best comparative data for examining broad scale impacts in the current study. However, future surveys should also include assessments in the spring/summer period, to better capture opportunistic nutrient indicator species.

Potential improvements also lie with increasing the spatial coverage of monitoring sites. While the broad scale arrangement of sites in the current survey sensibly included sites located at considerable distance from salmonid farms (generally > 2 km), inclusion of additional sites in much closer proximity to fish farms would greatly assist interpretation of salmonid farm impacts. Given the results of Oh. et al. (2015) and others, this would include more sites located < 0.5 km from sites, wherever practical.

A factor contributing to the limited spatial coverage captured in the current study is that the 'Edgar Barrett' method is resource intensive. Being an overall biodiversity assessment capturing abundance of macroalgae, fish and invertebrates, the method requires considerable underwater dive time. While a slightly modified 'Edgar-Barrett' method was employed in the current study, 4-5 hrs underwater dive time was required for each study site. The considerable dive time required places constraints on the number of sites and overall spatial coverage that can be reasonably achieved in a dive program.

One potential option for improving spatial coverage would be to develop a more rapid targeted approach to assessment of algal species of most concern, i.e. nutrient indicator and canopy-forming species. If a reliable, rapid assessment method could be developed, where sites could be surveyed in < 1 hour diver time, there would be far greater scope for more comprehensive spatial coverage of potential salmonid farm impacts. Development of a targeted approach to assess nutrient indicator species should also explore options for improved quantification of this particular group. Many of the nutrient indicator species are epiphytes (e.g. *Chaetomorpha billardieri*), that are often found growing mid-water amongst the algal canopy, rather than occurring on the reef substrate. While the quadrat method used in the current study provided some indication of epiphytic growth, it is recommended that alternative assessments are explored for quantifying this type of algal growth.

Despite some limitations when examining salmonid farming impacts, the 'Edgar-Barrett' method also has enormous benefits and should continue to form part of any future broad scale monitoring program. Importantly, the overall biodiversity assessment that the 'Edgar-Barrett' method provides allows the opportunity to examine unanticipated impacts on rocky reef communities. Furthermore, the suite of monitoring sites and long term dataset using this consistent methodology provides a valuable reference against which potential future changes can be assessed in the region.

*Overall summary*

Based on the time series analysis and the characterisation of sites from the 2015 survey, there was no strong evidence of broad scale changes in macroalgal assemblage's attributable to salmonid farming activities. Although the survey timing was not likely to capture peaks in abundance of nutrient indicator species, there was certainly no evidence of secondary effects on perennial species (e.g. canopy-forming brown algae).

A number of options for potential improvements were identified in the study. These primarily include increasing the spatial and temporal scope of monitoring and consideration of a more integrated approach to monitoring through inclusion of targeted surveys of nutrient indicator species.

# Implications

This study has provided an improved understanding of patterns of change on rocky reef communities in southeast Tasmania. The study provides an important contribution to continuation of the long term MPA dataset that can be used to assess broad scale changes to rocky reef communities in southeast Tasmania. Incorporation of new reef monitoring sites adjacent to recent or planned salmonid farm expansions also complements the MPA monitoring program, providing an important baseline and improved suite of assemblage types that can be used to investigate potential impacts of salmonid farming activities.

The current study also provides important insights into many of the issues surrounding effective monitoring of potential nutrient related impacts on macroalgal communities. For future monitoring activities, consideration should be given to broadening the spatial and temporal scope of the monitoring program, and developing a more targeted approach to tracking the abundance of nutrient indicator species. See Recommendations section below.

# Recommendations and further development

One of the main limitations associated with the current study relates to the restricted spatial and temporal scope of reef monitoring. In particular, timing surveys to coincide with expected periods of ephemeral algal growth would improve understanding of potential nutrient related impacts on macroalgal communities. Incorporating additional sites in closer proximity to salmonid farming operations would also greatly assist interpretation of potential salmonid farming impacts.

One potential option to more cost effectively increase the spatial and temporal scope of algal monitoring activities would be to develop a more targeted survey method that focuses on the algal taxa that are recognised as indicators of nutrient enrichment (e.g. opportunistic green algae as identified in the current study). A rapid survey of nutrient indicator species could potentially involve assessment of algal epiphytes colonising the dominant canopy-forming algae at each site, with potential for inclusion of multiple depth ranges and different canopy-forming species.

Assuming that an effective rapid assessment method can be defined, a sensible future monitoring approach would be to implement a targeted algal survey on a more frequent basis (e.g. 6 monthly), with the more detailed ‘Edgar-Barrett’ surveys conducted over longer time scales (e.g. every 3-5 years). While a targeted algal survey method will increase cost effectiveness of algal monitoring, including the ‘Edgar Barrett’ method in future monitoring activities is still considered vital. Proliferation of nutrient indicator species may eventually lead to structural change in macroalgal communities and detection of such changes necessitates the more detailed macroalgal assessment provided by the ‘Edgar Barrett’ method. There is also considerable value in continuing to monitor the long-term MPA monitoring sites for the purpose of identifying broad scale changes in reef communities.

The rationale for the approach defined above is that initial impacts would be expected to occur with ephemeral, nutrient indicator species (e.g. Arevalo et al. 2007, Oh et al. 2015, Russell et al. 2005) and these would be the focus of targeted surveys. In the event that nutrient indicator species became more widespread and persistent, then secondary effects on other components of the algal community (e.g. canopy-forming algae) would be more likely to occur. Such changes would be detected using the ‘Edgar Barrett’ method used in the current study.

# Extension and Adoption

The study used a collaborative approach, with field work and data analysis carried out by Aquenal and Marine Solutions. Scientific support and supply of the MPA dataset was provided by IMAS. A special condition of this project was to ensure linkages to Project 2015-024 "Managing ecosystem interactions across differing environments: building flexibility and risk assurance into environmental management strategies" (Catriona Macleod – Principal Investigator). A number of meetings have been held during the project period to ensure that the basis of this report's findings will contribute significantly to the development of practical research methodologies for Project 2015-024, as well as dissemination of information on the status of reef communities to a wider stakeholder group. This project will inform commercial and recreational fishing organisations (i.e. Tasmanian Abalone Council and Tarfish), the Tasmanian aquaculture industry and other relevant stakeholder groups interested in the health of Tasmania's rocky reef communities.

# Project materials developed

At each site video footage of the 5 m transect contour was taken, serving as a useful visual archive against which future changes could be assessed. The video footage was also used to produce a summary video for presentation purposes. The video includes:

- Summary of sites surveyed
- Brief description and footage of methodologies employed during the survey
- Short video of each of the unique macroalgal assemblage types that were identified during the survey

The video is approximately 7 minutes in duration and is suitable to upload to YouTube.

# Appendices

## List of researchers and project staff

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Dr Jeff Ross – Chief-Investigator, IMAS

Dr. Joe Valentine - Co-Investigator, Aquenal Pty Ltd.

Dr. Mark Jensen – Researcher, Marine Solutions

Dr. Craig Sanderson, Researcher, Aquenal Pty Ltd.

Laura Smith – Researcher, Marine Solutions

Elizabeth Oh – Researcher, Aquenal Pty Ltd.

Ian Cooksey – Researcher, Marine Solutions

Jeremy Lane – Researcher, Aquenal Pty Ltd.

## Intellectual Property

There is no specific IP associated with this project.

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