Rapid visual assessment surveys on rocky reefs in the Derwent Estuary

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May 2021

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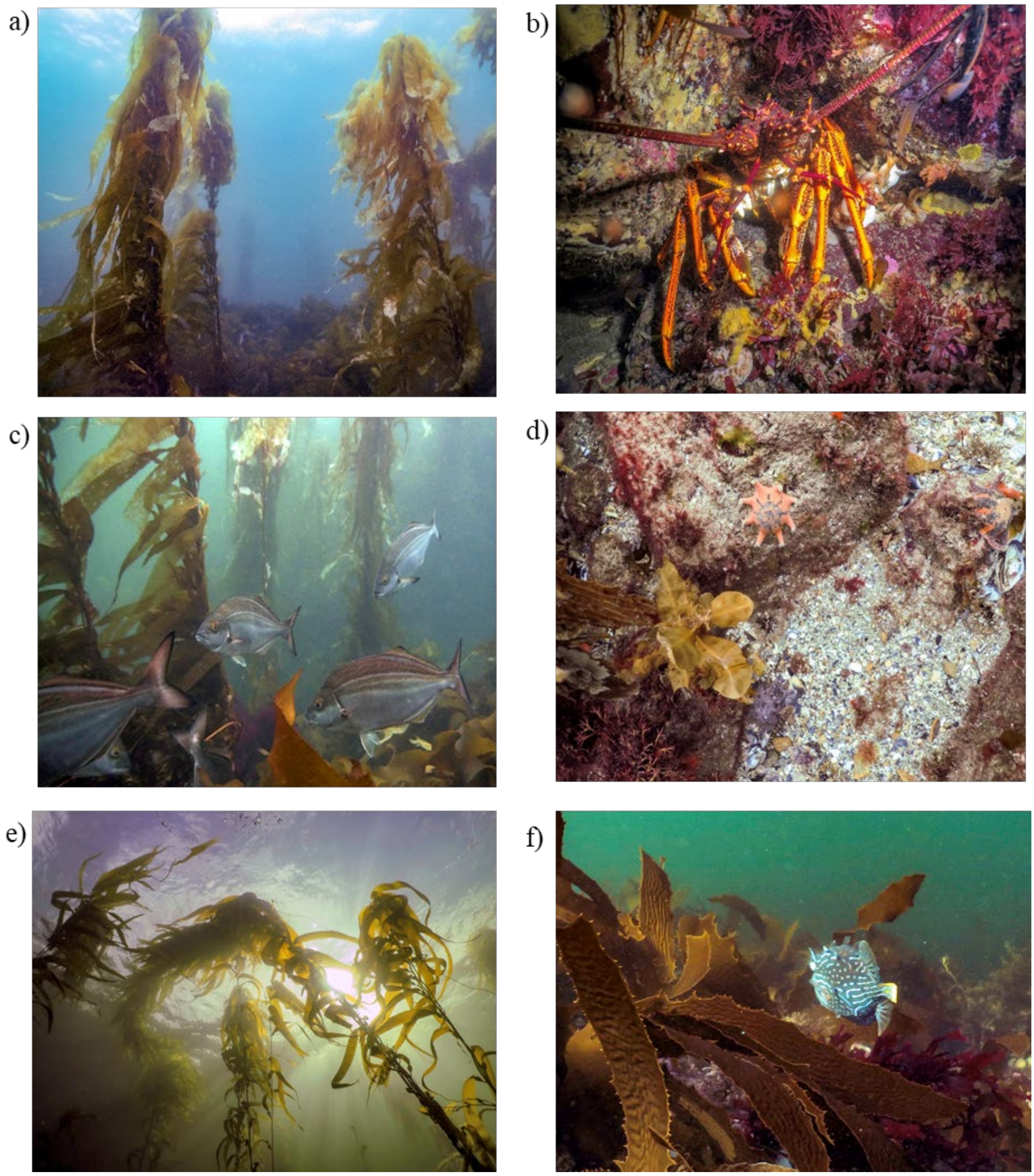
Summary

In 2019, the Derwent Estuary Program (DEP) engaged IMAS to assess the functional status of inshore temperate reef ecosystems within the Derwent estuary using the rapid visual assessment (RVA) methodology. The overall aim of these surveys was to examine whether the rocky reef communities could be used as a biological indicator of nutrient availability. The motivation for this study was the planned expansion of salmon farming in Storm Bay and the desire by the DEP to better understand reef condition in the Derwent estuary prior to this expansion. The RVA surveys provided valuable information on reef structure and function within the Derwent estuary, particularly on the biological response of reef systems to nutrient availability. All sites surveyed as part of this study had canopy cover of above 30%, with higher canopy cover generally observed in March compared to July. Our analysis suggested that reef at both Bellerive and Tranmere was exposed to low-moderate nutrient enrichment, as indicated by the relatively high levels of epiphytic algae observed at these sites, particularly in the March survey. Enrichment levels were not considered to be severe at Bellerive and Tranmere for several reasons. Firstly, macroalgal canopy is present at both sites in higher abundance than all other sites within the estuary. Secondly, the moderate levels of epiphytic algae that were observed in March appeared to be transient, with negligible epiphyte cover observed in July, and lastly, epiphytic algae was the only enrichment parameter to be present in significant cover. These surveys indicate that RVA provides a good indication of when reefs are subject to higher nutrient availability, with surveys conducted in 2020 providing a scientifically robust and important snapshot of reef function in the Derwent estuary. These surveys can therefore be used to benchmark any future change that may occur within this system.



Images:
a) *Macrocystis pyrifera* (giant kelp) at Lucas Point in March 2020,
b) *Jasus edwardsii* (southern rock lobster) at Lucas Point in March 2020,
c) *Latridopsis forsteri* (bastard trumpeter) swimming amongst the giant kelp at Lucas Point in March 2020,
d) Invertebrate and substrate at Bellerive Bluff in March 2020,
e) *Macrocystis pyrifera* (giant kelp) at Blackmans Bay in July 2020,
f) Male *Aracana aurita* (Shaw's cow fish) at Crayfish Point in July 2020.
Images: a-c) Olivia Johnson, d) Samuel Kruimink, e-f) Gabrielle Walley

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Introduction

The Derwent estuary in Southern Tasmania is a large (approx. 200 km^2) partially enclosed body of water that supports many aquatic habitats such as wetlands, saltmarshes, seagrass beds and rocky reefs. Rocky reefs cover approximately two percent of the total area of the Derwent estuary, primarily in the lower regions (Lucieer et al. 2007, Whitehead et al. 2010). Whilst these rocky habitats cover a relatively small area of the Derwent, they support a substantial proportion of the overall biodiversity of the estuary (Barrett et al. 2010, Coughanowr et al. 2015). The Derwent estuary is subject to a range of both natural and anthropogenic inputs. Sewage treatment plants and urban run-off result in direct anthropogenic nutrient additions into the estuary, while fresh-water inflows from the river Derwent will bring nutrients from catchment run-off, including inputs from agriculture (Wild-Allen & Andrewartha 2016). As well as natural and anthropogenic nutrient inputs, nutrient status is also dictated by hydrodynamic factors including tidal currents and residual circulation that effect nutrient dispersal (Wild-Allen & Andrewartha 2016).

Localised changes in water quality, and more specifically nutrient availability, can drive rocky reef algal community structure. If the nutrient status of a coastal ecosystem changes, then biological shifts may manifest, with subsequent effects on ecosystem function (White et al. 2021). There are several common ecological responses of temperate reef ecosystems to increased nutrient availability. The most extreme is the loss of canopy forming kelp and a proliferation of turfing algae (Eriksson et al. 2002, Connell et al. 2008). Other opportunistic algal types with fast growth rates, rapid reproduction and high demand for nitrogen also respond positively to nutrient enrichment (Oh et al. 2015). These include opportunistic green algae species from the genera *Ulva*, *Cladophora* and *Chaetomorpha* (Lavery & Mccomb 1991, Nelson et al. 2008), red algae such as *Asparagopsis armata* (Paul et al. 2006, Mata et al. 2010), along with several filamentous and epiphytic algal species (Oh et al. 2015). While rapid growth algae can initially act as a nutrient sink, effectively buffering the ecosystem from the effects of nutrient enrichment, under eutrophic conditions, these algae can form dense blooms, significantly altering ecosystem structure and function (Nelson et al. 2008).

Through FRDC project 2015-024, the Institute for Marine and Antarctic Studies (IMAS) developed and trialled methodology aimed at the detection of nutrient enrichment on reef ecosystems in regions of salmon aquaculture expansion. One of the methods developed through FRDC 2015-024 includes a targeted reef assessment technique for detection of nutrient enrichment on reef ecosystems – the "Rapid Visual Assessment" method (RVA) (Macleod et al. under review), which was subsequently validated in the southern D'Entrecasteaux Channel (White et al. 2021). This method involves the collection of multiple parameters relating to reef ecosystem function from quadrats at a fixed location. As nutrient enrichment favours the dominance of some functional groups over others, multivariate data analysis techniques can be used to track changes in ecosystem in relation to nutrient enrichment over time.

The method has since been adopted as a key component for reef monitoring through environmental licensing of salmon leases in Storm Bay, with logical extension into the Derwent. In 2019, the DEP engaged IMAS to undertake a rapid visual assessment (RVA) to assess the functional status of inshore temperate reef ecosystems within the Derwent estuary. The overall aim of these surveys was to examine whether the rocky reef communities could be used as a biological indicator of nutrient availability, with the RVA method considered ideal for this application. The motivation for this study was the planned expansion of salmon farming in Storm Bay and the desire by the DEP to better understand reef condition in the Derwent estuary prior to this expansion. Reef surveys conducted for the DEP as part of this report were aligned directly with the Storm Bay sampling for FRDC project 2019-131 so that they could be integrated into the larger dataset to provide regional context into the future.

Methods

From north to south the six sites surveyed were: Bellerive Bluff, Tranmere Point, Crayfish Point, White Rock, Blackmans Bay and Lucas Point (Figure 1, Table 1). The sites vary in exposure and oceanic influence, as well as proximity to anthropogenic nutrient sources in the Derwent. Lucas Point and Blackmans Bay are the most oceanic of the sites and periodically influenced by events of high swell. In terms of nutrient inputs, the River Derwentis currently the greatest source of nitrogen into the estuary (56%), with high levels of urbanisation in the lower catchment and the upper catchment heavily farmed (Wild-Allen & Andrewartha 2016). Sewage treatment plants account for 35% of the nitrogen inputs to the Derwent estuary and are likely to influence several sites (Wild-Allen & Andrewartha 2016).

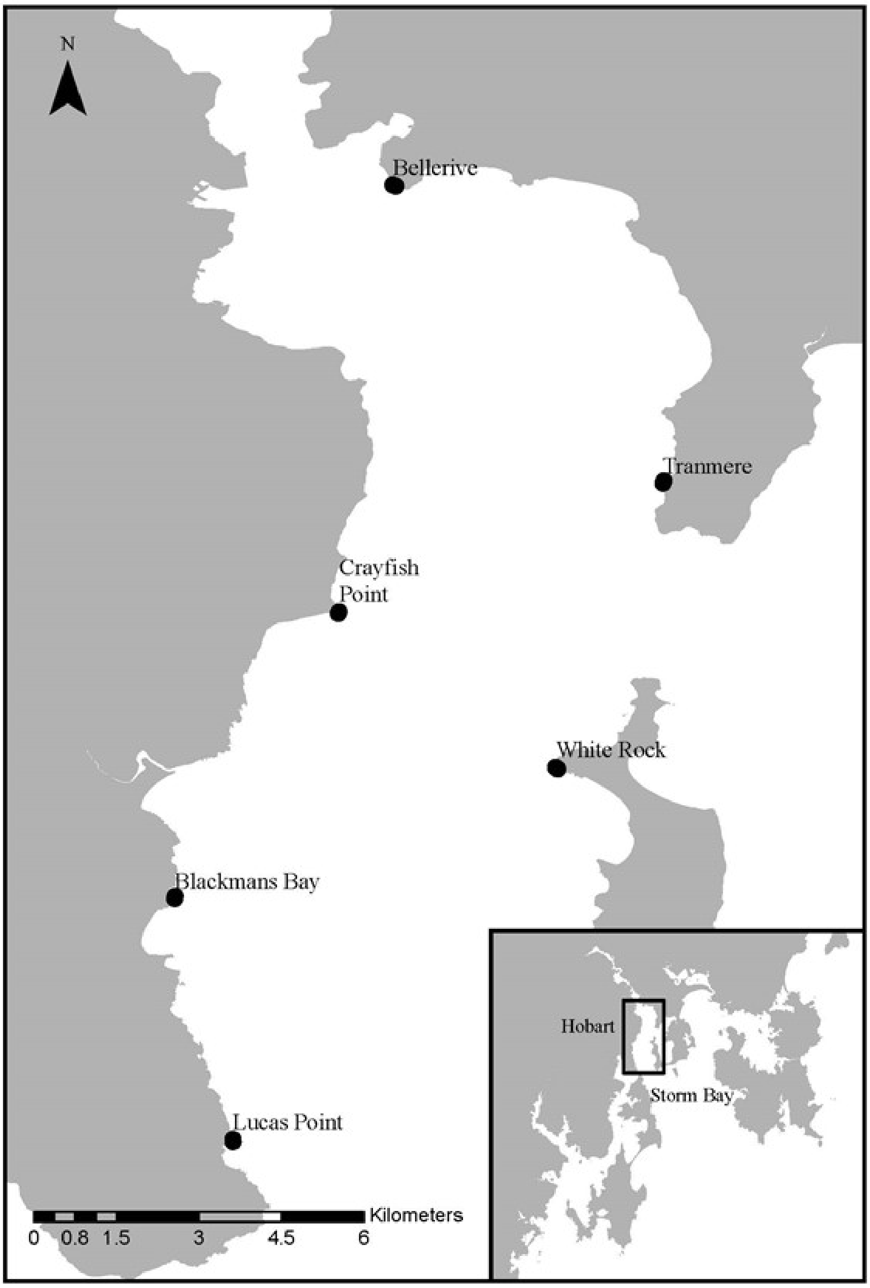

Figure 1 Map of the six rapid visual assessment sites undertaken by IMAS for the Derwent estuary monitoring program

Table 1. Waypoints for each of the six sites established and surveyed by IMAS (WGS 1984)

Site	Latitude	Longitude
Bellerive Bluff	-42.882	147.36521
Tranmere Point	-42.93075	147.40934
White Rock	-42.97714	147.39182
Crayfish Point	-42.95174	147.35646
Blackmans Bay	-42.99857	147.32958
Lucas Point	-43.03791	147.33908

Sites were surveyed in the first week of March in 2020 and then again in the last week of July and first week of August of the same year. RVA surveys were undertaken at all six sites. This method uses 15 functional parameters assessed within a 1 m^2 quadrat *in-situ* by divers using SCUBA. Of the 15 parameters, 10 assessed broad structural parameters associated with ecosystem function (i.e. 4 assessed the condition of the macroalgal canopy, 4 assessed the condition of the substrate and 2 related to trophic effects), while 5 related solely to enrichment responses. Broad functional parameters included percentage total canopy cover, sub-canopy brown, green and red algal cover, turfing algae cover, pink and red encrusting algal cover, sponge cover, levels of encrusting fauna, and numbers of the dominant major mobile invertebrates. Canopy cover was characterised into species and the dominant species of subcanopy algae and invertebrates were also recorded where possible except for red algae due to the diversity experienced in the study area. Enrichment parameters included percentage cover of epiphytic and filamentous algae, cover of opportunistic green (characterised by *Ulva*, *Cladophera* and *Chaetomorpha* in our sampling region) and opportunistic red species (characterised by *Asparagopsis armata* in our sampling region), along with the level of "dust" (sedimentation from the water column) covering the algae. The 15 parameters were incorporated into a scorecard, with all parameters assessed in each quadrat (Appendix 1).

A 50 m length of chain was embedded in the substrate to demarcate each site, along which 12 quadrats were assessed perpendicular and approximately 1.5 m distant from the chain. For each assessment, the quadrat was first installed, with a photograph taken for reference and archive. The diver then commenced the in-situ assessment using the scorecard (Appendix 1). All parameters were assessed in the full 1 m^2 quadrat, except for substrate parameters, which were sub-sampled using the 0.5m^2 subsection of the quadrat closest to the chain. The first two quadrats were assessed by both divers at each site for quality assurance of the data.

Patterns in functional parameters were investigated using the multi-variate software package PRIMER v7 (Plymouth Routines in Multivariate Research; Clarke and Warwick 2001) and its complementary software package PERMANOVA+(v7) (Anderson et al. 2008). To characterise reef function in the Derwent estuary (Section 1), a Bray-Curtis dissimilarity index was used to examine differences between samples and principal coordinates analysis (PCO) was undertaken to visualise patterns in data. The effect of site and sampling event was determined using PERMANOVA analysis, using a crossed design with both factors fixed.

Vector overlays using a Pearson correlation along with SIMPER analysis were used to identify key parameters driving trends in data. To investigate nutrient enrichment in Derwent estuary reef sites site means were calculated and differences across site and sampling event examined through vector and cluster analysis.

Results

Characterisation of Derwent estuary reef sites

Reef sites within the Derwent estuary were variable in terms of ecosystem function ($F_{5,140}$ = 8.96, P(perm) = 0.0001), with site differences based mainly on functional parameters relating to ecosystem structure, such as canopy cover, understorey and substrate (Figure 2, Figure 3). For example, Lucas Point tended to have much higher abundances of sponge and red understorey algae, whereas understorey brown algae was found in greater abundance at Crayfish Point (Figure 2, Figure 3Figure 3. Average percentage cover of a) canopy, b) understorey brown, c) understorey green and d) understorey red at all sites from the 2020 surveys., Figure 4). Overall, Crayfish Point and Lucas Point had the lowest degree of within-site variability (i.e. less highly dispersed through PCO and PERMDISP analysis), indicating a more consistent habitat and substrate between quadrats at these sites (Figure 2, Table 2).

Similarly, while average canopy was consistent across all sites surveyed at approximately 40-60% cover, there was a high level of variability between quadrats at some sites. Clusters for White Rock and Blackmans Bay were highly dispersed across the y-axis, which correlated with canopy cover (Figure 2). This suggests a patchy distribution of macroalgae within the Derwent estuary at these sites. We observed that *Ecklonia radiata* was the dominant canopy species at sites from Blackmans Bay north, although *Macrocystis pyrifera* (giant kelp) was also observed at the two southern sites, Lucas Point and Blackmans Bay (see general data summary in Appendix 2). At Lucas Point, *M. pyrifera* was the dominant canopy forming species, whereas it was present in much lower abundance at Blackmans Bay.

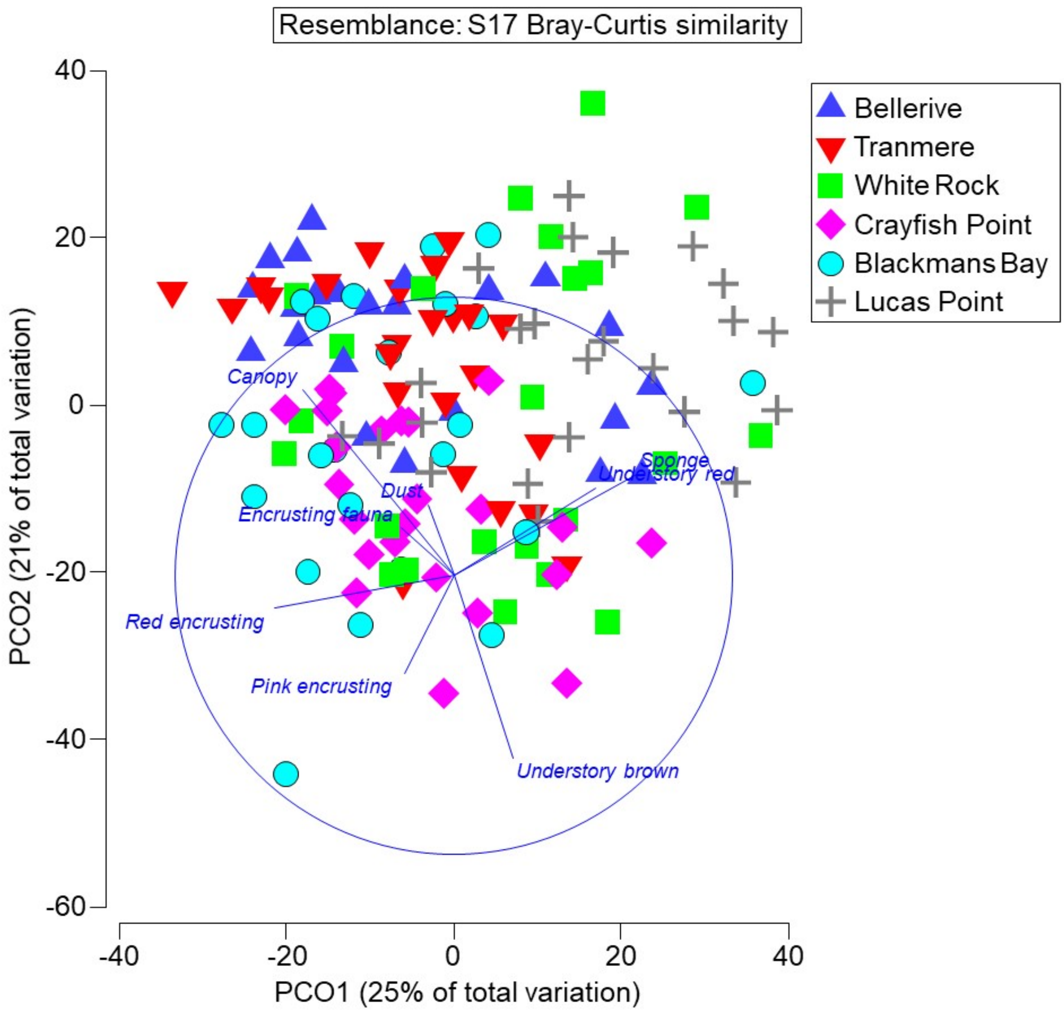

Figure 2 Principal coordinates analysis (PCO) on RVA parameter values across sites for the March and July 2020 sampling events. Each data-point represents an individual quadrat. Correlations between the first two principal coordinate axis and functional parameters are shown for parameters with r ⩾0.2. The length of the lines indicates the strength of the correlation, with the circle having a radius of 1.0.

Table 2. PERMDISP analysis examining the deviation of data from a centroid for each site. Note that the higher the average deviation the more dispersed the data

Site	Number of samples	Mean distance from centroid	Standard Error
Bellerive	23	27.87	1.80
Tranmere	24	28.06	2.24
White Rock	23	29.94	1.02
Crayfish Point	24	21.43	1.46
Blackmans Bay	23	29.94	2.02
Lucas Point	24	21.16	1.09

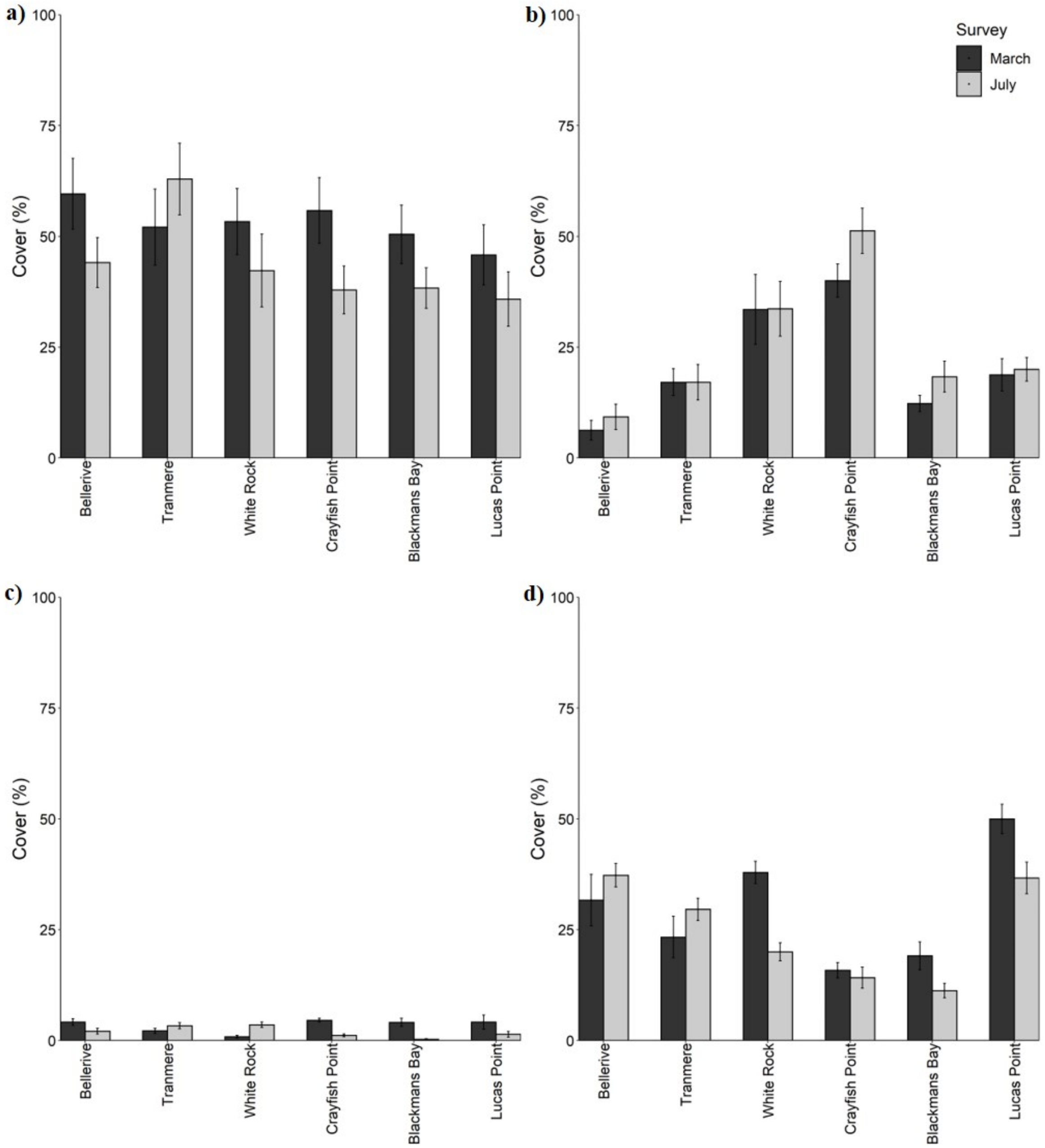

Figure 3. Average percentage cover of a) canopy, b) understorey brown, c) understorey green and d) understorey red at all sites from the 2020 surveys. The error bars represent the standard error of the mean.

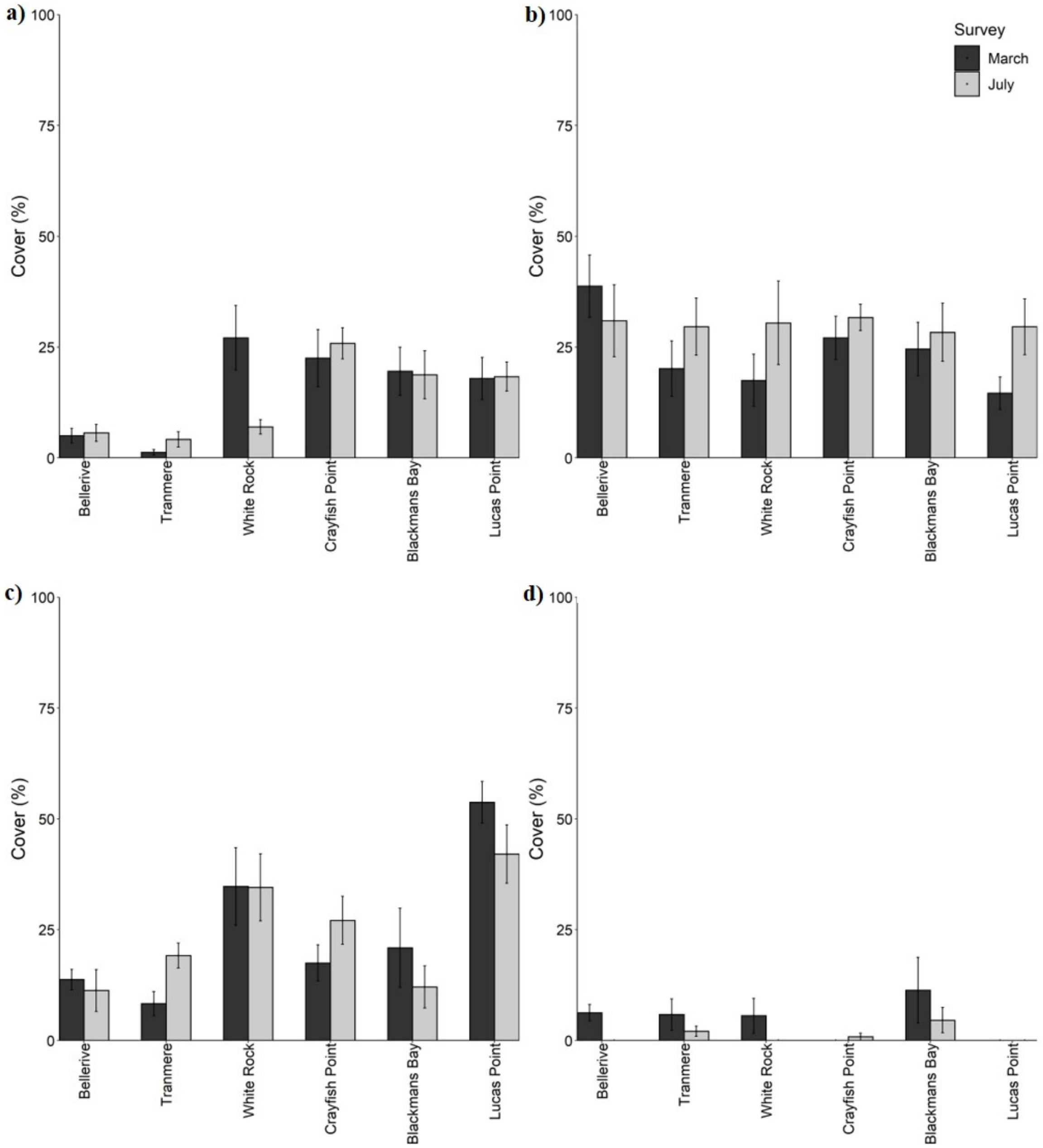

Figure 4. Average percentage cover of a) pink encrusting algae, b) red encrusting algae, c) sponge and d) turfing algae at all sites from the 2020 surveys. The error bars represent the standard error of the mean.

Changes in functional parameters were observed between March and July sampling events ($F_{1,140}$ = 4.59, P(perm) = 0.0005) (Figure 5) although, the way that parameters varied was highly site dependent, as indicated by the significant interaction term between site and sampling event in the PERMANOVA analysis ($F_{5,140}$ = 2.39, P(perm) = 0.0005). With the exception of Tranmere, lower canopy cover was observed at all sites in July compared to March (Figure 3). In March, understorey green algae was higher at the three western sites (Crayfish Point, Blackmans Bay and Lucas Point) and Bellerive, compared to Tranmere and

White Rock, where there was no difference between March and July (Figure 3). Variation between March and July surveys for all other function parameters relating to reef structure was highly site specific, with no real pattern observed.

Our multivariate analysis indicates that enrichment indicators were more likely to be present in quadrats in March compared to July, although this was also site dependent (Figure 5). Enrichment parameters such as epiphytic algae, nuisance green, and filamentous algae, as well as turfing algae were much more likely to be observed at Tranmere, Bellerive and to a lesser extent Blackmans Bay in March compared to July (Figure 5). These trends are explored further in the section below.

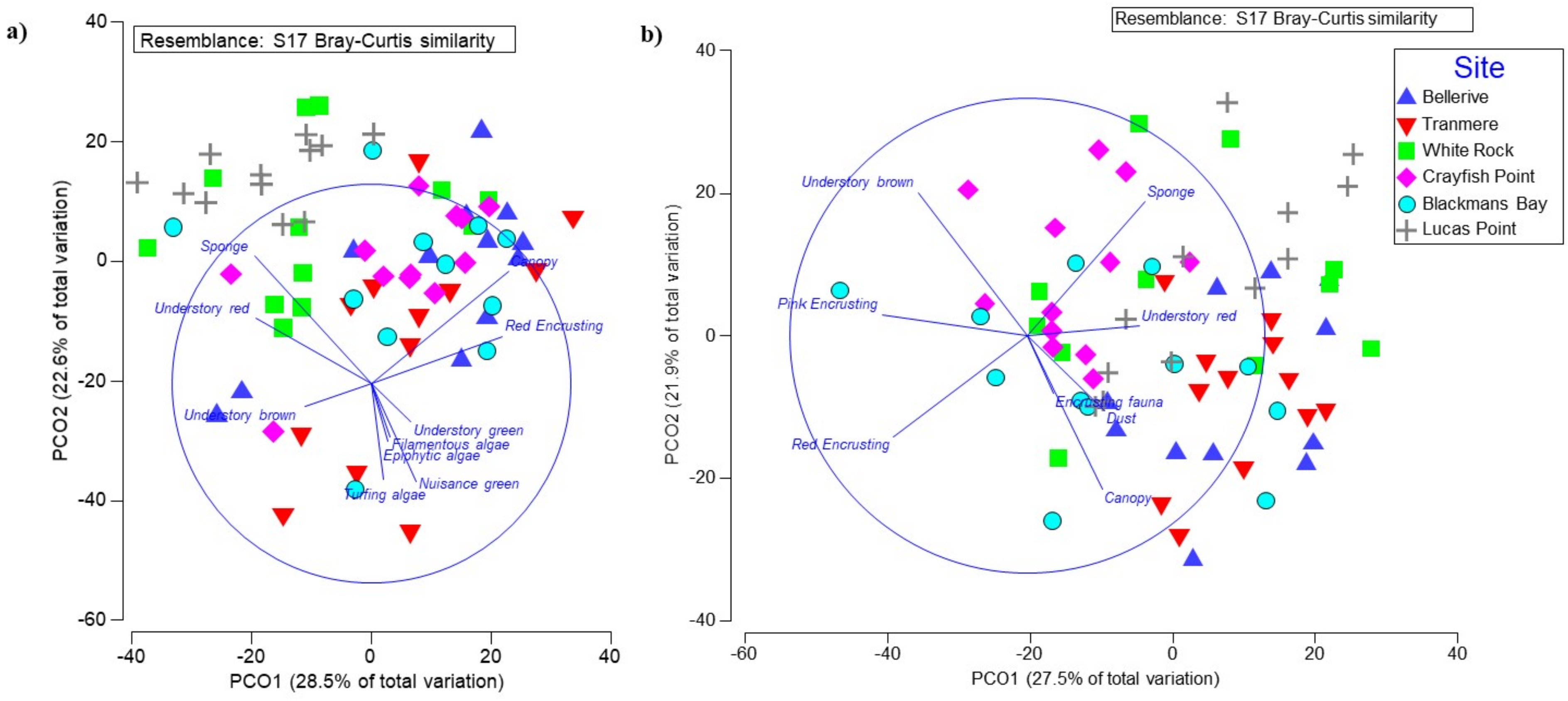

Figure 5 Principal coordinates analysis (PCO) on RVA parameter values across sites for the a) March and b) July sampling events. Each data-point represents an individual quadrat. Correlations between the first two principal coordinate axis and functional parameters are shown for parameters with r ⩾0.25. The length of the lines indicates the strength of the correlation, with the circle having a radius of 1.0.

Using RVA to detect nutrient enrichment in Derwent estuary reef sites

Of the six sites surveyed, nutrient enrichment was detected at Tranmere and Bellerive. These sites correlated with vectors for epiphytic algae, nuisance green algae, filamentous algae, turfing algae and dust through multivariate analysis (Figure 6). This trend was particularly evident in the March survey compared to the July survey (Figure 6). Of note, canopy cover covaried strongly with the enrichment parameters, indicating that in conjunction with elevated enrichment parameters, canopy cover was likely to be higher compared to other sites as well (Figure 6). Indeed, of all sites surveyed, Tranmere and Bellerive tended to have slightly higher canopy cover compared to other sites in the Derwent (Figure 3,Table 3).

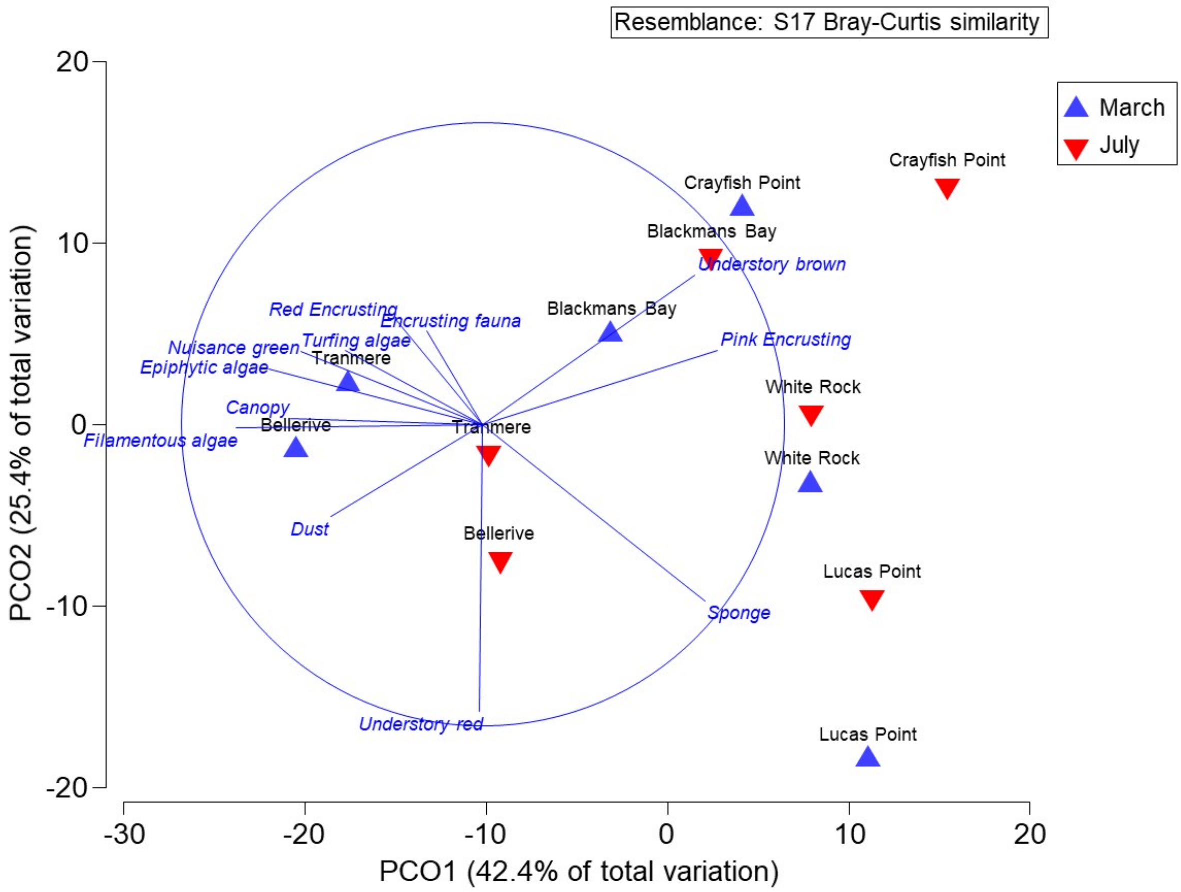

Figure 6. Principle coordinates analysis (PCO) on site-average RVA parameter values during the 2020 sampling events. Correlations between the first two principal coordinate axis and functional parameters are shown for parameters with r ⩾0.35. The length of the lines indicates the strength of the correlation, with the circle having a radius of 1.0

While the multivariate analysis provides us with an indication of sites subjected to nutrient enrichment, it does not necessarily give a measure of the degree of nutrient enrichment. For this, it is useful to examine the individual parameters. Epiphytic algae was by far the most conspicuous enrichment parameter, recording values of 20.4% and 17.9% in March at Bellerive and Tranmere respectively. However, values were considerably lower in July, being 2.3% and 3.8% at the same sites (Figure 7, Table 3). This indicates that the relatively high cover of epiphytic algae observed in March was transient; in the case of severe nutrient enrichment, we would expect to observe sustained high values for epiphytic algae. Consistent low levels of epiphytic algae were also observed at Crayfish Point (March: 3.9%, July 6.7%).

Filamentous algae and nuisance green algae were also observed at Bellerive and Tranmere in higher abundances compared to other sites, although average values were below 3% cover (Figure 7, Table 3). The exception to this is Blackmans Bay in March, where average values for nuisance green algae were 4.1% (Figure 7, Table 3).

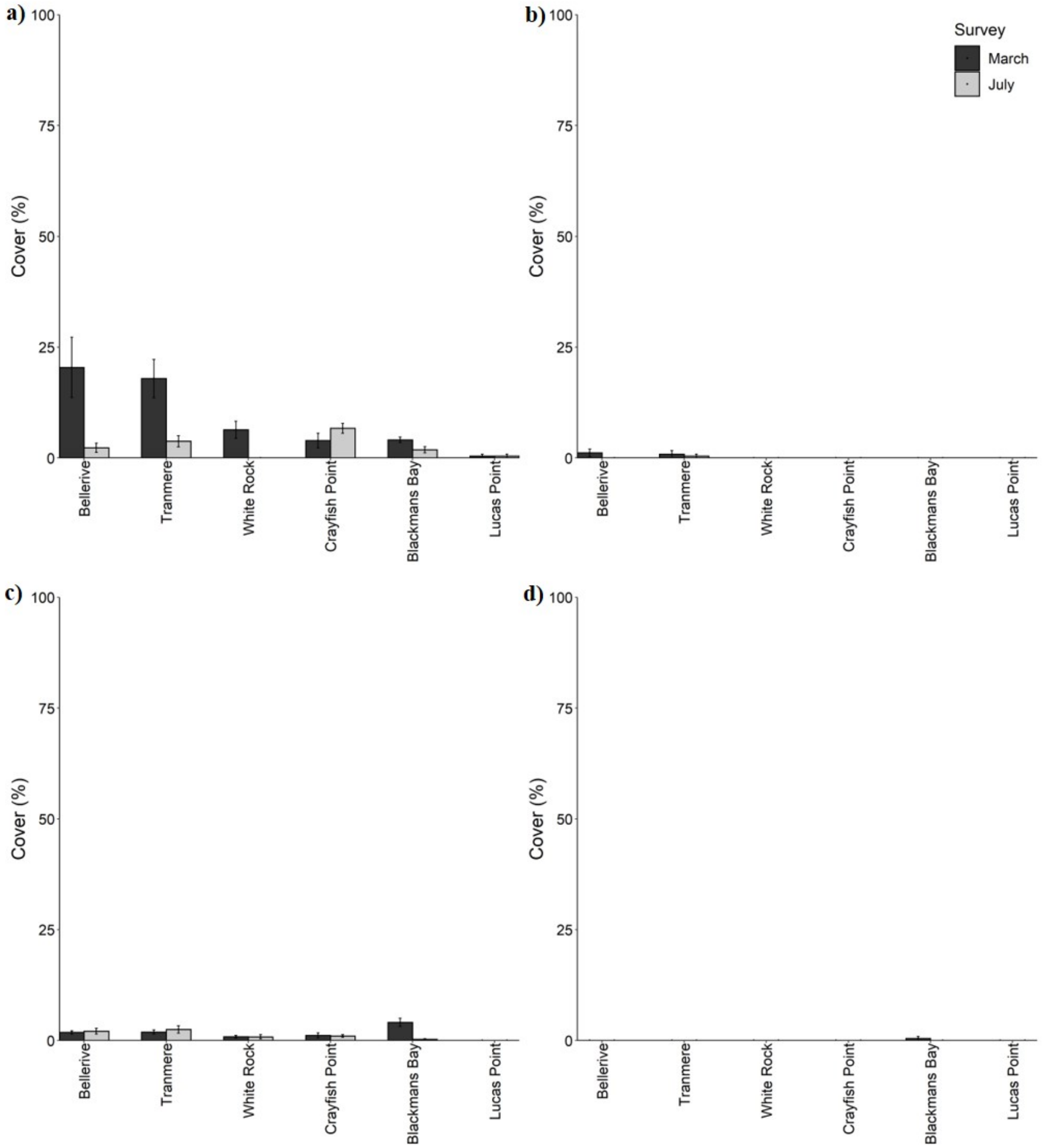

Figure 7. Average percentage cover of a) epiphytic algae, b) filamentous algae, c) nuisance green algae and d) nuisance red algae at all sites from the 2020 surveys. The error bars represent the standard error of the mean.

Table 3. Average percentage cover (± SE) for key functional parameters at all sites across 2020 surveys..

	Bellerive		Tranmere		White Rock		Crayfish Point		Blackmans Bay		Lucas Point	
March												
Canopy	59.6	±8.0	52.1	±8.6	53.3	±7.4	55.8	±7.4	50.5	±6.6	45.8	±6.8
Understory brown	6.3	±2.2	17.1	±3.0	33.5	±7.9	40.0	±3.7	12.3	±1.8	18.8	±3.6
Understory green	4.2	±0.8	2.2	±0.5	0.8	±0.3	4.6	±0.4	4.1	±0.9	3.3	±0.9
Understory red	31.7	±5.8	23.3	±4.7	37.9	±2.5	15.8	±1.7	19.1	±3.1	50.0	±3.3
Epiphytic algae	20.4	±6.8	17.9	±4.3	6.3	±1.9	3.9	±1.6	4.1	±0.6	0.4	±0.4
Filamentous algae	1.2	±0.8	0.8	±0.8	0.0	±0.0	0.0	±0.0	0.0	±0.0	0.0	±0.0
Nuisance green	1.8	±0.4	1.9	±0.5	0.8	±0.3	1.2	±0.5	4.1	±0.9	0.0	±0.0
Nuisance red	0.0	±0.0	0.0	±0.0	0.0	±0.0	0.0	±0.0	0.5	±0.5	0.0	±0.0
Pink encrusting	5.0	±1.6	1.3	±0.7	27.1	±7.3	22.5	±6.4	19.5	±5.4	17.9	±4.7
Red encrusting	38.8	±7.0	20.2	±6.2	17.5	±5.9	27.1	±4.9	24.5	±6.0	14.6	±3.6
Sponge cover	13.8	±2.3	8.3	±2.7	34.8	±8.7	17.5	±4.1	20.9	±8.9	53.8	±4.7
Turfing algae	6.3	±1.9	5.8	±3.5	5.6	±3.9	0.0	±0.0	11.4	±7.4	0.0	±0.0
July												
Canopy	44.1	±5.6	62.9	±8.1	42.3	±8.2	37.9	±5.4	38.3	±4.6	35.8	±6.1
Understory brown	9.3	±2.9	17.1	±4.0	33.6	±6.2	51.3	±5.1	18.3	±3.5	20.0	±2.7
Understory green	2.1	±0.6	3.3	±0.7	3.5	±0.6	1.2	±0.3	0.3	±0.2	1.4	±0.6
Understory red	37.3	±2.6	29.6	±2.5	20.0	±2.0	14.2	±2.4	11.3	±1.6	36.7	±3.6
Epiphytic algae	2.3	±1.0	3.8	±1.3	0.0	±0.0	6.7	±1.1	1.8	±0.7	0.4	±0.4
Filamentous algae	0.0	±0.0	0.4	±0.4	0.0	±0.0	0.0	±0.0	0.0	±0.0	0.0	±0.0
Nuisance green	2.1	±0.6	2.5	±0.8	0.8	±0.5	1.0	±0.3	0.3	±0.2	0.0	±0.0
Nuisance red	0.0	±0.0	0.0	±0.0	0.0	±0.0	0.0	±0.0	0.0	±0.0	0.0	±0.0
Pink encrusting	5.6	±1.9	4.2	±1.7	7.0	±1.6	25.8	±3.5	18.8	±5.4	18.3	±3.3
Red encrusting	30.9	±8.1	29.6	±6.4	30.5	±9.4	31.7	±3.0	28.3	±6.6	29.6	±6.3
Sponge cover	11.3	±4.7	19.2	±2.8	34.5	±7.6	27.1	±5.4	12.1	±4.7	42.1	±6.6
Turfing algae	0.0	±0.0	2.1	±1.1	0.0	±0.0	0.8	±0.8	4.6	±2.9	0.0	±0.0

Discussion

Overall, the RVA surveys provided valuable information on reef structure and function within the Derwent estuary, particularly on the biological response of reef systems to nutrient availability. In terms of maintaining ecosystem health and function, stable macroalgae canopy cover is key in temperate reef ecosystems (Bennett et al. 2016, Teagle et al. 2017). All sites surveyed as part of this study had canopy cover of above 30%, with higher canopy cover generally observed in March compared to July. In other regions where RVAs have been conducted (e.g. D'Entrecasteaux Channel, Storm Bay), there has also been a strong seasonal signal in the canopy data, with canopy cover higher in summer than in winter (White et al. 2021, Macleod et al. under review). With only two surveys (March and July), we are unable to determine if this is consistent within the Derwent estuary, although based on these initial findings, our data suggests canopy cover at these sites also follows a more regional seasonal trend.

The lowest values for canopy cover in March and July were recorded at Lucas Point, however, this is likely to be an artifact of the monitoring method. On both survey occasions, Lucas Point was observed to have a dense canopy of giant kelp (*Macrocystis pyrifera*) forming on the surface. As RVA uses benthic quadrats on the seafloor for quantifying cover, it doesn't provide an assessment of total canopy cover at sites where giant kelp is dominant. The canopy cover scored at Lucas Point largely represents the cover of *Ecklonia radiata* and *Phyllospora comosa* observed in quadrats. Although the method does not provide an assessment of giant kelp canopy cover, long-term changes in *E. radiata* or *P. comosa* canopy cover will reflect changes in the macroalgae community at this site. For example, dramatic increases in *E. radiata* or *P. comosa* could indicate a decline in giant kelp cover as more light penetrates through the surface supporting growth of these species (Wernberg et al. 2010). In south-eastern Tasmania, the relative cover of giant kelp is related to both nutrient availability and temperature (Mabin et al. 2019). Changes in giant kelp cover at this site may therefore reflect environmental perturbations occurring at a more regional level, as well as localised interactions with nutrient availability. Further investigation into more appropriate methods for monitoring giant kelp in the Derwent estuary may be worth considering.

The other structural parameter that varied between March and July surveys was understorey green algae. Many species of green algae will respond positively to light and nutrient stimulus. Therefore, an increase in productivity in the summer months, coinciding with increased light availability and seasonal nutrient supply, is not unexpected (Nelson et al. 2008, McGovern et al. 2019). Given the relationship between green algae growth and nutrient enrichment, large increases in understorey green algae cover at a site could indicate an increase in water column nutrient availability, particularly where observations coincide with an overall loss of brown algae cover (Stuart-Smith et al. 2008, Oh et al. 2015, Becherucci et al. 2018).

While our data demonstrates that RVA was a useful tool in understanding trends in macroalgal community function, these surveys also indicated that RVA on rocky reef in the Derwent estuary could be used as a valuable biological indicator of nutrient availability. Our data analysis suggested that reef at both Bellerive and Tranmere was exposed to moderate nutrient enrichment, as indicated by the relatively high levels of epiphytic algae observed at these sites, particularly in the March survey (Russell et al. 2005). Filamentous algae and nuisance green algae were also observed at these sites in higher levels compared to other sites, but overall, the percentage cover or these groups appears too low to have any long term effect on canopy cover.

Enrichment was considered to be moderate rather than high at Bellerive and Tranmere for several reasons. Firstly, macroalgal canopy is present at both sites in higher abundance than all other sites within the estuary. Loss of canopy will arise if a) canopy is effectively smothered by epiphytic or filamentous algae for a prolonged period (Morand & Merceron 2005, Oh et al. 2015) or b) canopy formers are unable to re-establish following a catastrophic die-back or removal event due to more rapidly responding species inhibiting recruitment on the substrate (Eriksson et al. 2002, Connell et al. 2008, Carnell & Keough 2014). Previous work in the D'Entrecasteaux Channel has found that even with 50-60% epiphytic or filamentous algae cover, macroalgae was still present at approximately 60% cover (Oh et al. 2015). Furthermore, low level nutrient additions have the potential to stimulate growth in perennial canopy forming macroalgal as well as more rapid nutrient responders (Carnell & Keough 2014). Therefore, it is not surprising to see greater canopy productivity at sites where there is higher environmental nutrient availability. Secondly, the moderate levels of epiphytic algae that were observed in March appeared to be transient, with negligible epiphyte observed in July. If the effects of nutrient availability are reversable in temperate reefs, any changes are likely to be short-term. It is when there are sustained effects that ecosystem function is likely to be significantly impaired (Morand & Merceron 2005). Lastly, epiphytic algae was the only enrichment parameter to be present in significant cover; if nutrient enrichment was severe, multiple enrichment parameters are likely be observed in high abundance simultaneously.

At Crayfish Point and Blackmans Bay there was the potential for very low-level nutrient enrichment. For example, in March, Blackmans Bay had comparatively high values of cover for nuisance green algae and Crayfish Point had sustained low levels of epiphytic algae, indicating a continuous nutrient source at this site. It would be unsurprising if these sites had some level of nutrient enrichment, given the proximity to sewage outfalls. For example, on average 1544 megalitres (ML) of domestic waste enters the Derwent estuary at Blackmans Bay each year (Coughanowr et al. 2015) and the Taroona outfall nearby to Crayfish Point discharges waste from the IMAS Aquaculture Facility. However, a longer timeframe for monitoring is needed to understand the more subtle variation in functional parameters in response to nutrient enrichment at these sites. What is evident, is the broadscale enrichment gradient that appears to be present from north to south. This gradient is heavily linked to exposure (i.e. greater wind and wave energy), with reef at Bellerive and Tranmere indicating higher levels of nutrient availability while having the lowest exposure. It is very hard to uncouple this interaction, with more sheltered sites naturally being more susceptible to nutrient enrichment as low water exchange often facilitates high primary productivity in elevated nutrient conditions (Valdivia et al. 2008).

While IMAS was funded by the DEP to deliver on one year of surveys, ongoing monitoring is currently being reviewed. If RVA monitoring was to be adopted into the DEP monitoring in the longer term, it would be ideal if it coincides with the Storm Bay project, which is currently undertaking RVA surveys at 28 sites throughout Storm Bay on a biannual basis. This alignment would allow for more regional context in terms of nutrient dynamics and the interaction between Storm Bay and the Derwent estuary. In terms of frequency, if resources are scarce, it would be recommended to reduce surveys to every second year and conduct two surveys within the year to obtain data around seasonality, rather than once-yearly surveys each year. A sustained presence across seasons is much more likely to have significant biological and functional effect on the reef than a bloom of algae that is transient in nature

(Keough & Quinn 1998, Gillanders & Kingsford 2002). Therefore, seasonal surveys within the same year is essential to understanding the magnitude of any nutrient response.

In terms of the number of the sites that are monitored within the Derwent estuary, our data suggests that each of the six sites surveyed for this study have something to offer in terms of the overall understanding of nutrient dynamics on reefs in the estuary. Bellerive and Tranmere both provide indication of what moderate nutrient enrichment might look like in terms of reef function. As such, if any of the other four sites presented similar relative functional parameters and became more similar (through multivariate analysis) to Bellerive and Tranmere, this would potentially indicate increases in nutrient availability. Blackmans Bay and Crayfish Point have potential for subtle enrichment effects corresponding to urban and sewage inputs, whereas White Rock and Lucas Point are at the mouth of the Derwent; any significant increases in nutrient availability in Storm Bay would be expected to be seen at these sites first.

While the RVA method is still relatively newly developed, it has thus far shown to be a good tool in providing a functional assessment for nutrient enrichment on reefs. These surveys have demonstrated the validity of using this method for this purpose when assessing reefs in the Derwent. However, this method does not define the source of the nutrient enrichment; multiple lines of evidence are generally needed for this. The most important line of evidence is long-term monitoring that allows a greater understanding of the variability in a system over time. This understanding allows us to place any observed change within the context of broadscale nutrient dynamics, both natural and anthropogenic (e.g. salmon farming, changes to sewage inputs, increasing urbanisation of the estuary). Furthermore, while RVA is a sensitive technique for monitoring nutrient enrichment and associated change in ecosystem function, it does not assess any subsequent effects on biodiversity. A key recommendation from Macleod et al (under review) was that reef biodiversity surveys on a 5-7 year cycle be considered in conjunction with RVA monitoring. The RVA surveys are a strong method for detecting change in ecosystem function; the biodiversity surveys can provide data around consequences of any shift in reef function. In addition to long-term monitoring, other lines of evidence for determining sources of nutrients that are worth consideration in the future include long-term water quality data, which is already being collected on an estuary-wide scale by the DEP (e.g. DEP 2020) and biochemical measures, such as stable isotopes (van Os 2020). Regardless of future monitoring, this survey provides a scientifically robust and important snapshot of reef function in the Derwent estuary in 2020. These surveys enrichment can therefore be used to benchmark any future change that may occur within this system.

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Appendix 1 – Data scorecard for RVA assessment

Circle Quadrat #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Total % canopy												
Pcom / Sarg %												
Era / others %												
% Sub canopy brown + major spp.												
% Sub-canopy green + major spp.												
% Sub-canopy red												
% Epiphytic algae on kelp												
% Filamentous algae												
% *Ulva/ Chaetomorpha*												
% *Asparagopsis*												
Substrate characterisation												
% UALC & type Pink vs. Att. Red	P R	P R	P R	P R	P R	P R	P R	P R	P R	P R	P R	P R
% Sponge & type												
% Turfing algae												
# Feather stars												
MMI spp and #												
Dust on algae (H/M/L/N)?												
Enc. spp. on algae? (H/M/L/N)												

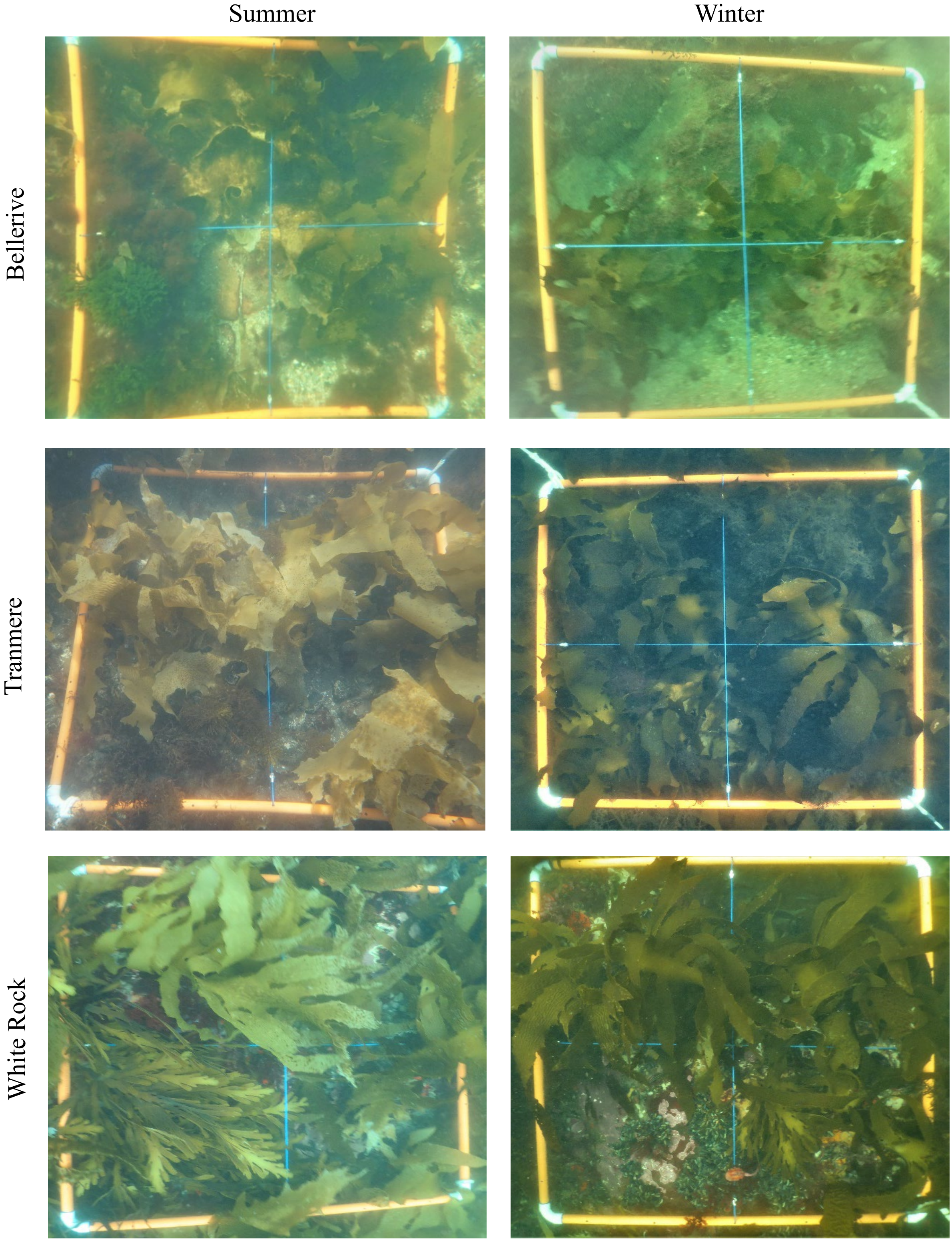
Appendix 2 – General data summary table and representative images

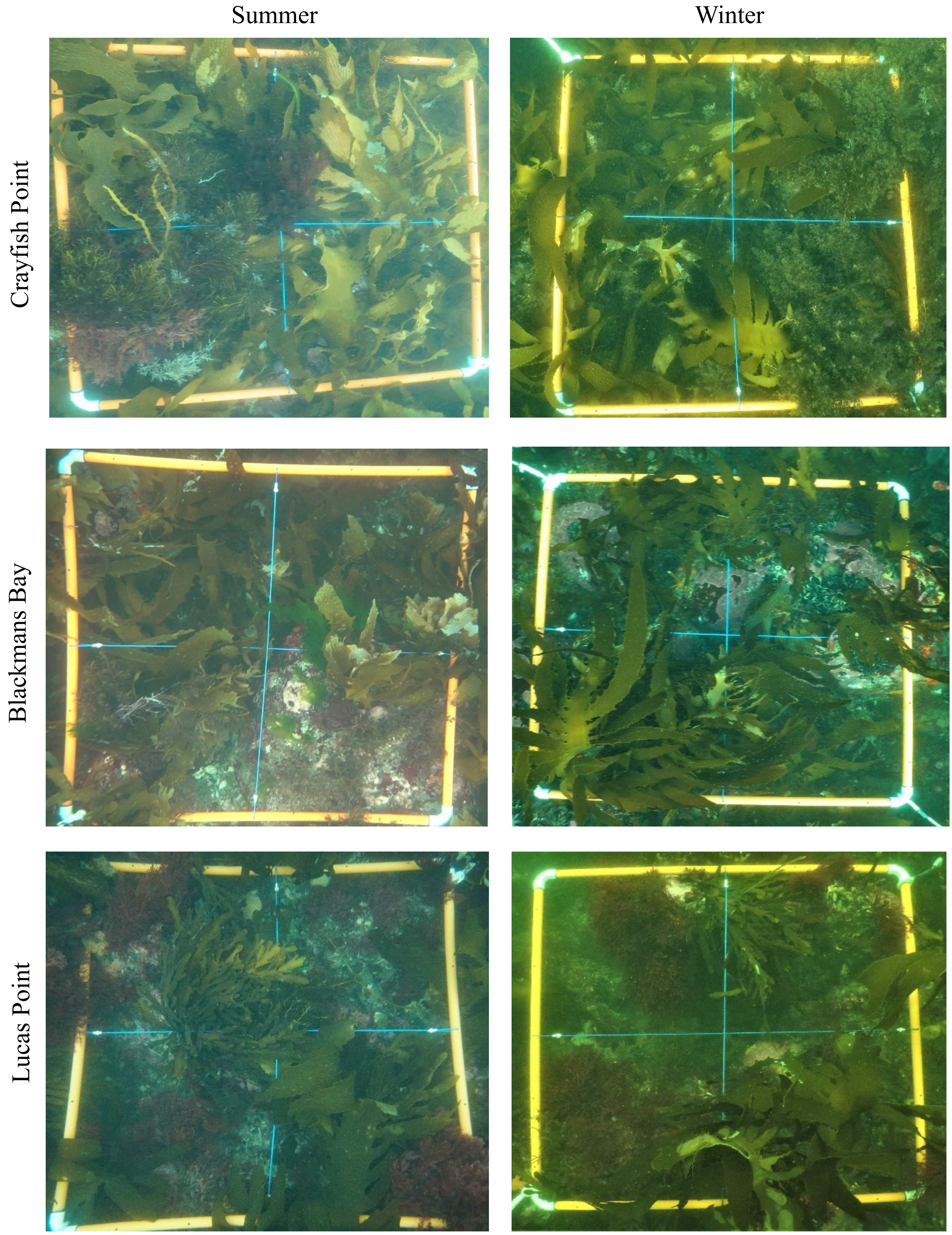
General data summary table:

	Season	Bellerive Bluff	Tranmere Point	White Rock	Crayfish Point	Blackmans Bay	Lucas Point
Canopy cover average across site	S	59.6%	52.1%	53.3%	55.8%	50.5%	45.8%
	W	44.1%	62.9%	42.3%	37.9%	38.3%	35.8%
Dominant canopy species	S	*Ecklonia radiata*	*Ecklonia radiata*	*Ecklonia radiata*	*Ecklonia radiata*	*Ecklonia radiata**	*Macrocystis pyrifera*
	W	*Ecklonia radiata*	*Ecklonia radiata***	*Ecklonia radiata*	*Ecklonia radiata*	*Ecklonia radiata*	*Macrocystis pyrifera*
Dominant sub canopy algae	S	Red	Brown and red	Brown and red	Brown and red	Brown, red and green	Red and brown
	W	Red	Brown and red	Brown and red	Brown and red	Brown and red	Red and brown
Nutrient indicators with average % cover	S	Epiphytic algae and nuisance green <25%	Epiphytic algae and nuisance green <20%	Epiphytic algae <10%	Epiphytic and nuisance green algae <10%	Epiphytic, nuisance green algae <15%	None
	W	Epiphytic algae <5%	Epiphytic algae and nuisance green <10%	None	Epiphytic algae <10%	Epiphytic algae <5%	None

* *Macrocystis pyrifera* was also observed on-site. ***Sargassum spp.* up to 30% at some sites.

Representative quadrats at each of the six sites for summer and winter.




Summer
Winter
Crayfish Point
Blackmans Bay
Lucas Point