Rapid visual assessment of rocky reef assemblages in Port Arthur

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Executive Summary

In response to public concern regarding the health of the marine environment in Port Arthur, the EPA commissioned IMAS to undertake Rapid Visual Assessment (RVA) surveys on reef ecosystems across the region. Samples of macroalgae were also collected from reef sites for stable isotope analysis, to help identify the likely sources of nutrients. The primary aim of these surveys was to evaluate the condition of inshore rocky reef ecosystems in Port Arthur and potential nutrient enrichment from the salmon lease located at the southern end of Long Bay (MF55). Fifteen sites were established, with sites directly adjacent to the lease (100 m), 400 m, and 1000 m away. Each of these sites was also designated a cardinal direction from the lease (north, south, east, west). The distribution of sites along the four cardinal directions from the lease was to help account for the effect of wave exposure on response parameters. Reference sites were also established in both Port Arthur (>3 km from the lease) and Fortescue Bay. Note that site selection was constrained by the availability of suitable habitat within the study area.

The sites directly adjacent to the lease (100 m sites) and the sites 400 m and 1000m to the north in Long Bay were all typical of an environment subject to low wave exposure and nutrient enrichment, including the proliferation of nuisance, epiphytic and filamentous algae and a lower canopy cover. Though wave exposure, water exchange and other sources of nutrients are undoubtedly influencing the observed patterns, the results at 100 m sites are consistent with the influence of nutrient enrichment from the salmon lease on the local rocky reef assemblage. Nitrogen isotope data also confirms that the salmon farm is a source of nutrients for the adjacent reef ecosystem. The degree of enrichment observed at sites 400 m and 1000 m north of the lease is likely to also be affected by terrestrial nutrient sources; how these inputs compare with those from the salmon lease was not tested as part of this study. While low to moderate effects of nutrient enrichment were evident as an elevated abundance of epiphytic, filamentous and nuisance algae at the 400 m and 1000 m sites to the east and south of the lease, attribution of these effects to salmon farming is problematic. With limited comparable baseline data available for reef ecosystems in Port Arthur, determining attribution for diffuse effects is difficult and requires multiple lines of evidence.

It is important to note that while the interaction between distance and direction from the farm made it difficult to de-couple wave exposure/water exchange and nutrient enrichment in our interpretation of results, the patterns observed highlight the susceptibility of low-exposure sites to nutrients, regardless of the source. Repeat surveys will provide greater insight regarding the persistence and nature of nuisance and opportunistic algal blooms in this region.

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Introduction

Kelp forests are often dominant on temperate inshore rocky reefs, supporting biodiversity and trophic linkages through the provision of three-dimensional habitat and food resources (Bennett et al. 2016, Teagle et al. 2017). While kelp forests are foundation habitats and thought to be relatively resilient to anthropogenic stressors, sustained organic enrichment can lead to loss of macroalgae and phase shifts in ecosystem function (Graham 2004, Connell et al. 2008, Teagle et al. 2017). The ability to identify when temperate reef ecosystems are under stress and therefore at risk of collapse represents a considerable challenge for management.

There are several common ecological responses of temperate reef ecosystems to organic enrichment. The most extreme is a loss of canopy-forming species and a proliferation of turfing algae (Eriksson et al. 2002, Connell et al. 2008). The proliferation of opportunistic (or "nuisance") algae species with fast growth rates, high output reproductive strategies and high demand for nitrogen are also associated with organic enrichment (Gorgula & Connell 2004, Oh et al. 2015). In general, established macroalgal communities are resilient to increased nutrient levels, with the growth of opportunistic algae regulated by competition with canopy-forming algae, grazing and physical disturbance, preventing opportunistic species from becoming dominant and replacing canopy-forming species (Bokn et al. 2003, Oh et al. 2015). However, if nutrient enrichment is prolonged or coupled with other stressors, there may be a degradation in the canopy, with the gradual replacement of canopy by opportunistic algae occurring (Worm et al. 1999, Benedetti-Cecchi et al. 2001, Gorgula & Connell 2004). These opportunistic species have a competitive advantage under heavy nutrient and sediment loads and further inhibit kelp recruitment and recovery.

As finfish aquaculture continues to grow in Tasmania's coastal zone there is increasing concern about the effects and interactions with other users and natural values (Lacharité et al. 2021). Concerns include the impact that waste materials released from farms will have on nearby reef ecosystems, particularly through the stimulation of nuisance algae and subsequent smothering effects on macroalgae. Through a large FRDC project (FRDC 2015-024), IMAS developed and trialled methodology aimed at detecting impacts of organic enrichment on reef ecosystems in regions of salmon aquaculture expansion (Ross et al. 2021). One of the methods developed through FRDC 2015-024 included a targeted reef assessment technique for detection of organic enrichment on reef ecosystems – the “Rapid Visual Assessment” (RVA) method. This method was developed throughout the lifespan of FRDC 2015-024, with validation occurring on a broadscale organic enrichment gradient in the southern D’Entrecasteaux Channel (Ross et al. 2021, White et al. 2021).

Port Arthur is a large coastal embayment on the Tasman Peninsula/Turrakana. It has strong heritage and tourism values, as well as being the site for shellfish and salmon aquaculture. The recent restocking of the salmon lease in Long Bay has triggered increasing public concern regarding impacts on surrounding ecosystems, including rocky reefs. While a Broadscale Environmental Monitoring Program (BEMP) is ongoing in Port Arthur, this is largely focused on assessing water quality and sediment condition, with no recent or ongoing studies into rocky reef condition. To better understand the interaction between the salmon lease and reef ecosystems in Port Arthur, IMAS was commissioned by the Environment Protection Authority (EPA) Tasmania to undertake RVA surveys in January and June 2021. Stable isotope analysis of major macroalgae species at each site was also requested as a means of determining the source of nitrogen stimulating growth in these species.

The primary aim of these surveys was to evaluate the condition of inshore rocky reef ecosystems in Port Arthur with regard to potential nutrient enrichment from the adjacent salmon lease, MF55, using the RVA method of rocky reef assessment in conjunction with stable isotope analysis. A secondary aim was to evaluate the effectiveness of the RVA method in assessing reef response to organic enrichment across a gradient of impact from the lease.

Methods

Study sites

Port Arthur is a relatively shallow (<50 m) embayment that opens to the Tasman Sea and has a wave exposure gradient that ranges from moderate exposure in the south and along the eastern shoreline, to low exposure or very sheltered in the north and along the western shoreline (Barrett et al. 2001). Approximately 227 ha of rocky reefs have been mapped within Port Arthur (Barrett et al. 2001). These habitats are primarily low-medium profile fringing reef, particularly in Long Bay, where they form a narrow band along the shoreline (Marine Solutions & Aquenal Pty Ltd 2015). There is a salmon farm located in Long Bay in the northern section of Port Arthur (marine farming lease MF55). Aquaculture of Atlantic salmon occurred at the Long Bay lease from 1986 to 2005, before ceasing for a twelve-year period prior to restocking by Tassal Group Ltd in spring 2017 (Aquenal Pty Ltd 2019). Baseline data on reef condition prior to restocking in 2017 is limited. There were surveys undertaken by Tassal Pty Ltd in 2013 and 2016 at four sites within Port Arthur to meet requirements of the Environmental Protection and Biodiversity Conservations Act (1999). These surveys focused on documenting the density of *Macrocystis pyrifera*, with differences in methodology, season, and location limiting their comparative value to this study. Over the time period of this study, fish were stocked on the Long Bay lease from October 2020 until April 2021 when all fish were removed for a fallowing period. Restocking of the lease occurred in September 2021 (EPA Tasmania, pers comm).

Twelve sites within Port Arthur and three sites in Fortescue Bay were surveyed in January and June 2021 (Figure 1). Within Port Arthur, sites were selected based on a gradient of proximity from the salmon lease site in Long Bay and where suitable substrate existed. Sites were classified as 100 m, 400 m, 1000 m or “PA reference”. Distance categories were determined based on proximity to the nearest active cage, rather than the lease boundary, with some variability around exact distance within categories due to habitat availability. Site selection for 100 m sites was constrained by the lack of rocky substrate near the lease; all rocky substrate within 100 m of an active cage was located to the eastern side of the lease and thus the design is constrained by a degree of spatial autocorrelation. To mitigate this, at least 50 m (the length of the transect) was allowed between each site, with the northern-most site extending beyond the area within the lease that is stocked. When fish were present on the lease, the middle and southern sections of the lease were stocked, whereas the northern portion of the lease was empty of cages at the time of the survey.

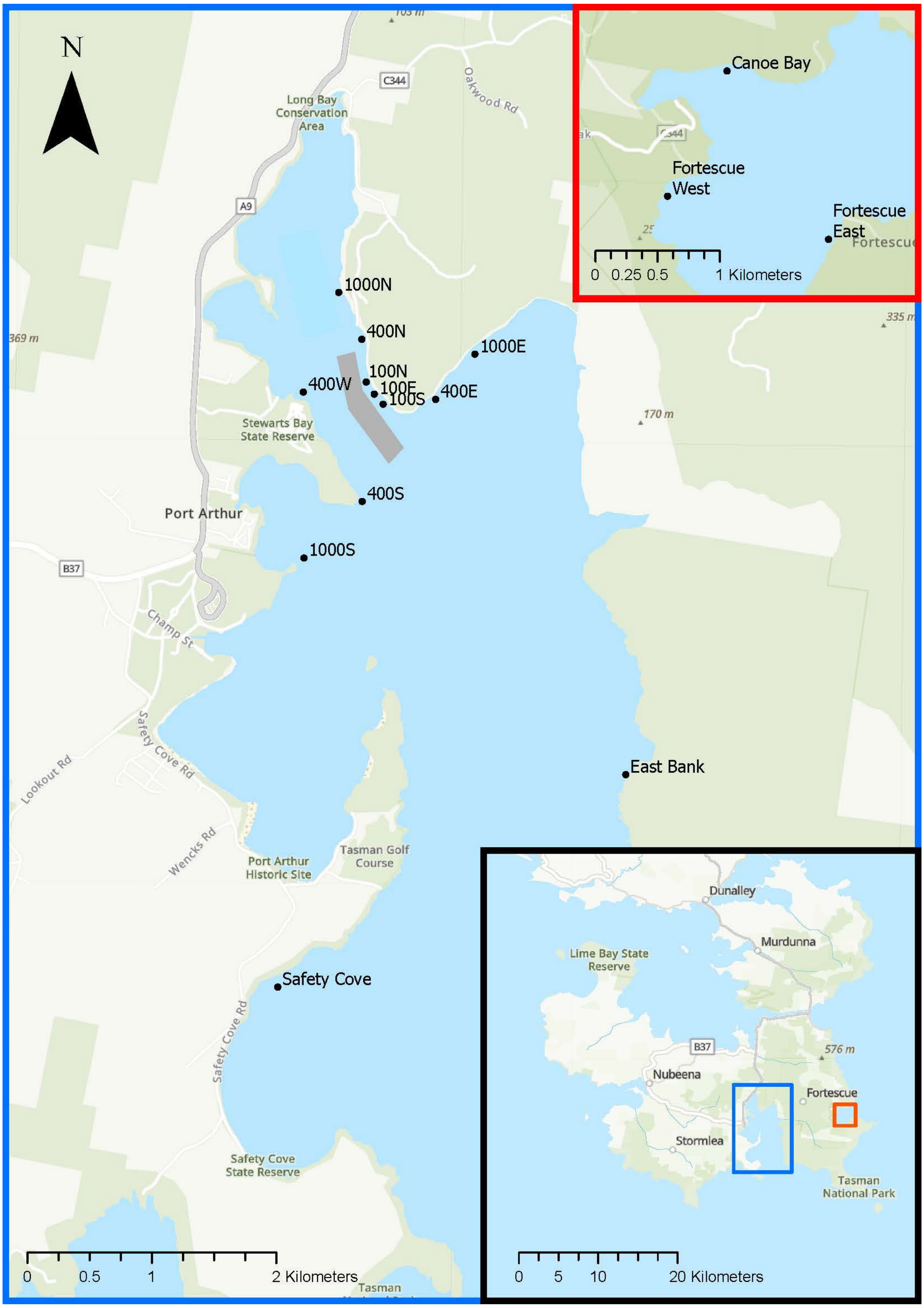

Figure 1: Map of the 12 Port Arthur sites and three Fortescue Bay sites surveyed in January and June 2021. The grey area represents the marine farming lease (MF55).

Each of the sites were allocated a cardinal direction (north, south, east, west) from the lease site to allow for testing the effect of wave exposure on macroalgae communities (Figure 1). Sites in the southern and eastern directions were subject to higher wave exposure than those in the northern and western directions from the lease. The reference sites within Port Arthur (Safety Cove and East Bank) were at a greater distance (>3 km) from the salmon lease and due to the shape of the embayment were subject to higher wave exposure than farm sites. The number of sites at various distances from the lease surveyed in each direction was limited by the availability of suitable reef substrate; there was no rocky substrate found north of site 1000 N that could be surveyed, with substrate at the top end of Long Bay consisting of soft sediments. Likewise, due to the shape of the embayment and the lack of continuous rocky substrate at appropriate depth, there was only one site (400W) in a westerly direction from the lease. Due to adverse weather conditions, East Bank was not surveyed in January.

An additional three reference sites in Fortescue Bay ("FB reference") were included to represent rocky reefs within a similar geographical area and exposure, but without any major anthropogenic nutrient sources, including salmon operations (Figure 1). Fortescue Bay is located approximately 10 km east of Port Arthur and is surrounded by the Tasman National Park and State Forest. While the catchment is at times subject to intensive forestry operations, Fortescue Bay itself has minimal human disturbance, with the only surrounding development being walking trails and a campground in the south-western corner of the bay.

RVA methods

RVA surveys in this study used the methods developed through FRDC 2015-024. In these methods, 15 functional parameters are assessed within 1 m^2 quadrats. Of the 15 parameters, 10 assess broad structural parameters associated with reef function (i.e. four assess the condition of the macroalgal canopy, four assess the condition of the substrate and two relate to trophic effects), while five relate solely to enrichment responses (Table 1). Broad structural parameters include percentage total canopy cover (characterised to species level), understorey brown, green and red algae cover, turfing algae cover, pink and red encrusting algae cover, sponge cover, levels of encrusting fauna, and numbers of the dominant mobile invertebrates. Enrichment parameters include percentage cover of epiphytic and filamentous algae, cover of nuisance or opportunistic green (characterised by *Ulva, Cladophora* and *Chaetomorpha* in our sampling region) and nuisance or opportunistic red species (characterised by *Asparagopsis armata* in our sampling region), along with the level of “dust” (sedimentation) covering the algae.

Table 1: Functional parameters for rapid visual assessment of temperate reef ecosystems in south-east Tasmania.

Functional parameter	***Expected response to increased organic enrichment***	***Reference***
Total canopy cover (including breakdown of species)	Decline	Connell et al. (2008), Eriksson et al. (2002), Benedetti-Cecchi et al. (2001)
Sub-canopy brown cover	Dependent on canopy response	
Sub-canopy green cover	Potential increase due to increased nutrient availability	Oh et al. (2015), Nelson et al. (2008)
Sub-canopy red cover	Potential increase due to higher sedimentation in water column. Overall increase in red+green:brown algae ratio expected in enhanced nutrient conditions	Stuart-Smith et al. (2008)
Turfing algal cover	Increase	Connell et al. (2008), Eriksson et al. (2002), Benedetti-Cecchi et al. (2001)
Pink encrusting algae cover	Potential decline and replacement by turfing or opportunistic algae, if canopy is lost	Burkepile and Hay (2006)
Red encrusting algae cover	Could decline as per pink encrusting, or increase due to changes in predation pressure or light conditions	Burkepile and Hay (2006)
Sponge cover (including breakdown of encrusting vs branching)	Likely to increase under mild organic enrichment and decrease under major organic enrichment	Strano et al. (2020)
Encrusting & epibiotic fauna	Potential increases with increases in opportunistic algae cover likely	Russell and Connell (2005), Burkepile and Hay (2006), Haugland et al. (2021)
Epiphytic algae cover	Increase	Oh et al. (2015), Fowles et al. (2018)
Filamentous algae cover	Increase	Oh et al. (2015), Lavery and McComb (1991)
Opportunistic green algae cover	Increase	Oh et al. (2015), Nelson et al. (2008), Fowles et al. (2018)
Opportunistic red algae cover	Increase	White et al. (2021)
“Dust” on algae	Increase (a reflection of sedimentation)	Anecdotal

At the start of each survey, two divers on SCUBA tension 50 m of rope between two eyebolts installed at each site. These two eyebolts are located on the 5 m depth contour. At each site, 12 x 1 m^2 quadrats are attached haphazardly along the transect line, with each quadrat, scored and then photographed for archival purposes. The quadrat is attached to a rope 1 m in length, which is tensioned when laying the quadrat. The 1 m^2 quadrat was sub-divided into four smaller 0.5 m^2 subsections to increase scoring accuracy. All parameters were assessed in the full 1 m^2 quadrat, except for substrate parameters, which were sub-sampled using the 0.5 m^2 subsection of the quadrat closest to the transect. Quadrats 1 and 2 at all sites were visually assessed by both divers for calibration and data QA/QC, while the remaining ten quadrats were each assessed individually.

Macroalgae collection for isotopes

Laminar samples of *Ecklonia radiata*, *Phyllospora comosa*, *Lessonia corrugata*, *Macrocystis pyrifera* and entire specimens of *Asparagopsis armata*, *Ulva* spp., *Chaetomorpha billardierii* and filamentous algae were collected from each site where these species were present. Post-collection, samples were placed immediately on ice and then freeze-dried upon return to IMAS Taroona. Samples were then ground into a fine powder using a ball mill, with a homogenised sub-sample sent to the School of Chemistry at Monash University for carbon and nitrogen isotope analysis. Data on the $\delta^{15}N$ value only is examined for this report, as it has been found by previous studies to be the best indicator of enrichment from aquaculture (Howarth et al. 2019, Ross et al. 2021).

Data analysis

Patterns in functional parameters were investigated using the multivariate software package PRIMER v7 (Plymouth Routines in Multivariate Research; Clarke et al. 2014) and its complementary software package PERMANOVA+(v7) (Anderson et al. 2008). A Bray-Curtis dissimilarity matrix was calculated, and principal coordinates analysis (PCO) undertaken to visualise patterns in the data. Vector overlays using a Pearson correlation were employed to identify key parameters driving trends in the data. A 3-way PERMANOVA with distance from the farm (factorial: 100 m, 400 m, 1000 m, PA reference, FB reference), direction from the farm (factorial: North, East, South, PA reference, FB reference) and sampling event (January/February and June) as fixed factors was undertaken. For this analysis, the site at 400 West was excluded as it was the only site in this direction. For factors shown to significantly contribute to the variation in the data through PERMANOVA analysis, a canonical analysis of principal coordinates (CAP) was then undertaken to better understand how distinct the groups within these factors are, along with Pearson correlation to identify the parameters that characterise these groups. A SIMPER routine was used to verify outcomes from Pearson's correlations. Means and standard errors for individual parameters indicated as key from the multivariate analysis were calculated and plotted to visualise trends in the data.

For stable isotope analysis, the effect of distance from the farm on the $\delta^{15}N$ value was examined using data pooled across all species of macroalgae. The effect of distance from the farm, direction from the farm and survey was tested using a 3-way ANOVA using R statistical software (R core team, 2022). To investigate normality of the data, residuals were plotted against fitted data and a Shapiro-Wilk test performed (Appendix II). Significant terms were subject to Tukey's pairwise testing.

Results

There was a clear effect of both distance and direction from the farm on macroalgal communities in Port Arthur (Figure 2, Table 2). While the effect of distance was evident, the influence of direction on the macroalgal community was more pronounced (Figure 2). However, the pattern with distance varied depending on direction from the farm, as indicated by the significant interaction term in *distance x direction* (P(perm) = 0.0006, CoV = 502), indicating that the change in macroalgal assemblage with distance varied depending on the direction of the site from the lease (Table 2). While there was a difference observed between the two survey events, this was relatively minor compared to the effects of distance and direction (Figure 2, Table 2).

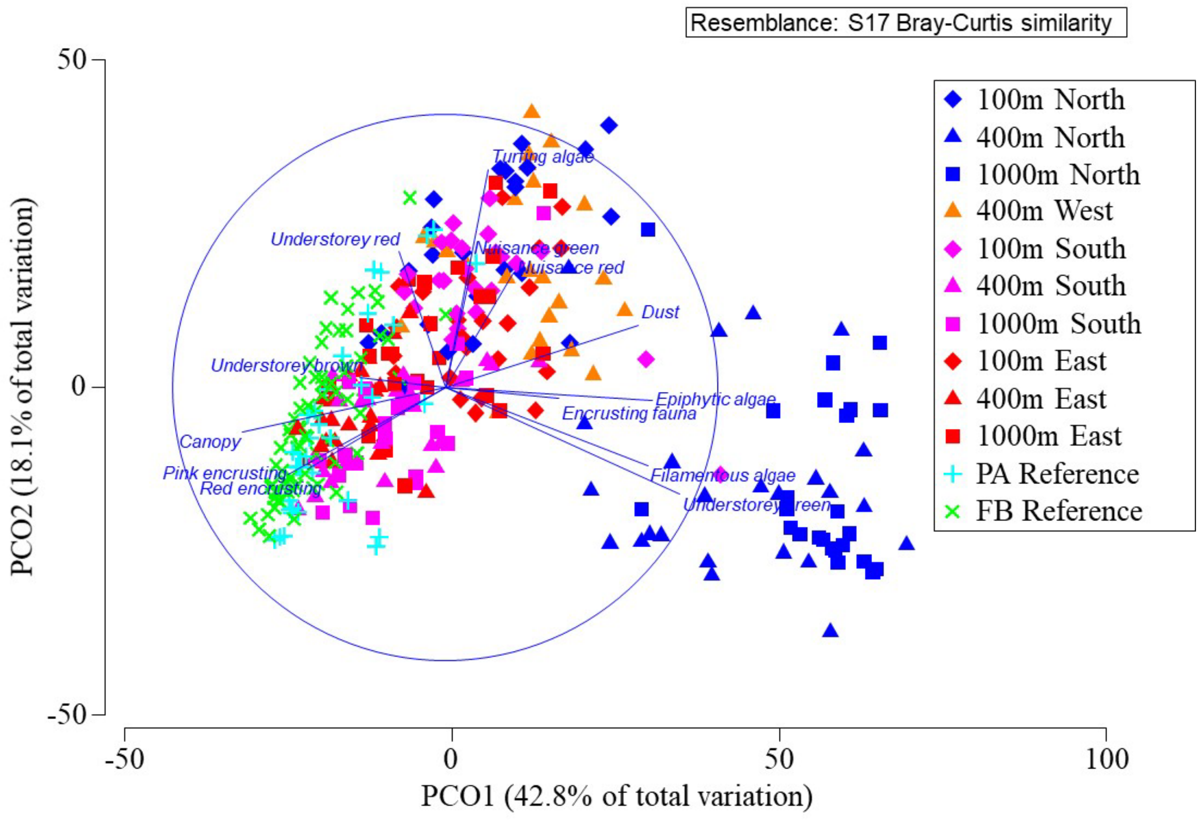

Figure 2. Principal coordinates analysis on RVA parameters, with each data point representing a single quadrat. Fitted vectors of parameters were calculated using Pearson's correlation. The length of the vectors indicates the strength of the correlation with the circle representing a perfect correlation of 1.

Table 2: Table of results for 3-way PERMANOVA (excluding 400 m W) including components of variation in the model.

Source	df	SS	MS	Pseudo-F	*P*(perm) value	Component of variation
Distance	2	2831	1415	8.0821	0.004	207
Direction	2	7128	3564	20.352	0.0007	565
Survey	1	919	919	5.2493	0.04	62
Distance x direction	4	4719	1180	6.7362	0.0006	502
Pooled residuals*	13	1680				175
Total	26	23168				

*df and SS for the terms *distance * survey* and *direction * survey* and *distance * direction * survey* were pooled with the residuals as they had negative estimates of components of variation.

To better understand the effects of distance and direction and how these factors may interact, data was examined through Canonical Analysis of Principal Coordinates (CAP). The CAP examining distance showed correlation of parameters with CAP axis 1, indicating that macroalgal canopy cover was higher at PA and FB reference sites compared with 100 m, 400 m and 1000 m sites (Figure 3). Sites at 100 m formed a cluster and were likely to be characterised by increases in nuisance red, green and turfing algae, relative to other sites (Figure 3). Sites located 400 m and 1000 m from the farm clustered together and were characterised by a range of parameters, from filamentous and epiphytic algae to sub-canopy brown. CAP indicated significant differences between distance groupings (trace statistic: 1.67, P: 0.0005). Overall, strong correlation of parameters that explain the expected enrichment gradient was achieved along CAP axis 1. Sites with high values for this axis were characterised by high canopy and pink encrusting algae cover (e.g. PA and FB reference sites), whereas sites with lower scores for this axis (e.g. 100 m, 400 m and 1000 m sites) were more likely to have higher values for enrichment parameters (nuisance green, nuisance red, epiphytic algae, dust, turfing algae).

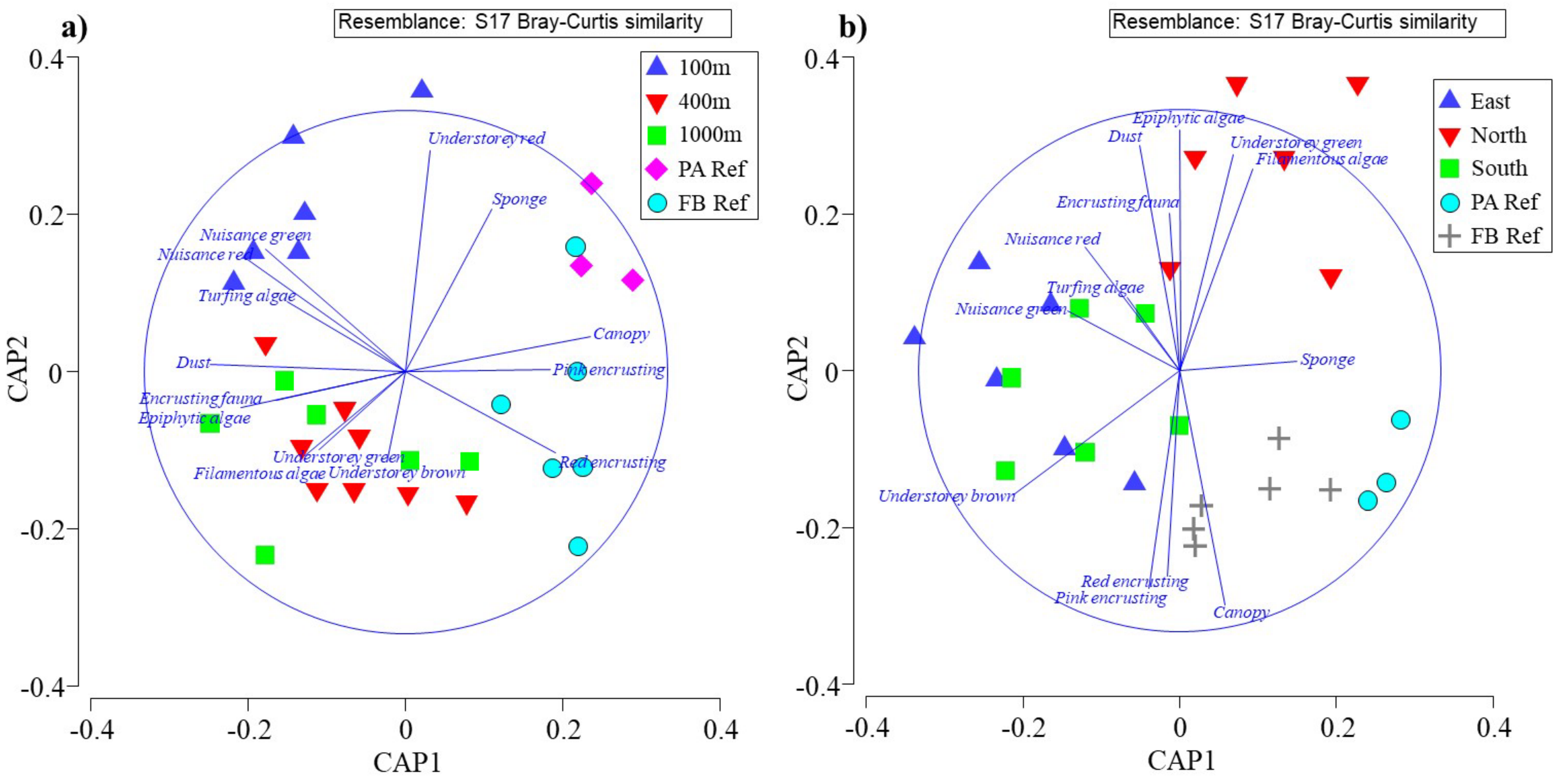

Figure 3: CAP ordination from a discrimination analysis with a) distance from the farm and b) direction from the farm as the test factor. Fitted vectors of parameters were calculated using Pearson's correlation. The length of the vectors reflects the strength of the correlation with the circle representing a perfect correlation of 1

The leave-one-out allocation procedure indicated that the 100 m and FB reference sites had the most consistent macroalgal communities, achieving correct classification for 83% of all samples in that group (see Appendix 4). This was followed by the PA reference sites (67%), although 400 m and 1000 m sites generally had poor predictability (37.5% and 16.7% respectively) and were misclassified between each other and FB reference sites. This indicates that sites immediately adjacent to or most distant from the lease are less variable, while intermediate sites are more variable. A closer examination of direction through CAP analysis indicates that sites north of the farm are distinct from all other groups, with sites in this direction characterised by higher cover of understorey green algae, filamentous algae, epiphytic algae and dust (Figure 3). East and south directions clustered together, as did the PA and FB reference sites (Figure 3).

Individual parameters were examined at a site level to better understand trends observed through multivariate analysis. Overall, canopy cover was highest at the PA and FB reference sites, where average cover ranged from 51-92% (Figure 4). Canopy was lowest at the 400 m and 1000 m North sites, where averages were 24.3 ± 6.5% and 9.2 ± 2.9% in January and 37.1 ± 9.5% and 11.3 ± 2.8% in June, respectively. At these two sites, understorey green algae (*Caulerpa* spp.) dominated instead, consistent with the multivariate analysis above. Canopy cover was generally higher in the January survey when compared with the June survey and encrusting pink algae was typically lower at sites north of the farm and at 100 m from the farm (Figure 4). An environmental gradient is evident in the sites to the north of the lease and within Long Bay, with 400 m West similar to the 100 m sites across canopy and understorey parameters and decreasing canopy cover and increasing understorey green evident as you move north of the lease into Long Bay (Figure 4).

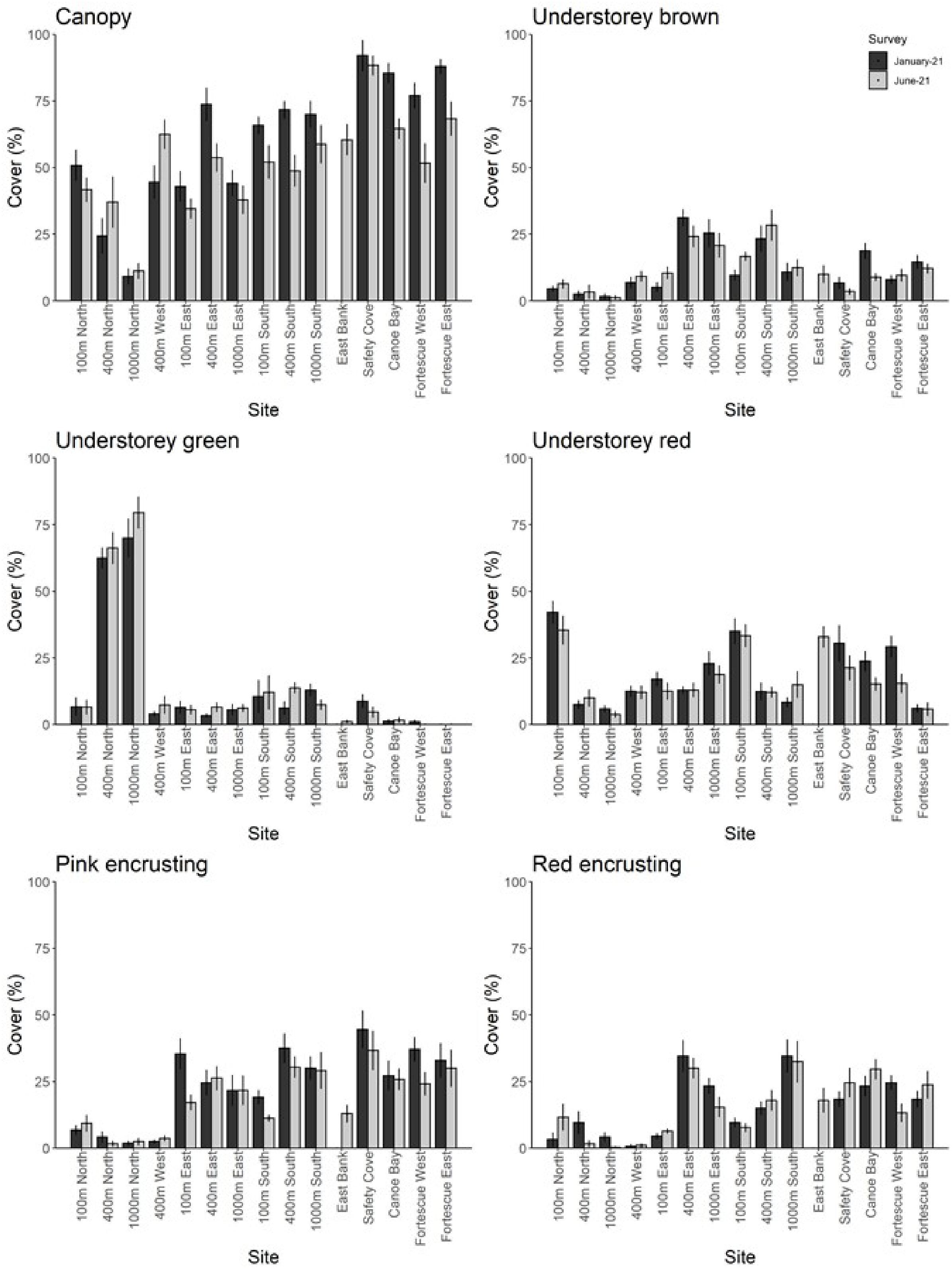

Figure 4: Percentage cover of major algae and substrate groups recorded through rapid visual assessment in both January (dark grey bars) and June (light grey bars) 2021 surveys.

Phyllospora comosa and *Ecklonia radiata* were the dominant canopy-forming macroalgae species, with *Sargassum* spp. and *Cystophora* spp. (c.f. *retroflexa*) also being relatively common (Figure 5). *P. comosa* was more abundant than *E. radiata* at Safety Cove, East Bank and the 400 m and 1000 m South sites. In contrast, *E. radiata* was dominant over *P. comosa* at the Fortescue Bay reference sites and the North, East and West sites within Port Arthur (Figure 5). *Sargassum* spp. and *Cystophora* spp. were common at the 100 m, 400 m and 1000 m sites, with *Sargassum* spp. cover being relatively consistent in the North, East and West directions from the farm (approximately 15-25% cover), as well as 100 m South. *Cystophora* spp. was generally present in lower abundance than *Sargassum* spp. (i.e. 10-20% cover), but was consistently present at 100 m, 400 m and 1000 m in all directions from the farm (Figure 5). Both *Lessonia corrugata* and *Durvillaea potatorum* were only observed at one site (East Bank) at very low percentage cover (<2% cover).

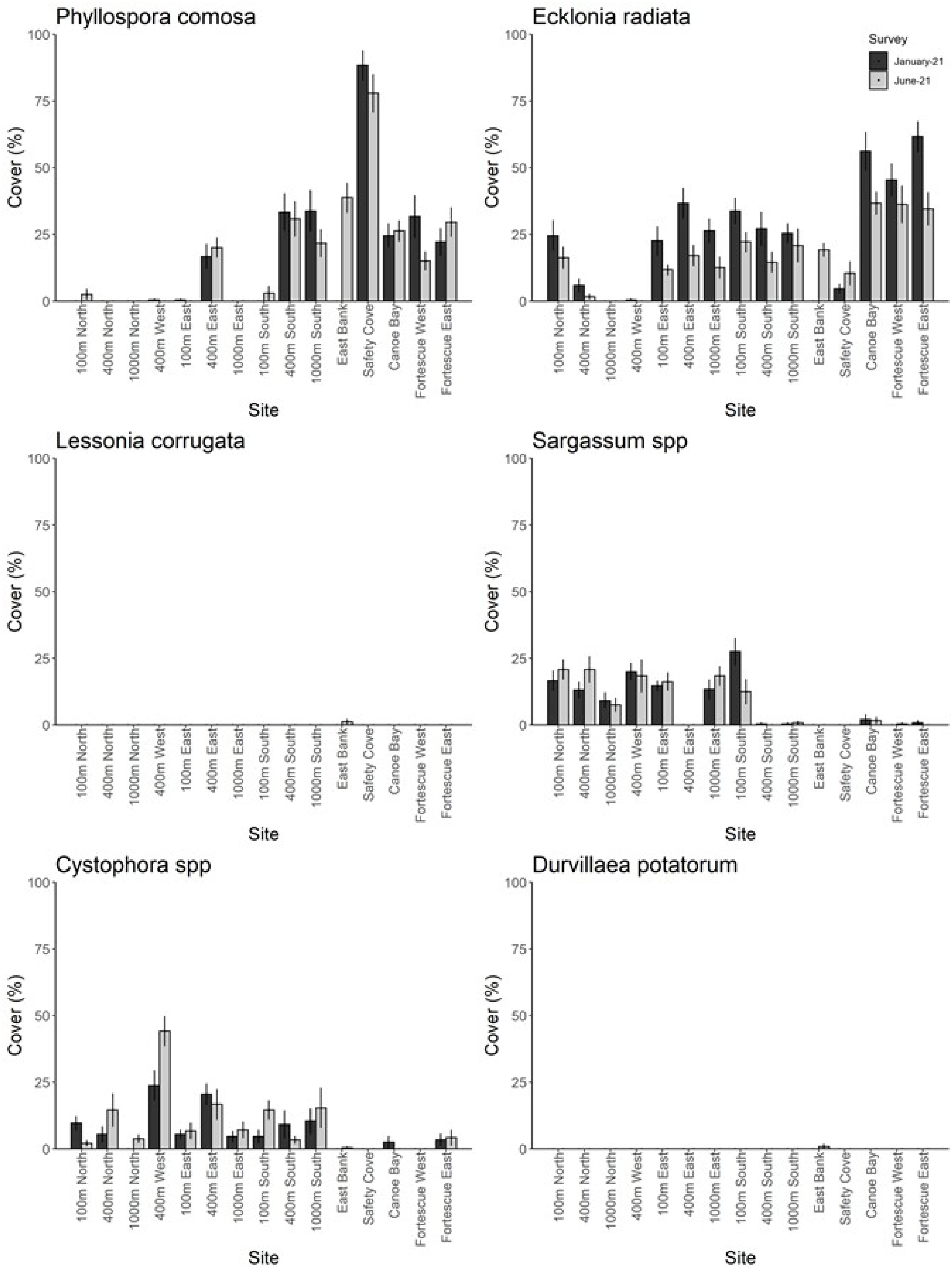

Figure 5: Percentage cover of major canopy-forming species recorded through rapid visual assessment in both January (dark grey bars) and June (light grey bars) 2021 surveys.

Epiphytic algae was most abundant at 1000 m North during the January survey (58.3 ± 5.1%) and recorded average values of >20% cover at 100 m East, 100 m South, 400 m North, 400 m West and 400 m South in one or both surveys (Figure 6). Similarly, filamentous algae at 1000 m North was very high in January (55.42 ± 4.33%), with high values (>20% cover) also recorded at 400 m North and 400 m West (Figure 6). Nuisance red and green algae were present in lower abundances than epiphytic and filamentous algae, with the highest values observed at the 100 m sites (ranging from an average of 4-21% across the sites), along with 400 m West, 1000 m East and 1000 m South (Figure 6). Nuisance algae cover was either negligible or absent from the PA and FB reference sites. Overall, epiphytic and nuisance algae did not show a strong response between surveys, with no consistent differences between the January and June surveys across sites (Figure 6).

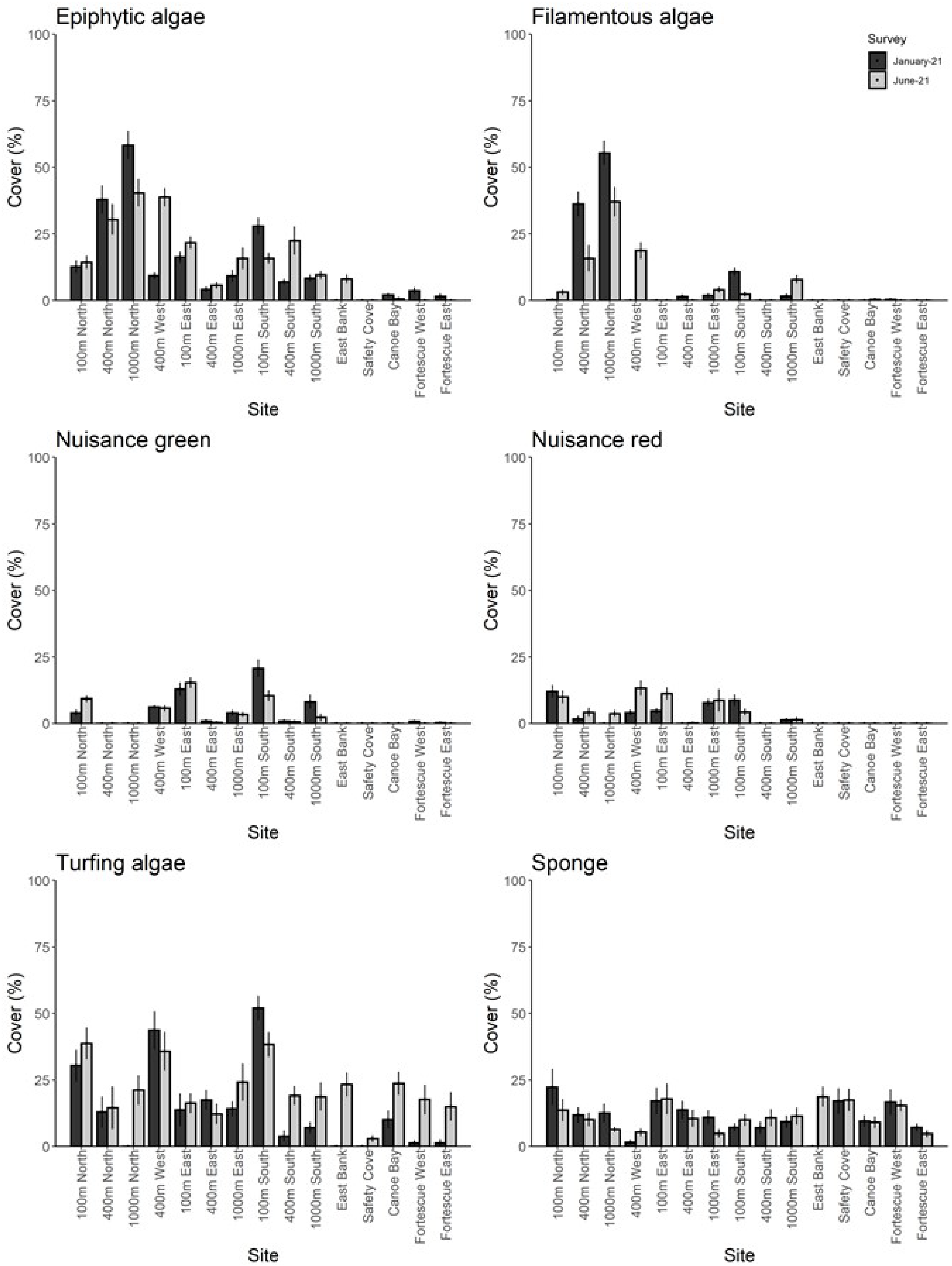

Figure 6: Percentage cover of enrichment parameters, turfing algae and sponge recorded through rapid visual assessment in both January (dark grey bars) and June (light grey bars) 2021 surveys.

There was a significant difference in the isotopic ratios of nitrogen in macroalgae between the January and June surveys, with $\delta^{15}N$ values less deplete in June compared to January (Figure

7). Distance from the farm was also a significant factor, with isotopic ratios of nitrogen in macroalgae increased significantly with distance from the farm in January (Table 3). Pairwise testing suggested that $\delta^{15}N$ values at 100 m sites in January were significantly depleted (4.97 ± 0.1‰) compared with all other distances across both January and June surveys (>6.00 ± 0.24‰). A gradient of increasing $\delta^{15}N$ values was evident from 400 m to the FB reference sites in January (Figure 7, Table 4), while values from the June survey are similar across all distances and comparable to the Fortescue Bay reference sites from January (Figure 7, Table 4). Direction from the farm was not a significant factor influencing nitrogen isotope values, nor was there a significant interaction between distance and direction. The *survey vs distance* interaction was only marginally non-significant.

Table 3: Table of results for 3-way ANOVA (excluding 400 m W) on $\delta^{15}N$ values of macroalgae samples obtained at each RVA site.

Factor	SS	df	F-value	Pr(>F)
Distance	6.67	2	9.86	0.0002***
Direction	0.20	3	0.20	0.90
Survey	28.4	1	83.9	0.0000***
Distance x direction	0.89	4	0.66	0.62
Distance x survey	1.99	2	2.94	0.06
Direction x survey	0.13	3	0.13	0.94
Distance x direction x survey	0.28	3	0.28	0.84
Residuals	19.9	59		

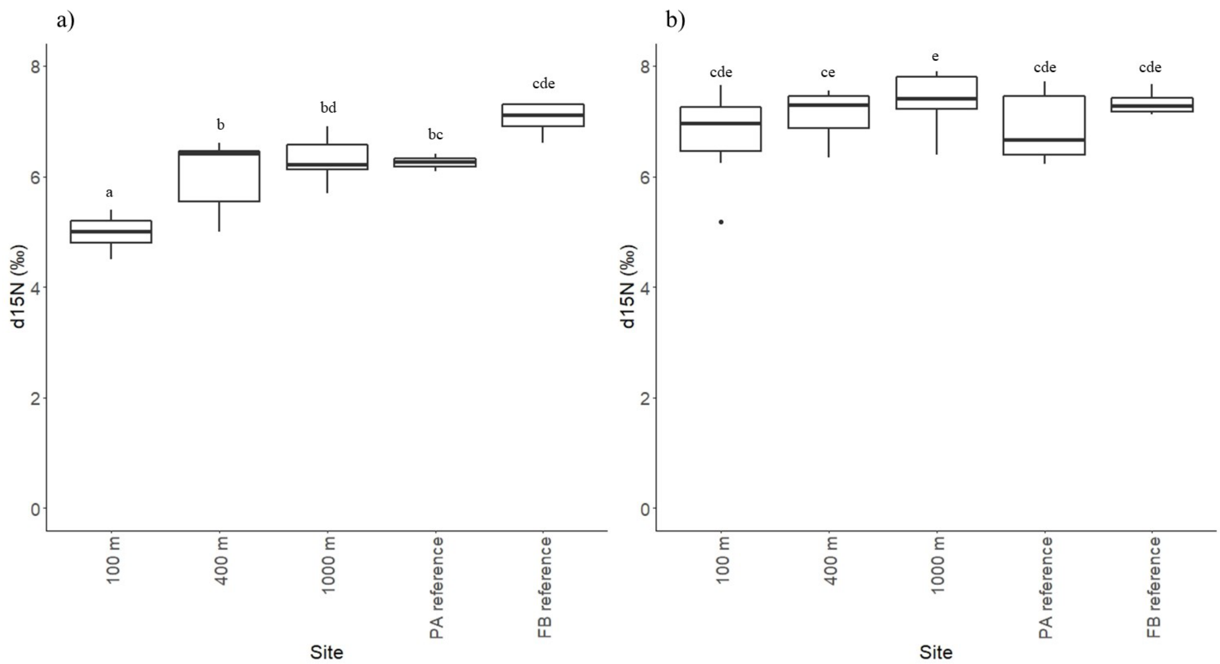

Figure 7: Values for $\delta^{15}N$ from macroalgae collected at rapid visual assessment sites in both a) January and b) June 2021 surveys.

Table 4: Mean $\delta^{15}N$ values ± standard error (SE) for macroalgae collected in January and June 2021, grouped by distance from the farm.

$\delta^{15}N$	**100 m**	**400 m**	**1000 m**	**Port Arthur Reference**	**Fortescue Bay Reference**
January	4.97 ± 0.10	6.00 ± 0.24	6.30 ± 0.18	6.57 ± 0.17	7.10 ± 0.20
June	7.01 ± 0.22	7.21 ± 0.16	7.47 ± 0.17	6.89 ± 0.19	7.33 ± 0.12

Discussion

Wave exposure has a strong influence on macroalgae communities in Port Arthur and the patterns observed in this study. While the influence of wave exposure in Port Arthur is clear, the patterns observed in the macroalgal communities and the stable isotope signatures both suggest that nutrient input from the salmon lease in Long Bay is likely to be influencing the adjacent reef ecosystems. Sites directly adjacent to the lease (i.e. 100 m sites) were generally characterised by higher abundances of nuisance red and green algae, "dust" on algae and a patchy macroalgae canopy. This response is consistent with that observed by Oh et al. (2015) on reefs adjacent to salmon aquaculture leases in the D'Entrecasteaux Channel and Nubeena, with macroalgal communities largely characterised by increases in opportunistic algae. In this study, patterns in stable isotope signatures of macroalgae provide further support that farm-derived nutrients are an important source of nutrient enrichment in Port Arthur. $\delta^{15}N$ values of macroalgae were more deplete at the 100 m sites compared with all other sites in the January survey when the lease was fully stocked with fish, but when the farm was not stocked in June there was no clear pattern in $\delta^{15}N$ values.

Although the influence of farming is likely at the 100 m sites directly adjacent to the lease, the full spatial extent of farm influence is far more difficult to discern. This is largely due to the confounding effect that wave exposure has on macroalgal-dominated reef communities and the subsequent difficulty in separating exposure versus enrichment effects (Edgar 1984, Hill et al. 2010). In our study, direction from the lease was used as a proxy for wave exposure, with the east and south sites subject to much higher wave exposure than sites to the north and west. Wave exposure was higher again at the Port Arthur reference sites. Thus, it is difficult to de-couple the effects of distance from the farm and direction from the farm; indeed our analysis suggests that the effect of distance depends on direction. Very high abundance of filamentous and epiphytic algae, macroalgal communities that are dominated almost entirely by understorey green algae from the genus *Caulerpa* and a very sparse *Sargassum* canopy were characteristic of the sites to the north. This assemblage is typical of a site subject to high nutrient enrichment and low wave exposure, both in Tasmania (Oh et al. 2015, Fowles et al. 2018) and more broadly (Kraufvelin et al. 2010, Pedersen et al. 2010). While Long Bay is where the effects of nutrient enrichment were most evident, attribution of these effects to different sources of nutrients is problematic. In addition to inputs from the salmon lease, nutrients are also entering via several small tributaries that drain into the north end of Long Bay (EPA Tasmania 2021). Likewise, low flushing will enhance the retention of nutrients, both anthropogenic and naturally occurring (Burkholder et al. 2006, Paerl et al. 2006). Reduced oceanic water exchange and lower flows in Long Bay will also compound the effects of nutrient enrichment through increased sedimentation, along with the recycling and metabolism of trapped nutrients (Fisher et al. 1982, Astill & Lavery 2001, Kamer et al. 2004, Plew et al. 2020). Thus, the response in Long Bay likely reflects a combination of nutrient inputs, including terrestrial and finfish aquaculture, and reduced wave exposure and water exchange.

While conditions in Long Bay at sites 400 m north, 1000 m north and 400 west were typical of low exposure and elevated nutrients, sites at 400 m and 1000 m in the east and south directions from the lease tended to be much more variable. While some of the functional parameters within the RVA are developed to be relatively wave exposure independent (e.g. *Ulva* spp. simply replaces *Chaetomorpha billardierii* in more exposed locations as the dominant "nuisance green" in this category), undoubtedly exposure will still affect the data. The 400 m and 1000 m south and east sites were generally characterised by higher abundance of epiphytic, filamentous, nuisance green and nuisance red algae when compared with reference sites in both Port Arthur and Fortescue Bay. Canopy cover was also generally lower at 400 m and 1000 m than at reference sites. Changes in the response metrics are consistent with those expected in nutrient enriched conditions; a similar response is seen at low to moderately enriched sites in the D'Entrecasteaux Channel (White et al. 2021) and Derwent estuary (White & Brasier 2021) across broadscale environmental gradients. With regard to farm gradients, Oh et al. (2015) reported a response in macroalgae assemblages out to 500-1000 m from salmon leases in the D'Entrecasteaux Channel and Nubeena, and Husa et al. (2014) reported responses in macroalgal communities up to 1 km distant from farms in Norway. Thus, a macroalgal response at these distances from an active farm may not be unexpected based on previous studies. However, in the absence of a robust baseline assessing macroalgal community composition and function, it is impossible to draw this conclusion for Port Arthur based on the data presented in this study alone. Overall, it is likely that there is some contribution by the salmon farm to nutrient loadings at sites 400 m and 1000 m east and south of the farm, however, the extent to which this contribution is affecting the ecology at these sites cannot be fully understood. Further RVA surveys and isotope collections in 2022 will increase replication at the site level, providing capacity to further investigate the interaction between distance and direction quantitatively.

The higher variability in functional parameters observed at the 400 m and 1000 m sites is likely due to a number of factors. Firstly, higher wave exposure at eastern and southern sites will dilute nutrient inputs from both anthropogenic and natural sources more quickly, corresponding to a more patchy distribution of opportunistic algae (Henríquez Antipa 2015). The mixed canopy assemblage will also contribute to variability at these sites (Goodsell & Connell 2005). Reference sites in this study were generally either *E. radiata* or *P. comosa* dominant with the other species being sub-dominant. In contrast, sites at 400 m and 1000 m regularly had 3-4 macroalgae species co-occurring with a relatively even distribution, each with a slightly different form and concomitant effects on ecosystem function (Eriksson et al. 2007, Coleman & Wernberg 2017). *P. comosa* and *E. radiata* are "substrate cleaners", with robust lamina that will sweep the rock surface clean of settling turfing or juvenile algae during swell events (Goodsell & Connell 2005, Wernberg et al. 2005, Smale et al. 2011). In comparison, the presence of *Sargassum* and *Cystophora* generally leads to a more patchy canopy with less uniform height. As the canopy tends to be broken, the sub-canopy beneath *Sargassum* and *Cystophora* tends to promote higher abundance of turfing, ephemeral and annual algae species, mainly due to increased light and substrate availability (Wernberg et al. 2005, Smale et al. 2011). The turfing algae tends to trap sediment, thereby creating a positive feedback loop that likely favours the growth of sediment-tolerant *Sargassum* over other canopy formers (Kawamata et al. 2012, Filbee-Dexter & Wernberg 2018). Both *Sargassum* and *Cystophora* are known to dominate reef ecosystems where there is lower exposure (Edgar 1984), so the presence of these species at these sites is not surprising and unlikely to be related to the presence of the farm. Without comparable baseline data, understanding canopy composition in relation to salmon farming activities is not possible. Regardless, the presence of these species in the canopy will likely increase the susceptibility of the reef at these sites to effects related to sediment accumulation and nutrient enrichment.

While we observed a difference in functional parameters between the January and June surveys, this difference was relatively minor compared to the effects of distance and direction from the farm. RVA surveys in the D'Entrecasteaux Channel, the Derwent estuary and Storm Bay have highlighted a shift in functional parameters between summer and winter surveys (IMAS 2020, White & Brasier 2021, White et al. 2021). This trend reflects the annual bloom and dieback of both perennial and annual algae species relating to seasonal variability in nutrient and light availability (Sanderson 1992, Shepherd & Edgar 2013). These trends were not observed consistently across all sites in Port Arthur. Canopy cover tended to be higher in the January survey than in the June survey, however the sites at 400 m north and west and 1000 m north recorded similar or higher canopy cover than in the June survey. Likewise, trends in the cover of epiphytic or opportunistic algae were site dependent. The very high values of epiphytic and filamentous algae at 400 m and 1000 m north were recorded in January, when higher light, temperature and nutrient levels create ideal conditions for growth (Sanderson 1997, O'Neill et al. 2015). While these large peaks were observed in the most sheltered sites in January, a presence (approximately ≥ 15%) of epiphytic algae at the 100 m sites, as well as sites north and west of the farm was observed across both surveys. The sustained presence of epiphytic and nuisance algae generally indicates the sustained presence of excess nutrient in the environment, usually of anthropogenic origin (Valiela et al. 1997, Thornber et al. 2008). As most sites with a sustained presence of epiphytic algae were in Long Bay, it is likely that hydrodynamic conditions are playing a role in the retention and cycling of nutrients (both natural and anthropogenic), contributing to the epiphytic loadings observed at these sites in the June survey (Viaroli et al. 1996, Astill & Lavery 2001, Plew et al. 2020). Without conducting surveys that corresponded directly to the start (~May) and end (~September) of the lease fallow period, we are unable to examine potential change in reef condition in Long Bay in response to fallowing. In the absence of other anthropogenic nitrogen inputs, it would be expected that any farm-derived nitrogen retained in Long Bay will slowly dissipate when the farm is fully destocked, although a thorough investigation into the nitrogen cycle and rates of recovery in relation to fallowing in Long Bay was outside the scope of this study.

Conclusions

Effects associated with low wave exposure and nutrient enrichment, such as a proliferation of nuisance, epiphytic and filamentous algae were observed at 100 m sites, along with the 400 m and 1000 m north sites in Long Bay. It is likely that the salmon lease at the southern end of Long Bay is contributing to the localised nutrient enrichment observed at the 100 m sites. Nitrogen isotope data demonstrates that the farm is a nutrient source for macroalgae communities at the sites directly adjacent (i.e. 100m) to the lease. At the more distant sites further to the north in Long Bay, the effects of exposure, flushing and other nutrient inputs are more difficult to discern. This is particularly problematic in the absence of baseline information on reef condition. There was also evidence of elevated abundances of epiphytic, filamentous and nuisance algae observed at the 400 m and 1000 m sites to the east and south of the lease relative to reference sites, albeit at much lower levels than the aforementioned sites. But again, it is difficult to untangle the interaction between exposure and any potential effects of farm induced nutrient enrichment in the absence of comparable baseline information on reef condition at these sites.

While it was difficult to de-couple wave exposure and nutrient enrichment in the interpretation of our results, it does highlight the sensitivity of low-exposure sites with reduced flushing to the effects of nutrient enrichment. Repeat surveys in 2022 will help us to better understand the effects of nutrient enrichment on reef condition in Port Arthur by providing increased statistical power and confidence, for both ecological and stable isotope data. Repeat surveys will also greater insight regarding the persistence and nature of any nuisance or opportunistic algae blooms in this region.

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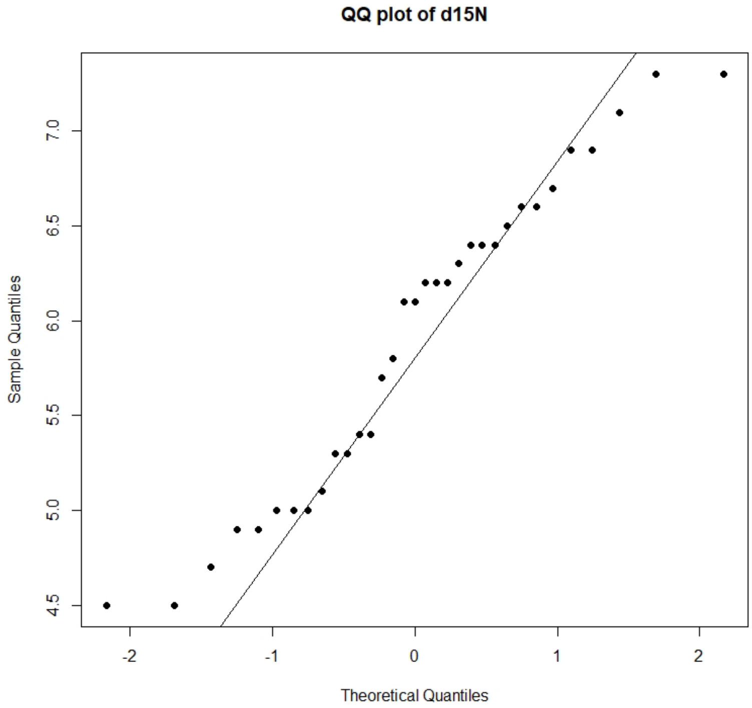
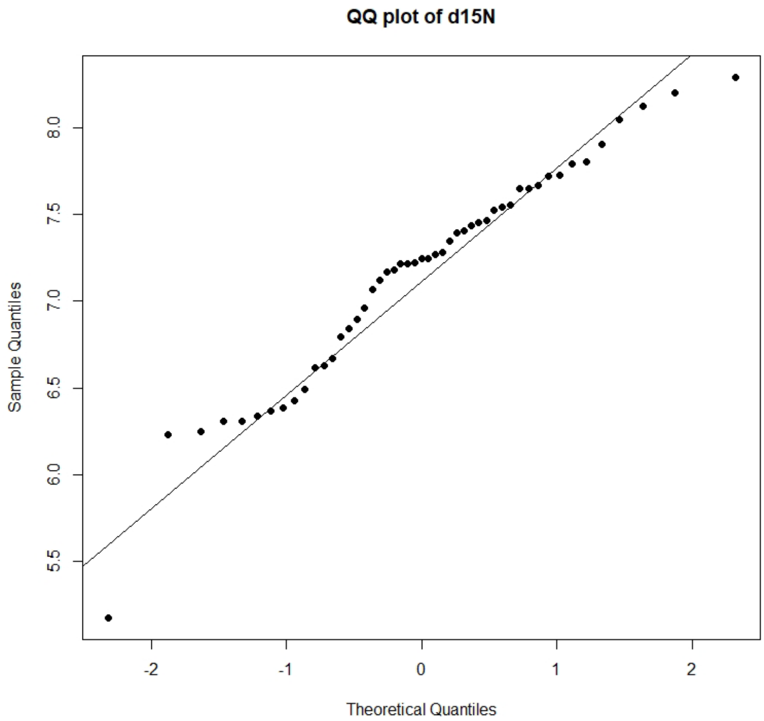
Appendix I: Rapid visual assessment (RVA) scorecard developed for assessing functional change on temperate reef ecosystems**.**

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 II: QQ plots and results from Shapiro-Wilk test for normality of $\delta^{15}N$ data





Shapiro-Wilke January $\delta^{15}N$:

W = 0.94744, p-value = 0.112

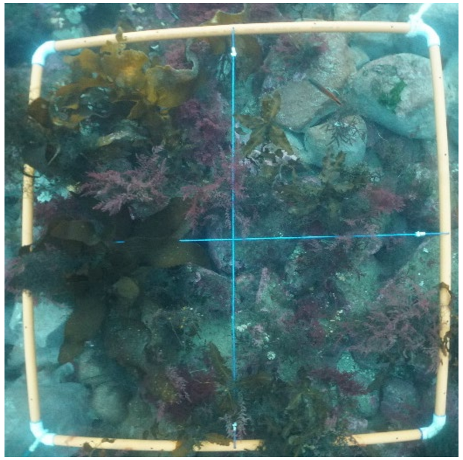
Shapiro-Wilke June $\delta^{15}N$:

W = 0.9612, p-value = 0.1062

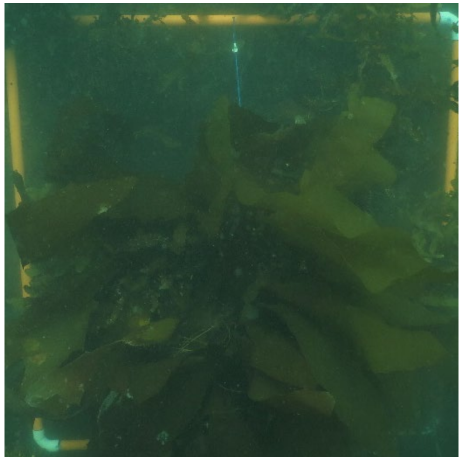
Appendix III: Representative photoquadrat images for each site, using a 1 m^2 quadrat frame.

100 m East (January)

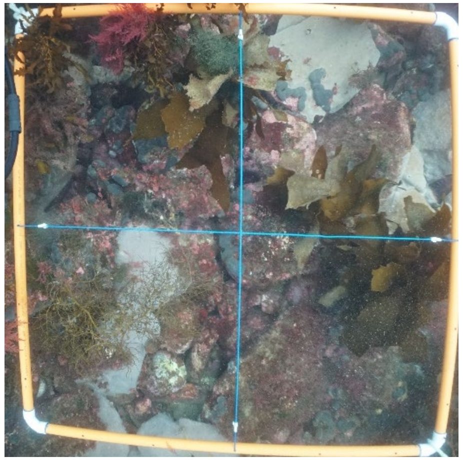
100 m East (June)



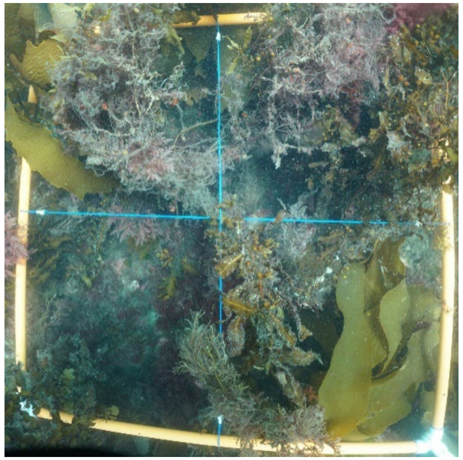
100 m North (January)



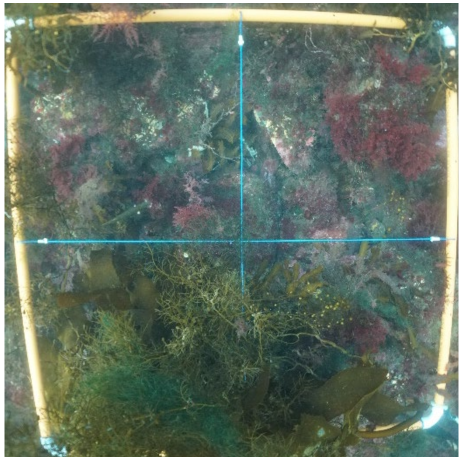
100 m North (June)



100 m South (January)

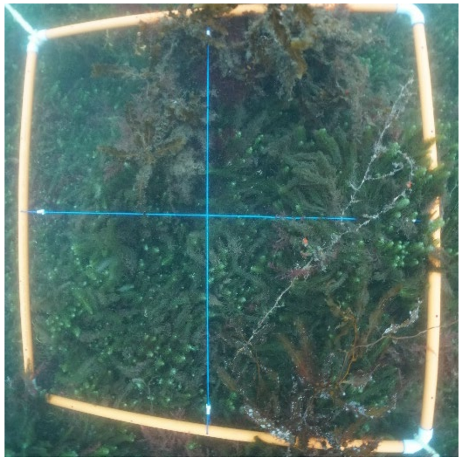


100 m South (June)



400 m North (January)

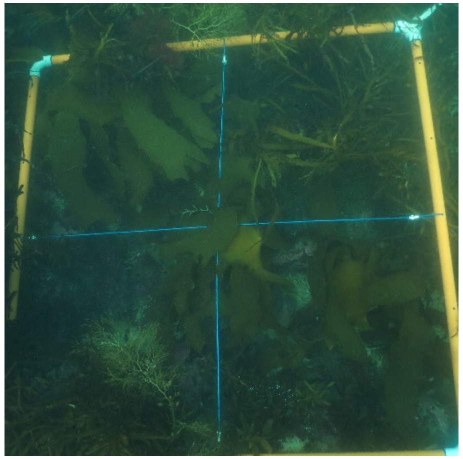
400 m North (June)



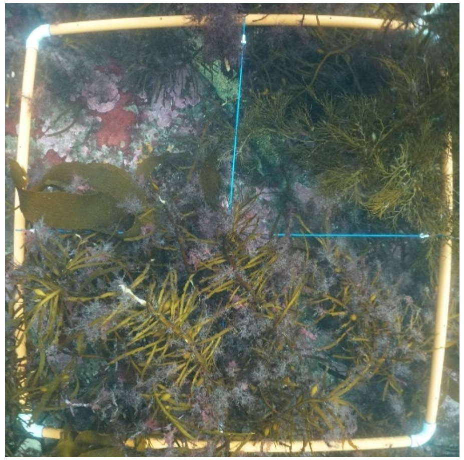
400 m East (January)

400 m East (June)

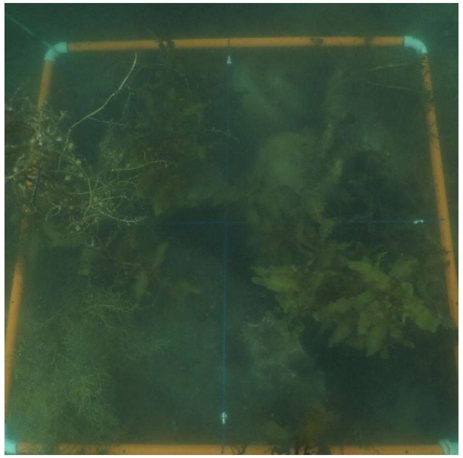
400 m South (January)



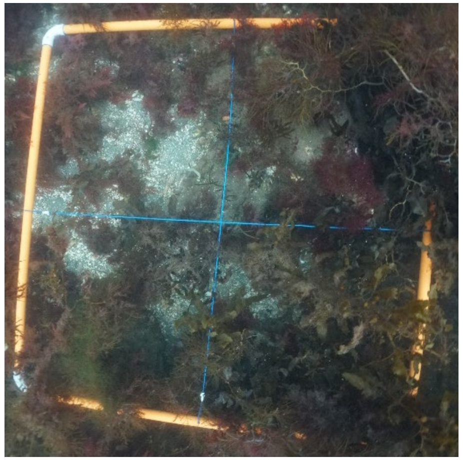
400 m South (June)



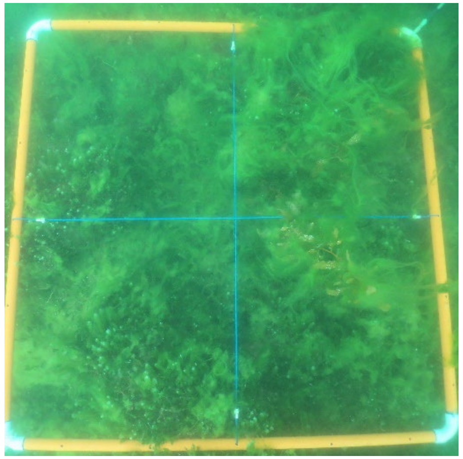
400 m West (January)



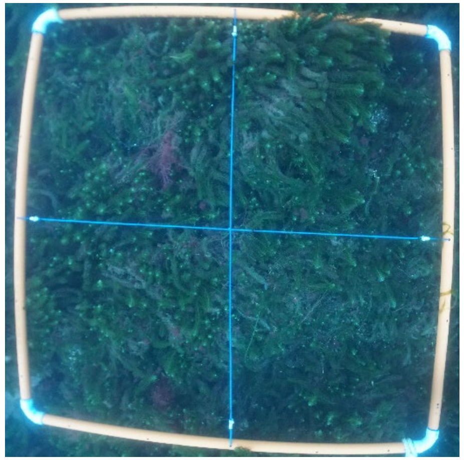
400 m West (June)



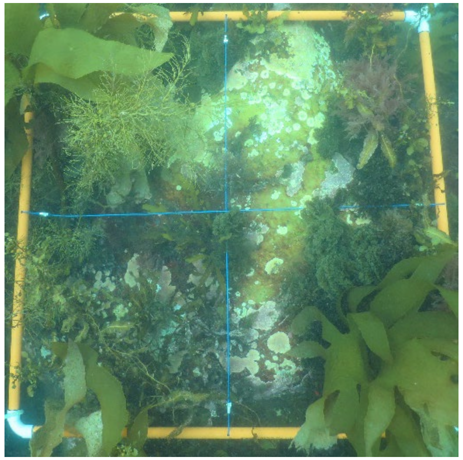
1000 m North (January)



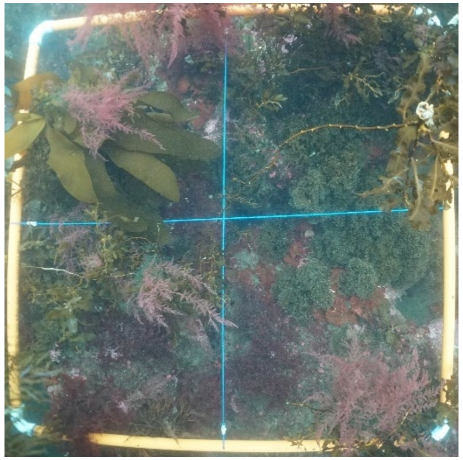
1000 m North (June)



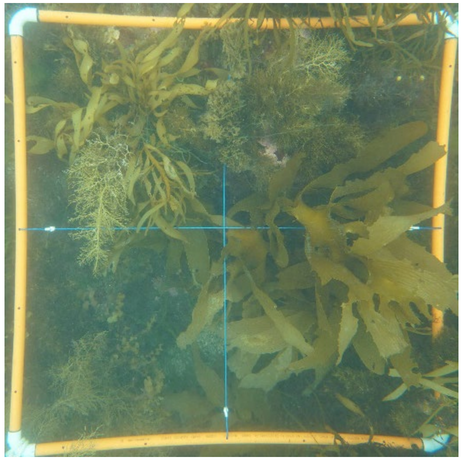
1000 m East (January)



1000 m East (June)

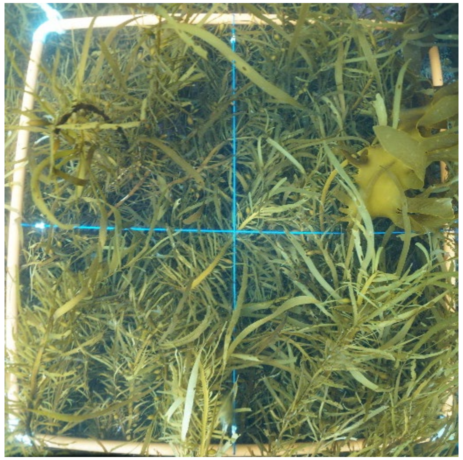


1000 m South (January)

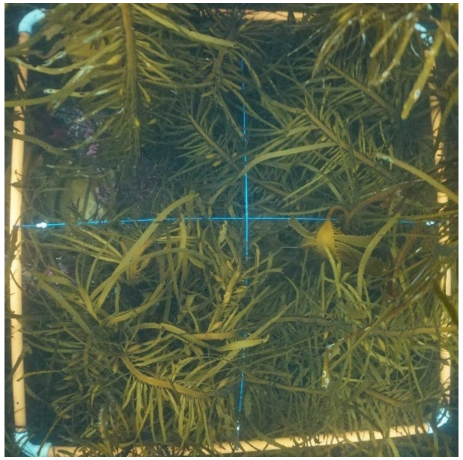


1000 m South (June)

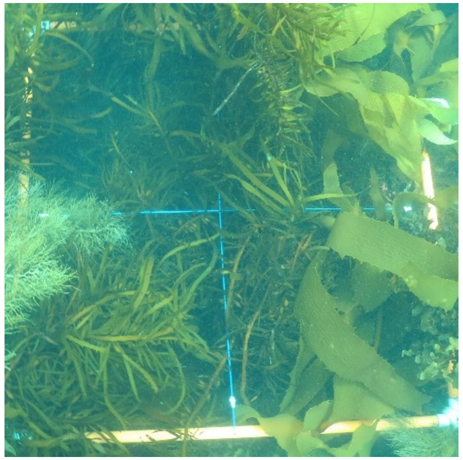
Safety Cove (January)



Safety Cove (June)

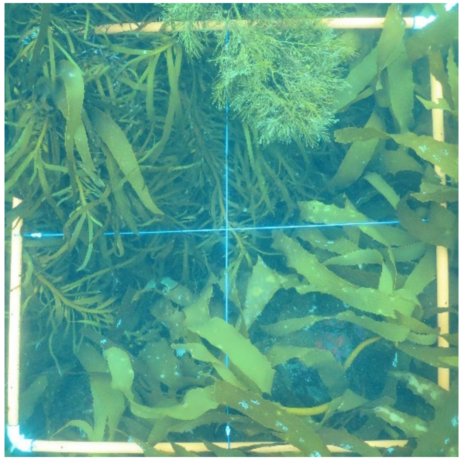


Canoe Bay (January)



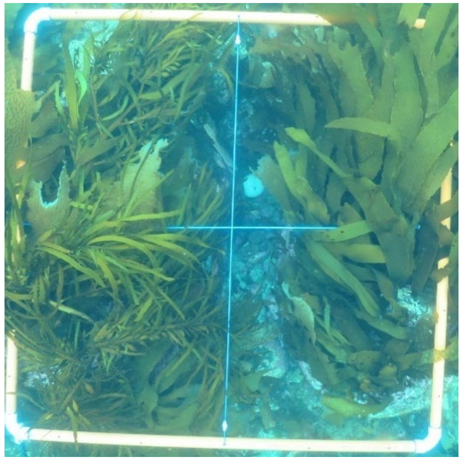
Canoe Bay (June)

Fortescue East (January)



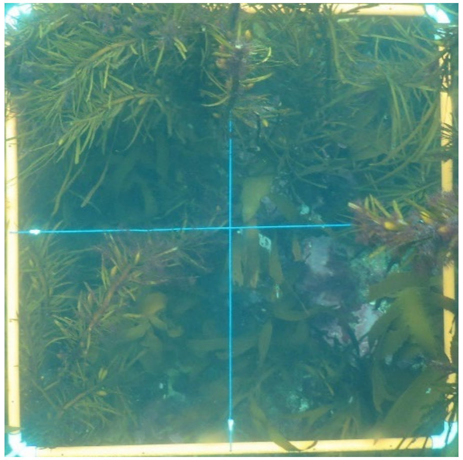
Fortescue East (June)

Fortescue West (January)



Fortescue West (June)

East Bank (June)



Appendix IV: Result tables from leave-one-out cross-validation

Leave one out cross-validation for distance from farm:

Orig. group	Classified						
	100m	400m	1000m	PA Ref	FB Ref	Total	% correct
100m	5	0	1	0	0	6	83.333
400m	1	3	3	0	1	8	37.5
1000m	0	4	1	0	1	6	16.667
PA Ref	0	0	0	2	1	3	66.667
FB Ref	0	0	0	1	5	6	83.333

Leave one out cross-validation for direction of site from farm:

Orig. group	Classified						
	East	North	South	PA Ref	FB Ref	Total	% correct
East	5	0	0	0	1	6	83.333
North	0	4	1	1	0	6	66.667
South	1	1	3	0	1	6	50
PA Ref	0	0	0	2	1	3	66.667
FB Ref	1	0	0	1	4	6	66.667

Appendix V: SIMPER results (two-way crossed)

SIMPER results (two-way crossed analysis of direction x distance) for complete RVA data showing the average abundance (% cover) of the typifying parameters within each distance group (100 m, 400 m, 1000 m, PA reference and FB reference) across all direction groups (East, North, South and Control [which includes both the Port Arthur and Fortescue Bay control sites]). Also shown for each parameter is the average within-group similarity (%) and the cumulative total (%) of their contribution to the overall similarity (70% cut-off).

	Average abundance (% cover)	**Average similarity (%)**	**Cumulative contribution (%)**
100 m			Average similarity: 66.88
Canopy	47.99	18.05	26.99
Understorey red	29.24	10.01	41.95
Turfing algae	31.60	9.63	56.34
Epiphytic algae	18.11	6.42	65.94
Pink encrusting	16.51	5.43	74.06
400 m			Average similarity: 66.86
Canopy	51.56	18.78	28.09
Understorey green	26.42	10.92	44.42
Pink encrusting	20.76	7.16	55.13
Understorey brown	18.82	6.19	64.39
Red encrusting	18.13	5.78	73.03
1000 m			Average similarity: 66.28
Canopy	38.54	14.63	22.07
Understorey green	30.26	11.19	38.95
Epiphytic algae	23.61	8.08	51.14
Filamentous algae	17.99	5.88	60.01
Red encrusting	18.39	5.61	68.47
Pink encrusting	17.79	5.22	76.35
Port Arthur Reference			Average similarity: 66.65
Canopy	80.28	33.64	50.48
Understorey red	28.19	8.94	63.90
Pink encrusting	31.39	8.59	76.78
Fortescue Bay Reference			Average similarity: 68.44
Canopy	72.50	33.99	49.67
Pink encrusting	29.54	10.72	65.33
Red encrusting	22.14	8.30	77.45

SIMPER results (two-way crossed analysis of direction x distance) for complete RVA data showing the average abundance (% cover) of the typifying parameters within each direction group (East, North, South and Control [which includes both the Port Arthur and Fortescue Bay control sites]) across all distance groups (100 m, 400 m, 1000 m, PA reference and FB reference). Also shown for each parameter is the average within-group similarity (%) and the cumulative total (%) of their contribution to the overall similarity (70% cut-off).

	Average abundance (% cover)	**Average similarity (%)**	**Cumulative contribution (%)**
East			Average similarity: 66.00
Canopy	47.85	19.58	29.67
Pink encrusting	24.44	8.11	41.95
Understorey brown	19.53	6.86	52.34
Red encrusting	19.04	6.73	62.54
Understorey red	16.18	5.86	71.41
North			Average similarity: 65.90
Understorey green	48.58	19.59	29.72
Epiphytic algae	32.35	10.72	45.98
Canopy	29.06	8.65	59.10
Filamentous algae	24.64	7.55	70.56
South			Average similarity: 68.12
Canopy	61.18	23.23	34.10
Pink encrusting	26.25	8.85	47.09
Turfing algae	23.22	6.39	56.47
Red encrusting	19.54	5.99	65.27
Understorey red	19.35	5.52	73.37
Reference (PA & FB)			Average similarity: 68.09
Canopy	75.09	33.92	49.82
Pink encrusting	30.16	10.30	64.95
Red encrusting	21.52	7.87	76.51

Appendix VI: Means and SE tables

Means ± standard error (SE) for major algae and substrate functional groups at the Port Arthur and Fortescue Bay sites in both January 2021 and June 2021.

	Canopy	Understorey brown	Understorey green	Understorey red	Pink encrusting	Red encrusting
January						
100m N	50.8 ± 5.7	4.5 ± 0.9	6.7 ± 3.3	42.1 ± 4.1	6.8 ± 1.6	3.3 ± 2.5
400m N	24.3 ± 6.5	2.5 ± 1.2	62.5 ± 3.7	7.5 ± 1.4	4.2 ± 1.9	9.6 ± 4.1
1000m N	9.2 ± 2.9	1.7 ± 0.9	70 ± 7.1	5.8 ± 1.2	1.8 ± 0.7	4.2 ± 1.6
400m W	44.6 ± 6.1	6.8 ± 1.9	3.9 ± 0.8	12.5 ± 1.9	2.4 ± 0.7	0.8 ± 0.4
100m E	42.9 ± 5.5	5.1 ± 1.7	6.4 ± 2.3	17.1 ± 2.5	35.4 ± 5.7	4.5 ± 0.9
400m E	73.8 ± 6.1	31.3 ± 3	3.3 ± 0.5	12.9 ± 1.3	24.6 ± 4.6	34.6 ± 5.8
1000m E	44.2 ± 4.7	25.4 ± 5.1	5.5 ± 2	22.9 ± 4.3	21.7 ± 5.6	23.3 ± 2.8
100m S	65.8 ± 3.2	9.6 ± 1.8	10.5 ± 6	35 ± 4.6	19.2 ± 2.5	9.6 ± 1.7
400m S	71.7 ± 3.2	23.3 ± 4.7	6.2 ± 2.4	12.4 ± 3.1	37.5 ± 5.3	15 ± 2.3
1000m S	70 ± 4.8	10.8 ± 3.3	12.9 ± 2.2	8.3 ± 1.7	30 ± 4.3	34.6 ± 6.1
East Bank	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Safety Cove	92.1 ± 5.7	6.7 ± 2.2	8.8 ± 2.4	30.4 ± 6.7	44.6 ± 7	18.3 ± 2.8
Canoe Bay	85.4 ± 3.7	18.8 ± 2.8	1.3 ± 0.7	23.8 ± 3.6	27.3 ± 5.4	23.3 ± 3.6
Fortescue W	77.1 ± 4.6	8 ± 1.5	1.1 ± 0.5	29.2 ± 3.9	37.1 ± 4.5	24.6 ± 2.6
Fortescue E	87.9 ± 2.6	14.6 ± 2.4	0 ± 0	6 ± 1.4	32.9 ± 6.3	18.3 ± 3
June						
100m N	41.7 ± 4.4	6.3 ± 1.6	6.5 ± 2.6	35.4 ± 5.2	9.3 ± 2.9	11.7 ± 4.9
400m N	37.1 ± 9.5	3.3 ± 2.6	66.3 ± 5.8	9.9 ± 3.1	1.7 ± 0.9	1.7 ± 1.1
1000m N	11.3 ± 2.8	1.3 ± 0.7	79.6 ± 5.9	3.8 ± 1.1	2.4 ± 1.3	0.3 ± 0.2
400m W	62.5 ± 5.3	9.2 ± 1.8	7.3 ± 3.2	12.1 ± 2.4	3.7 ± 1.1	1 ± 0.6
100m E	34.6 ± 3.6	10.4 ± 2.2	5.5 ± 1.6	12.5 ± 3	17.1 ± 2.7	6.4 ± 0.8
400m E	53.8 ± 5.2	24.2 ± 3.9	6.5 ± 1.6	12.9 ± 2.6	26.3 ± 4.4	30 ± 3.7
1000m E	37.9 ± 5.2	20.8 ± 4.4	6.2 ± 1.4	18.8 ± 3.2	21.7 ± 5.4	15.4 ± 3.6
100m S	52.1 ± 6.1	16.7 ± 1.5	12.1 ± 6.3	33.3 ± 4.1	11.3 ± 1.1	7.7 ± 1.5
400m S	48.8 ± 5.8	28.3 ± 5.7	13.8 ± 1.9	12.1 ± 1.9	30.4 ± 3.8	17.9 ± 3.8
1000m S	58.8 ± 7	12.4 ± 3.1	7.4 ± 1.8	14.9 ± 4.9	29.2 ± 6.7	32.5 ± 7.7
East Bank	60.4 ± 5.7	10 ± 3.1	1.1 ± 0.5	32.9 ± 3.8	12.9 ± 3.2	17.9 ± 4.5
Safety Cove	88.3 ± 3.6	3.5 ± 1.1	4.6 ± 1.9	21.3 ± 4.5	36.7 ± 7.2	24.6 ± 5.3
Canoe Bay	64.6 ± 3.7	8.9 ± 1.3	1.7 ± 0.9	15.2 ± 2.4	25.8 ± 3.9	29.6 ± 3.7
Fortescue W	51.7 ± 7.2	9.6 ± 2.3	0 ± 0	15.4 ± 3.5	24.2 ± 4.3	13.3 ± 3.3
Fortescue E	68.3 ± 6.3	12.1 ± 1.7	0 ± 0	5.8 ± 2.4	30 ± 6.8	23.8 ± 5.1

Means ± standard error (SE) for the major canopy-forming species recorded at the Port Arthur and Fortescue Bay sites in both January 2021 and June 2021.

	Phyllospora comosa	***Ecklonia radiata***	***Lessonia corrugata***	***Sargassum* spp.**	***Cystophora* spp.**	***Durvillaea potatorum***
January						
100m N	0 ± 0	24.6 ± 5.6	0 ± 0	16.7 ± 3.7	9.6 ± 2.6	0 ± 0
400m N	0 ± 0	5.8 ± 2.4	0 ± 0	13.1 ± 3	5.4 ± 2.9	0 ± 0
1000m N	0 ± 0	0 ± 0	0 ± 0	9.2 ± 2.9	0 ± 0	0 ± 0
400m W	0.4 ± 0.4	0.4 ± 0.4	0 ± 0	20 ± 3.1	23.8 ± 5.5	0 ± 0
100m E	0.4 ± 0.4	22.5 ± 5.3	0 ± 0	14.6 ± 1.9	5.4 ± 1.7	0 ± 0
400m E	16.7 ± 4.5	36.7 ± 5.5	0 ± 0	0 ± 0	20.4 ± 3.9	0 ± 0
1000m E	0 ± 0	26.3 ± 4.5	0 ± 0	13.3 ± 3.6	4.6 ± 1.9	0 ± 0
100m S	0 ± 0	33.8 ± 4.7	0 ± 0	27.5 ± 5.1	4.6 ± 2.4	0 ± 0
400m S	33.3 ± 7	27.1 ± 6.2	0 ± 0	0.4 ± 0.4	9.2 ± 5.1	0 ± 0
1000m S	33.8 ± 7.5	25.4 ± 3.6	0 ± 0	0.4 ± 0.4	10.4 ± 4.6	0 ± 0
East Bank	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Safety Cove	88.3 ± 5.6	4.6 ± 1.7	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Canoe Bay	24.6 ± 4.4	56.3 ± 7.1	0 ± 0	2.1 ± 1.7	2.5 ± 2.1	0 ± 0
Fortescue W	31.7 ± 7.9	45.4 ± 6	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Fortescue E	22.1 ± 5	61.7 ± 5.6	0 ± 0	0.8 ± 0.8	3.3 ± 2.2	0 ± 0
June						
100m N	2.5 ± 1.8	16.3 ± 4	0 ± 0	20.8 ± 3.6	2.1 ± 1	0 ± 0
400m N	0 ± 0	1.7 ± 0.9	0 ± 0	20.8 ± 4.8	14.6 ± 6.1	0 ± 0
1000m N	0 ± 0	0 ± 0	0 ± 0	7.5 ± 2.3	3.8 ± 1.4	0 ± 0
400m W	0 ± 0	0 ± 0	0 ± 0	18.3 ± 6.1	44.2 ± 5.5	0 ± 0
100m E	0 ± 0	11.7 ± 1.9	0 ± 0	16.3 ± 3.3	6.7 ± 2.8	0 ± 0
400m E	20 ± 3.6	17.1 ± 3.8	0 ± 0	0 ± 0	16.7 ± 5.6	0 ± 0
1000m E	0 ± 0	12.5 ± 3.9	0 ± 0	18.3 ± 3.5	7.1 ± 2.9	0 ± 0
100m S	2.9 ± 2.5	22.1 ± 3.6	0 ± 0	12.5 ± 4.5	14.6 ± 3.5	0 ± 0
400m S	30.8 ± 6.5	14.6 ± 3.8	0 ± 0	0 ± 0	3.3 ± 1.3	0 ± 0
1000m S	21.7 ± 5	20.8 ± 6.1	0 ± 0	0.8 ± 0.6	15.4 ± 7.3	0 ± 0
East Bank	38.8 ± 5.5	19.2 ± 2.4	1.3 ± 0.9	0 ± 0	0.4 ± 0.4	0.8 ± 0.8
Safety Cove	77.9 ± 7.1	10.4 ± 4.4	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Canoe Bay	26.3 ± 3.8	36.7 ± 4.2	0 ± 0	1.7 ± 1.1	0 ± 0	0 ± 0
Fortescue W	15 ± 3.4	36.3 ± 6.8	0 ± 0	0.4 ± 0.4	0 ± 0	0 ± 0
Fortescue E	29.6 ± 5.3	34.6 ± 6.1	0 ± 0	0 ± 0	4.2 ± 2.9	0 ± 0

Means ± standard error (SE) for enrichment parameters, turfing algae and sponge cover recorded at the Port Arthur and Fortescue Bay sites in both January 2021 and June 2021.

	Epiphytic algae	**Filamentous algae**	**Nuisance green**	**Nuisance red**	**Turfing algae**	**Sponge**
January						
100m N	12.7 ± 2.3	0.2 ± 0.2	4 ± 1	12.1 ± 2.3	30.4 ± 5.9	22.3 ± 6.7
400m N	37.9 ± 5.1	36.3 ± 4.6	0 ± 0	1.7 ± 1.1	12.9 ± 5.7	11.8 ± 2.7
1000m N	58.3 ± 5.1	55.4 ± 4.3	0 ± 0	0 ± 0	0 ± 0	12.6 ± 3.3
400m W	9.3 ± 1.1	0 ± 0	6.2 ± 0.6	4.1 ± 0.8	43.8 ± 7	1.6 ± 0.6
100m E	16.3 ± 2	0 ± 0	12.9 ± 2.3	4.7 ± 0.9	13.8 ± 5.9	17.1 ± 4.9
400m E	4.2 ± 0.8	1.4 ± 0.6	0.9 ± 0.5	0 ± 0	17.5 ± 3.6	13.8 ± 3.3
1000m E	9.2 ± 2.1	1.8 ± 0.7	4 ± 0.8	7.8 ± 1.3	14.2 ± 2.6	11 ± 2.5
100m S	27.9 ± 3	10.8 ± 1.4	20.7 ± 3.1	8.8 ± 2.1	52.1 ± 4.4	7.3 ± 1.4
400m S	7 ± 1	0 ± 0	0.8 ± 0.6	0 ± 0	3.9 ± 1.8	7.1 ± 2
1000m S	8.3 ± 1.1	1.7 ± 0.7	8.2 ± 2.5	1.3 ± 0.7	7.1 ± 1.9	9.3 ± 2.1
East Bank	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Safety Cove	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	17.1 ± 4.7
Canoe Bay	2 ± 0.7	0 ± 0	0 ± 0	0 ± 0	10.2 ± 3.2	9.6 ± 2
Fortescue W	3.7 ± 1.1	0.4 ± 0.4	0.8 ± 0.3	0 ± 0	1.3 ± 0.9	16.7 ± 4.7
Fortescue E	1.5 ± 0.9	0 ± 0	0.3 ± 0.2	0 ± 0	1.3 ± 1.3	7.2 ± 1.4
June						
100m N	14.3 ± 2.2	3.1 ± 0.9	9.3 ± 1.1	10 ± 2.3	38.8 ± 5.8	13.7 ± 4
400m N	30.4 ± 5.6	15.8 ± 4.8	0 ± 0	4.2 ± 1.5	14.6 ± 7.9	10.2 ± 2.4
1000m N	40.4 ± 5	37.1 ± 5.3	0 ± 0	3.8 ± 1.1	21.3 ± 5.4	6.4 ± 0.8
400m W	38.8 ± 3.3	18.8 ± 3	5.8 ± 1	13.3 ± 2.7	35.8 ± 7.1	5.4 ± 1.3
100m E	21.7 ± 2.1	0 ± 0	15.3 ± 1.8	11.3 ± 2.1	16.3 ± 3.5	17.9 ± 5.7
400m E	5.7 ± 1	0 ± 0	0.4 ± 0.2	0.2 ± 0.2	12.3 ± 3.6	10.6 ± 3
1000m E	15.8 ± 3.9	4 ± 0.8	3.4 ± 0.8	8.8 ± 3.9	24.2 ± 6.8	4.9 ± 1.4
100m S	15.8 ± 1.8	2.3 ± 0.7	10.5 ± 1.9	4.3 ± 1	38.3 ± 4.5	10 ± 1.9
400m S	22.5 ± 5.1	0 ± 0	0.7 ± 0.3	0 ± 0	19.2 ± 3.4	10.8 ± 3.1
1000m S	9.6 ± 1.3	7.9 ± 1.4	2.3 ± 1.3	1.4 ± 0.9	18.8 ± 5.1	11.4 ± 3
East Bank	8.1 ± 1.5	0 ± 0	0 ± 0	0 ± 0	23.3 ± 4.3	18.8 ± 3.6
Safety Cove	0 ± 0	0 ± 0	0 ± 0	0 ± 0	2.9 ± 1.1	17.5 ± 4
Canoe Bay	0.6 ± 0.4	0.4 ± 0.4	0 ± 0	0 ± 0	23.8 ± 4.2	9.2 ± 2
Fortescue W	0 ± 0	0 ± 0	0 ± 0	0 ± 0	17.7 ± 5.4	15.4 ± 2.1
Fortescue E	0 ± 0	0 ± 0	0 ± 0	0 ± 0	15 ± 5.2	4.8 ± 1.1