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Reassessment of intertidal macroalgal communities near to and distant from salmon farms and an evaluation of using drones to survey macroalgal distribution

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Executive Summary

Background

The salmon farming industry has significantly expanded in the last decade in South-eastern Tasmanian both in production (total production from Tasmania now estimated at 55,000 tonnes per annum) and in number and location of farms. Along with this expansion has been an increasing concern from the general community about the effects of salmon farms on the environment. This includes a reported spread of 'nuisance' algae in the intertidal zone; however, this has not been verified scientifically. As one of the main effects of salmon farming is an increase in nutrients to the environment from waste products, a possible flow-on effect could be a proliferation of macroalgal beds near salmon farming operations. However, a survey of intertidal areas in the Huon and D'Entrecasteaux Channel region in 2002/03 found no clear patterns of macroalgal abundance with distance from salmon farms, (Crawford et al 2006), and it was recommended that any future studies focus on surveying the abundance of key species in the intertidal, *Ulva* spp and *Hormosira banksii*, which are widely distributed and readily identified.

In this project researchers from the Institute for Marine and Antarctic Studies at the University of Tasmania repeated the survey of intertidal macroalgae conducted in 2002/03 to assess whether abundances have significantly changed at these sites. We also investigated monitoring macroalgal abundance at a larger spatial scale using Unmanned Aerial Vehicles (UAVs), commonly known as drones. Since the previous survey in 2002/03, the technology for UAVs has significantly advanced and they are now a much more cost effective option. However, the techniques and quantitative analyses required to monitor intertidal algal assemblages using drones have not been assessed.

This report discusses the results of the surveys assessing the percentage cover of intertidal macroalgae at different spatial scales using standard quadrat sampling and UAVs (drones), and discusses issues and limitations of monitoring in the intertidal zone in southern Tasmania.

Objectives:

(i) To repeat the assessment of intertidal macroalgal composition and abundance near to and distant from salmon farms in the Huon and D'Entrecasteaux Channel region eleven years after the initial assessment.

(ii) To evaluate the potential of using Unmanned Aerial Vehicles (drones) to monitor macroalgal distribution.

Methodology :

Intertidal macroalgal surveys were conducted by repeating the methods used in 2002/03 (Crawford et al 2006). In summary this methodology involved recording the percentage cover of all species of macroalgae at selected sites in replicate 1 m^2 quadrats in the mid and low intertidal, at three transects perpendicular to the shoreline and approximately 50 m apart at each site. Sites were chosen to be close to salmon farms (< 1 km), mid distance (1-3 km) and far from salmon (reference) (> 7km). Three new sites were added in this project at the request of industry, in the upper, mid and lower Channel. Surveys were conducted in autumn and spring in 2015 and 2016.

UAVs (drones) were trialled in December 2015 to map *Macrocystis* beds using a multi-rotor drone carrying a digital SLR camera flying over a 260 m section of coastline in the lower Hun estuary. The second trial in Port Esperance in March 2016 used a multi-rotor drone flying over a small area at low height to capture clear images of small areas of the intertidal, and a fixed wing AUV which flies higher and faster and provides images over larger areas at lower resolution.

Results/key findings

Although the percentage cover of all species of intertidal algae in the quadrats was recorded, the analysis focussed on the two dominant species types *Ulva* spp and *Hormosira banksii*. Similar to the previous surveys conducted in 2002/03, there were no clear patterns in abundance of *Ulva* or *Hormosira* with distance from salmon farms, even though production from salmon farms has increased substantially over this time. However, the abundance of *Hormosira* in 2015 and 2016 was significantly lower than in 2002/03. This species had almost disappeared from the mid tide region at nearly all sites in 2015-16, whereas the percentage cover of *Ulva* was significantly higher. These results suggest that factors other than nutrients from salmon farms were also influencing the abundance of intertidal algae, as the results were consistent across sites, regardless of distance from salmon farming operations.

The drone survey in December 2016 produced over 1500 photographs but only a portion of these were suitable for orthomosaic processing due to the system failing to deal with refraction issues in deep water during the image matching stage. Although boundaries of *Macrocystis* beds were visible and could be mapped, the refraction effects with water depth would likely hinder change analysis if the beds were mapped at a later date. Similarly, the drone surveys in March 2016 were not that successful because even at low tide sections of the intertidal were covered with water, and a depth of only 1 cm was found to severely limit camera recordings, including poor colour definition.

Implications for relevant stakeholder

This study has provided further information on the complexities and issues involved in developing monitoring programs to assess the impacts of nutrient inputs from salmon farms on the surrounding environment. Overall, the results suggest that the abundance of intertidal algae, whether at a small spatial scale of 1 m^2 quadrats or over a larger scale of hundreds of metres lengths of coastline, is not a reliable measure of the effects of salmon farm waste nutrients on the environment. Other factors likely influence the composition and abundance of intertidal algae and confound the effects from salmon farms. Also, monitoring in the intertidal zone was logistically difficult because the tidal range in southern Tasmania is only approximately 1 m and was often not completely exposed at low tide.

Keywords: intertidal algae, salmon aquaculture, nutrients, environmental monitoring, drones, unmanned aerial vehicles

Introduction

The Tasmanian salmonid aquaculture industry is now the largest seafood sector in Australia with production approaching 55,000 t of salmonids per annum and a farm gate value of ~$665 million (Tasmanian Salmon Growers Association website 9/8/16, available at http://www.tsga.com.au/). The industry's strategic plan is to double salmon production in Tasmania by 2030, and obtaining community acceptance for this expansion is an important issue for the industry.

A key impact of farming salmon on the environment is an increase in nutrients from fish excretory products and uneaten food. These nutrients have the potential to increase primary production of micro and macro- algae, which can proliferate in the intertidal zone where they are conspicuous to the community. Anecdotal evidence from community members suggests that intertidal macroalgae have increased near salmon farms; however there are no scientific data to support these reportings. Also, although studies of the effects of salmon farming on the environment in the Huon and D'Entrecasteaux Channel region have been ongoing since commercial salmon farming commenced in 1986, this monitoring has concentrated on water quality and subtidal benthic soft sediment communities, and hasn't included any assessments of rocky reef habitats or macroalgae.

In 2002-03 intertidal macroalgae on rocky reefs near to, and distant from, salmon farms in the D'Entrecasteaux Channel and Huon region was assessed by TAFI. Key outcomes from this assessment were:

- "intertidal algal communities, in particular the dominant species *Ulva* and *Hormosira*, show natural variation and no clear trends in abundance with distance from salmon farms", and
- "These results suggest that a simple ecological measure for the effects of increased nutrients on the environment would be to measure the abundance of *Ulva* and *Hormosira* in the mid intertidal zone at sites near to and distant from salmon farms in spring and autumn each year".

Since this intertidal macroalgal assessment 14 years ago, the production of salmon from the region has more than doubled. The proposed further expansion of salmon farming to new sites in south eastern Tasmania has elicited opposition from neighbouring residents, wild abalone fishers and environmental groups, and this has been well displayed in the media. One of their major concerns is lack of information on whether salmon farms are affecting intertidal and subtidal macroalgae, and no ongoing monitoring of these habitats. This highlights the importance of repeating the surveys more than a decade later to assess changes in intertidal macroalgal abundance and species composition around salmon farms.

In this project we repeated the macroalgae survey conducted in 2003 to assess whether macroalgal abundance has significantly changed at these sites. At the request of industry we also included an additional three sites: new reference site at Recherche Bay, a northern Channel site, and a mid Channel site > 5 km from salmon farms.

The ability to monitor coastal habitat at a larger scale relevant to fish farming has increased over the last decade with advancement in technology for Unmanned Aerial Vehicles (UAVs) carrying various sensors, commonly known as drones. These are becoming a more cost-effective option for monitoring agricultural environments, including salmon farms, and coastal habitats. However, methods to quantitatively assess coastal environmental change using drones, such as macroalgal distribution and abundance, have not been assessed. The effectiveness of this technique to monitor salmon farms is needed to maximise usage of this data and before it could be incorporated into monitoring programs. Therefore, we also investigated using drones to monitoring macroalgal communities on intertidal rocky shores and giant kelp *Macrocystis pyrifera* in the shallow subtidal. We partnered with the TerraLuma Research Group at University of Tasmania, who were keen to research the feasibility of using drones to monitor macroalgal communities. They provided UAV equipment, a pilot and use of laboratory facilities as an inkind contribution.

Objectives

1	To repeat the assessment of intertidal macroalgal composition and abundance near to and distant from salmon farms in the Huon and D'Entrecasteaux Channel region eleven years after the initial assessment.
2	To evaluate the potential of using Unmanned Aerial Vehicles (drones) to monitor macroalgal distribution.

Methods

Intertidal macroalgal surveys

The percentage cover of intertidal species of macroalgae was assessed in areas containing salmon farms (Port Esperance /Dover, the lower Huon Estuary, Tinderbox, Conningham, Bruny Island) and in areas with similar environmental conditions but no salmon farms (Southport, Recherche Bay and Gordon). The locations near salmon farming operations were further divided into those <1 km from cages of salmon and those 1-3 km away (Table 1). Three new sites were added at the request of industry: at Tinderbox to provide environmental information from the upper Channel region, a site at Gordon, representing the mid Channel region and > 5 km from a salmon farm, and at Recherche Bay as an additional site distant from salmon farms Figure 1, Table 2). Importantly, these new sites link with BEMP compliance sampling sites for water quality in these areas. Of note is that in the previous survey in 2002-03, sites on the western shoreline of South Bruny Island were monitored as reference sites; however salmon farms are now operating within 3 km of this shoreline.

Table 1. List of sites sampled and distance (km) from salmon farm leases. (PE = Port Esperance).

< 1 km (close)	1-3 Km (mid)	>7 km (far)
PE Tassal	PE Blubber Head	Recherche Bay 2
PE Hope Island	PE Charity Is	Recherche Bay 1
PE Stringers	Huon Garden Is.	Southport 1
Huon HAC	Tinderbox	Southport 2
Huon Surveyors	Conningham	Gordon
	South Bruny	

The locations of transects were originally chosen haphazardly, within the constraints that other sources of anthropogenic impact (such as small creeks, runoff from gardens etc) were avoided and habitat type was relatively sheltered with gently sloping rock platform at all sites. The sampling site locations were positioned and subsequently relocated using GPS.

Algal cover was measured at each site by placing three transect tapes down the shore, perpendicular to the water, from the upper intertidal to the low water mark. The percentage cover of algal species was measured in the mid and low intertidal regions using 1 m^2 quadrats and 100 point intersects, with 4 quadrats in the mid and three in the lower intertidal. (The upper intertidal was originally measured but contained little algae and was discontinued). The lower intertidal zone was photographed at each transect, and a photograph also taken across the shoreline, parallel to the water at the middle transect.

Figure 1. Map of the D'Entrecasteaux Channel showing the location of sampling sites for intertidal macroalgae.

Table 2. GPS points for intertidal algal sampling sites.

Intertidal algal sampling sites			
Site	Transect 1	Transect 2	Transect 3
Tinderbox	43.05844, 147.33186	43.05867, 147.33215	43.05881, 147.33250
	43.05861, 147.33177	43.05854, 147.33219	43.05864, 147.33259
Gordon	43.28030, 147.22090	43.28030, 147.22171	43.28022, 147.22200
	43.28067, 147.22104	43.28042, 147.22166	43.28035, 147.22206
Reserche Bay 1	43.54724, 146.88906	43.54700, 146.88925	43.54675, 146.88954
Finns Beach N	43.44729, 146.88928	43.54701, 146.88939	43.54673, 146.88941
Reserche Bay 2	43.54034, 146.89531	43.54099, 146.89457	43.53930, 146.89349
Gilhams Beach	43.54056, 146.89501	43.53986, 146.89478	43.53947, 146.89336
Southport 1	43.43925, 146.98312	43.43864, 146.98291	43.43839, 146.98282
Mundays Road	43.43918, 146.98336	43.43862, 146.98312	43.43834, 146.98302
Southport 2	43.43640, 146.97853	43.43608, 146.97786	43.43575, 146.97776
Cathkit Street	43.43624, 146.97861	43.43605, 146.97797	43.43573, 146.97790
Conningham	43.08227, 147.29488	43.08024, 147.29218	43.07996, 147.29195
	43.08238, 147.29489	43.08029, 147.29208	43.07998, 147.29194
Huon 1	43.27099, 147.07751	43.27101, 147.07782	43.27109, 147.07826
Hideaway Bay	43.27088, 147.07750	43.27089, 147.07784	43.27072, 147.07828
Huon 2	43.27925, 147.09541	43.27873, 147.09489	43.27861, 147.09464
Surveyors Bay	43.27919, 147.09542	43.27869, 147.09491	43.27854, 147.09469
Huon 3	43.28708, 147.14410	43.28702, 147.14415	43.28650, 147.14491
Huon Island	43.28701, 147.14400	43.28696, 147.14408	43.28641, 147.14166
Huon 4	43.26424, 147.14263	43.26437, 147.14248	43.26389, 147.14270
E Garden Island	43.26418, 147.14241	43.26435, 147.14232	43.26383, 147.14252
Port Esperance 1	43.32383, 147.03237	43.32417, 147.03198	43.32348, 147.03165
Charity Island	43.32379, 147.03252	43.32434, 147.03200	43.32333, 147.03162
Port Esperance 2	43.34228, 147.02948	43.34217, 147.02910	43.34245, 147.02995
Tassal HQ south	43.34224, 147.02949	43.34214, 147.02910	43.34239, 147.02999
Port Esperance 3	43.34686, 147.04387	43.34682, 147.04442	43.34691, 147.04323
Stringers	43.34681, 147.04336	43.34676, 147.04442	43.34687 147.04323
Port Esperance 3	43.33630, 147.03950	43.33656, 147.03933	43.33691, 147.03880
Hope Island	43.33628, 147.03946	43.33652, 147.03920	43.33682, 147.03876
Port Esperance	43.32041, 147.05378	43.32021, 147.05372	43.32004, 147.05426
Blubber Head 4	43.32040, 147.05367	43.32051, 147.05364	43.31997, 147.05414
Bruny Is	43. 37199, 147.18060	43. 37237, 147.18018	43. 36974, 147.18158
Venetat Point 1	43. 37189, 147.18051	43. 37222, 147.18005	43. 36973, 147.18144
Bruny Is 2	43.38350, 147.18469	43.38326, 147.18447	43.38393, 147.18537
N Connelys Beach	43.38364, 147.18450	43.38333, 147.18432	43.38397, 147.18531

Differences in macroalgal community structure between treatment sites were assessed using multivariate statistics including PRIMER and binomial generalised linear model analysis.

Monitor macroalgal distribution using drones

Unmanned Aerial Vehicle (UAV) trial surveys (drone-based macro algae mapping) were conducted in Summer (December 2015) and Autumn (March 2016). The first trial at Flathead Bay (near Surveyors Bay at the entrance to the Huon estuary) investigated mapping the *Macrocystis* beds and the second at Blubber Head in Port Esperance looked at intertidal zone macroalgae mapping.

The intertidal area was mapped using a multi-rotor UAV to provide very clear images (5-20 mm pixel resolution) of small areas when flying at 20-50 m height. For larger areas (10-100 ha), such as *Macrocystis* beds, a fixed wing UAV, which flies higher and faster and provides images of resolution 30-50 pixels, was trialled.

The mosaics were georeferenced either via accurate onboard positioning of the UAV or using surveyed ground control points. Ten 0.5 Multispectral UAV sensors and the derivation of spectral indices were also trialled for their ability to highlight differences in surface characteristics. This included capturing infrared and colour imagery using modified cameras, which should highlight the presence of macroalgae.

Results

Intertidal macroalgal surveys

Detailed results of percentage cover of each species at each site over the sampling period from autumn 2015 to spring 2016 will be deposited in the University of Tasmania's Research Data Management Portal.

Sampling at all sites, which had increased from 2002-03, periodically presented logistical issues, especially in spring when the weather was highly variable and strong winds were common. Not all 18 sites were sampled each season (except autumn 2015) because there were not enough days of calm weather during spring low tides. The Huon estuary was the most difficult region because several of the sites accessed by boats were in relatively exposed locations.

Analysis of the results has concentrated on *Ulva* sp and *Hormosira banksii* because these species were recommended as potential simple ecological measures of nutrient enrichment from the surveys conducted in 2002-03, and because there has been increasing concern from the general public in recent years about an increase in 'nuisance' algae, mostly *Ulva* species, in the D'Entrecasteaux Channel. However, *Ulva* is generally only common in the intertidal in spring as in summer the temperatures in the intertidal are generally too high for this species Figure 2).

(a) (b)

Figure 2 Reference site at Southport showing (a) dominance of *Hormosira banskii* in autumn 2016 and (b) predominately *Ulva* in spring 2016.

No clear trends in *Ulva* or *Hormosira* abundances with distance from salmon farms were apparent (Figure 3). The data averaged over all seasons sampled in 2015-2016 showed the highest percentage cover for both *Ulva* and *Hormosira* at the sites mid distance from salmon farms , i.e. in the 1-3 kg range from cages of salmon. For *Ulva,* however, this was not significantly different between sites at all distances from salmon cages, whereas *Hormosira* abundance was not significantly different between sites close to and distant from farms.

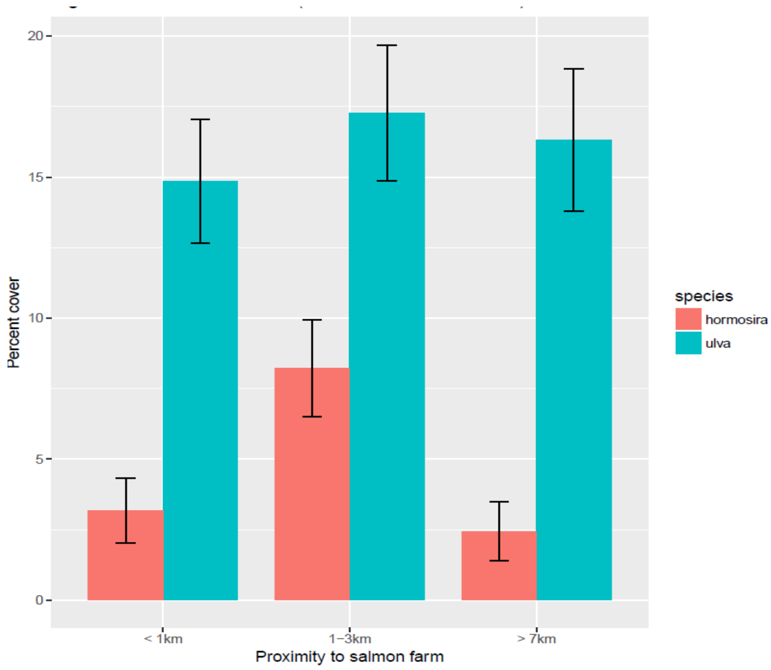

Figure 3. Percentage cover of *Ulva* and *Hormosira* with distance from salmon farms for all samplings in 2015-2016. Error bars are 95% confidence intervals.

Looking at the annual, seasonal and tidal height information in more detail (Figure 4, Table 3), season and year had a significant effect on percentage cover of *Ulva*, but not tidal height or distance from salmon farms. For *Hormosira*, the 'mid' distant sites significantly differed from the 'close' sites in percent cover, but the 'far' sites did not significantly differ from the 'close' sites. This suggests some other factor(s) at the 'mid' sites may be resulting in the higher percentage cover of *Hormosira.* Percentage cover of *Hormosira* was clearly significantly higher at low than mid tide.

Table 3. Results of binomial generalised linear model analysis for percentage cover of *Ulva* species and *Hormosira banskii* in different seasons and tidal heights in 2015-16. * P< 0.05, ** P<0.01, *** P< 0.001

***Ulva* species**

```
Coefficients:
                Estimate Std. Error z value Pr(>|z|)
(Intercept)   -1087.0093   370.4793  -2.934  0.00335 **
dist1-3km         0.2253     0.2127   1.059  0.28955
dist> 7km        -0.1130     0.2295  -0.492  0.62254
seasonspring      2.2864     0.2443   9.358  < 2e-16 ***
tidemid          -0.1151     0.1791  -0.642  0.52065
year              0.5377     0.1838   2.926  0.00344 **
```

Hormosira banskii

```
Coefficients:
              Estimate Std. Error z value Pr(>|z|)    
(Intercept) -39.79575  603.59695  -0.066  0.94743    
dist1-3km     1.07841    0.35600   3.029  0.00245 ** 
dist> 7km    -0.22540    0.49078  -0.459  0.64604    
seasonspring -0.36549    0.30349  -1.204  0.22847    
tidemid      -2.76398    0.49741  -5.557 2.75e-08 ***
year          0.01852    0.29947   0.062  0.95070    
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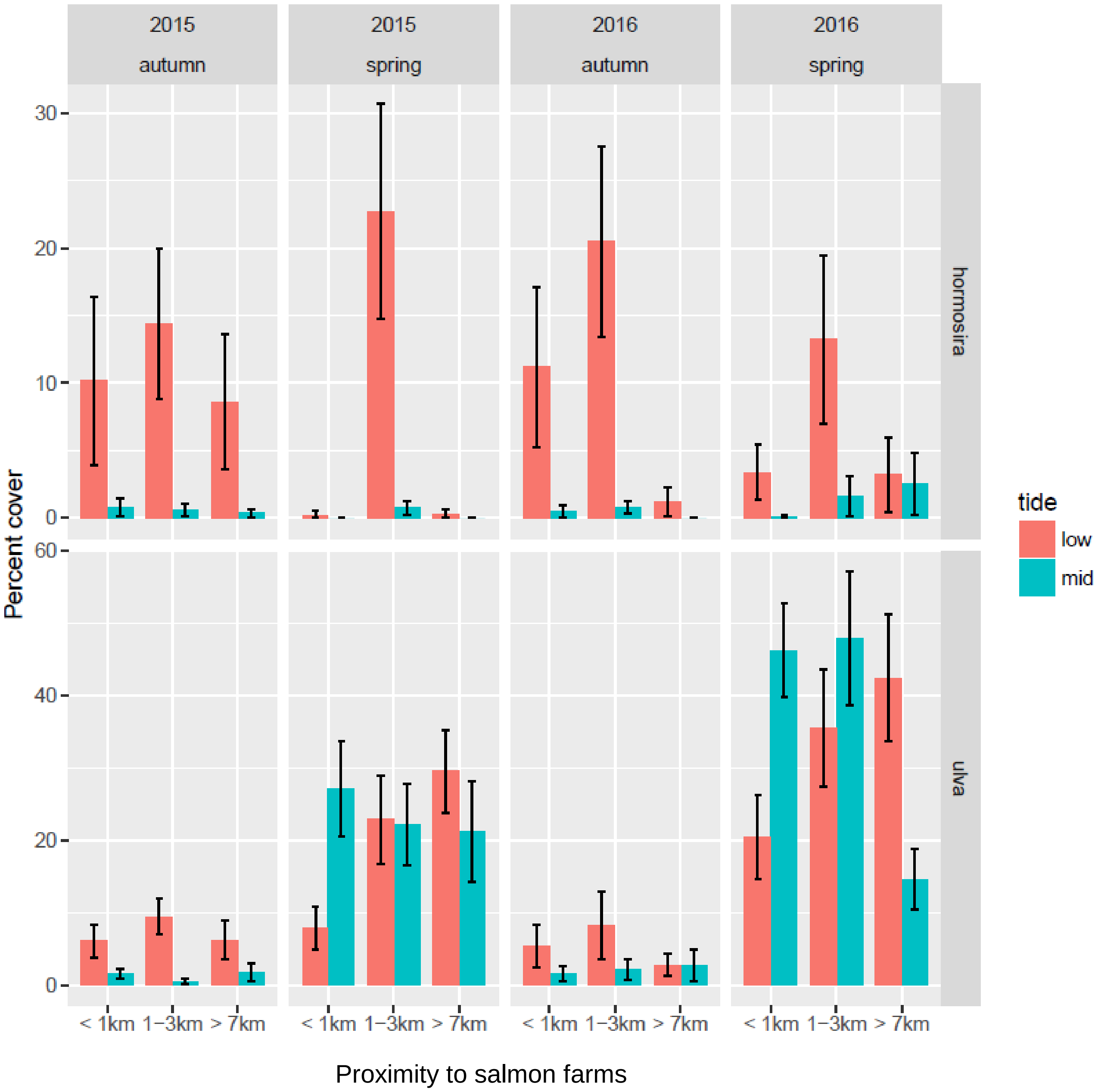


Figure 4. Percentage cover of *Ulva* and *Hormosira* in relation to distance from salmon farms in autumn and spring 2015 and 2016. Error bars are 95% confidence intervals.

When percentage cover from 2002/03 is compared with that at comparable sites in 2015/16 (Figure 5, Table 4), the data analysis shows that *Ulva* abundance was higher in spring than autumn, and higher in mid than low tide. It was also significantly higher in 2016 than 2002/03, but not between 2002/03 and 2015, which suggests that other factors were influencing the high abundance in 2016. *Hormosira* percentage cover was again significantly higher at ‘mid’ distance than ‘close’ sites, but not significantly different between ‘close’ and ‘far’, and also significantly higher at the lower tidal level than mid tide. Interestingly, there was a significant decline in *Hormosira* from 2002/03 to 2015 and 2016, especially in the mid tide zone region (Figure 5).

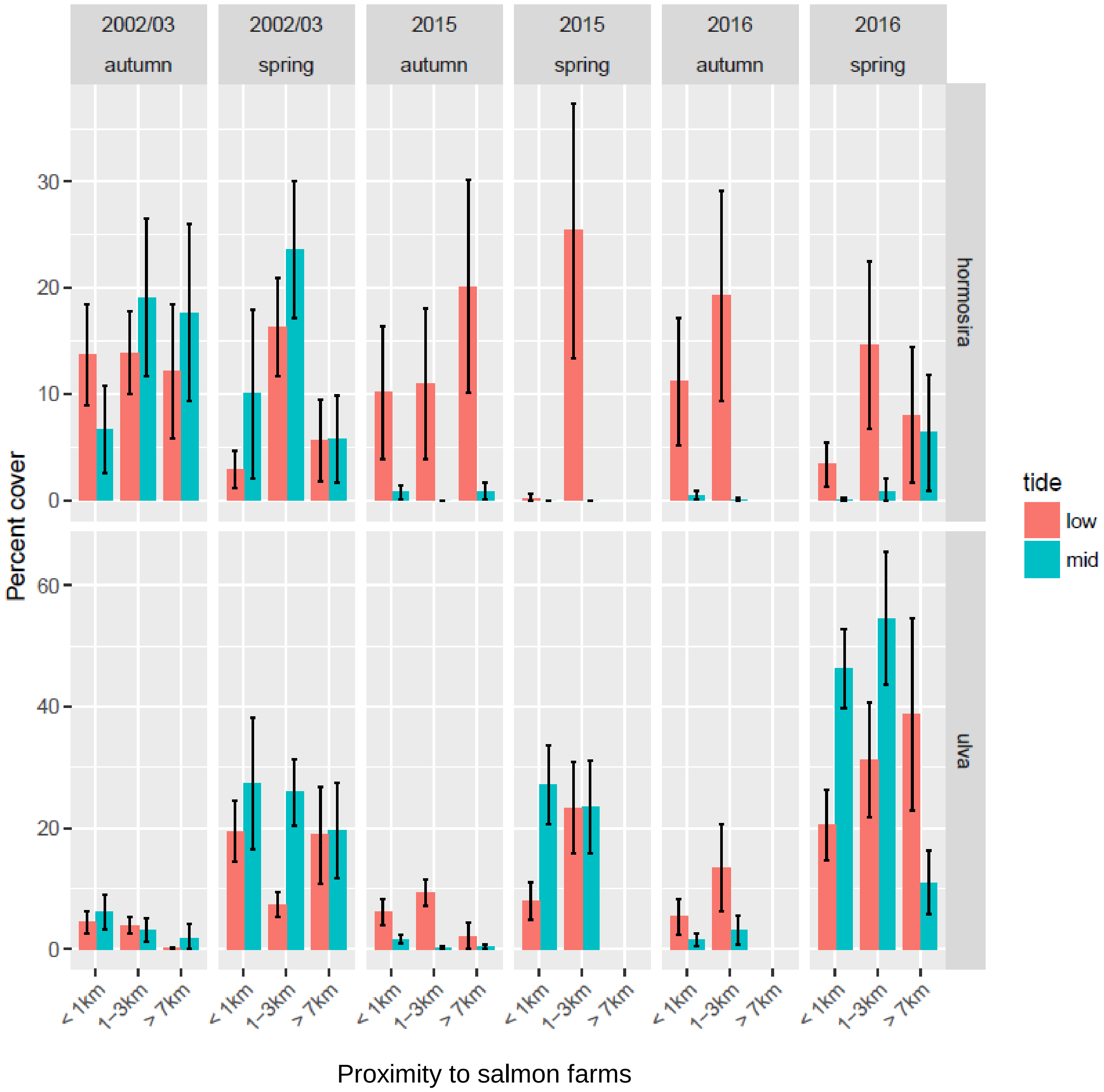


Figure 5. Percentage cover of *Ulva* and *Hormosira* in relation to distance from salmon farms in mid and low tide levels in autumn and spring 2002/03 and 2015 - 2016. Error bars are 95% confidence intervals.

Table 4. Results of binomial generalised linear model analysis comparing percentage cover of *Ulva* species and *H. banskii* in different seasons and tidal heights in 2015-16 to 2002/03. * P< 0.05, ** P<0.01, *** P< 0.001.

***Ulva* species**

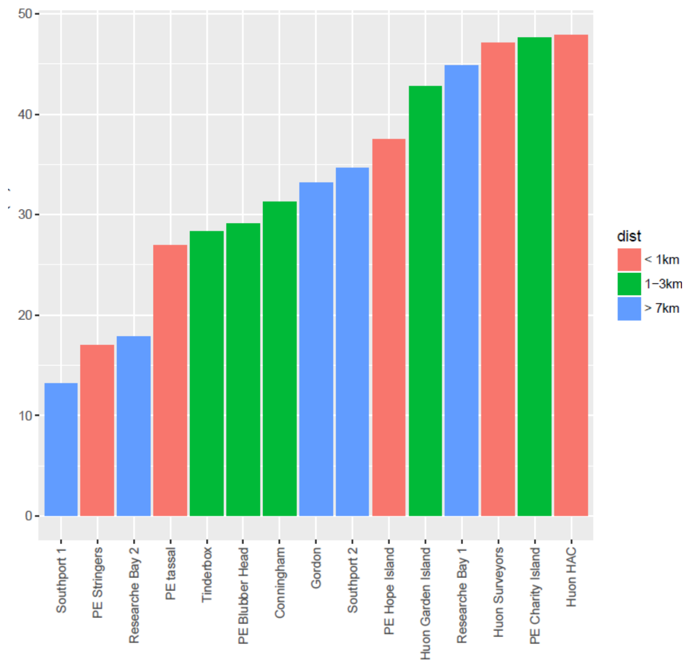
```
Coefficients:
             Estimate Std. Error z value Pr(>|z|)    
(Intercept)  -3.65086    0.26990 -13.527  < 2e-16 ***
dist1-3km     0.05809    0.18852   0.308  0.75796    
dist> 7km    -0.37884    0.26113  -1.451  0.14684    
seasonspring  2.08353    0.22835   9.124  < 2e-16 ***
tidemid       0.42462    0.17674   2.402  0.01628 *  
year2015     -0.01780    0.24598  -0.072  0.94233    
year2016      0.71580    0.19893   3.598  0.00032 ***
```

Hormosira banskii

```
Coefficients:
             Estimate Std. Error z value Pr(>|z|)    
(Intercept)   -2.2053     0.2335  -9.445  < 2e-16 ***
dist1-3km      1.0582     0.2360   4.485  7.3e-06 ***
dist> 7km      0.4713     0.3083   1.529  0.12635    
seasonspring  -0.1478     0.2021  -0.731  0.46474    
tidemid       -0.6656     0.2276  -2.924  0.00346 ** 
year2015      -0.7944     0.2786  -2.851  0.00435 ** 
year2016      -0.8180     0.2739  -2.987  0.00282 ** 
```

An examination of site specific coverage of *Ulva* and *Hormosira* averaged over seasons in 2015-16 also indicated varied results (Figure 6). The Huon estuary sites close to salmon farms had high coverage of *Ulva*, as did the site at Charity Island at Port Esperance (Figure 7) and the reference site at Recherche Bay. *Hormosira* coverage was highest at sites mid distant from salmon farms, and notably almost absent from six sites. A more detailed examination of *Hormosira* in Port Esperance in 2015-16 showed it was almost not existent at sites less than one km from salmon farms, but was a dominant species at the other two sites in Port Esperance at 1-3 km from pens of salmon.

Ulva *Hormosira*



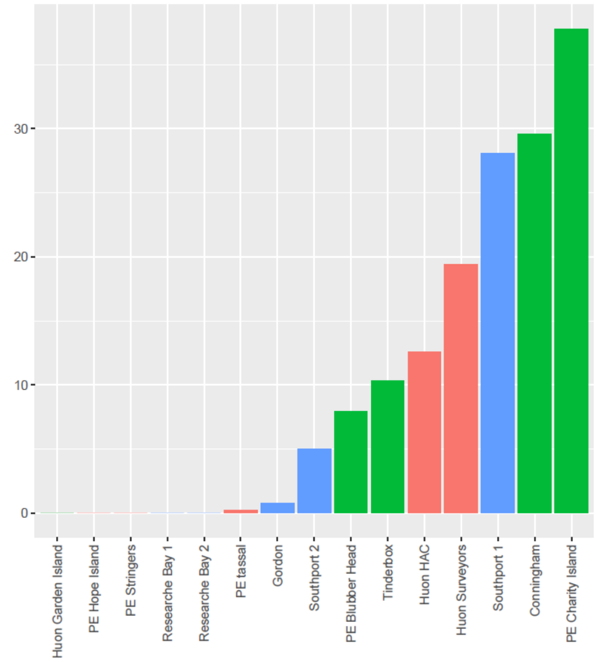


Figure 6. Percentage cover of *Ulva* and *Hormosira* at each site averaged over seasons in 2015-16.

Figure 7 . Cover of Ulva at Charity Island, Port esperance (1-3 km from salmon cages), spring 2016.

Drone survey and orthomosaic generation: Flathead Bay in the Huon estuary

On the 18th of December, 2015 between approximately 12:30pm and 2pm we flew a multirotor drone carrying a digital SLR camera over a 260 m section of coast at Flathead Bay. We flew five flight lines at a flying height of approximately 35-40 m (above ground level at the launch site), see Figure 8). We took over 1500 photographs and chose 852 images for orthomosaic processing (see Figure 9). Only 698 image successfully aligned during the 3D model generation (a precursor to orthomosaic generation). This is thought to be due to the system failing to deal with refraction effects in deep water during the image matching stage. A 10 mm resolution orthomosaic image was produced, as show in Figure 10 and Figure 11. Figures 12 and 13 show zoomed in views of the orthomosaic. From these it can be seen that for the shallow *Macrocystis* bed, six boundaries are visible and these could be mapped, however the water depth means that refraction effects would hinder change analysis if these boundaries were mapped again at a later date.

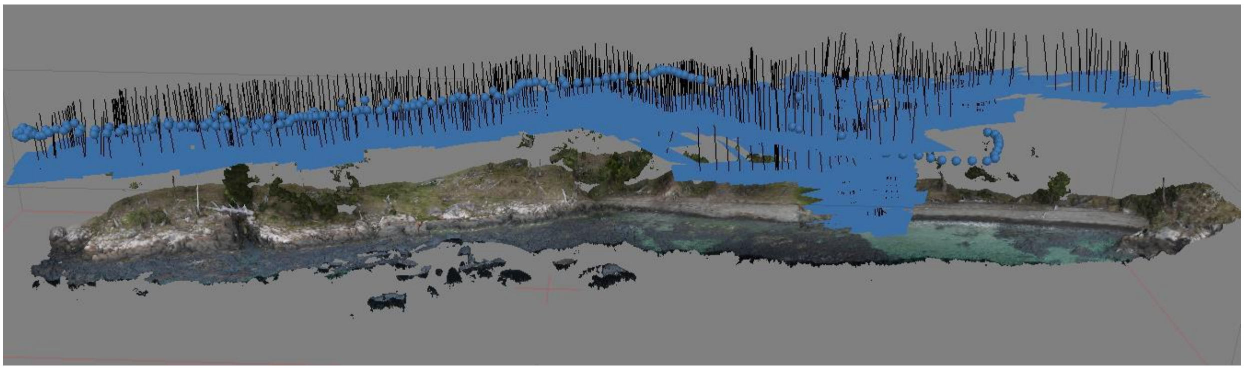


Figure 8: Perspective view 3D model and flight path

Figure 9: Example of drone image

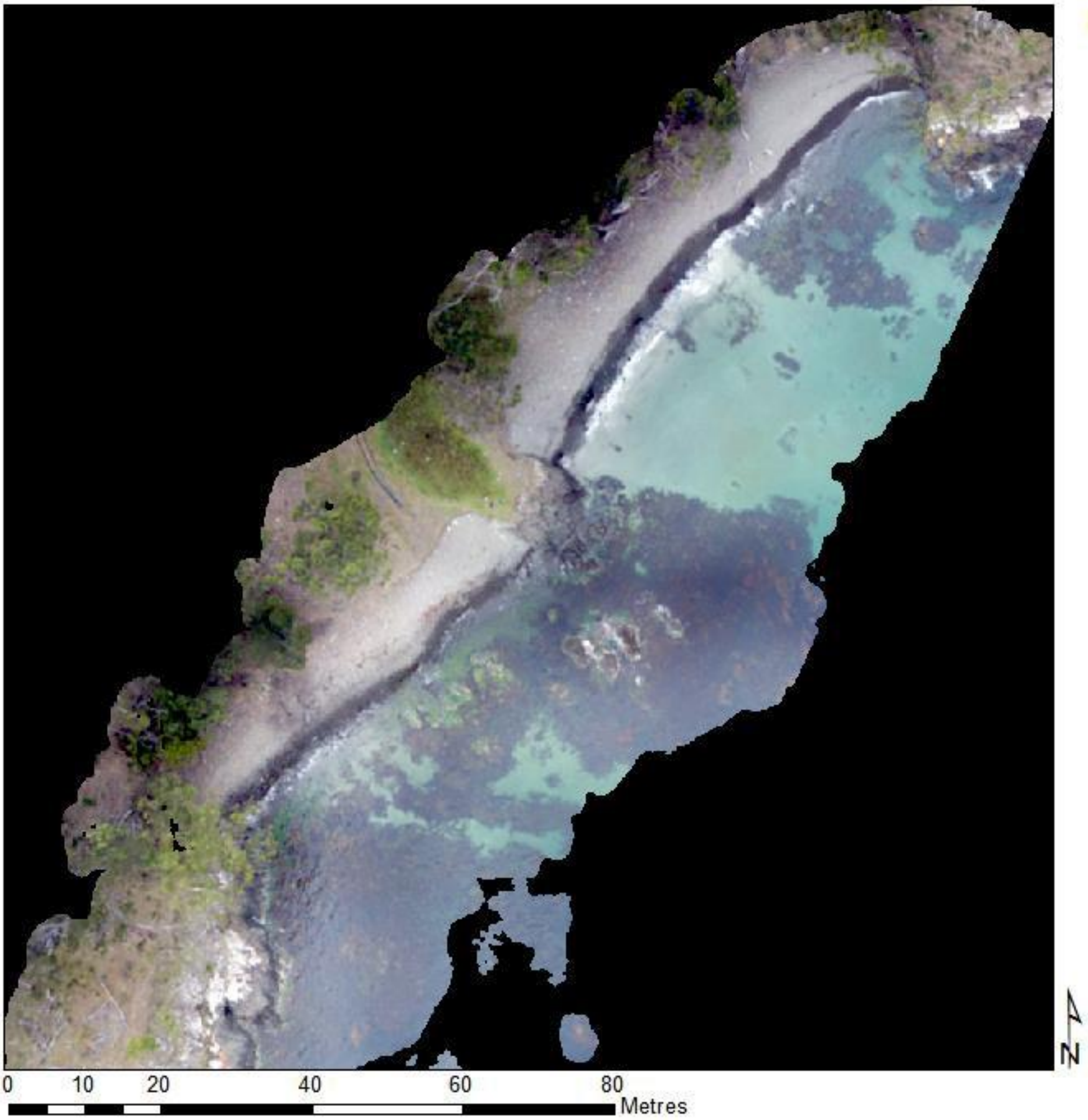


Figure 10: Northern section of orthomosaic

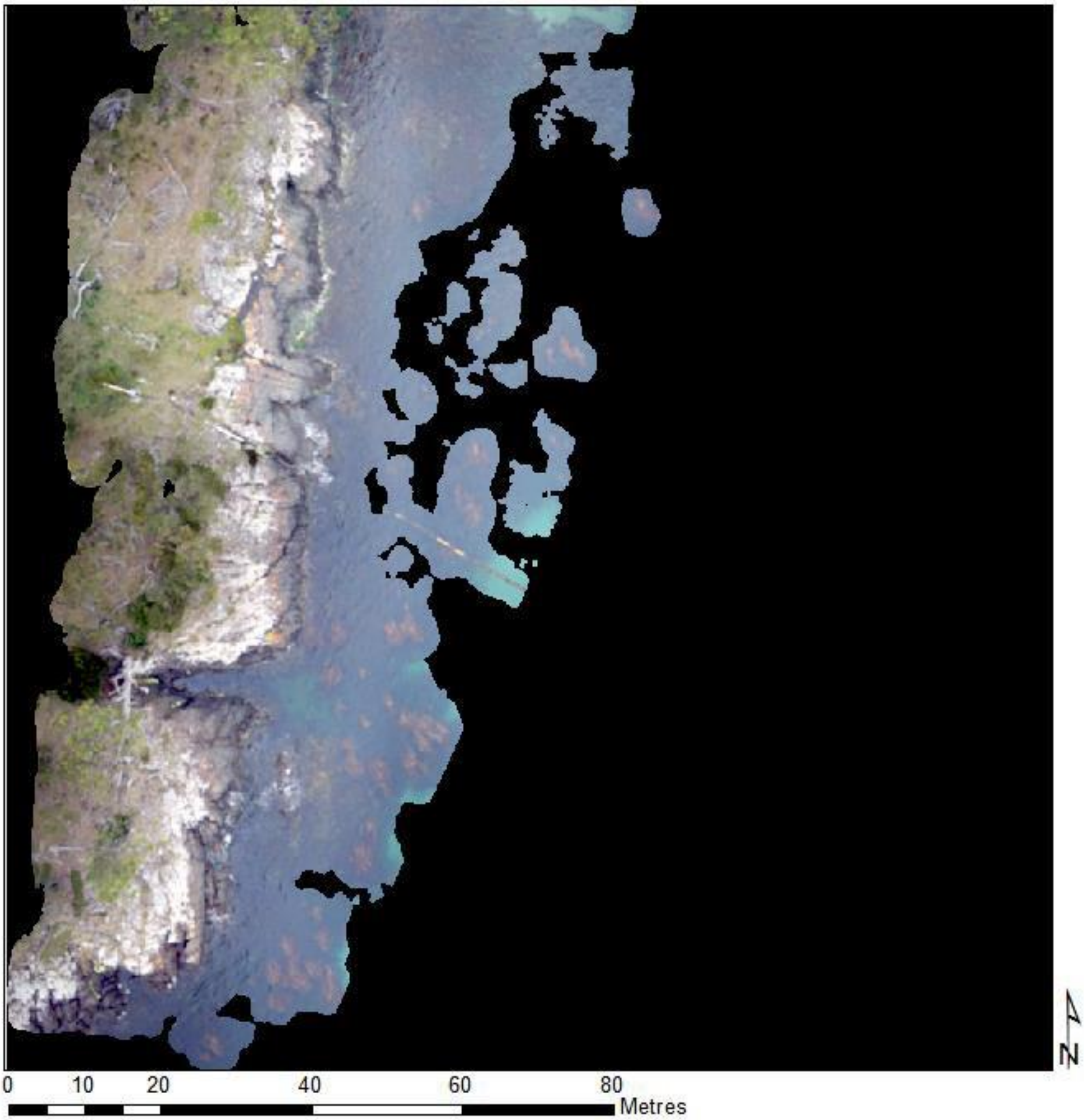


Figure 11: Southern section of orthomosaic

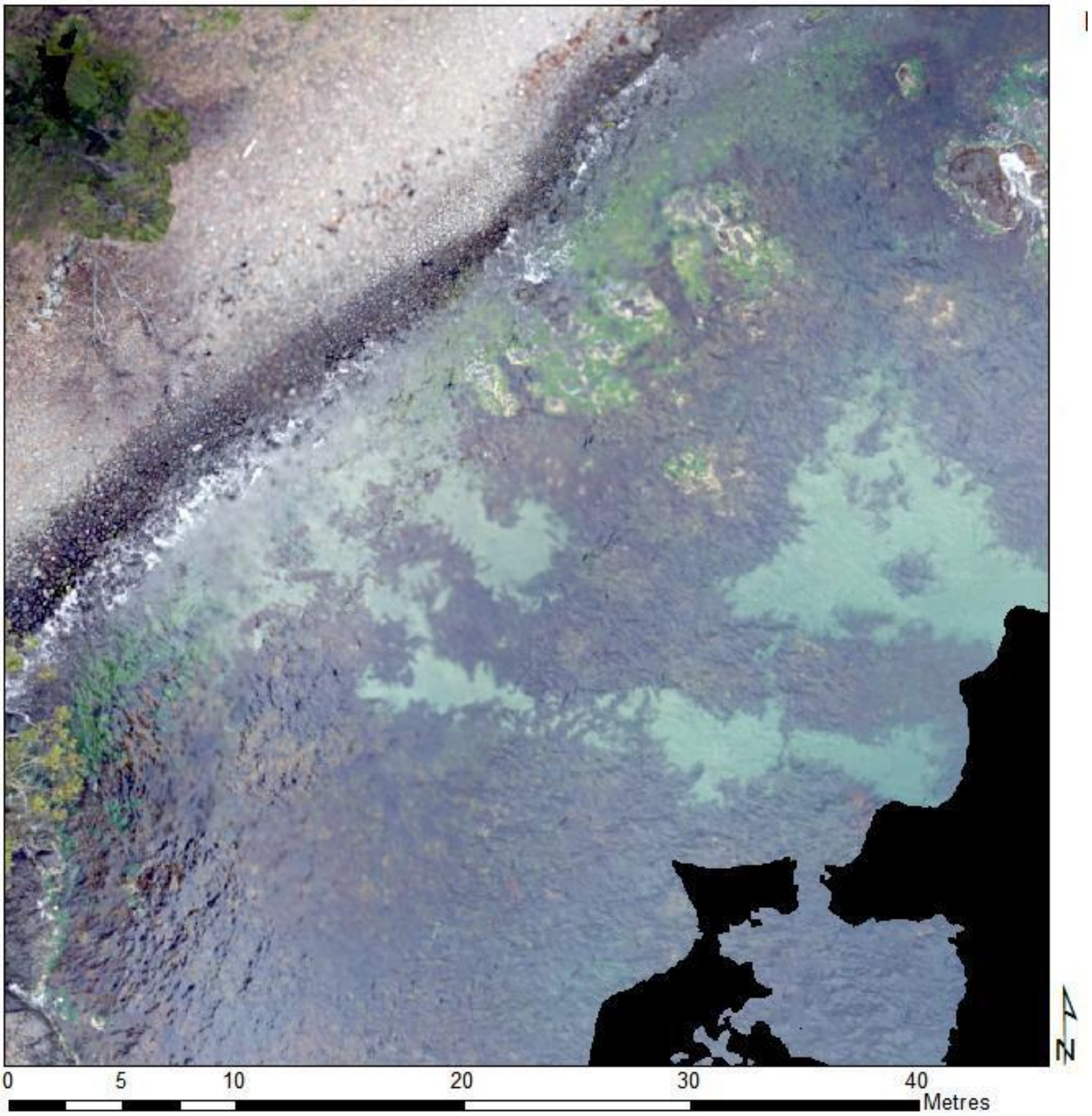


Figure 12: Close-up of macro algae beds

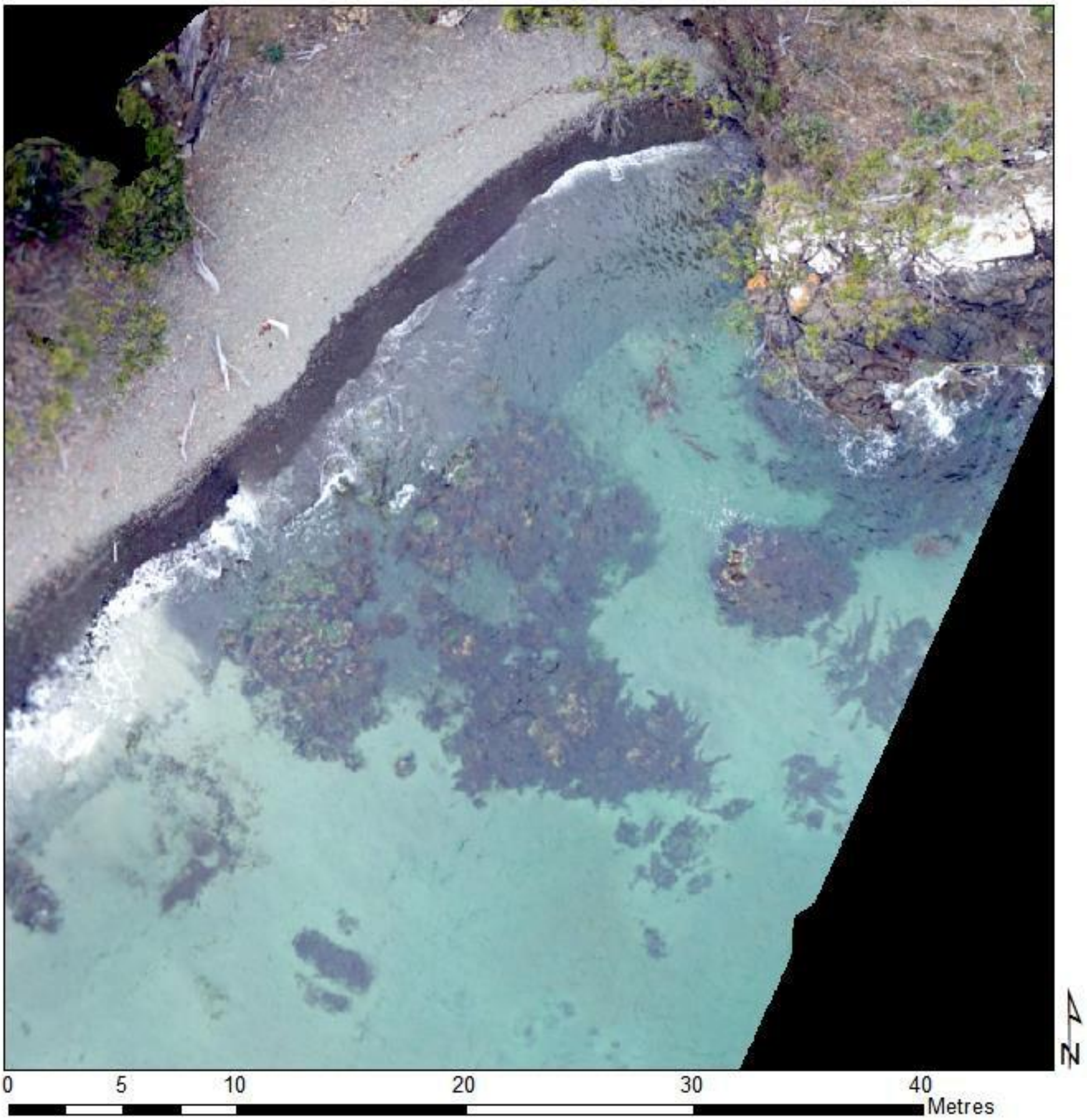


Figure 13: Close-up of macro algae beds (includes Figure 2 section)

Drone survey, orthomosaic generation and image classification trial: Blubber Head

On the 17th of March, 2016 between approximately 10am – 12pm we flew a multirotor drone carrying a digital SLR camera over a 200 m section of coast at Blubber Head. We flew four flight lines at a flying height of approximately 30 m (above ground level at the launch site), see Figure 14. Twelve ground control points were surveyed using RTK DGPS along with ten 1 m x 1 m quadrats. We took over 580 photographs and chose 462 images for orthomosaic processing. 459 image successfully aligned during the 3D model generation (a precursor to orthomosaic generation). A 6 mm resolution orthomosaic image was produced; the focus portion of this image is show in Figure 15 and a large scale view is shown in Figure 16.

A prototype hyperspectral camera was also flown over the site. Reference spectral measurements were recorded, including a range of vegetation types and rock and sand. Calibrations were also used. These data have not yet been successfully processed as we are still researching the processing workflow. The main concern with this dataset is the water depth. Even though we flew at low tide, most of the site was under water and even 1 cm of water severely limits what can be recorded by the sensor.

RGB Orthomosaic classification

Supervised image classification was trialled on the RGB (red, green, blue) image. To do this, field notes for ten quadrats in the mid-lower intertidal area were collected using our standard algal field survey methods with 1 m^2 quadrats and 100 point intersects (see Figures 17 -19). They were used to create classification training areas representing the 15 classes (see Table 5). The results were poor (see Figures 20 -21); however, this is not surprising as only the red, green and blue bands of the electromagnetic spectrum (i.e. reflected visible light) were used. Remote sensing image classification relies on defining spectrally separable classes and when only these three images bands are used, the classifier struggles to differentiate classes accurately. In addition to this issue, there were portions of the site that were submerged and the depth of that water impacts on the colour sensed by the camera. Variations in depth also cause issues. This is a major problem with this approach and whilst we did foresee that it may be an issue, we hoped that the low tides would allow us to capture imagery of the site without too much of it being submerged. Unfortunately, even at very low tide large sections of the site (and it seems all the other potential sites) were submerged.

The creation of so many classes was done in the hope that it would work; however, it was unsuccessful. A reclassification to ten Algal Divisions and class groupings (see Table 5) was attempted to see if fewer classes resulted in a better result. As shown in Figure 22 and Figure 23, this was not very successful with many obvious misclassifications.

Table 5: Taxon classes and divisions/groupings

Taxon	**Abbreviation**	**Algal Division/ Grouped Class**
Blue-green Algae (green-black congealed filaments)	blg	blue-green
Claulerpa simpliciuscula (dark green upright axes)	Csimpl	green
Cladoptiora sp. (light green filaments)	Clad	green
Codium fragile (dark green branched "spongey" texture)	CodFrag	green

Cystophora torulosa (light brown coarse branched)	CystTorul	brown
Filamentous brown algae	FilBr	brown
Heterozostera tasmanica (green thin leaves)	HetTas	seagrass
Hormosira banksia ("Neptunes necklace", commonly with epiphytic filamentous brown algae, *Northeia anomala*)	Hb	brown
Jania capillacea (finely branched pink-white coralline)	JCap	red
Ostrea angasi (Oyster)	Oyster	Rocks/Oysters/Sand
Bare rock and sand	Rock	Rocks/Oysters/Sand
Ulva (*Enteramorpha*) *intestinalis* (bright green +/- narrow membranous blades)	UlvInt	green
Deep water, weed	Deepwater_weed	Deepwater Weed
Deep water, no weed	Deepwater_noweed	Deepwater Not Weed
Reflecting rock (very bright)	-	Reflecting Rock

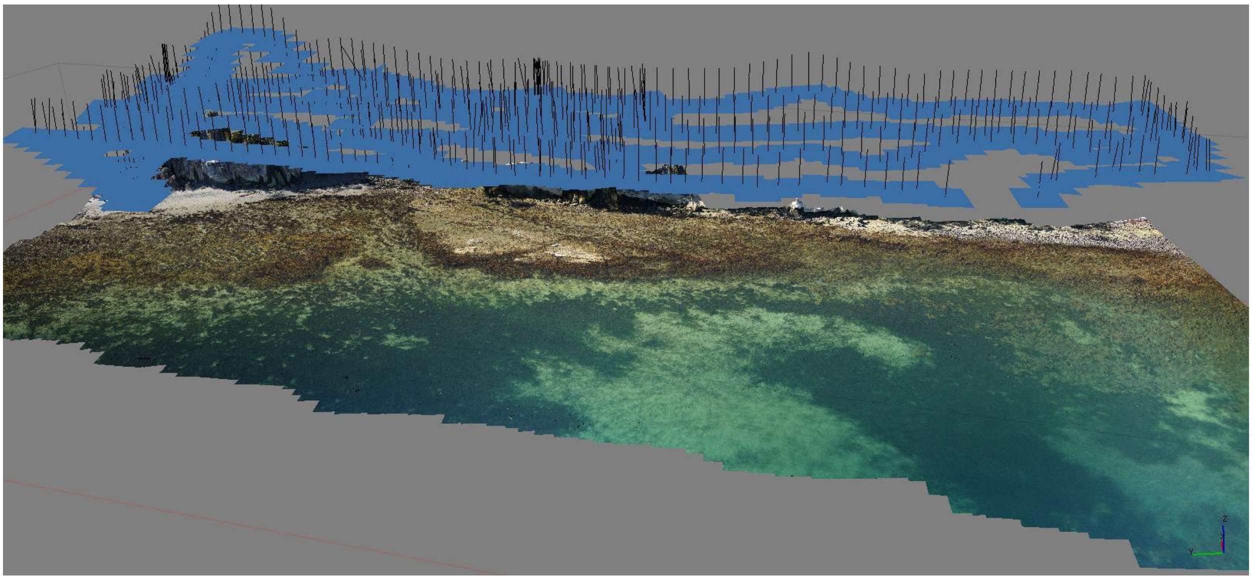


Figure 14: Perspective view 3D model and flight path

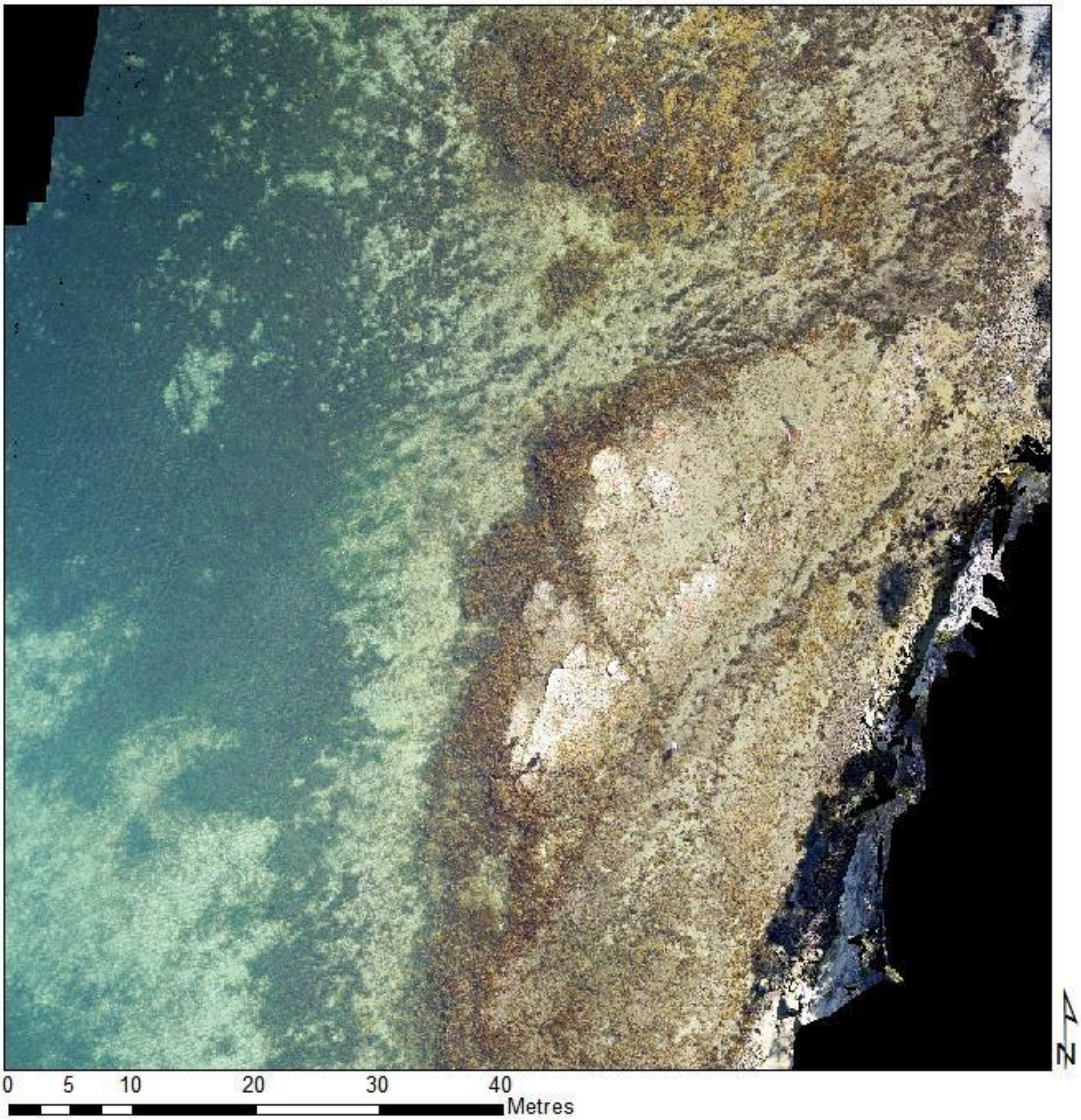


Figure 15: Portion of the generated orthomosaic

Figure 16: Zoomed in view of a section of the generated orthomosaic

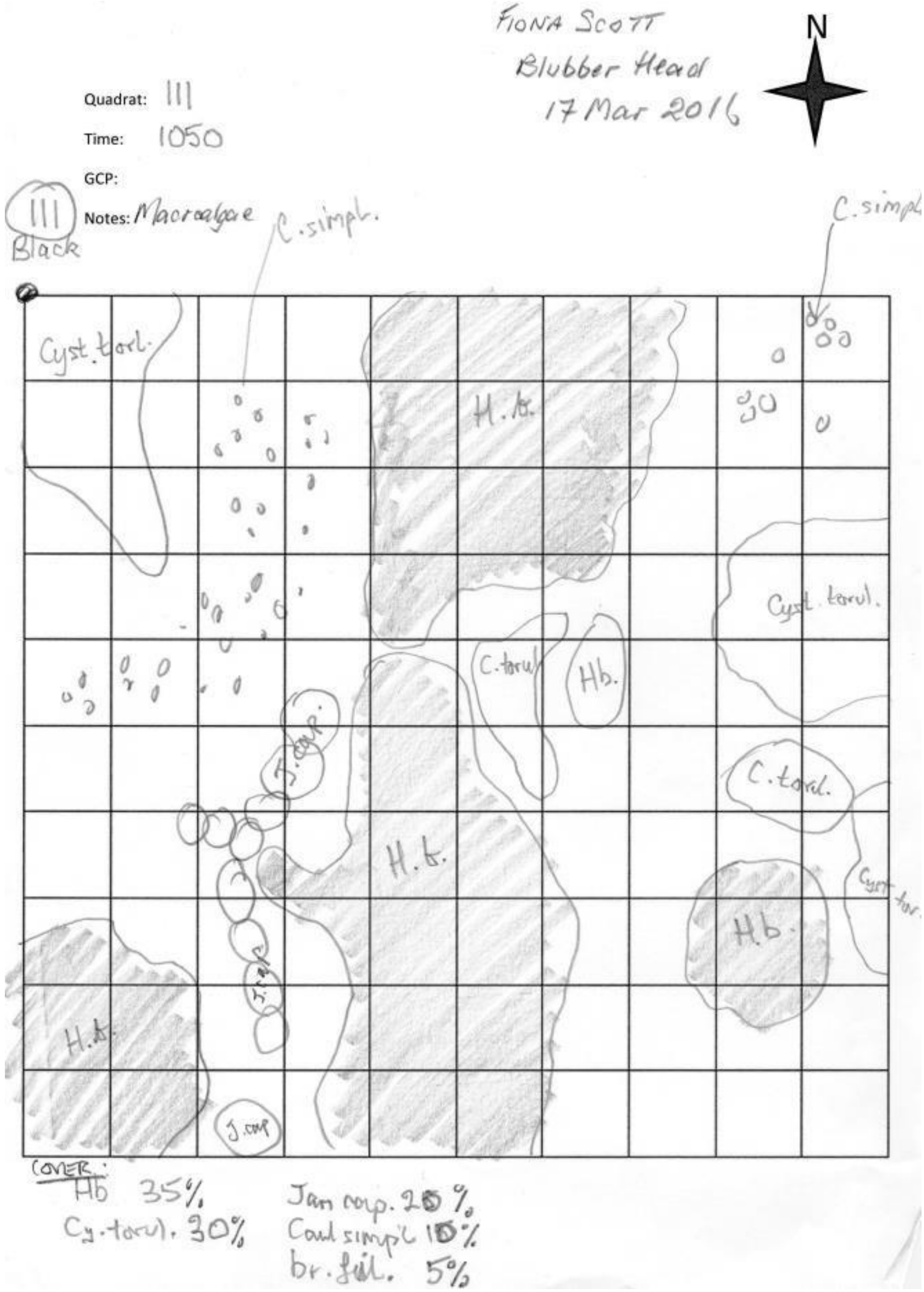


Figure 17: Example of field notes generated by Dr. Fiona Scott

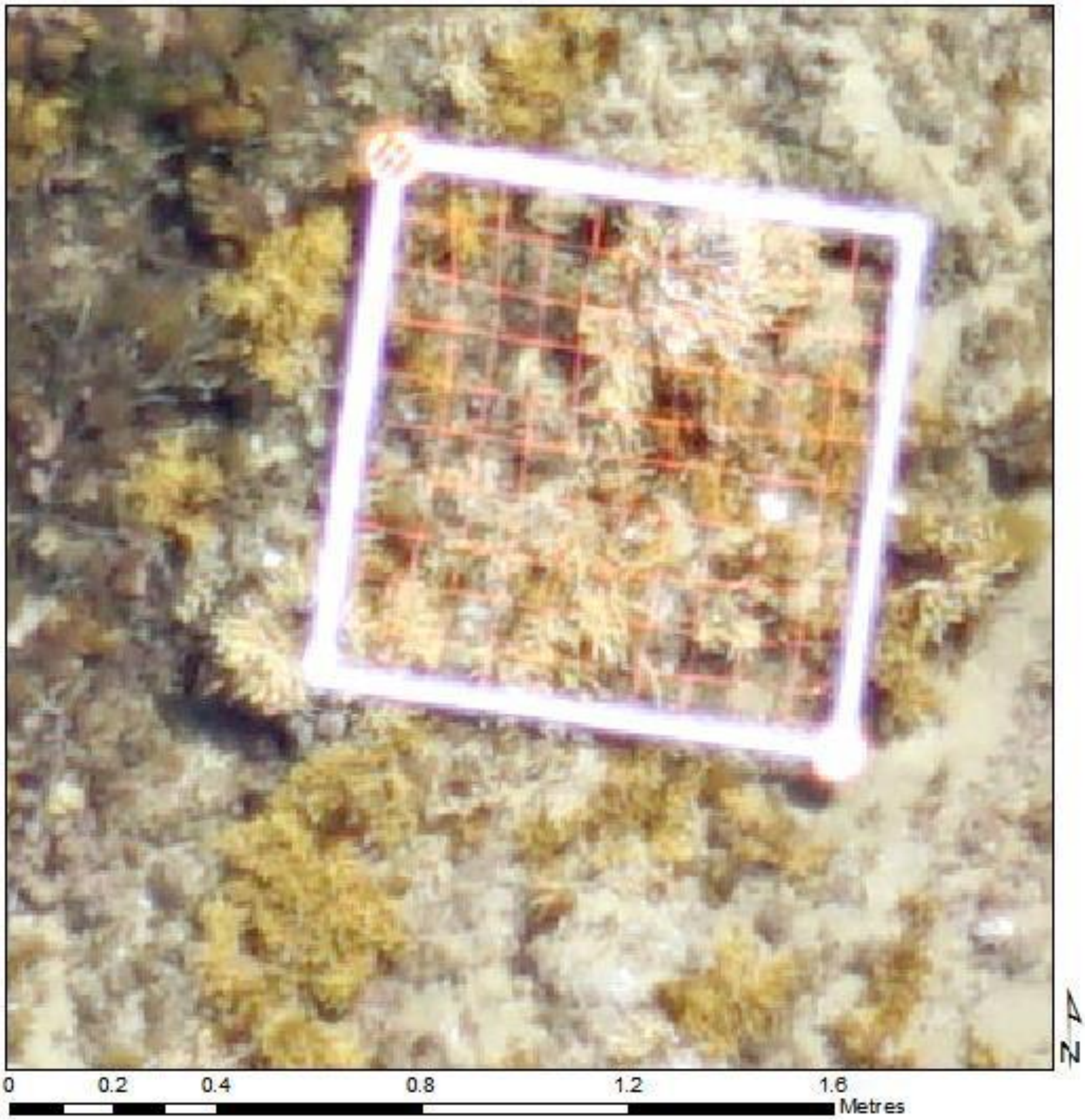


Figure 18: Close up of quadrat from field notes (Figure 10)

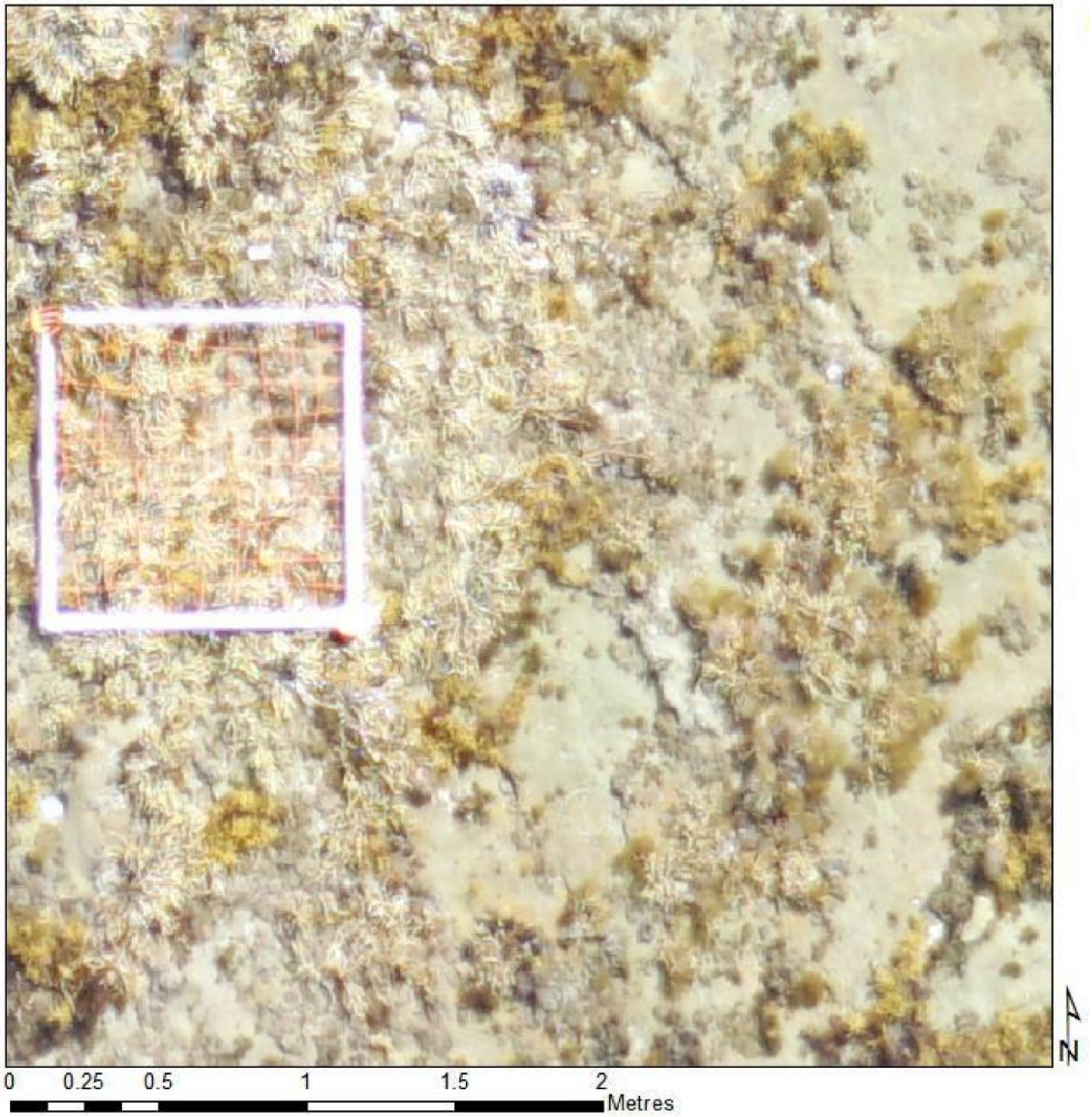


Figure 19: A close-up of a quadrat and submerged vegetation

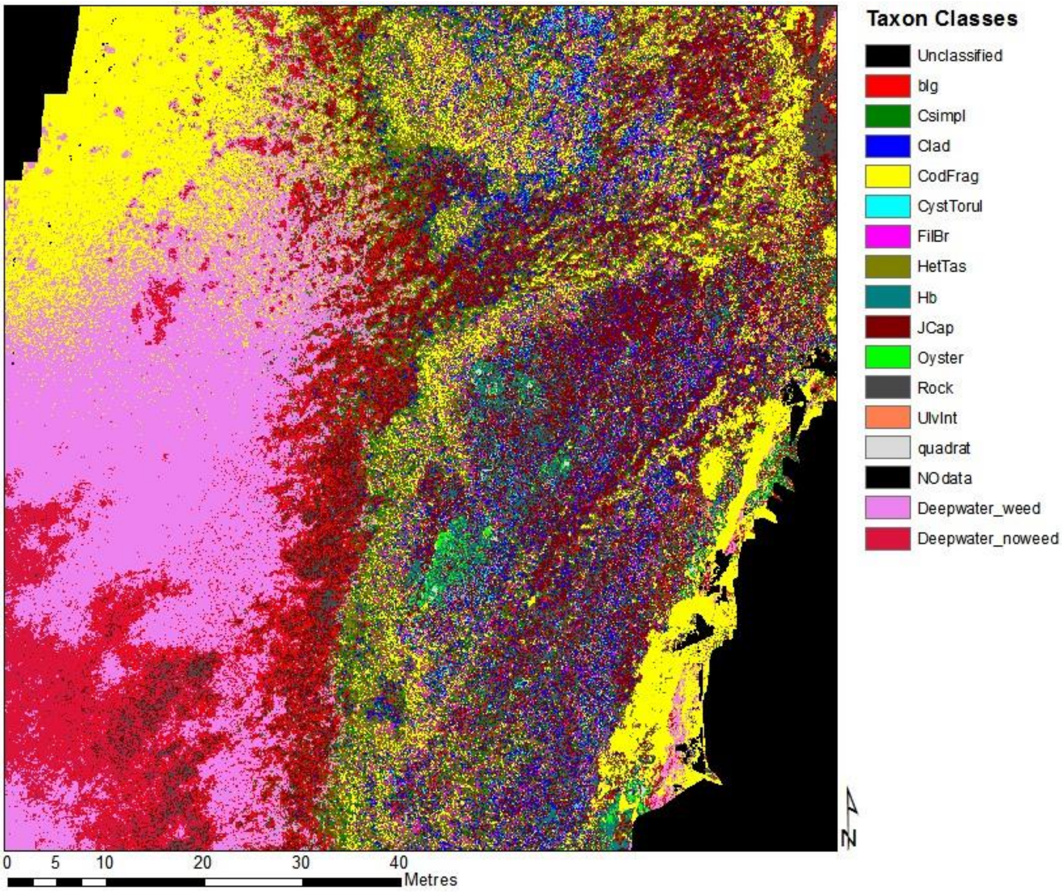


Figure 20: Taxon Classification Result (see Figure 8)

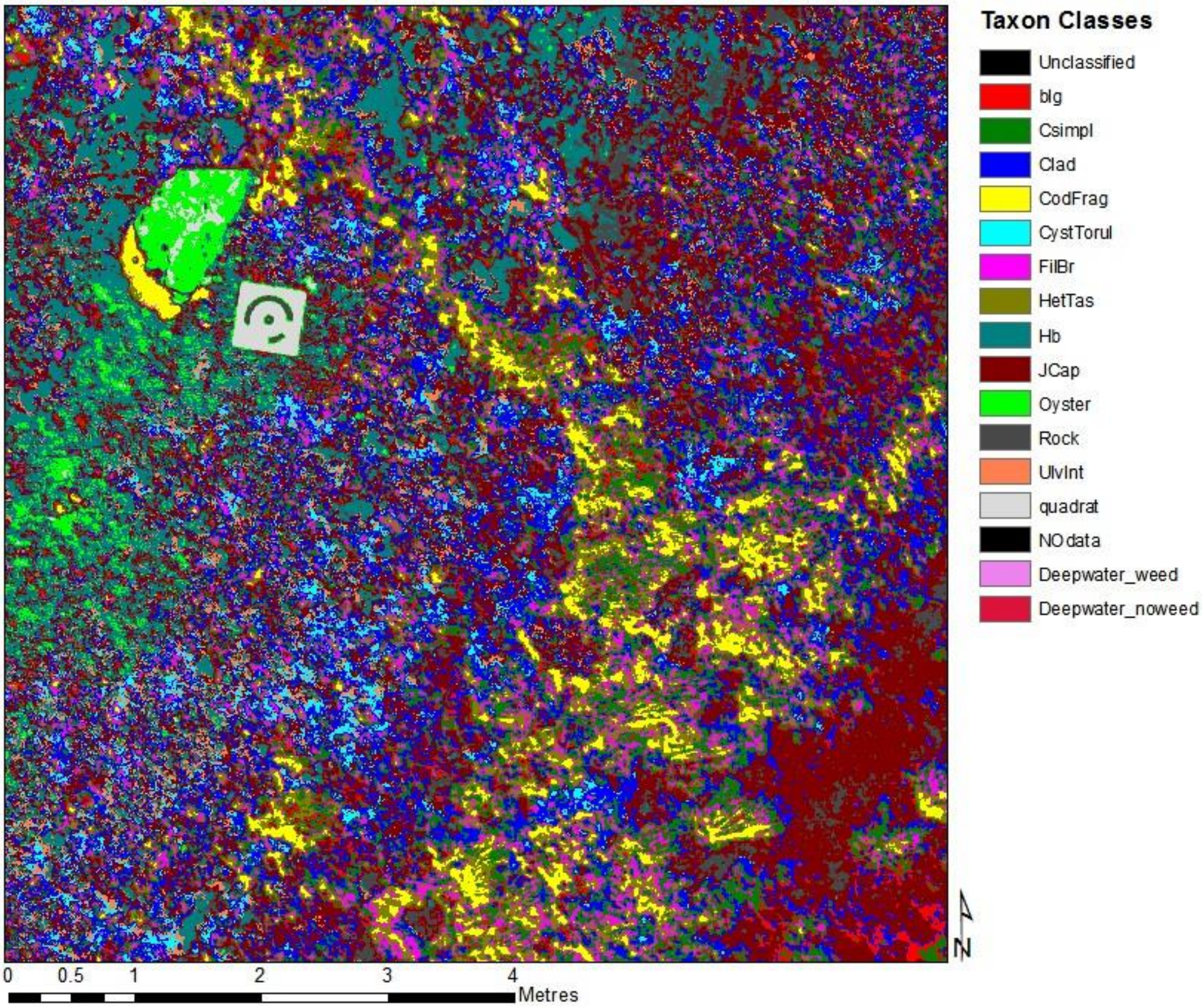


Figure 21: Zoomed in view of Taxon Classification Result (see Figure 16)

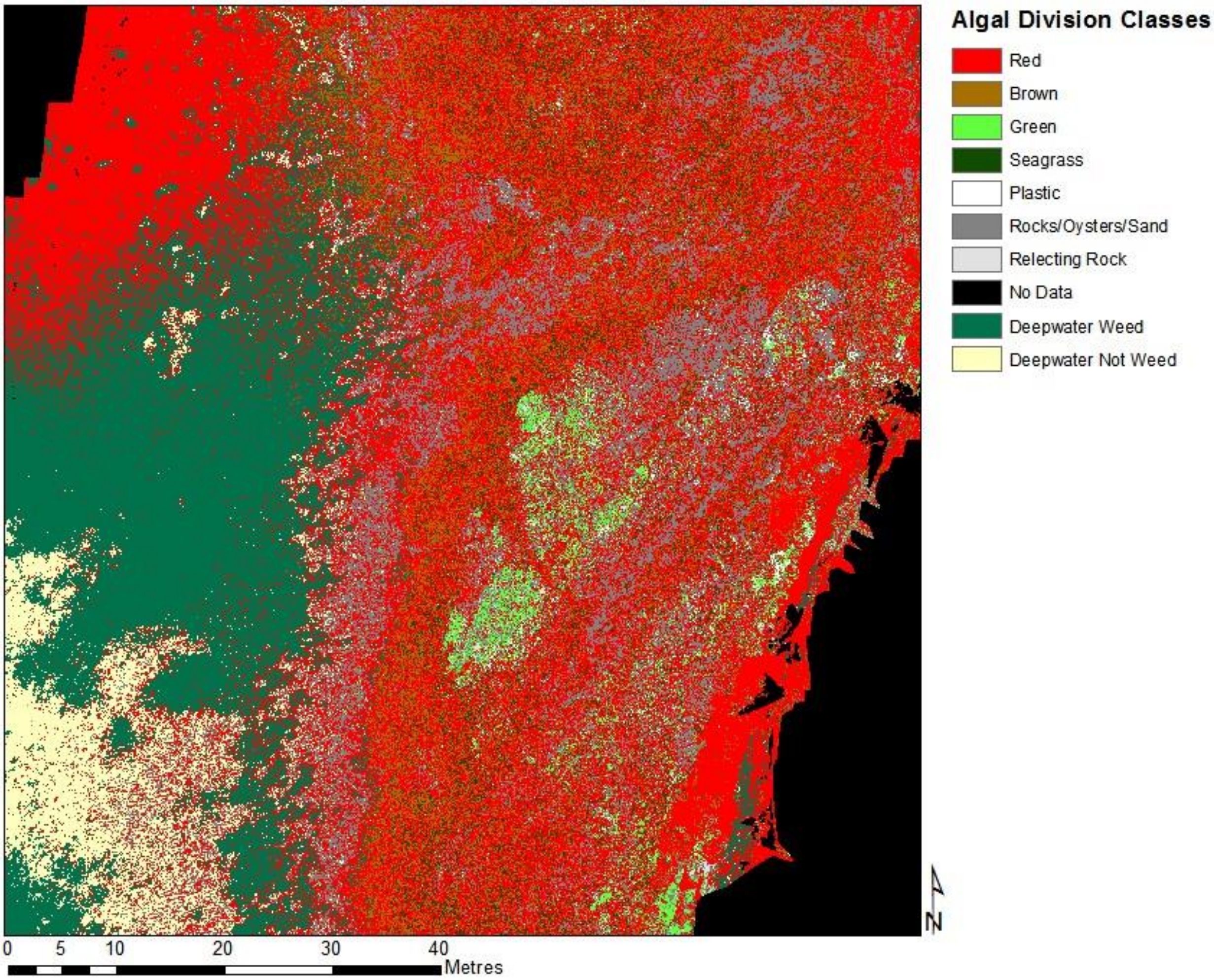


Figure 22: Reclassification into algal divisions (see Figure 15)

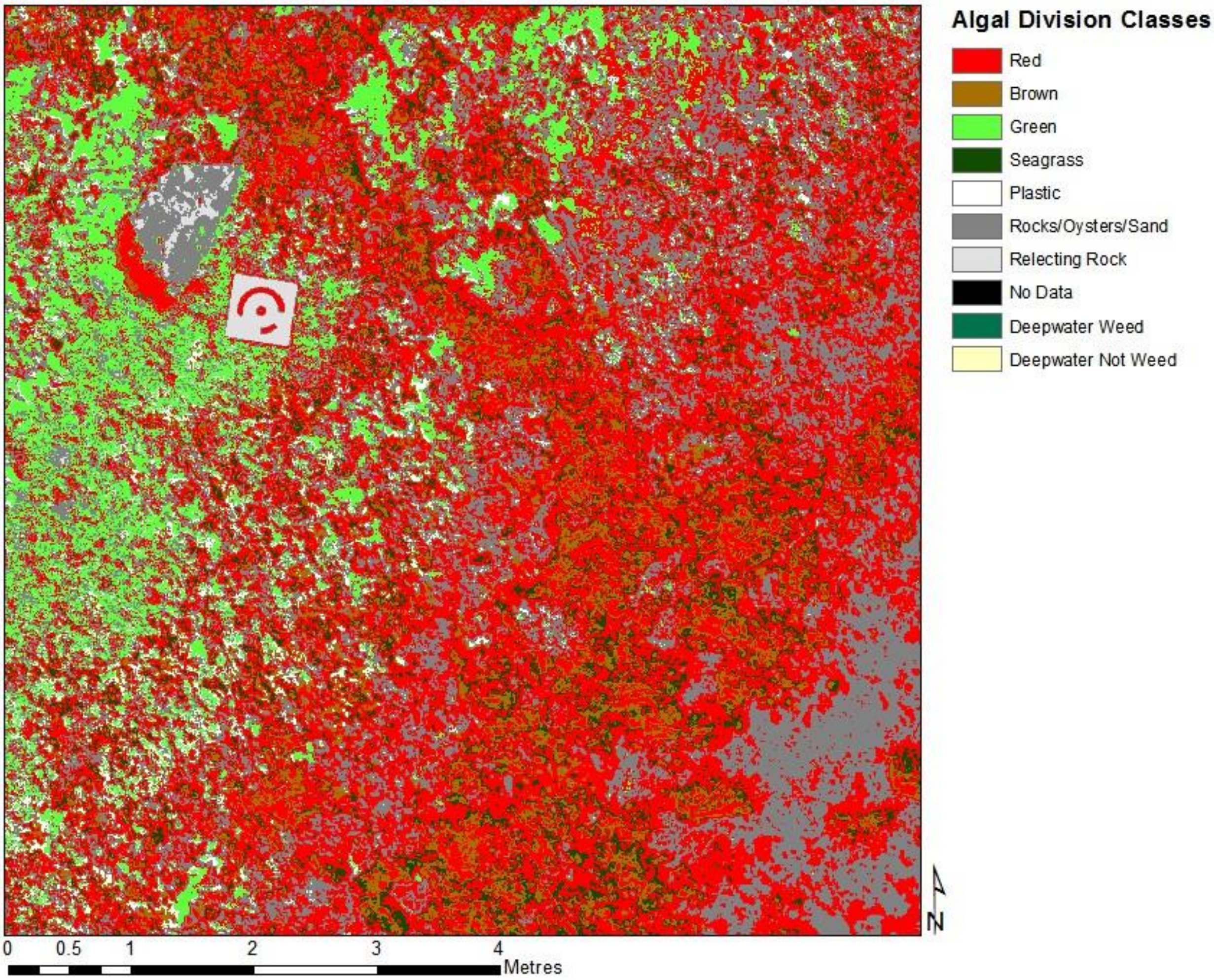


Figure 23: Zoomed in view of reclassification into algal divisions (see Figure 16)

Discussion and Conclusion

Salmon farming in Tasmania has significantly increased in recent years. In the decade from 2002-2003 to 2012-13 the value of farmed salmonids increased 222 per cent (by $343 million) and its production volume rose 179 per cent (by 27 553 tonnes), from ABARE Fisheries and Aquaculture Statistics 2013 (Stephan & Hobsbawn 2014). Production has continued to increase since 2012-2013 and production was estimated at 55,000 tonnes per annum in 2016 (http://www.tsga.com.au/history). The number and location of farms has also increased.

The previous survey of intertidal algae conducted in 2002-03 found no clear trends in abundance of intertidal algae with distance from salmon farms, but recommended that any future monitoring focus on the abundance of *Ulva* and *Hormosira* as these two species are common dominants of the intertidal zone and are readily identified. *Ulva* species are widely recognised as 'nuisance' algae that flourish in areas of high nutrient loading (Brown et al. 1990, Campbell 1999, 2001), whereas *Hormosira* is generally considered to have low tolerance to increased nutrient concentration. According to a review by Bellgove et al (2017) *Hormosira banksia* is an ecosystem engineer that contributes to the biodiversity of rocky intertidal communities, but is sensitive to anthropogenic disturbances, including coastal sedimentation and sewage effluent discharge. They also note that dominant intertidal brown algae generally decline in abundance at polluted sites and are replaced by opportunistic and turf-forming species such as *Ulva*.

Since the previous survey was conducted, the Tasmanian Government has received a number of complaints about increased nuisance algal cover in the intertidal, which highlighted the need to try and establish a monitoring program that could have community input. As a consequence, this project has focussed on abundance of a *Ulva* and *Hormosira* as these two species are easily identified by the community. However, data on all species present were collected and have been documented.

Over the two years of this study, the density of both *Ulva* and *Hormosira* varied widely between sites, and showed no clear difference with distance from salmon farms. This is a similar result to that obtained in 2002-03, even though the production of salmon had significantly increased between the two survey periods. A comparison of the results collected in this study with those from 2002/03 also indicated mixed results with distance from salmon farms. Nevertheless, *Ulva* was observed to be significantly more abundant in the mid tide region whilst *Hormosira* had almost disappeared from mid tide region in 2015-16 (Figure 4), except for a small amount of cover at sites >7 km from salmon farms in spring 2016. Also, the abundance of *Hormosira* in 2015 and 2016 was significantly lower than in 2002/03. A more detailed examination of *Hormosira* abundance in Port Esperance showed that sites surveyed in 2002-03 near the farms had 4-7% cover of *Hormosira*, compared with 0-0.1% *Hormosira* at 'close' farm sites in 2015-16. However, the site on Charity Island within 1-3 km of salmon farms had the highest percentage cover of *Hormosira* at 38%.

Overall, these results suggest that patterns of abundance of dominant and readily identifiable intertidal algae are highly variable and show no clear patterns with distance from salmon farms. This suggests that factors other than wastes from salmon farms are also affecting the abundance of algal species in the intertidal zone. The degree of wave exposure is expected to be important as *Hormosira*, for example, prefers sheltered coastal waters (Edgar 2008) and was not recorded at the more exposed Recherche Bay sites. Similarly, the topography and composition of the substrate are likely to be important, whether hard consolidated rock, boulder, pebbles, or sedimentary platforms. Generally, sites without *Hormosira* were steeper and consisted of much larger rocks and boulders than those with abundant *Hormosira*. A multifaceted combination of factors that determine intertidal algal community composition, including level of exposure, height of the reef above low water mark, distance and direction from the nutrient source, and competition and grazing pressure from invertebrates and fishes has also been noted in other areas (Brown et al 1990, Bellgrove et al 2017).

Surveys and analysis of subtidal algal communities on rocky reefs in the D'Entrecasteaux Channel, which also investigated changes to algal communities near to and distant from salmon farms using Marine Protected Area (MPA) monitoring data at sites inside and outside the MPAs over the period from 1992 to 2015, and more comprehensive monitoring in 2015 at sites related to salmon farm development provided similar conclusions to this study (Valentine et al 2016). Their results showed no consistent patterns of broad-scale change in macroalgal community structure over time. Fluctuations in the abundance of dominant taxa and functional groups where observed, but not a clearly defined directional change. Nutrient indicator species were generally low in abundance and variable, and did not show any trend of increasing over time. Similar to our results, peaks in abundance of these species occurred, but were not consistent between sites or between years, and interestingly, analogous patterns were observed at Maria Island, which is too distant to be impacted by salmon farms at that time. Valentine et al (2016) also discuss the consistent trend of significant variation in algal community structure between sites within a region, in their case for subtidal algae. They highlight the spectrum of physical factors affecting subtidal algal communities (as well as intertidal) that vary over small spatial scales, including wave exposure, rock type, background nutrients, sedimentation, light attenuation (e.g. from tannins) and grazing intensity.

Another study of subtidal algal communities in the D'Entrecasteaux Channel by Oh et al (2015), however, did detect changes in relation to distance from salmon farms. They used a gradient approach and found a significant difference in macroalgal assemblages between sites near fish farms (100 m) and reference sites 5 km distant, with the other sites showing characteristics in between these two. This difference was largely due to increased cover of nuisance algal species, whereas canopy-forming species remained relatively unaffected. These results are consistent with overseas studies where impacts of fish farms have been detected only in close proximity to salmon farms, and generally on a scale hundreds of metres. Field studies and modelling in relation to Integrated Multi-Trophic Aquaculture, in particular, have identified that increased nutrient concentrations from farmed salmon are only evident within a few hundred metres from the cages (e.g. Hadley et. al, 2016).

A different approach to understanding the effects of nutrient enrichment on rocky reef communities was undertaken by Luiz Henriquez in his PhD study, whereby he added nutrients to three reef systems in the D'Entrecasteaux Channel (Macleod et al 2016). He also found no effect of additional nutrients on the abundance of canopy forming algae, and an unclear picture for opportunistic species such as filamentous algae. More subtle physiological responses in several canopy- forming species were observed though, but these differed between the upper and lower channel, suggesting that effects of increased nutrients may depend on the prevailing environmental conditions.

The extended set of sampling sites surveyed in this project also highlighted some of the difficulties in logistics of monitoring the intertidal zone. Firstly, suitable low tides for monitoring only occur for a few days each month, sea conditions need to be sufficiently calm for dinghy access at a number of the sites, and people and equipment need to be available at that time. On occasions it was difficult to meet all these requirements, with the mouth of the Huon being the most difficult to access by boat due to rough weather. In addition, because of the low tidal range of approximately one meter in the area, low pressure weather systems can have a major impact and stop a low tide occurring, for example at Southport in Autumn 2016. The influx of nutrients from Southern Ocean waters upwelling into the region over winter can also have a major impact on nutrient concentrations, especially nitrates, in coastal waters. This rapid increase in nitrate over winter, falling to almost none in summer has been well documented, and significant interannual variation has been observed (Wild-Allen et al., 2011;Ross and Macleod, 2013). The major increase in *Ulva* in spring 2016 could be due to an influx of nutrients from southern ocean waters; however, nutrient data for the D'Entrecasteaux Channel region collected as part of the Broadscale Environmental Monitoring Program for salmon farms has not yet been released (J. Valentine, pers. comm. October 2017).

These results suggest that the abundance of intertidal algae is a difficult measure of nutrient enrichment, unless the monitoring is conducted at exactly the same location each time and with a large number of sites sufficient to detect changes in algal abundance due to different sources of nutrients. Techniques such as stable isotope analysis should also be considered to differentiate between nutrient sources. Nitrogen stable isotope values of *Ulva lactuca* have been shown to be highly sensitive and effective for establishing the extent of influence of wastewater inputs on high energy rocky shores in NSW (Oakes and Eyre 2015).

With the expansion of salmon farming in the region it is now difficult to find reference sites that are unlikely to be influenced by salmon farm wastes but have similar environmental characteristics to farmed areas, in particular topography and substrate type of the intertidal zone. In 2002-03 no salmon farms were in operation in Great Taylors Bay off Bruny Island and this location was chosen as a reference site for leases in the Huon and Port Esperance. However, several farms have since been established in Great Taylors Bay, as well as further out in the D'Entrecasteaux Channel at the mouth of the Huon and south from Port Esperance. As a consequence, the reference sites at Bruny Island surveyed in 2002-03 cannot now be used as a reference sites for the effects of salmon farming in the this area. Instead, Recherche Bay was sampled as a reference site as it is well flushed by southern ocean waters and unlikely to be impacted by salmon wastes. However, it is more exposed than most farming locations with a predominately steep boulder intertidal zone, making finding suitable reference sites very difficult. Likewise at Southport, where most of the shoreline is either sandy beach or cliff face, suitable sites were scarce.

Drone surveys

The trials using drones to monitor intertidal and subtidal algal cover have highlighted a number of issues that still need to be resolved before reliable quantitative data can be collected and assessed in a monitoring program. We were hoping to map the *Macrocystis* beds when they are most abundant and their fronds break the surface in spring; however, most of the *Macrocystis* was submerged when our trial was conducted. Furthermore, we had hoped that the low tides would allow us to capture imagery of the intertidal zone without too much being submerged. Unfortunately, even at very low tide large sections of the site (and it seems all the other potential sites) were submerged. As previously stated, even a small amount of water can impact the data received by the sensor and this in turn reduces the accuracy of the classification. We also foresee issues in change detection due to poor classification results and refraction effects The water depth means that refraction effects would hinder change analysis if these boundaries were mapped again at a later date.

The issues faced in these first trials are not readily resolved and submerged vegetation change monitoring is a research area that is not well advanced. Options for future research include capturing RGB imagery when the entire site is submerged and/or creating classes for each taxon at different depths. An alternative option is to assess the orthomosaics instead of field-based measurements for generating biodiversity statistics (i.e. the quadrat method). It may be possible to undertake a desktop survey using the imagery and generate statistics using more manual analysis rather than the semi-automated image processing techniques trialled here.

Monitoring the intertidal zone using drones also faced similar logistical issues to quadrat monitoring, and in particular, needed very calm conditions in which to fly the drones.

Implications

This study has provided further information on the composition and abundance of intertidal algae near to and distant from salmon farms in the D'Entrecasteaux Channel region of southeastern Tasmania. It has also provided additional understanding of the complexities and issues around developing monitoring programs to assess the impacts of nutrient inputs from salmon farms on the surrounding environment.

Overall, the results from this study suggest that the abundance of intertidal algae, whether at a small spatial scale of 1 m^2 quadrats or larger hundreds of metres lengths of coastline, is not a reliable measure of the effects of salmon farm waste nutrients on the environment. Other factors likely influence the composition and abundance of intertidal algae and confound the effects from salmon farms. These include nutrients from other sources, such as winter influx from the Southern ocean or run-off from land-based activities such as intensive agriculture. The algal cover is also influenced by the topography and substrate type and it is difficult to locate readily accessible potentially impacted and reference sites with the same characteristics for comparisons. The logistics of monitoring in the intertidal zone also proved difficult because the small tidal range in southern Tasmania is affected by air pressure, and some areas remain covered in water, affecting classification and causing refraction issues.

Recommendations

From the results obtained, which highlight the complexities and difficulties of monitoring intertidal algae as indicators of nutrient enrichment from salmon farms, it is not recommended that this type of monitoring is continued without a detailed assessment of other sources of nutrient input into the region and an experimental design with sufficient sites and techniques, such as stable isotope analysis, to detect effects of nutrient input from other sources. A major issue is that nutrients from other sources appear to be confounding the results, as shown by inconsistent patterns in abundance of intertidal 'nuisance' algal species with distance from salmon farms. Using drones to monitor at larger spatial scales also proved to be problematic because of interference from even very small depth of water.

Extension and Adoption

The results of this project were requested earlier this year by Tasmanian Government managers of salmon aquaculture and an overview of the results and recommendations were provided at that time.

Because the results are not as useful to industry as originally anticipated, we will not extend a major effort to communicate results to all of industry and the broader community. The report will be uploaded onto the IMAS website and the University of Tasmania Web Access Reporting Portal (WARP).

Project materials developed

A comprehensive set of photos taken at each site has been collated and may be useful in the future to investigate changes over time.

Appendices

List of researchers and project staff

Dr Christine Crawford – Principal Investigator, IMAS
Assoc. Prof. Arko Lucieer - Co-Investigator, UTAS
Dr Stephen Harwin - Co-Investigator, UTAS
Dr Joe Valentine, Aquenal Pty. Ltd.
Mr Sam Gray, Aquenal Pty. Ltd.
Dr Fiona Scott, IMAS
Darren Turner, UTAS

Intellectual Property

There are no IP issues associated with this project.

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