Measuring the footprint of land-based abalone aquaculture discharge points

Camille White, Samuel Lemm,
Megan Hartog & Craig Mundy

February 2025

Institute for Marine and Antarctic Studies, University of Tasmania, Private Bag 49,
Hobart TAS 7001

Enquires should be directed to:
Dr Camille White
Institute for Marine and Antarctic Studies
University of Tasmania
Private Bag 49, Hobart, Tasmania 7001, Australia
Camille.White@utas.edu.au
Ph. (03) 6226 8377
Fax (03) 6226 8035

Executive Summary

A small but well-established land-based abalone aquaculture industry has existed in Tasmania since the 1980s. As this industry looks to expand and innovate, a better understanding of the environmental performance of these sites has become important. The Institute for Marine & Antarctic Studies (IMAS) was commissioned by the Department of Natural Resources and Environment Tasmania (NRE Tasmania) to undertake a thorough survey of environmental conditions surrounding each of the four land-based abalone aquaculture facilities in Tasmania. This project was developed to examine the potential impact of nutrients discharged into the environment through farm outfalls, along with the incidence of escaped farm abalone in the environment. Specifically, the project had the following aims:

- Quantitatively assess subtidal and intertidal macroalgae communities to determine the impacts of nutrient discharge from farm outfalls;
- Determine the presence or absence of farm origin abalone adjacent to farm outfalls; and
- Examine the abundance, size structure and species composition of abalone populations in regions surrounding farms.

Two environmental surveys were undertaken at each land-based abalone site within a twelve-month period; during spring when nutrient effects were likely to be the most prominent and again across autumn and winter when farms were approximately at peak carrying-capacity. Multiple survey methods were used to characterise nutrient impacts and locate escaped farmed abalone in the environment.

At each location, the effects of mild nutrient enrichment on the environment, along with evidence of farmed abalone around outfall pipes was observed. Nutrient effects were highly variable depending on the location of interest, with wave exposure and/or water movement clearly a mitigating environmental factor. While evidence of nutrient enrichment was found at each discharge site, the variability in the data and lack of consistency between surveys would suggest that impacts are within the assimilatory capacity of the receiving environment at current levels of farm biomass. Overall, the environmental survey provides a valuable baseline for the effects of nutrient enrichment from land-based abalone aquaculture at current levels of on-site farm biomass. A better understanding of the magnitude and effects of nutrient inputs from abalone aquaculture within the context of all other nutrient inputs into

receiving environments will aid management into the future, particularly if expansion of the industry is likely to occur.

There was evidence of stock escaping from farms at the discharge point of each facility. Live escaped stock were found at the discharge point of farms at Dunalley, Bicheno and Stanley, suggesting that abalone can escape the farm via effluent treatment systems. A thorough search of cryptic habitat at the Clarence Point discharge point did not occur during the April/May survey, meaning the occurrence of stock escape cannot be conclusively ruled out at this location. Subsequent compliance surveys by NRE Tasmania found live abalone at this location. Empty farmed shells were also found on beaches near all farms. This suggests that stock may also be removed via birds or rodents directly from tanks or mortality bins, or through farm drain cleaning operations, where any accumulated abalone (empty shell or recently deceased) in lateral and main drains may be flushed into the environment. This was particularly evident at Clarence Point, where multiple shells, often very fresh, were found in vicinity of the discharge location.

The complexity of abalone populations, particularly at Stanley, has highlighted the challenges of assessing abalone escapes from aquaculture facilities using visual surveys alone. It becomes difficult to distinguish farmed stock from natural hybrids beyond the discharge point, with limited existing knowledge around the effects of diet and environment on shell morphology. Therefore the movement of farmed stock into the environment beyond the discharge point cannot be conclusively ruled out based on the results from this study. As all four farms have demonstrated evidence of escaped stock, the risk of disease transfer from farmed abalone to wild stock remains. There is only limited methodology available for determining the origin of individual animals, particularly for separating wild from hybrids in the broader environment and no methodology is available for successfully tracing larval export from farms, or F2 or F3 backcrosses into wild populations. Better understanding of the relationship between escaped abalone and wild stock will help to better assess the risk of this interaction in a Tasmanian context.

Table of Contents

Introduction

Abalone aquaculture was first developed in Japan approximately 60 years ago and has since become widespread, with Asia and South Africa now dominant in terms of the total biomass produced (Theil et al. 2004, FAO 2020). Within Australia, there are small but well-established industries in Victoria, South Australia, Western Australia and Tasmania that have existed since the 1980s (Theil et al. 2004). Abalone is presently considered a developing sector within Tasmania, with potential existing for expansion. There are currently four land-based abalone farms across the state that produced 287 tonnes of fish at a market value of approximately $10M in 2022 (Table 1; Tuynman et al. 2023). The main biomass produced at each of the farms consists of hybrid or "tiger" abalone, which are a cross between greenlip (*Haliotis laevigata*) and blacklip (*Haliotis rubra*) abalone. The majority of abalone produced in Tasmania is exported to Asia, with live abalone the primary export product.

Table 1: Details of the four land-based abalone producers in Tasmania.

Farm	Australian Ocean Biotechnology (Abtas)	Yumbah Aquaculture	JST Abalone	Jade Tiger Abalone
Location	Clarence Point	Bicheno	Stanley	Dunalley

In Australia, general production methods see abalone broodstock spawned within hatcheries to produce free-swimming veliger larvae. There is marked, consistent directionality in reproductive success in spawning hybrids, with breeding schemes using male *H. laevigata* and female *H. rubra* (Kube et al. 2024). Broodstock may be held on site, with hybrid animals being fertile and able to backcross with pure species (Brown 1995). The settled larvae are reared in nurseries on-site, where they feed on microalgal plates for approximately six months post-settlement (Theil et al. 2004). In other countries, microalgal plates and formulated diets are regularly supplemented with macroalgae, grown either in integrated systems or wild harvested (Daume 2006, Naidoo et al. 2006, Flores-Aguilar et al. 2007, Park & Kim 2013, Viera et al. 2016). In Tasmania, once abalone reach approximately six months of age, formulated diets are the main source of nutrition (NRE Tasmania, pers comm). Abalone are messy grazers and food breakdown and wastage are common problems, resulting in nutrient leaching from the feeds into the tanks (Ho 2006).

To support growth of the abalone industry in South Australia, SARDI/PIRSA undertook an environmental risk assessment addressing the potential impacts of abalone aquaculture on the environment (Theil et al. 2004). This study identified a primary research need to better determine the effects of nutrient discharges from land-based abalone aquaculture facilities on the environment. Other priority areas included the effects of abalone farms on aggregations of birds and the potential for disease and genetic transfer from cultured stock to wild stock, primarily through farm escapees (Theil et al. 2004). While the report by Theil et al. (2004) is over twenty years old, the environmental risks identified in that study remain relevant, with better understanding of these risks required to support the sustainable expansion of land-based abalone aquaculture in Tasmania.

In Tasmania, the Environmental Management and Pollution Control Act 1994 (EMPCA) states that any commercial premises with wastewater discharges of more than 100 kilolitres per day is classified as a level two activity and requires appropriate regulation (Schedule 2, Section 3(a)). As many of the land-based abalone facilities are scoping the possibility of expansion, understanding baseline environmental conditions surrounding discharge points will be necessary should wastewater entering the environment from land-based abalone aquaculture become regulated with an Environmental Management Plan.

Similarly, to aid innovation, some industry members have expressed interest in translocating farmed abalone across state borders to access genetic gains made by selective breeding programs on mainland Australia. The movement of live abalone from the mainland to Tasmania is currently restricted, mainly due to biosecurity concerns. However, NRE Tasmania is currently considering policy and assessment frameworks for abalone translocations proposals. This policy requires that for the risks posed from translocations to be sufficiently mitigated, effective escape prevention methods must be in place. There have been reports of escaped abalone from farms in Tasmania in the past, leading to a review process for the Marine Farming Licenses and Abalone Escape Prevention Plans associated with each farm. Nevertheless, prevention of escapes may be difficult, with the abalone sperm, eggs and the pelagic larval phase being microscopic and the use of fine mesh filters on out-pipes being impractical due to frequent blockages and high rate of water flow through farm systems. Likewise, larger abalone may be able to crawl out of holding tanks, through waste drainage systems and into the environment. Risks associated with the escape of farmed abalone into the wild include compromises to the natural genetic structure of wild populations and the being a potential vector in the spread of diseases (Theil et al. 2004). As such, there is a need to better understand the risks posed by land-based abalone aquaculture to the local marine environment.

NRE Tasmania requested through the Sustainable Marine Research Collaborative Agreement (SMRCA) that IMAS undertake a thorough survey of environmental conditions surrounding each land-based abalone aquaculture facility in Tasmania. Given the lack of research data around environmental risks associated with abalone aquaculture in Tasmania, this was developed to be a multi-faceted project, looking at the potential impact of nutrients discharged into the environment through farm outfalls, along with the incidence of escaped farm abalone in the environment. Surveys were to occur twice within the study period; during spring when nutrient effects were likely to be the most prominent and again across autumn and winter when farms were approximately at peak biomass. For this project, peak biomass was estimated by NRE Tasmania to coincide with the peak harvest period compiled over multiple years. Specifically, the project had the following aims:

1. Quantitatively assess subtidal and intertidal macroalgae communities to determine the impacts of nutrient discharge from farm outfalls;
2. Determine the presence or absence of farm origin abalone adjacent to farm outfalls; and
3. Examine the abundance, size structure and species composition of abalone populations in regions surrounding farms.

The data obtained through this project will help the State Government to better understand environmental risks associated with land-based abalone aquaculture.

Methods

Study sites

Each of the four sites across Tasmania had differing environmental conditions at their discharge locations (Figure 1). The Jade Tiger Abalone farm at Dunalley discharges directly into Frederick Henry Bay. The discharge environment at the outfall is loose cobble grading into compacted sand, interspersed with some larger rocks. The nearest continuous and consolidated reef habitat is approximately 400 m from the outfall pipe. The environment is protected from wind and swell and is comparatively low energy. This site was surveyed in November 2023 and May 2024, which corresponded to off-peak and peak biomass, respectively. Temperature was observed to be 16.0°C in November and 11.9°C in May. Salinity was similar between sampling events (November 2023: 34.48 ppt, May 2024: 35.75 ppt), with dissolved oxygen being 9.62 mg/L in November 2023 and 8.25 mg/L in May 2024.

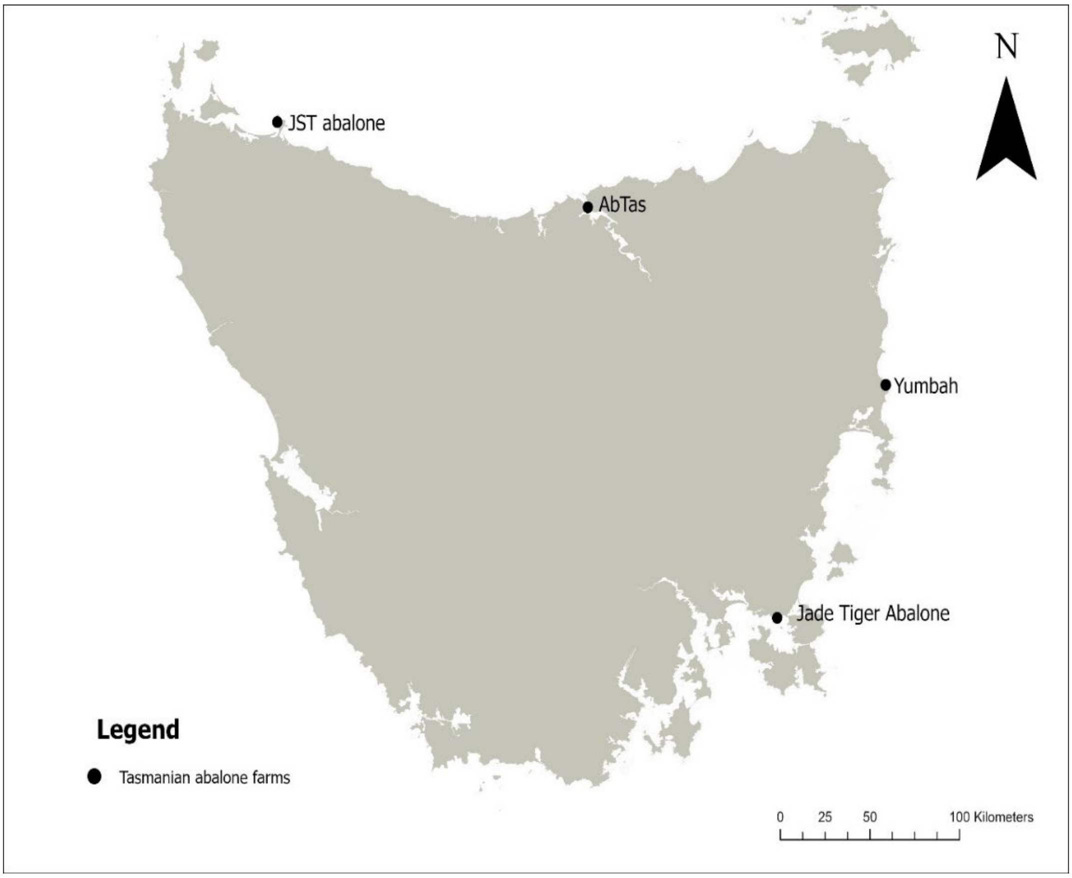


Figure 1: The distribution of the four land-based abalone aquaculture facilities across Tasmania.

The Abtas farm at Clarence Point is situated within the Tamar estuary, approximately 5 km from the estuary mouth. It also discharges directly onto cobble which graduates into a more sandy/silty environment directly behind a break-wall built around Garden Island. There is consolidated reef as part of the break-wall approximately 200 m from the discharge point. The discharge environment is protected from swell but is subject to the strong tidal currents that exist within the Tamar estuary. This site was surveyed in November 2023 and April/May 2024, which corresponded to off-peak and peak biomass, respectively. Temperature was observed to be 17.9°C in November 2023 and 16.8°C during April/May 2024. Salinity values reflected the expected variation given the estuarine environment and were 33.0 ppt in November 2023 and 35.5 ppt in April/May 2024 at the discharge point. Dissolved oxygen at the discharge site remained consistent across survey periods (7.97 mg/L in November and 7.93 mg/L in April/May 2024).

The Yumbah Aquaculture farm discharges directly into a high energy environment on the coast just south of Bicheno. The substrate is consolidated reef, mainly slab in formation with some larger rocks and boulders. The environment is oceanic and kelp forests dominate around the discharge point. There are two outfalls that were both investigated as part of this study; the main outfall to the south where the bulk of the water is discharged and the decommissioned hatchery outfall to the north, where a small amount of water is discharging from site. The Bicheno region was surveyed in December 2023 and July/August 2024, which corresponded to off-peak and peak biomass, respectively. Temperature was observed to be 17.3°C in December 2023 and 12.3°C in July/August 2024. Salinity at the discharge site largely reflected oceanic conditions (December 2023: 35.4 ppt, July/August 2024: 35.84 ppt), dissolved oxygen was not measured in December 2023, but in July/August 2024 it was 9.48 mg/L.

The JST Abalone farm in Stanley discharges into Perkins Bay on the western side of the Stanley Peninsula. While it is protected from oceanic swell, the environment is wind-dominated and the water column is largely well-mixed. The substrate in proximity to the discharge point is patchy reef, with cobble dominant at the discharge point. Vegetated soft-sediment and consolidated reef habitats both feature in the general environment within 500 m of the discharge point. This site was surveyed in November 2023 and August 2024, which corresponded to off-peak and peak biomass, respectively. Water temperature was 17.8°C in November 2023 and 12.3°C in August 2024, while salinity at the discharge site was oceanic

(>35.6 ppt). Dissolved oxygen was similar between surveys, being 8.06 mg/L in November 2023 and 8.43 mg/L in August 2024.

Survey methods

As noted above, all farm regions were surveyed twice within the duration of the project. Farms were notified that a survey would occur within the coming week prior to the first survey, with no prior notice of intent to survey provided before the second survey was conducted. While standardised methods were implemented where possible, given the variability in the discharge environment between sites, some adjustments were made at each site to ensure project aims were adequately addressed (Table 2, Figures 2-9). To address aims relating to nutrient enrichment, Rapid Visual Assessment (RVA) surveys were undertaken at 5 m depth at all sites, while shallow subtidal quadrat surveys (at approximately 0-1 m depth) were conducted adjacent to the shore at sites where this was possible (hereafter "shallow quadrat surveys"). In addition to this, where mixed or soft substrate habitats were present in the general environment around the discharge point, towed video was deployed to capture these habitats. The green seaweed *Ulva* spp. was also collected for stable isotope analysis, as an integrated measure of environmental nitrogen. To address aims relating to escaped stock, the abalone population was examined using 200 m transect swims or targeted search dives at each site. Intertidal surveys and shore walks were also undertaken in each region, in search of farm debris, shells or live abalone.

Table 2: Overview of the survey methods used at each site.

	Dunalley	Clarence Point	Bicheno	Stanley
RVA survey	✓	✓	✓	✓
Shallow quadrat survey	✓	✓		✓
Towed video				✓
Isotope collection	✓	✓	✓	✓
Abalone transect	✓	✓	✓	✓
Abalone targeted search	✓	✓	✓	✓
Shore walk	✓	✓	✓	✓
	Figure 2 Figure 3	Figure 4 Figure 5	Figure 6 Figure 7	Figure 8 Figure 9

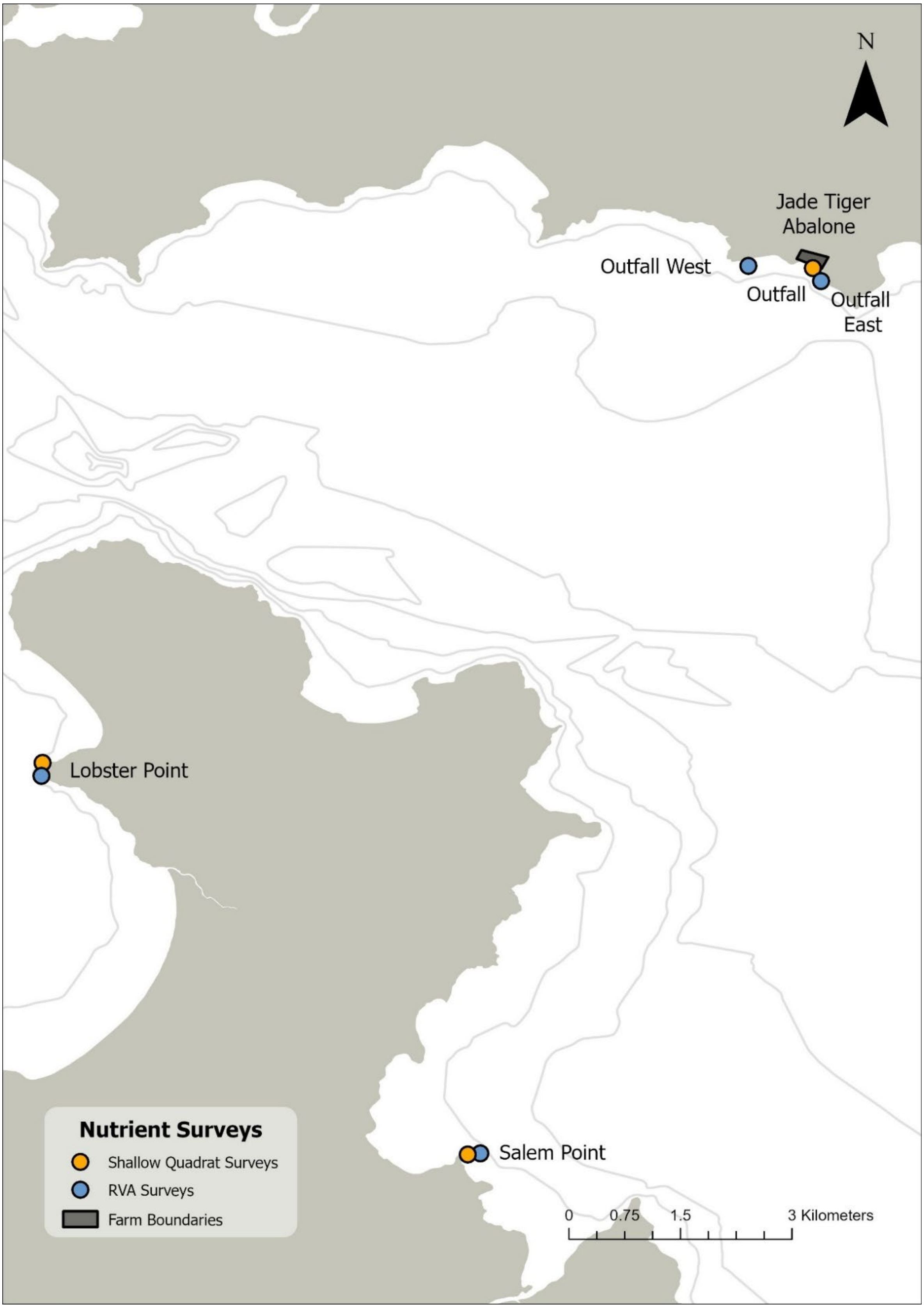


Figure 2: Map of nutrient assessment sites surveyed around the Jade Tiger Abalone farm in Dunalley in November 2023 and May 2024.

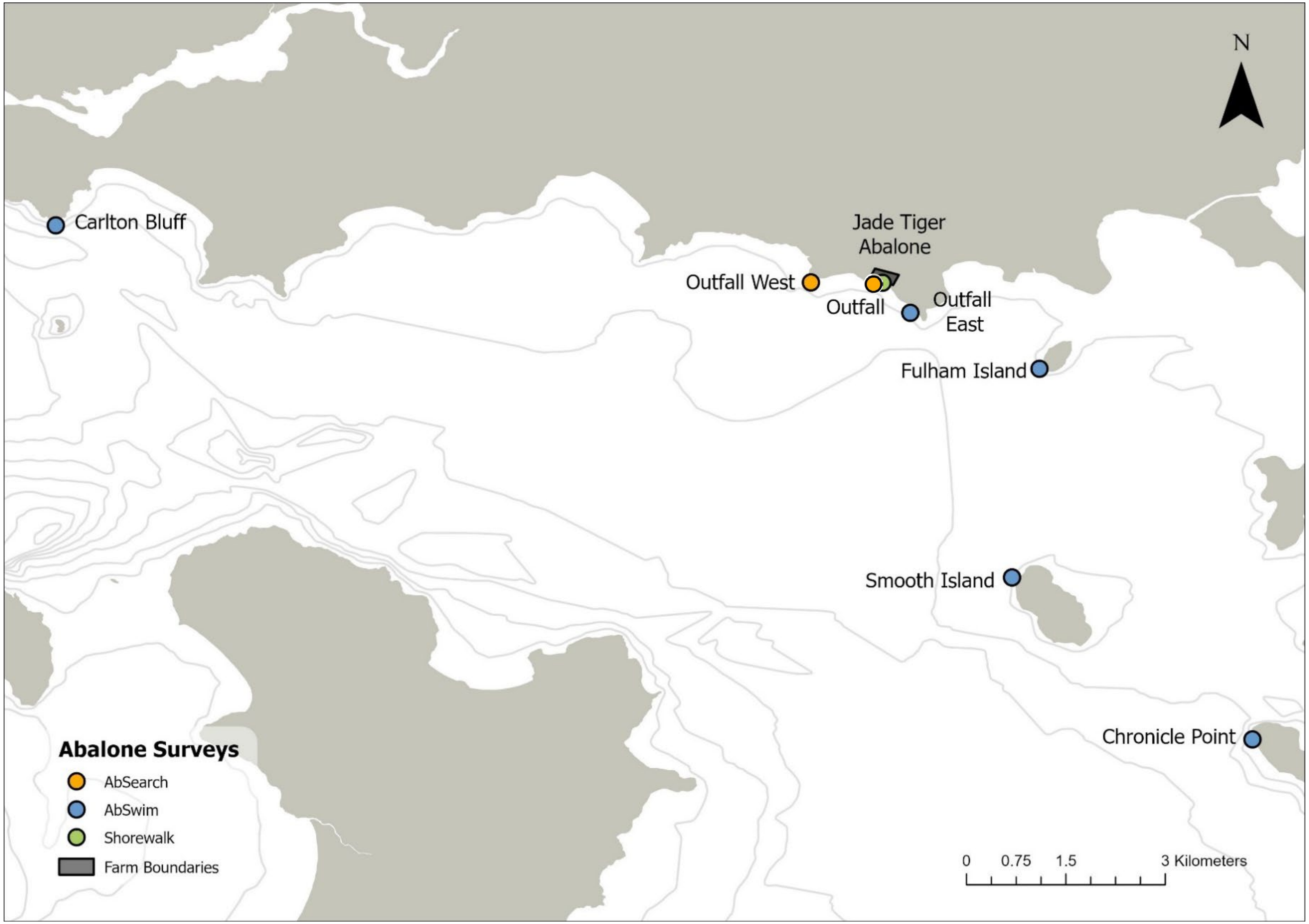


Figure 3: Map of abalone survey sites around the Jade Tiger Abalone farm in Dunalley surveyed in November 2023 and May 2024.

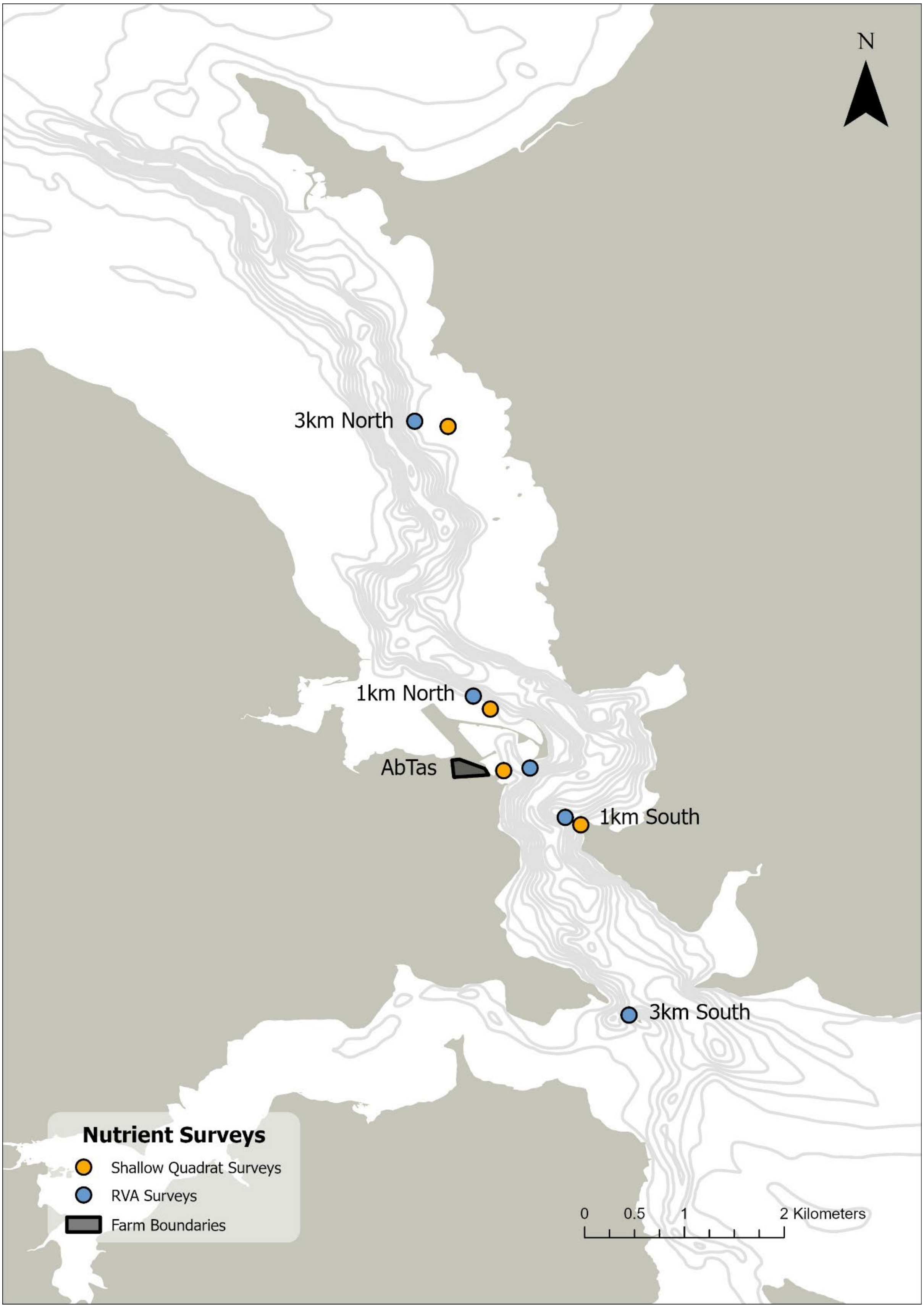


Figure 4: Map of nutrient assessment sites surveyed around the Abtas Marketing abalone farm in Clarence Point in November 2023 and April/May 2024.

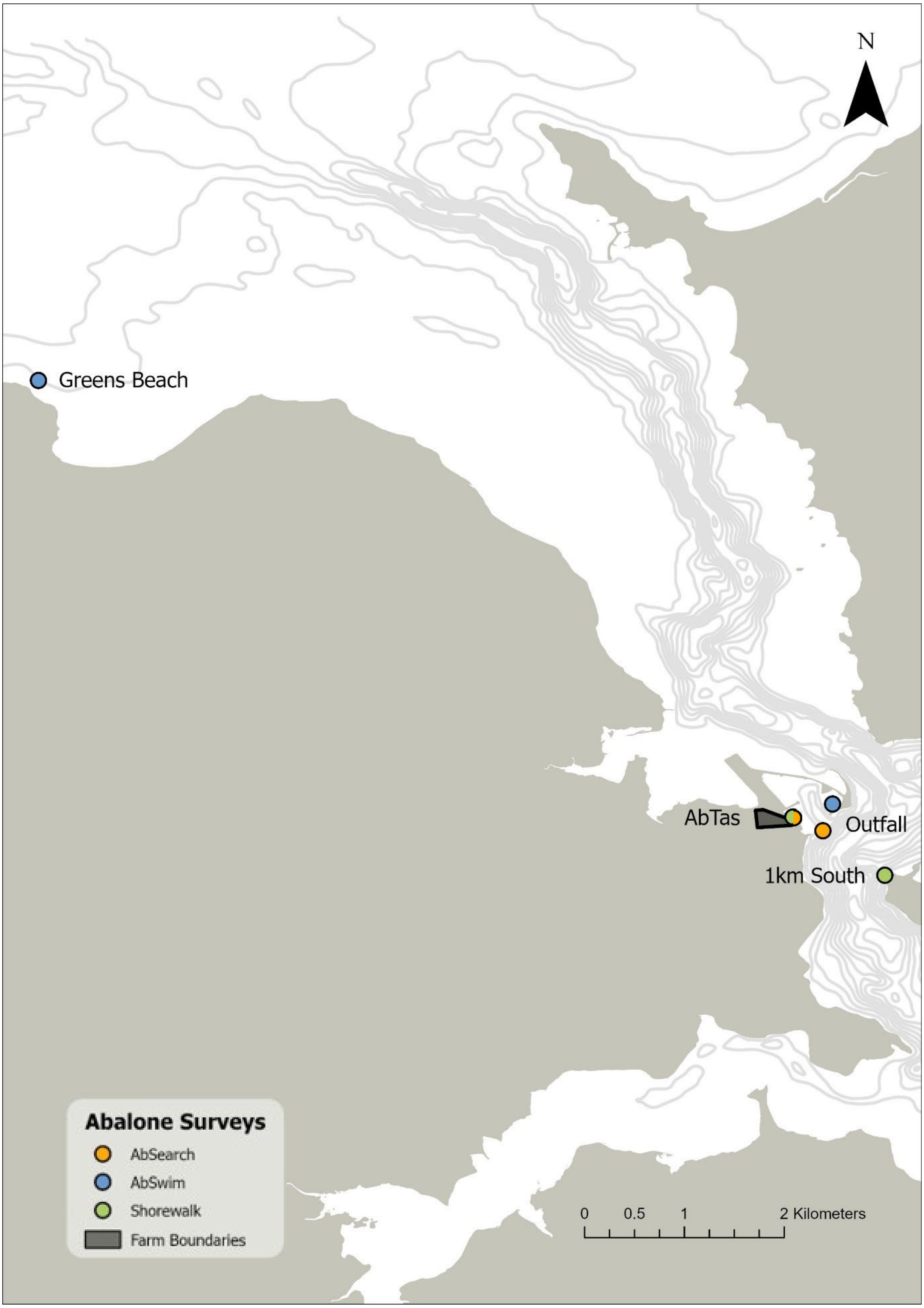


Figure 5: Map of abalone survey sites around the Abtas Marketing abalone farm in Clarence Point surveyed in November 2023 and April/May 2024.

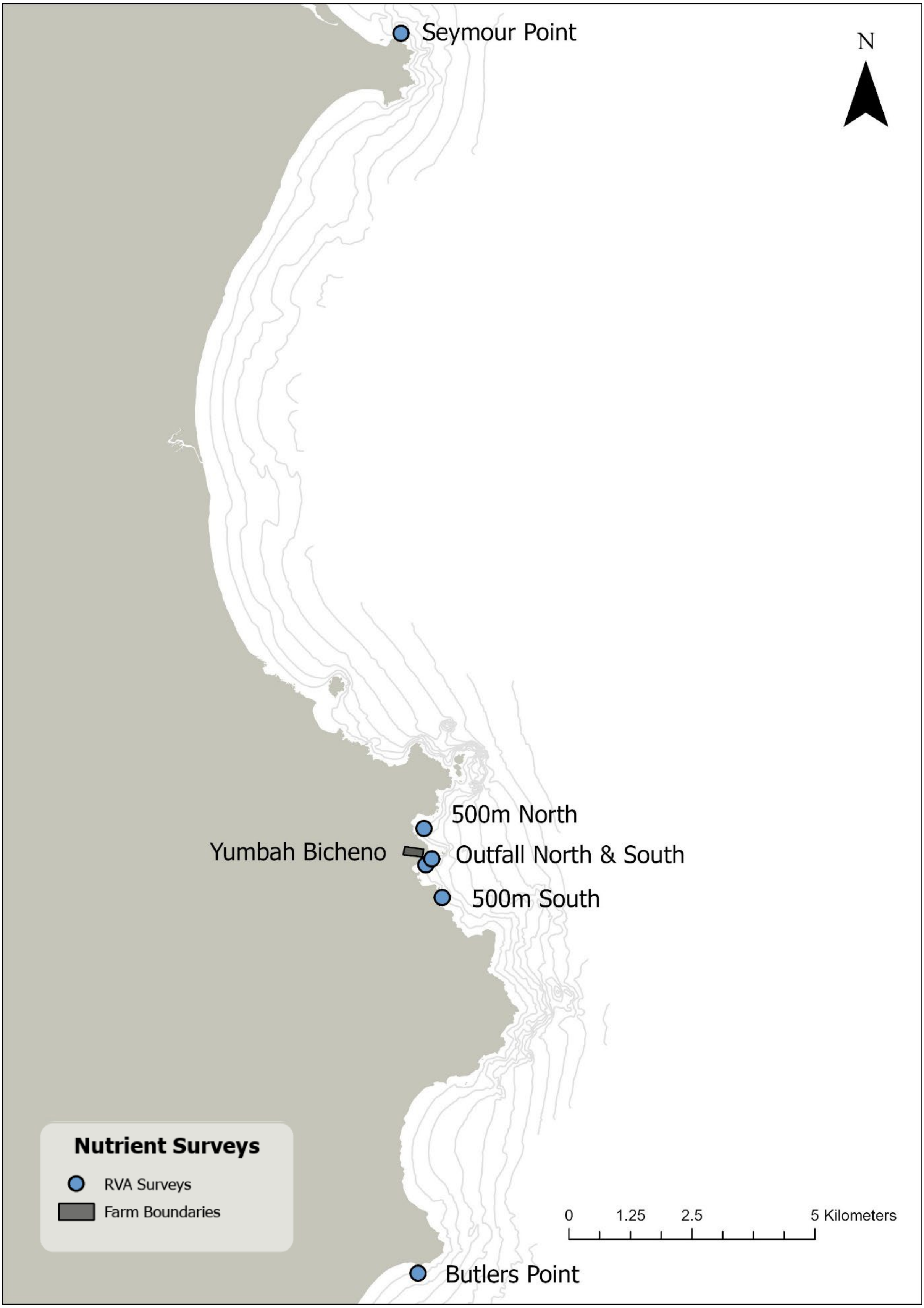


Figure 6: Map of nutrient assessment sites surveyed around the Yumbah Aquaculture abalone farm in Bicheno in December 2023 and July/August 2024.

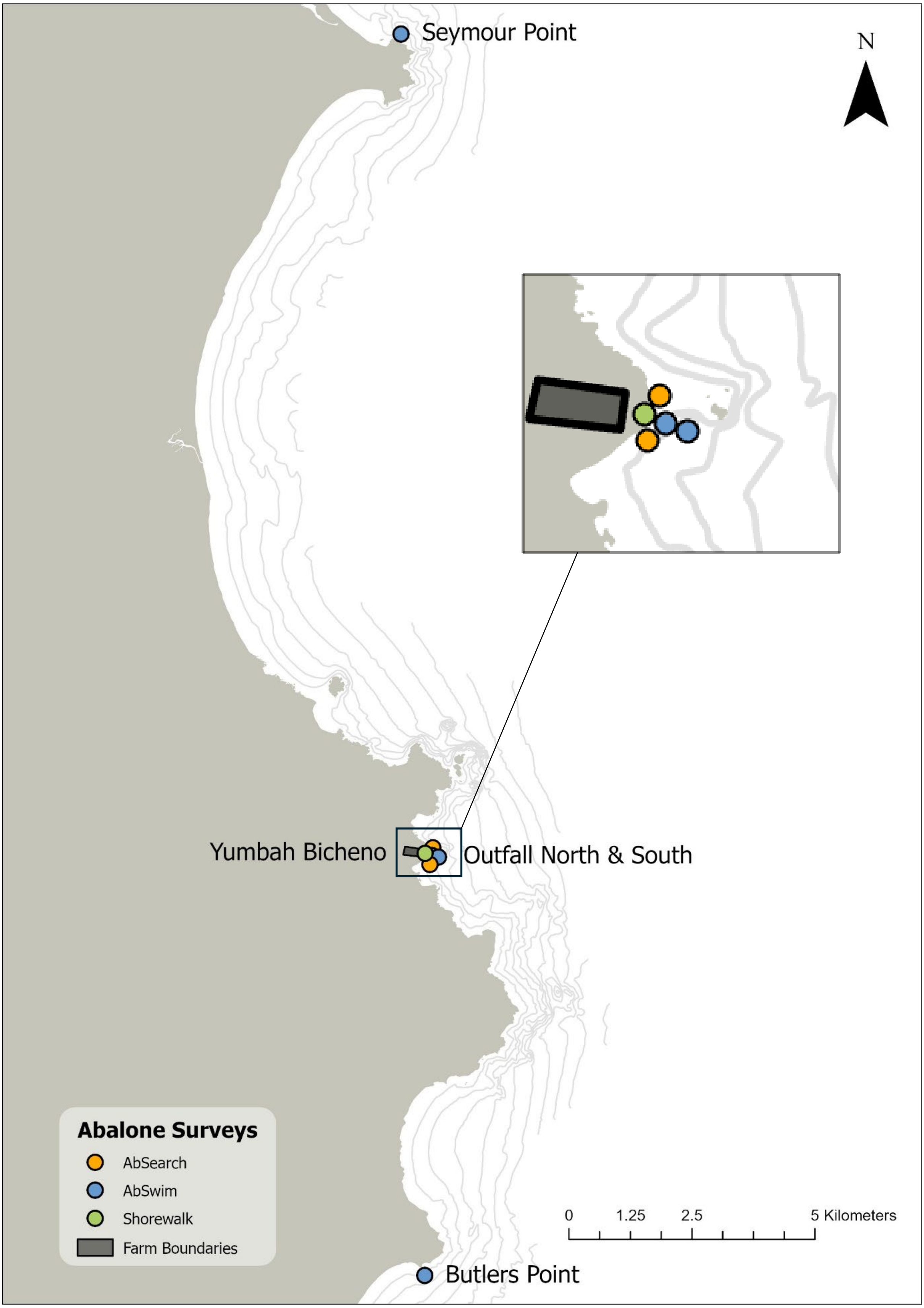


Figure 7: Map of abalone survey sites around the Yumbah Aquaculture abalone farm in Bicheno surveyed in December 2023 and July/August 2024.

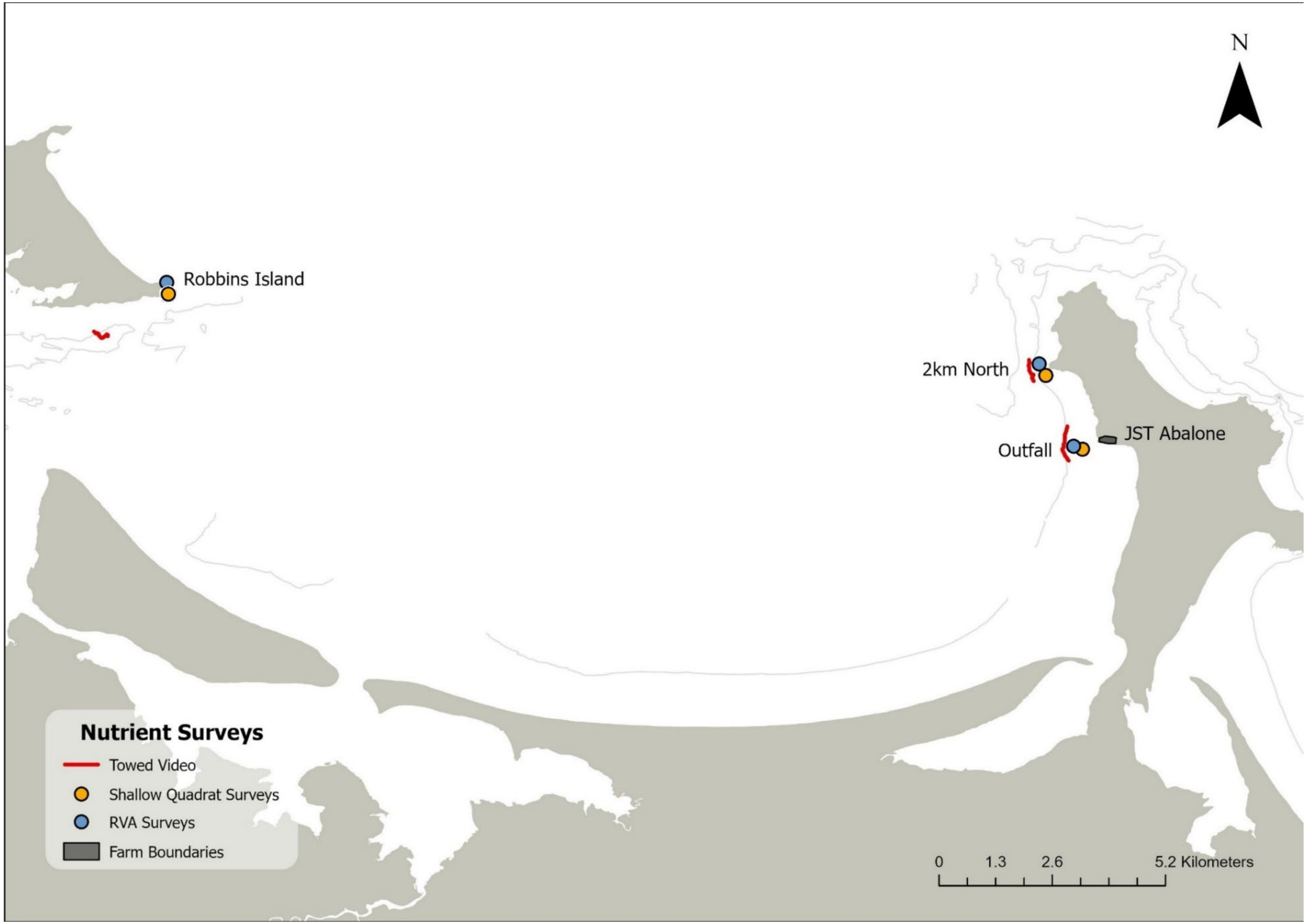


Figure 8: Map of nutrient assessment sites surveyed around the JST Abalone farm in Stanley in November 2023 and August 2024.

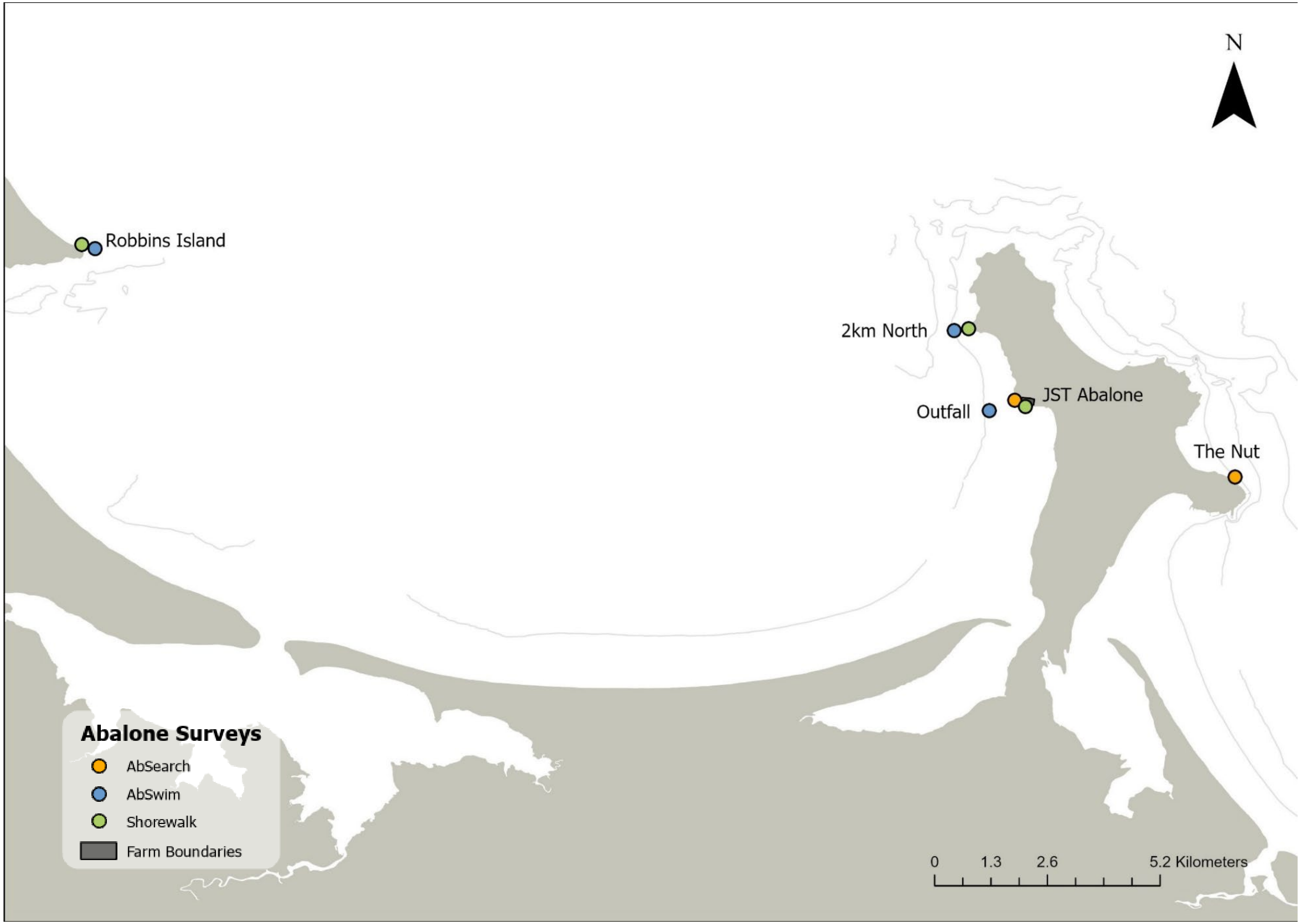


Figure 9: Map of abalone survey sites around the JST Abalone farm in Stanley surveyed in November 2023 and August 2024.

Rapid Visual Assessment (RVA) surveys

RVA surveys are diver-based reef health assessments that use the methods developed through FRDC 2015-024 (see Ross et al. 2021), with an adaptation applied for this study to account for the presence/absence of abalone within quadrats. As part of the RVA method, 15 functional parameters were assessed within 1 m^2 quadrats. Of the fifteen parameters, 10 assessed broad structural parameters associated with reef function (i.e. four assessed the condition of the macroalgal canopy, four assessed the condition of the substrate and two related to trophic effects), while the other five addressed the effects of nutrient enrichment. The broad structural characteristics assessed included 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/genotype of abalone present. Nutrient enrichment was addressed by assessing the percentage cover of epiphytic and filamentous algae, along with the cover of nuisance green (*Ulva* spp., *Chaetomorpha billardierii*, *Cladophora feredayi*) and nuisance red (*Asparagopsis armata*) algae species, along with the level of flocculant material (i.e. “dust”) covering any algae. Any abalone found in quadrats were measured and evaluated for morphology (see “Abalone swims” below).

At the start of each survey, a 50 m transect was deployed along the 5 m depth contour and tensioned between two shot lines in an area of continuous consolidated reef habitat. Where it was possible with availability of substrate, RVA surveys were conducted as close as possible to the farm discharge point, as well as at control locations more than 5 km distant and intermediate locations if time allowed. Along the length of the 50 m transect line, 12 x 1 m^2 quadrats were attached haphazardly via a 1 m length of rope, with each quadrat scored by the diver and photographed for archival purposes. The 1 m^2 quadrat was divided into four smaller 0.25 m^2 subsections to increase scoring accuracy. All parameters were assessed in the full quadrat, except for the substrate parameters, which were sampled using the 0.25 m^2 subsection of the quadrat which was closest to the transect line. The first two quadrats at all sites were scored by both divers for calibration and data QA/QC, while the remaining ten quadrats were split and scored individually.

Shallow quadrat surveys

Shallow quadrat surveys were conducted along a 50 m transect at a depth range of approximately 0-1 m, depending on the tidal range at each site. At each site, 12 x 1 m^2

quadrats were haphazardly placed along the 50 m transect, with each quadrat photographed for analysis. Suitable substrate did not exist in all locations; at the discharge point in Bicheno the rock slab prevented this depth range from being properly accessible and, as such, shallow quadrat surveys were not undertaken at this location.

Images were subsequently analysed using a guided visual estimation technique, where overall percentage cover was assigned to each of the major nutrient indicator algae species/groups that were observed in the images. Categories were as follows:

- Epiphyte total: overall epiphyte cover, including all species and categories below, provided they were growing epiphytically, rather than attached to rock or sandy substrate.
- Species and functional groupings: cover of opportunistic algae taxa (including *Ulva* spp., *Enteromorpha*/*Ulva intestinalis*, *Cladophora* spp., *Chaetomorpha billardierii*, *Grateloupia turuturu* and *Asparagopsis armata*) and functional groups (including epiphytic red algae, epiphytic green algae, filamentous algae). These species and groups were recorded regardless of whether they were growing epiphytically (in which case they were also included in the epiphyte total score) or on the substrate.

Towed video transects

Towed video transects were conducted at three sites in the Stanley region where mixed or vegetated soft substrate dominated the discharge environment and investigation of the associated seagrass beds for effects of nutrient enrichment was therefore necessary. Towed video surveys were conducted across the three sites in both November 2023 and August 2024. The towed camera unit comprised of a metal housing with LED light, two parallel downward-facing lasers for scale and downward and forward-facing GoPro HERO10 cameras. The frame was connected to the surface via a communications cable for topside monitoring and water column positional control using an electronic davit. Prior to each survey, the distance between the downward-facing lasers was calibrated to 25 cm to ensure the correct spatial measurement for the analysis of benthic still images.

The camera was towed at a speed of ≤1 kt along a depth contour between 5-8 m. The length of each tow track was ~20 minutes (which equated to ~300-600 m of habitat extent). Tows were designed to capture seagrass, although also encompassed some mixed reef/seagrass habitat.

Still images were extracted from the downward-facing video footage and annotated using TransectMeasure (SeaGIS) to provide quantitative data on epiphyte coverage and community composition of seagrass habitat across sites and survey periods. Approximately one image was analysed every 10 m throughout the tow, although this frequency was reduced for the August 2024 survey due to processing time and the homogeneity of habitat. Images were annotated to quantify the percentage cover of epiphytic algae, benthic biota and substrata. Fifty random points were overlaid on each image and annotations were allocated to each point. Where species identification was not possible, the CATAMI (Collaborative and Automated Tools for Analysis of Marine Imagery) classification scheme was used. The priority for this annotation was around identification of epiphyte and epifauna taxa growing on both macroalgae and macrophytes.

Ulva *collection and isotope analysis*

Entire specimens of *Ulva* spp. were collected where present from each site for nitrogen isotope analysis, which has been shown to be the best integrator of aquaculture-derived nitrogen where feeds are dominated by terrestrial material (Howarth et al. 2019, White et al. 2022). Post-collection, samples were placed on ice and then moved to the -20°C freezer before freeze-drying. Using a ball mill, samples were then ground into a fine powder. While samples were collected and processed, it was decided not to analyse them at this point, as the reliability of nitrogen isotopes is dependent on having a thorough understanding of the composition of feeds used by each farm at the time of sampling. This information has not been obtained as part of this project and consequently, samples are archived and can be revisited if required in the future.

Abalone swims

Abalone swims were conducted using a 200 m diver transect along suitable reef habitat at a depth contour between 3-12 m, depending on the site and the availability of habitat. Where possible, abalone swims were conducted as close as possible to the farm discharge point, as well as at control locations more than 5 km distant. Within 1 m each side of the transect, abalone were counted, measured to the nearest 5 mm and categorised into one of five morphology groups (BB: blackshell/blacklip, GG: greenshell/greenlip, BG: blackshell/greenlip, GB: greenshell/blacklip, FA: farmed origin). Farmed original abalone were identified primarily through their verdant green shells (jade or jade-striped), but also the ruby colouration on the base of their pale black foot.

Abalone searches

Where the environment was not suitable to undertake a transect-based diver survey, a general abalone search was conducted instead. For this method, a survey area was defined (generally constrained by the availability of rocky substrate) and an exhaustive search conducted therein. All abalone found were counted, measured to the nearest 5 mm and categorised into the morphology groups outlined above.

Shore walks

A combination of shallow subtidal snorkels and intertidal/shore walks were conducted at each region. Either one or both methods were implemented, depending on the site and whether habitat characteristics enabled access. These subtidal/intertidal surveys were conducted to gain qualitative information on both nutrient enrichment status and the identification of escaped abalone populations. Where possible, increased effort was placed on searches conducted around farm outfalls, with an emphasis on escaped farm populations, shell debris, and any algae indicating nutrient enrichment.

Nutrient sampling

At each RVA site, temperature, salinity and dissolved oxygen across the full water column were measured using a Seabird SBE19 plus CTD or a YSI 650 CTD. Seawater samples were collected using 10cc/mL syringes and filtered before being placed on ice and frozen prior to subsequent analysis for dissolved phosphorus, ammonia and nitrates. Nutrient results are shown in Appendix 1.

Results

Nutrient assessment surveys

Dunalley

Rapid visual assessment

The structure and function of reefs in the region around the Jade Tiger Abalone farm in Dunalley were typical of a low wave exposure environment subject to both natural and anthropogenic nutrients. The overall canopy cover at the outfall averaged approximately 25% total cover or lower, whereas both control sites were 50% cover or greater across both surveys (Figure 10). The canopy at all sites within Frederick Henry Bay was dominated by *Cystophora* spp. and *Sargassum* spp., whereas Lobster Point had higher cover of *Ecklonia radiata* (Figure 11). Understorey green algae was a feature at the Outfall East site, although this was also observed in relatively high abundance at the control site at Salem Point (Figure 10).

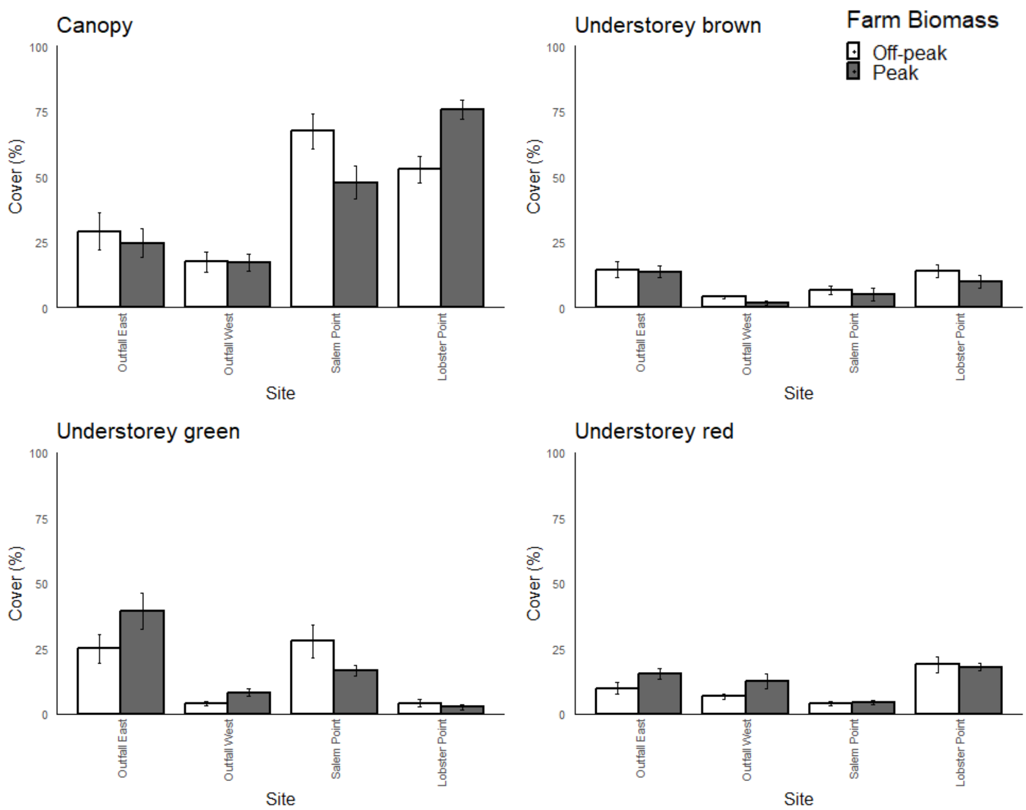


Figure 10: Percentage cover of major functional groups relating to canopy and understorey macroalgae in the Dunalley region across both November 2023 (off-peak biomass) and May 2024 (peak biomass).

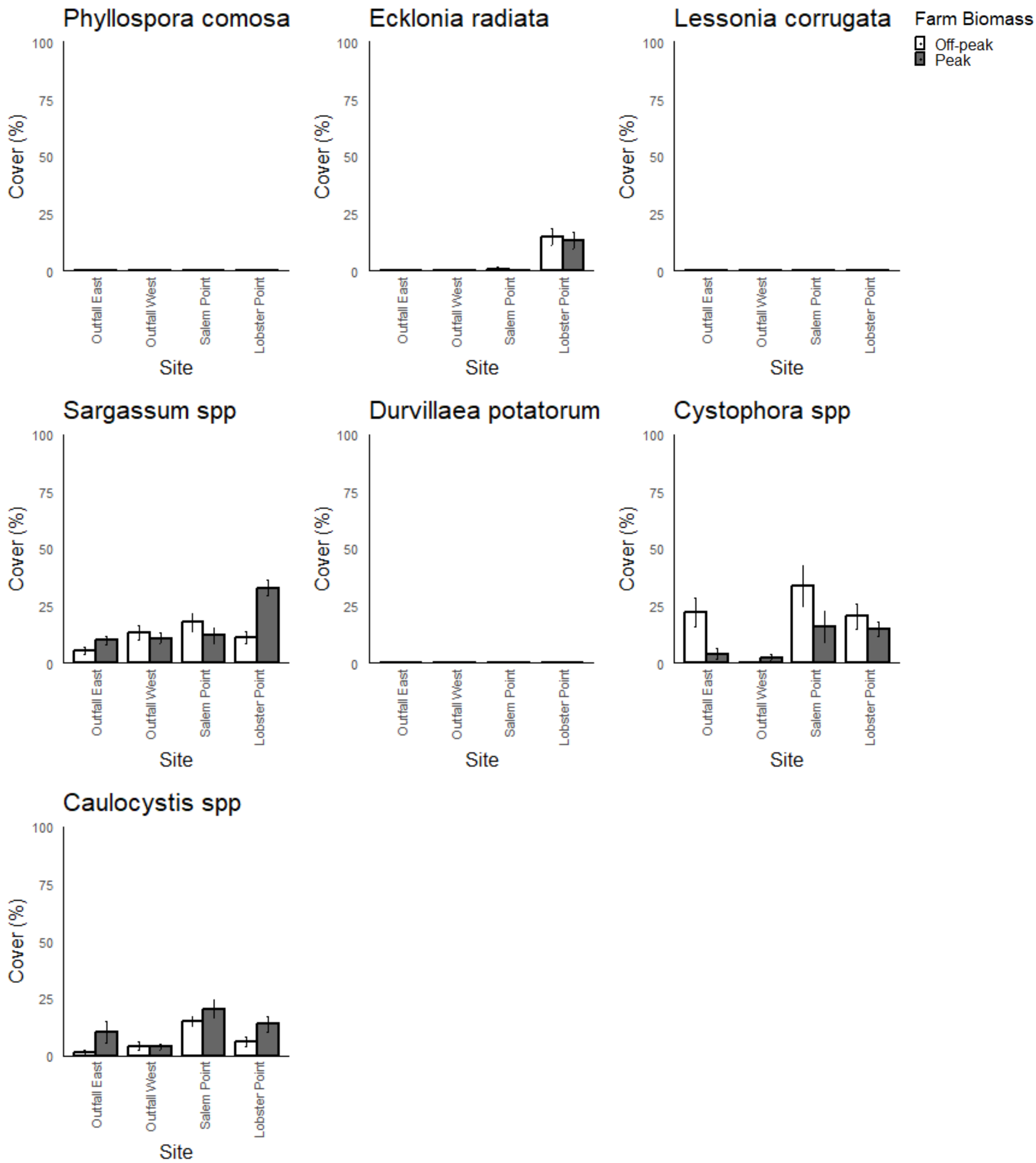


Figure 11: Percentage cover of the major canopy species of macroalgae in the Dunalley region across both November 2023 (off-peak biomass) and May 2024 (peak biomass).

Variation was observed in abundance of epiphytic and filamentous algae across the two surveys. In November 2023, abundance across all sites was between 10-20% cover for epiphytic algae and 0-15% cover for filamentous algae (Figure 12). In comparison, both epiphytic and filamentous algae recorded very high percentage cover in the May 2024 survey, with abundance increasing with decreasing wave exposure of the site (Figure 12). Nuisance green algae was observed at the two outfall sites at ≤ 5% cover, although this was comparable with abundances observed at Lobster Point during the November 2023 survey. High levels of sedimentation were observed at both outfall sites and Salem Point across both surveys, whereas Lobster Point was clearly subject to higher wave exposure, with lower levels of accumulated sediment.

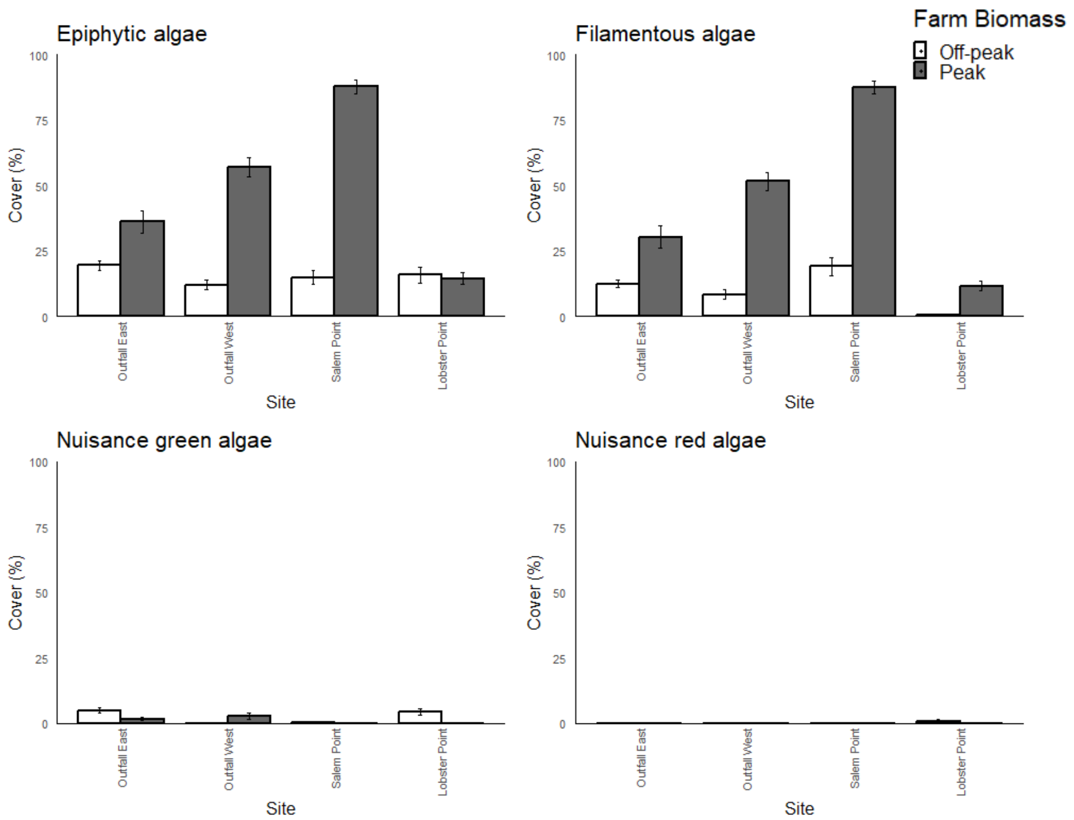


Figure 12: Percentage cover of nutrient enrichment parameters in the Dunalley region across November 2023 (off-peak biomass) and May 2024 (peak biomass).

Pink encrusting algae was more abundant at Lobster Point compared to all other sites for both surveys (Figure 13), which is not unexpected given the greater wave exposure at this site. Red encrusting algae was more common at the two outfall sites during the May 2024 survey and turfing algae was elevated at Outfall East in November compared to all other surveys (Figure 13).

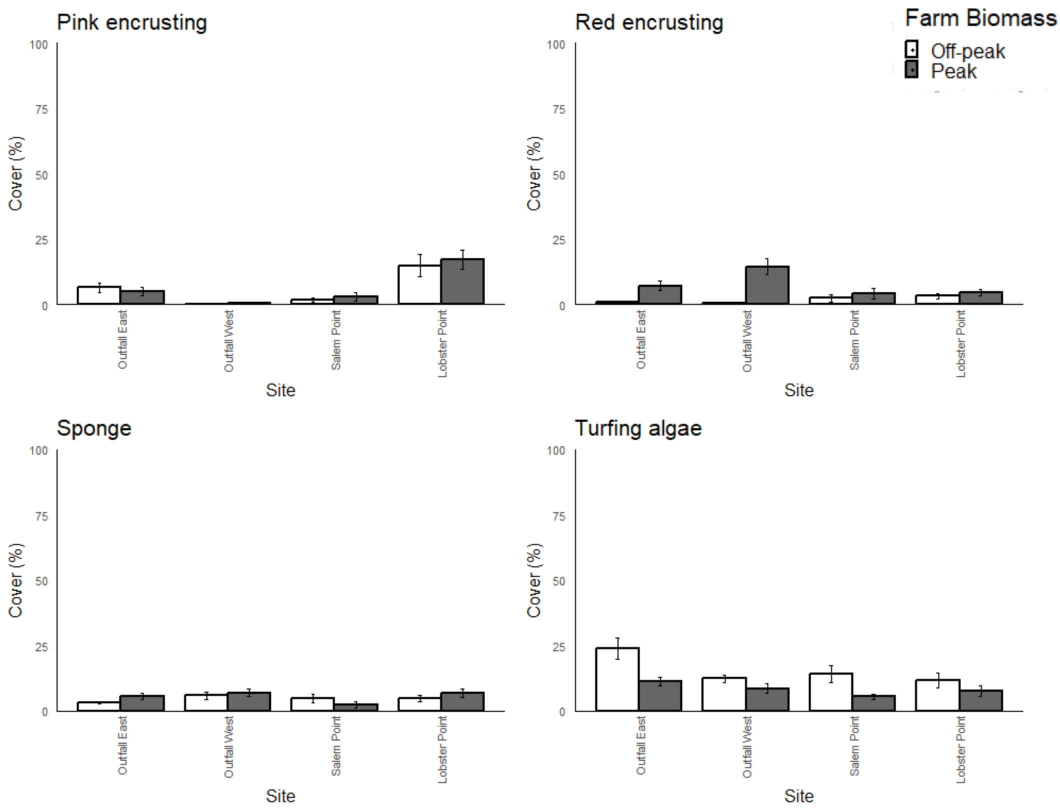


Figure 13: Percentage cover of substrate parameters in the Dunalley region across November 2023 (off-peak biomass) and May 2024 (peak biomass).

Shallow quadrat survey

The percentage cover of macroalgae was observed was variable by site and survey. Abundances of macroalgae tended to be lower at the outfall sites compared to Salem Point or Lobster Point, with the exception of the Outfall West site during the May survey (Figure 14). The trends observed in the nutrient indicator taxa/groups largely reflected the transient nature of the species and groups targeted through the shallow quadrat survey. For example, the abundance of filamentous algae was high (43.3 ± 4.3%) at Outfall West in November 2023, but a bloom of this algae (56.5 ± 3.7 % cover) was also observed at Salem Point further south in Frederick Henry Bay in May 2024 (Figure 15). Trends in filamentous algae observed from the deeper RVA quadrats were generally not reflected in the shallow quadrats. Nutrient indicator species were noticeably low in abundance, with the exception of *Ulva* spp. at Outfall East in November 2023 (28.5 ± 6.9 % cover; Figure 16). *Grateloupia* spp. was also observed in very low abundance at this site only (Figure 16).

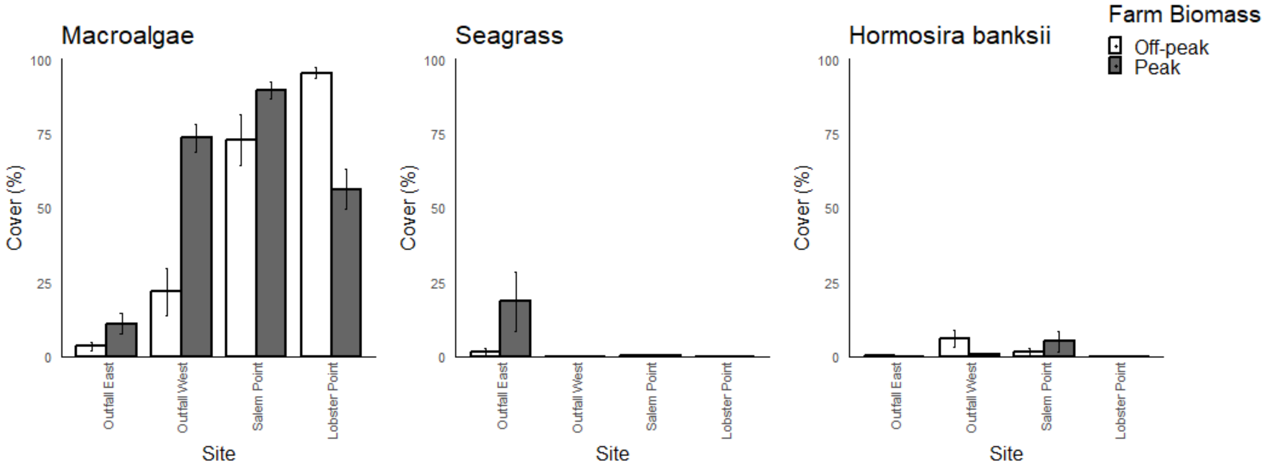


Figure 14: Percentage cover of foundation species/taxa from the November 2023 (off-peak biomass) and May 2024 (peak biomass) shallow quadrat surveys in the Dunalley region.

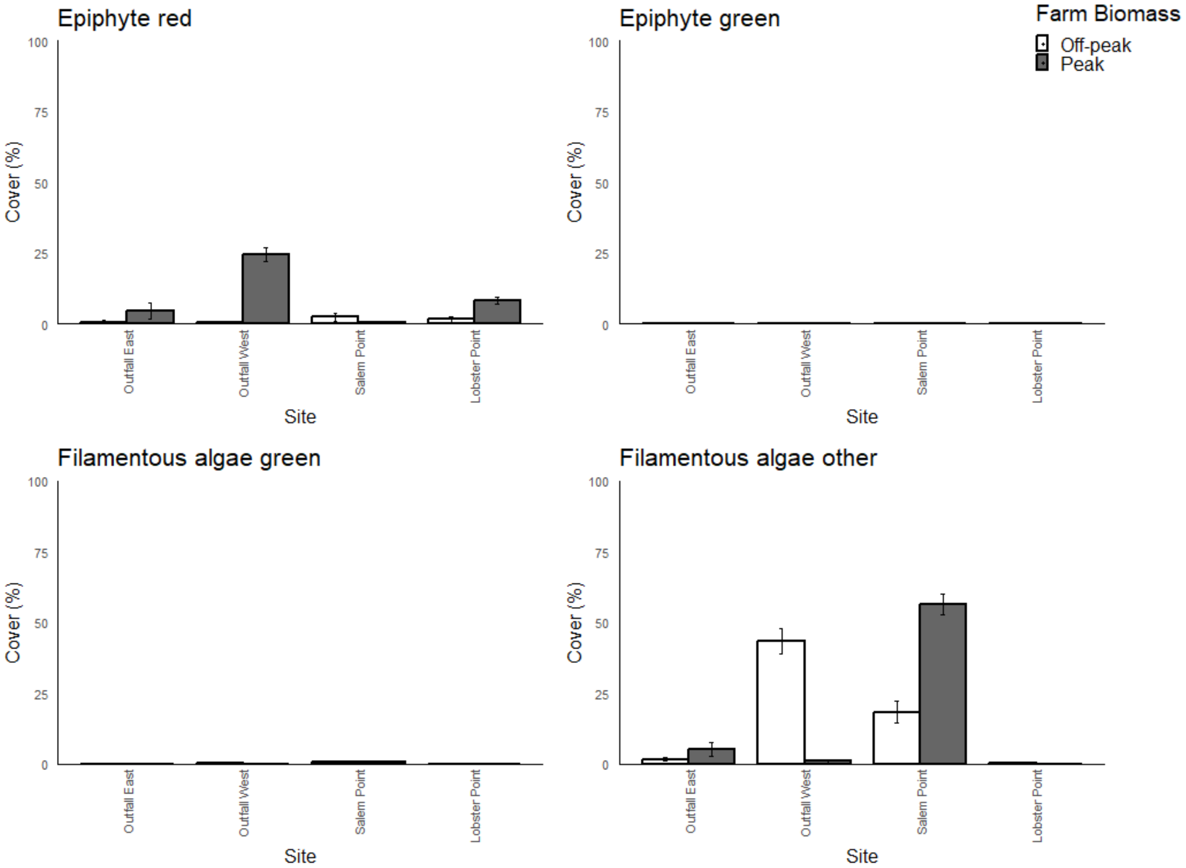


Figure 15: Percentage cover of functional groups relating to nutrient enrichment from the November 2023 (off-peak biomass) and May 2024 (peak biomass) shallow quadrat surveys in the Dunalley region.

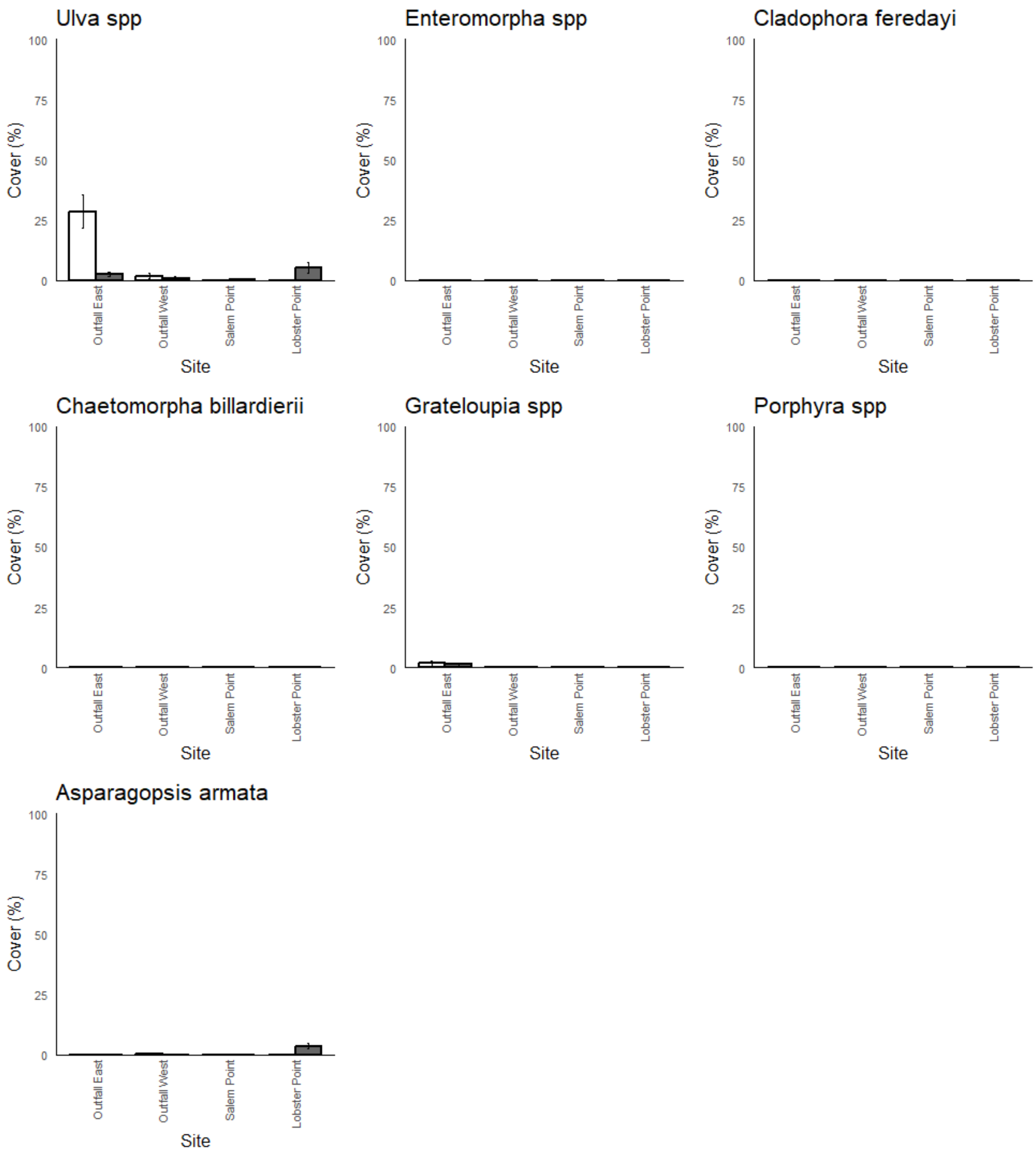


Figure 16: Percentage cover of nutrient indicator species from the November 2023 (off-peak) and May 2024 (peak) shallow quadrat surveys in the Dunalley region.

Clarence Point

Rapid visual assessment

The structure and function of reef communities surveyed in the Clarence Point region were generally typical of an estuary with strong tidal movement. Despite the environment around Clarence Point being relatively sheltered from wave exposure, canopy cover was over 60% for both surveys at the Outfall and 1 km North sites (Figure 17). Dominant canopy species across all sites were *Ecklonia radiata* and *Sargassum* spp., which is consistent with an estuary with strong water movement (Figure 18). The abundance of understorey macroalgae is indicative of a relatively high nutrient environment across the region, with understorey green algae being a feature at each site and understorey red algae being quite abundant across both surveys, particularly in comparison to understorey brown algae (Figure 17).

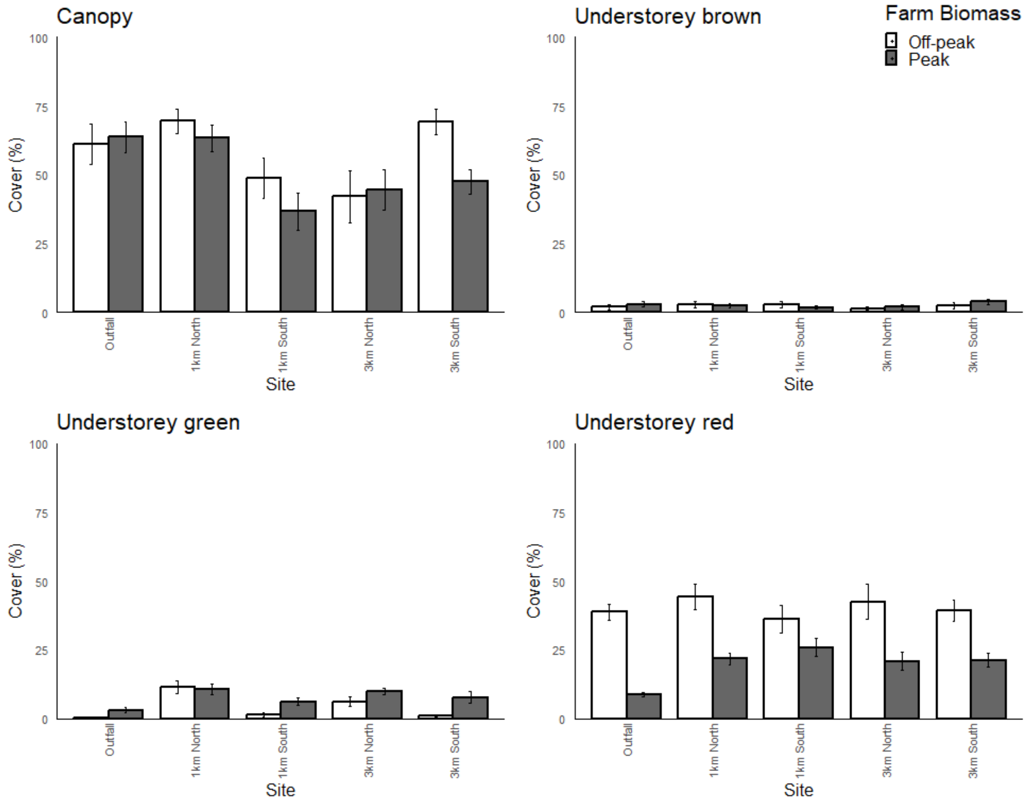


Figure 17: Percentage cover of major functional groups relating to canopy and understorey macroalgae in the Clarence Point region across both November 2023 (off-peak biomass) and April/May 2024 (peak biomass).

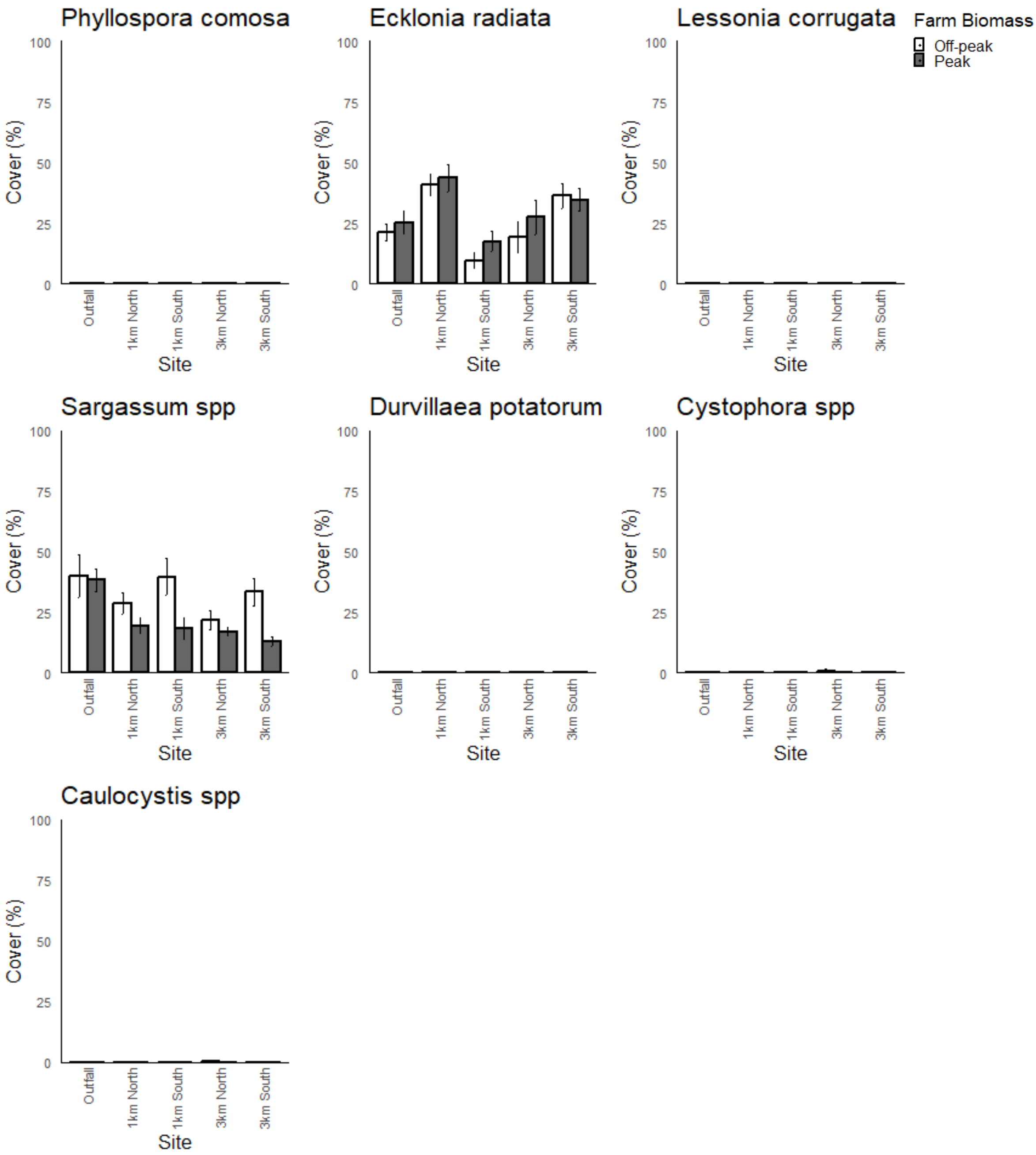


Figure 18: Percentage cover of the major canopy species of macroalgae in the Clarence Point region across both November 2023 (off-peak biomass) and April/May 2024 (peak biomass).

The enrichment parameters tended to be elevated across the region, with epiphytic algae, filamentous algae and nuisance green algae present at nearly all sites and surveys (Figure 19). The highest percentage cover (47.5 ± 6%) of epiphytic algae was recorded at the Outfall site during the April/May (peak biomass) survey, with this value considerably higher than for all other sites during this survey (≤ 25% cover). Elevated cover of epiphytic algae (44.2 ± 6.9%)

was also observed at 3 km North in the November 2023 (off-peak) survey (Figure 19). Nuisance green algae was present at all sites and surveys, indicating a relatively high nutrient environment across the estuary. At the Outfall site, *Chaetomorpha billardierii* was the dominant nuisance green algae species, whereas at all other sites, *Ulva* spp. or a mixed assemblage were more common.

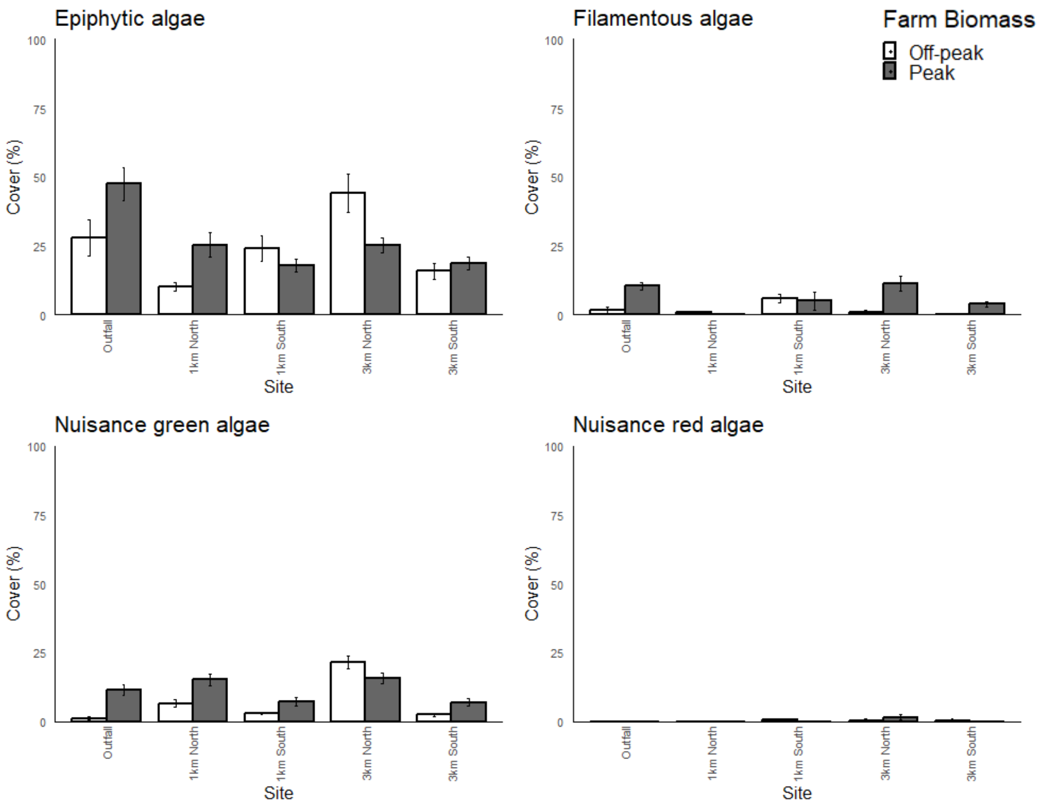


Figure 19: Percentage cover of nutrient enrichment parameters in the Clarence Point region across November 2023 (off-peak biomass) and April/May 2024 (peak biomass).

There were no discernible trends in substrate parameters across the Clarence Point region. Turfing algae was observed in relatively high abundance across all sites, likely due to the lower wave exposure in the Tamar estuary (Figure 20).

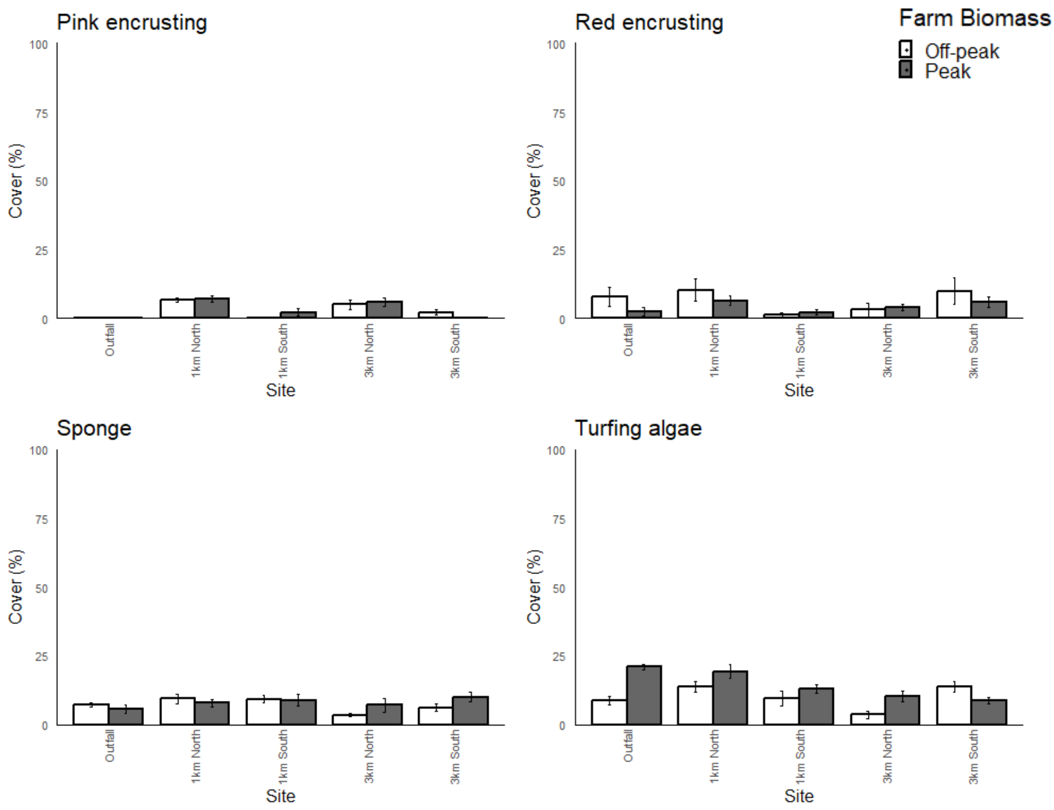


Figure 20: Percentage cover of substrate parameters in the Clarence Point region across November 2023 (off-peak biomass) and April/May 2024 (peak biomass).

Shallow quadrat survey

Data from the shallow quadrat surveys was highly variable across sites and surveys, reflecting the dynamic nutrient regime of the Tamar estuary. Considerable variability was observed between macroalgae and seagrass cover between the two surveys, particularly seagrass (*Heterozostera* spp.) at 1 km North, which was considerably higher in cover during the April/May 2024 survey when compared with the November 2023 survey (Figure 21).

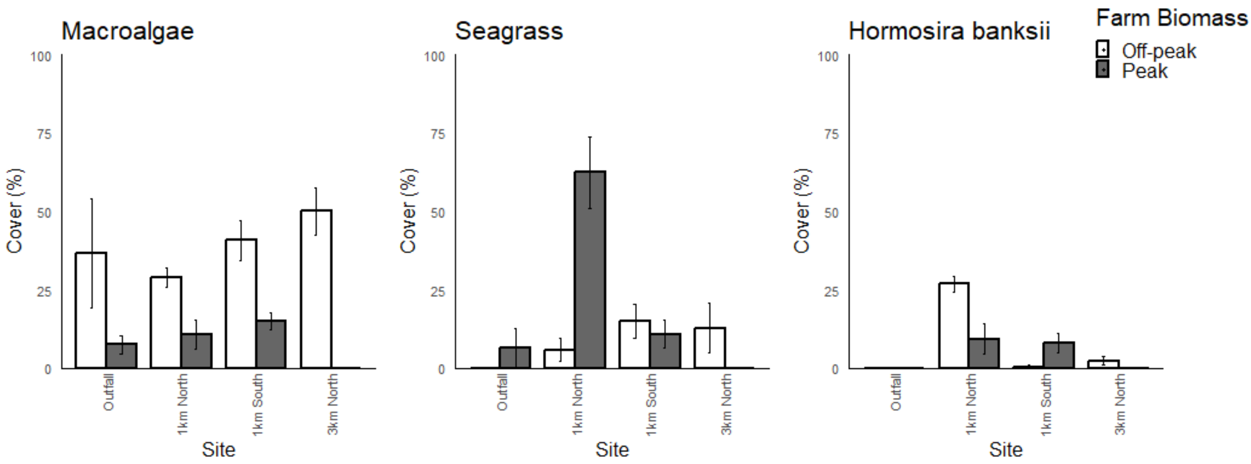


Figure 21: Percentage cover of foundation species/taxa from the November 2023 (off-peak biomass) and April/May 2024 (peak biomass) shallow quadrat surveys in the Clarence Point region.

Filamentous algae was common around the Outfall site during both surveys, averaging 52.5 ± 12% cover in November 2023 and 36.6 ± 9.4% in April/May 2024 (Figure 22). At the 1 km North and 1 km South sites in April/May 2024, filamentous algae was also in high abundance (63.3 ± 5.7% and 73.8 ± 3.7% at both sites, respectively), indicating the likely effects of a more regional nutrient stimulus driving growth during this survey period (Figure 22). For the nutrient indicator species, no trends were observed relating to distance from the discharge point (Figure 23). In general, these species were more common throughout the estuary in November 2023 than in April/May 2024 (Figure 23).

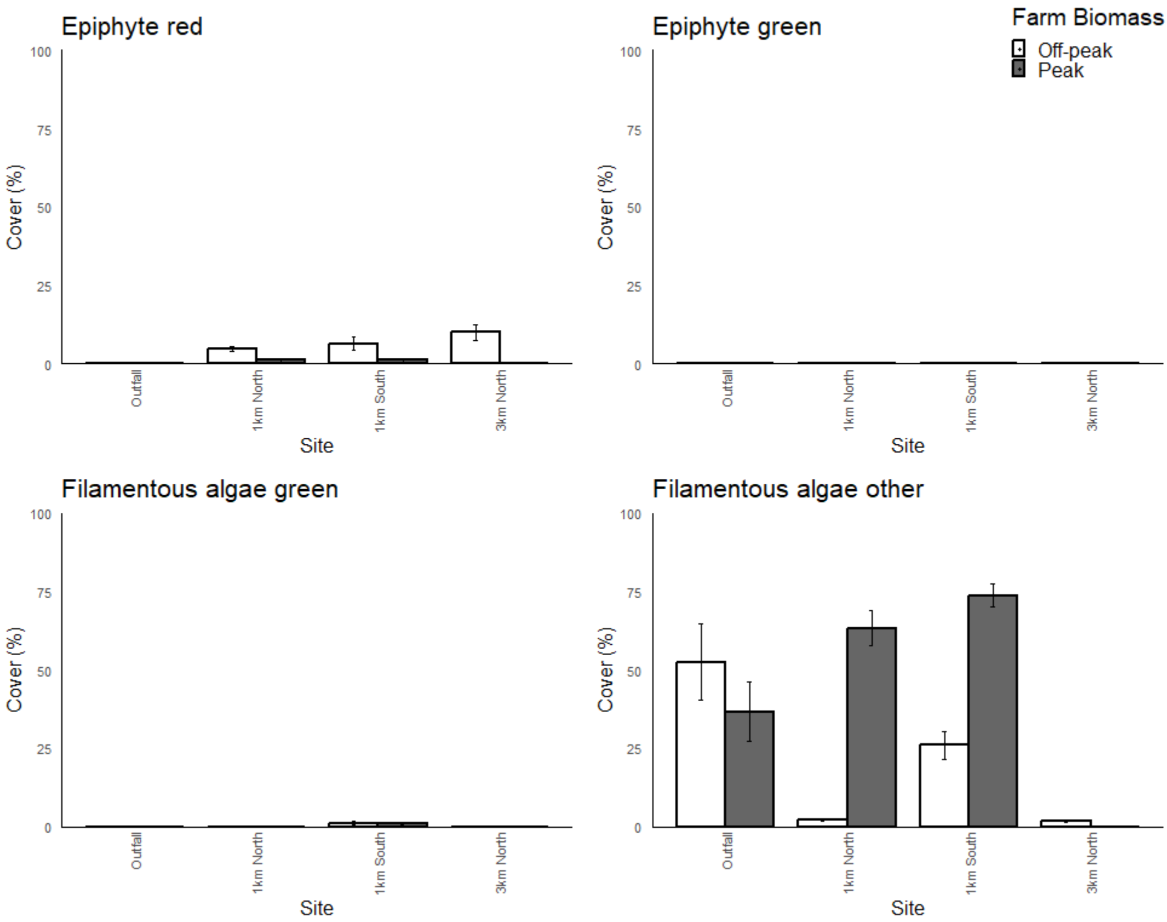


Figure 22: Percentage cover of functional categories relating to nutrient enrichment from the November 2023 (off-peak biomass) and April/May 2024 (peak biomass) shallow quadrat surveys in the Clarence Point region.

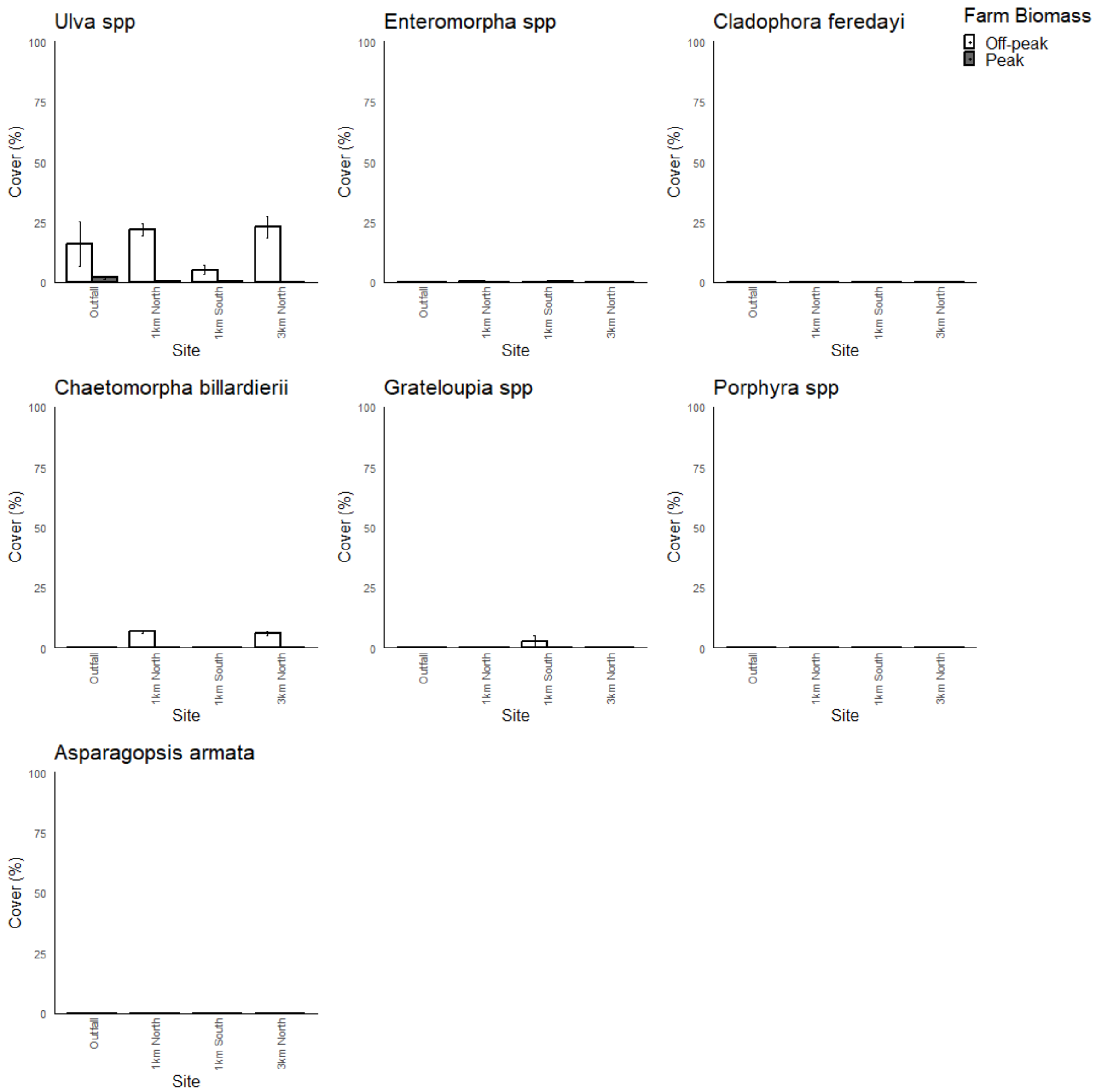


Figure 23: Percentage cover of nutrient indicator species from the November 2023 (off-peak biomass) and April/May 2024 (peak biomass) shallow quadrat surveys in the Clarence Point region..

Bicheno

Rapid visual assessment

The structure and function of reef communities in the vicinity of the Yumbah Aquaculture abalone farm at Bicheno were typical of a high-energy site in Tasmania. Average canopy cover across both surveys was typically high (>70% for at least one or both surveys) and dominated by *Phyllospora comosa* and *Ecklonia radiata* (Figure 24, Figure 25). In contrast, percentage cover of understorey brown and green algae was low, with understorey red algae the dominant understorey functional group (Figure 24). While blade length was not quantified as part of this study, the *P. comosa* was observed to be exceptionally tall (approximately 2-3 m) at both the outfall and 500 m sites and carried a higher biomass than the 5 km+ sites per plant.

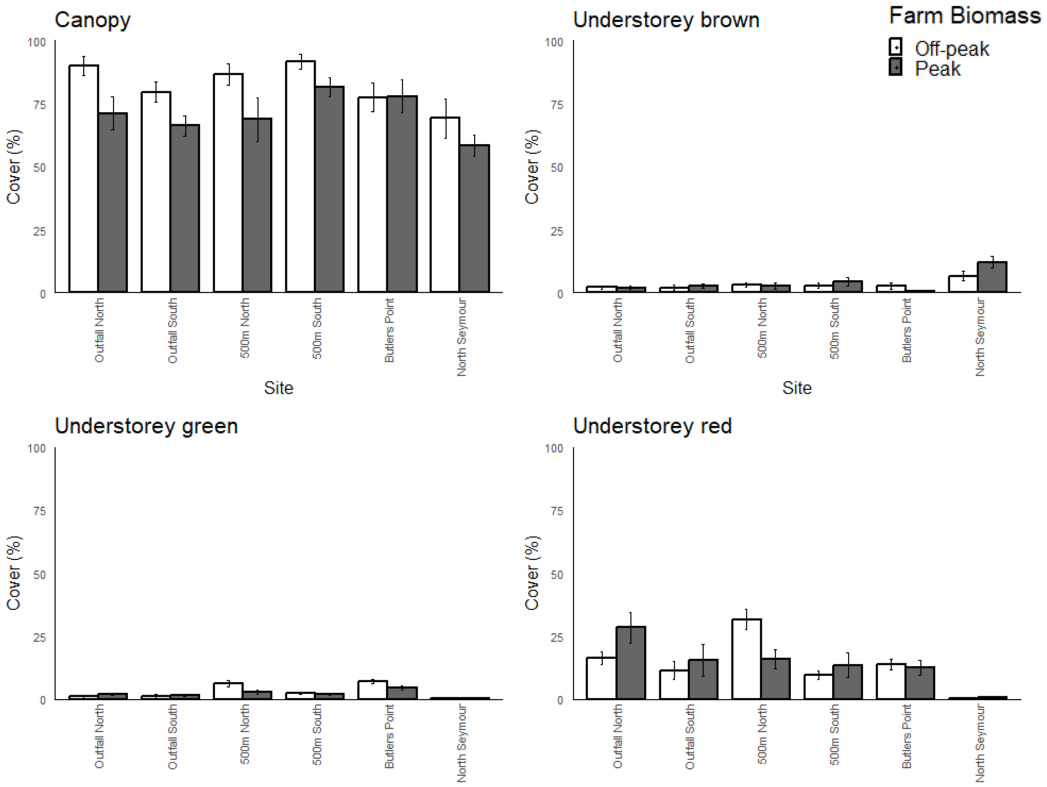


Figure 24: Percentage cover of major functional groups relating to canopy and understorey macroalgae in the Bicheno region across both December 2023 (off-peak biomass) and July/August 2024 (peak biomass).

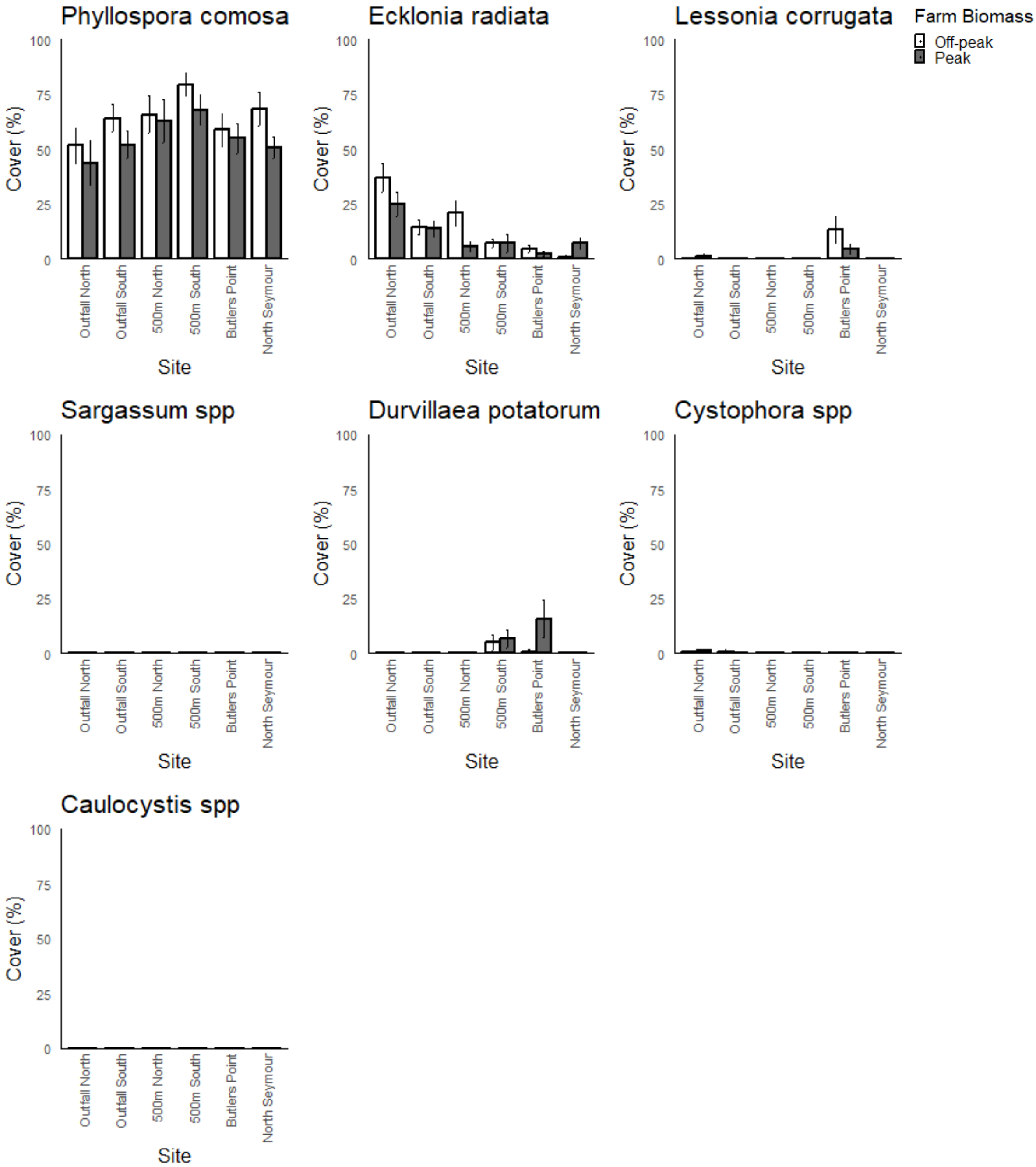


Figure 25: Percentage cover of the major canopy species of macroalgae in the Bicheno region across both December 2023 (off-peak biomass) and July/August 2024 (peak biomass).

The Bicheno region was characterised by very low cover of nutrient enrichment parameters (Figure 26). Epiphytic algae was only observed in any significant abundance at the Butlers Point site, which was >5 km from the discharge point. Neither epiphytic, filamentous or nuisance red algae were observed at either outfall site, although a very small amount of nuisance green algae was present during the July/August 2024 sampling period at Outfall South (Figure 26).

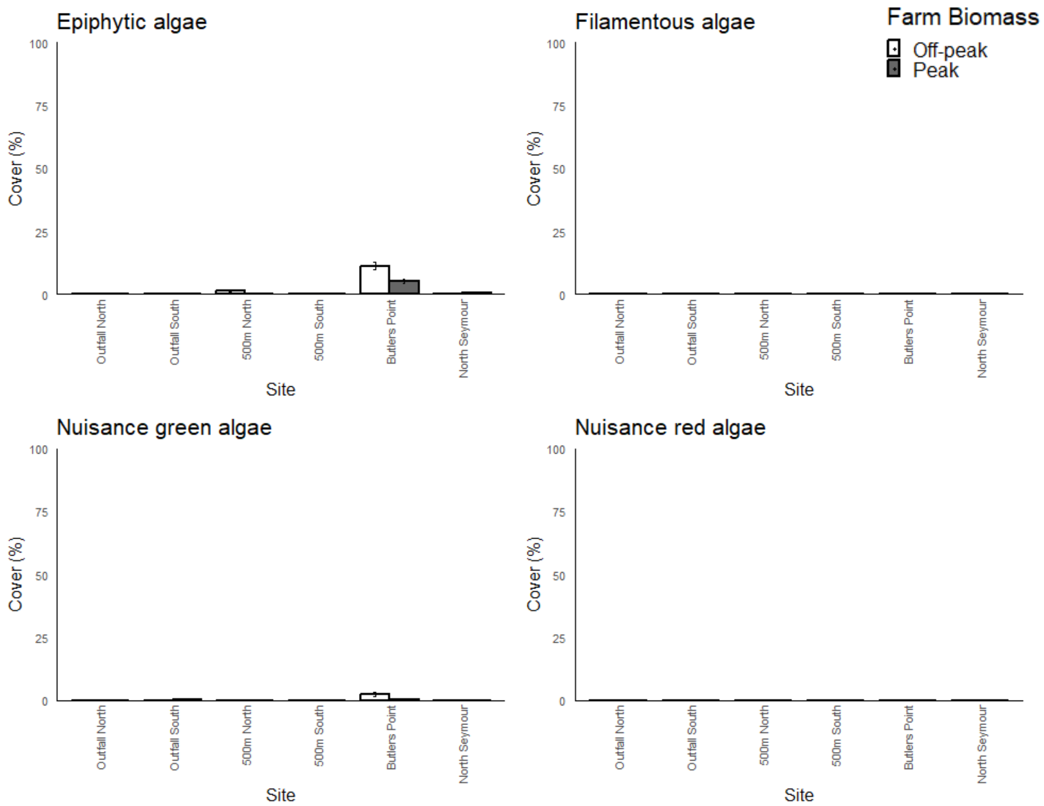


Figure 26: Percentage cover of nutrient enrichment parameters in the Bicheno region across December 2023 (off-peak biomass) and July/August 2024 (peak biomass).

There were no discernible trends in substrate parameters across the Bicheno region. Pink encrusting algae was relatively abundant across all locations and is likely a reflection of the high wave exposure environment in this region (Figure 21).

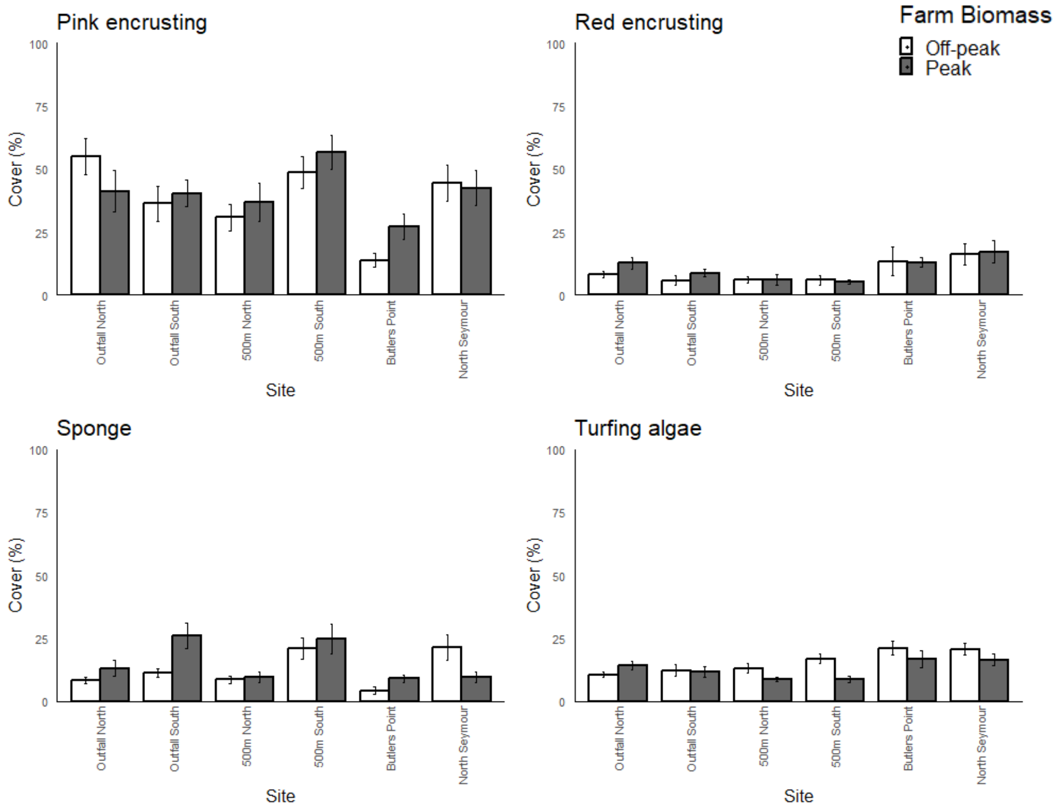


Figure 27: Percentage cover of substrate parameters in the Bicheno region across December 2023 (off-peak biomass) and July/August 2024 (peak biomass).

Stanley

Rapid visual assessment

The capacity to undertake rapid visual assessments of reef communities in the Stanley region was confounded by the patchiness of reef habitat. Where assessments were possible, sites were very similar in terms of structure and function across the region. Canopy cover was most abundant at the Outfall site, averaging more than 75% cover for both surveys (Figure 28). The canopy at all sites was dominated by *E. radiata* along with a diverse array of species from the genera *Cystophora* and *Sargassum* (Figure 29), which is typical of semi-sheltered reef systems in north-west Tasmania.

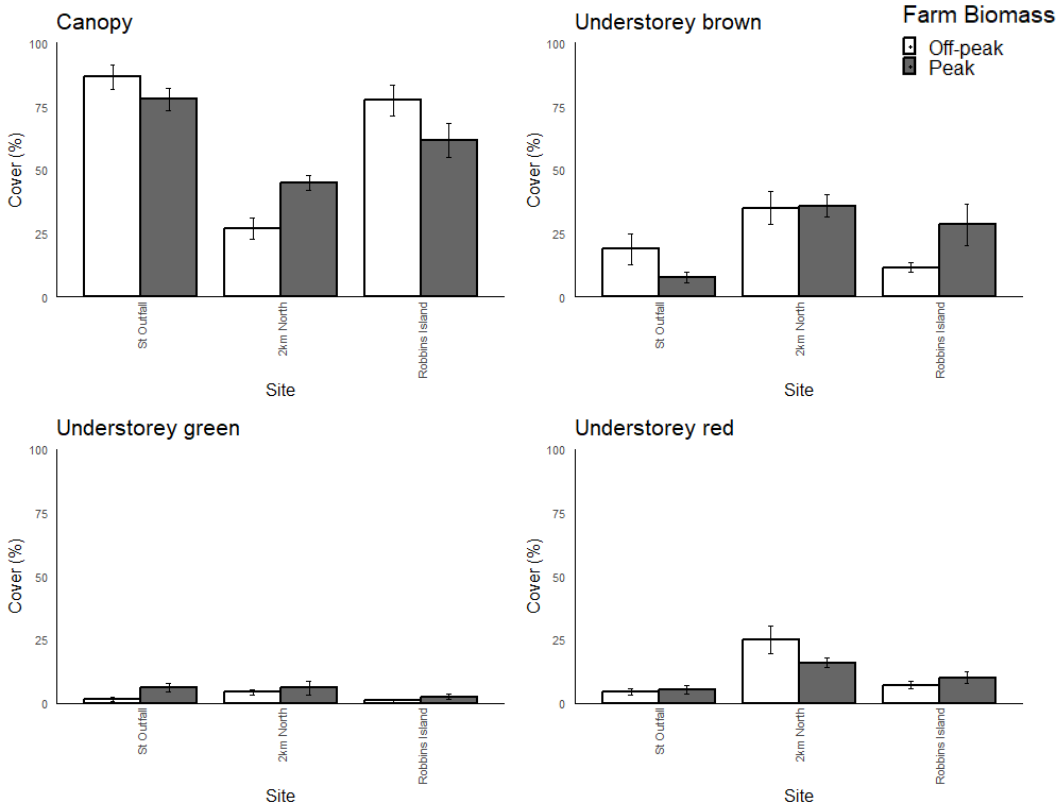


Figure 28: Percentage cover of major functional groups relating to canopy and understorey macroalgae in the Stanley region across both November 2023 (off-peak biomass) and August 2024 (peak biomass).

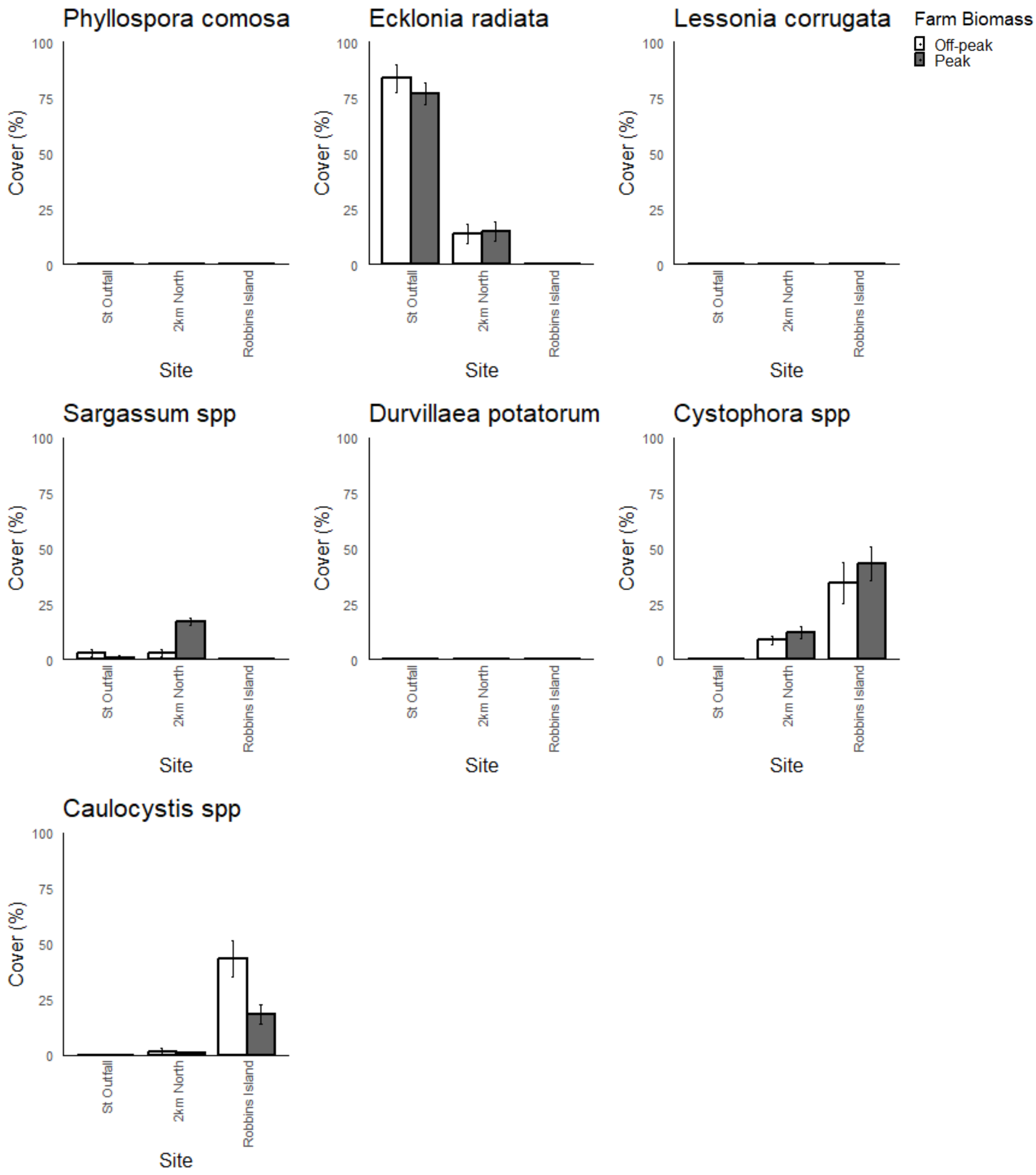


Figure 29: Percentage cover of the major canopy species of macroalgae in the Stanley region across both November 2023 (off-peak biomass) and August 2024 (peak biomass).

Of the enrichment parameters, epiphytic algae only occurred at low abundances (<15% cover) but was still a regular feature across all sites within the region (Figure 21). Filamentous, nuisance green and nuisance red algae were present in very low abundances (generally <2% cover) at both the Outfall and 2 km North sites across both surveys (Figure 21).

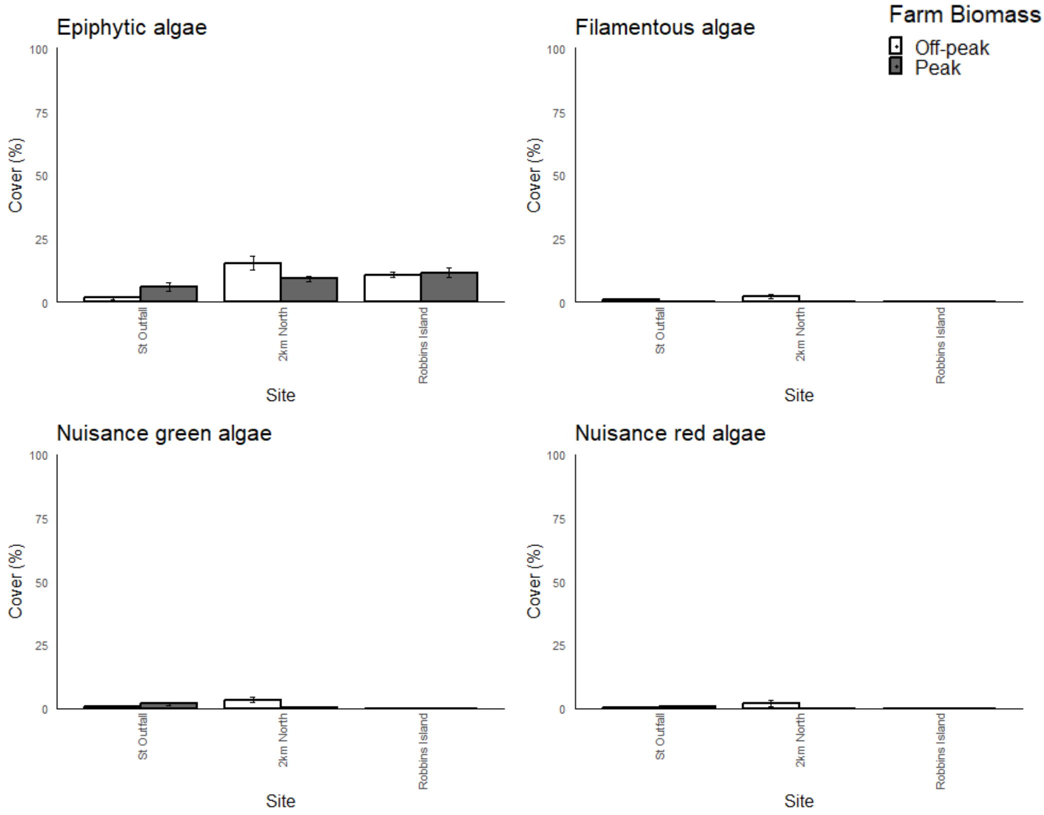


Figure 30: Percentage cover of nutrient enrichment parameters in the Stanley region across November 2023 (off-peak biomass) and August 2024 (peak biomass).

Red encrusting algae (both surveys), sponge (both surveys) and turfing algae (August 2024 survey) were generally elevated (approximately 20% cover) at the Outfall site compared to 2 km North and Robbins Island (Figure 25). Pink encrusting algae was lower (<5%) at the Robbins Island site in comparison to Outfall (25-30%) and 2 km North (20-25%), respectively (Figure 25).

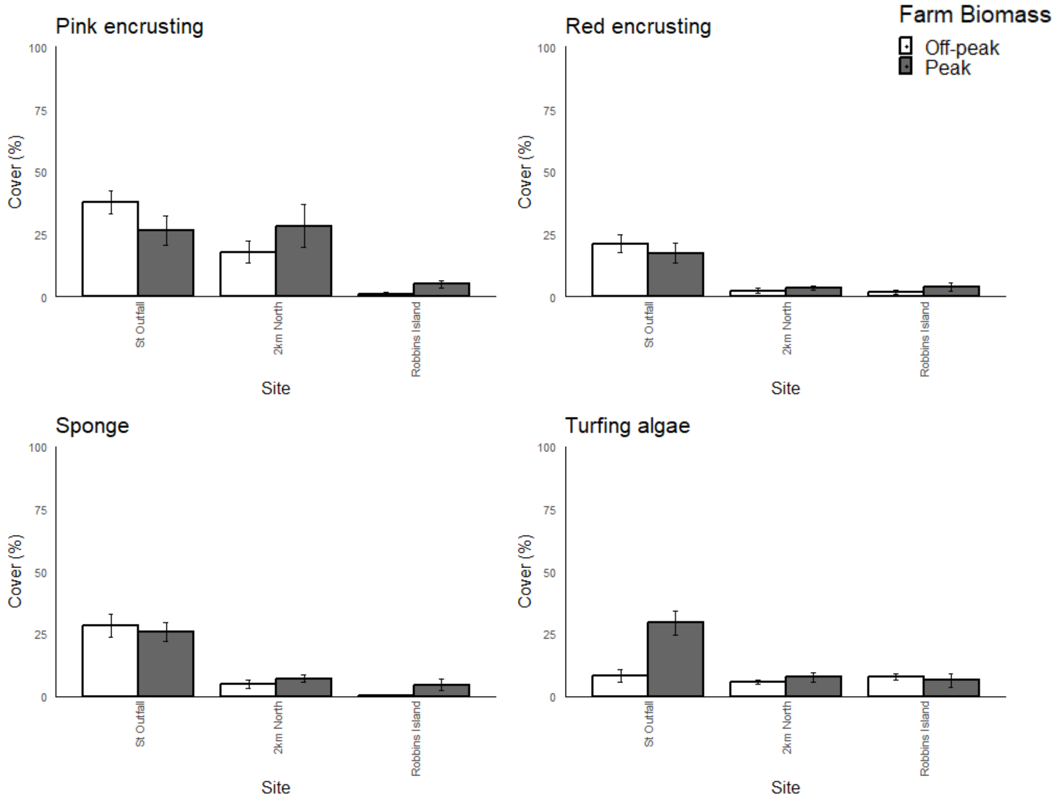


Figure 31: Percentage cover of substrate parameters in the Stanley region across November 2023 (off-peak biomass) and August 2024 (peak biomass).

Shallow quadrat survey

The shallow quadrat survey results highlight the ecological complexity of the receiving environment across the region. Macroalgae and seagrass cover was highly variable between site and survey at both the Outfall and 2 km North sites (Figure 32). Red and green epiphytic algae were observed in higher abundance at the Outfall site compared to other sites in November 2023, while filamentous algae was elevated across both Outfall (7.5 ± 1.6%) and 2 km North (6.58 ± 1.8) relative to Robbins Island (0.92 ± 0.5%) during the same survey (Figure 33). In August 2024, epiphytic and filamentous algae were observed in much lower abundances (Figure 33).

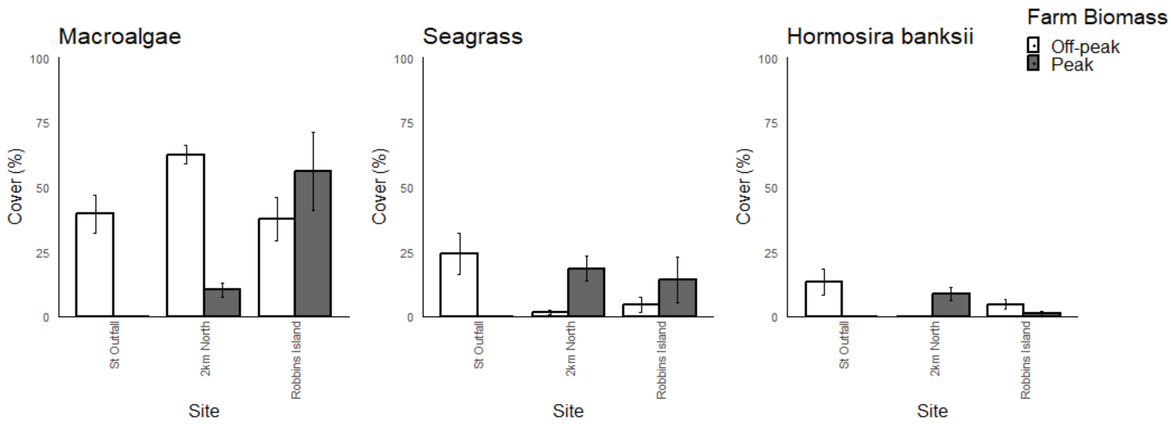


Figure 32: Percentage cover of foundation species/taxa from the November 2023 (off-peak) and August 2024 (peak) shallow quadrat surveys in the Stanley region.

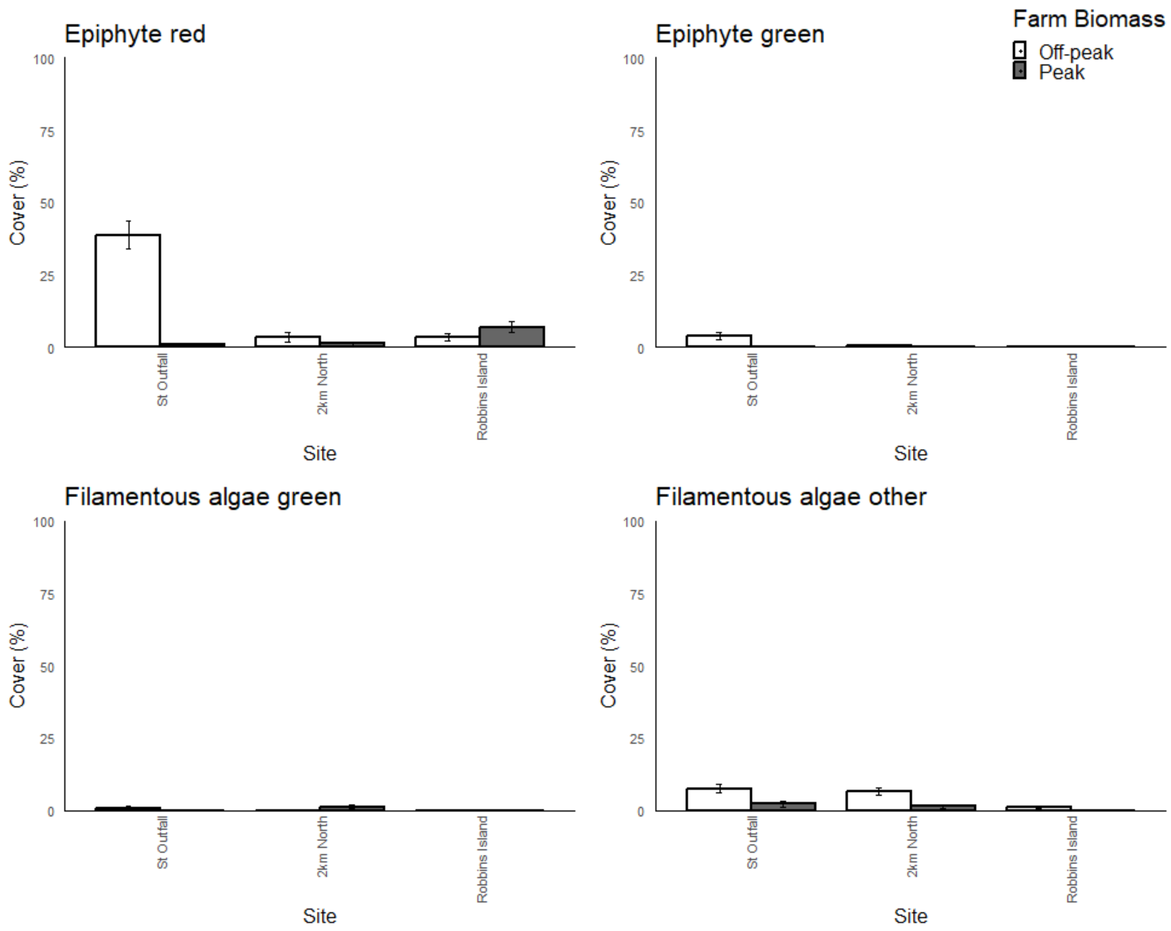


Figure 33: Percentage cover of functional categories relating to nutrient enrichment from the November 2023 (off-peak biomass) and August 2024 (peak biomass) shallow quadrat surveys in the Stanley region.

Several nutrient indicator species were elevated at the Outfall site compared to the other sites (Figure 34). *Ulva* spp. at the Outfall site was elevated across both November 2023 (7.67 ± 2.3%) and August 2024 (11.82 ± 4.23%) surveys compared to Robbins Island (0%; Figure 34). *Enteromorpha* spp. (15.64 ± 3.95%) and *Porphyra* spp. (16.55 ± 6.5%) were present in moderate abundances at the Outfall site compared to Robbins Island during the August survey only (Figure 34). No other nutrient indicator species were observed in either survey.

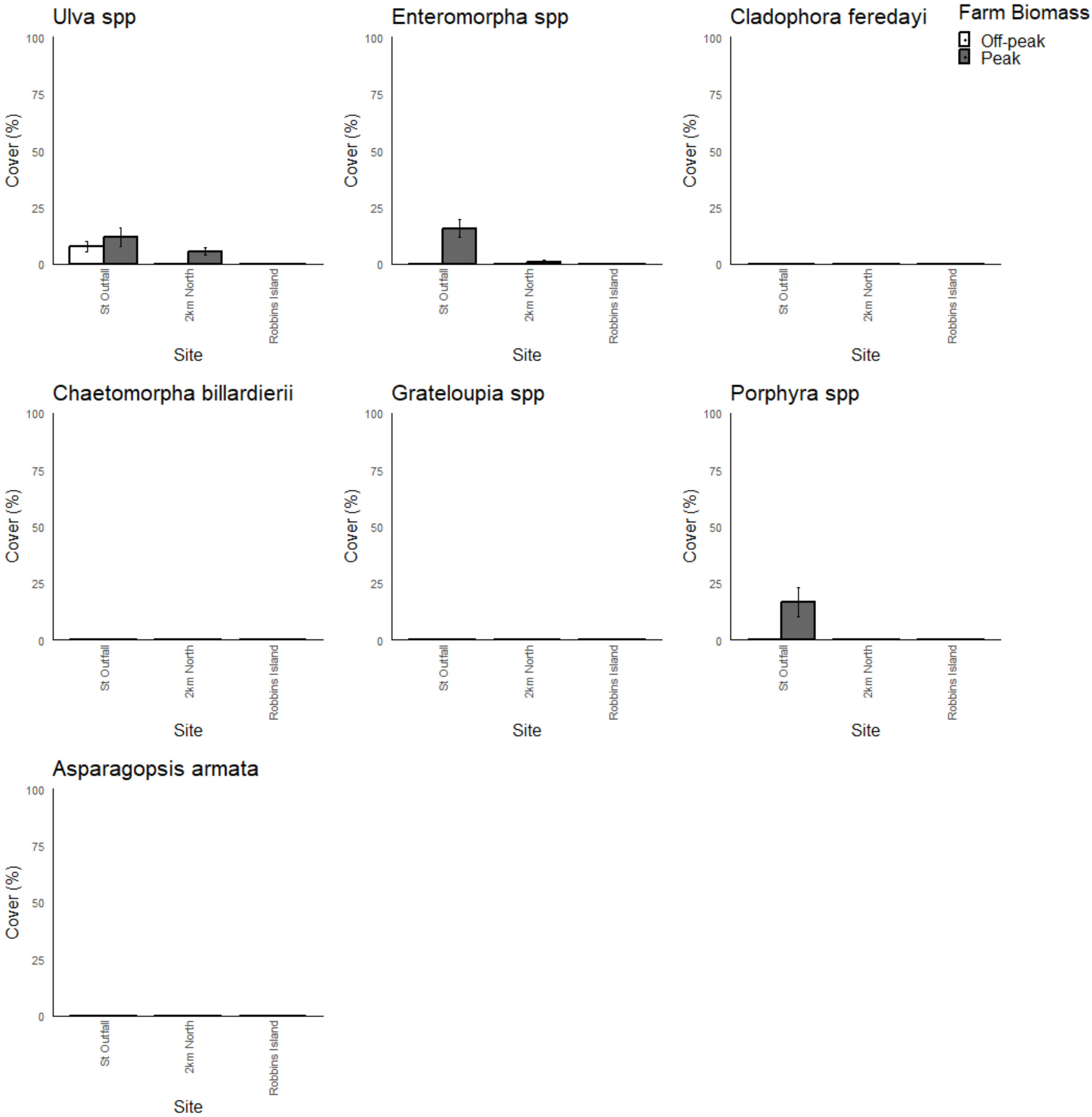


Figure 34: Percentage cover of nutrient indicator species from the November 2023 (off-peak biomass) and August 2024 (peak biomass) shallow quadrat surveys in the Stanley region.

Towed video

Dense seagrass was observed at each of the three sites, with these communities often spatially complex over small areas and supporting a wide range diversity in epiphytic flora and fauna. Total seagrass cover was highest at the Outfall site (96.25 ± 0.80% for November 2023, 76.26 ± 6.40% for August 2024), followed by Robbins Island (57.85 ± 2.27% in November 2023 and 81.55 ± 3.88% in August 2024) (Figure 35). *Posidonia australis* was the dominant seagrass present at Outfall, while *Amphibolis antarctica* dominated at both 2 km North and Robbins Island. Both *Halophila* spp. and *Zostera*/*Heterozostera* spp. were present at Robbins Island only, however at very low abundance. The percentage cover of epiphytic and filamentous algae growing on either seagrass or macroalgae was relatively low (<20%) across all three sites in the Stanley region, with no consistent seasonal differences between the November 2023 and August 2024 surveys (Figure 36). Filamentous brown and red algae were the most common nutrient indicator groups recorded at both 2 km North and Robbins Island. Cover of the nutrient indicator species *Asparagopsis armata*, *Chaetomorpha* spp. and *Ulva* spp. were minimal across all sites and surveys.

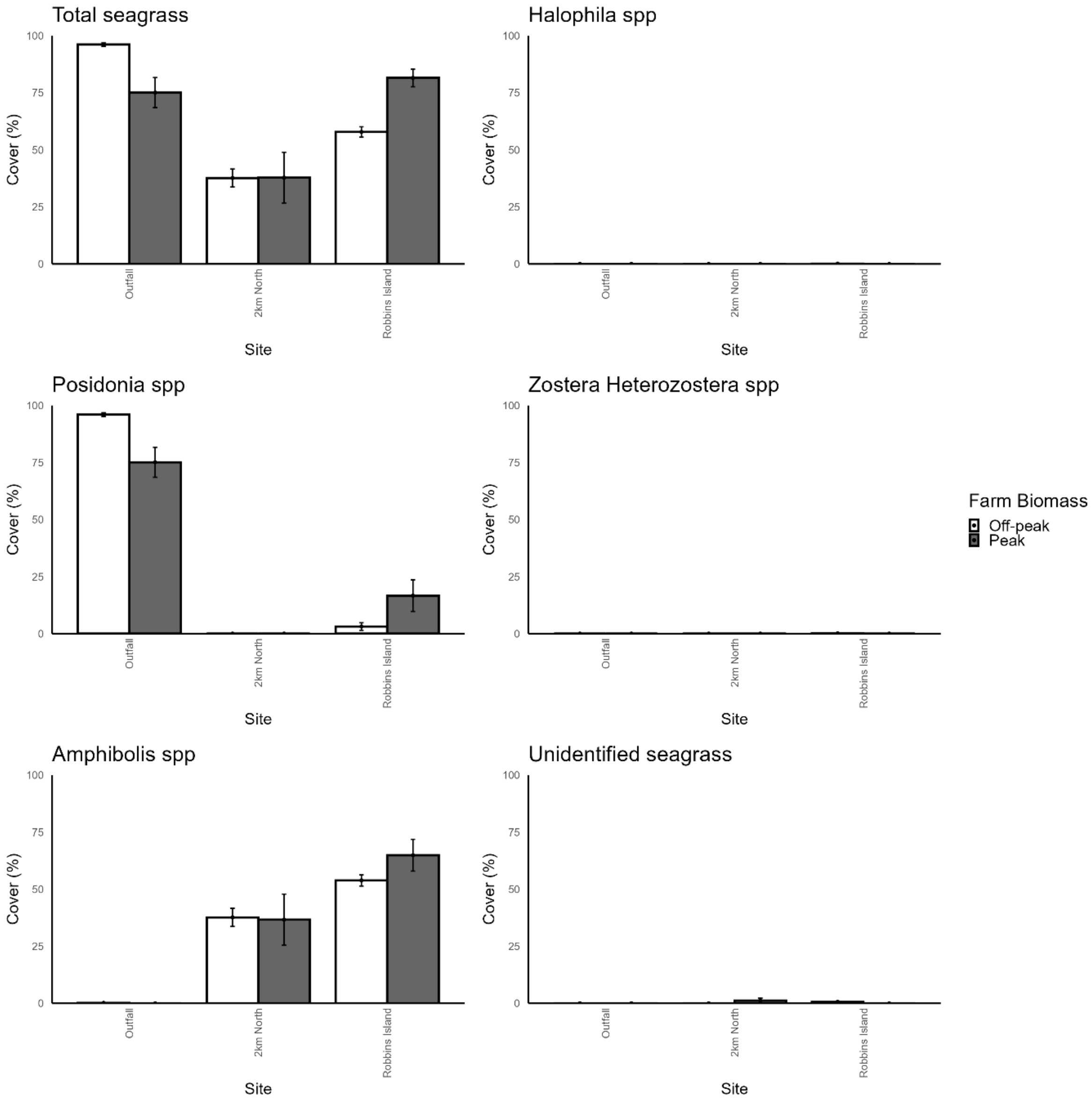


Figure 35: Percentage cover of seagrass species recorded during towed video transects in both the November 2023 (off-peak biomass) and August 2024 (peak biomass) surveys in the Stanley region.

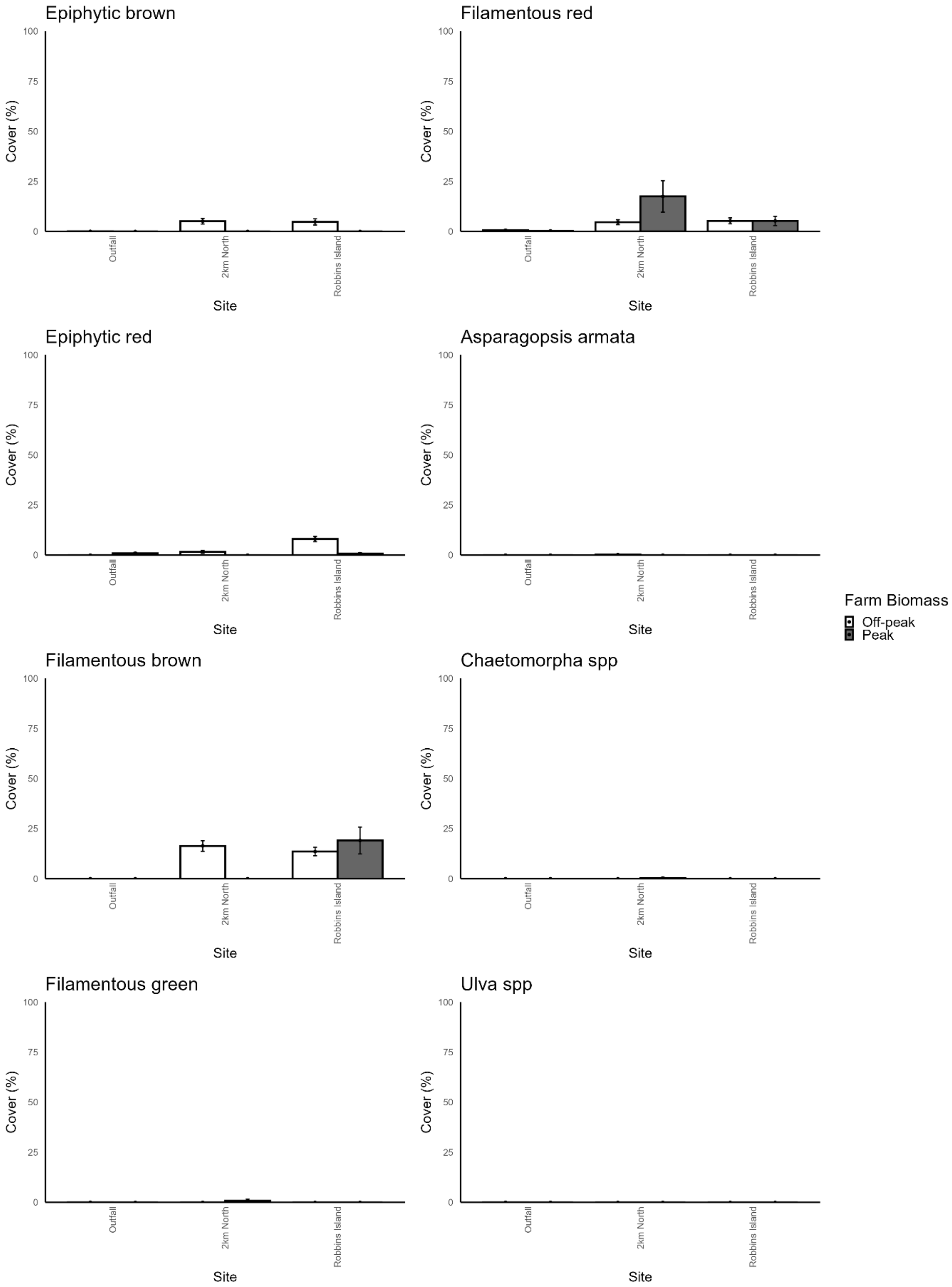


Figure 36: Percentage cover of epiphyte species/groups recorded during towed video transects in both the November 2023 (off-peak biomass) and August 2024 (peak biomass) surveys in the Stanley region.

Abalone surveys

Dunalley

Abalone abundance and morphotype

Abalone were found at the outfall site in both surveys, although all abalone observed during the November 2023 survey were classified as the blackfoot/blackshell (BB) morphotype (Figure 37). BB morphotype abalone found at the outfall site had some morphological irregularities and are possibly backcrosses from historic escape events, although this cannot be said with certainty based on morphological evaluation alone. While a conservative approach was adopted and these abalone were classified as BB morphology, crossbreeding between wild and escaped farm animals cannot be conclusively ruled out based on visual surveys. In May 2024, farm morphotype abalone (FA) were also found at the outfall site, both on the transect swim (n = 1) and through a direct search at the discharge point of the outfall pipe (n = 15; Figure 37, Figure 38). All abalone at sites beyond the outfall were BB morphotypes across both surveys. Size distribution of BB abalone was generally in the 120-150 mm range across all sites, although the population at Carlton Bluff was generally smaller than that observed inside Frederick Henry Bay. The FA abalone from the outfall site were generally smaller (70-80 mm).

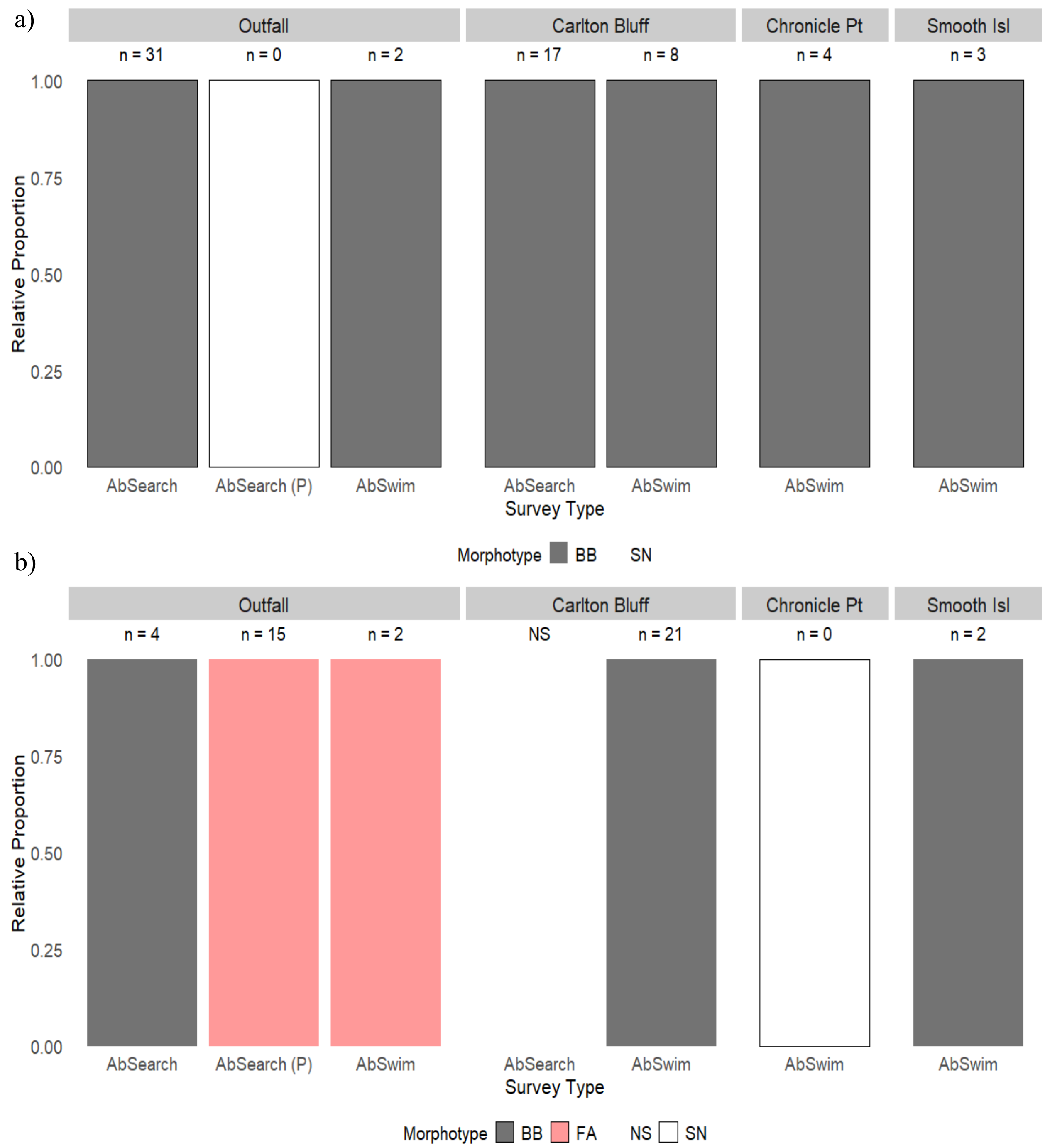


Figure 37: Abundance of abalone and the relative proportion of morphotype found in the Dunalley region during abalone swims and searches across a) November 2023 (off-peak biomass) and b) May 2024 (peak biomass), BB = Blackshell/blacklip, FA = Farm origin, NS = Not surveyed, SN = Surveyed, not found.

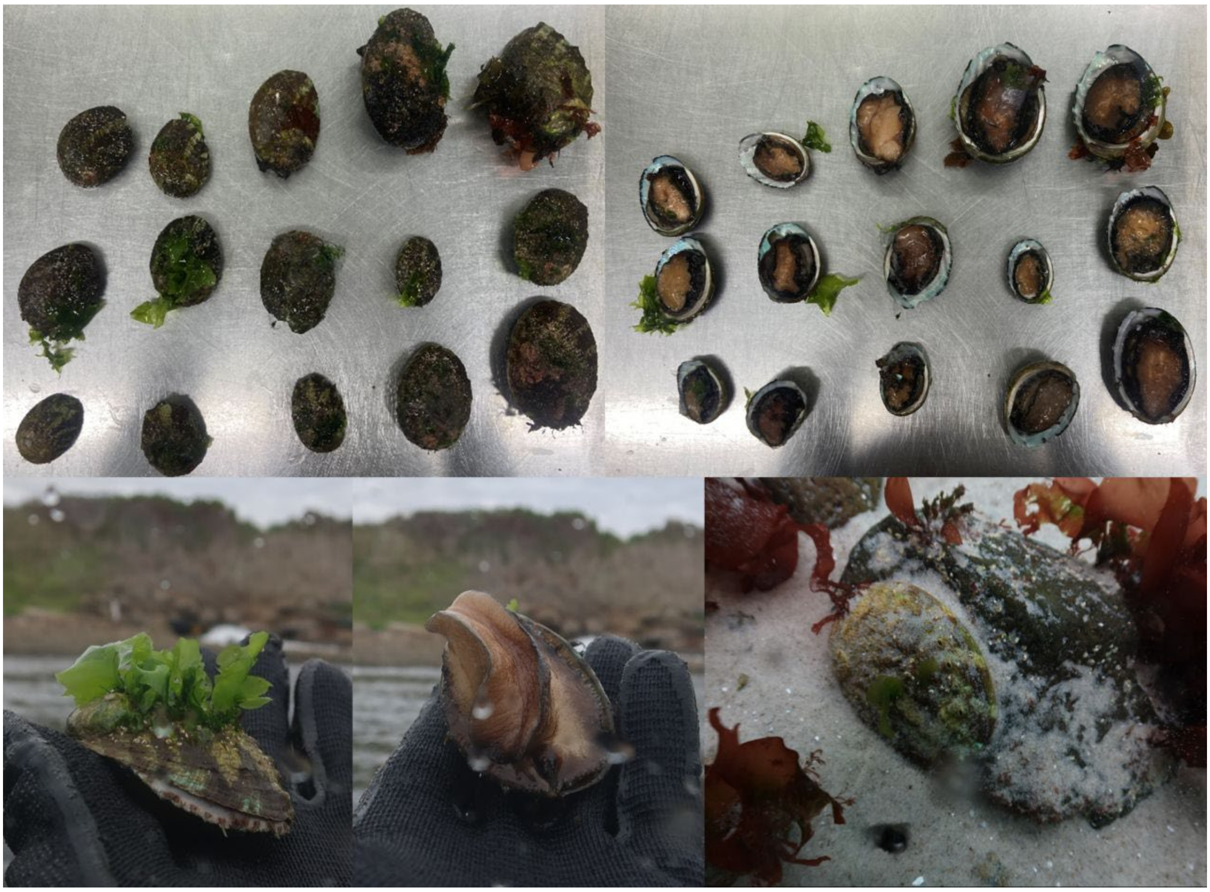


Figure 38. Farmed abalone collected from the subtidal zone in the vicinity of the Jade Tiger Abalone farm at Dunalley in May 2024.

Shore walk

No live or recently deceased abalone were detected during the shore walk at the outfall, however, shells that were of farm origin (FA morphology) were found during both the November 2023 and May 2024 intertidal surveys (Figure 39).

Figure 39: Abalone shells recovered from the shoreline in the vicinity of the Jade Tiger Abalone farm at Dunalley from November 2023 and May 2024.

Clarence Point

Abalone abundance and morphotype

While four sites were surveyed for abalone in the Clarence Point region, Greens Beach was the only site where they were located (Figure 40). The majority of abalone found at Greens Beach were of the BB morphotype, although one abalone from the November 2023 survey was of the blackshell/greenlip (BG) morphology (Figure 40). One abalone (BB morphology) was found on an RVA transect at Simmon's Mistake but is not included in the data presented below. The nearest consolidated reef to the outfall site was approximately 400 m to the south. This site was observed to have high sedimentation on the reef and no abalone were observed during either survey. The subtidal substrate at the discharge point was observed to be small rock/large cobble interspersed with sand. While this area was inspected during this project, the cryptic habitat was not extensively searched. During a subsequent search of the cryptic habitat at the discharge point by NRE Fisheries Officers on 19 August 2024, four farm-origin abalone were found in this habitat (NRE, pers comm.).

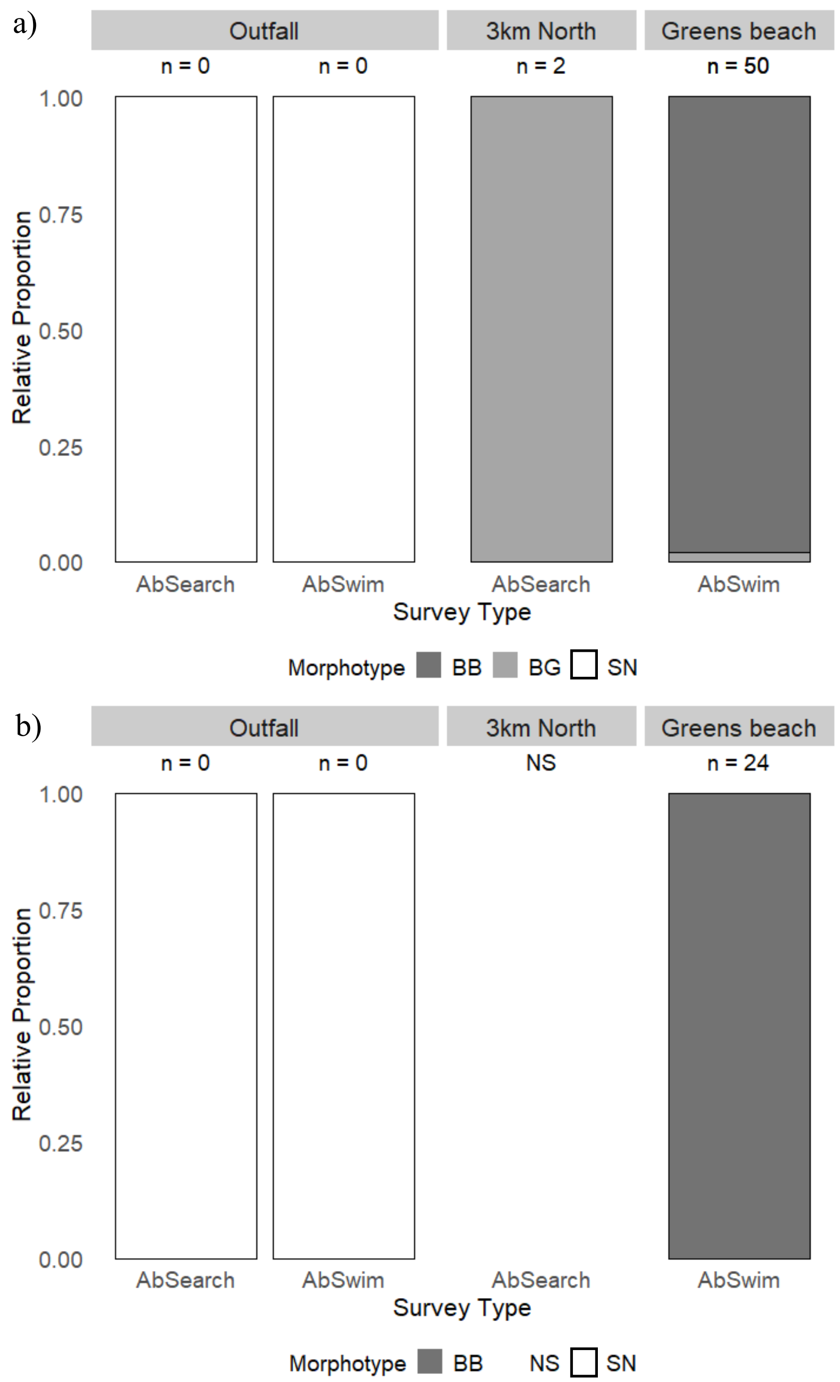


Figure 40: Abundance of abalone and the relative proportion of morphotypes found in the Clarence Point region during abalone swims and searches across a) November 2023 (off-peak biomass) and b) April/May 2024 (peak biomass), BB = black shell/black lip, NS = Not surveyed, SN = Surveyed, not found.

Shore walk

No live or recently deceased abalone were detected during the shore walk at the outfall site, however, shells of farm origin (FA morphology) that contained a small amount of residual abalone flesh were observed. Wildlife interactions with these shells were observed during surveys. There were also numerous empty shells of varying ages along the beach in the vicinity of the outfall (Figure 41).

Figure 41: Abalone shells recovered from the shoreline in the vicinity of the Abtas abalone farm at Clarence Point from November 2023 and April/May 2024.

Bicheno

Abalone abundance and morphotype

Abalone were observed at all sites across both surveys in the Bicheno region (Figure 42). Abalone of farm origin (FA) were observed at the outfall site during the July/August 2024 survey, primarily in cryptic habitat adjacent to the northern outfall site (old nursery outfall) (Figure 42, Figure 43). Of note, the area directly at the discharge point of the main southern drain was inaccessible during both survey periods due to adverse weather conditions and therefore was not surveyed and the presence or absence of abalone from this location cannot be determined. Where transects were performed, abalone were more abundant on the shallow transect compared with the deep transect and were more abundant in July/August 2024 compared with December 2023. Abalone of the BB morphotype at the outfall site were generally >90 mm, whereas abalone of FA morphology were smaller (<60mm). In terms of control sites, abalone were particularly abundant at North Seymour, covering a large size range, from cryptic and newly emergent animals <50 mm to 170-180 mm abalone (Figure 42, Figure 43).

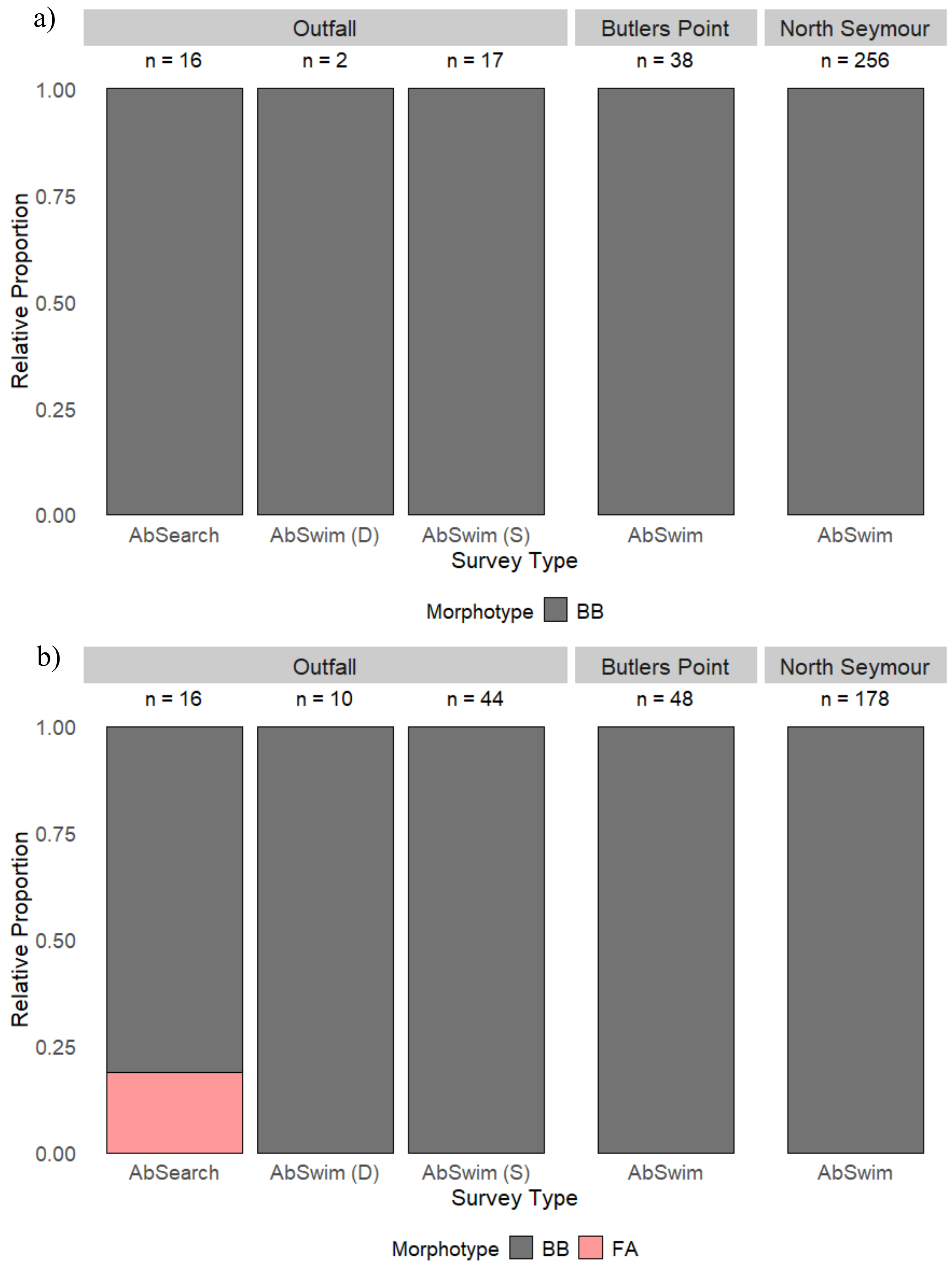


Figure 42: Abundance of abalone and the relative proportion of morphotype found in the Bicheno region during abalone swims and searches across a) December 2023 (off-peak biomass) and b) July/August 2024 (peak biomass), BB = Blackshell, blacklip, FA = Farm morphology.

Figure 43: Farmed abalone collected from the subtidal zone in the vicinity of the Yumbah Aquaculture abalone farm at Bicheno in August 2024.

Shore walk

No live or recently deceased abalone were detected during the shore walk at the outfall site, however, shells of farm origin (FA morphology) approximately 10-20 mm in size were observed at the northern outfall pipe (Figure 44). This outfall is associated with the decommissioned nursery area on site, with escapees detected here historically during compliance inspections. Several shells of farm origin were also found washed up on the beach 700 m north of the farm. Of interest, there was a high abundance of nutrient indicator species such as *Ulva* spp. and *Grateloupia turuturu* present within the outfall pipes.

Figure 44: Abalone shells recovered from the shoreline in the vicinity of the Yumbah Aquaculture abalone farm at Bicheno in July 2024

Stanley

Abalone abundance and morphology

Abalone were highly abundant across the Stanley region, covering a large array of morphotypes, including both BG (blackshell/greenlip) and GB (greenshell/blacklip) hybrids (Figure 31). Identification into one of the five morphotype categories was at times problematic, with a large degree of morphological diversity observed (Figure 32). While abundant across the region, abalone were most prolific at Robbins Island, where morphology was mainly split between BB, GG and GB morphotypes (Figure 31). Abalone of FA morphology were observed at the discharge point within the cobble/loose reef. These abalone included both cryptic (<50 mm) and emergent (>60 mm) individuals, which were observed after turning over rocks and looking in crevices (Appendix 2). On the abalone transect ("AbSwim"), at the outfall site hybrid animals were observed in both surveys. The AbSwim at the outfall location was approximately 400 m from the discharge point where continuous and consolidated reef could be found. Many of the hybrid animals (BG or GB) had very similar morphology to the FA abalone observed from the AbSearch directly at the discharge point. However the exact origin of these animals found 400 m from the discharge point cannot be determined using visual surveys alone as there are invariably natural hybrids on the reef as well. The animals found on the AbSwim at the outfall were therefore conservatively classified as natural hybrids, however, the possibility of farmed abalone also being present on reef habitat beyond the immediate discharge pipe cannot be conclusively ruled out based on the constraints of the methods used in this study. Overall, the majority of animals in this region were <130 mm, although several larger animals were observed at the outfall site.

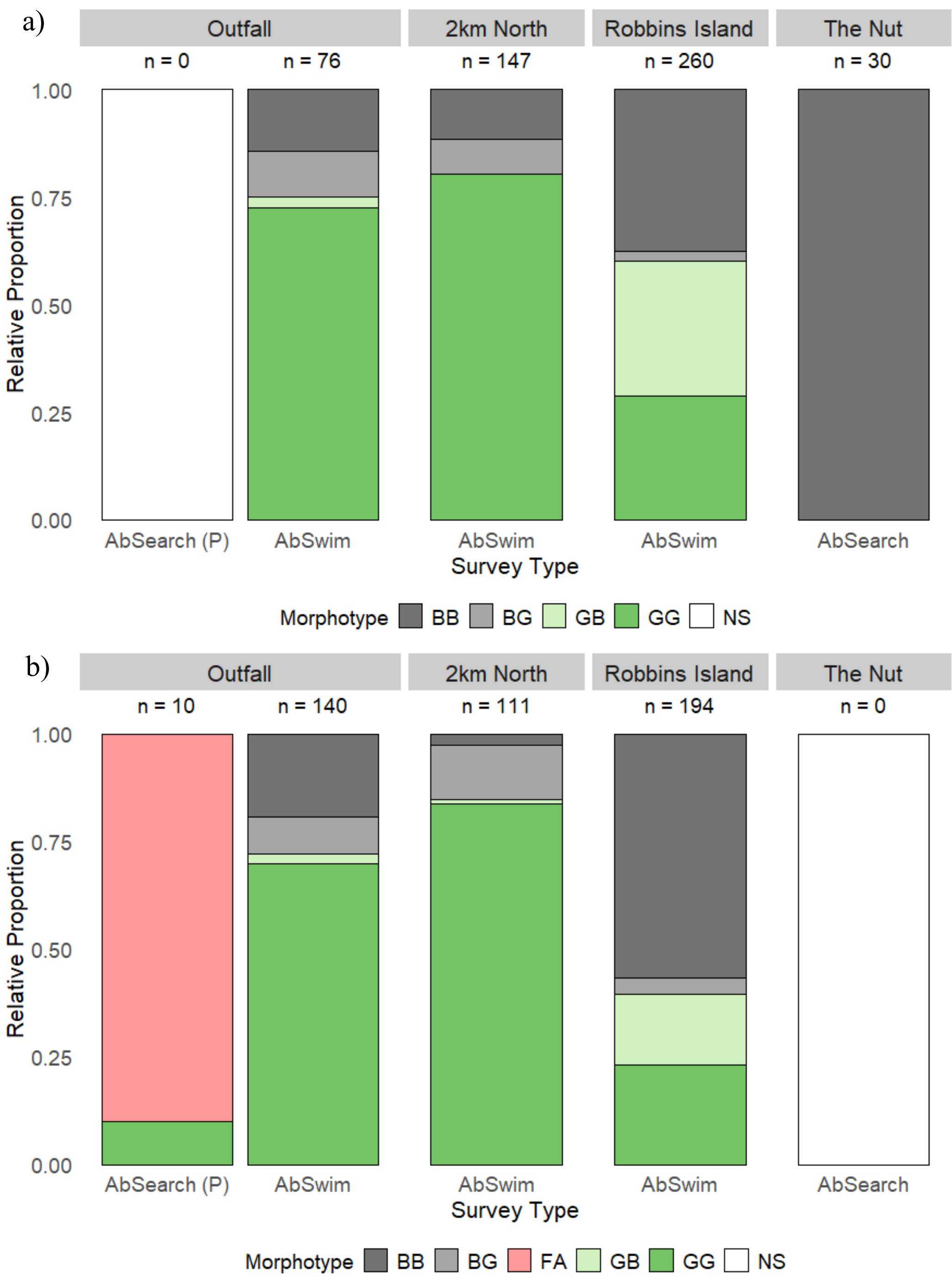


Figure 45: Abundance of abalone and the relative proportion of morphotypes found in the Stanley region during abalone swims and searches across a) November 2023 (off-peak biomass) and b) August 2024 (peak biomass) BB = Blackshell/blacklip, BG = Blackshell, greenlip, FA = Farm origin, GB = Greenshell/blacklip, GG = Greenshell/greenlip, NS = Not surveyed.

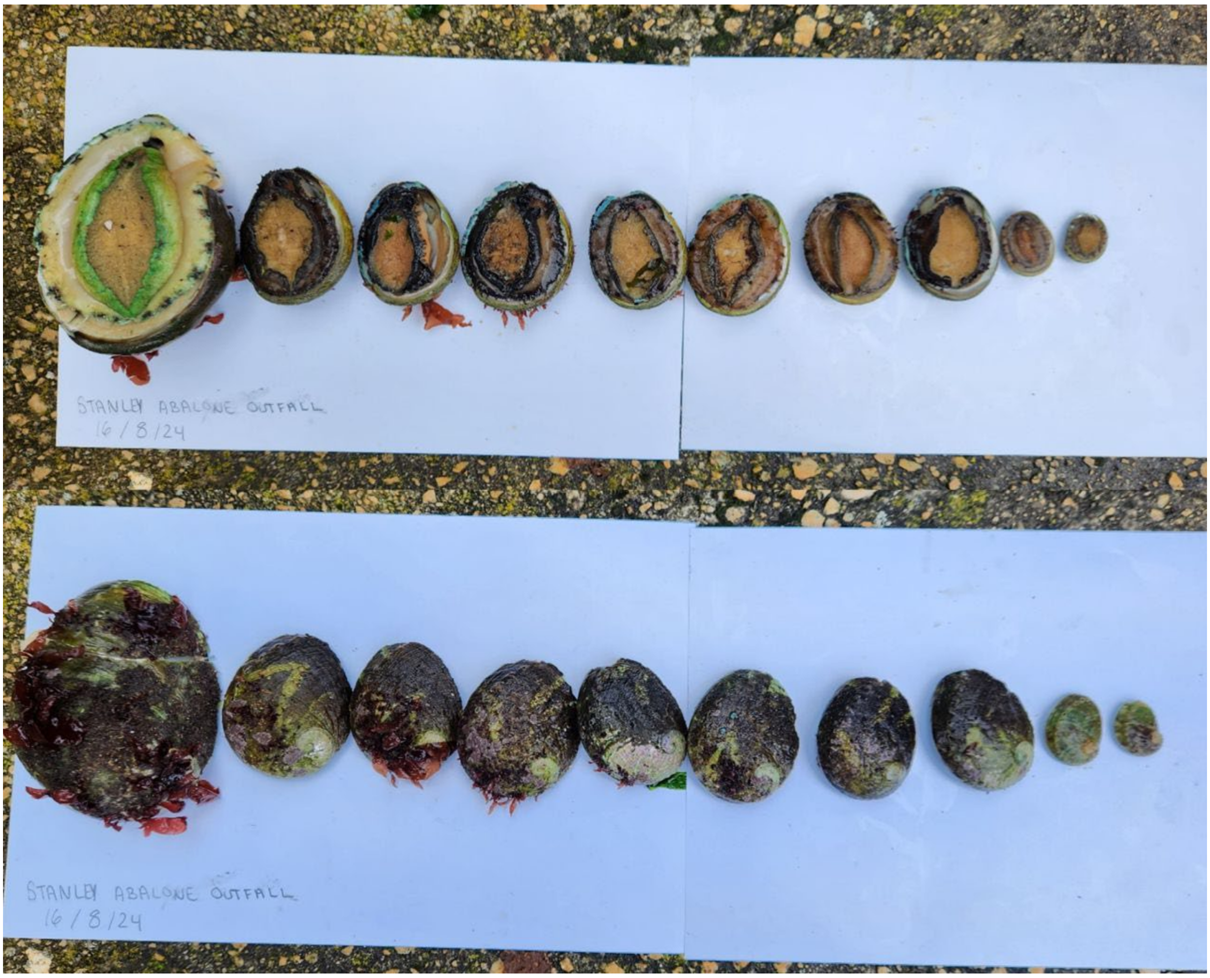


Figure 46: Farmed abalone collected from the subtidal zone in the vicinity of the JST Abalone farm at Stanley in August 2024.

Figure 47: Morphology of abalone found within the Stanley region across November 2023 and August 2024 surveys: a) BB – blacklip, b) GG – greenlip, c) BG – blackshell/greenlip, d) GB – greenshell/blacklip and e) FA – farmed.

Shore walk

No live or recently deceased abalone were detected during the shore walk at the discharge point, however numerous abalone shells of FA morphology were observed in close proximity to the discharge pipe. Of interest, there was a wide array of algae species observed in the inshore reef wrack, including a high abundance of nutrient indicator species such as *Ulva* spp., *Grateloupia turuturu* and *Undaria pinnatifida*. *Ulva* spp. and *G. turuturu* were also observed around the rim of the outfall discharge pipe.

Figure 48: Abalone shells recovered from the shoreline in the vicinity of the JST Abalone farm at Stanley from November 2023 and August 2024.

Discussion

The main aims of this project were to a) characterise discharge environments from land-based abalone aquaculture with regard to nutrient enrichment and b) assess whether there was any evidence of abalone escape from these facilities. At each farm site, mild nutrient enrichment was observed and farmed abalone were found at the discharge point.

All sites had signs of nutrient enrichment on reef and/or seagrass habitats in the vicinity of farm discharge points, although data from control sites and variation across surveys suggest that this enrichment is within the bounds of natural variability for each region of interest. Nutrient enrichment in coastal environments will manifest in a relatively predictable manner, with increases in the biomass of opportunistic macroalgal species being a reliable indicator of elevated nutrients in a system (Oh et al. 2015, Smale et al. 2020). Nutrient enrichment is a common occurrence in coastal ecosystems, with events such as coastal runoff following rainfall providing pulses of nutrients into the environment (Gillanders & Kingsford 2002). As such, there are many common species of algae in coastal ecosystems that have the biology and ecology to capitalise on these nutrient pulses, with excess nutrients rapidly assimilated into biomass (Teichberg et al. 2008, Kraufvelin et al. 2010). If nutrients are being readily assimilated by the ecosystem, then localised pulses of opportunistic algae are likely to be observed, rather than the sustained presence of these species across a broadscale, which would be indicative of nutrient levels exceeding the system's assimilatory capacity (Keough & Quinn 1998). In this study, a more sporadic occurrence of opportunistic algae, rather than a sustained presence, was observed. For example, epiphytic algae, filamentous algae, nuisance green/red algae or nutrient-associated species and groups were a feature of sites in close proximity to the discharge point across all farms surveyed, but were observed in high abundance or abundance elevated beyond control sites in only one of the two surveys. Only rarely was a more continuous presence observed and, in these instances, it was generally only in low abundances (e.g. *Ulva* spp. at the Outfall site at Stanley during the shallow quadrat surveys). Thus, macroalgae responses evident in this study suggest that nutrient outputs from abalone farms at current operating biomass are within the bounds of what can be assimilated and recovered by the ecosystem, without causing a long-term impact.

While sporadic or patchy increases in opportunistic algae was a uniform response across regions, the specifics around this were highly dependent on the region of interest, or sites within regions. For example, filamentous algae was a more common feature of the environment around Clarence Point, whereas epiphytic and nuisance algae, along with particular species of foliose nutrient-associated algae were more common around Stanley. Much of this variation can be explained by the effects of wave/wind exposure and/or water movement at each site, with the effects of nutrients likely to increase with decreasing exposure (Barron et al. 2003, Kraufvelin et al. 2010, White et al. 2022). Bicheno was the highest exposure site out of the four regions and also had the lowest incidence of nutrient indicators across all surveys, sites and methods used to capture this data. When examining data within regions, some evidence of a nutrient gradient related to an exposure gradient can be seen at both Dunalley (May 2024) and Clarence Point (April/May 2024). Data collected through this study indicates that the broader discharge environments for both these systems (Frederick Henry Bay and the Tamar estuary respectively) are subject to nutrient stress beyond the discharge from the land-based abalone aquaculture facilities. In these environments, a possible region-wide perturbation in nutrient regimes has led to a broadscale bloom of filamentous algae, the abundance of which increases as sites become more sheltered within Frederick Henry Bay and the Tamar estuary, respectively. As anthropogenic nutrients, such as that discharged from a land-based abalone aquaculture facility, are likely to be delivered as an ongoing, albeit low-level continuous input, care should be taken when discharging into environments that are more sheltered from wave or wind exposure. As the abundance of opportunistic algae was observed to be high on occasion at control sites, it is likely that the presence of opportunistic species at outfall sites observed in this study is within the natural variability of the system. A better understanding of the effects of nutrient inputs from abalone aquaculture within the context of all other nutrient inputs into these systems will aid regional-scale management of these discharges into the future, particularly if expansion of the industry is likely to occur. Given the observed capacity of nutrients discharged from abalone aquaculture systems to elicit a response in environmental macroalgae communities, exploration into how these nutrients could potentially be used for on-site culture of macroalgae as a food source for farmed abalone, as successfully undertaken in South Africa (Troell et al. 2006, Robertson-Andersson et al. 2009, Nobre et al. 2010) and Asia (Park & Kim 2013, Park et al. 2018, Cook 2019), may warrant further investigation.

This project used several methods to characterise nutrient effects in farm discharge environments. RVA surveys have been used extensively in south-east Tasmania to characterise the ecological effects of nutrients released by salmon aquaculture on nearby reef environments (White et al. 2021, White et al. 2022), along with urbanised nutrient run-off

(White & Brasier 2021). While these surveys are an effective tool for this purpose and provide state-wide context for results, they are contingent on finding at least 50 m of continuous hard substrate at a consistent depth of 5 m. As this was not always possible for this project, particularly around the point of discharge, other methods were used to supplement the RVA surveys. The shallow quadrat surveys targeted species of algae known to respond quickly to elevated nutrient concentrations, and towed video surveys have previously been tested on seagrass and mixed habitats to characterise environmental performance with regard to nutrients over a larger spatial area (McAnaney et al. 2024, White et al. In Prep). These methods provided different insights depending on the site of interest. Overall, the combined data provides a valuable baseline around the effects of nutrient enrichment from land-based abalone aquaculture at current levels of on-site farm biomass.

With regard to stock escaping from land-based aquaculture facilities into the environment, evidence was found at each discharge site that this was occurring. The escape of abalone from land-based aquaculture facilities has been an issue for the industry in the past, for example, in 2010 an established *H. laevigata*/hybrid population was found adjacent to the facility at Fulham Point, Dunalley (Mundy 2017). As the implementation of fine-mesh screens presents a logistical issue for farm management due to regular clogging, it is believed that juveniles can escape through the drainage system, eventually finding their way down the discharge pipe and into the environment. A major component of the escape issue is likely to occur during cleaning operations. When standpipes are pulled during cleaning, abalone around the standpipes are being washed directly down the drain (NRE pers comm). Abalone were found in the direct vicinity of the discharge pipe in the cryptic habitat, either as part of this study (Stanley, Bicheno and Dunalley) or through subsequent compliance surveys (Clarence Point). Potential risks associated with abalone escape include genetic alteration of wild stock and the introduction of diseases and parasites into wild populations (Theil et al. 2004). The Abalone Viral Ganglioneuritis (AVG), caused by the highly virulent herpes-like virus AbHV-1, first appeared in abalone farms in southern Victoria in 2005, with the virus subsequently spreading to the wild fishery in Victoria with significant ramifications for wild stock (Jones & Fletcher 2012). Access to the breeding program of hybrid *H. rubra/H. laevigata* in Victoria represents an opportunity for enhancement of industry productivity in Tasmania. However, Tasmania does not currently allow for the import of live abalone, with the potential for escape of stock from abalone aquaculture facilities cited as a barrier to import, and the potential spread of diseases considered a potential risk (Theil et al. 2004). As there is evidence of escaped abalone at the discharge point of all four farms, the risk of disease transfer needs to be carefully considered in the Tasmanian context.

With regard to genetic alteration of wild stock due to the presence of escapees, presently there is no satisfactory method for tracing escaped abalone in the wild, so understanding this risk in Tasmania is currently difficult. The majority of abalone cultured at farm sites in Tasmania are hybrids of *H. rubra* x *H. laevigata* due to the commercial superiority of the F1 generation compared to individuals of pure species (Elliott 2000, Kube et al. 2024). Due to the high chromosome compatibility, *H. rubra* and *H. laevigata* will readily hybridise in the wild as both F1 hybrids and subsequent backcrosses, due to the species distribution overlap (Kube et al. 2024). As *H. laevigata* is only found in Tasmania north of Musselroe Bay, if newly escaped F1 hybrids were present in the environment around Dunalley and Bicheno they would be obvious due to their intermediate morphological characteristics, as compared with the native population of pure *H. rubra*. However, for the two farms on the north coast where both species are present, more care needs to be taken in distinguishing farmed abalone from wild stock. While very few abalone were observed within the Tamar estuary, wild populations of both species were present around Stanley, with hybrids readily observed in sites both near and distant to the discharge point. Due to the limited dispersal of abalone during their larval phase (Miller et al. 2009, Miller et al. 2014), it is unlikely that hybrids found around Robbins Island are of farm origin (Miyake et al. 2017). However, it is impossible to determine whether hybrids found on reef within 400 m from the point of discharge are of either wild stock or of farm origin based on visual assessment alone, excepting where these animals have retained a very clear farm signature in their shell morphology.

The situation at Stanley highlighted the limitations of using visual surveys only to trace escaped abalone in the wild, particularly where wild populations include natural hybrids and subsequent backcrosses between hybrids with pure species within the F2 generation occurring naturally. Backcrossing may result in an animal with intermediate characteristics between the hybrid and pure species, creating a gradient of characteristics, which further confounds the problem. The uncertainty around backcrosses of farmed animals into wild populations was observed at Dunalley, where a number of abalone with predominantly *H. rubra* features also had a few unusual characteristics in both shell and foot. Thus, even in regions around Tasmania where only *H. rubra* is found, it is still difficult to assess with confidence the genetics of wild populations based on morphology alone. Other unknowns include how long the “farmed characteristics” (i.e. verdant jade shell, soft ruby-coloured foot) are likely to persist in escaped abalone once individuals have switched to an algal-based rather than a formulated diet. Farmed *H. rubra* abalone juveniles retained a distinctive morphology for up to two years in a reseeding trial in NSW (Chick 2010), although very little work has been done on hybrids or *H. laevigata*. Tracing of farmed abalone may be possible using shell biochemistry to detect a clear farm signature in the shell spire, with both isotopes and elemental profiling having potential promise. For instance, assessing fluctuations in carbon and oxygen isotopes in shells has been suggested as a potential method for tracing the origin of an animal and given the unique nitrogen isotope of some pellet diets, nitrogen isotopes may also be worth pursuing (Lee et al. 2002, Gurney et al. 2005, Naylor 2015). Elemental profiling has been previously used to trace the origin of fish and cephalopods using otoliths (Doubleday et al. 2022, Reis-Santos et al. 2023, Doubleday et al. 2025). Given the microchemistry of formulated diets is likely to be quite different from a natural diet, these techniques could also have application in tracing escaped farm abalone. Should tracing of farmed stock in the wild become a priority for government and industry, such methods could be explored further.

While this study focused entirely on the movement of juveniles and adults through waste-water discharge, or via rodents or birds, another potential pathway of escape is through larval dispersal from cultured stock post-spawning (Theil et al. 2004, Jones & Fletcher 2012). While shell biochemistry may provide some answers for tracing juvenile or adult individuals that have escaped through settlement ponds and subsequent discharge systems, it will be inadequate for tracing larval dispersal from aquaculture facilities into the wild. Modelling conducted by Hawkins & Jones (2002) suggests that the risk of larval survival is low, however, the model has never been empirically validated through on-farm sampling and there were several variables where solid data to input into the model did not exist. The model also only takes into account the risk of genetic mixing; disease risk or effects of raw sperm or eggs escaping the aquaculture facility were not investigated. Understanding spawning cycles of hybrid abalone and broodstock within the farm environment will help highlight periods of particular risk, along with how fecund hybrid animals are compared with the broodstock of pure species (Hawkins & Jones 2002, Kube et al. 2024). Gaining a better understanding of the magnitude of this problem, through in-farm or environmental sampling, could be worthwhile for managing this risk into the future.

Overall, despite the efforts of land-based aquaculture facilities to limit abalone escapes, this study indicates that escapes can still occur. There are many unknowns in trying to assess the extent to which escapes from farms represent a problem, along with the potential risk due to disease transfer or to genetic mixing due to crossover with wild stock. There is currently limited methodology available for determining the origin of individual animals, particularly hybrids, in the broader environment.

Site based summary

Fulham Point, Dunalley (Jade Tiger Abalone)

There was evidence of localised nutrient enrichment at the Jade Tiger Abalone farm in Dunalley, mainly through the presence of *Ulva* spp. in close proximity to the discharge point and the understorey on nearby reefs being skewed towards green and red algae as opposed to brown algae. While the abundance of filamentous and epiphytic algae was relatively high around the outfall sites, the abundance of these groups observed in locations distant from the discharge point would indicate that nutrients can be high across Frederick Henry Bay and driven more regionally, rather than being a point-source impact. At a broadscale, Frederick Henry Bay showed signs of nutrient stress and poor ecosystem health unrelated to the aquaculture facility discharge point. With regard to abalone escapes, farmed abalone were observed during the May 2024 survey around the discharge pipe. Shells were also found along the beach, indicating that farmed stock may be transported off the farm via both the discharge system and or by birds and rodents.

Clarence Point (Abtas)

There is evidence of broadscale nutrient enrichment across the Tamar estuary, and therefore distinguishing the effect of the Clarence Point outfall is difficult. Results from the broadscale survey would indicate that the Tamar estuary is subject to nutrient stress at a regional level, not necessarily associated with the discharge from the abalone aquaculture facility. Nonetheless, there were some signs of nutrient enrichment at the discharge point, although data from control locations and variability between surveys would suggest that what was observed is within the normal fluctuations of the system. Filamentous algae and *Chaetomorpha billardierii* were the nutrient-associated species/groups that were found in proximity to the discharge point during this study. With regard to abalone escapes from the Clarence Point facility, no live animals were observed during the abalone surveys, however, there was no extensive search of cryptic habitat (i.e. "rolling rocks") around the discharge point, where farmed abalone were found at all other sites. Subsequent compliance surveys targeting the cryptic habitat at the discharge point found four live animals of farm origin. There were many shells found on the beach, some appearing to be quite recently deposited, indicating that stock are likely to be moving off-site via birds, rodents or farm cleaning activities. Wildlife interactions with these shells were observed.

Bicheno (Yumbah Aquaculture)

As the Bicheno site discharges directly onto the open coastline, nutrient effects at this site were minimal, and were observational rather than quantified (e.g. the overtly lush *P. comosa* observed around the outfall and 400 m sites, and the proliferation of *Ulva* spp. directly at the point of discharge). With regard to abalone escapes, live animals of farm origin were observed at the northern discharge point during the July/August survey, with all live animals ≤ 60 mm. The immediate environment at the main southern discharge point was not searched thoroughly during either survey due to adverse weather conditions.

Stanley (JST Abalone)

The receiving habitat at Stanley was incredibly complex and characterising nutrient enrichment within this environment was relatively challenging. Data would indicate mild nutrient stimulation around the discharge point, characterised by the higher abundance of *Ulva* spp. and *Enteromorpha/Ulva intestinalis* compared to control locations. Dense *Ulva* spp. and *G. turuturu* were also observed at the immediate discharge point. However, variability of the data, particularly at a broader spatial scale, would indicate that current outputs of nutrients are within the assimilatory capacity of the receiving environment. With regard to abalone escapes, the situation in the receiving environment was extremely complex and without a tested method for detecting abalone escape, it is difficult to properly characterise the extent of any issue. Abalone of farm origin were observed at the point of discharge during the August survey. The majority of these were cryptic animals (juveniles) and were found through searching under rocks in the vicinity of the discharge point. Some larger animals were also found in the open. On reef habitat 400 m away, an array of hybrid abalone were observed, but as hybridisation occurs naturally between *H. rubra* and *H. laevigata*, the origin of these animals cannot be determined through visual assessment alone. The large number of farm-origin shells on the beach would suggest that farm stock is also moving off-site through transportation by either birds or rodents.

Acknowledgements

We would like to acknowledge all staff who assisted in the collection of field data, including Anna Darby, Alex Coutts, Caillin Wise, Ben Quigley, Jaime McAllister, Charlotte McAnaney, Davis Hinton and Grace Furness. We would also like to acknowledge the staff of the Aquaculture Branch at NRE Tasmania for their discussion, guidance and willingness to assist with this work. Thanks also to Jeff Ross, Nick Elliott and Brad Evans for academic support, particularly advice around abalone ecology and biology.

References

Barron C, Marba N, Duarte CM, Pedersen MF, Lindblad C, Kersting K, Moy F, Bokn T (2003) High organic carbon export precludes eutrophication responses in experimental rocky shore communities. Ecosystems 6:144-153

Brown LD (1995) Genetic evidence for hybridisation between Haliotis rubra and H. laevigata. Marine Biology 123:89-93

Chick RC (2010) Batch-Tagging Blacklip Abalone (<i>Haliotis rubra</i>) for Identification of Hatchery-Reared Individuals on Natural Coastal Reefs in New South Wales, Australia. Journal of Shellfish Research 29:209-215, 207

Cook PA (2019) Worldwide Abalone Production Statistics. Journal of Shellfish Research 38:401-404, 404

DAUME S (2006) THE ROLES OF BACTERIA AND MICRO AND MACRO ALGAE IN ABALONE AQUACULTURE: A REVIEW. Journal of Shellfish Research 25:151-157, 157

Doubleday ZA, Hosking L, Willoughby J, Dias M, Leclerc N, Nikolajew SB, Peharda M, Rézio AT, Trueman C (2025) Capitalizing on the wealth of chemical data in the accretionary structures of aquatic taxa: Opportunities from across the tree of life. Limnology and Oceanography Letters 10:18-36

Doubleday ZA, Martino JC, Trueman C (2022) Harnessing universal chemical markers to trace the provenance of marine animals. Ecological Indicators 144:109481

Elliott NG (2000) Genetic improvement programmes in abalone: what is the future? Aquac Res 31:51-59

FAO (2020) The State of World Fisheries and Aquaculture 2020. Prepared by the Food and Agriculture Organisation of the United Nations. Sustainability in action, Rome

FLORES-AGUILAR RA, GUTIÉRREZ A, ELLWANGER A, SEARCY-BERNAL R (2007) DEVELOPMENT AND CURRENT STATUS OF ABALONE AQUACULTURE IN CHILE. Journal of Shellfish Research 26:705-711, 707

Gillanders BM, Kingsford MJ (2002) Impact of changes in flow of freshwater on estuarine and open coastal habitats and the associated organisms. Oceanography and Marine Biology 40:233-309

Gurney LJ, Mundy C, Porteus MC (2005) Determining age and growth of abalone using stable oxygen isotopes: a tool for fisheries management. Fisheries Research 72:353-360

Hawkins CD, Jones JB (2002) Larval escape through abalone culture effluent systems: An analysis of the risk. Journal of Shellfish Research 21:805-809

Howarth LM, Filgueira R, Jiang D, Koepke H, Frame MK, Buchwald C, Finnis S, Chopin T, Costanzo SD, Grant J (2019) Using macroalgal bioindicators to map nutrient plumes from fish farms and other sources at a bay-wide scale. Aquaculture Environment Interactions 11:671-684

Jones JB, Fletcher WJ (2012) Assessment of the risks associated with the release of abalone sourced from Abalone Hatcheries for enhancement or marine grow-out in the open ocean areas of WA. Fisheries Research Report. Western Australian Department of Primary Industries and Regional Development

Keough MJ, Quinn GP (1998) Effects of periodic disturbances from trampling on rocky intertidal algal beds. Ecol Appl 8:141-161

Kraufvelin P, Lindholm A, Pedersen MF, Kirkerud LA, Bonsdorff E (2010) Biomass, diversity and production of rocky shore macroalgae at two nutrient enrichment and wave action levels. Marine Biology 157:29-47

Kube PD, McPherson L, Krsinich A, King H, Raidan FSS, Reverter A, Kijas J, Elliott NG (2024) Genetic variation and heterosis of the interspecific abalone hybrid of Haliotis rubra and H. laevigata. Aquaculture 580:740275

Lee Y-C, Kuo H-H, Chen Y-G (2002) Discrimination and abundance estimation of wild and released abalone <i>Haliotis diversicolor</i> using stable carbon and oxygen isotope analysis in northeastern Taiwan. Fisheries science 68:1020-1028

McAnaney C, White C, de Nys R, Maynard D, Kelly B, Tatsumi M, Hurd C, Lemm S, Nichols D, Zuccarello J, Wright J (2024) Baseline data to inform a new aquaculture industry: mapping the distribution, abundance and chemical variation in *Asparagopsis armata* around Tasmania. Institute for Marine & Antarctic Studies, Hobart, Australia

MILLER KJ, MAYNARD BT, MUNDY CN (2009) Genetic diversity and gene flow in collapsed and healthy abalone fisheries. Molecular Ecology 18:200-211

Miller KJ, Mundy CN, Mayfield S (2014) Molecular genetics to inform spatial management in benthic invertebrate fisheries: a case study using the Australian Greenlip Abalone. Molecular Ecology 23:4958-4975

Miyake Y, Kimura S, Horii T, Kawamura T (2017) Larval Dispersal of Abalone and Its Three Modes: a Review. Journal of Shellfish Research 36:157-167, 111

Mundy C (2017) Advice Note: Risk presented to Tasmania's wild abalone stocks from the perspective of genetics by the proposed translocation of farmed abalone stock from Victoria. In: Resources DM (ed), Hobart, Tasmania

Naidoo K, Maneveldt G, Ruck K, Bolton JJ (2006) A Comparison of Various Seaweed-Based Diets and Formulated Feed on Growth Rate of Abalone in a Land-Based Aquaculture System. J Appl Phycol 18:437-443

Naylor R (2015) Literature review of abalone ageing techniques. New Zealand Fisheries Assessment Report, Book 2015/77. Ministry for Primary Industries, Wellington

Nobre AM, Robertson-Andersson D, Neori A, Sankar K (2010) Ecological–economic assessment of aquaculture options: Comparison between abalone monoculture and integrated multi-trophic aquaculture of abalone and seaweeds. Aquaculture 306:116-126

Oh ES, Edgar GJ, Kirkpatrick JB, Stuart-Smith RD, Barrett NS (2015) Broad-scale impacts of salmon farms on temperate macroalgal assemblages on rocky reefs. Marine Pollution Bulletin 98:201-209

Park C-J, Kim SY (2013) Abalone Aquaculture in Korea. Journal of Shellfish Research 32:17-19, 13

Park M, Shin SK, Do YH, Yarish C, Kim JK (2018) Application of open water integrated multi-trophic aquaculture to intensive monoculture: A review of the current status and challenges in Korea. Aquaculture 497:174-183

Reis-Santos P, Gillanders BM, Sturrock AM, Izzo C, Oxman DS, Lueders-Dumont JA, Hüssy K, Tanner SE, Rogers T, Doubleday ZA, Andrews AH, Trueman C, Brophy D, Thiem JD, Baumgartner LJ, Willmes M, Chung M-T, Charapata P, Johnson RC, Trumble S, Heimbrand Y, Limburg KE, Walther BD (2023) Reading the biomineralized book of life: expanding otolith biogeochemical research and applications for fisheries and ecosystem-based management. Rev Fish Biol Fisher 33:411-449

Robertson-Andersson DV, Potgieter M, Hansen J, Bolton JJ, Troell M, Anderson RJ, Halling C, Probyn T (2009) Integrated seaweed cultivation on an abalone farm in South Africa. In: Borowitzka MA, Critchley AT, Kraan S, Peters A, Sjøtun K, Notoya M (eds) Nineteenth International Seaweed Symposium: Proceedings of the 19th International Seaweed Symposium, held in Kobe, Japan, 26-31 March, 2007. Springer Netherlands, Dordrecht

Ross J, Macleod C, White C, Hadley S, Moreno D, Bush F, Barrett N (2021) Managing ecosystem interactions across differing environments: building flexibility and risk assurance into environmental management strategies. FRDC Project No 2015/024. Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Australia

Smale DA, Pessarrodona A, King N, Burrows MT, Yunnie A, Vance T, Moore P (2020) Environmental factors influencing primary productivity of the forest-forming kelp Laminaria hyperborea in the northeast Atlantic. Sci Rep-Uk 10:12161

Teichberg M, Fox SE, Aguila C, Olsen YS, Valiela I (2008) Macroalgal responses to experimental nutrient enrichment in shallow coastal waters: growth, internal nutrient pools, and isotopic signatures. Marine Ecology Progress Series 368:117-126

Theil M, Wear R, Tanner JE, Bryars S, de Jong S (2004) Environmental risk assessment of land-based abalone aquaculture in South Australia. Innovative solutions for aquaculture planning and management, Book 5. SARDI, Adelaide

Troell M, Robertson-Andersson D, Anderson RJ, Bolton JJ, Maneveldt G, Halling C, Probyn T (2006) Abalone farming in South Africa: An overview with perspectives on kelp resources, abalone feed, potential for on-farm seaweed production and socio-economic importance. Aquaculture 257:266-281

Tuynman H, Cao A, Dylewski M, Curtotti R (2023) Australian fisheries and aquaculture statistics 2022, Fisheries Research and Development Corporation, ABARES, Canberra, December.

Viera MdP, Courtois de Viçose G, Fernández-Palacios H, Izquierdo M (2016) Grow-out culture of abalone aliotis tuberculata coccinea Reeve, fed land-based IMTA produced macroalgae, in a combined fish/abalone offshore mariculture system: effect of stocking density. Aquac Res 47:71-81

White C, Brasier MJ (2021) Rapid visual assessment surveys on rocky reefs in the Derwent Estuary. Institute for Marine and Antarctic Studies, Hobart, Tasmania

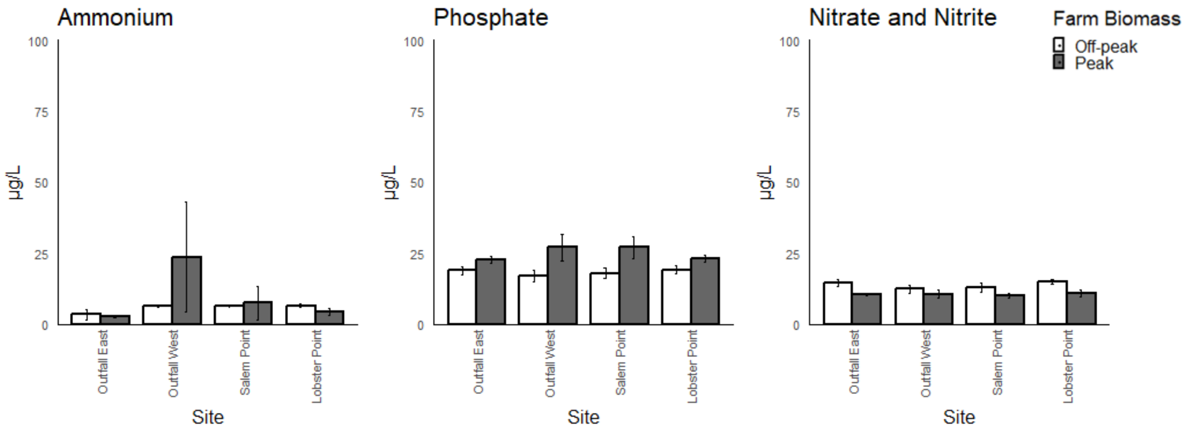
White C, Hartog M, Brasier M, Ross J (2022) Rapid visual assessment of rocky reef assemblages in Port Arthur, Tasmania. Institute for Marine and Antarctic Studies, Hobart, Tasmania

White C, McAllister J, Johnson O, Mundy C, Ross J (2021) Assessment of reef condition in the southern D'Entrecasteaux Channel. Hobart, Tasmania

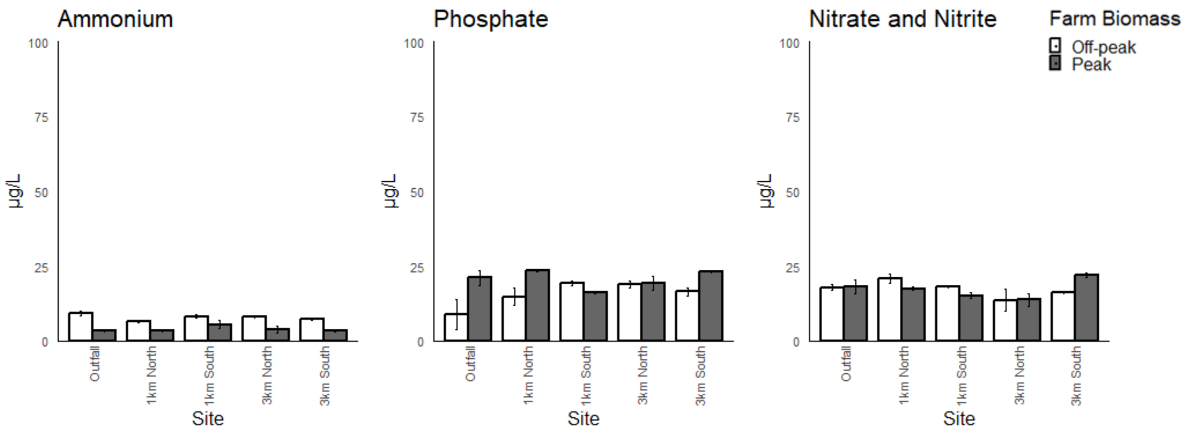
White C, Walley G, Hartog M (In Prep) Characterisation of algal communities in the Mercury Passage as a baseline for aquaculture. Institute of Marine & Antarctic Studies

Appendix 1

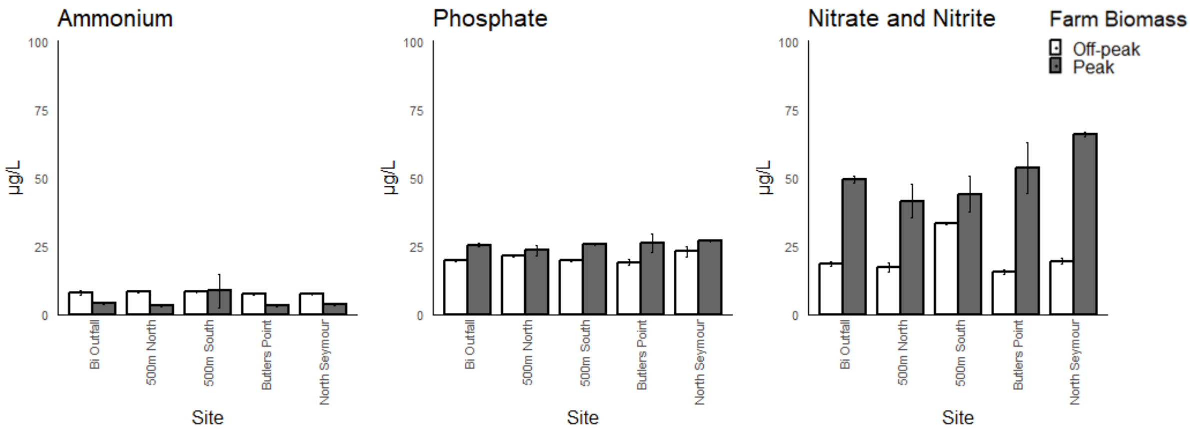
Nutrient data - Dunalley



Nutrient data – Clarence Point



Nutrient data – Bicheno



Nutrient data – Stanley