POPULATION SURVEY OF THE TASMANIAN LIVE BEARING SEASTAR *PARVULASTRA VIVIPARA* AT BAMBRA REEF, JUNE 2013

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EXECUTIVE SUMMARY

The Tasmanian live-bearing seastar *Parvulastra vivipara* (formerly known as *Patiriella vivipara*) is an endemic seastar, limited to a small number of sites in south east Tasmania. *P. vivipara* is one of only four seastar species worldwide known to bear live young (i.e. viviparous). The seastar is considered of high conservation value, due to its limited distribution and unique biology. *P. vivipara*'*s* conservation value was formally recognised in July 1998, when it was listed as an endangered species under the *Tasmanian Threatened Species Protection Act 1995*. *P. vivipara*'*s* listing was downgraded from 'endangered' to 'vulnerable' in 2008, following the discovery of new subpopulations. *P. vivipara* is currently listed as 'vulnerable' under the Commonwealth's *EPBC Act 1999*.

A population of *P. vivipara* occurs on Bambra Reef at Lauderdale. This is one of the three localities where *P. vivipara* were first described by Dartnall in 1969. The Bambra Reef *P. vivipara* population is susceptible to a range of anthropogenic impacts including habitat degradation and modification through processes such as the removal of suitable habitat, urban encroachment and run-off of pollutants. Introduced species such as the New Zealand seastar (*Patiriella regularis*) and the northern Pacific seastar (*Asterias amurensis*) also represent a potential threat to *P. vivipara* via interspecific competition, displacement and predation. Of more immediate relevance to the Bambra Reef population are climate change related impacts, particularly in relation to erosive storm events. During such storm events, sand is eroded from dune systems and transported to shallow sub-tidal environments, then transported northward with longshore drift. This process has the potential to bury Bambra Reef and the rocky intertidal zone beneath sand and cause the loss, or partial loss of the *P. vivipara* population.

Clarence City Council engaged Aquenal to undertake a population assessment of the Bambra Reef population in June 2013. Previous *P. vivipara* population surveys were conducted in 2000, 1998 and 1983. The main objectives of the current survey were to determine the local distribution and abundance of the seastar population at Bambra Reef, quantify key population demographic characteristics, and compare the survey results with previous population estimates. An additional objective of the current work was to establish transects that could be used for future monitoring of the status of the *P. vivipara* population.

The *P. vivipara* population at Bambra Reef was estimated to include ~8,400 individuals in June 2013. This population was estimated to encompass 943 m^2 of intertidal reef area. The highest densities were found in the central region of the reef, where the density reached 32/m^2. The highest densities of seastars were found amongst loose rocks in the 10-30 cm size range. In these habitats, *P. vivipara* were generally found beneath rocks and in associated microhabitats,

with occasional animals observed on the exposed rocks surfaces. It appears that *P. vivipara* has successfully reproduced in recent years, based on the existence of at least two cohorts in the population's size structure.

Comparisons of overall population numbers and average densities of *P. vivipara* population at Bambra Reef can be made over time. Abundance estimates in the current survey (~8,400 individuals; average density in mid-intertidal zone 5.8/m^2) were lower than those recorded in 2000 (~17,500 individuals; average density 8.9/m^2), but considerably higher than those recorded in 1983 (~400 individuals) and 1998 (~100 individuals). Maximum densities also appear slightly lower than 2000, with a maximum of 32/m^2 in the current survey and a maximum of 65/m^2 in 2000. The spatial extent of population also appears to have changed. In the current survey the area occupied by *P. vivipara* was 943 m^2 compared to 450 m^2 in 2000 and 35 m^2 in 1998. No comparison could be made with the 1983 survey, since the area occupied by seastars was not documented at the time.

There appears to have been considerable variability in the *P. vivipara* population size and density at Bambra Reef over the last 30 years. Nevertheless, considerable threats to the population remain. Given the existing potential threats, particularly from climate-change related impacts and shifting sand, future monitoring of the Bambra Reef population is recommended. Future population monitoring at Bambra Reef should adopt the methodological details and approach used in the current study to ensure comparable results through time. This includes details for making quantitative estimates of population densities, overall population size and spatial extent.

Future population monitoring should focus on the mid and mid-high intertidal zone, given that no *P. vivipara* were present in the low intertidal zone. It should also incorporate an estimate of total intertidal reef area, since differences in reef area are potentially a key indicator of threat to the *P. vivipara* population. Higher resolution sampling of *P. vivipara* using fixed quadrat positions over smaller spatial scales may also be warranted to provide more precise estimates of seasonal variability in density and population size structure. Ultimately, ongoing monitoring provides important quantitative information that may be used to manage the *P. vivipara* population on Bambra Reef.

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1. INTRODUCTION

1.1 CONSERVATION VALUE AND STATUS OF PARVULASTRA VIVIPARA

The Tasmanian live-bearing seastar *Parvulastra vivipara* (formerly known as *Patiriella vivipara*) is an endemic seastar, limited to a small number of sites in south east Tasmania. *P. vivipara* is one of only four seastar species worldwide known to bear live young (i.e. viviparous). The seastar is considered of high conservation value, due to its limited distribution and unique biology. *P. vivipara*'*s* conservation value was formally recognised in July 1998, when it was listed as an endangered species under the *Tasmanian Threatened Species Protection Act 1995*. *P. vivipara*'*s* listing was downgraded to 'vulnerable' in 2008, following the discovery of new subpopulations (DPIPWE 2012). *P. vivipara* is also listed as vulnerable under the Commonwealth's *EPBC Act 1999*.

1.2 ECOLOGY OF PARVULASTRA VIVIPARA

The Tasmanian live-bearing seastar is a small species, with a maximum reported radius of up to 15 mm (Dartnall 1970), and an average adult radius of approximately 10 mm (Prestedge 1998). *P. vivipara* usually has five arms, although specimens with two, four or six arms have been identified in small numbers (Prestedge 1998). The seastar is orange to pale yellow in colour on both the dorsal (upper) and ventral (lower) surfaces. According to Dartnall (1969) this coloration distinguishes *P. vivipara* it in Tasmania from *P. exigua* (blue-green ventral surface) and *Patiriella regularis* (off-white ventral surface).

When first described, *P. vivipara* was the only known seastar species to that incubates its live young inside the gonads (Dartnall 1969). This reproductive mode is known as viviparity, and is a very rare feature amongst marine invertebrates, particularly amongst the phylum Echinodermata. An additional three viviparous seastars have now been identified (Byrne 1996, also refer to Prestedge 1998), two of which are species with small geographic ranges on mainland Australia (*Parvulastra parvivipara* and *Patiriella pseudoexigua*), while the third is a Japanese species belonging to the genus *Asterina. P. vivipara* is a simultaneous hermaphrodite, and therefore has the potential for self-fertilization as well as cross-fertilization with other individuals (Byrne 1996). When the young rupture from the gonadal sacs, they emerge on the surface of the parent and appear as tiny miniature adults. The average number of young produced by one individual in a year was found by Prestedge (1998) to range between 2 to 5, although Byrne (1996) recorded an average unborn clutch size of 17.6 in dissected *P. vivipara* from Midway Point.

A major implication of this viviparous mode of reproduction is that *P. vivipara* cannot disperse widely, unlike species with free-swimming (planktonic) larval stages. The majority of seastar species have planktonic life history stages, and therefore a greater ability to disperse and colonise new areas. *P. vivipara* is relatively sedentary, exhibiting very slow movement and

colonisation rates (Hoggins 1976). Given these reproductive and biological traits, *P. vivipara* is likely to be susceptible and slow to recover from habitat disturbances.

P. vivipara individuals breed throughout the year, with the peak reproductive season incorporating spring and summer months (Dartnall 1969, Hoggins 1976, Prestedge 1998). A number of factors may influence the timing of reproduction, such as temperature, salinity, light and food availability (Hoggins 1976). *P. vivipara* may live for 8 to 10 years, making it the longest-lived of the viviparous seastars that have been investigated (Prestedge 1998).

Feeding in *P. vivipara* is influenced by a range of environmental conditions, including tidal condition and temperature (Prestedge 1998), with feeding reduced in association with reduced immersion times and colder winter temperatures. *P. vivipara* mainly feeds between dusk and dawn on the film of algae and other microorganisms that occur on exposed rock surfaces, with animals returning to areas beneath rocks during the day time (Dartnall 1969, Hoggins 1976). *P. vivipara* counts undertaken at Pitt Water indicate that 60% of the population may be under rocks at any one time (Horner 1997). Adult seastars have also been observed to come to the top of rocks to feed during the day when the weather is overcast and dull light prevails, however, juveniles are rarely seen on exposed rock surfaces (Prestedge 1998).

1.3 *Distribution, habitat and abundance of Parvulastra vivipara in Tasmania*

P. vivipara has only been found in intertidal waters in southeast Tasmania and is known reliably from 13 locations. The northernmost population occurs at Pitt Water, while a population at Southport Lagoon represents the southernmost known population (Prestedge 2001a cited in DPIPWE 2012). The distribution of *P. vivipara* is extremely fragmented as all known populations are relatively small and isolated. The populations are separated by distances that exceed the presumed dispersal capacity of the species (Prestedge 2001a). *P. vivipara* is found on rocky areas in the upper intertidal zone, usually under rocks or in crevices (DPIPWE 2012). The species prefers gently sloping, sheltered shores, characterised by rocks often no more than 20 to 30 cm high. Some small colonies seem to be very habitat specific, with some preferring dolerite and others sandstone (DPIPWE 2012). The different populations vary in size from less than 20 individuals to several thousand. The largest population is located at Pitt Water (population estimate 326 000 individuals; DPIPWE 2012).

1.4 *Distribution, population size and threats to Parvulastra vivipara population at Bambra Reef*

The Bambra Reef population is one of the three localities where *P. vivipara* was first described by Dartnall (1969). Previous population estimates for the Bambra Reef population include 400 (1983; Prestedge 1998), 100 (1998; Prestedge 1998) and 17,505 (2000; Rowland 2001). The most recent population estimate undertaken in 2000 puts the Bambra Reef population as the second largest population currently known (Rowland 2001). The nearest population to Bambra

Reef occurs at Mays Point, where a very small population exists (estimated population size 13 individuals (Polanowski 2002). During the most recent population estimate at Bambra Reef in 2000, the population was estimated to be spread over an area of ~450 m^2, from a total area of intertidal reef estimated to be ~1500 m^2.

Bambra Reef is a low profile rocky reef that consists of fissured dolerite bedrock strewn with detached boulders, stones and cobbles, with varying levels of sandy sediment between the stones. Small rock pools are found amongst the reef (Rowland 2001). The reef extends from below the high water mark, to the shallow subtidal zone. The reef/sand edge occurs at approximately 3 m depth. The total area of Bambra Reef including intertidal and subtidal components appears to be quite variable through time, from 85,020 m^2 to 16,840 m^2 (Whitehead 2012). The variation in the previously recorded extent of Bambra Reef may reflect the low profile of the reef and its susceptibility to partial sand burial, potentially related to sand movement from storm erosion along the coast.

The Bambra Reef *P. vivipara* population is susceptible to a range of impacts that apply to the species across its known distributional range. Many of the *P. vivipara* populations are in close proximity to areas inhabited by humans and consequently are impacted by habitat degradation and modification through a variety of anthropogenic processes such as removal of suitable habitat, urban encroachment and run-off of pollutants (TSSC 2009). Another potential impact is interspecific competition, displacement and potential predation by introduced seastars such as the New Zealand Seastar (*Patiriella regularis*) and the northern Pacific seastar (*Asterias amurensis*).

Perhaps the most immediately relevant threat to the Bambra Reef population is climate change related impacts, particularly in relation to erosive storm events. During storm events sand is eroded from dune systems and transported to shallow sub-tidal environments, then transported northward with longshore drift (Whitehead 2012). This process has the potential to bury Bambra Reef and the rocky intertidal zone beneath sand and cause the loss, or partial loss of *P. vivipara* (Whitehead 2012). In this context, the Bambra Reef and Mays Point seastar populations were recently identified as one of six major environmental asset types in the Lauderdale area at risk of climate change related impacts (Whitehead 2012). It has been deemed of high priority to retain these rocky habitats in good condition for the vulnerable seastars and to monitor the populations at both sites (Whitehead 2012).

1.5 OBJECTIVES OF CURRENT SURVEY

Following more than ten years since the last *P. vivipara* population survey, Clarence City Council engaged Aquenal to undertake a population assessment of the Bambra Reef population. The main objectives of the survey were to delineate the spatial extent of the seastar population at Bambra Reef, quantify key population demographic characteristics, and compare the survey results with previous population estimates at this site. An additional objective of the current

work was to establish transects that could be used for future monitoring of the status of the *P. vivipara* population.

2. SURVEY METHODS

The population survey incorporated two stages; (1) qualitative assessment of *P. vivipara* distribution on Bambra Reef; and (2) quantitative estimates of seastar density using strip transects. A summary of the survey approaches is provided in Table 1, while more detailed description is provided below:

2.1 QUALITATIVE ASSESSMENT AND DELINEATION OF PARVULASTRA VIVIPARA DISTRIBUTION.

This component of the survey involved determining the presence or absence of *P. vivipara* at various locations across Bambra Reef. Sample locations were distributed across the entire intertidal zone and at each location the GPS coordinates were recorded and a 1 m radius was searched for *P. vivipara* (see Figure 1 for survey area). Particular effort was made to delineate the boundaries of the *P. vivipara* population. Back in the laboratory, the results from the survey were overlaid on a georectifed aerial image. Estimates of reef area were also made using aerial imagery. The total reef area (incorporating intertidal and subtidal components) was estimated using aerial imagery and depth readings made during a concurrent bathymetry survey. The area of intertidal reef was also estimated from the aerial image, with the lower limit of the intertidal zone defined by the upper edge of the brown macroalgal band.

2.2 QUANTITATIVE SURVEYS OF PARVULASTRA VIVIPARA

Quantitative surveys were undertaken using strip transects. Transects were set in three zones on Bambra Reef:

1. 'Mid-high' intertidal zone. Two transects in this zone were positioned adjacent to the reef-sand edge on the shoreward boundary of the intertidal reef.
2. 'Mid intertidal' zone. Four transects were positioned at approximately mid-tide level in this zone.
3. Lower intertidal zone. Two transects in this zone were positioned at approximately low tide level.

Each transects started in the centre of the reef, radiating towards the reef edge. The transect lengths varied between 20 – 32 m.

A further two transects were positioned perpendicular to the shoreline, to better characterise the population distribution in relation to shore height. For all transects, the start and end

positions were recorded using a handheld GPS. The position of transects are illustrated in Figure 1.

On each transect, all *P. vivipara* present within 0.25 metres either side of this transect line were counted in 2 m long 'blocks', with each block incorporating 1 m^2 area of reef. Within each survey block, the reef was thoroughly searched. Where boulders and stones were present, they were carefully turned over and checked for the presence of *P. vivipara*, before being returned to their original position on the reef. Measurements of the diameter of each individual *P. vivipara* counted were made using vernier calipers. The presence of other native (e.g. *Parvulastra exigua*) and introduced seastars (e.g. *Patiriella regularis*) was also noted.

The physical characteristics of the reef within each survey block was also recorded during the transect surveys. This included a description of the reef structure (e.g. flat rock, stones), the presence of sand patches, along with a description of the reef profile (e.g. elevated ridge).

Table 1 Sampling design summary and dates of Bambra Reef *Parvulastra vivipara* surveys. See Figure 1 for position of transects.

Surveys	Tide level	Transects	Transect codes
Population delineation (presence/absence) Survey date: 18 June 2013 (Low tide 0.66 m at 0848)	Entire intertidal zone	No transects, qualitative presence/absence data	
Quantitative transects (*P. vivipara*/m^2) Survey dates: 19 June 2013 (Low tide 0.70 m at 0922) 20 June 2013 (Low tide 0.75 m at 0959)			
Parallel transects	Low intertidal Mid intertidal Mid-high tide	2 transects 4 transects 2 transects	LT1, LT2 MT1, MT2, MT3, MT4 MHT1, MHT2
Perpendicular transects	Mid – high through to low intertidal	2 transects	PT1, PT2

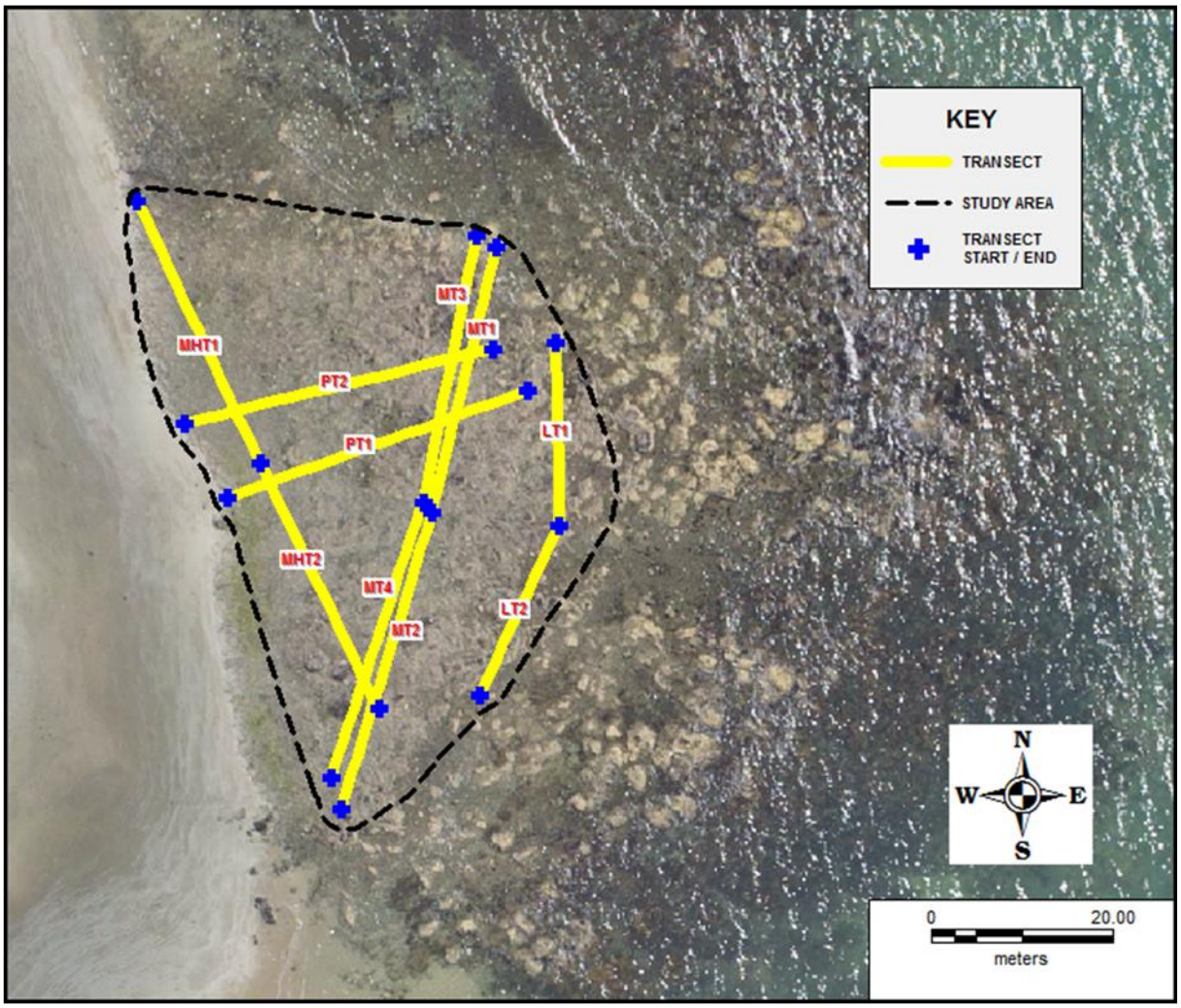

Figure 1 Survey area (dashed line) and survey transects (solid lines).

3. RESULTS

3.1 PARVULASTRA VIVIPARA DISTRIBUTION AND ABUNDANCE

Based on the qualitative assessment and the transect surveys, the population could be delineated (Figure 2). *P. vivipara* seastars were found from the shoreward edge of the reef to approximately low tide level. The *P. vivipara* population was estimated to occupy 943 m^2, out of a total of 5,465 m^2 intertidal reef (as estimated from aerial imagery; January 2013), constituting approximately 17 % of the intertidal reef area.

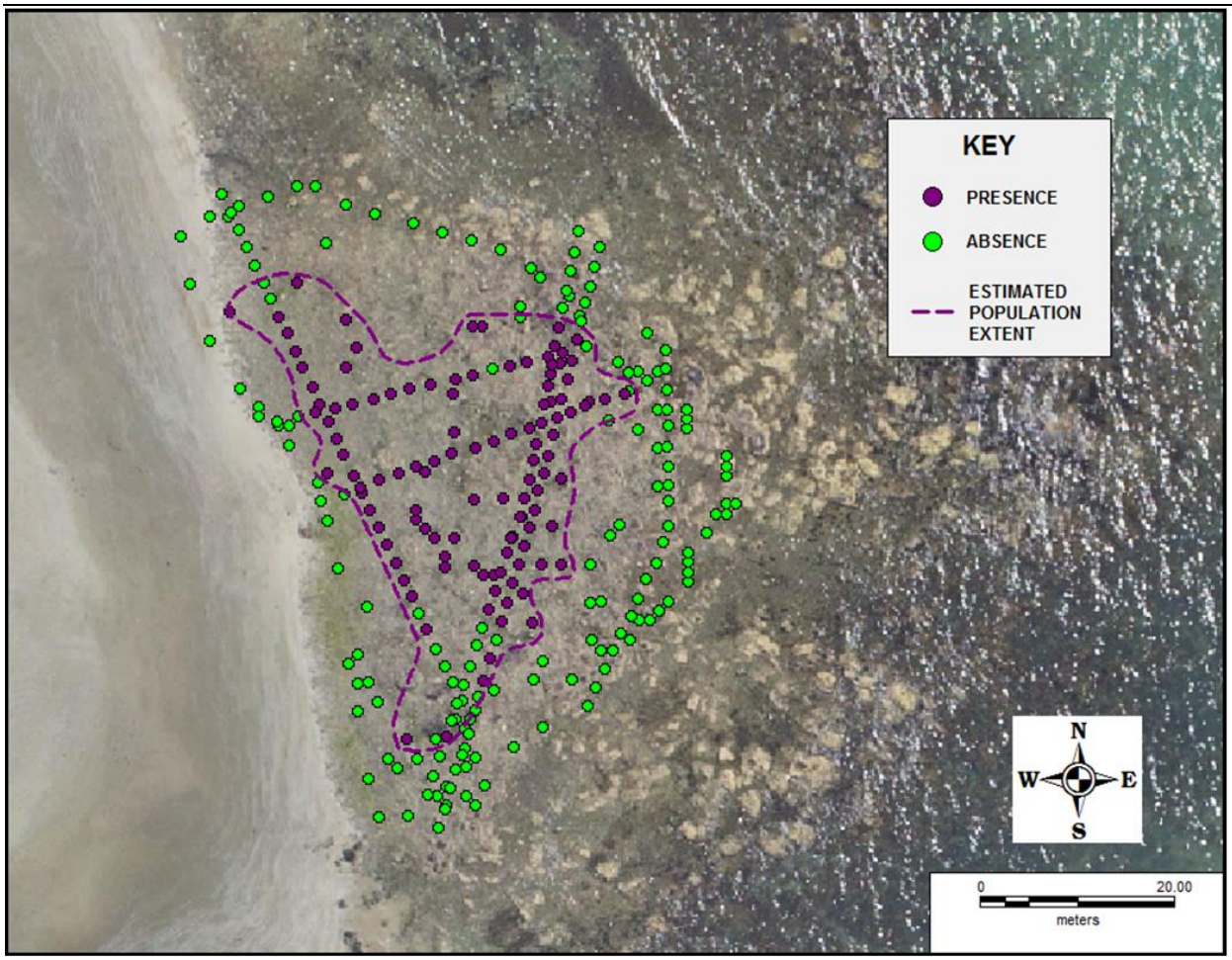

Figure 2 Delineation of the *Parvulastra vivipara* population on Bambra Reef based on presence/absence data.

During the transect survey a total of 626 individual *P. vivipara* were counted and measured. The highest mean densities were recorded in the mid-intertidal zone (Figures 3, 4; 5; mean density across 4 transects = 5.8/m^2; maximum density = 32/m^2). *P. vivipara* was present at lower densities in the mid-high intertidal zone (Figures 3, 4; 5; mean density across 2 transects = 2.1/m^2), but was not detected from transects in the lower intertidal zone. The maximum density recorded during the survey was 32/m^2. The highest density of seastars tended to be found in the central region of the mid-intertidal zone, with abundance declining towards the seaward edge and reef boundaries at the northern and southern extremities of the reef (see Figures 3, 4; 5).

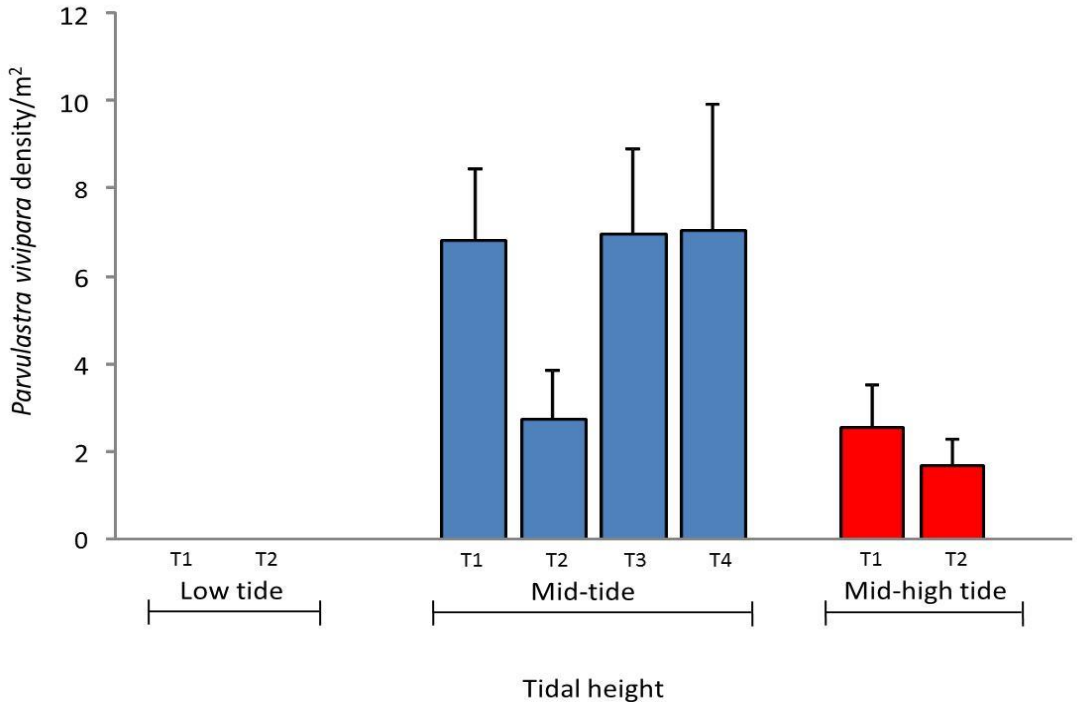

Figure 3 Density of *Parvulastra vivipara* (juveniles and adults) observed along parallel transects at different tidal heights on Bambra Reef. Bars represent mean density per 1 m^2 block (+ SE).

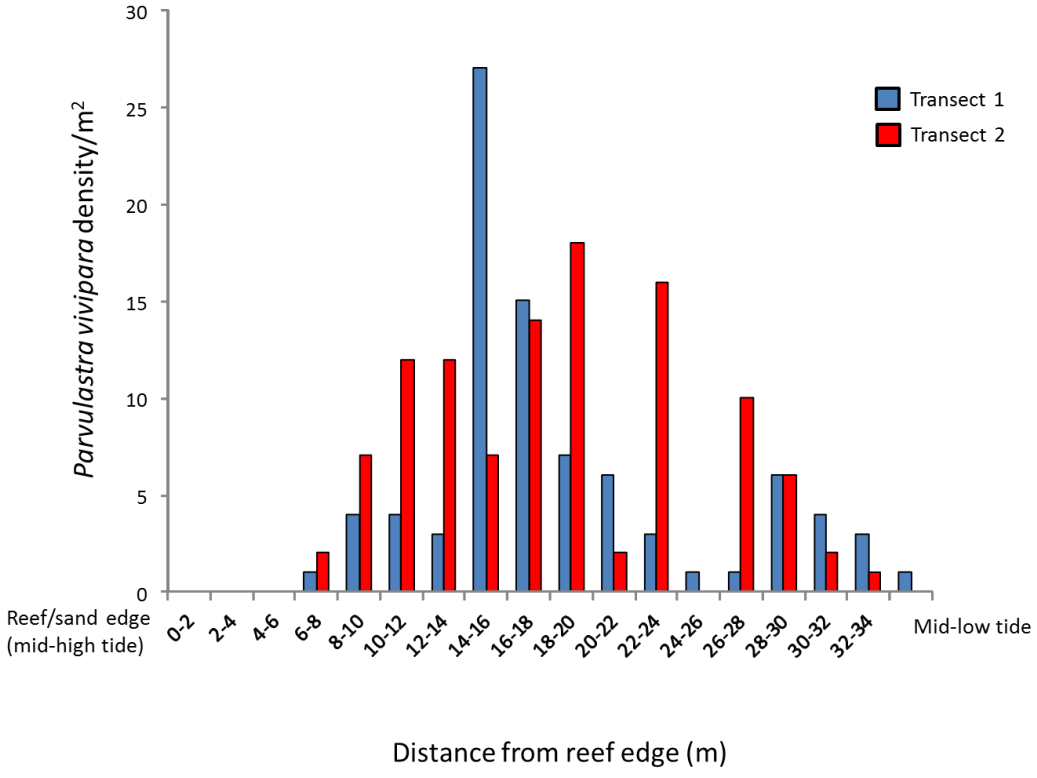

Figure 4 Density of *Parvulastra vivipara* measured at Bambra Reef on two transects set approximately perpendicular to the shoreline. Bars represent counts per 1 m^2 block.

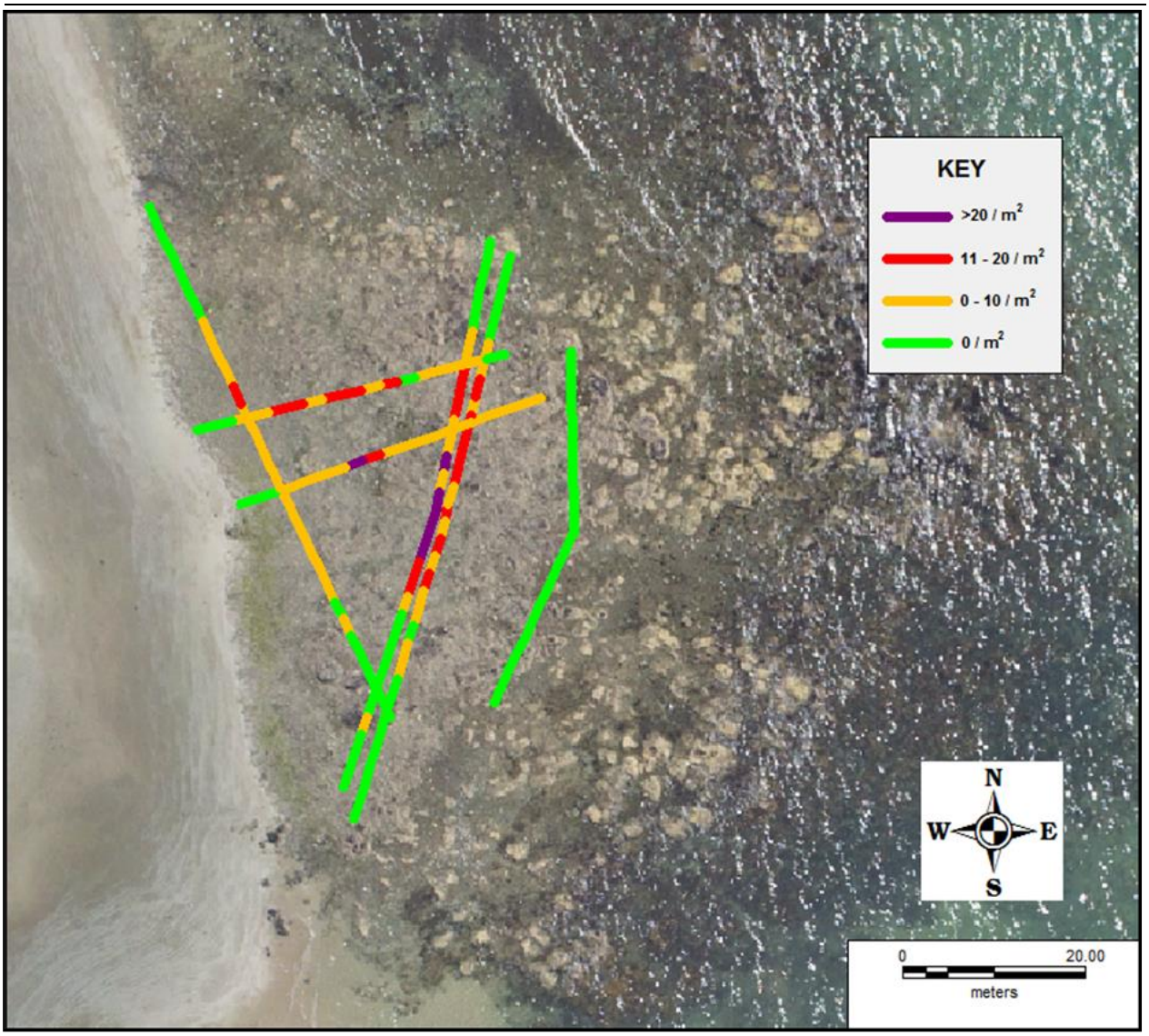

Figure 5 Distribution and relative density of *Parvulastra vivipara* on Bambra Reef, based on detailed transect observations. Survey transects were divided into 1 m^2 blocks (2 x 0.5 m). The map shows *P. vivipara* density for each 1 m^2 block. Transect dimensions are drawn to scale.

Juvenile *P. vivipara* (defined as seastars ≤ 4 mm) were commonly observed during the survey. The distribution of juveniles was comparable to the adult distribution, with the proportion of juveniles observed being similar across the various transects (Figure 6). Overall, approximately 19 % of seastars counted were juveniles.

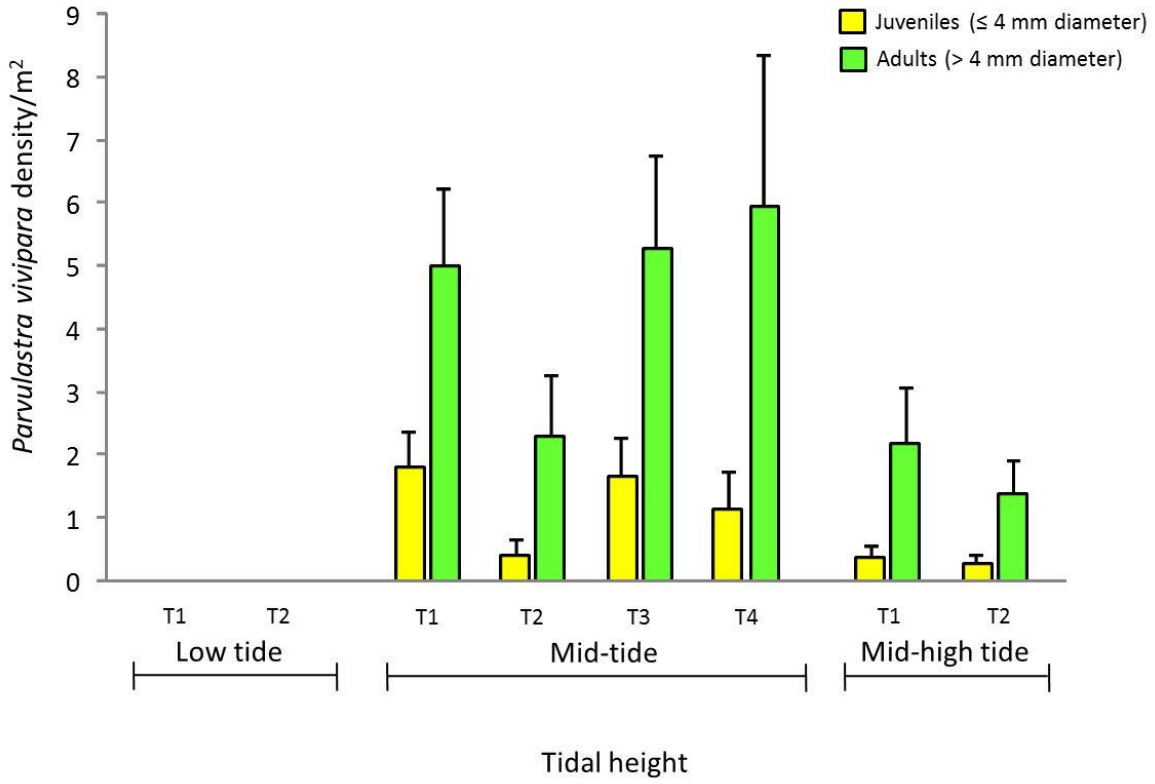

Figure 6 Density of juvenile and adult *Parvulastra vivipara* observed along parallel transects at different tidal heights on Bambra Reef. Bars represent mean density per 1 m^2 block (+ SE).

P. vivipara were most commonly found amongst loose stones and boulders 10 - 30 cm in diameter (see Appendix 2, Plate 1, images i, ii). Some individuals were observed on exposed rock surfaces, these observations tended to coincide with the inundation of intertidal rock pools. *P. vivipara* were most often attached to rock surfaces, however, a considerable number were also observed attached to smooth shell fragments (see Appendix 2, Plate 2 images iv, v). Where there was more topographic relief on the reef (i.e. raised ridges and large boulders), *P. vivipara* was rare or absent. These areas of higher complexity tended to coincide with the low intertidal/shallow subtidal zone, and were often associated with high mussel abundance (Appendix 2, Plate 2, image v).

Raw data from quantitative surveys is provided in Appendix 3.

3.2 PARVULASTRA VIVIPARA POPULATION SIZE

To determine an estimate of overall population size, the reef was divided into three zones based on the results of transect and qualitative surveys. The area of each of these zones was estimated by outlining polygons in GIS software.

The different zones and *P. vivipara* population characteristics were as follows:

(1) Area of low density (0-10/m^2) estimated as 531 m^2. Average density 3.7/m^2.

(2) Area of moderate (11-20/m^2) estimated as 335 m^2. Average density 13.3/m^2.

(3) Area of high density (> 20/m^2) estimated as 77 m^2. Average density 26.2/m^2.

Based on these variables, the overall total population size was calculated at 8,438 individuals on Bambra Reef. It should be noted that this estimate involved significant extrapolation and approximation, given that of the 943 m^2 of reef where *P. vivipara* was identified to be present, 148 m^2 was surveyed using quantitative transects. Accordingly, an estimate of approximately 8,400 is considered more realistic. The estimate is considered conservative, since some seastars are likely to remain in cryptic habitats and avoid detection during surveys.

3.3 PARVULASTRA VIVIPARA POPULATION STRUCTURE

The population structure characteristics for *P. vivipara* measured during the field survey are provided in Table 2 and Figure 7. While the average *P. vivipara* diameter was 8 mm, there appears to be at least two cohorts based on the size-frequency data (Figure 7). These include one cohort with a mode of 6 mm and another with a mode of 12 mm.

Table 2 Population size structure characteristics

Population characteristics (diameter in mm)	
Mean size	**8.3**
Median	**8**
Size range	**2-17**

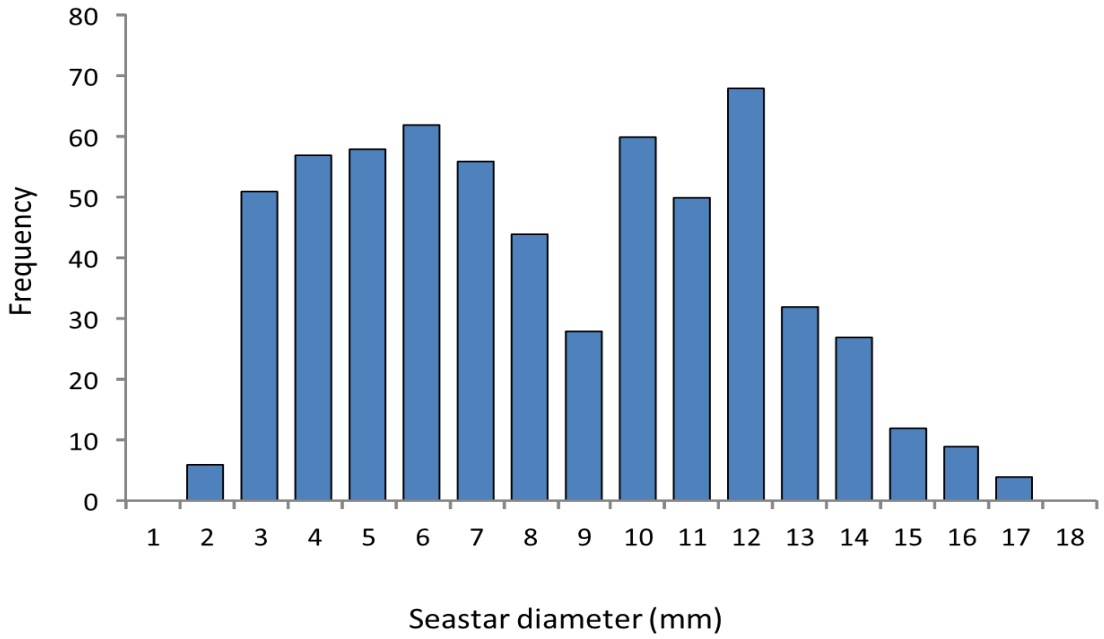

Figure 7 Size-frequency distribution of *Parvulastra vivipara* measured at Bambra Reef

3.4 OTHER ECOLOGICAL OBSERVATIONS

A diverse range of plants and animals were observed on Bambra Reef during the *P. vivipara* surveys (see Appendix 2, Plate 3). A number of other seastar species, including introduced (*Patiriella regularis*) and native species (*Meridiastra calcar*, *Coscinasterias muricata*, *Parvulastra exigua*, *Uniophora granifera*) were observed. Whilst there are anecdotal observations of the northern Pacific seastar *Asterias amurensis* in the Lauderdale area, none were observed during the current survey. While *P. vivipara* was most common in the mid and mid-high intertidal zone, most of the other seastar species tended to be found in the mid-low intertidal zone.

A range of mollusc species were abundant on Bambra Reef. Gastropod molluscs (e.g. *Austrocochlea* sp., *Bembicium* sp., *Lepsiellea* sp.), in particular, were abundant throughout the intertidal zone, while bivalve molluscs (*Limnoperna pulex*, *Mytilus galloprovincialis*, *Crassostrea gigas*) were most common in the lower intertidal zone, especially on the more exposed reef ridges. The tubeworm *Galeolaria caespitosa* was also patchily distributed across the reef, while various chiton species were abundant on the underside of rocks. The most common crustacean observed on the reef was the New Zealand half crab *Petrolisthes elongatus*. Other mobile invertebrates observed included the common shore crab and the sea hare *Aplysia* sp.

Macroalgal cover was generally low across the reef, with abundance increasing in the lower intertidal/immediate subtidal. The only exception was the shallow north-eastern fringe, where a patch of green algae (*Ulva* sp.) was evident, potentially an indication of localised nutrient enrichment on the reef. Macroalgal species observed in the lower intertidal/immediate subtidal region included *Hormosira banksii*, *Caulocystis cephalornithos*, *Cystophora* spp. and *Sargassum* spp.

4. DISCUSSION AND CONCLUSIONS

4.1 POPULATION ESTIMATE AND DISCUSSION

This work represents a rigorous assessment of the Bambra Reef population and the first survey for more than ten years. The *P. vivipara* population at Bambra Reef was estimated to include approximately 8,400 individuals, with the extent of the population estimated to encompass 943 m^2 of intertidal reef area. The highest densities were found in the central region of the reef. It appears successful reproduction has occurred in recent years, based on the existence of at least two cohorts in the population size structure.

In terms of habitat preferences, the highest densities of seastars were found amongst loose rocks in the 10-30 cm size range. In these habitats, *P. vivipara* were generally found beneath rocks and in associated microhabitats, with occasional animals observed on the exposed rocks surfaces. Such habitat preferences have been described previously for the Bambra Reef population (Prestedge 1998) and also for the largest known *P. vivipara* population that occurs on sandstone reefs at Pitt Water (Aquenal 2000).

4.2 COMPARISON WITH PREVIOUS SURVEYS AT BAMBRA REEF AND ELSEWHERE.

In terms of overall population number and densities, estimates in the current survey (~8,400; average density in mid-intertidal zone 5.8/m^2) were lower than recorded in 2000 (~17,500; average density 8.9/m^2; Rowland 2001), but considerably higher than recorded in 1983 (~400; Prestedge 1998) and 1998 (~100; Prestedge 1998). Maximum densities also appear slightly lower than 2000, with a maximum of 32/m^2 in the current survey and a maximum of 65/m^2 in 2000. In terms of the extent of population, in the current survey the area was 943 m^2 compared to 450 m^2 in 2000 and 35 m^2 in 1998. No comparison could be made with the 1983 survey, since the area was not documented (Prestedge 1998).

It must be recognised that whilst there are apparent differences between surveys, variation between studies may also manifest due to differences in survey methodologies. The 2000 study used four 4 m^2 quadrats that were each sub-sampled to give a total search area of 1.6 m^2. In the current study approximately 148 m^2 of reef area was searched on the survey transects. For the 1983 and 1998 estimates, quantitative surveys were not used, with results limited to a single population estimate. The density and population estimates in the current study are considered the most accurate and robust conducted to date. This reflects the relatively high search effort that was used compared to previous surveys. In comparison with surveys at nearby populations, the densities recorded at Bambra Reef appear relatively low. For example, average densities recorded from Pitt Water range from 4 to 103 per m^2 (Aquenal 2005).

The proportion of juveniles in the current study also appears slightly lower than measured in 2000. In the current study, the proportion of juveniles was 19%, compared to 41% juveniles in

2000 (Rowland 2001). Whilst speculative, this difference could be explained by the different timing of the 2000 survey, potentially reflecting higher juvenile abundance following spring reproduction. It must also be recognised that the confidence of juvenile abundance estimates is considered higher in the current study, given that 626 animals (including adults and juveniles) were counted, compared to a total of just 59 animals recorded in 2000 (Rowland 2001).

Another potentially important aspect of *P. vivipara* population surveys relates to behaviour. Previous work has noted that the animals feed at night or during overcast conditions (Prestedge 1998). Such behaviour could have implications for monitoring data if animals are more readily detectable during certain conditions. However, at Bambra Reef most animals occurred amongst loose stones, which can be easily be overturned and searched, so effects on density estimates are considered unlikely in this study.

4.3 CURRENT THREATS AND LIKELY IMPACTS

The isolated nature of Bambra Reef and the fact that it is bounded by sand means that the population is potentially very vulnerable to both natural and anthropogenic impacts. The most likely natural impact is likely to be storm events. As Prestedge (1998) noted, the rock shelf at Bambra Reef can be subjected to considerable wave action, which has the potential to disturb *P. vivipara* populations.

A range of anthropogenic impacts have the potential to influence the Bambra Reef population, such as impacts associated with reduced water quality from sewerage spills, septic tank seepage or storm water runoff (Prestedge 1998). The patch of ephemeral green algae observed on a section of Bambra Reef in the current survey is potentially related to such localised elevated nutrients conditions. Improvements to sewage infrastructure currently underway in the Lauderdale area should reduce the likelihood of nutrient related impacts on water quality.

In relation to introduced species, competition, displacement and potential predation by introduced seastars currently does not appear to be having major impact on the *P. vivipara* population. It appears that there is some habitat separation between *P. vivipara* and *Patiriella regularis*, with *P. regularis* occurring at lower levels of the intertidal zone. With regard to *Asterias amurensis*, none were observed in the intertidal zone in the current study. Based on observations in the Derwent River, it is the relatively high energy intertidal zone at Bambra Reef is unlikely to be suitable for *A. amurensis*.

As noted in the introduction, climate change related impacts potentially represent the greatest threat to the *P. vivipara* population. During erosive storm events sand is eroded from dune systems and transported to the shallow sub-tidal environments, then transported northward with longshore drift (Whitehead 2012). This process has the potential to bury Bambra Reef and

the rocky intertidal zone beneath sand and cause the loss, or partial loss of *P. vivipara* (Whitehead 2012).

While there appears to be some variability in the overall extent of Bambra Reef (Whitehead 2012), past measurements have included intertidal and subtidal sections of reef. From the perspective of *P. vivipara*, it is important to monitor changes in extent of intertidal reef. The intertidal area estimated as part of the current study (5,465 m^2) exceeds the estimate of 1,500 m^2 made in September 2000 (Rowland 2001). There are limitations when comparing these estimates, since the criteria used to determine the intertidal area were not defined in the 2000 assessment. It is recommended that a consistent approach to quantifying the intertidal habitat is included as part of future *P. vivipara* monitoring activities (see section 4.5 below).

4.4 POTENTIAL TRANSLOCATION ACTIVITIES

It has been suggested previously that translocation of *P. vivipara* may be considered in the future (Whitehead 2012). Such activities would involve translocation of *P. vivipara* from the Bambra Reef to new sites that provide more secure habitat, with the aim of preserving the potential genetic diversity that the colony may contain (Whitehead 2012). Translocation has been successfully undertaken elsewhere (e.g. Aquenal 2005). If translocation activities are proposed it is important that risks to the current colonies and also to the native fauna and flora at the potential translocations sites are thoroughly assessed (Whitehead 2012).

In relation to potential translocation activities, it is important to identify triggers for management action and the appropriate management steps if the Bambra Reef colony is at risk of localised extinction due to sediment burial. As noted earlier, measurement of the area of intertidal reef and suitable *P. vivipara* habitat is viewed as an important element of identifying triggers for management actions. The effect of sand nourishment activities (Aquenal 2013) or potential groyne construction may also need to consider the *P. vivipara* population (Whitehead 2012). Such activities need to assess the risk level to *P. vivipara* caused by altered sand deposition (Whitehead 2012).

4.5 FUTURE MONITORING AND RECOMMENDATIONS

There appears to have been considerable variability in the *P. vivipara* population size and density at Bambra Reef over the last 30 years. Nevertheless, considerable threats to the population remain. Given these potential threats, particularly from climate-change related impacts, future monitoring of the Bambra Reef population is recommended. Monitoring should sensibly adopt the approach used in the current study, including quantitative estimates of population densities, overall population size and population extent. It would be of considerable benefit to future comparisons if the transect methodology used in the current survey is applied

in future surveys, since this would eliminate potential differences in population estimates as a result of different survey methodologies. For future monitoring purposes, transects should focus on the mid and mid-high intertidal zone, given that no *P. vivipara* were present in the low intertidal zone. Ongoing monitoring of the *P. vivipara* population also has the added benefit of tracking other potential threats (e.g. introduced species). Higher resolution sampling of *P. vivipara* using fixed quadrat positions over smaller spatial scales may also be warranted to provide more precise estimates of seasonal variability in density and population size structure.

Future monitoring should also incorporate an estimate of intertidal reef area, since differences in reef area is potentially a key indicator of threat to the *P. vivipara* population. A consistent approach is also recommended for determination of intertidal reef area. Ultimately, ongoing monitoring of reef area and *P. vivipara* population status provides important quantitative information that may be used to guide management of Bambra Reef.

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APPENDIX 1 GEOGRAPHICAL COORDINATES (GDA 94, ZONE 55) FOR TRANSECTS.

Tide Level	Transect	Code	Start		End	
			Easting	Northing	Easting	Northing
Low	1	LT1	540976	5250821	540976	5250844
Low	2	LT2	540976	5250821	540968	5250804
Mid	1	MT1	540962	5250823	540968	5250847
Mid	2	MT2	540962	5250823	540948	5250791
Mid	3	MT3	540961	5250824	540967	5250853
Mid	4	MT4	540961	5250824	540951	5250794
Mid-high	1	MHT1	540943	5250829	540928	5250853
Mid-high	2	MHT2	540943	5250829	540956	5250801
Perpendicular	1	PT1	540940	5250825	540972	5250836
Perpendicular	2	PT2	540934	5250833	540969	5250841

APPENDIX 2 IMAGES TAKEN DURING SAMPLING ACTIVITIES AT BAMBRA REEF

Plate 1. Images taken during Bambra Reef surveys: (i, ii) Typical *P. vivipara* habitat: (iii-vi) *P. vivipara* individuals observed during survey, (vi) juvenile *P. vivipara* beneath rock.

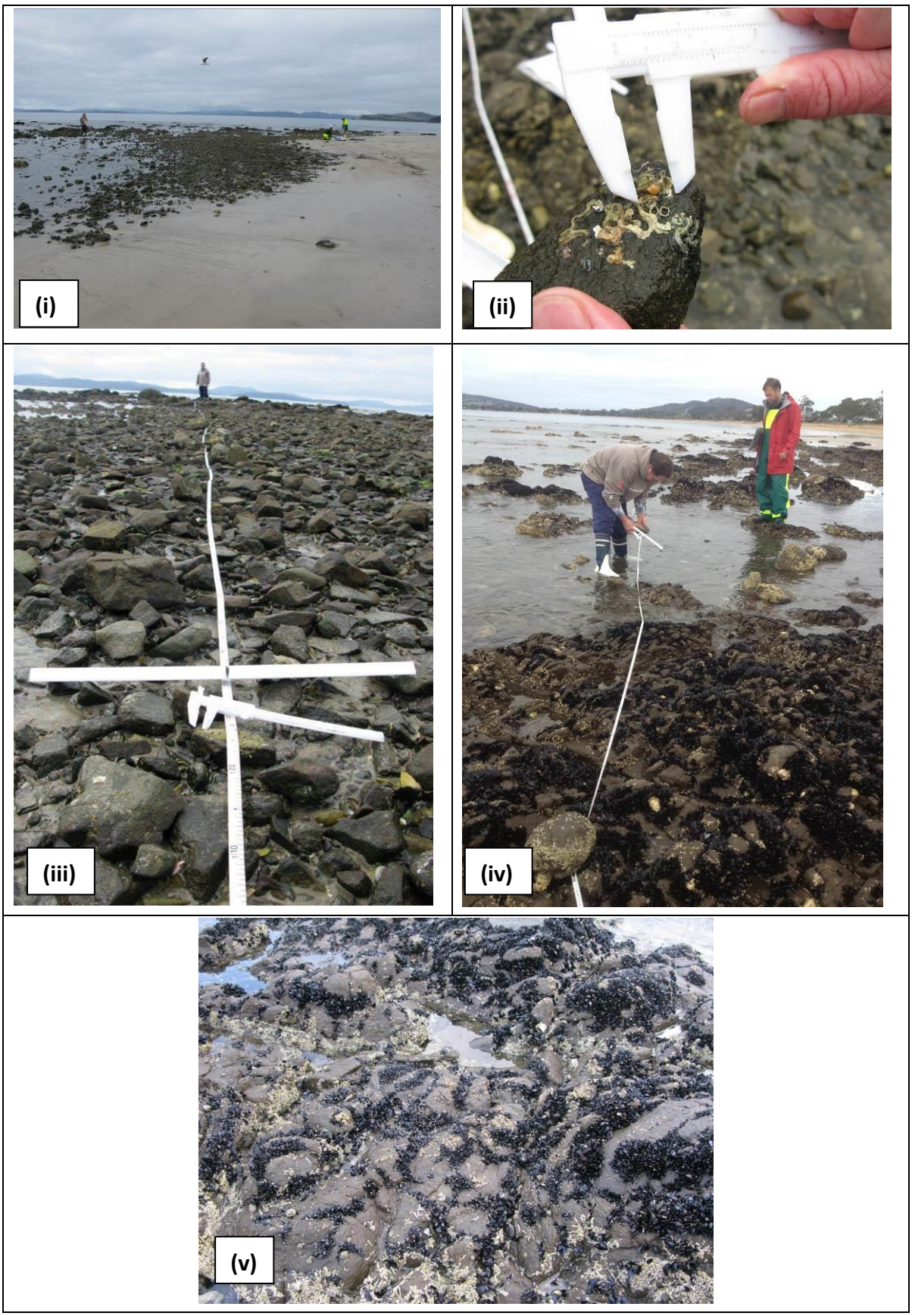

Plate 2. Images taken during Bambra Reef surveys: (i) reef overview; (ii) measuring *P. vivipara* juvenile; (iii,iv) transect surveys; (v) mussel dominated reef ridges (poor *P. vivipara* habitat).

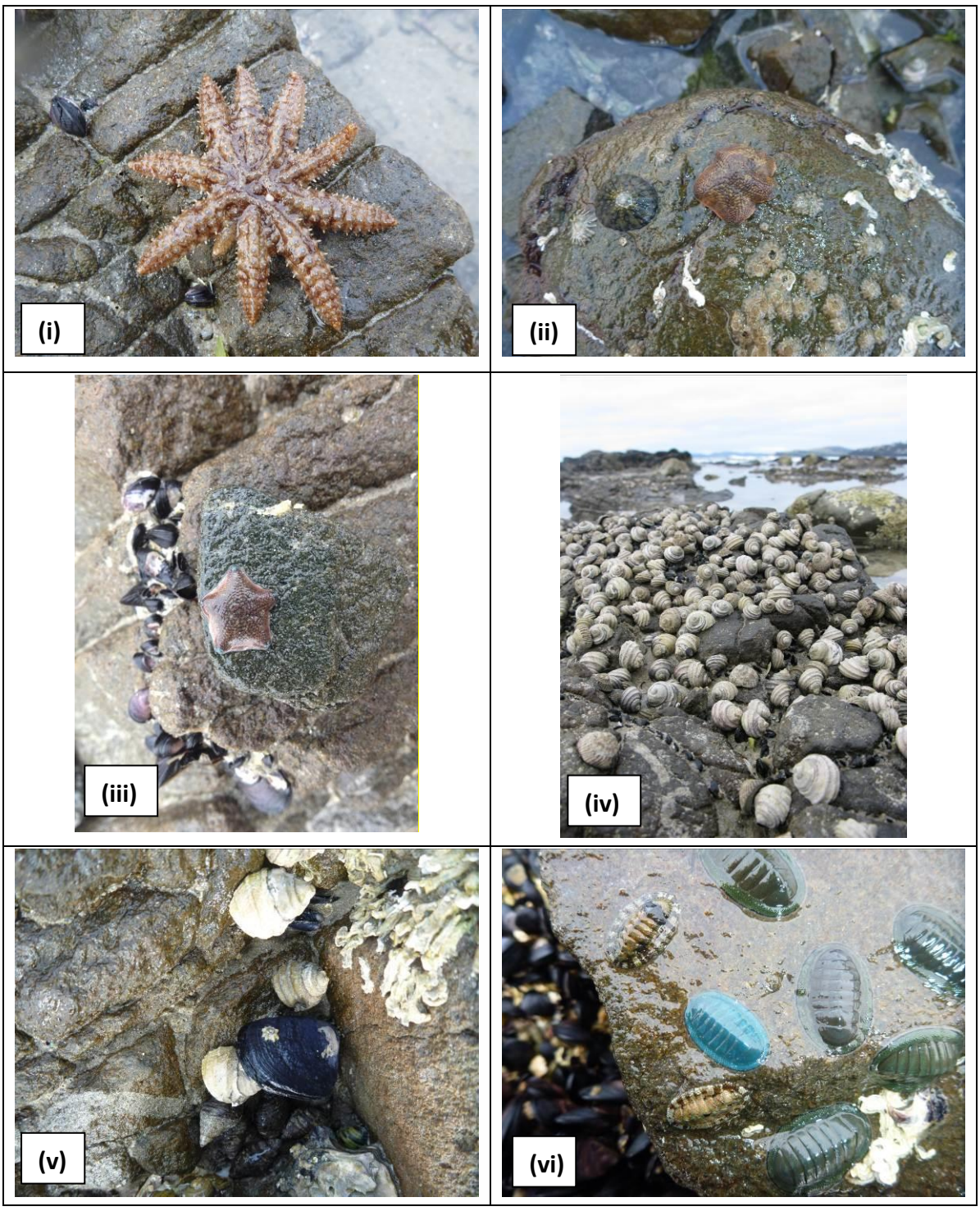

Plate 3. Images taken during Bambra Reef surveys: (i) *Coscinasterias muricata*; (ii) *Parvulastra exigua*; (iii) *Patiriella regularis*; (iv, v) gastropod molluscs; (vi) chitons on underside of rocks.

APPENDIX 3 RAW DATA FROM QUANTITATIVE SURVEYS

Tide level	Transect No.	ID	Start GPS east	Start GPS north	End GPS east	End GPS north	Transect distance	Reef structure/Comments	Juveniles (/m2)	Adults (/m2)	Total (/m^2)
Low	T1	LT1	540976	5250821	540976	5250844	0-2	Flat rock; mussels on ridges (30 cm height), *Hormosira banksii* in depressions, *Meridiastra calcar* and *P. exigua* present	0	0	0
Low	T1	LT1	540976	5250821	540976	5250844	2-4	Flat rock; mussels and oysters on ridges (30 cm height), *Hormosira* in depressions, *Meridiastra calcar* and *P. exigua* present	0	0	0
Low	T1	LT1	540976	5250821	540976	5250844	4-6	Flat rock with 15 cm high ridges; 40 % mussels, 10 % tubeworms	0	0	0
Low	T1	LT1	540976	5250821	540976	5250844	6-8	Flat rock with some loose stones; 20 % mussels	0	0	0
Low	T1	LT1	540976	5250821	540976	5250844	8-10	Flat rock with some loose stones; 20 % mussels	0	0	0
Low	T1	LT1	540976	5250821	540976	5250844	10-12	Flat rock with small stones; 10 % tubeworms	0	0	0
Low	T1	LT1	540976	5250821	540976	5250844	12-14	Flat rock with small stones	0	0	0
Low	T1	LT1	540976	5250821	540976	5250844	14-16	Flat rock with 20-50 cm boulders; oysters and mussels on boulder tops, macroalgae in depressions (*Hormosira banksii* and *Caulocystis* sp.)	0	0	0
Low	T1	LT1	540976	5250821	540976	5250844	16-18	Flat rock with 20-50 cm boulders; oysters and mussels on boulder tops, macroalgae in depressions (*Hormosira banksii* and *Caulocystis* sp.)	0	0	0

Tide level	Transect No.	ID	Start GPS east	Start GPS north	End GPS east	End GPS north	Transect distance	Reef structure/Comments	Juveniles (/m2)	Adults (/m2)	Total (/m^2)
Low	T1	LT1	540976	5250821	540976	5250844	18-20	Flat rock; oysters and mussels on boulder tops, macroalgae in depressions (*Hormosira banksii* and *Caulocystis* sp.)	0	0	0
Low	T2	LT2	540976	5250821	540968	5250804	0-2	Flat rock with raised ridges; mussels on ridge tops	0	0	0
Low	T2	LT2	540976	5250821	540968	5250804	2-4	Flat rock with loose stones	0	0	0
Low	T2	LT2	540976	5250821	540968	5250804	4-6	Flat rock with loose stones	0	0	0
Low	T2	LT2	540976	5250821	540968	5250804	6-8	Flat rock with some stones	0	0	0
Low	T2	LT2	540976	5250821	540968	5250804	8-10	Undulating flat rock; patchy mussels	0	0	0
Low	T2	LT2	540976	5250821	540968	5250804	10-12	Undulating flat rock with ridges; mussels on ridge tops	0	0	0
Low	T2	LT2	540976	5250821	540968	5250804	12-14	Flat rock with some stones	0	0	0
Low	T2	LT2	540976	5250821	540968	5250804	14-16	Flat rock with some stones	0	0	0
Low	T2	LT2	540976	5250821	540968	5250804	16-18	Flat rock with some stones and thin sand layer	0	0	0
Low	T2	LT2	540976	5250821	540968	5250804	18-20	Flat rock with some stones and thin sand layer	0	0	0
Mid	T1	MT1	540962	5250823	540968	5250847	0-2	Flat rock with small loose stones; *Patiriella exigua* present	3	8	11
Mid	T1	MT1	540962	5250823	540968	5250847	2-4	Flat rock with small loose stones	1	5	6
Mid	T1	MT1	540962	5250823	540968	5250847	4-6	Flat rock with small loose stones; encrusting tubeworms and mussels	7	10	17
Mid	T1	MT1	540962	5250823	540968	5250847	6-8	Flat rock with sparse stones; 20 % mussel cover	2	13	15
Mid	T1	MT1	540962	5250823	540968	5250847	8-10	Flat rock with small loose stones; 10 % mussel cover	5	7	12

Tide level	Transect No.	ID	Start GPS east	Start GPS north	End GPS east	End GPS north	Transect distance	Reef structure/Comments	Juveniles (/m2)	Adults (/m2)	Total (/m^2)
Mid	T1	MT1	540962	5250823	540968	5250847	10-12	Flat rock with small loose stones; 5 % tubeworm, 5 % mussels	4	10	14
Mid	T1	MT1	540962	5250823	540968	5250847	12-14	Flat rock with sparse stones; < 5 % mussel and tubeworm cover	2	7	9
Mid	T1	MT1	540962	5250823	540968	5250847	14-16	Flat rock with small loose stones; 5 % tubeworm, < 5 % mussels	0	11	11
Mid	T1	MT1	540962	5250823	540968	5250847	16-18	Flat rock with sparse stones; < 5% mussel and tubeworm cover	2	4	6
Mid	T1	MT1	540962	5250823	540968	5250847	18-20	Flat rock with sparse stones; < 5% mussel and tubeworm cover	1	0	1
Mid	T1	MT1	540962	5250823	540968	5250847	20-22	Flat rock, elevated ~0.5 m; large boulder with 30 % mussel and tubeworm	0	0	0
Mid	T1	MT1	540962	5250823	540968	5250847	22-24	Flat rock dominant; 5% tubeworm, < 5 % mussel	0	0	0
Mid	T1	MT1	540962	5250823	540968	5250847	24-26	Flat rock with ridges, 50 % mussel, 10 % tubeworm	0	0	0
Mid	T1	MT1	540962	5250823	540968	5250847	26-28	Flat rock with sparse cover of small stones; < 5 % mussel and tubeworms	0	0	0
Mid	T1	MT1	540962	5250823	540968	5250847	28-30	Flat rock with sparse cover of small stones; < 5 % mussel and tubeworms	0	0	0
Mid	T2	MT2	540962	5250823	540948	5250791	0-2	Flat rock with small (10-20 cm) loose stones	0	6	6
Mid	T2	MT2	540962	5250823	540948	5250791	2-4	Flat rock with small loose stones	4	8	12
Mid	T2	MT2	540962	5250823	540948	5250791	4-6	Flat rock with very small loose stones	1	8	9
Mid	T2	MT2	540962	5250823	540948	5250791	6-8	Flat rock with small loose stones	1	13	14
Mid	T2	MT2	540962	5250823	540948	5250791	8-10	Flat rock (slightly raised) with small loose stones	0	1	1

Tide level	Transect No.	ID	Start GPS east	Start GPS north	End GPS east	End GPS north	Transect distance	Reef structure/Comments	Juveniles (/m2)	Adults (/m2)	Total (/m^2)
Mid	T2	MT2	540962	5250823	540948	5250791	10-12	Flat rock with some loose stones	1	1	2
Mid	T2	MT2	540962	5250823	540948	5250791	12-14	Flat rock, slightly raised; Mussels (*Limnoperna pulex*) 20 %	0	0	0
Mid	T2	MT2	540962	5250823	540948	5250791	14-16	Flat rock with small loose stones	0	1	1
Mid	T2	MT2	540962	5250823	540948	5250791	16-18	Flat rock with some loose stones	0	1	1
Mid	T2	MT2	540962	5250823	540948	5250791	18-20	Flat rock with loose stones; slightly raised; 60-70 % mussels	0	0	0
Mid	T2	MT2	540962	5250823	540948	5250791	20-22	Flat rock with loose stones	0	0	0
Mid	T2	MT2	540962	5250823	540948	5250791	22-24	Flat rock with loose stones; 4 *Coscinasterias muricata*	0	0	0
Mid	T2	MT2	540962	5250823	540948	5250791	24-26	Flat rock with loose stones	0	0	0
Mid	T2	MT2	540962	5250823	540948	5250791	26-28	Flat rock with loose stones	0	0	0
Mid	T2	MT2	540962	5250823	540948	5250791	28-30	Flat rock with loose stones	0	0	0
Mid	T2	MT2	540962	5250823	540948	5250791	30-32	Sand 80%; Rock 20%	0	0	0
Mid	T2	MT2	540962	5250823	540948	5250791	32-34	Sand 90%; Rock 10%	0	0	0
Mid	T3	MT3	540961	5250824	540967	5250853	0-2	Flat rock with small loose stones; < 5 % mussel and tubeworms	5	19	24
Mid	T3	MT3	540961	5250824	540967	5250853	2-4	Flat rock, two 30 cm rocks; 5 % mussels, 5 % tubeworms	2	5	7
Mid	T3	MT3	540961	5250824	540967	5250853	4-6	Flat rock with small loose stones; 5 % mussels, < 5 % tubeworms	7	14	21
Mid	T3	MT3	540961	5250824	540967	5250853	6-8	Flat rock with 30 cm diameter rock, 15 % mussels, 5 % tubeworms	0	7	7
Mid	T3	MT3	540961	5250824	540967	5250853	8-10	Flat rock, sparse stones; 40 % mussels, < 5 % tubeworms	1	4	5

Tide level	Transect No.	ID	Start GPS east	Start GPS north	End GPS east	End GPS north	Transect distance	Reef structure/Comments	Juveniles (/m2)	Adults (/m2)	Total (/m^2)
Mid	T3	MT3	540961	5250824	540967	5250853	10-12	Undulating flat rock up to 0.5 m elevation, 10-15 % mussel, 10-15 % tubeworm	2	10	12
Mid	T3	MT3	540961	5250824	540967	5250853	12-14	Flat rock with small loose stones; < 5 % mussel, < 5 % tubeworms	5	6	11
Mid	T3	MT3	540961	5250824	540967	5250853	14-16	Undulating flat rock, two 20 cm rocks < 5 % mussel, 10 % tubeworm	2	9	11
Mid	T3	MT3	540961	5250824	540967	5250853	16-18	Flat rock; < 5 % mussels and tubeworms	0	2	2
Mid	T3	MT3	540961	5250824	540967	5250853	18-20	Undulating, elevation to 0.4 m; 15 % tubeworm	1	3	4
Mid	T3	MT3	540961	5250824	540967	5250853	20-22	Undulating, elevation to 0.6 m, one large boulder; 30 % mussel	0	0	0
Mid	T3	MT3	540961	5250824	540967	5250853	22-24	Undulating, elevation to 0.6 m; 50 % mussel, 20 % tubeworm	0	0	0
Mid	T3	MT3	540961	5250824	540967	5250853	24-26	Flat rock with large rocks (40 cm diameter); 15 % mussels, 5 % tubeworms	0	0	0
Mid	T3	MT3	540961	5250824	540967	5250853	26-28	Flat rock; 20 % mussel, 15 % tubeworms	0	0	0
Mid	T3	MT3	540961	5250824	540967	5250853	28-30	Flat rock; 10 % mussel, 20 % tubeworms	0	0	0
Mid	T4	MT4	540961	5250824	540951	5250794	0-2	Flat rock with small (10-20 cm) loose stones	1	24	25
Mid	T4	MT4	540961	5250824	540951	5250794	2-4	Flat rock with small loose stones	4	28	32
Mid	T4	MT4	540961	5250824	540951	5250794	4-6	Flat rock with some small loose stones; slightly elevated reef profile	9	19	28
Mid	T4	MT4	540961	5250824	540951	5250794	6-8	Flat rock with some small loose stones; slightly elevated reef profile	1	11	12
Mid	T4	MT4	540961	5250824	540951	5250794	8-10	Flat rock with small loose stones	3	10	13

Tide level	Transect No.	ID	Start GPS east	Start GPS north	End GPS east	End GPS north	Transect distance	Reef structure/Comments	Juveniles (/m2)	Adults (/m2)	Total (/m^2)
Mid	T4	MT4	540961	5250824	540951	5250794	10-12	Flat rock with small loose stones	0	2	2
Mid	T4	MT4	540961	5250824	540951	5250794	12-14	Flat rock with small loose stones	0	0	0
Mid	T4	MT4	540961	5250824	540951	5250794	14-16	Flat rock with small loose stones	0	0	0
Mid	T4	MT4	540961	5250824	540951	5250794	16-18	Flat rock with some small loose stones; slightly elevated reef profile; mussels present	0	0	0
Mid	T4	MT4	540961	5250824	540951	5250794	18-20	Rock pool, thin sand layer, small stones	0	0	0
Mid	T4	MT4	540961	5250824	540951	5250794	20-22	Flat rock, elevation to 0.5 m; mussels	0	0	0
Mid	T4	MT4	540961	5250824	540951	5250794	22-24	Flat rock, elevation to 0.5 m; mussels	0	0	0
Mid	T4	MT4	540961	5250824	540951	5250794	24-26	Flat rock with small loose stones	0	1	1
Mid	T4	MT4	540961	5250824	540951	5250794	26-28	Flat rock with slightly raised profile, mussels, *Coscinasterias muricata*	0	0	0
Mid	T4	MT4	540961	5250824	540951	5250794	28-30	Flat rock with small loose stones, thin sand covering	0	0	0
Mid	T4	MT4	540961	5250824	540951	5250794	30-32	Flat rock with small loose stones, thin sand covering	0	0	0
Mid-High	T1	MHT1	540943	5250829	540928	5250853	0-2	Loose stones and rubble on sand/flat rock	0	1	1
Mid-High	T1	MHT1	540943	5250829	540928	5250853	2-4	Loose stones and rubble on sand/flat rock	1	0	1
Mid-High	T1	MHT1	540943	5250829	540928	5250853	4-6	Loose stones and rubble on sand/flat rock; Coscinasterias muricata present	0	3	3
Mid-High	T1	MHT1	540943	5250829	540928	5250853	6-8	Loose stones and rubble on sand/flat rock	1	2	3
Mid-High	T1	MHT1	540943	5250829	540928	5250853	8-10	Loose stones and rubble on sand/flat rock	2	11	13

Tide level	Transect No.	ID	Start GPS east	Start GPS north	End GPS east	End GPS north	Transect distance	Reef structure/Comments	Juveniles (/m2)	Adults (/m2)	Total (/m^2)
Mid-High	T1	MHT1	540943	5250829	540928	5250853	10-12	Loose stones and rubble on sand/flat rock	0	7	7
Mid-High	T1	MHT1	540943	5250829	540928	5250853	12-14	Loose stones and rubble on sand/flat rock	1	8	9
Mid-High	T1	MHT1	540943	5250829	540928	5250853	14-16	Loose stones and rubble on sand/flat rock	0	1	1
Mid-High	T1	MHT1	540943	5250829	540928	5250853	16-18	Loose stones and rubble on sand/flat rock	1	2	3
Mid-High	T1	MHT1	540943	5250829	540928	5250853	18-20	Loose stones and rubble on sand/flat rock, sand and shell grit; green filamentous algae (*Ulva*)	0	0	0
Mid-High	T1	MHT1	540943	5250829	540928	5250853	20-22	Loose stones and rubble on sand/flat rock; green filamentous algae (*Ulva*)	0	0	0
Mid-High	T1	MHT1	540943	5250829	540928	5250853	22-24	Loose stones and rubble on sand/flat rock; green filamentous algae (*Ulva*)	0	0	0
Mid-High	T1	MHT1	540943	5250829	540928	5250853	24-26	Loose stones and rubble on sand/flat rock; green filamentous algae (*Ulva*)	0	0	0
Mid-High	T1	MHT1	540943	5250829	540928	5250853	26-28	Sand with stones	0	0	0
Mid-High	T1	MHT1	540943	5250829	540928	5250853	28-30	Sand with stones	0	0	0
Mid-High	T1	MHT1	540943	5250829	540928	5250853	30-32	Sand with stones; sand edge at 32 m	0	0	0
Mid-High	T2	MHT2	540943	5250829	540956	5250801	0-2	Stones over sand/flat rock, sand in depressions; < 5 % tubeworm cover	0	1	1
Mid-High	T2	MHT2	540943	5250829	540956	5250801	2-4	Stones over sand/flat rock, sand in depressions; < 5 % tubeworm cover	0	2	2
Mid-High	T2	MHT2	540943	5250829	540956	5250801	4-6	Stones over sand/flat rock, sand in depressions; < 5 % tubeworm cover	0	3	3
Mid-High	T2	MHT2	540943	5250829	540956	5250801	6-8	Stones over sand/flat rock, 50 % sand	0	2	2

Tide level	Transect No.	ID	Start GPS east	Start GPS north	End GPS east	End GPS north	Transect distance	Reef structure/Comments	Juveniles (/m2)	Adults (/m2)	Total (/m^2)
Mid-High	T2	MHT2	540943	5250829	540956	5250801	8-10	Stones over sand/flat rock, 50 % sand	0	5	5
Mid-High	T2	MHT2	540943	5250829	540956	5250801	10-12	Stones over sand/flat rock, 20 % sand	2	6	8
Mid-High	T2	MHT2	540943	5250829	540956	5250801	12-14	Stones over sand/flat rock, 10 % sand	1	1	2
Mid-High	T2	MHT2	540943	5250829	540956	5250801	14-16	Stones over sand/flat rock, 10 % sand	0	1	1
Mid-High	T2	MHT2	540943	5250829	540956	5250801	16-18	Stones over sand/flat rock, 10 % sand	0	0	0
Mid-High	T2	MHT2	540943	5250829	540956	5250801	18-20	Flat rock with stones; 5 % tubeworms	1	0	1
Mid-High	T2	MHT2	540943	5250829	540956	5250801	20-22	Flat rock, low number of small stones	0	0	0
Mid-High	T2	MHT2	540943	5250829	540956	5250801	22-24	Flat rock, low number of small stones, 30 % sand	0	0	0
Mid-High	T2	MHT2	540943	5250829	540956	5250801	24-26	Flat rock, elevation to 0.5 m; 50 % mussels	0	0	0
Mid-High	T2	MHT2	540943	5250829	540956	5250801	26-28	Flat bedrock, few stones; depressions with sand and *Gracilaria* (red algae)	0	0	0
Mid-High	T2	MHT2	540943	5250829	540956	5250801	28-30	Flat rock, elevation to 30 cm; 50 % mussels	0	0	0
Perpendicular	T1	PT1	540940	5250825	540972	5250836	0-2	Sand and stones; *Coscinasterias muricata*	0	0	0
Perpendicular	T1	PT1	540940	5250825	540972	5250836	2-4	Sand and stones	0	0	0
Perpendicular	T1	PT1	540940	5250825	540972	5250836	4-6	Flat rock, sand and stones	0	1	1
Perpendicular	T1	PT1	540940	5250825	540972	5250836	6-8	Flat rock with small stones on sand	0	4	4
Perpendicular	T1	PT1	540940	5250825	540972	5250836	8-10	Flat rock with small loose stones	1	3	4
Perpendicular	T1	PT1	540940	5250825	540972	5250836	10-12	Flat rock with sand and small loose stones	1	2	3
Perpendicular	T1	PT1	540940	5250825	540972	5250836	12-14	Flat rock with sand and small loose stones	6	21	27

Tide level	Transect No.	ID	Start GPS east	Start GPS north	End GPS east	End GPS north	Transect distance	Reef structure/Comments	Juveniles (/m2)	Adults (/m2)	Total (/m^2)
Perpendicular	T1	PT1	540940	5250825	540972	5250836	14-16	Flat rock with sand and small loose stones	2	13	15
Perpendicular	T1	PT1	540940	5250825	540972	5250836	16-18	Flat rock with sand and small loose stones	0	7	7
Perpendicular	T1	PT1	540940	5250825	540972	5250836	18-20	Flat rock, stones, slightly raised profile; mussels on raised sections	0	6	6
Perpendicular	T1	PT1	540940	5250825	540972	5250836	20-22	Flat rock, stones, slightly raised profile; mussels on raised sections	1	2	3
Perpendicular	T1	PT1	540940	5250825	540972	5250836	22-24	Flat rock, stones, slightly raised profile; mussels on raised sections	0	1	1
Perpendicular	T1	PT1	540940	5250825	540972	5250836	24-26	Flat rock, stones, slightly raised profile; mussels on raised sections	0	1	1
Perpendicular	T1	PT1	540940	5250825	540972	5250836	26-28	Flat rock with small stones	1	5	6
Perpendicular	T1	PT1	540940	5250825	540972	5250836	28-30	Flat rock with small stones	1	3	4
Perpendicular	T1	PT1	540940	5250825	540972	5250836	30-32	Flat rock with few small stones	0	3	3
Perpendicular	T1	PT1	540940	5250825	540972	5250836	32-34	Flat rock with few small stones	0	1	1
Perpendicular	T2	PT2	540934	5250833	540969	5250841	0-2	Stones on sand	0	0	0
Perpendicular	T2	PT2	540934	5250833	540969	5250841	2-4	Stones on sand and flat rock	0	0	0
Perpendicular	T2	PT2	540934	5250833	540969	5250841	4-6	Stones on sand and flat rock; <5 % tubeworms	1	1	2
Perpendicular	T2	PT2	540934	5250833	540969	5250841	6-8	Flat rock with small stones	3	4	7
Perpendicular	T2	PT2	540934	5250833	540969	5250841	8-10	Flat rock with small stones	2	10	12
Perpendicular	T2	PT2	540934	5250833	540969	5250841	10-12	Flat rock with small stones	0	12	12
Perpendicular	T2	PT2	540934	5250833	540969	5250841	12-14	Flat rock with small stones	0	7	7
Perpendicular	T2	PT2	540934	5250833	540969	5250841	14-16	Flat rock with small stones	1	13	14
Perpendicular	T2	PT2	540934	5250833	540969	5250841	16-18	Flat rock with small stones	2	16	18

Tide level	Transect No.	ID	Start GPS east	Start GPS north	End GPS east	End GPS north	Transect distance	Reef structure/Comments	Juveniles (/m2)	Adults (/m2)	Total (/m^2)
Perpendicular	T2	PT2	540934	5250833	540969	5250841	18-20	Flat rock with small stones, slightly raised profile reef, mussels	0	2	2
Perpendicular	T2	PT2	540934	5250833	540969	5250841	20-22	Flat rock with small stones, slightly raised profile reef, mussels	3	13	16
Perpendicular	T2	PT2	540934	5250833	540969	5250841	22-24	Flat rock with small stones, slightly raised profile reef, mussels	0	0	0
Perpendicular	T2	PT2	540934	5250833	540969	5250841	24-26	Flat rock with small stones	0	10	10
Perpendicular	T2	PT2	540934	5250833	540969	5250841	26-28	Flat rock with small stones	2	4	6
Perpendicular	T2	PT2	540934	5250833	540969	5250841	28-30	Flat rock with small stones	0	2	2
Perpendicular	T2	PT2	540934	5250833	540969	5250841	30-32	Flat rock with stones, some large, some raised profile sections	0	1	1
Perpendicular	T2	PT2	540934	5250833	540969	5250841	32-34	Flat rock with small stones	0	0	0