The distribution of larval fish assemblages of Gulf St Vincent in relation to the positioning of sanctuary zones

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Declaration

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Abstract

The supply of larval fish to an area and their subsequent settlement there is an important driver of population growth. By protecting settlement habitat and reducing mortality due to fishing, sanctuaries within areas that are replenished by larval fish offer enhanced potential for population growth. Little is known about the larval assemblages that occur in Gulf St Vincent and what may drive them. This study aimed to assess the larval assemblages of Gulf St Vincent, the potential replenishment of larvae into the Gulf's sanctuary zones, and the difference between assemblages in Gulf St Vincent and other temperate regions. It was found that the larval assemblages present within Gulf St Vincent are significantly different to those found in other temperate Australian regions in comparable seasons. Further, differences in larval assemblages were present between different latitudinal zones of the Gulf itself. The larval community structure differed between the Central and South, and North and South, and average late-autumn and winter species richness and diversity where higher in the Central zone of the Gulf than in the South, while total species richness was lowest in the North and equal in the Central and South. Significant differences between fish the community structures of different life stages suggest that diversity and abundance estimations of juvenile, sub-adult and adult fish stocks may be biased by underwater visual census techniques. This study highlights that sanctuaries within Gulf St Vincent could play a vital role for protection of settlement habitats of unique larval communities and thus may enhance potential population growth through larval supply and recruitment. The positioning of the sanctuaries in the North and South works to encapsulate the different larval communities that occur in these zones. The data obtained in this study provides baseline information which is vital for assessing the efficacy of the sanctuary zones in the future and for understanding the processes that drive the ecological systems in the area.

Introduction

Larval fish and population growth

Populations of marine species can remain stable or grow by two means. Juveniles, sub-adults or adults may migrate into the area, or settlement stage larval fish may recruit to the area (Booth *et al.* 2000; Planes *et al.* 2000; Wen *et al.* 2013). While migration may allow for increased local populations, growth in this manner is often less significant than population growth via recruitment (Stockhausen *et al.* 2000; Gerber *et al.* 2005). Recruitment occurs when pelagic (open ocean living) larval fish settle into benthic (bottom living) zones and then become part of the local population (Caley *et al.* 1996). Fish that recruit to an area may originate from larvae spawned from other areas or in the area in which they eventually recruit to (natal or self-recruitment) (Planes *et al.* 2000; Harrison *et al.* 2012). While some level of self-recruitment may occur, for small areas a greater proportion of recruitment often comes from larvae spawned externally to the area (Caley *et al.* 1996; Planes *et al.* 2000). Larvae of coral trout (*Plectropomus macula*) and stripey snapper (*Lutjanus carponotatus*) on the Great Barrier Reef, for example, have been demonstrated to have self-recruitment rates of just 7% and 22% respectively, with the remaining larvae recruiting to other areas (Harrison *et al.* 2012).

Due to the openness of marine systems and populations, as well as the larval phase of many marine species being pelagic, the process of recruitment is complex (Caley *et al.* 1996; Pineda *et al.* 2010). Often, after being dispersed as eggs, pelagic larval fish continue to disperse passively and actively, until they reach the settlement phase of their life-cycle (Planes *et al.* 2000). Settlement is the phase at which the larvae select benthic habitats to settle into, transferring from pelagic to the benthos (Connell 1985). After settlement, recruitment occurs, in which the settled fish move into different habitats or join local juvenile and adult populations (Connell 1985). The number of larvae that subsequently transition into juveniles and adults is strongly affected by the number of larvae supplied to the area as well as processes such as competition, predation and habitat quality (Keough and Downes 1982; Pineda *et al.* 2010). These processes result in low survivorship of larvae, and movement of settled larvae and new recruits away from the area (Keough and Downes 1982; Pineda *et al.* 2010). In general higher larval supply leads to potentially higher settlement and greater potential for recruitment (for example see Stephens Jr *et al.* 1986). In turn, this allows for potentially higher population growth (Booth *et al.* 2000). If larvae do not arrive in any given

area they cannot settle and subsequently recruit there, and therefore cannot contribute to the local population growth. Where recruitment does not occur, population growth may be minimal or non-existent, and when mortality rates are increased beyond those that are natural, population decline is likely to eventuate (Caley *et al.* 1996). Due to the isolation of Saba Marine Park, off Saba Island in the Caribbean, lack of larval supply and subsequent recruitment has been attributed as a cause for a lack of significant population growth after closure to fishing (Roberts 1995). The study in Saba Marine Park highlights that larval supply and subsequent settlement often differs spatially. This is due to the dispersive pelagic phase. Spatial variation in larval abundances and diversity has been shown to occur in terms of depth, proximity to shore and between specific areas (Leis 1986; Doherty 1991; and others). This variation is a function of habitat selection of settlement stage larvae, abiotic water conditions (e.g. temperature and salinity), and factors such as currents and tides which may aid or hinder supply to an area (Doherty 1991). Larval supply also differs temporally as different species spawn at different times and have different lengths of dispersion time prior to settlement (Doherty 1991; Gray and Miskiewicz 2000).

For populations of *Balanus* glandula (barnacles), *Jasus edwardsii* (spiny lobsters), *Dascyllus trimaculatus* and *Dascyluss flavicaudus* (damselfishes), *Thalassoma bifasciatum* (bluehead wrasse), *Plectropomus maculatus* (coral trout), and *Lutjanus carponotatus* (stripey snapper) positive correlations have been found between the abundances of different life stages (Gaines and Roughgarden 1985; Victor 1986; Schmitt and Holbrook 1996; Schmitt and Holbrook 1999; Freeman *et al.* 2012; Wen et al. 2013). In these studies, researchers looked specifically at individuals observed as having recently settled into the benthos and correlated their abundances to those of either juveniles or adults in the area. The findings of such correlations in species of barnacles and lobsters as well as fish, suggest that, although post-settlement processes and home ranges will differ between species, correlations between different life stages can still be present (Grosberg and Levitan 1992). Larval recruitment could therefore significantly facilitates population enhancement. Observations of recently settled fish rely on knowledge of where settlement locations occur, and thus there is a significant limitation as to the studies that can be done using these methods. An alternative method is to look at the supply of settlement-stage larval fish rather than the abundance of newly settled fish. Irrespective of correlation strength between larval and post-settlement stages (which may be reduced due to a greater time lapse between the recorded life stages), this method could still the inherent link between consecutive stages (Stephens Jr *et al.* 1986; Caley *et al.* 1996).

Such correlations have been undergone for the *Stegastes partitus* (bicolour damselfish), the *Lythrypnus dalli* (blue-banded goby), the *Ruscarius creaseri* (formerly *Artedius creaseri;* roughcheek sculpin), and *Sillaginodes punctate* (King George whiting) (Stephens Jr *et al.* 1986; Hamer and Jenkins 1997; Valles *et al.* 2001; Grorud-Colvert and Sponaugle 2009). In all cases strong, positive, correlations were found between the abundances of settlement-stage larvae and that of newly settled fish. Extrapolating this, in light of correlations being present between abundances of newly settled fish and juvenile or adult fish, it can be expected that abundances of settlement-stage larvae can show a certain degree of correlation to that of juvenile or adult fish. Looking at abundances of larvae as close to settlement-stage as possible might therefore be informative of that of younger fish (newly settled or juveniles) (Stephens Jr *et al.* 1986; and others). Where a positive correlation exists between larval supply and juvenile and adult fish this could allow assessments to be made using larval fish abundances as to the likelihood of population growth occurring in an area.

Sanctuary zones and Gulf St Vincent

At the forefront of management for the protection of marine environments and species, marine parks can allow for enhanced population growth (Halpern 2003). Zonation within marine parks dictates the activities and access allowed in an area based on specific aims of protection and thus governs the level of protection specifically defined areas receive (Marine Parks Act 2007). By prohibiting fishing, sanctuary zones offer the highest level of protection against overexploitation. As mortality due to fishing is eliminated, these zones have the greatest potential for species population enhancement (Halpern and Warner 2003). Further, by protecting habitats and maintaining habitat complexity biodiversity can be sustained (Halpern and Warner 2003). A review of 89 studies looking at the efficacy of a total of 112 sanctuary zones found that on average biological measures, such as size, were significantly higher within the sanctuary zones than external to them or prior to their establishment (Halpern 2003). The occurrence and extent of such benefits are largely species specific, and may be dependent on their life history traits (Nardi *et al.* 2004; Claudet *et al.* 2010). Marine parks also allow increases in the abundance of adult fish within sanctuaries and proximate fished areas (Rowley 1994; Gaines *et al.* 2010; Harrison *et al.* 2012). For long term benefits of sanctuary zones to eventuate, populations must be able to be sustained and have the potential for growth. Understanding the mechanisms that govern the potential for population growth and how such mechanisms link to sanctuary zones is therefore vital.

Three marine parks, brought into effect in October 2014, are located in Gulf St Vincent (DEWNR 2013). These are Encounter Marine Park, Upper Gulf St Vincent Marine Park and Lower Yorke Peninsula Marine Park. Throughout the three marine parks, 17 sanctuary zones have been established, 11 of which are located within Gulf St Vincent. While the sanctuary zones were not designed specifically for the purpose of fish population enhancement, due to the absence of mortality due to fishing, they are the areas where population enhancement has the highest potential to occur. Due to the link between consecutive life stages, the supply of larvae to a sanctuary zone could increase the potential for population enhancement. As larvae move both passively and actively, the positioning of sanctuary zones is important. (Caley *et al.* 1996; Freeman *et al.* 2012; Wen *et al.* 2013). Located between the Fleurieu and Yorke Peninsula of South Australia, Gulf St Vincent is an inverse estuary covering an area of approximately 7000 km^2 (de Silva Samarasinghe and Lennon 1987). Large knowledge gaps exist in relation to the abundance and diversity of fish in Gulf St Vincent, even less is known about the larval supply of the area, and no data exists on the patterns of larval assemblage that occur within the Gulf. What is known is largely species specific, focussing on species that are commercially important or endemic to the area, and fails to look at diversity (Dimmlich *et al.* 2004; and others). To date, through targeted studies of commercially important species, only a few larval species have been recorded in the area. These species are *Sillaginodes punctata (*King George whiting) (Neira *et al.* 1998), *Engraulis australis* (Australian anchovy) (Neira *et al.* 1998 and Dimmlich *et al.* 2004), *Hyporhamphus melanochi* (southern garfish) (Noell and Ye 2008), *Sardinops sagax* (Pacific sardine) (Dimmlich *et al.* 2004), *Spratelloides robustus* (blue sprat) (Neira *et al.* 1998 and Rogers *et al.* 2003), *Pelates octolineatus* (western striped grunter) (Neira *et al.* 1998), *Lesueurina platycephala* (flathead sandfish) (Neira *et al.* 1998), *Pagrus auratus* (Australasian snapper) (Neira et. al 1998 and Saunders 2009) and *Syngnathidae* spp. (seahorses, pipefish and sea dragons) (Neira *et al.* 1998). While these species are known to occur in the area, their distributive patterns are unquantified. As other studies of larval assemblages, both in temperate Australia and other regions worldwide, show larval assemblages to vary spatially, spatial variation of larvae can be expected to occur within Gulf St Vincent (see for example Muhling and Beckley 2007; Keane and Neira 2008; and others).

While addressing the knowledge gaps surrounding marine sanctuaries and larval supply in general and the lack of information of larval assemblage patterns in Gulf St Vincent specifically, this study aims to assess the following hypotheses:

1) driven by environmental attributes, larval distribution will differ spatially within Gulf St Vincent, with distinct populations likely to occur at the head and mixed populations likely to occur at the mouth;
2) the overlap of larval communities with sanctuary zones will highlight the potential for enhanced population growth within the sanctuary; and
3) the larval communities of Gulf St Vincent will be similar to those of neighbouring Spencer Gulf, but will be different to those in other temperate Australian regions.

Methods

Study area

Located between the Fleurieu and Yorke Peninsula of South Australia, Gulf St Vincent is an inverse estuary covering an area of approximately 7000 km^2 (de Silva Samarasinghe and Lennon 1987). A maximum depth of approximately 45 m occurs at the mouth of the Gulf, while minimum depths of around 5 m occur at the head (Petrusevics 1993; de Silva Samarasinghe 1998). Sea surface temperatures within the Gulf are generally higher at the head and lower at the mouth, during summer, with the pattern reversed in winter (Bye 1976). Gulf St Vincent is an inverse estuary, with salinity increasing towards the head of the Gulf (de Silva Samarasinghe and Lennon 1987). The patterns of salinity within Gulf St Vincent reflect the currents that occur in the area. As seen in Figure 3 b, the area is subject to a clockwise inflow along the western side that outflows through the central regions, and a small anticlockwise circulation on the eastern side (Bye 1976; de Silva Samarasinghe and Lennon 1987; de Silva Samarasinghe 1998). These circulation patterns do not differ seasonally and are present irrespective of wind direction (Bye 1976 and de Silva Samarasinghe 1998). In contrast, the direction and magnitude of circulation at the head of the Gulf varies seasonally dependent on wind and tides (Bye 1976). Together the abiotic factors of sea surface temperature, salinity and currents can be expected to influence the distribution of all life-stages of fish in the area (see for example Bruce and Short 1990). Fish distribution is further influenced by substratum type, which too differs throughout the Gulf. Generally, mangroves

and seagrasses make up around 95% of the cover in the northern area where shallower and calmer conditions occur, while as much as 40% of the area towards the mouth and extending into Investigator Strait is rocky reef (Shepherd and Sprigg 1976; Edyvane 1999). Inherently these different substratum types offer differing habitat complexity, with reefs more complex than seagrasses (Shepherd and Sprigg 1976).

This study took place at 10 locations positioned along a latitudinal gradient in Gulf St Vincent (Figure 1). While maintaining even spacing across the latitudinal gradient, where possible the sites were positioned to correlate with sanctuary zones (as can be seen in Figure 1). By encompassing the largest latitudinal gradient as possible, this study can encapsulate spatial variation and assess differences between the larval assemblages at the head of the Gulf, which are likely to be isolated, and the mouth of the Gulf, which are likely to be mixed and receive greater influx from the open ocean. Prior to commencement of this study, a permit (number MR00014-1) was obtained to allow scientific research to be undergone within the sanctuary zones present in Gulf St Vincent.

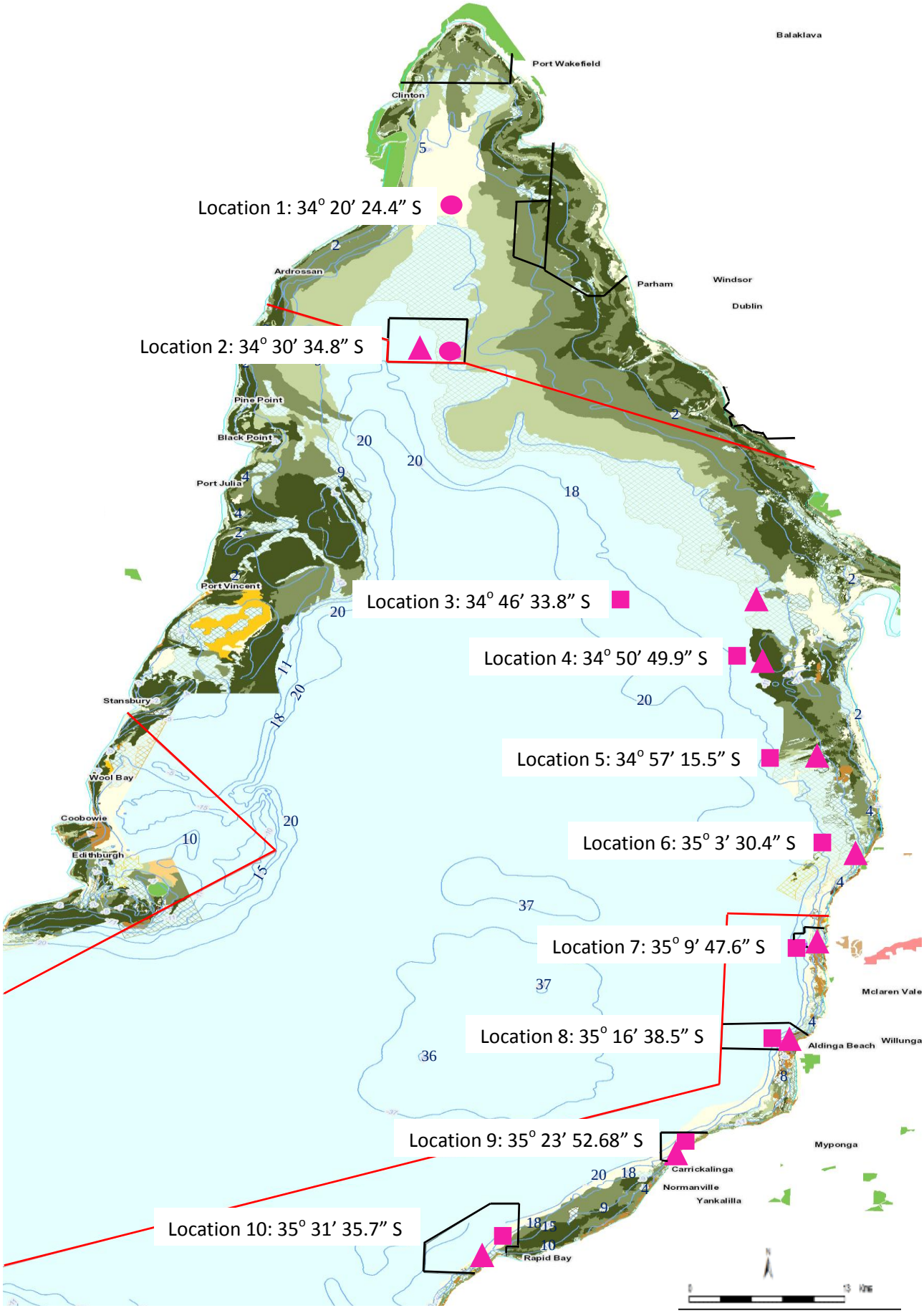

Figure 1. Map of Gulf St Vincent, showing bathymetry (depth in m), marine parks (red outline), sanctuary zones (black outline), and sampling locations with approximate latitude (pink markers). Circle markers represent water depth of 10m, triangle markers represent water depth of 15m and square markers represent water depth of 20m. Legend is given on the following page. Map generated at Nature Maps SA (2014).

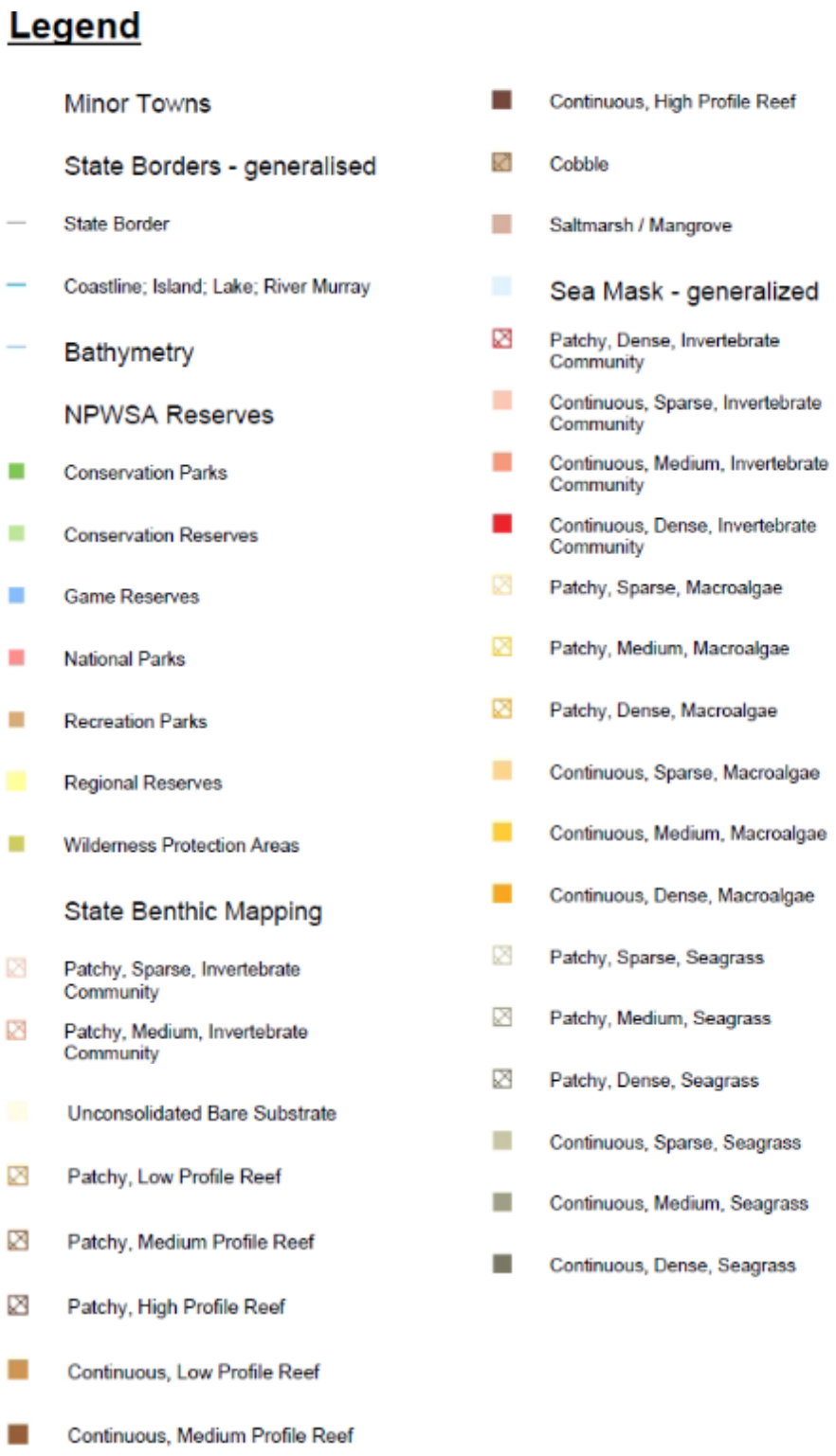

Figure 1 – continued. Map of Gulf St Vincent legend. Map generated at Nature Maps SA (2014).

Aim 1 – Larval distribution patterns:

Larval sampling

Larval fish were sampled during three sampling periods; April-May, June-July and August 2014. In each sampling period all 10 locations were sampled over the fewest number of consecutive as possible, dependent on weather. To account for changing conditions spatially and temporarily, recordings of salinity, temperature, moon phase, and habitat type were made (see Appendix A and Table 1). While variation in abundances may exist on a larger temporal scale (between years) coarse relative spatial distribution patterns should remain roughly similar from year to year (Doherty 1991). Confining the study to one year should therefore work to demonstrate predominate relative latitudinal patterns of late-autumn and winter spawners. During the initial sampling period, except for at the most northern which had limited variation of depth, two sites were sampled at each location. The shallower sites, 10 m water depth at two northernmost locations and 15 m at other 8 locations, were representative of inshore locations and the deeper, 15 m at second northernmost location and 20 m at other eight locations, of offshore. During the second and third sampling periods, only inshore sites were sampled. Focus on inshore was due to enabling better correlation to adult data and substrate, and allowing analysis of the largest latitudinal gradient possible. Further, initial analysis of sampling period 1, during which all sampling was carried out at the same depth below surface, showed no difference in the larval assemblages of inshore and offshore locations (see Appendix B). A GPS reading was taking during the initial sampling period to allow the same locations to be sampled in subsequent periods.

Prior to any sampling, ethics approval was obtained to allow sampling of animals (approval number S-2014-061), and all sampling was conducted, and reported, under Primary Industries and Regions SA: Fisheries and Aquaculture's S115 ministerial exemption number 9902676, with specified allowance under Schedule 2 to sample with mesh of size 0.5mm. Larval fish were sampled using Twin Ring nets (Sea-Gear Model 9600). Designed for collection of late- or settlement-stage larvae, the frame consisted of two stainless steel rings; each with a mouth diameter of 75 cm positioned alongside each other and joined in the centre by a swivel (Figure 2). By reducing net avoidance of settlement-stage, active-swimming, larvae, the large mouth diameter worked to enhance catchability (Stehle 2007). All sampling was conducted during daytime. Each net, fastened to the rings by net collars, had a length of 3 m. The 3 m length encompassed a 1.5 m cylindrical top section, which worked to improve filtration efficiency, and a 1.5 m conical section (Kelso *et al.* 2012). Standard mouth to length ratios used for larval

sampling range from 1:3 to 1:5; with a ratio of 1:4 this net fell within the recognised standard for efficient sampling (Kelso *et al.* 2012). One net was of mesh size 500 µm while the other was mesh of 1000 µm in size. Having one net of 500 µm and the other of 1000 µm allowed the most diverse catch to be achieved, by balancing clogging of the net and extrusion of larvae, and allowed an analysis to be done to determine the most effective and efficient net size for the area (Smith *et al.* 1968). A PCV cod end was attached to end of each net for larval collection. Mesh on one side of each cod end, to allow filtration, matched the mesh size of the net to which it was attached.

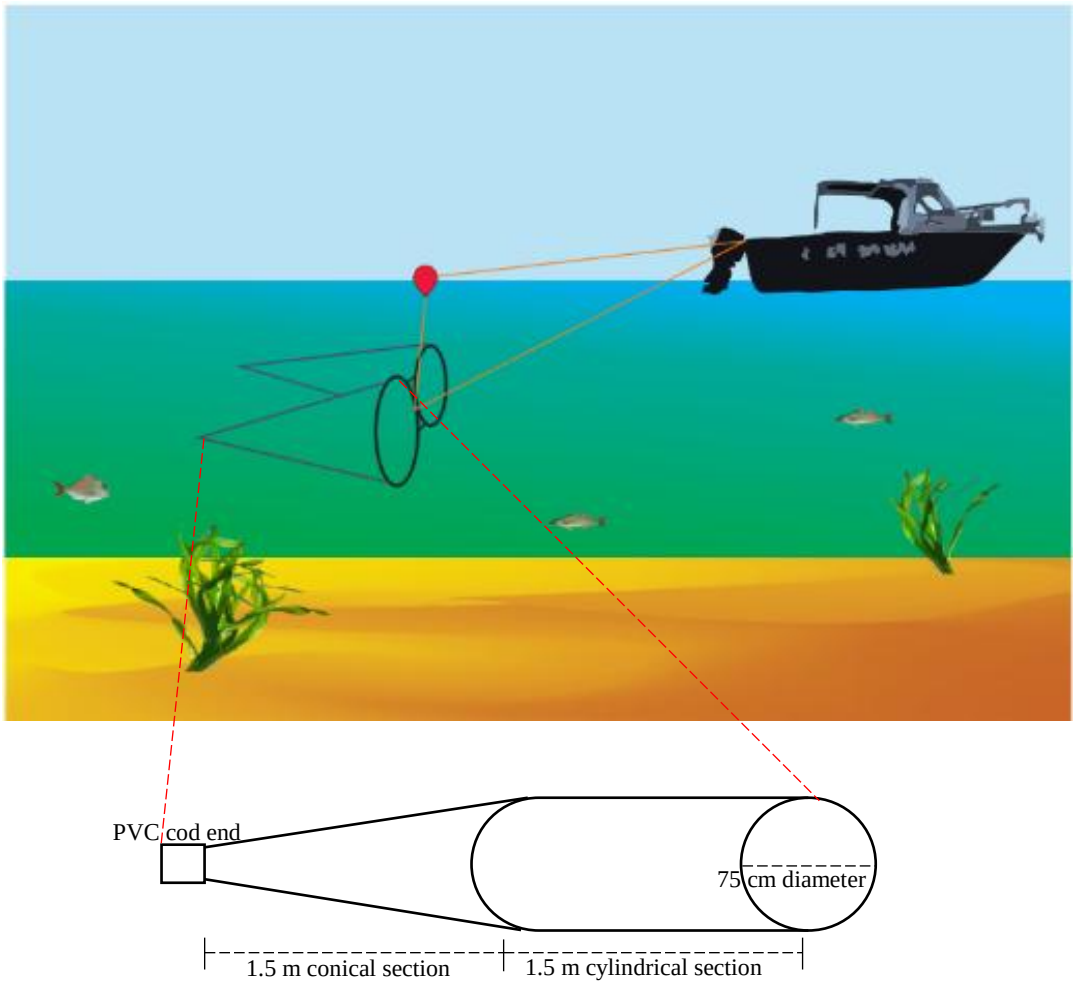

Figure 2. Diagram of nets being towed, showing attachment of net to buoy to maintain desired sample depth, and basic net design of Twin Ring nets (Sea-Gear Model 9600). Note figures are not to scale.

As the number of larvae sampled is directly related to the amount of water filtered through the nets, volume filtered was calculated for each tow to allow abundances to be converted to concentrations (i.e. number of larval per 1 m^3 of water) (Muhling *et al.* 2008). During the initial sampling period this was achieved by the use of a mechanical flowmeter (Sea-Gear MF315) however, due to loss of the flowmeter, for the subsequent sampling periods calculations were

made based on distance towed, with recording a GPS position at the start and end of each tow. On one occasion both methods were used and the volume filtered determined by each method only differed by 6 m^3, with the average volume sampled throughout the study being 364.16 m^3. As greater differences in volume filtered existed between tows (see Appendix A), the change between methods is not expected to have been an issue. During sampling, to allow the nets to sink into the water column, weight was suspended from the centre swivel (Leis 1991). During the first sampling period the weight consisted of a 5 kg depressor. A depth sensor attached to the top of the swivel showed that the nets did not go deeper than an average of 2 m below the surface. To enable sampling at greater depths, and thus allow samples to be collected closer to the substrate and thus where settlement-stage larvae are more likely to occur (Leis 1986; Muhling and Beckley 2007), during the two subsequent sampling periods an extra 10 kg was added to net frame.

All sampling was conducted with the assistance of DEWNR personnel and a student volunteer from a boat owned and operated by DEWNR. Upon arrival at a desired location and water depth, nets were deployed from the stern of the boat. To sample 5 m above the substrate, as is common practice for sampling settlement-stage larvae (Kelso *et al.* 2012; Miskiewicz pers. comm. 2014), 40 m of tow rope was released before being hitched off, a constant angle of approximately 45^o was maintained between the rope and the boat, and the boat travelled at a constant towing speed of approximately 1 m/s (2 knots) (Johnson and Morse 1994; and others). Further, to prevent the nets sampling deeper than the desired depth, a buoy was attached to the net's centre swivel by a rope of equal length to the desired sampling depth (Figure 2) (Leis 1986). The attached depth sensor allowed an average sampling depth to be recorded, accounting for any lift of the nets that may have occurred due to tidal activity or boat speed. The nets were towed horizontally for 15 minutes before being retrieved. On the initial sampling period retrieval utilised a single-speed hand manual winch. This was replaced with an electric winch for the two following sampling periods to compensate for the greater weight and to increase retrieval speed, thereby decreasing the opportunity for larvae to escape. Once retrieved, the nets were hung vertically over the deck of the boat and rinsed with a deck hose. During rinsing, water pressure was kept to a minimum, balancing the need to remove larvae and organic matter caught in the net whilst not damaging the larvae, and the cod ends were angled to avoid a heavy flow of water into them and further reduce damage to larvae. The sample in each cod end was then emptied into its own container containing clove oil. This immediately euthanized the larvae. To preserve the larvae, ethanol was then added to each container until they contained a solution of at least 70% ethanol (as per Choat *et al.* 1993; Johnson and Morse 1994; and others). In the Southern Seas Ecology laboratory at

the University of Adelaide, the samples were sorted; removing any larval fish from the sample, and storing them in 100% ethanol. Identification was then undergone with the help of temperate larval expert Dr Anthony Miskiewicz, the use of the larval identification guide 'Larvae of temperate Australian fishes: laboratory guide for larval fish identification' (1998), and a compiled list of fish species that have previously been recorded in the area (see Appendix C).

Analysis

Data obtained during sampling periods 1, 2 and 3, was analysed individually and as a pooled collection. Initial analysis of sampling period 1 found no significant difference between the larval assemblages in each mesh size (see Appendix B), and so samples from the 1000 µm mesh were used. This reduced the number of early-stage larvae and was more time efficient in terms of sorting. In assessing the difference between inshore and offshore and mesh size from sampling period 1, each zone was analysed separately. Analyses were carried out in PERMANOVA with depth (fixed) and mesh size (fixed) as factors, for the Central and South zones, and only mesh size as a factor for the North Zone. Analysis of larval abundances in the 1000 µm mesh was then carried out using nMDS, ANOSIM, PERMANOVA, SIMPER and BEST/BIOENV packages of Primer+ and linear regression tools of SPSS. For all tests significance level was set at 0.05. For individual periods and the periods pooled, tests were carried out to determine differences in the larval assemblage indices of: community structure, total abundance, species richness and Shannon's H' diversity. Analysis was undergone with zone as a fixed factor. Factor zone consisted of three levels; North, Central, and South (see Figure 3 b and Appendix A), and the division of locations into zones was based on nMDS of the environmental variables at each location across the three periods (Figure 3 a), as larval fish are likely to show some correlation with environmental conditions (see for example Hart *et al.* 1996; Green and Fisher 2004). For the analysis of the three periods combined, period was an additional random factor. Factor period consisted of three levels; period 1, period 2, and period 3. For the single factor analyses of the individual periods ANOSIM was used for significant tests between the zones as it is more robust when dealing with small replication. For analysis with two factors, such as the pooled periods, PERMANOVA was used. Where samples had no larvae a dummy variable was used to ensure all data was included in statistical comparisons.

Aim 2 – Sanctuary replenishment and population growth:

The Department of Environment, Water and Natural Resources provided data on juvenile, sub-adult and adult fish recorded by underwater visual census (UVC) during February 2012. UVC

was undergone along transects at depths of up to 10m. Transects located at three sites, Dodd's Beach, Myponga South and Myponga Point, respectively lie 0.75km, 1.78km and 3.17km from location 9 of the larval study, and transects located at three sites, Rapid Head Windmill, Sunset Cove South and Salt Creek/Nev's Windmill, respectively lie 0.53km, 7.10km and 3.7km of location 10 of the larval study. As there is an average distance of approximately 17km between the locations of the larval studies, these transects are in relatively close proximity of the locations. At each of the six sites four replicate transects were surveyed. The raw data from DEWNR was sorted, grouping each species recorded into size classes representative of 'juvenile', 'sub-adult' and 'adult'. Grouping of size classes was carried out objectively, taking the maximum size each species can grow to and making each size class cover a range a third of the size of the maximum. Counts where then converted to relative abundances of each size class and each species for each replicate transect.

Analysis

Larval data from locations 9 and 10 of the three periods pooled was converted to relative abundance of each. Community structure of the larvae at these two sites was then compared to the community structure of juveniles, sub-adults and adults using PERMANOVA. While the UVC fish surveys were conducted approximately two years prior to the larval study the aim is only to test for correlations in the relative compositions of the communities. Sanctuary zone locations are considered during the interpretation of results, with comparisons made between the larvae found in sanctuary zones and those found outside sanctuary zones. This allowed assessment of potential supply and recruitment to sanctuary zones, and thus the potential for enhanced population growth.

Aim 3 – Larval communities of Gulf St Vincent and other temperate areas:

Larvae from the pooled periods were compared to larvae from two other temperate Australian studies to assess the similarities and dissimilarities between the larval communities. Studies for comparison are:

- Spencer Gulf – 'Survey of Planktonic Larvae Near Point Lowly' (Miskiewicz 2010),
- Sydney coastal waters – 'Larval Fish Assemblages in South-east Australian Coastal Waters: Seasonal and Spatial Structure' (Gray and Miskiewicz 2000).

These studies were selected as they provided larval counts in a specified volume of water from the same seasons, late-autumn and winter, as the current study, and were conducted at similar

depths using similar sampling techniques. While the Sydney coastal waters study also had data from deeper/offshore samples, these were excluded.

Analysis

Comparisons between this study and others were done using the ANOSIM Primer+ package to assess only the indices of community structure and total abundance. Richness and Shannon's H' diversity were not assessed as they would require the studies to have the same sampling effort, due to richness inherently increasing with greater sampling effort (Gotelli and Colwell 2001).

Results

Aim 1 – Larval distribution patterns:

Post-hoc tests of the environmental variables across the periods pooled allowed separation of the 10 locations into 3 zones: North, Central and South; with the environmental variables of each zone being significantly different to the other zones (North and Central $p < 0.001$, North and South $p = 0.003$, and Central and South $p = 0.037$). This is supported by clear visualisation of the separation between the zones in the nMDS based on environmental variables (Figure 3 a). All subsequent analyses therefore used these three zones as factor levels. Consisting of locations 1 and 2 (Figure 3 b), the North zone had an average temperature of 14.12^{o}C, average salinity of 39, and had seagrass and unconsolidated habitat (Table 1). Sampling in the North was undergone at an average distance of 12.32 km from shore, with samples taken at an average of 5.87 m above the seafloor with the moon an average of 61.30% visible (Table 1). Consisting of locations 3, 4 and 5 (Figure 3 b), the Central zone had an average temperature of 14.30^{o}C, average salinity of 38.61, and was dominated by seagrass habitat (Table 1). Sampling in the Central zone was conducted at an average distance of 6.90 km from shore and 9.42 m above seafloor with the moon an average of 73.66% visible (Table 1). Consisting of locations 6, 7, 8, 9 and 10, the South zone (Figure 3 b) had an average temperature of 14.30^{o}C, average salinity of 37.33, and was a mix of seagrass and rocky reef habitat (Table 1). Sampling in the South zone was conducted at an average distance of 0.83 km from shore and 9.01 m above seafloor with the moon an average of 85.35% visible (Table 1).

Table 1 Environmental variables, and their standard deviations, of each zone. Temperature is degrees Celsius, moon phase is % moon visible, salinity is ppt, distance to shore is in km, distance from seafloor is m, and for habitat type S = seagrass, U = unconsolidated, R = reef. Detail of individual locations in Appendix A.

	Temperature	**Moon phase**	**Salinity**	**Distance to shore**	**Distance from seafloor**	**Habitat type**
North	14.1±1.6	61.3±32.4	39.0	12.3±4.2	5.9±1.5	S and U
Central	14.3±1.8	73.7±31.4	38.6±0.6	6.9±1.6	9.4±2.8	S
South	14.3±2.3	85.4±33.6	37.3±0.6	0.8±0.4	9.0±3.0	S and R

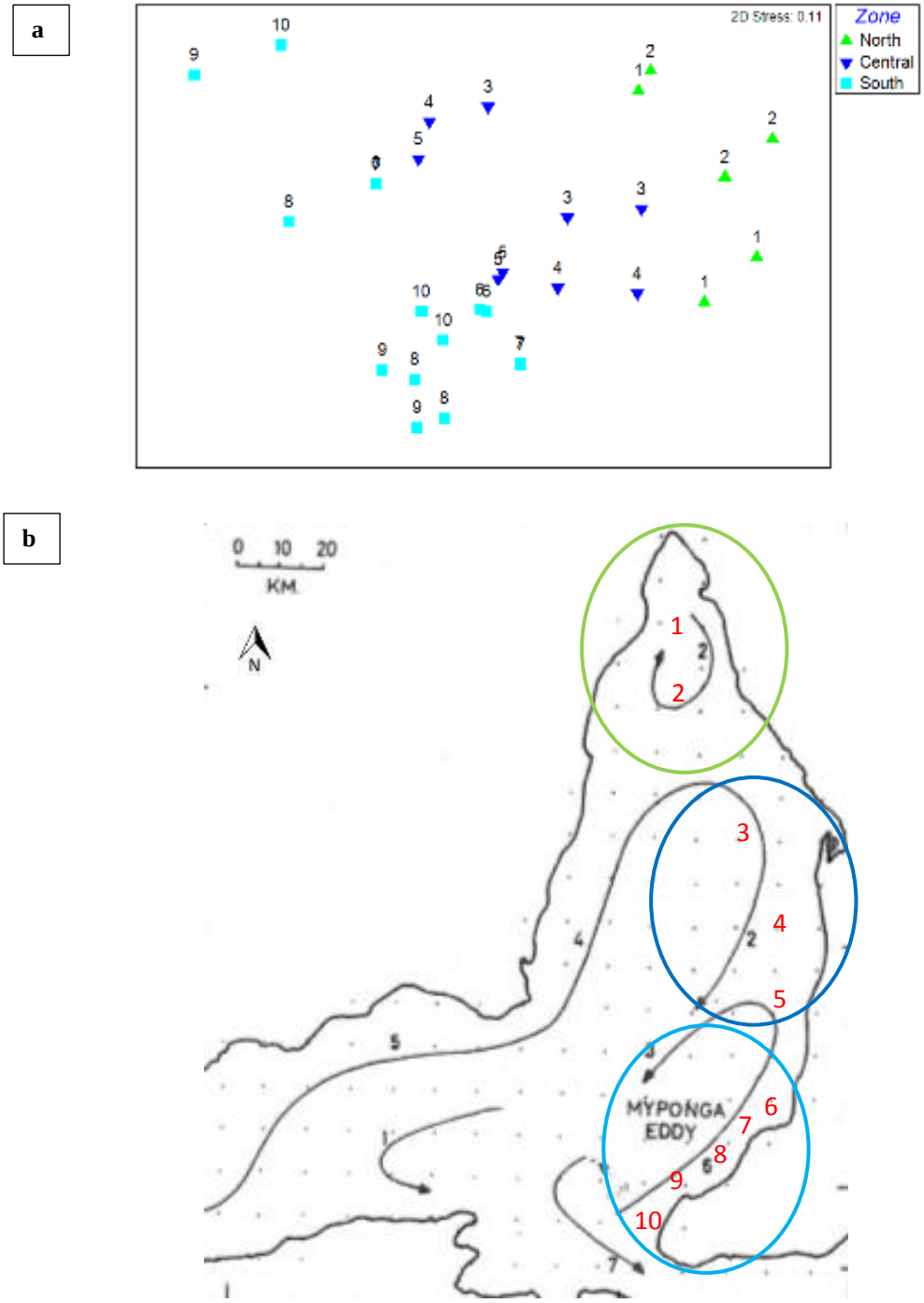

Figure 3 a) nMDS of the environmental variables across the three sampling periods pooled, showing division of locations (number 1 – 10) into zones, where North zone is in green, Central zone is in dark blue, and South zone is in light blue; and b) Circulatory patterns present within Gulf St Vincent and division into zones is visualised by the circles with North in green, Central in dark blue and South in light blue. Note: spacing of zones and locations is not to scale. Image adapted form (Bye 1976, p. 149).

Table 2. Statistical post-hoc results, from PERMANOVA, of the three sampling periods pooled. Significant differences are highlighted. Interaction (zone x period) was insignificant for all assemblage indices, with p > 0.32. No post-hoc test was done between the zones for abundance as no significant differences (p = 0.48, MS 1129.9) were found in the initial test.

	Zone (df = 2)							**Period** (df = 2)						
	MS	**North – Central**		**Central - South**		**South - North**		**MS**	**1 - 2**		**2 - 3**		**3 - 1**	
		Sig.	Test stat.	Sig.	Test stat.	Sig.	Test stat.		Sig.	Test stat.	Sig.	Test stat.	Sig.	Test stat.
Community	3445.5	0.147	1.56	0.041	1.99	0.008	2.82	6871.8	<0.001	3.41	0.002	2.14	0.037	1.71
Abundance								9637.9	<0.001	3.25	0.001	2.77	0.177	1.35
Richness	1173	0.087	2.43	0.049	2.83	0.210	1.66	2635.2	0.003	3.18	0.081	1.77	0.085	1.79
Shannon's H'	193.3	0.182	2.02	0.034	4.70	0.423	0.97	89.6	0.016	2.78	0.316	1.06	0.120	1.48

Table 3. Statistical results, from ANOSIM, of individual sampling periods. Significant differences are highlighted.

		Zone					
		North - Central		**Central - South**		**South - North**	
		Sig.	R statistic	Sig.	R statistic	Sig.	R statistic
Period 1	Community	0.600	0.00	0.125	0.32	0.619	-0.07
	Abundance	0.400	0.00	0.375	0.01	0.714	-0.16
	Richness	0.300	0.29	0.446	0.01	0.714	-0.14
	Shannon's H'	0.400	0.08	0.571	-0.09	0.619	-0.02
Period 2	Community	0.100	0.92	0.036	0.47	0.143	0.40
	Abundance	0.200	0.50	0.839	-0.19	0.143	0.31
	Richness	0.400	0.04	0.482	-0.03	1.000	-0.31
	Shannon's H'	1.000	-0.42	0.054	0.52	0.048	0.58
Period 3	Community	0.300	0.33	0.500	-0.01	0.667	-0.12
	Abundance	0.700	-0.25	0.804	-0.20	0.905	-0.24
	Richness	0.400	-0.04	0.762	-0.12	0.750	-0.09
	Shannon's H'	0.300	0.17	0.750	-0.16	0.762	-0.10

Table 4. BEST results of individual periods and periods pooled, giving the environmental variable(s) with the strongest correlation.

		BEST	Correlation
Period 1	Community	Habitat type	0.12
	Abundance	Distance to shore and Salinity	-0.047
	Richness	Distance from seafloor	0.009
	Shannon's H'	Habitat type	0.044
Period 2	Community	Moon phase and Habitat type	0.289
	Abundance	Moon phase and Habitat type	0.073
	Richness	Temperature	0.109
	Shannon's H'	Salinity	0.678
Period 3	Community	Distance from seafloor	0.646
	Abundance	Habitat type and Distance from seafloor	0.413
	Richness	Temperature, Habitat type and Distance from seafloor	0.457
	Shannon's H'	Habitat type and Distance from seafloor	0.276
Periods 1,2,3	Community	Temperature	0.289
	Abundance	Temperature	0.116
	Richness	Temperature	0.188
	Shannon's H'	Habitat type	0.051

Periods 1 and 2 were significantly different for the indices of community ($p < 0.001$) (Figure 4 a), total abundance ($p < 0.001$), richness ($p = 0.003$), and Shannon's H' ($p = 0.016$) (Table 2); with period 2 having greater total abundance richness and Shannon's H' (Figure 4 b, c, d). Periods 2 and 3 were significantly different for the indices of community ($p = 0.002$) and total abundance ($p = 0.001$) (Table 2 and Figure 4 a), with period 2 having greater total abundance (Figure 4 b); and periods 1 and 3 had significantly different communities ($p = 0.037$) (Table 2, Figure 4 a). These differences between periods were driven by *Meuschenia* spp. (leather jackets) which had dissimilarity contributions of 48.33% for periods 1 and 2, 29.24% for periods 1 and 3, 39.01% for periods 2 and 3.

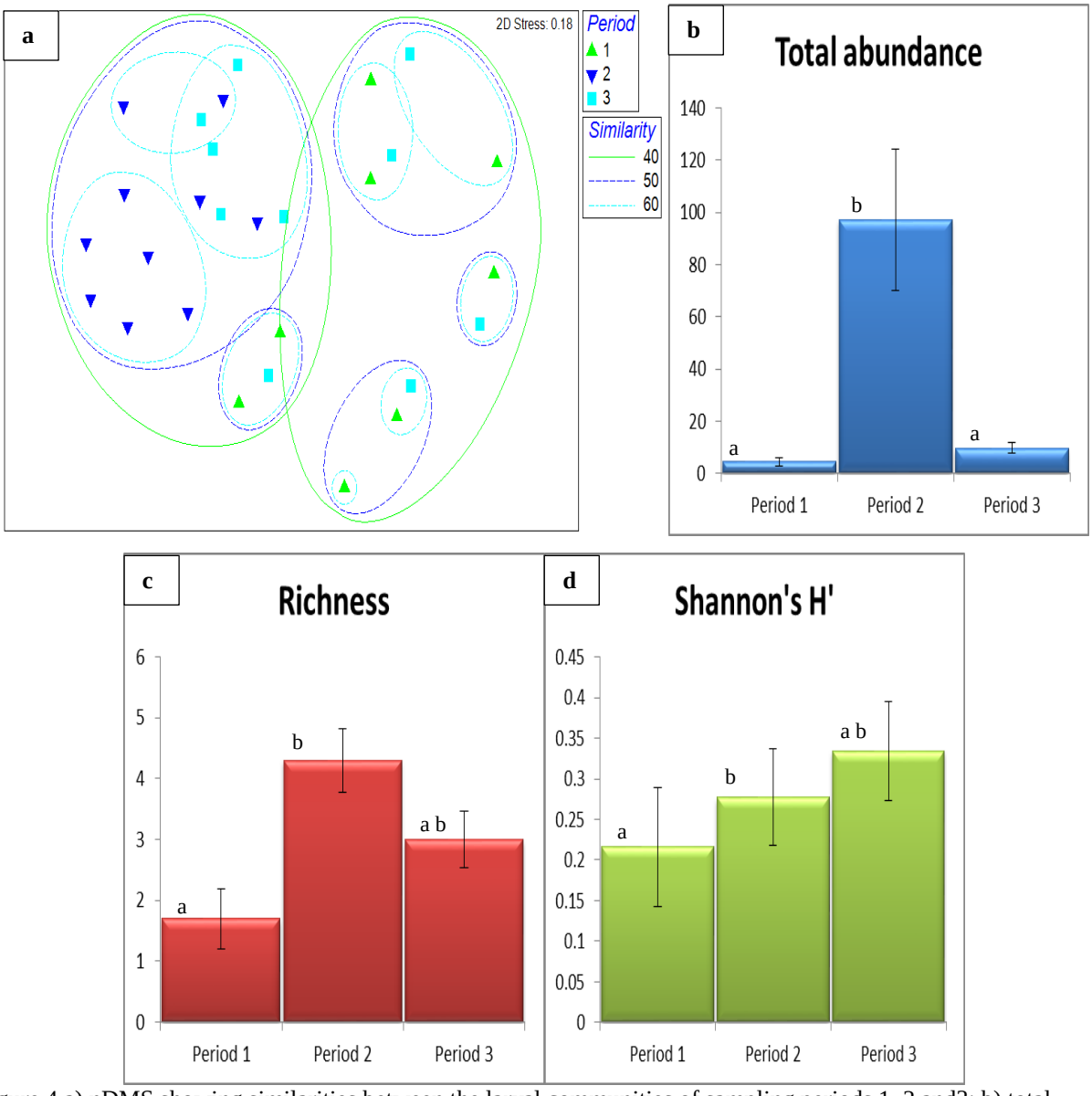

Figure 4 a) nDMS showing similarities between the larval communities of sampling periods 1, 2 and3; b) total abundances of each sampling period with standard error and letters showing significant differences; c) richness of each sampling periods with standard error and letters showing significant differences; and d) Shannon's H' of each sampling period with standard error and letters showing significant differences. Different letters represent significant differences.

Community structure was significantly different (p = 0.036) between the Central and South zones of sampling period 2 (Table 3). This difference was driven by the *Gymnapistes marmoratus* (South Australian cobbler) (23.99% dissimilarity contribution). No other significant differences for community structure were present in the individual sampling periods. Pooling the data of the three sampling periods found significant differences in the communities of North and South (p = 0.008) and the communities of Central and South (p = 0.041) (Table 2, Figure 5), driven by *Meuschenia* spp. (30.68% dissimilarity contribution) and *Tripterygiidae* spp. (triple-fin blenny) (18.53% dissimilarity contribution) respectively. Moon phase and habitat type accounted for 28% of the variation in community structure in period 2, while temperature explained 28% of the variation in community structure of the pooled periods (Table 4).

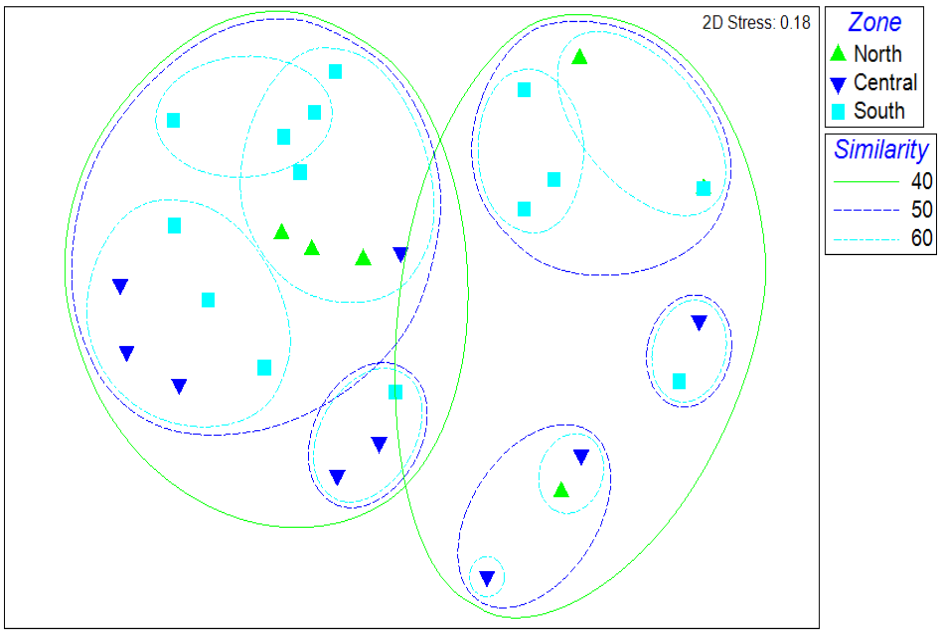

Figure 5. nMDS of similarity in larval communities in each location, for factor zone, with three levels of zone: North, Central and South.

Total abundance did not differ between the zones when the periods were analysed individually or pooled (Tables 2 and 3). However, in period 2, 53% of the variation can be explained by a significant (p = 0.015) increasing linear regression across the latitudinal gradient, and for the pooled periods 57% of the variation can be explained by a significant (0.007) increasing linear regression across the latitudinal gradient (Figure 6).

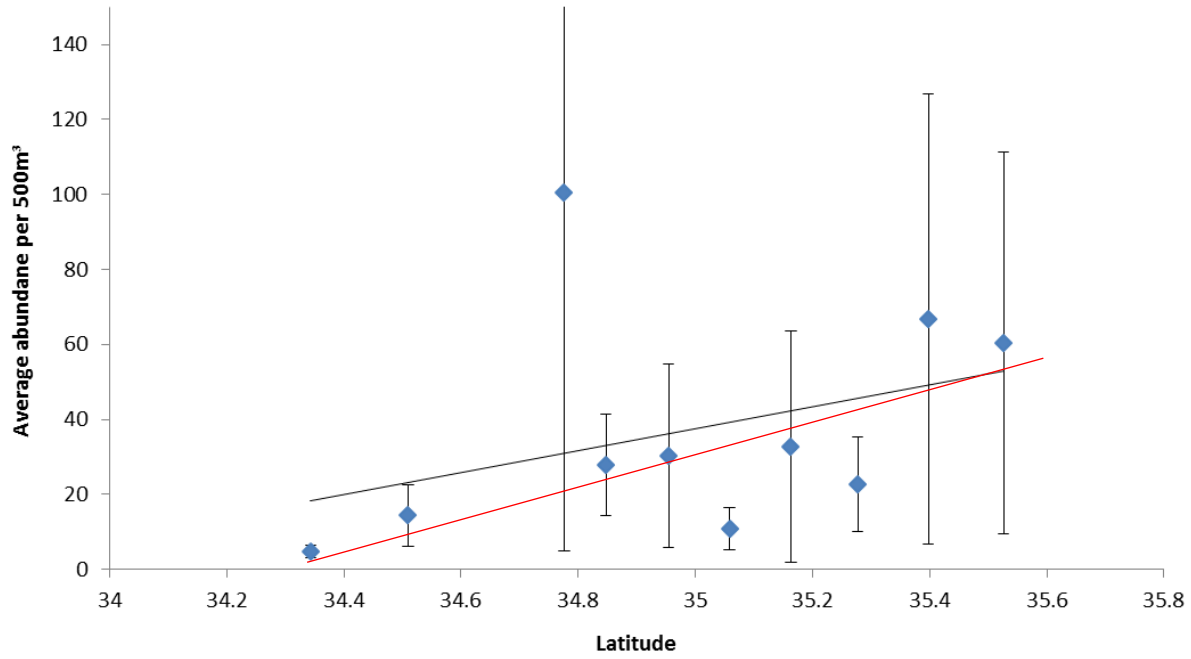

Figure 6. Average total abundance with standard error at each location for the three sampling periods, showing an increasing linear trend from north to south. Red line gives the trend with the outlier at location 3 excluded (R^2 = 0.574, p = 0.007), and black line gives the trend with the outlier included (R^2 = 0.029, p = 0.293). The outlier was excluded as it was resultant of high number of one species being present in one trawl, and so was a random occurrence.

Richness showed no significant differences between the zones of the individual periods (Table 3), but for the pooled periods richness was significantly higher (p = 0.049) in the Central zone than in the South (Table 2, Figure 7).

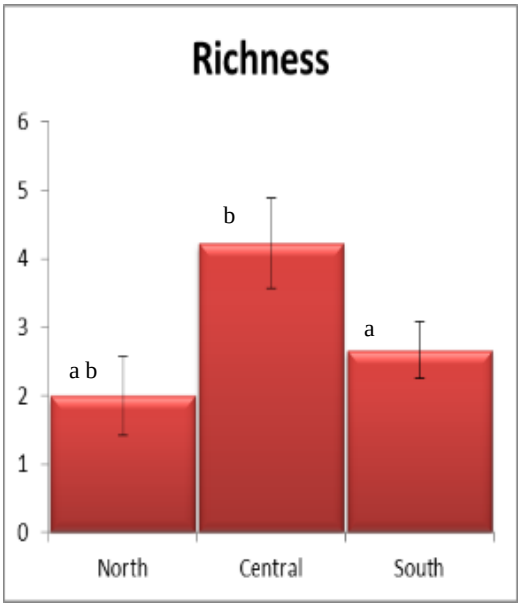

Figure 7. Average richness of each zone for the pooled sampling periods, with error bars and letters symbolising significant differences (where different letters represent significant differences).

Shannon's H' diversity index was significantly greater in the North than the South zone of period 2 ($p = 0.048$) (Table 3), with salinity explaining 67% of the variation (Table 4). When the sampling periods were pooled, Shannon's H' significantly differed ($p = 0.034$) between the Central and South zones, with diversity greater in the Central zone.

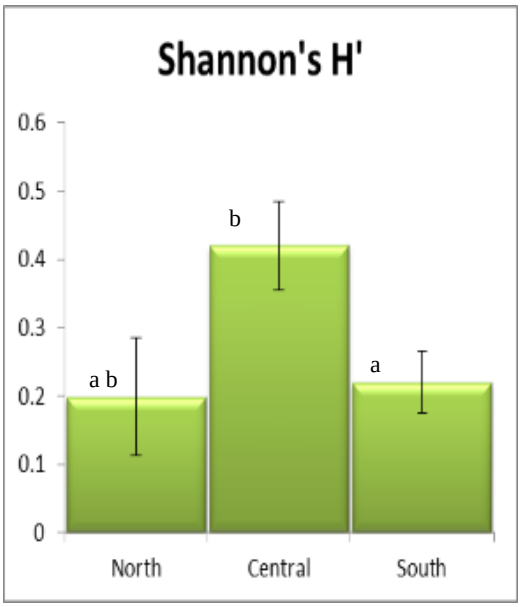

Figure 8. Average Shannon's H' of each zone for the pooled sampling periods, with error bars and letters symbolising significant differences (where different letters represent significant differences).

While richness and Shannon's H' diversity are higher on average in the samples from the Central zone than from the South, the species that contribute to the richness of each sample means that across all samples the Central and South zones actually contain the same number of species, thus total richness in the Central and South zones are equal (Figures 9 and 10). The North zone has a total richness of 4, and the Central and South zones have a total richness of 12 (Figures 9 and 10).

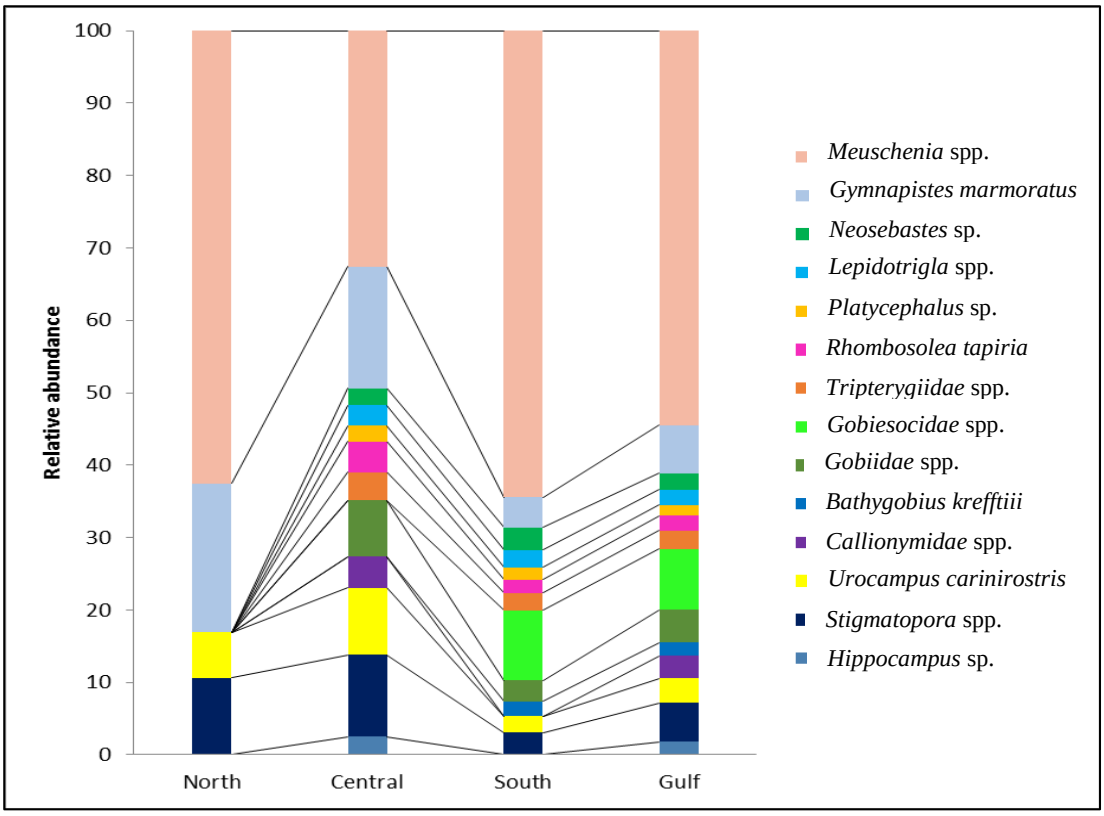

Figure 9. Average contribution (%) of each species to the larvae found in each zone and to Gulf St Vincent as a whole. Species that only occurred as individuals in the offshore sites or in the smaller (500 µm) mesh have been excluded. The outlier that was excluded in total abundance analysis due to being driven by one species in one sample has been excluded here.

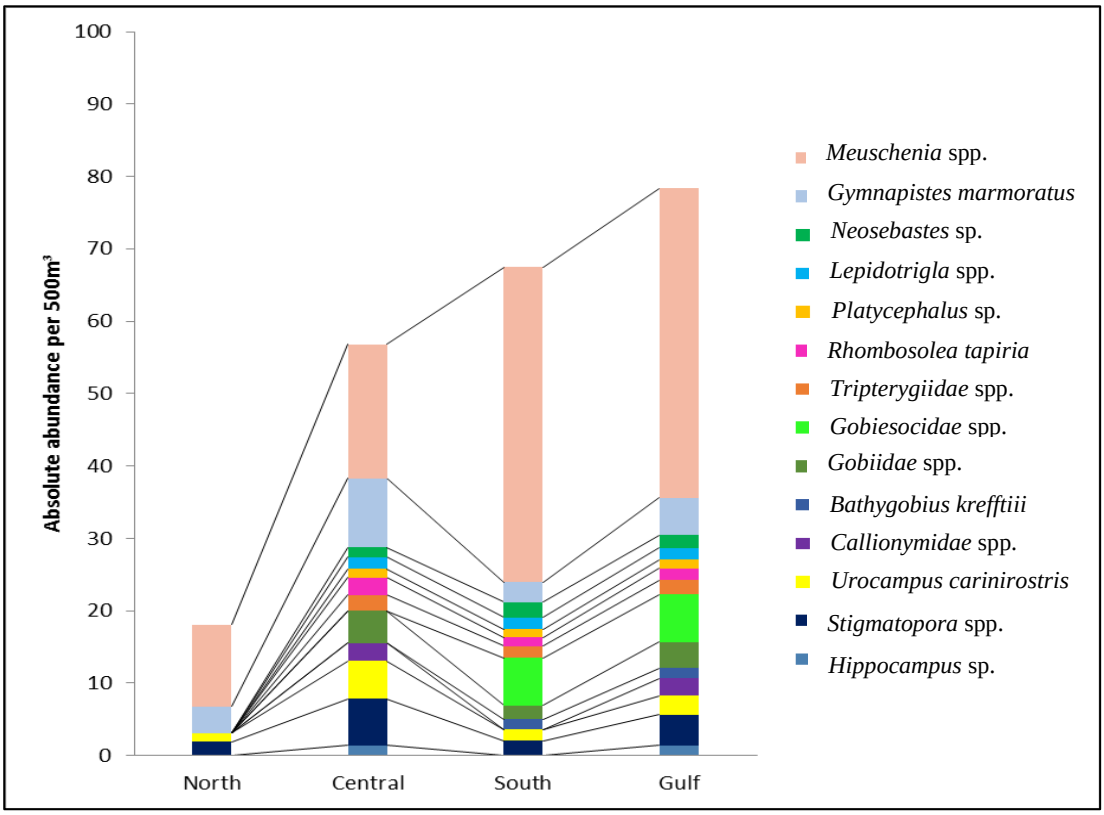

Figure 10. Absolute abundance of each species to the larvae found in each zone and to Gulf St Vincent as a whole. Species that only occurred as individuals in the offshore sites or in the smaller (500 µm) mesh have been excluded. The outlier that was excluded in total abundance analysis due to being driven by one species in one sample has been excluded here.

Aim 2 – Sanctuary replenishment and population growth:

Significant differences were found between the community structures of each of the life stages: larvae, juvenile, sub-adult and adult. All p-values, for post-hoc comparrisons, between life stages were 0.0001. Figure 11 shows separation, and thus dissimilarity, between the different life stages, and clustering, and thus similarity, within the life stages.

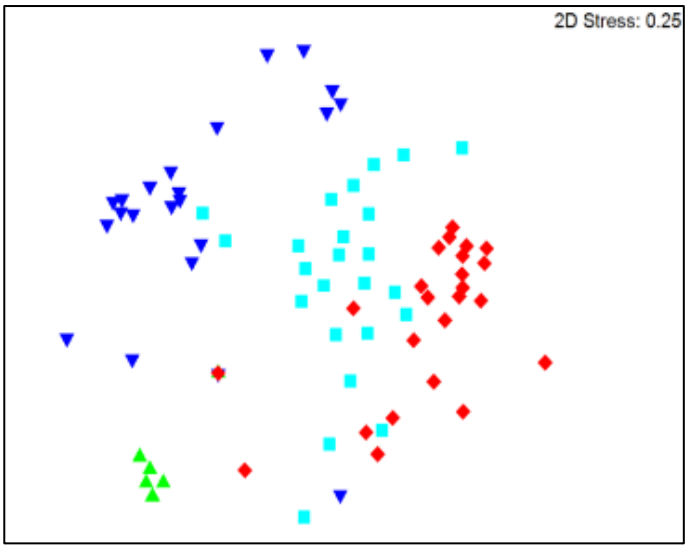

Figure 11. nMDS of similarity between different life stages, showing larvae in green, juvenile in dark blue, sub-adult in light blue, and adult in red.

One location in the North zone and four locations in the South zone are within sanctuaries (Figure 12). A difference in the larval assemblages between these zones therefore has potentially important implications; as, if the larvae settle in the zone, they contribute to the potential population growth and thus efficacy of the sanctuary. In the North zone, while average species richness is the same within and outside sanctuary zones, outside the sanctuary has higher total richness (Figure 12). In the South zone, both average richness per sample and total richness are higher in the sanctuary than outside the sanctuary (Figure 12). However as a greater number of locations in the South zone are sanctuaries than non-sanctuaries there is an inherently greater potential for higher richness to be encapsulated. In the North zone, *Urocampus carinirostris* larvae were only sample outside the sanctuary, but were present in thesanctuaries of the South (Figure 12). *Callionymidae* spp. and *Hipppocampus* sp. occur only in the Central zone where there are no sanctuaries (Figure 12). In the South zone, all species found outside sanctuaries were also found within sanctuaries (Figure 12).

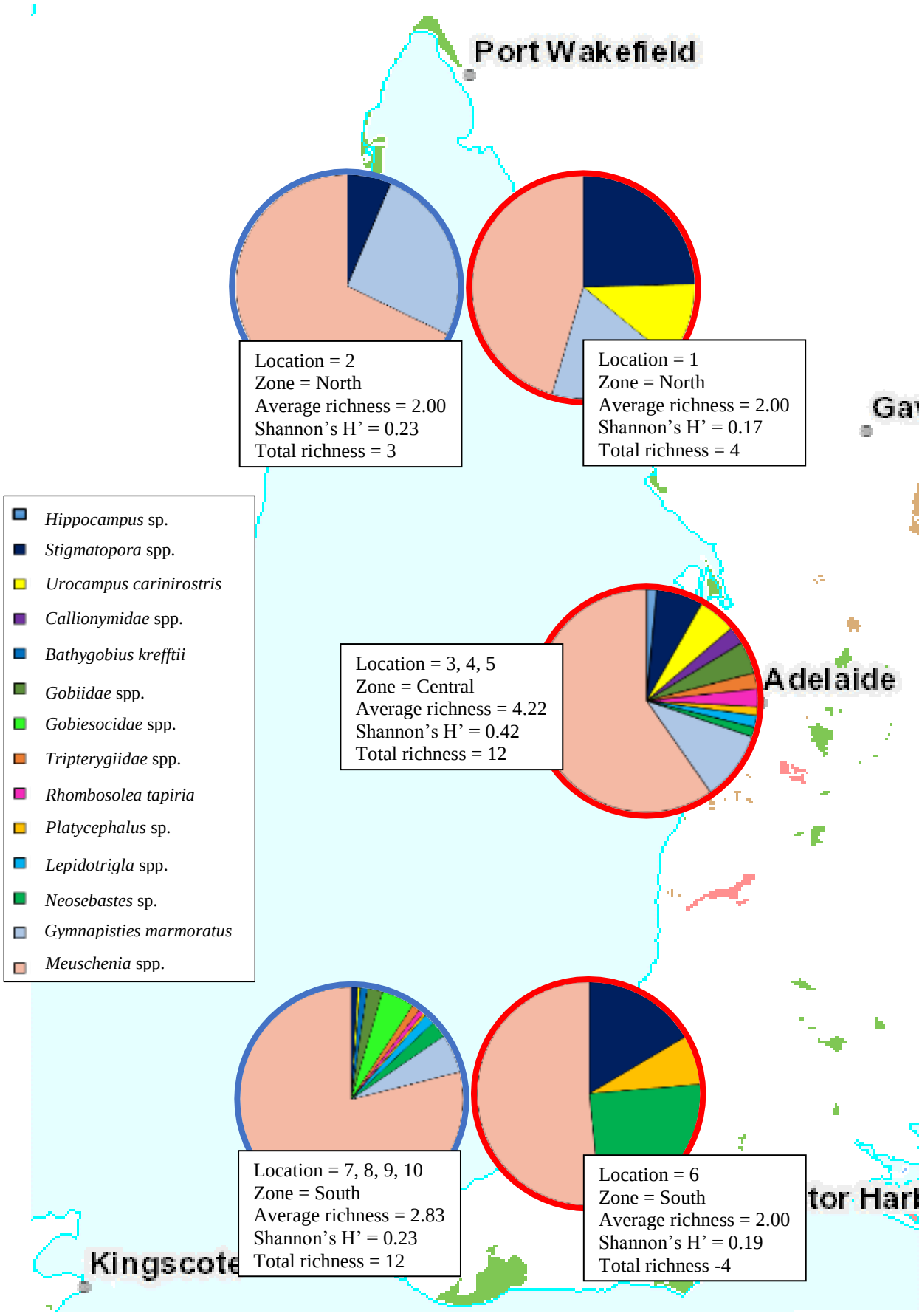

Figure 12. Relative abundances of species in each zone: North, Central and South; depicting total richness inside (blue outlie) and outside (red outline) sanctuaries. Note richness and Shannon's H' given in text boxes are averages for the zone/sanctuaries within zone.

Aim 3 – Larval communities of Gulf St Vincent and other temperate areas:

The community structures of Spencer Gulf and Sydney coastal waters were significantly different from each other and from that of the pooled sampling periods of this study (Table 5, Figure 13 a). Total abundance was significantly different between Sydney coastal waters and Spencer Gulf ($p = 0.041$), and Sydney coastal waters and Gulf St Vincent ($p < 0.001$). The total abundances of Spencer Gulf and Gulf St Vincent were not significantly different ($p = 0.859$) (Table 5, Figure 13 b).

Table 5. PERMANOVA results of temperate study comparison, showing in yellow results of total abundance comparison, and in orange community structure comparison.

	Sydney		**Spencer Gulf**		**Gulf St Vincent**	
	Sign.	R stat.	Sign.	R stat.	Sign.	R stat.
Sydney			0.041	1.00	<0.001	0.98
Spencer Gulf	0.042	1.00			0.859	-0.20
Gulf St Vincent	<0.001	1.00	<0.001	0.42		

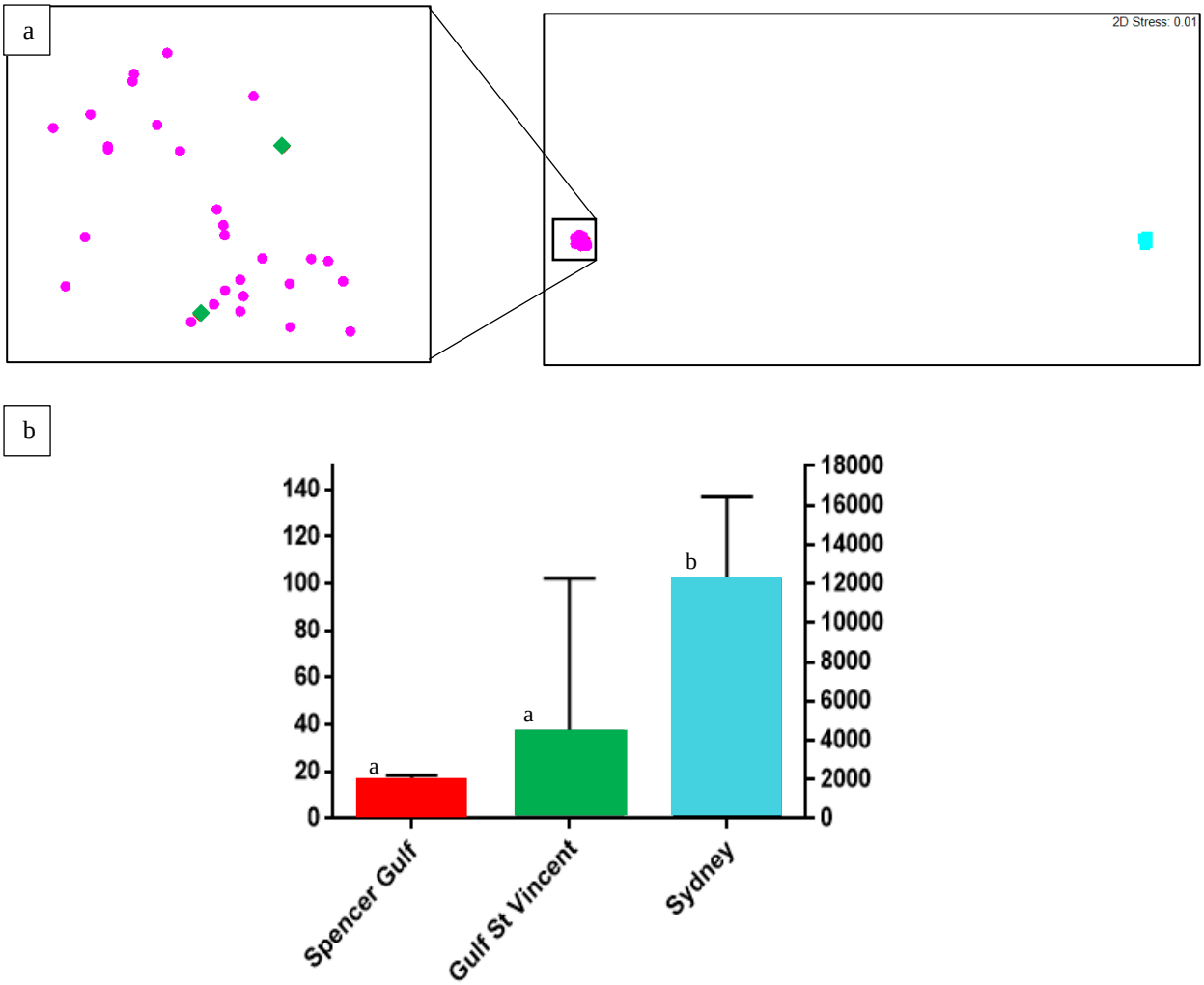

Figure 13 a) nMDS of similarity between the larval communities of different temperate Australian areas, showing WA in green, east Australia in dark blue, Sydney in light blue, Spencer Gulf in red, and Gulf St Vincent in green with stress 0.01; b) total abundance of larvae per 500 m^3 at each temperate region, with Spencer Gulf and Gulf St Vincent on left axis and Sydney on right axis, showing standard deviation and letters symbolising significant differences (where different letters represent significant differences).

Discussion

Aim 1 – Larval distribution patterns:

The pooling of the sampling periods found that the late-autumn and winter larval communities differed between the North and South zones as well as between the Central and South zones; that average species richness and Shannon's H' were both highest in the Central zone; and that total abundance increased linearly across the latitudinal gradient of the Gulf from North to South. The hypothesis of larval distributions varying spatially within Gulf St Vincent is therefore upheld for late-autumn and winter communities. As the patterns found for the pooled periods are unlike those obtained by analysis of individual sampling periods, even though differences exist for at least one assemblage index between each of the periods, it is clear that one sampling period alone is not driving the pattern of larval assemblages. The following interpretations are therefore based on the overall results of the pooled periods.

While remembering that they are larvae, and thus have not yet settled into the benthos, and so may continue to move, either passively or actively, prior to settlement, the patterns observed are indicative of the processes governing the ecological systems in the area. Differences in larval community structure between zones may, at least partially, be governed by assemblage patterns of adult fish. While larvae may be widely dispersed (Caley *et al.* 1996), the adult species present in each zone, and their abundance within each zone, is likely to contribute to the larvae supplied to the area. As adults, over 35% of the species sampled in this study are demersal brooders, laying demersal eggs and caring for them (Table 6) (Patzner 2008). While pelagic spawners release eggs into the open water, resulting in widespread dispersal, demersal spawners release eggs closer to the substrate and have been shown to disperse less than pelagic eggs/larvae, remaining closer to shore and dominating shallow environments (Hickford and Schiel 2003; Patzner 2008). Dispersal, particularly passive dispersal, is restricted in demersal spawners as the eggs have parental care until well developed larvae emerge (Hickford and Schiel 2003; Patzner 2008). The larvae of demersal spawners are often larger and stronger than those of pelagic spawners, and so any dispersal that does occur is often more active. Larvae from demersal spawners that are present as adults in specific areas, be it North, Central, South or a combination of the three zones, may therefore be retained in that zone(s). While pelagic larvae may disperse more readily, the currents present in Gulf St Vincent (Figure 3 b) may restrict or influence their dispersal. Larvae from an adult fish that is present and spawns in the North zone may be somewhat retained in the area due to the circular current at the head of the Gulf (Figure 3 b). Alternatively, larvae from an adult fish present and spawning in the South may be dispersed by

the anti-clockwise circulation on the south-eastern coast, limiting its supply to the South zone (Figure 3 b). While the currents could offer explanation for the recorded differences in larval communities between North and South, and Central and South, the magnitude and direction of the currents are suggestive of a greater difference between the North and Central zones than the Central and South (Figure 3 b). While this is not reflected in the results, with the larval communities of the North and Central not significantly different from each other (Table 2), this mismatch may be due to the habitats of the North and Central zones both being dominated by seagrass and thus more similar to each other than the South zone which is a mix of seagrass and reef habitat. North and Central zones having similar habitat may mean that species present as adults in the North are also as adults in the Central. Therefore, while currents may prevent a proportion of the larvae in the North being distributed to the Central zone, and vice-versa, if the same adult species are spawning in each zone the larval communities are likely to be similar. The currents recognised to occur in the area coupled with the late-autumn and winter larval communities of this study demonstrate the occurrence of a relatively distinct community structure in the North and mixed communities in the Central and South. While BEST analysis deemed that the environmental variable of temperature was most responsible for differences in community structure, temperature explaining 28% of the variation, and temperature is known to directly affect spawning time and survival of larvae (e.g. Green and Fisher 2004), there is no temperature difference between the Central and South and the temperature in the North is only slightly different (Table 1, Figure 14). Although a variable co-linear to temperature may better explain the variation, not enough is known from this study.

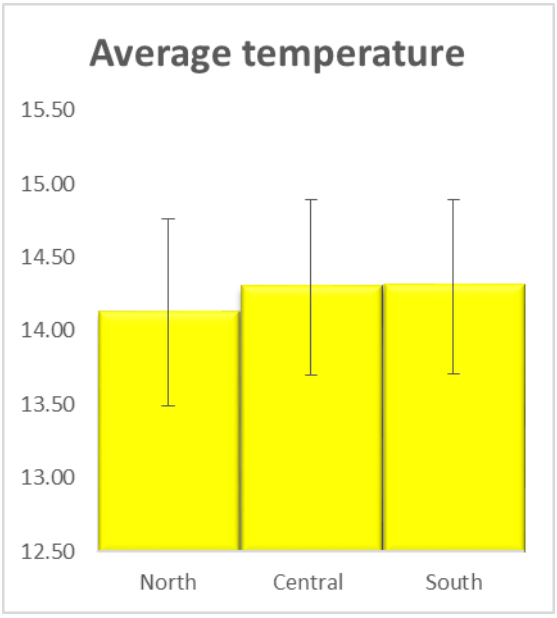

Figure 14. Average temperature in each zone for the pooled sampling periods showing standard error.

Average species richness and Shannon's H' diversity index were both found to be highest in the Central zone. However, across all samples, total richness was equal between the Central and South (Figure 9 and 10). This is indicative of the larvae in the Central zone having higher catchability, as in each sample a greater richness occurred, and may be due to the Central zone having less habitat complexity than the South, leaving larvae more exposed with the nets able to sample directly over or through the seagrass. Total species richness being highest in the Central and South zones could be due to Central zone being a frontal zone within the Gulf, and the South being a frontal zone between the Gulf and open ocean. A frontal zone is the mixing of two different water masses and can result in a peak in diversity where the overlap occurs as species found in each water mass overlap (Petrusevics 1993). As can be exemplified by salinity (Figure 15), the Central zone is characterised conditions between the extremes of the North and South. By presenting mid-level conditions, the Central zone could support a greater number of species (Bruce and Short 1990). It supports the overlap between species that are present in the North and in the South. The South as a frontal zone between the Gulf and the open ocean supports high species richness in the same manner. While recordings of environmental variables were not made in this study, a change in conditions between the Gulf and open ocean has been previously noted, with the open ocean having lower salinity and temperatures (Petrusevics 1993). The likelihood of a frontal zone being present in the South zone of the Gulf and its presence influencing high species richness is supported due to the occurrence of such a phenomenon in neighbouring Spencer Gulf, which as another inverse estuary is subject to similar environmental patterns (Bruce and Short 1990). Bruce and Short (1990) found that species richness, diversity and abundance all peaked within the frontal zone that was found across the mouth of Spencer Gulf. Although such frontal zones between the Gulfs and open ocean are more prominent in summer months they are still present in autumn and winter (Bruce and Short 1990). In Gulf St Vincent, the high total species richness in the South and Central may be heightened due to greater influx of species from the open ocean being carried in by the currents which circulate in from the open ocean and up through the mouth and centre of the Gulf (Figure 3 b). By supporting greater total species richness the Central and South zones have the potential to support greater diversity. While average diversity is highest in the Central zone (Figure 8) high total richness of the South zone suggests total diversity would also be high in the South zone. High diversity in the Central and South is likely to be at least somewhat due to the habitat type, as higher habitat complexity inherently supports higher diversity (Gratwicke and Speight 2005). While all three zones have seagrass habitats, the Central zone is closer than the North to the reef habitats that are present in the South, and these reef habitats offer greater complexity than the seagrass (Shepherd and Sprigg 1976). While complexity supports higher diversity, the mixed

seagrass and reef habitats are of greater significance as many of the species sampled live in seagrass and reef habitats as adults, and thus larvae of these species are likely to look to settle in seagrass and reefs (Table 6).

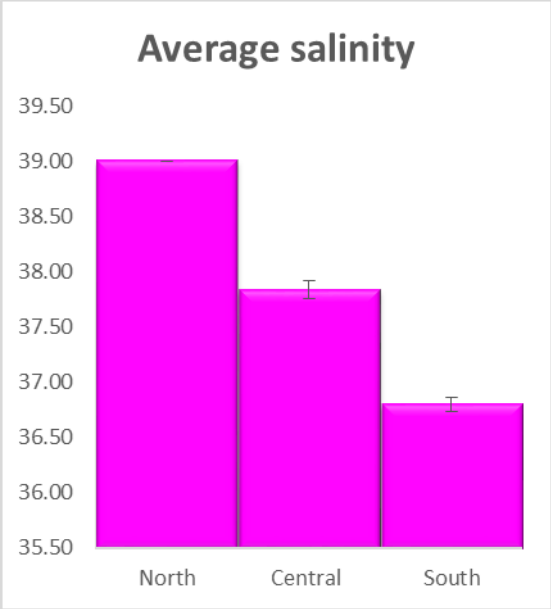

Figure 15. Average salinity in each zone for the pooled sampling periods showing standard error.

Table 6. Spawning method and habitat preference of species sampled. *sourced from: Patzner 2008, # sourced from Gomon *et al.* 2008.

Species	**Egg position**	**Habitat larvae sampled in**	**Adult habitat**
Hippocampus sp.	Live young*	Seagrass	Seagrass beds, weed#
Stigmatopora spp.	Live young*	Seagrass, unconsolidated	Seagrass beds, weed#
Urocampus carinirostris	Live young*	Seagrass, unconsolidated	Seagrass beds, weed, algae#
Callionymidae spp.	Pelagic eggs*	Seagrass	Muddy/sandy/shelly bottoms#
Bathygobius krefftii	Demersal/nest spawners*	Reef	Seagrass beds#
Gobiidae spp.	Demersal/nest spawners*	Seagrass, reef	Seagrass beds, mangroves, reefs, sandy/muddy bottoms#
Gobiesocidae spp.	Demersal/nest spawners*	Reef	Seagrass beds, rocky/shelly bottoms, reefs#
Tripterygiidae spp.	Demersal/nest spawners*	Seagrass, reef	Grass and algal beds, reefs, rocky/hard bottoms, weed#
Rhombosolea tapiria	Pelagic eggs*	Seagrass, reef	Sandy bottom#
Platycephalus sp.	Pelagic eggs*	Seagrass, reef	Reefs, sandy/shelly/muddy bottoms, seagrass#
Lepidotrigla spp.	Pelagic eggs*	Seagrass, reef	Sandy/muddy bottom#
Neosebastes sp.	Pelagic eggs*	Seagrass, reef	Reefs, hard bottoms#
Gymnapistes marmoratus	Pelagic eggs*	Seagrass, reef, unconsolidated	Seagrass#
Meuschenia spp.	Demersal eggs*	Seagrass, reef, unconsolidated	Reefs, weed#

While reflecting the presence of frontal zone and subsequent high total species richness in the South zone, the linear increase in total abundance from north to south is also likely to be habitat related. Although the Central zone may have the most seagrass habitat the South has greater

habitat complexity and variety. The locations sampled in the South zone are representative of seagrass and reef habitats but are also in close proximity to sandy, muddy or shelly bottoms, which the larvae may encounter prior to settling as they are not restricted to the location from which they are sampled. As adults nearly 43% of the species sampled have some preference for sandy, shelly of muddy bottoms (Table 6). While sandy bottoms are also present near the locations in the Central and North zones these zones don't have reef habitats, which are recognised to support greater diversity than seagrass (Gratwicke and Speight 2005), in close proximity. The South zone therefore has the most habitat variety. Increased habitat variety offers the potential for a greater number of individuals to co-exist (Gratwicke and Speight 2005). Total abundance being greater towards the south of the Gulf may be heightened by the habitat there being of better quality. While benthic mapping is needed to quantify the quality of habitat, this is postulated as the area is most removed from the metropolitan coastline and thus pollution and habitat degradation is likely reduced. Further, as the southern region of the Gulf is the mouth of the estuary, this region may receive greater larval supply from the open ocean. Such increased larval supply could be aided by the currents along both the western and eastern costs of the Gulf (Figure 3 b).

On a species level patterns of interest can be seen across the zones for some of the sampled species. *Meuschenia* spp. (leather jackets) can be seen to dominate the late-autumn and winter larval assemblages of each zone (Figure 9). The dominance of one or a few species is common in studies of larval fish assemblages, and particularly in studies over late-autumn and winter, where the number of fish that have peak spawning is reduced (Potter *et al.* 1993; Muhling and Beckly 2007; Keane and Neira 2008; and others). In winter studies, adults of multiple species may spawn and thus that species may be present as larvae but, as environmental conditions are less favourable for many species, the number that have peak spawning is minimal, which leads to that species, or few species, dominating. The dominance of *Meuschenia* spp. in this study could be due to peak spawning in late-autumn and winter, but assessments during other seasons is needed to determine if such a peak occurs. A peak in spawning during late-autumn and winter would however be unlikely to be the sole explanation for such dominance, as other species, such as *Gymnapistes marmoratus* (South Australian Cobbler), experience peak spawning in these seasons (Neira 1989). The dominance of *Meuschenia* spp. is likely to be a combination of the fact that they spawn in late-autumn and winter and are demersal spawners (Table 6). Larvae of demersal spawners are on average larger than pelagic spawners and thus may be less likely to be extruded through the nets while sampling (Hickford and Schiel 2003; Patzner 2008). Further, demersal larvae have previously been demonstrated to remain closer to shore, dominating

shallow environments, than pelagic spawners which are likely to disperse further. While *Bathygobius krefftii* (Krefft's frillgoby), *Gobiidae* spp. (gobies), *Gobiesocidae* spp. (clingfishes), *and Tripterygiidae* spp. are also spawned demersally, they may not have peak spawning in the sampling seasons of this study. Although *Meuschenia* spp. larvae have the highest contribution to all three zones (Figure 9), it should be noted that they occur in greatest abundance in the South zone (Figure 10). This is likely to be due to their preference as adults, and thus selection for as larvae, for reef habitats (Table 6). Aside from *Meuschenia* spp., the larvae sampled that are spawned demersally were not found in the North zone, with *Bathygobius krefftii* and *Gobiesocidae* spp. only found in the South (Figure 9 and 10). This absence from the North zone and restriction of two of the taxa to one zone may demonstrate the more restricted dispersal of demersal spawners (Hickford and Schiel 2003; Patzner 2008). *Neosebastes* sp. (scorpionfish), *Lepidotrigla* spp. (searobins), *Platycehalus* sp. (flathead) and *Rhombosolea tapiria* (greenback flounder) are also absent as larvae from the North zone (Figure 9 and 10), only occurring in the Central and South. These are pelagic spawners (Table 6) and so should experience wider spread dispersal (Hickford and Schiel 2003; Patzner 2008). Currents may be dispersing them through the Central and South and preventing them from reaching the North, as the currents go up through the Gulf and then circulate back down prior to reaching the North zone (Figure 3 b). Adult data would also provide insight into the reasons for the larval distribution patterns, as, for example, if adults are present in the North zone then the larvae may only actively disperse there closer to settlement. Also of interest are the patterns of the Syngnathidae species; *Urocampus carinirostris* (hairy pipefish), *Stigmatopora* spp. (pipefishes) and *Hippocampus sp.* (seahorse). While *Urocampus carinirostris* and *Stigmatopora* spp. larvae are present in all three zones, their abundances were highest in the Central zone (Figure 10) and *Hippocampus* sp. was only found in the Central zone (Figures 9 and 10). This could be due to the Central zone having the most seagrass (Figure 1) and Syngnathidae preferring seagrass habitats as adults (Table 6). Syngnathids bear live young, resulting in reduced dispersal in many Syngnathidae species as the young settle into the adult habitat immediately upon release (Patzner 2008). Their larval patterns are thus likely to be highly dependent on adult patterns. While this study has highlighted some patterns that may occur for these Syngnathidae taxa in late-autumn and winter, as they are often cryptic species, remaining close to the substrata (Patzner 2008), sampling with plankton nets may not be the best method for completely capturing the true patterns of these taxa. That being said, highlighting presence of these taxa within Gulf St Vincent still works to present potential management implications. Like *Hippocampus* sp. *Callionymidae* spp. (dragonets) were also only found in the Central zone (Figures 9 and 10). As adults they favour muddy, sandy or shelly bottoms so may move offshore, either in the Central zone or elsewhere, prior to settling.

Prior to this study only larvae of *Sillaginodes punctate, Engraulis australis, Hyporhamphus melanochi, Sardinops sagax, Spratelloides robustus, Pelates octolineatus, Lesueurina platycephala, Pagrus auratus* and *Syngnathidae* spp. had been recorded at similar depths in Gulf St Vincent (Neira *et al.* 1998; Rogers *et al.* 2003; Dimmlich *et al.* 2004; Noell and Ye 2008; Saunders 2009). Therefore, aside from species of the Syngnathidae family, the species sampled in this study are different to those previously recorded as larvae in Gulf St Vincent. This study therefore recognises the occurrence of more species as larvae in the area, providing important baseline data. Studies of larval assemblages in other areas, both worldwide in environments vastly different to Gulf St Vincent and in other temperate Australian areas, larval species richness and abundances are known to be higher in spring and summer months, when environmental conditions are more favourable, than in late-autumn and winter (Potter *et al.* 1993; Muhling and Beckly 2007; Keane and Neira 2008; Mifsud *et al.* 2010; and others). For example, a study in neighbouring Spencer Gulf found species richness to be approximately 5 times higher in summer than in winter (Mifsud *et al.* 2010). The species richness and diversity of larval fish within Gulf St Vincent is therefore likely to be higher than that encapsulated by this study. Future studies that assess larval distribution patterns in Gulf St Vincent during seasons not explored in this study would be insightful as to the true diversity.

Aim 2 – Sanctuary replenishment and population growth:

As the structure, richness and diversity of larval community structures can drive the assemblage characteristics of juvenile and adult communities due to the inherent link between life stages (Stephens Jr *et al.* 1986; Caley *et al.* 1996), the need for protection of those areas that receive supply of unique, diverse or abundant larval assemblages, by means such as sanctuaries, can be recognised. While all life stages in this study were significantly different from each other, demonstrating no correlation between life stages, these differences are likely due to temporal variations or methodological downfalls. The temporal variations occur on a scale of years, with juvenile, sub-adult and adult data obtained two years prior to larval data, and on the scale of season, with juvenile, sub-adult and adult data recorded in summer and larval data being obtained in late-autumn and winter. Methodical issues include possible species bias of underwater visual census, as species that are smaller or more cryptic may be underestimated in counts. The likelihood of such estimation is exemplified by 79% of the larval species sampled not being recorded in the older life stages, although inherently species that are present as larvae should be present in older life stages, even if strong correlations in abundance do not exist. An additional methodological error is that only the two most southern larval sampling locations had

data on older life stages, and thus an overall picture of correlations in the Gulf was not possible. Because of the possibility of such confounding effects, life stage analysis of this study will be discounted and the following discussion of management implications will be based on the theory, as demonstrated in larger scaled studies, that correlations between life stages do exist in nature (Gaines and Roughgarden 1985; Victor 1986; Schmitt and Holbrook 1996; Schmitt and Holbrook 1999; Freeman *et al.* 2012; Wen et al. 2013; and others).

Differences in late-autumn and winter larval assemblages between the zones of Gulf St Vincent could have management implications. By protecting natural habitats sanctuary zones offer increased settlement opportunities (Halpern and Warner 2003). Further, if larval fish settle within a sanctuary zone, where mortality due to fishing is eliminated, they can become part of the local population resulting in enhanced population growth (Stockhausen *et al.* 2000; Gerber *et al.* 2005). Currently one sanctuary is present in the North zone of Gulf St Vincent and four sanctuaries are present in the South Zone of Gulf St Vincent. These sanctuaries could therefore work to enhance settlement opportunities of the larval communities of the North and South, which are distinct from each other, and higher population growth in the long term for the species present within the sanctuaries, provided they do settle there. While larvae of one species, *Urocampus carinirostris*, were sampled in a non-sanctuary area in the North zone (Figure 12), movement of the species into the sanctuary is probable and the species occurs within the sanctuaries in the South. All species sampled as larvae in the South were present in the sanctuaries (Figure 12). While the Central zone has no sanctuaries and has a significantly different larval community to the South zone, all species except for *Hippocampus* sp. and *Callionymidae* spp. are present as larvae within a sanctuary zone (Figure 12). Further, while present in the North and South, and thus where sanctuaries are, *Stigmatopora* spp., *Urocampus carinirostris, Gobiidae* spp., *Tripterygiidae* spp., *Rhombosolea tapiria* and *Gymnapisties marmoratus* all had highest larval abundances in the Central zone, where there are no sanctuaries (Figures 10 and 12). If the larvae settle close to where they were sampled, i.e. with high abundances outside of sanctuaries, the current sanctuaries may not best protect the settlement habitats of these specific species and may not offer the highest potential for their population growth. Future studies within Gulf St Vincent could discern changes in the larval patterns temporally, on a scale of seasons and years, to better estimate the potential for protecting the fish species present in the Gulf. The current study can only highlight that greatest protection of late-autumn and winter spawners may not be achieved, but can recognise that the sanctuaries in the North and South, where all but two of the sampled taxa occur, may provide adequate protection of the settlement habitats of the sampled species and thus may provide potential for population

growth. As the South zone had highest total species richness and four sanctuaries are present in this zone, while efficacy cannot yet be determined, the potential replenishment of larvae into sanctuary zones is exemplified. Wen and colleagues (2013) study in the Keppel Island group of the Great Barrier Reef found that for population of *Plectropomus maculatus* and *Lutjanus carponotatus* the supply, and subsequent settlement, of larvae to the study sites was a stronger driver of population growth than whether the area was open or closed to fishing. As sanctuaries, areas that are closed to fishing, have been shown to better facilitate population growth than areas that are open to fishing, coupling areas of larval supply and positioning of sanctuaries should maximise the potential for population growth (Stockhausen *et al.* 2000; Gerber *et al.* 2005). While the sanctuaries of Gulf St Vincent are too new for closure to fishing to have had an effect, the data of this study therefore provides important baseline information that suggests larvae have the potential to be supplied to the sanctuaries and thus could enhance future population growth. By providing baseline data, it allows future detection of spatial and temporal changes in larval assemblages both within and external to sanctuary zones.

Aim 3 – Larval communities of Gulf St Vincent and other temperate areas:

The importance of protecting the areas that are supplied with rich or diverse larval communities within Gulf St Vincent is further enhanced by the uniqueness of its larval communities compared to the larval communities found in other temperate Australian regions. While variation existed in the larval assemblages between the zones of Gulf St Vincent, when compared to data from other temperate Australian areas the Gulf St Vincent larval data is clustered, showing higher similarity to each other, irrespective of zone, than to Sydney coastal waters (Figure 13 a). This works to show that the variation within Gulf St Vincent is a true pattern in nature and strengthens the significance of the larval assemblages in the Gulf being different to other areas. While the larval communities of Gulf St Vincent may be expected to be different to other temperate regions, due to the sensitivity of fish and in particular larvae, to environmental conditions, it was expected that the larval communities of Gulf St Vincent would be similar to those of neighbouring Spencer Gulf. However, this was not the case. As Gulf St Vincent runs along the Adelaide metropolitan coastline it may be subject to significantly higher levels of pollutants than Spencer Gulf. McKinley and colleagues (2011) showed that contamination, among other things, can completely alter larval community structure, and so this could explain the differences in community structure between Spencer Gulf and Gulf St Vincent. Investigation into the tolerance of individual species sampled in each study to different pollutants, as well as other environmental conditions, would allow better explanation of the differences. However, this is

not possible in the scope of this study as, due to inherent variation in species of the same family or genera (for example Feminella and Matthews 1984), it would require all taxa to be identified to species level. While the late-autumn and winter larval communities of Spencer Gulf and Gulf St Vincent were significantly different, the two South Australian estuaries did not differ in terms of total larval abundance. This means that different species are dominating the communities of Spencer Gulf and Gulf St Vincent, and is what would occur if levels of pollutants, or other environmental variables, are different between the areas (McKinley *et al.* 2011). While Gulf St Vincent is dominated in late-autumn and winter by *Meuschenia* spp. (contributing 15.53% to the dissimilarity between the two Gulfs), in the same months Spencer Gulf is dominated by *Gobiidae* spp. and *Clinidae* spp. (contributing 23.05% and 19.70% respectively to the dissimilarity between the Gulfs). Differences were found between the late-autumn and winter larval community structure and total abundance of Gulf St Vincent, and Spencer Gulf, and Sydney coastal waters, with Sydney coastal waters having significantly greater abundance than both the Gulfs (Figure 13 b). This is likely due to Sydney coastal waters being open ocean environment, i.e. not an estuary, in which more mixing between adjacent areas may occur and resulting in increased larval supply. Further, South Australia has high species endemism and so larval communities in the Gulfs of South Australia are likely to be dominated by different species than in the Sydney coastal waters, resulting in significantly different community structures (DSEWPC 2012).

Conclusion:

This study highlighted salinity, habitat type, and large-scale current patterns as potentially important drivers of the late-autumn and winter larval assemblages of Gulf St Vincent. The larval assemblages of Gulf St Vincent in late-autumn and winter are unique from those in other temperate Australian areas in comparable seasons. Protection of the habitats that receive supply of different larval communities present within the Gulf is therefore important to enhance settlement potential and lead to long term population growth. Differences in larval assemblages between zones of the Gulf substantiate the need for multiple sanctuaries. Although no correlations were found between life stages in this study, larval supply to an area remains an important process in population enhancement. Therefore, the sanctuary zones in the area, through protecting natural settlement habitats of unique late-autumn and winter larval assemblages, and eliminating mortality due to fishing offer enhanced population growth of these late-autumn and winter spawners. While highlighting patterns present in late-autumn and winter, this study provides novel baseline data; qualifying and quantifying the presence of different

larval species in the area, and in doing so indicating presence and diversity of adult fish species. Such baseline data is important for understanding processes that govern the ecological systems in the area, but also works to allow analysis of the impact of the sanctuaries in the future by providing data obtained prior to the sanctuaries coming into effect.

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Appendix A – Recorded variables of each location sampled. For 'zone' N = North, C = Central and S = South.

	Location	Zone	Latitude	Water depth	Temperature (degrees C)	% moon visible	Salinity	km to shore	Sample distance from seafloor	Habitat type	Volume filtered (m^3)
Period 1	1	N	34 20 24.4	10m	16.10	88.3	39	12.8	8m	Unconsolidated	264.48
	2	N	34 30 34.8	10m	16.20	88.3	39	16.07	8m	Seagrass 30%	278.39
	2	N	34 30 19.1	15m	16.30	88.3	39	14.89	13m	Sand	359.82
	3	C	34 46 33.8	15m	16.51	88.3	38	8.39	13m	Seagrass 30%	286.39
	3	C	34 46 50.5	20m	16.90	88.3	38	19.9	18m	Sand	244.04
	4	C	34 50 49.9	15m	16.88	94.2	38	7.22	13m	Seagrass 90%	285.70
	4	C	34 50 28.56	20m	17.13	94.2	38	9.35	18m	Sand	227.43
	5	C	34 57 15.5	15m	16.59	94.2	37.5	4.66	13m	Seagrass 50%	212.61
	5	C	34 57 23.5	20m	16.98	94.2	37.5	8.43	18m	Sand	316.61
	6	S	35 3 30.4	15m	16.44	94.2	37	1.11	13m	Seagrass 30%	376.29
	6	S	35 2 51.9	20m	16.70	94.2	37	4.02	18m	Sand	371.00
	7	S	35 9 47.6	15m	16.44	99.9	37	1.1	13m	Seagrass 30%	345.11
	7	S	35 9 55.1	20m	16.96	99.9	37	1.88	18m	Sand	359.77
	8	S	35 16 38.5	15m	17.20	99.9	37	0.971	13m	Reef	352.44
	8	S	35 16 30.3	20m	17.15	99.9	37	1.42	18m	Sand	352.44
	9	S	35 23 52.68	15m	18.80	0.1	36.5	0.137	13m	Reef	338.11
	9	S	35 23 8.06	20m	18.67	0.1	36.5	0.83	18m	Unconsolidated	458.42
	10	S	35 31 35.7	15m	18.23	0.1	36.5	0.42	13m	Seagrass 50%	680.12
	10	S	35 29 58.83	20m	18.50	0.1	36.5	2.13	18m	Unconsolidated	259.80
Period 2	1	N	34 20 24.4	10m	12.94	15.7	39	6.57	4.39m	Unconsolidated	439.12
	2	N	34 30 34.8	10m	14.19	15.7	39	16.13	5.06m	Seagrass 30%	388.08
	3	C	34 46 33.8	15m	13.75	15.7	39	8.44	6.61m	Seagrass 30%	412.72
	4	C	34 50 49.9	15m	13.79	15.7	39	7.25	5.61m	Seagrass 90%	429.88
	5	C	34 57 15.5	15m	12.36	98.1	39	4.78	9.30m	Seagrass 50%	189.15

Appendix A. Recorded variables of each location sampled. For 'zone' N = North, C = Central and S = South. - Continued

	6	S	35 3 30.4	15m	12.69	98.1	38	1.37	8.27m	Seagrass 30%	433.84
	7	S	35 9 47.6	15m	12.43	100	38	1.13	5.40m	Seagrass 30%	418.44
	8	S	35 16 38.5	15m	13.10	100	38	1.01	6.88m	Reef	381.04
	9	S	35 23 52.68	15m	13.07	100	37	0.15	8.18m	Reef	411.84
	10	S	35 31 35.7	15m	13.53	100	37	0.56	8.80m	Seagrass 50%	424.16
Period 3	1	N	34 20 24.4	10m	12.07	79.9	39	6.63	4.52m	Unconsolidated	385.44
	2	N	34 30 34.8	10m	13.25	79.9	39	15.69	5.27m	Seagrass 30%	334.40
	3	C	34 46 33.8	15m	14.15	79.9	39	8.63	7.61m	Seagrass 30%	371.36
	4	C	34 50 49.9	15m	12.44	88.4	39	7.93	7.08m	Seagrass 90%	466.84
	5	C	34 57 15.5	15m	12.18	88.4	39	4.83	9.55m	Seagrass 50%	431.20
	6	S	35 3 30.4	15m	12.64	88.4	38	1.36	8.20m	Seagrass 30%	374.44
	7	S	35 9 47.6	15m	12.62	99.9	38	1.25	5.34m	Seagrass 30%	390.28
	8	S	35 16 38.5	15m	12.35	99.9	38	1.18	5.43m	Reef	394.68
	9	S	35 23 52.68	15m	12.24	99.9	37	0.16	5.79m	Reef	424.60
	10	S	35 31 35.7	15m	12.77	99.9	37	0.57	7.91m	Seagrass 50%	332.64

Appendix B – Difference between inshore and offshore larval assemblages, and differences in larval assemblages due to mesh size.

North community structure

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Me	1	127.14	127.14	0.10013	1	2	0.8325
Res	2	2539.5	1269.8				
Total	3	2666.7					

Central community structure

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
De	1	6171.4	6171.4	2.3915	0.0798	8734	0.0934
Me	1	3242.5	3242.5	1.2565	0.3116	8737	0.3137
DexMe	1	5034.8	5034.8	1.9511	0.1522	8769	0.1515
Res	8	20644	2580.5				
Total	11	35093					

South community structure

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
De	1	2072.3	2072.3	1.4379	0.1857	9923
Me	1	845.34	845.34	0.58657	0.6565	9915
DexMe	1	898.09	898.09	0.62318	0.6461	9936
Res	16	23058	1441.2			
Total	19	26874				

North total abundance

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Me	1	200.75	200.75	7.6243E-2	1	2	0.8683
Res	2	5265.9	2633				
Total	3	5466.7					

Central total abundance

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Me	1	2021.5	2021.5	2.1814	0.1604	8266	0.1602
De	1	2224	2224	2.4	0.1424	8254	0.1412
MexDe	1	105.19	105.19	0.11351	0.8703	8241	0.8673
Res	8	7413.4	926.67				
Total	11	11764					

South total abundance

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
De	1	405.02	405.02	0.21325	0.8062	9917
Me	1	1619.8	1619.8	0.85284	0.4236	9944
DexMe	1	569.8	569.8	0.30001	0.7313	9921
Res	16	30388	1899.3			
Total	19	32983				

North richness

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Me	1	100	100	0.11077	1	2	0.8076
Res	2	1805.6	902.78				
Total	3	1905.6					

Central richness

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Me	1	33.333	33.333	0.1092	0.7527	208	0.8185
De	1	1026.1	1026.1	3.3614	0.1151	207	0.0942
MexDe	1	185.87	185.87	0.60887	0.4699	209	0.4726
Res	8	2442.1	305.26				
Total	11	3687.4					

South richness

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
De	1	619.13	619.13	0.70558	0.4333	4993	0.4361
Me	1	114.94	114.94	0.13099	0.837	5030	0.8194
DexMe	1	619.13	619.13	0.70558	0.4466	4974	0.4323
Res	16	14040	877.48				
Total	19	15393					

North Shannon's H'

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Me	1	42.787	42.787	1	1	1	0.4254
Res	2	85.575	42.787				
Total	3	128.36					

Central Shannon's H'

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
De	1	191.77	191.77	2.4223	0.1614	2271	0.1553
Me	1	10.236	10.236	0.12929	0.759	2270	0.7402
DexMe	1	53.934	53.934	0.68126	0.3983	2284	0.4368
Res	8	633.35	79.169				
Total	11	889.29					

South Shannon's H'

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
De	1	120.73	120.73	1.456	0.2399	8282	0.2433
Me	1	5.4342	5.4342	6.5536E-2	0.7975	8205	0.8122
DexMe	1	119.76	119.76	1.4443	0.2402	8239	0.2464
Res	16	1326.7	82.919				
Total	19	1572.6					

Appendix C – Species that may be present with Gulf St Vincent

Table of fish species that have previously been recorded in Gulf St Vincent – taxa highlighted in apricot are recognised as occurring in the Gulf in 'Larvae of temperate Australian fishes: laboratory guide for larval identification' (Neira *et al.* 1998), taxa highlighted in purple were recognised as occurring in the Gulf in 'Fishes of Australia's southern coast' (Gomon *et al.* 2008); and taxa highlighted in yellow were recognised as occurring the Gulf in 'Survey of planktonic larvae near Point Lowly (Mifsud *et al.* 2010). Species with * are present in the adult data used in this study.

Order	Family	Genus	Species	Common name
Argentiniformes	Argentinidae	Argentina	australiae	silverside
Atherinformes	Atherinidae	Atherinson	hepsetoides	deepwater hardyhead
		Atherinosoma	elongata	elongate hardyhead
			microstoma	smallmouth hardyhead
		Kestratherina	brevirostris	shortsnout hardyhead
			esox	pikehead hardyhead
		Leptatherina	presbyteroides	silver fish
Beloniformes	Hemiramphidae	Hyporhamphus	melanochir	southern garfish
			regularis	river garfish
	Scomberesocidae	Scomberesox	saurus scomberoides	saury
Berycifomes	Berycidae	Centroberyx	gerrardi	bight redfish
			lineatus	shalowtail
	Trachichthyidae	Paratrachichthys	macleayi	sandpaper fish
		Trachichthys	australis	southern roughy
Clupeiformes	Clupeidae	Etrumeus	teres	muray round herring
		Hyperlophus	vittatus	sandy sprat
		Sardinops	sagax	pilchard
		Spratelloides	robustus	blue sprat
		Sprattus	novaehollandiae	Australian sprat
	Engraulidae	Engraulis	australis	anchovy
Gadiformes	Moridae	Eeyorius	hutchinsi	finetooth beardie
		Lotella	rhacina	largetooth beardie
		Pseudophycis	bachus	red cod
			barbata	bearded rock cod
			breviuscula	bastard red cod
Gasterosteiformes	Pegasidae	Pegasus	lancifer	sculptured seamoth
	Sygnathidae	Stigmatopora	argus	spotted pipefish
			nigra	widebody pipefish
			narinosa	gulf pipefish
		Campichthys	galei	gale's pipefish
			tryoni	tryon's pipefish
		Heraldia	nocturna	upside-down pipefish
		Hippocampus	bleekeri	potbelly seahorse
			breviceps	shorthead seahorse
			abdominalis	bigbelly seahorse
		Histiogamphelus	cristatus	rhino pipefish
		Hypselognathus	horridus	shaggy pipefish
			rostratus	knifesnout pipefish
		Phycodurus	eques	leafy seadragon
		Filicampus	tigris	tiger pipefish
		Idiotropiscus	australe	pygmy pipehorse
		Urocampus	carinirostris	hairy pipefish
		Kaupus	costatus	deepbody pipefish
		Kimblaeus	bassensis	trawl pipefish
		Leptoichthys	fistularius	brushtail pipefish

		Lissocampus	caudalis	smooth pipefish
			runa	javelin pipefish
		Maroubra	perserrata	sawtooth pipefish
		Notiocampus	ruber	red pipefish
		Phyllopteryx	taeniolatus	common seadragon
		Pugnaso	curtirostris	pugnose pipefish
		Solegnathus	robustus	robust pipehorse
		Stipecampus	cristatus	ringback pipefish
		Vanacampus	moargaritifer	hairy pipefish
			phillipi	port phillip pipefish
			poecilolaemus	longsnout pipefish
			vercoi	verco's pipefish
Mugiliformes	Mugilidae	Aldrichetta	forsteri	yelloweye mullet
		Liza	argentea	goldspot mullet
		Mugil	cephalus	sea mullet
Perciformes	Aplodactylidae	Aplodactylus	arctidens *	marblefish
	Apogonidae	Siphamia	cephalotes *	wood's siphonfish
		Vincentia	badia	scarlet cardinalfish
			conspersa *	southern cardinalfish
			macrocauda	smooth cardinalfish
	Arripidae	Arripis	georgianus *	Australian herring
			truttaceus *	western Australian salmon
	Blenniidae	Parablennius	tasmanianus	Tasmanian blenny
		Ommobranchus	anolius	oyster blenny
	Callionymidae	Eocallionymus	papilio	painted stinkfish
		Foetorepus	calauropomus	common stinkfish
		Repomucenus	calcaratus	spotted dragonet
	Carangidae	Trachurus	declivis	common jack mackerel
			novaezelandiae	yellowtail scad
		Naucrates	ductor	pilotfish
		Pseudocaranx	dentex	white trevally
			wrighti	skipjack trevally
			georgianus	silver trevally
		Seriola	lalandi	yellowtail kingfish
			hippos	samsonfish
	Cepolidae	Cepola	australis	Australian bandfish
	Chaetodontidae	Chelmonops	curiosus *	western talma
	Cheilodactylidae	Cheilodactylus	nigripes *	maggie perch
		Dactylophora	nigricans *	dusky morwong
		Nemadactylus	macropterus	jackass morwong
			valenciennesi	blue morwong
	Clinidae	Heteroclinus	sp. 2	whitley's weedfish
			sp. 4	coleman's weedfish
			sp. 5	fewray weedfish
			sp. 6	milward's weedfish
			adelaide	Adelaide weedfish
			eckloniae	kelp weedfish
			heptaeolus	ogilby's weedfish
			johnstoni	johnston's weedfish
			macrophthalmus	large-eye weedfish
			perspicillatus	common weedfish
			puellarum	little weedfish
			roseus	rosy weedfish
			tristis	longnose weedfish
			wilsoni	wilson's weedfish

		Ophiclinops	pardalis	spotted snake blenny
			varius	variegated snake blenny
		Ophioclinus	antarcticus	Adelaide snake blenny
			brevipinnis	shortfinn snake blenny
			gabrieli	frosted snake blenny
			gracilis	blackback snake blenny
			ningulus	variable snake blenny
		Cristiceps	australis	southern crested weedfish
		Peronedys	anguillaris	eel snake blenny
		Sticharium	clarkae	clark's snake blenny
			dorsale	slender snake blenny
	Dinolestidae	Dinolestes	lewini *	longfin pike
	Enoplosidae	Enoplosus	armatus *	old wife
	Gempylidae	Thyrsites	atun	barracouta
		Rexea	solandri	gemfish
	Gerreidae	Parequula	melbournensis *	silverbelly
	Gobiesocidae	Genus C	sp. 2	slender clingfish
		Alabes	dorsalis	common shore eel
			hoesei	dwarf shore eel
		Aspasmogaster	liorhyncha	smoothsnout clingfish
			tasmaniensis	tasmanian clingfish
		Cochleoceps	bassensis	broadhead clingfish
			bicolor	western cleaner clingfish
			spatula	spadenose clingfish
		Creocele	cardinalis	broad clingfish
		Parvicrepis	sp. 1	longsnout clingfish
			sp. 2	obscure clingfish
			parvipinnis	smallfin clingfish
		Posidonichthys	hutchinsi	posidonia clingfish
	Gobiidae	Pseudogobius	olorum	bluespot goby
		Nesogobius	sp. 1	opalescent sandgoby
			sp. 2	threadfin sandgoby
			sp. 4	groovedcheek goby
			sp. 5	sicklefin sadgoby
			greeni	twinbar goby
			maccullochi	gridled goby
			pulchellus *	sailfin goby
		Favonigobius	lateralis	southern longfin goby
		Arenigobius	bifrenatus	bridled goby
		Gobiopterus	semivestita	glass goby
		Afurcagobius	tamarensis	tamar goby
		Bathygobius	krefftii	krefft's frillgoby
		Callogobius	depressus	flathead goby
			mucosus	sculptured goby
		Mugilogobius	platynotus	flatback mangrove goby
		Redigobius	macrostoma	largemouth goby
		Tasmanogobius	gloveri	glover's tasmangoby
			lasti	scary's tasmangoby
		Tridentiger	trigonocephalus	trident goby
	Kyphosidae	Tilodon	sexfasciatus *	moonlighter
		Scorpis	aequipinnis *	sea sweep
		Kyphosus	sydneyanus *	silver drummer
		Girella	zebra *	zebrafish
		Neatypus	obliquus*	footballer sweep
		Girella	tricuspidata *	luderick

	Labridae	Achoerodus	gouldii *	western blue groper
		Austrolabrus	maculatus *	blackspotted wrasse
		Bodianus	frenchii	foxfish
		Dotalabrus	aurantiacus *	castelnau's wrasse
		Eupetrichthys	angustipes	snakeskin wrasse
		Notolabrus	fucicola	purple wrasse
			parilus *	brownspotted wrasse
			tetricus *	bluethroat wrasse
		Ophthalmolepis	lineolata	southern maori wrasse
		Pictilabrus	laticlavius *	senator wrasse
		Pseudolabrus	psittaculus	rosy wrasse
		Haletta	semifasciata	blue weed whiting
		Siphonognathus	beddomei *	pencil weed whiting
			caninis *	sharpnose weed whiting
	Leptoscopidae	Lesueurina	platycephala	flathead sandfish
		Crapatalus	munroi	pink sandfish
	Mullidae	Upeneichthys	vlamingii *	bluespotted goatfish
	Odacidae	Heteroscarus	acroptilus *	rainbow cale
		Olisthops	cyanomelas *	herring cale
	Pempheridae	Parapriacanthus	elongatus *	elongate bullseye
		Pempheris	klunzingeri *	rough bullseye
			multiradiata *	bigscale bullseye
			ornata *	orangelined bullseye
	Pentacerotidae	Pentaceropsis	recurvirostris *	longsnout boarfish
	Percophidae	Enigmapercis	reducta	broad duckbill
	Pinguipedidae	Parapercis	ramsayi	spotted grubfish
			haackei	wavy grubfish
	Plesiopidae	Paraplesiops	meleagris *	southern blue devil
		Trachinops	noarlungae *	yellowhead hulafish
	Pomacentridae	Parma	victoriae *	scalyfin
	Serranidae	Caesioperca	lepidoptera	butterfly perch
			rasor *	barber perch
		Epinephelus	sp.	southern rockcod
			lanceolatus	queensland groper
		Hypoplectrodes	nigroruber *	banded seaperch
			maccullochi	halfbanded seaperch
		Lepidoperca	occidentalis	slender orange perch
		Acanthistius	serratus	western wirrah
		Othos	dentex *	harlequin fish
	Sillaginidae	Sillago	schomburgkii	yellowfin whiting
			bassensis	souther school whiting
			findersi	eastern school whiting
		Sillaginodes	punctata	king george whiting
	Sparidae	Acanthopagrus	butcheri	black bream
		Pagrus	auratus	snapper
	Sphyraenidae	Sphyraena	novaehollandiae *	snook
	Terapontidae	Pelates	octolineatus	western striped grunter
		Pelsartia	humeralis	sea trumpeter
	Tripterygiidae	Brachynectes	fasciatus	barred threefin
		Helcogramma	decurrens *	blackthroat threefin
		Lepidoblennius	marmoratus	western jumping bleny
		Trianectes	bucephalus	bighead threefin
		Trinorfolkia	clarkei	clark's threefin
			cristata	crested threefin
			incisa	notched threefin
Pleuronectiformes	Paralichthyidae	Pseudorhombus	arsius	largetooth flounder

			jenynsii	smalltooth flounder
	Pleuronectidae	Rhombosolea	tapirina	greenback flounder
Scorpaeniformes	Neosebastinae	Neosebastes	scorpaenoides	common gurnard perch
	Platycephalidae	Leviprora	inops	longhead flathead
		Platycephalus	aurimaculatus	toothy flathead
			speculator	southern bluespotted flathead
			bassensis	southern sand flathead
			conatus	deepwater flathead
			laevigatus	rock flathead
			richardsoni	tiger flathead
			cirronasa	tassel-snout flathead
	Scorpaenidae	Scorpaena	papillosa	southern red scorpionfish
	Tetrarogidae	Gymnapistes	marmoratus	soldierfish
		Centropogon	latifrons	western fortescue
		Glyptauchen	panduratus	goblinfish
	Triglidae	Lepidotrigla	spinosa	shortfin gurnard
			modesta	cocky gurnard
			papilio	spiny gurnard
			vanessa	butterfy gurnard
		Chelidonichthys	kumu	red gurnard
		Pterygotrigla	polyommata	latchet
Tetraodontiformes	Monacanthidae	Acanthaluteres	brownii	spinytail leatherjacket
			spilomelanurus	bridled leatherjacket
			vittiger	toothbrush leatherjacket
		Brachaluteres	jacksonianus	southern pygmy leatherjacket
		Eubalichthys	bucephalus	black reef leatherjacket
			cyanoura	bluetail leatherjacket
			gunnii	gunn's leatherjacket
			mosaicus	mosaic leatherjacket
		Meuschenia	flavolineata *	yellowstripped leatherjacket
			freycineti *	sixspine leatherjacket
			galii *	bluelined leatherjacket
			hippocrepis *	horseshoe leatherjacket
			scaber	velvet leatherjacket
			venusta	stars-and-stripes leatherjacket
		Nelusetta	ayraud	ocean leatherjacket
		Scobinichthys	granulatus	rough leatherjacket
		Thamnaconus	degeni	bluefin leatherjacket
	Tetraodontidae	Contusus	brevicaudus	prickly toadfish
			richei	barred toadfish
		Lagocephalus	lagocephalus	ocean puffer
			sceleratus	silver toadfish
		Omegophora	armilla *	ringed toadfish
			cyanopunctata	bluespotted toadfish
		Polyspina	piosae	orangebarred puffer
		Tetractenos	glaber	smooth toadfish
		Torquigener	pleurogramma	weeping toadfish

Appendix D – Larvae caught per 500m^3 at each location

Table showing the number of fish, rounded to the nearest whole number, per 500m^3 sampled at each location

			Sample period 1																															
			Site 1		Site 2				Site 3				Site 4				Site 5				Site 6				Site 7				Site 8				Site 9				Site 10			
			10m		10m		15m		15m		20m		15m		20m		15m		20m		15m		20m		15m		20m		15m		20m		15m		20m		15m		20m	
Family	**Genus**	**Species**	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm	0.5mm	1mm
Clupeidae	Hyperlophus	vittatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Spratelloides	robustus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sygnathidae	Hippocampus sp.		0	0	0	0	0	0	0	0	0	0	2	2	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	Stigmatopora spp.		4	4	0	0	0	0	2	2	0	0	7	2	0	0	0	0	0	0	7	3	1	0	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
	Urocampus	carinirostris	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blenniidae	Ommobranchus	anolius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Callionymidae spp.			0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Gobiidae	Bathygobius	krefftii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Gobiidae spp.		4	0	0	0	0	0	5	3	2	0	4	0	0	0	2	0	0	0	3	0	0	0	1	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
	Redigobius	macrostoma	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gobiesocidae	Gobiesocidae spp.		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sillaginidae	Sillaginodes	punctata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Tripterygiidae spp.			0	0	0	0	0	0	0	2	0	0	0	0	4	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pleuronectidae	Rhombosolea	tapiria	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Platycephalidae	Platycephalus	speculator	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Platycephalus sp.		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triglidae	Lepidotrigla spp.		0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Neosebastinae	Neosepastes sp.		0	0	0	0	0	0	0	0	0	2	5	2	0	2	0	0	5	3	9	4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Tetrarogidae	Gymnapistes	marmoratus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Monacanthidae	Meuschenia spp.		0	0	0	0	1	0	0	0	0	2	4	5	0	0	7	0	13	2	3	4	0	0	1	0	36	4	4	1	11	0	1	1	0	0	0	0	0	2

			Sample period 2										Sample period 3									
			Site 1	Site 2		Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 1	Site 2		Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
			10m	10m	15m	15m	15m	15m	15m	15m	15m	15m	15m	10m	10m	15m	15m	15m	15m	15m	15m	15m	15m	15m
Family	**Genus**	**Species**	1mm	1mm	1mm	1mm	1mm	1mm	1mm	1mm	1mm	1mm	1mm	1mm	1mm	1mm	1mm	1mm	1mm	1mm	1mm	1mm	1mm	1mm
Clupeidae	Hyperlophus	vittatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Spratelloides	robustus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sygnathidae	Hippocampus sp.		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	Stigmatopora spp.		1	1	0	23	8	4	0	1	0	0	2	0	1	0	1	5	0	0	0	0	0	0
	Urocampus	carinirostris	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Blenniidae	Ommobranchus	anolius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Callionymidae spp.			0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gobiidae	Bathygobius	krefftii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Gobiidae spp.		0	0	0	4	8	2	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0
	Redigobius	macrostoma	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gobiesocidae	Gobiesocidae spp.		0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0
Sillaginidae	Sillaginodes	punctata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tripterygiidae spp.			0	0	0	0	3	0	0	1	0	2	0	0	0	0	0	1	2	0	1	0	0	0
Pleuronectidae	Rhombosolea	tapiria	0	0	0	0	0	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Platycephalidae	Platycephalus	speculator	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Platycephalus sp.		0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Triglidae	Lepidotrigla spp.		0	0	0	0	0	2	0	0	0	1	0	0	0	0	1	1	0	0	0	1	2	0
Neosebastinae	Neosepastes sp.		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	3	1	0	0
Tetrarogidae	Gymnapistes	marmoratus	1	5	5	17	13	7	0	1	0	1	0	3	6	5	0	0	1	0	0	5	4	3
Monacanthidae	Meuschenia spp.		5	22	10	248	22	57	20	88	37	181	158	0	7	1	0	3	5	1	0	11	4	15