Demersal and epibenthic fauna in a temperate marine embayment, Cockburn Sound, Western Australia: determination of key indicator species

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Abstract

With the advent of Ecosystem-Based Fisheries Management accurate information on non-commercial species distributions and abundances has become essential. This study examined the demersal and epibenthic faunal diversity in Cockburn Sound, an important recreational and commercial fishing, boating and industrial locality in Western Australia, to provide a baseline dataset of species distributions and abundances, and to determine indicator species for future long-term monitoring. Short research trawls were undertaken in seven sites sampled three times in two seasons. A total of 216 taxa from six phyla were collected. Many of the species (24%) were rare, collected from one site at one time and only 16% were common and widespread occurring at all sites in most surveys. Motile species dominated the communities. Species richness and community diversity was highest at the northern sites at the entrance to the Sound and graded to lowest richness and diversity in the enclosed southern end. Average abundance and biomass was low throughout the Sound compared to other areas along the Western Australian coastline. This study found eight species that provided good representation of overall community patterns in the Sound that can be used as indicator species in future monitoring of this impacted embayment.

Keywords: biodiversity, baseline survey, long term monitoring, research trawls, Owen Anchorage, EBFM, EAFM, resource condition targets (RCTs)

Introduction

Trawling has been used as a fishing methodology for centuries in northern hemisphere waters (Roberts 2007) and since the mid 1900s in Australia, however, rigorous documentation of all of the fauna collected using trawls is limited as fisheries management studies have traditionally only collected data on the commercial species captured. Recently there has been recognition of the need to provide accurate information on the identity, distribution and abundance of the non-commercial species captured by trawling (diversity studies) to enable fisheries to be managed within the context of the whole ecosystem rather than just as single species, 'ecosystem approach to fisheries management' (EAFM) or 'ecosystem-based fisheries management' (EBFM) (Cotter *et al.* 2009). This is particularly important for determining the impacts of fishing on non-target species and the potential interactions of target species with predator and prey species in the area.

Cockburn Sound (32° 12' S, 115° 43' E) and Owen Anchorage (32° 07' S, 115° 45' E), Western Australia (Fig. 1), are used for recreational and commercial fishing, boating, and as industrial ports (Cambridge & McComb 1984; Kendrick *et al.* 2000; Kendrick *et al.* 2002). Extensive industrial development has occurred along the eastern edge of Cockburn Sound, with more development proposed. Between the 1950s to 1970s discharge from industry resulted in elevated levels of nitrogen and heavy metals, and large scale loss of seagrass (77% from 1967 levels) due to epiphytic growth (Kendrick *et al.* 2002). Water quality in Cockburn Sound has improved since the 1970s but there has been no substantial recovery of seagrasses on the eastern shelf adjacent to the coastline (Kendrick *et al.* 2002). Seagrass cover at Parmelia Bank has remained relatively constant between 1965 and 1995 (~ 45%, Kendrick *et al.* 2000). However, there is evidence of recovery of seagrasses on Success Bank north of Owen Anchorage, with increases in cover from 21% in 1965 to 43% in 1995 (Kendrick *et al.* 2000).

Four commercial fisheries operate in these waters: West Coast Purse Seine Fishery, targeting herring and ilisha (Clupeidae) including the Australian Sardine *Sardinops neopilchardus* (Steindachner, 1879); Cockburn Sound Fish Net Fishery, targeting Australian Herring *Arripis georgianus* (Valenciennes, 1831) and Southern Garfish *Hyporhamphus melanochir* (Valenciennes, 1847); Cockburn Sound Line and Pot Fishery, targeting Blue

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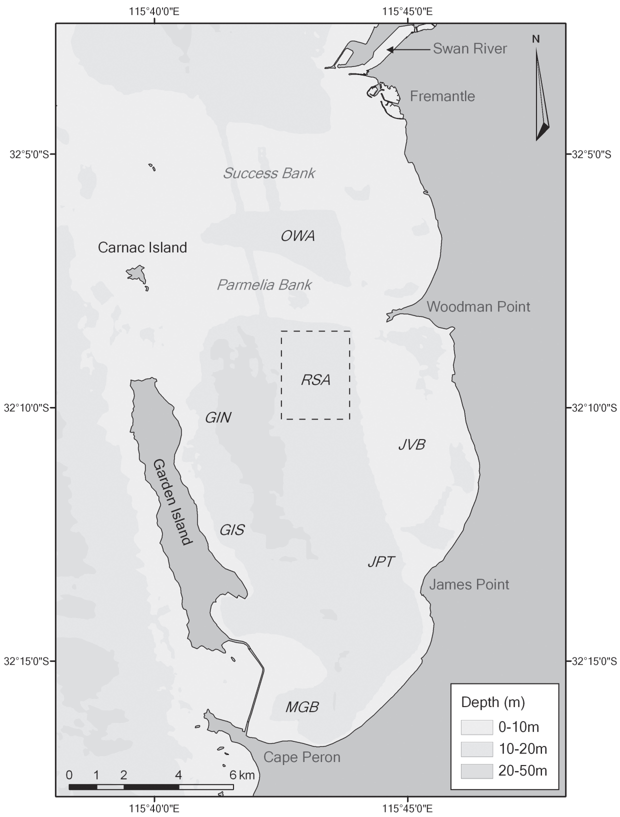

Figure 1. Map of Cockburn Sound and Owen Anchorage showing the seven locations sampled. Sites: Owen Anchorage (OWA); Research Area (RSA); Garden Island north (GIN); Garden Island south (GIS); Mangles Bay (MGB); James Point (JPT); Jervois Bay (JVB).

Swimmer Crab *Portunus armatus* A. Milne-Edwards, 1861[1], Snapper *Pagrus auratus* (Bloch & Schneider, 1801), octopus (Octopodidae), squid (Loliginidae), and various skates and rays (Rhinobatidae and Myliobatidae); and the West Coast Beach Bait Fishery, targeting Sandy Sprat *Hyperlophus vittatus* (Castelnau, 1875). Moreover, Cockburn Sound is recognised as an important spawning and nursery area for a number of commercially and recreationally targeted species including Blue Swimmer Crab *Portunus armatus* (Potter *et al.* 1996), Western King Prawn *Melicertus latisulcatus*[2] (Kishinouye 1896) (Penn 1975, 1976), Snapper *Pagrus auratus* (Lenanton 1974; Wakefield 2006), Sandy Sprat *Hyperlophus vittatus* (Gaughan *et al.* 1996), and King George Whiting *Sillaginodes punctata* (Cuvier, 1829) (Hyndes *et al.* 1998).

Despite the importance of Cockburn Sound to industry, commercial and recreational activities, published diversity studies of the Sound and Owen Anchorage are limited. The majority of studies have focussed on seagrasses (Cambridge & McComb 1984; Cambridge *et al.* 1986; Walker *et al.* 2001; Kendrick *et al.* 2002; Vanderklift & Jacoby 2003). Numerous trawl surveys undertaken by the Western Australian Department of Fisheries (DoF) have recorded information on selected commercially important species, *e.g.* Snapper *Pagrus auratus*, Blue Swimmer Crab *Portunus armatus*, and Western King Prawn *Melicertus latisulcatus* (Lenanton 1974; Penn 1977). By comparison diversity surveys of the fauna of the area are predominantly in unpublished reports, and the numbers and species of taxa reported have been influenced by sampling methods employed and habitats sampled (Table 1). Generally, the fauna in Cockburn Sound is typical of the central Western Australian coast, which is regarded as an overlap zone, and contains species of both tropical and temperate origin as well as west coast endemics (Wells & Threlfall 1980; Hutchins 1994). The faunal community in Cockburn Sound is recognised as distinct from the adjacent open waters due mainly to a higher proportion of some tropical species *e.g.* Western Gobbleguts *Apogon rueppellii* Günther, 1859, Western Butterfish *Pentapodus vitta* Quoy & Gaimard, 1824 and Fanbelly Leatherjacket *Monacanthus chinensis* (Osbeck, 1765) (Hutchins 1994) and also due to the presence of a unique habitat, the deep (~20 m) enclosed central basin with its extensive soft sediments, that is not represented anywhere else on the central west coast (Wilson *et al.* 1978).

Long term monitoring of an entire biological community is rarely undertaken as identifying all species in a community is time consuming, expensive and requires specialised expertise (Jones & Kaly 1995). For this reason the use of indicator species is often suggested as a means to monitor the health of an ecosystem and to be used as surrogates so identification and characterisation of the entire community is not required (Lackey 2003). However, the identification of appropriate indicator species can be difficult and frequently requires some prior knowledge of the system to be monitored, as well as background information on the species that occur there (Jones & Kaly 1995; Bustos-Baez & Frid 2003). One current focus in this area of research in Australia is the development of resource condition targets (RCTs) and to determine baseline levels of variability within biological communities that can be used as a reference point to track changes over time (NRM 2003). Such studies have been initiated, for example biodiversity associated with prawn and scallop fisheries in Shark Bay and Exmouth Gulf (Kangas *et al.* 2007) and other bycatch studies in tropical (Poiner *et al.* 1998; Pitcher *et al.* 2000; Stobutzki *et al.* 2000; Stobutzki *et al.* 2001) and temperate (Laurenson *et al.* 1993; Dixon *et al.* 2005; Svane *et al.* 2009) Australian waters, but for many areas there is little information available on the diversity and abundance of species present. In addition, this is not usually available in the published literature.

[1] The Blue Swimmer Crab in Australia has until recently been known as *Portunus pelagicus* (Linnaeus 1758), a recent revision of this species complex (Lai *et al.* 2010) now recognises four species based on morphological, genetic and biogeographic considerations. The species that occurs in most of Australia including Cockburn Sound is now recognised to be *Portunus armatus*. We use this name throughout but *Portunus pelagicus* is still used in the literature.

[2] In the scientific literature the Western King Prawn is also known as *Penaeus latisulcatus* and *Penaeus* (*Melicertus*) *latisulcatus*. Pérez Farfante and Kensley (1997) revised the genus *Penaeus* and upgraded *Melicertus* to full generic status and although this has caused considerable controversy the name has not been rescinded. Hence, we have used the current valid scientific name.

Table 1

Summary of previous biodiversity studies in Cockburn Sound. Sampling method: [sd]scuba diving, [sc]shore collections, [d]dredges, [v]Van Veen grab, [t]trawling, [bs]beach seine, [sn]seine nets.

Taxon	No. species	Method	Survey Year	Reference
Cnidarians	28	sd, sc, d	1950 s, 1970 s	Marsh 1978a
	10	v	1993	Cary *et al.* 1995
	4	v	1978	Wells 1978
Crustaceans	47	v	1993	Cary *et al.* 1995
	21	v	1978	Wells 1978
	2	sn	1995	Vanderklift & Jacoby 2003
	11	t, bs	1977 - 1978	Dybdahl 1979
Molluscs	40	v	1993	Cary *et al.* 1995
	34	v	1978	Wells 1978
	1	sn	1995	Vanderklift & Jacoby 2003
Bivalves	157	sd, sc, d	1950 s, 1970 s	Wilson *et al.* 1978
Gastropods	119	sd, sc, d	1950 s, 1970 s	Wilson *et al.* 1978
Cephalopods	3	t, bs	1977 - 1978	Dybdahl 1979
Echinoderms	18	v	1993	Cary *et al.* 1995
	75	sd, sc, d	1950 s, 1970 s	Devaney 1978; Marsh 1978b
	7	v	1978	Wells 1978
Chordates	9	v	1993	Cary *et al.* 1995
ascidians	5	v	1978	Wells 1978
fishes	55	sn	1995	Vanderklift & Jacoby 2003
	1	v	1978	Wells 1978
	130	t, bs	1977 - 1978	Dybdahl 1979

Here, we aimed to: 1) describe the epibenthic and demersal fauna at a number of sites in Cockburn Sound and Owen Anchorage, thus providing essential baseline data on the species present, their distribution, abundance and biomass, and 2) identify a subset of species that might be useful as indicator species for future monitoring of the area.

Methods

Study sites

Cockburn Sound is the southern section of a large basin that stretches north to the mouth of the Swan River at Fremantle (Fig. 1). The Sound is bounded to the west by Garden Island and has shallow banks (< 10 m) on its other three sides: Parmelia Bank to the north, the southern flats to the south, and the eastern shelf adjacent to the coastline. These three shallow banks are dominated by seagrass meadows, small patches of limestone reef, and extensive soft sediment areas. The central basin of Cockburn Sound has a muddy bottom. To the north of Cockburn Sound beyond Parmelia Bank lies Owen Anchorage, a small deep embayment that has Success Bank as its northern boundary (Fig. 1).

This study was undertaken from April 2007 to February 2008. Seven sites were visited during the three survey periods; six sites in Cockburn Sound and one in Owen Anchorage (Fig. 1). Sites were chosen in part by DoF sites that are sampled as part of ongoing monitoring of the blue swimmer crab populations in Cockburn Sound and provide a good coverage of recruitment and spawning areas. These sites were added to during this project to get a representative sample of the benthic fauna in Cockburn Sound. The six sites within Cockburn Sound were in the vicinity of Mangles Bay (MGB), James Point (JPT), Jervois Bay (JVB), toward the southern (GIS) and northern (GIN) ends of Garden Island and the northern part of the deeper basin area (RSA). RSA is situated within an area historically designated as the 'Research Area', which has been the location of numerous trawl surveys conducted by the DoF since 1971 (Lenanton 1974; Penn 1977). The site sampled in Owen Anchorage (OWA) was in the deeper basin area (*ca* 15 m, Fig. 1).

Field sampling

Trawling of all seven sites occurred over two nights. Three replicate shots were taken at each site during each survey, with the start point and bearing of each trawl allocated randomly within each site area, except for OWA in December 2007 as the nets failed to deploy on the final shot so only two shots were completed. Sixty two trawl shots were completed during the three survey periods, due to boat availability the first two surveys occurred in different months (Survey 1: 3rd April (RSA, GIS, MGB) and 2nd May 2007 (OWA, GIN, JVB, JPT); Survey 2: 29th October (GIN, GIS, JPT, MGB) and 12th December 2007 (OWA, RSA, JVB); and Survey 3: 12th (RSA, JVB, JPT, MGB) and 13th February 2008 (OWA, GIN, GIS).

All sampling was undertaken on the Western Australian Fisheries research vessel *RV Naturaliste*. Trawls were *ca* 5 minutes of bottom trawl time at *ca* 3.5 knots using twin rig demersal otter trawl system. Fiveminute trawls were used to reduce sorting time and processing of the catch. Nets used were Fiddy Flier: width (6 fathoms, 11 metres), cod end (mesh size 45 mm) and wings (48mm), sweep length (~1.3 m) and otter board length (~1.8 m). The nets had a 10 mm ground chain that was positioned two links in front of the ground rope. The effective opening of each net was *ca* 7.3 m wide by *ca* 1 m high.

Onboard the port and starboard net contents were kept separate and each side was sorted into rough taxon groupings. The invertebrate catch was sorted to species where possible for all phyla except for ascidians. Ascidians were identified to form (colonial or solitary), except for some distinct solitary forms that could be identified to species. Each species (or form) was counted and weighed, although for many sessile species it was difficult to determine the number of colonies or individuals as they had been fragmented during the collection process. Larger specimens were weighed to the nearest 50 g, and smaller specimens to the nearest 1 g. When species identification was not possible in the field, specimens were frozen or preserved in ethanol to enable further examination in the laboratory. Larger specimens of fishes were identified, weighed (to the nearest 10 g) and measured (mm Total Length, TL) onboard and then returned to the water in the same location they had been caught. All smaller specimens of fishes were retained and stored frozen. These were later processed at the Western Australian Fisheries and Marine Research Laboratories (WAFMRL), where they were identified to species and a total weight for each species was obtained (to the nearest 0.01 g). The largest and smallest individuals for each species in each sample were measured (mm TL), with the exception of snapper, where a fork length (mm FL) was obtained for every individual.

Faunal identification

Invertebrates were identified at the Western Australian Museum (WAM) in consultation with WAM staff (see Acknowledgements) and using the available literature including field guides (Wells & Bryce 1985, 1993; Edgar 1997; Norman & Reid 2000), taxonomic texts (Shepherd & Thomas 1982, 1989; Lamprell & Whitehead 1992; Wilson *et al*. 1994; Shepherd & Davies 1997; Lamprell & Healy 1998; Hooper & Van Soest 2002; Poore 2004), original species descriptions and expertly identified specimens in the WAM collections. Except for ascidians, an attempt was made to identify all specimens to species, with a particular focus on sponges, molluscs, echinoderms and crustaceans due to the available expertise. Species names were standardised according to current accepted scientific and common names using the appropriate Australian Faunal Catalogues (Hooper & Wiedenmayer 1994; Rowe & Gates 1995; Davie 2002b, a) or web resource (ABRS 2008; CSIRO 2008).

Fishes were identified using a field guide (Hutchins & Swainston 1986) at WAFMRL. WAM staff verified the names of some species of fishes that were difficult to identify. Scientific and common names were validated using the Codes for Australian Aquatic Biota (CAAB) fish species list (CSIRO 2008). At least one of each invertebrate species and selected fish species were retained and these are permanently kept in the Western Australian Museum Collections (list of species retained is available, Johnston *et al.* 2008).

Data analysis

The counts and weights for each taxa from each trawl shot were standardised for abundance (individuals m^{-2}) and biomass (grams m^{-2}) using the swept area of the net. The swept area was calculated as the product of the size of the openings of the two nets (m), the effective spread of each net (*ca* two thirds the head rope length) and the distance trawled (m). All analyses were carried out in PRIMER v6.1.11 and PERMANOVA v1.0.1. Three univariate measures of diversity were calculated using the standardised abundance data of all taxa, species richness (S), Shannon diversity index (H′) and Pielou's evenness index (J′). S is the number of species or taxa, $H' = \Sigma_i p_i \log_e(p_i)$, where p_i is the proportional abundance of the i^{th} species, and $J' = H' / \log S$. Univariate analyses of variance (ANOVA) were used to test for differences in these diversity measures, total abundance and biomass among sites, surveys and their interaction using PERMANOVA. No transformations were done and the resemblance measures for each variable were produced using Euclidian distance. The sampling design was a crossed design with site and survey being random factors. To be conservative and because the design was slightly unbalanced a Type III (partial) sums of squares model was used. Permutation of the residuals under a reduced model was used to generate the p values (999 permutations were used).

Multivariate analyses were conducted using two main approaches: 1) pattern exploration in order to reveal how the samples grouped and 2) testing for differences between the predetermined factors of site and survey. Both sets of analyses were conducted on the species only dataset by first removing taxa that included mixed species, *e.g.* ascidians. For both approaches the data was square root transformed so that rare species would contribute to the patterns observed, and the Bray–Curtis distance measure was used to preserve the abundance structure of the dataset (Clarke & Warwick 2001b). Non-metric multidimensional scaling (nMDS) and cluster analyses were used to explore faunal community groupings with the significance of the groupings assessed using the similarity profile test (SIMPROF) (Clarke & Gorley 2006). The species that contributed to these groupings were then identified using similarity percentages (Clarke & Warwick 2001b). Species that discriminated between sites or sampling periods were determined by the dissimilarity to standard deviation ratio (Diss/SD) and the average abundance in each group. Species that typified a group were determined from Diss/SD, with species with a Diss/SD > 2 being selected. This cut off value was determined as the intercept of the lineal regression of Diss/SD values. Two groups of species were then identified as 1) those that typify the groups being compared (high Diss/SD but equal average abundance) and 2) those that discriminate between groups (high Diss/SD but different average abundances between groups).

The second approach tested the significance of differences between the predetermined factors of site and survey using permutation multivariate analysis of variance (PERMANOVA) and canonical analysis of principal coordinates (CAP) (Anderson *et al.* 2008). PERMANOVA tested for differences in the entire community among sites and surveys and the interaction of these factors against the ANOVA model. PERMANOVA was undertaken as a permutation of the residuals under a reduced model using type III sums of squares. CAP was used to look for an axis through the data cloud that best explained the variation. The adequacy of the CAP plot was indicated by the Leave-one-out allocation success (LoA). This is an indication of how well each tow was allocated to the correct site or survey, and the first squared canonical correlation (δ^2) shows how well the first axis separates out sites or surveys. A high δ^2 (*i.e.* close to 1) indicates good discrimination of groups by the first axis. The species that contributed to differences in site and survey were assessed by plotting species on the CAP biplot if they had a Spearman's correlation coefficient ≥ 0.6.

BVStep was used to identify a subset of species that might be useful to target for future monitoring. This analysis is a forward selection backward elimination procedure that examines the entire dataset sequentially removing species to generate a subset of species that provide high correlation (assessed by the Spearman correlation coefficient, ρ) to the entire species dataset (Clarke & Warwick 2001b; Mistri *et al.* 2001; Clarke & Gorley 2006). The stepwise selection was run using Spearman's rank correlation with cut off criteria of rho >0.95 and delta rho < 0.001. A random selection of starting variables was used with a minimum of 6 variables and 10 restarts. BVStep was run on both the abundance and biomass datasets to generate lists of species that would give a similar result in the MDS plots of the relationships among sites and surveys. These lists were then compared to compile a short list of potential indicator species that might be suitable for ongoing monitoring, giving consideration to 1) occurrence on both lists, 2) trophic level, 3) whether the species is targeted by commercial or recreational fishers in the Perth Metropolitan area and 4) how easily the species can be accurately identified in the field. Almost no local data on trophic levels is available for the majority of the species found so these levels were allocated based on what the families or phyla are known to consume from other studies. Achievable field identification was coded as yes: the species is represented in readily available field identification books (Hutchins & Swainston 1986; Edgar 1997) and there are no other species that occur in Cockburn Sound that might be confused with this species; moderate: field identification achievable if identifier knows relevant characters, species may or may not be illustrated in a field guide; no: species requires microscopic examination or dissection to confirm identification.

Results

Species composition, biomass and abundance

A total of 216 taxa from six phyla were identified during the study (a full list of all taxa including counts and weights is available in Johnston *et al*., (2008). This included 141 invertebrate taxa and 75 fish taxa (Porifera: 32 species and 1 taxa; Cnidaria: 2 species and 5 taxa; Crustacea: 30 species and 1 taxa; Mollusca: 37 species and 1 taxa; Echinodermata: 28 species; Chordata: Ascideacea: 3 taxa; Chordata: Pisces: 73 species and 2 taxa). All identified species have either previously been collected in Cockburn Sound and Owen Anchorage or are well within their expected range. The only exceptions to this were a snapping shrimp *Alpheus* cf. *rapax* and Asymmetric Goatfish *Upeneus* cf. *asymmetricus*, which are both considered to be predominantly tropical species. However, these identifications need to be confirmed with detailed taxonomic study, which was beyond the scope of this study. The only introduced species collected was the Streaked Goby *Acentrogobius pflaumii*, at GIN and RSA during the October/December 2007 survey.

Many of the species were rare and only collected at one site on one sampling occasion (52 species, *ca* 24 % of the total). Only 35 species (*ca* 16 %) could be considered common and widespread, occurring at all sites and in most surveys (Table 2). Taxa of mixed species that occurred at all sites were orange sea pens *Cavernularia* spp., all ascidians, both colonial and solitary forms, and the Lefteye Flounder *Arnoglossus* spp. The seastar *Stellaster inspinosus* was common at the three northernmost sites (OWA, RSA & GIN) but absent from the other sites. Some species were common across sites and surveys, but missing from one site. For example, the sea cucumbers *Cercodema anceps* and *Colochirus quadrangulatus*, an urchin *Temnopleurus michaelseni*, and Southern Fiddler Ray *Trygonorrhina fasciata* were all absent from MGB.

There were no general trends in total abundance and biomass across sites and surveys but abundance was significantly different due to a site and survey interaction (Table 3). The highest mean abundance occurred at some sites in February 2008 (MGB, GIS & GIN) and at others in April/May 2007 (JPT, JVB, RSA & OWA) (Fig. 2). The

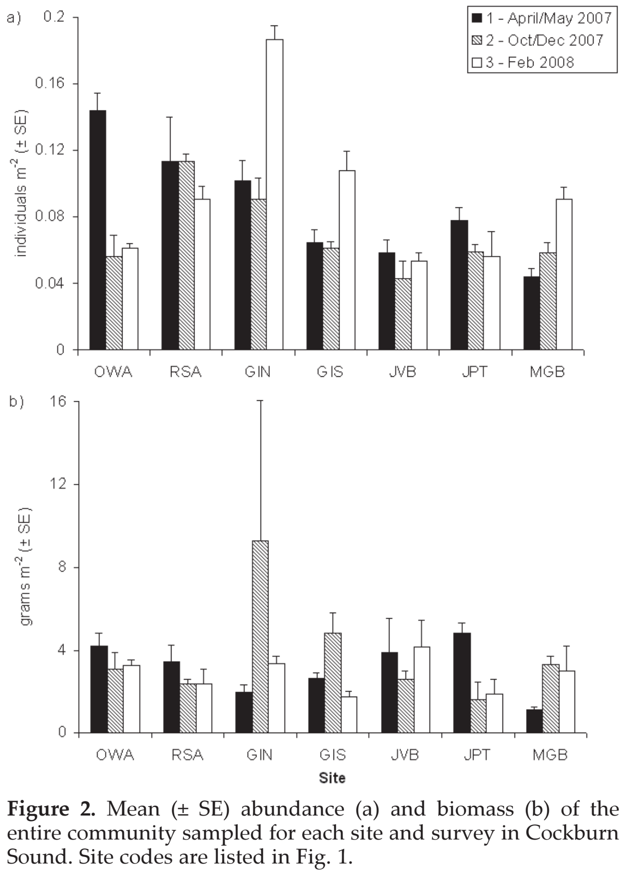

Figure 2. Mean (± SE) abundance (a) and biomass (b) of the entire community sampled for each site and survey in Cockburn Sound. Site codes are listed in Fig. 1.

Table 2

Common, widespread and important taxa collected from each site and survey in Cockburn Sound. Sites: OWA, Owen Anchorage; RSA, Research Area; GIN, Garden Island North; GIS, Garden Island South; JVB, Jervois Bay; JPT, James Point; MGB, Mangles Bay. Survey Periods: 1 – April/May 2007, 2 – Oct/Dec 2007, 3 – Feb 2008. * *Metapenaeopsis* spp. includes *M. fusca* and *M. lindae*, insufficient specimens were collected during survey 1 to separate these two species.

Taxa	Common name	OWA			RSA			GIN			GIS			JVB			JPT			MGB		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Cnidaria																						
Anthozoa																						
Cavernularia spp.	sea pen	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•
Arthropoda: Crustacea																						
Decapoda																						
Belosquilla laevis	mantis shrimp		•	•	•	•	•		•	•	•	•	•		•	•	•	•	•	•	•	•
Melicertus latisulcatus	Western King Prawn	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•
Metapenaeopsis fusca	velvet prawn			•		•	•		•	•	•	•	•		•	•		•	•	•	•	•
Metapenaeopsis lindae	Lynda's Velvet Prawn		•	•		•	•		•	•		•	•		•	•	•	•	•		•	•
Metapenaeopsis spp.*	velvet prawn	•			•			•						•			•					
Portunus pelagicus	Blue Swimmer Crab	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Portunus rugosus	swimmer crab	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Thalamita sima	Four-lobed Swimmer Crab		•	•		•	•			•		•	•		•	•	•	•	•		•	•
Mollusca																						
Gastropoda																						
Euprymna tasmanica	Southern Bobtail Squid	•		•	•	•	•	•	•	•		•	•	•	•		•	•	•	•	•	•
Sepia braggi	Bragg's Cuttlefish	•		•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•		•
Sepia novaehollandiae	cuttlefish	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•		•
Sepioteuthis australis	Southern Calamari Squid	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•		•
Echinodermata																						
Crinoidea	featherstars																					
Comatula purpurea			•	•	•	•	•	•	•	•			•		•		•		•	•		
Asteroidea	seastars																					
Astropecten preissi		•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•
Luidia australiae		•	•	•	•	•	•	•	•	•	•	•	•	•				•	•	•		
Stellaster inspinosus		•	•	•	•	•	•	•	•	•												
Ophiuroidea	brittlestars																					
Macrophiothrix spongicola			•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•		•	
Echinoidea	urchins																					
Temnopleurus michaelseni			•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•			
Holothuroidea	sea cucumbers																					
Cercodema anceps		•	•	•	•	•	•	•	•	•	•	•	•	•	•		•					
Colochirus quadrangularis		•	•	•	•	•	•	•	•	•	•	•			•		•		•			
Chordata																						
Ascidiacea	sea squirts																					
Herdmania sp.			•	•		•			•	•	•	•			•		•		•	•		
ascidian spp. - colonial			•	•	•		•	•	•	•	•	•	•		•		•	•			•	
ascidian spp. - solitary		•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•		•	
Pisces																						
Anoplocapros amygdaloides	Western Smooth Boxfish	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•
Apogon rueppellii	Western Gobbleguts	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Arnoglossus spp.	lefteye flounder	•		•	•	•	•	•	•	•	•	•		•	•		•	•	•			•
Diodon nicthemerus	Globefish	•	•	•					•		•	•	•	•	•	•	•	•	•	•	•	•
Heterodontus portusjacksoni	Port Jackson Shark	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•			•	•
Inegocia japonica	Rusty Flathead	•	•	•	•	•	•	•	•	•	•	•	•	•			•	•	•	•	•	•
Lepidotrigla papilio	Spiny Gurnard	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Maxillicosta scabriceps	Little Gurnard Perch	•		•		•	•	•	•	•			•	•	•	•	•	•	•		•	
Monacanthus chinensis	Fanbelly Leatherjacket	•	•	•		•	•	•	•	•	•	•		•	•			•			•	•
Myliobatis australis	Southern Eagle Ray			•	•	•	•		•	•	•	•	•	•	•	•	•	•	•		•	•
Onigocia spinosa	Midget Flathead	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Pagrus auratus	Snapper	•		•			•			•		•	•		•	•	•	•	•			•
Parapercis haackei	Wavy Grubfish	•	•	•	•	•	•	•	•	•		•		•	•		•	•		•	•	•
Parequula melbournensis	Silverbelly	•	•	•	•			•	•	•				•		•	•		•	•	•	•
Pegasus volitans	Slender Seamoth	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•
Pentapodus vitta	Western Butterfish	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•		•	•	
Pseudocalliurichthys goodladi	Longspine Dragonet	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Pseudocaranx georgianus	Sand Trevally	•		•	•		•	•	•	•	•		•	•		•	•		•	•		•
Pseudocaranx wrighti	Skipjack Trevally	•		•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•		•
Pseudorhombus jenynsii	Smalltooth Flounder	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Sillago burrus	Western Trumpeter Whiting	•	•	•	•	•	•	•	•	•	•	•	•	•			•	•	•	•	•	•
Trygonorrhina fasciata	Southern Fiddler Ray	•		•	•		•	•	•	•	•	•	•		•				•			
Upeneichthys vlamingii	Bluespotted Goatfish	•	•	•	•			•	•	•			•	•		•		•				•

mean biomass was highest at some sites (JPT, RSA & OWA) in April/May 2007 and other sites (MGB, GIS & GIN) in October/December 2007. The high mean biomass and standard error at GIN in October/December 2007 was due to the capture of a large (estimated to weigh *ca* 150 kg) Smooth Stingray *Dasyatis brevicaudata* in one tow.

Diversity measures

Species richness (S) varied among sites and surveys but was only significantly different among sites (Table 3). Mean S ranged from 24 (MGB in April/May 2007) to 56 species (GIN in February 2008) and was generally highest at GIN and OWA (mean across all months 50 and 47 species, respectively) and lowest at MGB (27 species, Fig. 3). Species diversity (H′) and evenness (J′) also varied significantly among sites and surveys (Table 3). H′ ranged from 2.2 (GIN & GIS in February 2008 and RSA in April/May 2007) to 3.1 (OWA in February 2008) and J′ ranged from 0.5 (GIN in February 2008) to 0.8 (JVB in October/December 2007 and OWA in February 2008, Fig. 3). OWA and GIN had similar species richness values to each other but OWA had higher diversity and evenness than GIN indicating that more species had similar abundances across the community at OWA than at GIN. At GIN the community was dominated by a few species. RSA and GIN generally had the lowest evenness values indicating that the communities at these sites are dominated by fewer species compared to the other sites where more species have similar abundances.

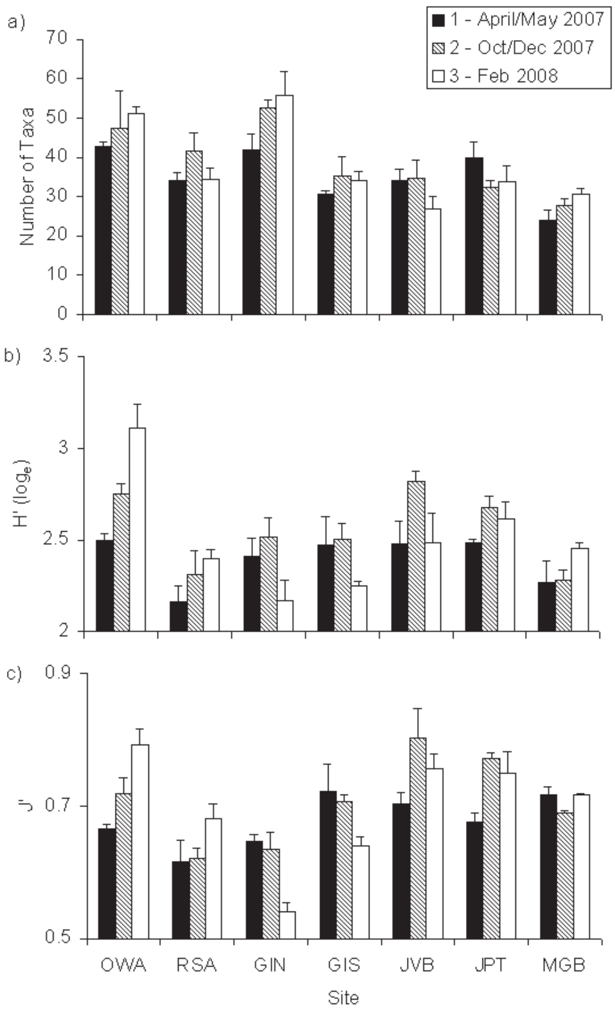

Figure 3. Mean (± SE) species richness (a), diversity (b), and evenness (c) indices for each site and survey in Cockburn Sound. Site codes are listed in Fig. 1.

Table 3

Differences in univariate measures of the faunal community among sites and surveys in Cockburn Sound using ANOVA for a) total abundance and b) biomass, c) species richness (S), d) Shannon diversity (H') and e) Pielou's evenness (J'). Significant results are bolded.

Source	df	SS	MS	Pseudo-F	P
a) total abundance					
Site	6	0.038	0.006	2.231	0.115
Survey	2	0.007	0.003	1.158	0.378
Site x Survey	12	0.034	0.003	9.095	**0.001**
Res	42	0.013	0.000		
Total	62	0.092			
b) total biomass					
Site	6	34.822	5.804	0.542	0.801
Survey	2	12.909	6.454	0.604	0.605
Site x Survey	12	128.500	10.709	1.334	0.182
Res	42	337.240	8.030		
Total	62	514.550			
c) species richness (S)					
Site	6	3631.800	605.300	10.387	**0.001**
Survey	2	136.710	68.354	1.175	0.359
Site x Survey	12	700.270	58.355	1.683	0.133
Res	42	1456.600	34.681		
Total	62	5963.700			
d) species diversity (H')					
Site	6	1.618	0.270	3.158	**0.027**
Survey	2	0.276	0.138	1.622	0.241
Site x Survey	12	1.027	0.086	3.258	**0.007**
Res	42	1.104	0.026		
Total	62	4.092			
e) species evenness (J')					
Site	6	0.151	0.025	3.600	**0.026**
Survey	2	0.010	0.005	0.711	0.539
Site x Survey	12	0.084	0.007	4.772	**0.002**
Res	42	0.062	0.001		
Total	62	0.308			

Community groupings and discriminating species

Clustering and unconstrained ordination of the abundance data resulted in six groups (a–f) that were significant using SIMPROF ($p < 0.1$ %) at 50 % similarity (Fig. 4). JVB (group's d–f) was significantly different from the rest of the sites. Group d consisted of one shot that was sampled in December 2007 and the faunal

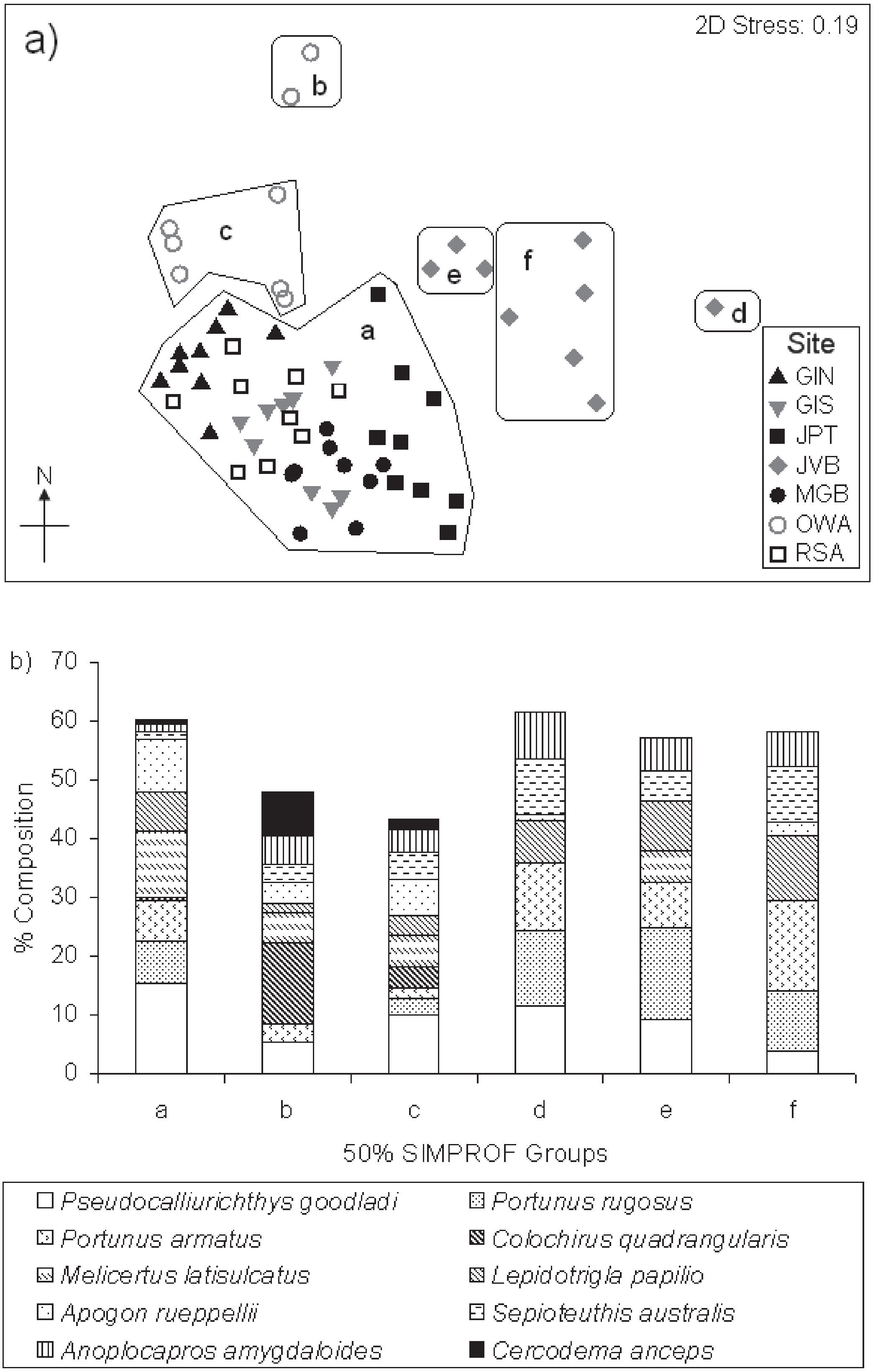

Figure 4. Two-dimensional ordination (a) of abundance (individuals m^{-2}) of species only for each site and survey. Groups (a–f) at 50 % similarity were significant as determined by SIMPROF, $p < 0.1$ %. The top ten species that contributed to these groupings are displayed (b).

Table 4

Discriminating species for each 50 % similarity SIMPROF grouping based on abundance (Fig. 4, Groups a–f) determined from SIMPER analysis, where Diss/SD > 5.7, $r^2 = 0.4$. Groups not listed had no species fitting the criteria used.[1]all species are in higher abundance in this group except where indicated, [2]abundance is higher in this group, *Species are in equal abundance in both groups so not able to discriminate between them.

Indicator species	a vs. b[1]	b[1] vs. c	b[1] vs. d[2]	b[1] vs. e[2]	b[1] vs. f[2]	c vs. d[1]	d[1] vs. e[2]	d[1] vs. f
Phylum Porifera								
Echinodictyum clathrioides						●	●	●
Igernella sp. C1						●	●	●
Semitaspongia sp. C1						●	●	
Tedania sp. C1						●	●	●
Tethya cf. *ingalli*						●	●	
Phylum Arthropoda								
Fultodromia nodipes							●	●
Hyastenus sebae						●	●	
Melicertus latisulcatus							●[2]	
Pilumnus fissifrons						●	●	
Portunus pelagicus			●*					
Portunus rugosus				●[2]			●[2]	
Thalamita sima							●	
Phylum Mollusca								
Bedeva paivae		●		●				
Sepioteuthis australis			●*					
Phylum Echinodermata								
Astropecten preissi			●		●			
Cercodema anceps			●					
Cladolabes schmeltzii	●	●		●	●			
Colochirus quadrangularis	●		●	●	●			
Coscinasterias muricata						●	●	
Luidia australiae			●		●			
Stellaster inspinosus	●		●	●	●			
Temnopleurus michaelseni			●				●[2]	
Phylum Chordata								
Gymnapistes marmoratus				●	●			
Lepidotrigla papilio			●[2]		●[2]			
Neosebastes pandus	●			●	●			
Omegophora armilla							●	
Pagrus auratus							●	
Pegasus volitans			●					
Pentapodus vitta							●	
Pseudocalliurichthys goodladi							●[2]	
Sillago bassensis							●[2]	
Sillago burrus			●		●			

community included a mixture of sponge species and associated fauna (Fig. 4, Table 4). Group e consisted of May 2007 samples and group f of the remaining December 2007 samples and all February 2008 samples. Group e had a higher abundance of five species, *Melicertus latisulcatus*, *Portunus rugosus*, *Temnopleurus michaelseni*, *Pseudocalliurichthys goodladi* and *Sillago bassensis*, compared to group d (Table 4). OWA in December 2007 (group b) had a very different community from the remaining sites and this was due to a high abundance of the sea cucumber *Colochirus quadrangulatus* and the presence of another sea cucumber *Cladolabes schmeltzii* (Figs 4a–c, Table 4). The seastar *Stellaster inspinosus* and Bighead Gurnard Perch *Neosebastes pandus* also contributed to this separation. The remaining OWA samples formed group c, the sea cucumber *Cladolabes schmeltzii* and a murex gastropod *Bedeva paivae* separated group c from group d (Table 4). The remaining samples formed group a. Significant structure was detected at > 50 % similarity, forming groups due to sites and surveys. This is evident on the nMDS ordination where the samples form a gradient from north to south and east to west (Figs 4a and b).

Clustering and ordination of the biomass data resulted in nine groups (a–i) that were significant using SIMPROF ($p < 0.1$ %) at 50% similarity (Fig. 5). The patterns were broadly similar to the abundance data with groupings according to the site collected and displaying a north/south and east/west gradient visible on the nMDS ordination (Fig. 5b). Within these trends were groupings according to survey that indicated seasonal variation in the biomass of the community. Groups d and g formed due to the high biomass of a single individual of a Black Stingray *Dasyatis thetidis* (25.2 kg) at GIS in October 2007 (group d) and a Smooth Stingray *Dasyatis brevicaudata* (estimated to weigh *ca* 150 kg) at GIN in October 2007 (group g). Removing these large individuals did not change the site groupings and the two resemblance matrices were significantly similar with a correlation of 0.96, $p<0.001$. *Dasyatis brevicaudata* also contributed to group a as one of the top ten species by weight, and is the main species that separates group g from all other groups except group a (Table 5). The presence of four species of sponge and their associated fauna also separates group g from all other groups (Table 5). The higher biomass of Silverbelly *Parequula melbournensis* at OWA in May 2007 separated this group from all other groups (Fig. 5, Table 5). *Dasyatis thetidis* was the main species that drove the separation of one sample at GIS in October 2007 from the rest of the groups (group d), but the triton *Cymatium* cf. *exaratum*, the sea slug *Pleurobranchus peroni* and Little Weed Whiting *Neoodax balteatus* also contributed to this separation (Fig. 5, Table 5).

Community composition was significantly different among sites and surveys for estimates of both abundance and biomass (Table 6). The constrained ordination (CAP) separated all of the sites based on abundance, with JVB being most different from the other sites due to the abundance of the Western Smooth Boxfish *Anoplocapros amygdaloides*, sand dollar *Peronella lesueuri*, and Southern Calamari Squid *Sepioteuthis australis* (Fig. 6). The mantis shrimp *Belosquilla laevis* was associated with JPT and MGB (Fig. 6). *Stellaster inspinosus* was associated with the northern sites OWA, RSA and GIN. Species that were positively correlated with different survey periods and thus indicated higher abundance and biomass in those respective periods, included the cuttlefish *Sepia novaehollandiae* and Sand Trevally *Pseudocaranx georgianus* in February 2008 and Mosaic Leatherjacket *Eubalichthys mosaicus* in October/December 2007 (Figs. 6 and 7).

The two commercially important species, Snapper *Pagrus auratus* and Blue Swimmer Crab *Portunus armatus* were not strongly correlated with a particular site, indicating they were well distributed throughout

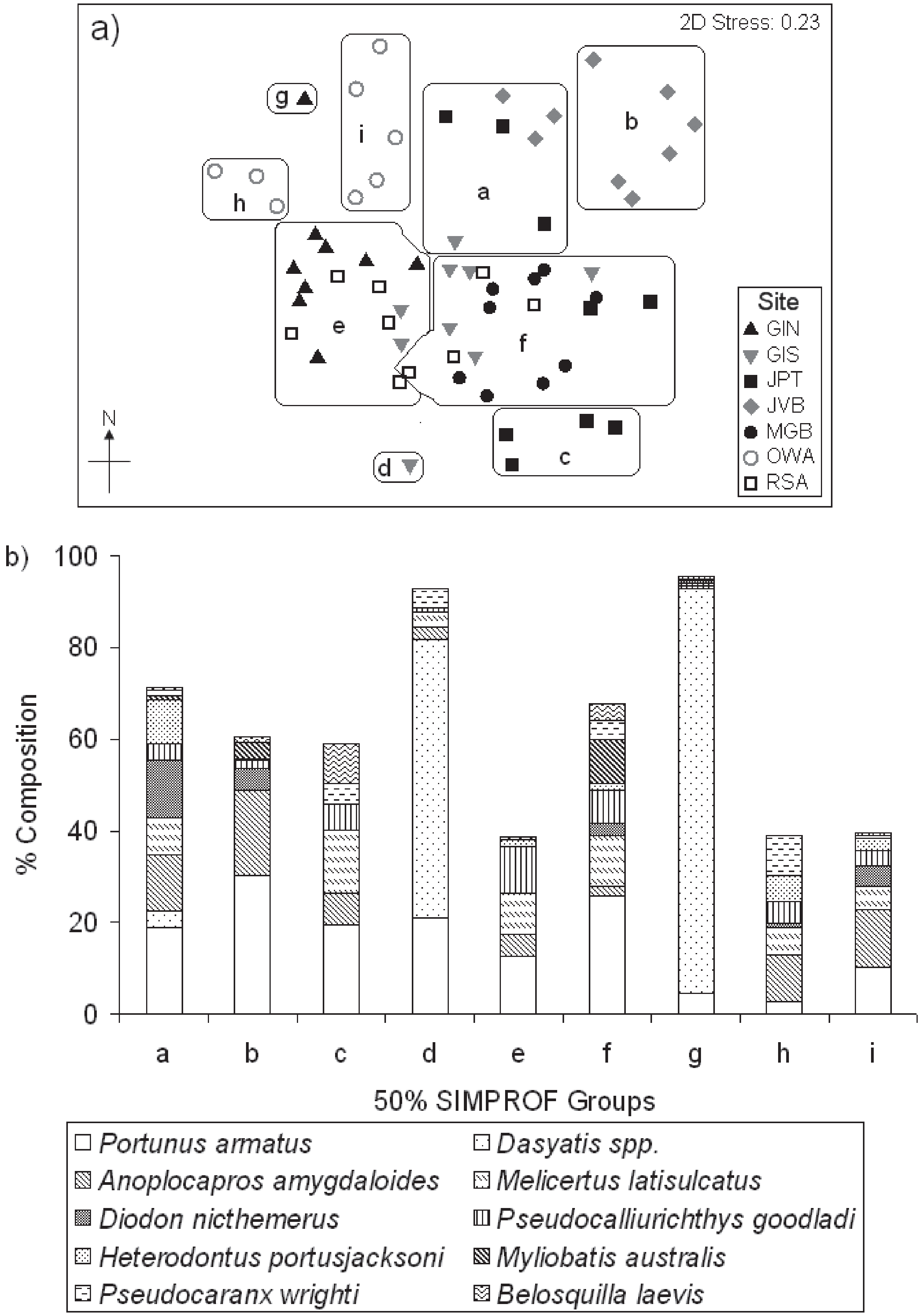

Figure 5. Two-dimensional ordination (a) of mean biomass (g m^{-2}) of species only, for each site and sampling period. Groups (a–h) were identified at 50% similarity and were significant as determined by SIMPROF, p < 0.1 %. The top ten species that contributed to these groupings are displayed (b).

Table 5

Discriminating species for each 50 % similarity SIMPROF grouping based on biomass (Fig. 5, Groups a–i) determined from SIMPER analysis, where Diss/SD > 3.7, $r^2 = 0.2$. See Table 5 for explanation of superscripts.

Indicator species	a vs. d^1	a vs. g^1	a vs. h^1	b vs. d^1	b vs. g^1	b vs. h^1	b vs. i^1	c vs. d^1	c vs. g^1	c vs. h^1	d^1 vs. e	d^1 vs. f	d^1 vs. h^2	d^1 vs. i	e vs. g^1	f vs. g^1	f vs. h^1	g^1 vs. h^2	g^1 vs. i
<u>Phylum Porifera</u>																			
Ciocalypta sp. C1		○			○				○							○		○	○
Holopsamma sp. C1									○							○		○	○
Leucosolenida sp. C1		○			○				○						○			○	○
Tethya cf. ingalli									○									○	
<u>Phylum Arthropoda</u>																			
Belosquilla laevis													○						
Hyastenus sebae		○							○						○	○		○	
Metapenaeopsis fusca	○	○											○					○	○
Metapenaeopsis lindae	○	○											○					○	
Melicertus latisulcatus				○	○		○							○					○
Pilumnus fissifrons		○							○									○	
Portunus pelagicus								○	○				○					○	
Thalamita sima													○						
<u>Phylum Mollusca</u>																			
Aplysia dactylomela		○			○				○							○			
Cymatium cf. *exaratum*	○			○				○			○	○	○						
Euprymna tasmanica													○^{2}					○	
Pleurobranchus peroni	○	○		○	○			○	○			○	○	○		○		○	○
Sepiadarium austrinum					○				○									○	○
Sepioloidea lineolata					○														○
<u>Phylum Echinodermata</u>																			
Cercodema anceps								○	○									○	
Colochirus quadrangularis					○											○		○	
Comatula purpurea																		○	○*
Echinocardium cordatum	○			○									○						
Luidia australiae					○														
Macrophiothrix spongicola																		○	
Peronella lesueuri									○						○				
Stellaster inspinosus		○			○				○							○			
Temnopleurus michaelseni				○									○					○	
<u>Phylum Chordata</u>																			
Anoplocapros amygdaloides																		○^{2}	
Brachaluteres jacksonianus		○			○				○							○			○
Dasyatis brevicaudata					○				○						○	○		○	○
Dasyatis thetidis	○			○				○			○	○		○					
Engraulis australis													○	○					
Eubalichthys mosaicus		○			○				○									○	○
Gymnapistes marmoratus					○														
Heterodontus portusjacksoni													○^{2}						
Hippocampus subelongatus					○				○									○	
Hyporhamphus melanochir													○	○					
Inegocia japonica				○	○														
Lepidotrigla papilio																		○	
Monacanthus chinensis		○							○										
Neoodax balteatus	○			○				○					○						
Onigocia spinosa																		○	
Parequula melbournensis			○			○				○			○^{2}				○	○^{2}	
Pentapodus vitta						○				○			○^{2}						
Platycephalus longispinis					○				○	○						○			○
Pomatomus saltatrix		○			○				○							○		○	
Pseudocalliurichthys goodladi					○														
Pseudocaranx wrighti				○	○	○		○		○								○^{2}	
Sillago bassensis										○									
Sillago burrus				○	○			○*											
Spratelloides robustus		○			○				○						○	○		○	○
Trygonorrhina fasciata	○	○																	
Upeneichthys vlamingii																○			

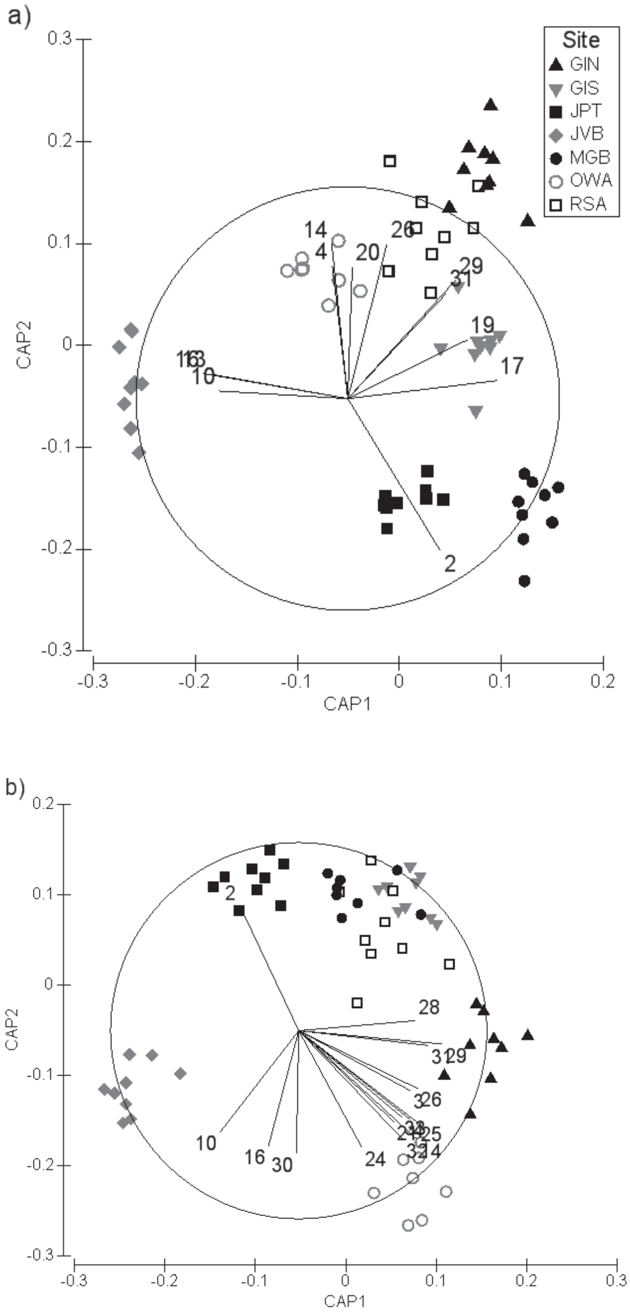

Figure 6. Canonical analysis of principal coordinates (CAP) for abundance (δ^2 = 0.97, LoA = 98%; Fig. 6a) and biomass (δ^2 = 0.95, LoA = 90%; Fig. 6b) for differences in the faunal community amongst sites in Cockburn Sound. Species with a Spearman's correlation coefficient > 0.6 are plotted. Length of the lines represents the strength of the correlation and the direction in relation to each axis represents a negative or positive correlation to that axis. **Invertebrates**: *Amusium balloti*[1]; *Belosquilla laevis*[2]; *Cercodema anceps*[3]; *Colochirus quadrangularis*[4]; *Holopsamma* sp. C1[5]; *Luidia australiae*[6]; *Metapenaeopsis fusca*[7]; *Metapenaeopsis lindae*[8]; *Melicertus latisulcatus*[9]; *Peronella lesueuri*[10]; *Sepia braggi*[11]; *Sepia novaehollandiae*[12]; *Sepioteuthis australis*[13]; *Stellaster inspinosus*[14]; *Thalamita sima*[15]. **Fishes**: *Anoplocapros amygdaloides*[16]; *Apogon rueppellii*[17]; *Eubalichthys mosaicus*[18]; *Inegocia japonica*[19]; *Lepidotrigla papilio*[20]; *Monacanthus chinensis*[21]; *Onigocia spinosa*[22]; *Pagrus auratus*[23]; *Parequula melbournensis*[24]; *Pentapodus vitta*[25]; *Platycephalus longispinis*[26]; *Pseudocaranx georgianus*[27]; *Pseudocaranx wrighti*[28]; *Pseudocalliurichthys goodladi*[29]; *Sillago bassensis*[30]; *Sillago burrus*[31]; *Upeneichthys vlamingii*[32]; *Urolophus paucimaculatus*[33].

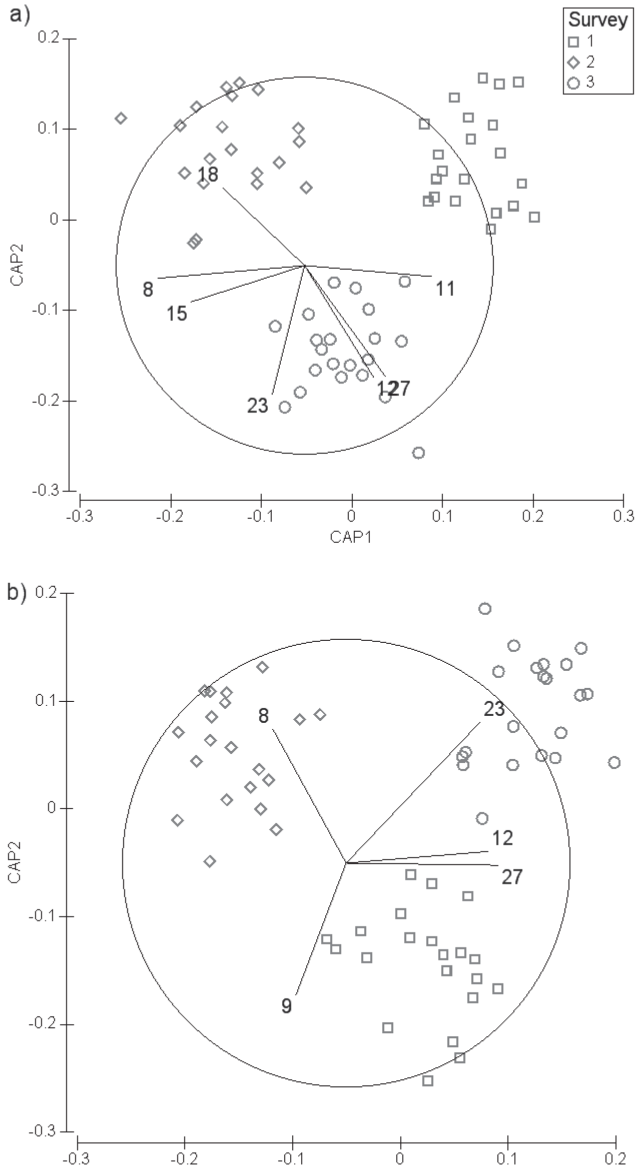

Figure 7. CAP for abundance (δ^2 = 0.87, LoA = 100%; a) and biomass (δ^2 = 0.89, LoA = 98%; b) for differences in the faunal community amongst surveys in Cockburn Sound. See Figure 6 for species abbreviations.

Cockburn Sound. Snapper *Pagrus auratus* showed a positive correlation with survey 3, due to a higher abundance and biomass during February 2008 (Fig. 7).

The results from these two multivariate statistical approaches concur and were beneficial in describing slightly different features of the community structure. Sites and surveys were generally different from each other. Overall, the trends exhibited by the diversity and evenness of the faunal community showed a gradient from north to south and were higher at the northern site, *i.e.* Owen Anchorage (OWA), and decreased to their lowest at the southernmost site, *i.e.* Mangles Bay (MGB).

The BVStep results for the abundance data selected 18 species and for the biomass data 29 species that

Table 6

Differences in the faunal community among sites and surveys in Cockburn Sound for a) abundance and b) biomass. PERMANOVA results are based on 999 permutations on the residuals under a reduced model. Significant results are bolded.

Source	df	SS	MS	Pseudo-F	P
a) abundance					
Site	6	35700	5949.9	4.4508	**0.001**
Survey	2	11524	5762	4.3157	**0.001**
Site x Survey	12	16067	1338.9	2.8914	**0.001**
Residuals	41	18985	463.05		
Total	61	82039			
b) biomass					
Site	6	36269	6044.9	3.9204	**0.001**
Survey	2	9044.8	4522.4	2.9359	**0.001**
Site x Survey	12	18525	1543.7	2.0157	**0.001**
Residuals	41	31401	765.87		
Total	61	95351			

adequately represented the multivariate patterns of the full species dataset (Table 7). Twelve species occurred on both lists, however four of these species *Sepia novaehollandiae,* Rusty Flathead *Inegocia japonica,* Spiny Gurnard *Lepidotrigla papilio* and Skipjack Trevally *Pseudocaranx wrighti* can not currently be accurately identified in the field and so based on our criteria may not be suitable for ongoing monitoring as they would need to be destructively sampled. The remaining eight species *Belosquilla laevis, Cercodema anceps, Colochirus quadrangularis, Melicertus latisulcatus, Portunus armatus, Parequula melbournensis, Pentapodus vitta,* and *Pseudocalliurichthys goodladi* (bolded in Table 7) can be considered suitable indicator species for the epibenthic and demersal communities of Cockburn Sound and targeted for future monitoring.

Table 7

List of possible indicator species for Cockburn Sound. Bolded species are those that met criteria listed in the methods and are thus suggested for use as indicator species. See methods for definitions of the criteria used to select indicator species. Abundance (a) and biomass (b).

Species	a	b	Taxa	Trophic level	Targeted	Field id achievable
Astropecten preissi		○	seastar	carnivore	no	yes
Belosquilla laevis	●	○	**mantis shrimp**	**carnivore**	**yes**	**yes**
Cercodema anceps	●	○	**sea cucumber**	**filter feeder**	**no**	**yes**
Colochirus quadrangularis	●	○	**sea cucumber**	**filter feeder**	**no**	**moderate**
Luidia australiae		○	seastar	carnivore	no	yes
Macrophiothrix spongicola	●		brittlestar	detritivore	no	no
Metapenaeopsis lindae	●		prawn	carnivore/ detritivore	no	no
Melicertis latisulcatus	●	○	**prawn**	**carnivore/ detritivore**	**yes**	**yes**
Peronella lesueuri		○	sand dollar	detritivore	no	yes
Phorbas sp. C1		○	sponge	filter feeder	no	no
Portunus armatus	●	○	**crab**	**detritivore**	**yes**	**yes**
Portunus rugosus	●		crab	detritivore	no	moderate
Sepia braggi	●		cuttlefish	carnivore	no	moderate
Sepia novaehollandiae	●	○	cuttlefish	carnivore	yes	moderate/no
Sepioteuthis australis	●		squid	carnivore	yes	yes
Stellaster inspinosus		○	seastar	detritivore	no	yes
Anoplocapros amygdaloides		○	fish	omnivore	no	yes
Apogon rueppellii	●		fish	omnivore/carnivore	no	yes
Dasyatis brevicaudata		○	fish	carnivore	no	moderate
Dasyatis thetidis		○	fish	carnivore	no	moderate
Diodon nicthemerus		○	fish	carnivore	no	yes
Heterodontus portusjacksoni		○	fish	carnivore	no	yes
Inegocia japonica	●	○	fish	carnivore	yes	no
Lepidotrigla papilio	●	○	fish	carnivore	possibly	no
Myliobatis australis		○	fish	carnivore	no	yes
Neosebastes pandus		○	fish	carnivore	yes	moderate
Onigocia spinosa		○	fish	carnivore	yes	no
Parequula melbournensis	●	○	**fish**	**omnivore**	**no**	**moderate**
Pentapodus vitta	●	○	**fish**	**carnivore**	**yes**	**yes**
Pseudocalliurichthys goodladi	●	○	**fish**	**carnivore**	**no**	**moderate**
Pseudocaranx georgianus		○	fish	planktivore	yes	no
Pseudocaranx wrighti	●	○	fish	planktivore	yes	no
Sillago bassensis		○	fish	carnivore	yes	moderate
Sillago burrus		○	fish	omnivore	yes	moderate
Trygonorrhina fasciata		○	fish	carnivore	yes	yes

Discussion

Community structure

Most of the 216 taxa collected during this study were either previously known from Cockburn Sound and Owen Anchorage or they were within their known geographic range in Western Australia. The three exceptions were two tropical species (*Alpheus* cf. *rapax* and *Upeneus* cf. *asymmetricus*) that require confirmation of their identification and an introduced species, *Acentrogobius pflaumii*. Fifty-two species (24 %) were rare, *i.e.* reported at one site in one survey, and only 35 species (16 %) were considered common, *i.e.* found at all sites in most surveys. This large component of rare species in biological faunal communities (*i.e.* log series distribution) is common and has been reported from a variety of habitats and locations and is likely the result of many complex processes acting to produce the species distribution patterns observed (Carney 2007).

There were no consistent patterns in mean abundance and biomass among sites or surveys. For example, mean abundance was higher in February 2008 at MGB but at OWA in May 2007, and mean biomass was highest at some sites in April/May 2007 (*e.g.* JPT, RSA & OWA) and other sites (*e.g.* MGB) in October/December 2007). These variations are most likely due to differences in the timing and location of spawning and recruitment and/or aggregation behaviour (*e.g.* schooling) of some of the component species resulting in clustered distributions. We found that only a few species were typical of a particular survey period *e.g.* the cuttlefish *Sepia novaehollandiae*, which was more abundant in February 2008 and the swimmer crab *Portunus rugosus*, which had a higher biomass in April/ May 2007. As sampling in this study occurred during different seasons in 2007 and 2008, interannular variation in seasonal composition of the community structure could not be determined. It would be important for future surveys to compare results from previous surveys undertaken at the same time of year to account for possible differences in abundance and biomass as a result of population variation due to seasonality.

Biomass patterns were heavily influenced by the occasional presence of single large individuals such as the smooth stingray *Dasyatis brevicaudata* at GIN in one tow (*ca* 150 kg). Multivariate analyses indicated that abundance was a better discriminator of the differences among sites and surveys in community composition than biomass. The community we sampled was dominated by motile species, where abundance is likely to be a good indication of their contribution to the community. In communities that are dominated by sessile species abundance tends to be underestimated due to the lower selectivity of prawn trawl gear for sessile species, so in these communities considerations of the biomass might be expected to give different results than those of abundance.

A comparison of species composition and abundance between this study and others has been difficult due to the differing methods of sampling used such as a Van Veen grab (Wells 1978; Wells & Threlfall 1980; Cary *et al.* 1995) to sample infauna, scuba diving, shore collections, and dredges (Devaney 1978; Wilson *et al.* 1978; Marsh 1978a, 1978b) to sample a wide variety of benthic fauna, and seine nets (Dybdahl 1979; Vanderklift & Jacoby 2003) for fishes over seagrass beds. All of these studies sampled a different community to the demersal and epifaunal community sampled in this study with a trawl net. Many have also concentrated on a phylum or group of animals rather than a comprehensive survey of all groups (*e.g.* Wells, 1978 – molluscs; Dybdahl, 1979 – fishes; Marsh, 1978 – echinoderms), although some of these studies were companion studies with the different groups collected at the same time. Many of these studies are also unpublished and therefore data has not been standardised for easy comparison, for example, although Dybdal (1978) used a trawl method, he presented abundance data as totals and not means. A variety of standardisations are used in the literature (*e.g.* catch h^{-1}, number m^{-2}, number per nautical mile) and this also makes it difficult to compare abundance or biomass of species in Cockburn Sound with other trawl studies on similar embayments in Australia or internationally (Freese *et al.* 1999; Hobday *et al.* 1999; Ungaro *et al.* 1999; Callaway *et al.* 2002).

A recent project undertaken along the Western Australian coastline (NHT funded Marine Futures project) used identical trawl methods (trawl duration and gear) to sample biodiversity and these data will provide a direct comparison for the faunal community in the Sound, but papers from that study are still in preparation. However, we have examined that data and found that compared to other areas along the Western Australian coastline average abundance and biomass in Cockburn Sound is very low. Average abundance and biomass for all sites in Cockburn Sound and Owen Anchorage was 0.08 individuals per m^{-2} and 3.2 g m^{-2}, this is lower than sandy sediment areas at Rottnest Island and Jurien Bay (0.5 individuals m^{-2}/ 26 g m^{-2}, and 0.3 individuals m^{-2}/ 23 g m^{-2} respectively, Sampey *et al.* unpublished data), and much lower than biomass in areas with extensive sponge communities (*e.g.* Cape Naturaliste, 256 g m^{-2}, Broke Inlet, 360 g m^{-2} and Middle Island, 182 g m^{-2}, Sampey *et al.* unpublished data). Abundances in Cockburn Sound (average of 150 individuals per nautical mile) were also lower than sites in Shark Bay reported with low abundances (245 to 330 individuals per nautical mile, Kangas *et al.*, (2007). These low abundances are possibly attributed to the highly impacted state of the marine environment in Cockburn Sound on account of prolonged industrialisation of its terrestrial boundaries as well as port and boatbuilding facilities in the area. Such anthropogenic impacts on the environment of the Sound have been widely documented, such as the widespread degradation of seagrass beds (Kendrick *et al.* 2000; Kendrick *et al.* 2002) and the negative effects on nursery areas.

Variation among sites

Species richness and community diversity varied among sites with the southernmost site at Mangles Bay (MGB) having the lowest species richness (27 species) and two of the northernmost sites GIN and OWA, having the highest diversity (50 and 47 species, respectively). Owen Anchorage (OWA) also had the highest evenness value suggesting that this site was more diverse than the other sites, *i.e.* consisting of more species with similar abundances. This trend of higher species richness in the northern end of the sound compared to the southern end has been observed previously for epibenthic (Devaney 1978; Wilson *et al.* 1978; Marsh 1978b) and infaunal (Cary *et al.* 1995) invertebrates and this trend has persisted over decades (1950s, 60s, 70s, 80s and the current study). There is a gradient in sediment type from the northern to the southern end of the Sound with the bottom in the northern end consisting of fine calcareous sand interspersed with patches of shelly gravel, whereas in Mangles Bay the sediment is composed of thick grey mud (Wilson *et al.* 1978). Additionally, a strong environmental gradient has developed in Cockburn Sound since the 1950s with much higher nutrient levels occurring in the southern compared to the northern end. It is likely that this nutrient gradient has reinforced the initial pattern of species richness that might have formed due to substrate differences.

Owen Anchorage (OWA) had a different trawled community compared to the other sites, mainly due to a higher number of rare species, *e.g.* the sea cucumber *Cladolabes schmeltzii* (in October/December 2007), and the higher abundance of common species, *e.g.* the seastar *Stellaster inspinosus*, sea cucumber *Colochirus quadrangulatus*, Bighead Gurnard Perch *Neosebastes pandanus* and Silverbelly *Parequula melbournensis*. Owen Anchorage is subjected to fewer severe anthropogenic impacts than Cockburn Sound. The water quality of Owen Anchorage is not considered to be as compromised as Cockburn Sound (Oceanica 2007), and there is evidence of seagrass recovery at Success Bank (Kendrick *et al.* 2000; Kendrick *et al.* 2002), which borders Owen Anchorage to the north. The seagrass beds at Success Bank are known to have higher species richness than adjacent bare sand areas (Brearley & Wells 1998). The close proximity of these banks to Owen Anchorage may mean species can move between seagrass and sand, and increase species diversity at this site. Larger amounts of seagrass and wrack were collected in trawls in OWA compared to all sites in Cockburn Sound, thus supporting the suggestion that seagrass proximity could influence the higher species diversity found at this site.

Jervois Bay (JVB) was significantly different from all other sites. This was in part due to a single trawl shot in December 2007 that collected a mixture of sponges and associated fauna, and partly due to a higher abundance of some species at JVB compared to other sites. For example, higher abundances of Western Smooth Boxfish *Anoplocapros amygdaloides* were found at JVB compared to GIS and RSA, Southern Calamari Squid *Sepioteuthis australis* compared to MGB and JPT, and swimmer crabs *Portunus armatus* and *P. rugosus* compared to OWA. JVB was shallower than all other sites sampled and contained some hard substrate that provided attachments for sponges and ascidians, which were not found as extensively at the other sites. Earlier studies within Cockburn Sound identified five main benthic habitats or biotypes, including 1) peripheral sills, spits and banks, 2) the central basin, 3) slopes, 4) hard substrates and 5) the north eastern (NE) shelf (Devaney 1978; Wells 1978; Wilson *et al.* 1978; Marsh 1978a, 1978b; Wells & Threlfall 1980); each of these biotypes had a distinguishing faunal assemblage. Five of the sites sampled in Cockburn Sound in this study were located in the central basin biotype (*i.e.* RSA, GIN, GIS, JPT & MGB), whereas JVB was located within the NE shelf biotype.

The seastar *Stellaster inspinosus* previously had a more widespread distribution and was common throughout Cockburn Sound during surveys in the 1950s and 1970s when it was found at JPT (1950s) and GIS (1950s and 1970s) (Marsh 1978b), but was absent from these sites during the current study. This may indicate altered substrate and/or water quality at these latter sites as the species is a deposit feeder. However, seastars are known to have variable recruitment (Balch & Scheibling 2001) and longer term monitoring would be required to determine if the current absence of this species at the southernmost sites was due to poor recruitment in recent years, or a decline in the population due to anthropogenic-induced changes to the ecosystem.

Future Monitoring of Indicator Species

We identified eight species (five species of invertebrates and three species of fishes) that might be suitable for ongoing monitoring in Cockburn Sound. The main criteria that were considered in compiling this list were their presence on both the biomass and abundance lists of the BVStep analysis. This indicated that these species gave a good representation of the community patterns compared to the full species dataset, and thus were able to discriminate between sites or surveys based on both biomass and abundance. Furthermore, we gave consideration to whether they could be accurately identified in the field and returned to their habitat, or would need to be destructively sampled. The short list of eight species encompassed a range of trophic levels and a mixture of targeted (commercially and recreationally fished) and non-targeted species. We excluded some species from our short list due to the difficulty of identifying them in the field. Differential survival of trawled species is known (Wassenberg & Hill 1989; Hill & Wassenberg 1990; Wassenberg *et al.* 2002), with fishes, cephalopods and sponges all suffering high mortality rates and consequently being unlikely to survive trawling. If specimens are retained and an accurate identification is made they could be used in monitoring programs, and would add further trophic levels to the species being studied. For example the inclusion of Skipjack Trevally *Pseudocaranx wrighti* would have included a planktivore and a species of sponge (Porifera) would have added a filter feeder to the species being monitored.

Cary *et al.* (1995) suggested some indicator species from their study in Cockburn Sound and Warnbro Sound, including species of amphipods, polychaete worms, molluscs and an echinoderm species, but most of these were small infaunal species that were not captured in our study on account of the trawling methodology used. Of the ten fish species (*Sillago robusta, Choerodon cephalotes, Pentapodus vitta, Synodus sageneus, Monacanthus chinensis, Engyprosopon grandisquama, Inegocia japonica, Parapercis nebulosa, Pelates octolineatus, Lethrinus genivittatus* and two invertebrate taxa (*Luidia maculata* and Porifera) Kangas *et al.* (2007) suggested as suitable indicator species in Shark Bay due to their susceptibility to trawling, only *Pentapodus vitta* occurred on our short list of indicator species. *Inegocia japonica* occurred at both locations but was excluded from our short list due to identification issues, however as they are unlikely to survive and provided they are retained and accurately identified they could be used. The remaining species listed by Kangas *et al*. (2007) did not meet our selection criteria for indicator species or are tropical species that do not occur in Cockburn Sound. The issue of accurate field identifications was not discussed by Kangas *et al*. (2007).

Our ability to accurately identify many species in the field is limited due to the current state of taxonomic knowledge. For example, *Sepia novaehollandiae* was present at all sites but had a higher abundance in February 2008. *S. novaehollandiae* can be confused with *S. apama*. Both these species are likely to be retained by fishers. Accurate identification is usually achieved through examination of the cuttlebone, for which the animal needs to be dissected. Monitoring of a species that needs to be destructively sampled is not desirable as this will likely result in an alteration in community structure over time. Separation of these two species may be possible in the field as *S. apama* has two rows of flap-like papillae above the eyes (Norman & Reid 2000) clearly visible in preserved specimens of *S. apama* but absent in *S. novaehollandiae* (A. Reid pers. com). Whether these papillae would be visible in trawled animals remains to be determined as they could be retracted during the collection process. Colour patterns may also be useful in separating these species (and others) in the field but further taxonomic work is required to resolve these issues. It would be useful to undertake a photographic study of live specimens and confirm identifications with laboratory examination of the specimens, with the aim of producing an identification guide.

The results from this survey represent a comprehensive assessment of the status of the epibenthic and demersal faunal communities collected by trawls in Cockburn Sound and Owen Anchorage in 2007 and 2008. Information on the faunal communities of Cockburn Sound from previous decades (1950s through to 1990s) is available in the form of unpublished reports containing information on the identity of various components of the communities and their relative abundances and distributions at various sites throughout the Sound (Devaney 1978; Wells 1978; Wilson *et al.* 1978; Marsh 1978a, 1978b; Wells & Threlfall 1980). Digitising these historic datasets would allow some interpretation of changes in species abundances and community composition over time (*e.g.* Currie & Parry 1999; Hobday *et al.* 1999). In addition, an analysis of these historic data sets may provide a wider selection of suitable indicator species (*e.g.* Bustos-Baez & Frid 2003). The problem with comparing species richness and diversity measures from different sampling regimes can be ameliorated by calculating a measure of taxonomic distinctness, a standardised measure of species richness (Warwick & Clarke 1998; Clarke & Warwick 2001a; Salas *et al.* 2006). Using such a measure would allow for the comparison of the historic datasets with the results of the current study.

A useful approach for future work would be to have environmental managers give site rankings to areas based on factors such as level of pollution. This approach has been employed for sites and estuaries in the Auckland region with promising results (Hewitt *et al.* 2005). The addition of environmental data to this biological dataset would allow explicit linking of the faunal community to environmental parameters in Cockburn Sound.

Conclusions

The findings from the univariate and multivariate analyses highlighted some characteristic features of the faunal community composition at various sites. In general, the sites differed from each other with a gradient in community composition from higher diversity and evenness in the north at Owen Anchorage (OWA) to the south at Mangles Bay (MGB), where the community was dominated by a few species. A west to east gradient was also present, although this was largely determined by differences in the community composition at Jervois Bay (JVB), compared to the other sites sampled.

This study identified eight potential indicator species that are easily identified in the field and for which little is known of their biology and the importance of Cockburn Sound for their life history strategy. More detailed information on potential indicator species distributions and abundances with respect to habitat, topography and anthropogenic influences within Cockburn Sound would assist in the interpretation of the faunal communities discussed in this study, and in future monitoring studies.

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