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► **To cite this version:**

T. O'hara, A. Williams, S. Ahyong, P. Alderslade, T. Alvestad, et al.. The lower bathyal and abyssal seafloor fauna of eastern Australia. *Marine Biodiversity Records*, 2020, 13 (1), 10.1186/s41200-020-00194-1 . hal-03090213

HAL Id: hal-03090213

<https://hal.science/hal-03090213>

Submitted on 29 Dec 2020

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RESEARCH

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The lower bathyal and abyssal seafloor fauna of eastern Australia

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Abstract

Background: Our knowledge of the benthic fauna at lower bathyal to abyssal (LBA, > 2000 m) depths off Eastern Australia was very limited with only a few samples having been collected from these habitats over the last 150 years. In May–June 2017, the IN2017_V03 expedition of the RV *Investigator* sampled LBA benthic communities along the lower slope and abyss of Australia's eastern margin from off mid-Tasmania (42°S) to the Coral Sea (23°S), with particular emphasis on describing and analysing patterns of biodiversity that occur within a newly declared network of offshore marine parks.

Methods: The study design was to deploy a 4 m (metal) beam trawl and Brenke sled to collect samples on soft sediment substrata at the target seafloor depths of 2500 and 4000 m at every 1.5 degrees of latitude along the western boundary of the Tasman Sea from 42° to 23°S, traversing seven Australian Marine Parks.

Results: The biological sampling included 35 beam trawls, 28 Brenke sleds, 8 box cores, 20 surface meso-zooplankton tows, and 7 Deep Towed Camera transects. In total, 25,710 specimens were identified to 1084 taxonomic entities, including 847 species-level, 144 genus-level and 69 family-level and 24 higher-level taxa. Of the species-level taxa, only 457 were assigned species-level taxonomic names, which implies that up to 58% of the collected fauna is undescribed. In addition, the ranges of numerous species have been extended to include the western Tasman Sea.

Conclusions: The lower bathyal and abyssal fauna of soft sediment seafloors off eastern Australia has been systematically surveyed for the first time. The resultant collections will provide the foundation for much future ecological, biogeographical, phylogenetic and taxonomic research.

Keywords: Deep sea, Infauna, Epifauna, Taxonomy, Biodiversity, Biogeography, Australia, Tasman Sea

Background

Deep-sea ecosystems are one of the world's major ecological research frontiers, giving us new perspectives on macro-ecological questions (Danovaro et al. 2014). The deep sea is characterised by very cold water, extreme pressure, little to no light and limited food, with organic

matter residues sinking from surface waters or transported down continental margins (Rex and Etter 2010).

Our knowledge of the benthic fauna at lower bathyal to abyssal (LBA; > 2000 m) depths off Eastern Australia is very limited, despite the presence of a large abyssal basin in the Tasman Sea. The H.M.S. *Challenger* (U.K.) took a single biological dredge sample (station 165, almost empty) in 1874 in 4754 m (Murray 1895). The *Galathea* expedition (Denmark) collected from 8 abyssal

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stations across the Tasman Sea in 1951–2 (Bruun 1957). Cruise 16 of the RV *Dmitry Mendeleev* (U.S.S.R.) trawled two abyssal samples from the Tasman Sea on its way across Southern Australia and up past Norfolk Island in 1975–1976. Finally, the RV *Tangaroa* (New Zealand) collected biological material at abyssal depths when searching for manganese nodules in 1982 on a transect between New Zealand and Sydney (Glasby et al. 1986). However, only three of these samples occurred within the Australian Exclusive Economic Zone (EEZ) and none from the newly created eastern network of Australian Marine Parks. Consequently, the composition of the LBA fauna of the western Tasman Sea was largely unknown.

The Tasman Basin formed 90–52 mya through the tectonic rifting of Australian and New Zealand continental masses (Gaina et al. 1998). It now extends from the Marion and Chesterfield plateaus off Queensland in the north (24°S) to south of Tasmania (48°S) before opening up into the Southern Ocean. A south-north spreading ridge formerly existed in the centre of the basin (Gaina et al. 1998). Subsequently, the north-south chain of Tasmanid seamounts were created along the Lord Howe Rise by the Australian plate moving over a crustal hot-spot from 33.5–6.4 mya (Keene et al. 2008).

The upper continental slope along eastern Australia is broadly convex from the shelf break down to 1500 m (Keene et al. 2008). At mid slope depths (until 3000 m) it is more concave, with the upper section sometimes forming an escarpment. On the lower slope there can be a series of steplike rocky ledges down to the abyssal plain at 4500–5000 m. The margin is frequently dissected by canyons, some of which start at shelf depths (Huang et al. 2014), and slumps due to slope failure (Hubble et al. 2012). Sediment accumulates on the upper slope and sometimes on flatter surfaces at mid and lower slope depths where bottom currents are not too strong (Keene et al. 2008). The composition of the sediments is depth-dependent. Terrestrial siliceous and biogenic carbonate sediments occurring on the shelf and upper slope, and finer pelagic-derived sediments (mainly coccolith and foraminifera remains) on the lower slope and abyssal plain (Keene et al. 2008). Below the lysocline at 3600 m, carbonate particles dissolve and sediments form a fine ooze (Martinez 1994).

There are two main current trajectories through the Tasman Sea according to depth (Tomczak and Godfrey 2003). The counter-clockwise southern Pacific gyre circulates shallow water from the Coral Sea, south along the Australian continental margin (East Australian Current) until about 32–35°S before heading eastward to northern New Zealand, although eddies move south as far as Tasmania (Ridgway and Dunn 2003). Antarctic Intermediate Water (AAIW) is present at ~1000 m,

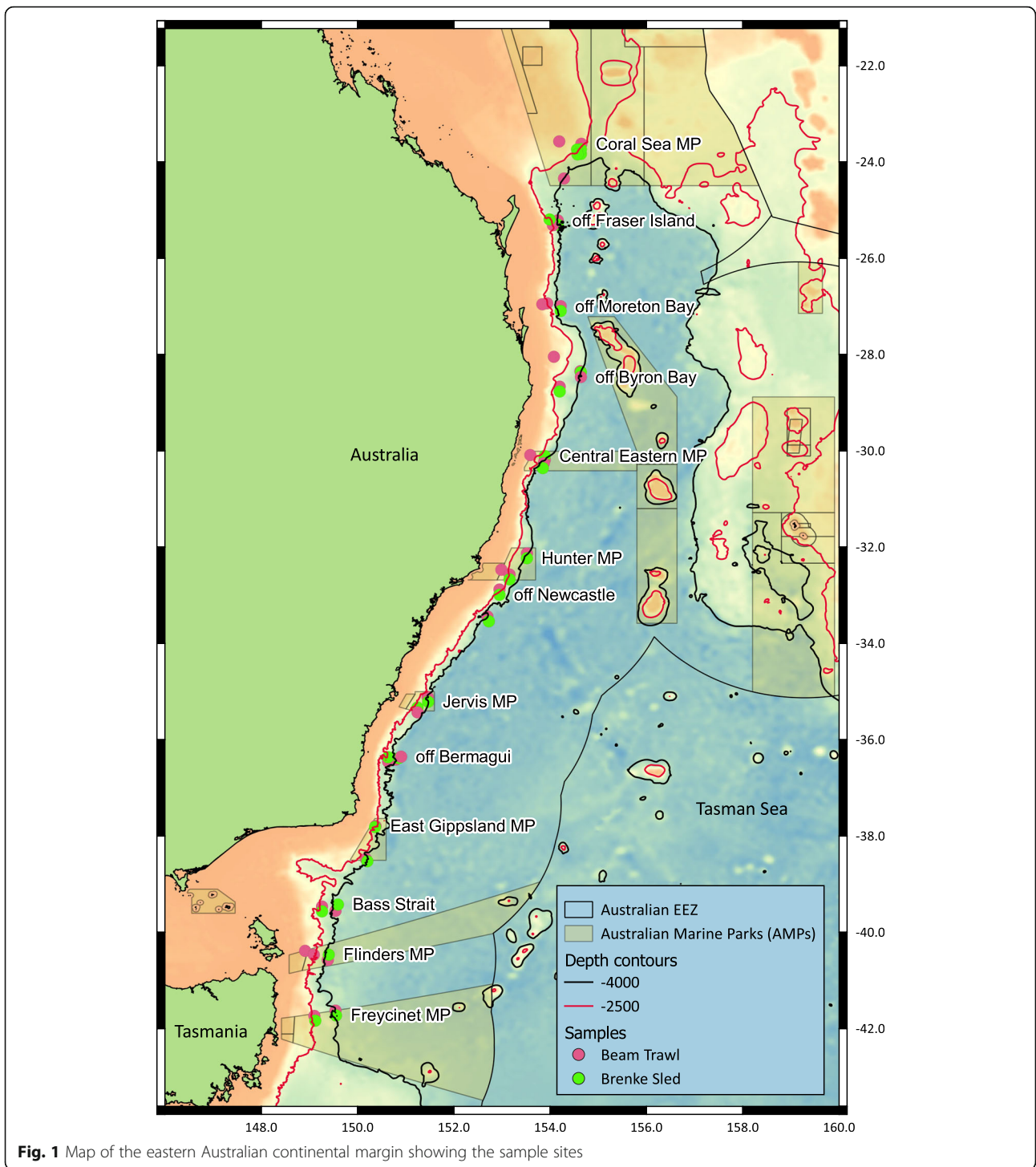
entering the Tasman Sea from two directions, one flowing from the south-west and the other from the north and east, the latter having become entrained by the surface gyre in the southern Pacific east of New Zealand. Both North Atlantic Deep Water (NADW) (at ~2500 m) and Antarctic Bottom Water (ABW) (~4–5000 m) flow in from the south-west along the Australian margin, forming clockwise eddies at the northern end of the basin, with a net southern flow back down the Lord Howe Rise (Condie 1994; Tilburg et al. 2001). The northward flow of these deep currents is strong enough to remove sediment from the Australian lower continental slope leaving a rocky surface (Keene et al. 2008).

Oceanographic factors such as temperature, salinity and oxygen are relatively invariant within each water mass (Ridgway et al. 2002). ABW at 4000 m is relatively cold (1.1 °C), salty (34.72‰) and oxygenated (4.49 ml/l). NADW at 2500 m is slightly warmer (1.9 °C), the same salinity and slightly less oxygen (4.13 ml/l). AAIW at 1000 m is warmer again (5.0 °C), slightly less salty (34.47) and less oxygenated (4.06). There are no hypoxic ($O_2 < 1.7$ ml/l) or anoxic (< 0.02) oxygen minimum zones in the Tasman Sea (Falkowski et al. 2011). The flux of particulate organic carbon (POC) to the seafloor varies with net primary production (NPP) in surface waters, seasonal variation in NPP (POC is increased if NPP is seasonal), and the depth of the seafloor (more POC gets consumed in the water column) (Lutz et al. 2007). Both NPP and seasonality of NPP is higher at southern latitudes in the Tasman Sea. Away from the coast, the waters of the northern Tasman Sea are oligotrophic. While the sediments of the continental slope are well oxygenated and bioturbation is abundant, the carbon content of the sediments is less than 1% (Keene et al. 2008), which is poor by global standards (Seiter et al. 2004).

In May–June 2017, the IN2017_V03 expedition of the RV *Investigator* sampled LBA benthic communities along the lower slope and abyss of Australia's eastern margin from off mid-Tasmania (42°S) to the Coral Sea (23°S), with particular emphasis on describing and analysing patterns of biodiversity that occur within a newly declared network of offshore marine parks (O'Hara et al. 2020a, b). This paper summarises the fauna collected by the expedition.

Methods

The study design was to deploy a 4 m (metal) beam trawl (Lewis 2010) and Brenke sled (Brenke 2005) to collect samples on soft sediment substrata at the target seafloor depths of 2500 and 4000 m at every 1.5 degrees of latitude along the western boundary of the Tasman Sea from 42° to 23°S, traversing seven Australian Marine Parks (AMPs) (Fig. 1). In addition, a few beam trawl



samples were collected at 1000 m and a few box-corer samples at southern sites (until technical difficulties precluded its further use). A single deep-towed video transect (1500–2500 m) was completed within each Marine Park. Each site was mapped (bathymetry and backscatter) prior to deployment using a Kongsberg EM 122 multibeam sonar. Environmental data (temperature,

salinity, pressure) were collected by a Sea-Bird SBE37SM sensor mounted on the Brenke Sled.

Samples were sorted, weighed and preserved (generally in 95% ethanol, the rest in formalin) on-board into broad taxonomic groups, and sent to taxonomic experts. The following groups of megafauna were subsequently identified to operational taxonomic units (OTUs, mostly

to species, some to genus or family) and counted: sponges, hydroids, sea anemones and zooanthids, hexacorals and octocorals, barnacles, isopods, decapods, pycnogonids, annelids, echinoderms, molluscs, tunicates and fish.

Freshly collected material was photographed on-board the ship, predominantly by Karen Gowlett-Holmes (KGH, invertebrates), John Pogonoski (JP, fish), Alastair Graham (AG, fish), Jerome Mallefet (JM, general) and Robert Zugaro (RZ, general).

Results

The expedition biological sampling included 35 beam trawls, 28 Brenke sleds, 8 box cores, 20 surface mesozooplankton tows, and 7 Deep Towed Camera transects. Here we present results predominantly from the beam trawls and Brenke sleds (Fig. 1). The multibeam sonar revealed a continental slope topography that was much more complex and rugged than expected, with the margin incised by numerous canyons, sediment slumps, cliffs and other areas of exposed rock (Fig. 2). This complicated the placement and duration of sampling. The depth of the samples differed from the target as follows: 4000 m (3754–4800 m), 2500 m (1761–2963 m), and 1000 m (932–1257 m) (Tables 1 and 2). Sample 080 from 1225 m included a decaying manta ray with associated scavengers and predators. Sample 100 included a dead pilot whale skull and vertebrae which hosted *Idas* bivalves and *Osedax* worms (not previously reported from Australia).

In total to date, 25,710 specimens have been identified to 1084 taxonomic entities (Figs. 3, 4 and 5, Supplementary Table S1), including 847 species-level, 144 genus-level and 69 family-level and 24 higher-level taxa. Twenty-nine species have been newly described from the survey. Of the species-level taxa, only 457 have been assigned species-level taxonomic names, which implies that up to 58% of the collected fauna is undescribed.

Porifera

M. Ekins

Over one hundred and twenty Porifera specimens were collected during the expedition, of which half were Demospongiae and half were Hexactinellida (the glass sponges). Of the Demospongiae, there were only four orders representing the four families of Ancorinidae, Polymastiidae, Niphatidae and Cladorhizidae. The Cladorhizidae (carnivorous sponges) were by far the most commonly collected family with 40 specimens, which is surprising considering that many of these species are only several millimetres in length.

Most notable from this expedition was the finding of 17 new species of carnivorous sponges, belonging to seven of the nine known genera of Cladorhizidae:

Abyssocladia, *Asbestopluma*, *Chondrocladia*, *Cladorhiza*, *Lycopodina* and *Euchelipluma* (Ekins et al. 2020). Also remarkable is that only two previously well-known carnivorous species were collected i.e. *Chondrocladia clavata* and *Lycopodina calyx*. Another commonly collected sponge was *Radiella irregularis* and two potential new species of *Radiella*. There was only one other Demospongiae sponge that could be identified to a described species *Echinostylinos reticulatus*, the remaining 22 OTUs of Demospongiae will be new to science.

The class Hexactinellida was represented by four orders, containing eight families in order of number of specimens found: Hyalonematidae, Pheronematidae, Rossellidae, Farreidae, Aulocalycidae, Euplectellidae and the Euretidae with the solitary species *Pleurochorium cornutum*. The most common glass sponges were the large *Pheronema pilosum*, *Semperella schulzei*, and the stunning *Monorhaphis chuni*, with its metre long glass spicules. Amongst the glass sponges there were another seven described species and 16 new species. Unfortunately all 11 specimens of the Farreidae are a Farreidae/Euretidae *incertae sedis*, which has been repeatedly recovered from Australian and New Zealand seamounts as long dead fragments which cannot yet be assigned to a living species (Reiswig and Kelly 2011).

Overall this assemblage of sponges is to be expected from the Abyssal depths. It consists of glass sponges that have adapted to the 150 fold increase in silicon in the water and use it to create large glass structures, or those that have adapted to carnivory in an attempt to secure more reliable food resources. Many of the sponges collected on this expedition have been described from previous expeditions to the Pacific at Abyssal depths (Ridley and Dendy 1886, 1887; Lévi 1964, 1993; Koltun 1970). Interestingly there were no sponges collected on this expedition that matched to those previously collected from the Great Australian Bight (Sorokin et al. 2017; MacIntosh et al. 2018; Williams et al. 2018a; O'Hara et al. 2020a). Whilst more than half of the sponge specimens collected on this voyage are unknown, almost three quarters of the species are new. This indicates the high diversity of sponges on the abyssal plains and continental slopes that are still to be fully described.

Hydrozoa

J.E Watson & T.D. O'Hara

Eight species of thecate hydroids (Leptothecata) were collected from depths of 1151–4173 m, including three previously known species (*Acryptolaria angulata*, *Cryptolaria abyssicola*, *Zygophylax concinna*), three newly described species (*Hebella* sp. nov., *Amphisbetia* sp. nov., *Lytocarpia* sp. nov.) and two species (*Hebella* sp., *Halecium* sp.) which were too inadequate or in too poor a condition for identification (Watson 2019).

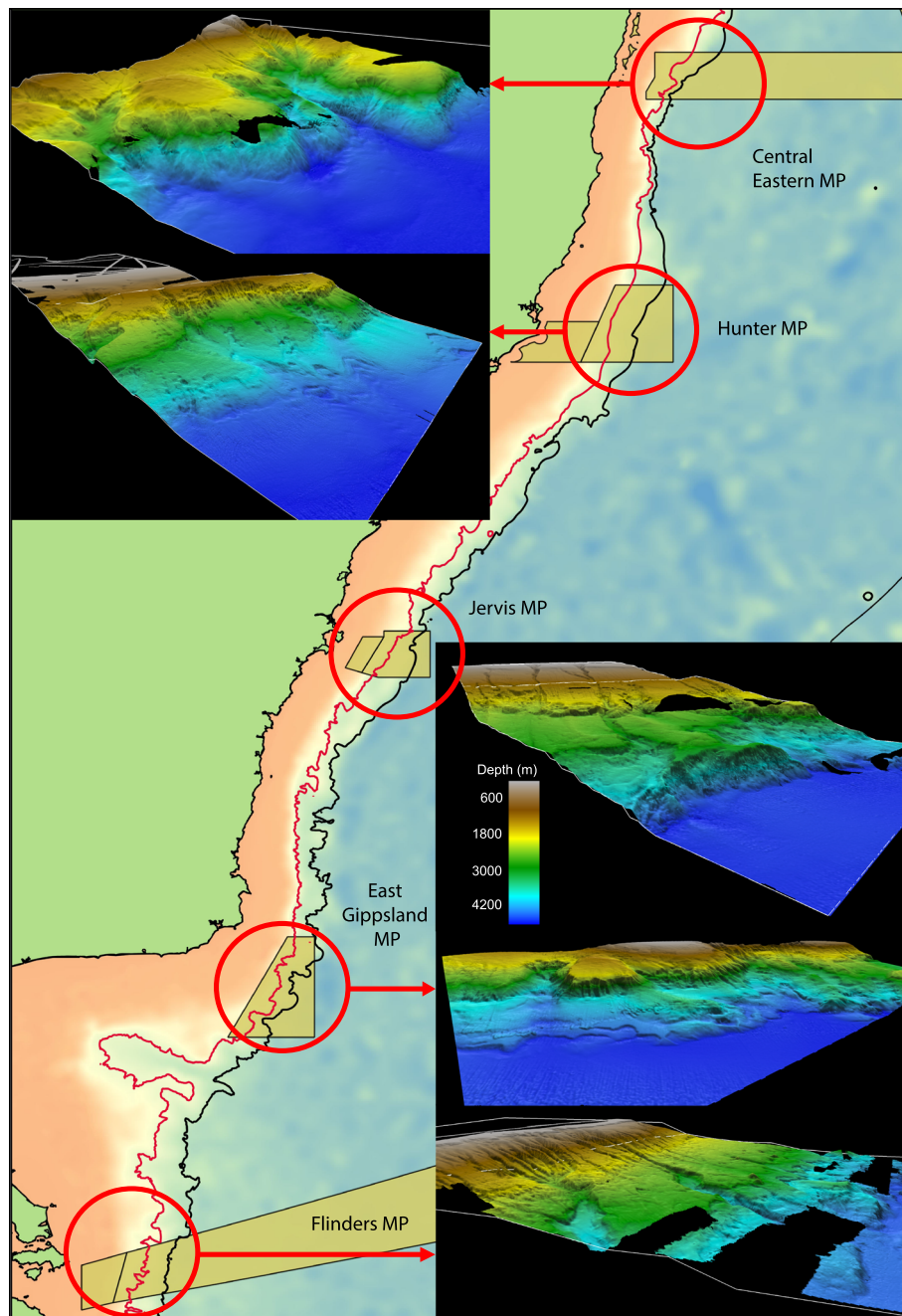


Fig. 2 Multibeam topology of five Marine Parks on the eastern Australian continental margin (map elements as Fig. 1)

Abyssal hydroids recorded from Challenger Station 160 from a depth of 4755 m were previously the only published reports of the abyssal hydroid fauna from Australia. They recorded two species, *Cryptolarella abyssicola* and *Halisiphonia megalotheca* (Allman 1888). Hydroids from the continental shelf have been reported from the Great Australian Bight (Bale 1914a, b, 1915; Watson 2018) and off New South Wales (Ritchie 1911).

None of these studies included material deeper than 100 m.

Cryptolarella abyssicola was by far the most abundant species with 12 records. The species is a wide-ranging abyssal hydroid that has previously been recorded under various names from the Southern, Eastern Pacific and Atlantic Oceans in 2470–6328 m (Calder and Vervoort 1998; Marques et al. 2005). The Australian range of *C.*

Table 1 Beam trawl sample location, depth, date

Stn	Location	Lati-tude	Longi-tude	Mid depth (m)	Date (d/m/y)	Area sampled (m ²)
004	Freycinet MP	-41.731	149.120	2785	18/5/17	29,584
006	Freycinet MP	-41.626	149.552	4037	18/5/17	30,344
013	Flinders MP	-40.386	148.928	1041	20/5/17	7908
014	Flinders MP	-40.464	149.102	2392	20/5/17	15,348
015	Flinders MP	-40.473	149.397	4126	20/5/17	10,572
022	Bass Strait	-39.462	149.276	2726	22/5/17	11,756
030	Bass Strait	-39.552	149.553	4165	23/5/17	29,312
032	East Gippsland MP	-38.479	150.184	3851	24/5/17	11,580
035	East Gippsland MP	-37.792	150.382	2459	25/5/17	15,352
043	Bermagui	-36.351	150.914	4800	27/5/17	14,824
044	Bermagui	-36.355	150.644	2754	27/5/17	17,972
053	Jervis MP	-35.114	151.469	3981	28/5/17	16,792
056	Jervis MP	-35.333	151.258	2643	29/5/17	15,976
065	Newcastle	-33.441	152.702	4226	30/5/17	13,992
067	Newcastle	-32.985	152.952	2803	31/5/17	19,748
069	Hunter MP	-32.479	152.994	1021	3/6/17	12,508
070	Hunter MP	-32.575	153.162	2534	3/6/17	26,260
078	Hunter MP	-32.138	153.527	4004	4/6/17	19,608
080	Central Eastern MP	-30.099	153.596	1225	5/6/17	16,096
086	Central Eastern MP	-30.098	153.899	2473	5/6/17	13,384
088	Central Eastern MP	-30.264	153.870	4441	6/6/17	18,328
090	Byron Bay	-28.677	154.203	2574	7/6/17	15,400
097	Byron Bay	-28.355	154.636	3782	8/6/17	27,508
099	Byron Bay	-28.371	154.649	3789	9/6/17	14,416
100	Byron Bay	-28.054	154.083	1006	9/6/17	18,968
101	Moreton Bay	-26.946	153.945	2548	9/6/17	11,564
102	Moreton Bay	-27.008	154.223	4269	10/6/17	18,332
104	Moreton Bay	-26.961	153.848	1104	10/6/17	13,352
109	Fraser Island	-25.221	154.164	4005	11/6/17	18,156
115	Fraser Island	-25.325	154.068	2346	11/6/17	11,976
121	Coral Sea MP	-23.587	154.194	1053	13/6/17	13,352
122	Coral Sea MP	-23.751	154.639	2349	13/6/17	13,548
128	Coral Sea MP	-23.631	154.660	1765	13/6/17	13,964
135	Coral Sea MP	-24.352	154.291	4001	15/6/17	19,812

abyssicola is now extended along the south-eastern Australian coast from cool temperate Tasmania in the south to the subtropical Coral Sea. *Acryptolaria angulata* has been found from deep water in the Indian Ocean, Indo-west Pacific, New Caledonia and New Zealand (Vervoort and Watson 2003). The two new records of *Zygophylax concinna* extends its range from the only known record found off Sydney (Ritchie 1911) and to the depth range of 100 m to 3754 m.

Three new species occur in the collection from the genera *Hebella*, *Amphisbetia* and *Lytocarpia*. The first

two were recovered from depths of 4133 m and 4131 m respectively from eastern Bass Strait, Victoria. *Amphisbetia* is a moderately common hydroid genus from shallow coastal environments of southern Australia (Watson 1973), so the record from 4131 m possibly indicates that it is a floating fragment from a shallow water colony entrained in the trawl net. With more material, the new species of *Lytocarpia* from the Coral Sea, may prove to be a diminutive subspecies of *L. spiralis*, a common deep water species from around New Zealand (Vervoort and Watson 2003).

Table 2 Brenke Sled sample location, depth, date

Stn	Location	Lati-tude	Longi-tude	Mid depth (m)	Date (d/m/y)	Area sampled (m ²)
005	Freycinet MP	-41.730	149.135	2784	18/05/17	2985
009	Freycinet MP	-41.626	149.560	4028	19/05/17	4587
016	Flinders MP	-40.463	149.415	4130	21/05/17	4753
023	Bass Strait	-39.462	149.277	2734	22/05/17	2951
031	Bass Strait	-39.422	149.604	4160	23/05/17	3850
033	East Gippsland MP	-38.521	150.213	4085	24/05/17	2872
040	East Gippsland MP	-37.815	150.373	2673	25/05/17	1724
042	off Bermagui	-36.385	150.863	4730	26/05/17	5897
045	off Bermagui	-36.360	150.644	2787	27/05/17	4587
054	Jervis MP	-35.117	151.473	3953	28/05/17	2827
055	Jervis MP	-35.335	151.259	2666	28/05/17	4074
066	off Newcastle	-33.448	152.733	4286	30/05/17	6193
068	off Newcastle	-32.993	152.957	2854	31/05/17	3941
076	Hunter MP	-32.577	153.161	2507	3/06/17	4548
079	Hunter MP	-32.131	153.527	4031	4/06/17	3909
087	Central Eastern MP	-30.113	153.898	2479	6/06/17	3301
089	Central Eastern MP	-30.263	153.859	4425	6/06/17	3550
096	off Byron Bay	-28.678	154.204	2578	7/06/17	4909
098	off Byron Bay	-28.371	154.647	3782	8/06/17	4324
103	off Moreton Bay	-27.000	154.223	4270	10/06/17	7426
110	off Fraser Island	-25.220	154.160	4007	11/06/17	6648
119	off Fraser Island	-25.206	153.991	2308	12/06/17	3674
123	Coral Sea MP	-23.749	154.641	2305	13/06/17	4125
131	Coral Sea MP	-23.748	154.643	2327	14/06/17	4975
132	Coral Sea MP	-23.756	154.568	2156	14/06/17	4296
134	Coral Sea MP	-23.750	154.572	2124	14/06/17	4054

There were surprisingly few species and few locality records in the collection considering the extensive latitudinal range of the survey. This may be an artefact of decrease in hydroid diversity with depth, the sampling gear used, or sampling of predominantly sedimentary substrates.

Several siphonophores we also collected, including the characteristic mushroom-shaped bracts (Just et al. 2014; O'Hara et al. 2016) of the benthic rhodaliid species *Dendrogramma enigmatica* from off Bermagui (operation 044) and in Jervis Marine Park (056) in 2650–2821 m. small denuded rhodaliid pneumatophores were also found in operation 056 and off Byron Bay (090 and 100) which may or may not be *Dendrogramma*. The pelagic bluebottle *Physalia utriculus* was caught, probably from the sea surface, in an abyssal beam trawl sample (op 030) off eastern Bass Strait.

Actiniaria and Corallimorpharia

M.L. Mitchell & A.L. Crowther

The IN2017_V03 expedition represents the first time we can compare the actiniarian faunal composition by depth and latitude along the Eastern Australian coast. The bathyal and abyssal Actiniaria fauna collected off the Eastern coast of Australia totalled 111 lots (325 specimens) from 29 operations across all latitude and depths. The mid-lower bathyal depths (1500–3500 m) contained the most lots (57 with 126 specimens). However, the highest number of specimens were collected from abyssal depths (< 3500 m), with 34 lots (136 specimens). The remainder (20 lots, 63 specimens) were collected from the upper bathyal depths (> 1500 m). Eleven lots of Corallimorpharia were also collected from mid-lower bathyal and abyssal depths, but not from upper bathyal depths. Corallimorpharians have not been identified lower than order.

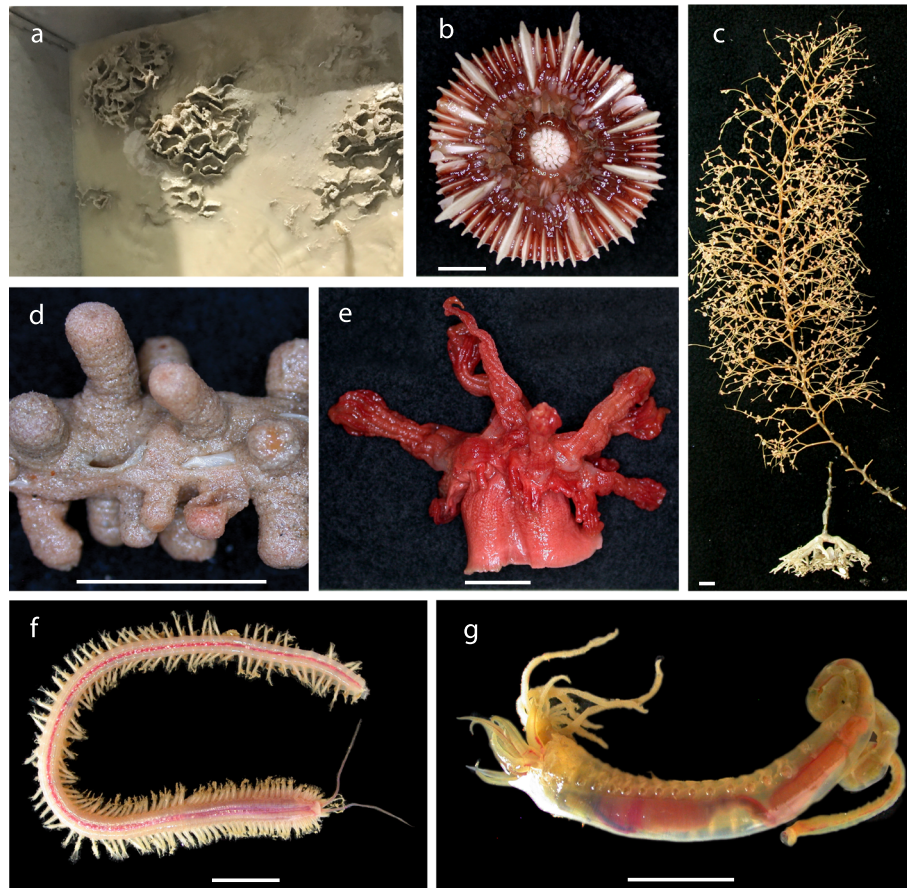


Fig. 3 Shipboard photographs of Porifera, Cnidaria and Annelida. **a** sponge *Ljmadictyum* collected in a box core (op 011, 2393 m, JM); **b** cup coral *Stephanocyathus coronatus* (op 080, 1194–1257 m, KGH); **c** *Chrysogorgia* gorgonian (op 121, 1013–1093 m, KGH); **d** zoanthid in the family Parazoanthidae (sp; 1) (op 069, 1006–1036 m, KGH); **e** soft coral *Anthomastus* (op 003, 2948–2787 m, KGH); **f** sigalionid polychaete worm in the genus *Neoleanira* (op 080, 1194–1257 m, KGH); **g** melinnid polychaete in the genus *Melinnopsis* (op 056, 2650–2636 m, KGH). Scale bar = 1 cm

Representatives of two families dominated all latitudes of the survey: Hormathiidae and Amphianthidae. These were also the only two families that were collected from the deepest (4800 m) to the shallowest operation (1006 m).

Not surprisingly, representatives of Hormathiidae were sampled from all depths, and across the range of latitudes, with 49 lots (149 specimens) collected. Hormathiids are known to consistently dominate the actiniarian fauna catch of deep sea surveys (Fautin et al. 2013; MacIntosh et al. 2018), as shown here, with hormathiids not only being most sampled (149 specimens), but also the greatest diversity (12 OTUs), compared to other families. The Hormathiid *Paracalliactis rosea* was the most prevalent OTU (21 lots, 60 specimens), found in a wide range of latitudes. This species was not sampled from abyssal depths; however, the deepest collection from this survey (> 3000 m) is similar to the depth this species was collected from in the Great Australian Bight (MacIntosh et al. 2018). *Actinauge* species were

only represented in the lower latitudes of Bass Strait and Freycinet. The few specimens of Hormathiidae collected from abyssal depths were unable to be identified to genus at present.

Representatives of Amphianthidae (24 lots, 121 specimens) were collected from a wide range of depths (1000–4000 m), and throughout the extent of the latitudinal range sampled (Coral Sea MP to Freycinet MP). Specimens were identified to genera, representing eight OTUs; a similar diversity to that found in the Great Australian Bight. More work is needed to determine species identities and distribution. Unlike hormathiids, the Amphianthidae were found mostly at lower depths (> 2500 m), and in greater numbers in the southern latitudes.

The Actinostolidae, another common faunal component of the deep sea, were found in far fewer numbers at shallower depths < 2500 m. Actinostolids were lacking in many sites, although *Sicyonis* species were found in their greatest number near Freycinet. The remaining families;

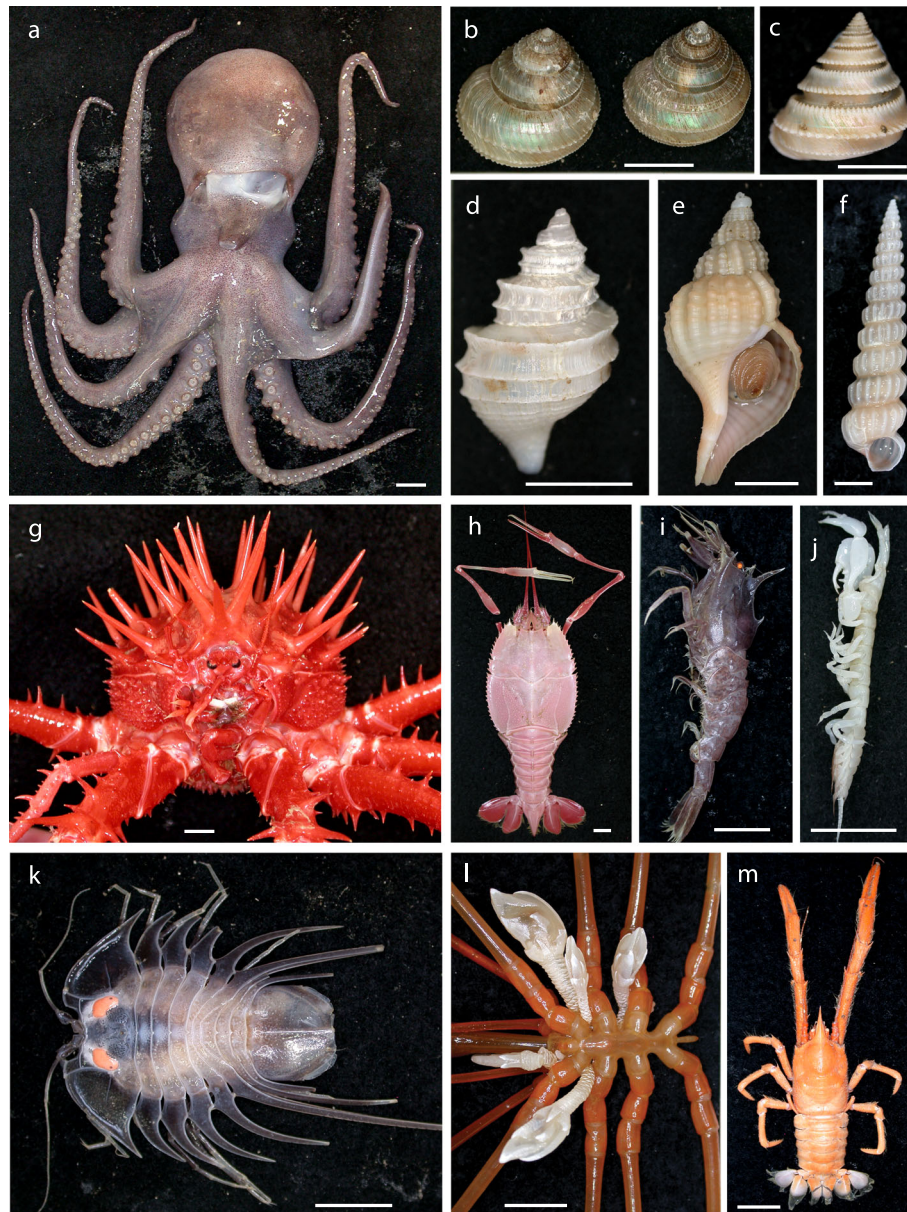


Fig. 4 Shipboard photographs of Mollusca and Arthropoda. **a** *Muusoctopus* (op 004, 2820–2751 m, KGH); **b** gastropod, *Calliotropis* (op 004, 2820–2751 m, KGH); **c** *Calliotropis* gastropod (op 069, 1006–1036 m, KGH); **d** raphitomid snail *Phymorhynchus* (op 015, 4114–4139 m, KGH); **e** ranellid snail (op 013, 932–1151 m, KGH); **f** small predatory wentle-trap sea snail *Epitonium* (op 069, 1006–1036 m, KGH); **g** spiny king crab *Neolithodes bronwynae* (op 035, 2338–2581 m, KGH); **h** widespread blind lobster *Pentacheles laevis* (op 069, 1006–1036 m, KGH); **i** deep-sea armoured shrimp *Metacrangon* (sp 1) (op 080, 1194–1257 m, KGH); **j** abyssal tanaid (op 006, 4022–4052 m, KGH); **k** serolid isopod *Brucerolis victoriensis*; **l** The barnacle *Litoscalpellum*, epibiont on the pycnogonid *Colossendeis tasmanica* (op 035, 2338–2581 m, KGH); **m** squat lobster *Munidopsis kensleyi* (op 121, 1013–1093 m, KGH). Scale bar = 1 cm

Actiniidae, Actinoscyphiidae, Liponematidae and Sargartiidae were uncommon, and were represented by a single specimen in some instances. The actiniid *Stylobates birtlesi* was collected from one operation at 1000 m, and this fits with the recorded depth range of the specimens but extends the distribution (Crowther et al. 2011). Previously, this was known only to occur off southern Queensland, and now from off Byron Bay in New South

Wales. From the limited representation of four families we are unable to make any inferences regarding faunal contribution via depth or latitude.

Of the specimens we were able to identify to species (*Stylobates birtlesi*, *Paracalliactis rosea*, and *Monactis vestita*), these new records provide a distribution expansion as indicated by the World Register of Marine species (WoRMS, see <http://www.marinespecies.org/>) and

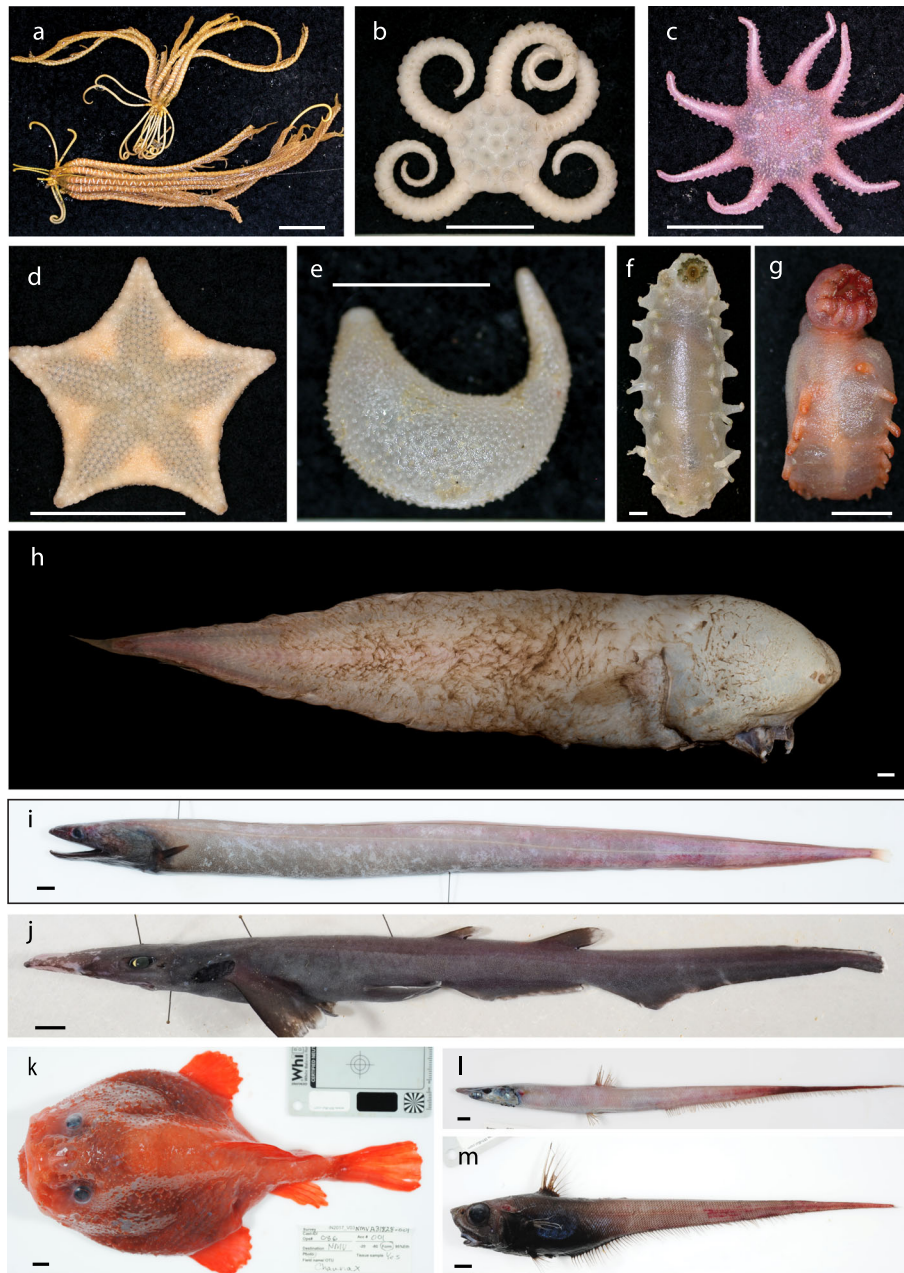


Fig. 5 Shipboard photographs of Echinodermata and Chordates. **a** the crinoid *Thalassometra* cf. *gracilis* (op 069, 1006–1036 m, KGH); **b** widespread abyssal brittlestar *Amphiophiura bullata* (op 015, 4114–4139 m, KGH); **c** multi-armed seastar *Crossaster multispinus* (op 069, 1006–1036 m, KGH); **d** sponge eating asteroid *Hoplaster kupe* (op 014, 2298–2486 m, KGH); **e** U-shaped holothurian *Echinocucumis ampla* has the mouth and anus protruding from the mud (op 035, 2338–2581 m, KGH); **f** holothurian *Oneirophanta mutabilis* (op 128, 1770–1761 m, KGH); **g** deposit feeding elasipod holothurian *Amperima furcata* (op 035, 2338–2581 m, KGH); **h** faceless cusk fish *Typhlonus nasus* (op 053, 3952–4011 m, RZ); **i** southern cut-throat eel *Histiobranchus australis* is widespread in southern oceans (op 056, 2650–2636 m, JP/AG); **j** pinocchio catshark, *Apristurus australis* (op 069, 1006–1036 m, JP/AG); **k** red coffin fish *Chaunacops coloratus* (op 086, 2429–2518 m, JP/AG); **l** allied halosaur, *Aldrovandia affinis* (op 069, 1006–1036 m, JP/AG); **m** kapala whiptail, *Nezumia kapala* (op 069, 1006–1036 m, JP/AG). Scale bar = 1 cm

the Great Australian Bight sampling program (MacIntosh et al. 2018). Not unlike other deep-sea surveys, a proportion of samples (74%) were taxonomically unresolved to species, genus or family, and eight OTU's could only be resolved to order level. These unresolved

identifications may represent new species and distributions; this survey highlights the diversity of the abyssal actiniarian fauna present around Australia and our paucity of knowledge regarding their distribution by not only latitude, but depth as well.

Zoantharia

H. Kise

Species of order Zoantharia are generally known as colonial sea anemones and are characterized by having two rows of tentacles and a unique bilateral arrangement of the mesenteries. Zoantharians can be found in a wide variety of marine environments (Fujii and Reimer 2013). Zoantharian taxonomy has been considered chaotic due to few diagnostic morphological characteristics and the presence of large amounts of intraspecific variation (Burnett et al. 1997; Reimer et al. 2004). However, molecular phylogenetic techniques have improved the taxonomy and systematics of zoantharians. As a result of previous studies using molecular phylogenetic techniques combined with morphological and ecological data, three families and 12 genera have been described since 2007 (e.g. Reimer et al. 2007, 2008; Fujii and Reimer 2011, 2013; Sinniger et al. 2013; Montenegro et al. 2015; Kise et al. 2019a).

In Australia, zoantharian diversity and taxonomy in shallow waters have been relatively well documented (see Haddon and Shackleton 1891; Burnett et al. 1995, 1997; Philipp and Fautin 2009). However, little or no information is focused on zoantharians in Australian deep-seas due to difficulty of collection. During RV *Investigator* expedition in 2017, 31 specimens were collected from the deep-seas of Australia. Molecular phylogenetic analyses combined with morphological observations showed that specimens collected from the Australian deep-sea contain 10 different morphological species. Kise et al. (2019b) formally described hermit crab-associated species *Epizoanthus australis* and *E. gorgonus* based on the specimens collected from Australian deep-seas. As well, echinoderm-associated species *Epizoanthus* sp. 1 is almost certainly an undescribed species.

Deep-sea zoantharians have recently attracted attention as there is apparently much undiscovered diversity (Reimer et al. 2007; Sinniger et al. 2013; Carreiro-Silva et al. 2017; Kise et al. 2018). In fact, several undescribed *Epizoanthus* species were found in this current study. Thus, investigation of deep-sea zoantharian diversity can contribute to a better understanding of the systematics and evolutionary history of zoantharians.

Octocorallia

P. Alderslade & K. Moore

The collection yielded 540 octocoral specimens comprising 15 families across 2 orders (Alcyonacea & Pennatulacea), and included 5 new genera and 15 new species. Because sampling was mostly on soft bottom habitat, pennatulids (sea pens) dominated, accounting for 396 specimens. With a cosmopolitan distribution, the most common abyssal sea pen is *Umbellula* and it was therefore not surprising that species of this genus represented about a third of the collection.

Of the 95 specimens of the sea pen *Porcupinella*, 63 were identified as the North Atlantic species *P. profunda* described by López-González and Williams (2011) from the Porcupine Abyssal Plain. In an earlier paper (Dolan 2008), similar specimens were described under the name *Umbellula carpenteri*, but two different colony forms were illustrated: one lot looking like *P. profunda* from the same original location, and one *Umbellula*-like lot from the South Indian Ocean showing a markedly curved rachis. López-González & Williams synonymised the author's Porcupine Abyssal Plain samples with *P. profunda* but assigned her curved samples, whose main taxonomic feature was not well illustrated, to an unnamed species of the genus *Umbellula*. However, both colony forms are present in the material from our collection, and notably they were collected together from the same operations and with intermediate colony forms present, suggesting that they be treated as the same species (Fig. 6a, b).

Specimens of another species of sea pen, morphologically assignable to *Umbellula*, show traits that suggest it requires a new genus and a putative new family, which could probably accommodate other nominal species of *Umbellula* as well. A new species of *Porcupinella* is also present. There are 26 previous Australian records (GBIF) of the sea pen genus *Kophobelemnon* and of these only 6 have been identified to a species – *K. macrospinosum*. Of the 67 *Kophobelemnon* specimens in our collection, nearly one third can be assigned to this species. The remainder represent one known and four new species.

A new species of the rare, small, encrusting soft coral *Scyphopodium* provides a new record for Australia and also a considerable range extension for the genus, only having been previously reported from Iceland and southern Africa. The uncommon genus *Telestula* is represented by 13 nominal species, but the literature is very inadequate and probably fewer than half of these species are valid. Our material contains 9 specimens comprising 3 unidentifiable species and a specimen of *Telestula spicuola robusta* previously only recorded from Hawaii. The collection of the gorgonian *Acanella rigida* is possibly only the third valid report of this species since it was first described from the *Challenger* expedition, and the first time recorded outside of Indonesia and the Philippines (Fig. 6c). A new genus of gorgonian from the Family Isididae, Subfamily Mopseinae, is also noteworthy for the attractive appearance of the polyp sclerites (Fig. 6d).

Annelida

L. M. Gunton, M. N. Georgieva, E. Kupriyanova, R. S. Wilson, H. Paxton, P. Hutchings, A. Murray, I. Burghardt, J. A. Konsgrud, T. Alvestad, J. Zhang & N. Budaeva

Over 6000 annelid specimens were recorded from combined bathyal and abyssal beam trawl, Brenke sled and box core samples (Gunton et al. submitted). Samples

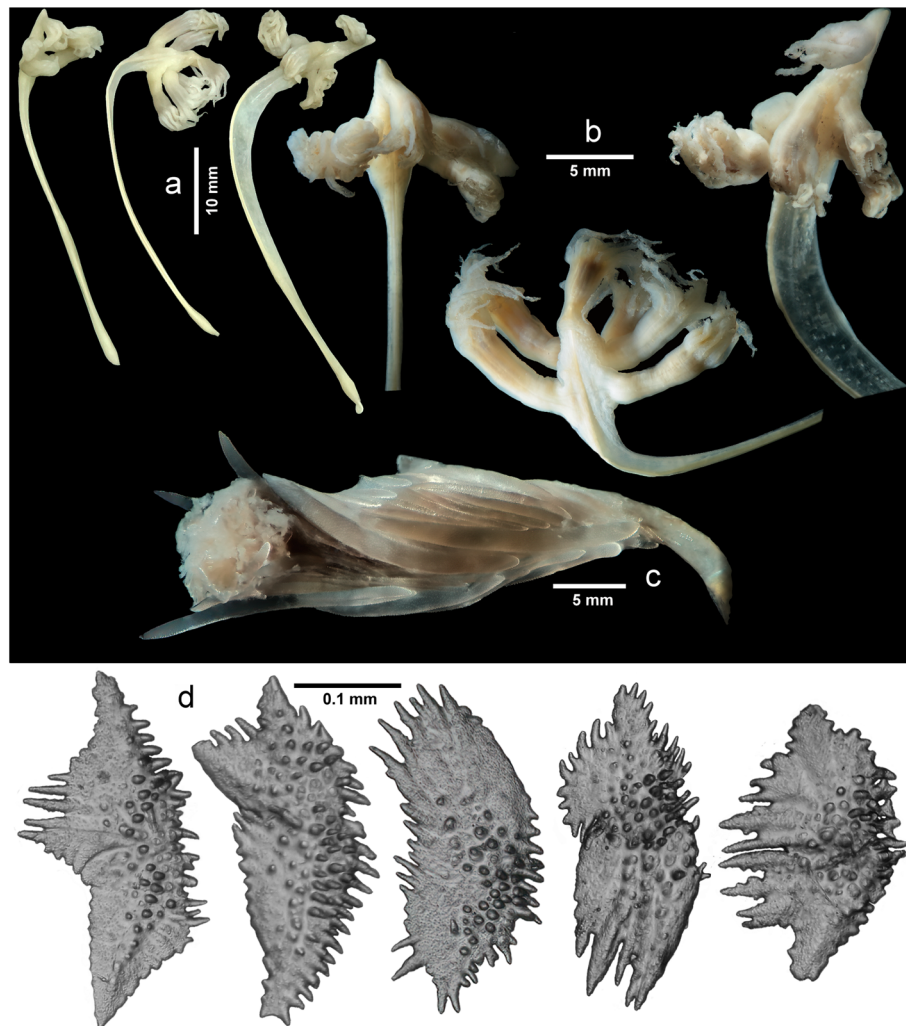


Fig. 6 Octocorallia. *Porcupinella profunda* **a** whole colonies and **b** polyp region; *Acanella rigida* terminal polyp; **d** Isididae new genus, polyp body sclerites

included representatives of polychaetes, Sipuncula and Echiura. The polychaetes, the most abundant group (5800 individuals), were composed of 47 families and at least 205 species/OTUs. Serpulidae (908 individuals), Dorvilleidae (470), Sigalionidae (413), Aphroditidae (381) and Ampharetidae (342) were the most abundant polychaete families. These results are similar to those of the global abyssal polychaete fauna, where ampharetids made up 10% of the total number of polychaete species recorded below 2000 m depth and serpulids were also abundant (3% total number of deep-sea species recorded) (Paterson et al. 2009). The families Ampharetidae and Serpulidae were also dominant in a large scale study of the deep Great Australian Bight (GAB) at 192–5032 m depth (MacIntosh et al. 2018). The high total abundance of serpulids in the beam trawl samples is mostly a result of operations 097 and 099 (around 3780

m) where the trawls retrieved numerous pebbles with calcareous tubes of serpulids (mainly *Bathyvermilia* n. sp.) attached.

Our preliminary morphological examinations suggest that the most species-rich families were Polynoidae (17 species), Onuphidae (13), Serpulidae (12), Acrocirridae (10) and Maldanidae (10). Serpulidae, Onuphidae and Polynoidae also had a high species richness in the deep GAB along with the Spionidae, Cirratulidae, Syllidae and Paraonidae (MacIntosh et al. 2018). The most abundant species in this study were *Bathyvermilia* n. sp. (Serpulidae), and *Laetmonice yarramba* (Aphroditidae).

This study yielded around 188 annelid species that could not be designated a Latin binomial name and may be new to science (88% of a total 214 annelid species). To date, six species have been described: sabellariids

Gesaia csiro and *Phalacrostemma timoharai* (Zhang et al. 2020), melinnids *Melinnopsis chadwicki* and *M. gardelli* (Gunton et al. 2020), and pectinariids *Petta investigatoris* and *P. williamsonae* (Zhang et al. 2019). The species currently being described include five onuphid species (Genus: *Nothria*), two ampharetids (*Amage*, *Anobothrus*) and four serpulids (*Bathyvermilia*, *Hygloporomatus*, *Spriodiscus*).

As this is the first dedicated study of Australian eastern abyssal fauna, a number of species have been reported for the first time in Australian waters and have geographic range extensions. A new species in the genus *Myriowenia* (Oweniidae) is reported from deep Australian waters, the genus having only been reported in Australia once before from 60 m off the coast of New South Wales (Capa et al. 2012). The genus *Boguella* (Maldanidae) is also reported for the first time in Australian waters. The abundant aphroditid scaleworm, *Laetmonice yarramba*, previously recorded from around Australia in 60–523 m depth (Hutchings and McRae 1993), has been recorded now from the deep GAB (189–3884 m) and from the present study in the lower bathyal and abyssal environments ranging from southern Queensland to Tasmania (932–4800 m). The wide geographic and bathymetric distribution, as well as its morphological variability, strongly suggest it is a species complex. *Laetmonice yarramba* is likely carnivorous, preying on both mobile macrobenthos, sessile foraminifera and carrion (Jumars et al. 2015), its large (4–8 cm) and robust body may increase the likelihood of its collection during beam trawl sampling methods. The sternaspid *Sternaspis* cf. *annenkovae* is reported from Australia, morphologically these specimens most resembled *S. annenkovae*, a species described from deep (3980–4070 m) waters in the north-western Pacific, however, genetically the Australian specimens were very similar to specimens identified as *Sternaspis* cf. *williamsae* collected from the deep north-western Pacific (Drennan et al. 2019).

During the beam trawl sampling operation 100 (depth 999–1013 m) the skull and vertebrae of a pilot whale (possibly *Globicephala macrorhynchus*) were collected, the first natural whale fall reported from Australian waters. A high abundance and diversity of annelids was associated with the whale bones. Annelids found on the bones included representatives of the typical 'bone-eating' Siboglinidae (*Osedax* n. spp.), numerous specimens of the dorvilleid *Ophryotrocha*, a genus that is often abundant and diverse at whale falls and other organically enriched habitats, as well as Orbiniidae, Phylodocidae (*Eumida* sp.) and Protodrilidae. A detailed study and description of the whale bone associated fauna is ongoing.

Cirripedia

A.M. Hosie

A total of 400 cirripede specimens were collected during the survey, comprising 5 families, 18 genera and 34 species/OTUs. The Scalpellidae was the most diverse family, represented by 24 species (143 specimens), however the Verrucidae was the most abundant family with 220 specimens collected (5 species). *Gibbosaverruca navicula* and *Cristallinaverruca* sp.1 were the most abundant species with 106 and 72 specimens collected, followed by *Metaverruca recta* with 28. More than half of the specimens of these species were collected in a single collecting event each, indicative of a patchy distribution within the survey area. Diversity was highest in depths less than 3000 m with 19 species exclusively collected in depths less than 3000 m, compared with 7 found only at depths greater than 3000 m.

The diversity and composition of taxa above species level are consistent with what is known of bathyal and abyssal barnacle fauna in Australia (Jones et al. 1990; MacIntosh et al. 2018). The species identified are largely wide-ranging in tropical and warm-temperate latitudes with only *Arcoscalpellum* cf. *gryllum* being a potential Australian endemic and two species, *Teloscalpellum* cf. *gracile* and *Trianguloscalpellum hamulus*, that are restricted to the Indo-Australian area. Significantly, only 13 (38%) species are shared with those collected during the surveys of the eastern Great Australian Bight, the only other comparable collection of Australian deep sea barnacles (MacIntosh et al. 2018). These shared species demonstrate a connection between northern and southern areas of the Australian bathyal and abyssal zone.

Only one species, *Litoscalpellum* sp. nov., is considered to be new to science with any certainty, while the remaining OTUs will require further study of similar species. The newly recorded species for Australia, *Arcoscalpellum* cf. *sculptum* and *Litoscalpellum crinitum*, are range extensions south from tropical waters (Zevina 1981), while *Neoscalpellum* cf. *crozieri* was previously known only from the western Indian Ocean (Young 2007).

The present collection contains many taxonomically valuable specimens, including good ontogenetic series for *Amigdoscalpellum vitreum* and *Litoscalpellum* sp. nov. This is of particular importance for genera such as *Annandaleum*, *Litoscalpellum*, *Neoscalpellum* that are characterised by significant ontogenetic shifts in the calcification of the capitular plates, making the identification of small numbers of specimens difficult, especially juveniles as these often are indistinguishable from other genera (Young 1990). The specimens will also be of value for phylogeographic studies as these specimens provide a wide geographic and latitudinal coverage that links the specimens collected from the Great Australian Bight to the deep seas of the tropical Indo-West Pacific.

Isopoda

K. L. Merrin

The isopod collection consists of 4229 specimens from both beam trawl and Brenke sleds, all of which have been identified to family level, with 94% from the suborder Asellota. This high proportion of asellotes is expected at these depths (beyond 1000 m) as this suborder is the dominant isopod group in these habitats.

In total, 27 families were identified. The Munnopsidae was the most commonly collected family, making up 39.8% of the total isopod numbers. The next most common family was the Ischnomesidae (14.6%), followed by Desmosomatidae (13.2%) and the Haploniscidae (11.4%). The high prevalence of the Munnopsidae in these samples was not surprising as studies have found that this family is the most common family in the deep sea. In the north Pacific abyssal regions around the Kuril-Kamchatka Trench, Munnopsidae have made up around half of all isopod specimens collected, 53.9% in Golovan et al. (2018) and 47.4% in Elsner et al. (2015), while in the Southern Ocean (Atlantic sector) Munnopsidae have made up 50% of all isopod specimens (Brandt et al. 2007). In this study, the Ischnomesidae were the second highest in total isopod numbers, in contrast to other studies where the Desmosomatidae were the second most collected (Brandt et al. 2007; Elsner et al. 2015; Golovan et al. 2018). The most commonly collected non-asellote isopod was from the family Serolidae. There were 12 families who were represented by ten or less specimens.

In general, the Brenke sled samples collected from 4000 m showed more isopod diversity (in terms of families) than those from 2500 m. There were only two non-asellote families, the Gnathiidae and Arcturidae that were collected from 4000 m, all the other non-asellotes were restricted to depths of 2500 m and above.

All collected isopod families except one have been previously recorded from Australian waters (MacIntosh et al. 2018; pers. obs), however several have not had any species formally described from them. The family Urstylidae, which until now, has only been recorded from the Argentine Basin and the Clarion-Clipperton Fracture Zone (Riehl et al. 2014) was collected from off Bermagui at 4730 m (operation 042). No Serolidae were collected north of the Hunter region (operation 070).

Decapoda

C. A. Farrelly & S. T. Ah Yong

The IN2017_V03 survey of 1261 decapods comprised 31 families, 61 genera and 108 species, all from typical deep-water groups. Of these, 17 are new to science, 30 represent new records for the east coast of Australia and 15 for Australia as a whole (Ah Yong 2019; Farrelly and Ah Yong 2019). Significant extensions in depth ranges

were also found for seven species (five dendrobranchi-ates, one caridean and one munidopsid).

Most new species from the voyage were from the Caridea (8%) and Anomura (5.5%). The highest number of new Australian records was in the Anomura and the highest number of new east coast records was in the Caridea (10%). Six species from the ECA survey are endemic to Australia and five of these (4.6%) are endemic to the east coast. The majority of species from the survey are widespread: 75% (81 species) have wider Indo-West Pacific ranges; 10% (11 species) have broader Southern Ocean or sub-Antarctic ranges and 28% (30 species) are circumglobal, occurring in both the Atlantic and Indo-Pacific. Three species of hermit crab (Paguridae) represent new generic records for Australia: *Catapaguroides microps*, *Chanopagurus atopus*, and *Icelopagurus crosnieri* and three species of the brachyuran crab *Ethusina* (Ethusidae) are the first identified species of this family and genus recorded in Australia (Ah Yong and Farrelly 2018).

The 15 new Australian records represent significant range extensions with most of the nearest previous records of these species from neighbouring Indo-West Pacific localities, including New Caledonia, Vanuatu, Wallis and Futuna Islands, and Indonesia, although several species were otherwise only found more distantly, including Taiwan (*Chanopagurus atopus*), the Philippines and the Bay of Bengal (*Munidopsis arietina*) (Baba et al. 2008). Other range extensions with more proximate previous records include *Gordonella kensleyi*, *Glyphocrangon tasmanica*, *Neolithodes bronwynae* and *Munidopsis crassa*, all previously known from the northeastern Tasman Sea; and *Ethusina castro* and *E. rowdeni* previously known from only a single specimen each from northeastern New Zealand (Ah Yong 2008; Ah Yong and Farrelly 2018). In addition, the survey extended the range of 30 species from adjacent regions to the north or south, or west from the Lord Howe Rise and Norfolk Ridge. Five species, previously known only from Western Australia were also recorded.

All of the undescribed species belong to genera already recorded from Australian waters, although their nearest congeners may not be Australian. For example, the nearest relatives of two new species of squat lobsters, *Munida* sp. and *Munidopsis* sp., occur farther afield in the Indo-West Pacific (Baba et al. 2008). *Glyphocrangon* cf. *ferox*, has its closest relative in Madagascar (Komai 2004) and *Lebbeus* sp. most closely resembles species from New Zealand and Hawaii (Rathbun 1906; Ah Yong 2010).

Ninety-nine species (92%) were found in the bathyal zone (1000–3500 m) with almost two-thirds (64) of these recorded between 1000 and 1500 m. Twenty-three species (21%) were collected from the abyss (3500 + m). This represents a decrease in diversity of 77% from

bathyal to abyssal depths as 76 species fall out below 3500 m. Fifteen species (65% of abyssal species) were recorded from both bathyal and abyssal depths. Thirty-three species from the voyage were also recorded from the Great Australian Bight surveys (MacIntosh et al. 2018) with seven of these from abyssal depths. This degree of species overlap probably reflects the geographic proximity of the survey areas (i.e., eastern Australia and southern Australia, respectively) in combination with the southern flowing East Australian Current.

The Decapoda of the bathyal sea floor along the eastern coast was dominated numerically by deep-water hermit crabs (Parapaguridae; 37%), followed by the deep-sea lobsters (Polychelidae) (10%), squat lobsters (Munididae, Munidopsidae, Chirostylidae; 5%) and a number of shrimp families (Mematocarcinidae, 8%; Sergestidae, 6%; Crangonidae, 5%; Benthescymidae, 5%). Several families of brachyuran crabs were also recorded from bathyal depths (Cyclodorippidae, Cymonomidae, Homolidae, Ethusidae, Goneplacidae, Inachidae and Geryonidae), though most of these were from the 1000 m trawls. The abyssal fauna was dominated by the Nematocarcinidae (25%), Crangonidae (20%), Benthescymidae (17%), Munidopsidae (squat lobsters) (16%), Acanthephyridae (10%) and Aristeidae (4%). Significantly fewer parapagurids, polychelids and sergestids were recorded at abyssal depths (all dominant at bathyal depths) and some groups such as the brachyurans, glyphocrangonids, chirostylids and pagurids were not recorded in any abyssal samples.

A marked increase in species diversity with decreasing latitudes was observed for sample sites close to 1000 m (18 species from the Hunter operations compared to 33 species from the Coral Sea). Many species were recorded from southern to northern operations but the largest number of brachyuran, anomuran and polychelid species was recorded from the northern operations from off Byron Bay and the Coral Sea. In contrast, the survey data of the lower bathyal waters (1500–3500 m) showed no pattern of increasing diversity with decreasing latitude (11 species from Freycinet, Tasmania, and 13 from the Coral Sea with various peaks of higher diversity in between). A latitudinal comparison of abyssal plain Decapoda also showed no increase in diversity from south to north, with four species recorded from Freycinet and three from the Coral Sea.

Pycnogonida

D. Staples

The IN2017_V03 collection is represented by 111 specimens assigned to 6 described species and 16 potentially new species. Seven species were collected using the Brenke Sled and 15 using the beam trawl. Only three species were recorded using both methods. Because the Brenke Sled has not been used elsewhere in Australian

deep sea surveys comparison between regions can only be effectively based on the trawled material. It is apparent that had the Brenke Sled been used the number of Great Australian Bight (GAB) species could have been increased significantly. Without exception all Brenke Sled material consists of small, fine specimens that would easily go undetected amongst bulk collections associated with trawls and dredges. In this regard the Brenke Sled is a most effective collection method.

The most abundant and diverse genus represented in this collection is *Colossendeis* with 58 specimens belonging to 8 species. *Colossendeis* is a deep-sea genus that includes the largest pycnogonids, often with far-ranging distributions. Because of their size, with leg spans commonly ranging from 30 to 50 cm in Australian waters, *Colossendeis* is the most conspicuous genus represented in deep-sea trawls. Observations using ROV cameras of large specimens treading water or 'swimming' support the probability that distribution is assisted by slow-moving deep-sea currents whilst suspended in the water column. The most abundant species in this collection with 29 specimens is *Colossendeis tasmanica* recorded from 999 to 2939 m depth. This species is readily confused with *C. colossea* but differences are well supported morphologically and by (unpublished) molecular data. *Colossendeis tasmanica* is well represented in the GAB and probably in the NORFANZ collections as *C. colossea*. *Colossendeis colossea* is a pan-oceanic species recorded at depths of 420–5200 m worldwide and because of their similarities it is most likely that geographic and bathymetric records of the two species are confused.

A notable record in this collection is that of *Ascorhynchus cooki*. This species is one of seven rarely recorded 'giant' species in the genus. Nine specimens were collected from seven sites at depths 2336–2821 m. This species has been collected previously from sites SW of Macquarie I., N of Chatham Rise and SE of Cook Strait at depths of 1463–2992 m. It was also collected on an RV *Investigator* trial voyage south of Tasmania at 2750 m depth. It is likely that these specimens will enable the synonymy of this species with another, predominantly North Atlantic Ocean species, and if this is correct it will broaden the distribution considerably from the US east coast and the west coast of Africa. Shallow-water specimens of *Ascorhynchus* have been observed burrowing into the sand and it is suspected that grain size plays a part in their distribution. Based on morphological characteristics it can be assumed that a similar partial interstitial existence is shared by deep-water forms such as *A. cooki*. This species is also represented in GAB collections. Nine post-larval specimens found attached to feeding tentacles of the benthopelagic holothuroid *Psychropotes* are suspected to be this species. These specimens represent more than one stage of development but

the most mature forms are beginning to develop characteristics of *A. cooki* and are suspected to be this species. Hitching a ride on a benthic-pelagic holothuroid not only broadens the spread of the species gene pool but assists settlement on fine sediments which accommodate both the feeding of the holothuroid and the burrowing of the pycnogonid. Presumably the fine sediments also support the food source of the adult pycnogonid. The holothuroid was collected by beam trawl at Jervis MP at 2636 m depth.

The record of *Nymphon trituberculatum* is only the second for this species and the first female specimen. The type locality for this species is recorded as the 'Great Australian Bight' but the coordinates given for this station (Eltanin 20–134, 59° 48' S, 144° 45' E, 3200–3259 m) are on the Southeast Indian Ridge. The finding of this species along Australian eastern coast raises the possibility that the incorrect Eltanin station data has been assigned to the type locality.

Bivalvia

H. MacIntosh

The bivalve fauna consisted of 218 lots with a total of 1563 specimens, comprising 21 families, 33 genera and 59 species. All families and genera of bivalves collected were known from bathyal to abyssal environments, and overall patterns of abundance and diversity match reported trends from other deep sea regions (Knudsen 1970; Allen 2008; Kamenev 2017). While there are few deep water collections from eastern Australian to make reference to, affinities could be seen with the deep-sea bivalve fauna of neighbouring regions. The southern operations (South of Newcastle) showed considerable overlap with bivalves from the deep Great Australian Bight (MacIntosh et al. 2018). North of Newcastle and into the Coral Sea, the fauna resembled that collected in the waters around New Caledonia (Dijkstra 1994; Poutiers and Bernard 1995).

Almost half of the specimens recovered ($n = 718$, 46%) were from three common, near-cosmopolitan deep-sea species: *Bentharca asperula* (Arcidae, $n = 147$), *Propeamussium meridionale* (Propeamussiidae, $n = 226$) and *Abra profundorum* (Semelidae, $n = 345$). These three species were found in small numbers across multiple sites, but occasionally occurred in high abundances: *B. asperula* $n = 103$ in trawl 102, *P. meridionale* $n = 153$ in trawl 053 and *A. profundorum* $n = 136$ in trawl 065. Most other species were rare or sparsely distributed, with over a quarter of species ($n = 16$, 27%) known only from single specimens; almost half ($n = 25$, 42%) were found only at single sites.

It is interesting to note these three species all exemplify adaptations of suspension-feeding bivalves to deep-sea conditions, where plankton is scarce. *Abra*

profundorum is primarily a deposit feeder and employs its ctenidia for particle sorting (Allen and Sanders 1966). *Propeamussium meridionale* retains filamentous gills but has secondarily evolved carnivorous feeding, closing its valves on small prey items (Morton and Thurston 1989). *Bentharca asperula* remains a suspension feeder and instead shows adaptations to cope with the paucity of food, including enlarging the ctenidia and lowering metabolic rates (Oliver and Allen 1980).

The Protobranchia are primitive bivalves characterised by simple ctenidia and the presence of palps for deposit-feeding. This mode of feeding is well suited to deep-sea soft sediments and protobranchs are often the dominant bivalve fauna in abyssal environments (Allen 1979). Here 16 species of protobranchs were recorded, including representatives of the Sareptidae, Siliculidae and Yoldiidae, poorly known in Australian waters. Significantly more protobranch species were recovered in this survey compared to surveys in southern Australia (MacIntosh et al. 2018), likely due to the use of Brenke sleds here, which captured more small infauna than beam trawls.

Carnivory is also common in deep-sea bivalves. In 'septibranch' bivalves, the gill filaments are fused into a single muscular septum. This diaphragm-like structure, coupled with a large, sensitive inhalant siphon allows septibranchs to rapidly inhale prey like small crustaceans and larvae (Morton 1981, 1987). Notable septibranchs recovered include the spectacularly sculptured *Spinosipectella costeminens* (Verticordiidae) an unknown species of *Halonympha* (Halonymphidae), and two species of *Cetoconcha* (Cetoconchidae). These latter two genera have been previously split from larger families (Cuspidariidae and Poromyidae respectively) on the basis of small morphological characters, and fresh genetic material collected here may allow testing the monophyly of these groupings.

The beam trawls and brenke sleds targeted soft sediment substrates, but in several operations wood and whale bone were serendipitously recovered. These organic falls serve as islands amongst the ooze and host their own unique deep-sea fauna (Smith et al. 2015). Associated with whale and fish bones, two species of bathymodioline mussels in the genus *Idas* sp. could be separated on the basis of shell morphology and internal musculature. Identifications of these are tentative, however, as the taxonomy of the Bathymodiolinae is in a state of flux, with genetic studies revealing many cryptic species (Lorion et al. 2010; Thubaut et al. 2013).

Woody debris was recovered at several sites, hosting three species of Xylophagidae. These bivalves are obligate wood-borers, the deep sea counterpart of the shallow-water Teredinidae, or "shipworms". Both burrow into wood with specially-modified shell valves and derive nutrition from with the aid of symbiotic, cellulose-

digesting bacteria (Knudsen 1961; Distel et al. 2011). Like many deep-water taxa, the diversity of Xylophagidae in Australian waters remains largely unknown.

Gastropoda

F. Köhler, F. Criscione & A. Hallan

In all, 291 lots of Gastropoda were retrieved from the sampled bathyal to abyssal environments along the eastern Australian coast, containing 963 individuals. Altogether, these lots represented 136 species or morphologically distinguishable OTUs from at least 88 genera and 45 families. Only 15 species have so far been assigned an available taxonomic name. One species, *Bouchetispira ponderi*, has been formally described from this survey in the previously monotypic family Bouchetispiridae (Hallan et al. 2020). While many other OTUs have remained tentatively identified to genus- or species level, there is no doubt that several of these yet unidentified OTUs will eventually be assigned with an available species name pending further consultation with experts for various gastropod groups. Nonetheless, a significant proportion of the sampled gastropod fauna is considered to be new to science. For example, we consider the vast majority of the 44 OTUs in the family Raphitomidae (Neogastropoda: Conoidea) as undescribed. With regards to the numbers of collected individuals, the most abundant species were representatives of the families Abyssochrysidae, Eucylichidae, Mangeliidae, Philinidae and Turritellidae. The systematically most diverse family is the Raphitomidae (Conoidea), accounting for nearly one third of all gastropod species.

Our identifications have revealed high rates of bathymetric turnover with little overlap between species present at different depths. We have distinguished 27 species/OTUs among samples collected at about 1000 m, 79 at about 2500 m, and 40 at about 4000–4800 m depth. Among these, fewer than 20 species have been collected in more than one depth layer. The highest species diversity was generally recorded at mid- to lower bathyal depths of around 2500 m. Here, we also observed a noticeable decrease in the sampled species diversity along a south-to-north gradient.

The bathyal and abyssal gastropod fauna of Australia has remained poorly documented and few deep water collections are available for a faunal comparison. We recorded some overlap with the fauna of the Great Australian Bight as reported by MacIntosh et al. (2018) particularly at the southernmost sampling sites. Several species have been recorded from both areas, the eastern Australian Abyss and the Great Australian Bight, such as *Bathytoma agnata* (Borsoiniidae), *Oocorys sulcata* (Cassidae), *Calliotropis carinata* and *C. canaliculata* (Eucyclidae), *Enixotrophon carduelis* (Muricidae), *Tritia ephamilla* (Nassariidae),

and *Globiscala cf. boaespei* (Epitoniidae). In addition, nine putatively undescribed species retrieved from the eastern Australian abyss were also reported from the Great Australian Bight. Of these, four belong to the Conoidea, the by far most diverse gastropod superfamily. However, for the majority of species/OTUs, no overlap has been recorded between the eastern Australian abyss and the Great Australian Bight. This observation may be indicative of considerable regional endemism in the gastropod fauna of the Australian deep sea.

The gastropods sampled during the eastern Australian voyage of the RV *Investigator* represent altogether six ecological feeding guilds, with predators comprising the vast majority of species, largely belonging to the order Neogastropoda. In addition, deposit-feeders, grazers and parasites were each about equally represented in terms of species numbers, while suspension feeders (Calliostomatidae and Turritellidae) and scavengers (Nassariidae) were the least diverse guilds (four species overall).

The majority of samples and species were collected by beam trawls while the Brenke sledge sampled comparatively few gastropods of small size, which would otherwise slip through the mesh of the beam trawl. Because of the overall low numbers of smaller gastropods in the size range of under 10 mm, we consider the smaller-sized gastropod fauna as under-sampled owing to the specific limitations of the deployed collecting gear.

General patterns of diversity as here described for the gastropods of the eastern Australian abyss are consistent with faunal patterns described for other regions of the world. A high proportion of undescribed species-level diversity has also been recorded in deep-sea surveys in New Caledonia (Bouchet et al. 2008). Similarly, conoideans are frequently found to dominate marine gastropod faunas from the intertidal to abyssal depths, including the deep-sea in New Caledonia (Bouchet et al. 2008).

The observed turnover in species composition across depth layers has also been observed for other gastropod faunas. For the northern Atlantic, a three-layered faunal composition has traditionally been described consisting of a shelf fauna (to about 300 m depth), a slope to bathyal fauna (to about 2500 m depth), and an abyssal fauna (extending to about 6000 m depth). However, in tropical waters a more frequent turnover between faunal assemblages at additional depth layers between about 200 and 1500 m depth has been reported (Bouchet et al. 2008).

Some notable differences have been observed in comparison with the gastropod fauna of the Southern Ocean where a steep decrease in species diversity has been reported with increasing depth (Brandt et al. 2009). Brandt et al. (2009) reported that species numbers dropped to around 20 species at depths below

1200 m, whereas we recorded significantly higher cumulative species numbers at depths of 2500 m and even 4000 m across the eastern Australian continental margin.

Cephalopoda

J. K. Finn & C. C. Lu

A total of 15 cephalopod specimens were collected in beam trawls over the course of this survey. These specimens represent 4 families and at least 6 species. While the total number of cephalopods collected is quite low, this survey increased the known distribution of multiple species and included at least one new record for Australia.

The majority of specimens collected during this survey were deep-water cirrate octopods, family Opisthoteuthidae. Six specimens of *Opisthoteuthis pluto*, were collected at operations 022, 080, 100 and 121. While previously reported to occupy a distribution including the continental slope waters from the Great Barrier Reef to Tasmania (Lu and Dunning 1998), this survey increased the known maximum depth for this primarily benthic species from 1254 m (Lu and Dunning 1998) to at least 2692 m.

Among the cirrate octopods, the most well-known are the Dumbo Octopuses (genus *Grimpot euthis*), nicknamed on account of their large fins, and deemed by some to resemble the ears of Disney's Dumbo the Flying Elephant. This survey provided the first record of *Grimpot euthis* from Australian waters. Two specimens of *Grimpot euthis* were collected at operations 035 and 044. Both specimens were found to be consistent with *Grimpot euthis abyssicola*, described from a single specimen collected at 3180–3154 m on the adjacent slope (35°35.1'S 160°57.1'E) (O'Shea 1999).

The next most numerous taxa collected during this survey were the deep-water incirrate octopuses, *Muusoctopus* spp. (family Enteroteuthidae). Four specimens of *Muusoctopus* spp. were collected at operations 004 (2820–2751 m), 080 (1257–1194 m) and 100 (999–1013 m), including a large specimen with a mantle length of approximately 180 mm. Historically these octopuses have been treated under the invalid name *Benthoctopus* (e.g. Lu 2001). Gleadall et al. (2010) proposed *Muusoctopus* as a replacement name. The specimens collected during this survey will be invaluable to a much-needed review of the deep-water octopods of Australian waters.

Single representatives of two oegopsid squid species (family Mastigoteuthidae) were collected in beam trawls during this survey.

Mastigoteuthis psychrophila is a deep-water mesobathypelagic squid distributed circumpolarly throughout the Antarctic (Nesis 1977). A single specimen of *Mastigoteuthis psychrophila* was collected in a beam trawl in the Freycinet CMR off eastern Tasmania (operation

004). This specimen represents the most northerly confirmed record of this species, and potentially the deepest. On reporting the catches of the *Dmitry Mendeleev* in subantarctic and Antarctic waters, Nesis (1977) noted that, while the depth of *M. psychrophila* varied with latitude, the species occupied water with consistent hydrological conditions. While in the south specimens were collected at 500 m, and in the north at 1500 m, all specimens were encountered in water with a temperature approximately 2.1 °C, salinity approximately 34.7‰ and an oxygen content of about 5 ml/l. The beam trawl specimen collected during this survey appears to be consistent with this latitude/depth trend, being encountered both further north and deeper than the material reported by Nesis (1977). While some doubt exists as to the actual collection depth of this specimen (as it was collected in an open beam trawl and hence may have been caught while the gear was descending or ascending), interestingly the hydrological conditions of the operation closely match those reported by Nesis (1977) as suitable for this species: temperature 1.8 °C, salinity 34.7‰, oxygen 4.3 ml/l. While not officially detailed in this report, an additional specimen of *M. psychrophila* was collected in a demersal fish trawl in the early stages of this survey (41°37.608'S, 149°8.958'E; NMV F245709). The northerly locations of these records are consistent with catches at similar latitudes in New Zealand (Braid and Bolstad 2015) and the suspicion that *M. psychrophila* may exist to approximately 40°S in the Atlantic (Young 2017).

The second mastigoteuthid squid collected during this survey was an *Idioteuthis cordiformis*. While previously reported from the survey region (Lu 2001) and sampled depth (Roper and Jereb 2010), the most notable aspect of this specimen (in relation to the survey) is its size. With a mantle length of 270 mm, this specimen is the largest squid collected during this survey. *Idioteuthis cordiformis* is however reported to be the largest of all mastigoteuthid squids, attaining mantle lengths to 1000 mm (Young 2017).

During this survey a single sepiolid of the genus *Heteroteuthis* was collected. While eastern Australian records have historically been referred to as *Heteroteuthis serventyi* (e.g. (Lu 2001)), and more recently *H. dagamensis* (see Vecchione et al. 2013), a recent report of *H. hawaiiensis* from southern Australia (MacIntosh et al. 2018) highlights the need for a thorough review of this genus from Australian water. It is anticipated that the collected specimen will aid this review.

Crinoidea

M. Eléaume

In total 498 specimens of crinoid were collected during the 2017 expedition. One deployment only accounted

for 402 specimens. Other deployments yielded from 1 to 20 specimens. These specimens represented at least 7 different species for which only tentative identifications are given: *Adelatelecrinus* cf. *vallatus*, *Bathycrinus* cf. *australocrucis*, *Democrinus* cf. *japonicus*, *Monachocrinus* cf. *aotearoa*, *Pentametrocrinus* cf. *semperi*, *Thalassometra* cf. *gracilis* and an unidentified representative of the feather star family Antedonidae.

Most of these species were collected in small numbers except *Thalassometra* and *Democrinus*. Both were collected in large numbers during operation 069, and this station may represent the optimal habitat for these two species. *Adelatelecrinus*, *Pentametrocrinus* and *Democrinus* were all restricted to depths from 1000 to 2000. *Thalassometra* was collected mainly from depths around 1000 with some occurrences to 2500 m (Operation 086). *Monachocrinus* was collected at depths exceeding 2500 m and also at depths around 4000 m. Some Bourguetiacrinina occurrences, collected at intermediate depths once attributed to a species may help bridge this gap. *Adelatelecrinus*, *Pentametrocrinus*, *Democrinus*, *Thalassometra* and unidentified Antedonidae, were collected from the two northernmost explored ecoregions Manning-Hawkesbury and Tweed-Moreton. *Pentametrocrinus* and *Bathycrinus* are restricted to Tweed-Moreton and *Monachocrinus* occurred from Bassian to Manning-Hawkesbury.

The crinoids from the eastern coast of Australia display bathymetric and geographic contrasted distributions. More detailed taxonomic resolution is needed to help understand the biogeographic implication of these preliminary results.

Asteroidea

C. Mah

Surveys of Bathyal and Abyssal regions in Eastern Australia yielded a total of over 52 species of sea stars (Asteroidea) including at least six undescribed species. Nearly all of the identified species were new occurrences for the Australian region.

At least one specimen of an undescribed species of *Evoplosoma* was collected. Based on in situ observations by Mah (Mah 2015a, b) *Evoplosoma* has been regularly observed feeding on deep-sea octocorals, particularly those which form large deep-sea “forests” such as the “bamboo” corals (family Isididae), suggesting that these coral habitats occur off the Australian coast.

Among the rarest of the sea stars collected were new occurrences of the velatidans *Pythonaster* and two individuals of *Myxaster*, both in the family Myxasteridae. Both of these genera occur at great depth (> 2000 m and > 1000 m respectively) and are among the most seldom encountered of deep-sea asteroids (Mah et al. 2012). Fewer than 2 dozen specimens of either genus are

known from museum collections. These are the first occurrence records of these mysterious animals from Australian waters.

Multiple occurrences of different “slime stars” in the genus *Hymenaster* and the related genus *Calyptraster* were collected. New discoveries showing gut contents of these taxa from the Great Australian Bight suggest deposit feeding or predation on molluscs present in both genera. *Hymenaster* contains numerous species, some of which occur widely throughout the world but it is likely that several new species occur in Australian waters but taxonomic difficulties must be addressed before this work can progress.

At least three deep-water freyellid sea stars were collected, including *Astrocles*, *Freyella* and *Freyastera*. Freyellids are members of the Brisingida, unusual asteroids which extend their multiple, elongate arms into the water column and capture food as it is caught by pedicellariae present on needle-like arm spines. Of the three genera collected, *Astrocles* represents a likely new species, and the first occurrence of this genus from the Southern Hemisphere.

Of the total number of species recorded, several of them are members of families which occur or have been observed on soft sediment, including the Astropectinidae, the Porcellanasteridae, and to a lesser extent the Zoroasteridae and the Benthoplectinidae. These groups are widely different from one another, but have adaptations which permit them to exploit soft-bottom settings in different ways. Porcellanasterids for example, occur on abyssal plains and exploit finer mud than astropectinids which occupy a broad range of habitats and different sedimentary settings.

Ophiuroidea

T.D. O'Hara

The ophiuroid fauna consisted of 78 species, 296 species-sample lots, and 9192 specimens. The abyssal fauna (> 3500 m) is very similar to that described for the North Atlantic Ocean (Paterson 1985) including the species: *Ophiosphalma armigerum*, *Perlophiura profundissima*, *Amphiophiura bullata*, *Ophiura irrorata*, *Ophiacantha cosmica*, *Ophiotya simplex* and *Amphiura daleus/verrilli*. Most of these species have been recorded across the Atlantic, Pacific and Indian oceans, although this needs to be confirmed by genetic data. One exception is *Ophiosphalma armigerum* which occurs throughout the Atlantic and across the Indian Ocean to southern Australia (as far as Hunter MP), but is replaced in the tropical west Pacific by *O. fimbriatum* and *O. glabrum*.

There was a clear temperate-tropical transition at mid bathyal depths. Temperate species included *Astrodia tenuispina*, *Ophiura spinicantha*, *Ophiocten australis*, *Ophiuroglypha verrucosa*, *Ophioplinthus accommodata*,

Ophiocamax applicatus, *Ophiacantha sollicita*, *Ophier-nus vallincola*, *Amphilepis neozelandica*, and *Ophaictis amator*. Many of these animals have been found previously in the Great Australian Bight and off New Zealand. *Ophiocten australis* occurred in huge numbers at some operations (e.g. $n = 1685$ in beam trawl 022 and $n = 519$ in sample 056). The northern group included *Amphio-phiura sculptilis*, *A. ornata*, *A. paraconcava*, *Ophiomu-sium granosum*, *Ophiosphalma fimbriatum* and *O. coricosum*. These are all typical animals found by French surveys around New Caledonia. *Amphiophiura paracon-cava* was often abundant ($n = 396$ from sample 115 and $n = 1308$ from 128).

The widespread carnivore *Ophiura flagellata* was numerous ($n = 49$) in the sample (080) with rotting mantra shark, but also in sample 104 ($n = 62$) which did not contain an obvious carcass. A few specimens represented interesting extensions of geographic range. *Amphio-phiura inops* (sample 070) is otherwise known only from the Antarctic. *Ophiotoma paucispina* was previous known only from a few specimens collected by the Alba-tross in the tropical eastern Pacific (1891–1904). One specimen collected from the abyss off Newcastle (sample 067) has been confirmed by multi-locus DNA data to be a new genus within the Ophiotomidae.

Echinoidea

A. Miskelly

Eleven species of echinoid were identified, with most being new records for Australia. Of particular interest is the first record for an aeropsid spatangoid in Australian waters, *Aeropsis* sp., collected from 2600 to 2746 m. It is perhaps the most elongate and laterally compressed of all spatangoids (heart urchins), and is different to all other spatangoids in the position of the periproct (anal area) on the aboral (upper) surface. As is the case with deep water irregular echinoids, this species does not resemble their shallow water relatives. *Brissopsis oldhami*, known previously from New Zealand, also is a new record. Records from off Bass Strait indicate similar depths to *Aeropsis*. It has the more typical spatangoid form.

The schizasterid *Aceste ovata* is a widespread, highly specialised non-petaloid spatangoid that was collected from around 4000 m depth off Bass Strait. It displays a peculiar deep anterior notch, infused with dense funnel-building tube feet that construct a channel for moving seawater over the aboral surface for respiration. Previously it was only known from Australia by one record off Portland, Victoria at 1087 m.

One species each of *Aspidodiadema* and *Caenopedina* were recorded, but, due to their small size and condition, were not able to be identified to species level. Both genera are widespread throughout the Indo-Pacific, so their presence was not unexpected. The saleniid,

Salenocidaris hastigera, recorded from off Byron Bay NSW, Newcastle NSW, and Fraser Island, Qld at depths ranging from 1000 m to 2900 m, while not new for Australia, was previously known only from off Norfolk Island. It is widespread throughout the Indo-Pacific region.

Notocidaris bakeri, the only cidarid species recorded, was previously collected around New Zealand.

Echinothuriids were represented each by one species of *Tromikosoma*, *Hygrosoma*, and *Sperosoma*.

Typically, these fragile echinoids tend to fracture easily when sampled from deep water, losing spines and pedicellariae. It is possible that they are known also from off New Zealand. The temnopleurid *Prionechinus sagittiger* was an exciting discovery. This species was collection by the *Challenger* expedition from off Papua New Guinea at depths of 1990 m (Agassiz 1881) but little is known about its biology.

Holothuroidea

P.M. O'Loughlin, M. Mackenzie & T.D. O'Hara

The bathyal and abyssal fauna found off eastern Australia was similar at the genus-level to that found in many similar habitats elsewhere in the Pacific and Atlantic Oceans (Billet 1991). In this study, the peak of diversity was at mid to lower bathyal depths (1500–3000 m) again similar to that found elsewhere (Billet 1991). More than 41 taxa were identified to species-level, including more than 12 potentially new species in the genera *Pso-lus*, *Peniagone*, *Ellipinion*, *Molpadiodemas* (numerous), *Benthodytes* ($\times 2$), *Paroriza*, *Gephyrothuria*, *Molpadia* ($\times 4$), *Protankyra*, *Prototrochus* and *Myriotrochus*. However, several other identifications were tentative. Cryptic species-complexes with wide distributions are known to be common amongst echinoderms and future revisions based both on molecular and morphological data may well distinguish Australian species from those living in other oceans. Conversely, deep-sea holothurian phylo-geographies published to date have found complexes of species with overlapping geographic and bathymetric distributions (Ross 2012; Gubili et al. 2017).

The mid to lower bathyal fauna includes taxa from all seven recognised holothuroid orders (Miller et al. 2017), although in terms of abundance, the orders the Elasi-poda (particularly *Amperima furcata* and *Benthodytes* sp. nov 1) and Persiculida (*Pseudostichopus peripatus* and *Molpadiodemas* spp) dominated. The abyssal fauna (> 3500 m) was generally a subset of the lower bathyal fauna, with the addition of the unusual U-shaped in-faunal species *Ypsilothuria bitentaculata*. The upper bathyal (< 1500 m) fauna was also a subset of the lower bathyal fauna with the addition of *Orphnurgus insignis* and an undetermined *Benthodytes*.

Several species found in the survey are widespread and their biology has been studied in more detail elsewhere. *Enypniastes eximia* (sometimes known irreverently as the 'headless chicken'), a pelagic elasipod that only descends to the seabed to feed (Miller and Pawson 1990), was opportunistically collected in beam trawl 080 at 1225 m in the Central Eastern MP. Some of the holothurians in the family Elpidiidae are also likely to be able to swim, at least for short periods (Rogacheva et al. 2013). *Scotoplanes globosa* (the sea pig), collected at 2785 m in the Freycinet MP, forms vast herds on oceanic abyssal plains and has been called the most common megafaunal animal on the planet (Rowe et al. 2017). *Psychropotes longicauda*, a large purple species with a prominent sail-like dorsal appendage of unknown function, is known to be a cryptic species complex (Gubili et al. 2017). It has one of the largest eggs of any echinoderm (up to 4.4 mm in diameter) and appears as if it can metamorphose directly into juveniles in the plankton, having been found thousands of meters above the seafloor (Billet and Huggett 1987). The majority of the epifaunal and bathypelagic species are likely to be deposit feeders. *Oneirophanta mutabilis*, another species complex (Ross 2012), has been reported to continuously feed and excrete like a "conveyor belt" (Moore and Roberts 1994). It has been estimated to bioturbate up to one third of the seafloor where it is common (Witbaard et al. 2001). In many locations only females have been found, suggesting it is parthenogenetic or that males become fertile only under certain conditions (Ramirez-Llodra et al. 2005). Numerous animals that live buried in the sediment (infauna) were also collected, from the tiny *Protankyra* and *Echinocucumis* to the large *Molpadia*. The 'skin-digging' tanaid *Exspina typica* was found in the coelomic cavity of two *Pseudostichopus peripatus* specimens collected from Freycinet CMR at 2820 to 2751 m. This is the first record of *E. typica* parasitising this particular species of holothuroid, however it has previously been observed in the intestine and body cavity of other holothuroid hosts, and an association between this parasitism and deep-water environments was confirmed by Alvaro et al. (2011).

Tunicata

M. Ekins

From the 100 tunicates collected during the IN2017_V03 expedition, there were only six different species from four different families and five genera. All species collected from this voyage have previously been collected in abyssal trawls from Antarctica, Australia, the Indian and Pacific Oceans. There is only one potential new species from this expedition, *Protocholozoa* cf. *anthos* but, unfortunately it was damaged during collection and the description of a new species will have to

wait until another specimen is recovered. *Asjirus indicus* was the most commonly collected ascidian, collected from Victoria up to the Coral Sea, from 1000 to 4000 m in depth. This is a species with a worldwide deep water distribution. *Culeolus anonymus* was the second most commonly collected ascidian, also collected from Victoria to off Fraser Island, Queensland. This species has been recorded from subantarctic to Antarctic waters in the Pacific and Atlantic Oceans previously. The other species recorded on this voyage include *Culeolus recumbens*, *Pharyngodictyon mirabile* and *Dicarpa lata*. There were also recorded on this voyage salps *Metcalfina hexagona* and *Thetys vagina* as well as the ubiquitous *Pyrosoma atlanticum*.

Monniot and Monniot (2003) have previously conducted extensive abyssal tunicate work in the Pacific concentrating mainly around New Caledonia and Kott (1969, 1971) has studied the deep water Antarctica ascidians. The abyssal fauna collected on this expedition is very similar to abyssal fauna from the Antarctic and deep tropical waters, showing an obvious connection via the deep cold waters. The Tasman Sea and Australia, including the Coral Sea and Great Australian Bight, were surveyed by RV *Dmitry Mendeleev* during 1975–1976. The ascidians collected during that expedition were described in Sanamyan and Sanamyan (1999).

Pisces

M. F. Gomon, J. J. Pogonoski, D. J. Bray, A. Graham

The RV Investigator IN2017_V03 Abyssal Survey was Australia's first attempt to systematically sample the abyssal benthic communities of a segment of the eastern Australian coastline bordering the continent. Although occasional collections had been previously made at similar depths in Australian waters, those efforts were for the most part one-off serendipitous shots at random localities undertaken during projects with quite different goals (Tanner et al. 2018; Williams et al. 2018b). Some in fact were part of worldwide sampling efforts, like collections of the *Challenger* expedition undertaken in the mid-1800s, which meant vast distances between trawls to cover such a wide geographic area (Günther 1887).

Consequently, little is known about the diversity and distribution of abyssal species in Australian waters and how it compares with this interconnected environment around the world. The initial perception of fish species taken in the recent dedicated survey supported the wide held view that abyssal diversity is low and those present are widely distributed in the world oceans. Although a majority of the species encountered during this abyssal project had been previously collected, a significant number represent new records for Australia's Exclusive Economic Zone.

Although the survey targeted depths of 2500 and 4000 m, the nature of the bottom topography encountered necessitated sampling shallower or deeper on some transects, which meant the overall catch composition included deep slope as well as abyssal and pelagic species, the latter taken in the course of shooting and retrieving non-opening and closing sampling gear. Of the more than 100 fish species collected, a little over two-thirds were bottom associated demersal species, with the remaining third pelagic forms, represented by both adults and/or early life stages, the latter in some cases of inshore species. About half of the bottom living species taken were abyssal with the other half confined to the lower parts of the continental slope. The catch included one carcass, the remains of a greatly deteriorated manta ray *Mobula birostris* with a pelvis almost a metre across.

At least seven of the 33 or more abyssal species (21%) collected are confirmed first records for Australia's EEZ with a similar number still awaiting definitive identifications. The new records include *Typhlonus nasus*, *Chaunacops coloratus*, *Acanthonus armatus*, *Lycenchelys antarctica* and the three cuskeels – *Paraphyonus bolini*, *P. rassi* and *Sciadonus pedicellaris* noted in Nielsen et al. (2019). Virtually all of these species have extensive geographical distributions, and despite their obvious limited mobility, some, like the colourless, live-bearing, virtually, if not completely blind gelatinous cusk-eels, likely remain close to “home” their entire lives. An ophidiiform group comprising the live-bearing family Bythitidae and the egg laying Ophidiidae, is one of two dominant evolutionary lines in the deepest parts of our oceans worldwide. The latter includes *Typhlonus nasus*, dubbed the “Faceless Fish” by a member of the fish team for its lack of discernible eyes, eye-like nostrils and underslung mouth, which initially masked its family relationships. In the end, it and the four other examples collected were found to be a species that was originally described from the Coral Sea just outside Australia's EEZ 140 years ago, but is only now verified as occurring in Australian waters. Examples of this ophidiiform group also included the massive *Spectrunculus grandis*, initially described from Japanese waters a year before the previous species, and reaching well over a metre in length. Both are widely distributed in Indian and Pacific oceans. Although the two examples reach quite a large size, many species occurring at these depths tend to be rather small, rarely exceeding 10–20 cm in length. The aphyonid-clade of cusk eels collected by the expedition was reviewed by Nielsen et al. (2019) who recognised five distinct species around Australia.

Another particularly diverse group at abyssal depths is the order Aulopiformes, ranging from the ferocious looking deepsea lizardfishes *Bathysaurus ferox* (family Bathysauridae), their extensive gape so full of needle-like

teeth that they spill out onto the sides of the jaws, to the stilt-perched tripodfishes (family Ipnopidae) that await patiently on their prolonged fin rays for meals to come to them. The latter family was represented in the survey by eight long-finned species and three bottom huggers, including the odd looking Spiderfish of the genus *Ipnops* with large yellowish luminous oval plates where eyes should be and a second Australian specimen of the Shortarse Feelerfish *Bathymicrops brevianalis*. The species identity of the *Ipnops* remains in question, as the DNA of several specimens analysed (Coral Sea) differs from that of specimens collected in the Great Australian Bight. The tripodfishes represented comprised a significant proportion of the total number of species known to occur in the Indian and Pacific Oceans (Sulak 1977).

From a biomass perspective, members of the Basketwork Eel family Synaphobranchidae were important with seven species taken during the survey and the Southern Cut-throat Eel, *Histiobranchus australis*, which attains a length of about 70 cm, present at almost all of the 2500 m collection sites from Tasmania to the Coral Sea, demonstrating its dominance in this environment. Prior to recent deep-water sampling made possible by the RV *Investigator's* increased capability, this species was known in Australia from one or two specimens collected during international exploration. So, an apparently rare species is now seemingly common with over 30 specimens known from Australia. Basketwork eels are among the most numerous and often collected of the deep benthic fishes worldwide where they feed indiscriminately on available prey.

The brilliant red-orange Red Coffinfish *Chaunacops coloratus*, previously known only from the northern Pacific and eastern Indian Oceans, is one of the deepest dwelling members of a particularly deep, bottom living family of anglerfishes. Underwater videos taken in the Pacific show this species to puff up by inhaling water in an attempt to intimidate predators before “beating feet” when the ploy doesn't work. Other members of this family are generally confined to the continental slopes of the world.

Some shallow dwelling families of the temperate Northern Pacific, like the scorpionfish relatives the Snailfishes (family Liparidae) and the Eelpouts (family Zoarcidae) are absent in the shallows of the Southern Hemisphere, but do have examples in the southern deep-sea. For the most part these species dwell on the slopes of seamounts above the abyssal plain, but a specimen of the eelpout genus *Lycenchelys antarctica* was represented by a single specimen that is the first record for continental Australia. This is, as the name implies, an Antarctic species, which may have been a vagrant carried northwards by north flowing Antarctic Bottom Water that supplies abyssal waters of the world.

The expedition provided a significant glimpse of Australian ichthyo-diversity at these depths. The results show a similarity with that of other parts of the lower bathyal and abyss in world oceans.

Discussion

The IN2017_V03 expedition of Australia's premier research vessel *Investigator* was the first to systematically sample lower bathyal to abyssal habitats (2000–5000 m) in Australia's Exclusive Economic Zone. It traversed seven newly declared marine parks in Commonwealth waters off the eastern margin of Australia from 15th May to 16th June 2017, including Freycinet, Flinders, East Gippsland, Jervis, Hunter, Central Eastern and Coral Sea Marine Parks. The voyage mapped much of the deeper water habitats of these parks using high resolution multi-beam data and systematically sampled the benthic habitats, principally using video transects, small beam trawls and epibenthic sleds. Importantly, the survey traversed both areas of high primary productivity at temperate latitudes near Tasmania and more oligotrophic areas of the northern Tasman Sea.

The current paper does not include all the smaller crustaceans (e.g. ostracods, amphipods, tanaids) or groups like nematodes that were collected by the Brenke sled. These await further taxonomic examination. Indeed, the collections represent a valuable morphological and genetic resource for the continuing study of the Australian marine fauna. The survey also targeted soft-sediment habitats avoiding areas of exposed rock. Exposed rocky substrata were common at the base of the continental margin, where strong bottom currents clear sediment and produce "moats" at the edge of the abyssal plain. Other areas of rock occurred at bathyal depths on the sides of canyons and edges of escarpments (Keene et al. 2008). The fauna of these rocky areas is generally different from that on soft-sediment substrata, even at abyssal depths (e.g. Simon-Lledó et al. 2019).

Given the lack of previous knowledge, it is not surprising that over half of the fauna is new to science. The fact that 42% of the taxa could be assigned a species name is evidence of the widespread ranges of many bathyal and abyssal species. Many species, genera and even families have now been reported from Australian waters for the first time.

The relationships of the fauna are dependent on latitude. The species off SE Australia are shared with the southern Indian Ocean, the Southern Ocean or New Zealand. Some species extend as far as the North Atlantic Ocean. The fauna off NE Australia is typically distributed at similar depths across the tropical Indo-Pacific Oceans (approximately less than 30° latitude in both hemispheres). Emerging DNA evidence supports these patterns. For example, DNA evidence shows that the

abyssal ophiuroid *Ophiosphalma armigerum* occurs from the North Atlantic Ocean, around South Africa to the southern Tasman Sea. Whereas this species is replaced in tropical latitudes across the Indo-Pacific by the species *O. fimbriatum* and *O. glabrum*, the latter extending to the Clarion Clipperton Zone in the NE Pacific (Christodoulou et al. 2019). It is unclear what biogeographic processes could give rise to a temperate-tropical biogeographical transition at abyssal depths (O'Hara et al. 2020b).

Determining levels of endemism will have to await taxonomic revisions or phylogeographic studies of many deep-sea animal groups. Available evidence is too fragmentary for most species to establish distributional ranges with any certainty. Under-sampling is known to cause over-estimation of apparent endemism (Coddington et al. 2009). Nevertheless, some groups appear to exhibit elevated levels of regional differentiation around Australia. For example, only two sponge species were found to be shared between the lower bathyal and abyssal fauna off eastern Australia and that found in the Great Australian Bight off southern Australia.

It is difficult to compare the diversity of deep-sea communities across regions due to the great variability in collection gear and taxonomic coverage (Gray 2002). Fortunately, lower-bathyal and abyssal collections from the Great Australian Bight (GAB, 1700 km to the west of the IN2017_V03 sampling transect) have been collected using the same gear (beam trawl from the RV *Investigator*) and were identified by many of the same taxonomists that are co-authors of this paper (MacIntosh et al. 2018; Williams et al. 2018a). Using multivariate statistics, rarefaction and model-based ranked abundance distributions (RAD), we compared animal abundance and species richness between samples from the GAB to those from the south and north sectors of our voyage (O'Hara et al. 2020a). Samples with the highest standardised abundance and species richness were found at depths of 2500–3000 m off SE Australia. These samples are situated under a seasonal plankton bloom, and carbon flux to the seafloor was identified as the most important measured environmental variable driving the RAD models (O'Hara et al. 2020a). From this peak, abundance and richness decreased both with depth and distance, in both north and westerly directions (GAB region). These findings are congruent with the findings of a global study on ophiuroids by Woolley et al. (2016), who found that peaks of species richness at lower bathyal and abyssal depths occurred in temperate zones associated with peaks in surface productivity. This pattern differs from that in shallow water, which exhibits the well-known latitudinal decrease in richness from tropical to polar regions (Tittensor et al. 2010; Woolley et al. 2016).

The lower bathyal and abyssal (2000–5000 m) fauna of Australia is now known from the GAB and from off the eastern coast (O'Hara et al. 2020a). But many gaps remain in our knowledge of the seafloor fauna from Australia's Exclusive Economic Zone, the third largest of any nation. In particular, we have little to no information about the deep-sea fauna of the west coast, from off SW Western Australia to the Timor Trench. Other gaps include off Western Bass Strait, southern Tasmania, the Coral Sea Basin, and around most of Australia's offshore islands.

Conclusions

The lower bathyal and abyssal fauna of soft sediment seafloors off eastern Australia has been systematically surveyed for the first time. The result is a rich collection of invertebrates and fish that considerably improves the knowledge of the composition and distribution of southern hemisphere faunas from this depth range. Approximately 58% of the identified taxa could not be assigned to a described species. Many described species are recorded from the Tasman Sea for the first time. The resultant collections will provide the foundation for much future ecological, biogeographical, phylogenetic and taxonomic research.

Supplementary information

Supplementary information accompanies this paper at <https://doi.org/10.1186/s41200-020-00194-1>.

Additional file 1: Supplementary Table S1. Provisional list of taxa identified from the voyage IN2017_V03.

Acknowledgements

The authors wish to thank the CSIRO Marine National Facility (MNF) for its support in the form of sea time on RV *Investigator*, support personnel, scientific equipment and data management. All data and samples acquired on the voyage are made publicly available in accordance with MNF Policy. We also thank all the scientific staff and crew who participated in voyage IN2017_V03; participating taxonomists who chose not to join the list of authors, Lisa Goudie (sponges), Ella Lejune (sponges, Queensland Museum) and Candice Untiedt (octocorals, University of Tasmania); and voyage participants, Jérôme Malfet (Université Catholique de Louvain) and Robert Zugaro (MV), who contributed photos.

Authors' contributions

TOH, AW & NB designed the study and TOH & AW led the voyage. DB, MEK, MEI, CAF, MNG, AG, MG, KGH, FK, EK, MM, KM, JP, DS participated in the voyage. TOH co-ordinated the manuscript. TOH, STA, PA, TA, DB, IB, NB, FC, ALC, MEK, MEI, CAF, JFK, MNG, AG, MG, KGH, LMG, AH, AMH, PH, HK, FK, JK, EK, CCL, MM, CH, HM, KLM, AM, MLM, KM, AH, PMO, HP, JP, SD, JEW, RSW, JZ provided taxonomic identifications and biodiversity descriptions. The author(s) read and approved the final manuscript.

Funding

Project funding was provided by the Marine Biodiversity Hub, supported through the Australian Government's National Environmental Science Program (NESP). Funding bodies were not involved in the design of the study, the collection, analysis, and interpretation of data, or in the writing of the manuscript.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request. Specimens are lodged at participating Australian museums (Museums Victoria, Australian Museum, Queensland Museum and Tasmanian Museum and Art Gallery) and are available for study.

Ethics approval and consent to participate

The material was lawfully collected under the following permits: (1) Access to Biological Resources in a Commonwealth Area for Non-Commercial Purposes, AU-COM2017-352; (2) Approval for Activity in a Commonwealth Marine Reserve, CMR-17-000455; (3) Australian Fisheries Management Authority Scientific Permit, 100339 + 3; (4) Queensland Government General Fisheries Permit, 191670; (5) Museums Victoria Animal Ethics Committee approval, MV AEC 17001.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Received: 5 January 2020 Accepted: 24 August 2020

Published online: 18 September 2020

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