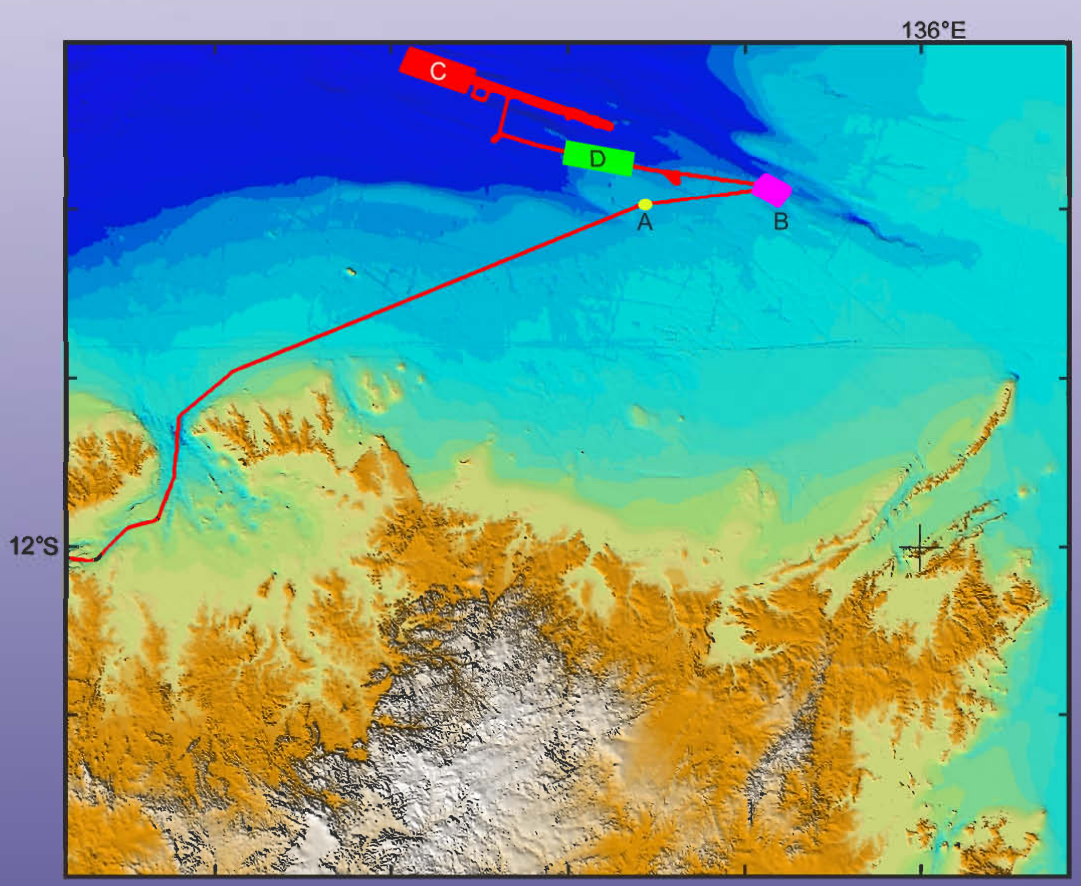
Biological Survey of the Arafura Sea

A National Oceans Office, Australian Museum, and CSIRO project



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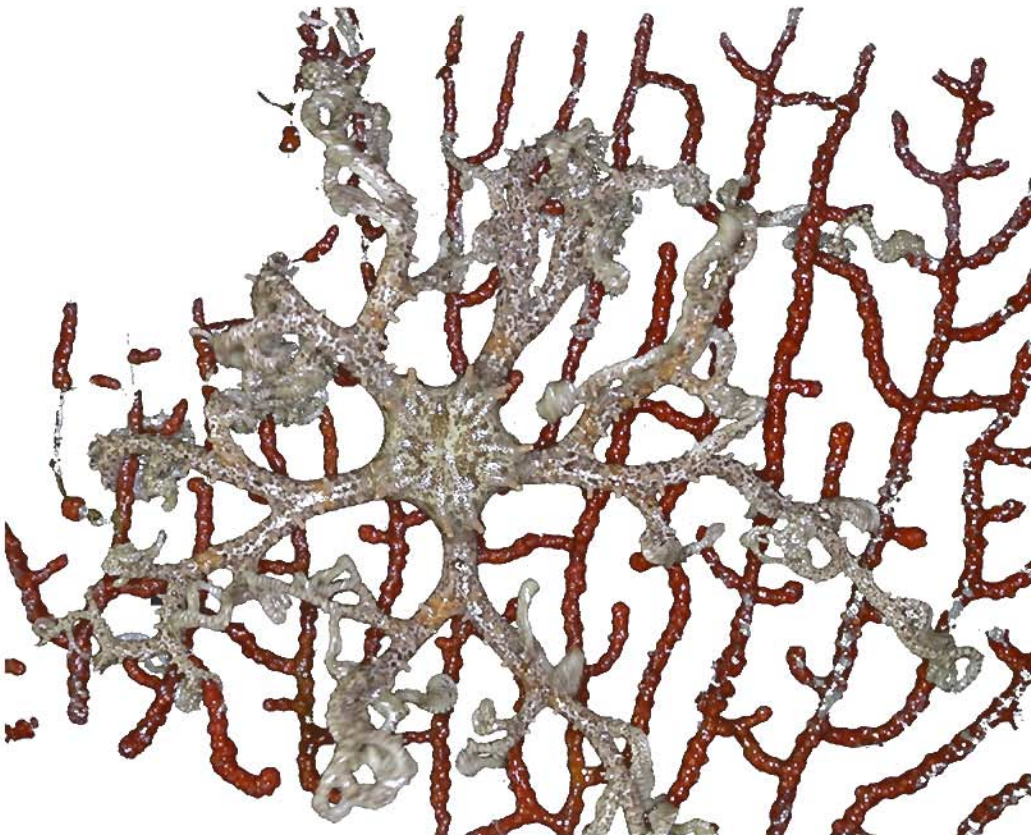

Arafura Sea Biological Survey[1]
Report on RV *Southern Surveyor* Expedition 05/2005
28 April - 28 May 2005

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Summary

In the first benthic biological survey of the Arafura Sea, a 2-person team collected 107 samples from 56 stations on *Southern Surveyor* voyage 05 of May 2005. This program was conducted opportunistically in conjunction with a Geoscience Australia geological survey of selected regions in the Arafura Sea. This survey only covers approximately 5% of the total Arafura Sea, but it provides a valuable shallow to deep transect across the region in depths ranging from 69 to 234 metres. At least 245 macroscopic species, including a diverse variety of invertebrates (e.g., sponges, corals, sea anemones, tunicates, worms, crustaceans, brittle stars, feather stars) and 6 small fish species, were photographed and documented with preliminary identifications. The sediments from many samples were washed using 300µm screens and the screened materials preserved for later identification. These sedimentary samples might contain hundreds of macrofaunal invertebrate species at millimetre and submillimetre scales and are currently being processed and documented. Species accumulation curves relative to sampling effort from the large animal data do not level off, which indicates that the survey has not captured all of the species richness in this region. This report includes two large appendices, one with the locality and sample data from the expedition and the second with digital images of the larger species extracted from the samples.

1 This report was prepared for the Department of the Environment and Heritage – National Oceans Office by the Australian Museum. The views expressed in this report are not necessarily those of the Commonwealth. The Commonwealth does not accept reponsibility for the contents of this document.

Introduction

This report describes a biological survey of the Arafura Sea by the RV *Southern Surveyor* (voyage SS 05/2005). The expedition was planned by Geoscience Australia (GA) Graham Logan and Andrew Heap as a survey of potential hydrocarbon seep sites and "environmental" geology. A collaborative partnership between Geoscience Australia, CSIRO and the Department of the Environment and Heritage (DEH) - National Oceans Office (NOO) involves chartering the National Facility RV *Southern Surveyor* for marine scientific research voyages. The biological survey in the Arafura Sea was part of a three-voyage marine science survey in northern Australian waters between 23 February and 28 May 2005. This third voyage, the "*Arafura Sea Natural Hydrocarbons Seeps and Benthic Mapping Survey*" focused on naturally occurring seepage of hydrocarbons in the sea-floor. The survey began in Darwin on 29 April 2005 and returned on 28 May, with the purpose of collecting seismic and oceanographic data, mapping the sea floor and taking geological samples over various habitats. While the voyage has a primary objective of geological and physical mapping and analysis, it presented a unique opportunity for collecting baseline information on the biodiversity of a smaller region within the Arafura Sea (approximately 5% of the total regional area). The biology team, consisting of Karen Gowlett-Holmes (CSIRO, Hobart) and George Wilson (Australian Museum), opportunistically extracted faunal samples during the geological program. This

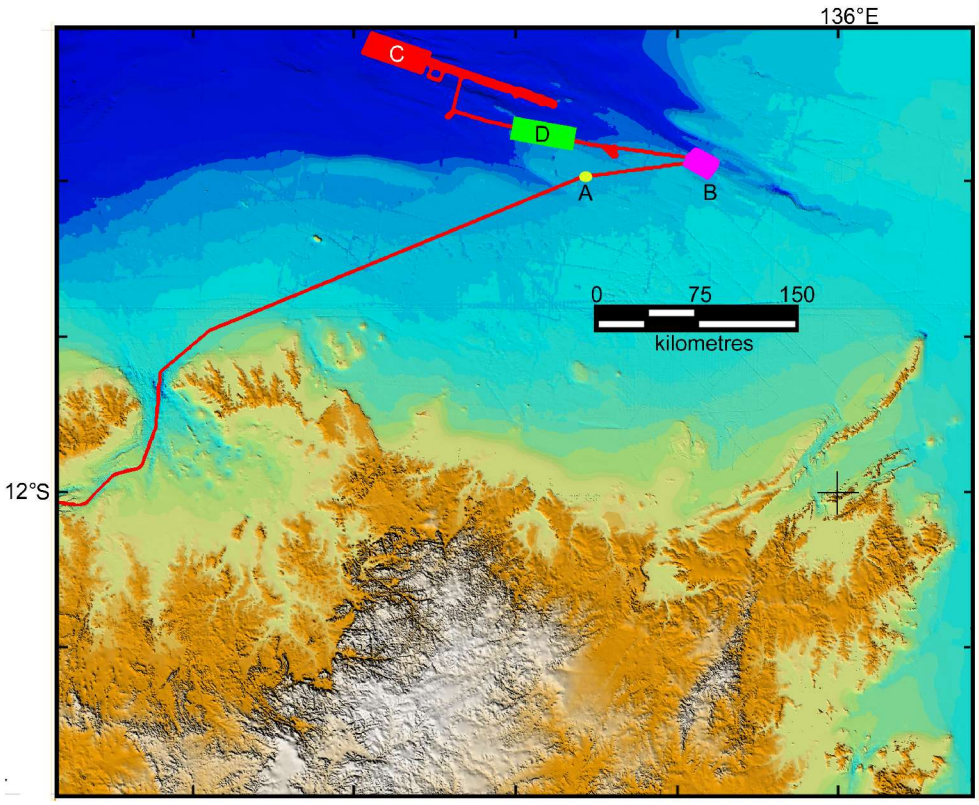

Figure 1 - Arafura Sea and general areas sampled during SS 05/2005. Red line indicates approximate expedition track. Source: Geoscience Australia

biological work is funded by NOO (DEH) and funds from the Natural Heritage Trust of Australia Reserve, DEH Marine Division, Marine Protected Areas Taskforce.

The general sampling pattern was developed by the GA staff prior to the voyage, and refined while underway based upon information received from the sea floor swath mapping and sub-bottom profiles. The voyage plan can be found on CSIRO's National Facility website (http://www.marine.csiro.au/nationalfacility/). Figure 1 shows the general sampling areas in the Arafura Sea investigated during the expedition, designated areas A through D. These areas are all within the Australian Exclusive Economic Zone (AEEZ) and represent approximately 5% of the Arafura Sea within the AEEZ. Area A, depth of 74mm was meant to be a sea floor sensor emplacement, but owing to equipment problems, only benthic samples were taken. Area B, depth 69-103m, included a sea floor emplacement, and a survey of geological "benthic environments." Area C, depths ranging from 87-234m, was an elongate polygon trending ESE-WNW and had the highest number of samples; this area was divided into sampling regions during the expedition (described below). Area D was added during the expedition because extra time was available for another sample series; it comprised primarily oozy hemipelagic sediments in 90-107 m depth.

Our aim for the post-expedition processing includes identifying the fauna to the lowest taxonomic category possible, preferably to the species level. The identifications will be done as collaboration with marine taxonomic colleagues in an Australian network of museum taxonomists, and will be the subject of later reports. Only preliminary, unverified identifications of approximately 245 species of macroscopic specimens (megafauna – visible to camera surveys, without magnification) are recorded herein from this expedition, along with digital images (see appendices). The preliminary findings and parallel research in nearby regions (Rainier, 1991) suggest that this region may have hundreds of unrecorded species from many phyla.

Prior Programs

This survey represents the first detailed benthic ecological study of the Arafura Sea. Prior to this survey, this region has had biological exploration related to fishery resources. The Soviets collected fishery data in Australian waters during 1963-1975, (Koslow et al., 1998). Trawling studies in the region by the RV *Soela* during 1980s collected primarily fish and by-catch invertebrates (CSIRO 1980). John Paxton (Australian Museum) recorded 55 fish records from one voyage, but added only a single record in the marine invertebrate database: *Portunus sanguinolentus* (a swimmer crab). Other more recent CSIRO voyages to this region primarily targeted fishes & sharks (e.g., the "Rachel" program: Stevens et al., 2000). RV *Southern Surveyor* voyages SS 02/1997, 08/1997 and 03/1998 obtained samples from shallower waters of this region during 1997-1998, under the leadership of John Salini as part of a bycatch sustainability project (CSIRO 1997, 1998). None of these programs have extensively sampled the invertebrate benthos of the Arafura Sea. Thus despite the opportunistic nature of our biological sampling, all data recovered on this region will be valuable.

Environmental Setting of the Arafura Sea

The Arafura Sea is a semi-enclosed continental shelf basin between northern Australia and Indonesian land masses. It is part of the Sahul shelf area that straddles the Indian Ocean-Australian continental plates. The geology of the region has been reviewed by Jongsma (1974) and Veevers (1971). The AEEZ region of the Arafura Sea visited by this expedition had depths ranging from 70-90 metres deepening toward the northwest to below 200m. The topography (Fig. 1; see also Grim & Edgar, 1998) includes the Arafura Channel, a submerged stream valley deepening toward the northwest at Area B, and an elongate ridge, Pillar Bank, along the same trend at Area C. Climatically, this sea is fully tropical and experiences the relatively stable trade winds during part of the year and intermittent monsoonal flows during the austral summer periods. It has a warm-water current flowing from the Pacific into the Indian Ocean called the Indonesian Throughflow (Tomczak and Godfrey, 1994). This current has a substantial influence on the climate of the entire region because it transports heat and moisture to the Indian Ocean and adjacent land masses. During the last glacial maximum, the shallower parts of the Sea were above sea-level and the Throughflow was cut off converting the Sea into a large embayment opening toward the West. From approximately 11,000-8,000 years before present, the region experienced a marine transgression that converted it from a shallow marine embayment to a shelf basin and shallow sea. As a result of this history and geography, the sediments of the Arafura Sea are calcium carbonate rich with substantial but varying fractions of carbonate sand and subfossil shell fragments. Many sediments sampled during the expedition had shells from shallow-water organisms, including oysters, a diverse assemblage of other tropical molluscs, corals, bryozoans, coralline algae and Foraminifera. These components possibly indicate previous shallow water environments, such as mangrove swamps, coral reefs, shallow lagoons or sea grass beds. The benthic boundary layer (from the seafloor to 30-50 metres above the bottom) at most sites was turbid, often well above the sediment interface, indicating ongoing sedimentary transport across the entire region. Although some current may be related to the Indonesian Throughflow, a large component of the flow at the sea floor may be influenced by the high tidal range of this region, exceeding a 5 metre vertically. Consequently, relatively high currents were observed at the sea floor, particularly at the hard grounds of Area B and ridges on Pillar Bank at Area C. Such areas had high populations of large sessile filter-feeding biota, such as sponges, octocorals and comatulacean crinoids. The deeper sites where the re-suspended fine sediments were apparently settling had high water-content hemipelagic oozes and had a minor megafaunal component in the samples. These contrasting sediment types should have substantially different invertebrate assemblages. The temperatures in the benthic boundary layer varied from 22-25°C in the shallower samples that were near the mixed layer above the strong thermocline (depth 70-90 metres), to 14-16°C in the deeper regions of Area C (depth 230 metres). Although these temperatures are not typical deep-sea temperatures (typically below 8°C), we observed the presence of some deep-water faunal elements, such as stalked crinoids, hexactinellid sponges and deep-water pedunculate barnacles.

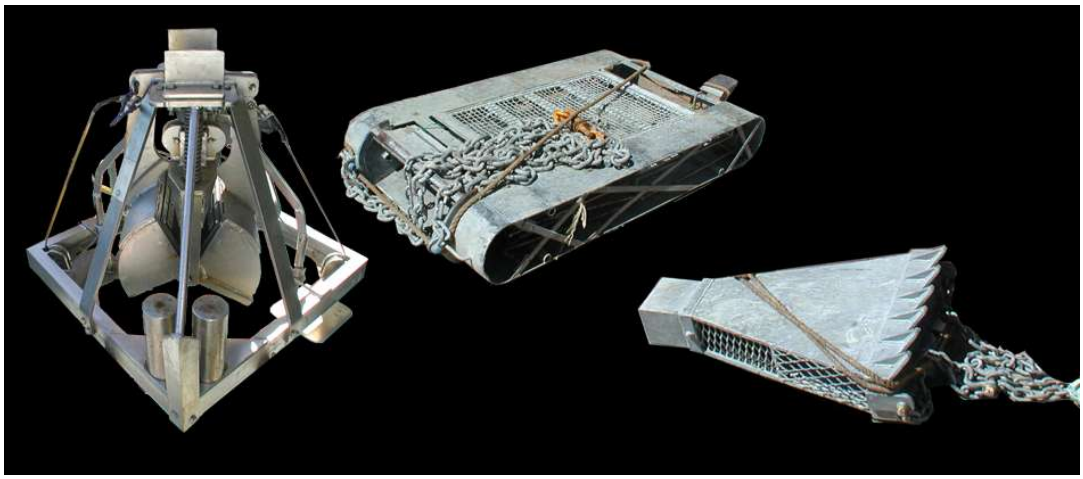

Figure 2 - samplers, left to right: Smith-Macintyre grab, small epibenthic sled, and Diamantina dredge (not to same scale). Source: G. Wilson

Sampling Methods

The sample pattern chosen by GA staff was based on geomorphology, with stations within each area being chosen using information from the swath map and sub-bottom profiler. Consequently, samples within each sampling area (see Appendix 1) cannot be considered statistically independent. This non-independence could affect some conclusions that might be made on the pattern and scale of the benthic assemblages. Nevertheless, as indicated above, the synoptic data on the fauna will be valuable.

Our primary sampling devices (Fig. 2) were the Smith-Macintyre grab that captures a surface area of approximately 0.10 m^2, a small epibenthic sled (described in Poore et al., 1987), a Diamantina dredge and a standard rock dredge. The grab collected nearly quantitative[2] samples from relatively firm sediments. The grab did not operate in fine oozes. In such situations, the epibenthic sled was used to collected qualitative[3] surface samples. The dredges were used on rocky surfaces, with Diamantina dredge being particularly good at scraping fauna from hard grounds, but often clogged with deeper clayey mud. In addition, the GA program operated a tethered video camera that gave intermittent views of the sea floor and a large gravity corer for sedimentary properties. Additionally a CTD (tethered package with sensors for conductivity (salinity) temperature and depth, with a transmissometer for particulates in the water and closable bottles for various water samples) lowering was deployed several times during each sampling series. The data from these latter devices are not treated here.

The strategy for collecting biology samples was based on available time and the placement of the sampling stations. As mentioned above, four areas (A-D) were sampled during the expedition. Within each area, numerous stations were designated. At each station, the GA program collected the following types of samples: a CTD if it was the first or last of a sampling series, a grab sample for bulk sediments, additional

2 The Smith Macintyre grab cannot be considered completely quantitative, i.e., providing an unbiased sample from a known and well-defined area. The grab has significant bow wave that tends to deflect soft surface sediment away from the sampled area. The grab's quantitative ability is further diminished by losses of surface material after sample recovery owing to an inability to expose the undisturbed sample surface while still in the grab.

3 Qualitative samplers recover approximate species abundance relationships from an undefined or unknown surface area; such samples cannot be considered quantitative.

biology grabs (usually one extra), one or several gravity cores, a camera lowering and, depending on the site, either a dredge or a epibenthic sled. Because the stations within each area were spaced closely, the biology team decided to collect only one biology grab at each station for most of the stations. At many stations, the bulk geology grab sample was also processed for fauna after the geological subsample was removed. These latter samples can be considered only qualitative because the geological subsample was not of a consistent size. Epibenthic sleds or rock dredges were not collected at all sites because they recovered large amounts of material that required much time to process. Consequently, only 2-4 Stations within each Area were chosen for biological sleds or dredges. The epibenthic sled and grab samples specifically targeted the abundant and diverse macrofaunal biota at size scales below a few centimetres, whereas the dredges were useful for the larger sessile organisms. Large motile organisms were unlikely to be sampled owing to the relatively small coverage of the samples. As a result, few fish species were collected, although this region is known from previous surveys to have a relatively diverse ichthyofauna (Koslow et al., 1998).

Sample processing. We recorded and photographed macroscopic organisms larger than 2 cm, including a variety of sponges, echinoderms, octocorals, bryzoans, worms, molluscs, decapod crustaceans, and the occasional fish (see Appendix 2). Large organisms that were photographed were labelled and preserved individually for later study. Each container was given an index number along with the sample identification. The sediment samples were given two separate treatments depending on whether they were quantitative or not. The quantitative biology grab samples were fully processed for fauna. The non-quantitative samples were subsampled, primarily targeting high water content (oozy) material, where most of the organisms should be found. In some cases, the grab samples that had been used for the geological sample were rinsed into the elutriation bin and thick clayey subsurface sediment was discarded. The epibenthic sled often collected more material than could be practicably washed in the available time, so the material was subsampled, again collecting specifically surface oozes that were present. All biological sediment samples were lightly washed through fine mesh screens (0.3mm mesh) by elutriation (Fig. 3), wherein filtered sea water was used to lift the lighter specimens and silt from the heavier sediment. Many samples had large components of shells, shell gravel and sand. To recover as much of the fauna as possible, such samples were repeatedly elutriated and the wash water tipped into the screen. The heavy material was discarded after no specimens were found in the screen after a wash cycle. This procedure may lose heavy bodied invertebrates such as molluscs, so subsamples of of the coarse material were taken to assess the degree of loss. All specimens were preserved either in ~4% formaldehyde-seawater solution or 80% ethanol. Within 2-4 days on board the ship, the formaldehyde-

Figure 3 - Elutriating sediments during SS05/2005. Source: K. Gowlett-Holmes

seawater fixed samples were washed in fresh water and transferred to 80% ethanol. A few bulk samples were preserved in 100% ethanol for possible molecular DNA analysis. All containers were tightly sealed and packed for transport later to either the Australian Museum in Sydney or the Museum and Art Gallery of the Northern Territory.

Expedition Narrative

In the following, activities and results at each of the sites are described briefly. Each of the site descriptions is accompanied by a small diagram showing the distributional pattern of the samples.

Area A (Fig. 1). The first site (Station 001) was a level region around 74 m deep (09.9°S 134.5°E) and had sediments that were grey-green calcareous ooze. In such sediments, the grab didn't trigger on bottom contact because the sediment was not sufficiently stiff. We usually deploy a Van Veen grab in such circumstances, but the ship didn't have one. The epibenthic sled was used with the closures in the mouth tied open; the opening plates would not be depressed by the soft ooze, so disabling that feature was necessary. We got a good haul that took approximately 12 hours to process.

Area B - "BRUCE" emplacement site (Fig. 4). This site (station 002, part of Area B), at 92 m deep (09.8°S 134.5°E), was in the centre of a submerged gulley and had a sandy substrate. The grabs triggered easily, and we got 3 grabs in quick succession and a epibenthic sled haul. The sand proved to be easier to wash, so all samples were done within 12 hours. Despite seeing little in the camera lowering, we obtained quite a few animals in the samples, including a "frog" crab (Raninidae) and a possibly new species of "duckbill" eel in one of the grabs. Both sites A & B were in shallow water or exposed during the last glacial period, so they had many dead tropical mollusc shells of the sort that one would find on coral reefs or shallow sea grass beds. I saved a collection of the dead shells from the second sled lowering for the malacologists.

Area B - 3-5 May 2005 (Fig. 4). The biology sampling pattern included 2 grabs (1 geology, 1 biology) at most stations with 2 epibenthic sleds among the series. More sleds would have been difficult to process and might have been redundant in any case. Operations began on the afternoon of May 3 (local time) and over the next 2 days, we collected 9 biology grabs and one sled. The Smith-Macintyre grab refused to trigger at one station owing to very soft sediments. A support rod on the grab broke during the second to last station, and the backup grab did not work as efficiently. On the

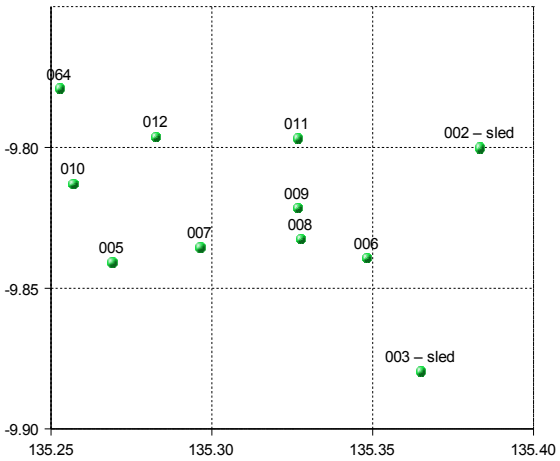

Figure 4 - Area B biology sites (Station number indicated at each position), y axis latitude S, x axis longitude E, in decimal degrees

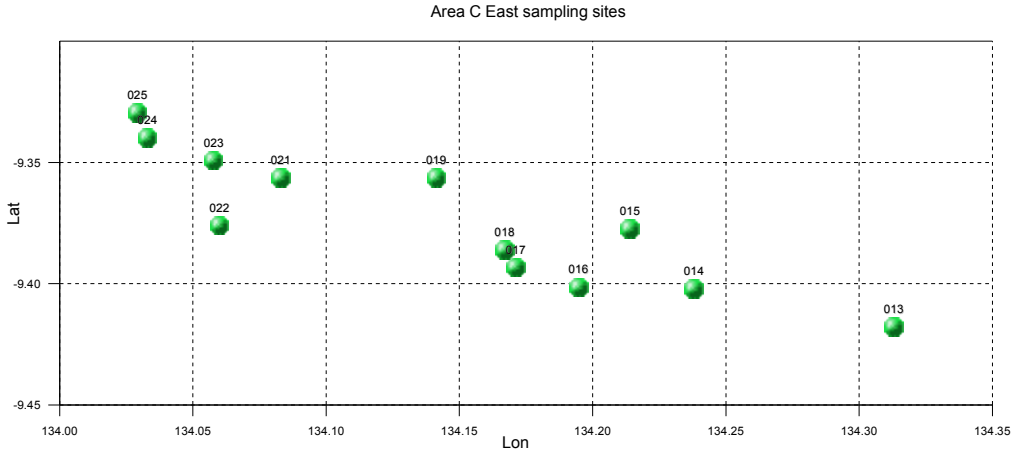

Figure 5 - Area C East biology sites (Station number indicated at each position), y axis latitude S, x axis longitude E, in decimal degrees

last station, the backup took one sample, but refused to fire on further lowerings. Because time was short, we took what we had for biology from the last 2 grabs that were taken for the sediment analysis. The rest of 5 May was spent processing the samples.

Area C – East, 10-12 May 2005 (Fig. 5). After a few days of swath mapping, we completed 2 intensive days of sampling. Fourteen stations were sampled, bringing our sample total up to 46 Smith-Macintyre grabs, 4 epibenthic sleds and 7 Diamantina dredge hauls. The eastern end of Area C includes mixed grounds with a large gulley running approximately from ESE deepening to WNW. The most eastern area is heavily impacted with currents and has substantial exposures of rocky or hard grounds. A dredge in this area collected substantial numbers of sessile epifauna. Other sites ranged from gravelly sand, subfossil coral rubble, to fine oozy marine sediments at the deeper stations. The biology effort documented more than 130 distinct species, with the number of cnidarian filter feeders captured jumping abruptly after the first dredge haul (DR001). That sample alone contained around 67 species that were large enough to photograph, with many different types of octocorals. Karen Gowlett-Holmes commented that some species appear to be similar to those in Darwin Harbour, so some may be typically shallow water fauna. Several different species of crinoid ("feather stars" Echinodermata) were collected and our ophiuroid ("brittle star", Echinodermata) species list became longer.

Area C Centre, 12-14 May 2005 (Fig. 6). The central part of Area C included 6 stations that were deeper than the eastern series, ranging from 112-187 metres. The first 4 stations to the south of the centre were in areas of higher current. The first 4 sites had varying amounts of calcareous sand, subfossil broken shells and coral rubble. All camera lowerings showed poor visibility, suggesting recent resuspension of the oozy surface layer. Some coral bits were identified as belonging to species known from Darwin Harbour. Some shells, echinoderms & coral skeletons, may have been more recent, part of the local community – just not alive. At the 4 south central stations, we only took grabs because the sediments appeared to be reasonably productive with tiny specimens. The fifth and sixth stations were in a somewhat

featureless area in the northern part of this region. Attempts with Smith-Macintyre grabs were unsuccessful, probably owing to soft sediment not being stiff enough to trigger the grabs. We used epibenthic sleds for these to get surface sediment.

During this series, we removed an active ophiuroid (brittle star), possibly family Ophiodermatidae, from grab 48. This species played dead when it was taken to the lab for photography, but after settling under the camera, a touch of its arm caused it to jump quickly away. To our surprise, it also emitted bright blue-green flashes from the underside of its arms just before it jumped. We were not aware that ophiuroids had this bioluminescent ability (although we have subsequently learned that bioluminescense is known among some shallow water species: M. Byrne & T. O'Hara, pers. comm.). Some biology samples consisted of only large organisms recovered from the geology grab samples, but we also processed the sediment from many of these, too. Two dredge hauls were rich in large sessile filter feeders. These yielded many large specimens that could be tentatively identified. Octocorals (Cnidaria) appear to have at least 36 species, mostly from the dredge hauls across hard grounds. The ophiuroids (Echinodermata) include 15 species, but we also collected many decapod crustaceans, including 5 species of snapping shrimp (Alpheidae) and 6 species of thalassanidean ghost shrimp. The latter are probably responsible for many of the burrows we see in the camera images.

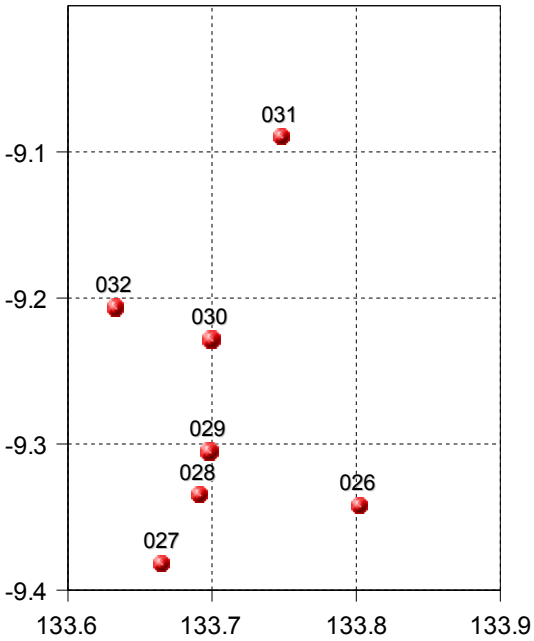

Figure 6 - Area C Centre biology sites (Station number indicated at each position), y axis latitude S, x axis longitude E, in decimal degrees

Swath Mapping, 16 May 2005. This non-sampling period was spent collating data and notes, and transferring most of the previous formalin-seawater samples to ethanol.

Area C – West, 17-20 May 2005 (Fig. 7). These sites were mostly north and west of Pillar Bank with one station on the ridge; together they covered a range of habitats from oozy marine sediments grading through sandy or shell gravelly muds to hard rocky sea floor. Because of the large number of stations in this region, the sampling periods were divided into two groups, referred to as "West" and West II," with a period of swath mapping for one day separating the two groups. The Smith-Macintyre grab broke again on hard grounds during the series and lost a spring. Fortunately, the GA mechanics were able to fix it within a few hours by using parts from the backup grab, so we resumed collecting grabs toward the end of the series. The rocky and hard substrates had quite a few interesting attached filter feeders including octocorals, anemones, sponges and crinoids ("feather stars"; Echinodermata), some of which we

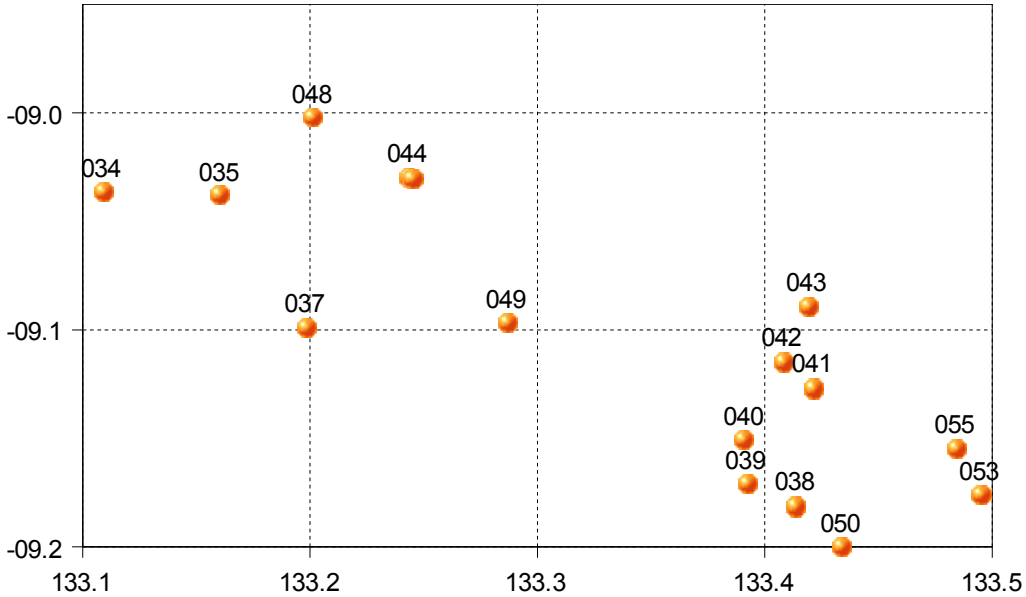

Figure 7 - Area C West biology sites (Station number indicated at each position), y axis latitude S, x axis longitude E, in decimal degrees

recovered from grabs and dredges. The Biology Team identified stalked crinoids ("deep-sea lilies"; family Pentacrinitidae?) in camera lowerings and collected a few sections of dead stalks in the samples (see photo in Appendix 25021801-043GR069B-003-Pentacrinitidae-sp1.tif). Other members of the deep-water fauna present include possible hexactinellid sponges and primitive pedunculate barnacles.

Area C South, 21-22 May 2005 (Fig. 8). A small series of samples was taken on the south side of Pillar Bank. Because the deep hemipelagic sediments south of the bank were too soft to trigger the Smith-Macintyre grab, we obtained several epibenthic sled hauls, two of which were reasonably good. Initial hauls were poor because the ropes that held the doors in the mouth of the sled open had come undone. I replaced them with a strong nylon rope, so all subsequent hauls have been large. In addition, I requested that the sled be recovered more slowly (30m/min) so the washing on recovery is much less; the 80-90m/min recovery rate of the big winch puts enough hydrodynamic pressure on the ooze to just push it through the mesh of the bag. Seas have been favourable, so loss by surge has not been a problem.

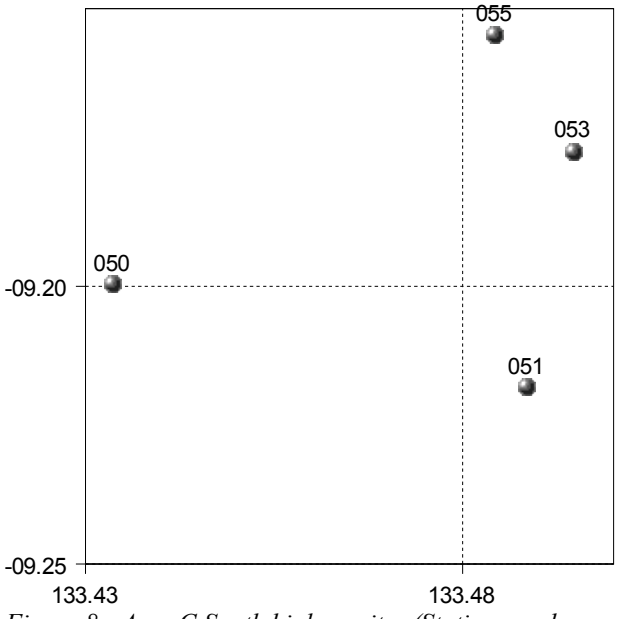

Figure 8 - Area C South biology sites (Station number indicated at each position), y axis latitude S, x axis longitude E, in decimal degrees

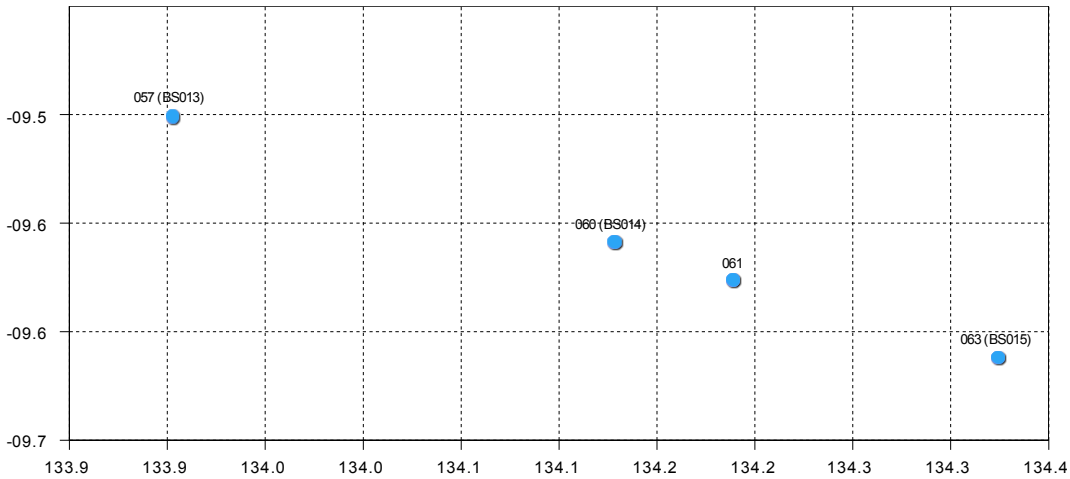

Figure 9 - Area D biology sites (Station number indicated at each position), y axis latitude S, x axis longitude E, in decimal degrees

The hemipelagic muds (water-column derived sediments with some terrigeneous material) have all been a greenish-grey, somewhat gelatinous ooze with little sand or shell grit. Such areas are obvious in the acoustic subbottom profiler because the surface layer is thick (>100 metres), is relatively homogeneous with few internal layers and does not return as strong an acoustic return as harder subbottom layers. During this series, previously identified large epifaunal species that we have observed elsewhere on the bank were recovered in a large dredge haul. A tubular hexactinellid sponge was seen in one camera lowering, but not collected.

Area D, 24-25 May 2005 (Fig. 9). A fourth area was added late in the expedition because we had extra time; no days were lost to bad weather, and the failure of the air gun system early in the voyage meant that little time was spent on seismic profiling. Sites were investigated in an approximately rectangular area south of the eastern end of Area C. Stations were designated in an approximate diagonal across the area, and the standard series of samples were taken at each station. Because the soft sediments did not trip the grab, we took 3 epibenthic sled samples, one at each end of the diagonal and one in the centre of the area. Additionally, the grab worked once out of the 28-30 tries at area D, so we washed what remained from that sample after the geologists took out the bulk geology subsample. At all sites, the sediment were fine high water content greenish-grey oozes with some fine sandy grit that was near 300 microns, clogging the sieves. Many polychaete worms were seen in the sieves.

Results

Observations made during the expedition

Various observations are Reported here that were made regarding several of the sites, which should not be considered summaries of those sites (see next section).

Area A & B. Although we cannot evaluate the tiny preserved specimens in the containers, the larger specimens could be partially identified and documented on board. From areas A and B, which are around the same depth range 70-90m, we

collected more than 50 distinct taxa in the 2-10 cm range from all lowerings, all documented photographically. Some specimens were too small to document; these were preserved separately from the main samples. Given these figures, the sedimentary invertebrate fauna could be nearly an order of magnitude more diverse than these larger organisms, somewhere around 500 species. A rough "back of the envelope" calculation, made in the biology proposal for this project, suggested that this area could have as many as 1000 invertebrate species. If the order of magnitude "rule of thumb" is the case, these sites took our program half way toward that goal.

Here are a few examples of the biology results, all of which are now documented with digital photographs and detailed accompanying data. We have collected 3 small (3cm) stomatopod crustacean species ("mantis shrimps) that appear to represent two different families. The thallassanidean crustaceans ("ghost shrimp") were abundant in these two areas and and may be a major bioturbator of the sediment, given the high density of burrows that we saw in the video camera lowerings. The thalassanideans may include 5 distinct species in two different families (Callianassidae, Upogebiidae), and additional species may be found after the samples are processed. The Ophiuroidea ("brittle stars", Echinodermata) top these with at least 6 species recovered from this site, probably belonging to at least 3 different families. Two species of the ophiuroids are unusual because their central disk is tiny (only 2-3 mm wide) but the arms are long (30-40 mm!) and thick, almost like octopus arms. The polychaetous annelids ("bristle worms") are the dominant group of marine benthos, but are typically too small to document on board ship. Nevertheless, we have digital images of 4 large species, including an elongate polynoid ("scale worm"). Because the Arafura Sea is poorly surveyed, many of these 50 species could be new, unknown to science.

Area C East. Although this region is below the mixed layer (ending at the thermocline 70-80m), we observed substantial currents below 100 metres depth. As a result, whenever we encountered hard substrates, the filter feeding megafauna were in abundance, especially at the upper margin of ridges where the current is most intense, providing the best position for filter feeders.

Area C West. Stalked crinoids, seen at this area, are an Palaeozoic relict group found only in the deep sea. They are known from southern deep waters around Australia but these observations may represent a new record for this region. We did not collect live specimens, but their presence was noted in the camera lowerings and in the several samples where individual stem sections were recovered. Because other known deep-sea taxa such as deep-water hermatypic corals and stalked barnacles were seen in the same area, the deeper regions of the shelf may be partially in the bathyal biogeographic zone.

Area C Centre. This part of Area C included shallower sections on Pillar Bank with few fines in the sediment ranging to hemipelagic oozes in deeper regions to the North. The grabs failed to trigger in the latter. The deepest site, however, was adjacent to the slope of the bank and had sediment with a substantial fraction of shell gravel. The benthic boundary layer of this subregion was extremely turbid in all camera lowerings.

Area C South. This area was sited on the southern flank of Pillar Bank, and had depths ranging from 136-182 metres. The shallower stations were higher on the bank and consisted of coarser sediments with several grabs and a rock dredge that collected oyster shells, coral and bryozoan fragments. The deeper sites, as elsewhere consisted of soft bioturbated sediments with few epifauna.

Area D. This area was placed closer to land and shoaler on the continental slope so samples had depths ranging from 90 to 107 metres. The entire area had featureless a muddy sea floor with some bioturbation and burrows. Samples here yielded few large specimens.

General Observations

Tables 1 & 2 list the number of samples obtained, their geographic coverage, and the number of lots and phyla collected. We obtained many samples (either in grabs or epibenthic sleds) from the oozy marine sediments, so study of the preserved materials at the Australian Museum and other Museums will be informative. The submillimetre fauna preserved from the sediments may be an order of magnitude more speciose than

Table 1 – Depth, location and number of samples recovered during SS2005/05.

	A	B	C East	C Centre	C West	C West II	C South	D
Depth (m)	74	69-103	87-140	112-187	124-220	161-234	136-182	90-107
mean Latitude	-09.900	-09.802	-09.373	-09.277	-09.136	-09.058	-09.181	-09.612
mean Longitude	134.501	135.281	134.139	133.700	133.347	133.262	133.489	134.19
Stations	1	12	13	7	8	6	5	4
Biol. Samples	1	26	29	11	16	14	6	4

Table 2. Number of lots (individual containers) of specimens or sample fractions collected at each Area during SS2005/05.

Area	Sample Fractions	Annelida	Brachiopoda	Bryozoa	Chordata	Cnidaria	Crustacea	Echinodermata	Echiura	Mollusca	Nemertea	Porifera	Sipuncula	**Total**
A	4	2					3	1		2				**8**
B	20	11		2	5	14	30	10		6			3	**81**
C-Centre	13			1		1	4	2		1	1			**10**
C-East	28	8	5	9	2	56	27	23		5	1	4		**140**
C-South	6	1		1		5	3	2		2		9		**23**
C-West	32	8	1	5	1	32	10	21	1	4		17		**100**
D	5				2	1		1						**4**
Total	**108**	**30**	**6**	**18**	**10**	**109**	**77**	**60**	**1**	**20**	**2**	**30**	**3**	**474**

the large megafaunal specimens documented in the appendices, so study at the Museums should substantially improve our understanding of the fauna of the Arafura Sea. These will be covered in later reports.

The region sampled by this program is an important consideration because one may not be justified in extrapolating our results to the entire Arafura Sea within the AEEZ.

1. The areal coverage was small; all samples in aggregate only subsume approximately 5% of the total area of the Arafura Sea AEEZ.
2. The region sampled possibly didn't cover all potentially different ecosystems. The expedition sampled a diagonal swath following the Arafura Channel and Pillar Bank, and did not sample along the outer shelf to the northeast (near the Arafura Sill) nor to the southwest of the region (near the Timor Sea). Because the region has an East to West gradient defined by the Indonesian Throughflow, we also might expect to see some species turnover.

Many species may ultimately prove to occur along the entire outer shelf, but the test of this assertion will require another survey from parts of the Arafura Sea not sampled by this expedition. The transect, however, does provide the first information of this type from the Arafura Sea, so these results will be useful for formulating hypotheses about the biogeographic relationships of the Sea with other regions around Australia.

For the larger documented species (see appendices), the question arises as to how well we have sampled these larger organisms. We recovered many (245) of these larger species from 107 samples, so one could suspect that we have good sample of the fauna from the region. Species accumulation curves provide a non-parametric way of assessing this question. As more and more samples are collected from a region or province, new species encountered should decline; a cumulative curve of species and sampling effort should tend toward an asymptote, or levelling off as the sampling effort increases. For the purposes of this study, the sampling effort is shown in 4 different ways (Fig. 10, counterclockwise from upper left): by Stations over all samples (each including a dredge, an epibenthic sleds and/or 1-2 grab samples each), by dredges, by epibenthic sleds and by grabs. The station curve is inconsistent because each station could have a dredge, an epibenthic sleds and/or 1-2 grab samples each, and thus might have greatly differing quantities of sample. A good example was DR001, which recovered 67 species alone, while stations without such dredges would recover substantially fewer specimens and species. Nevertheless, the station curve rises with increasing number of stations and does not appear to level off. The dredge sample curve jumps abruptly, because individual dredge samples were inconsistent and captured highly differing numbers of specimens. Nevertheless the curve, after a few sudden jumps, appears to rise continuously in the later samples. The epibenthic sled samples appears to level off but this may be an artifact. The epibenthic sled samples collected in the latter part of the expedition were only from oozy hemipelagic sediments, which tended to have few large specimens. Thus the levelling off is owing to the absence of large specimens, rather than a lack of new species encountered. This effect is observed in diversity studies where the screen size is relatively large (1-5 mm and above): because oozy sediments are dominated by mostly submillimetre infauna (such as polychaetes and small crustaceans), the measured “diversity” is low compared to coarser sediments. In actuality, the reverse is the case if the tiny

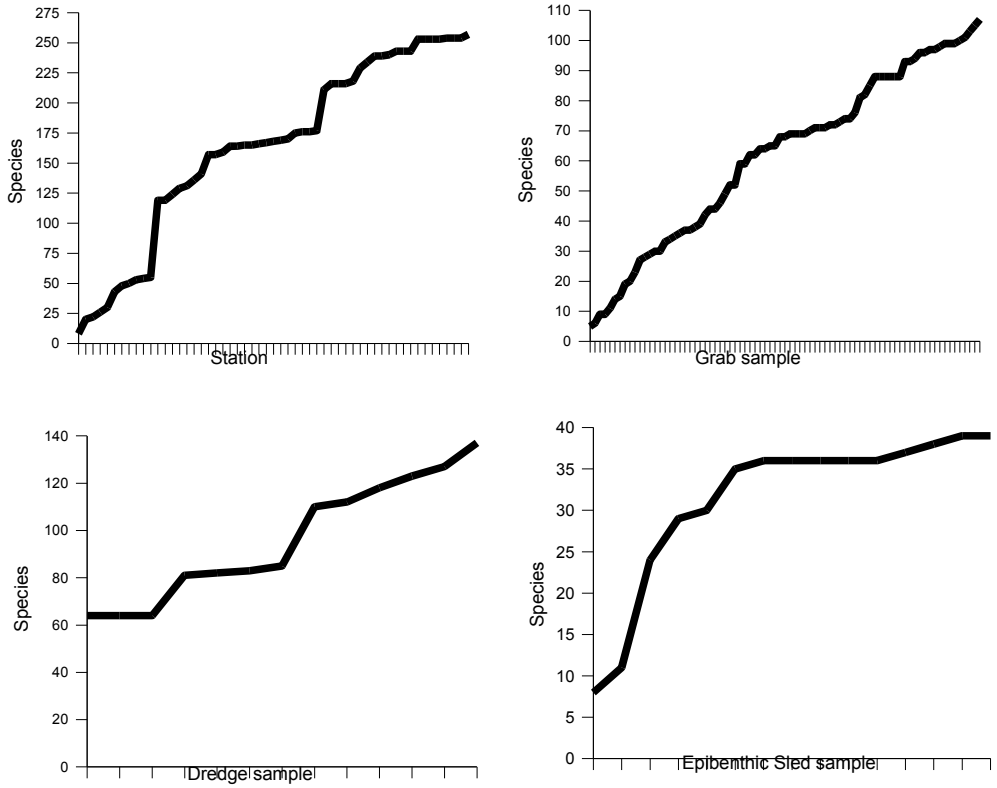

Figure 10 - Species accumulation curves for different sampling effort types from voyage SS05/2005. Samples arranged chronologically.

submillimetre part of the fauna is included (see discussion in Just & Wilson, 2004). The grab species accumulation curve is approximately linear because for the large specimens, grabs are more quantitative than for the less consistent sized dredge and epibenthic sled samples. We were able to recover all large specimens from each grab, regardless of whether it was used for geology or not. The grab also captures a consistent area (when it does trigger). The grab also selected against soft sediments because it failed to trigger, so it lacks the seemingly low diversity samples found in the epibenthic sleds from such sediments. The grab curve rises relatively evenly without break or inflection and does not appear to reach a leveling-off region. From even the well-sampled and relatively small Area B, the last few grab samples were still recovering new species not previously encountered. From these considerations, I conclude that we have not discovered all large species present in the subregion sampled from the Arafura Sea and, indeed, we may have only recovered a small fraction of the total megafaunal biodiversity. On the other hand, we now know of more species than we have prior to this cruise.

Description of the Data

Appendices that follow this report contain the data and images collected on this expedition. Appendix 1 contains a description of the sample numbering format, locality data for all samples collected, a listing of all specimens and samples with

index numbers, and an index of each large species identified and documented photographically. Appendix 2 contains a photographic summary of the digital images of all 245 species. The images are arranged by taxon according to the CSIRO CAAB (Codes for Australian Aquatic Biota) system (Yearsley et al. 1997; Rees et al. 1999); these codes are a continuously maintained and expanding 8-digit system for aquatic organisms in the Australian region maintained by CSIRO Division of Marine Research, and has recently been expanded to cover all phyla.

Conclusions

On the voyage SS05/2005, the biology team collected and preserved hundreds of species from the Arafura Sea, many of which may be new undescribed species, as well as many lots of macrofaunal samples, derived from the elutriation of benthic samples. We emphasise that this is a preliminary program, especially in view of the megafaunal species accumulation curve for grab samples, which does not level off, and because the sampling pattern cannot represent the entire Arafura Sea owing to its limitation to the areas around the Arafura Channel and Pillar Bank. Nevertheless this shallow to deep transect afforded by the geological sample pattern provides information that heretofore has not been available for this region. The data derived from the ongoing study of the sedimentary macrofauna, now in progress, will provide an excellent first step toward a much richer understanding of the distribution of benthic biodiversity in the Arafura Sea, and how it relates to other regional diversity hotspots around the Australian continent.

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