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ScienceDirect
Polar Science 5 (2011) 75−87
http://ees.elsevier.com/polar/

CEAMARC, the Collaborative East Antarctic Marine Census for the Census of Antarctic Marine Life (IPY # 53): An overview

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Received 13 April 2011; revised 18 April 2011; accepted 19 April 2011
Available online 27 April 2011

Abstract

The Census for Antarctic Marine Life (CAML, IPY Project 53) aimed to investigate the distribution and abundance of Antarctic marine biodiversity and how it will be affected by climate change. It was a major ship-based research programme in the austral summer of 2007−2008 involving scientists from 30 countries and 19 vessels. The Collaborative East Antarctic Marine Census (CEAMARC) was a multinational contribution to CAML involving scientists and students from several nations using three ships from Australia, Japan and France surveying the one area. This collaboration was a highly coordinated and comprehensive survey of the plankton, fish, benthos, oceanography and geophysical conditions of the waters north of Terre Adélie and George V Land of Eastern Antarctica. CEAMARC has provided a robust benchmark of the marine life in this poorly studied sector and will help to establish the monitoring of future changes in this region.

Keywords: CEAMARC; CAML; Marine biodiversity; Pelagic; Benthos

1. Introduction

The Census of Antarctic Marine Life (CAML) set a challenge to understand the marine biodiversity of the Antarctic, from virus to vertebrates, in all habitats, biomes and regions, and across all fields of study to strengthen our knowledge of ecosystem dynamics in this high latitude, ocean system. CAML aimed to determine what is known, unknown and probably unknowable about the Southern Ocean, and provide a better understanding of the diversity and status of

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doi:10.1016/j.polar.2011.04.009

Antarctica's marine life that could be obtained only through a multi-scale level of investigation (Gutt et al., 2010; Schiaparelli and Hopcroft, 2011; Stoddart, 2011; www.caml.aq). The CAML was the first major programme since BIOMASS (Biological Investigations of Marine Antarctic Systems and Stocks, El-Sayed, 1994) to involve multiple nations and ships to study the Antarctic marine biodiversity in a comprehensive and integrated manner. Various surveys were conducted around Antarctica either as individual national projects or through consortia of nations.

That challenge was taken up by Australia, France, Japan and Belgium, brought together during CAML in 2007/08 to conduct the Collaborative East Antarctic Marine Census (CEAMARC). The survey focussed on the continental shelf, slope and oceanic waters north of Terre Adélie and George V Land, studying the plankton, fish, and benthos, together with oceanographic processes and the assessment of geomorphology and substratum of the underlying seabed. All four collaborating nations have previously conducted biological, oceanographic, and geological research in the region, indicating it to be an area of rich and interesting biodiversity over diverse habitats.

The CEAMARC survey area extended eastward from 138°E, just west of the French station of Dumont d'Urville, to the Mertz Glacier Tongue at approximately146°E, and northward from the coast to 62°S. The continental shelf extends 120–130 km from the coast with a shelf break located at depths of 500–550 m. The continental slope reaches 2000 m and has a complex network of submarine canyons extending across the shelf and over the shelf break (Carburlotto et al., 2006). On the shelf there are two major banks shoaling to about 200 m, the Adélie Bank and Mertz Bank, which alternate with very deep inner-shelf depressions of 500 m to more than a 1000 m depth. Some of these depressions are large, notably the George V and Adélie Basins but there are other smaller glacial basins (Beaman and Harris, 2003, 2005; Post et al., 2010, Fig. 1).

A previous geological survey by Australia of the continental shelf of the region, included an assessment of the geomorphology of the seafloor and substrate type, and led to an initial classification of the benthic habitats and biotypes (Beaman and Harris, 2003, 2005). More extensive geomorphological and habitat assessment during CEAMARC (Post et al., 2010, 2011), indicated that gravelly sediments only occur along the continental slope whereas muddy and sandy sediments dominate respectively over depressions and banks. The seabed was shaped by past glacial ice sheet which has created basins but also moraine on banks. Much of the seabed in this area is less than 440 m depth and therefore subject to regular scouring by icebergs calved from glaciers along the coast, which has consequences on benthic assemblages and fish (Beaman and Harris, 2005; Causse et al., 2011; Gutt et al., 2007; Koubbi et al., 2010; Post et al., 2011).

At the time of CEAMARC, the eastern edge of the area was bordered by the Mertz Glacier ice tongue which extended northward more than 80 km from the coast. Immediately to the west of the ice tongue, and positioned over the George V Basin, is the Mertz Glacier Polynya (Smith et al., 2011). This is a region that remains as open water throughout the year because of the combination of strong offshore winds, prevailing westerly flowing currents and the shelter provided to the east by the ice tongue. The constant contact between cold air and the sea surface in winter produces vast quantities of sea-ice which is blown northwards out of the polynya. As the sea-ice forms it rejects heavy more saline water (Lacarra et al., 2011; Marsland et al., 2004) which sinks to become deep flowing Antarctic Bottom Water. It was anticipated that at some stage the Mertz Glacier ice tongue would detach and would have an immediate physical impact on the seabed, as well as the biological communities in general through altered oceanographic conditions and current flow. The ice tongue broke off in February 2010 producing iceberg C28 approximately 80 × 40 km in size (Young et al., 2010).

Since 2004, France with the support of Belgian, Italian and Australian researchers have been conducting series of plankton and fish surveys of the continental shelf area. The ICOTA (Coastal Ichthyology in Terre Adélie) programme primarily focused on fish larvae and juvenile and adults of demersal fish. Later, the ICO^{2}TA (Integrated Coastal Ocean Observations in Terre Adélie) programme extended the pelagic work focussing more on the Antarctic silverfish *Pleuragramma antarcticum* and incorporating plankton studies, especially the euphausiid *Euphausia crystallorophias*, which along with *P. antarcticum* are key prey species of predators foraging on the shelf. Both the ICOTA and ICO^{2}TA programmes have provided further indication that the topography and hydrology of the shelf affect the distribution of fish, larvae of fish and euphausiids and plankton (Koubbi et al., 2009, 2011; Vallet et al., 2009). The programmes were the foundation for CEAMARC itself, and provide the data which allow time-series analyses of the fish and plankton in the region, included in this special issue.

The CEAMARC area corresponds with Area C of Japanese Antarctic Research Expedition STAGE

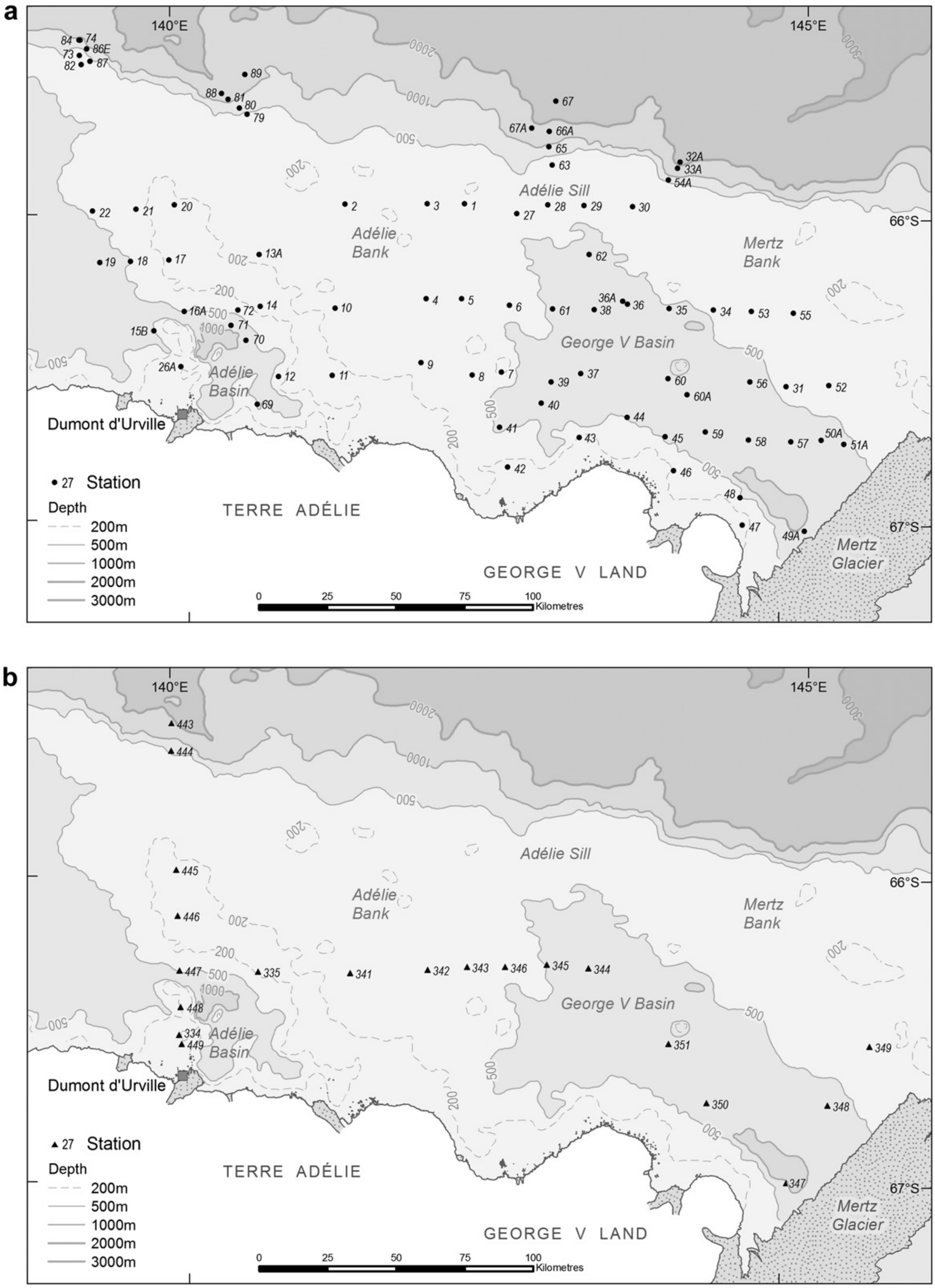

Fig. 1. Station positions for *RSV Aurora Australis* (a) and RV *l'Astrolabe* (b) during CEAMARC 2007/08.

(Studies on the Antarctic Ocean & Global Environment) program. Japan has conducted a number of voyages in this region between 60°S and the coast to study the sea-ice ecology. This included a four ship time-series study in 2001/02, in collaboration with Australia, along the southern end of the 140°E World Ocean Circulation Experiment (WOCE) SR3 transect (Hunt and Hosie, 2003, 2005, 2006; Odate and Fukuchi, 2002). Much of that work focussed on the distribution of plankton, krill and fish of the upper 200 m of the water column, and their role in the sea-ice zone dynamics. Of particular interest was the relationship of the biota to the persistent cool-water eddy centred around 64°S on 140°E (Hirawake et al., 2003).

A more broad scale survey of the region was conducted by Australia to understand the ecology of Antarctic krill and to assess the abundance of krill for the purposes of setting catch limits by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) (Nicol et al., 2000a,b).

The previous biological surveys conducted in the CEAMARC area all involved some collaboration amongst the nations working in the region but all were limited to some degree by available resources. For example previous studies of the benthic realm were limited to coastal zones (Gutt et al., 2007) and the George V Basin (Beaman and Harris, 2005). Very little information existed on the meso- and bathypelagic realm and the transition between the oceanic and neritic provinces was not studied simultaneously. The CEAMARC survey provided a unique opportunity to conduct a more coordinated and comprehensive survey of the region using the RSV *Aurora Australis* (Australia), TRV *Umitaka Maru* (Japan) and RV *l'Astrolabe* (France). Scientists and students from seven countries participated resulting in a new and enhanced level of international collaboration in a region of the Antarctic that has received far less attention than the Atlantic and Indian Ocean (Prydz Bay region) sectors.

2. Target biota

While the aim of CAML was to understand the marine biodiversity of all levels, many taxonomic groups and habitats have been poorly studied below 200 m depth. Some important differences in the composition of the fish fauna, as well as striking inter- and intra-specific differences at cytogenetic level have already been observed in the coastal fish fauna (from 0 to 200 m depth) of the Terre Adélie sector, suggesting important divergences between populations (Ozouf-Costaz et al., 1999). We investigated the diversity of the fish fauna (from gene level to fish habitats) and compared these with similar studies in other sectors around Antarctica. Knowledge of the composition and community structure of the benthos was essential to help explain the distribution of bottom and near-bottom dwelling fish. Further, there was inherent value in studying the benthos to understand the evolution of the communities and how they have adapted to the unique Antarctic environment, which has long been isolated from other continental systems. Some groups are poorly represented in the Antarctic or absent, such as decapods shrimps and crabs (Clarke et al., 2004), whereas for other groups there is a very high general and localised species endemism, e.g. amphipods, ascidians, echinoderms, sponges, pycnogonids, isopods, and polychaetes (David et al., 2005; Monniot et al., 2011; Munilla and Soler Membrives, 2009; Primo and Vasquez, 2007). For example 33 ascidians species have been identified from material collected during CEAMARC, three of them are new, one of them is recorded for the second time and half of these 33 species has an exclusive Antarctic distribution. The Antarctic benthos is noted for its high degree of species diversity, high biomass and gigantism among some groups (Arnaud, 1974; Aronson et al., 2007; Brey and Gerdes, 1999; Clarke and Johnston, 2003; Davison and Franklin, 2002; Gage, 2004; Griffiths et al., 2009; Woods et al., 2009). The target groups for the benthos included, cephalopods, pycnogonids, teleost fish, crustaceans, bivalve molluscs, cnidarians, ascidians, sea-stars, crinoids and sea urchins. This is primarily due to the specific expertise of Muséum national d'Histoire naturelle (MNHN) Paris but all major taxonomic groups will eventually be processed by appropriate international experts coordinated by MNHN. A total of 17 institutes from seven nations are involved.

The macrozooplantkon of the upper water column, surface to 200 m, have been moderately well-sampled in eastern Antarctic waters between Syowa Station and the Ross Sea (Chiba et al., 1998, 2001; Hosie, 1994; Hosie and Cochran, 1994; Hosie et al., 2000; Tanimura et al., 2008a,b; Toda et al., 2010). However, the main target of past research was Antarctic krill *Euphausia superba* as a key species in the Antarctic marine food web, as well as being a target fishery. Macrozooplankton were studied, often more as a by-catch, but detailed diversity and community ecology studies were undertaken. Smaller mesozooplankton, such as small copepods of $<3-4$ mm, have been poorly studied, as have the deep-water zooplankton fauna and gelatinous zooplankton in general. There have been few comprehensive studies of the meso- and bathypelagic species, yet the information that does exist suggests very high species diversity (Hosie and Stolp, 1989; Ikeda et al., 1986; Toda et al., 2010). Gelatinous zooplankton often dominate the deeper waters, but they have often been ignored, in part because some are difficult to sample and preserve due to their fragility. CEAMARC, together with the wider CAML program, specifically targeted the meso-zooplankton and gelatinous zooplankton and especially the zooplankton in the deeper water layers.

3. Sampling plan

Sampling in the CEAMARC area was partitioned amongst the ships according to the general habitat studied. The RSV *Aurora Australis* surveyed the benthic communities and demersal fish of the continental shelf and slope down to 2000 m. The TRV *Umitaka Maru* targeted plankton, pelagic and meso-pelagic fish both on and north of the shelf, and the *l'Astrolabe* conducted additional plankton sampling in the inshore coastal region.

Sampling by *Aurora Australis* in the study area commenced on 22 December 2007 (Table 1). Over the next 29 days, 81 stations were surveyed. The topography and the previous habitat classification of Beaman and Harris (2005) were used to predetermine the positions of the stations in order to get representative samples from most habitat types and depths (Fig. 1a). Various traditional sampling gear such as beam trawls (two types 3 m wide × 1.39 m high, and 4.2 m wide × 0.5 m high), benthic sleds, box corers and sediment grabs (Smith-McIntyre and Van Veen types) were used. A high-definition digital video camera was used on 33 of the 3 m beam trawl deployments and a high-resolution digital still camera was used on 39 of the 3 m beam trawl deployments. These provided unprecedented visual information on the biota and habitat type in the path of the trawl, as well as images in their natural disposition of organisms that are prone to being poorly sampled or damaged by traditional sampling. Qualitative and semi-quantitative analyses of the video and still images are still continuing for the purposes of classifying the habitat type and biological communities (Post et al., 2011).

The effects of iceberg gouging on benthic communities and how they responded were of particular interest, as it provided useful indication of the potential impacts of bottom trawling. Sidescan sonar and a towed underwater video were used in conjunction with the beam trawl camera to provide additional data to classify the extent and type of scouring (Beaman and O'Brien, 2009).

In support of the biological sampling, full water column conductivity-temperature-depth (CTD) probe casts were made at each station, in collaboration with the IPY project Climate in Antarctica and Southern Ocean (CASO) (Lacarra et al., 2011). Geochemical studies will also be undertaken for the IPY-GEOTRACES project.

Table 1
Summary of sampling schedule.

Vessel	Start of Sampling	End of sampling	No. Stations	Main sampling gear
RSV *Aurora Australis*	22 December 2007	19 January 2008	81	3 m beam trawl 4.2 m beam trawl CTD and Niskin bottles Van Veen Grab Smith-McIntyre grab Box corer Benthic sled Digital camera and video Continuous Plankton Recorder
RV *l' Astrolabe*	10 January 2008	18 January 2008	20	WP2 net Bongo net CTD and Niskin bottles
TRV *Umitaka Maru*	28 January 2008	12 February 2008	23	RMT 1 + 8 net IYGPT net WP2 net Norpac net Multinet Visual Plankton Recorder CTD and Niskin bottles Continuous Plankton Recorder

The *Umitaka Maru* survey commenced on 29 January 2008, sampling the pelagic communities, protists, plankton, fish and cephalopods through the water column at 23 stations over 15 days, supported by CTD casts (Table 1, Fig. 2). Sampling commenced at 62°S north of the shelf break, and proceeded south along 140°E before continuing west-east across the shelf into the George V Basin. Stations on the shelf were matched as close as possible to stations sampled by the *Aurora Australis* and *l'Astrolabe*. Again, a suite of traditional sampling gear was employed, such as Niskin bottles on a CTD rosette for microbial studies, various plankton nets (WP2, Norpac) to sample the epipelagic zone, and nets to sample the meso- and bathypelagic zones such as a multiple Rectangular Midwater Trawl 1 + 8 (RMT 1 + 8, a standard krill and macrozooplankton survey net in Antarctica), and an International Young Gadoid Pelagic Trawl (IYGPT) net. In order to target the pelagic biota poorly sampled by traditional methods, notably gelatinous zooplankton, video imaging was also employed on this voyage supported by genetic analysis to help identify the species that could be caught. An Autonomous Visual Plankton Recorder (AVPR) developed by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) was used at 10 sites, profiling the water column down to 1000 m, taking both high-resolution video and still images of plankton (Lindsay, 2010). The system also proved useful for classifying and mapping the vertical distribution of marine snow.

L'Astrolabe also conducted a plankton and CTD survey of the epipelagic zone of the continental shelf approximately three weeks prior to the *Umitaka Maru*. Sampling commenced on 10 January, and 20 sites were sampled over 9 days (Table 1, Fig. 1b). CTD cast were conducted and waters samples from 0 to 200 m were collected at all 20 sites, and zooplankton samples were collected by both WP2 and bongo nets at 19 of the stations. This produced useful comparative data with those collected by *Umitaka Maru* a few weeks later, but more importantly, it continued an important time-series dataset on plankton (Swadling et al., 2011) and ichthyoplankton (Koubbi et al., 2011) collected in the CEAMARC area annually by *l'Astrolabe* since 2004, and later in 2009, 2010 and 2011. This has provided essential information on annual variation of

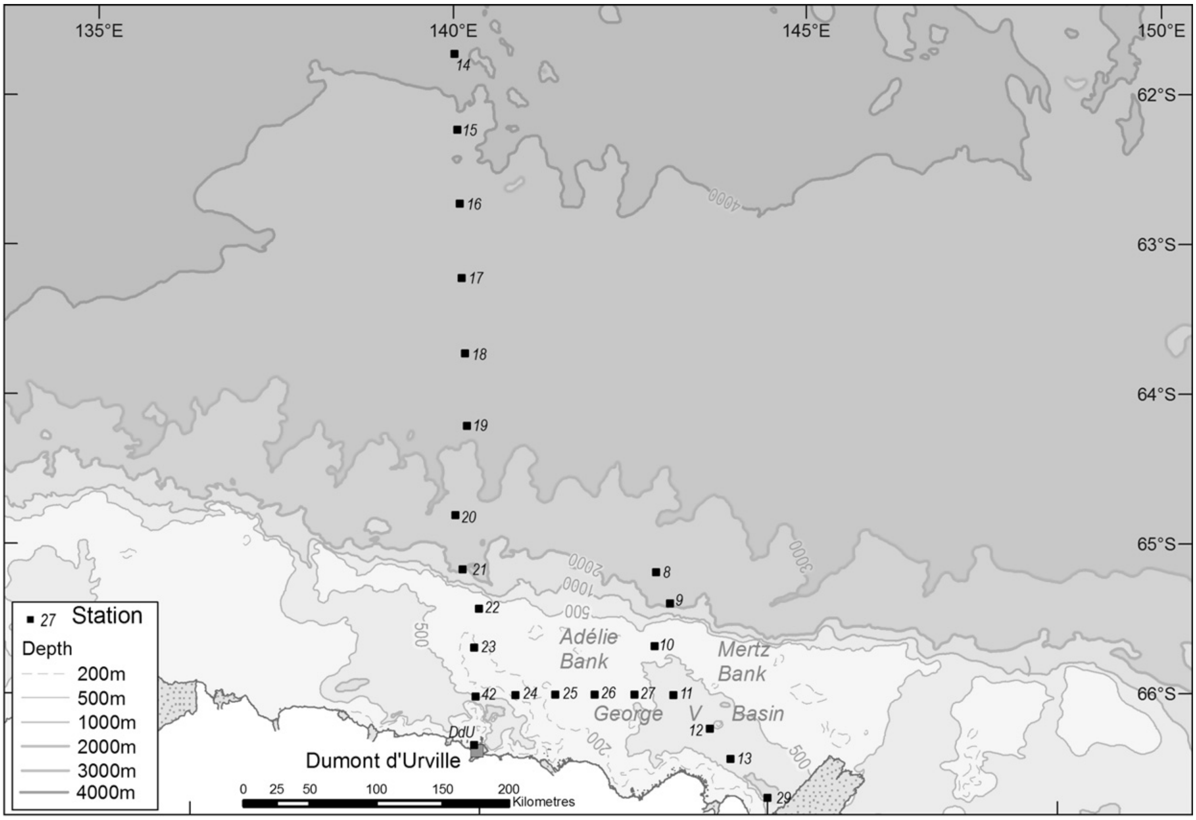

Fig. 2. Station positions for TRV *Umitaka Maru* during CEAMARC 2007/08.

distribution and abundance of the larvae of fish, especially *Pleuragramma antarcticum*, as well as important prey groups such as euphausiids, copepods and phytoplankton.

A particularly important part of the CEAMARC survey was the collection of tissue for DNA barcoding of teleost fish (*Aurora Australis* and *Umitaka Maru*), zooplankton (*Umitaka Maru*) and benthic biota (*Aurora Australis*). The tissue samples were also used for studies of molecular taxonomy, phylogeographic and phylogenetic studies (Dettai et al., 2011a,b). This not only helped identify species and hence the breadth of biodiversity, but also the rate of speciation and evolution patterns within this region and between regions. Tissue samples were also taken during the *Aurora Australis* and *Umitaka Maru* voyages for lipid trophic markers analysis (Mayzaud et al., 2011) and stable isotope analysis to define the trophic relationships of the fish, benthic communities and higher predators (Cherel et al., 2011; Giraldo et al., 2011).

Both the *Aurora Australis* and *Umitaka Maru* towed a Continuous Plankton Recorder (CPR) through most of the Southern Ocean south of Australia on route to and from the CEAMARC survey area (Takahashi et al., 2011). This extended the plankton sampling further north of the CEAMARC area, putting the zooplankton composition and patterns observed in the survey area in context with those of the rest of the Southern Ocean sampled by CPR in 2007/08 and with the larger long term Southern Ocean CPR Survey dataset (Hosie et al., 2003: http://aadc-maps.aad.gov.au/aadc/cpr/index.cfm). The CPR was considered an important survey tool to map the biodiversity of plankton for CAML and the CPR tows conducted from the CEAMARC vessels contributed along with other CAML vessels towing CPRs to a circum-Antarctic synoptic assessment of the mesozooplankton in the summer of 2007/08.

4. Achievements

The papers contained herein are a sort of literary *amuse bouche*, a taste of the work completed to date and an indication of the results still to come.

It is hard to estimate the total volume of samples from all three vessels. Just as an example some 1000 primary samples were collected, as individual net hauls, bottle samples, and sediment samples from 124 sites. For the benthic and demersal samples alone, these were further sorted on board in to 3630 samples or taxonomic lots, comprising one to several individuals for further identification. These were then re-sorted in France to 5633 samples (not including fish, which were identified and studied separately) before detailed taxonomic identification at MNHN or distributed to other experts in Australia, France, Germany, USA, UK, Belgium, Chile and South Africa, along with additional molecular or ecological analyses. From the benthic samples, some 20,000 specimens from 16 phyla were kept for analysis. Approximately 1300 samples of these were taken for COI DNA barcoding, which comprised a substantial contribution to the CAML Barcoding project (Dettai et al., 2011a,b; Grant and Linse, 2009).

An initial ecoregionalisation of the CEAMARC data has been undertaken to determine the biotic assemblages in relation to their geophysical environment in the region using just the fish data from the IYGPT and beam trawls, and using presence-absence data to standardise between nets (Koubbi et al., 2010). Initial results proved useful for describing the ocean zone offshore, more so than over the shelf, for the pelagic ecoregionalisation, whereas the benthic regionalisation based on demersal fish showed a clear difference between continental margins, inner-shelf depressions, banks and coastal zones. The results also showed good correspondence with the past habitat regionalisation by Beaman and Harris (2005) and the new habitat descriptions using CEAMARC data by Post et al. (2010, 2011). The potential has been demonstrated for subsequent defining of a more fine-scale comprehensive ecoregionalisation to describe the biodiversity and habitat preference once the full dataset of plankton, fish, benthos, hydrological, glacial and geophysical data have been combined.

CEAMARC has added considerably to the knowledge of fish species from the area. Early surveys in the eastern Antarctic region had together listed 15 fish species (Blanc, 1961; Hureau, 1962, 1970; Hureau and Arnaud, 1964). The BROKE (Baseline Research on Oceanography, Krill and the Environment) East survey found 21 pelagic fish species (Hoddell et al., 2000) and the French ICOTA project also documented 21 species, although these were mainly demersal (Koubbi et al., 2010). When adding CEAMARC to those surveys, a total of 91 fish species have now been identified in the region belonging to 21 families. 51% of the species belong to the neritic notothenioids, followed by the mesopelagic lantern fish (myctophids), with the Liparidae (Duhamel et al., 2010) and Zoarcidae also well represented. In total 58 species from 8 families are demersal, although some have pelagic stages (Causse et al., 2011). It is clear that the sampling strategy employed, both the use of multiple types of equipment and the extension of the range of sampling beyond that previous attempted, was substantially superior than past surveys and has allowed us to increase significantly the number of species known from this area. This includes the discovery of a new species of fish belonging to the zoarcid eel-pout family (Iglésias et al., in press). Only rays and the toothfish *Dissostichus mawsoni* were missing from our samples but they are known to be present in the area, either as a result of exploratory fisheries for toothfish sanctioned by CCAMLR or, as was the case for rays, they were recorded by the beam trawl cameras.

Sampling conducted from the *Umitaka Maru* allowed precise definition of the transition between the oceanic and the neritic pelagic fish assemblages. The size structures and abundances of meso- and bathypelagic fish were clearly linked to the position of fronts (Slope Front, and Southern Boundary of the Antarctic Circumpolar Current) and the vertical structure of water masses, particularly near the sill between the George V Basin and the deep canyons of the shelf break (Moteki et al., 2011; Koubbi et al., 2011).

In addition to enhancing our knowledge of fish diversity, a detailed study of the trophic position of different fish species was carried out using stable isotope analysis and compared with previous studies of seabirds and mammals foraging in the region (Cherel et al., 2011). There was a particular focus in CEAMARC on understanding the ecology, feeding strategy and trophic role of the Antarctic silverfish *Pleuragramma antarcticum*, an important prey species, and a number of papers in this issue are dedicated to this species (Giraldo et al., 2011; Koubbi et al., 2011; Mayzaud et al., 2011; Vallet et al., 2011). Long term monitoring of larvae of *P. antarcticum* has been conducted from 2004 to 2010 on board *l'Astrolabe* which has identified the position of potential spawning grounds and has enabled assessment of inter-annual variations of this key pelagic species in the neritic zone. The CEAMARC survey allowed us to determine the ontogenetic changes in the trophic position using stable isotopes of C and N (Giraldo et al., 2011) or fatty acid trophic markers (Mayzaud et al., 2011). Larval diets have also been studied for *P. antarticum* in context of the trophic ecology and habitat preferences of this key species (Vallet et al., 2011).

The plankton and krill studies showed the offshore pelagic zone as having a clear distinction between surface waters (0–200 m), an intermediate layer (200–600 m) and deeper layers below 600 m. The studies reinforced the paradigm that the shelf break is a major biogeographic boundary between the offshore waters dominated by Antarctic krill and larger copepod species and the neritic community (Amakasu et al., 2011; Ono et al., 2011). *E. superba* was primarily abundant just north of the shelf edge, with other euphausiids such as *Thysanoessa macrura* and *Euphansia. frigida* more abundant further north. The neritic ice krill *Euphausia crystallorophias* was typically abundant on the shelf (Vallet et al., 2011). However, overall the upper surface waters in both oceanic and neritic regions were dominated by copepods. Inter-annual variations in mesozooplankton were also examined using the data from past surveys from *l'Astrolabe* during the period 2004 to 2008. These showed considerable variation in plankton abundance between years that is unlikely to be caused by temperature or salinity as these parameters remained relatively constant between years. Instead, the variation in abundance was more likely a response to a combination of localised features, such as sea-ice thickness and extent of cover, the position and extent of the Mertz Polynya, local wind conditions and bathymetric features (Swadling et al., 2011).

The stratified net hauls and AVPR have provided the first deep sampling of zooplankton in the meso-bathypelagic layers for this region, especially for the gelatinous zooplankton. The gelatinous zooplankton are a difficult group taxonomically, and these would take some time to analyse and identify properly. It has been hypothesised that gelatinous zooplankton, particularly cnidarians, are likely to increase in dominance as a result of global warming and there was good preliminary indication from this survey that gelatinous zooplankton, especially large medusae were more abundant than in previous surveys in the region. During CEAMARC, 63 of the 131 species of cnidarian medusa known from Antarctic waters were observed in the survey area. This included the rediscovery of species not recorded for many decades, and the discovery potentially of new species. Some species that were taxonomically in doubt can now be re-described and modern molecular genetics techniques can be used to confirm their taxonomic place.

Analysis of the benthic samples will also take some time to complete due to the volume of samples and diversity of taxonomic groups. Much has been done already with the demersal fish (Causse et al., 2011) and the DNA barcoding of fish and benthos (Dettai et al., 2011a,b). Among the radiation studies, two teleost fish species flocks have been recognised according to the criteria of Eastman and McCune (2000), mainly using samples from CEAMARC: Trematomine (Lautredou et al., 2010) and artedidraconids (Lecointre et al., 2011). Moreover, some 15 h of video data and 1800 still images have been collected and preliminary analyses using semi-quantitative methods have highlighted the value of digital imaging to define habitat variability and community composition at a much finer scale than can be achieved by traditional trawling. In particular, the analysis of the visual data has led to an early significant achievement. A number of unique calcareous benthic communities of high biodiversity were identified as deep as 860 m, close to the calcium carbonate (aragonite) saturation horizon – the depth at which calcium carbonate in its aragonite form will dissolve unless actively maintained by a biological process. Any change in the position of the saturation horizon, through a change in temperature or decrease in pH is likely to affect these unique communities. Two of these areas have subsequently been declared Vulnerable Marine Ecosystems based on the visual imaging alone. The visual data were presented to the CCAMLR XXVII meeting in Hobart November 2008, which recognised the deep coral-sponge communities as being of high conservation value due to the high biodiversity of unique benthos. This resulted in CCAMLR registering two areas of 400 km^2 as VMEs (Post et al., 2010). Appropriate conservation measures were set to protect both VMEs from further bottom fishing in these areas. One VME is located on the shelf slope north of Dumont d'Urville centred around station 79–81 (Fig. 1a), the other (station 65) on the shelf slope of the Adélie Sill where Antarctic bottom flows out of the George V Basin (Fig. 1a).

Another major achievement was an extensive Education and Outreach programme that provided schools and the general public with information on the progress of CEAMARC through dialogues, video and still images from scientists on board ship being sent daily from the ships to the CAML (www.caml.aq) and CEAMARC (http://mersaustrales.mnhn.fr/) websites. Students were able to interact to some degree with shore- and ship-based scientists to ask questions about the CEAMARC science. At a higher level, 12 Ph.D. and 13 M.Sc. students participated on the voyages or have used data/samples from CEAMARC for their dissertations. A substantial number of the near 50 CEAMARC scientists were also early career scientists, some of them are first authors or co-authors of papers of this special issue. All this has led to a renewed and enhanced collaboration between the participating countries, notably building on the existing bilateral collaborations between Australia, Japan, France and Belgium. This collaboration and the results of CEAMARC will further benefit future generations of scientists and students.

5. Conclusion

From the outset, the CEAMARC project was considered ambitious. In many respects we have exceeded our expectations in terms of the volume of samples and data collected, and the breadth of science completed. However, there is still more we can learn about the ecology of the region. Extensive samples of plankton, fish and benthos were collected for genetic and molecular analyses to improve our taxonomic knowledge and address the CAML objective of understanding species radiation. Detailed traditional taxonomic analyses, combined with new genetic analytical methods have defined new geographic and/or bathymetric distributions for many species, recorded a number of rare species, and identified a number of potentially new species of gelatinous zooplankton and benthic organisms.

We also knew prior to the survey that the Mertz Glacier Tongue would at some stage break off, leading to scouring of the seafloor and benthic communities, and potentially altering both the hydrographic flow through the region and the production of sea-ice. The glacial tongue did break off in February 2010. CEAMARC has collected sufficient samples with sufficient sampling intensity and resolution to set the required benchmark of biodiversity in the survey area for the pelagic, meso-bathypelagic and benthic environments. The data will then be combined with the geomorphology, sediment types and well defined hydrographic and sea-ice models to develop detailed habitat models for individual species and communities prior to the detachment of the Mertz Glacier Tongue. Subsequent surveys will then be able to determine the degree of change resulting from the ice tongue event.

The long term aim once all data have been collated is to attempt a combined pelagic-benthic regionalisation of the CEAMARC region that will provide the required foundation of biodiversity that will allow us to track changes over time and to help address conservation issues such as Marine Protected Areas or Vulnerable Marine Ecosystems. The biodiversity benchmark and the subsequent ecoregionalisation models will also allow us to:

- Compare other changes in biodiversity with future CAML surveys and also with past surveys.
- Define legacy sites in the survey area for future CAML surveys and interim annual or biennial

monitoring programmes to monitor the effects of climate change.

- Determine which species are most likely to be affected by climate change and those most likely to survive.
- Contribute to models looking at long term changes in species composition, ecosystem structure and function, survivorship of key species, effects of global warming, ocean acidification, and impacts on ecosystem service.
- Study the impact of trawling and iceberg scouring on the benthic and demersal communities.
- Compare pelagic, demersal and benthic communities in the survey area with those in the other CAML survey areas around Antarctica.

A quick oceanographic survey of the CEAMARC area has since been conducted by Australia from the *Aurora Australis* in January 2011 to determine how much the hydrology has changed in the area. Some biology was also conducted. The results of that voyage are still pending. However, at sometime in the future - in 5, 10 or 20 years time - another comprehensive census will need to be conducted again in order to properly gauge the degree of change in biodiversity, natural or otherwise. A single census is not enough. The challenge for the current generation of students and young scientists will be to conduct that census, and if necessary, develop new methods to improve our knowledge further.

Acknowledgements

We are extremely grateful to all the scientists, students, officers, crew and cadets of the ships, for their efforts, their commitment and their camaraderie that have made CEAMARC so successful. It has been an outstanding team. We are also grateful to the authors for their contributions to this special issue and the referees for their time and effort. The support and dedication of the Polar Science office in Tokyo, Editor-in-Chief Prof. Kazuo Shibuya and his secretarial team of Ayuko Natori, Yoriko Hayakawa, Haruko Fujii and Mami Iwadare, needs to be acknowledged especially for their ability to maintain the editorial process at a time of great difficulty in Japan following the East-Japan Earthquake and Tsunami. The CEAMARC voyages were supported by the Australian Antarctic Division as AAS project no. 2792, by the French polar institute IPEV (ICOTA programme 281, ICO^{2}TA programme 1142, and REVOLTA programs), Zone Atelier Antarctique of CNRS, the MNHN and the ANR Glides and ANTFLOCKs (USAR n°07-BLAN-0213-01), the Grant-in Aid for Scientific Research from the Japan Society for the Promotion of Science (Nos. 114255012 and 19255014), the Tokyo University of Marine Science and Technology, the National Institute of Polar Research, and by BELSPO (Belgium) through PELAGANT and the PADI (SD/BA/851) programmes. Finally, on a personal note I (GWH) would like to thank my guest associate editors for their excellent contribution, and also Prof. Michael Stoddart, Project Leader of CAML, ably assisted by CAML Project Manager Dr Victoria Wadley, for the confidence and support in letting me lead the CEAMARC project.

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