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

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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.

Summer hydrography on the shelf off Terre Adélie/George V Land based on the ALBION and CEAMARC observations during the IPY

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We report on the hydrographic observations collected on the Antarctic continental shelf between 138° E and 146° E as part of the CEAMARC and ALBION projects in December 2007–January 2008. A total of 140 quasi-synoptic CTD (Conductivity–Temperature–Depth) casts were analysed to map the spatial distribution of the summer hydrographic properties. Seven distinct hydrographic regimes were identified based on regional topographic features and the presence of specific water masses. These regimes are associated with spatial contrasts in the distribution of the High Salinity Shelf Water (HSSW) and the Modified Circumpolar Deep Water (MCDW). In particular, the HSSW distribution confirms the unique character of Commonwealth Bay in terms of extreme bottom salinity and dissolved oxygen values. The bay appears to be a preferred region for both dense shelf water formation and storage. The systematic survey of the Adélie Depression shows the ubiquitous presence of

HSSW in the depression, and over the Adélie Sill as a 60 m thick layer at the centre of the sill. This water is dense enough to mix down the continental slope and form Antarctic Bottom Water. Upstream of the sill, the HSSW is shown to sit over the topography with indications of recirculation. The D'Urville Trough, another deep basin on the shelf, is filled with warmer and fresher water that is too light to contribute to the formation of AABW. The D'Urville Trough appears to collect MCDW which enters at the shelf break over the Adélie Bank and spreads over the northern slope of the trough. Another branch of MCDW enters in the eastern Adélie Sill and is found almost everywhere in the Adélie Depression with the noticeable exception of the coastal bays. Additional CTD casts collected during the ALBION-2009 experiment in January 2009 suggest that most of the features observed in 2008 in the Adélie Depression should be robust on a year-to-year basis although summer 2009 was characterized by fresher dense shelf waters.

A GIS approach to estimating interannual variability of sea ice concentration in the Dumont d'Urville Sea near Terre Adélie from 2003 to 2009

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A Geographic Information System (GIS)-based investigation into the interannual variability of sea ice concentration was conducted in the Dumont d'Urville Sea off the Terre Adélie coastline, south of 65° S and between 139 and 146° E. Sea ice concentration data derived from Advanced Microwave Scanning Radiometer-EOS (AMSR-E) data were analysed for the period 2003 to 2009. Sea ice concentration was found to be least variable in three regions, namely the Buchanan Bay/Watt Bay region (143–145° E), along 65.5° S (west of 144.5° E), and the Adélie Bank northeast of Dumont d'Urville near 66° S, 140.5° E. The remaining areas had relatively high interannual variability, in particular the Adélie Basin (66° S, 140° E) and the outer fringe of the Mertz Glacier Polynya (MGP). In general, higher sea ice concentration conditions were experienced in the west of the study area (i.e., where annual fast ice recurs), and open water dominated in the MGP and in the northeast. The years 2007–2009 experienced greater persistence of higher sea ice concentration than earlier years. This study provides a baseline for assessing changes in the regional sea ice regime that may occur since the calving of the Mertz Glacier in February 2010.

Interannual variability of zooplankton in the Dumont d'Urville sea (139° E – 146° E), east Antarctica, 2004–2008

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Spatial and temporal variability of zooplankton was studied during five summers (2004–2008) in the Dumont d'Urville Sea, east Antarctica. The species recorded, based on the catch of a 500 μ m-mesh Bongo net, were typical of southern

continental shelf communities in Antarctica, including *Euphausia crystallorophias*, polychaetes, pteropods and biomass-dominant copepods. There was a strong degree of temporal variation in abundance, possibly related to the thickness and extent of the sea ice cover during each spring prior to the surveys. Total mean abundance was highly variable between years, with a minimum of 961 ind. 1000 m⁻³ in 2004 (range 65–3407 ind. 1000 m⁻³) and a maximum of 15,627 ind. 1000 m⁻³ in 2005 (range 5109–33,869 ind. 1000 m⁻³). Spatially, within each year, abundances were also variable, and there were no uniform patterns in abundance from year to year. Water column physical characteristics (temperature and salinity) were relatively constant and did not contribute substantially to variation between the years. It is likely that variation in zooplankton distribution was largely related to a combination of localised features, such as the thickness and extent of sea ice cover, the position and extent of the Mertz Polynya, local wind conditions and bathymetric features.

Surface zooplankton distribution patterns during austral summer in the Indian sector of the Southern Ocean, south of Australia

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We investigated the composition, distribution and abundance of micro- and mesozooplankton in the Southern Ocean, south of Australia during the austral summer (December–February) of the 2007/08 season using a Continuous Plankton Recorder (CPR). Four CPR tows were conducted during two separate oceanographic voyages under the CEAMARC (Collaborative East Antarctic Marine Census) project. High zooplankton abundance was recorded on each transect in the Polar Frontal Zone (PFZ) and the Inter Polar Frontal Zone (IPFZ). The community structure in these zones was dominated by common taxa including the ubiquitous small calanoid copepods, *Oithona similis* and *Calanus simillimus*, accounting for >70% of the total abundance, and copepod nauplii, foraminiferans and appendicularians of the genus *Fritillaria* spp. also occurred along most of the survey transects. Total zooplankton abundance was comparatively consistent along the four transects, and ranged between 119.8 and 144.7 ind m⁻³. The results of cluster and IndVal analyses revealed that the dominant species/taxa show similar associations, abundance and distribution patterns on all four transects. There was no evidence of a change of surface zooplankton abundance at the time of towing in this study. Detecting the various distribution patterns of micro- and mesozooplankton species/taxa, and the accumulation of high quality data collected by a consistent methodology will contribute to determining the consequences of climate change impacts on the ecosystem.

Euphausiid community structure and population structure of *Euphausia superba* off Adélie Land in the Southern Ocean during austral summer 2003, 2005 and 2008

Atsushi Ono, Masato Moteki, Kazuo Amakasu, Ryoji Toda, Naho Horimoto, Daisuke Hirano, Takashi Ishimaru, Graham W. Hosie

The distribution and community structure of euphausiids and the population structure of *Euphausia superba* were investigated mainly along 140° E off Adélie Land in the Indian Ocean sector of the Southern Ocean during the austral summers of 2003, 2005 and 2008. Euphausiids were collected from six discrete depth layers, primarily between 0 and 2000 m, using an RMT 8 net. *Euphausia frigida* and *Euphausia triacantha* mainly occurred north of the Southern Boundary of the Antarctic Circumpolar Current (SB) whereas *E. superba* was distributed south of the SB, and occurred abundantly in the continental slope area where Antarctic Winter Water was observed. *E. frigida* and *E. triacantha* occurred in the upper 200 m during the night whereas they were mainly found below 200 m during the daytime. Cluster analysis on stations suggested that the SB is an important biological boundary for euphausiid communities. The population structure of *E. superba* in 2003 was different from that of 2005 and 2008. While large mature individuals dominated in 2003, small immature krill (juveniles and subadult males) were more abundant in 2005 and 2008. Further sea-ice extension in the preceding winter in 2005 and 2008 likely provided favourable conditions for spawning and survival. A cluster analysis based on similarity of the maturity stages of *E. superba* revealed that mature males and gravid females (stage IIIC–E) were mainly distributed in the offshore area and mesopelagic zone, while juveniles and subadult males were found in the epipelagic zone of the continental slope area. Therefore, it is considered that *E. superba* migrates to the offshore area and mesopelagic zone as it grows.

Interannual variations in euphausiid life stage distribution in the Dumont d'Urville Sea from 2004 to 2008

Carole Vallet, Jean-Philippe Labat, Martina Smith, Philippe Koubbi

Euphausiid larvae were caught by oblique tows of a double-framed bongo net at 118 stations along the coast of Terre Adélie during every summer from 2004–2008.

Larvae of *Euphausia crystallorophias* Holt and Tattersall and *Thysanoessa macrura* G.O. Sars were observed in the study area every year in contrast to larvae of *Euphausia superba* which were absent during the entire period of sampling. Highest abundances of both species were observed during the summer of 2005 and the lowest in the summer of 2004. Larvae of *E. crystallorophias* dominated every year and comprised more than 80% of the total abundance of euphausiid larvae. Within species, the calyptopis stages especially calyptopis 1 of *E. crystallorophias* dominated compared to furcilia stages of *T. macrura* which were less abundant. For both species, spatio-temporal variations in abundances of developmental stages were significantly correlated to density and salinity of the deep water layer. In the case of calyptopis 3 of *E. crystallorophias*, spatio-temporal variations were correlated with the number of days between the end of the sea ice retreat and the sampling day and for *T. macrura* inversely correlated to temperature of surface water layer. These variations are discussed and related to the timing of sea ice

retreat, the sea ice concentration as well as metabolic conditions of adults of both species during their spawning period.

Sexual dimorphism in body shape of Antarctic krill (*Euphausia superba*) and its influence on target strength

Kazuo Amakasu, Atsushi Ono, Masato Moteki, Takashi Ishimaru

Sexual dimorphism in the body shape of Antarctic krill (*Euphausia superba*) was investigated and its influence on target strength (TS) was clarified using a theoretical scattering model. The TS which is used to convert acoustic backscatter to krill density was also presented. Body shape data were obtained from 456 specimens (54 juveniles, 200 males, and 202 females) collected off Adélie Land using a Rectangular Midwater Trawl. The sexual dimorphism manifested as a swollen cephalothorax in female krill with body lengths exceeding 40 mm. The TS of female krill was higher than those of male krill at low frequencies, even when body lengths were the same. This is because of the Rayleigh scattering region and the transition region to the geometric scattering region. The influence of the sexual dimorphism on the TS was small at frequencies exceeding 70 kHz, which are close to the geometric scattering region. The regression curve derived from the predicted TS of 456 specimens was in reasonable agreement with the measured TS in other previous studies, and the regression curve could be applied to the acoustic surveys of Antarctic krill.

Distribution and density of Antarctic krill (*Euphausia superba*) and ice krill (*E. crystalloporhys*) off Adélie Land in austral summer 2008 estimated by acoustical methods

Kazuo Amakasu, Atsushi Ono, Daisuke Hirano, Masato Moteki, Takashi Ishimaru

From January to February 2008 the training research vessel TRV *Umitaka Maru* conducted a comprehensive oceanographic survey of the waters around the 140° E meridian off Adélie Land as part of the Collaborative East Antarctic Marine Census (CEAMARC) project. The acoustic component of this survey was conducted using a scientific echosounder operating at 38 and 70 kHz to estimate the distribution and density of Antarctic krill (*Euphausia superba*) and ice krill (*E. crystalloporhys*). In addition, the relationship between the vertical distribution of Antarctic krill and the water temperature structure along the 140° E meridian was investigated. Antarctic krill were distributed in the waters of the continental slope at 65–66° S and the maximum value of the mean areal density ρ in 1 nautical mile (nmi) intervals was 4344 inds. m⁻². Ice krill were distributed in the neritic waters of the continental shelf to the south of the 66° S and the maximum ρ in 1 nmi intervals was 23,669 inds. m⁻². Along the 140° E meridian, Antarctic krill were mainly distributed at the water temperatures below 0.5 ° C. Although they were mostly distributed shallower than approximately 100 m, dense aggregations at approximately 180–200 m were also observed, which coincided with a depression of the water temperature structure.

Size distribution of meso- and bathypelagic fish in the Dumont d'Urville Sea (East Antarctica) during the CEAMARC surveys

Philippe Koubbi, Percy-Alexander Hulley, Patrice Pruvost, Pauline Henri, Jean-Philippe Labat, Victoria Wadley, Daisuke Hirano, Masato Moteki

The pelagic fish community of the Dumont d'Urville Sea (East Antarctica) was investigated during the 2008 austral-summer using IYGPT (International Young Gadoid Pelagic Trawl) samples taken in different depth layers from the surface to 1000 m. The aim of this paper is to describe the mesopelagic fish community and its size distribution. The family Myctophidae dominated the mesopelagic ichthyofauna, while bathylagids were abundant in deeper hauls. Bathylagids, *Cyclothone* spp., *Gymnoscopelus opisthopterus*, *Electrona antarctica*, *Protomyctophum bolini*, and *Krefflichthys anderssoni* were the most abundant taxa in the samples and showed size stratification with depth. Community and size structuring appear to be influenced by the hydrology and by the proximity of the continental margin, as well as a relationship to the circulation of the Modified Circumpolar Deep Water.

Spatial distribution of pelagic fish off Adélie and George V Land, East Antarctica in the austral summer 2008

Masato Moteki, Philippe Koubbi, Patrice Pruvost, Eric Tavernier, Percy-Alexander Hulley

Pelagic fish assemblages and community structure were examined along longitudinal and meridian transects off Adélie and George V Land, East Antarctica, in the austral summer 2008. Fish were sampled with an RMT 8 net principally from six discrete depth layers (0–50–100–200–500–1000–2000 m) in the oceanic zone and from three depth layers (0–50–100–200 m) over the continental shelf zone. A total of 20,281 individuals from 27 species were collected. *Pleuragramma antarcticum* was the most dominant species by number (18,710 inds), followed by *Chionodraco hamatus* (768), *Trematomus newnesi* (375), *Cyclothone microdon* (101), *Electrona antarctica* (92), *Bathylagus antarcticus* (51) and *Notolepis coatsi* (54). Cluster analysis revealed that the fish community was clearly divided at the Antarctic Slope Front into separate oceanic and shelf assemblages, being dominated by mesopelagic fish and notothenioids, respectively. The Southern Boundary of Antarctic Circumpolar Current likely restricted a more northern distribution of notothenioids in the upper 200 m. Mesopelagic fish dominated the large biomass below 500 m and notothenioids dominated that in the upper 100 m. It is considered that mesopelagic fish in the oceanic zone would unlikely be eaten by seabirds because no distinctive diel vertical migration to the surface layer was observed. In the neritic zone, notothenioids (*C. hamatus*, *T. newnesi* and *P. antarcticum*) possibly play an important role as prey items for flying seabirds, penguins and other notothenioids fish especially in the shallow depth stratum (0–100 m).

Spatial distribution and inter-annual variations in the size frequency distribution and abundances of *Pleuragramma antarcticum* larvae in the Dumont d'Urville Sea from 2004 to 2010

Philippe Koubbi, Colleen O'Brien, Christophe Loots, Carolina Giraldo, Martina Smith, Eric Tavernier, Marino Vacchi, Carole Vallet, Jean Chevallier, Masato Moteki

This paper investigates the abundance and distribution of *Pleuragramma antarcticum* larvae by size class in the Dumont d'Urville Sea from 2004 to 2010. Samples were collected between Dumont d'Urville station and the Mertz Glacier Tongue onboard the RV / *Astrolabe* for studying the inter-annual and spatial distribution of fish larvae and the TRV *Umitaka Maru* for looking at life stages vertical distributions. The seabed depression adjacent to the Mertz Glacier Tongue and in Commonwealth Bay hosted high abundances of small *P. antarcticum* larvae, while larger larvae were found in lower abundance and further offshore. We found that canyons, sea ice, stability of the water column and temperatures are important features for determining suitable areas for young larvae.

Food preferences of larvae of Antarctic silverfish *Pleuragramma antarcticum* Boulenger, 1902 from Terre Adélie coastal waters during summer 2004

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Ichthyoplankton samples were collected from 19 to 31 January 2004 in the Dumont d'Urville Sea (East Antarctic shelf). The Nototheniidae *Pleuragramma antarcticum* comprised more than 90% of the sampled larvae. Gut contents of 95 *P. antarcticum* larvae were examined. Most larvae fed on phytoplankton, especially diatoms, whereas some other specimens had a mixed diet with phyto- and zooplankton prey. A single specimen fed exclusively on copepods. The stomach contents was dominated by three diatoms taxa, such as *Thalassiothrix antarctica*, *Fragilariopsis* spp. and *Chaetoceros* spp. Prey selection was apparently food density dependent, with an inverse relationship between food abundance and selection feeding. Larvae selected positively some diatoms, such as *Coscinodiscus* spp. and *T. antarctica*, presenting a low concentration in the water column compared to *Fragilariopsis* spp., which were strongly negatively selected. During summer, larvae were opportunistic feeders with a broad trophic niche, which allowed them to switch between different food types.

Ontogenic changes in the feeding ecology of the early life stages of the Antarctic silverfish (*Pleuragramma antarcticum*) documented by stable isotopes and diet analysis in the Dumont d'Urville Sea (East Antarctica)

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The feeding ecology of the notothenioid fish *Pleuragramma antarcticum* was studied in the Dumont d'Urville Sea (East Antarctica) near the French Antarctic station. Stable isotopes ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) and diet contents were used in order to study

dietary shifts between fish larvae and juveniles. All specimens had low $\delta^{13}\text{C}$ values ($<-24\text{‰}$), a main characteristic of high-Antarctic pelagic species. Fish larvae showed differences in both carbon and nitrogen ratios when compared with juveniles. Muscle $\delta^{15}\text{N}$ values showed a difference of one trophic level ($\approx 3\text{‰}$) between larvae (6.7‰) and juveniles (9.7–10.0‰) and a trophic position of tertiary consumers. Diet content analyses (stereomicroscope and scanning electron microscopes) indicated that larvae are omnivorous, feeding on phytoplankton (mainly diatoms) as well as on zooplankton species. A positive relationship between $\delta^{15}\text{N}$ values and size was found and indicated a carnivorous diet for older specimens.

Lipid composition of the Antarctic fish *Pleuragramma antarcticum*. Influence of age class

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Larvae and juvenile stages of *Pleuragramma antarcticum* have been collected in the Dumont D'Urville Sea (East Antarctica) during summer 2008 on board the TRV Umitaka Maru during the CEAMARC survey. Detailed analyses of their lipid class and fatty acid compositions were carried out. *P. antarcticum* showed a pronounced ontogenic lipid accumulation with increasing size. Larvae displayed a dominance of polar lipids (83% of total lipids) and low percentage of triglycerides (7%). Conversely juveniles showed an increasing accumulation of triglycerides (up to 72.4%). The fatty acid composition of polar lipids remained rather stable between stages with 22:6n-3 and 20:5n-3 as dominant contributors. The relatively minor ontogenic changes, e.g. increase of monounsaturated and decrease of C18 polyunsaturated fatty acids, may reflect the influence of differences in diet. Triglycerides showed that all three age classes are well segregated in term of fatty acid composition. Larvae triglycerides are characterized by significant percentages of 16:0, 20:5n-3, 20:6n-3 and to a minor extent 18:4n-3, which suggest a prymnesiophyte based diet. Juveniles are characterized by larger percentages of C20:1 and C22:1 acids, considered as markers of *Calanus* type copepods. The increasing contribution of 18:1n-9 in the triglycerides of the older juveniles suggests a gradual and increasing shift from a copepod dominant diet to an euphausiid dominant diet. Fatty acid trophic markers pattern suggests a shift from a phytophagous and omnivorous diet for larvae to a carnivorous diet for juveniles.

Demersal ichthyofaunal shelf communities from the Dumont d'Urville Sea (East Antarctica)

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The RSV Aurora Australis survey allowed the first comprehensive study of the demersal ichthyofaunal environment and of the diversity of the Dumont d'Urville Sea. We observed a high dominance of the Notothenioidei in both the number of species

and in integrated abundances. The Nototheniidae was the most abundant family with 44.7% of the total integrated abundance, followed by Bathydraconidae (18.8%). *Trematomus eulepidotus* was the dominant species with 19.9% of the total individuals catch. Nevertheless, 43 of the 53 species caught could be considered as very rare. The Bathydraconidae was the most diversified family with 11 species caught. The highest integrated abundances of fish were found from 400 to 800 m. Well-structured species communities were observed, with high species richness from 570 to 681 m. The richest zones were located along the basins and along their upper-sides. Statistical analyses indicated large-scale spatial patterns in species composition, with clear differences in fish communities from the continental slopes, the basins and on the shelf. At a finer spatial scale, the current in the George V Basin and iceberg scouring on the banks and their sides tended to create locally heterogeneous small-scale habitats. We suggest that the glacial history and the structured habitats allowed successive colonisations of the seabed by demersal fish.

Isotopic niches of fishes in coastal, neritic and oceanic waters off Adélie land, Antarctica

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We used the stable isotope method to investigate the ecological niches of Antarctic fishes, with $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ as proxies of fish habitats and dietary habits, respectively. Muscle isotopic signature was measured for each of 237 delipidated tissue samples from 27 fish species collected offshore Adélie Land, East Antarctica. Overall, $\delta^{13}\text{C}$ values ranged from -25.3‰ to -18.2‰ , thus allowing characterizing of the fish habitats, with inshore/benthic species having more positive $\delta^{13}\text{C}$ signatures than offshore/pelagic ones. No clear difference in the $\delta^{13}\text{C}$ values of pelagic fishes was found between species living in neritic and oceanic waters. Overall, the $\delta^{15}\text{N}$ signatures of neritic pelagic and epibenthic fishes encompassed 1.0 trophic level (3.1‰), a higher difference than that (1.4‰) found within the oceanic assemblage. Fishes with the lowest and highest $\delta^{15}\text{N}$ values are primarily invertebrate- and fish-eaters, respectively. The isotopic niches of fishes illustrate the different mechanisms allowing coexistence, with most fishes segregating at least by one of the two niche axes ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$). Muscle isotopic values also document interindividual foraging specialization over the long-term in coastal benthic fishes, but not in more offshore pelagic species. Finally, the $\delta^{15}\text{N}$ signatures of fishes overlap with those of penguins and seals, indicating that seabirds and marine mammals share the upper levels of the Antarctic pelagic ecosystem with some large fish species. In conclusion, the concept of isotopic niche is a powerful tool to investigate various aspects of the ecological niche of Antarctic fishes, thus complementing the use of other conventional and non-conventional approaches.

DNA barcoding and molecular systematics of the benthic and demersal organisms of the CEAMARC survey

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The Dumont d'Urville Sea (East Antarctic region) has been less investigated for DNA barcoding and molecular taxonomy than other parts of the Southern Ocean, such as the Ross Sea and the Antarctic Peninsula. The Collaborative East Antarctic MARine Census (CEAMARC) took place in this area during the austral summer of 2007–2008. The Australian vessel RSV Aurora Australis collected very diverse samples of demersal and benthic organisms. The specimens were sorted centrally, and then distributed to taxonomic experts for molecular and morphological taxonomy and identification, especially barcoding. The COI sequences generated from CEAMARC material provide a sizeable proportion of the Census of Antarctic Marine Life barcodes although the studies are still ongoing, and represent the only source of sequences for a number of species. Barcoding appears to be a valuable method for identification within most groups, despite low divergences and haplotype sharing in a few species, and it is also useful as a preliminary taxonomic exploration method. Several new species are being described. CEAMARC samples have already provided new material for phylogeographic and phylogenetic studies in cephalopods, pycnogonids, teleost fish, crinoids and sea urchins, helping these studies to provide a better insight in the patterns of evolution in the Southern Ocean.