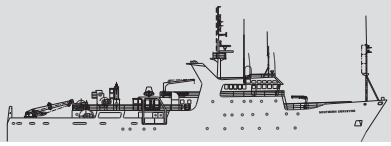

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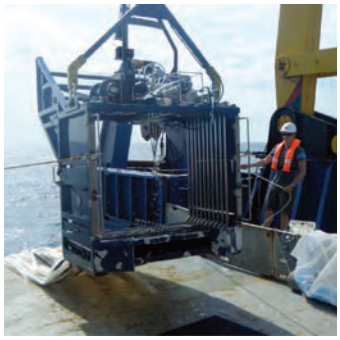
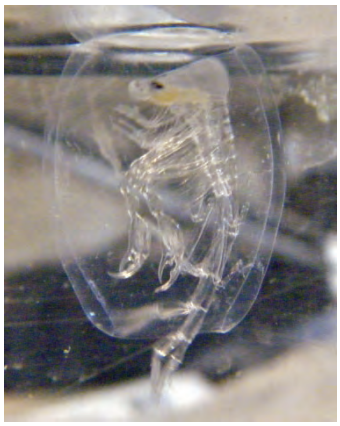
voyage summary SS2010_v08





SS2010_v08

Krill in 3D – Vertical stratification and spatial distribution of krill communities in the East Australian Current

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Voyage period

Start: 22/09/2010

End: 05/10/2010

Port of departure: Sydney, Australia

Port of return: Sydney, Australia

Responsible laboratory

Fisheries And Marine Environmental Research, University of NSW
School of Biological Earth and Environmental Sciences,
University of NSW, UNSW, SYDNEY 2052, Australia

Chief Scientist

Dr. Matthew D Taylor
Fisheries and Marine Environmental Research, University of NSW

Prof. Iain M Suthers
Fisheries and Marine Environmental Research, University of NSW

Scientific Objectives:

Greater than 90% of the organic matter exported from the epipelagic zone (surface – 100 m) is remineralised into nutrients, microelements and CO_2 in the mesopelagic zone (100 – 1000 m), and returned to the surface on decadal scales or less (Karl et al., 2008). The mesopelagic zone therefore significantly dampens the downward transfer of organic matter to the deep ocean, and acts as a positive feedback to global warming. Despite their importance in understanding the efficiency of the biological pump, little is known about the processes that control the remineralisation of CO_2 in the mesopelagic zone, or its regional variation. These are considered to be related to relationship between the epipelagic and mesopelagic food-webs, both of which are generally poorly studied in temperate systems. This is necessary to understand outcomes of climate variation from nutrients to fish and whales. We will achieve this by characterising the energetic linkages between epipelagic and mesopelagic food webs, to determine the storage and passage of energy. We will identify how oceanographic variability affects the outcomes of interspecific interactions across spatially separated communities, and the consequences for ecosystem dynamics.

Our overall scientific objective was to describe the euphausiid community in the temperate EAC, and establish linkages between euphausiids and other zooplankton, and oceanography. Specifically this project will:

1. Investigate krill diversity and life histories in the temperate EAC in 3 dimensions, accounting for variation in community composition across latitudinal, cross-shelf, and vertical gradients;

2. Evaluate the relationship between oceanography, and krill and fish biomass and distribution;

3. Determine trophic relationships amongst co-occurring euphausiid species using stable isotope analysis, and trophic interactions with other zooplankton;

4. Investigate the ecosystem properties of krill in different habitats through size frequency analyses, using a Laser Optical Plankton Counter (LOPC) to detect euphausiids, and evaluate the effect of euphausiids on biomass size spectrum (BSS) model parameters and fish larvae.

The study will survey vertical stratification in euphausiid and zooplankton communities between the epi-pelagic and mesopelagic zone, and connectivity between these two zones during the day and night. Four cross-shelf transects will be undertaken along the NSW coast:

1) Tasman Current (~34.5°S);
2) Stockton Bight (~33.0°S);
3) EAC separation zone (~32°S);
4) The EAC (~30.5°S).

Final latitudes were determined just prior to the voyage from MODIS SST and chlorophyll images, and sampling was undertaken in relation to oceanographic features including a cold core and warm core eddy. MOCNESS deployments will occur at 3 stations along each transect over two days, with the net being towed along the respective isobaths at each station.

Voyage Objectives

1) To sample krill on the shelf, slope and ocean at 4 latitudes off the NSW coast, by deployments of the Multiple Opening Closing Environmental Sampling System (MOCNESS). This unit will comprise the standard Southern Surveyor EZ net, which has been equipped with environmental sampling equipment belonging to the University of New South Wales and fitted to the net frame. This equipment will include a Seabird19plus SEACAT CTD equipped with Wetlabs FLNTU, a Brooke Ocean Laser Optical Plankton Counter (LOPC), and a strobe light.

2) Deployment of the CTD and vertical hauls of the N70 net from 50 m depth at each station to collect high resolution oceanographic information, collect water samples for phytoplankton, and zooplankton in the upper mixed layer.

3) Continual collection of acoustic backscatter data from that EK500 at 38 kHz and 120 kHz frequency along the voyage track to correlate with vertically stratified EZ net samples.

Results

1. Investigate krill diversity and life histories in the temperate EAC in 3 dimensions, accounting for variation in community composition across latitudinal, cross-shelf, and vertical gradients;

The entire epipelagic (100 m - surface) and upper mesopelagic (500 m - 100 m) assemblage was sampled across 4.5° of latitude, with the Rectangular Midwater Trawl (RMT) and Multiple Opening and Closing Environmental Sampling System (MOCNESS). Transect 1 commenced off the southern NSW coast, at 35.80S 152.00E, at the centre of a stable warm core eddy (Figure 1 and 2). A CTD transect was undertaken from this point west to 35.32S 150.77E, and comprised 7 stations which terminated in shelf water of approximately 120 m depth (Figure 3). RMT and MOCNESS deployments were undertaken at 8 stations along this transect and included 2 stations in the WCE centre, 2 stations at the WCE edge, 2 stations on the slope and 2 stations on the shelf; and deployments were replicated across day and night over 2 days. Due to problems with the MOCNESS this transect was sampled with the RMT at the commencement of the voyage. Once repairs were made and Transects 2 and 3 sampled, we returned to sample Transect 1 as per the original design with the MOCNESS.

At the conclusion of Transect 1 the ship travelled to the centre of a persistent cold-core eddy (CCE, 33.81S 153.11E) to commence Transect 2 into the Stockton Bight (32.82S 152.23E; Figure 1 and 2). Over the days preceding sampling a large surface chlorophyll signature at the centre of the CCE had been decreasing, and was almost completely non-existent upon arrival at the station. We hypothesised this was due to grazing and expected to find a mature zoo/ichthyoplankton community in the eddy. Sub-surface chlorophyll fluorescence was moderately high within the CCE (~30 m depth; Figure 4). MOCNESS deployments were undertaken at 12 stations along this transect and included 2 stations in the CCE centre, 4 stations radiating out toward the CCE periphery, 2 stations in off-shelf waters, 2 stations on the slope and 2 stations on the

shelf directly in the Stockton Bight. As for Transect 1, deployments were replicated across day and night over 2 days. Shelf and slope stations along Transect 2 were shifted north approximately 11' to avoid heavy shipping traffic off Newcastle Harbour, as reflected in Figure 1. An additional CTD and 2 MOCNESS deployments were made at the centre of the CCE 3.5 days after the conclusion of sampling at Transect 2.

Following Transect 2, Transect 3 was commenced just south of the separation zone of the EAC (from 32.02S 153.35E to 31.88S 152.89E; Figure 1). Transect 3 included a short supplementary transect directly at the separation of the EAC at Diamond Head from 31.75S 153.05E to 31.75S 152.85E (CTD stations only; Figure 1). Ten CTD stations and 6 MOCNESS stations were sampled in total, including the full and supplementary transect.

The adaptive design above allowed us to both sample krill (and the mesozooplankton community) in 3-dimensions, as well as opportunistically sampling the oceanography and biology of mesoscale variability within the EAC.

N70 nets were also deployed at each CTD station (n = 2 per CTD station) to sample salp abundance and biomass as per SS10/2008 and SS05/2009. Biomass of Thalia democratica was much lower on this voyage than in previous voyages, however there were good numbers of other species (Salpa fusiformis and Thetys vagina) captured in some tows

2. Evaluate the relationship between oceanography, and krill and fish biomass and distribution;

A diverse zooplankton community was sampled. The major community components were copepods, krill, amphipods, salps, chaetognaths, pteropods, fish and scyphozoan jellyfish. Overall, copepods dominated zooplankton abundance at all stations, while sample wet weight was generally dominated by euphausiids, fish and / or salps. Substantial jellyfish blooms were observed in the warm core eddy when it was visited for the second time on day 11 of the voyage.

Several species of krill were sampled including Euphausia recurva, E. similis, E. spinifera, Thysanoessa gregaria and Thysanoessa spp., Thysanaopoda acutifrons, T. tricuspidata and Thysanopoda spp. (potentially T. johnsonii), Nematoscelis microps and N. difficilis, and Stylocheiron spp.. The most abundant species were E. recurva, E. similis and T. gregaria. The latter two species showed a strong diel migration, with adults occurring in the mesopelagic (200-500m) during the day and migrating into the upper 200m at night.

The other euhphausiid species samples also exhibited a diel migration, occurring in the lower mesopelagic (200-100m) during the day and migrating into the upper epipelagic at night;

Significant diel migration was also observed amongst other zooplankton groups. Large pelagic decapods and mesopelagic fish were mostly absent from nets during the day, indicating that they occurred predominantly below 500m depth. At night decapods were a frequent catch in the 500-100m depth zone while deep water fish species, particularly myctophids, were found up the surface where they were collected with neuston nets. These substantial feeding migrations

(>500m) represent a significant transfer of carbon, acquired in the epipelgic through predation, into the deep ocean. As was the case with euphausiids, many species (including salps, copepods, pteropods), migrated within the epipelagic, from the deeper epipelagic layers during the day to the surface layers at night.

The mesopelagic zone typically comprised a distinct suite of species. As mentioned above, these included E. similis, T. gregaria, decapods and myctophids. In addition, a number of copepod species were prevalent, including Paraeuchaeta spp. and Pleuromamma spp., We also observed relatively high densities of as yet unidentified small calanoid copepods (3-4 mm). This species is of particular interest as it represents a food source for mesopelagic predators, while its size indicates that it is most likely a grazer and hence a potential conduit of surface production to deeper waters.. Surface layers were also dominated by copepods (Sapphirina sp., Eucalanus sp.), chaetognaths, salps (Salpa and Thalia) and other gelatinous zooplankton at times, pilchards and carangids. Approximately 48 species of (non-myctophid) larval fish were captured throughout the voyage, and several species of pteropods were present across the depths and sites sampled

Overall the mesopelagic layers had the lowest abundance and biomass of zooplankton, while the surface 100m, where the majority of phytoplankton biomass resided, had the highest. Filtering of water collected at each stations, from the surface, chlorophyll max and 500m, showed that very little phytoplankton escaped the epipelagic zone, suggesting high and efficient grazing activity.

Some significant differences were also observed between transects. Stylocheiron spp. were only observed in the warm core eddy and did not appear to be as abundant as in previous years (SS05/2009 and SS010/2008). The pteropod Cavolina was most abundant in the CCE and WCE stations, while pteropods of the type Clio / Cressis were most abundant on the northern EAC transect (Transect 3). The cold-core eddy contained a mature zooplankton community including a good biomass of krill, many large copepods, whilst on-shelf stations appeared to dominated with smaller copepods and no discernable stratification of the community (despite stratification in the water column). Both the cold and warm core eddies had a relatively high biomass of krill, mesopelagic decapods and fish, compared to low densities in stations on the northern EAC transect. The EAC transect was almost completely dominated by copepods, and overall the community was in an early stage of development (juvenile and larval stages).

Please note these are general relationships from on-board sample analysis, and need to be confirmed as samples are sorted in our home laboratories, to quantify abundance/density/biomass and confirm species identification.

3. Determine trophic relationships amongst co-occurring euphausiid species using stable isotope analysis, and trophic interactions with other zooplankton

Approximately 1500 samples were sorted from half of the nets as they came aboard the ship. Samples were sorted for later processing and stable isotope analyses from every second MOCNESS or RMT deployment, which involved the removal and identification of approximately 30,000 organisms by our team of scientists (Figure 6). These samples will be progressively analysed over coming years to explore the relationships between epipelagic and mesopelagic food webs. The other 50% of samples were fixed in 5% formalin.

4. Investigate the ecosystem properties of krill in different habitats through size frequency analyses, using a Laser Optical Particle Counter (LOPC) to detect euphausiids, and evaluate the effect of euphausiids on biomass size spectrum (BSS) model parameters and fish larvae.

This voyage included 69 deployments of the Laser Optical Particle Counter (LOPC). The LOPC was received from Brooke Ocean directly prior to the voyage, and the first deployments of the unit were made attached to the MOCNESS. Data (Figure 7) will be post-processed after the voyage, including analysis of both size and shape distributions, and development of depth specific normalised biomass spectra.

Model parameters will be related to the zooplankton and ichthyoplankton community sampled using the MOCNESS, and related to oceanographic variables.

5. Extend observations of the distribution and biomass of gelatinous zooplankton (salps, Thalia democratica) off eastern Australia, and to assess their growth rate in different water masses.

For every CTD profile, we made two vertical hauls with a traditional N70 net used by Thompson in the 1940s, and during our voyages in 2008 and 2009. We also retained salps in liquid nitrogen for later assessment of their growth rate (RNA:DNA) ratio. Our attempts to repeat rearing experiments from 2009 were marginally successful, in part because of the low abundance of salps this year.

Fishing Gear Used

1. Multiple Opening Closing Net and Environmental Sampling System (MOCENSS)

The standard MNF EZ net was configured with a Seabird SBE19plusV2 to sample temperature, pressure, salinity, dissolved oxygen, pH, turbidity, chlorophyll, and photosynthetically active radiation. The SBE19plusV2 was mounted on the roof of the EZ box, between the circuit pressure housing and the cam motor. The net was also equipped with a Laser Optical Plankton Counter (LOPC), a data logger and power-pack for the LOPC, and a strobe light (auto-activated when in water). The unit was deployed in a 5 x 330 µm net configuration with each net spread across two net positions (bottom connected to net position 1, top connected to net position b, and so on). In this configuration, each of the 10 available net positions opened and closed a net respectively. This allowed nets to be deployed at specific depths (the unit could be sent to the deepest depth without fishing, and then each net opened and closed independently of the following net, at appropriate depths). Deploying only 5 nets in the EZ box also facilitated improved net lock function, due to reduced net bunching.

2. Modified N70 net

A 70 cm diameter ring net, with 53 cm long 4 mm mesh (formerly ¼" mesh), a 97 cm long 400 um mesh section (formerly silk, 70 mesh/inch), a 135 cm long 225 um mesh section (formerly silk, 200 mesh/inch, Kemp and Hardy 1929). This is the same net used on SS10/2008 and SS05/2009, and similar to that of Harold Thompson in 1938-1941. Vertical hauls were made from 50 m using a small hydraulic capstan winch (modified crab puller) at about 1 m s-1.

Voyage Narrative

Day 1 (22/09/2010) – Mobilisation

- Weather: Perfect, slight swell, sunny 0-10 knot wind.
- Mobilisation commenced at 08:00 AEST, and the ship left White Bay at 16:30 AEST.
- 12 h steam to centre of warm core eddy, inductions completed.

Day 2 (23/09/2010) – Warm core eddy and Transect 1

- Weather: Perfect, slight swell, sunny 0-10 knot wind.
- Completed 12 h steam. Most scientific staff got their sea legs by morning
- 0600 AEST start on the bridge with 3 toolbox meetings (CTD, EZ, and N70 winch), followed by CTD test cast to 1000 m (salinity minimum). Hands on training on handling water for nutrients, DO and salinity, given to team A and B.
- Brian Hunt took care of training for water preparation for chlorophyll/HPLC/POM filtrations, and phytoplankton preservation in lugols. Both vacuum pumps performed poorly, so the decision was made to sample water for the above from the maximum depth, chlorophyll max and surface (i.e. n = 3 chlorophyll/HPLC/POM/phytoplankton per CTD station)
- The Transect 1 CTDs were commenced immediately after the test cast and training
- The first MOCNESS deployment occurred at approximately 22/09/2010 23:55 UTC, looked promising with all auxiliary sensors functional. Once the net hit ~250 m the leak-detect light activated on the EZ console in the Ops room, and the EZ software stopped logging and the MOCNESS was brought back on deck.
- The CTD transect (7 CTD stations) was completed in the evening, and some salp chains, large squid and sharks were sighted while undertaking night-time CTDs.

Day 3 (24/09/2010) – Transect 1

- Weather: Perfect, slight swell, sunny 0-10 knot wind.
- The MOCNESS was not ready for deployment at the end of the CTD transect, so the RMT was fitted to the towed body winch and had a depth sensor and flow meter attached. RMT deployments were made at each of the proposed MNESS stations. We endeavoured to stratify our sampling by doing two RMT deployments at each station (for slope and ocean stations only). The first deployment involved sending the RMT to 500 m very rapidly, fishing between 500 m and 400 m relatively slowly (for 15 minutes), and then retrieving it very rapidly. The second deployment involved sending the RMT to 100 m, and raising it to surface over 10 minutes. Only one net was deployed to 100 m at each of the shelf stations.
- At approximately 1730 AEST the EZ was fitted back to the towed body winch and ready for a second test deployment. MOCNESS sensors were activated and the net had a smooth deployment off the ship. At 60 m the leak detect sensor activated and the net was rapidly retrieved for further investigation into the source of the leak.
- At 1830 AEST the decision was made to dispense with the MOCNESS for the remainder of Transect 1 to time to have another attempt at rectifying the leak. The second set of RMT day/night samples along Transect 1 commenced at 1930 AEST.
- The RMT samples were sorted on board and frozen for later analysis that align with the initial design, with the exception of definitive stratification across depths.

Day 4 (25/09/2010) – Transect 1

- Weather: Perfect, slight swell, sunny 10-15 knot wind.
- Transect 1 was completed with 31 RMT deployments to 500 and 100 m depth, which captured good numbers of krill and a good diversity of other organisms.
- Shortly after commencing transit to Transect 2, the MOCNESS was ready for a third test deployment. The leak was detected in another connector plug, and the plug was replaced. The communication problems were also sorted out.
- No leaks were detected after this third deployment, all nets deployed successfully and the trip sensors were functioning. After the test, a few tweaks were made to the unit whilst we proceeded on a 16 h steam to the cold core eddy and the start of Transect 2.
- Saw whales breaching off Jervis Bay and a beautiful sunset over the coast.

Day 5 (26/09/2010) – Cold core eddy

- Weather: Cloudy, moderate swell, 15-20 knot wind.
- We arrived on station at approximately 0930 AEST and launched directly into a CTD/MOCNESS transect across a small cold core eddy, heading in toward the commencement of the Stockton Bight cross-shelf transect (Transect 2).
- An initial CTD cast revealed the eddy was well mixed up to 500 m. The general features of the eddy included high surface chlorophyll, and temperature at 400 m of approximately 8 Celsius. Special features of the eddy included a region of suspected "Ford" water at 25 m (which was also detected by the glider travelling through the eddy in previous weeks), and a bifurcate chlorophyll max at 20 m and 75 m. Each Chl max was sampled separately and filtered for chlorophyll extraction, HPLC to identify the phytoplankton community, and POM isotope signature.
- Following the initial CTD station the MOCNESS was deployed at 5 depths (500-400 m; 400-200 m; 200-100 m; 100-50 m; and 50-surface). The deep water krill community in the CCE was dominated by adult Euphausia similis, whereas the surface layer was dominated by E. similis furcilia and calyptopis and Thysanessa gregaria adults. There were minimal Thalia democratica captured in the MOCNESS or N70 shots within the eddy, and most depths were dominated by small copepods.

Day 6-8 (27/09/2010 – 29/09/2010) – Transect 2

- Weather: Cloudy, moderate swell, 15-20 knot wind.
- The CTD transect across Transect 2 were completed at about 1900 AEST and MOCNESS deployments commenced immediately.
- Stockton Bight was characterised by warm and productive water on the shelf, with temperatures rapidly descending to depth (Figure 4).
- There was heavy ship traffic in the Stockton Bight awaiting passage into Newcastle Harbour, so Transect 2 had to be shifted to the north approximately 11' of latitude to avoid traffic. Despite this, earlier in the morning some MOCNESS deployments had to be retrieved and redone as ships attempted to cross the path of the Southern Surveyor.
- Some Neuston and N70 tows were performed in an attempt to capture live salps and fish for experimentation. A few Thalia democratica were captured for onboard experiments, which were largely unsuccessful. Fish captured were in poor condition, so were not used for onboard experiments.

- At station MNESS47 it was noticed that the light was no longer working on the Wetlabs FLNTU sensor (chlorophyll and turbidity) attached to the MOCNESS-SBE19plusV2. The unit was removed for examination. A flood of the unit was suspected, and the sensor was not refitted to the SBE19plusV2.
- Transect 2 MOCNESS sampling concluded at 0800 AEST, and transit to Transect 3 commenced.
- Roughly 5 fish captured in neuston nets for trials in controlled temperature fish experiments to this point. Most of these were myctophids and did not survive well in captivity.

Day 9-11 (30/09/2010 – 02/10/2010) – Transect 3

- Weather: Clearing, moderate swell, 5-15 knot wind, heavy swell in the EAC.
- We arrived at about 2000 AEST and commenced a CTD transect along Transect 3 without event.
- The EAC was pushing right up on the shelf off Crowdy Head, and drawing cool saline water up the slope which stimulated very high chlorophyll fluorescence in the shallow water adjacent to the coast (Figure 5).
- The MOCNESS stations across Transect 3 was commenced at 0700 AEST 30/09/2010, and continue for the next 18 h.
- As the first series of Day/Night MOCNESS tows finished early it was decided to travel up the point of separation at 31.75S for a supplementary CTD transect. The EAC was extremely close to the coast, and a CTD/N70 deployment was undertaken on the shelf (in coastal water), in the frontal zone between the EAC and the coast (characterised by a rapid increase and decrease in fluorescence and temperature respectively, on the underway thermosalinograph), and in the EAC proper.
- After the supplementary transect we proceeded south back to Transect 3 and completed the MOCNESS deployments. These concluded at 0700 AEST 2/10/2010, at which point we commenced transit back to Transect 1 to undertake a further CTD transect and MOCNESS transect (as only the RMT was used at the commencement of the voyage).
- The transit included an ADCP transect across the entire CCE east of Transect 2, which produced a clear current profile of the CCE, secondary circulation, and the interface between the CCE and the Transect 1 WCE (Figure 8).
- At the centre of the CCE we stopped and deployed an Argo float. At this site we also undertook 2 additional MOCNESS tows which yielded good numbers of krill and small fish.
- The Neuston net was also deployed at this point and captured Thalia democratica and juvenile carangids for on board experiments by Iain Suthers and Will Figueira respectively.
- 10 carangids captured in Neuston net (above) put into controlled temperature tanks, all at 17°C.

Day 12-14 (03/10/2010 – 05/10/2010) – Transect 1 repeat

- Weather: Raining, cloudy, moderate swell, 5-15 knot wind
- We arrived back at the warm core eddy for our final CTD and MOCNESS transects at 0430 AEST 03/10/2010. A CTD transect was commenced from the centre of the warm core eddy (WCE), and consisted of two stations each followed by a MOCNESS deployment.
- When Transect 1 was reached a full CTD transect was undertaken into the coast just south of Jervis Bay (to approximately 80 m of water) – this involved the addition of another CTD station on the western end of Transect 1. This station was characterised by a dramatic drop in temperature and dramatic increase in chlorophyll, suggesting cold water being drawn up the slope potentially by the WCE (not visible on Figure 3, which shows the cross shelf profile from the first visit to Transect 1).
- The CTD transect was finished at 20:00 03/10/2010 and the final Day/Night MOCNESS transects commenced.
- Half of controlled temperature experiment fish acclimated to 21°C. All fish monitored for the remainder of the trip.

Summary

Overall SS2010_v08 was an impressive success. The key objective of this voyage was to examine the epipelagic and mesopelagic communities simultaneously, and at the same time gather high-resolution oceanographic data with which to assess the factors driving community structure and distribution. We have sampled the zooplankton community in the EAC and its associated features to 500 m across 5 degrees of latitude, and with overlapping, high-resolution oceanographic data, we are well placed to achieve this key objective. The euphausiid assemblage in this area has not been examined in detail since the 1970s. Our samples will allow us to understand how the potential consequences of climate change for this important assemblage, and how carbon flux between oceanic communities may be affected.

We found that overall the community was dominated by large numbers of copepods, and a high biomass of krill, with variation in size and diversity across vertical and spatial scales. Vertical hauls with the N70 net revealed far fewer salps than in previous voyages (e.g. SS10/2008 and SS05/2009), and the low abundance of salps corresponded with a high overall biomass of krill. We found low zooplankton biomass in the mesopelagic zone, and the highest in the epipelagic zone. This corresponded with phytoplankton concentration, and showed very little phytoplankton escaped the upper epipelagic layer. We observed high variation in the epipelagic community, whilst the mesopelagic community appeared more stable. Eleven species of krill were present in our samples, with some displaying migration between the mesopelagic and epipelagic zone between day and night.

We were fortunate to have opportunistically sampled a cold core eddy and warm core eddy for both fish and zooplankton through the course of our voyage. These samples will contribute to our understanding of the biological outcomes of oceanographic

variability, and represent an important extension of the data gathered through Integrated Marine Observing System (IMOS) sea glider deployments. Growth of fish captured within these eddies will be related to productivity, eddy age and degree of development, as sampled using sea gliders over previous months.

We have sorted over 30,000 organisms from our plankton tows, and now have 1500 samples for stable isotope analysis. We have also filtered almost 2 metric tonnes of water to derive the chemical signature of particulate organic matter at the base of the food chain, and to characterise the phytoplankton assemblage using HPLC. Multiple chlorophyll maxima were frequently observed and sampled between the surface and 70 m, and HPLC will reveal whether these represent a bifurcation in autotroph communities. Stable isotope data will allow us to determine the sources and sinks of carbon, and how this varies from north to south, from shelf to ocean, and between epipelagic and mesopelagic zones.

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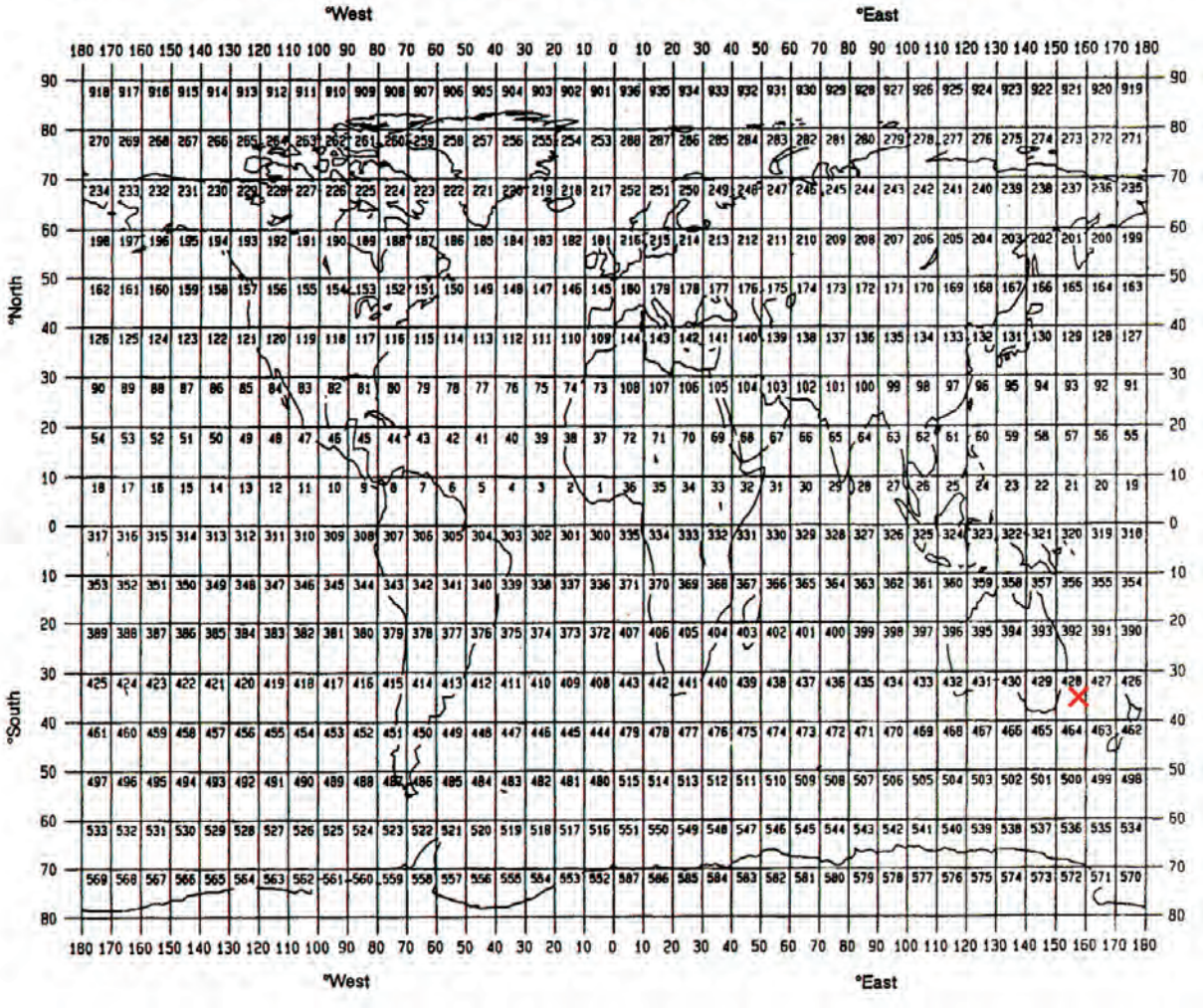
MARSDEN SQUARES

GEOGRAPHIC COVERAGE - INSERT 'X' IN EACH SQUARE IN WHICH DATA WERE COLLECTED



MOORINGS, BOTTOM MOUNTED GEAR AND DRIFTING SYSTEMS									
Item No	**PI** See page above.	**APPROXIMATE POSITION**						**DATA TYPE**	**Description**
		LATITUDE			**LONGITUDE**				
		deg	min	N/S	deg	min	E/W		
1	A	34	30	S	152	48	E	D05	ARGO float activated and deployed

SUMMARY OF MEASUREMENTS AND SAMPLES TAKEN					
Item No.	**PI** see page above	**NO** see above	**UNITS** see above	**DATA TYPE**	**DESCRIPTION**
1	A,B	35	casts	H10, P02 B01, B02 B08, B71	CTD and nutrient profiles
2	A,B,C	69	tows	B09, B11 B13, B14 B21, B72 H17, H21 H28, H32	MOCNESS (330 um), oblique hauls across various depths between 500 m and the surface. Up to 5 nets deployed per tow, with overlying size structure (LOPC) and CTD (SBE19plusV2) measurements.
3	A.B	68	tows	B09, B14 B72	N70 vertical haul plankton net, 0.7 m diameter, 0.4-0.2 mm mesh. Two, 50 m vertical hauls at all CTD stations
4	A	14	days	H71, H13 D71	Underway instruments including ADCP
5	A	14	days	B28	EK500 and EA500 echo sounders

CURATION REPORT	
Item No.	**Description**
1	Electronic and nutrient data held by CSIRO and on FAMER server (UNSW) indefinitely ; Chl/POM/HPLC/phytoplankton (in liquid-N2) held by UNSW until analysis (analysis is destructive).
2	EZ electronic data held by CSIRO and on FAMER server (UNSW) indefinitely ; LOPC and SBE19plusV2 data held on FAMER server (UNSW) indefinitely; Samples (formalin preserved and frozen) held by UNSW for 5 years or until analysis complete (if later) .
3	Samples (formalin preserved) held by UNSW for 5 years or until analysis complete.
4	Electronic data held by CSIRO and on FAMER server (UNSW) indefinitely.
5	Electronic data held by CSIRO, IMOS, and on FAMER server (UNSW) indefinitely.

Personnel list

Scientific Participants

Name	Affiliation	Role
Matt Taylor	UNSW	Chief Scientist
Iain Suthers	UNSW	Scientist
Will Figueira	USYD	Scientist
Brian Hunt	UBC	Scientist
Ben Harris	UNSW	PhD Student
Natasha Henschke	UNSW	PhD Student
Paloma Matis	USYD	Honours Student
Lauren Ooi	UNSW	Masters Student
Nikki Best	UNSW	Masters Student
Joshua Humphries	UNSW	PhD Student
Brendan Kelaher	NSW DECCW	Scientist
Stephen McCullum	CMAR	MNF Voyage Manager
Matt Sherlock	CMAR	MNF Electronics Support
Anoosh Sarraf	CMAR	MNF Computing Support
Mark Rayner	CMAR	MNF Hydrochemistry Support

Marine Crew

Name	Role	Name	Role
Mike Watson	Master	Rose Croasdale	IR
John Barr	First Mate	Kel Lewis	IR
Simon Smeaton	Second Mate	Rod Langham	IR
Robert Cave	Chief Engineer	Ben McLucas	IR
Jason Searle	1st Engineer	Geri Byrne	Chief Cook
Bill Bourne	2nd Engineer	Robert Dittko	Second Cook
John Howard	Boatswain	Kate Gould	Chief Steward

Acknowledgements

We thank the captain of the RV Southern Surveyor, Mike Watson, and his crew for their seamanship

and enthusiasm, and also the dedication of the CSIRO Marine staff who made the science possible. Special mention must go to Matt Sherlock 'Holmes', who saved the voyage in its early stages by diagnosing and repairing several faults with the EZ net. Overall, the dedication and support the MNF team were second to none. We acknowledge funds from UNSW and the ARC which enabled us to purchase ~$200,000 worth of instrumentation to use on the voyage. We also acknowledge a School of Biological Earth and Environmental Science (UNSW) start-up grant to MDT which supported this voyage. Final acknowledgment must go to the Marine National Facility overall for their support and providing the ship time, and the steering committee for providing MDT with the opportunity to act as Chief Scientist at such an early stage in his career.

Matt Taylor
Chief Scientist

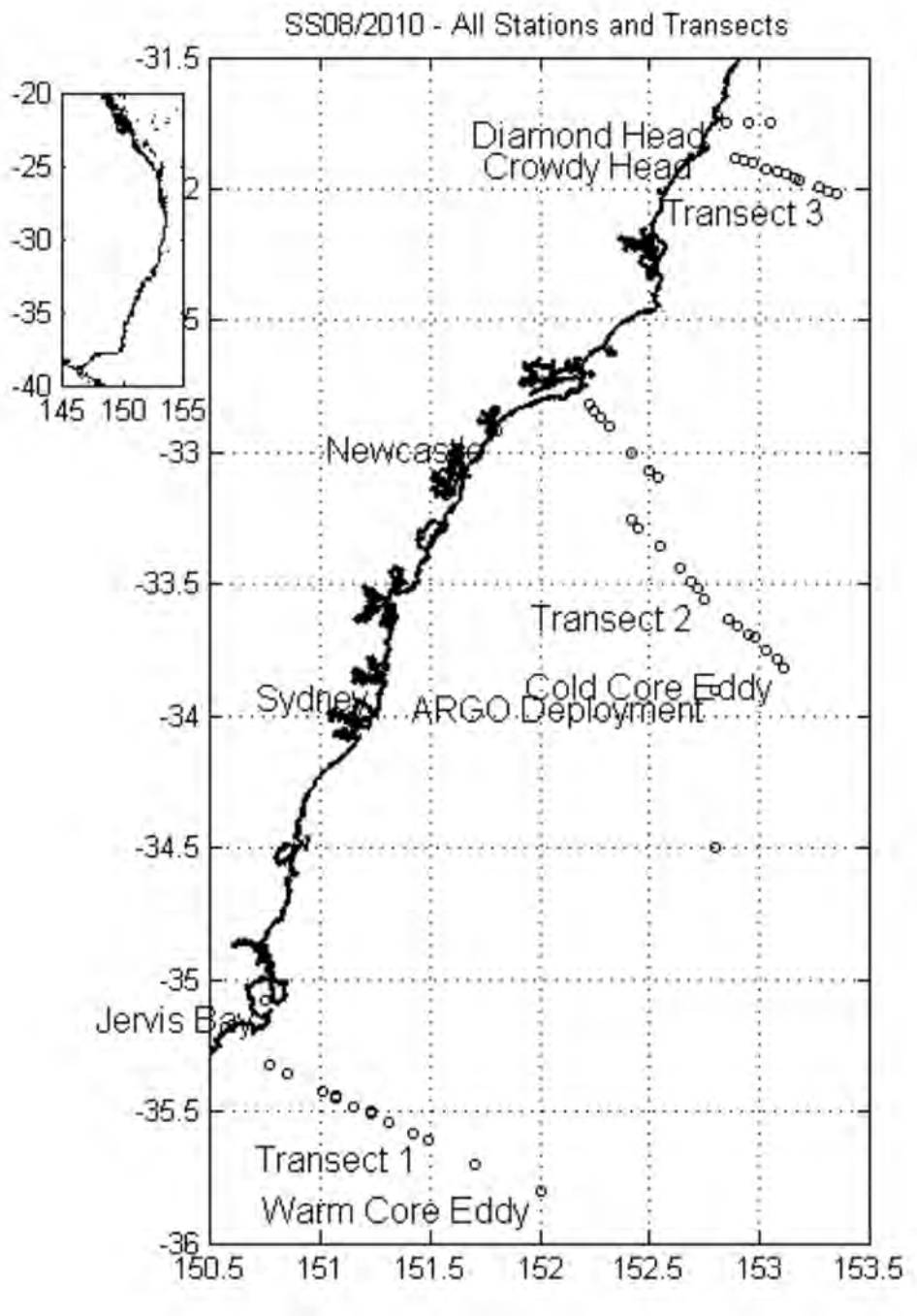


Figure 1: All stations sampled on SS2010_v08

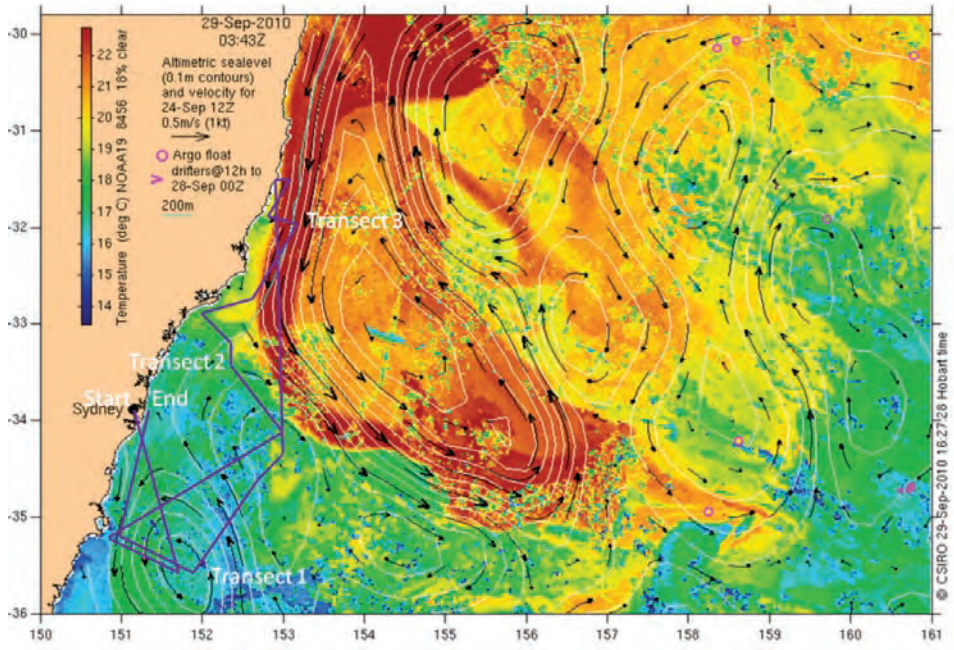


Figure 2: SS2010_v08 voyage track overlaid on SST image (SST image correct at midpoint of voyage)

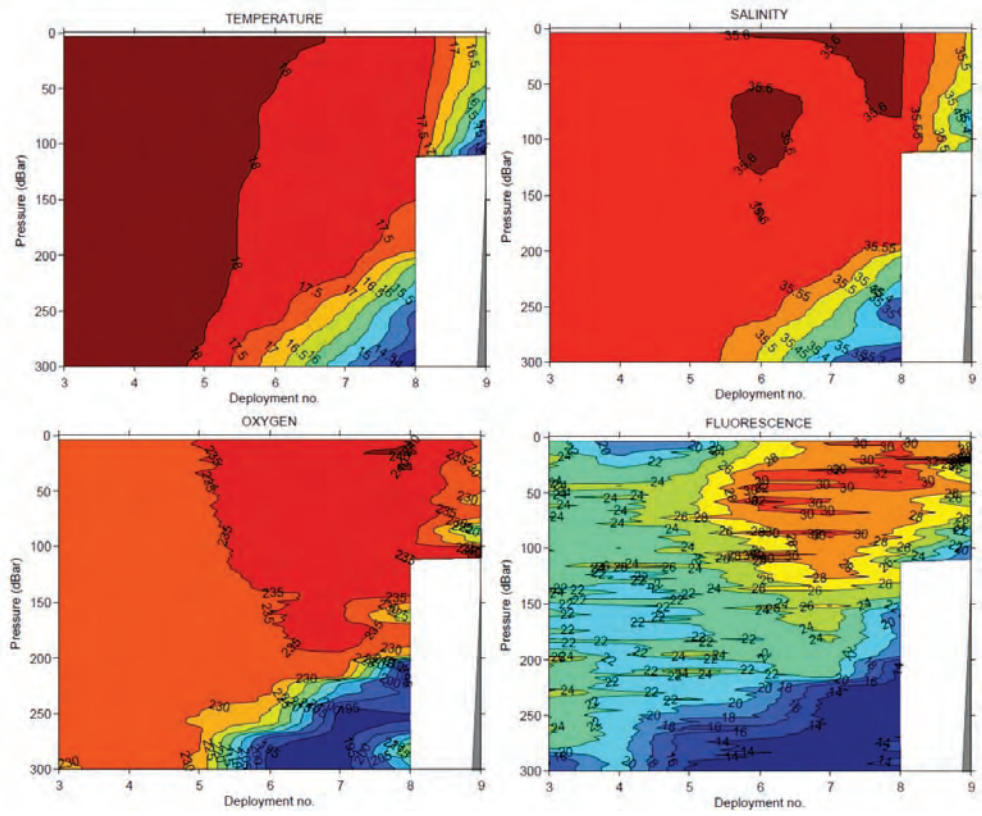


Figure 3: SS2010_v08 Transect 2 cross-shelf contour plot showing key oceanographic parameters

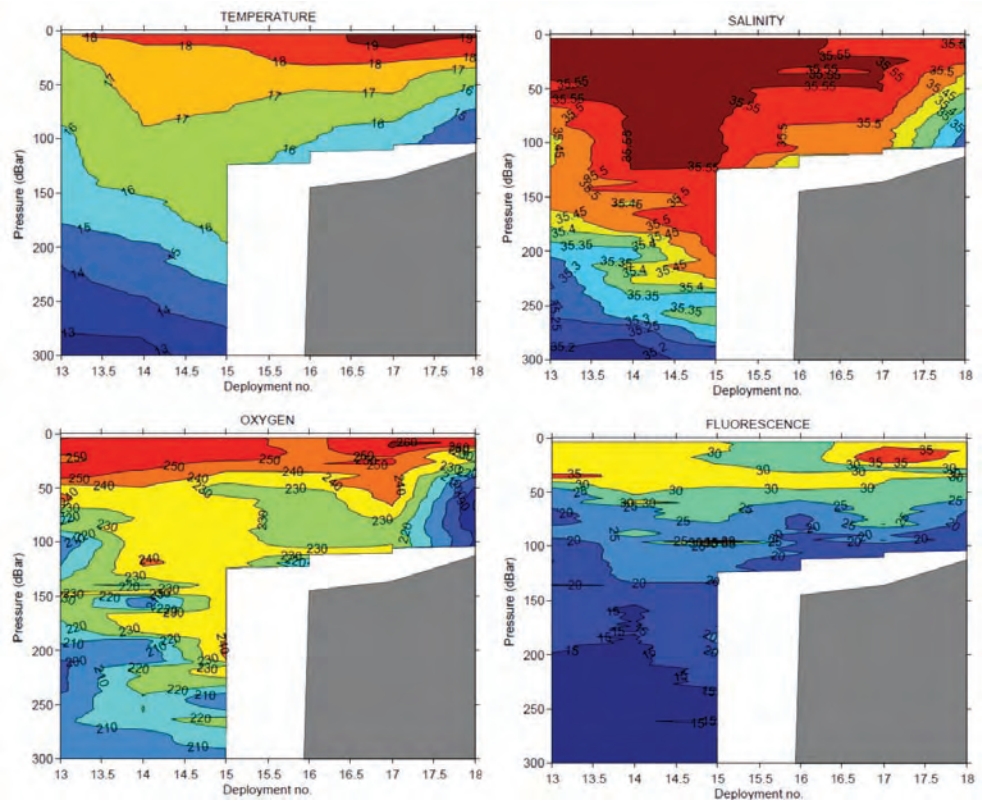


Figure 4: SS2010_v08 Transect 2 cross-shelf contour plot showing key oceanographic parameters

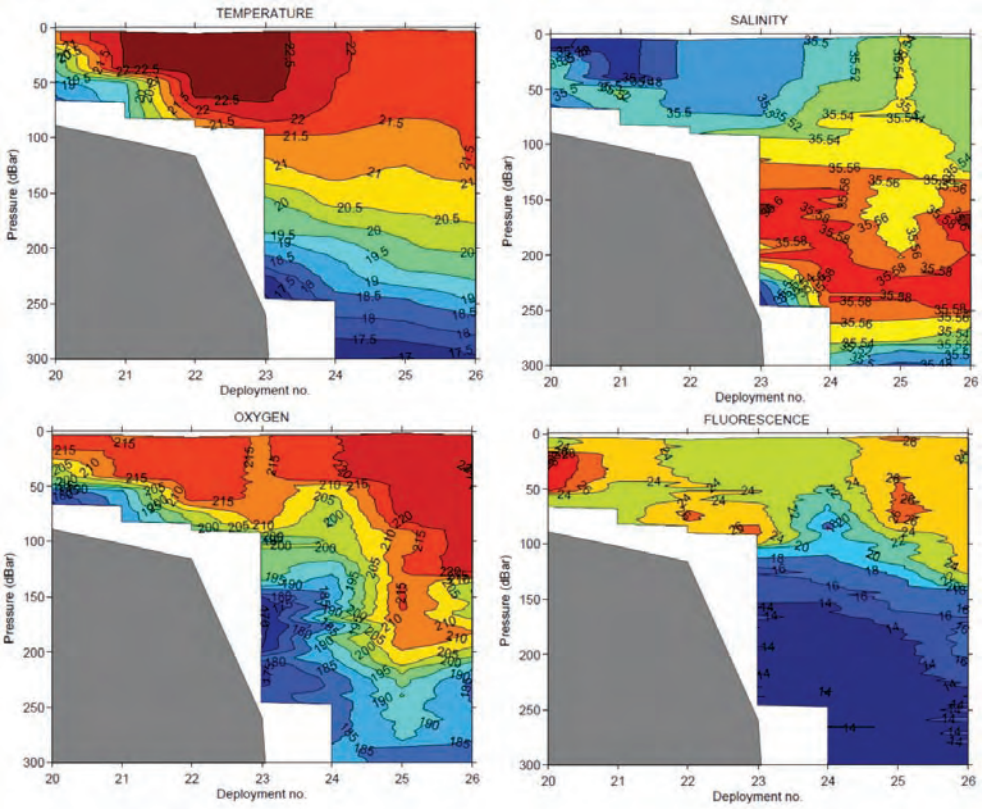


Figure 5: ss2010_v08 Transect 3 cross-shelf contour plot showing key oceanographic parameters

Figure 6: ss2010_v08 science team at work in the RV *Southern Surveyor* Fish Lab, sorting MOCNESS samples for stable isotope analysis.

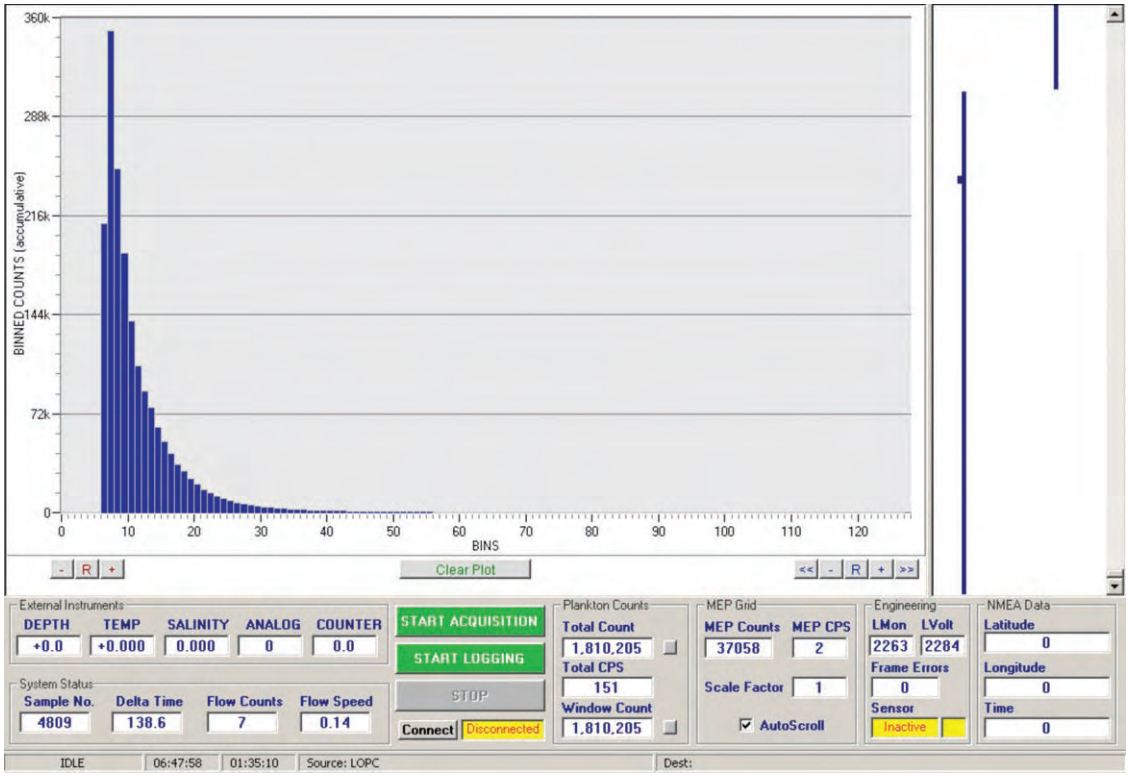


Figure 7: Laser Optical Plankton Counter replay after a ss2010_v08 MOCNESS deployment, showing the number of planktonic particles counted over a wide size spectrum.

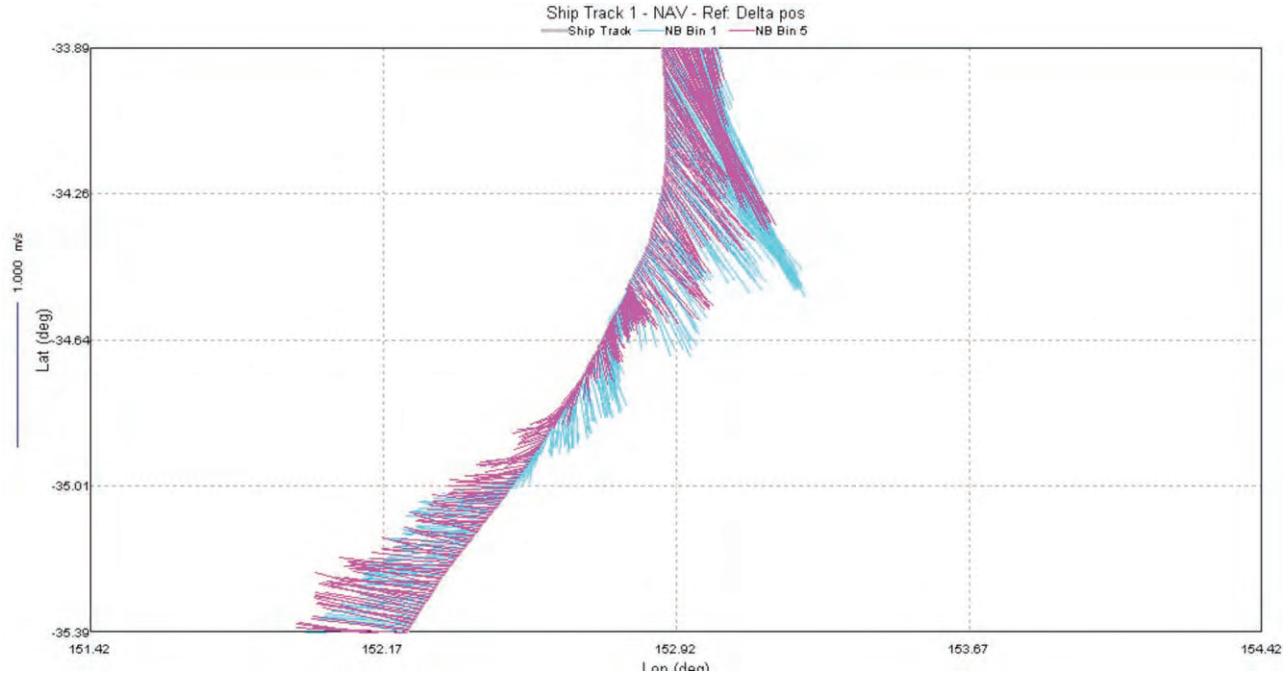


Figure 8: ADCP transect across cold core eddy and south into warm core eddy.

Appendix 1 – All stations sampled on ss2010_v08

Date	Transect	Station	Station Ref	Time	Lat_DD	Long_DD	Details
22/09/2010	Port			9:00	Port	Port	Safety induction and briefing
22/09/2010	Port			10:00	Port	Port	Load equipment and set up
22/09/2010	Transit to WCEDDY		Transit	16:00	Port		Steam to Tranns 1, toolboxes, test CTD cast
23/09/2010	CTD Test Cast		CTD Bottle Test	4:00	35.800	152.000	
23/09/2010	WCEDDY	Centre	CTD3	4:00	35.800	152.000	
23/09/2010	WCEDDY	Centre	MNESS1	5:00	35.800	152.000	RMT100 and 500, samples processed for isotopes
23/09/2010	1		Transit	6:30			
23/09/2010	1	Ocean	CTD4	7:30	35.700	151.700	
23/09/2010		Ocean	MNESS2	8:30	35.700	151.700	RMT100 and 500, samples processed for isotopes
23/09/2010	1		Transit	10:00			
23/09/2010	1	Ocean	CTD5	11:00	35.612	151.495	
23/09/2010	1		Transit	12:00			
23/09/2010	1	Slope	CTD6	12:49	35.542	151.316	
23/09/2010	1		Transit	13:49			
23/09/2010	1	Slope	CTD7	14:38	35.482	151.156	
23/09/2010	1		Transit	15:38			
23/09/2010	1	Shelf	CTD8	16:32	35.420	151.010	
23/09/2010	1		Transit	17:32			
23/09/2010	1	Shelf	CTD9	18:27	35.320	150.770	
23/09/2010	1	Shelf	MNESS3	19:00	35.320	150.770	
23/09/2010	1	Shelf	MNESS4	20:30	35.360	150.850	RMT100 and 500, samples processed for isotopes
23/09/2010	1		Transit	22:00			
24/09/2010	1	Slope	MNESS5	22:32	35.448	151.076	
24/09/2010	1	Slope	MNESS6	0:02	35.482	151.156	RMT100 and 500, samples processed for isotopes
24/09/2010	1		Transit	1:32			
24/09/2010	1	EAC	MNESS7	2:00	35.542	151.316	
24/09/2010	1	EAC	MNESS8	3:30	35.580	151.420	RMT100 and 500, samples processed for isotopes
24/09/2010	1	EAC	MNESS9	7:00	35.612	151.495	
24/09/2010	1	EAC	MNESS10	8:30	35.580	151.420	RMT100 and 500, samples processed for isotopes
24/09/2010	1		Transit	10:00			
24/09/2010	1	Slope	MNESS11	10:32	35.506	151.233	
24/09/2010	1	Slope	MNESS12	12:02	35.482	151.156	RMT100 and 500, samples processed for isotopes
24/09/2010	1		Transit	13:32			
24/09/2010	1	Shelf	MNESS13	14:05	35.420	151.010	
24/09/2010	1	Shelf	MNESS14	15:35	35.360	150.850	RMT100 and 500, samples processed for isotopes
24/09/2010	1	Shelf	MNESS15	19:00	35.320	150.770	
24/09/2010	1	Shelf	MNESS16	20:00	35.360	150.850	Samples processed for isotopes
24/09/2010	1		Transit	21:00			
25/09/2010	1	Slope	MNESS17	21:32	35.448	151.076	
25/09/2010	1	Slope	MNESS18	22:32	35.482	151.156	Samples processed for isotopes
25/09/2010	1		Transit	23:32			
25/09/2010	1	EAC	MNESS19	0:05	35.542	151.316	
25/09/2010	1	EAC	MNESS20	1:05	35.580	151.420	Samples processed for isotopes
25/09/2010	1		Transit	2:05			
25/09/2010	1	EAC	MNESS21	7:00	35.612	151.495	
25/09/2010	1	EAC	MNESS22	8:30	35.580	151.420	Samples processed for isotopes
25/09/2010	1		Transit	10:00			
25/09/2010	1	Slope	MNESS23	10:32	35.506	151.233	

Date	Transect	Station	Station Ref	Time	Lat_DD	Long_DD	Details
25/09/2010	1	Slope	MNESS24	12:02	35.482	151.156	Samples processed for isotopes
25/09/2010	1		Transit	13:32			
25/09/2010	1	Shelf	MNESS25	14:05	35.420	151.010	
25/09/2010	1	Shelf	MNESS26	15:35	35.360	150.850	Samples processed for isotopes
25/09/2010	Transit T2	CCEDDY	Transit	17:05	34.000	152.800	
26/09/2010	2	CC1	CTD10	5:00	33.813	153.108	
26/09/2010	2	CC1	MNESS27	6:00	33.813	153.108	Samples processed for isotopes
26/09/2010	2	CC1	MNESS28	7:30	33.780	153.075	
26/09/2010	2	CC2	MNESS29	9:00	33.750	153.030	Samples processed for isotopes
26/09/2010	2	CC2	CTD11	10:30	33.703	152.975	
26/09/2010	2	CC2	MNESS30	11:30	33.703	152.975	
26/09/2010	2	CC3	MNESS31	13:00	33.692	152.947	
26/09/2010	2	CC3	MNESS32	14:30	33.653	152.900	Samples processed for isotopes
26/09/2010	2	CC3	CTD12	16:00	33.632	152.858	
26/09/2010	2		Transit	17:00			
26/09/2010	2	Ocean	CTD13	18:30	33.558	152.750	
26/09/2010	2		Transit	19:30			
26/09/2010	2	Ocean	CTD14	20:30	33.437	152.633	
26/09/2010	2		Transit	21:30			
26/09/2010	2	Shelf	CTD15	22:30	33.353	152.542	
26/09/2010	2		Transit	23:30			
27/09/2010	2	Shelf	CTD16	0:30	33.002	152.415	
27/09/2010	2		Transit	1:30			
27/09/2010	2	Shelf	CTD17	2:30	32.903	152.320	
27/09/2010	2		Transit	3:30			
27/09/2010	2	Shelf	CTD18	4:30	32.817	152.225	
27/09/2010	2	Shelf	MNESS33	9:30	32.817	152.225	Samples processed for isotopes
27/09/2010	2	Shelf	MNESS34	11:00	32.842	152.250	
27/09/2010	2		Transit	12:30			
27/09/2010	2	Slope	CTD19	13:30	33.092	152.533	Samples processed for isotopes
27/09/2010	2		Transit	15:00			
27/09/2010	2	Slope	MNESS35	16:00	33.067	152.500	Samples processed for isotopes
27/09/2010	2	Slope	MNESS36	16:30	33.252	152.415	
27/09/2010	2		Transit	17:30			
27/09/2010	2	Ocean	MNESS37	19:00	33.487	152.683	Samples processed for isotopes
27/09/2010	2	Ocean	MNESS38	20:30	33.517	152.717	
27/09/2010	2	Ocean	MNESS39	22:00	33.558	152.750	Samples processed for isotopes
27/09/2010	2	Ocean	MNESS40	22:00	33.517	152.717	
27/09/2010	2		Transit	22:00			
28/09/2010	2	Slope	MNESS41	0:00	33.287	152.448	Samples processed for isotopes
28/09/2010	2	Slope	MNESS42	2:30	33.092	152.533	
28/09/2010	2		Transit	4:00			
28/09/2010	2	Shelf	MNESS43	5:00	32.868	152.273	Samples processed for isotopes
28/09/2010	2	Shelf	MNESS44	5:45	32.842	152.250	
28/09/2010	2	Shelf	MNESS45	6:30	32.817	152.225	Samples processed for isotopes
28/09/2010	2	Shelf	MNESS46	7:30	32.842	152.250	
28/09/2010	2		Transit	8:30			
28/09/2010	2	Slope	MNESS47	10:00	33.067	152.500	Samples processed for isotopes
28/09/2010	2	Slope	MNESS48	12:00	33.092	152.533	
28/09/2010	2		Transit	13:30			
28/09/2010	2	Ocean	MNESS49	16:00	33.487	152.683	Samples processed for isotopes
28/09/2010	2	Ocean	MNESS50	17:30	33.517	152.717	
28/09/2010	2	Ocean	MNESS51	19:00	33.558	152.750	Samples processed for isotopes
28/09/2010	2	Ocean	MNESS52	20:30	33.517	152.717	
28/09/2010	2		Transit	22:00			
29/09/2010	2	Slope	MNESS53	0:30	33.287	152.448	Samples processed for isotopes

Date	Transect	Station	Station Ref	Time	Lat_DD	Long_DD	Details
29/09/2010	2	Slope	MNESS54	3:00	33.092	152.533	
29/09/2010	2		Transit	4:30			
29/09/2010	2	Shelf	MNESS55	5:30	32.868	152.273	Samples processed for isotopes
29/09/2010	2	Shelf	MNESS56	7:00	32.842	152.250	
29/09/2010	Transit to Transect 3			8:30			
29/09/2010	Arrive Transect 3			8:00	32.017	153.350	
29/09/2010	3	Ocean	CTD20	20:00	32.017	153.350	
29/09/2010	3		Transit	21:30			
29/09/2010	3	Ocean	CTD21	22:06	31.992	153.267	
29/09/2010	3		Transit	23:06			
29/09/2010	3	Slope	CTD22	23:42	31.965	153.180	
29/09/2010	3		Transit	0:42			
29/09/2010	3	Slope	CTD23	1:18	31.943	153.120	
29/09/2010	3		Transit	2:18			
30/09/2010	3	Slope	CTD24	2:54	31.925	153.030	
30/09/2010	3		Transit	3:54			
30/09/2010	3	Shelf	CTD25	4:30	31.902	152.963	
30/09/2010	3		Transit	5:30			
30/09/2010	3	Shelf	CTD26	6:06	31.883	152.885	
30/09/2010	3	Shelf	MNESS57	7:06	31.883	152.885	Samples processed for isotopes
30/09/2010	3	Shelf	MNESS58	8:36	31.890	152.923	
30/09/2010	3		Transit	10:06			
30/09/2010	3	Slope	MNESS59	11:06	31.935	153.078	Samples processed for isotopes
30/09/2010	3	Slope	MNESS60	12:06	31.943	153.120	
30/09/2010	3		Transit	13:06			
30/09/2010	3	Ocean	MNESS61	14:06	31.992	153.267	Samples processed for isotopes
30/09/2010	3	Ocean	MNESS62	15:36	32.005	153.307	
30/09/2010	3	Ocean	MNESS63	19:00	32.017	153.350	Samples processed for isotopes
30/09/2010	3	Ocean	MNESS64	20:30	32.005	153.307	
30/09/2010	3		Transit	22:00			
30/09/2010	3	Slope	MNESS65	23:00	31.958	153.158	Samples processed for isotopes
1/10/2010	3	Slope	MNESS66	0:30	31.943	153.120	
1/10/2010	3		Transit	2:00			
1/10/2010	3	Shelf	MNESS67	3:00	31.902	152.963	Samples processed for isotopes
1/10/2010	3	Shelf	MNESS68	4:30	31.890	152.923	
1/10/2010	3	Shelf	MNESS69	7:00	31.883	152.885	Samples processed for isotopes
1/10/2010	3	Shelf	MNESS70	8:30	31.890	152.923	
1/10/2010	3		Transit	10:00			
1/10/2010	3	Slope	MNESS71	11:00	31.935	153.078	Samples processed for isotopes
1/10/2010	3	Slope	MNESS72	12:00	31.943	153.120	
1/10/2010	3		Transit	13:00			
1/10/2010	3	Ocean	MNESS73	14:00	31.992	153.267	Samples processed for isotopes
1/10/2010	3	Ocean	MNESS74	12:00	32.005	153.307	
1/10/2010	SEPZONE		Transit	13:30			
1/10/2010	SEPZONE	EAC	CTD31	16:30	31.750	153.050	
1/10/2010	SEPZONE		Transit	17:00			Deploy Neuston to catch pillies
1/10/2010	SEPZONE	FRONT	CTD32	17:30	31.750	152.950	
1/10/2010	SEPZONE		Transit	18:00			Deploy Neuston to catch pillies
1/10/2010	SEPZONE	COAST	CTD33	18:30	31.750	152.850	NOTE: DEPTH OF 40 m
1/10/2010	SEPZONE		Transit	19:00			Deploy Neuston to catch pillies
1/10/2010	3	Shelf	MNESS75	20:00	31.883	152.885	Samples processed for isotopes
1/10/2010	3	Shelf	MNESS76	21:30	31.890	152.923	
1/10/2010	3		Transit	23:00			
1/10/2010	3	Slope	MNESS77	0:00	31.935	153.078	Samples processed for isotopes

Date	Transect	Station	Station Ref	Time	Lat_DD	Long_DD	Details
2/10/2010	3	Slope	MNESS78	1:00	31.943	153.120	
2/10/2010	3		Transit	2:00			
2/10/2010	3	Ocean	MNESS79	3:00	31.992	153.267	Samples processed for isotopes
2/10/2010	3	Ocean	MNESS80	4:30	32.005	153.307	
2/10/2010	Transit to Transect 1				6:00		
3/10/2010	Arrive Transect 1				6:00		
2/10/2010	ADCP Transect 1 (Transit to this point)					14:00	33.800 152.800
2/10/2010	ADCP Transect 2				18:00	34.500	152.800
2/10/2010	ARGO Float Deployment					18:00	34.500 152.800
2/10/2010	CCEEDDY	CCE4	MNESS81	19:00	34.500	152.800	
2/10/2010	CCEEDDY	CCE4	MNESS82	20:00	34.500	152.800	
3/10/2010	ADCP Transect 3 (Transit to this point)					21:00	35.800 152.000
3/10/2010	1	Centre	CTD34	4:30	35.800	152.000	
3/10/2010	1	Centre	MNESS83	5:30	35.800	152.000	Samples processed for isotopes
3/10/2010	1		Transit	7:00			
3/10/2010	1	Ocean	CTD35	8:05	35.700	151.700	
3/10/2010	1	Ocean	MNESS84	9:05	35.700	151.700	Samples processed for isotopes
3/10/2010	1		Transit	10:35			
3/10/2010	1	Ocean	CTD36	11:40	35.610	151.490	
3/10/2010	1		Transit	12:40			
3/10/2010	1	Slope	CTD37	13:30	35.540	151.310	
3/10/2010	1		Transit	14:30			
3/10/2010	1	Slope	CTD38	15:19	35.480	151.150	
3/10/2010	1		Transit	16:19			
3/10/2010	1	Shelf	CTD39	17:13	35.420	151.010	
3/10/2010	1		Transit	17:43			
3/10/2010	1	Shelf	CTD40	18:38	35.320	150.770	
3/10/2010	1	Shelf	CTD41	19:08	35.320	150.770	
3/10/2010	1	Shelf	MNESS85	19:38	35.320	150.770	
3/10/2010	1	Shelf	MNESS86	21:08	35.360	150.850	Samples processed for isotopes
3/10/2010	1		Transit	22:08			
3/10/2010	1	Slope	MNESS87	22:40	35.440	151.070	
3/10/2010	1	Slope	MNESS88	0:10	35.480	151.150	Samples processed for isotopes
3/10/2010	1		Transit	1:40			
4/10/2010	1	EAC	MNESS89	2:28	35.540	151.310	
4/10/2010	1	EAC	MNESS90	3:58	35.580	151.420	Samples processed for isotopes
4/10/2010	1	EAC	MNESS91	7:00	35.610	151.490	
4/10/2010	1	EAC	MNESS92	8:30	35.580	151.420	
4/10/2010	1		Transit	10:00			Samples processed for isotopes
4/10/2010	1	Slope	MNESS93	10:45	35.500	151.230	
4/10/2010	1	Slope	MNESS94	12:15	35.480	151.150	
4/10/2010	1		Transit	13:45			Samples processed for isotopes
4/10/2010	1	Shelf	MNESS95	14:30	35.420	151.010	
4/10/2010	1	Shelf	MNESS96	16:00	35.360	150.850	
4/10/2010	Clean up and slow transit to Botany Bay						
5/10/2010	Arrive Botany Bay to collect pilot			8:00			

CSR/ROSCOP PARAMETER CODES

M01	Upper air observations
M02	Incident radiation
M05	Occasional standard measurements
M06	Routine standard measurements
M71	Atmospheric chemistry
M90	Other meteorological measurements

	PHYSICAL OCEANOGRAPHY
H71	Surface measurements underway (T,S)
H13	Bathythermograph
H09	Water bottle stations
H10	CTD stations
H11	Subsurface measurements underway (T,S)
H72	Thermistor chain
H16	Transparency (eg transmissometer)
H17	Optics (eg underwater light levels)
H73	Geochemical tracers (eg freons)
D01	Current meters
D71	Current profiler (eg ADCP)
D03	Currents measured from ship drift
D04	GEK
D05	Surface drifters/drifting buoys
D06	Neutrally buoyant floats
D09	Sea level (incl. Bottom pressure & inverted echosounder)
D72	Instrumented wave measurements
D90	Other physical oceanographic measurements

	CHEMICAL OCEANOGRAPHY
H21	Oxygen
H74	Carbon dioxide
H33	Other dissolved gases
H22	Phosphate
H23	Total - P
H24	Nitrate
H25	Nitrite
H75	Total - N
H76	Ammonia
H26	Silicate
H27	Alkalinity
H28	PH
H30	Trace elements
H31	Radioactivity
H32	Isotopes
H90	Other chemical oceanographic measurements

	MARINE CONTAMINANTS/POLLUTION
P01	Suspended matter
P02	Trace metals
P03	Petroleum residues
P04	Chlorinated hydrocarbons
P05	Other dissolved substances
P12	Bottom deposits
P13	Contaminants in organisms
P90	Other contaminant measurements
B01	Primary productivity
B02	Phytoplankton pigments (eg chlorophyll, fluorescence)
B71	Particulate organic matter (inc POC, PON)
B06	Dissolved organic matter (inc DOC)
B72	Biochemical measurements (eg lipids, amino acids)
B73	Sediment traps
B08	Phytoplankton
B09	Zooplankton
B03	Seston
B10	Neuston
B11	Nekton
B13	Eggs & larvae
B07	Pelagic bacteria/micro-organisms
B16	Benthic bacteria/micro-organisms
B17	Phytobenthos
B18	Zoobenthos
B25	Birds
B26	Mammals & reptiles
B14	Pelagic fish
B19	Demersal fish
B20	Molluscs
B21	Crustaceans
B28	Acoustic reflection on marine organisms
B37	Taggings
B64	Gear research
B65	Exploratory fishing
B90	Other biological/fisheries measurements

	MARINE GEOLOGY/GEOPHYSICS
G01	Dredge
G02	Grab
G03	Core - rock
G04	Core - soft bottom
G08	Bottom photography
G71	In-situ seafloor measurement/sampling
G72	Geophysical measurements made at depth
G73	Single-beam echosounding
G74	Multi-beam echosounding
G24	Long/short range side scan sonar
G75	Single channel seismic reflection
G76	Multichannel seismic reflection
G26	Seismic refraction
G27	Gravity measurements
G28	Magnetic measurements
G90	Other geological/geophysical measurements