

VOYAGE SUMMARY SS08/2003

Title

Meso-scale eddies off SW Australia: death traps or nurseries for fisheries recruitment?

Itinerary

Departed Fremantle 1000 hrs, October 1 2003 Arrived Fremantle 2000 hrs, October 22 2003

Principal Investigator

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Scientific Objectives

We intended to test the following hypotheses:

- 1. Nutrient pumping, enhanced production and suppression of N-fixation occur in the cyclonic eddy;
- 2. Fish larvae and rock lobster phyllosoma are preferentially aggregated within the anticyclonic eddy;
- 3. The nutritional status of larvae is highest in the cyclonic eddy compared to the surrounding waters and to the anticyclonic eddy;
- 4. The downward flux of organic matter is highest in the cyclonic eddy.

Voyage Objectives

The voyage objective was to study, in detail, both a cyclonic eddy and an anticylonic eddy off WA, and more specifically:

- 1. To measure nutrient concentration gradients inside and outside the eddies and to estimate their fluxes;
- 2. To estimate the rate and extent of 1^{ary} and 2^{ndary} production inside and outside the eddies;
- 3. To estimate the contribution of nitrogen fixation to total primary production inside and outside the eddies;
- 4. To determine the abundance of larvae inside and outside the eddies;
- 5. To measure the downward flux of organic matter in the two eddies.

Voyage Track

All stations sampled



Voyage Objectives:

All desired measurements were made within both Eddies, except that

- loss of contact with the sediment trap buoy limited the number of sediment trap deployments in Eddy C (the second eddy studied) to a single long deployment rather than many short deployments, and
- 2. the SeaSoar mapping was occasionally interrupted by technical failure and in that case was replaced with CTD drops along the same eddy transect.

Scientific Objectives:

We put forward the following hypotheses:

1) Nutrient pumping, enhanced production and suppression of N-fixation occur in the cyclonic eddy

We already have clear evidence that nutrient pumping in Eddy C (the cyclonic eddy) was quite different than we expected in 1. We will possibly disprove this hypothesis. The cyclonic eddy was capped by a layer of temperate water, limiting the upwelling signature in the temperature and salinity field to a small upward-pointing cone in the centre of the eddy. Associated with this cone was a spherical high-fluorescence signature suggesting phytoplankton growth (and therefore nutrient upwelling and/or particle accumulation) in the immediate vicinity of the upwelling. However, we say no evidence of large-scale upwelling, and it is unlikely that the deep upwelling we saw could impact surface nitrogen fixation.

2) Fish larvae and rock lobster phyllosoma are preferentially aggregated within the anticyclonic eddy

Very cursory preliminary evidence suggests that larvae avoided the very low-nutrient anti-cyclonic eddy. Daytime catches of larvae were low and fish larvae appeared to remain below the eddy until night, when they rose into it. A very limited number of lobster larvae were observed.

3) The nutritional status of larvae is highest in the cyclonic eddy compared to the surrounding waters and to the anticyclonic eddy

Preliminary observation suggest the anticyclonic eddy may have contained more biomass than the cyclonic eddy, and the cyclonic eddy was dominated by a large grazing population of salps, which may have decimated the biomass. If the cyclonic eddy consisted of a relatively self-contained mass of water (which does not discount the possibility of internal currents that may yet aggregate particles), the dominance by salps may represent the end of a succession of the plankton community, which had a finite reserve of nutrients.

4) The downward flux of organic matter is highest in the cyclonic eddy

While we have the data needed to determine whether this is the case, they will need more analysis before we are certain of the final magnitude of the flux in each eddy.

Voyage Narrative

We departed Fremantle at 1000h on October 1st 2003, and steamed towards SRFME Station E (31 50.93 S 114 48.61 E) for a test station (see voyage track). We executed a 500 m CTD cast, test-ran the size-fractionation filtration systems on board, and took replicate oblique Bongo Net tows. We field tested the SeaSoar mapper, and assessed the performance of the EZNet on the deck. The EZNet needed bolts redrilled before it could be used, which would take several hours. The SeaSoar subsequently developed a leak (water had entered the casing covering the wing controllers) and it was suggested that the mapper would not be ready the following morning for the first E-W transect of our first target eddy, a counter-clockwise eddy named Eddy B by Ming Feng (CSIRO Floreat), who had helped us map and identify suitable eddies leading up to the voyage. We therefore planned 9 CTD casts for our first transect of Eddy B, starting ca. 6 am on October 2nd (2200 h UTC Oct 1), evenly spaced between 113 and 111 E, along the 31.5 S line. David Griffin (CSIRO Hobart) had estimated that the centre of Eddy B was at ~112 E 31.5 S. Halfway through this transect, it was discovered that the SeaSoar looked dry, however had blown a fuse and needed further testing. From Hobart, David Griffin also noted that an Argo float had surfaced in the eddy known as Eddy C, to the NW of Eddy B, and sent us the profile data for information. David's assessment at that point was that Eddy C was not strongly upwelling, which might argue against studying it in detail as a counterpoint to Eddy B. We reached the western perimeter of Eddy B at 111 45 E 31 30 S.

Our basic plan from then on was to sample over ~10 d in three main eddy areas: Perimeter, at the edge of the eddy (know to be a theoretical site of a biological production maximum), Body, the most rapidly rotating area of the eddy, and **Centre**, the core, zero-velocity region of the eddy. Between these sampling stations, we aimed to do a series of continuous SeaSoar transects across full eddy diameters (as time permitted). Each set of stations and associated SeaSoar transect was considered a "pass", and we planned to map 6 eddy diameters (6 passes) for each eddy studied. From the western Perimeter of Eddy B we steamed as quickly as possible to the eddy Centre as determined from the deepest point of the warm water contour in the line of CTD casts. The centre was a little to the N of the first estimated Centre point, so we relocated to 111 45E 31 15S, and did the first of a series of sampling stations in the Centre. This included CTD and Bongo nets at night, the first deployment in the Centre of Eddy B of the Sediment Traps at dawn, followed by a day station in the Centre. The basic structure of Eddy B was a single deep bowl of warm water to 300 – 400 m (Fig. 1) Our sediment trap array consisted of an Iriduim buoy tethered to two cross-frames of sediment traps, one at 80 and one at 180 m. For Centre stations we sampled as close as possible to the position of zero velocity, repositioning by following the ADCP vectors. In the strong counterclockwise rotation of Eddy B, the ADCP vectors provided a highly reliable estimate of our position – a SW current indicated we were SE of the Centre; a SW current indicated were NW of the Centre, etc. This relocation, however, demanded close co-ordination and communication between the Voyage Leader, other navigators on the scientific staff, and the Bridge. Because the Eddy Centre was constantly moving, not just rotating, this repositioning was necessary each time we targeted the Eddy Centre. This occasionally demanded rapid changes in ship direction and in scheduling for the scientific staff, the Bridge, and the crew.

We subsequently noted that the buoy positions being sent via Iridium satellite from the sediment traps indicated the array was circling rapidly around the eddy Centre, which gave us a continuous estimate of how the Centre moved. We found this especially useful since it meant we did not have to rely on instantaneous ADCP data. On October 7 (LT) the traps were circling around 111 45 E 31 08.56 S, our new estimate of Eddy B Centre position.

We then steamed to the N, pausing in the Eddy Body for another CTD/Bongo station before steaming further N to the Perimeter of Eddy B. This took us into a strong SW jet of water between Eddy B and Eddy C. Our first SeaSoar transect was initiated from 111 40 E 32 15 N moving due south through the eddy Centre at 8 kn, undulating from 0 – 200 m. We resolved the S perimeter of the Eddy. The SeaSoar data provided a remarkable snapshot of the eddy shape, and with the fluorometer sensor, allowed us to map the high-fluorescence Perimeter region of the eddy in a manner which we had not fully anticipated. These data were crucial in allowing us not just to confirm the existence of such a region around Eddy B, but to give us the critical capacity to revisit the region to target it for biological experiments. We concluded that for such meso-scale features, the SeaSoar mapper is the instrument of choice, and simply cannot be compared with any other sampling method in terms of its resolution, its flexibility, and the quality of data generated. As the cruise progressed we became more enthusiastic about these data and became more and more willing to spend precious ship time on SeaSoar mapping to get reliable snapshots of the rapidly-changing eddy dynamics.

Another maintenance-demanding instrument we relied on was the EZNet, which did not have a successful deployment until late October 4 (local time). The initial problems involved the height setting of the ring bolts on each net and the firing mechanism, which did not perform, such that the first samples were integrated 0 - 450 m. This was rectified by Oct. 4.

We tracked, sighted, and successfully brought the sediment traps on board after a difficult retrieval in which the 40 m floats of the array caught under the ship's hull and snapped off. It was acknowledged that the entry and exit for instruments off the back deck of the Southern Surveyor leaves something to be desired, in particular, there is a difficulty in deck personnel reaching the incoming mooring / instrument to steady it while it is brought on board. The Iridium buoy sustained a minor dent. The mooring needed work and we therefore did not immediately re-deploy as originally planned.

The subsequent transects of Eddy B were similar to the first, along different Eddy axes (SW – NE; SE-NW; E – W), with Centre, Body and Perimeter stations (Fig. 1), and a variation only in our reliance on the SeaSoar. On two transects we let out more cable on the SeaSoar allowing it to undulate as deep as 400 m, and actually mapped the perfect bottom bowl-shape of Eddy B. We confirmed that the "productive perimeter" was typical of the entire perimeter of the eddy. Two later temporary failures of the SeaSoar were compensated for with CTD drops.

Our last station in Eddy B was a set of intensive Centre experiments. Observations had been made of a large suspended population of marine diatoms at Centre Eddy B, mostly large Chaetoceros species. We considered this anomalous in the sense that nitrate levels were non-detectable throughout the surface waters of Eddy B, and we did not quite understand how such a large population of heavily silicified phytoplankton could survive any length of time in such an environment. Our experiments were designed to investigate 1) whether the cells were carrying deep nitrate in their internal pools, and 2) whether there were vertical gradients in the cells' species composition and/or physiology within the strangely uniform chlorophyll maximum layer which extended as a constant fluorescence signal from the surface right to 100 m depth. We also executed deep day and night EZNet tows and did a deep nutrient cast to 1000 m. These experiments took ca. 13.5 h of wire / deck time, and were completed at ca. 9000h local time on Oct 10.

Before departing Eddy B for Fremantle, we did one last SeaSoar run NW from Centre Eddy B to Centre Eddy C as estimated by David Griffin. As we did so, we again crossed the strong jet between the two eddies, and with the SeaSoar resolved an interesting surface fluorescence signature associated with this (possibly Leeuwin Current?) feature. Our trip to Eddy C was designed partly to gain more information as to the suitability of Eddy C as a study site. David had also suggested the possibility of our studying and eddy to the NE of Eddy B, Eddy F, a newly forming clockwise eddy that might be better for our purposes (e.g., examining nitrogen upwelling dynamics) if it had a clearer upwelling signature than C. Feelings amongst the scientific staff were mixed, since Eddies B and C formed a clear "dipole", were adjacent to each other, and had formed on the coast (possibly from the same baroclinic instability) roughly at the same time. Eventually it was decided that despite the fact that Eddy C was not a typical upwelling eddy as they have previously been defined, it might be typical for the region as a whole, and therefore would be of great interest to study especially given its sister-status to Eddy B. We decided to deploy the Sediment traps in Eddy C to collect rotational information from its positions while we steamed to Fremantle. Again, the satellite estimate of Centre Eddy C did not seem to be correct based on the ADCP vectors, and upon arrival in the "Centre" we had to steam SW a considerable distance (45 minutes' steam) before the vectors shifted to something that looked like a Centre position. However, the ADCP readings were highly variable. It was immediately apparent that Eddy C had a surface rotation which was much less clear than Eddy B, and that the surface currents were less easy to read. We deployed the sediment trap array (1715 h LT Oct 10) as close as we could to the Eddy Centre but were less confident of that position than we had been in Eddy B. After sampling the Centre of Eddy C, we were more confident that this was an interesting feature biologically – we noted a fluorescence maximum at 100 -120 m, a strongly stratified surface layer with several distinct water masses, and very cold water at depth (Fig 2). We then departed for Fremantle for a personnel exchange, with Lynnath Beckley exchanged for Dan Gaughan. For a large part of this distance, we steamed at 8 km and towed the SeaSoar, which was redeployed for testing after some minor repairs. This SeaSoar transect continued without incident from 0615 LT to ~2300 LT on Oct 11.

We lost contact with the sediment trap buoy at 1400 h local time on October 11. The buoy had been transmitting rapidly, but suddenly stopped. Subsequent analysis has confirmed that there was a battery failure involved. The Argo float that had surfaced in Eddy C re-surfaced there, providing another profile and confirming that Eddy C was actually capped with ~100 m of temperate water, such that upwelling was generally confined to the region between 1000 and 500 m depth. Our first attempt at an E – W SeaSoar across Eddy C (Oct 13 am LT) was cancelled due to high seas, and we replaced this with CTD stations every 0.25 degree of longitude. Without the SeaSoar, having lost contact with the sediment traps, and with a much more complex set of surface signatures, it was extremely difficult to determine the location of the Centre of Eddy C. In terms of ship management, we had to change course a number of times, and the Voyage Leader depended heavily on the skills and the goodwill of those on the Bridge to support this "eddy tracking". By plotting the geographic distribution of the depth of the 14 degree contour, the depth of the main thermocline, and the surface temperature, I eventually managed to determine the general oceanographic signature of the Eddy C Centre, which was where the upwelling was greatest, and where the main thermocline was deepest. In other words, the Centre of Eddy C seemed, very roughly, to be where a surface lens of warm water was at its deepest, and the deep upwelling signature rose to its shallowest point. This resulted in an odd convergence of the deep and surface water signatures, and highly compressed temperature and density contours right at the eddy Centre. Repeatedly, the Centre position estimates seemed just off-centre oceanographically, when we arrived on station. It was not until we collected the high-resolution continuous SeaSoar data across Eddy C that we managed to understand why: the Centre of Eddy C was a tiny area no more than a few square nautical miles, where the upwelling signature reaches upwards in a cone shaped like a seamount to meet the bottom of the warm surface lens. Without SeaSoar data, we almost invariably ended up on the shoulder of the "seamount" signature. In Eddy C in particular, the resolution of the SeaSoar was critical in allowing us properly to map the feature. Without the SeaSoar the fine-scale features of Eddy C would have been largely invisible to us.

In Eddy C, as in Eddy B, we executed biological sampling stations at the Eddy Centre, Body and Perimeter. In general because Eddy C was smaller, there were fewer time constraints between adequately sampling the Eddy diameter with SeaSoar, and fitting in a full roster of biological productivity stations. We observed a large population of salps at the surface in Eddy C, which seemed to have decimated the phytoplankton population. Eddy C seemed surprisingly low in biomass of organisms compared to Eddy B. Interestingly, Eddy C also had a significant productive Perimeter (Fig. 2). But the most intriguing feature was a ball-shaped fluorescence feature superimposed directly on top of the upwelling "seamount" feature. It was impossible not to conclude that we had found real upwelling-driven production at last, but the small spatial extent of the feature and the extremely localized nature of the patch of chlorophyll indicated it was like no upwelling we were familiar with from other systems.

Repeated sweeps scanning at night for the strobe of the sediment traps were unsuccessful in locating them. We had a difficulty even postulating their whereabouts, since we had so much less understanding of the surface circulation of Eddy C than of Eddy B. While crossing the eddy towing the SeaSoar near the Centre at ~2400 h LT on October 20, the sediment trap strobe was spotted from the Bridge, in the dead Centre of the eddy. General joy and cries of Eureka were followed by a smooth and uneventful array retrieval. This also confirmed that despite its overall clockwise rotation, Eddy C had a strong surface convergence wholly atypical of an "upwelling" eddy.

Final Experiments in Eddy C focussed on the productive Perimeter of C, with intensive measurements of production and organism abundance.

The last SeaSoar transect through Eddies B and C together was cut short by the unfortunate illness of First Mate Roger Pepper. We steamed directly to Fremantle at full throttle, arriving at the dock at ~2000h LT October 22nd.

Summary

In general, I consider Voyage 08/2003 to have been highly successful. The EZNet and the SeaSoar were crucial to this success. Despite being high-maintenance instruments, and occasionally failing, they allowed us to sample in ways otherwise impossible. The EZNet provided stratified sampling for the zooplankton and fish teams. The SeaSoar illuminated key oceanographic features and provided data that generated exceptional excitement and formed the basis for novel insights in this study. Other than the difficulty with some of the instrument deployment and retrieval from the stern of the Southern Surveyor, the ship itself was well equipped for the voyage, and generally well-run.

Personnel

Scientific Participants:

Anya Waite – UWA, Chief Scientist / Day Watch Leader Stephane Pesant – UWA, Scientist (Deputy Chief) Peter A. Thompson – CSIRO, Scientist / Night Watch Leader Lynnath Beckley – Murdoch, Scientist (Leg 1) Dan Gaughan – Fisheries WA, Scientist (Leg 2) Joanna Strezlecki – CSIRO, Scientist Barbara Muhling – Murdoch, Student Harriet Patterson – CSIRO/UWA, Student Carrie Holl – Georgia Tech, Student Lindsay Pender – CSIRO NatFac, Voyage Manager / Computing / EZ Net Mark Underwood – CSIRO NatFac, Electronics Technician Mark Rayner – CSIRO NatFac, Hydrochemistry David Terhell – CSIRO NatFac, Hydrochemistry

Marine Crew:

Ian Taylor – Master Roger Pepper – Chief Officer John Boyes – Second Officer Roger Thomas – Chief Engineer Robert Cave – First Engineer John Hinchcliffe – Second Engineer Malcom McDougall – Bosun Tony Hearne – IR Manfred Germann – IR Graham McDougall – IR Paul O'Neill – IR Phil French – IR David Willcox – Chief Steward Peter Williams – Chief Cook Alan Sessions – Second Cook

We were happy with the support we received from the Southern Surveyor Operations Officer, CSIRO Support Personnel and Ships Crew. We especially acknowledge the outstanding contribution to our voyage by Lindsay Pender and Mark Underwood, who between them kept the EZNet and SeaSoar up and running. They also provided unswerving support for the scientific objectives of the cruise, and vital advice on logistics and communication with the ship's officers and crew.

Our voyage presented significant challenges in navigation through moving eddies, and therefore represented challenges in communication between scientific staff (the Cruise Leader in particular), the Bridge staff, and the crew. I wish to acknowledge the exceptional support that the Master, Chief and Second Officers provided to us in remaining flexible, understanding and humorous throughout. Their support served to keep the crew informed on the quick scheduling changes required to service our voyage objectives, and even in the most awkward circumstances the crew remained very willing to assist us.

A functional telephone in the fish laboratory would be very helpful on voyages such as ours. The only times when communication with the Bridge was not ideal occurred when the Cruise Leader needed to spend long stretches of time in that lab, and was not readily reachable by phone or intercom. This was overcome occasionally by allocating a radio to the Cruise Leader, however a telephone would be most appropriate.

Anya Waite Chief Scientist

Figure 1. Vertical profiles of temperature, salinity, fluorescence and light (PAR) at the centre and perimeter of Eddy B.





Figure 2. Vertical profiles of temperature, salinity, fluorescence and light (PAR) at the centre and perimeter of Eddy C.



