

Final Student Report 2009

Thesis Title:

Incorporation of larval fishes into a developing anticyclonic eddy of the Leeuwin Current: timing, sources and pathways

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My PhD research investigated the cross-shelf transport and entrainment of larval fishes during the formation of meso-scale eddies of the Leeuwin Current (LC). This research program was initiated following the hypothesis that the Leeuwin Current and its eddies may be responsible for the cross-shelf transport and offshore loss of biomass from the continental shelf. It had previously been established that the Leeuwin Current largely responsible for the observed variability within marine populations inhabiting the shelf although the mechanisms remained unknown.

To achieve this, two research voyages aboard the Australian National facility R.V. *Southern Surveyor* in May 2006 and May 2007 specifically targeted two anti-cyclonic warm-core eddies off the south-western Australian coast. This project is jointly supervised by Assoc. Prof. Lynnath Beckley (Murdoch University) and Dr. Ming Feng (CSIRO) and is part of the Western Australian Marine Science Institution research portfolio (WAMSI – Node 2 *Climate processes, predictability and impacts in a warming Indian Ocean*).

The major hypotheses of this project were:

1. The formation of meso-scale eddies of the Leeuwin Current results in the cross-shelf (seaward) advection of shelf-origin fish larvae.

2. Entrainment of neritic larvae into eddies leads to their mortality as a result of adverse transport away from coastal nursery habitats.
3. Eddies provide oases in an otherwise oligotrophic ocean which are conducive to larval growth and development.

1. Data collection and analyses

Field data collection required intensive, ship-based operations conducted during both research voyages, utilising a suite of oceanographic and biological instrumentation. Large oceanographic and biological datasets were collected with which to address the specific research hypotheses. Specifically, satellite and oceanographic data was employed to examine the role of the Leeuwin Current and eddy evolution as mechanisms of cross-shelf transport of biomass, namely larval fishes, from the continental shelf. Sampling of zooplankton and larval fishes utilised three different net gears; a neuston net to sample surface waters, a paired bongo net for depth integrated samples from the surface to a maximum depth of 150 m and a multiple opening-closing EZ net which is equipped with ten nets for the purpose of vertically stratified sampling of the water column. A combined total of 438 plankton samples were obtained from both cruises. This study required the extraction and identification of larval fishes from all plankton samples. Taxonomic identification of larval fishes was an important part of my research and resulted in over 42,000 larval fish being identified. Larval fish assemblages were examined to ascertain the influence of cross-shelf transport and the incidence of incorporation into the evolving warm-core eddies. Furthermore, larval fishes were also utilised as time-dependent tracer to compliment the oceanographic analyses examining the mechanisms, pathways and timing of cross-shelf transport.

2. Major Findings Summarised

1. Biomass, including chlorophyll *a* and the larvae of planktonic biota such as larval fishes, from the continental shelf is subjected to cross-shelf, offshore transport and incorporation into warm-core Leeuwin Current eddies during their evolution off south –western Australia
2. The Leeuwin Current is the major transport pathway for shelf-origin water and its constituent biomass to evolving warm-core eddies; offshore transport from the adjacent shelf was apparent from velocity data although this process remains to be quantified
3. The oceanography across the eddy field, which incorporated offshore and shelf waters, was dynamic and was characterised by strong spatio-temporal variability associated with mixing (e.g. mixed layer depths and water masses) and the velocity field
4. The high concentration of chlorophyll *a* offshore in the eddies compared to the surrounding ocean indicated that warm-core eddies are important in the localised, seasonal and recurrent enhancement of productivity offshore which will have significant trophic implications
5. Larval fish assemblages, particularly in the eddies, reflected strong mixing of source waters, i.e. Leeuwin Current, shelf and oceanic. Furthermore, the respective occurrence of the larvae of oceanic fishes over the shelf and the larvae of coastal fishes offshore revealed strong onshore-offshore coupling off south-western Australia
6. The night time concentration of larval fishes in the upper 80 m of the water column throughout the study region was independent of specific

oceanographic features, for example the thermocline, and the velocity field both of which were spatially and temporally variable. It was concluded that the vertical distribution patterns were in response to other behavioural, physiological or external factors which regulate this type of diel migration

7. This study concluded that the generally low abundance of larvae of neritic (demersal, pelagic and coastal) fishes indicated that adult spawning of many of these fishes occurs in spring and summer and is probably timed to avoid adverse transport associated with a strong Leeuwin Current and evolution of warm-core eddies

3. Research Findings Discussed

A detailed analysis of the meso-scale oceanography and cross-shelf exchange off SW Australia resulted in identification of transport pathways and sources of water to an eddy during its formation. In accordance with that previously suggested by Feng *et al.* (2007), our data indicate that the LC was the main source of water to the eddy and that due to on-shelf mixing, the LC provided an indirect pathway for the transport of shelf-origin water and biota to the eddy. Satellite ocean colour data revealed high surface chlorophyll *a* concentrations on the shelf and in an evolving warm-core eddy which was in contrast to the surrounding ocean. Due to the proximity of the eddies to the shelf break it is reasonable to assume that chlorophyll *a* was derived, at least in part, from the shelf. This initial observation pointed to cross-shelf transport and incorporation of shelf-origin biomass into an evolving eddy. Furthermore, the concentration of high chlorophyll *a* biomass within the eddy indicated that eddies are important in the localised, seasonal and recurrent enhancement of offshore productivity which probably has significant positive trophic implications.

Examination of temperature and salinity data concluded that three water masses were present within the region of meso-scale circulation. A modified LC signature dominated most of the study region while LC and sub-tropical surface water (STSW) were not as widely distributed. The regional dominance of this water mass, particularly in the eddy field, is apparently typical of the oceanography off southwestern Australia during late austral autumn and winter coinciding with peak LC flow and eddy evolution. The eddy field, which incorporated shelf and offshore waters, was characterised by dynamic oceanography and properties such as mixed layer depth and the velocity field were highly variable both spatial and temporally.

A Lagrangian study using satellite-tracked drifters deployed in the LC meander and at the perimeter of, and within the eddy characterised the upper ocean circulation and gave estimates of transport at these locations during eddy evolution. Results of the drifter study, for example the ejection of a drifter from the eddy which indicated that exchange between the eddy centre and shelf break occurred as the eddy evolved, will have significant implications when considering the transport and fate of planktonic biota. Although the use of physical tracers alone was insufficient in evaluating the timing of, and pathways for the incorporation of shelf biomass to the eddy, the use of time-dependent tracers, in this case larval fishes, provided useful elucidation

As well as the utilisation as time-dependent tracers of cross-shelf transport, the influence of the physical oceanography in driving patterns in the horizontal distributions of larval fish assemblages was examined. Larval fish assemblages were

dominated by meso-pelagic taxa while neritic (shelf) species were in much lower concentrations within the study region. The respective distributions of larvae of coastal and oceanic meso-pelagic fish species at offshore and shelf locations highlighted the strong onshore-offshore coupling of advective transport which is largely facilitated by circulation of the LC. Furthermore, it demonstrated that cross-shelf transport was enhanced off south-western Australia during eddy evolution. Larval fishes were concentrated higher offshore in the eddy compared to the surrounding ocean and the occurrence of neritic larvae, including inshore reef-dwelling families such as the Gobiidae (Gobies) and Tripterygiidae (Triple-fin blennies), within the eddy confirmed that the larvae of neritic fishes are subject to offshore advection and incorporation into eddies during formation. That many of the coastal larvae occurring within the eddies had tropical origins pointed to the LC as the major transport pathway. In addition, larval fish assemblages within the eddy were reflective of the mixing of its source waters, i.e. LC, shelf and oceanic water.

Larval fish assemblages showed significant night time vertical structuring based on the analysis of the five depth strata. Significantly higher concentrations of larval fishes occurred in the upper 80m of the water column and diversity at the family level was also highest within this depth range. However there was no apparent relationship between the vertical distributions of larval fishes with specific oceanographic features for example the thermocline and there was no correlation with the velocity field. It was concluded that the night time vertical distribution of larval fishes was probably in response to other behavioural, physiological or external factors which regulate this type of diel migration and which are species specific

This study concluded that there is a generally low abundance and diversity of the larvae of neritic (demersal, pelagic and coastal) fish species occurring in the region off south-western Australia during late autumn and winter. Peak abundances of the larvae of most coastal fish taxa, and therefore adult spawning, occur during late spring / summer indicating that these populations are reliant on processes other than LC transport for dispersal and recruitment of larvae. Spawning by many neritic finfish species off Western Australia appears to be timed to avoid the potentially deleterious offshore transport associated with peak LC flow and eddy formation during late austral autumn and winter. It is thus concluded that the seasonal formation of meso-scale, anticyclonic warm-core eddies of the LC have little direct influence upon coastal teleost fishes, particularly in terms of adverse transport and enhanced mortality.

4. Publications

Holliday, D., Stieglitz, T.C., Ridd, P.V. & Read, W.W. (2007). Geological controls and tidal forcing of submarine groundwater discharge from a confined aquifer in a coastal sand dune system. *Journal of Geophysical Research* **112**, C04015.

Paterson, H. L., Feng, M., Waite, A. M., Gomis, D., Beckley L. E., **Holliday, D.**, Thompson, P. A. (2007). Physical and chemical signatures of a developing anti-cyclonic eddy of the Leeuwin Current, Eastern Indian Ocean. *Journal of Geophysical Research* **113**, C07049.

Holliday, D., Beckley, L.E., Olivar, M.P. (In prep.). Incorporation of larval fishes into an evolving eddy of the Leeuwin Current off SW Australia.

Holliday, D., Feng, M. (In prep.). Latitudinal and cross-shelf dynamics of the Leeuwin Current off Western Australia.

Holliday, D., Waite, A.M., Feng, M., Beckley, L.E., Thompson, P.A. (In prep.). Cross-shelf transport associated with the evolution of an anti-cyclonic warm-core Leeuwin Current eddy.

Holliday, D., Beckley, L.E. (In prep.). Vertical distributions of larval fishes within a large eddy field off south-western Australia: Implications for transport.

5. Conference Papers

Holliday, D., Beckley, L.E., Feng, M., Waite, A.M. (2009). Timing, sources and pathways for the incorporation of larval fishes into a developing anti-cyclonic eddy of the Leeuwin current, SW Australia. MOCA-09 Joint Assembly including The International Association for the Physical Sciences of the Ocean, Montreal, Canada.

Holliday, D., Beckley, L.E., Feng, M., Waite, A.M. (2009). Shelf-ocean connectivity: the role of eddies in cross-shelf exchange of larval fishes off SW Australia. Australian Marine Sciences Association conference. Adelaide, South Australia.

Holliday, D., Beckley, L.E., Feng, M., Waite, A.M. (2009). Lost at sea? The influence of meso-scale oceanographic features on larval fish assemblages off SW

Australia. 8th Indo-Pacific Fish Conference and Australian Society for Fish Biology joint symposium. Fremantle, Western Australia.

Holliday, D., Beckley, L.E. and Feng, M., Waite, A.M., Thompson, P.A. and Olivar, M.P. 2009. Sources of, and pathways for, the incorporation of larval fishes into a developing warm-core eddy of the Leeuwin Current, SW Australia. Advancing the Science of Limnology and Oceanography (ASLO), Nice, France.

Holliday, D., Beckley, L.E. and Feng, M. 2007. Cross-shelf transport of larval biota during formation of a Leeuwin Current eddy. Australian Marine Science Association (AMSA) conference, University of Melbourne, Victoria.

Beckley, L.E., **Holliday, D.**, Muhling, B.A., Gaughan, D.J. and Waite, A.M. 2007. Leeuwin Current eddies and potential impacts upon Western Australian coastal fisheries. AMSA conference, University of Melbourne, Victoria.

Holliday, D., Paterson, H.L., Beckley, L.E., Waite, A.M., Feng, M., Thompson, P.A. (2007). Evidence for cross-shelf transport of neritic biota during formation of a Leeuwin Current eddy. The 2nd Leeuwin Current Symposium, The Royal Society of Western Australia, University of Western Australia, Perth.

Waite, A. M., Feng, M., Picheral, M., Gorsky, G., **Holliday, D.**, Beckley, L.E., Thompson, P. A., Pesant, S., Paterson, H. L., Duarte, C. M. and Agusti, S. 2007. Particle trapping by a vortex off Western Australia. American Society for Limnology and Oceanography (ASLO), Santa Fe, New Mexico.

Beckley, L.E., **Holliday, D.**, Muhling, B.A., Waite, A.M. and Gaughan, D.J. 2006. Swings and roundabouts! Leeuwin Current eddies and potential impacts on Western Australian fisheries. Australian Society for Fish Biology, Hobart, Tasmania.

6. Workshops and Seminars

Holliday, D., Beckley, L.E. and Feng, M. 2008. Meso-scale circulation of the Leeuwin Current, eddy formation and the distributions of larval fish assemblages. WAMSI Node 1 annual symposium, CSIRO Floreat, Perth.

Holliday, D., Beckley, L.E. and Feng, M., Waite, A.M., Thompson, P.A. 2008. Meso-scale circulation of the Leeuwin Current, eddy formation and the distributions of fish larvae. Western Australian Marine Sciences Institution Node 2 seminar, CSIRO Floreat, Perth, Western Australia.

Holliday, D., Beckley, L.E. and Feng, M. 2007. Cross-shelf transport of larval biota during formation of a Leeuwin Current eddy. Australian Marine Sciences Association student workshop, Rottnest Island, Western Australia.

Holliday, D. and Beckley, L.E. 2007. Cross-shelf transport induced by meso-scale eddies of the Leeuwin Current: implications for larvae of neritic biota. Western Australian Marine Sciences Institution Node 2 seminar, Perth, Western Australia.

Holliday, D. and Beckley, L.E. 2006. Cross-shelf transport induced by meso-scale eddies of the Leeuwin Current: implications for larvae of neritic biota. Australian Marine Sciences Association student workshop, Rottnest Island, Western Australia.