Corella, 1990, 14(4): 113-118

THE LEEUWIN CURRENT

GEORGE CRESSWELL

CSIRO, Division of Oceanography, Box 1538 G.P.O., Hobart, Tas. 7001

Received 6 July, 1990

The Leeuwin Current is an unexpected current because it carries water from the tropics to south-western Australia and then eastward, possibly as far as Tasmania. In some places and at some times it has speeds up to 3.5 knots, thereby rivalling the East Australian Current. This paper outlines some of its features.

INTRODUCTION

The earliest evidence for a southward-flowing warm current off western Australia came from observations of warm waters and tropical marine flora and fauna around the Abrolhos Islands (~29°S) by naturalist Saville-Kent in 1897. In 1922 Halligan, a hydrographer, inferred such a current from temperature maps derived from merchant ship measurements. Further, he reported "a warm southerly and easterly surface current from the vicinity of Cape Leeuwin" with speeds of 0.3–0.4 knots.

Since that time studies of currents, water properties and plankton have contributed to the description of a warm, low-salinity current that starts off NW Australia and runs down to Cape Leeuwin where it pivots to flow eastward across the Great Australian Bight. The response of CSIRO satellite-tracked drifters to this current was quite dramatic some fifteen years ago and led to it being called the Leeuwin Current. The *Leeuwin* (Lioness in English) was a Dutch ship that explored eastward towards the Bight in 1622.

The Leeuwin Current flows principally, but not exclusively, in autumn and winter. It probably influences the coastal climate; it acts as a conduit to bring tropical marine fauna and flora to southern Australia; and it appears to play an important role in the migration of several species of fish and birds. It is unusual in that it flows southward and into the wind. Other current systems on the eastern sides of oceans — the Benguela, Canary, Peru, and California current systems of the Atlantic and Pacific Oceans — flow equatorward.

Features of the Leeuwin Current and the marine environment of Western Australia are outlined in the following sections.

THE LEEUWIN CURRENT SYSTEM: DIMENSIONS AND SPEEDS

Off NW Australia the Leeuwin Current is broad and shallow (200 km by 50 m) and has speeds of up to 1 knot. It accelerates along its southward path and by the time Cape Naturaliste is reached (33°S) it can have speeds up to 2 knots. There its warm waters are some tens of km wide and can be as deep as 200 m. The Current further accelerates in the Cape Leeuwin vicinity and speeds of up to 3.5 knots have been measured just beyond the shelf edge between the Cape and Esperance. Eastward from Cape Leeuwin its warm waters spread quite close to shore, although the maximum speeds at midshelf are only 1 knot.

Changes in the strength of the Leeuwin Current are reflected in mean sea level changes at coastal stations. These typically show an annual amplitude of 15–20 cm, with highest values in March (NW shelf) to May or June (SW Australia); this seasonal movement of the sea-level maximum reflects the southward passage of the Leeuwin Current pulse. It is worth mentioning that passing weather patterns commonly produce sea level changes of 40 cm; these have periods of several days.

All along its path southward from NW Australia, the Leeuwin Current both meanders and "spins up" eddies. It provides these eddies with warm "fresh" waters while, at the same time, takes cold "salty" waters from them. This mixing contributes to a progressive cooling and increase in salinity along the path of the Current. The eddies out from the west coast are both clockwise and anticlockwise and are roughly 150 km in diameter. Speeds of up to 2 knots have been measured in them and their lifetimes can be over two months (Fig. 1).

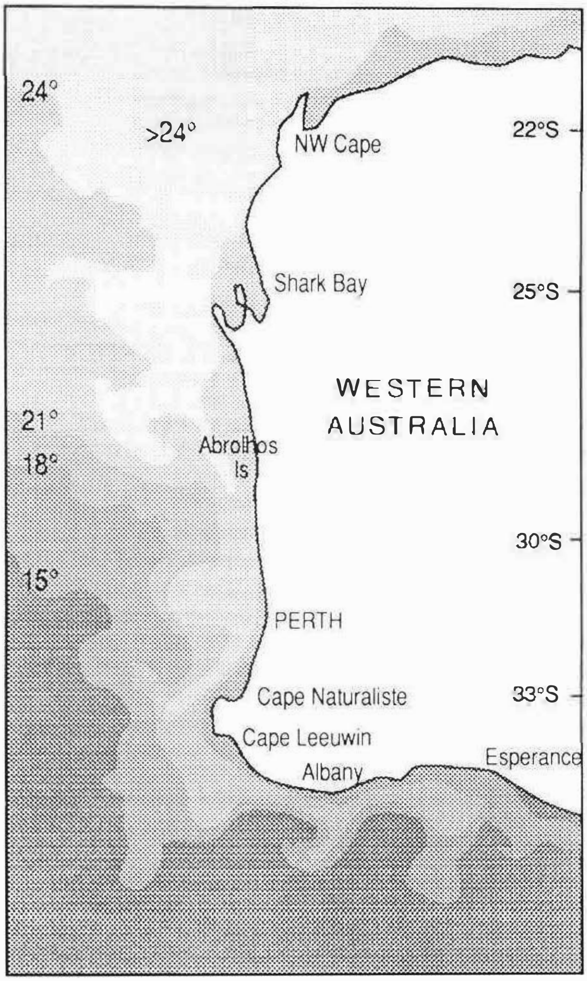

Figure 1. *The surface temperature distribution off western Australia as determined from an infrared satellite image from 15 June 1984. The Leeuwin Current starts as a broad fan of warm water (>24°C) off the north-west and progresses southward to Cape Leeuwin and then eastward to the Great Australian Bight. There are eddies, meanders and offshoots associated with the Leeuwin Current. Mixing, radiation and evaporation cause its waters to cool and become saltier as they progress.*

As it runs eastward the Leeuwin Current loses vast amounts of water into offshoots that can extend up to several hundred kilometres southward. The offshoots are 50 km wide and 150 m deep and have trough-shaped cross sections. On their western sides are southgoing currents and on their eastern sides are northgoing currents; the speeds are up to 2 knots and turbulence between the two streams gives rise to overturning and mixing. The offshoots drive clockwise and anticlockwise eddy-pairs 100 km diameter on their eastern and western sides respectively.

Below the Leeuwin Current, and extending over a depth range of several hundred metres, is a reverse undercurrent of up to 0.5 knots.

WATER TYPES OF THE WESTERN AUSTRALIAN REGION

The following waters are encountered in the upper 500 m in the subtropics west of Australia:

The Leeuwin Current: Surface, low-salinity (<35.00 parts per thousand), high-temperature (>24°C), low-nutrient, tropical waters that spread south from 20°S in autumn and winter. Off Rottnest Island (32°S) the winter salinity is 35.20–35.40 and the Leeuwin Current holds the sea surface temperature there above 22°C until after June.

South Indian Central waters are high-salinity (>35.80) with temperatures of 17°–19°C and are found near the surface off Australia's SW corner. They sink to several hundred metres as they spread northward as an undercurrent, with mixing progressively lowering their salinity. In summer they extend to 12°S and in winter to 16°S. The northward spread is arrested by the westward flow of the relatively low-salinity (<34.5) South Equatorial Current. The South Indian Central waters are also prevented from reaching the continental shelf between 10° and 20°S by the low-salinity Leeuwin Current source waters.

The West Australian Current: Surface, high-salinity (>35.90), low-nutrient, subtropical waters with temperatures of 20°–22°C at 30°S. In summer they are carried northward to 25°S and down to 100 m depth.

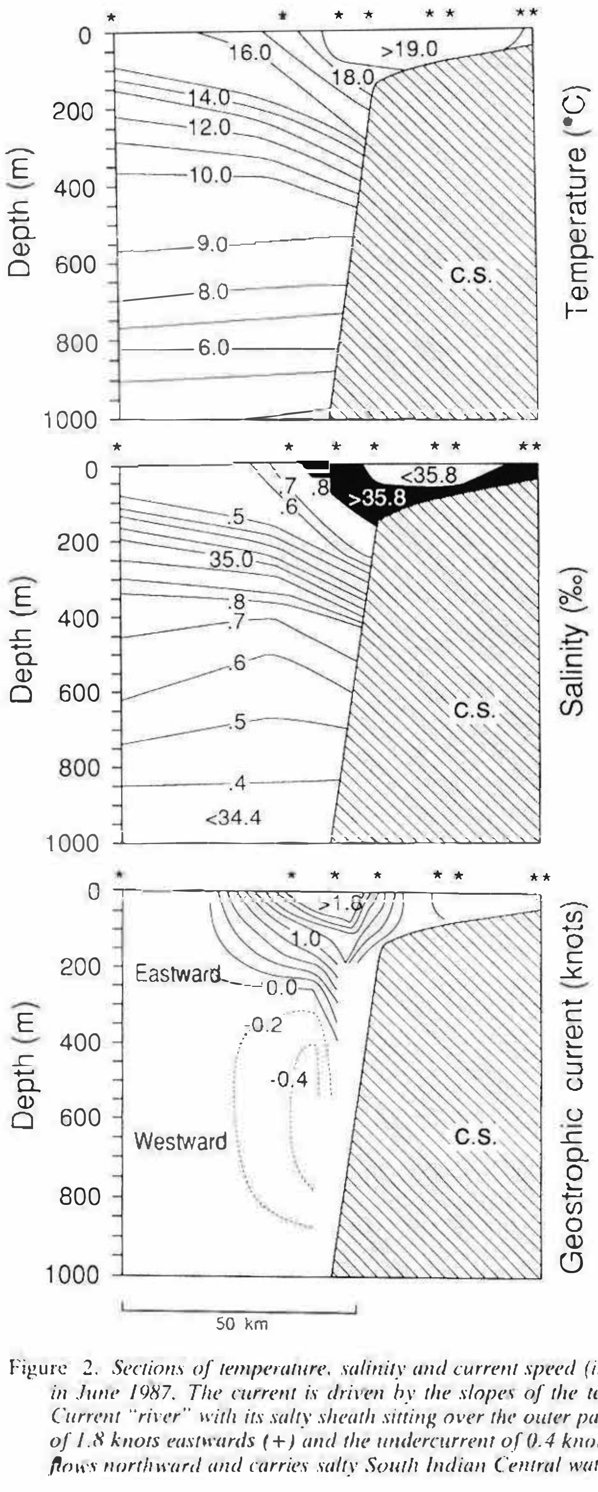

Figure 2. *Sections of temperature, salinity and current speed (inferred from density) along a line out from the coast west of Albany in June 1987. The current is driven by the slopes of the temperature and salinity structures. Note the warm surface Leeuwin Current "river" with its salty sheath sitting over the outer part of the continental shelf (C.S.); also the near surface current speed of 1.8 knots eastwards (+) and the undercurrent of 0.4 knots westwards (−). Off the western continental shelf this undercurrent flows northward and carries salty South Indian Central water.*

Tropical oxygen minimum: Subsurface (100–150 m), low salinity (<35.00), low-oxygen (< 150μM*), tropical water spreading southward to about 26°S in late summer and autumn.

Subtropical oxygen maximum: Subsurface (400–500 m), low-salinity (<35.00) waters of the subtropical oxygen maximum (>175μM) drifting northward to about 14°S in winter.

The Leeuwin Current spreads southward over, and mixes with, South Indian Central water, thereby becoming progressively more saline and cooler with increasing latitude. Seasonal variations in solar heating, evaporation-precipitation effects, dynamical uplifting of South Indian Central water, mixing, and the supply of waters of the Leeuwin and West Australian Currents are controlling factors for the temperature and salinity of the surface layer off western Australia.

When the Leeuwin Current turns to the east at Cape Leeuwin it leaves a region where its salinity is less than the ambient (~35.8 South Indian Central water) and enters one where its salinity is higher than the ambient 35.5. In the second (fresher) regime the Leeuwin Current has been observed to carry with it a sheath of salty South Indian Central water. The sheath is then slowly lost downstream through energetic mixing with the fresher offshore waters (Fig. 2).

EFFECTS ON SHELF WATERS

The effects of the various currents on the waters of the continental shelf were first monitored at a hydrology station on Rottnest Island at a water depth of 50 m. There is a southward flow of low-salinity water in autumn/winter and a northward flow of high-salinity water in summer. The northward flow is opposite to the southward open ocean summer flow and is probably the effect of a predominantly southerly wind stress on the shallow waters of the shelf. The arrival each

*Micro-molar, a rough division by 50 gives mg/l.

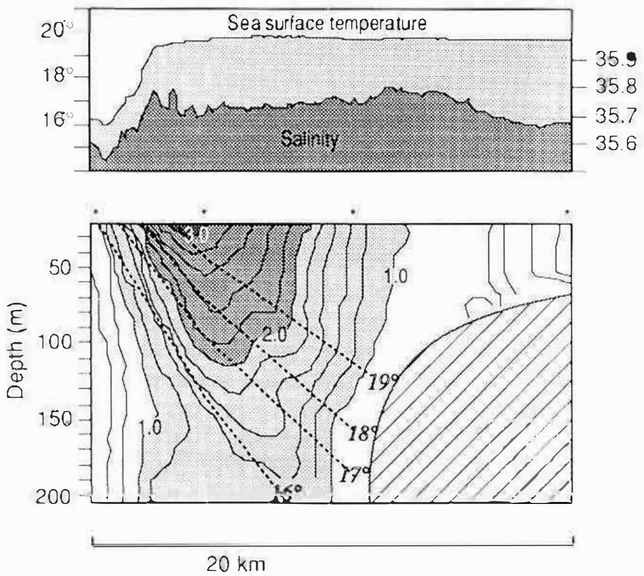

Figure 3. *A section (bottom panel) showing the current structure measured by RV* Franklin *several days after the temperature and salinity sections of Figure 2. Current speeds greater than 1.0, 2.0 and 3.0 knots are shaded progressively darker. The isotherms measured by expendable temperature probes are shown. Note the surface temperature and salinity front (top panel) on the offshore edge of the Leeuwin Current. This is where the speed dramatically decreases and where considerable overturn and mixing take place.*

autumn of the low-salinity waters of the Leeuwin Current at the Rottnest Island 50 m hydrology station produces an annual salinity variation of roughly 0.5. Recent work as part of the Leeuwin Current Interdisciplinary Experiment, LUCIE, quite clearly showed the major effect of the Leeuwin Current to occur at the outer shelf.

Current measurements at the southern part of the NW Shelf showed the Leeuwin Current to run parallel to the bottom topography and to be strongest at the shelf break in February and June, reaching a maximum speed of 0.5 knots (Fig. 3).

THE SOURCE REGION

The waters NW of Australia appear to contain the source region for the Leeuwin Current. Historical temperature-depth profiles were interpreted by Gentilli in 1972 to show that the autumn and winter throughflow pulse from the Pacific to the Indian Ocean becomes isolated off NW Australia by a reversal of the flow in spring. Over the summer this water becomes a warm homogeneous 'raft', which then spreads southward (as the Leeuwin Current) during the following autumn and winter (Figs 4 and 5).

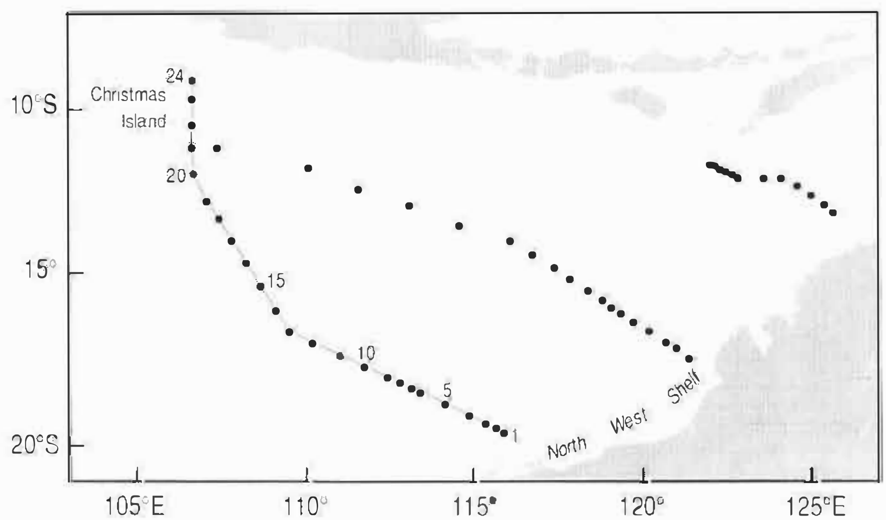

Figure 4. *A chart of the triangle between NW Australia and Indonesia showing the station positions occupied by RV* Franklin *in October 1987 enroute to and beyond Christmas Island.*

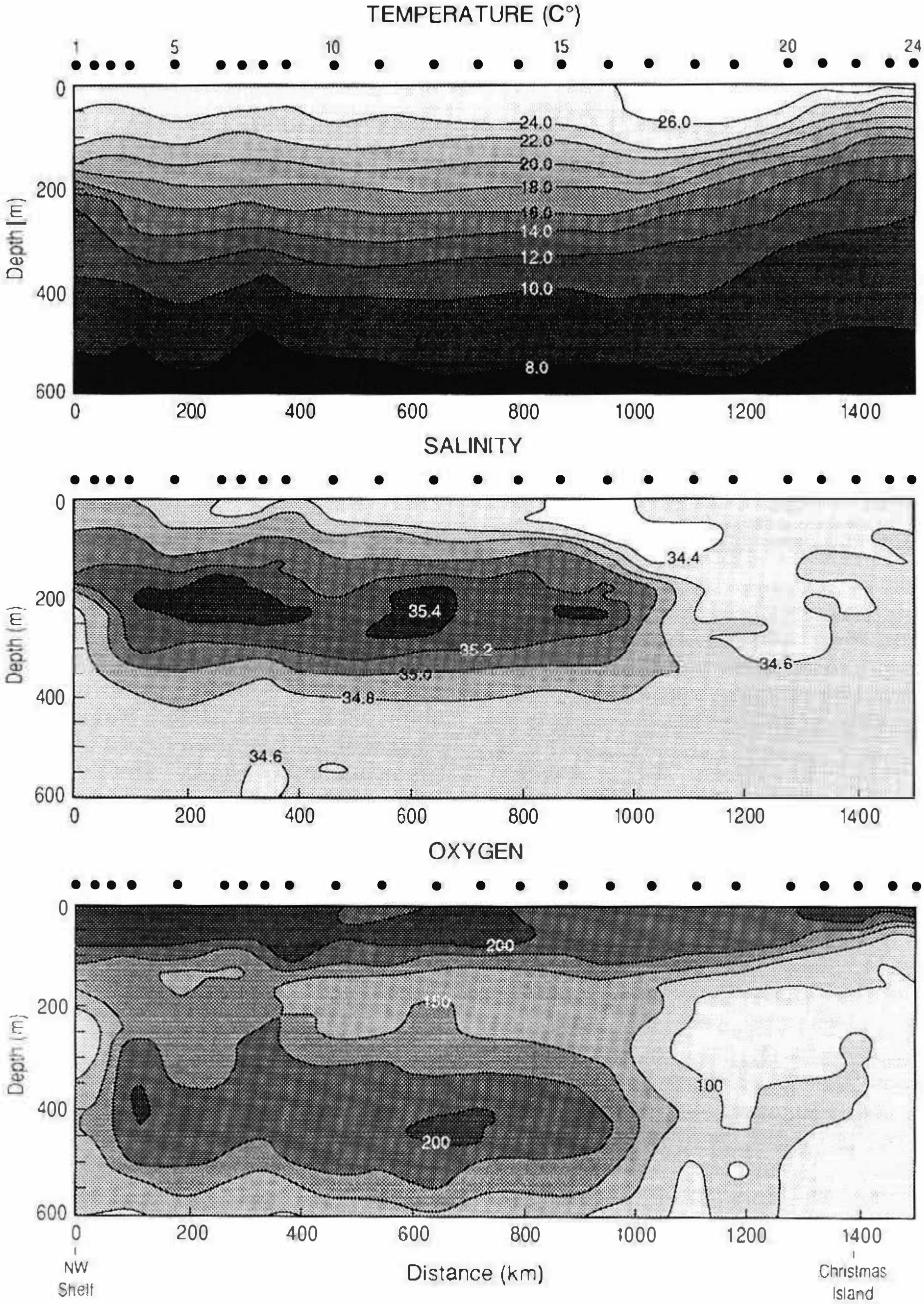

Figure 5. *The station positions* ● *corresponding to those shown in Figure 4 from the North West Shelf to Christmas Island are shown at the top of each panel. The warm, low salinity surface layer serves as the source of the Leeuwin Current. The slope of the subsurface isotherms between stations 16 and 24 drives the South Equatorial Current from east to west past Christmas Island. The salinity section shows a maximum that is due to the northward flowing South Indian Central water. The oxygen section shows both the Tropical Oxygen Minimum water spreading southward at 150–250 m and the Subtropical Oxygen Maximum water spreading northward at 300–500 m.*

INTERANNUAL VARIABILITY

The extent of interannual variations in the strength of the Leeuwin Current is not known. It has been found that anti-ENSO (ENSO: el Niño — Southern Oscillation) events are accompanied by higher than normal sea-level at Darwin and Port Hedland, and suggested that the enhanced sea-level along Western Australia is associated with a stronger than normal Leeuwin Current. This suggestion finds support in the Rottnest Island records, which, for the 1973 76 anti-ENSO event, showed low salinities suggestive of an enhanced flow of low-salinity water from the tropics.

WHY IS THERE A LEEUWIN CURRENT?

According to Stuart Godfrey of CSIRO the Leeuwin Current is different from other eastern boundary currents in a number of ways, which appear to be linked in a feed-back loop. The first unusual feature of the Leeuwin Current is that the current flows directly into the wind, thereby carrying warm water pole-wards.

This is probably the reason for a second unusual feature: there is a strong heat flux out of the ocean from the waters of the Leeuwin Current, rather than into the ocean as in all other eastern boundary currents. This heat loss favours convection and hence the formation of deep mixed layers, which are a third unusual feature of the Leeuwin Current. Thompson argued in 1984 that these deep mixed layers are essential to the maintenance of the observed large alongshore pressure gradient (a fourth unusual feature of the Leeuwin Current). Drawing these points together, the warm waters flow downhill to the south, in response to the alongshore pressure gradient, thereby over-coming the efforts of the wind to push them northward. The wind is much less effective in moving a deep surface mixed layer than a shallow one.

So far, there is no explanation why all these linked features occur off Western Australia and not in other eastern boundary currents, but it might be due to the Pacific to Indian Ocean throughflow, as Gentilli suggested. The question is still very much open.

BIOLOGICAL IMPLICATIONS

The Leeuwin Current obviously can carry passive organisms hundreds of kilometres and along the south coast this was first noted by Wood, who suggested a current to be responsible for the distribution of dinoflagellates that he observed from SW Australia to Tasmania. It is also possible that other creatures may actively take advantage of the Leeuwin Current to transport their eggs, larvae and juveniles; examples of this are the Southern Bluefin Tuna that spawn off NW Australia and the Australian salmon and herring that migrate from South Australian waters to spawn off SW Australia.

Also, while the exact mechanism may be debat-able, Pearce and Phillips have found recently that the settlement of western rock lobster puerulus larvae to the nearshore reefs of Western Australia is higher in anti-ENSO years with a strong Leeuwin Current.

On a smaller scale, during LUCIE the seaward edge of the Leeuwin Current on the continental shelf at Rottnest Island was observed to be a region of congregation for dolphins, yellow-nosed albatross and pilchards. Depth sounders revealed considerable marine life in the waters down to the bottom.

SELECTED FURTHER READING

Church, J. A., Cresswell, G. R. and Godfrey, J. S. (1989). The Leeuwin Current. In 'Poleward Flows along Eastern Ocean Boundaries'. (Eds S. Neshyba, C. N. K. Mooers and R. L. Smith.) Pp. 230–252. (Springer-Verlag: New York.)

Gentilli, J. (1972). Thermal anomalies in the Eastern Indian Ocean. *Nature, Physical Sciences* **238**: 93–95.

Godfrey, J. S. and Ridgway, K. R. (1985). The large-scale environment of the poleward-flowing Leeuwin Current, Western Australia: longshore steric height gradients, wind stresses and geostrophic flow. *J. Phys. Oceangr.* **15**: 481–495.

Pearce, A. F. and Phillips, B. F. (1988). ENSO events, the Leeuwin Current and larval recruitment of the western rock lobster. *J. Cons. Int. Explor. Mer* **45**: 13–21.

Rochford, D. J. (1969). Seasonal interchange of high and low salinity surface waters off South-west Australia. Division of Fisheries and Oceanography Technical Paper No. 29.

Wood, E. J. F. (1954). Dinoflagellates in the Australian region. *Aust. J. Mar. Freshw. Res.* 5: 171–351.