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WIND-DRIVEN OCEAN SURFACE TRANSPORT AROUND AUSTRALIA

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Abstract

Fofonoff's computational method for determining wind-induced ocean transport from atmospheric pressure data has been applied to the Australian area. The method showed offshore drift in Western Australia to peak during the summer months, thereby supporting the suggestion that the rock lobster larvae may commence their migration by riding these currents.

INTRODUCTION

Fofonoff (1962) developed a computational method for determining wind-induced ocean transport using as data a 5° grid of monthly mean sea level atmospheric pressures. Wickett (1967) applied the technique to a time series study of North Pacific zooplankton concentrations. He found that the zooplankton concentration off California showed a dependence on the amount of southward surface transport one year previous in an area 1,200 miles away to the NW. In this area strong southerly surface transport could divert enriched waters from the Alaskan gyre across the underlying eastward geostrophic flow. Once across they could travel southward on the California Current.

Aagaard (1970) has applied the technique to the Greenland and Norwegian Seas to show that the observed major persistent features of the circulation can be quantitatively explained as wind-driven.

Several fisheries in Australia - such as the rock lobster industry in Western Australia (Chittleborough and Thomas, 1969) - depend heavily on the successful marathon migrations of larvae. These larvae will ride the ocean currents as have countless generations of their predecessors. In the absence of direct measurements, Fofonoff's method, albeit subject to the data quality and the validity of the method per se, can give an input of information. With this in mind the method was adapted for a southern hemisphere grid.

Additionally, in collaboration with Mr W.P. Wickett of the Fisheries Research Board of Canada, the computer program for the 5° grid of monthly mean pressures was modified to act on a 2° grid of daily pressures for studying oceanographic events in the N.E. Pacific coastal domain (Wickett and Thomson, unpublished). This program was then adapted for grids along the east and west Australian coasts.

METHOD

In Fofonoff's method geostrophic winds are calculated from pressure gradients in the atmospheric pressure 5° grid and then, by applying a contraction and a rotation to account for surface friction, the surface winds are calculated. The pressure gradients at each point come from finite differences of pressure calculated from the pressure at the point and at the six nearest points. The action of the wind stress on the sea theoretically gives rise to the Ekman spiral: in the southern hemisphere the surface current vector is 45° to the left of the wind and the deviation increases with depth while the vector magnitude decreases. Ekman's (1905) calculations were the case of non-accelerated drift currents in an idealized ocean for which the equations of motion were

$$2\omega u \sin\phi = \frac{A}{\rho}\frac{\partial^2 v}{\partial z^2}$$
$$-2\omega v \sin\phi = \frac{A}{\rho}\frac{\partial^2 u}{\partial z^2} \qquad (1)$$

where A is the eddy viscosity coefficient (cf. Neumann and Pierson, 1966). The solution is given by

$$u = V_0 e^{-(\pi/D)z}\cos(45^\circ - \frac{\pi}{D}z)$$
$$v = V_0 e^{-(\pi/D)z}\sin(45^\circ - \frac{\pi}{D}z) \qquad (2)$$

with $V_0 = \tau/\sqrt{2\omega A\rho \sin\phi}$.

τ is the surface stress and D is the Ekman depth (= $\pi\sqrt{A/\rho\omega \sin\phi}$) which, for A having an average value of 100 cm^{-1} gm sec^{-1}, is about 50 metres for latitude 30°. At this depth the current vector has reduced to $e^{-\pi}$ times the surface value, about 1/23, and is oppositely directed to the surface current vector.

If u and v are integrated between depths $z = 0$ and $z = \infty$, assuming the wind to be in the y direction, then the total mass transport is in the x direction and is $\tau/2\omega \sin\phi$. In other words the transport is 90° away from the wind direction; for the southern hemisphere the latitudes, ϕ, are taken to be negative so the deflection is to the left.

To calculate the surface speed, V_0, from the mass transport values given in this report the association is that a transport of 1,000 metric tons sec^{-1} km occurs with a surface speed of 8.5 cm/sec or very roughly 200 km/month. Once again A has been taken to be 100 cm^{-1} gm sec^{-1} and in the southern hemisphere the surface velocity vector will be 45° to the right of the transport vector.

Fofonoff assumed a square - law velocity dependence for the wind stress; the zonal (easterly) and meridional (northerly) components were respectively

$$\tau_\lambda = \rho_a C_D (u_s^2 + v_s^2)^{\frac{1}{2}} u_s$$
$$\tau_\phi = \rho_a C_D (u_s^2 + v_s^2)^{\frac{1}{2}} v_s , \qquad (3)$$

where ρ_a is mean atmospheric density, C_D a constant drag coefficient, and u_s and v_s the surface wind components. The zonal and meridional components of Ekman transport are then

$$U_E = \tau_\phi/2\omega \sin\phi$$
$$V_E = -\tau_\lambda/2\omega \sin\phi \qquad (4)$$

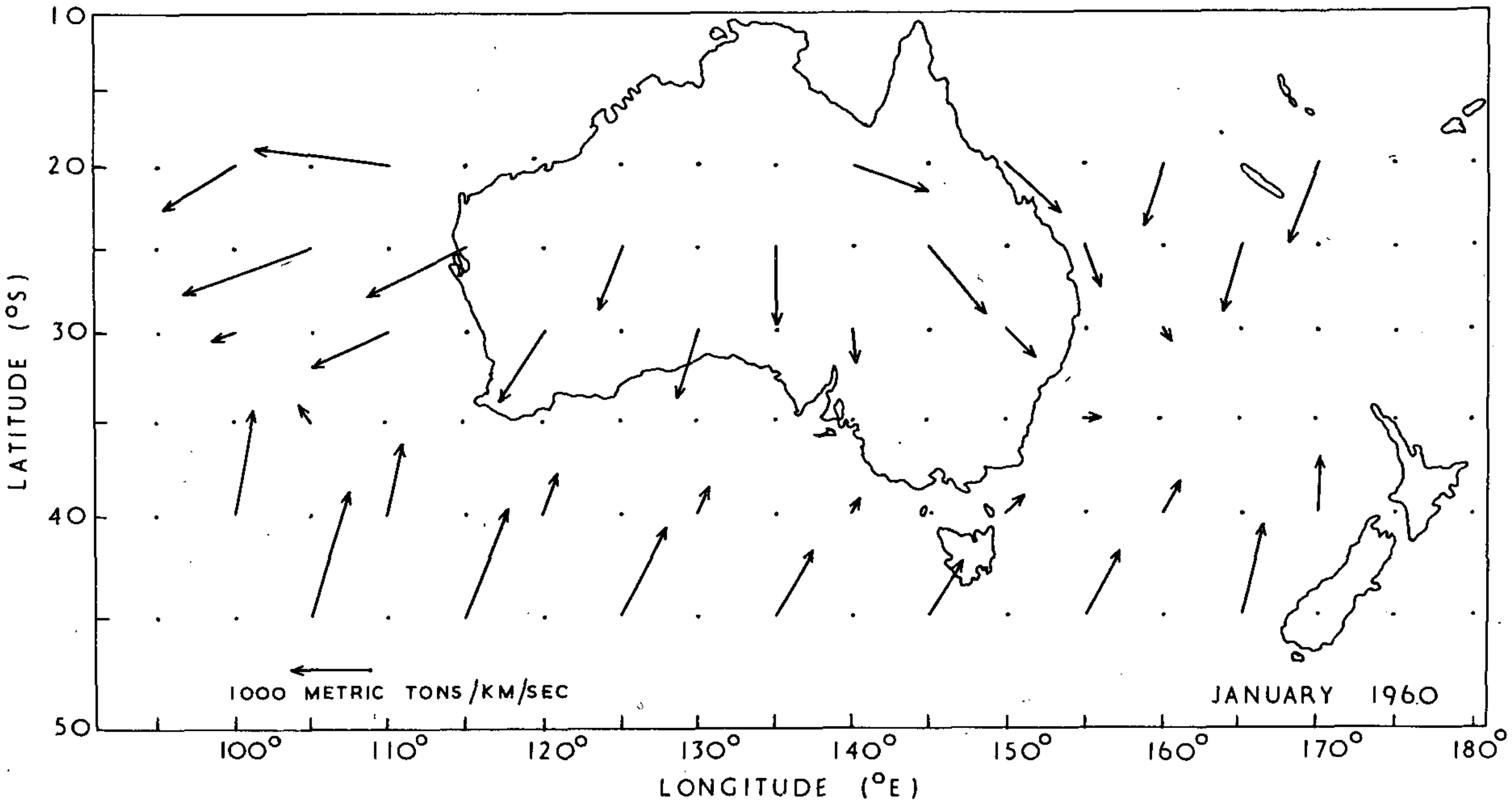

Fig. 1.- An ocean surface transport map for January 1960. The vectors are determined from a 5° grid of monthly mean atmospheric pressures.

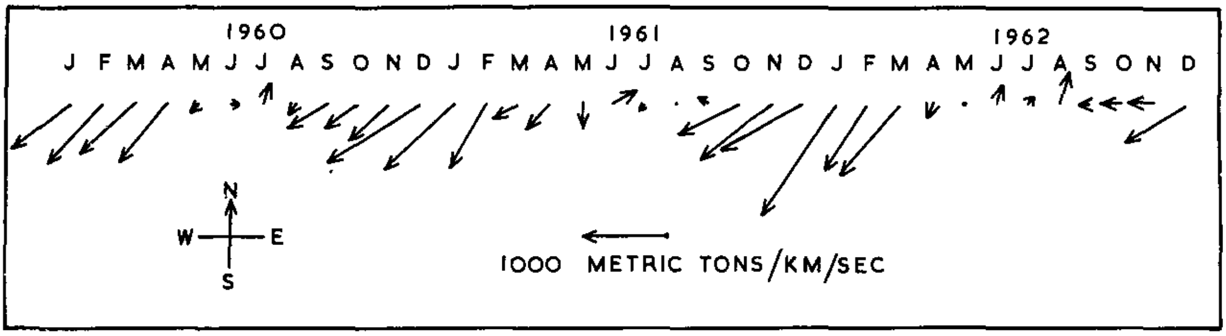

Fig. 2.- A time series of surface transport vectors for 30°S., 115°E. determined from a 5° grid of monthly mean atmospheric pressures.

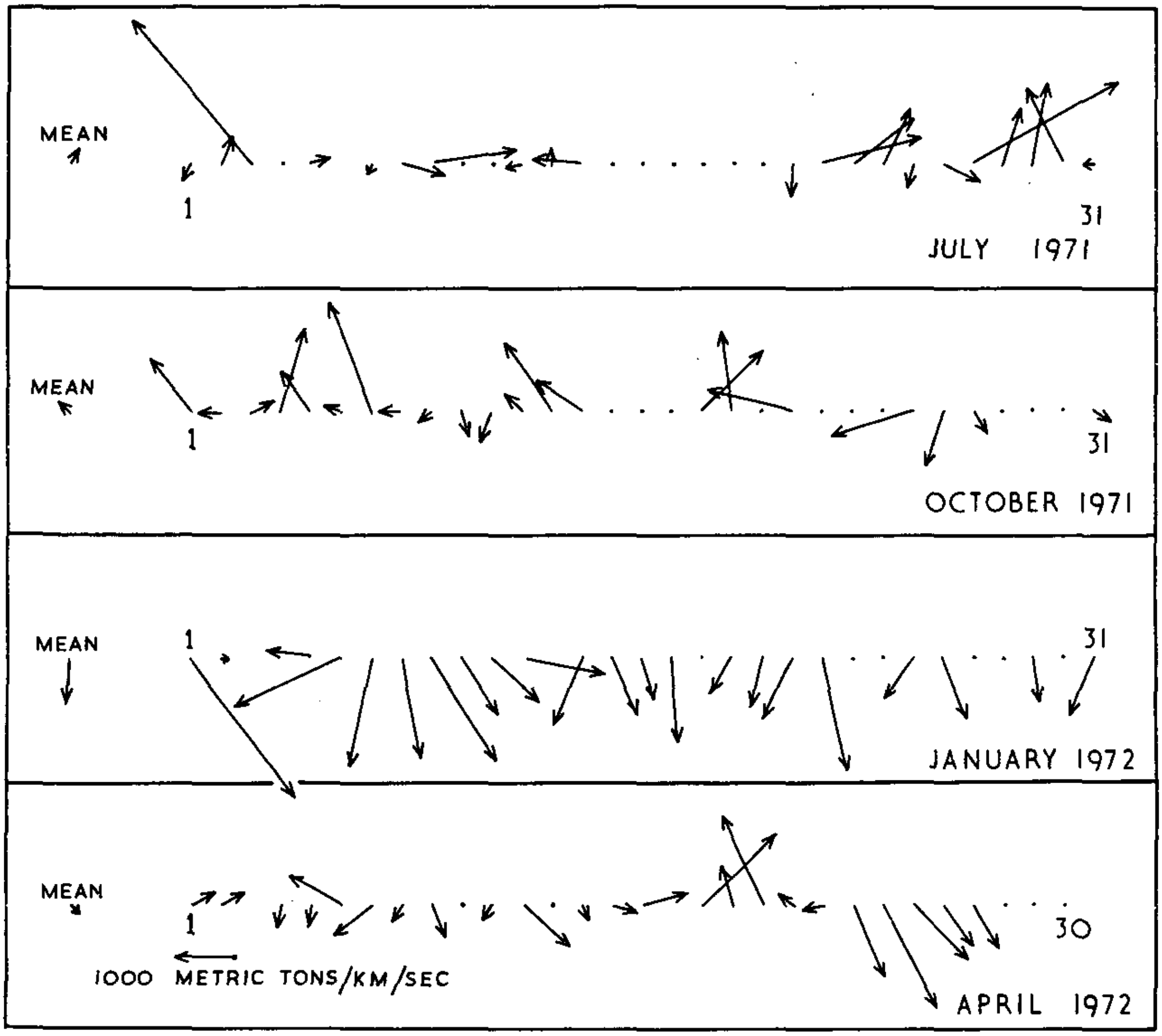

Fig. 3.- Time series of surface transport vectors for 30°S., 114°E. determined from a 2° grid of daily atmospheric pressures for selected months.

5° Grid of Monthly Mean Pressures

To perform the transport calculations in the present work values were required for the contraction and rotation of the geostrophic wind vector, the drag coefficient, C_D, and the mean atmospheric density, ρ_a. The contraction factor was 0.7, as used by Fofonoff, while the rotation, based on empirical results for relatively low latitudes (Carstensen, 1967), was 20°. The drag coefficient, C_D, was 0.0026 (Wu, 1969) and the mean atmospheric density was 0.00122, as used by Fofonoff.

The data used were monthly mean atmospheric pressure maps for the southern hemisphere for 1960-1962. These maps are published by the South African journal "Notos", with the most recent ones available being those for 1962. They were scaled at points on a 5° grid. Surface transports were machine plotted for the region 20°S.-45°S., 100°E.-170°E. as if Australia did not exist. Then an overlay map was used during reproduction (cf. Wickett _et al._, 1968). The final maps unrealistically show surface transports on the continent. Only one map, that of January 1960, has been reproduced here (Fig. 1); the others are on file and readily available to interested parties.

Because of the interest in the western rock lobster larval migration a time series of surface transport vectors was drawn for 30°S., 115°E., the centre of the reef biological studies (Fig. 2). It is particularly interesting that during the summer months, from November to March when the larvae are hatching, the offshore transport maximizes. Note also that the wind driven surface vector $\vec{V}_0$ would be 45° to the right of the transport vectors drawn, or generally due west.

2° Grid of Daily Pressures

The drag coefficient, C_D, for daily pressure values was taken to be 0.0012. 2° grids were selected for the western and eastern Australian coastal strips, the former for possible application to the western rock lobster larvae migration. The computer programs for both are working but at this time we will only treat the time series of transport vectors for 30°S., 114°E. in Western Australia.

As the 5° grid work for 1960-1962 had revealed seasonal variations in the transport, the daily atmospheric pressure maps for the months of July and October 1971, and January and April 1972, were scaled at points on a 2° grid. For the point 30°S., 114°E. the pressure gradients came from pressure values for the points: 28°S., 112°E. and 116°E.; 30°S., 110°E., 114°E, and 118°E.; 32°S., 112°E. and 116°E. Figure 3 shows the daily transport vectors and the monthly means for the four months. Reasonably consistent and strong southward transports occurred in January. Note that the surface vector, $\vec{V}_0$, would be to the southwest.

CONCLUSIONS

Fofonoff's method of determining surface transports from a 5° grid of mean monthly atmospheric pressures has shown offshore transport in Western Australia to peak during the summer months. It is during these months that the rock lobster larvae hatch and are transported seawards. Chittleborough and Thomas (1969) were the first to propose offshore surface wind drift as the important process for the larval offshore transport.

It is not apparent from the transport vectors calculated in this report how the larvae could return to the coast.

The method was adapted to a 2° grid of daily atmospheric pressures and the months of July, October, January and April for 1971/72 were treated. Maximum surface transport occurred during January although it was directed southward. The corresponding actual surface vector, V_0, would have been directed to the SW.

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REFERENCES

AAGAARD, K. (1970).—Wind-driven transports in the Greenland and Norwegian Seas. *Deep-Sea Res.*, 17(2), 281-291.

BARBEE, W.D. (1965).—Deep circulation, Central North Pacific Ocean: 1961, 1962, 1963. *U.S. Coast and Geodetic Survey, Research Paper, U.S. Govt. Print. Off., Wash.*, 104 pp.

CARSTENSEN, L.P. (1967).—Some effects of sea-air temperature difference, latitude and other factors on surface wind-geostrophic wind ratio and deflection angle. *Fleet Numerical Weather Facility, Monterey, California, Tech. Note*, 29.

CHITTLEBOROUGH, R.G., and L.G. THOMAS (1969).—Larval ecology of the Western Australian marine crayfish, with notes upon other panulirid larvae from the Eastern Indian Ocean. *Aust. J. mar. Freshwat. Res.*, 20, 199-223.

EKMAN, V.W. (1905-6).—On the influence of the earth's rotation on ocean-currents. *Ark. Mat. Astr. Fys.*, 2(11), 1-53.

FOFONOFF, N.P. (1962).—Machine computations of mass transport in the North Pacific Ocean. *J. Fish. Res. Bd Canada*, 19(6), 1121-1141.

NEUMANN, G., and W.J. PIERSON (1966).—Principles of physical oceanography. Englewood Cliffs, N.J., Prentice-Hall.

WICKETT, W.P. (1967).—Ekman transport and zooplankton concentration in the North Pacific Ocean. *J. Fish. Res. Bd Canada*, 24(3), 581-594.

WICKETT, W.P., J.A.C. THOMSON, and L.V. PIENAAR (1968).—Surface transport charts for the North Pacific Ocean, 1963-1966. *Tech. Rep. Fish. Res. Bd Canada,* 51.

WU, J. (1969).—Wind stress and surface roughness at air-sea interface. *J. geophys. Res.,* 74(2), 444-445.

DIVISION OF FISHERIES AND OCEANOGRAPHY REPORTS

1. THOMSON, J.M. (1956).- Fluctuations in catch of the yelloweye mullet *Aldrichetta forsteri* (Cuvier and Valenciennes) (Mugilidae).
2. NICHOLLS, A.G. (1957).- The Tasmanian trout fishery. I. Sources of information and treatment of data.
3. NICHOLLS, A.G. (1957).- The Tasmanian trout fishery. II. The fishery of the north-west rivers.
4. CHITTLEBOROUGH, R.G. (1957).- An analysis of recent catches of humpback whales from the stocks in Groups IV and V. Prepared for the International Commission on Whaling.
5. CSIRO AUST. (1957).- F.R.V. "Derwent Hunter". Scientific report of Cruises 3/56, 4/56, 5/56.
6. COWPER, T.R., and DOWNIE, R.J. (1957).- A line-fishing survey of the fishes of the south-eastern Australian continental slope.
7. DAVIS, P.S. (1957).- A method for the determination of chlorophyll in sea-water.
8. JITTS, H.R. (1957).- The ^{14}C method for measuring CO_2 uptake in marine productivity studies.
9. HAMON, B.V. (1957).- Mean sea level variation on the coast of New South Wales.
10. NICHOLLS, A.G. (1957).- The Tasmanian trout fishery. III. The rivers of the north and east.
11. NICHOLLS, A.G. (1957).- The population of a trout stream and the survival of released fish.
12. CSIRO AUST. (1957).- F.R.V. "Derwent Hunter". Scientific report of Cruise 6/56.
13. CHAU, Y.K. (1957).- The coastal circulation of New South Wales from drift card results 1953-56.
14. KOTT, P. (1957).- Zooplankton of East Australian waters 1945-1954.
15. CSIRO AUST. (1958).- F.R.V. "Derwent Hunter". Scientific report of Cruises 1/57 - 4/57.
16. ROCHFORD, D.J. (1958).- The seasonal circulation of the surface water masses of the Tasman and Coral Seas.
17. CHITTLEBOROUGH, R.G. (1958).- Australian catches of humpback whales 1957. Prepared for the International Commission on Whaling.
18. CSIRO AUST. (1958).- Australian documents prepared for the UNESCO Conference on the Oceanography of the Tasman and Coral Seas held at Cronulla, August 9-14, 1958.
19. CSIRO AUST. (1958).- F.R.V. "Derwent Hunter". Scientific report of Cruises 5/57–8/57.
20. CSIRO AUST. (1959).- F.R.V. "Derwent Hunter". Scientific report of Cruises DH9/57–12/57.
21. CSIRO AUST. (1959).- F.R.V. "Derwent Hunter". Scientific report of Cruises 13/57–16/57.
22. ROBINS, J.P. (1958).- F.R.V. "Marelda". Scientific report of Cruises July 1957 - May 1958.
23. CHITTLEBOROUGH, R.G. (1959).- Australian humpback whales 1958. Prepared for the International Commission on Whaling.
24. CSIRO AUST. (1959).- H.M.A.S. "Queensborough" and "Quickmatch". Scientific reports of a cruise March 24 - April 26, 1958.
25. CSIRO AUST. (1959).- H.M.A.S. "Warrego". Scientific reports of Cruises W1/57 and W1/58.
26. THOMSON, J.M. (1959).- Summary review of a scientific survey of Lake Macquarie by CSIRO Division of Fisheries and Oceanography.
27. CSIRO AUST. (1958).- F.R.V. "Derwent Hunter". Scientific report of Cruises 1/58–9/58.
28. WOOD, E.J.F. (1963).- Check-list of dinoflagellates recorded from the Indian Ocean.
29. CHITTLEBOROUGH, R.G. (1960).- Australian catches of humpback whales 1959. Prepared for the International Commission on Whaling.
30. CSIRO AUST. (1960).- F.R.V. "Derwent Hunter". Scientific report of Cruises 10/58-20/58.
31. CHITTLEBOROUGH, R.G. (1961).- Australian catches of humpback whales, 1960.
32. CSIRO AUST. (1961).- F.R.V. "Derwent Hunter". Scientific report of Cruises 1/59-10/59.
33. CSIRO AUST. (1963).- F.R.V. "Derwent Hunter". Scientific report of Cruises 11/59-4/60.
34. CHITTLEBOROUGH, R.G. (1962).- Australian catches of humpback whales, 1961.
35. CHITTLEBOROUGH, R.G. (1963).- Australian catches of humpback whales, 1962.
36. WOOD, E.J.F. (1963).- Checklist of diatoms recorded from the Indian Ocean.
37. HYND, J.S., and VAUX, D. (1963).- Report of a survey for tuna in Western Australian waters.
38. BANNISTER, J.L. (1964).- Australian whaling 1963. Catch results and research.
39. CSIRO AUST. (1965).- F.R.V. "Derwent Hunter". Scientific reports of Cruises 1950-56.

40. *CSIRO AUST.* (1967).- 20th Marine Science School May 22-27, 1966.

41. KESTEVEN, G.L. (1967).- Colombo Plan fishery resources research, India, Report to Government of India.

42. *CSIRO AUST.* (1967).- 21st Marine Science School May 23-June 2, 1967.

43. JITTS, H.R. (1968).- Data collected by Australian participants during the May, 1968 sea trials of SCOR/UNESCO working group 15 on "Photosynthetic Radiation in the Sea".

44. NEWELL, B.S. (1969).- Dispersal of pulp mill effluent in Hospital Bay, Tasmania.

45. NEWELL, B.S. (1969).- Total transport and flushing times in the lower Tamar River.

46. HAMON, B.V. (1969).- Review Papers. I. "Current-effect" on sea level. II. Oceanic eddies.

47. LOCKWARD, D.R. (1970).- Portable temperature-chlorinity bridge (S-T meter) instruction manual.

48. COWPER, T.R. (1970). - Scientific reports of cruises of T.S. Fukushima Maru, F.V. Suruga Maru.

49. NEWELL, B.S. (1971). - Chlorinity and temperature distribution in Deception Bay, Queensland, 1968-69.

50. CRESSWELL, G.R. (1971). - Current measurements in the Gulf of Carpentaria.

51. MAJOR, G.A., DAL PONT, G., KLYE, J. and NEWELL, B. (1972). - Laboratory techniques in marine chemistry: a manual.

52. CRESSWELL, G.R. (1972). - Wind-driven ocean surface transport around Australia.