# Inorganic Phosphate, Organic Phosphorus, and Nitrate in Australian Waters

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# INORGANIC PHOSPHATE, ORGANIC PHOSPHORUS, AND NITRATE IN AUSTRALIAN WATERS

By L. F. Kirkwood*

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*Summary*

Data from 1958 to 1966 were used to chart distributions of inorganic phosphate, organic phosphorus, and nitrate at 0, 50, 200, and 500 m.

The amount of inorganic phosphate between 200 and 500 m in the waters south of 15°S. was nowhere greater than 1·50 μg-atom/l.

There was no seasonal pattern in the variations in the amounts of inorganic phosphate at 200 and 500 m.

The maximum inorganic phosphate in the upper 500 m at stations in the richest Australian areas was *c.* 2·10 μg-atom/l. The corresponding figure for stations in rich areas, e.g. off the coasts of South-West Africa and Somali, is *c.* 2·50 μg-atom/l.

Seasonal means of organic phosphorus at 0 and 50 m ranged from less than 0·2 to greater than 0·3 μg-atom/l. Higher values were mainly north of 15°S. in winter (April–September) and south of 35°S. in summer (October–March).

Seasonal means of nitrate at 0 and 50 m ranged from 0·0 to greater than 5·0 μg-atom/l. Higher values were mainly north of 15°S. in winter and south of 30°S. in summer.

## I. Introduction

The concentrations of nutrients in Australian waters are of specific importance to the marine biologist, marine ecologist, and marine geologist. No comprehensive study of the distributions of these nutrients in Australian waters has been made, although Rochford (1962, 1963) has analysed data for some areas of the south-east Indian and south-west Pacific Oceans.

This paper presents most of the nutrient data for 1959–66 as a series of charts for various depths and, where possible, for two 6-month periods arbitrarily designated summer and winter. For inorganic phosphate, time plots have also been prepared, and data for the richest Australian waters are compared with data for overseas areas recognized as high in inorganic phosphate.

## II. Data and Methods

Data were collected between 1958 and 1966 on the oceanographical cruises listed as follows:

*Diamantina.*—Cruises 1/59, 2/59, 1/60, 2/60, 3/60, 1/61, 2/61, 3/61, 1/62, 2/62, 1/63, 2/63, 3/63; data in CSIRO Aust. Oceanographical Cruise Reports Nos. 1–5, 7–11, 14, 15, 21, 23–5. Cruises 3/62, 4/62, 1/64, 2/64; data on file, World Data Centres, Moscow and Washington. Cruises 5/63, 6/63, 3/64, 4/64, 5/64, 1/65, 3/65, 1/66; data on file, CSIRO, Cronulla.

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*Gascoyne*.—Cruises 1/60, 2/60, 1/61, 2/61, 1/63; data in CSIRO Aust. Oceanographical Cruise Reports Nos. 1–5, 7–11, 14, 15, 21, 23–5.

Cruises 3/61, 2/62, 4/62, 5/62, 2/63, 3/63, 4/63, 5/63, 2/65, 5/65; data on file, World Data Centres, Moscow and Washington.

Cruises 1/62, 1/64, 3/64, 4/64, 5/64, 6/64, 3/65, 4/65, 6/65, 7/65, 8/65, 9/65; data on file, CSIRO, Cronulla.

*Atlantis* (1966).—Data on file, World Data Centres, Moscow and Washington.

*Crawford*, Cruise 22, 1958.—Data in Metcalf (1960).

### (*a*) *Inorganic Phosphate*

The numbers of stations sampled between October and March (summer) and between April and September (winter) within 2° squares are shown in Figure 1.

Inorganic phosphate values are orthophosphate of unfiltered seawater in $\mu$g-atom/l. These have been multiplied by 1·15 to correct for salt error.

For 0, 50, and 200 m the data were divided into summer and winter. Mean seasonal concentrations at each depth were calculated for 1° squares. This was done by averaging the data within each square.

For 500 m the mean concentrations for 1° squares were calculated irrespective of the time of year.

### (*b*) *Organic Phosphorus*

The numbers of stations sampled during each season within 2° squares are shown in Figure 2.

Organic phosphorus is the difference in orthophosphate equivalent ($\mu$g-atom/l) between the total phosphorus (CSIRO Aust. 1965) and the inorganic phosphate of unfiltered seawater. The values were corrected for salt error as above.

The data were divided into summer and winter and the mean seasonal concentrations at 0 m and at 50 m were calculated for 1° squares as above. Because the number of squares for which data were recorded was considerably less than for inorganic phosphate, the charts have been prepared using a different method; values are shown by cross-hatching restricted to those squares from which samples were drawn.

### (*c*) *Nitrate*

The numbers of stations sampled within 2° squares during each season are shown in Figure 3.

Nitrate values are the sum of nitrate and nitrite of unfiltered seawater in $\mu$g-atom/l (CSIRO Aust. 1965).

The charts were prepared as in (*b*) above.

## III. Results

### (*a*) *Inorganic Phosphate*

(i) *0, 50, and 200 m Depth*

(1) *Summer* (*October–March*).—During these months, the mean concentrations for the 1° squares at the surface varied from less than 0·10 $\mu$g-atom/l to greater

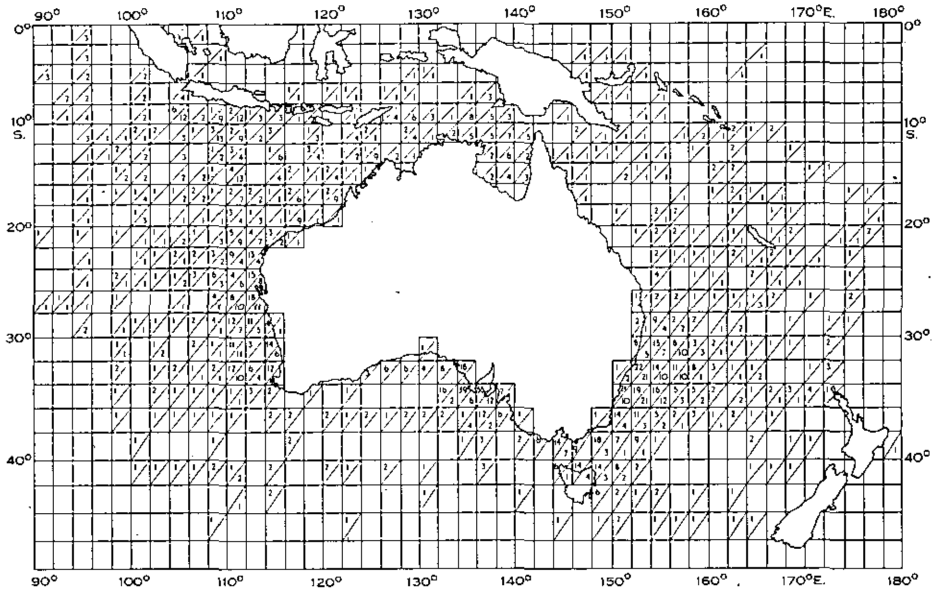


Fig. 1.—Numbers of stations sampled for inorganic phosphate during summer and winter within 2° squares (summer/winter).

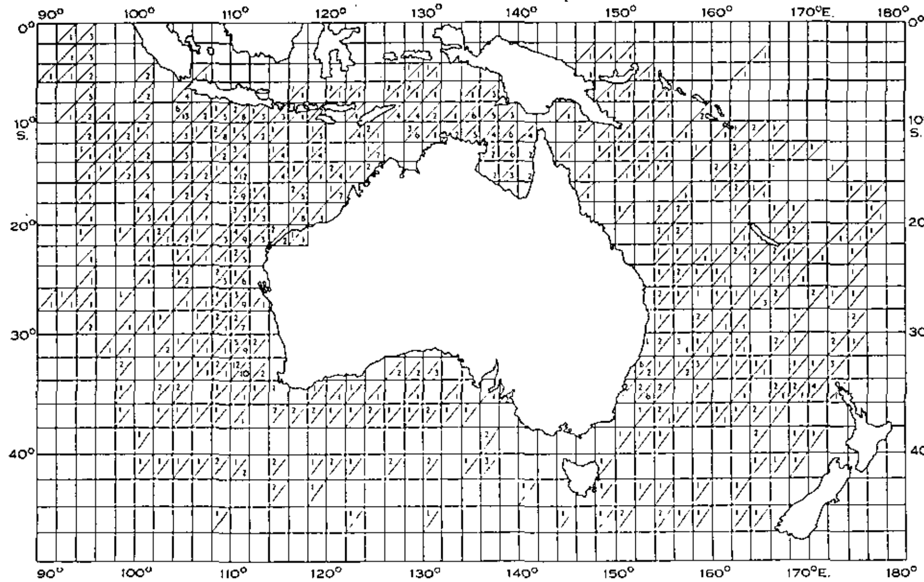


Fig. 2.—Numbers of stations sampled for organic phosphorus during summer and winter within 2° squares (summer/winter).

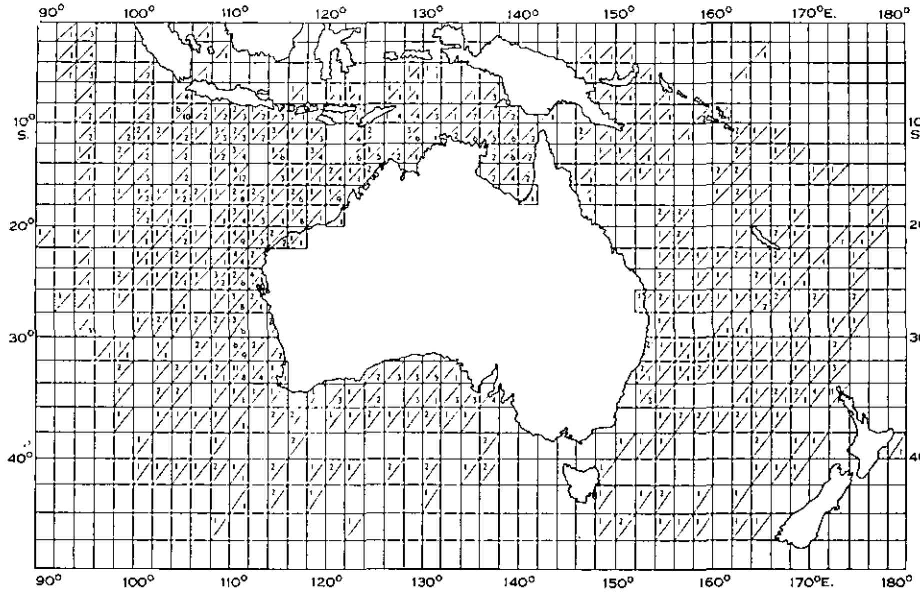


Fig. 3.—Numbers of stations sampled for nitrate during summer and winter within 2° squares (summer/winter).

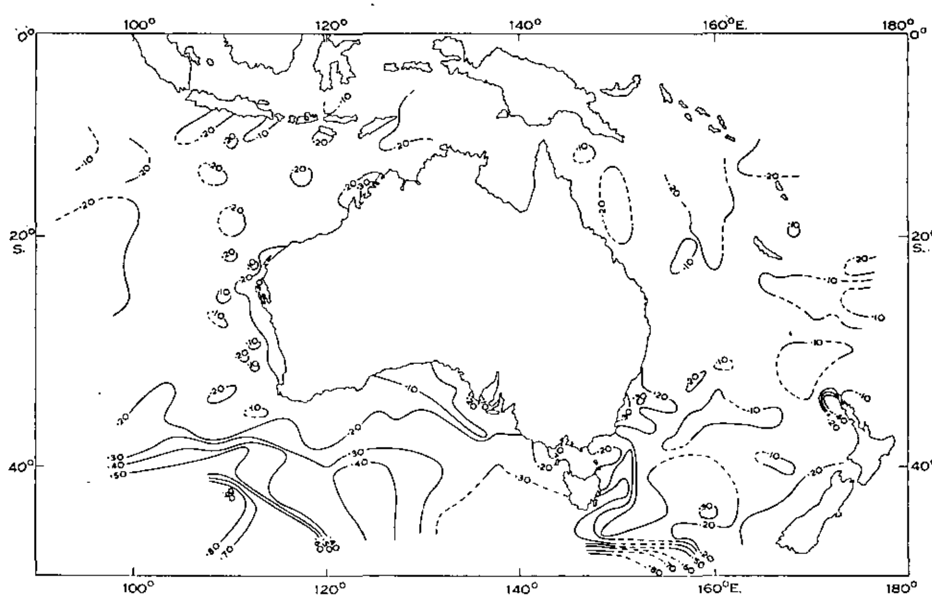


Fig. 4.—Mean inorganic phosphate content (μg-atom/l) at 0 m in summer. The contours are drawn from averages for 1° squares. The contour interval is 0·10 μg-atom/l.

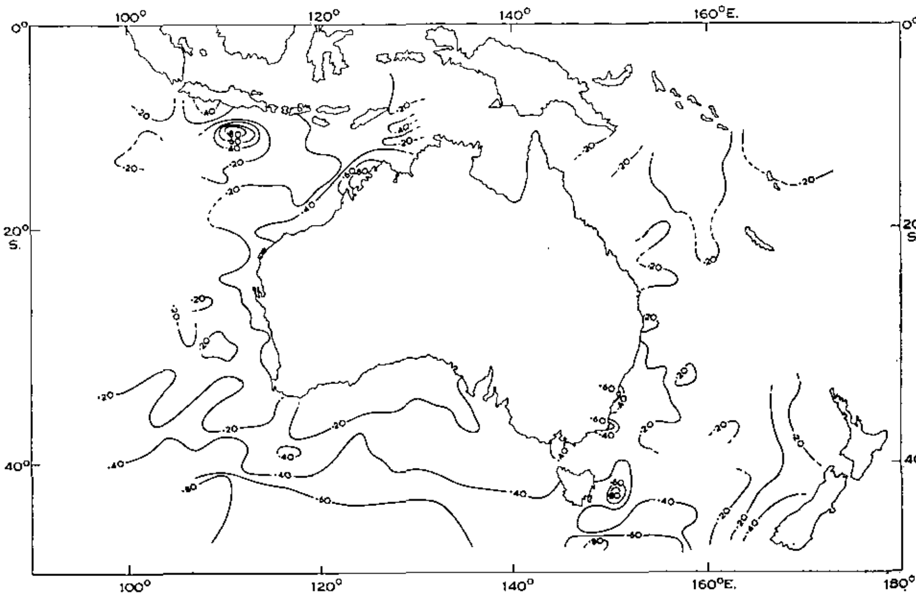


Fig. 5.—Mean inorganic phosphate content (μg-atom/l) at 50 m in summer. The contours are drawn from averages for 1° squares. The contour interval is 0·20 μg-atom/l.

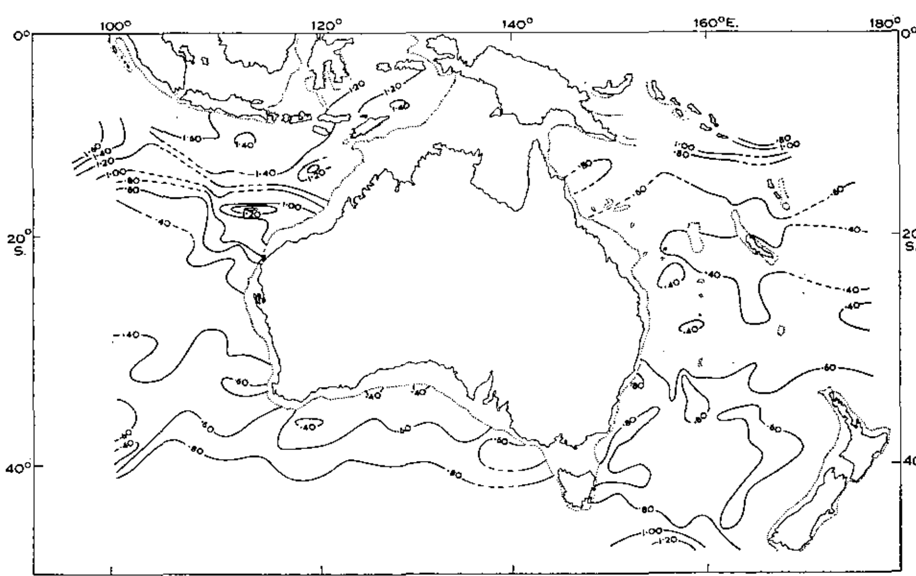


Fig. 6.—Mean inorganic phosphate content (μg-atom/l) at 200 m in summer. The contours are drawn from averages for 1° squares. The contour interval is 0·20 μg-atom/l. The 200 m depth contours are shown by the fine dotted lines.

than 0·90 $\mu$g-atom/l (Fig. 4). The higher values were south of 40°S. The lower values were in isolated areas further north and generally away from the coast. These areas were of greatest extent between 20 and 40°S. in the Coral and Tasman Seas.

At 50 m the highest values, i.e. greater than 0·80 $\mu$g-atom/l, were to the south and north-west (Fig. 5). The poorest waters with mean content less than 0·20 $\mu$g-atom/l were in central latitudes away from the coast and also in the Coral Sea.

At 200 m. the values ranged from less than 0·40 $\mu$g-atom/l to greater than 1·60 $\mu$g-atom/l (Fig. 6). The higher values were to the north-west and the lower values were in a belt between 20 and 30°S.

(2) *Winter* (*April–September*).—There were no summer data for the eastern Arafura Sea. The winter data in this region showed an area having a mean content greater than 0·60 $\mu$g-atom/l at the surface (Fig. 7). Elsewhere there were several relatively small areas with values less than 0·10 $\mu$g-atom/l but generally the mean inorganic phosphate content was slightly higher than for the summer months.

At 50 m (Fig. 8) the rich water to the north was again present with mean content as high as 1·40 $\mu$g-atom/l. Values were considerably lower in other areas, particularly in the Coral Sea and between 15 and 40°S. in the south-east Indian Ocean.

At 200 m the distribution, similar to that for summer, showed higher mean content in the waters to the north-west with values of around 1·80 $\mu$g-atom/l (Fig. 9). Again the lowest values, i.e. less than 0·40 $\mu$g-atom/l, were mainly between 20 and 30°S. The overall mean content was comparable with that for the summer months at this depth.

(ii) *500 m Depth*

Figure 10 shows that at 500 m the highest mean content was greater than 2·20 $\mu$g-atom/l and was in the north and north-west. Values between 1·40 and 1·59 $\mu$g-atom/l were in scattered areas between 30 and 43°S. but in the south-east Indian Ocean these were from single readings only. The lowest values of around 1·00 $\mu$g-atom/l were mainly to the west of the continent and south of 20°S.

(iii) *Seasonal Variations at 200 and 500 m Depth*

Two-degree squares, having the best available monthly representation of data for 200 and 500 m, were used to construct the plots shown in Figures 11, 12, and 13. For the Indian Ocean, the tropics and subtropics are represented but, because of a lack of data, only a subtropical square could be used for the Pacific Ocean.

There was no apparent seasonal variation in the inorganic phosphate content at either 200 m or at 500 m.

For the square in the tropical waters (Fig. 11) the values at 200 m varied from 1·48 to 1·97 $\mu$g-atom/l (mean was 1·71 $\mu$g-atom/l with s.d. of 0·12). At 500 m the variation was from 1·86 to 2·35 $\mu$g-atom/l (mean was 2·16 $\mu$g-atom/l with s.d. of 0·10).

The Indian Ocean subtropical square (Fig. 12) had values at 200 m ranging from 0·12 to 0·82 $\mu$g-atom/l (mean was 0·45 $\mu$g-atom/l with s.d. of 0·11).

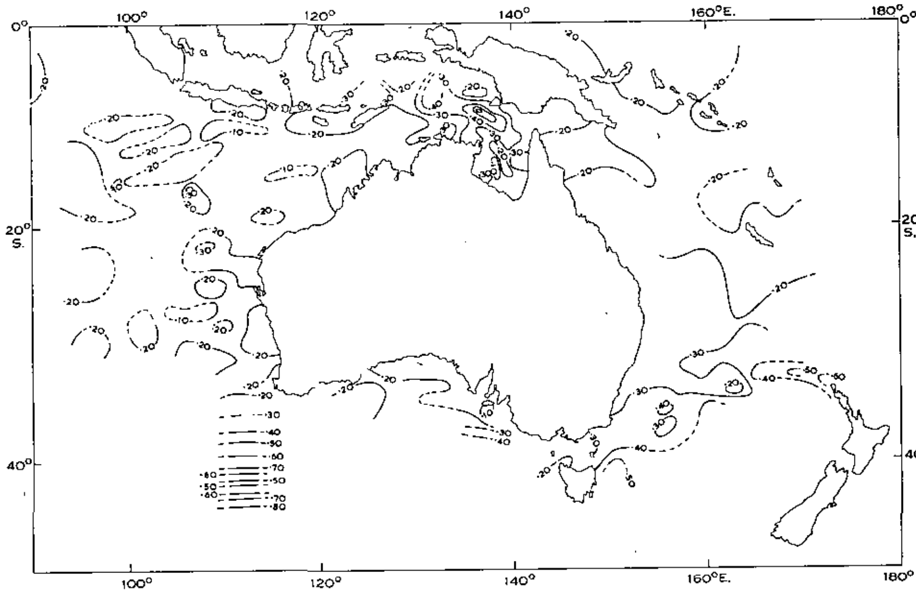


Fig. 7.—Mean inorganic phosphate content (μg-atom/l) at 0 m in winter. The contours are drawn from averages for 1° squares. The contour interval is 0·10 μg-atom/l.

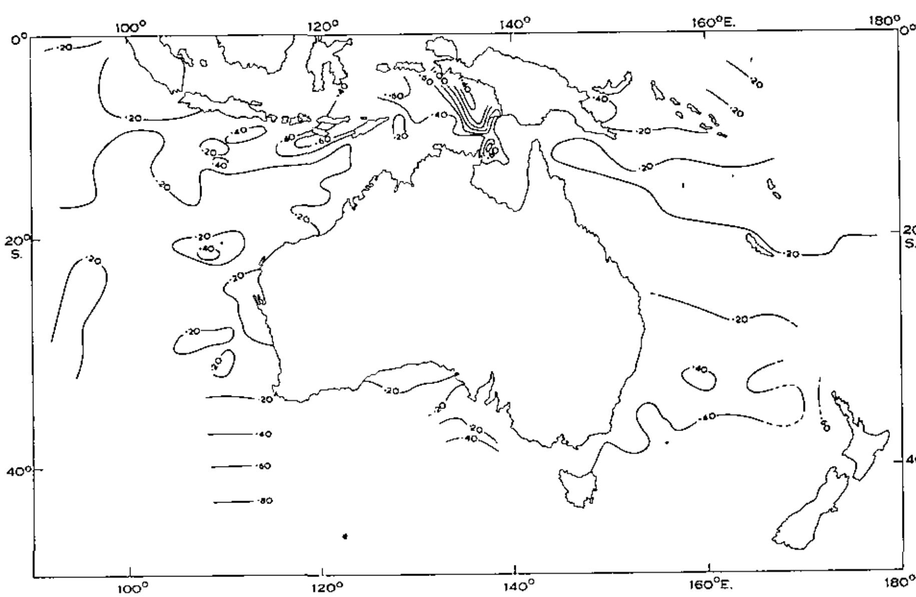


Fig. 8.—Mean inorganic phosphate content (μg-atom/l) at 50 m in winter. The contours are drawn from averages for 1° squares. The contour interval is 0·20 μg-atom/l.

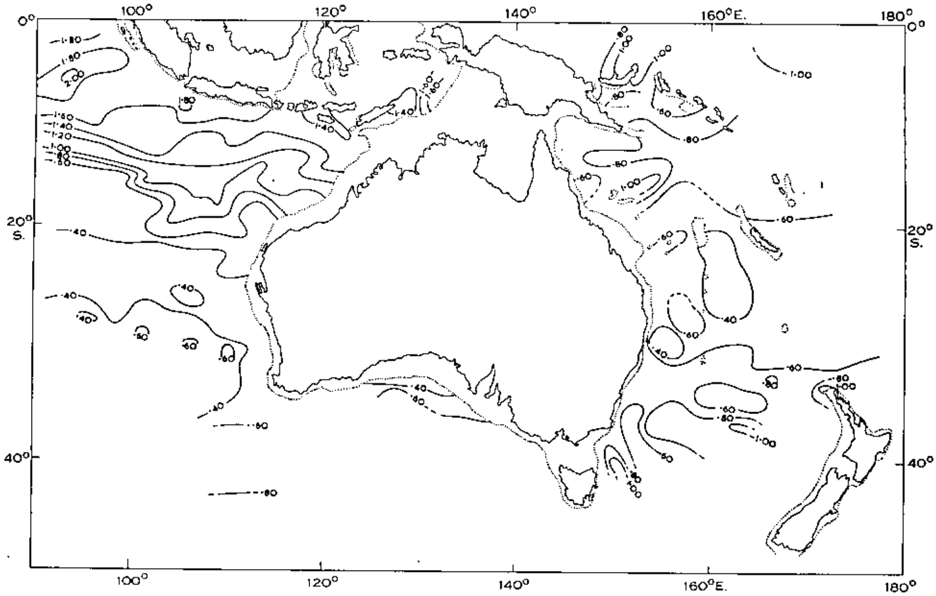


Fig. 9.—Mean inorganic phosphate content (μg-atom/l) at 200 m in winter. The contours are drawn from averages for 1° squares. The contour interval is 0·20 μg-atom/l. The 200 m depth contours are shown by the fine dotted lines.

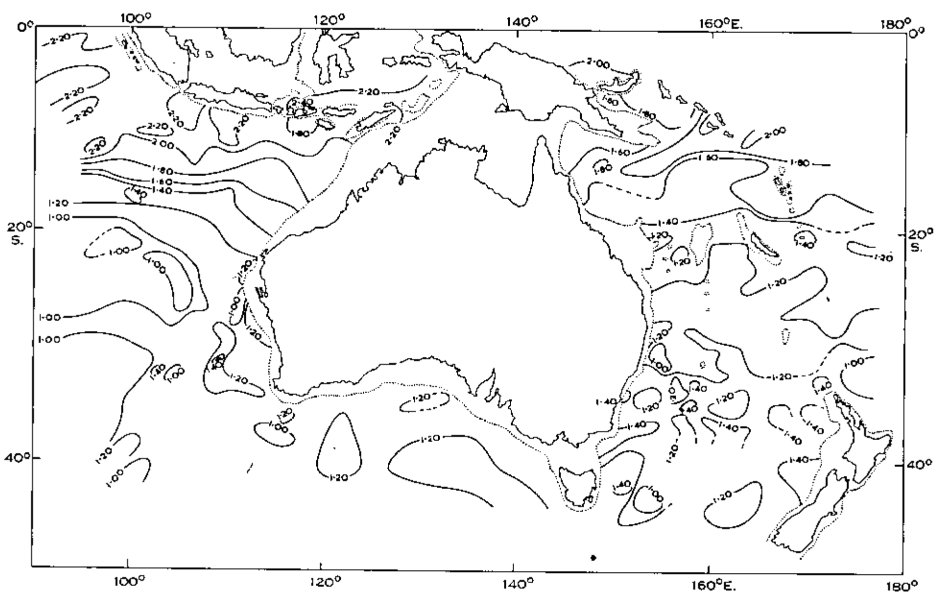


Fig. 10.—Mean inorganic phosphate content (μg-atom/l) at 500 m. The contours are drawn from averages for 1° squares. The contour interval is 0·20 μg-atom/l. The 500 m depth contours are shown by the fine dotted lines.

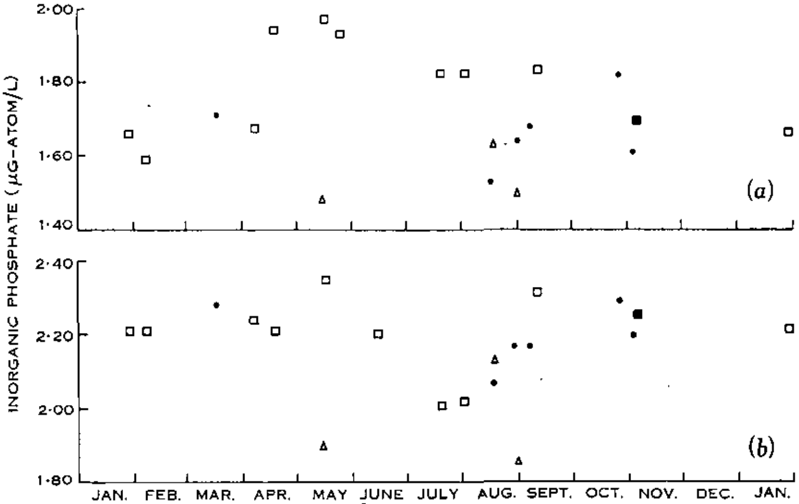


Fig. 11.—Time plots of the recorded values of inorganic phosphate (μg-atom/l) at (*a*) 200 m and (*b*) 500 m for the 2° square 8–10°S., 104–106°E. In Figures 11–13 the symbols show the year each value was recorded: ■ 1960, ▲ 1961, ● 1962, □ 1963, △ 1964, × 1965, + 1966.

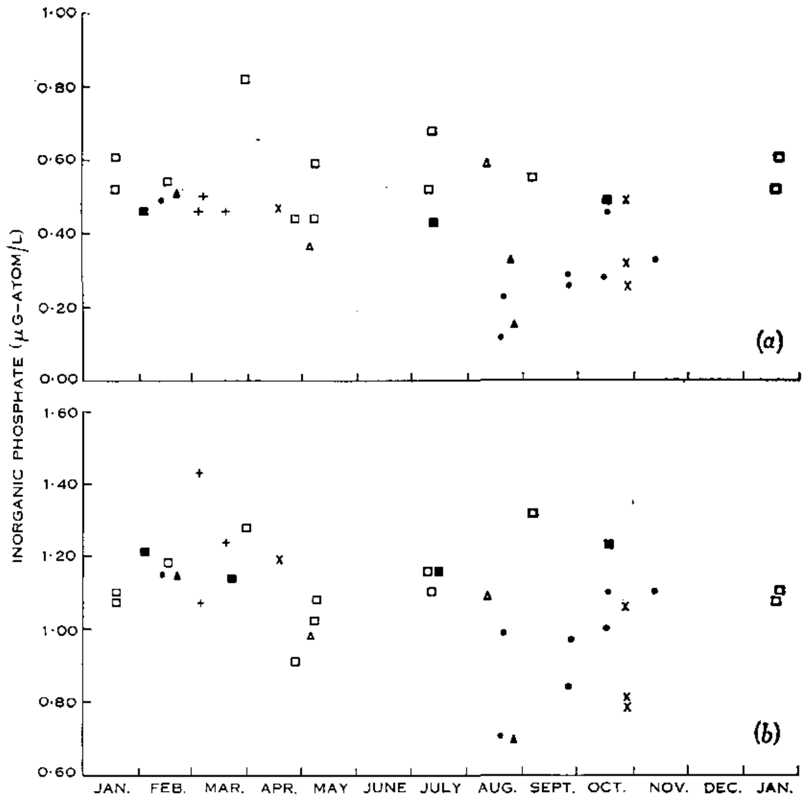


Fig. 12.—Time plots of the recorded values of inorganic phosphate (μg-atom/l) at (*a*) 200 m and (*b*) 500 m for the 2° square 31–33°S., 110–112°E. For coding see Figure 11.

The range in values at 500 m was from 0·70 to 1·43 µg-atom/l (mean was 1·07 µg-atom/l with s.d. of 0·12).

The Pacific Ocean subtropical square (Fig. 13) had values at 200 m ranging from 0·22 to 1·18 µg-atom/l (mean was 0·67 µg-atom/l with s.d. of 0·19). At 500 m the values ranged from 0·74 to 1·70 µg-atom/l (mean was 1·27 µg-atom/l with s.d. of 0·24).

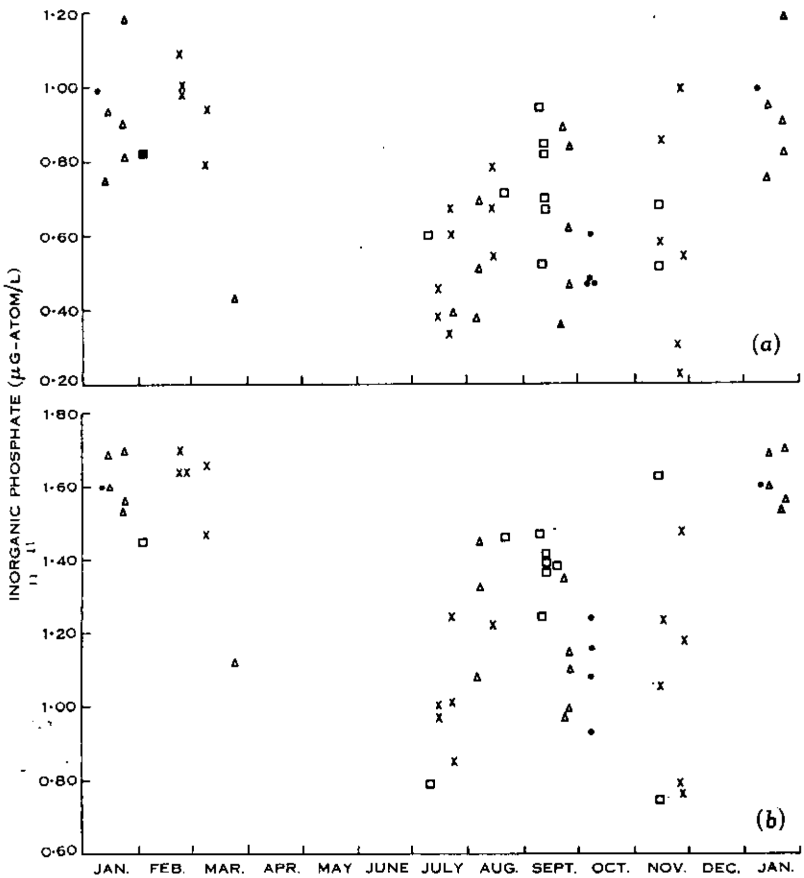


Fig. 13.—Time plots of the recorded values of inorganic phosphate (µg-atom/l) at (*a*) 200 m and (*b*) 500 m for the 2° square 33–35°S., 152–154°E. For coding see Figure 11.

The plots show that the tropical area always had a much higher inorganic phosphate content at 200 m and at 500 m than either of the subtropical areas. Comparing the latter two areas, the one in the Pacific Ocean had the more variable content as shown by the standard deviations.

## (iv) *Profiles*

The profiles selected (Fig. 14) are used to give a comparison between the inorganic phosphate content in the richest Australian waters (as shown by Figs. 1–5) and in the relatively rich areas elsewhere. The content was generally higher at the two non-Australian stations than at either of the Australian stations. Although high

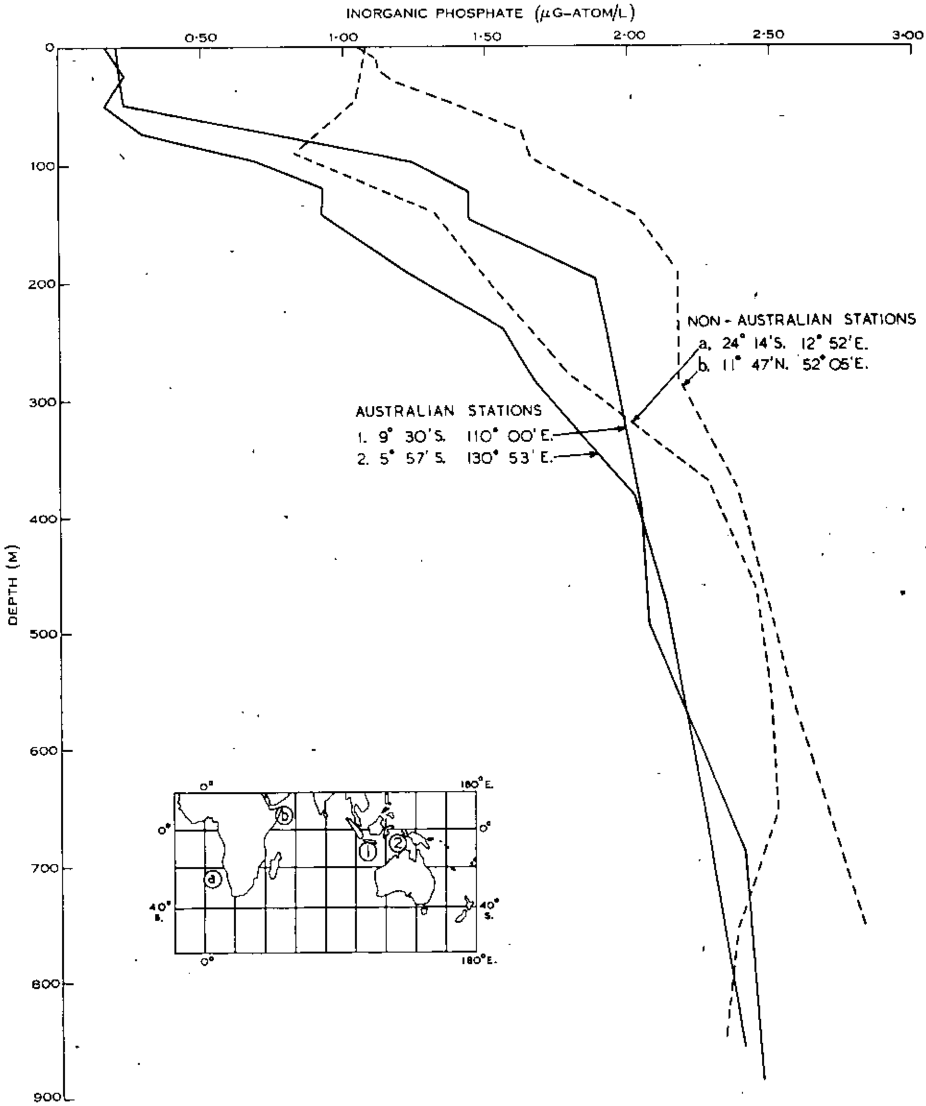


Fig. 14.—Depth profiles of the inorganic phosphate content (μg-atom/l) for selected stations. The non-Australian stations occur (see inset map) in the rich upwelling areas (*a*) of the Benguela Current off the west coast of Africa and (*b*) adjacent to the Somali coast during the south-west monsoon season.

values at 0 and 50 m occurred in the eastern Arafura Sea (see page 8) these have not been included in the profiles as they result from upwelling that is seasonal and highly localized.

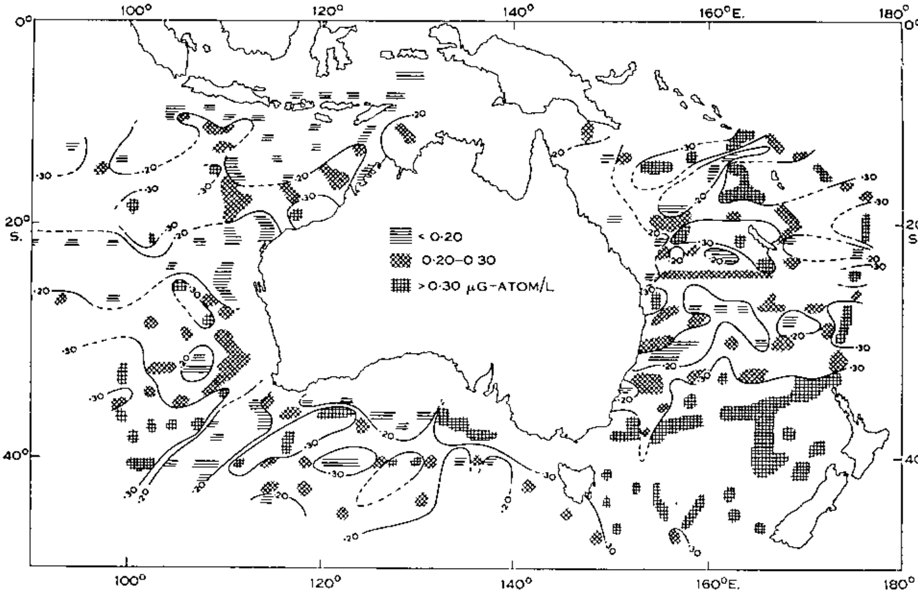


Fig. 15.—Mean organic phosphorus content (μg-atom/l) at 0 m in summer. Cross-hatching shows averages for 1° squares within which samples were taken.

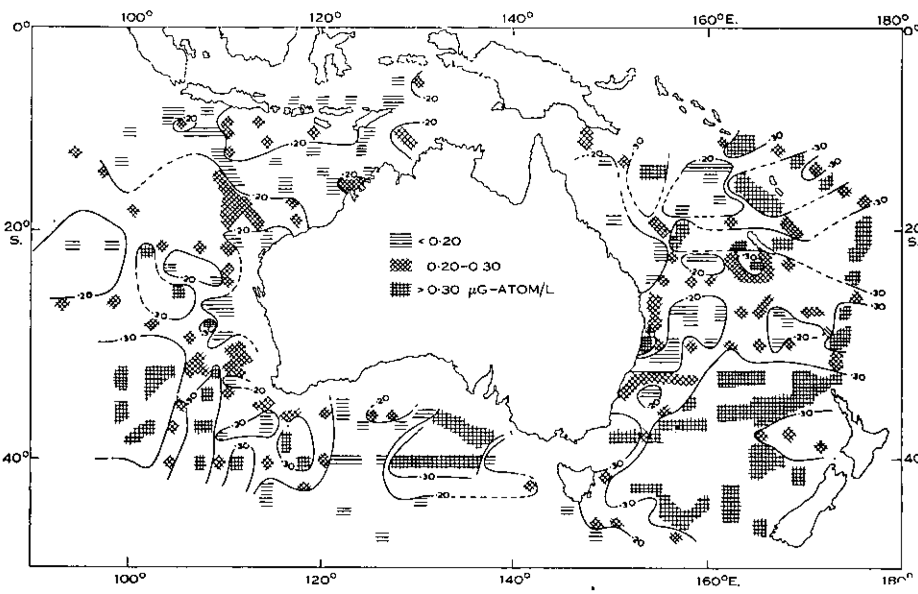


Fig. 16.—Mean organic phosphorus content (μg-atom/l) at 50 m in summer. Cross-hatching shows averages for 1° squares within which samples were taken.

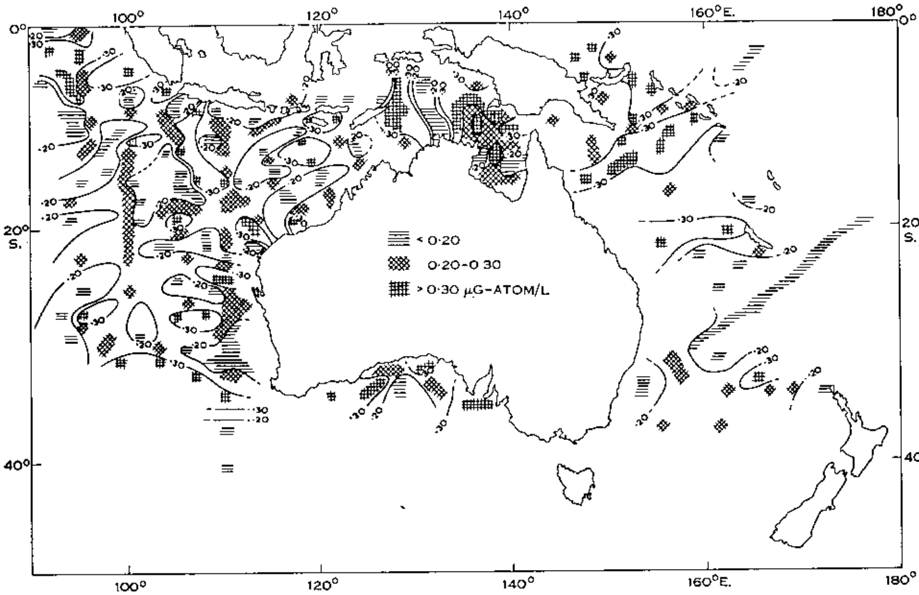


Fig. 17.—Mean organic phosphorus content (μg-atom/l) at 0 m in winter. Cross-hatching shows averages for 1° squares within which samples were taken.

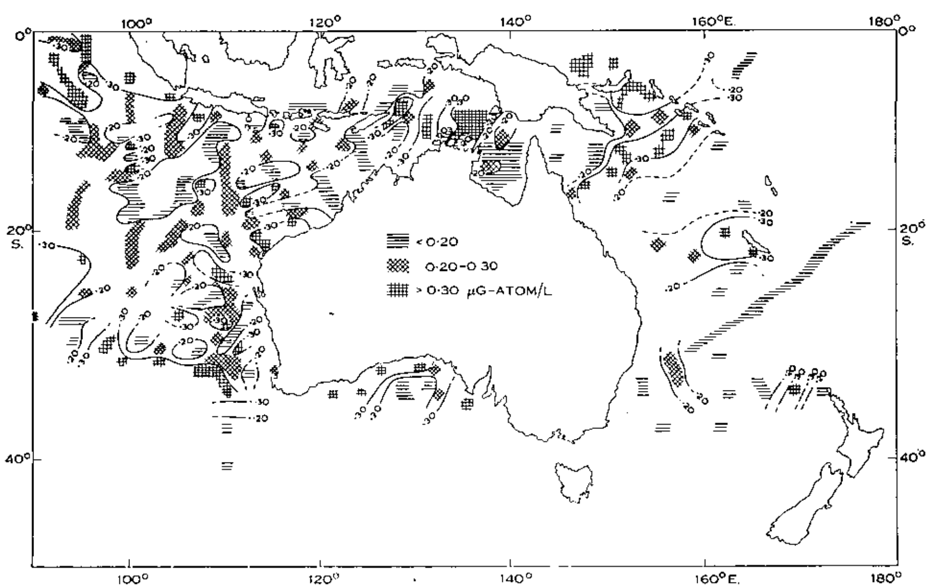


Fig. 18.—Mean organic phosphorus content (μg-atom/l) at 50 m in winter. Cross-hatching shows averages for 1° squares within which samples were taken.

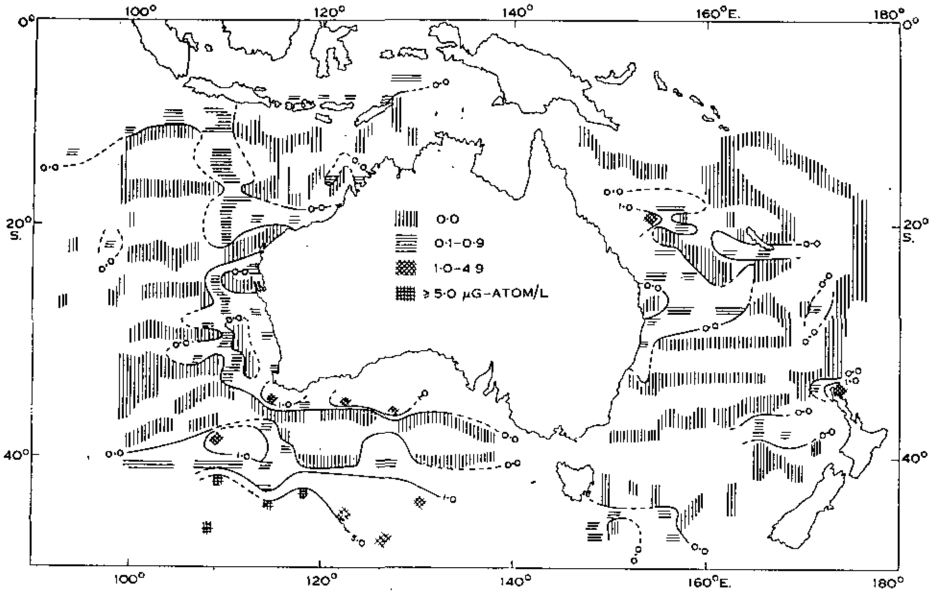


Fig. 19.—Mean nitrate content (μg-atom/l) at 0 m in summer. Cross-hatching shows averages for 1° squares within which samples were taken.

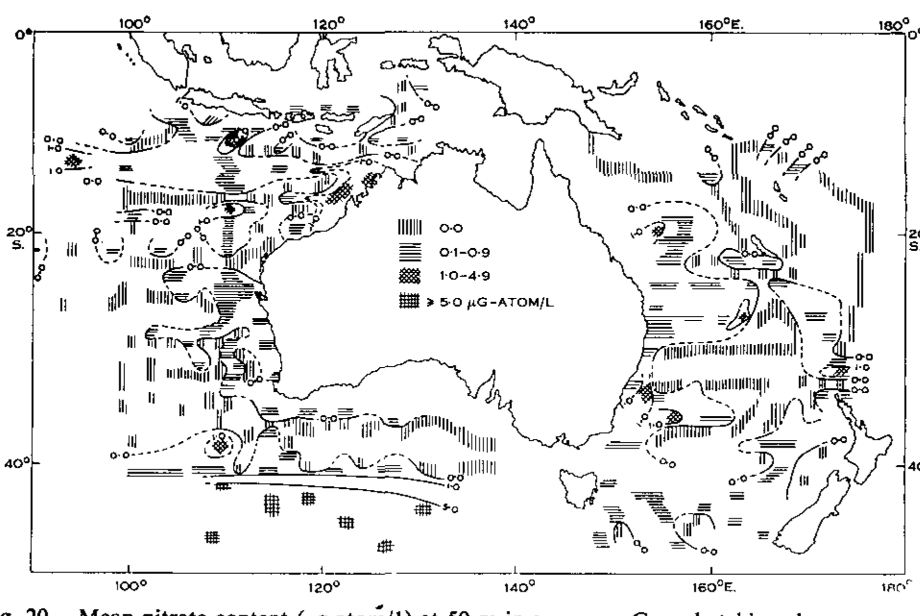


Fig. 20.—Mean nitrate content (μg-atom/l) at 50 m in summer. Cross-hatching shows averages for 1° squares within which samples were taken.

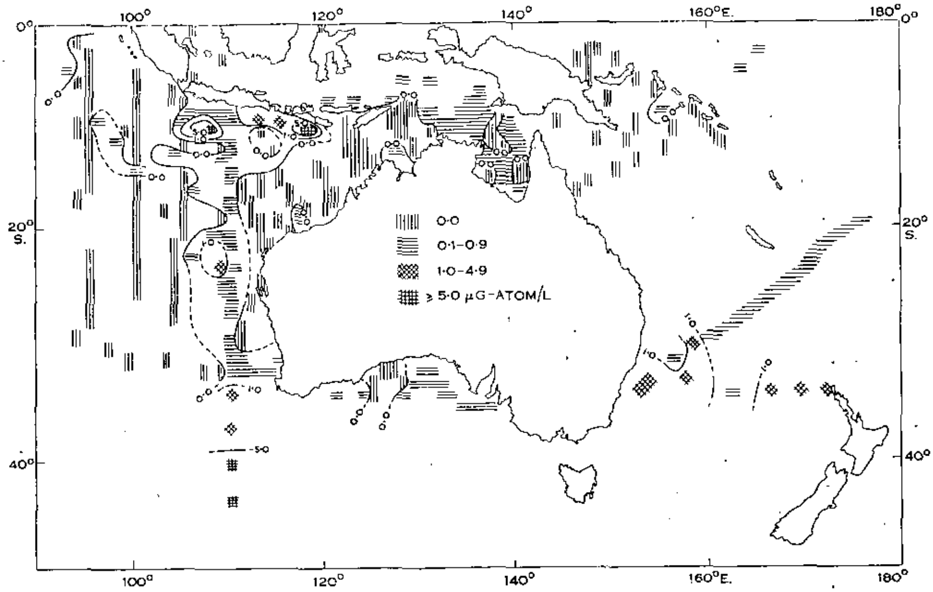


Fig. 21.—Mean nitrate content (µg-atom/l) at 0 m in winter. Cross-hatching shows averages for 1° squares within which samples were taken.

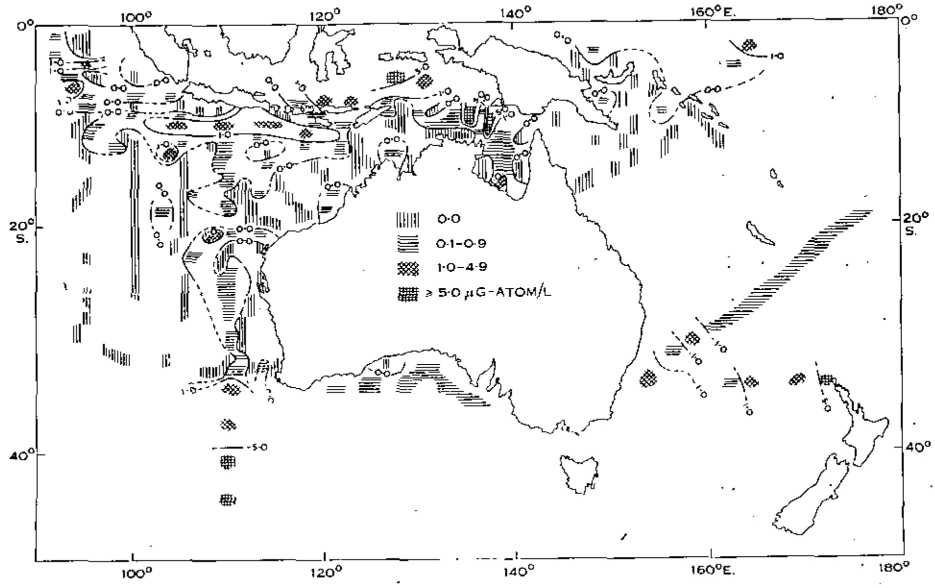


Fig. 22.—Mean nitrate content (µg-atom/l) at 50 m in winter. Cross-hatching shows averages for 1° squares within which samples were taken.

### (b) *Organic Phosphorus*

(i) *0 and 50 m Depth*

(1) *Summer* (*October–March*).—At the surface the largest areas with a mean organic phosphorus content greater than 0·30 μg-atom/l were south of 30°S. (Fig. 15). Within these areas the highest values, with a maximum of 1·85 μg-atom/l, were in the Tasman Sea. The poorest waters had a mean content less than 0·20 μg-atom/l and were mainly north of 30°S. in the Indian Ocean.

At 50 m the richest waters were again far more extensive in the Tasman and Coral Seas (Fig. 16). The highest value of 1·07 μg-atom/l was near the Solomon Islands.

(2) *Winter* (*April–September*).—Figure 17 shows that at the surface in winter there were areas of water with mean organic phosphorus content greater than 0·30 μg-atom/l within a belt centred on 10°S. and extending from 90 to 160°E. Areas to the south with these higher values were far less extensive than for the summer months. This difference might not be significant because there was a poorer regional coverage of data in winter. The highest mean content at the surface in winter was 1·90 μg-atom/l in the Coral Sea.

At 50 m the distribution (Fig. 18) was similar to that at the surface. The highest mean content was in the Arafura Sea.

### (c) *Nitrate*

(ii) *0 and 50 m Depth*

(1) *Summer* (*October–March*).—The surface waters richest in nitrate were to the south-west of the continent (Fig. 19) where mean content was as high as 1·48 μg-atom/l. Elsewhere the values were much lower and only two small areas had a mean content greater than 1·0 μg-atom/l.

At 50 m the highest values of between 5·0 and 10·3 μg-atom/l were again to the south-west. However, at this depth, numerous areas further north had mean content between 1·0 and 4·9 μg-atom/l (Fig. 20). The regions with no detectable nitrate had a smaller extent at 50 m than at the surface.

(2) *Winter* (*April–September*).—The richest areas in winter were to the north and north-west at both the surface (Fig. 21) and at 50 m (Fig. 22). The highest mean nitrate content at the surface was 20·2 μg-atom/l while at 50 m it was 12·8 μg-atom/l. The extent of the areas with no detectable nitrate decreased slightly from the surface to 50 m. Although these areas correspond to waters of generally low inorganic phosphate content, the latter was never found below *c.* 0·06 μg-atom/l.

## IV. References

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