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# THE PROBLEM OF THE ISLAND MASS EFFECT ON CHLOROPHYLL AND ZOOPLANKTON STANDING CROPS AROUND MARE (LOYALTY ISLANDS) AND NEW CALEDONIA

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## ABSTRACT

The island effect on plankton biomass is tested at two different sites: Mare, a coral island directly facing the prevailing surface currents with no lagoon and no land drainage; the second site to the southwest of New Caledonia has a wide lagoon and important run-offs. Since the sole coastal chlorophyll "a" increase (<20%) is observed at the latter site and no correlation is found with vertical mixing or the thermal structure, we conclude that such an island effect is mainly due to transports from land and lagoon. Secondly, there is no relation between integrated chlorophyll "a" and zooplankton dry weights, like in most neritic ecosystems, because of the short-term variability (scale of days) of the meteorological and hydrological parameters. Finally, significant mid-term (scale of months) biomass variations are observed in this oligotrophic environment.


The "island mass effect" on phytoplankton and zooplankton biomasses and production is rather well documented, although the causative mechanisms are variable and not always obvious: eddies (Emery, 1972), upwelling in the wake of the island (Moore, 1949), increase of the amplitude of internal waves (Sander, 1973; 1981), vertical mixing in island channels (Gilmartin and Revelante, 1974), and interactions with the benthos and run-off from land (Doty and Oguri, 1956). The general result of these studies (see "discussion" for references), is a coastal enrichment of phytoplankton and for most of them, of zooplankton, with a possible positive gradient from off- to inshore.

The search for such an effect is particularly important in oligotrophic areas, such as the southwestern Pacific Ocean, and is the aim of the PROCAL (PROduction CALédonienne) program of ORSTOM oceanographic center in Noumea. Two sites, with different enrichment mechanisms, were chosen. The first, Mare Island, which is the southernmost Loyalty island (Fig. 1), may be influenced mainly by rather simple modifications of surface currents, without any disturbance by other islands since it receives the southeasterly trade winds, directly. Moreover, Mare is a coral island approximately 30 km wide, that was lifted above the sea level by tectonics (maximum altitude: 138 m) and has almost no land drainage. Finally, it has no continental shelf and, therefore, no lagoon and reduced influence from the benthos. The second site is off southwestern New Caledonia (Uitoe transect, Fig. 1) and represents a different case: besides the hydrological modifications that are expected around New Caledonia, land-drainage and exchanges with the wide lagoon (10 n.m. at Uitoe) are other important possible effects on plankton production of the near open-ocean. In order to test the possible increase in phyto- and zooplankton standing crops, a series of transects were made around Mare and off sw New Caledonia, each transect consisting of three stations, at 2, 10 and 30 nautical miles from the coast, the first station being no closer to the coast for safety reasons. Each cruise around Mare was in January, April, September and November 1983, with R.V. Coriolis, and consisted of 6 transects (Fig. 1). Each cruise included a 2-day survey of the surface currents and one or two several-day-long stations for the study of short-term variability of hydrological and planktonic parameters—vertical distribution and production assessments. The second

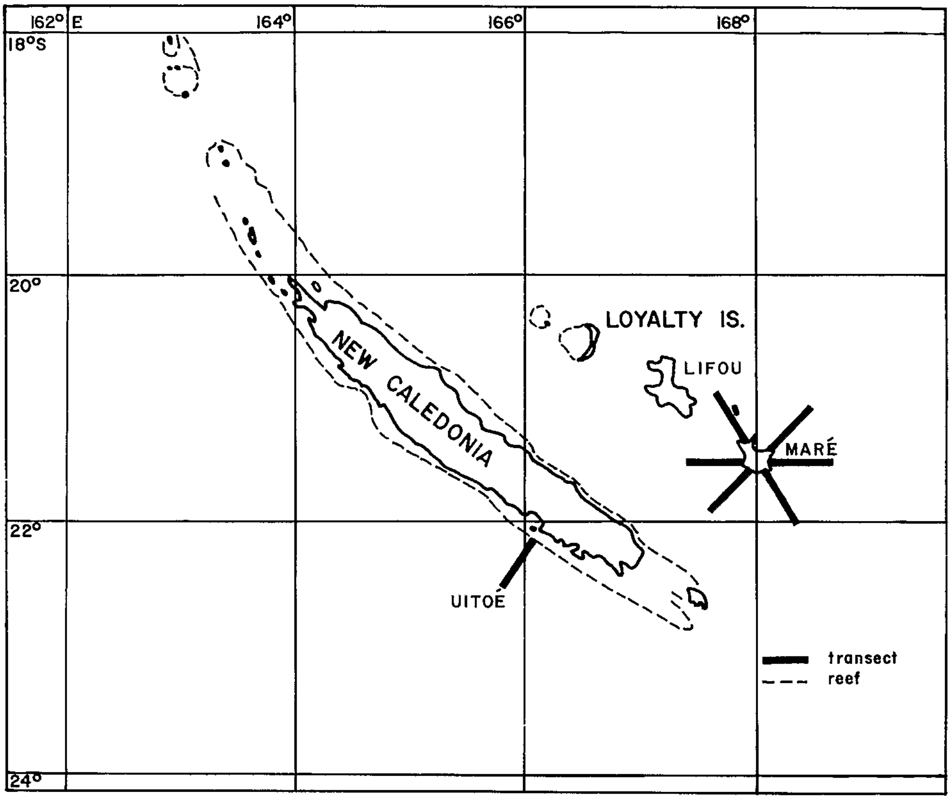


Figure 1. Positions of cruises off sw New Caledonia (Uitoe) and Mare Island.

part of the PROCAL program, the Uitoe transect off sw New Caledonia, consisted of a monthly cruise of R.V. Vauban from July 1983 until July 1984.

Both data sets on Mare and Uitoe will be used in order to answer the following questions: is there any particular enrichment area with respect to the island? Is there any off-inshore gradient? What is the magnitude of mid-term variations of biomasses (time scale of one to several months)?

## Methods

*Surface currents* were estimated around Mare Is. with a G.E.K. (geomagnetic electro kinetograph) system (Guillerm, 1980) on 12 inshore-offshore transects at each cruise. Chlorophyll "a" was measured as follows: Water was sampled between 0 and 200 m with a 12-Niskin-bottle rosette coupled with a Bissett-Berman STD probe, during the cruises around Mare Is. and with 14 individual bottles during the Uitoe cruises. Chlorophyll "a" was subsequently analyzed following Holm-Hansen et al. (1965) and its concentrations were integrated with the usual trapezoid method from 0 to 200 m, to get the amounts per square meter. In all cases, this depth was far below the deep chlorophyll maximum and displayed little or no chlorophyll. Mesozooplankton standing stocks were measured from one vertical plankton haul with a WP-2 net (Unesco, 1968) from 0 to 200 m at each of the chlorophyll "a" stations. Zooplankton (>200 $\mu$m) was sieved on a 5-mm metal screen, dried at 60°C for 24 h and deep-frozen until its weighing in the laboratory. Zooplankton standing stock may be expressed as mg dry weight per square meter, provided the filtered volume is measured (with a T.S.K. flow-meter) and the wire length out, corrected for angle when necessary. In the present study, day values were preferred because they were measured at all stations of the Uitoe transect and because they make 72% of the data collected during the transects around Mare. In the latter case, when night data had to be used, they

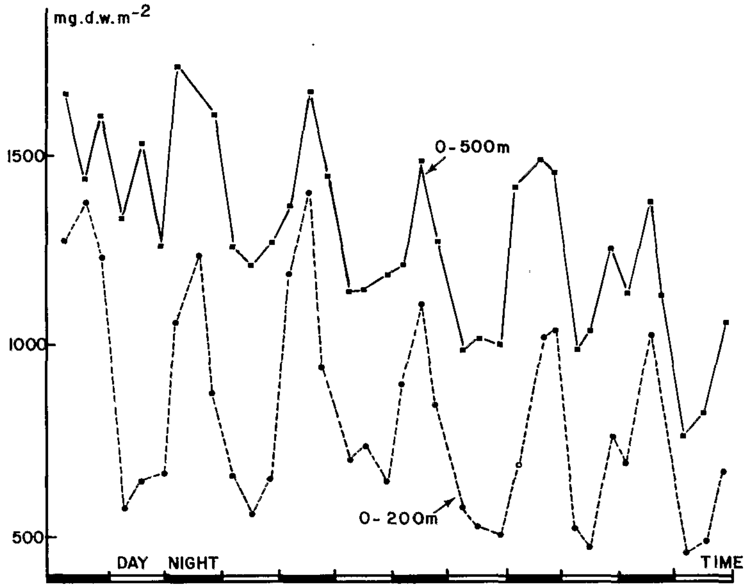


Figure 2. Diel variations of zooplankton dry weights in the 0–200-m and 0–500-m layers at a 6-day-long station 10 n.m. east of Mare (18–24 April 1983).

were multiplied by the average day/night ratio of 0.49 (standard error: 0.070) which was computed on 9 several-day long stations around Mare Is., where vertical hauls could be made every four hours. An illustration of the diel variations of zooplankton biomasses is given in Figure 2 for a 6 day-long station, 10 n.m. east of Mare Island.

Statistical tests and correlation coefficients are non-parametric ones and the level of significance is 5%.

## Results

*Surface Currents and Plankton Spatial Distribution Around Mare Island.*—It can be seen in Figure 3 that surface currents have a general westward direction (maximum speed: 40 cm $s^{-1}$), similar to the trade winds direction. But there are noticeable differences from one cruise to the other: southeasterly currents may be observed in January and November and northeasterly ones, in April and September; a divergence occurs leeward of Mare, but it is disturbed by the Loyalty current which flows towards the southeast (lower left of Fig. 3), resulting in a convergent vortex, west of Mare in September and November.

There is no clear link between the surface currents patterns and the distribution of 0–200-m chlorophyll "a," as drawn from the 18-station networks (Fig. 4). The area of highest chlorophyll "a" is neither systematically close to the shore, nor at a definite position: it is near the coast, east of Mare in April, north in September, southeast in November, whereas it is offshore and northwards in January. When the 6 transects of the 4 cruises are considered, higher chlorophyll "a" values are found at the coastal station on only 11 of 24 cases, and no particular transect seems to dominate. The same observation is true for the level of the deep chlorophyll maximum (DCM), which could be modified by the island effect: it is shallower at the coastal station than at the other two, in half of the cases (12 of 24 cases) and for no particular transect. Similarly, the chlorophyll concentration at the DCM level is highest at the coastal station on 7 of 24. Therefore, whatever the period or the transect, stations near the coast (2 n.m. offshore) do not display

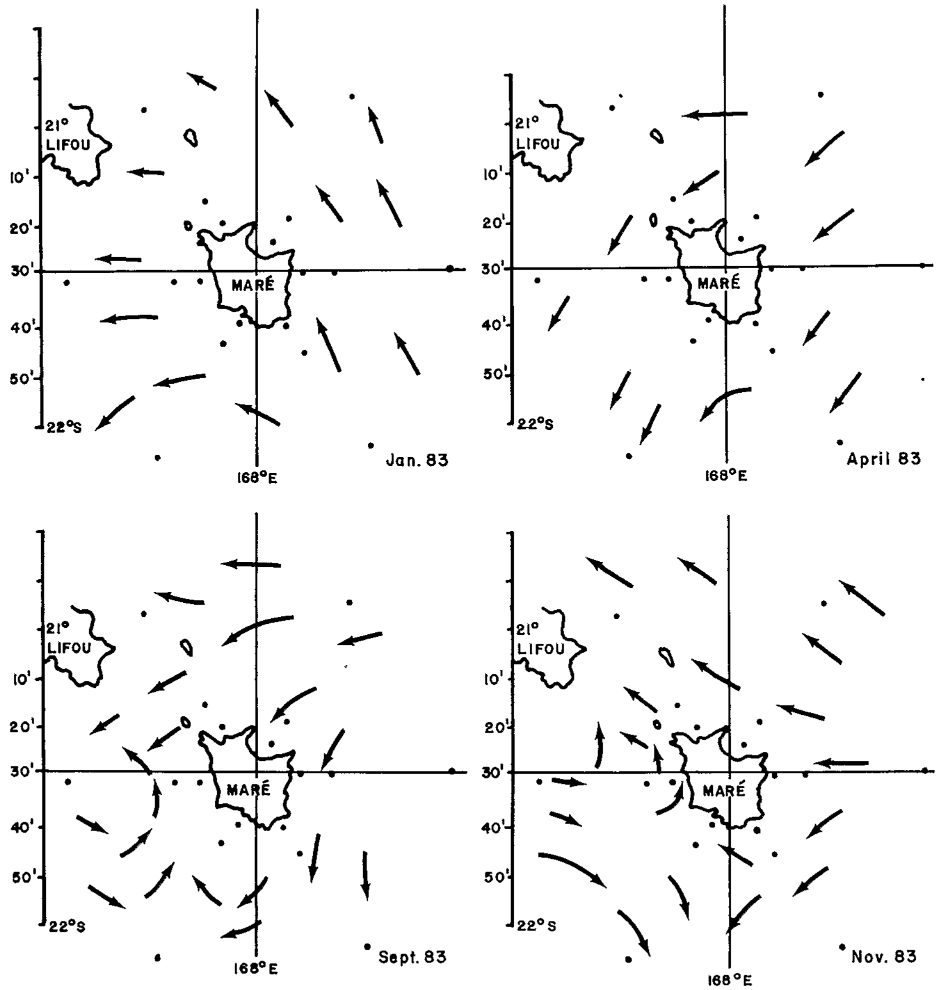


Figure 3. Surface current directions around Mare Island at the four periods of the year as evidenced by G.E.K. surveys. Dots refer to chlorophyll and zooplankton station positions.

any particular feature as far as chlorophyll is concerned and, inversely, the same conclusion applies to stations at 10 and 30 n.m. offshore. However, the important point is the variations of chlorophyll "a" values from one period to the other (Fig. 4). Thus, the mean value, calculated for each cruise, is 55 mg $m^{-2}$ in January, 48 in April, but only 21 in September and 29 in November, the higher concentrations of austral summer being linked with a shallower DCM (88 and 71 m in January and April, respectively) than the winter ones (105 m in September and November).

Highest values of zooplankton dry weights are always observed near the coast (west of Mare in January, April and November, south in September) and the coastal station displays the highest biomass of the three stations of all western transects (i.e., leeward) but not for the other five transects (Fig. 5). The spatial distributions of zooplankton and chlorophyll "a" are different. So are the time variations: highest mean zooplankton dry weights (665 mg $m^{-2}$) are from the September cruise, which exhibits the lowest chlorophyll. Such data for the zoo-

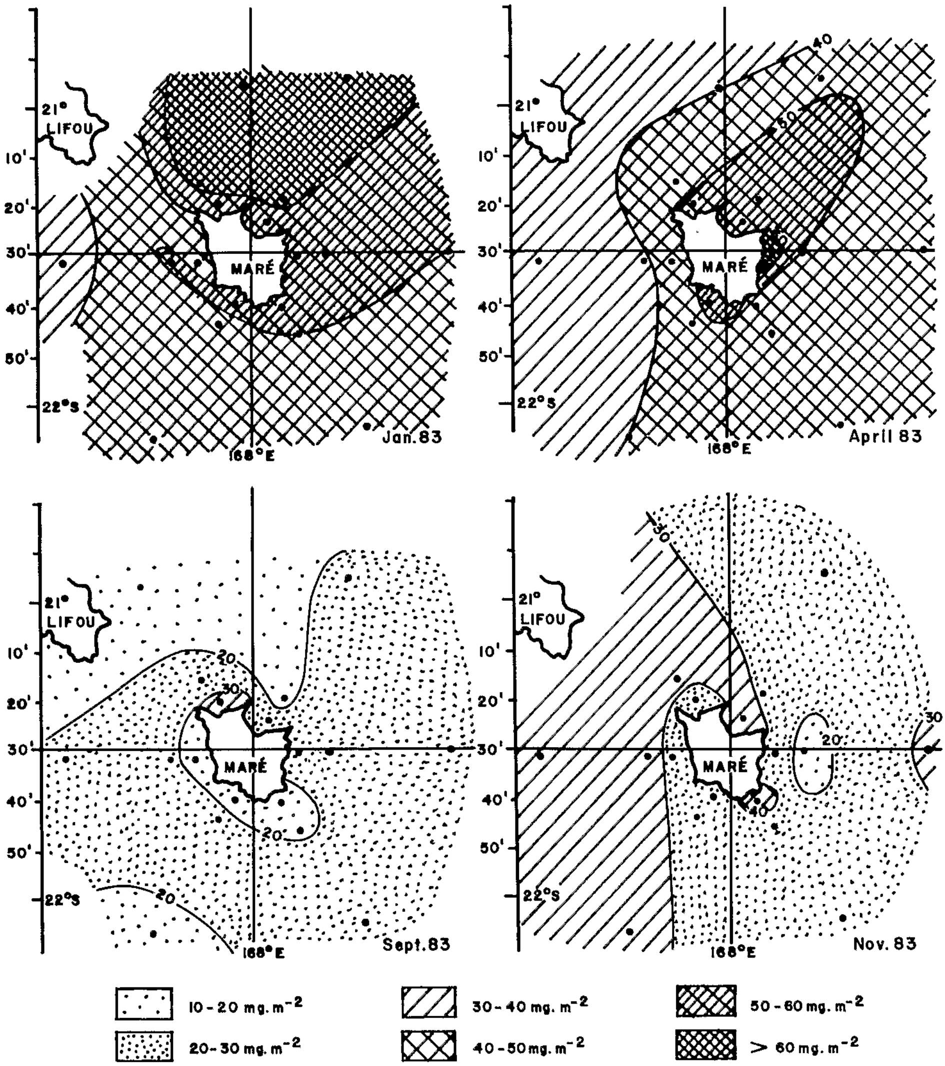


Figure 4. 0–200-m integrated chlorophyll "a" geographical distribution around Mare Island at the four periods of the year.

plankton are quite representative of the biomass in the upper layer. Thus, the mesozooplankton caught with the WP-2 net (200–5,000 $\mu$m) makes 78% of the 50–5,000 $\mu$m dry weight, on average, a result obtained at the long stations where two nets (50 and 200 $\mu$m) were used simultaneously. The smaller fraction of the mesozooplankton (200–500 $\mu$m) makes only 22.5% of the total dry weight (200–5,000 $\mu$m). As far as the vertical distribution is concerned, the upper 0–200-m layer includes 65.2% of the 0–500-m dry weight around Mare Island and 74.6% at the Uitoe monthly transects.

To summarize, Mare seems to disturb the surface currents pattern, but the only detected island effect on plankton is a zooplankton enrichment, westward. However, time variations are marked from one cruise to the other.

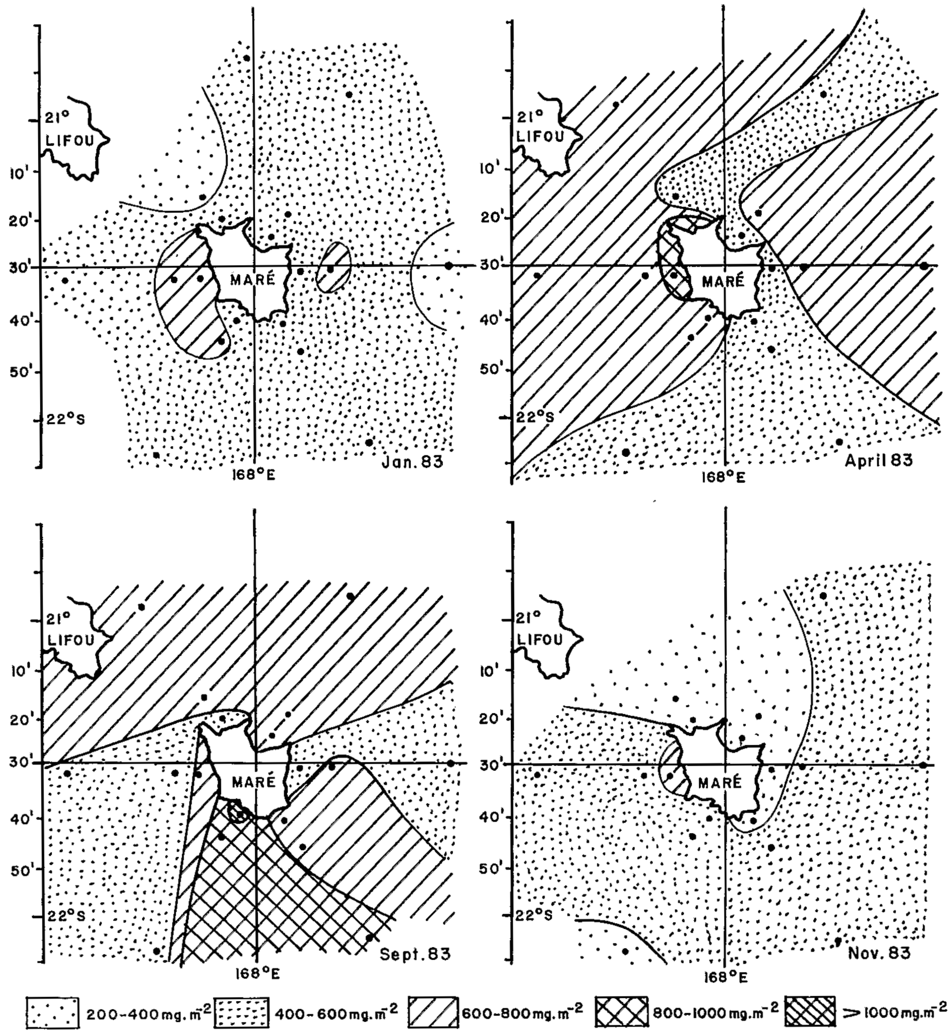


Figure 5. Zooplankton dry weights in the 0–200-m layer around Mare Island at the four periods of the year.

*Chlorophyll and Zooplankton Stocks off Southwest New Caledonia (Uitoe transect).*—The coastal increase in chlorophyll "a" is clearer here than around Mare: on 6 of 9 occasions, the coastal station is the richest of the three (Fig. 6) and there is an offshore-inshore decrease in half of the cases. But the difference is more significant when the station, located 30 n.m. offshore, is compared to the other two: its integrated chlorophyll is lower than that at 10 and 2 n.m. offshore in 7 of 9 cases (the difference would not be significant with the sign test at the 5% level): on the average, for the 10 Uitoe transects, chlorophyll of the offshore station is 82% of the chlorophyll of the 10 n.m. station and 88% of the 2 n.m. one.

No such difference can be seen on zooplankton dry weights: the gradient is observed in 2 of 10 cases and the coastal station is the richest on 4 occasions (Fig. 6). As around Mare, time variations are greater for integrated chlorophyll than

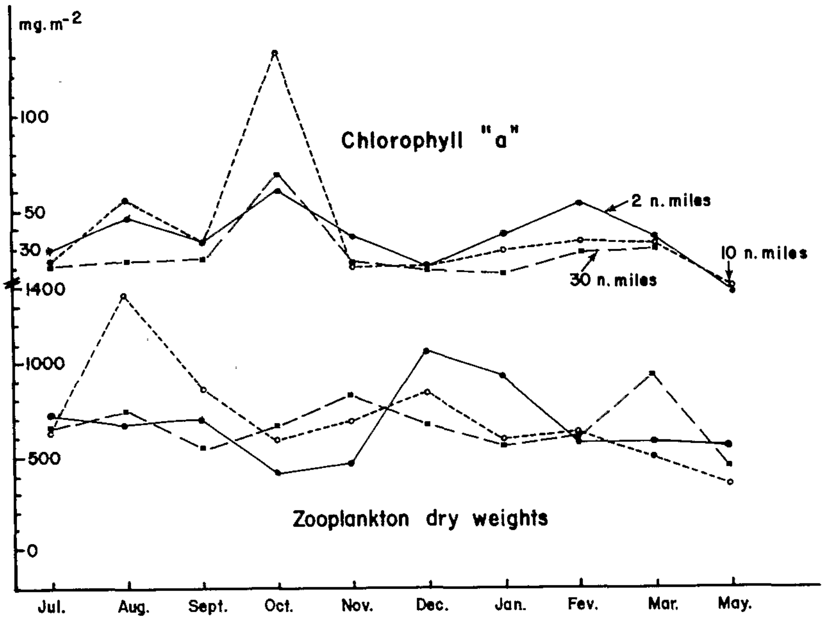


Figure 6. Time variations of zooplankton dry weights and chlorophyll "a" for the 0–200-m layer and for the three stations of the Uitoe transect (July 83–May 84).

for zooplankton dry weights: ratio between the maximum chlorophyll value (October) and the minimum one (May) is 5.2 whereas it is closer to 2 for zooplankton, maxima of which occur in August and December and the minimum, in May. Finally, the mean dry weight is lower around Mare (562 mg m$^{-2}$; N = 71) than off sw New Caledonia (671 mg m$^{-2}$; N = 30).

## Discussion

If the "island mass effect" is expected to produce a coastal increase of planktonic standing stocks (or a decrease, eventually), all around an island or on a particular

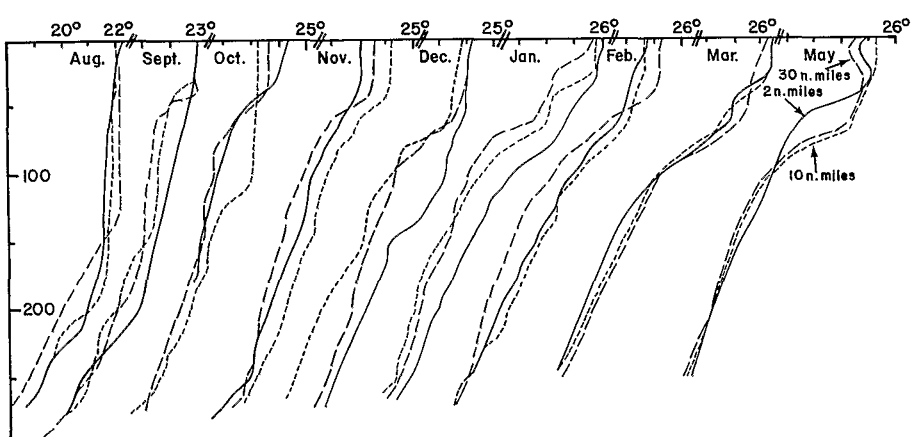


Figure 7. Thermal vertical profiles at the three stations of the Uitoe monthly transect.

site (e.g., leeward), it can be concluded that there is no such effect for chlorophyll "a" around Mare and for zooplankton dry weight off sw New Caledonia. This result is conflicting with most other studies about the island effect on chlorophyll and primary production: a coastal enrichment, sometimes with an offshore-inshore gradient, was observed by Doty and Oguri (1956), and Gilmartin and Revelante (1974) in Hawaii, Sander and Steven (1973) and Sander (1981) in Barbados, and Simpson et al. (1982) in the Scilly islands. But, in their recent work, Dandonneau and Charpy (1985) observed a variable effect on sea surface chlorophyll concentrations (SSCC) in the South Pacific: there was no correlation between SSCC and the distance from the nearest island around New Caledonia and Loyalty islands; a negative correlation (i.e., an increase of SSCC from offshore to inshore) was found around volcanic islands of the Central Pacific (Vanuatu, Fiji, Tonga, Samoa) and a positive one around Tuamutu islands (atolls), in the easternmost part of their study. Other variable results appear in zooplankton studies. No island effect was observed in Hawaii by King and Hida (1954)[1] around small islands of the eastern Pacific by Bennet and Schaefer (1960)[1] and around Mururoa Atoll (French Polynesia) by Bourret et al. (1979). But an island effect was evidenced at Palau and Yap by Tokioka (1942)[1], Bermuda by Moore (1949)[1], Marquesas Islands by Jones (1962) and Barbados by Sander and Steven (1973). Such divergent conclusions about the island mass effect may be explained by the variety of the spatial scales considered, of the trophic levels under study, and of the situations encountered. (1) The spatial scale of previous studies fluctuates from one mile to several hundred miles. Here, we concentrated on the effect of Mare Island itself or southern New Caledonia, but not on the effect of the whole archipelago, that might—or might not—increase the planktonic standing stocks on a larger space scale. (2) Bound to it, is the trophic level: phytoplankton and mesozooplankton are linked with hydrology and nutrients quite closely, whereas micronekton and nekton display a much wider distribution due to their important migrations. (3) Finally, the island effect concept is applied to a great variety of situations, that are not always comparable, at least because the enrichment processes are different. For instance, run-offs may be expected from high islands (volcanic or not), but not from low coral islands, such as atolls, of similar surfaces. Another case is the existence, or lack, of a lagoon around an island, with the consecutive exchanges between the lagoon and the open-ocean. As far as physical processes are concerned, a vertical advection created by a divergence in the wake of the island, might bring nutrients into the photic layer when the thermocline and associated nutricline are shallow, but have no effect when it is deep, such as around New Caledonia and Mare, and more generally in the western boundaries of the tropical ocean. The problem of the variety of the situations is not the aim of the present study. We shall focus on the interpretation of our observations dealing with two trophic levels and two different island cases, i.e., lagoon and run-off at Uitoe and none at Mare.

The chlorophyll "a" enrichment off sw New Caledonia, which is observed in most cases, may be due either to hydrological perturbations or to transport of chlorophyll and nutrients from the wide lagoon. Indeed, a vertical mixing appears near the coast, as the maximum thermal gradient in the 0–200-m layer is generally greater offshore than shorewards during the trade-wind season: this appears in Figure 7 from August until February, except in the October transect. In such situations, the integrated chlorophyll is greater at the coastal station in all 6 cases.

[1] Original references not seen, cited in Jones (1962).

When there is no difference in vertical thermal gradients between the coastal and offshore stations, as happens in October, March and May, chlorophyll is not lower at the coastal stations. Moreover, there is no significant correlation between the value of the maximum thermal gradient for the 0–200-m layer and the integrated chlorophyll (correlation coeff. = −0.174 for 29 stations), so that local effect of vertical mixing on phytoplankton biomass is uncertain or null. This conclusion, together with the lack of coastal enrichment around Mare, an island without lagoon and land drainage, make us favor the second hypothesis—i.e., the nutrient and chlorophyll output from the lagoon—for the observed coastal chlorophyll increase off sw New Caledonia. In spite of the lack of direct observations of nutrients and chlorophyll exchanges in the Uitoe pass, this hypothesis is reasonable since a great part of the waters of the sw lagoon are pushed in a nw direction by the trade winds, which blow 70% of the time (Dandonneau et al., 1981), and are exported offshore by the Uitoe pass, which is at the start of the transect. This could influence chlorophyll values of both stations, located at 2 and 10 n.m.

The zooplankton enrichment area, west of Mare, is the only observed "island mass effect" and is located leeward. The lack of a chlorophyll increase there could be interpreted as the result of an inverse relationship between zooplankton and phytoplankton. But no signficant correlation is found between existing data on chlorophyll and dry weights from both transects and long stations of that area (Spearman rank correlation coefficient: 0.348 for 12 pairs). The observed zooplankton increase might also have no significance, since it is based on only four cruises. At last, there may be no correlation between zooplankton dry weight and chlorophyll, either because of unsteady ecosystems, or because the link between the two trophic levels is loose. In fact, no significant correlation was found between the two variates at Mare ($r = -0.150$; N = 71) as well as Uitoe ($r = 0.056$; N = 29), even when cruises were considered separately. This lack of correlation seems to be a common feature of neritic ecosystems, in contrast to open-ocean ecosystems (Le Borgne, 1981) where a close relationship between phyto- and zooplankton is observed frequently. It can be attributed to an island effect or, more generally, to the effect of short-term variability (order of one to several days) of physical parameters in coastal regions, as pointed out by Walsh (1976). In such systems, a short-term variability of meteorologial and, thence, hydrological parameters, yields short-term variations in phytoplankton biomasses, but not to herbivore standing stocks, because of their longer life cycle. Moreover, mesozooplankton around Mare is likely to be dominated by omnivorous and carnivorous animals. One argument for this is the great importance of carnivorous jelly-like organisms in the major size-fraction of mesozooplankton (500–5,000 $\mu$m). Therefore, zooplankton biomass distribution is rather independent of chlorophyll and does not display important short-term variations as the chlorophyll does.

Finally, an interesting point of the present study is the magnitude of midterm variations (order of one to several months) in an oligotrophic environment, a system which is commonly described as a steady one. Thus, there is a significant difference between chlorophyll values of January and April and those observed in September and November (Fig. 4). Surprisingly, highest values are observed in austral summer around Mare, whereas Dandonneau and Gohin (1984) found the highest values of sea surface chlorophyll in austral winter, south of 20–22°S, in the South Pacific for the 1978–1982 period. They interpreted this as the result of the winter increase of vertical mixing. This discrepancy may be due to the use of surface values in one case and integrated ones in the other, or to abnormal oceanic conditions during the 1982–1983 El Nino (Donguy, pers. comm.). However, our data on zooplankton dry weight fit better with Dandonneau and Gohin's result, the maximum values being in September in Mare, and August, September and December for Uitoe.

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