THE SEASONAL VARIATIONS OF SALINITY IN THE JAVA SEA

D.PETIT, P.COTEL, D.NUGROHO

ABSTRACT

The climate in the Javanese basin is a monsoon regime : dry from June to September and humid from November to March. In regions seasonally subject to substantial precipitation, salinity is one of the more important factors affecting the distribution and abundance of fauna. For this reason, stationary vertical profiles have been performed to measure the variations of salinity. These measurements took place during the acoustic surveys carried out in the Java Sea in the framework of the PELFISH Project. Two surveys covering the central part, the first one in October, the second one in February, supply spatial and bathymetric localization of different water masses. Other transects, from Semarang (Central Java) to the Matasiri Islands, all along the north coast of Java, towards the China Sea and on the Kalimantan continental shelf, complete the information. Three factors seem to control the seasonal dynamics of the waters : the local precipitation systems, the direction of the winds and the dissymetric topography of the basin. In the dry season (south-eastern winds), desalinization starts in the North which is less deep. Its progression to the South is made by vertical mixing. In wet season (north-western winds), it is also in the North that the desalinization begins, leading to a temporary inversion of the salinity gradient. The latter will then be restored after the front of precipitation has moved southwards. The return to the dry season leads to a homogenization of salinity. Inter-annual climatic variations seem important and make difficult to have an interpretation based on localized observations in time and space. There is an annual longitudinal gradient where the western part being more steady in salinity than the eastern one, but there is also a latitudinal dissymetry induced by the bathymetry and the northern origin of desalinization.

KEYWORDS : environment, Java Sea, salinity.

ABSTRAK

Iklim di laut Jawa mengikuti pola musim dimana musim kering berlangsung pada bulan Juni hingga September, sedangkan musim hujan pada bulan November hingga Maret. Pada perairan yang secara musiman dipengaruhi oleh curah hujan, salinitas merupakan salah satu faktor yang penting dalam perubahan sebaran dan kelimpahan fauna. Atas dasar keadaan tersebut, variasi salinitas berdasarkan ruang dan waktu di laut Jawa telah diamati melalui pengukuran pada sejumlah stasion pada saat survey akustik yang merupakan bagian dari kerjasama proyek penelitian PELFISH. Dua survey yang meliputi bagian tengah laut Jawa yang dilaksanakan pada bulan Oktober dan Februari menunjukkan adanya perbedaan pola sebaran massa air menurut ruang dan kedalaman perairan. Beberapa pelayaran pada kurun waktu yang berbeda dengan liputan sepanjang jalur Semarang menuju pulau-pulau Matasiri, pantai utara Jawake arah Laut Cina selatan dan perairan paparan Kalimantan melengkapi informasi tersebut. Tiga faktor diduga berperan dalam dinamika musiman perairan yaitu : curah hujan lokal, arah angin serta ketidak simetrikan dasar perairan. Pada musim kering (angin tenggara) proses peningkatan salinitas diawali dari utara pada perairan dangkal yang kemudian bergerak kearah selatan melalui percampuran tegak (vertikal mixing). Pada musim hujan (angin barat laut), proses penurunan salinitas juga dimulai dari utara dan kemudian terjadi pembalikan sesaat gradient salinitas yang selanjutnya terus bergerak kearah selatan hingga batas pengenceran oleh curah hujan. Berulangnya musim kering menyebabkan proses homogenisasi salinitas. Perubahan tahunan keadaan cuaca sangat berperan penting namun perubahan ini menyebabkan kesulitan dalam proses intepretasi yang didasarkan pada pengamatan lokal menurut waktu dan ruang. Gradient tahunan secara membujur terdapat di perairan ini dimana, salinitas perairan bagian barat relatif tetap dibandingkan bagian timur. Demikian pula terdapat ketidaksimetrikan menurut perbedaan lintang yang disebabkan oleh perbedaan kedalaman perairan serta proses penurunan salinitas yang diawali pada subperairan bagian utara.

KATA KUNCI : lingkungan, Laut Jawa, salinitas.

Limiting its extension from 4°00 S to the Makassar Strait and from 3°00 S to the Karimata Strait, the area of the Java Sea represents approximately 442,000 km^2 (Fig. 1, Durand and Petit, 1995). This sea of an average depth of 40 m and slowly sloping towards the East, is wide open at its two extremities, allowing exchanges with neighbouring basins. The whole region is subjected to monsoon system. A rather dry season with southern trade winds lasts from June to September. The rainy season, under the influence of north-west trade winds stretches from November to March. In Java, rainfalls reach 1700 mm, which represents an annual average on thirty years (Fontanet and Chantefort, 1978). But in the same interval, the annual variation reaches more than 30%. From June 1992 to May 1995, salinity measurements were carried out during acoustic surveys. They are used to outline the seasonal cycle of salinity.

MATERIAL AND METHODS

The presented observations concern the results of the vertical profiles of measurements carried out along Semarang (Central Java) -- Matasiri Islands transects during surveys in June, September, October, November and December 1992, two big surveys towards the east from 108°30 E (October 1993, February 1994) as well as three surveys : towards the China Sea (April 1993), on the eastern continental shelf of Kalimantan (February 1995) and in the south-west of the Java Sea (May 1995).

An autonomous CTD vertical Profiler SEABIRD was used; this probe measures the pressure, temperature and conductivity at each 50 cm approximately. The use of this appliance is easy. While the ship stopped, the Profiler is lowered slowly after stand-by at the surface for adjusting its thermal equilibrium. Measurements are stored within the probe and then transferred at the end of the cruise. Different softwares are used in the calculation of average salinity and representation of bathymetric sections (Petit *et al.*, 1997).

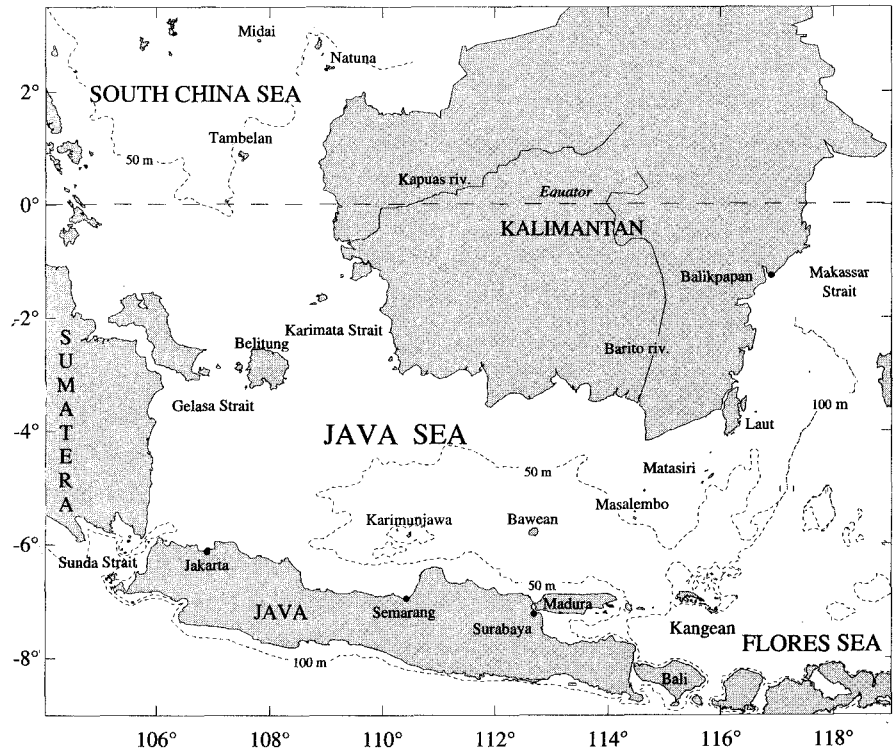

Figure 1 The Java Sea and its surroundings.
Gambar 1 Laut Jawa dan sekitarnya.

In full wet season

Java Sea

The February 1994 survey covered three quarters of the Java Sea on the eastern part (the deepest part). Figure 2 shows the distribution of hydrologic stations performed to obtain averaged salinity. The latter presents a decreasing gradient SW - NE, perpendicular to the axis of dominant winds. The values vary from 33.5 to 31.2‰, and the NW - SE diagonal of the Java Sea corresponds quite well to the 32.7‰ isohaline. On the Javanese coast, limited desalinization can be sensed only by the presence of a channel with the least salinity in front of Semarang.

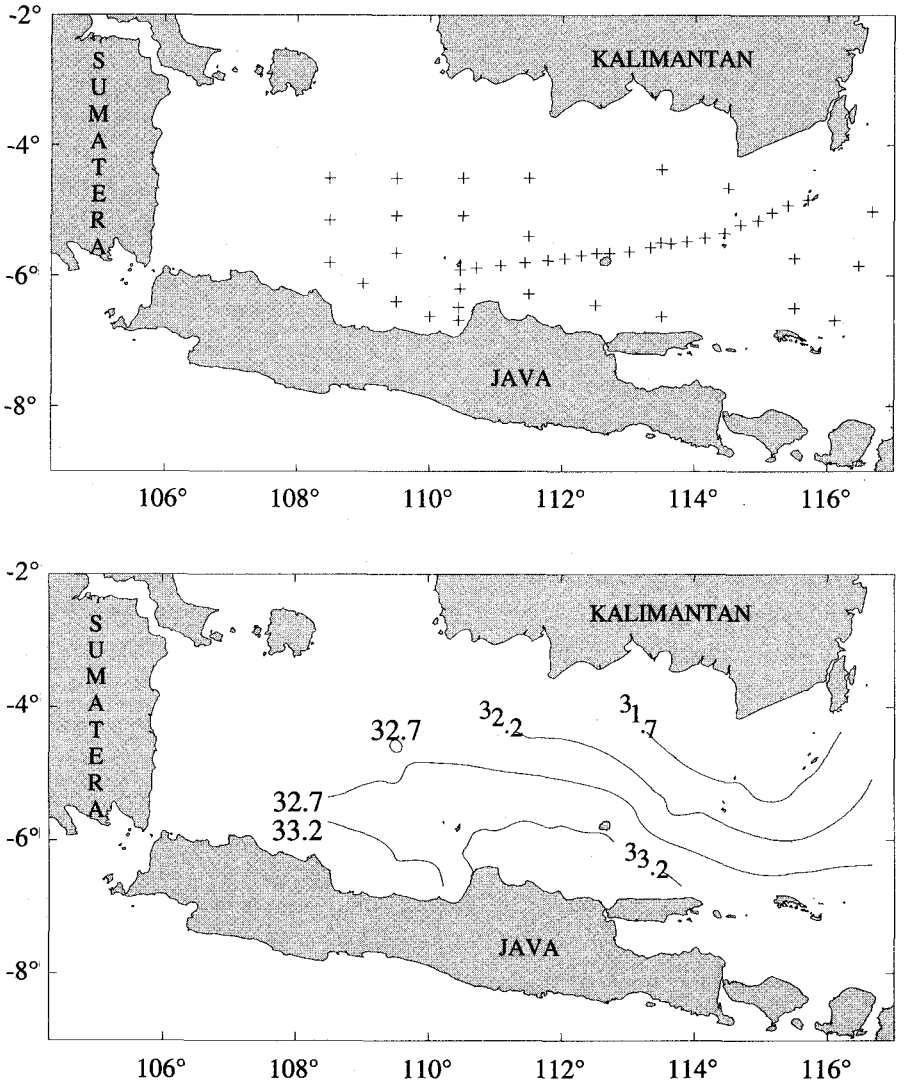

Figure 2 **February 1994 (Survey 41) : Location of stations (up) and mean salinities (down) in the Java Sea.**

Gambar 2 **February 1994 (survey 41) : lokasi stasion (atas) dan rata-rata salinitas (bawah) di laut Jawa.**

The northern vertical section indicates two sources of desalinization. One very important is in the East, of the Barito River, and acting until the South of the Java Sea (Fig. 3). The other less so is in the West, undoubtedly coming from the Karimata Strait. The median and south sections show that the more salinized waters (>33‰) continue toward the West. They are still linked in depth with the more oceanic salinities of the East (33.5‰). Below 40 m depth, the water stays above 33‰, up to 109° E.

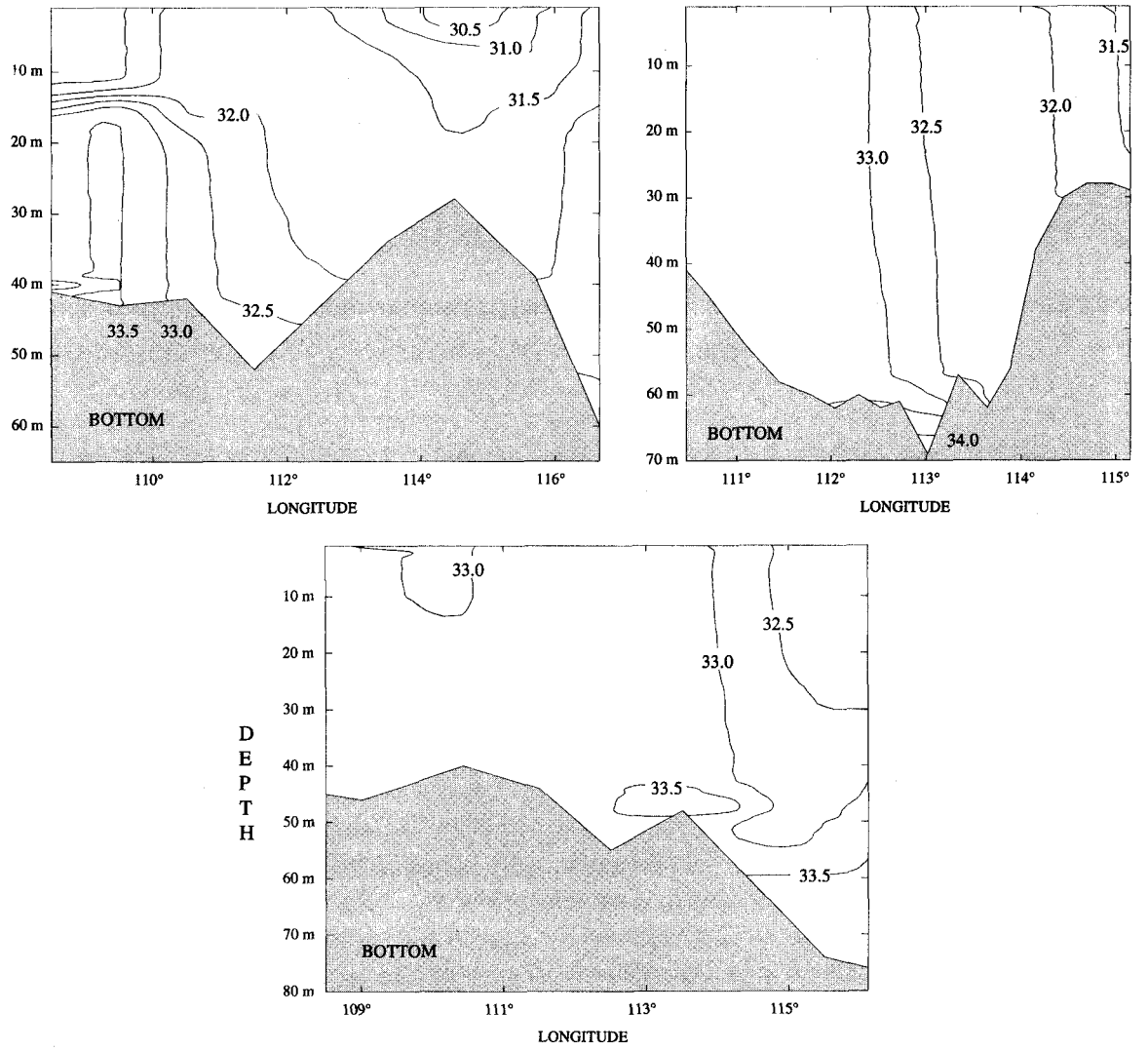

Figure 3 **February 1994 : Vertical profiles of salinity, north and medium sections (up), south section (down).**

Gambar 3 **Februari 1994 : Penampang tegak salinitas pada subperairan bagian utara dan tengah (atas) dan bagian selatan (bawah).**

Eastern continental shelf of Kalimantan

The February 1995 survey concerned the continental shelf of Kalimantan, in the Makassar Strait. The most coastal stations are situated at less than 25 miles from the shore. They show a marked desalinization in the North of Balikpapan and above all in the South (latitude of Pulau Laut, Fig. 4). The latter desalinization, 32‰ (Fig. 5), joins up with the one that stretches from Pulau Laut to the South, in February 1994 (31.7‰). But the major part of the plateau is still occupied by water which is above 32.5‰, on average. The northern flux is sufficiently important to limit the desalinization which remains coastal.

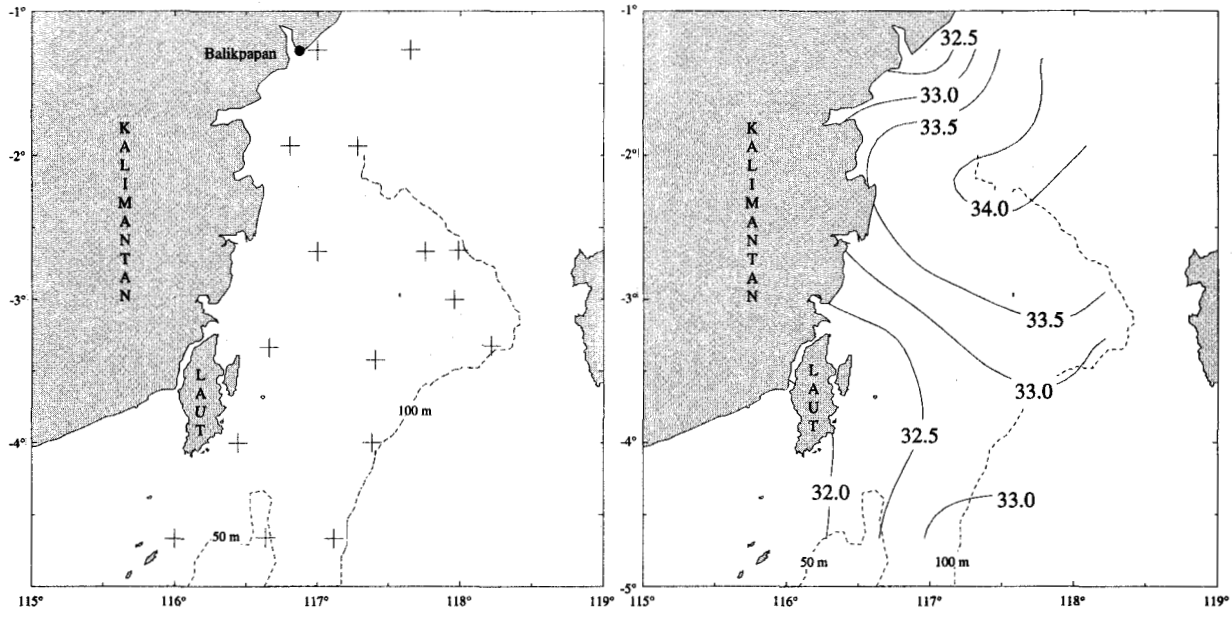

Figure 4 **February 1995 (Survey 51) : Location of stations (left) and mean salinities (right) on the continental shelf of Kalimantan (Makassar Strait).**

Gambar 4 **Februari 1995 (survey 51) : *lokasi stasion* (kiri) dan rata-rata salinitas (kanan) di paparan daratan Kalimantan (Selat Makasar).**

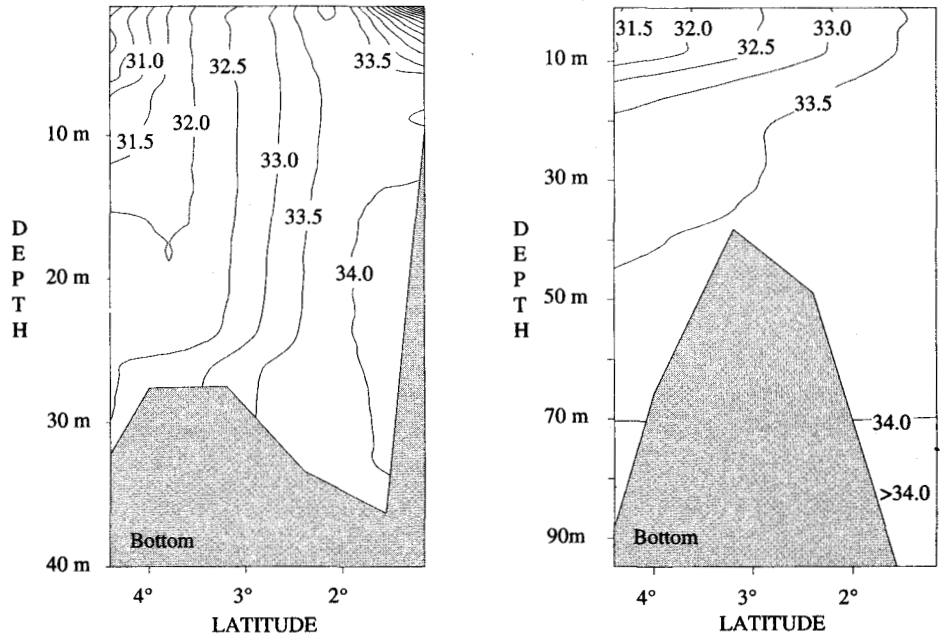

Figure 5 **February 1995 : Vertical profiles of salinity in the Makassar Strait : left, along the coast, right close to the continental slope.**

Gambar 5 **Februari 1995 : Penampang tegak salinitas di Selat Makasar : kiri, sepanjang pantai; kanan, disekitar kelandaian daratan.**

End of the rainy season

In the Karimata Strait

The April 1993 survey (Fig. 6) from Semarang to the South of the China Sea, gives the haline situation while the dominant winds are still slightly from the West and the surface waters still have a tendency to divert towards the Java Sea. The difference of average salinity between the Java Sea and the Karimata Strait is very slight. In the central part of the strait, the water is above 33.5‰, putting aside a desalinization at the latitude of the Kapuas River (Kalimantan), the average salinity drops only close to the Bay of Semarang.

According to the vertical sections (Fig. 7), the separation between the waters from the South of China Sea and that of the Java Sea is slightly marked (first twenty meters). But the ascent of the bottom up to 25 m depth by 4°00 S makes difficult the circulation of "bottom" waters, more salted, between both seas.

In the Java Sea, although the sampling is only represented by two transects, it seems that the haline situation has changed since February (Fig. 2 and 7) : at the longitude 110° E, the haline gradient to the North is reversed and there is, in April, a strong vertical gradient up to the North of the Karimunjawa Islands.

In the south-western Java Sea

Some observations were carried out all along the west Java coast, from Semarang to the eastern side of Sumatra, in May 1995 (Fig. 8). The representation of average salinities brings not much information : it seems that a slight gradient subsists all along the coast. The lowest salinities are found along Sumatra. By comparison with April 1993 survey, the average salinity of the northern stations is 0.5‰ lower. Also, it does not seem that there is an important entry of water through the Sunda Strait.

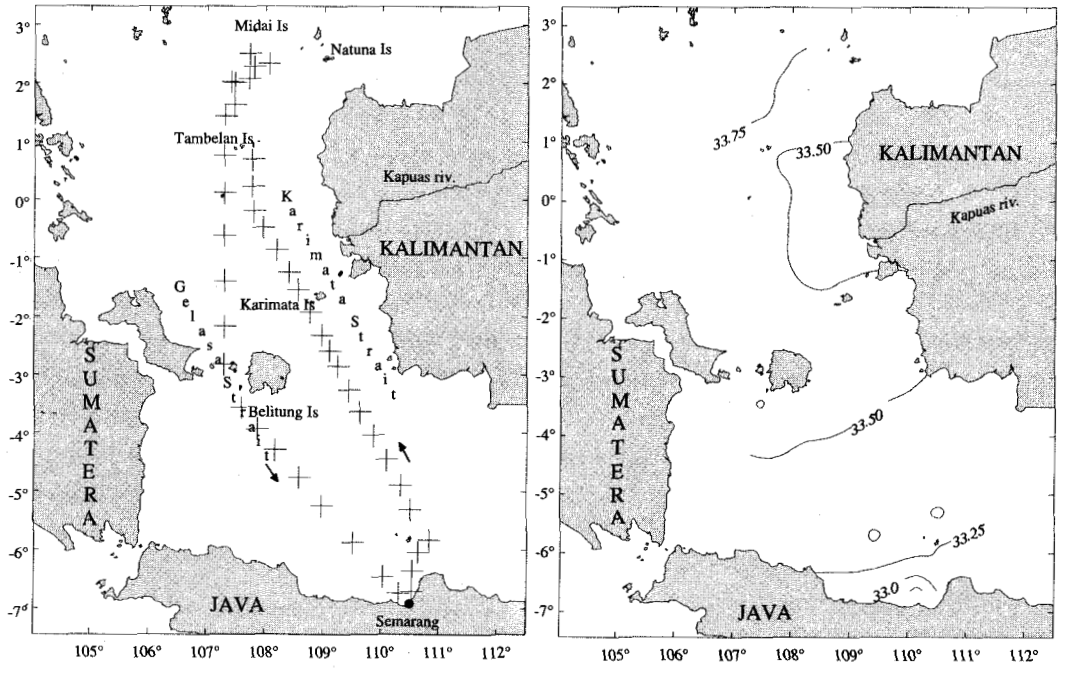

Figure 6 **April 1993 (Survey 31) : Location of stations (left) and mean salinities (right) from Semarang (Central Java) to the South China Sea.**

Gambar 6 **April 1993 (survey 31) : lokasi stasion (kiri) dan rata-rata salinitas (kanan) sepanjang jalur pelayaran Semarang menuju Laut Cina Selatan.**

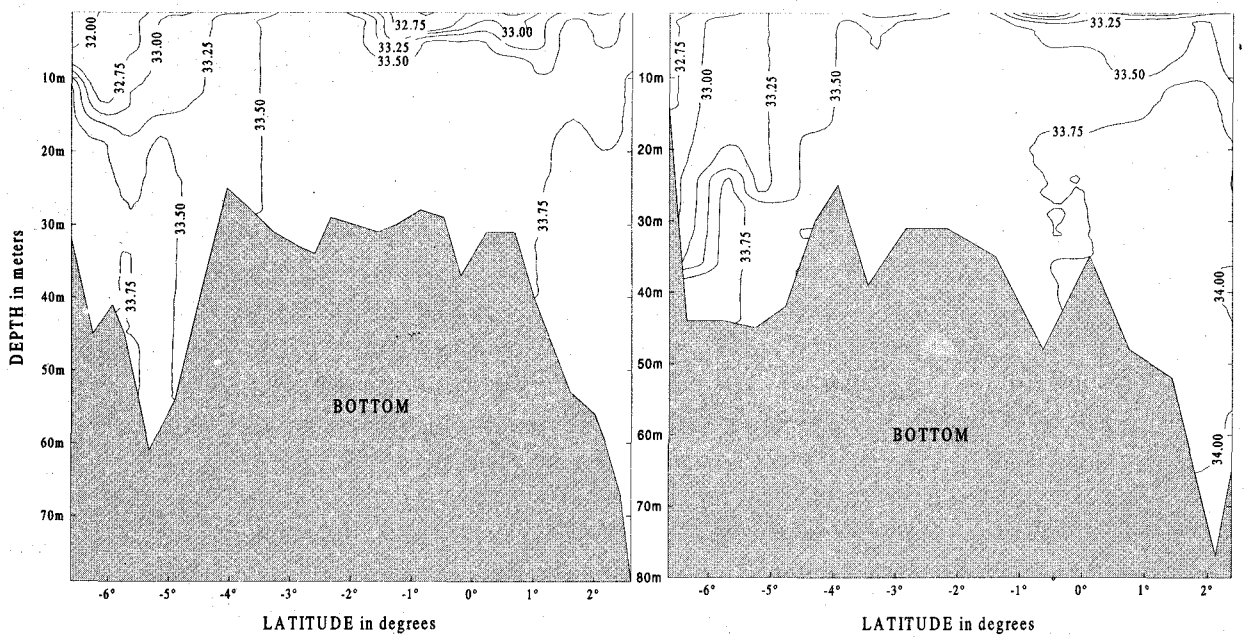

Figure 7 **April 1993 : Vertical profiles of salinity, from Semarang to the South China Sea; left, one way by the Karimata Strait, right, return by the Gelasa Strait, ten days later.**

Gambar 7 **April 1993 : Penampang tegak salinitas pada jalur pelayaran Semarang ke Laut Cina Selatan (kiri) dan Selat Karimata (kanan) yang diulangi melalui Selat Gelasa 10 hari kemudian.**

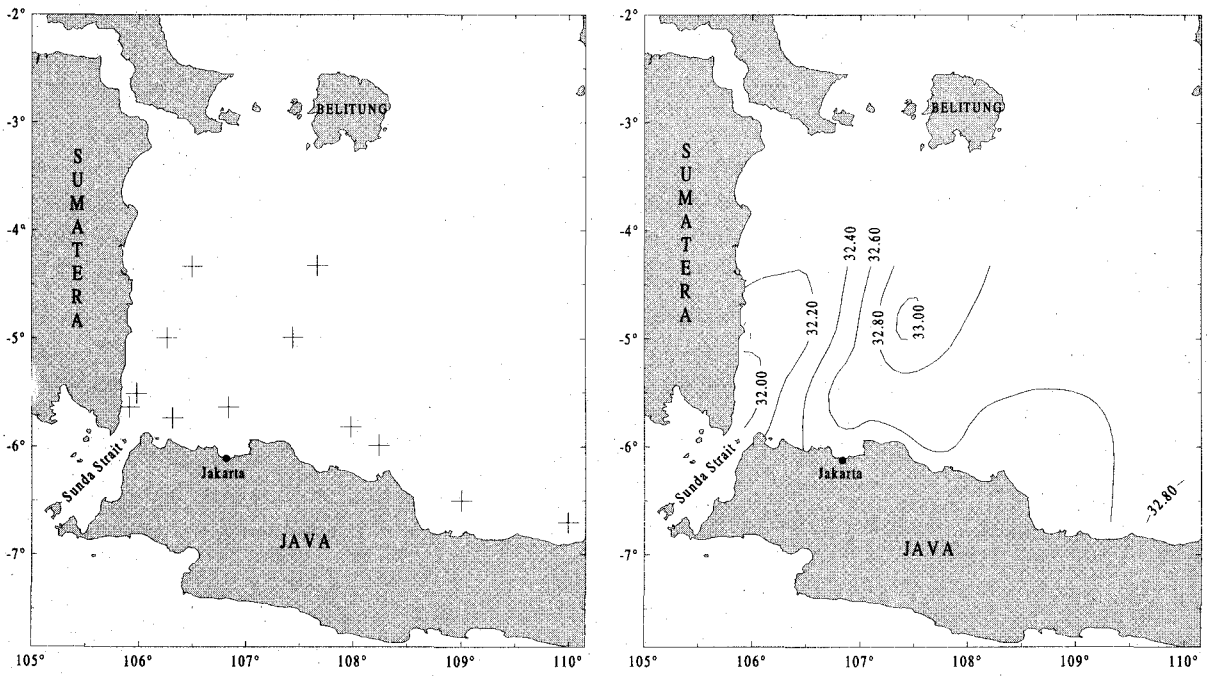

Figure 8 **May 1995 (Survey 53) : Location of stations and mean salinities in the Southwest of the Java Sea.**

Gambar 8 **Mei 1995 (survey 53) : Lokasi stasion dan rata-rata salinitas di subperairan barat daya laut Jawa.**

In the dry season

The stations during the survey of October 1993 had, more or less, the same location as the one of February 1994. Figure 9 represents the geographic distribution of average salinities. Practically the same orientation of isohalines can be found as in February 1994, but here the haline gradient NE -- SW is reversed. The 34.5‰ isohaline has more or less replaced the 32.7‰ isohaline of February. In the area covered by the survey, a slight desalinization remains along Java in the south-western part. Between February and October, the average deviations passed from 2.3 to 1.1‰.

The vertical sections (Fig. 10) indicate that the penetration of the water occurs above all, in the North, in the shallower part : the 34.5‰ reaches 111° E in the North, 112° E at the latitude of the Karimunjawa -- Bawean Islands, and is occasional in the southern part. According to the average salinity values, one can consider that the quasi-entirety of the water has been replaced, until 108° E.

The wet to dry season evolution along Karimunjawa - Matasiri transects

These transects, achieved in 1992, allow one to follow the evolution of desalinization.

In June (Fig. 11), the 32.3‰ isohaline is at 112° E, so quite east. The western values, less than 31.8‰, are lower than the ones met in precedent months (April 1993 : 32.7‰, in front of Semarang as well as in the west of Java, in May 1995). There is no longer a vertical gradient, likely because of a strong mixing.

At the end of September, the desalinization is well advanced. By 112° E, the 34‰ waters can be met. The deviation between salinities has not changed since June.

In October, the desalinization of the basin is at its maximum : the isohalines did advance to the West and the 34‰ waters reaches 111° E. But the comparison between October 1992 and 1993 shows that from one year to the other, the level of desalinization changes. In 1992, the 34.5‰ waters penetrated until 114° E, reaching 112° E in 1993.

One month later, the high salinity waters have already started their retreat towards the East. Waters, less than 33.3‰, arrived from the West. Doubtless, it concerns residual waters and that advance indicates that waters coming from the Karimata Strait began their entry into the Java Sea. By 112° E, it needs almost three months for the water to gain 1.7‰ in salinity and only one month to drop 1‰.

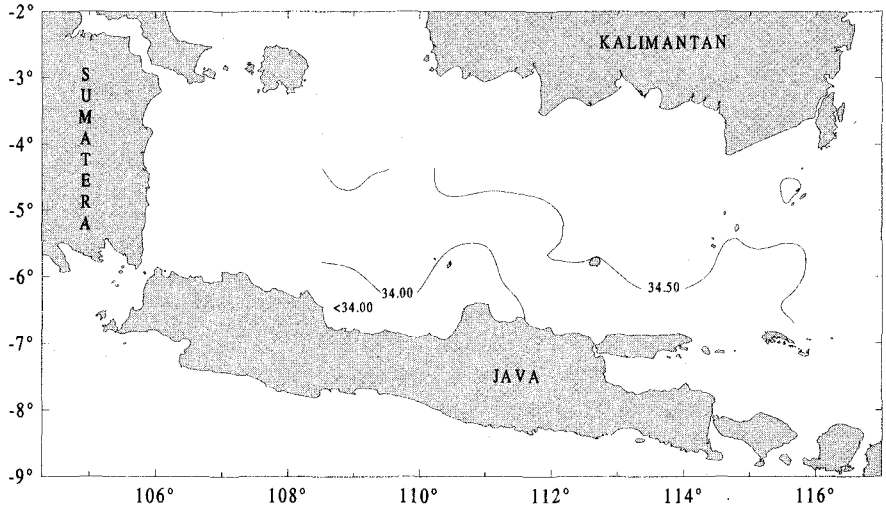

Figure 9 **October 1993 (Survey 34) : Mean salinities in the Java Sea (for the location of stations, see Figure 2).**

Gambar 9 **Oktober 1993) survey 34) : Rata-rata salinitas di laut Jawa (lokasi stasion tertera pada Gambar 2).**

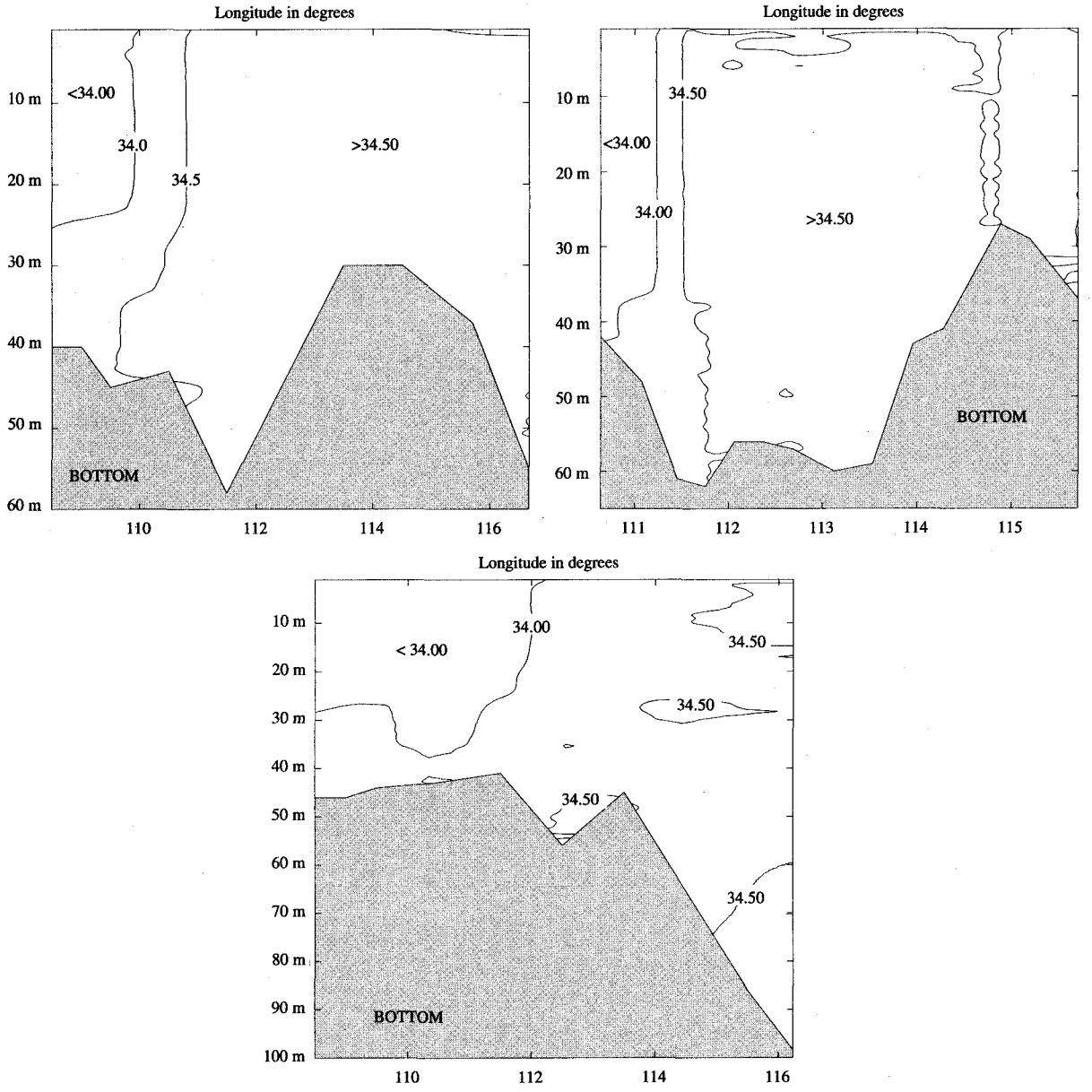

Figure 10 **October 1993 : Vertical profiles of salinity, up to down, north, medium, south section.**

Gambar 10 **Oktober 1993 : Penampang tegak salinitas pada subperaian bagian utara, tengah dan selatan (dari atas ke bawah).**

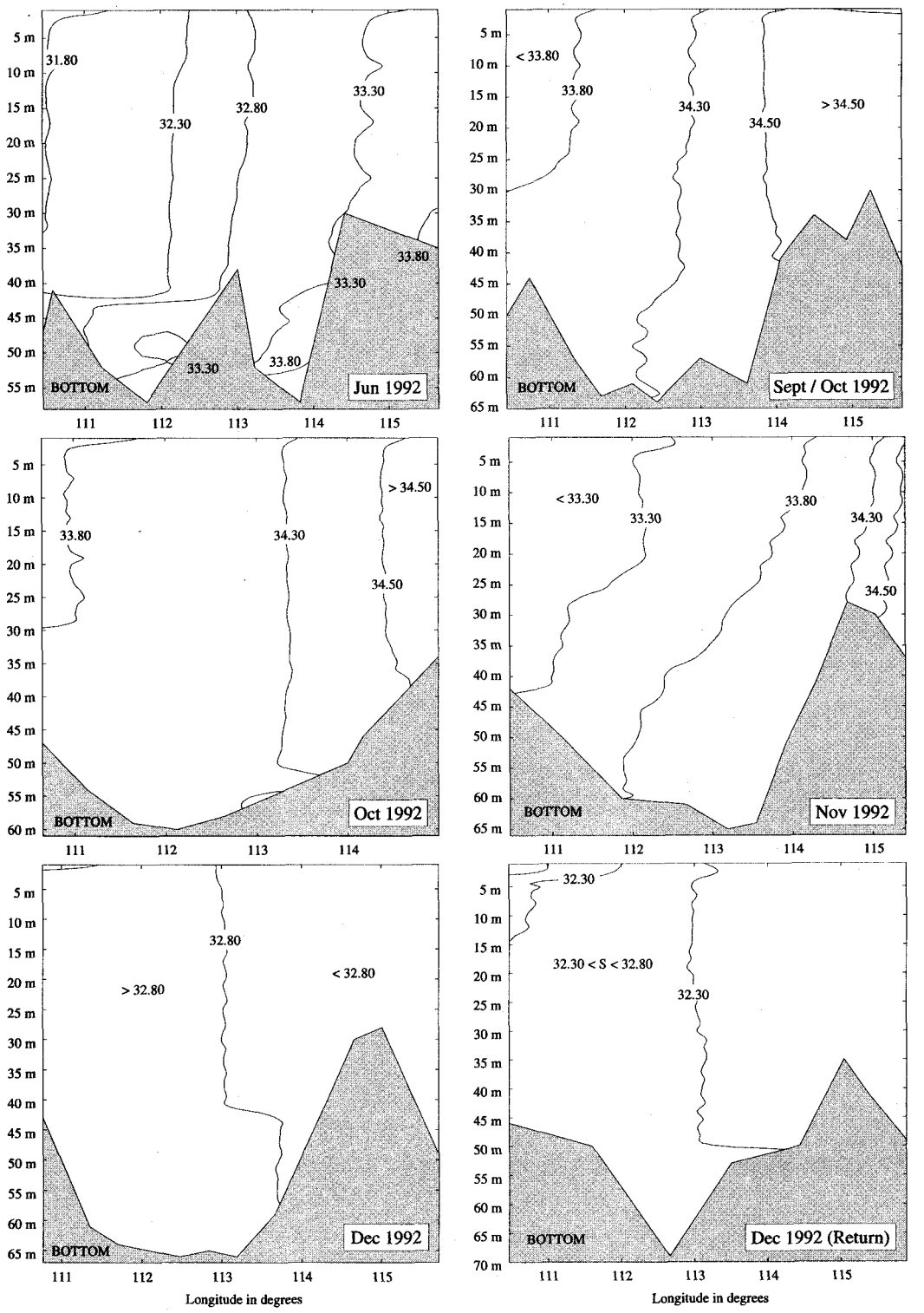

Figure 11 **In 1992, vertical profiles of salinity along the transect Karimunjawa - Matasiri Islands; the return in December took place 20 miles south of the one way.**

Gambar 11 **Tahun 1992. Penampang tegak salinitas sepanjang jalur pelayaran Karimun Jawa menuju pulau-pulau Matasari; pengulangan pada bulan Desember dilakukan pada jalur pelayaran 20 mil selatan sejalar jalur keberangkatan.**

On the December transect, the real desalinization appears, coming from the North and invade first the shallow zones, around the Matasiri Islands. That desalinization, pushed by west winds quickly gets through the middle of the Java Sea. At the return from Matasiri, the isohaline 32.8‰ is already located at 113° E south of the Bawean - Masalembo axis, isolating to the West, waters of 33‰. It is doubtless this pocket of more salted water that will be met in February on the north coast of Java.

CONCLUSION

The climate of the Java Sea is a typical monsoon climate (Veen, 1953; Fontanet and Chantefort, 1978) with a complete inversion of winds. The wet season, in the Java Sea, lasts from December to March with periods of strong wind (Potier and Boely, 1990) coming from the Northwest. Farther north (Karimata Strait), it begins earlier (October - November), following the southern movement of the atmospheric Inter-Tropical Front (Fontanet and Chantefort, 1978). The dry season occurs from June to September with more regular south-eastern winds. The impact of heavy rainfalls on Sumatra and Kalimantan linked with the circulation due to the wind during the wet season, and the one of the entry of oceanic water pushed by east wind in the dry season, were represented by Veen (1953) and by Wyrtki (1961). The two authors, using principally "ship" surface data, represent the movement of waters throughout the Java Sea, relating it to the regional environment by means of average isohalines.

The existing gaps in our observations, from 1992 to 1995, make it difficult to fully understand the haline mechanisms, all the more so since the phenomena seem a bit more complex than those previously described in a regional perspective. Wyrtki (1956) underlined the existence of important inter-annual variations joined to those of precipitation. They make difficult to get a seasonal description based on data acquired from several years. These variations have been indicated here, in April - May and in October. However, even incomplete, our observations permit a better knowledge of the seasonal evolution of the waters in the Java Sea.

Veen (1953) established that average surface salinity varies annually from 30.8 to 34.3‰ in the eastern part and is more limited towards the West, from 109° E, between 30.6 and 32.6‰. On the Semarang - Matasiri transect, the extremes were found in June (31.8‰) and in October (34.5‰); on the bottom by 30 m deep, the minimal value descends to 31.2 in February. There is thus approximately the same deviation along the vertical than in surface; the western part was not sufficiently prospected to present the values, but at the longitude of the Karimunjawa Islands, the seasonal deviation of 3-4‰, in the eastern part (February -- October), drops to 1.7‰ (June - October) only.

As Wyrtki said (1961), "the vertical curves of salinity show an almost homogeneous salinity from the surface to the bottom over the more shallow regions." The majority of the vertical curves show a quasi verticality of isoplethes. But in period of strong desalinization, important vertical gradients can appear before mixing, leading to local vertical deviations acting, likely, on the pelagic fish distribution (February, April).

Localization and evolution of the haline characteristics in the Java Sea seem influenced by three main factors :

- the regime of the rains on the side basins (abundance and period),
- the system and direction of the seasonal winds,
- the topography of the Java Sea basin.

This last factor, permanent, acts in the same way on the movements and the exchanges, whatever the annual variation of the others. Largely open to the East, the Java Sea communicates with the Karimata Strait by a section half the size. In period of north-western monsoon, the topography will not be opposed to the circulation of superficial waters. It is not the same in period of south-eastern monsoon where the exits by the strait attempt to limit the outcoming flow. This also can have an effect on differential movements of the fauna between the opposite seasons. In the East, the basin presents a

dissymetric bathymetric topography between the North and the South (Durand and Petit, 1995), the sector close to Kalimantan being distinctively less deep. Well exposed to dominant winds when the rains become weak, it is in this zone, that the desalinization of the Java Sea will begin, by flow, while in the southern deeper part, it seems more related to a vertical mixing. Close to the first sources of desalinization, the northern zone will rapidly be invaded by the continental waters. This area presents the bigger annual haline deviations.

The progress of the marine wet season occurs apparently in three stages. From November, the lowering of eastern wind combined with the beginning of western wind, will progressively stop the desalinization and favour a return to the East of less haline stagnant waters from the western part. But, the precipitations also begin on the west borders of Kalimantan, east borders of Sumatra and in the Karimata Strait.

The real desalinization seems to begin in December. As a consequence of precipitations begun in November, it is going on towards the South and appears on our Karimunjawa - Matasiri transect by the East near the supply of freshwater (Barito River). The quick extension to the South is doubtless favoured by occasional inversion of winds. From the situation observed in February, one can see the consequence of this second phase : the isolation of a mass of higher salinity on the northern side of Java.

Unfortunately, the third stage has not been sufficiently observed. According to Wyrtki (1961), about one month goes by between the moment of maximum rain and its effect on the sea. So, he estimated that the maximum desalinization will take place in March. Soeriaatmadja (1956) showed obviously, by 5° - 6° S a surface maximal desalinization in February - March. The surface values reported as much by Wyrtki as by Soeriaatmaja are as a whole, inferior to those found during PELFISH surveys. It could suppose that in February 1994, the observed situation was due to lateness of precipitation. The few observations of April 1993 and May 1995 indicate that, in the third phase of desalinization, a « normal » salinity gradient -- a salinity increasing towards the centre of the basin -- is re-established. The major biological effect of desalinization in the Java Sea would occur later than the date of maximum precipitation leads to suppose : in May, when vertical homogenization is practically accomplished.

Wyrtki (1961) underlines the importance of exchanges through the Karimata Strait with the penetration of waters at 32‰, into the Java Sea, between January and June. One finds on the north section in February 1994 (Fig. 3), a tongue of 31‰ water which could be this trace. The survey of April 1993 shows that, at least certain years, waters of 33.5‰ can try to enter the Java Sea, especially by the Gelasa Strait. But what is the biological importance of this phenomenon ? At this time in the Java Sea, the waters are close to their maximal desalinization. The exchange would be weak, due to the shallowness of the strait; furthermore, it could not persist a long time with the next inversion of the monsoon winds admitting as Wyrtki, that, in the Java Sea, the current is the same in the whole water mass.

By comparison with the wet season, the desalinization of the Java Sea seems to be a much simpler phenomenon. According to the average situation of October, the « cleaning » of the basin will be intensively completed by the northern side, by flow and mixing.

In conclusion, the study of salinity variations, no longer limited to surface observations, corroborates the previous global conclusions. It also makes particular seasonal situations appear and better localize water masses. The Java Sea presents a W - E gradient of its environmental characteristics, the western part having lower haline variation than the eastern one. But, there is also a latitudinal dissymetry of the basin, because the southern part, deeper, keeps later higher salinities. Wyrtki noted that "these water movements may be expected to have considerable bearing on the movements of fish and their eggs and larvae." Potier and Boely (1990) showed the influence of the monsoon on the level of catch. Repeated short time observations at the beginning and at the end of the wet season could clarify the migratory movements and help to delimit the reproduction areas that have already been suggested (Sadhotomo and Potier, 1995).

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DISCUSSION

(Chairman Dr. PASARIBU)

Dr. MERTA

Q : - Regarding to Figure 2, showing the location of the oceanographic stations in the Java Sea, I wonder why ¼ of the Java Sea, the western part, has not been covered with stations. Some of stations are close together, some are lacking. The repartition doesn't seem consistent with a suitable oceanographic spread.

A : - Obviously, we should have better information if the western and northern parts (or more places) had been prospected. The problem we faced was to cover the maximum of the Java Sea in the short time of 12 or 13 days only. It was the ultimate autonomy of the research vessel. That is why we have selected this survey design which was covering more or less the most important part of the deep waters of the Java Sea. We have performed many profiles along the transect Semarang-Matasiri, because for us, it was the track of reference and we tried to obtain the highest description of this transect.

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