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Seasonal Variations in Temperature, Sality and Density In- and off Ise Bay

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Abstract

Seasonal variations in temperature, salinity and density in- and off Ise Bay are examined by statistical data analyses. The observational data during the period from 1985 to 1989 obtained by Aichi Fisheries Research Institute and by Fisheries Research Institute of Mie are used to present the monthly mean horizontal maps and those of their standard deviations. It is pointed out that horizontal difference in the sea surface temperature (SST) between in and out of Ise Bay is largest in spring and smallest in summer to autumn. Although no prominent spatial change in SST is detected in summer, the horizontal temperature difference more than 3°C is found at a depth of 30 m. It is also pointed out that the salinity fields are strongly influenced by the river discharge especially in summer. The horizontal differences in sea surface salinity (SSS) are very large (more than 12‰) in summer, but very small in winter (about 3‰). As the less saline water is confined to the shallower layer less than 10 m, the horizontal salinity difference at depths more than 10 m is rather small in all seasons. On the whole, clear seasonal cycle of the oceanic condition of Ise Bay is demonstrated by the presented monthly mean maps.

Key words: coastal front, cabbeling, river discharge and the Ise Bay

Introduction

Ise bay is a shallow bay with a mean depth of 18 m. This bay is furthermore characterized by the relatively large river discharge by three the big rivers, Kiso-gawa, Nagara-gawa and Ibi-gawa, locating at the innermost of the bay.

There have been many observations on the oceanic conditions of Ise Bay[1−4]. In particular, the formation of coastal fronts is one of the most important phenomena for the oceanic conditions of Ise Bay, which have a significant influence on the water exchange of Ise Bay. Recently, two datailed hydrographic observations on the coastal fronts were made in December 1989 and November to December 1990[5]. It was shown by these observations that the two fronts as for the temperature and salinity differences were detected; one in south to the Chita Peninsula and the other in east to the Kamishima. The density maximum was observed at the front east to the Kamishima, in which occurrence of the cabbeling was suggested. On the other hand, sea level differences around Ise Bay were examined[6] and the specific volume change and the effect of wind stress are shown to be responsible for the sea level change.

Seasonal variations of the hydrographic conditions such as the temperature, mean flow and water exchange have been also studied[1−2]. However, as their analysis is confined to the inner region of Ise Bay, the seasonal

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variations have not been well eximined in relation to those of the outer region of the bay. The oceanic area off Ise Bay has various variations in temperature and salinity caused by approaching of the warm eddies detached from the Kuroshio[7]. Therefore, it is very important to examine the interaction between in and off of Ise Bay. As a first step to the study on this problem, historical data analysis on the in- and off Ise Bay is carried out in the present study. Monthly mean map of the temperature, salinity and denstity will be presented in the following. The details of the adopted observational data will be mentioned in the next section. The results of the data analysis will be described in the section 3. Summary and discussion will be made in the section 4.

Data

Fig. 1 shows the observational stations of Aichi Fisheries Research Institute and those by Fisheries

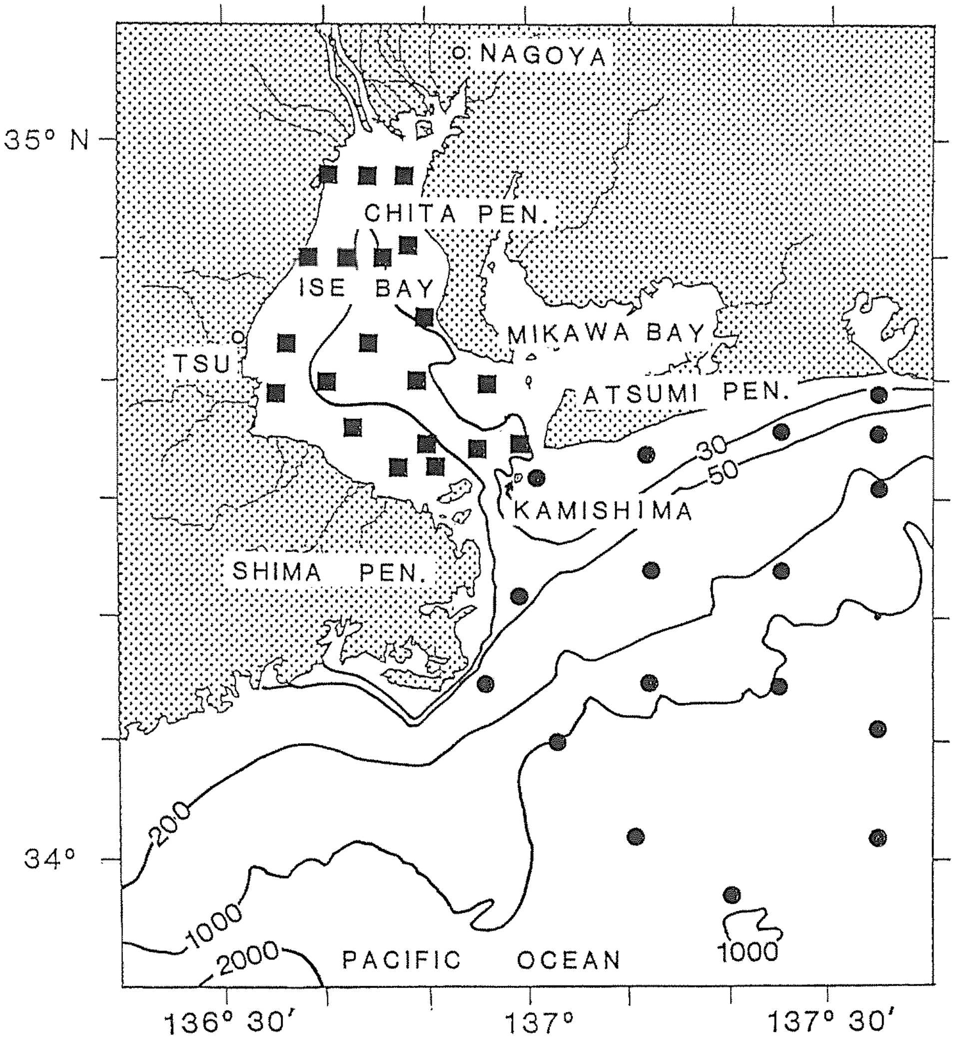

Fig. 1. Location of observational stations of Aichi Fisheries Research Institute (closed circles) and by Fisheries Research Institute of Mie (closed squares). Depth contours (in meter) are also shown.

Research Institute of Mie. The temperature and salinity data have been observed monthly at these observational points. The data during the period from 1985 to 1989[8,9] are used to present the monthly mean horizontal maps. Density (σt) is calculated from the temperature and salinity data adoped. Standard deviations are also calculated for temperature, salinity and density data will be shown in the similar forms. Although montly data at the depths of 0 m, 2 m, 5 m, 20 m and 30 m were presented by Fisheries Research Institute of Mie and those at the depths of 0 m, 10 m, 20 m, 30 m, 50 m, 75 m, 100 m, 150 m, 200 m, 300 m, 400 m, 500 m, 600 m, 700 m and 800 m were done by Aichi Fisheries Research Institute, the montly mean horizontal maps of those data at the depths of 0 m, 10 m, 30 m and 50 m are presented in this paper because of the shallow depth of Ise bay with a mean depth of 18 m.

Results

Temperature

The horizontal temperature distributions at the depths of 0 m, 10 m, 30 m and 50 m are displayed in Figs. 2, 3, 4 and 5, respectively. On the whole, a clear seasonal cycle is found: at a sea surface, the horizontal temperature difference is largest in spring and smallest in summer to autumn. It should be noted that a monthly mean temperature in May (September) is much colder (warmer) than in January (July) in Ise Bay, which suggested that there exists a clear time lag against the atmospheric temperature change with a maximum in August and minimum in January[4]. Relatively large standard deviation (STD) of SST is found in winter in an outer bay and in summer in an inner bay. The large STD in winter is due to approaching of the warm water detached from the Kuroshio[7] and that in summer is caused by large river discharges with variable temperature and spatial change of its diffusion. At the depth of 10 m (Fig. 3), a similar temperature distribution to SST are found in late autumn to winter, while temperature is lower than SST in summer to early autumn. In the latter period, the horizontal temperature difference more than 4°C is found, which is a clear contrast to approximately homogeneous horizontal distribution of SST. At the depth of 30 m (Fig. 4), changes similar to those of 10 m to SST are recognized: the temperature at the depth of 30 m shows larger horizontal difference (5–7°C) in winter to spring and smaller difference (2–3°C) in summer to autumn, whereas those of SST are (6–8°C) and (0–1°C), respectively. Almost common temperature distribution in winter to early spring suggests that the winter cooling and formation of mixed layer has a significant influences on the temperature fields, while the summer warming is rather confined to a shallower layer and it results in relatively larger horizontal temperature difference at depths of 10–30 m. Relatively large STD of temperature at depths deeper than 30 m is detected in summer to autumn. In particular, STD of temperature is larger than spatial change at a depth of 50 m, which suggests that warm water detached from the Kuroshio[7] has an important effect on the temperature fields.

Salinity

The horizontal salinity distributions at the depths of 0 m, 10 m, 30 m and 50 m are displayed in Figs. 6, 7, 8 and 9, respectively. At a surface, a clear seasonal cycle is detected: relatively high salinity water occupies Ise Bay in winter, but it is replaced by remarkably less saline water in summer by large river discharge. It should be noticed that the STD of salinity is very large in the bay, which suggests that the large river discharge in summer occurs at irregular intervals with a remarkable spatial difference in its horizontal diffusion. The horizontal difference in sea surface salinity (SSS) is very large (more than 12‰) in summer, but it is small in

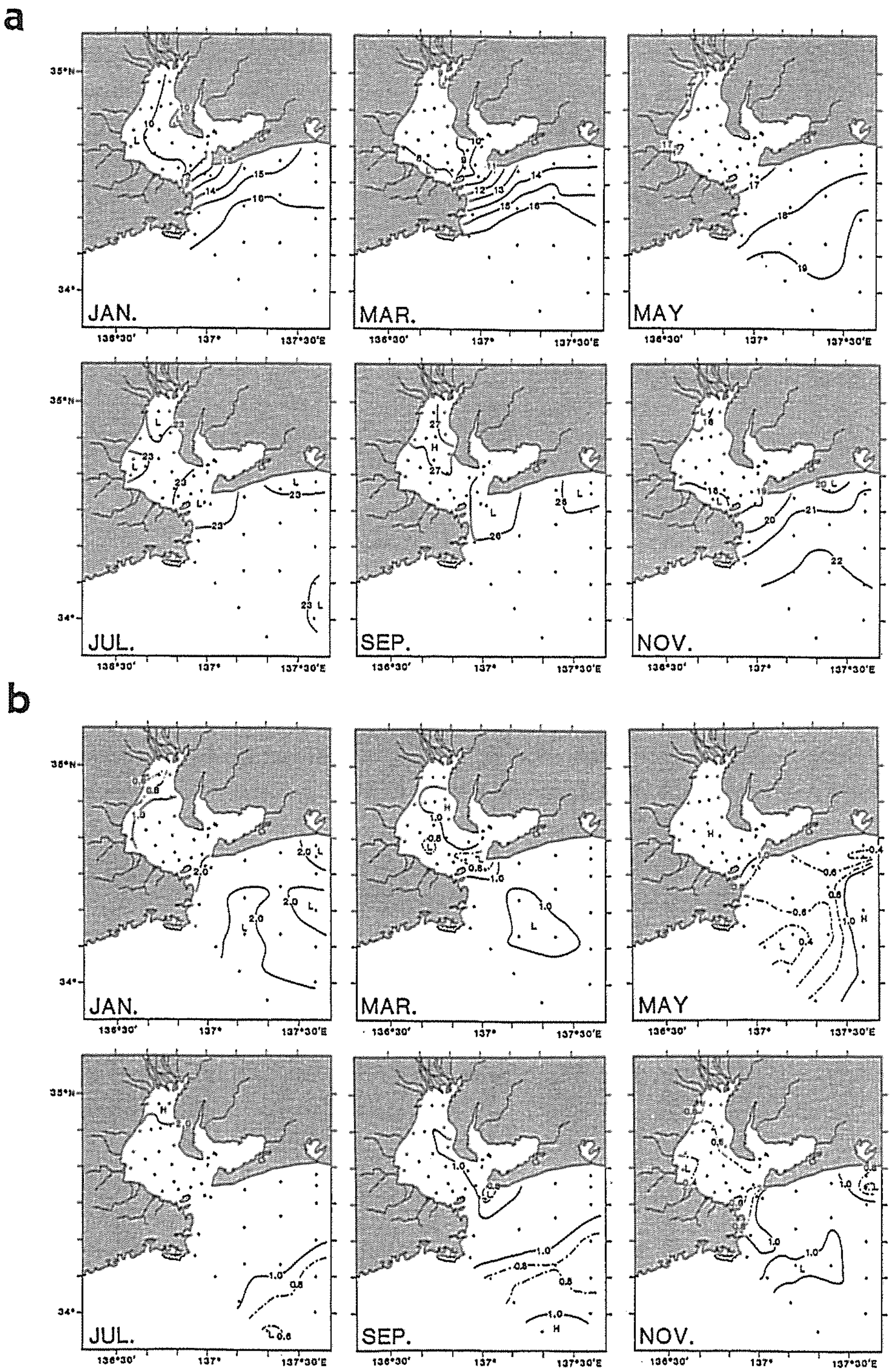

Fig. 2. (a) Monthly mean temperature distributions at a depth of 0 m and (b) their standard deviation. Major (minor) isolines are shown by solid (dot) lines.

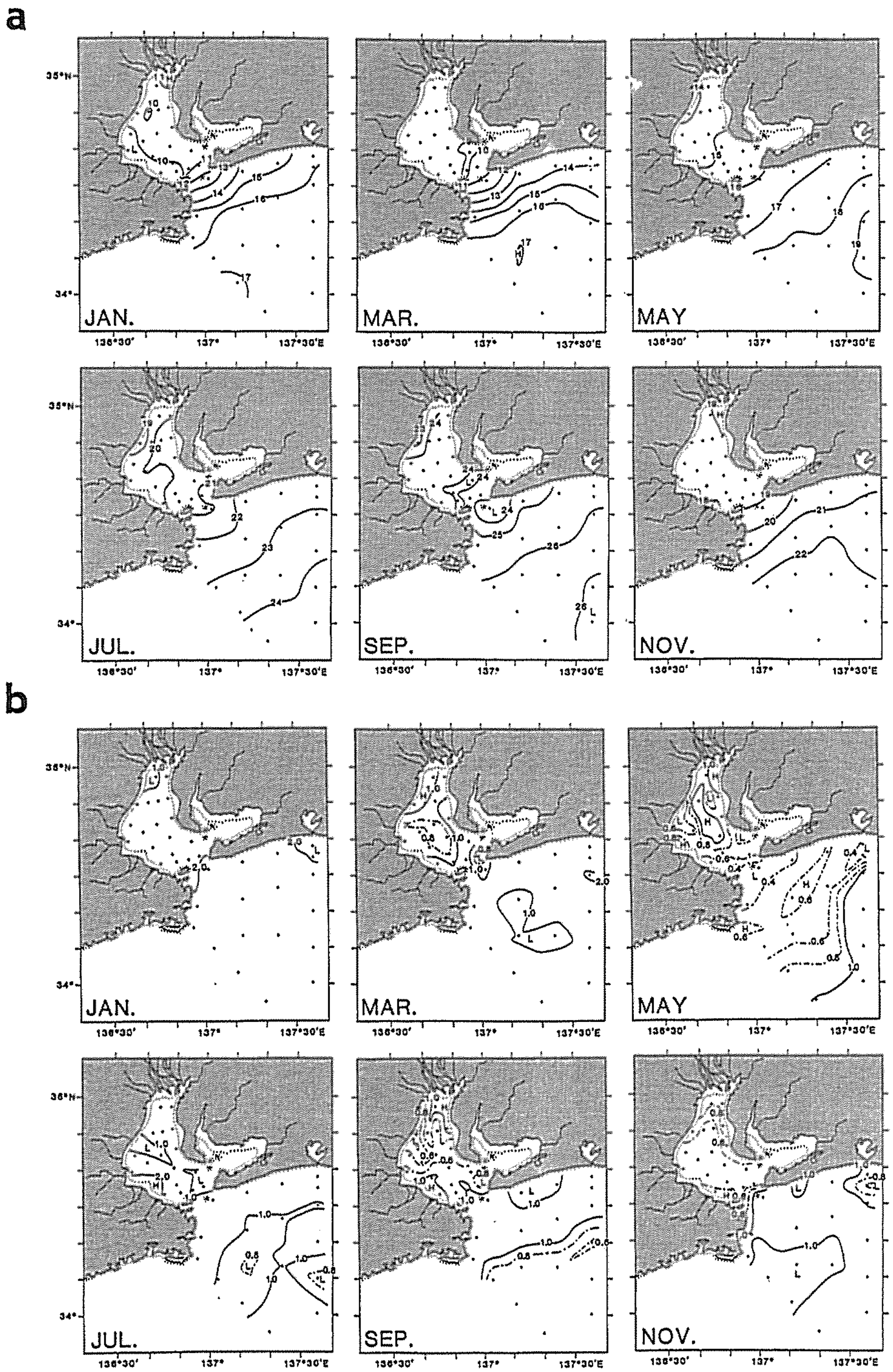

Fig. 3. Same as in Fig. 2 but for a depth of 10 m. The isopleth of the depth of 10 m is shown by small dot line.

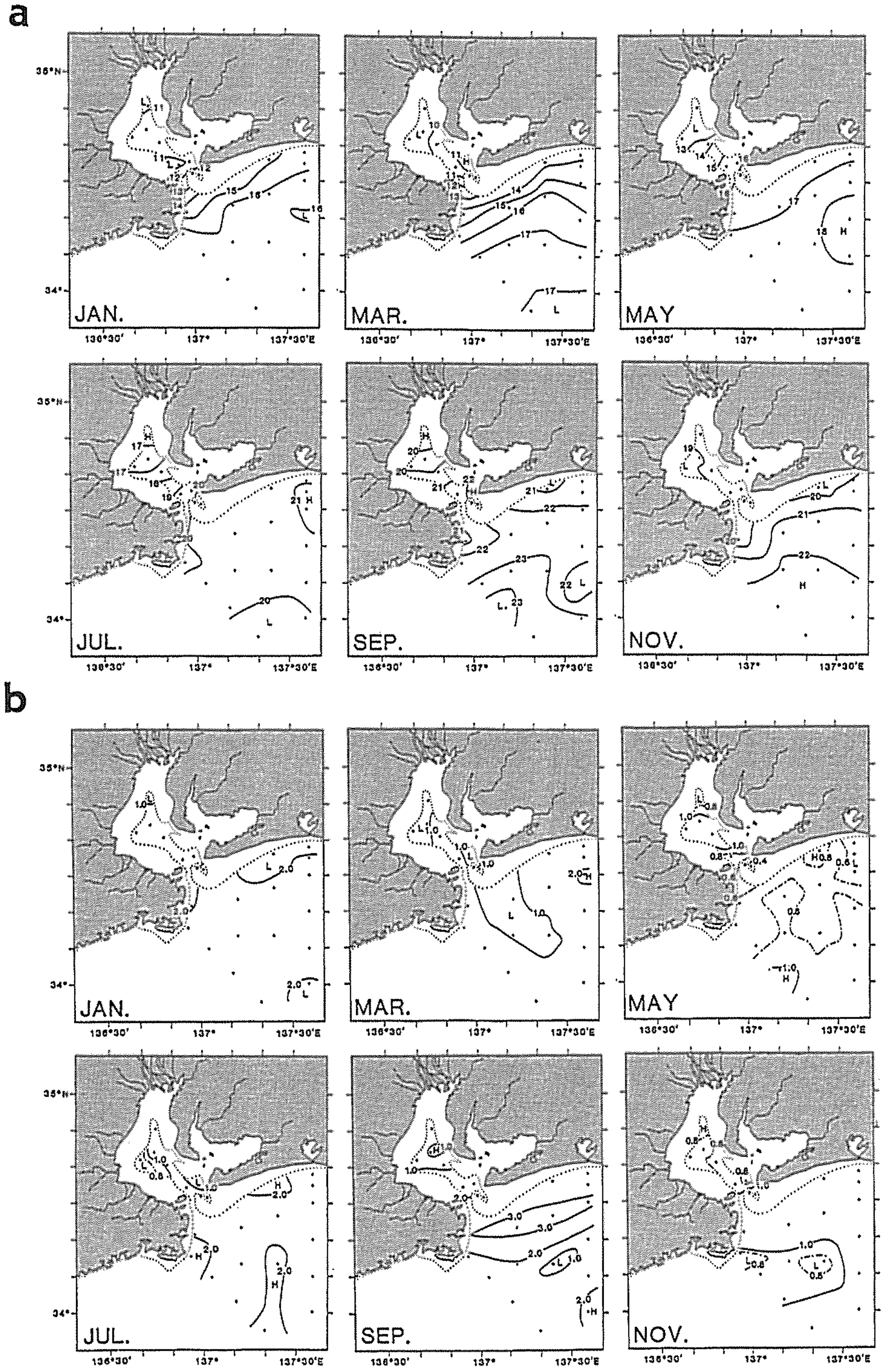

Fig. 4. Same as in Fig. 3 but for a depth of 30 m.

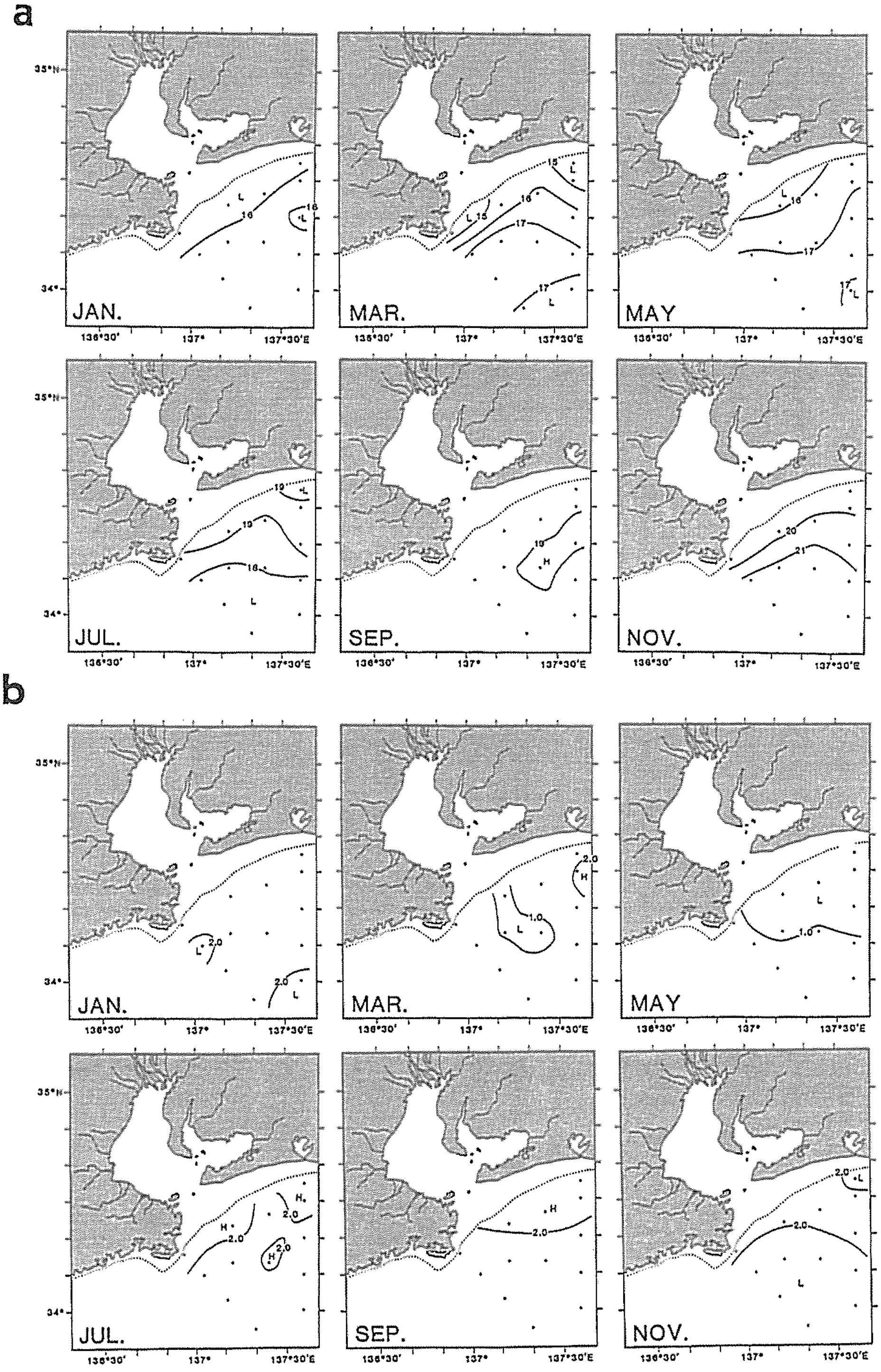

Fig. 5. Same as in Fig. 3 but for a depth of 50 m.

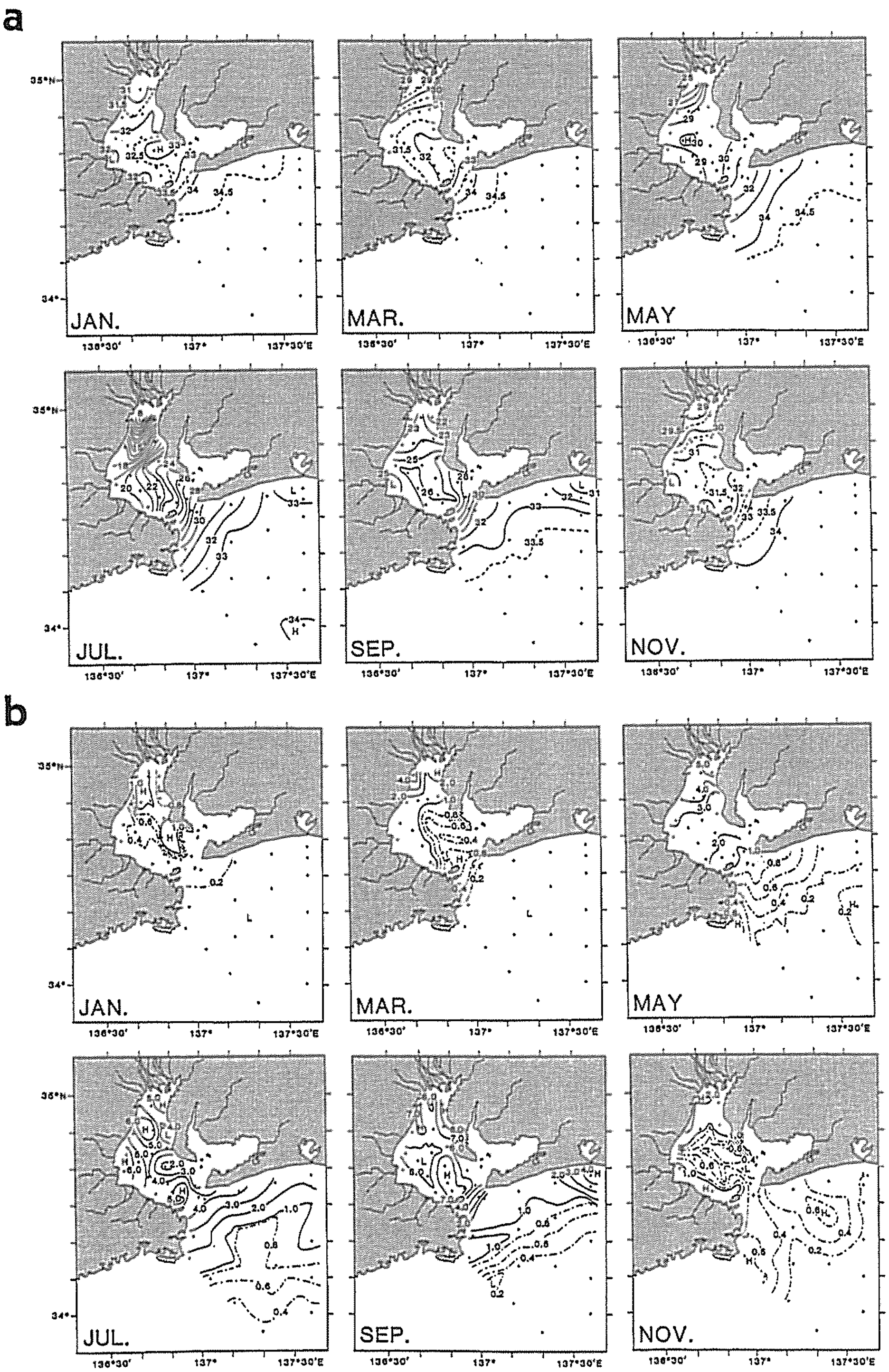

Fig. 6. (a) Monthly mean salinity distributions at a depth of 0 m and (b) their standard deviation.

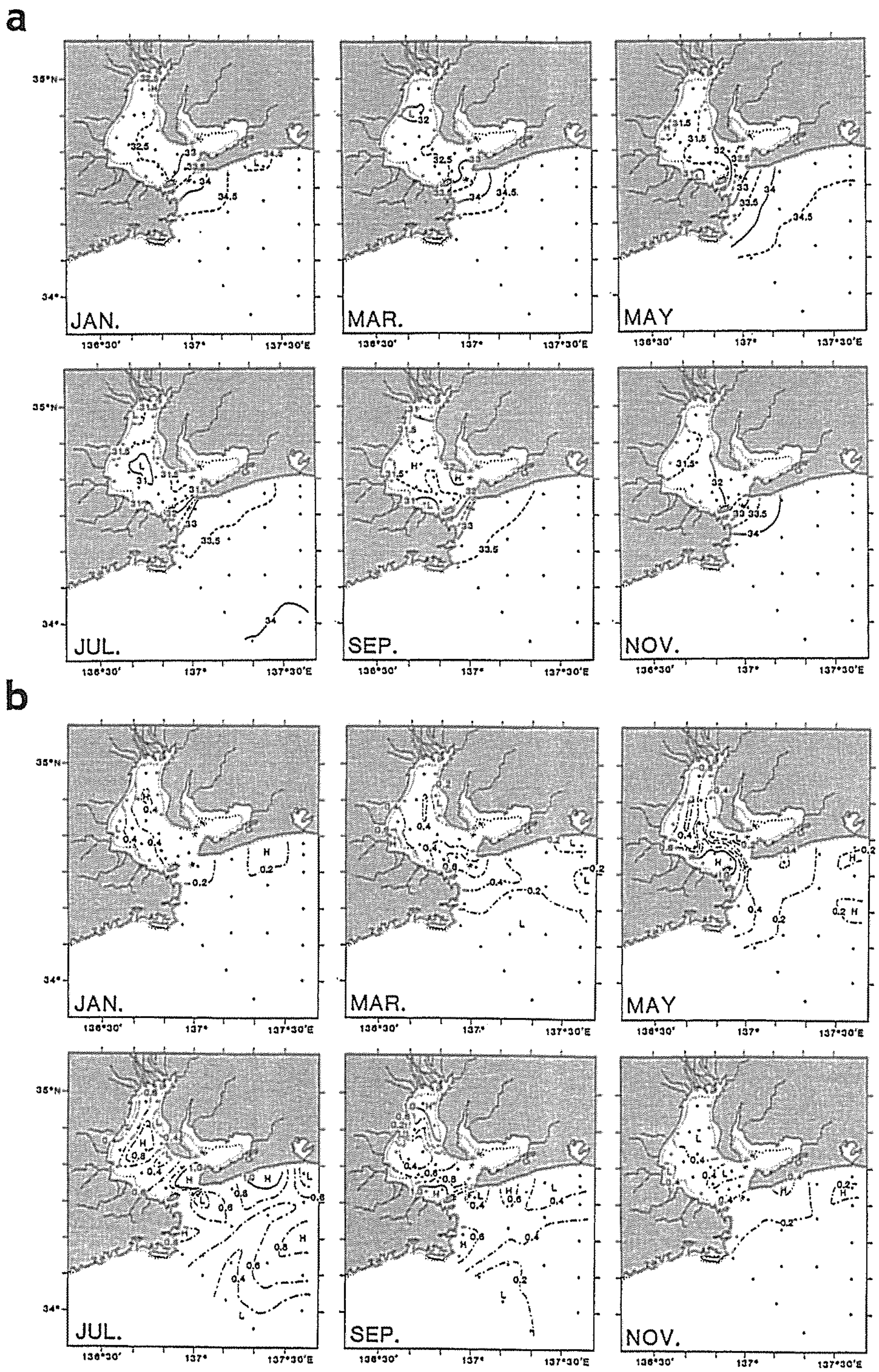

Fig. 7. Same as in Fig. 6 but for a depth of 10 m. The isopleth of the depth of 10 m is shown by small dot line.

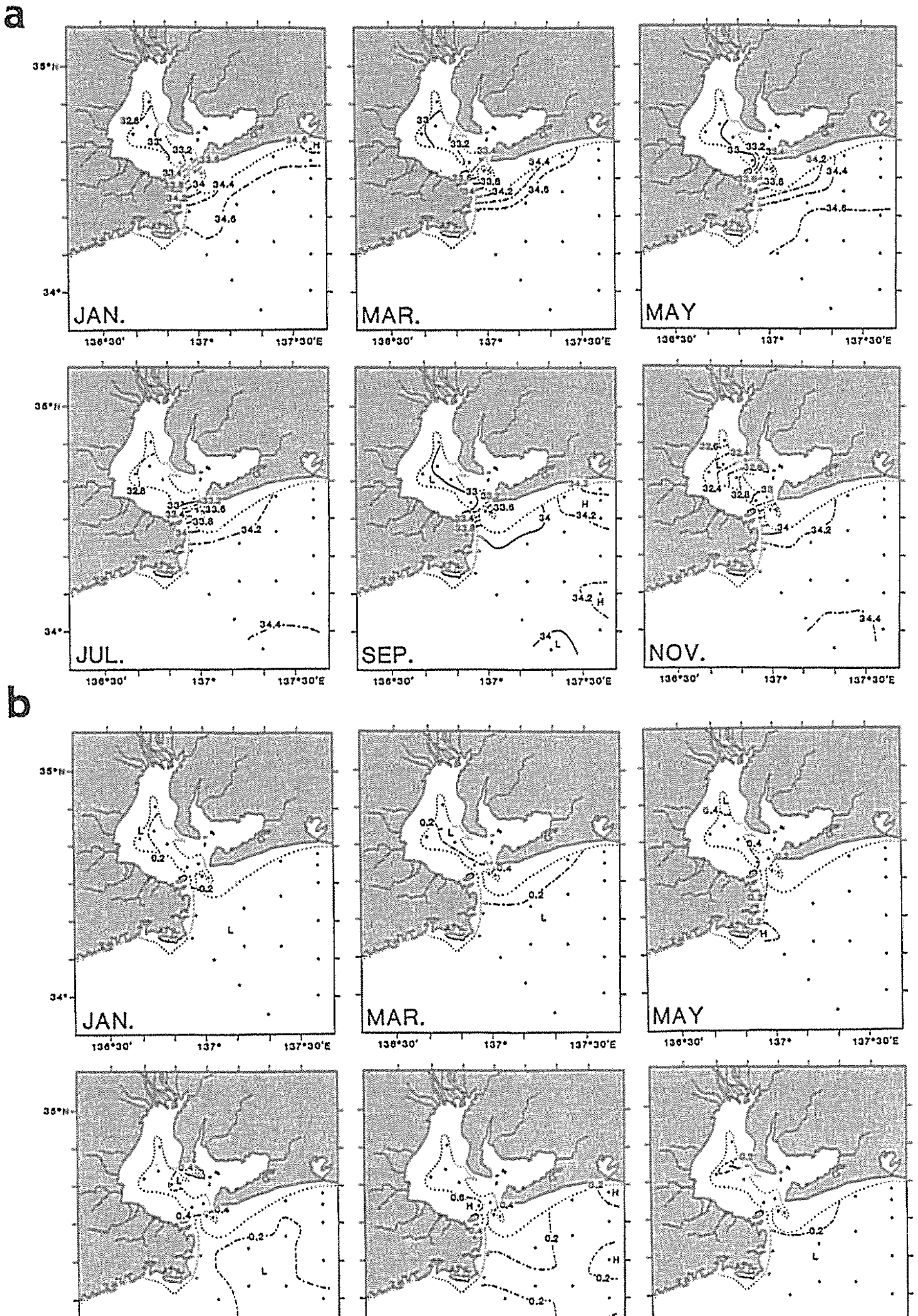

Fig. 8. Same as in Fig. 7 but for a depth of 30 m.

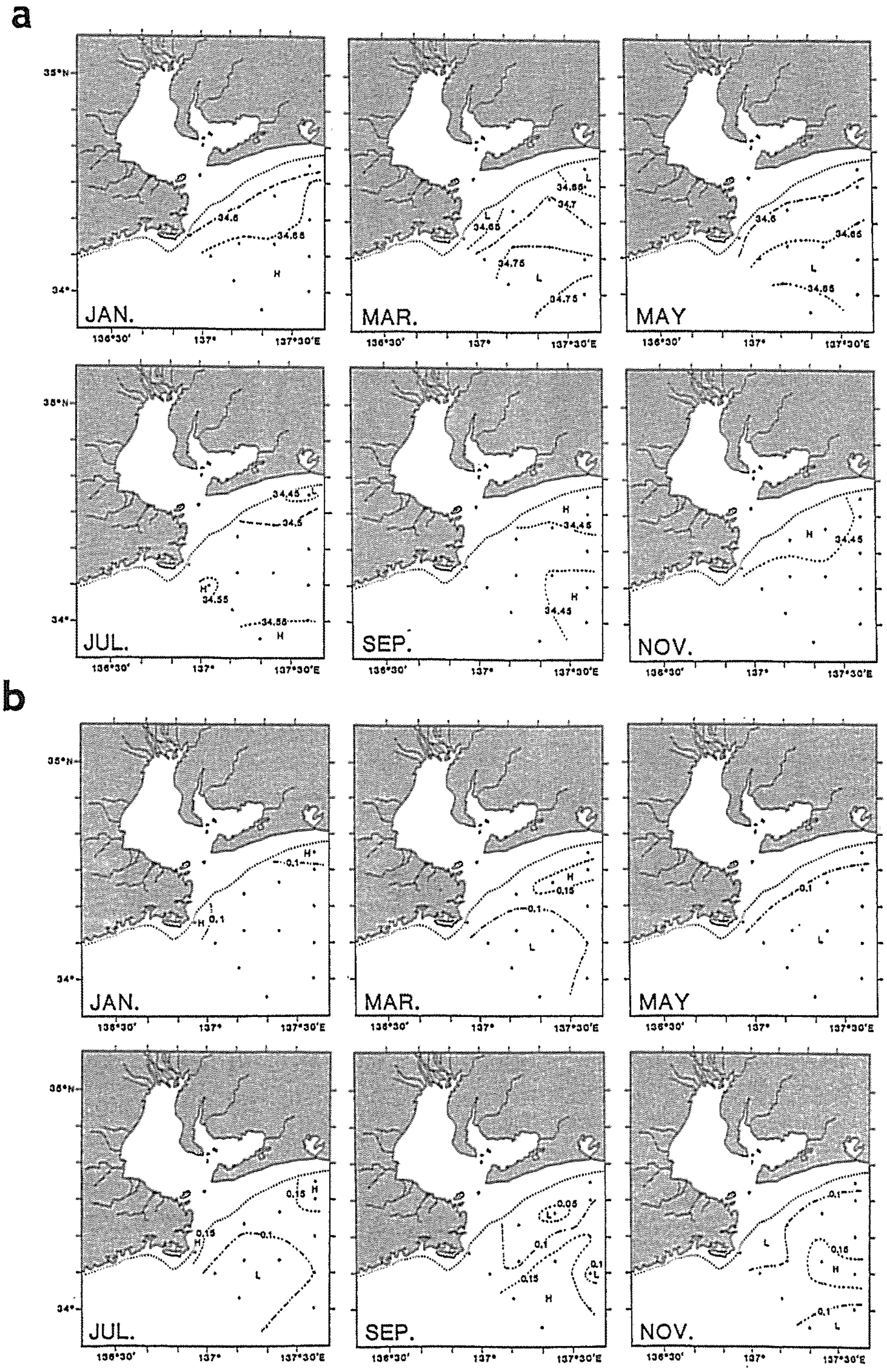

Fig. 9. Same as in Fig. 7 but for a depth of 50 m.

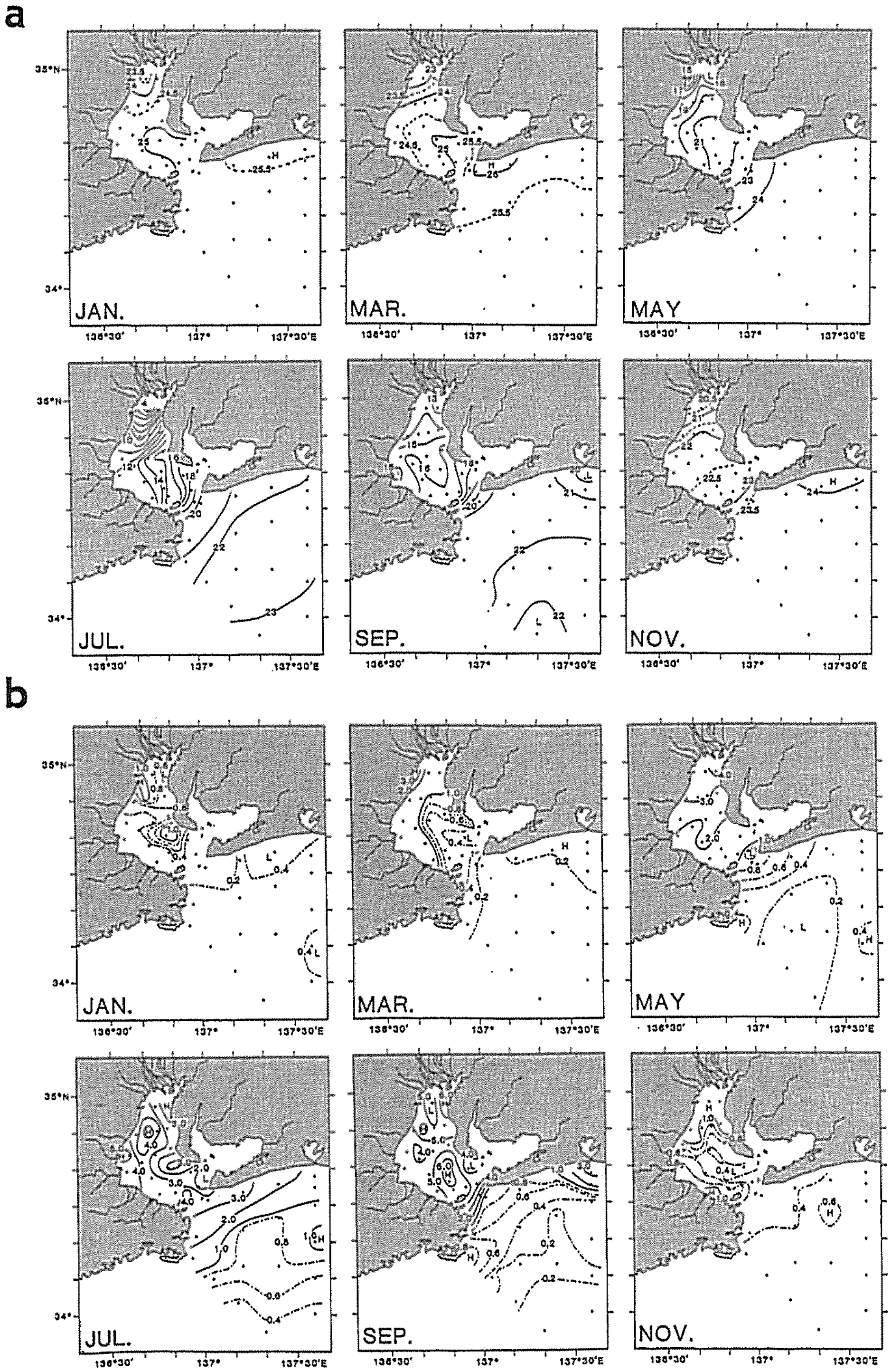

Fig. 10. (a) Monthly mean density (σt) distributions at a depth of 0 m and (b) their standard deviation.

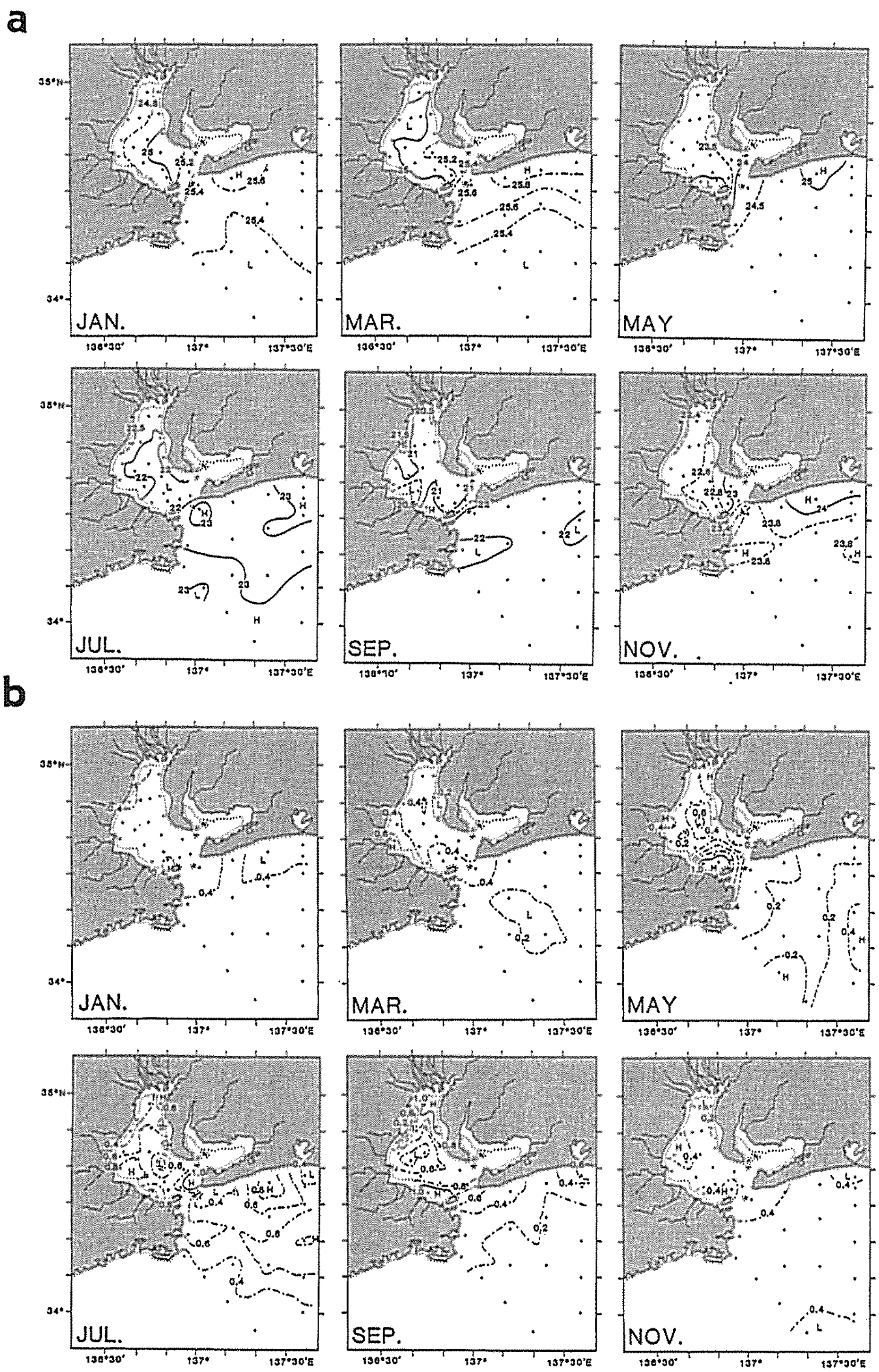

Fig. 11. Same as in Fig. 10 but for a depth of 10 m. The isopleth of the depth of 10 m is shown by small dot line.

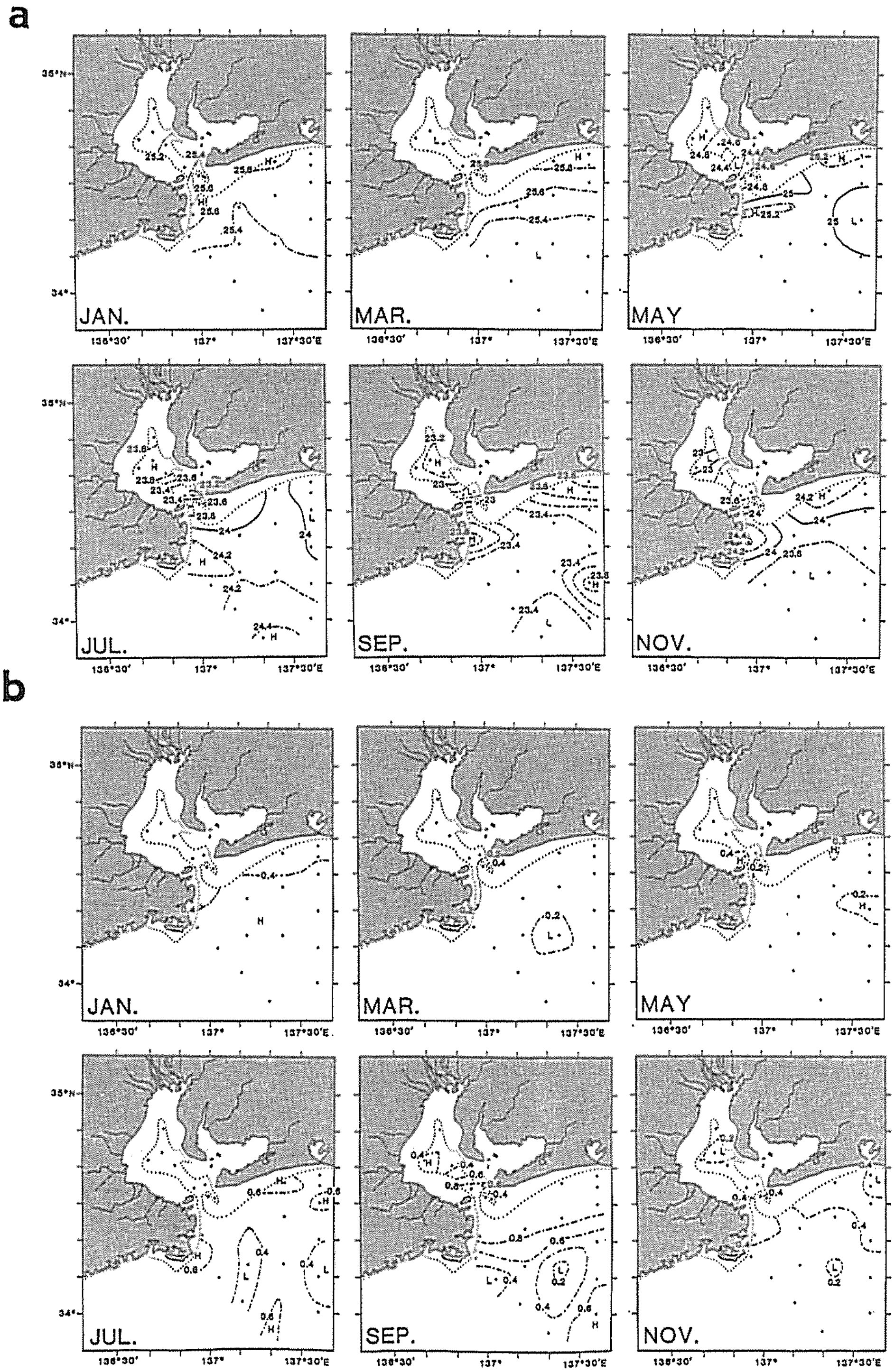

Fig. 12. Same as in Fig. 11 but for a depth of 30 m.

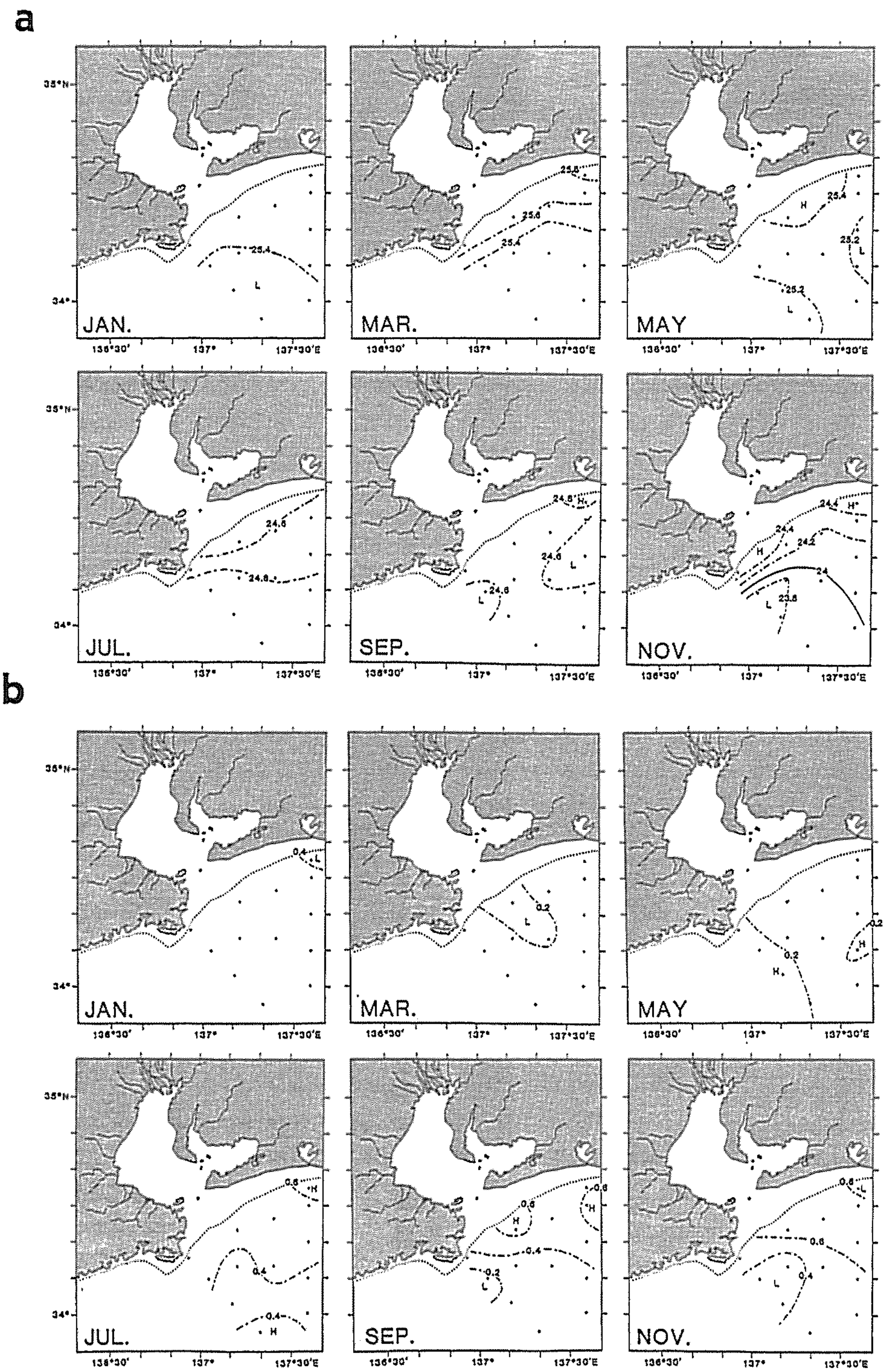

Fig. 13. Same as in Fig. 11 but for a depth of 50 m.

winter (about 3‰).

As the less saline water is confined to a shallower layer less than 10 m, the seasonal change in salinity is relatively small in Ise Bay (Figs. 7, 8 and 9). Therefore, the water less than 30‰ is not observed even in summer. It should be also noticed that the horizontal salinity difference at depths more than 10 m is very small in all seasons: the maximum (minimum) annual horizontal salinity difference in summer (winter) is 3.5‰ (2‰) at a depth of 10 m and 1.5‰ (1.5‰) at a depth of 30 m. At a depth of 50 m (Fig. 9), saline water more than 34.6‰ is observed in winter to early spring. Because the Kuroshio water is characterized by the salinity more than 34.5‰ and the STD is relatively small to be less than 0.15‰, the high salinity water in Fig. 9 suggests that the Kuroshio water oppupies deeper layer of the outer area of Ise Bay.

Density

The horizontal density (σt) distribution at depths of 0 m, 10 m, 30 m and 50 m are displayed in Figs. 10, 11, 12 and 13, respectively. At a surface in Ise Bay, the density depends on salinity, which is most prominent in summer due to larger river discharges. Although the horizontal temperature difference in the Irago Passage in winter to spring is formed (Fig. 2), the horizontal density difference is unclear. This is caused by the density compensation between the less saline cold water in the bay and saline warm water originated from the Kuroshio water. Nevertheless, in summer, the large horizontal density difference with a large STD, which is common to SSS, are formed by the large river discharge. Because the horizontal temperature difference is rather small in summer, the density compensation would be difficult in summer, which yields larger horizontal density difference. In an outer areas of Ise Bay, relatively low density water less than 22 (in σt unit) is observed in summer, while the high density water is observed in winter. The low density water in summer is formed by outflow of inner bay water diluted by river discharged water. Together with the distribution of the low SSS less than 34‰ shown in Fig. 6, the inner bay water flows out and occupies a wide area off Ise Bay.

At a depth of 10 m (Fig. 11), the horizontal density difference is small in winter. Since the influence of the river discharged water is confined to a shallower layer less than 10 m (Figs. 6 and 7), the horizontal density difference at a depth of 10 m is small in summer.

At a depth of 30 m, the seasonal change in density is almost common to that of the 10 m depth with a further weakening of horizontal difference. The weakening is mainly due to the smaller influence of the river discharged water that is most prominent at a surface. One of the characteristic features at a depth of 30 m is a formation of the density maximum area along the Irago Passage in spring. Because of mixing of the less saline cold water in the bay and saline warm water off the bay, formation of the cabbeling is suggested. At a depth of 50 m (Fig. 13), almost STD of σt are relatively larger than spatial change in σt. However, amplitude of the seasonal change in σt is about 1.5 in σt unit is larger than that of STD, in which maximal and minimal σt are found in early spring (25.5) and in late autumn (24.0).

Discussion

Seasonal variations in the hydrographic conditions in- and off Ise Bay were examined by use of the historical data during the period from 1985 to 1989 observed by Aichi Fisheries Research Institute and by Fisheries Research Institute of Mie. The montly mean horizontal maps of temperature, salinity and density and those of their STD were presented. The main results are summarized as follows.

(1) The horizontal difference in SST in and out of Ise bay is largest in spring and smallest in summer to autumn. Although no prominent spatial change in SST is detected in summer, a horizontal temperature difference more than 3°C is formed at depths from 10 m to 30 m.

(2) The salinity fields are strongly influenced by the river discharge in summer. The horizontal difference in SSS is very large (more than 12‰) in summer, but it is very small in winter (about 3‰). As the less saline water is confined to a shallower layer less than 10 m, horizontal salinity difference at depths deeper than 10 m is very small in all seasons.

(3) Becuase density depends on salinity in Ise Bay, density distribution is similar to salinity distributions in all seasons. In particular, low density water diluted by river discharged water is found in out of Ise Bay, which suggests that the coastal water diffuses in wider area off Ise Bay. The density maximum is found at the Irago Passage in spring and the occurrence of the cabbeling is suggested.

Many problems are left out. The details of STD caused by interannual variations should be examined by the comparison of each month data. As the horizontal distributions have been clarified by this study, the vertical change in the three values will be presented in a succeeding paper. Furthermore, more detailed analyses and quantitative discussions are needed for dynamics of the seasonal variation of Ise Bay. These examinations will be also carried out in near future.

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伊勢湾内外の水温塩分密度の季節変化

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伊勢湾内外の水温，塩分，密度の季節変化を統計的に調べた。愛知県水産試験場と三重県水産技術センターによる1985年から1989年の海洋観測結果を用いて水温，塩分，密度の月別平均水平分布およびその標準偏差分布の図を提出した。海面水温の水平方向の差異は春に最大で，夏から冬に最小となる。夏に海面水温は一様となるが，30 m 深では 3°C 以上の水平方向の差異を生じる。塩分分布は特に夏に河川水の影響を強く受ける。海面塩分の水平方向の差異は夏に非常に大きく12‰を越えるが，冬には小さく 3 ‰程度である。低塩分水の分布は 10 m 以浅に限られるため，10 m 以深の塩分の水平方向の差異は一年中小さい。全体として，顕著な伊勢湾の海況の季節変化が月別平均図から明らかになった。