DIURNAL VARIATIONS IN BIOLOGICAL CHARACTERISTICS OF KRILL, *EUPHAUSIA SUPERBA* DANA, TO THE WEST OF THE SOUTH ORKNEY ISLANDS, 24 MARCH TO 18 JUNE 1990 - BASED ON DATA REPORTED BY A BIOLOGIST-OBSERVER

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Abstract

Investigations of diurnal variations in the size composition of *Euphausia superba* were carried out on the commercial trawler *Grigory Kovtun* near the South Orkney Islands from March to June 1990. Observations at six daily stations were carried out in various locations inside the fishing area. Each station consisted of a series of catches made using a standard commercial trawl (9 to 12 tows per station, over one day). An increase in the total average size of animals caught in periods of light or darkness was noted at several stations. Increases in the proportion of males in the catch, as well as an increased difference between average length of males and females in the layer fished were indicative of these variations. Diurnal variations of females size composition were usually less evident. These changes were related to diurnal vertical migrations of krill which were noted on echosounder recordings. Trawling depths usually corresponded to the depth of the largest concentration of krill. Within swarms males initiate diurnal vertical migrations. In the absence of diurnal migrations (particularly late in the season), diurnal variations in size composition of krill catches were less evident or non existent. The significance of these observations in relation to krill size composition data obtained from standard surveys (only one sample of krill per station) is discussed. A gradual decrease in the average size of krill from the end of March to June was observed in the fishing area. The following three causes of the observed variations in krill composition are considered: (i) post-spawning mortality of large specimens; (ii) body shrinkage of krill due to a decrease in food availability; and (iii) size selectivity of krill by commercial fisheries.

Résumé

Des études des variations diurnes de la composition en tailles de *Euphausia superba* ont été menées à proximité des îles Orcades du Sud de mars à juin 1990 à bord du chalutier industriel le *Grigory Kovtun*. Des observations ont été effectuées à six stations quotidiennes en divers emplacements dans la zone de pêche. A chaque station, une série de captures a été réalisée au moyen d'un chalut industriel standard (de 9 à 12 traits par station, sur une journée). A plusieurs stations on a observé une augmentation de la taille moyenne totale des animaux capturés en des périodes de jour ou de nuit. On a constaté que ces changements étaient dûs d'une part à une augmentation de la proportion de mâles dans la capture et d'autre part à une différence croissante de longueur moyenne entre les mâles et les femelles dans la couche de pêche. Les variations diurnes de la composition en tailles des femelles

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n'étaient pas aussi évidentes. Ces changements dépendaient des migrations verticales diurnes du krill, qui apparaissaient sur les enregistrements par échosondeur. La profondeur de chalutage correspondait en général à celle de la plus grande concentration de krill. Les mâles dans les essaims sont à l'origine des migrations diurnes verticales. En l'absence de migration diurne (notamment tard dans la saison), les variations diurnes de la composition en tailles des captures de krill étaient moins évidentes où même inexistantes. Les auteurs examinent l'importance de ces observations par rapport aux données sur la composition en tailles du krill provenant de campagnes d'évaluation standard (seul un échantillon de krill par station). De fin mars à juin on a observé une diminution progressive de la taille moyenne du krill dans la zone de pêche. On a examiné les trois causes suivantes des variations observées dans la composition du krill: i) mortalité de grands spécimens en période de post-ponte; ii) contraction du corps du krill causée par une diminution de la nourriture disponible; et iii) sélectivité de la taille du krill par les pêcheries commerciales.

Резюме

Исследования дневных изменений в размерном составе *Euphausia superba* проводились с марта по июнь 1990 г. на борту промыслового судна *Григорий Ковтун*, работавшего на промысловом участке около Южных Оркнейских о-вов. Наблюдения выполнялись на шести суточных траловых станциях в пределах промыслового участка. Каждая станция состояла из серии уловов, полученных стандартным коммерческим тралом (9-12 тралений за станцию, в течение суток). На нескольких станциях наблюдалось увеличение среднего размера особей, выловленных при дневном свете или в темноте. Было установлено, что эти изменения были связаны с возрастающей долей самцов, а также с разницей средней длины самцов и самок в облавливаемом слое. Дневные изменения в размерном составе самок обычно были менее очевидными. Эти изменения были связаны с дневными вертикальными миграциями криля, которые регистрировались эхолотом. Глубины траления обычно совпадали с глубиной наибольшей концентрации криля. Во время дневных вертикальных миграций самцы первыми начали миграцию передвигаясь внутри скоплений. Когда суточная миграция не наблюдалась (в частности в конце сезона) дневные изменения в размерном составе в уловах криля были менее явны или вообще не обнаруживались. В настоящей работе рассматривается значение этих наблюдений в отношении данных по размерному составу криля, полученных в результате стандартных съемок (только одна выборка за станцию). С конца марта по июнь на промысловом участке наблюдалось постепенное снижение среднего размера криля. Рассматриваются следующие причины отмеченных изменений в составе криля: (i) посленерестовая смертность крупных особей; (ii) сужение криля в результате уменьшения кормовой базы; и (iii) промысловая селективность криля.

Resumen

Desde marzo a junio de 1990, se llevó a cabo un estudio de las variaciones diurnas en la composición por talla de *Euphausia superba* a bordo del arrastrero comercial *Grigory Kovtun*, cerca de las islas Orcadas del Sur. Estas observaciones se realizaron en seis estaciones diarias ubicadas dentro de la zona de pesca, y consistieron de una serie de capturas realizadas mediante un arrastre comercial estándar (de nueve a 12 arrastres por estación en un día). En varias de estas estaciones se constató un aumento en la talla promedio de los animales capturados durante el día o en períodos de oscuridad. Se obtuvo una indicación de estas variaciones por el aumento en la proporción de machos en las capturas, así como por la gran diferencia entre la talla promedio de los machos y hembras del estrato de pesca. Generalmente las variaciones diurnas en la composición por talla de las hembras fueron menos evidentes. Estos cambios están relacionados con las migraciones verticales diurnas del kril, que fueron registradas mediante una ecosonda. Normalmente las profundidades de arrastre correspondieron a la profundidad de la mayor concentración de kril. Dentro de las concentraciones, los machos son los que comienzan la migración vertical diurna. A falta de las migraciones diurnas (especialmente hacia el final de la temporada), las variaciones diurnas en la composición por talla de las capturas de kril fueron menos evidentes, o no existentes. Este documento estudia la importancia de estas observaciones en relación a la composición por talla del kril obtenida de prospecciones estándar (solo una muestra de kril por estación). Desde el final de marzo hasta junio, se observó una disminución gradual de la talla promedio del kril en la zona de pesca. Se consideran los tres factores siguientes como causales de la variación observada en la composición del kril: (i) mortalidad de los ejemplares grandes después de la puesta; (ii) reducción de la talla del kril debido a la disminución de alimento; y (iii) selectividad del tamaño del kril por las pesquerías comerciales.

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1. INTRODUCTION

Routine investigations of the state of the *Euphausia superba* population which are carried out during standard surveys, consist of only one sample per station. These samples are collected on different days and at different times of the day. Therefore, during size-composition comparisons doubts remain as to whether krill specimens belong to a single or several statistical sub-populations. This problem is especially so for different areas of various frontal zones. Until now the only way to resolve these doubts has been by size composition analysis. Moreover, euphausiids captured in the same place but at different times of the day can show notable size differences. Diurnal variations of this type are well known. Diurnal variations in *E. superba* swarm density have been determined from hydroacoustic studies (Hampton, 1985; Miller and Hampton, 1989), and net sampling data (Nast, 1982). The situation in respect of diurnal variations in *E. superba* size composition is not clear. This information is not normally obtained from standard surveys.

Diurnal variations in the size composition of krill catches were studied by a biologist-observer in March to June 1990 on board the Russian trawler *Grigory Kovtun* near the South Orkney Islands. Results of his observations are discussed below.

2. MATERIALS

Six 24 hour stations were carried out by the fishing vessel *Grigory Kovtun* in the fishing area near the South Orkney Islands from the end of March to the middle of June, 1990 (Table 1). At each station a series of catches was made using a standard commercial trawl. From every catch one hundred specimens of *E. superba* were examined and subjected to biological analysis. Field observations were carried out by the biologist-observer, Dr A.V. Vagin.

The location of each station is shown in Figure 1. The starting and finishing points of every haul were recorded. The stations covered quite a large area and extended from northwest to southeast. Stations I, IV and V overlapped, as did Stations III and VI. Station II was located further south.

3. RESULTS

3.1 Diurnal Variations in the Composition of *E. superba*

Data on average body size of *E. superba* per haul (for all stations) are given in Figure 2. These data show different average sizes of *E. superba* obtained for each station. Measurements for Stations I to VI were: 45.8 - 44.4 - 43.5 - 41.9 - 41.1 - 43.1 mm. Despite the complexity of the curves this pattern can be also seen in Figure 2 which compares the size curves relative to the ordinate on each graph. It is also clearly visible, that the average body size of animals changes during the day. Size differences for Stations I to VI were: I - 2.3, II - 6.5, III - 2.4, IV - 2.7, V - 4.7, VI - 4.00 mm. These differences were estimated using a chi-square criterion at a confidence level of 0.9.

Differences in total average size of *E. superba* among stations is also related to the geographical position of the stations (see Figure 1). For example, Stations II, III and VI characterised by the intermediate average body size of krill, were positioned along the southern and western periphery of the regions, whereas Stations IV and V with the smallest specimens were located inshore. However, areas of the last two stations coincided with the area of Station I (which contained the largest specimens).

Comparison of length curves for each stations shows, that the average size of animals is most variable during the light period of a day (Figure 2). All stations may be subdivided into two groups. Stations I, II, IV and VI tended towards an increase in krill average size. Stations III and VI did not demonstrate such a tendency or it was not clearly evident (Station VI).

Comparison shows that the similarity of the length curves for Stations III and VI may not be coincidental, because these stations are located close to each other. In the eastern area, where all other stations were carried out, diurnal variations in the average size of *E. superba* were predominant. Data from Stations I, IV and V are particularly similar. These stations were carried out practically in the same area (Figure 1).

3.2 Consideration of the Possible Causes of Diurnal Variations in the Size Composition of *E. superba* Catches

Variations in the size composition of *E. superba*, described above, are not straightforward. In the case of random distribution of krill swarms the length curves should be irregular and dissimilar. The very regularity and similarity of the curves from most stations prove the regularity of trends and related processes in the *E. superba* population.

Analysis shows that the sex ratio and the average size of males change invariably in the samples (Figure 2). Several examples of this trend may be seen in Figures 3a, b and c. At Station I variations in the size composition of males were much stronger than for females over periods from 0 to 2, 2 to 4 and 6 to 8 hrs (the proportion of males was 27.0, 49.5 and 31.5% respectively). The same is typical for Station II over periods from 8 to 10, 12 to 14 and 22 to 24 hrs (the proportion of males was 29.8, 41.2 and 33.3% respectively), however more obvious variations in the size composition of females were also observed. At Station IV variations in total size composition of *E. superba* were mainly connected with variations in size composition of males (proportion of males was 32.0, 38.3 and 33.3% respectively) over periods from 6 to 8, 12 to 14 and 18 to 20 hrs. Some changes were also observed in females, but they were less evident than at Station II.

Similar trends were observed in data from other stations. As a rule, variations in size composition of males and females took place non-synchronously - but changes were clearly evident, whereas variations in size composition of females were less obvious.

During late autumn/winter the average size of males was consistently larger than that of females (Makarov, 1991). It should be stressed that 50% level of sex ratio of *E. superba* for all samples from every station corresponded with particular size intervals: 47 to 48 mm for Station I, 43 to 44 or 45 to 46 mm for Station VII (see Figure 4) and so on.

Variations in the average size of *E. superba* in trawls catches was found to be unrelated to changes in rate and difference in size composition between males and females. Graphs for all size stations and for all hauls further demonstrate these trends. These graphs (Figure 5) show the relationship between total average size of animals for each catch (sample), size difference between males and females and proportions of males (% males). Some sets of data were scaled in order to assist their comparison (see explanation in Figure 5).

Correlation between the total average sizes and the proportion of males is clearly visible for Stations I and II and more or less clear correlation can be seen on the graphs for Stations III and V. Correlation is rather weak for Stations IV and VI. Correlation between the total average sizes and variation in size values between males and females is evident from the data for Stations I and V, and partially for Station II, however there is no such correlation at the other stations.

Changes in the proportion of males usually corresponds to variations in average size of *E. superba.*

The most complex situation was observed at Stations III, IV and VI. For most of the day all three curves on each graph showed poor correlation. Analysis showed that during the first part of the day (Station III), and during the second part of the day (Station VI) the curve of total average size was influenced by variations in the average size of females (see Figure 6). The last curve corresponds to the curve of total average size.

Disagreement between curves for the second part of the day at Station III may be explained by opposing trends of size variation between males and females on the one hand and the proportion of males on the other.

A very different pattern emerged at Station IV. Agreement between curves occurred in the middle of the day. As may be seen in Figure 5, curves for most stations increased their complexity towards the end and at the beginning of the day. This irregularity is possibly typical at Station IV during the larger part of the day.

One may conclude that the main factor determining variations in total average size of *E. superba* in the study area over a one day period is a change in the ratio of males, because in most cases both of these parameters show synchronous variations.

Variations in the average size of males also determine the total average size of all krill.

The third factor, namely variations in the average size of females, is only sometimes a significant factor.

In the course of analysis it is necessary to keep in mind trawling depth. As a rule, trawling depth corresponds to the layer of maximum aggregation density of *E. superba.*

Data on this subject are given in Figure 7. Curves of depth changes are shown and are compared with total average size and the proportion of males.

Three trawling regimes were employed:

(i) surface towing during the night and under surface towing during the day (Stations II, IV and V);

(ii) surface towing during the day and under surface towing during the night (Station III); and

(iii) towing in a more or less constant layer throughout a 24 hour period (Stations I and VI).

At Station I hauls were conducted near the surface, while at Station VI hauls were made in a deeper layer. This difference reflects the seasonal migration of *E. superba* to the deeper layers (see Table 1 for the timing of stations). According to the hydroacoustic data krill (at Stations II, IV and V) tended to occupy surface layers at night, but during the day krill moved downwards (100 to 200 m depth was the upper boundary of swarms). At Station III diurnal migrations of swarms showed the opposite pattern.

The combination of diurnal variations in total average size of *E. superba* and variations in trawling depth does not show complete correlation, which indicates that both parameters are comparatively independent (Stations II, IV and V). A direct relationship between these parameters was observed at Station I, however, the relationship was inverse. The average size of *E. superba* decreased as trawling depth increased and vice versa. The same is true for values of the percentage of males. At Station III some increases in trawling depth was accompanied by an increase in the total average size during the first light period of the day but the total average size remained unchanged in the middle of the night (in spite of a considerable increase in trawling depth). Finally, irregular variations in trawling depth around Station VI did not influence average size values for *E. superba.*

Larger animals first tended to form aggregations when swarms of *E. superba* moved into deeper water during the light part of the day at Stations II, IV and V. This segregation is weaker if swarms are distributed near the surface (Station I), although large specimens also tended to concentrate here. Diurnal variation in average size were not observed when migration of *E. superba* showed the opposite pattern (e.g., at Station III). In the case of non-migrating krill which occupy deep layers, the segregation by size does not occur (Station VI).

It may be concluded that specimens of various size are distributed initially uniformly. In the case of migrating swarms larger specimens move up or smaller specimens move down more quickly (males at first) and larger krill aggregate first. At night they mix with smaller specimens, which tends to lower total average size of night catches.

Our task was not to compare our results with previously obtained information on this subject. Here we only refer to a study of Watkins *et al.*, (1986) who dealt with rather small krill. They reported diurnal variations in total average length of *E. superba*, i.e., an increase in this parameter during the night.

4. CONCLUSION

The above data on changes in various demographic parameters of *E. superba* swarms demonstrate a connection between these changes and diurnal vertical migrations of *E. superba*. Differences in average size can be as large as 6.5 mm during the day. This fact must be taken into account in the routine investigation of *E. superba*. Vertical migrations gradually end at the beginning of winter and krill form stable concentrations at a certain distance from the surface.

Observed diurnal variations in total average size of *E. superba* as well as changes in other demographic parameters, are quite interesting from a methodological point of view. They show, that this fact should keep in mind when comparing data on size composition of *E. superba* captured in different places. Oblique tows through a rather large water volume are recommended for reliable krill sampling. Single or serial horizontal towing inside a specific layer only would produce incomparable data (e.g., see data on swarms near Elephant Island (Watkins *et al.*, 1986)).

Diurnal differences in demographic parameters may be more noticeable in other seasons e.g., in summer, when *E. superba* spawns. Krill exhibit much more diverse physiological characteristics during this period.

Biological investigations carried out on commercial vessels would allow studies on some aspects of krill biology which cannot be studied during a standard survey. These investigations should also include collection of relevant information on the environment which is of real significance when explaining various biological features of *E. superba*.

Our data also showed that the average size of *E. superba* decreased during a two and a half month period in a comparatively small area (cf. data on Stations I, IV and V, whose positions overlap). There may be several causes of this decrease (see also Vagin, 1991 - Figure 2). It may be connected with post-spawning mortality of larger specimens. Moreover, this is possibly a season when body shrinkage of *E. superba* is taking place (Ikeda and Dixon, 1982) due to a decrease of food availability. Finally, the possibility of the selective capture of large specimens of *E. superba* as a result of commercial fishing activity should not be excluded. Such selectivity affects animals of intermediate size (Brinton and Antezana, 1984). This problem, however, is very complex.

These three explanations are not contradictory. However, if spatial differences in the size composition of *E. superba* inside the area being fished is taken into account, together with the possibility of swarm drifting with the current, one may conclude that there is a real possibility of drift influence (see also Brinton and Antezana, 1984). The time interval between Stations I and V is sufficient for such a passive movement of swarms to occur. *E. superba* size distribution is irregular and, moreover, in a region of dense swarms size distribution is highly variable (see also Watkins *et al.*, 1986). Therefore sampling at a limited number of stations cannot give a suitable answer as to the reasons for the gradual decrease of *E. superba* size over the whole study area.

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Table 1: Details of sampling stations (South Orkney Islands, 24 March to 16 June, 1990).

Station Number	Time	Number of Hauls (samples)
I	27 to 29 March	10
II	10 to 11 April	12
III	10 to 11 May	9
IV	26 May	12
V	9 to 10 June	11
VI	16 June	10

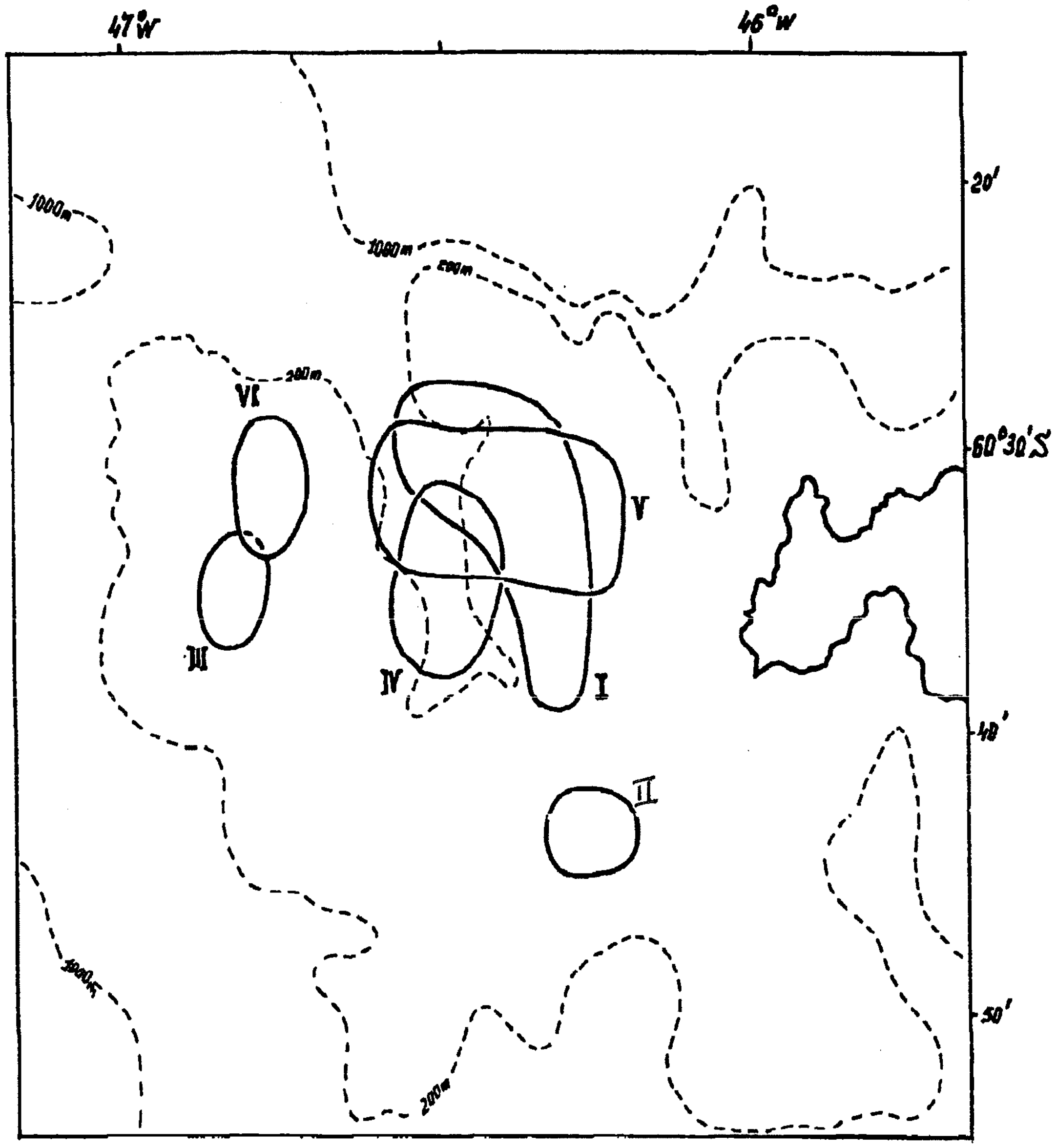


Figure 1: Location of sampling stations.

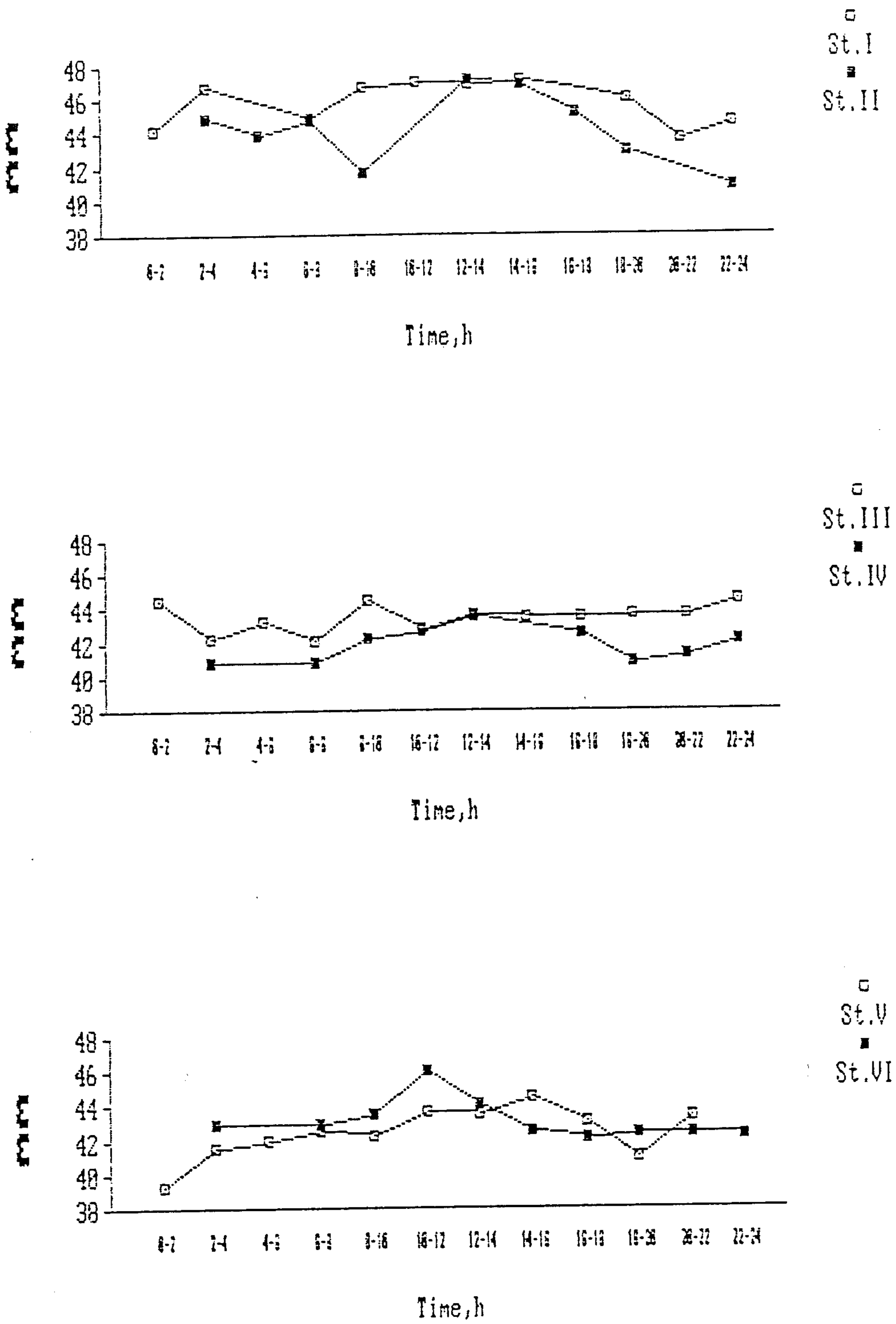


Figure 2: Average total length of *E. superba* at sampling stations.

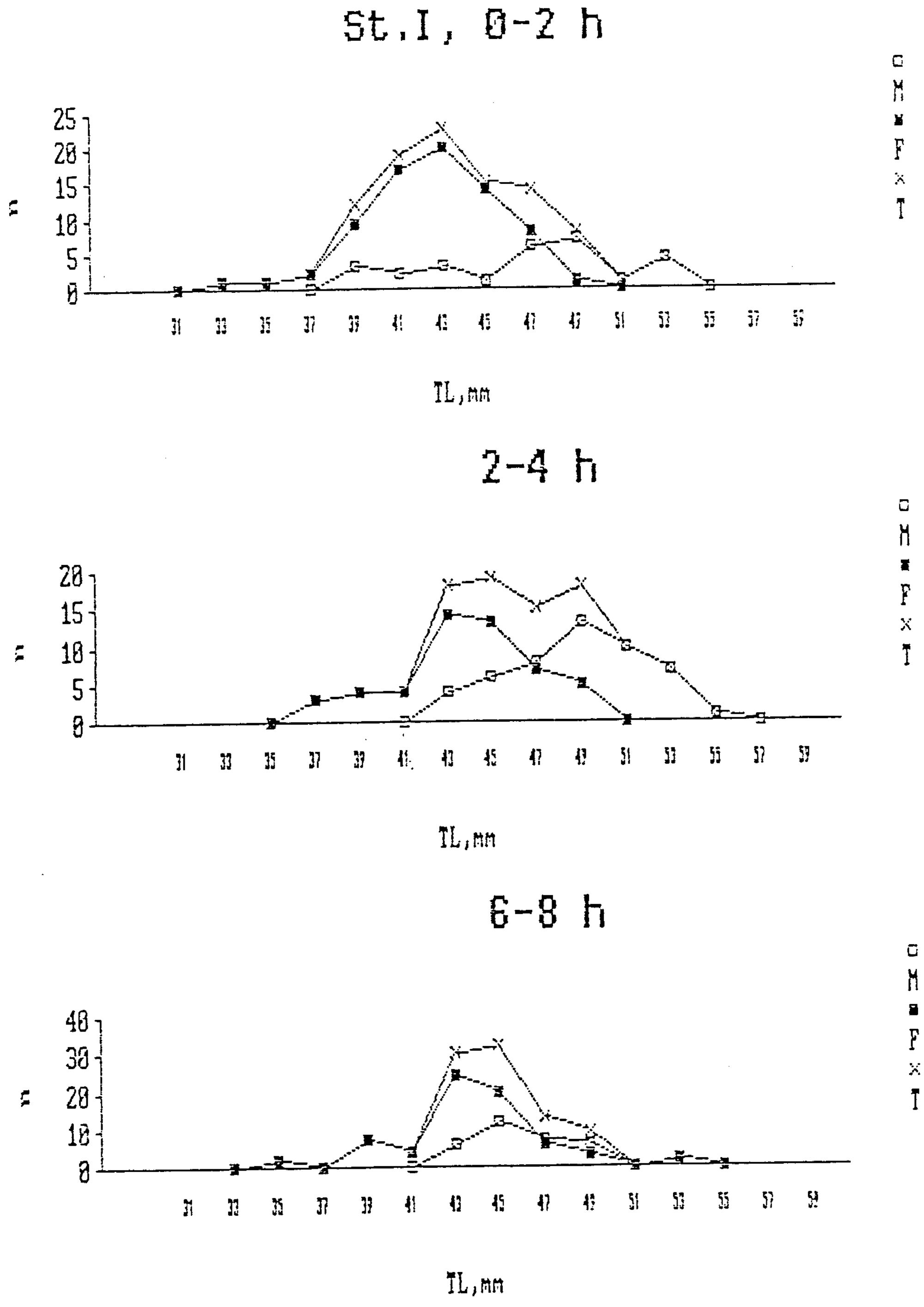


Figure 3a: Example of size composition of *E. superba*: T - total, M - males, F - females at selected points of Station I.

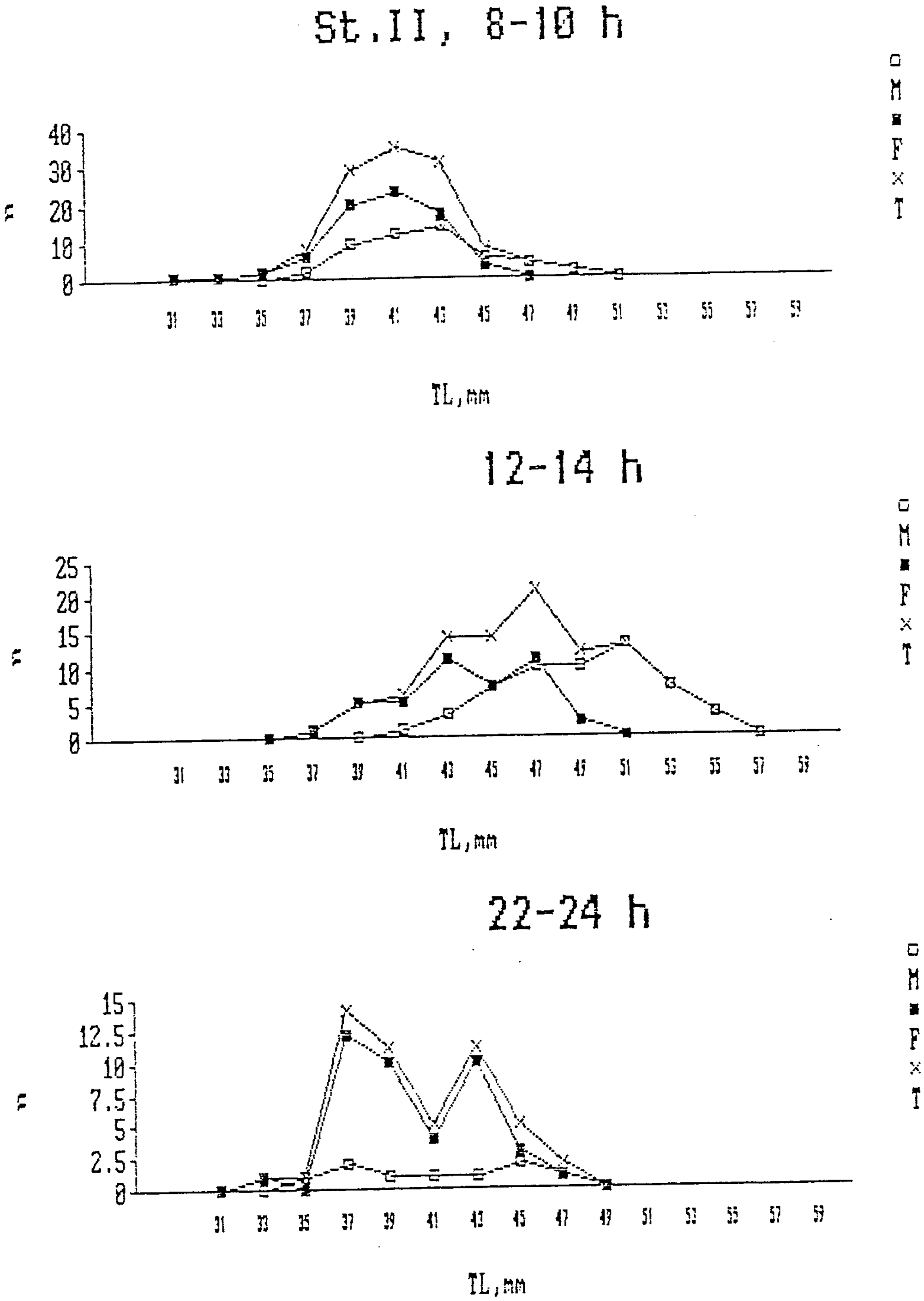


Figure 3b: Example of size composition of *E. superba*: T - total, M - males, F - females at selected points of Station II.

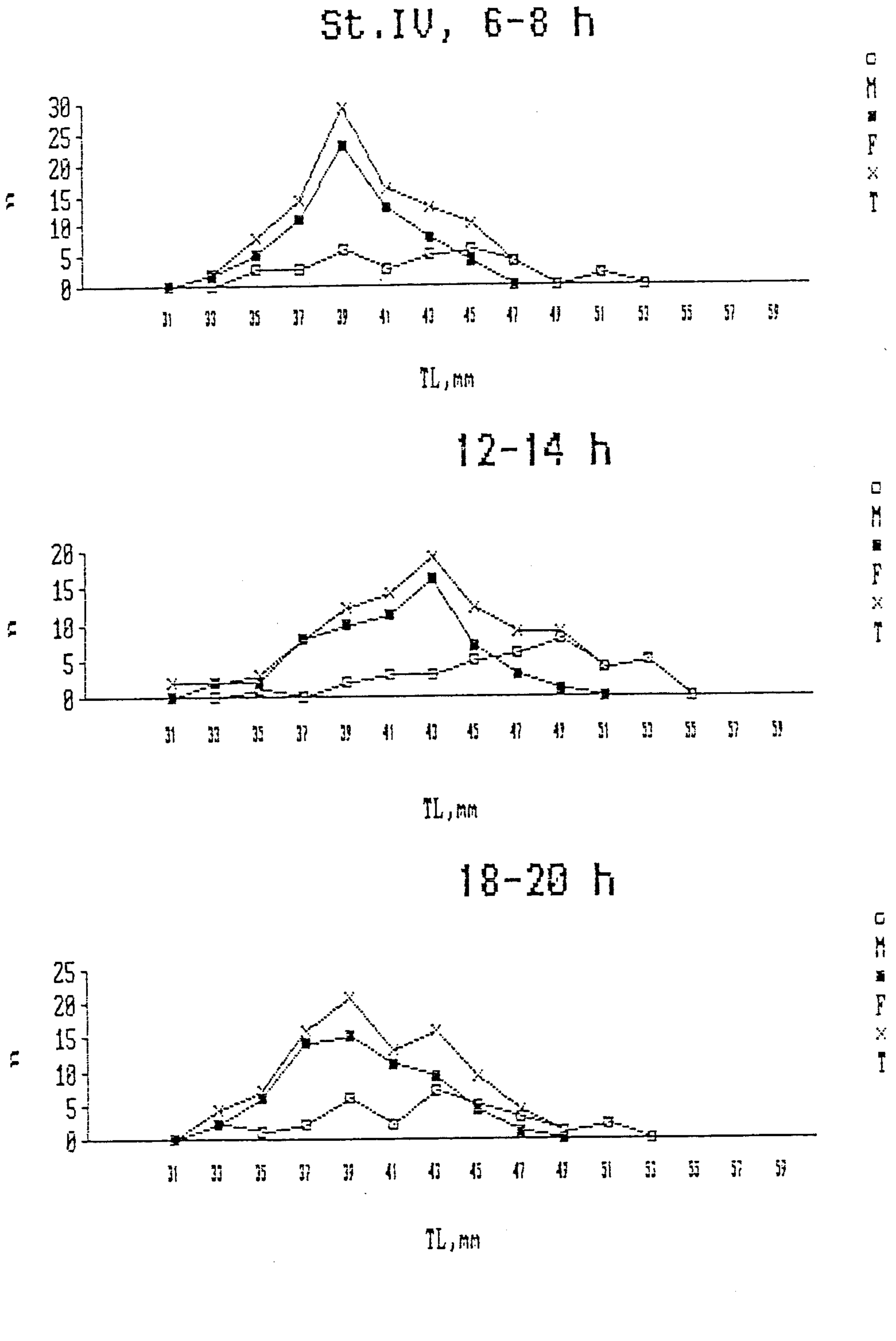
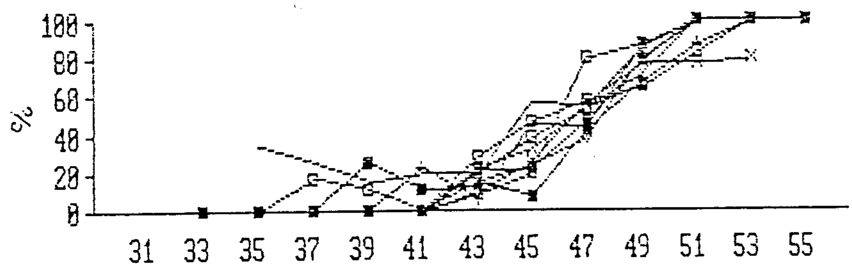


Figure 3c: Example of size composition of *E. superba*: T - total, M - males, F - females at selected points of Station IV.

St.I



St.VI

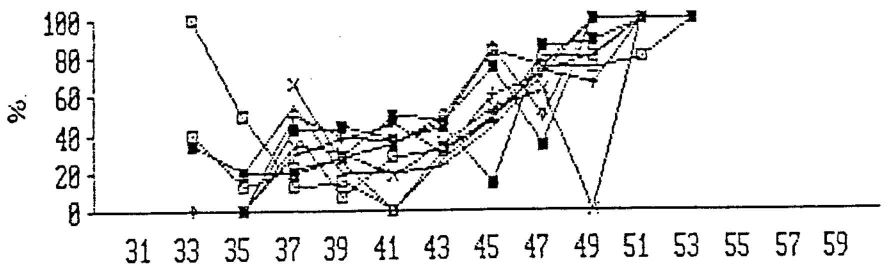


Figure 4: Changes of sex ratio of *E. superba* for Stations I and IV (% of males).

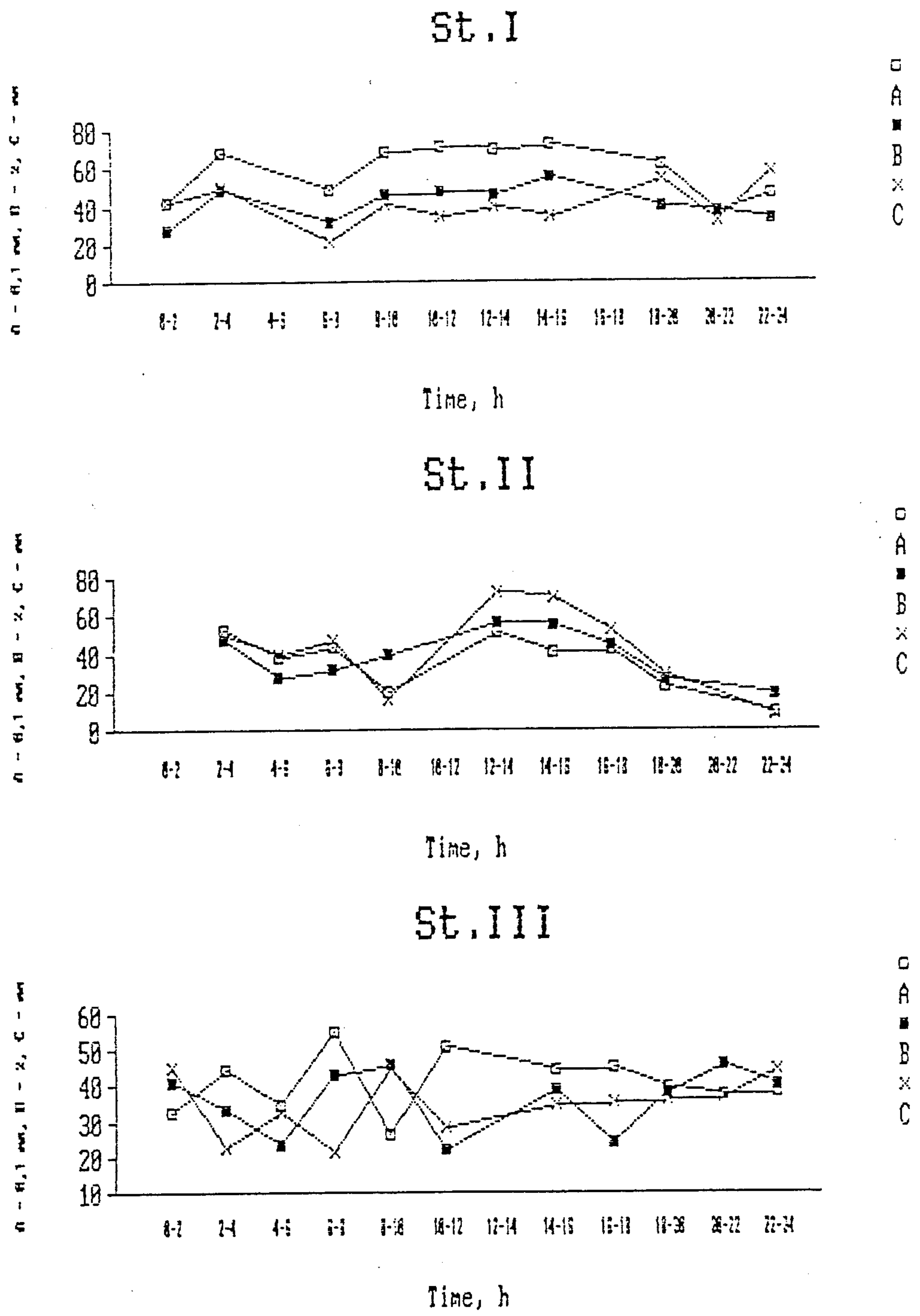


Figure 5: Diurnal variations in the size composition of *E. superba* at each station. A - average length of males - average length of females x 10; B - % of males; C - total average length (TL - 40) x 10.

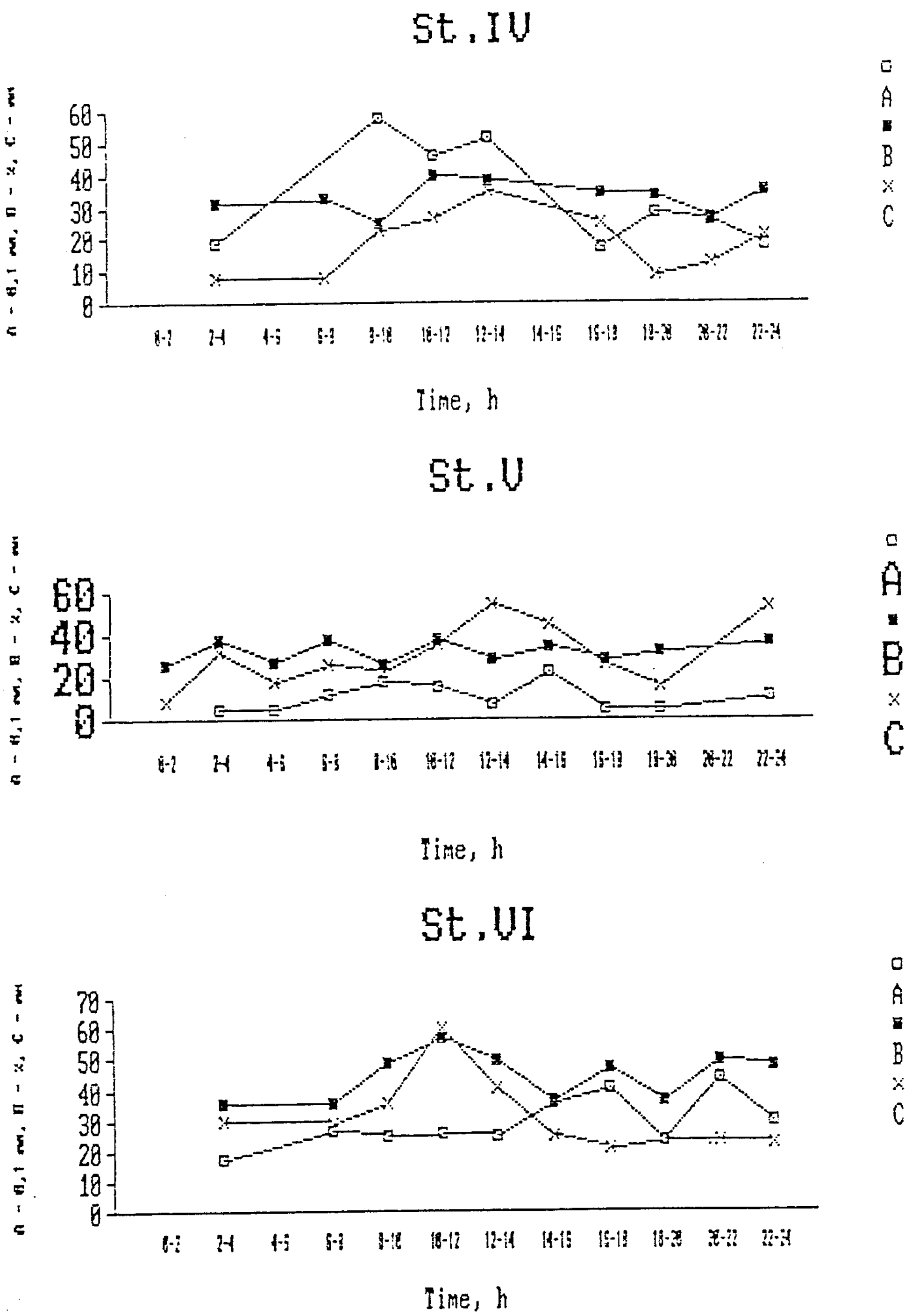


Figure 5 (continued)

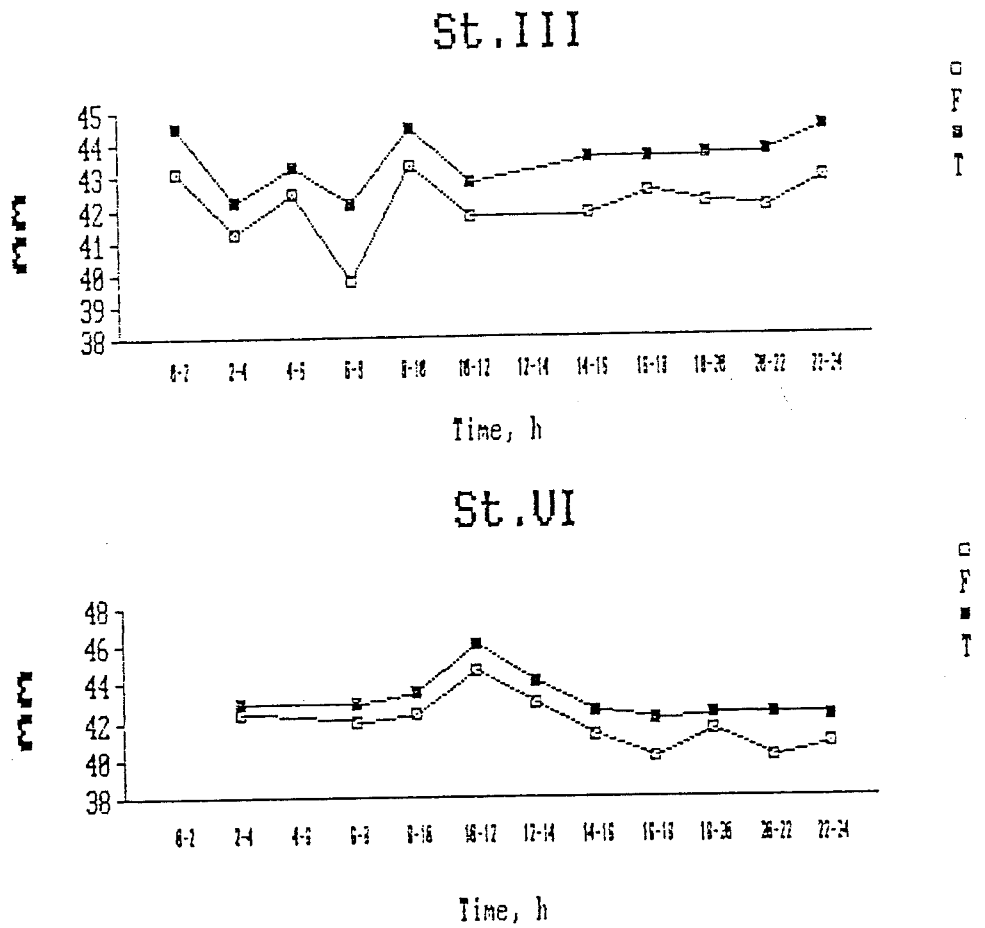


Figure 6: Total average length (T) and average length of females (F) of *E. superba* at Stations III and VI.

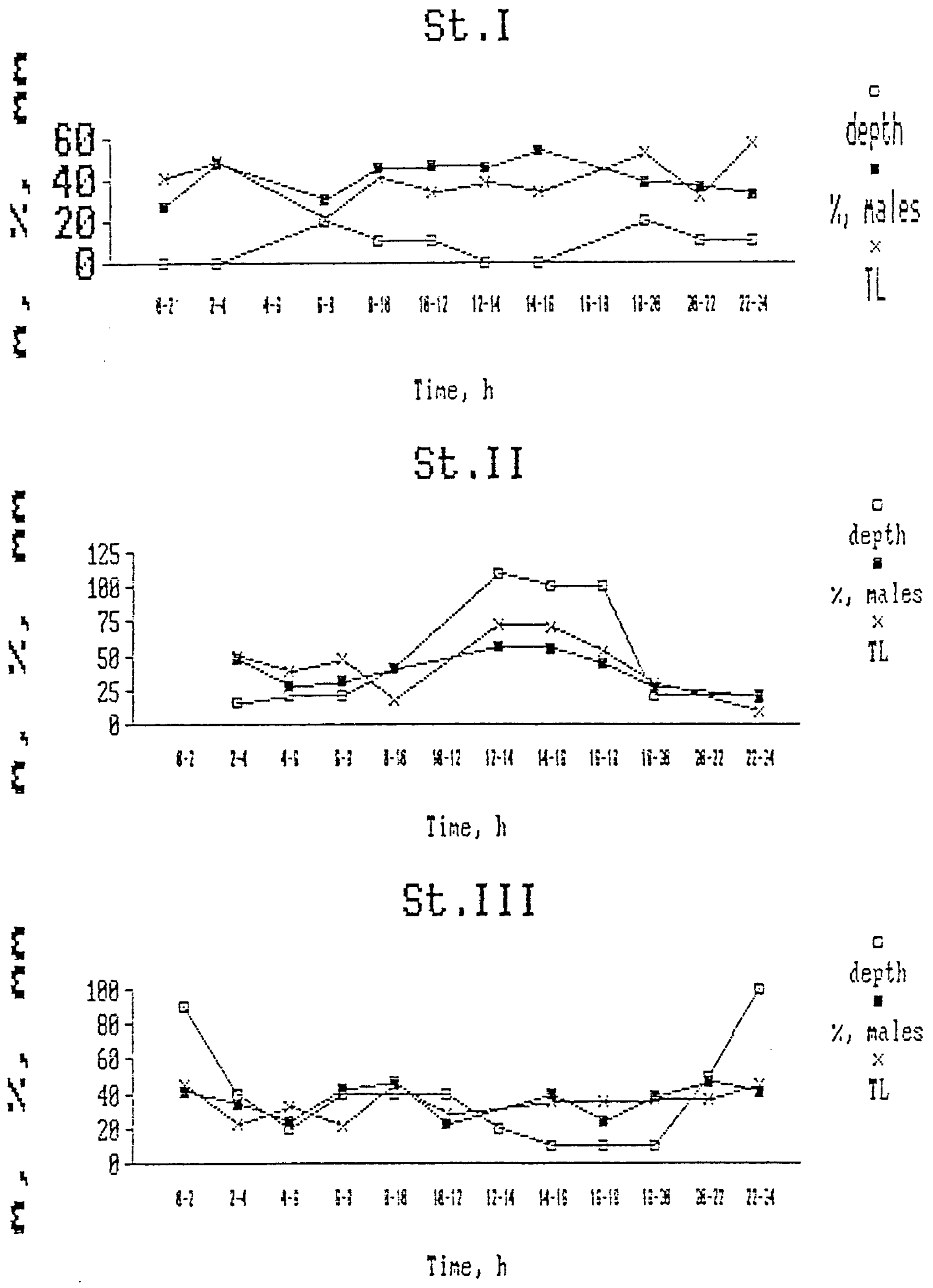


Figure 7: Catch depth, % of males and total average length of *E. superba* at each station. Depth at Station V is scaled by 1:10.

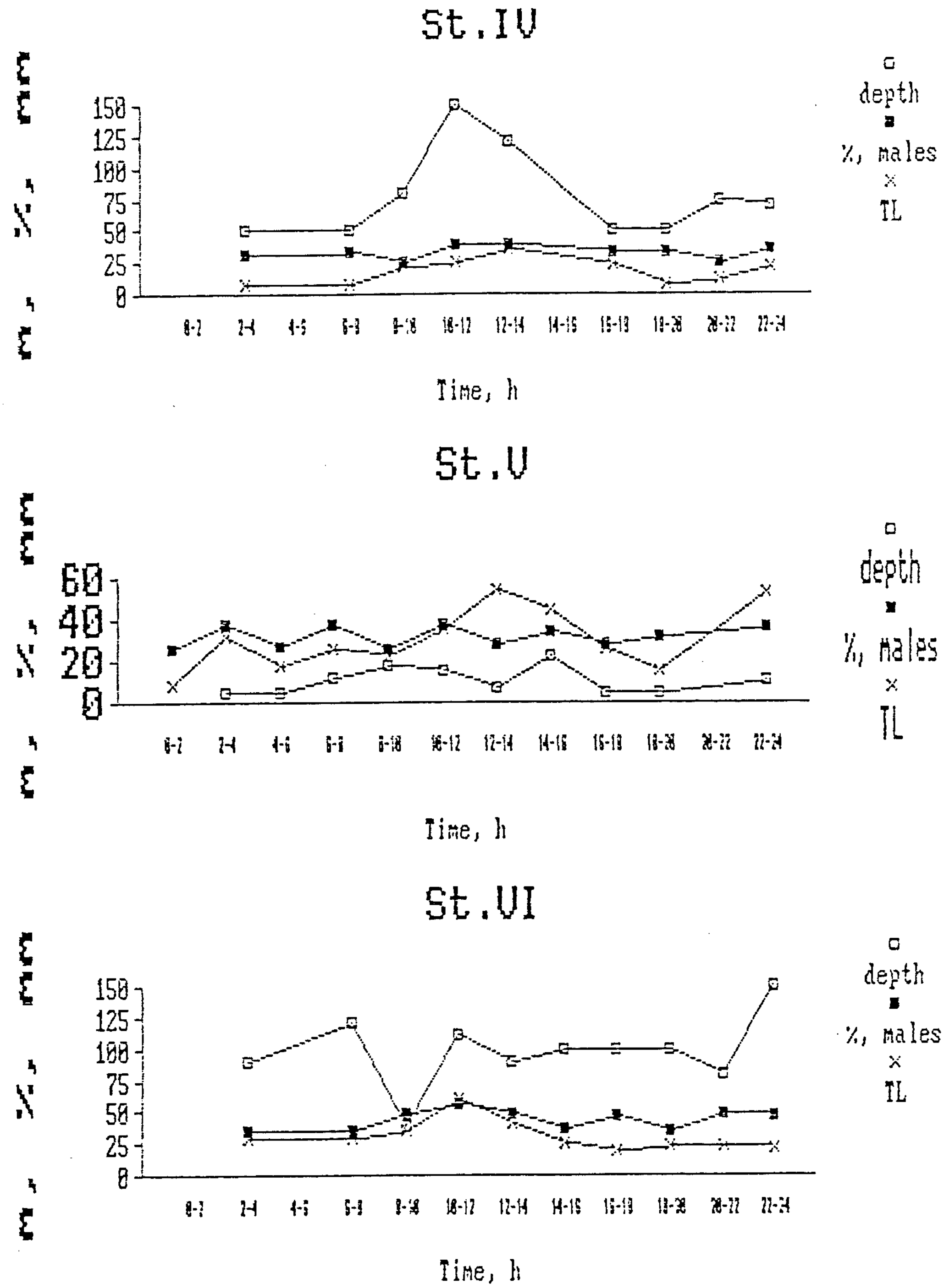


Figure 7 (continued)

Légende des tableaux

Tableau 1: Détails des stations d'échantillonnage (îles Orcades du Sud, du 24 mars au 16 juin 1990).

Légende des figures

Figure 1: Position géographique des stations d'échantillonnage.

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