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# DISTRIBUTION AND TRANSPORT OF MESOZOOPLANKTON DURING TIDAL CYCLES AT A FIXED STATION IN THE NORTHERN GERMAN WADDEN SEA

by

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## ABSTRACT

In the northern German Wadden Sea samples of mesozooplankton were taken at an anchor station in a tidal channel at intervals of 1 h over 24 h. Species composition and quantities changed during the tidal cycle. Summation of the number of individuals per taxonomic group showed that the species composition differed with the tidal phase. Some species groups, e.g. the cirripede nauplius-larvae, echinoderm larvae and mollusc larvae were found in higher abundance during flood tide, whereas other organisms, e.g. cirripede cypris-larvae, were more abundant during the ebb tide. Tidal variations of the various mesozooplankton groups in the Wadden Sea are discussed in relation to a directed transport as an integrated part of life strategy of these organisms.

## INTRODUCTION

The sediments of the Wadden Sea are relatively well investigated, in comparison with the pelagic system. Because of its special hydrographic environmental factors, it can be expected, that the pelagic system has some characteristics, which differ from coastal water bodies. To qualify and quantify these differences and the transport processes between these regions, a German inter-disciplinary project, called TRANSWATT (transport, transfer and transformation of biomass elements in the Wadden Sea) has started in 1994, which includes this study. This project is mainly concerned with eutrophication and nutrient fluxes between North Sea and Wadden Sea and terrestrial coastal zones. Quantification of plankton, i.e. bacterio- myco-, phyto- and zooplankton, and its transport, is an important part of this project.

The Wadden Sea zooplankton consists of organisms from the North Sea and from brackish water (Fransz 1983), due to the hydrographical

influence of the estuaries. Mesozooplankton of the Wadden Sea near the island Sylt mainly consists of calanoid copepods in terms of abundance and biomass (Hickel 1975, Fransz et al. 1991, Beusekom & Diel-Christiansen 1993). In the German coastal zone in general the mesozooplankton species assemblage is temporary dominated by planktonic larvae of zoobenthos, i.e. meroplankton, forming the largest part of biomass and abundance. Especially polychaete larvae and cirripede larvae are abundant in Wadden Sea areas (Martens 1980, Heiber 1988). The mesozooplankton communities are governed by seasonal and tidal variations. Tidal variation of species composition was also described from southern German coast between the Elbe and Weser estuaries (Giere 1968, Heiber 1988) and for the Dutch Wadden Sea (Wolf 1973). The main objective of this paper is to verify, if there is a transport of mesozooplankton towards the Wadden Sea or towards the North Sea in the studied area.

## MATERIAL and METHODS

Zooplankton was collected in spring (May,12. 14:00 p.m. - May,13. 16:00 p.m.) and in summer (July,16. 11:00 a.m. - July,17. 12:00 noon) of 1994. Hourly sampling over a period of at least 24 hours was done at a fixed station in the main stream of a tidal channel (Hever) in the northern (Schleswig-Holstein) German Wadden Sea, on board of RV "Victor Hensen". Co-ordinates of the anchor position in spring and summer were 54°28,7 N / 08°40,7 E. A quantity of 30 litres of surface sea water per sample was taken, using a 30l water bottle. The sample was screened through a 160$\mu$m mesh sieve, in order to collect mesozooplankton of the size fraction 200$\mu$m - 2mm. Immediately after collection the plankton was preserved in a 1% buffered formalin solution. In the laboratory quantitative and qualitative analyses were undertaken, using a stereo microscope.

The abundance of selected main zooplankton groups during tidal cycle were represented by hourly frequency distributions (Fig.1, Fig.2). Only mesozooplankton groups were taken into consideration, that were continuously present. One daily tidal cycle consists of two flood and two ebb tides. To study a possible transport of organisms into the Wadden Sea or towards the North Sea, or the presence of organisms in the same water column, the counted individuals$\cdot m^{-3}$ per sample of the two flood phases and ebb phases were added separately. The resulting two sums, consisting of an equal sample number (12 samples, total number of samples: 24), were opposed to each other (Table 1, Table 2). The extra samples (>24) of each experiment (May,12. 14:00-16:00 and July,17. 8:00 + 9:00) were disregarded. Three assumptions were made to explain the resulting differences between the sum of individuals per flood tide and ebb tide: (i) If the sum of flood samples minus sum of ebb samples is positive, some zooplankton organisms are retained in the Wadden Sea, (ii) if the

difference is negative, there must be a transport towards the North Sea, and (iii) if there is no difference or only a slight one, the organisms exhibit a uniform distribution in this area. A high difference indicates a relation between abundance of the zooplankton group and tidal cycle. To compare zooplankton with constantly high densities and zooplankton with low densities, the proportional difference of outflowing number in relation to inflowing number, is also displayed (Table 1, Table 2).

## RESULTS

Frequency distributions of selected mesozooplankton groups (Fig.1, Fig.2), during tidal cycles, demonstrated tidal changes in abundance. In May the number of individuals·$m^{-3}$ per sample showed variations of up to a fivefold quantity in terms of cirripede nauplius-larvae (1000-4833 ind.·$m^{-3}$) and to a tenfold quantity in the case of cirripede cypris-larvae (367-3833 ind.·$m^{-3}$). The highest abundance of cypris-larvae was recorded at low tide, just after the onset of flood tide (Fig.1). The cirripede nauplii reached the highest numbers in the middle of ebb tide in this tidal channel. Calanoid copepods, both adults and sub-adult copepodites, revealed the highest abundance (2900-3100 ind.·$m^{-3}$) during the night hours (22-23:00, Fig.1). Hydrozoans, gastropod larvae and echinoderm larvae reached their maximum (567, 667 and 900 ind.·$m^{-3}$) short before high tide.

In July the calanoid copepods (Fig.2), mainly consisting of adults and copepodites of *Acartia* spp., *Centropages hamatus* and to a lower extent of *Temora longicornis* and *Pseudocalanus elongatus*, showed generally an extreme high abundance (mean: 10551 ind.·$m^{-3}$) in comparison with May (mean: 1364 ind.·$m^{-3}$). Again the maximum (17867 ind.·$m^{-3}$) in number - in surface samples - was reached during night hours (23-01:00, Fig.2). The included rotifers clearly revealed the highest abundance (up to 8533 ind.·$m^{-3}$) in the flood phases. Cirripede larvae, especially the cypris-larvae, were not abundant like in May. The cirripede nauplii only showed a slightly higher number during flood tides. The polychaete larvae (max.: 14700 ind.·$m^{-3}$), mostly belonging to the spionid family, nearly reached the same dominance as the calanoid copepods (Fig.2). The abundance was slightly higher during flood tides. Hydrozoans, mainly consisting of *Obelia* spp., *Rathkea octopunctata* and *Bougainvillia ramosa*, showed a threefold increase (mean: 729 ind.·$m^{-3}$) in comparison with the tidal cycle in May (mean: 233 ind.·$m^{-3}$).

The calculated differences between flood and ebb tides, during the spring experiment, are shown in Table 1. The results revealed, that of calanoid copepods, cirripede nauplius-larvae, polychaete larvae, echinoderm larvae, gastropod larvae, bivalve larvae, cyphonautes-larvae of bryozoans and in hydrozoans, more individuals entered the Wadden Sea with the flood phases, than afterwards left during the ebb phases. In contrast to these firstly mentioned organisms, in other mesozooplankton groups, as

the cirripede cypris-larvae, the trochophore-larvae of polychaetes and the harpacticoid copepods, more individuals leave the Wadden Sea, than enter it. In calanoid copepods, in polychaete larvae and in hydrozoans the number of inflowing and outflowing individuals is not distinct, meaning, that they are probably distributed in a homogeneous way in this part of the Wadden Sea. A small input of organisms into the Wadden Sea can be seen in echinoderm larvae, in larvae of molluscs and in the cyphonautes-larvae of bryozoans, which do belong to the meroplankton. The most remarkable difference by number can be seen in cirripede larvae. Over 50% of the entered cypris-larvae were missing in the ebb tide and therefore remained in the Wadden Sea, but 38% more nauplius-larvae of the cirripedes, than entered the Wadden Sea, were carried out. The harpacticoid copepods, not representing high densities in surface samples, seemed to show a strong offshore directed transport (Table 1, see also discussion).

The species composition of the second tidal experiment in summer 1994 (16.-17. July) differed from that of spring. As a consequence, some more species groups were included in Table 2 (ctenophore larvae, appendicularians, rotifers, *Noctiluca*), others (echinoderm and bryozoan larvae) were left out, because of neglectable low abundance. The data revealed a more than doubled total number of mesozooplankton organisms in summer. This was also displayed in the absolute difference in number of individuals per tidal phase (Table 2). The second tidal experiment showed a different pattern, in tidal distribution of zooplankton groups, from that of May. Cladocerans (*Podon* and *Evadne* species), which were always found in low densities, seemed to be transported towards the open sea. With the exception of the cladocerans, all main taxonomic groups exhibited positive values of numerical difference, meaning the entering of organisms into the Wadden Sea was stronger, than towards the North Sea. The highest difference is demonstrated by the rotifers. 61,22% of the inflown individuals were missing in the ebb tide. A strong input towards the Wadden Sea was also recognized in cirripede cypris-larvae and trochophore-larvae. Referring to the cirripede larvae the transport direction was in agreement with the first experiment. Trochophore-larvae were also transported into the Wadden Sea in summer, in contrast to spring. The abundance of hydrozoans, the ctenophore larvae, the mollusc larvae, the polychaete larvae and cirripede nauplius-larvae was slightly higher during the flood tides, meaning that about 20-35% of these organisms remain in the Wadden area. The most important holoplanktonic groups, like the appendicularians, the calanoid copepods and the dinoflagellate *Noctiluca scintillans*, revealed an approximately equal abundance in flood and ebb tides, probably due to a completely mixed distribution in the studied area.

## DISCUSSION

The attempt to describe a qualitative transport of organisms from or into the Wadden Sea may not yet be interpreted quantitatively. For this aim a continuous plankton recording over a complete tidal cycle would be necessary, in addition to biomass estimates. Also the water transport and its velocity need to be investigated. A possible lateral transport of zooplankton organisms in this study is disregarded. Nevertheless, the data reveal a distinguished reaction to tidal cycles in each taxonomic group. In some meroplanktonic larvae the adaptations of their life cycles to environmental conditions seem to result in an active use of tidal currents to be transported into other regions. This is most obviously the case in cirripede larvae. The cypris-larvae, just before their metamorphosis to a benthic organism and not feeding (Luther 1987), are transported into the Wadden Sea, where the possibility to find an adequate substrate to settle down, is much higher near the coast. In contrast to this, cirripede nauplius-larvae, in the phase of distribution of their species and feeding, are transported to offshore waters. A high abundance facilitates the distribution and the probability of survival in this developmental stage. In studies of other regions, e.g. the Dutch Wadden Sea, similar, supporting results were established. Wolf (1973) assumed an active swimming of cypris-larvae as the only explanation for the continuing presence of groups, i.e. patchy occurrence, of these types of larvae, even in tidal currents with accompanying high turbulence. In cirripedes the eggs are kept within the shell, until grown-up nauplii are released (Luther 1987). As pelagic eggs usually undergo a high mortality, keeping the eggs in a safe cover and releasing larvae, which are able to swim, may result in a higher survival rate, without increasing the reproductive effort. Larval release of the nauplii in the cirripede genus *Semibalanus*, was found to be coupled with phytoplankton blooms, meaning the availability of food, and was stimulated by a high concentration and close contact of the diatom *Skeletonema* (Starr et al. 1991). All these results demonstrate a non-random distribution pattern of meroplanktonic larvae, like in the case of cirripedes, but all behaviour, well adapted to the environmental conditions.

The role of the harpacticoid copepods in the Wadden Sea, up to now, remains unclear. Because of hydrographic conditions, as the strong turbulence, also meiobenthic harpacticoid copepods were continuously found in plankton samples (Giere 1968, Heiber 1988, own data). As they are relatively abundant, it is interesting to know, whether they also feed in the water column and therefore also may play an important role in trophic relationships in the pelagic system of this area. After Bouwman (1983) meiobenthic harpacticoid copepods are consumed by polychaetes, shrimps and flatfishes. The observed transport of harpacticoid copepods to offshore regions in the spring experiment may not reflect normal conditions. A transport of coastal meiobenthic copepods towards the North Sea by tidal cycles would mean a loss of individuals into deeper

water. The summer experiment in contrast showed a reversed transport of harpacticoid copepods into the Wadden Sea.
The high percentage of benthos larvae and the obvious seasonal transport of meroplanktonic larvae in and out of the Wadden Sea led to the conclusion, that this coastal zone may also serve as a nursery area for benthic organisms, similar as it is already described for fish larvae and juveniles.

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**Table 1:** Summation of flood and ebb phases by number of individuals / $m^3$ of main mesozooplankton groups, during a 24 hour tidal cycle experiment in May 1994; (+) means transport into Wadden Sea, (-) means transport towards North Sea, (%) percentage of individuals from flood, which lack in the ebb tide and remain in the Wadden Sea

| taxonomic group | Σ individuals of 2 outflow phases | Σ individuals of 2 inflow phases | absolute difference | in % |
|---|---|---|---|---|
| calanoid copepods | 16200 | 16600 | +400 | +2,41 |
| harpacticoid copepods | 1400 | 533 | -867 | -162,66 |
| cirripede cypris-larvae | 9533 | 20401 | +10868 | +53,27 |
| cirripede nauplius-larvae | 36366 | 26300 | -10066 | -38,27 |
| polychaete larvae | 17734 | 18301 | +567 | +3,10 |
| trochophore-larvae | 19368 | 17266 | -2102 | -12,17 |
| echinoderm larvae | 4332 | 5432 | +1100 | +20,25 |
| bivalve larvae | 8334 | 10432 | +2098 | +20,11 |
| gastropod larvae | 3000 | 3701 | +701 | +18,94 |
| cyphonautes-larvae of bryozoans | 1301 | 1633 | +332 | +20,33 |
| hydrozoans | 2532 | 2835 | +303 | +10,69 |

**Table 2:** Summation of flood and ebb phases by number of individuals / $m^3$ of main mesozooplankton groups, during a 24 hour tidal cycle experiment in July 1994 (further explanations see above and in text)

| taxonomic group | Σ individuals of 2 outflow phases | Σ individuals of 2 inflow phases | absolute difference | in % |
|---|---|---|---|---|
| hydrozoans | 8233 | 10733 | +2500 | +23,29 |
| ctenophore larvae | 1533 | 2033 | +500 | +24,59 |
| gastropod larvae | 4367 | 6667 | +2300 | +34,50 |
| bivalve larvae | 12033 | 18033 | +6000 | +33,27 |
| polychaete larvae | 97833 | 127933 | +30100 | +23,53 |
| trochophores | 1633 | 2967 | +1333 | +44,94 |
| cladocerans | 1067 | 867 | -200 | -23,08 |
| calanoid copepods | 137100 | 137233 | +133 | +0,10 |
| harpacticoid copepods | 4967 | 8033 | +3067 | +38,17 |
| appendicularians | 14633 | 16833 | +2200 | +13,07 |
| cirripede cypris-larvae | 1367 | 2300 | +933 | +40,58 |
| cirripede naupl.-larvae | 15367 | 20333 | +4967 | +24,43 |
| rotifers | 7600 | 19600 | +12000 | +61,22 |
| Noctiluca/flagellates | 3626967 | 3832900 | +205933 | +5,37 |

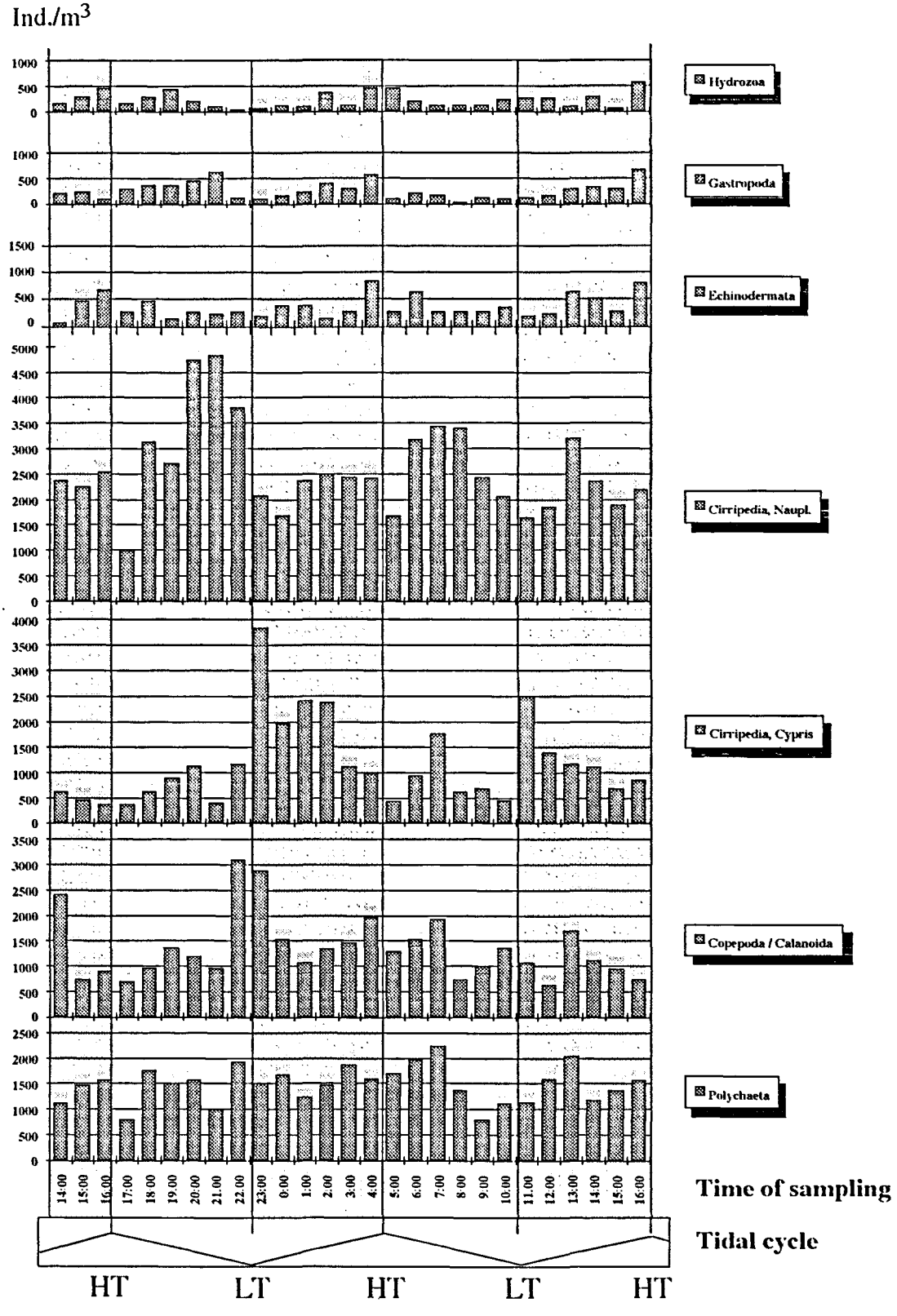


**Fig.1:** Hourly variation of the abundance (individuals/$m^3$) in meso-zooplankton groups during a tidal cycle experiment (27 h) in the northern German Wadden Sea (Hever, 12.-13.5.94), LT= low tide, HT= high tide, shaded areas symbolize flood phases.

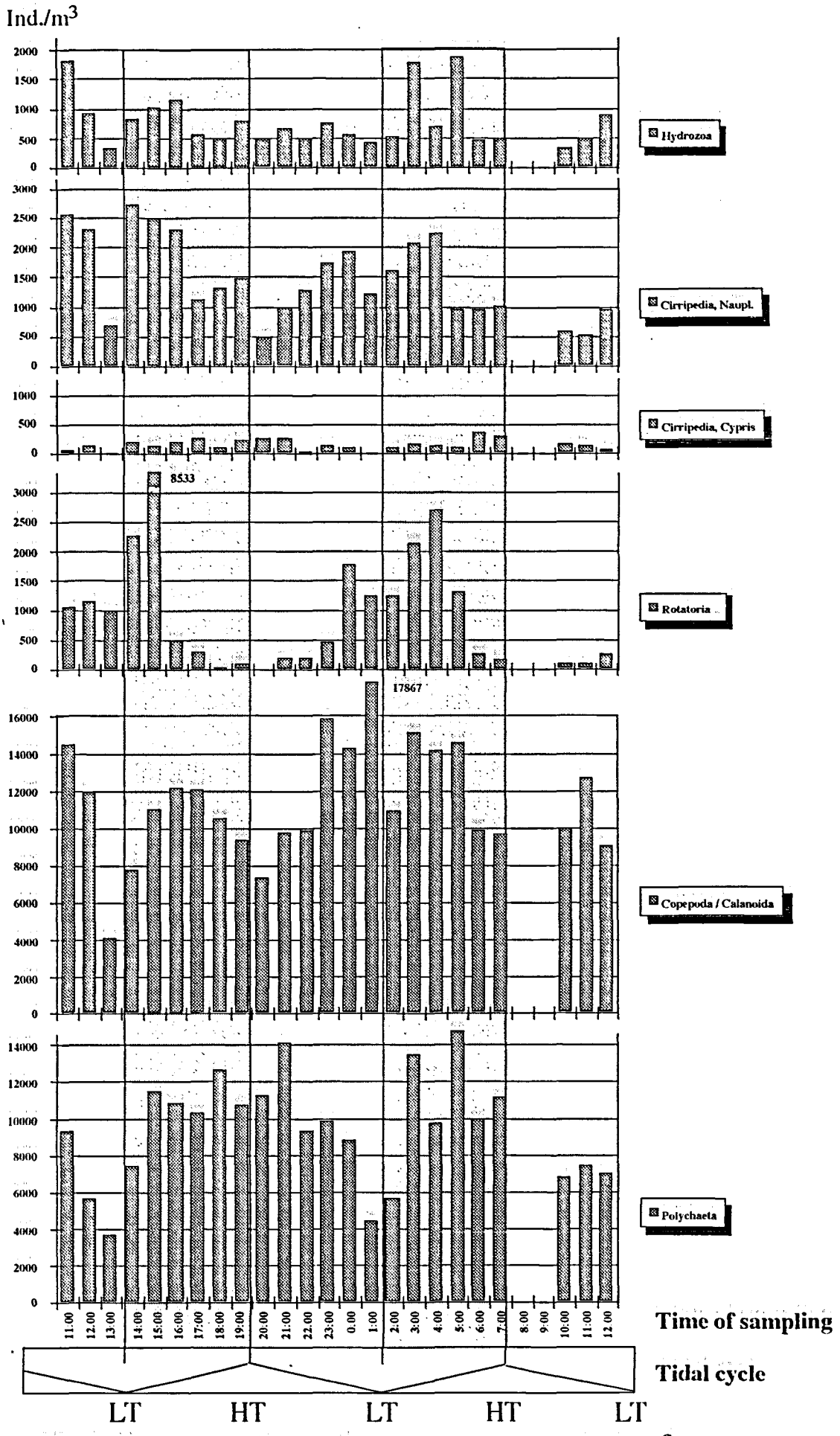


**Fig.2:** Hourly variation of the abundance (individuals/m$^3$) in meso-zooplankton groups during a tidal cycle experiment (26 h) in the northern German Wadden Sea (Hever, 16.-17.7.94).