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Non-Indigenous Organisms Introduced via Ships into German Waters

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Abstract

Ballast water has been recognized as a major vector for the introduction of non-indigenous organisms. Commissioned by the Federal Environmental Agency, Berlin, a joint research project between the Institut für Meereskunde Kiel and the University of Hamburg was initiated to provide information on possible harmful effects of non-indigenous organisms introduced into German waters by ship traffic. The study aims at a thorough taxonomic assessment of planktic and benthic organisms found in ballast water, tank sediment and on ship hulls. Over a period of three years about 300 vessels calling at German ports were visited. So far about 350 botanical and zoological taxa were found, of which roughly 30 percent comprised foreign organisms, non-indigenous to the Baltic and North Sea. In addition, the survival of plankton organisms in ballast water tanks was studied by accompanying a container vessel on its voyage from Singapore to Bremerhaven. Initial results are reported here.

Introduction

Carlton (1985) has given a comprehensive review of ballast water as a mechanism for dispersing aquatic organisms and has provided evidence that thereby a world-wide transfer of organisms between the continents takes place. Recently observed mass developments of non-indigenous species in various parts of the world, causing severe ecological and even economical damage, have brought the problem of ballast water transport into general focus (Carlton & Geller 1993, Hedgpeth 1993). Examples are the Zebra Mussel (*Dreissena polymorpha*) (Roberts 1990), the cladoceran *Bythotrephes cederstroemi* (Sprules et al. 1990) and the European River Ruffe (*Gymnocephalus cernuus*) (Waldichuk 1990), which have invaded the Great Lakes in North America. While the two latter species affect the original food web structure by outcompeting indigenous species, *Dreissena* causes high economical damage by clogging pipes in water pumping and discharge systems. The ctenophore *Mnemiopsis leidyi*, a species from the southern east coast of North America, has become a dominant member of carnivorous zooplankton in the Black Sea ecosystem, affecting the recruitment of commercial fish stocks by predation on fish larvae and their prey organisms (Harbison & Volovik 1993). Another North American species, the spionid polychaete *Marenzellaria viridis*, has established itself in the Baltic Sea (Norkko et al. 1993) and almost entirely replaced the indigenous polychaete *Nereis diversicolor* in some areas (Zmudzinski 1993). Marine aquaculture is threatened by the world-wide transport of toxic phytoplankton species in ballast water tanks, especially of cyst-forming dinoflagellates which are able to survive long periods of unfavourable conditions (Hallegraeff et al. 1988, 1990).

After the occurrence of new toxic algal blooms in Australian waters, evidently established there by ballast water transport from Japan, Australian scientists have taken the lead in intensifying ballast water research (Hallegraeff & Bolch 1991, 1992) and urging the IMO (International Maritime Organisation) to take up the ballast water problem as an official issue in regulating international ship traffic. As a first reaction the 'International guidelines for preventing the introduction of unwanted aquatic organisms and pathogens from ships' ballast water and sediment discharges' were adopted by IMO (1991), the main recommendation being to exchange ballast water, as far as weather and safety conditions permit, when crossing deep open ocean waters. This measure would greatly reduce the danger of transferring freshwater or near-shore marine organisms to other areas, as clear nutrient-exhausted open ocean water is usually characterized by a sparse plankton community, the members of which are unable to survive under the far more changeable environmental conditions in coastal areas.

In 1992, a joint research project between the Institut für Meereskunde Kiel and the University of Hamburg commissioned by the Federal Environmental Agency in Berlin was launched to investigate flora and fauna carried by international ship traffic to German ports and to assess the ecological risk arising from the introduction of non-indigenous species to German waters. The flora is identified in Kiel and the fauna in Hamburg. The practical work and main burden of the project is shared between two junior scientists, S.G. and M.D., while two senior scientists, J.L. and G.A., are the advisors bearing the main responsibility.

Material and Methods

A large variety of ocean-going vessels calling at German ports were investigated for their ballast water content. In addition, newly docked vessels were inspected for the presence of sediment and larger organisms in emptied ballast water tanks as well as for fouling organisms on the hull. The majority of samples were collected at the overseas harbours of Hamburg (76 %) and Bremerhaven (18 %). Other ports which were only occasionally visited include Rostock and Kiel (Western Baltic), Rendsburg (Kiel Canal), Brake, Elsfleth, Bremen (River Weser) and Wilhelmshaven (North Sea). The vessels investigated were mainly cargo ships, the most frequent type being container vessels followed by combi ships, bulk carriers and car transporters. A few passenger liners, research vessels and even navy ships were visited as well.

Three methods were employed for sampling ballast water. The first was opening a manhole permitting direct access to the tank and taking a sample with a small plankton net (mesh size 10 µm). Such an 'ideal' sample taking was, however, very rarely possible, a mere 6 times out of a total of 136 inspections. The reasons usually given by the ship's crew were inaccessibility of suitable manholes because of overlying cargo, a strict interpretation of safety regulations and lack of manpower needed for opening and closing a tank during the short and busy schedule in the port.

The second method, which was employed 69 times, was to pump ballast water through a sounding pipe in the tank with the help of a hand-pump. These sounding tubes have a diameter of about 6 cm and a length of up to 20 m. The maximum depth of water level that could be reached by the hand-pump was 9 m. Very modern vessels do not have sounding tubes any more, since nowadays water content in the tanks is solely controlled by electronical meters.

The third method, employed 43 times, was drawing water from a small tap on the ballast water pump. Water obtained by the second and third methods were filtered through a 10 µm plankton net, usually 100 l per sample, and preserved for phytoplankton and zooplankton analysis in 4 % formalin and 70 % ethanol, respectively. Depending on time and distance from the laboratory, small subsamples were left unpreserved for inspection of living organisms. On 18 occasions, when emptied tanks were inspected, it was possible to take plankton samples out of the residual bottom water.

The abiotic factors regularly measured in ballast water were temperature, salinity and oxygen by means of portable electrochemical probes and pH with a portable pH-meter.

As already mentioned, sediment and hull samples were obtained from newly docked vessels. Entering emptied tanks sometimes needs special precautionary measures, as non-ventilated tanks may contain toxic gases such as methane or hydrogen sulphide. At the beginning of the project it was therefore decided to purchase a breathing apparatus and to undergo a special training course with the local fire-brigade. A gas mask also provides protection against pathogenic germs, e.g. cholera bacteria, which might be present in ballast water. It turned out later that in most cases the inspected tanks were well-ventilated.

Sediment samples were taken from the tank bottom and from construction frames on the walls. Fouling organisms were scraped from the walls, too. Sometimes it was possible to catch larger organisms such as crabs and fish in the residual water by means of a small landing net. Preservation methods were the same as with plankton samples. Unpreserved sediment samples were stored in a refrigerator for future cyst-hatching experiments. For making a semiquantitative comparison of fouling samples possible, a patch measuring roughly 10 x 10 cm was usually scraped off the hull.

In May 1995 the German container ship 'DSR America' was accompanied during a 23 day cruise from Singapore to Bremerhaven in order to investigate the survival of tropical plankton in ballast water tanks on their way to northern Europe through a daily check of environmental conditions (temperature, salinity, oxygen and pH value) and plankton content. Environmental conditions were recorded in 4 tanks, in the forepeak and aftpeak tank and in two opposite side tanks on starboard and port side. The first tank was filled after departure from Singapore and the three others after a stop in Colombo (Sri Lanka). Plankton survival was controlled in two tanks, in the aftpeak tank and one of the later filled side tanks. 100 l samples were taken daily through opened manholes and filtered through a 10 µm plankton net. Species determination and counting were, as far as possible, completed on board.

Results

Fig. 1 shows the positon of ballast water tanks in a modern container vessel. They consist of a series of double bottom tanks, topside tanks and a forepeak and aftpeak tank. The ballast water capacity of large vessels may exceed 20,000 t. Bulk carriers, when travelling without cargo, can transport more than 100,000 t.

Vessels from almost all parts of the world connected through international ship traffic were investigated (Fig. 2). 308 vessels were inspected between March 1992 and July 1995, yielding a total of 335 plankton, sediment and hull samples (Fig. 3). Their geographical origin is shown in Fig. 4.

Altogether, over 350 different taxa were found; more than 100 comprised unicellular algae and about 250 zoological species or taxa. Even with the help of experts, an exact systematical identification was rather difficult in a number of cases. Therefore the genus could only be listed. The number of organisms found in 100 l ballast water varied between one and several hundred specimens. A total of 15,000 specimens have been analysed so far, about two-thirds comprising plankton organisms and 1,000 and 4,000 specimens from sediment and hull samples, respectively.

The main phytoplankton groups recorded are diatoms, dinoflagellates, chloro- and cyanophytes. Diatoms and chlorophytes were more common than dinoflagellates. Fig. 5a shows the regional distribution of the samples and presence of the main groups. It is interesting to note that in quite a number of cases no phytoplankton was found at all, especially in samples from the Indian Ocean, South-West America and the open ocean.

Sediment samples analysed so far showed the presence of empty cysts of dinoflagellates belonging mainly to the genus *Protoperidinium*. It is unknown where the hatching took place, in the tank or before ballasting.

The main group of organisms recorded in ballast water from all regions are planktic crustaceans (Fig. 5b). Mollusc, polychaete and fish larvae occurred quite frequently. What is interesting is the occurrence of rotifers and nematods. Rotifers inhabit mainly freshwater and low-saline brackish water. Their presence can be taken as an indication of the origin of the ballast water. Nematods are benthic organisms. Their presence points to the fact that ballasting occurred in a nearshore shallow area where the sediment was stirred up. The presence of chlorophytes (Fig. 5a) may be interpreted in the same way. A classification of the salinity of the ballast water shows that in 3 % salinity was below 5 ‰, 32 % fell into the range 5-30 ‰ and 65 % contained high-saline water above 30 ‰.

The dominance of crustaceans recorded is also mirrored in their species diversity. Of 250 taxa recorded in total for the organisms, 152 species (62 %) were crustaceans with 57 copepod species encountered primarily in plankton samples. Molluscs rank second with 57 species (23 %). Cirripeds and bivalves were the predominant hull organisms. Foraminiferids occurred mainly in sediment samples.

A first estimate shows that about 30 % of the 350 species recorded are to be regarded as non-indigenous. Tab.1 gives an overview of the systematical groups where foreign species were encountered. It is interesting to note that the plankton samples contained only 4 groups with non-indigenous species, while the number of groups found in sediment and hull samples was almost twice as high.

Tab. 1 Systematical groups in which non-indigenous taxa were recorded and location of records

Systematical unit	Plankton	Sediment	Hull
Diatomophycea	+	+	
Dinophycea	+	+	
Foraminifera	+	+	+
Turbellaria			+
Rotifera	+		
Gastropoda		+	+
Bivalvia		+	+
Cladocera	+	+	
Ostracoda		+	+
Copepoda	+		
Cirripedia		+	+
Decapoda		+	+
Bryozoa			+

The study on the survival rate of plankton in ballast water tanks on board the container vessel 'DSR America' on its way from Singapore via Colombo to Bremerhaven focussed on two tanks. Fig. 6a shows the concentration of phytoplankton cells in the aftpeak tank filled close to Singapore. After some oscillations during the first few days, there was a strong decrease resulting in an about 90 % reduction in cell number on the tenth day after departure. The bulk were diatoms of which 30 species were identified at the beginning, whereas dinoflagellates, represented by 13 species, started with a much lower concentration and disappeared on day 13. On arrival in Bremerhaven after a 23 day cruise, only 4 species of diatoms had survived.

Zooplankton exhibited a similarly sharp decrease in the aftpeak tank as phytoplankton. Of 24 taxa recorded on the second day after filling, only 4 survived the cruise. These were a few specimens of the benthic harpacticoid copepod *Tisbe graciloides*, a turbellarian, a gastropod and a bivalve larva. Juvenile copepods constituted the predominant zooplankton component at the beginning. Their abundance decreased rapidly during the first 5 days (Fig. 6b).

A similar decrease in diversity from 16 to 4 species was observed in the second tank filled after departure from Colombo on the way to Bremerhaven. Surprising in this case, however, was the observation that *Tisbe graciloides* had considerably increased in concentration after the 14 day cruise.

Fig. 7 shows the temperature records for the 4 tanks with the sea surface temperature for comparison. Tank temperatures followed sea temperature with a delay of one to two days. It is interesting to note that apparently it was not the temperature drop that was responsible for the sharp fall in species number and concentration of phyto- and zooplankton observed in the aftpeak tank, as this occurred before temperature changed. Oxygen and pH showed comparatively little variation over the whole cruise. An oversaturation of up to 126 % was recorded from the fourth to the seventh day, when the vessel was pitching and rolling due to an increased wind force of 6-7 Bf. Since the tank was not completely filled, the overlying air was mixed into the water, leading to the observed oversaturation with oxygen. Although the rolling of the water in the tank could have had an adverse effect on delicate plankton organisms, the main concentration drop (Fig. 6a, b) had already occurred before, so that this effect can also be ruled out. A third possible explanation could lie in the organisms having been damaged through the pumping system, causing a subsequent high mortality.

The transition from warm to cold temperature will generally harm ballast water organisms to a lesser extent than the other way round, since a temperature decrease is physiologically easier to tolerate than an increase. To show how strong the temperature increase is that ballast water organisms may be exposed to the seasonal change of sea surface temperature during a cruise from the west coast of North America to northern Europe and vice versa is shown in Fig. 8. The year-round high tropical temperatures met in passing the Panama Canal will probably in most cases act as a barrier for the transport of boreal and temperate organisms from one area to the other.

Discussion

The investigation of ballast water tanks and hulls of ocean-going vessels for the presence of living organisms as proof of a possible transfer mechanism by which non-indigenous species are able to establish themselves in foreign ecosystems is the first step in assessing the ecological and also economical risks involved. Therefore after the pioneer work by Carlton (1985) on organisms and that by Australian researchers on phytoplankton (Hallegraeff et al. 1988, 1990, Hallegraeff & Bolch 1991, 1992), further studies in other countries were initiated, e.g. in Canada (Subba Rao et al. 1994).

Investigation of ballast water proved, however, much more difficult than initially thought. The main problem is opening the manhole of a tank for adequate sampling. During our study, we only succeeded a few times in persuading a ship's crew to open a manhole. Since we had no official backing from local governmental or harbour authorities, we first had to politely approach shipping agencies and shipyards before being allowed to take samples at all. The two other sampling methods employed, hand-pumping through sounding pipes and tapping of the pump system, constitute a compromise which did not work satisfactorily in all cases.

More information on environmental conditions in ballast water tanks and on survival of organisms will help to evaluate the risks of transport (Rigby & Hallegraeff 1994). Following the fate of the organisms from ballasting to deballasting through repeated checking of the conditions on board will yield interesting results. Our study showed a rapid decline of plankton concentration during the first days after filling the tanks. The reason, however, is not yet clear.

The second step in evaluating the ecological and economical risk involved in transporting non-indigenous species by ship traffic is to study their geographical distribution and range of tolerable environmental conditions, their trophic relationships and behaviour by means of a thorough literature review. If experimental conditions permit, it may in some cases be possible to successfully culture such organisms in the laboratory for conducting detailed studies on their ecological tolerance during their life cycle.

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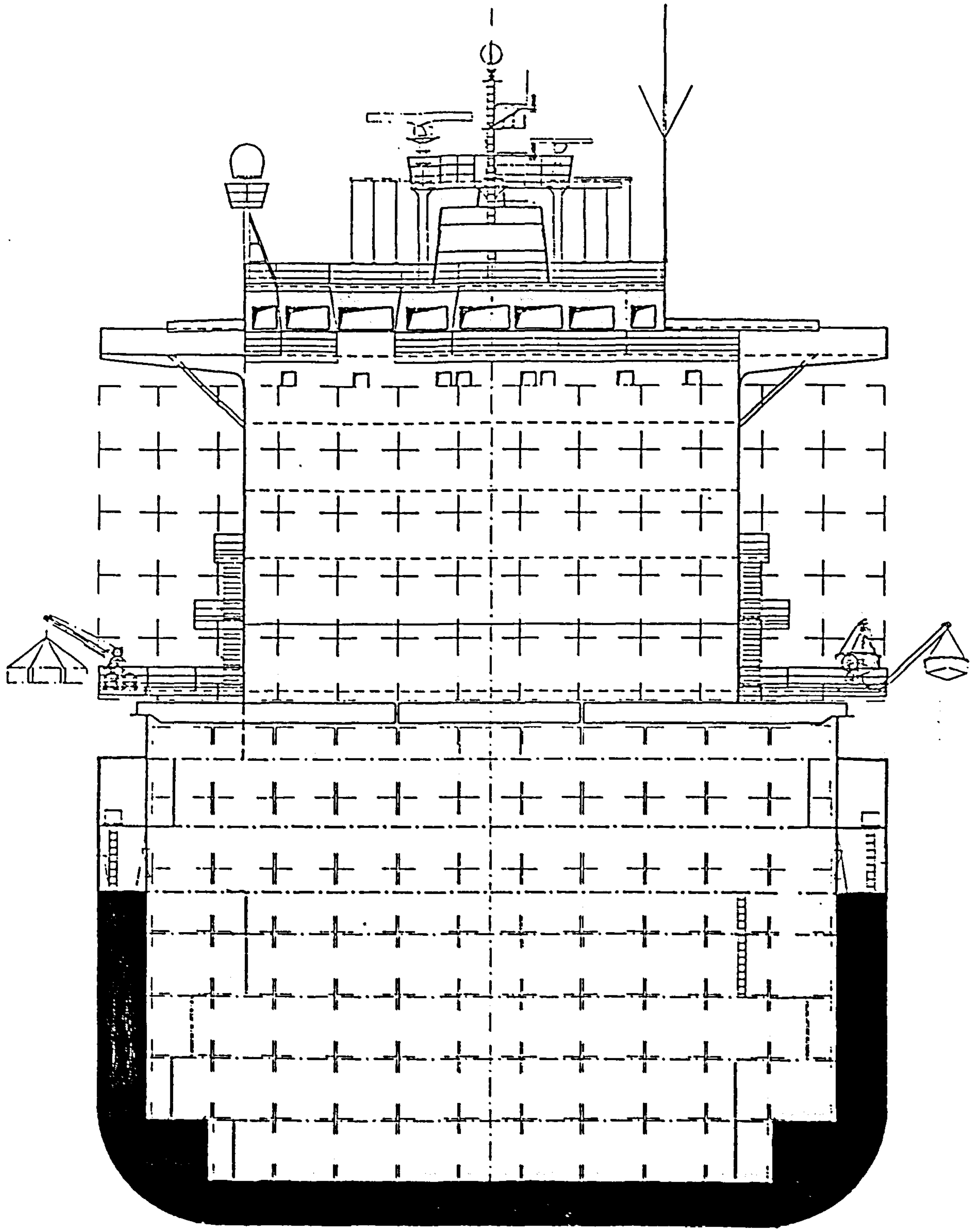

Fig. 1: Chematic-cross-section through a modern container vessel showing the position of the ballast water tanks (shaded).

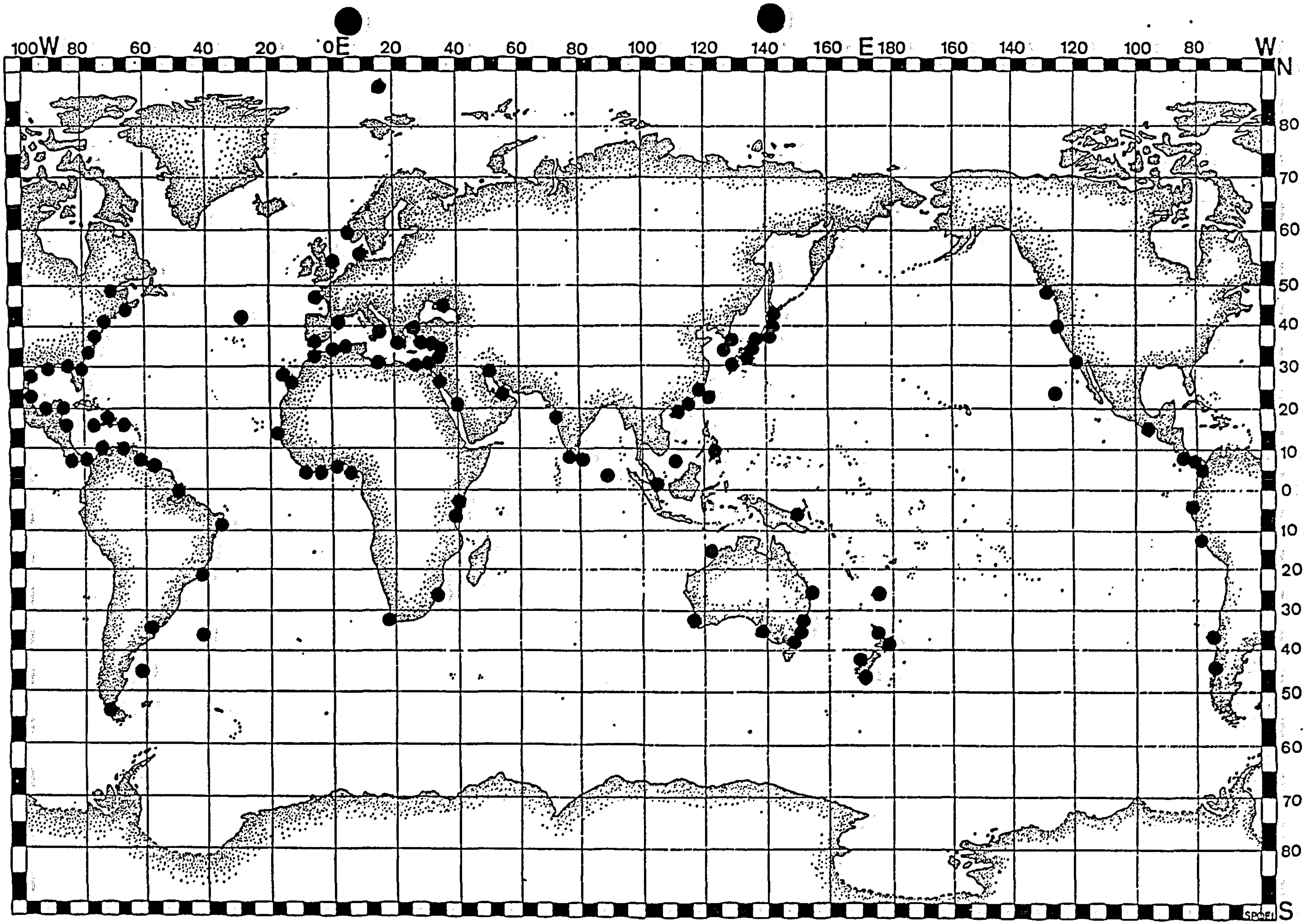

Fig. 2: Geographical origin of vessels investigated.

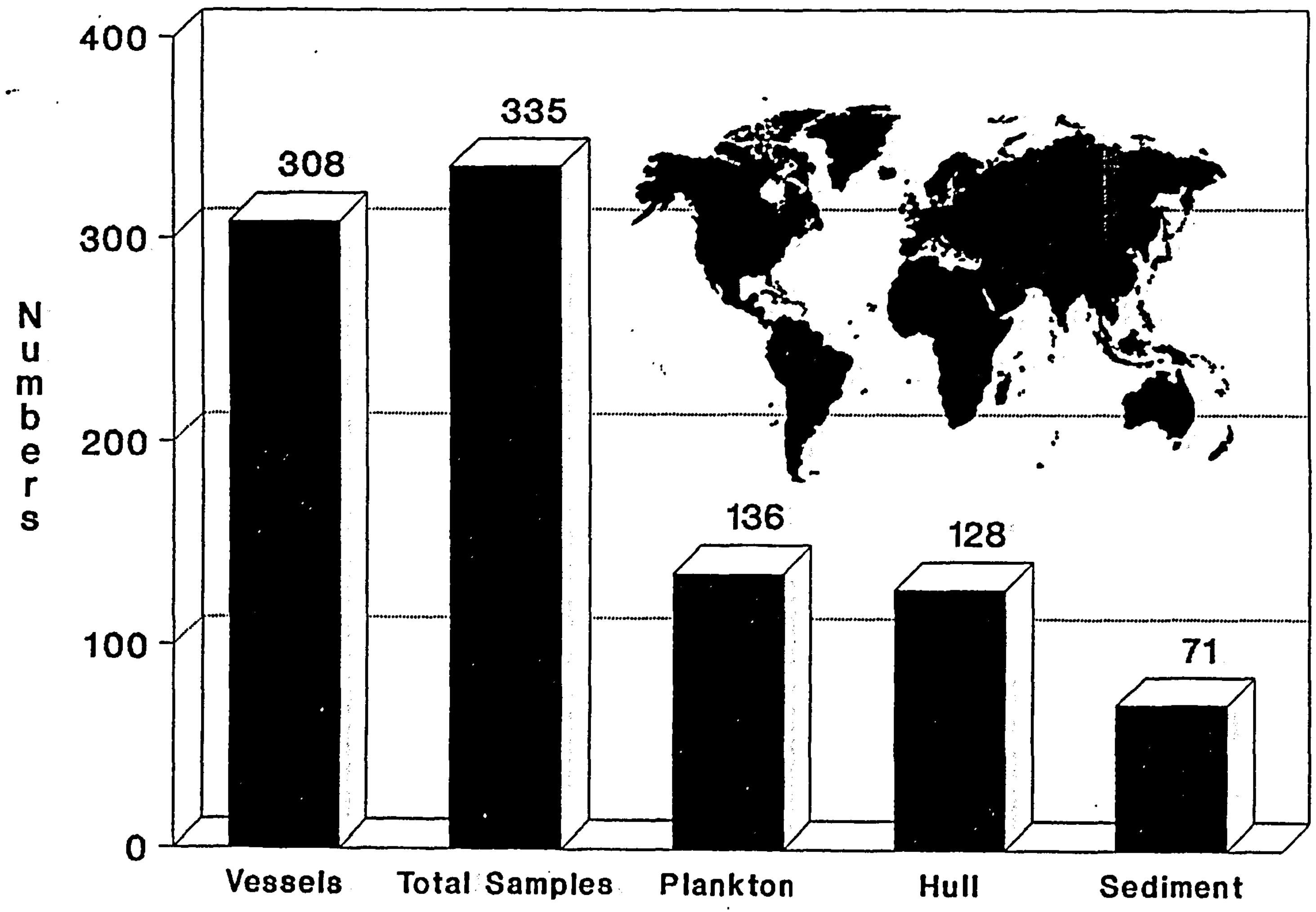

Fig. 3: Number of vessels investigated, total number of samples and specification of samples (March 1992 - July 1995).

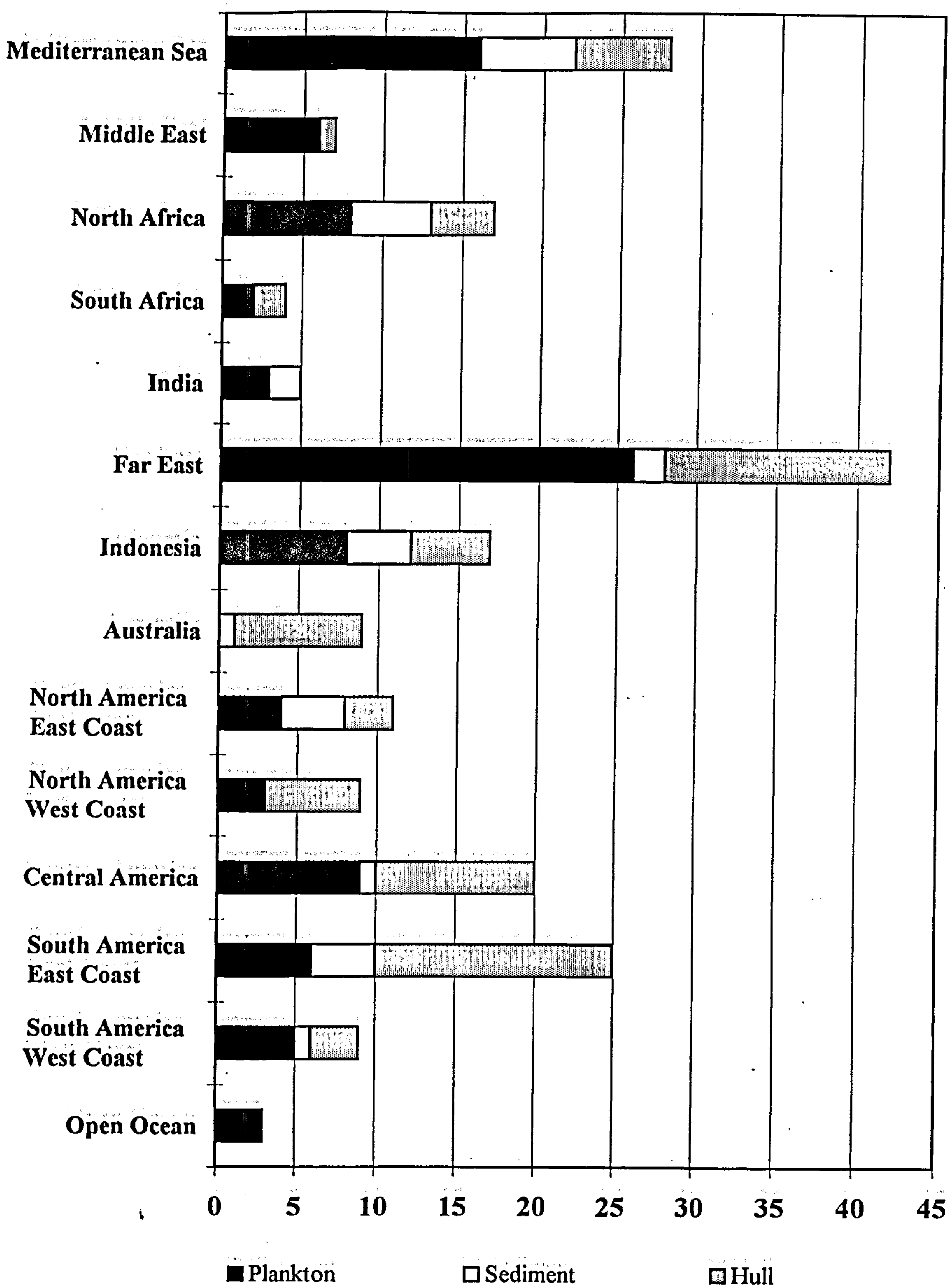

Fig. 4 : Number of plankton, sediment and hull samples according to their geographical origin

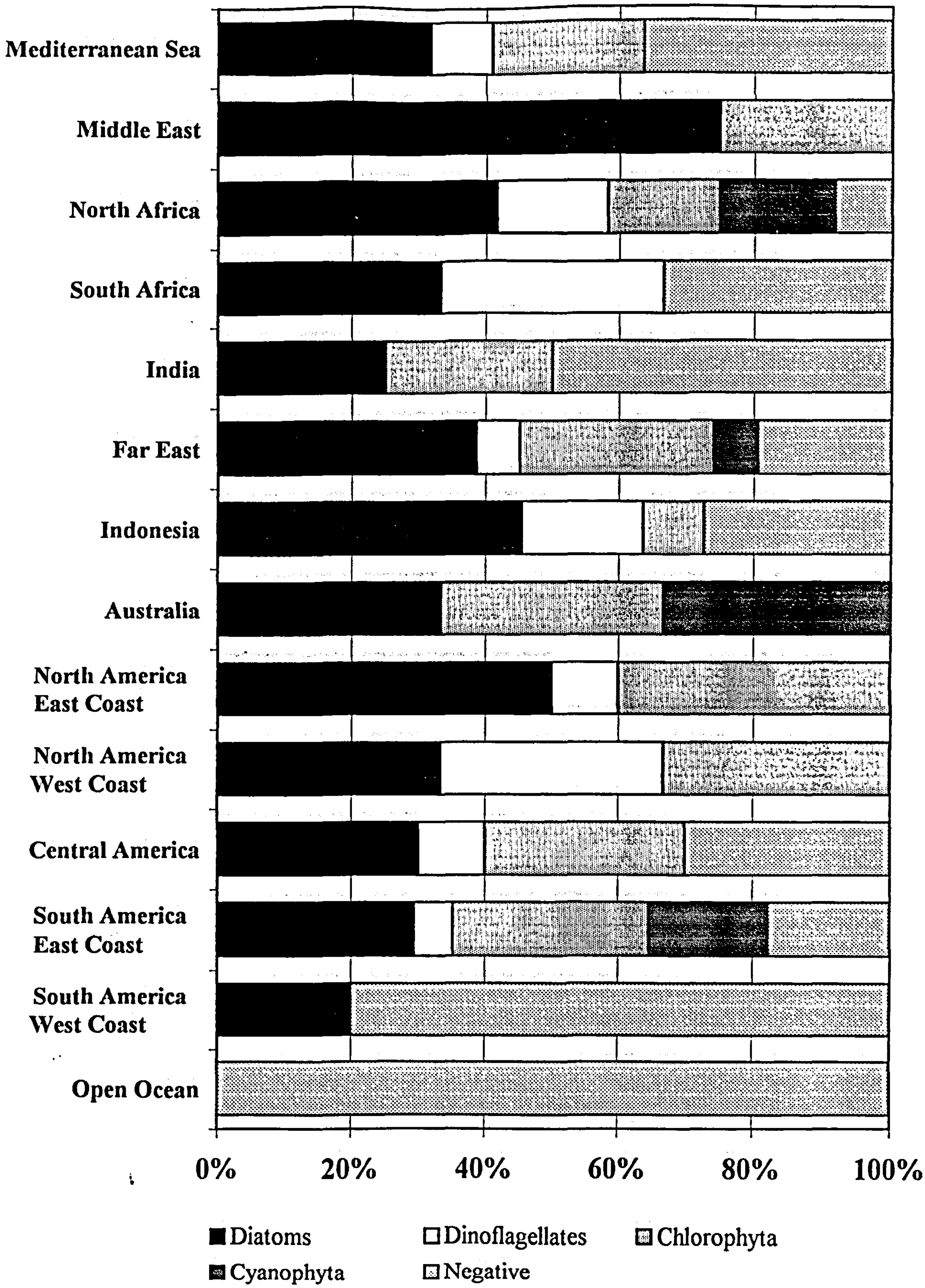

Fig. 5a : Unicellular algae present (%) in ballast water samples according to their geographical origin

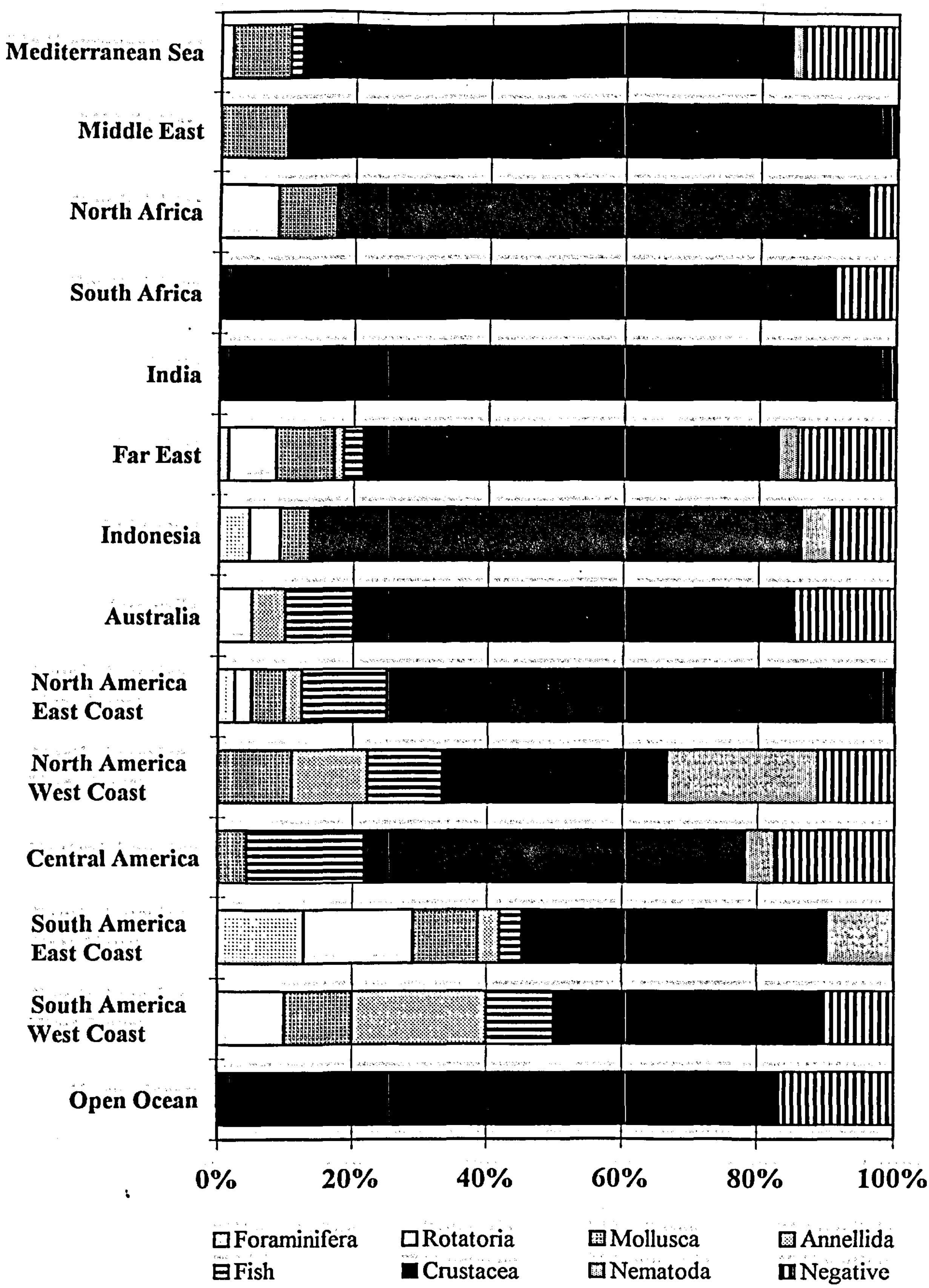

Fig. 5b : Organisms present (%) in ballast water samples according to their geographical origin

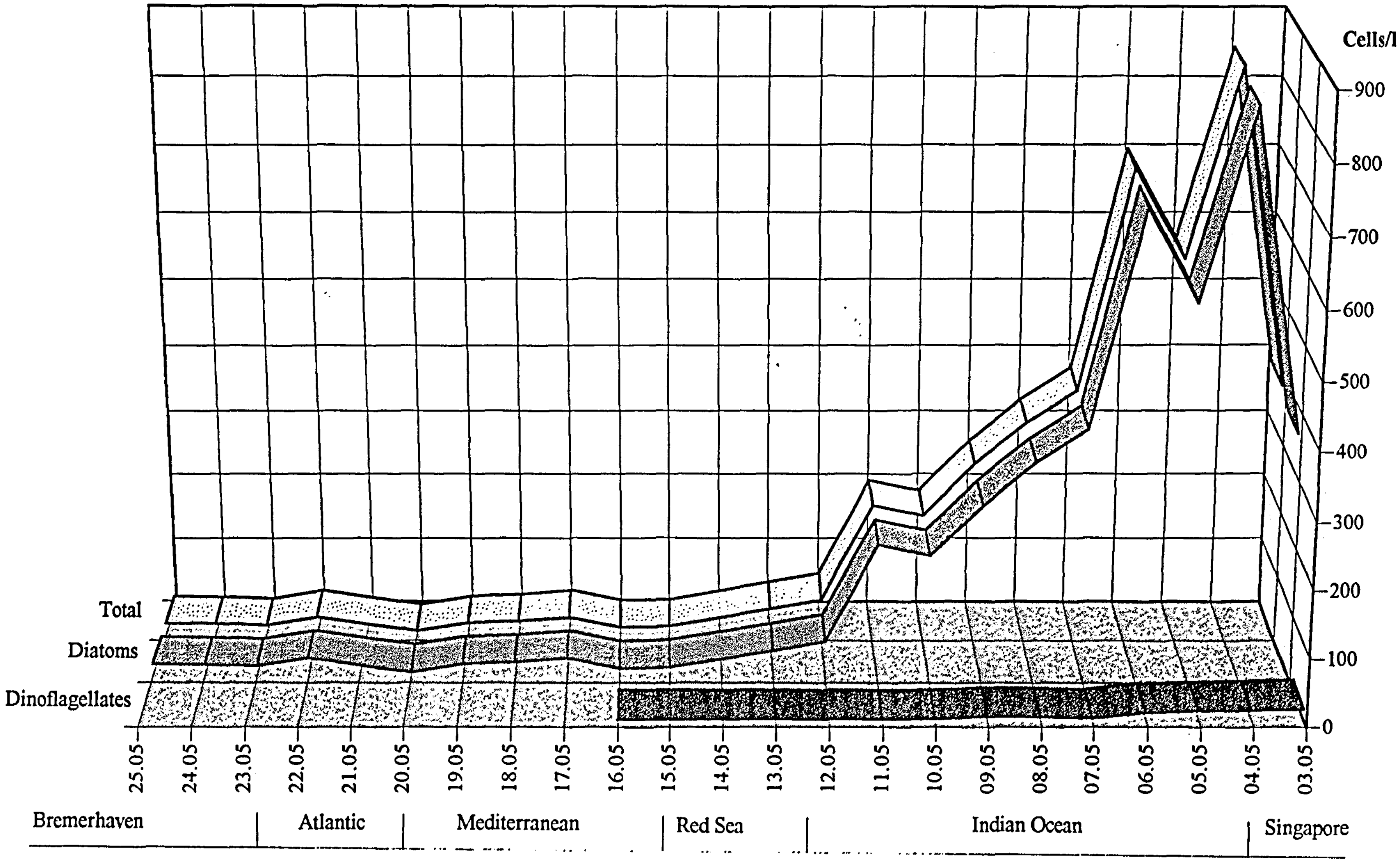

Fig. 6a : Concentration of phytoplankton cells in the aftpeak ballast water of 'DSR-America'

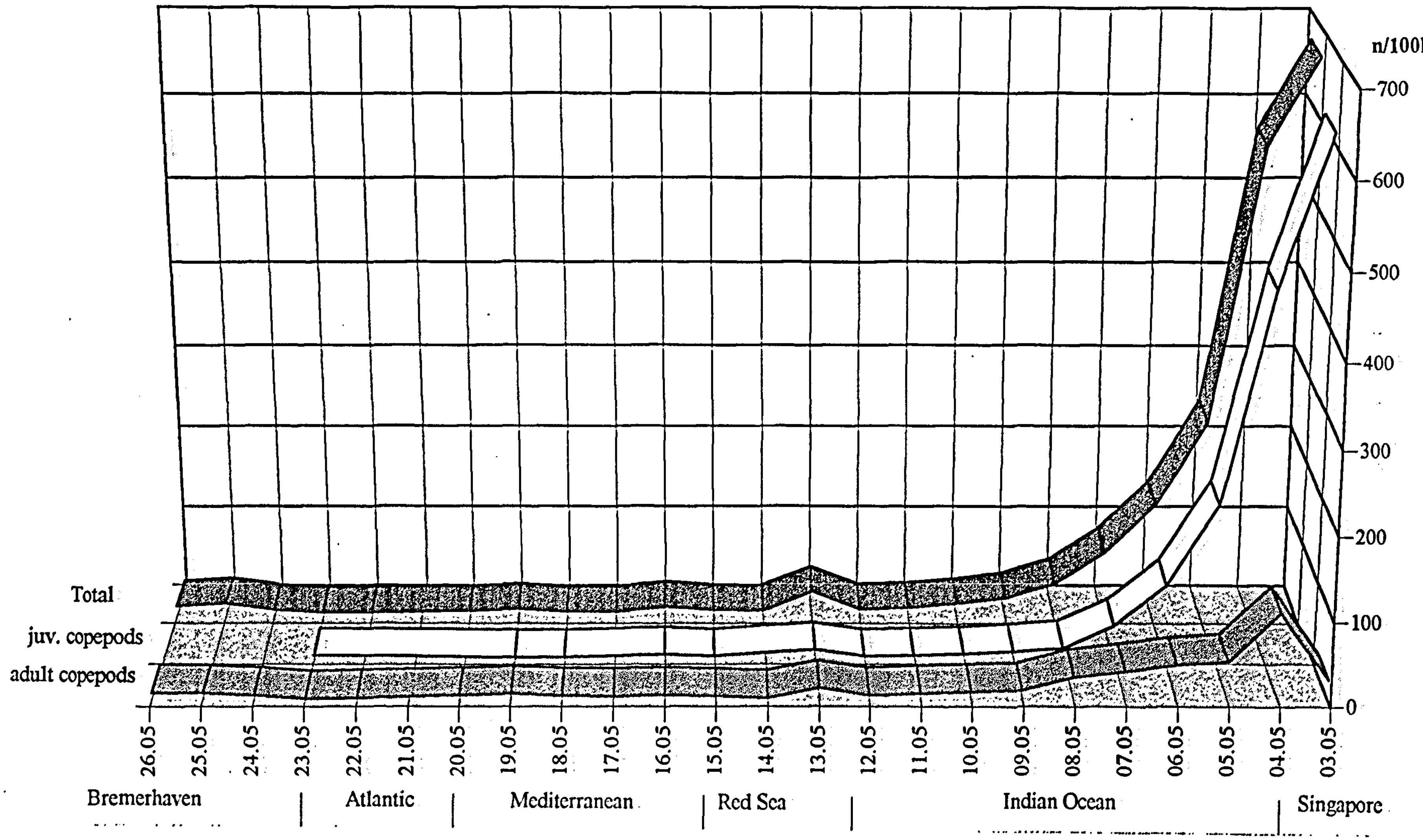

Fig. 6b : Concentration of zooplankton organisms in the aftpeak ballast water of 'DSR-America'

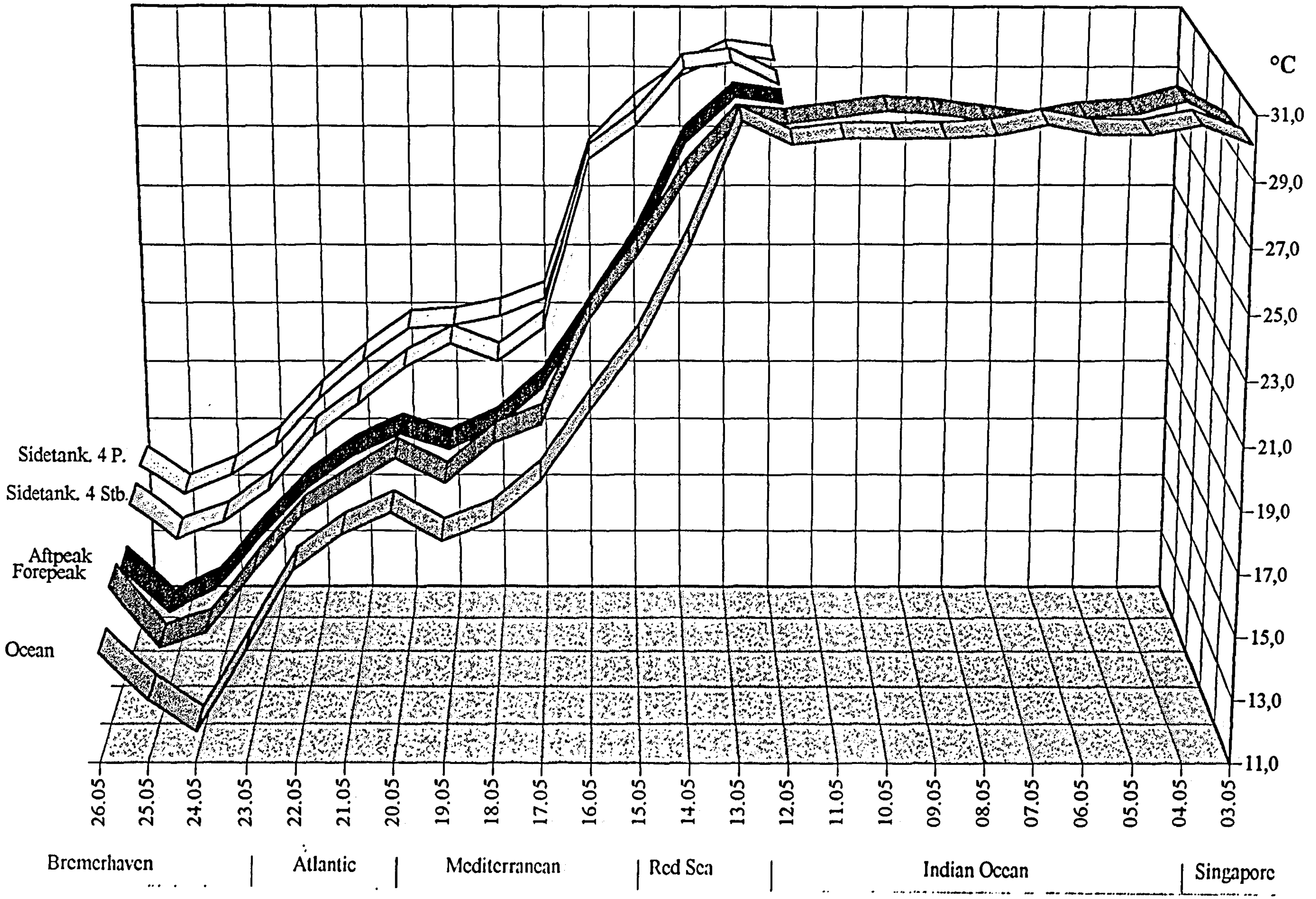

Fig. 7 : Temperature variation in different ballast tanks and the open ocean during the cruise from Singapore to Bremerhaven on board the 'DSR America'

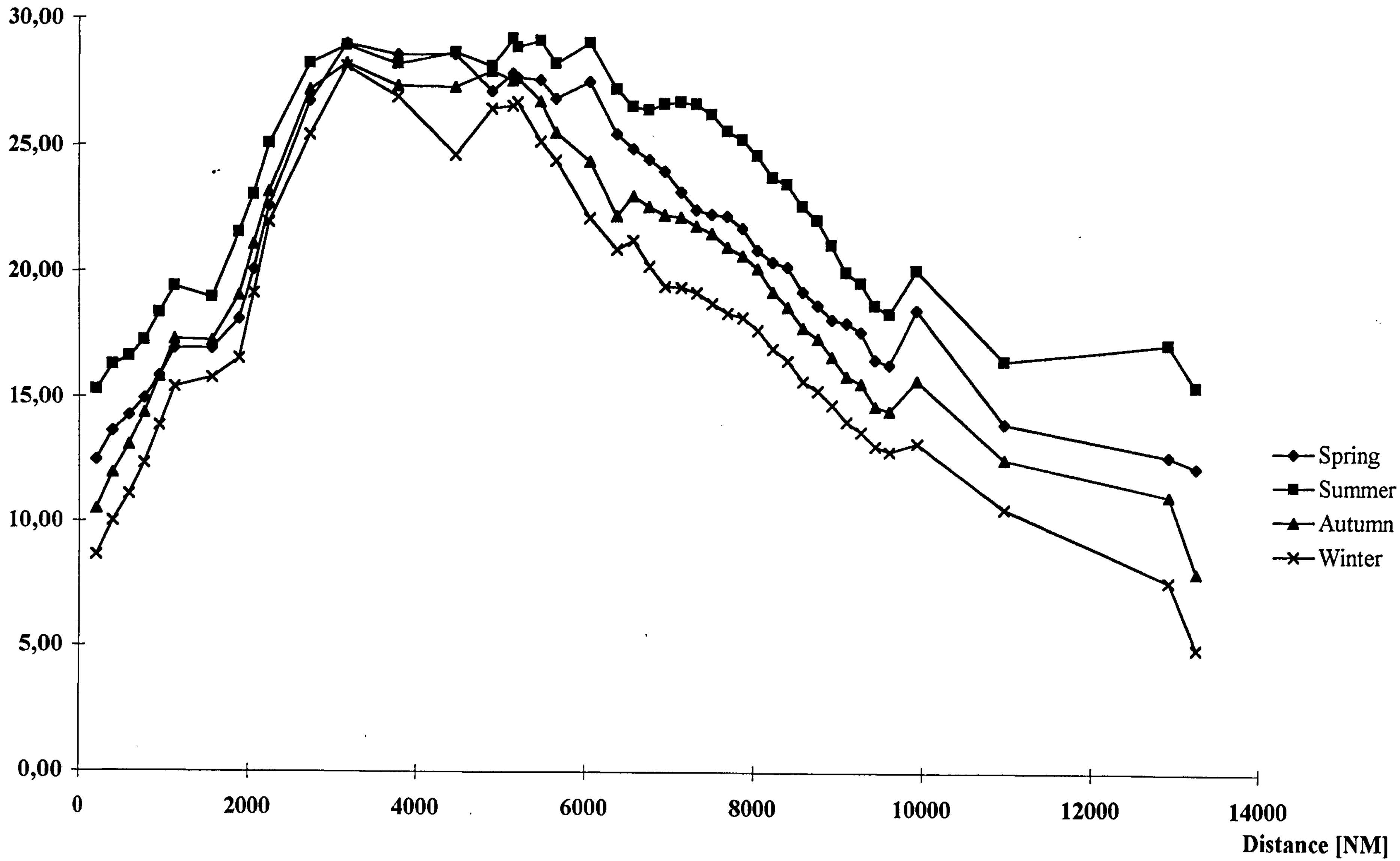

Fig. 8 : North-west American shipping route (Vancouver - Bremerhaven)
Seasonal mean ocean surface temperature
(data from Climatological Atlas of the World Ocean, NOAA 1983)