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Introduction

Deficiency of nutrients, especially nitrogen compounds, is probably the main factor limiting marine primary production [1,2]. The pollution of restructed bodies of water with large amounts of nitrogen and phosphorus compounds can lead to heavy blooms of phytoplankton. This process is well known as eutrophication.

In the case of the North Sea, eutrophication takes place both by natural processes, e.g. the inflow of nutrient rich upwelling ocean water and the run-off from land, as by the introduction of nitrogen and phosphorus compounds by man, e.g. from sewage, effluents or fertilizer run-off. The relative importance of both processes is not well described at the moment.

In this paper a rough estimation is given about the significance of the eutrophication of the North Sea by man. Calculations are made about the possible increase of nitrogen and phosphorus concentrations in the North Sea and the obtained values are compared with some experimental results from literature and from a nitrogen survey in the Dutch coastal area and in the English Channel.

Nitrogen compounds

The sea contains several inorganic and organic nitrogen compounds. The principal inorganic form of nitrogen are nitrate ion (1-500 µg NO_3-N/l), nitrite ion (< 0.1-50 µg NO_2-N/l) and ammonium (< 1-50 µg NH_4-N/l) [2]. The occurrence of dissolved and particulate organic nitrogen compounds is associated with marine organisms. Under the influence of biological factors and by physical effects, such as the sinking of dead organisms and the upwelling of subsurface water, the total-nitrogen concentration of seawater is in the range of 1-500 µg N/l .

The general levels of nitrogen concentrations in sub-surface waters in the Atlantic (300-400 µg N/l) seems to be considerably lower than those in the Pacific and Indian Oceans(500-600 µg N/l) [2]. From this it seems reasonable to take for the total-nitrogen concentration of the ocean waters entering into the North Sea a value of about 300 µg N/l.
A simple calculation will show that the inflow of nitrogen compounds from river water and from the Baltic may be neglected. The annual inflow of 100-200 km3 of fresh water with a maximum nitrogen content of about 250 µg N/l [2] and the effective Baltic inflow of some 500 km3 with maybe a somewhat higher nitrogen value pale into insignificance beside the annual inflow of 20,000-30,000 km3 of ocean water. Therefore, the natural total.nitrogen concentration of the North Sea water may be taken as about 300 µg N/l, largely determined by the inflow of nutrient rich ocean waters.

The amount of nitrogen compounds entering into the environment by man has been estimated at about 10,000 ton of N per year per million of inhabitants [3]. The discharge of these compounds into the North Sea may be calculated from this value and the number of inhabitants living in the countries around the North Sea. As some countries are discharging only a part of their effluents into the North Sea, an estimation is necessarily of the part of the effluents which will ultimately be transported into the North Sea (see Table I). According to this, the number of inhabitants discharging there effluents directly or indirectly (by rivers or via the English Channel and the Kattegat) into the North Sea has been taken as about 100 million. From this the total amount of nitrogen compounds introduced by man into the North Sea becomes in the order of 1 million ton of N. The North Sea contains 55.000 km3 of water with a residence time of about 2-3 year. The annual imput of some 20 µg N/l by man may in the long run increase the average amount of nitrogen compounds in the water by 5-10 %. However, as of course the mixing in the North Sea is far from completeness the enrichment of nitrogen compounds in the coastal areas will be much more pronounced. At the other hand, from the hydrographic model of the North Sea of Laevastu [4] one may expect lower enrichments factors in the central North Sea and in those areas where large bodies of clean ocean water are entering into the North Sea, e.g. at the Northwest inflow and at the Channel inflow.

In the Dutch coastal waters large quantities of nitrogen compounds will enter the sea by the river Rhine, Meuse and Scheldt and by several pipelines and outfalls along the coast and in the estuaries. From the hydrographic pattern of the Dutch coastal waters as given in figure 1, it can be seen that annually about 100 km3 of fresh water from the continent is mixed with about 900 km3 of ocean water flowing into the North Sea through the Strait of Dover to give 1000 km3 of coastal water with an average salinity of 32 ‰. As the volume of the Dutch coastal waters is about 150 km3, the residence time of the water in it will be in the order of two months. With the imput of the effluents of about 40 million people in the Rhine, Meuse and Scheldt basins, the natural concentration of nitrogen compounds in the Dutch coastal waters of 300 µg N/l may increase on an average with some 100-200 % giving values in the range of 500-1000 µg N/l.

Phosphorus compounds

Phosphorus occurs in sea water in a variety of forms, such as free orthophosphate, dissolved organic phosphorus and particulate phosphorus. The total-phosphorus content in the sea water is in the range of < 1-70 µg P/l [2] and closely parallels that of nitrogen compounds as it is regulated by the same agencies. Just as for nitrogen compounds the general levels of phosphorus concentrations of sub-surface waters in the Atlantic (30-50 µg P/l) seems to be considerably lower than those in the Pacific and Indian Oceans (60-100 µg P/l) [2,5].

In the English Channel maximum winter phosphate values of about 20 µg P/l are reported [5], but considerable fluctuation seems to occur [6]. Values reported from the Scottish coastal water indicates about the same phosphorus concentrations as in the English Channel [7].

As was the case for nitrogen compounds, under natural conditions the main sources of phosphorus for the North Sea are clearly the oceanic waters. River water, with a natural phosphorus content of about 20 µg P/l and the Baltic inflow does not contribute significantly to the average natural phosphorus concentrations in the North Sea.

Therefore, the natural total-phosphorus concentration of North Sea water may be taken as about 20 µg P/l.

The amount of phosphorus compounds entering into the environment by man has been estimated at about 1.000-2.000 ton of P per year per million inhabitants [3]. We will take the lower value as the most acceptable one, as it is uncertain which fraction of this phosphorus load will indeed reach the sea when released into rivers and estuaries as it may be partially bounded to bottom sediments.

The same calculation as has been given for the concentrations of nitrogen compounds brings the annual total imput of phosphorus compounds into the North Sea by man on about 100.000 ton P, which may increase the average phosphorus concentration in the water by about 10 %.

In the Dutch coastal waters the 40 million people from the Rhine, Meuse and Scheldt basins will annually release 40.000 ton P. From this and the hydrographic pattern of the area as given in figure 1, it can be calculated that the natural concentration of phosphorus compounds in the Dutch coastal waters of about 20 µg P/l may increase on an average with about 200-300 % giving a value between 50 and 100 µg P/l.

The calculated values for the total-phosphorus concentrations in the North Sea and in the Dutch coastal waters correspond reasonably well with the orthophosphate measurements of Johnston and Jones [7] and Tijssen [8] in winter periods. In the Dutch coastal waters Tijssen found phosphate concentrations in the range of 30-60 µg P/l in February 1968. In the more inshore waters such as the Eastern Scheldt and the Dutch Wadden Sea total-phosphate concentrations between 50 and 500 µg P/l are commonly found, which indicates the strong enrichment of these waters with phosphorus compounds.

Experimental

Water samples were taken from ships of Rijkswaterstaat along the Dutch coast (see figure 2) and during a cruise of the research vessel "Tridens" in the English Channel (see figure 3). The samples were kept deep frozen until analysis. Total-nitrogen analysis were performed in the unfiltered water according to the method of Koroleff [9]. All nitrogen compounds were oxidized to nitrate by heating samples of 10 ml during one hour in a closed bottle with an alkaline persulfate solution at 100 °C. Nitrate formed is determined as nitrite, according to Shinn [10] and Bendschneider and Robinson [11], after reduction in a 15 cm Cd-Cu column [12].

Results and discussion

The experimental results of the total nitrogen determinations in the Dutch coastal waters and in the English Channel are given in the Tables II- VII and are graphically represented in the figures 4- 8.

Nitrogen concentrations in the Dutch coastal waters and in the English Channel agreed reasonable well with the calculated ranges. As could be expected the highest nitrogen concentrations are found close to the coastline. Values of 1-2 mg N/l near to the beaches are no exceptions. Further out of the coastline the nitrogen concentrations rapidly decrease to values in the range 500-1000 µg N/l. At a distance of about 30-40 km from the coastline total-nitrogen concentrations are not very different from the values found in the English Channel under the influence of the Channel inflow.

The total nitrogen concentrations in the surface and sub-surface samples from the English Channel are in good agreement with the nitrate-nitrogen values in the sub-surface waters of the Atlantic as given Riley and Chester[2]) : 300-400 μg N/l.

In view of the seasonal[4]) and long term [6]) changes in the inflow of ocean water into the North Sea and due to analytical errors, it seems hardly possible to detect a 5-10 % increase in the nitrogen concentration of the North Sea as a whole. However, on the basis of the calculations given and the experimental results in the Dutch coastal waters, it seems plausible that such an increase has indeed taken place. Therefore, one may expect that a slight increase in the productivity of the North Sea has taken place at the moment. Indeed there appears to have been, during the past decade, a real increase in the natural productivity of the North Sea bottom living fish [13]), but this effect is not necessary related to man-made eutrophication.

The absence of biological effects in the strongly eutrophicated Dutch coastal waters is difficult to understand. It is possible that these effects are obscured to a large extent by the relative high amount of suspended particulate matter in these areas, making light penetration the limiting factor in productivity.

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TABLE I: Population of the countries around the North Sea (1971).

Country	Population	Direct or indirect discharging into the North Sea
Belgium (+ Lux.)	10.0	10
Denmark	4.9	4
France	50.8	10
Federal Republic of Germany	59.5	50
Netherlands	13.3	13
Norway	3.9	1
Sweden	8.0	2
United Kingdom	55.7	20
All countries	206.1	> 100

TABLE II - Total nitrogen concentrations of the line I.

1973	28 June		17 July		14 August	
Sample code	µgat/l	µg/l	µgat/l	µg/l	µgat/l	µg/l
1	122	1708	118	1652	108	1512
2	88	1232	106	1484	58	812
3	92	1282	112	1568	68	952
4	100	1400	52	728	61	854
5	15	210	32	448	80	1120
6	22	308	29	406	42	588
6 A	-	-	24	336	-	-
6 B	-	-	26	364	-	-

TABLE III - Total nitrogen concentrations of the line II.

1973	28 June		17 July		14 August	
Sample code	µgat/l	µg/l	µgat/l	µg/l	µgat/l	µg/l
7	32	448	80	1120	60	840
8	48	672	77	1078	69	966
9	40	560	83	1162	74	1036
10	64	896	47	658	45	630
11	24	336	43	602	39	546
12	38	532	37	518	30	420
12 A	-	-	26	364	-	-
12 B	-	-	19	266	-	-

TABLE IV - Total nitrogen concentrations of the line III.

1973	17 July		2 August		14 August	
Sample code	µgat/l	µg/l	µgat/l	µg/l	µgat/l	µg/l
13	81	1134	44	616	64	896
14	65	910	51	714	54	756
15	60	840	52	728	50	700
16	53	742	54	756	47	658
17	50	700	45	630	50	700
18	45	630	42	588	37	518
18 A	-	-	-	-	23	322
18 B	-	-	-	-	16	224

TABLE V - Total nitrogen concentrations of the line IV.

1973	17 July		1 August		14 August	
Sample code	µgat/l	µg/l	µgat/l	µg/l	µgat/l	µg/l
19	91	1274	54	756	90	1260
20	89	1246	48	672	64	896
21	57	798	43	602	62	868
22	54	756	36	504	49	686
23	30	420	35	490	51	714
24	37	518	-	-	38	532
24 A	-	-	-	-	25	350
24 B	-	-	-	-	22	308

TABLE VI - Total nitrogen concentrations of the line V.

1973	9 July		17 July	
Sample code	µgat/l	µg/l	µgat/l	µg/l
25	-	-	100	1400
26	-	-	95	1330
27	-	-	95	1330
28	109	1526	-	-
29	134	1876	-	-
30	136	1904	-	-
31	40	560	-	-
32	42	588	-	-
33	57	798	-	-
34	35	490	-	-
35	82	1148	-	-
36	67	938	-	-
37	125	1750	-	-
38	230	3220	-	-

TABLE VII - Total nitrogen concentrations in water samples from the English Channel.

1973	17-22 August	
Sample code	µgat/l	µg/l
K_1	21	294
K_2	21	294
K_3	28	392
K_4 a)	24	336
K_5 b)	20	280

a) sample taken from 55 m depth
b) sample taken from 40 m depth

Figure 1

Schematic picture of the hydrografic pattern of the Dutch coastal waters.

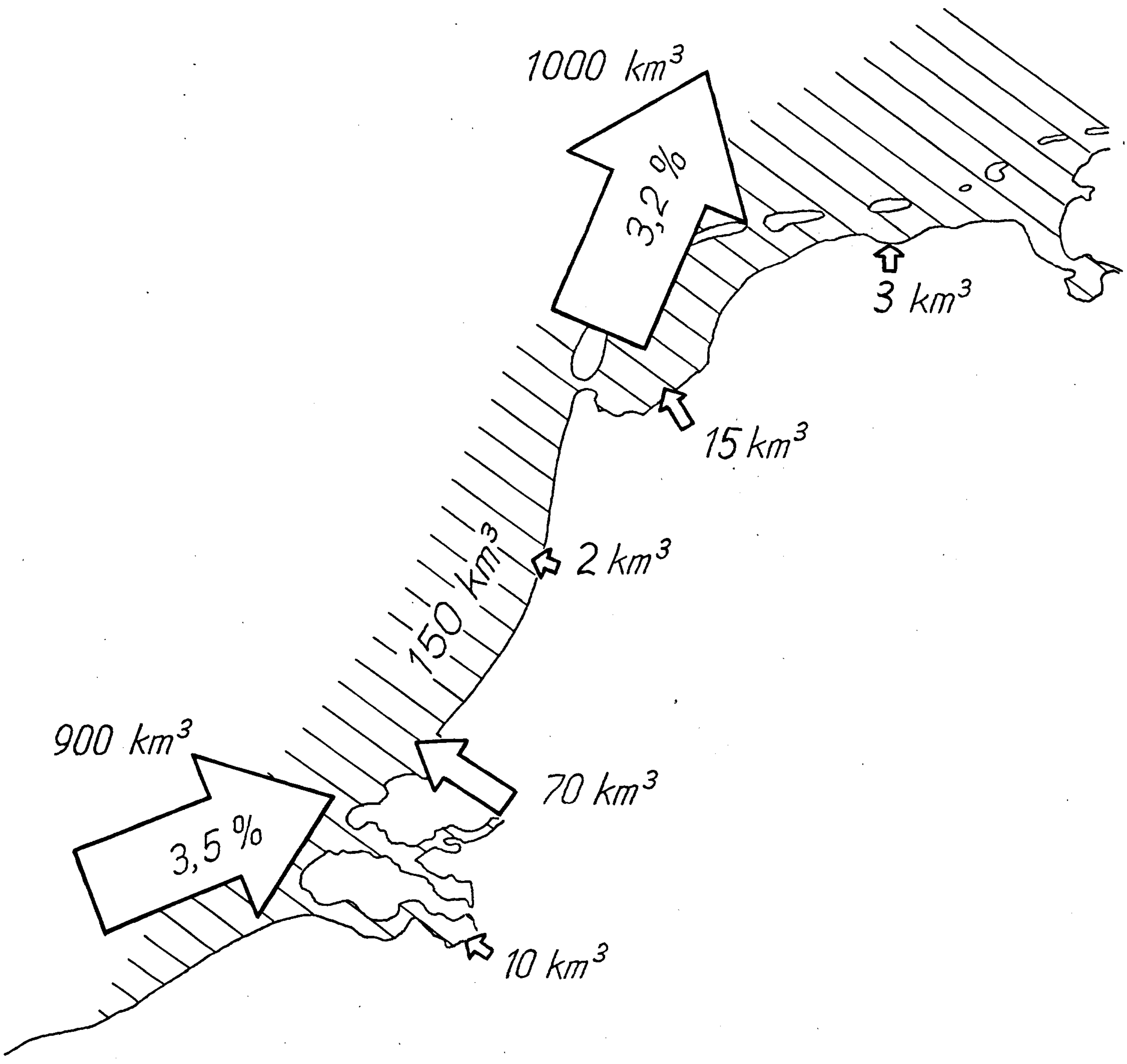


Figure 2 - Sampling lines in the Dutch coastal area.

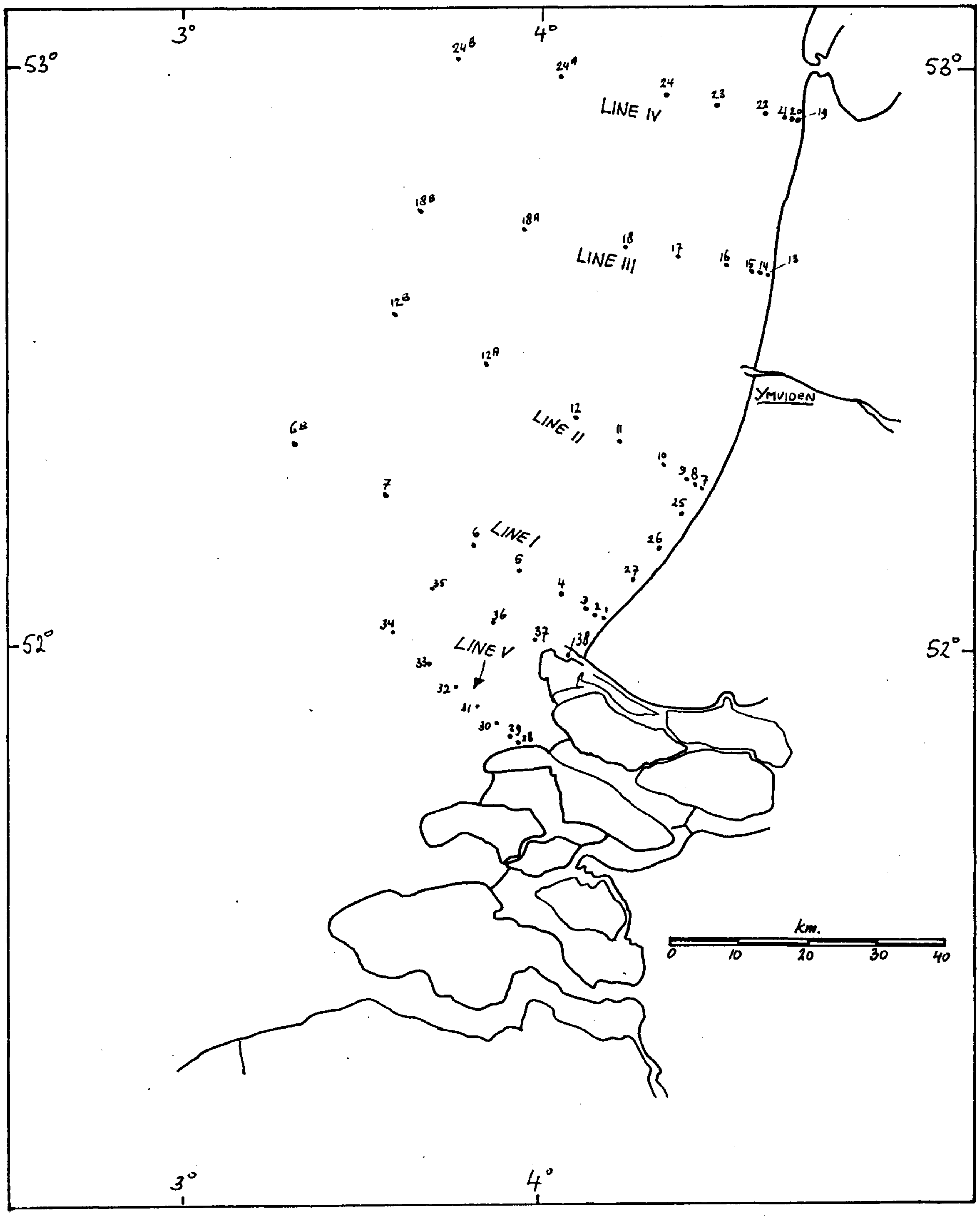
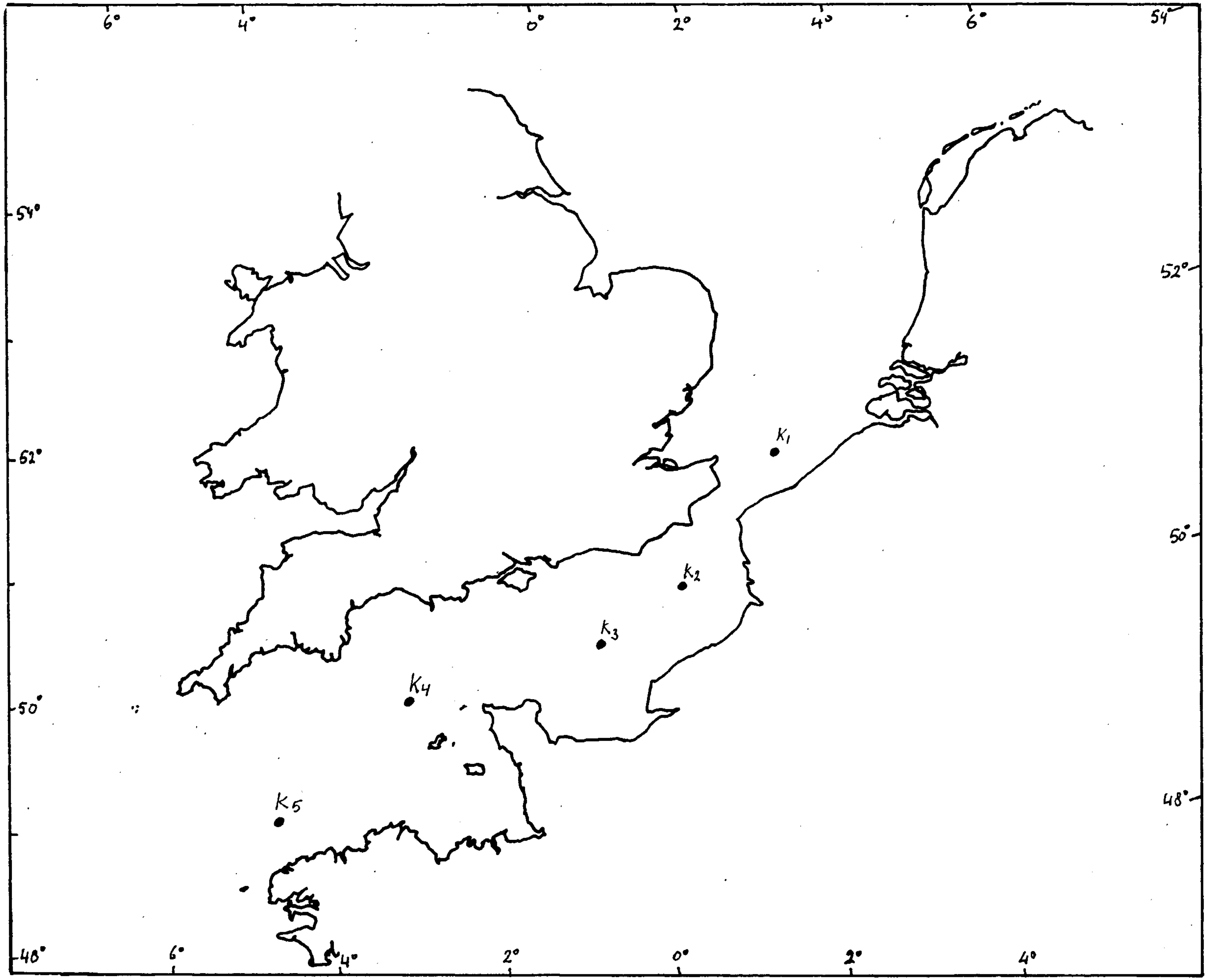


Figure 3 - Sampling stations in the English Channel.



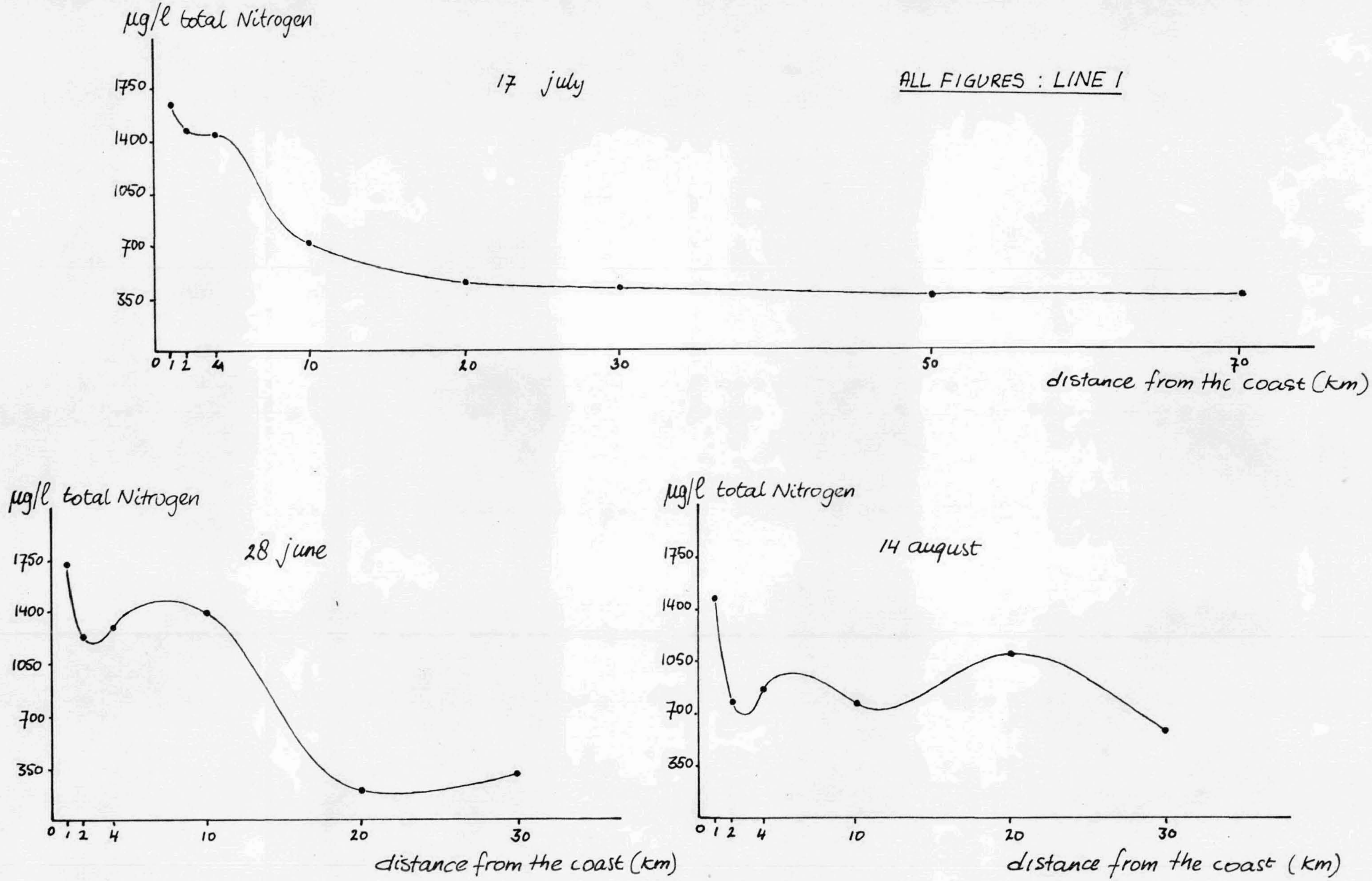


Figure 4 - Total nitrogen concentrations of the line 1.

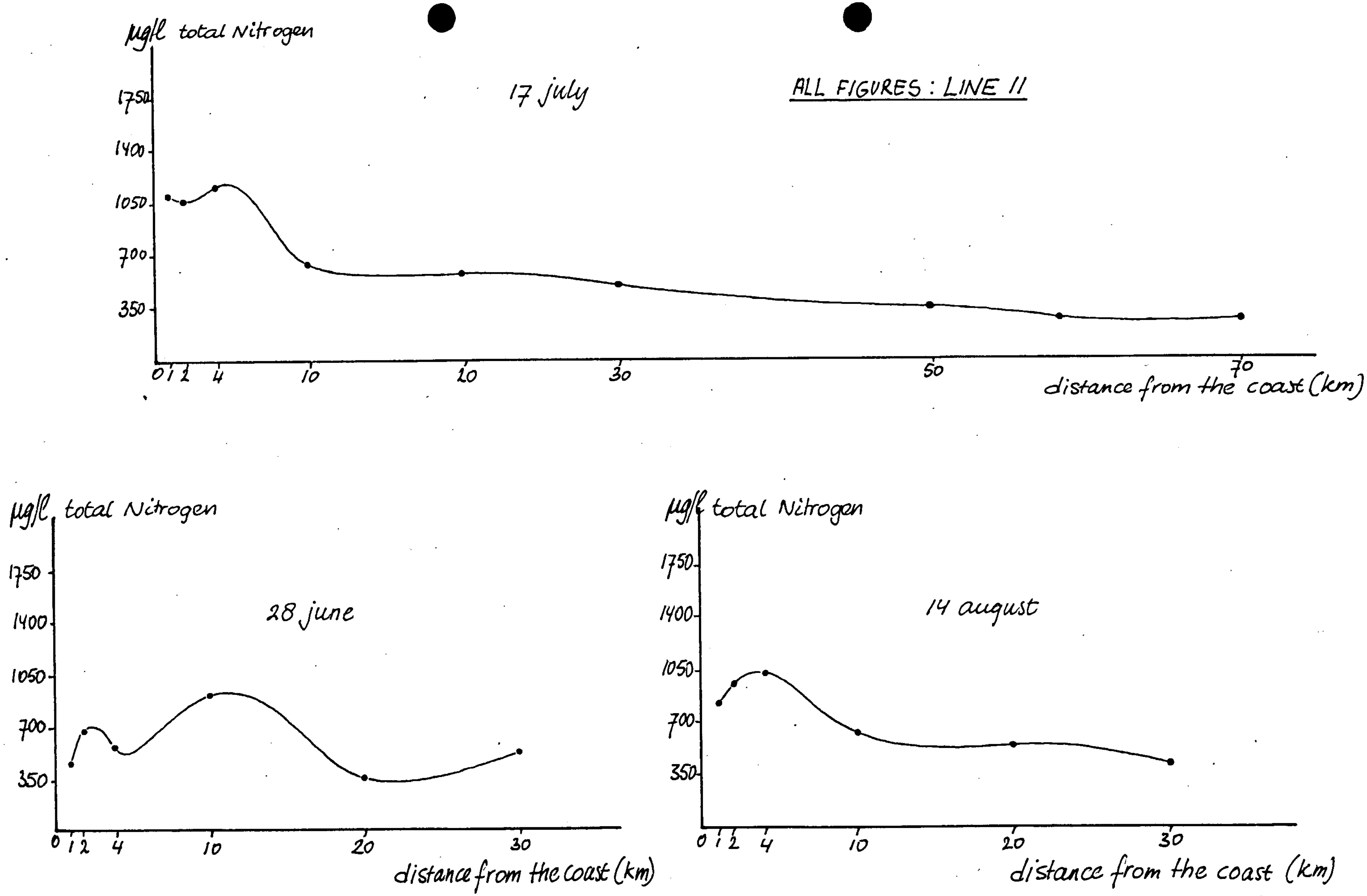


Figure 5 - Total nitrogen concentrations of the line II.

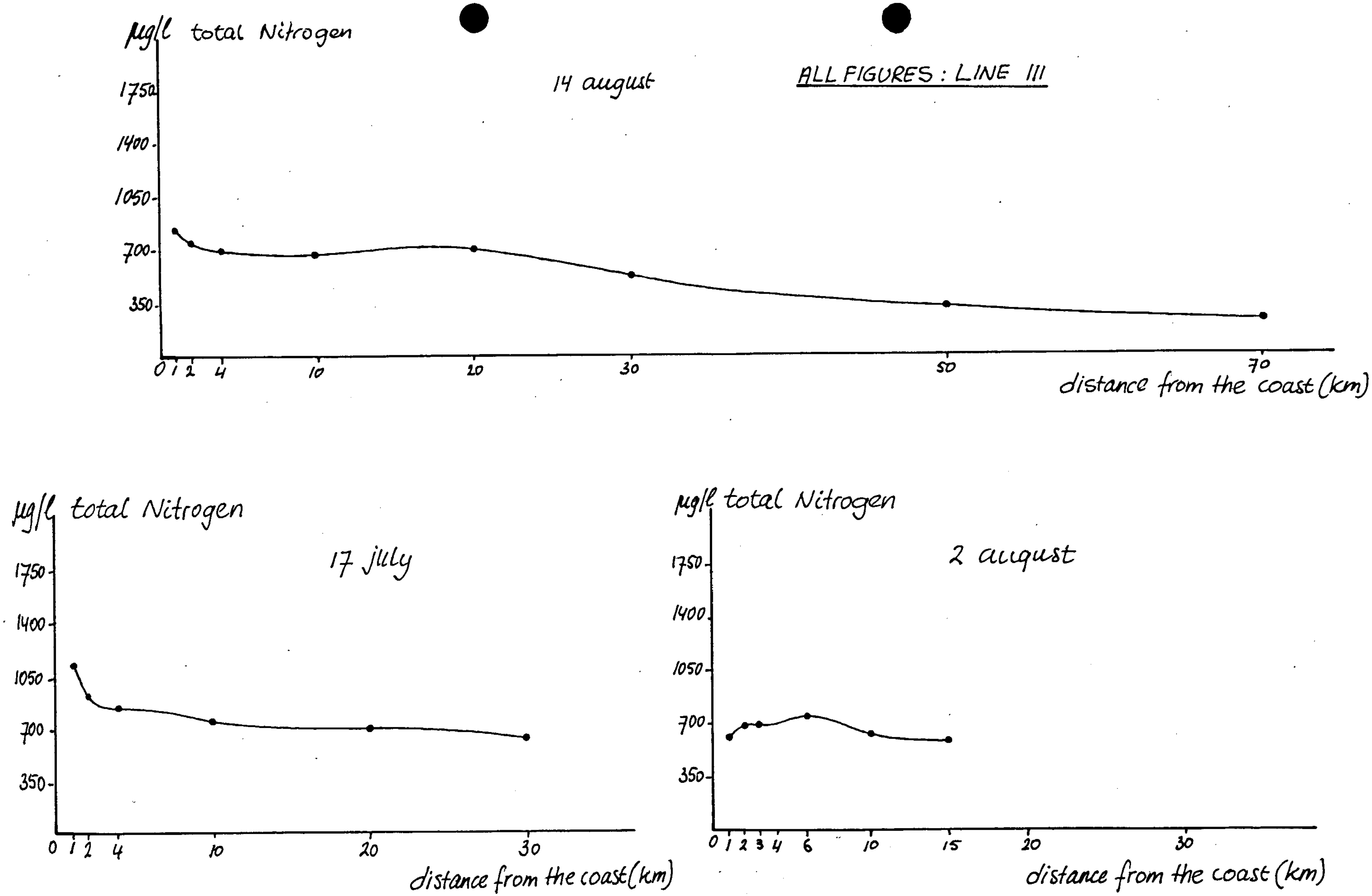


Figure 6 - Total nitrogen concentrations of the line III.

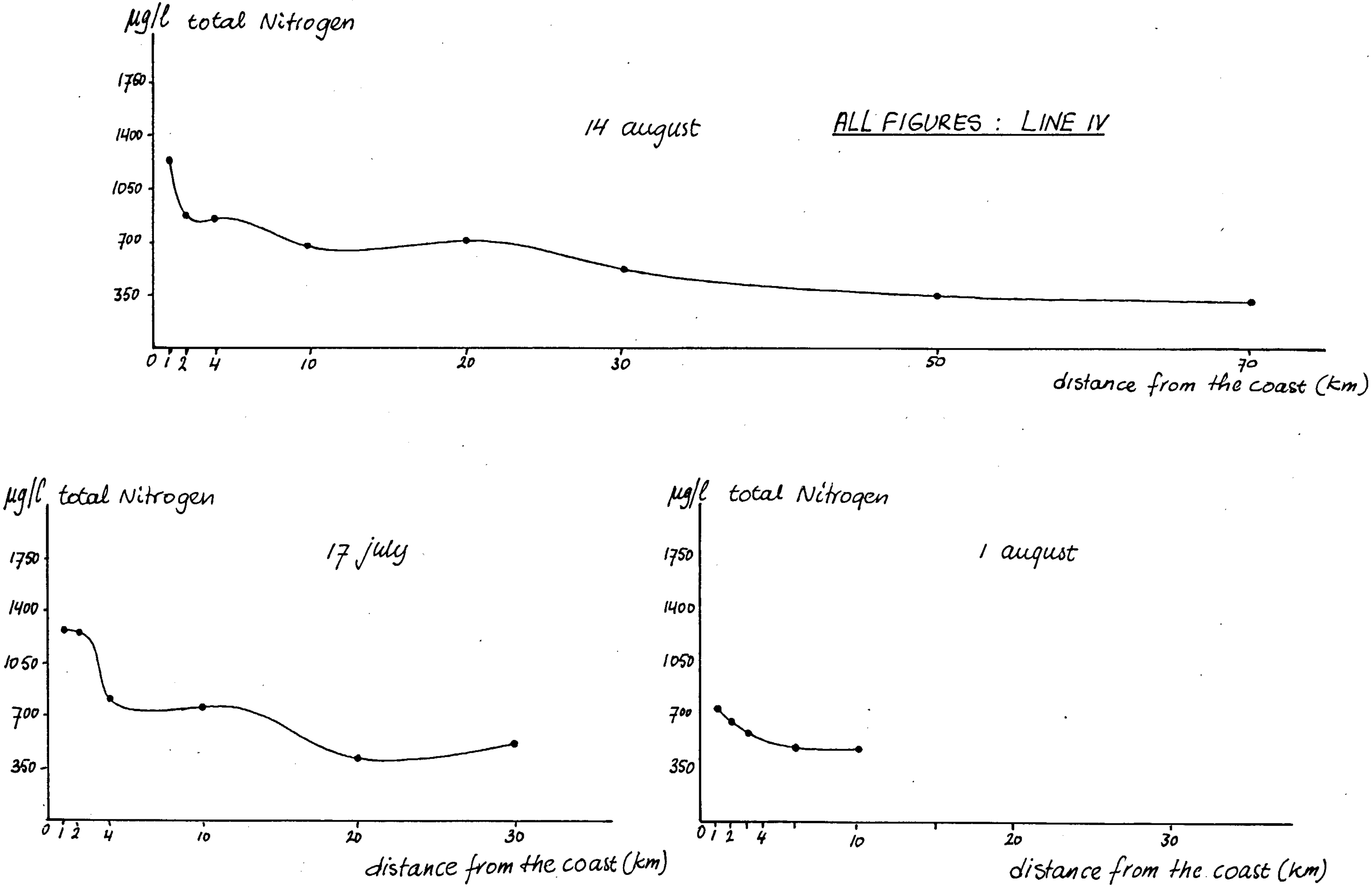


Figure 7 - Total nitrogen concentrations of the line IV.

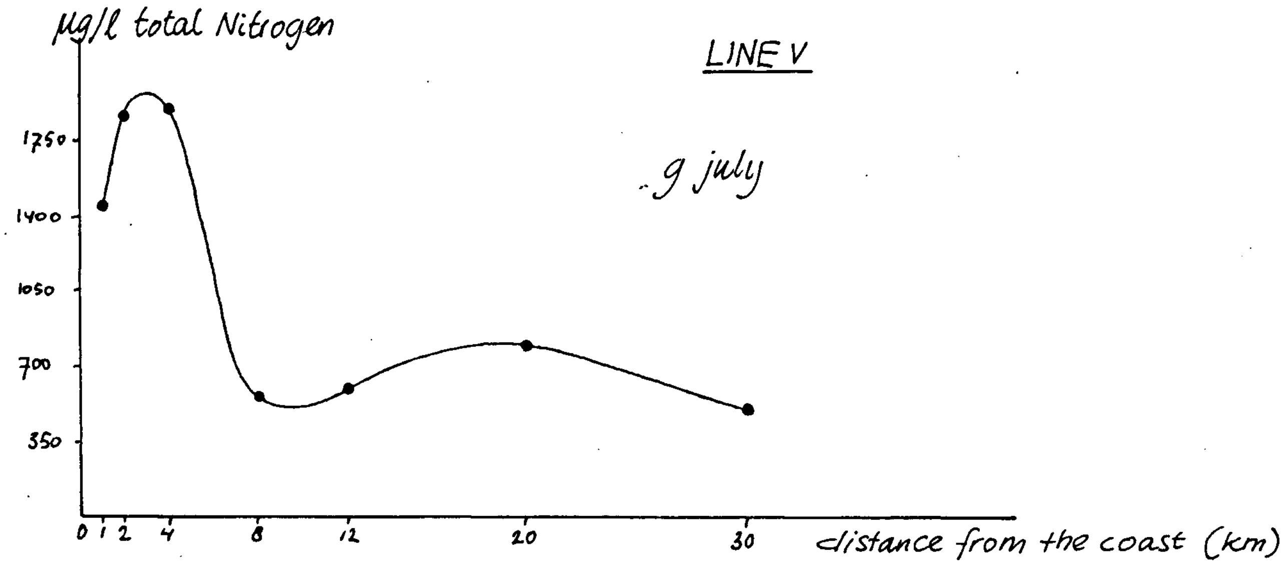


Figure 8 - Total nitrogen concentrations of the line V.