I.C.M.B.-C.I.P.S.

MATHEMATICAL MODEL OF
POLLUTION IN THE NORTH SEA

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EXPERIMENTAL STUDY OF THE POSSIBLE TOXIC EFFECTS OF POLLUTANTS PRESENT IN WATER SAMPLES OF THE NORTH SEA AND THE SCHELDT ESTUARY, THROUGH ACCUMULATION IN AN EXPERIMENTAL PELAGIC FOOD CHAIN

by

G. PERSOONE and G. UYTTERSPROT

State University of Ghent
Laboratory for Biological
Research in Environmental
Pollution

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1. Introduction and Methodology

As the present report is the continuation of experiments started in 1972 we should like to refer the reader to our previous technical report : 1972/Physiol.-Synthese 03, in which the motivation of the present study and the methodology are described in detail.

Briefly summarizing, it was intended to find out if, starting from rather large volumes of natural seawater samples taken at different places in the North Sea and the Scheldt estuary, we would be able to detect any influence of polluting substances on the three trophic levels of an experimental pelagic food chain.

The experiments were carried out as follows : mass culturing of a marine unicellular alga (Dunaliella viridis TEODORESCO) in 30 liters of each seawater sample; feeding of 100.000 Artemia salina larvae for 2 days with the harvested algae, and finally feeding 2 fish (Brachydanio rerio HAMILTON) for about one month with the deep-frozen Artemia larvae.

For each experiment half of the harvested algae and brine shrimp larvae, as well as the two test fish were sent to specialized laboratories for chemical analyses.

2. Sampling procedures and sites

In Fig. 1, which gives the covered investigation area of the Mathematical Model of the North Sea, two regions of interest have been selected, the first is adjacent to the belgian coast, the second one is the Scheldt estuary up to the mouth of the Rupel.

In the coastal region 40 liter water samples have been collected since 1972 at sites located in the triangle formed by the shore-line and the sampling points 1, 8 and 5. The precise location of the sampling stations is given in Fig. 2. As can be seen from the graph, there are two distinct sampling regions, one parallel to the coast-line (points 1007, 1020, 1035, 1034, 1049, 1065, 1097, 1096, 1167 and 1251) another one more off-shore (points 1258, 1257, 1275, M 55 and M 06).

In the Scheldt estuary the 7 sampling points were the following (Fig. 3) :

1. Hansweert at Buoy 44
2. Hansweert at Buoy 55
3. Doel
4. Buoy 94
5. Loodswezen
6. Rupelmonding
7. Boerenschans

3. Results

a. First trophic level : the Algae

Table 1 shows the results of the mass culturing of algae on 30 liter water samples. From these data, it is clear that the growth rate of the algae differs considerably from one place to another, due to differences in water quality (including the possible presence of pollutants).

In some cases, we could already harvest the algae after 3 days, in other ones, we had to wait one week to have a sufficient algal biomass.
In general the algal growth was faster on the natural sea-waters than in the artificial sea-water control. Since the salinity of the estuarine water samples had to be raised by addition of synthetic sea salts, it is quite normal that the growth of the algae in these media was slower compared to the algal growth in the off-shore waters.

b. Second trophic level : the Artemia larvae

As neither the exact rate of growth, nor the mortality of the brine shrimp larvae have been determined precisely, we cannot give any data on the effects of a possible toxicity on this link caused by algal contamination. Daily observations showed, however, that generally the survival was very high but that at the end of the experiment there were notable differences in larval growth rate. In three cases there was a rather high mortality of the brine shrimp larvae namely for points : 1251, M 55 and 1258. These mortalities had an indirect repercussion on the third trophic level of our experimental food chain (Brachydanio rerio). Indeed, instead of being able to feed the fish with Artemia larvae for about one month, the smaller quantities of food only lasted for shorter periods, ranging from two to three weeks.

c. Third trophic level : Brachydanio rerio

As already mentioned, the feeding period varied from 15 up to 33 days depending on the quantity of food available. In 8 of the 22 experiments mortality of the test-animals occurred. In 5 cases both fish died, in 3 other cases only one. No mortality occurred in the control.
Typical symptoms of intoxication have been observed even

several days before death : continual rotation of the animal around its longitudinal (cranio-caudal) axis, a symptom which intensified with time. After 3 days while still rotating around their longitudinal axis, the fish started to swim around in circles, which, became smaller and smaller. Death then followed within 48 hours.
As the number of test-organisms was very limited, we could not examine them histologically. The symptoms, however, all seem to indicate a disturbance of the equilibrium and coordination centers probably pointing to lesions of the cerebellum and periferic nerve system.

From table 1, it appears that most of the mortalities occurred during the third week of feeding, (14 to 22 days after the first feeding). Other mortalities were noted in the fourth and even the fifth week.

As several experiments had to be stopped due to the lack of food after 2 to 3 weeks, it is not excluded that other cases of fish mortalities could have occurred if the experiments would have been continued.

In Figs. 2 and 3 the results concerning the third trophic level have been plotted. The much higher mortality in the North Sea samples compared to those in the Scheldt estuary is striking. Indeed in 7 samples of the latter we only found 1 case of toxicity (1 dead fish after 21 days in the sample from Buoy 94).

Along the belgian coast, we found 4 cases of fish mortality, all from samplings made in the area offshore from Nieuwpoort to Ostend.

In the open sea, we found 3 cases of toxicity : 1 at point 6 (1 dead fish), the 2 others at points 1275 and 1257 with in both cases death of the 2 test-fish.

d. Chemical analyses of the experimental organisms

As already mentioned after each experiment 50 % of the algal biomass as well as 50 % of the Artemias and both the test-fish were sent to specialized laboratories for detailed chemical analyses.[1]

The information which we have received is unfortunately rather poor, which, as we were told, appears to be due to the small weight of the samples; thus the number of analyses possible was limited.

Furthermore, due to a lack of coordination between the implicated laboratories, the test material has undoubtedly not been fully exploited.

Anyhow, the only information which we received until now is the amount of mercury and copper in the algae (first trophic level) and the level of pesticides and PCB's in some of the fishes (third trophic level).
These data are shown in Table 2.

4. Discussion

Before entering details, it has to be kept in mind that each result should only be correlated to that particular water sample collected "... at a certain moment of a certain day at a certain place... ".

This means that if one wants to statistically correlate mortalities with the possible presence of pollutants at that specific moment in that particular water, one needs thorough chemical analyses of the sea-water in question.
At the start of the experiment it was agreed that we would obtain all this information. In reality, none of the 22 samples have been analyzed for organic pollutants. Moreover only those from the Scheldt estuary have been examined for the presence of heavy metal ions (Zn, Cd, Pb, Cu).

([1]-*Laboratorium voor Farmacognosie en Fytochemie, V.U.B.*
-Institut de Recherches Chimiques, Tervuren
-Ministerie van Landbouw)

With only very poor chemical data available on the fish, and with no data concerning the presence of either inorganic or organic pollutants in the water, it was virtually impossible to detect the very death cause of our test-animals. Nevertheless the following interesting facts were noted :

1. The water of the Scheldt estuary apparently didn't very much harm our tentative food chain, although from previous chemical analyses it is clear that the water is strongly polluted.
   This leads us to conclude that the fish mortalities in North Sea water samples are due either to other toxicants, or that the concentration(s) of pollutants in the samples of the Scheldt estuary at the very moment of sampling, just happened to be below the "critical" level of intoxication.

2. In the North Sea most of the water samples collected a few miles offshore the coast between Nieuwpoort and Oostende, showed to be toxic through accumulation of some (unknown) substance(s) into the food chain; those east of Oostende on the contrary did not influence the test-organisms. As the considered region is undoubtedly influenced by discharges from the coastal area, it is probable that chemicals released by either sewers or by the Nieuwpoort or Ostend harbours are at the origin of these numerous fish mortalities. Comparing Fig. 2 and Table 2, it is striking that points 1007, 1020, 1035 and 1049 show a much higher concentration of mercury in the algae (with a maximum of 3,5 ppm for point 1035).
   Moreover, if one compares the "period to fish-death" at these particular points (between Nieuwpoort and Ostend) to that of the other points where a fish kill occurred too (offshore area), it is striking that the toxicity occurs much earlier in the former (already starting during the second week).

So it is quite possible that mercury, either or not acting synergetically with other pollutants could be in some way correlated with the fish-mortalities.

3. Further offshore between points MO 6 and MO 7 all the examined water samples were in some way toxic to either the second or the third link of our experimental food-chain.
This time it is striking that the area in question is a region where there is a regular dumping of solid, semi-solid and liquid industrial wastes.
Points 1258, 1275, M 55 and 1257 all lie in the dumping zone of "Bayer-Antwerp". According to their own data they had already dumped about 50.000 tons of residues from the processing of Ti O_2 in 1970 (mostly H_2SO_4, $FeSO_4$ and other inorganics such as Ti- and Vd-salts).

Point MO 6 appears to be the dumping site of the "Koninklijke Nederlandse Gist- en Spiritusfabrieken" which, from January to June 1971 released 1.300 tons "kieselguhr" and biodegradable organic material, the exact nature of which is, however, not stipulated.
Point 1251 lies at the mouth of the Scheldt estuary and the Artemia mortality corroborates very well with our previous findings relating to the bad quality of the sea-water at that place (PERSOONE and UYTTERSPROT, 1972).
In a recent report (PERSOONE and UYTTERSPROT, 1973) it was shown that sediment extracts of that particular locale strongly inhibit the growth of marine unicellular algae.

TABLE 1

Identity of samples	Original salinity in (°/₀₀)	Number of days of culturing of algae	Density of algae at the harvest (in 10^6 cells/ml)	Visible mortality in the second link *Artemia salina*	Number of days until first fish mortality	Number of days until second fish mortality	End of the experiment (food exhaustion (in number of days)
A. Control	34	7	1,6	–	–	–	32
B. North Sea							
1007	↑	4	2,4	±	15	–	21
1020		3	2,1	±	14	20	–
1035		7	3,2	–	14	28	–
1034		5	2,1	–	–	–	32
1049		7	2,0	–	18	20	–
1065		4	1,6	–	–	–	25
1097	More than 30 °/₀₀	6	1,9	–	–	–	25
1096		4	2,0	–	–	–	32
1167		6	1,6	–	–	–	32
1251		3	2,2	+	–	–	15
1258		4	2,0	+	–	–	15
1275		4	2,1	–	30	31	–
1257		4	2,2	–	22	24	–
M 55		4	1,9	+	–	–	15
M 06	↓	3	1,6	–	21	–	30
C. Scheldt estuary							
Hansweert Buoy 44	22	3	2,4	–	–	–	25
Hansweert Buoy 55	21	6	1,7	–	–	–	33
Doel	14	5	1,7	–	–	–	33
Buoy 94	10	5	1,5	±	21	–	22
Loodswezen	6	7	1,2	–	–	–	31
Rupelmonding	3	4	1,8	–	–	–	23
Boerenschans	10	7	1,1	–	–	–	32

TABLE 2

Identity of sample	ALGAE		FISH											
	Concentration of Cu^{2+}	Concentration of Hg^{2+}	Lindane	Heptachlor	Aldrin	Heptachlor epoxide	DDE	Dieldrin	Endrin	TDE	DDT	Methoxychlor	Chlordane	PCB
A. Control	38,3	0,10	+	–	–									
B. North Sea														
1007	56,8	1,25	+	+	+	+	0,34	0,25	0,125	–	0,12	+	+	+
1020	52,7	0,46												
1035	96,9	3,48	–	0,4	0,005	0,17	–	0,25	0,2	–	0,05	–	+	+
1034	10,0	0,09												
1049	66,9	0,23	+	+	–	–	–	–	0,05	–	0,015	+	+	+
1065	86,0	0,10	+	–	–	–	0,3	1,11	0,015	–	0,05	0,03		
1097	44,9	0,12												
1096	81,5	0,09												
1167	59,8	0,19												
1251	40,5	0,08												
1258	?	?												
1275	63,7	0,19												
1257	44,6	0,19	+	–	–	0,015	0,275	0,19	0,15	–	0,175	0,1	+	+
M 55	68,7	0,10												
M 06	50,8	0,12	+	–	–	0,03	0,35	0,24	0,15	–	0,12	+	+	+
C. Scheldt estuary														
Hansweert Buoy 44	73,6	0,12												
Hansweert Buoy 55	?	?												
Doel	?	?												
Buoy 94	46,8	0,12	+	–	–	–	0,3	0,09	–	–	–	0,05	+	+
Loodswezen	98,7	0,11												
Rupelmonding	53,4	0,06												
Boerenschans	74,2	0,32												

5. Conclusions

In the 15 water samples of the North Sea we found 3 cases of mortality at the second (herbivorous) level and 7 at the third (carnivorous) level. There was but one case of fish mortality (one test-animal) in the Scheldt estuary where everybody should have expected a much higher mortality to occur in this apparently very polluted river as compared to the open sea.

The following facts, in our opinion, sufficiently prove that these mortalities are not "accidental" or due to a bad condition of the test-organisms at the start of the experiment.

In 5 of the 7 cases of fish mortality both test-organisms died (we remind you that each fish was kept in a separate aquarium).

In the 6th case (point 1007) the experiment had to be stopped after 21 days due to the lack of food, and it is worth to be mentioned that for the adjacent points 1020 and 1035, the second fish mortality was noted after 20 and 28 days respectively.

Accidental fish mortalities, due to technological failures or bad handling should statistically be more evenly distributed over the 46 individual aquaria in which 1 fish was daily fed for weeks.

There is, moreover, an obvious gregariousness in two distinct areas of the points in which mortality occurred.

It is interesting to note that one of these areas is a dumping site, and that the other one is situated westly from Ostend, whereas the eastern sampling points seem to be unaffected.

From the present study it is clear that at some sites of the North Sea, there are one or more substances in the water which, through the effect of "biological magnification" affect the higher trophic levels.

In several cases these toxicities resulted in death of the test-organisms.
By absence of thorough chemical analyses of the water at the start of the experiments as well as of the contaminated algae, brine shrimp larvae and fish, it is impossible to identify the exact cause of the mortalities in the second and third link of the food chain.
Although it should be emphasized once the more that such types of experiments should be accompanied by thorough chemical analyses in order to detect the possible cause of the toxicity, it is however not certain that these analyses will in all the cases reveal the very nature of the toxicant.
Indeed, according to AUBERT (1972) : "les analyses chimiques peuvent donner des présomptions sur la toxicité éventuelle des eaux résiduaires, mais les influences conjuguées des différents éléments ou l'action simultanée d'un mélange d'effluents ne peuvent être prévus".
So, no doubt that in the next future, analogous tests will prove to be most useful to predict the possible toxic effects of wastes on the different levels of the trophic pyramid, as to assess the harmful effect of some chemicals present in such minute concentrations in the water that they can't be detected chemically.

6. Literature cited

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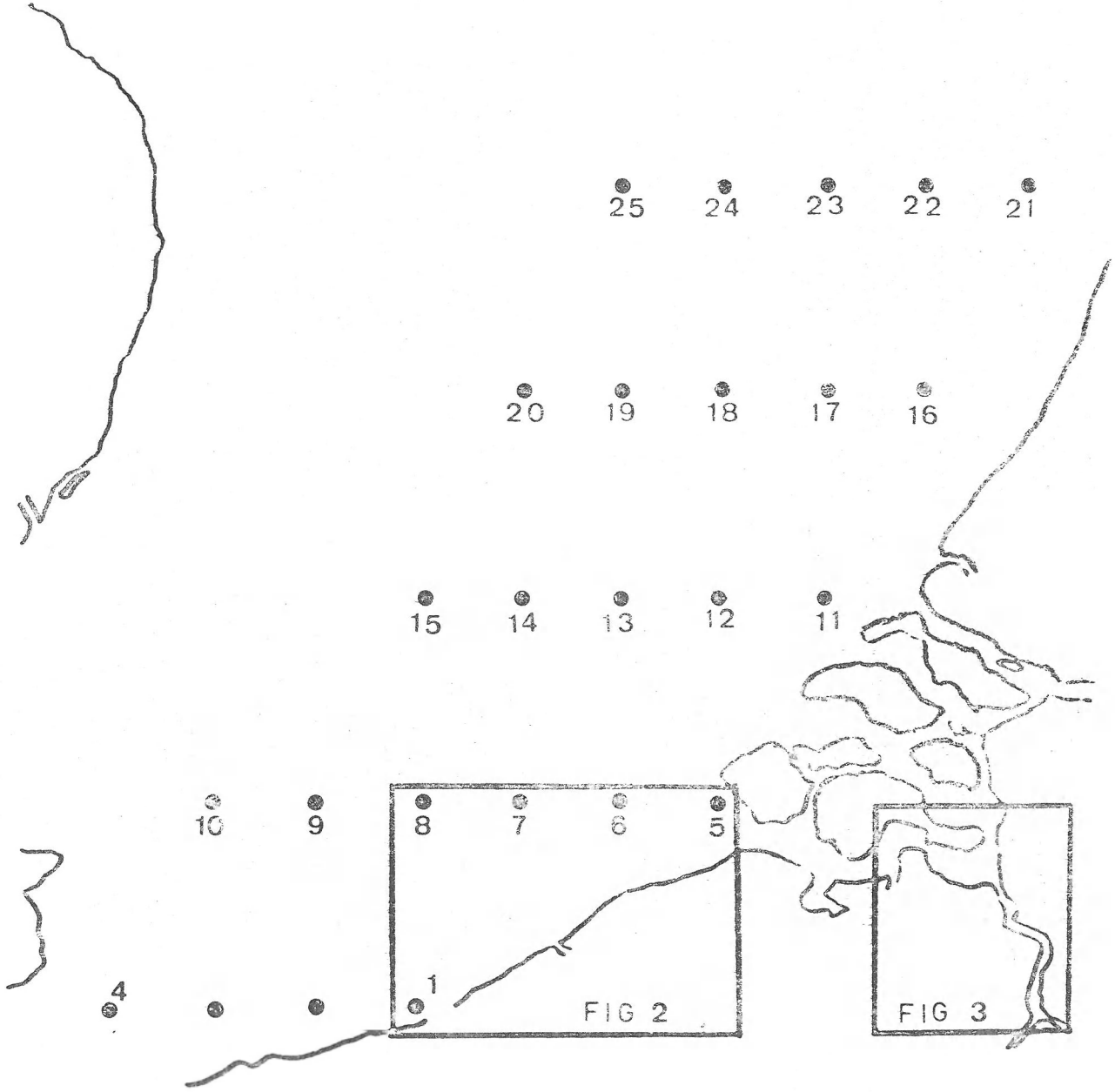
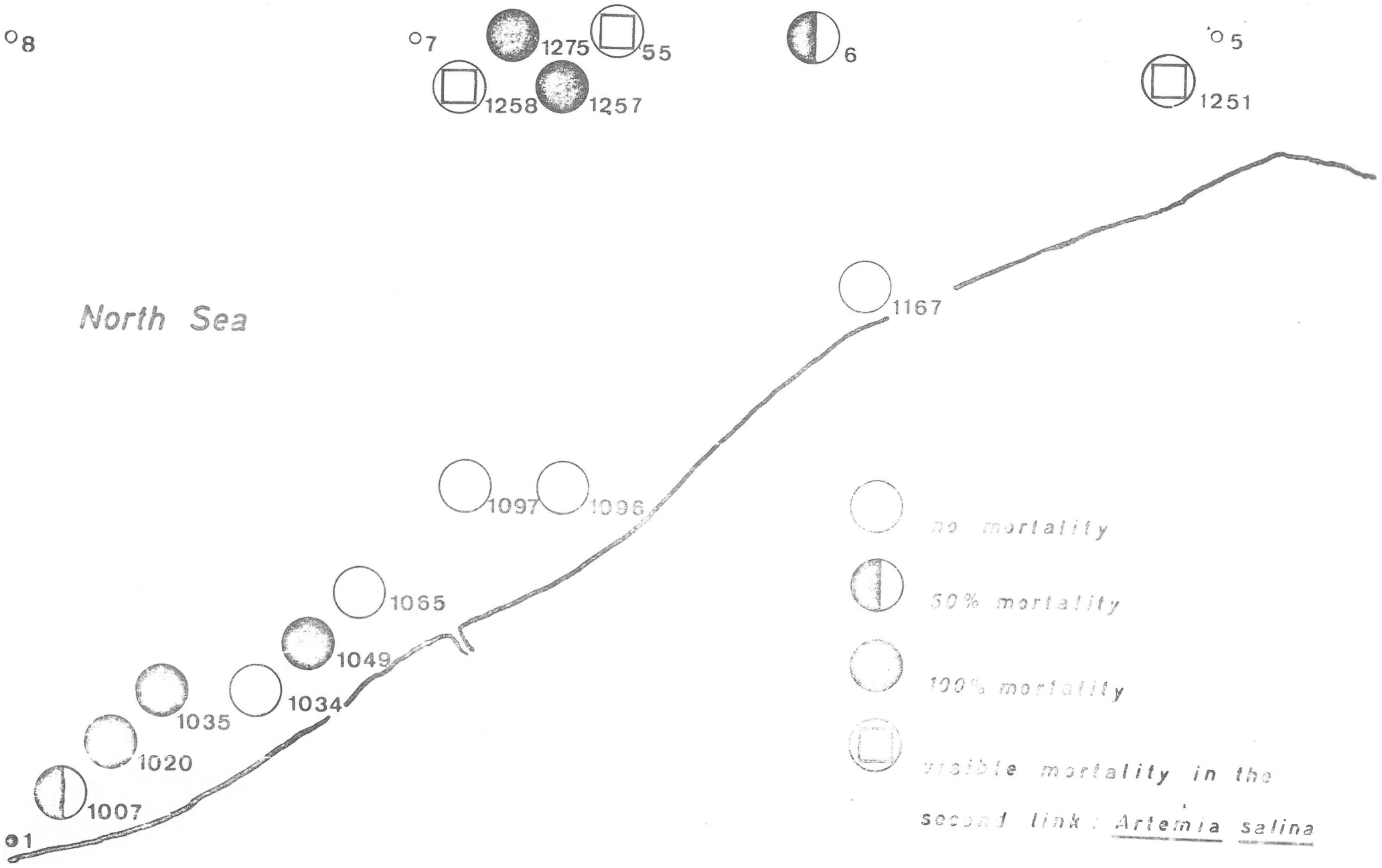
AREAS OF INVESTIGATION

FIG 1



MORTALITY OF FISH

FIG 2



MORTALITY OF FISH

FIG 3