C.I.P.S.
MATHEMATICAL MODEL OF MARINE
POLLUTION IN THE NORTH-SEA

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ON THE EFFECTS OF DUMPED ORGANIC INDUSTRIAL WASTE DERIVING FROM THE PRODUCTION OF PROTEOLYTIC ENZYMES ON DENSITY, DISTRIBUTION AND QUALITY OF FISH AND SHRIMPS.

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1. INTRODUCTION.

The effects of dumped industrial organic waste from the production of proteolytic enzymes on the fish and shrimp stocks were studied in the area of an approved dumping ground about eight miles from the Belgian coast. To this end observations on a monthly basis were carried out on the density and the distribution of fish, shrimps and other marine organisms. On the other hand a preliminary study was made on the dispersion and destruction of the waste, on the behaviour of shrimps in an aquarium system and on the quality and shelf life of the shrimps caught in this area.

Characteristics of the waste and method of disposal.

On February the 17th, 1970, the Ministry of Communications issued a permit for the dumping of organic industrial waste from the production of proteolytic enzymes of a factory located at Bruges.

The dumping place is situated on 51°28' N and 3°09' E (figure 1). The dumping started on the 10th August 1970 and still continues once a month. The quantity of dumped material was 947,5 tons for 1970, 3.272 tons

(x) Working group "Biology" (Commission for Applied Scientific Research in Sea Fisheries - T.W.O.Z. - I.R.S.I.A.).

for 1971 and 2.895 tons for the first 10 months of 1972.

A special dumping barge towed by a tug-boat of the Belgian marine administration is used. The dumping lasts about two hours during which the vessels describe a figure 8 at a speed of 2,5 knots.

The waste has a black colour and consists of heterogeneous particles of ca 1 cm diameter together with some lumps of ca 20 cm diameter.

The composition of the waste determined by the Institute for Chemical Research, Tervueren (1) was as follows (average of two samples) :

Water : 61,7 %

Dry matter : 38,3 % consisting of diatomaceous earth with 56 % organic matter

Analysis of the ash : 1 to 5 % Ca, P, Al and S
0,1 to 0,3 % Fe and Mg
30 to 100 ppm B
10 to 30 ppm Pb, Cu, Ti and Ga

COD : 275 mg O_2/l

BOD_5^{20} (1 g waste/l) : 288 O_2/l

pH : 7,5 (1 g/l)

It should be remarked that these data are in good agreement with the figures provided by the laboratory of the factory before the start of the dumping operations (2).

2. DISPERSION AND DESTRUCTION OF THE WASTE IN THE OPEN SEA.

2.1. Trawling results.

Several special surveys were undertaken in order to investigate the dispersion and destruction of the waste. To this end the dumping

process was observed at sea. The waste disappeared immediately into deeper waters and only a few particles were temporarily floating. It should be mentioned that the specific weight of the waste is 1,06 to 1,08 g/cm^3 compared with 1,03 for sea-water (2).

After trawling across the dumping ground about one hour after disposal, the net contained much waste material. This experiment thus confirmed that most of the material sinks quite rapidly to the sea-bottom. On the other hand it cannot be denied that the waste lumps constitute an obstacle to fishing during a few days in the dumping area.

The next experiment consisted in a trawling survey on the dumping place ten days after the dumping activity. With the exception of a few lumps of maximum 20 cm diameter no waste was found in the net.

Occasional trawling in circles of about two miles from the center of the disposal area during one year did not show any presence of the material in any direction.

2.2. Drifters and hydrological results.

Transportation of the waste products can mainly take place by means of depth-currents. Leloup's investigations indicate these currents to have a NE direction along the Belgian coast (3). In order to confirm these findings in the particular area under investigation, 70 sea-bed drifters were thrown into the sea during the dumping on March the 15th, 1972. After 9 months 13 drifters were recovered. The results of these recoveries are shown in table 1 and on figure 2. Three drifters were recovered in the Western Scheldt, whereas most of the others were found near Zealand. The general movement oscillates from East to North-East confirming Leloup's results (3).

3. DISTRIBUTION AND DENSITY OF COMMERCIAL FISH, SHRIMPS AND OTHER MARINE ORGANISMS.

3.1. Material and methods.

Monthly series of hauls were carried out by the R.V. "Hinders" during the period November 1971 - October 1972. The catch resulting from a 15 minutes' haul was sampled in the dumping area and in a reference area (4 stations) (figure 1). This area was chosen in accordance with the observations mentioned in 2.2 in order to have a waste-free area in the vicinity of the disposal place.

Fishing took place during day time with the otter trawl (mesh size 18 mm).

The whole catch of commercial fish was examined and classified in age-groups of 0, I, II and III and more years. For the sake of conciseness, the final results were grouped in "undersized" and "sized" species (limits mentioned in 3.2.1) and expressed in numbers of individuals per hour fishing.

The catch of non-commercial fish and invertebrates was examined on a qualitative and a semi-quantitative basis.

3.2. Results.

3.2.1. Commercial fish and shrimps.

The distribution and the density of fish and shrimps in the area studied can be described as follows :

- Plaice (Pleuronectes platessa L.) - (figure 3) :

The undersized plaice (<24 cm length) were abundant during the summer period. The density of the 0- and I groups in the dumping area was

in this period generally higher than in the reference area, with a maximum of 320 individuals per hour fishing in July 1972.

The sized plaice (> 24 cm length) were less frequent in both areas and no clear differences between the density in the dumping area and the control area were found.

- Dab (Limanda limanda L.) - (figure 4).

The undersized dabs (< 19 cm length) showed relative high fluctuations during the sampling period. During the months of December, June and September a higher stock density was found on the dumping place, and there seems to be a SE migration confirmed by a higher density during January and July in the reference area. The trend in the densities of the sized dabs (> 19 cm length) on the other hand appeared fairly identical in both areas.

- Sprat (Sprattus sprattus L.) - (figure 5).

No sized sprats (> 10 cm) were found during the test period. The frequensies of the undersized specimens did not allow to draw any conclusions at this moment.

- Whiting (Merlangus merlangus L.) - (figure 6).

The amount of undersized whiting (< 19 cm length) was, during the period studied, always higher in the disposal area than in the control area. Two maxima were found in the dumping area ; one in June (160 individuals per hour fishing) and one in September (228 individuals per hour fishing) compared with respectively 75 individuals per hour fishing and 63 individuals per hour fishing in the reference area.

No differences were noted concerning the stock densities of sized whiting (> 19 cm length) in both areas.

- Sole (Solea solea L.) - (figure 7).

The strong 1971 year-class of soles (born in May-June 1971) is reflected in the high values during the winter months. The decrease in numbers in the following period was a general phenomenon on the Belgian and Dutch coasts (4). Higher densities of undersized soles (< 24 cm length) were found in the reference area.

The amount of sized soles (> 24 cm length) was in both areas too small to draw any conclusions.

- Shrimps (Crangon crangon L.) - (figure 8).

As well for sized (> 54 cm length) as for undersized (< 54 cm length) shrimps the density was higher in the dumping area.

The undersized shrimps showed two maxima in the dumping place (June : 23.284 individuals per hour fishing and August : 17.748 individuals per hour fishing), whereas the sized shrimps showed one peak (August : 13.872 individuals per hour fishing).

- Other commercial fish.

The quantity of other commercial species was too small to draw any conclusions. For the sake of completeness, these species were : cod (Gadus morhua L.), herring (Clupea harengus L.), grey gurnard (Trigla gurnardus L.), horse mackerel (Trachurus trachurus L.), tub gurnard (Trigla lucerna L.) and mackerel (Scomber scombrus L.), twaite shad (Alosa finta L.), pout (Gadus luscus L.) and flounder (Pleuronectes flesus L.).

3.2.2. Other marine organisms.

The presence of the different species in the by-catch is listed in table 2, grouped in three categories of abundancy.

About nine species were frequently abundant during the yearcycle : Pleurobrachia pileus Flem., Actinia aquina L., Asterias rubens L., Ophiura texturata Lam., Macropodia rostrata L., Macropipus holsatus Fabr., Eupagurus bernhardus L., Agronus cataphractus L. and Gobius minutus Pella.

The quantity of these species in the dumping area seemed not to differ very much from those in the reference area. In all 36 different species were observed.

3.3. Discussion.

The Belgian coast is well-known as a nursery ground for many marine species. The relative high number of undersized individuals confirms this fact. The O-, I- and II groups have normally high fluctuations when compared month by month. Also there are substantially great annual differences as regards the breeding success. This first approach, however, as regards the influence of the dumped material on the stocks, showed no negative effects on the different species after two years' dumping. As a matter of fact higher densities of plaice, whiting and shrimps were found in the dumping area compared with those in the reference area. On the other hand, there seemed to be a relation between the whiting and shrimps stocks. Indeed, the maxima for shrimps obtained in June and August in the dumping area were of the same level as the maxima for whiting. The decrease in July was also apparent for both species. This phenomenon may be contributed to predation (5).

4. BEHAVIOUR OF SHRIMPS IN AN AQUARIUM SYSTEM.

In addition to the population studies, a screening test in aquarium was carried out to investigate the effects of the dumped material on the behaviour of shrimps.

These crustaceans were used with respect to their commercial importance and their relative abundance in and around the dumping area.

Shrimps are rather resistant and amenable to captivity and are in addition also very convenient for this kind of experimentation due to their small length (< 54 mm).

4.1. Material and methods.

The test water was taken a few miles off shore in an unpolluted area. The temperature was held at 15° C. Plastic troughs of 2 liter containing each 10 shrimps were used.

Comparative tests were started on the influence of two amounts (respectively 2 and 10 mg/cm^2 or 0,5 and 2,5 g/l) of waste on the shrimps. These quantities were considered to fall in the range likely to be found on the sea-bottom shortly after disposal. Similar quantities of fish were fed to the reference organisms. Additionnally, an experiment was set up where both fish and waste were given. The water and feed or waste were renewed every two days. The water was normally aerated.

4.2. Results.

The waste did not float at the surface when it was added to the sea water ; it rapidly sunk to the bottom. This confirms the observations in the open sea (see 2.1.). After a short period it was dispersed into the water, mainly due to the aeration movement, and only small loose inert precipitates were left on the bottom.

The shrimps in the different aquaria were still alive after 20 days. There were no apparent differences in general behaviour towards light, sound and feed between the "treated" and "untreated" crustaceans.

In this first approach it could not be clearly established whether the shrimps fed on the waste or had a preference for fish or waste when both were present.

4.3. Discussion.

These observations showed no negative effect on shrimps during a relatively short period and confirmed so far the results of the population studies.

This experiment is being continued on a long term basis in an attempt to determine a specific value of threshold for the organic waste involved, both in an aerated and a non aerated system. The latter is important when taking the high COD and BOD into account.

5. QUALITY ASSESSMENT OF SHRIMPS CAUGHT IN THE DUMPING AREA.

A few months after the beginning of the dumping operations, different complaints by fishermen reporting the capture of shrimps with strong off-odours in the dumping area were noted. Hence, it was decided to carry out a quality survey of the shrimps in that area.

5.1. Material and methods.

The shrimps caught on the 5 fixed stations were cooked in brine at sea and cooled as customary. Their salt content was 2,5 to 3,5 %. On land they were stored in closed jars at 0° C and analyzed organoleptically and chemically after 1, 5, 8, 12 and 14 days. Organoleptic assessment was performed by a panel of four members on colour, odour, taste and texture. The objective quality methods used were :

- Total volatile bases (TVN) : by the method of Lücke and Geidel (6) as modified by Antonacopoulos (7).
- Ammonia : by accelerated microdiffusion (8).
- Total volatile acids (TVA) : by the method of the AOAC (9) but using Antonacopoulos' still ; 500 ml were distilled over.
- Hypoxanthine : according to Jones et al. (11).

The experiments were carried out six times at regular intervals during a one year's period.

5.2. Results and discussion.

In the first experiment (December 1971), the organoleptic judgment showed the shrimps from the dumping area to have a marked off-odour ressembling nutrient broth which made them commercially valueless. This odour disappeared after about two days. The peeled shrimps were of normal quality. In the surrounding area, this phenomenon was not noticed.

Shortly afterwards, however, the factory change its waste disposal technique resulting in lumps with a less compact structure enhancing the rate of dispersion.

During the following five surveys, the taste panel could not detect any more off-odours. Moreover, there were no significant differences in sensory scores during further storage between shrimps from the dumping area and from the surrounding area. They had about the same shelf life of 10 to 12 days.

These observations were confirmed by the results of the chemical determinations. Although some expected differences occurred between the five experiments, the general spoilage patterns were the same and no significant differences were noted between the two areas. The average patterns for TVN, TVA, ammonia and hypoxanthine are given in figure 9.

Moreover, when comparing those data with results obtained during earlier experiments (12) with shrimps caught about 15 to 20 miles more to the West, practically no differences appeared and the spoilage curves were very similar (figure 9).

These tests indicate that the dumping of the organic waste involved did not alter the quality and shelf life of shrimps. It should be added that no organoleptic deviations were noticed on fish caught in the dumping area.

6. CONCLUSIONS.

1. The waste material sinks rapidly to the sea-bottom and its rate of dispersion seems to be rather high. Nevertheless, it cannot be denied that the waste lumps represent an obstacle to fishing during a few days after dumping in the area involved.

2. The influence of the dumped material on the commercial fish and shrimp stocks showed no negative effects.

3. The quantity of the different non commercial organisms in the dumping area did not seem to differ very much from those in the surrounding areas.

4. A first approach to the behaviour of shrimps in an aquarium system showed no adverse effects during a test period of 20 days.

5. The organic waste did not influence the quality and shelf life of shrimps.

SUMMARY.

A one year's study was made in the area of a dumping ground off the Belgian coast to define the effects of dumped industrial organic waste from the production of proteolytic enzymes on the fish and shrimp stocks. The waste material sinks rapidly to the bottom and its rate of dispersion seems rather high. Some obstacle to fishing occurs during a few days after dumping owing to the waste lumps present. The influence of the dumped material on the fish and shrimp stocks showed no negative effects. A first approach to the behaviour of shrimps in an aquarium system indicated no adverse effects. The organic waste did not influence the quality and shelf life of shrimps.

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Table 1 - Recovery data of the sea-bed drifters.

Release point : 51° 28' N/3° 09' E

Release date : 15 - 3 - 1972

	Days absent	Position of recovery
1	20	Vlakte van de Raan
2	29	2 miles SE of Goeree
3	29	2 miles SE of Goeree
4	29	2 miles SE of Goeree
5	40	Wielingen
6	43	51°40'N/3°35'E
7	46	Noord Beveland
8	47	Eastern Scheldt estuary
9	63	51°40'N/3°40'E
10	71	51°30'N/3°15'E
11	78	Brouwerhavense Gat
12	79	51°55'N/3°50'E
13	99	Ellemontsdijk

Table 2 - Distribution of marine organisms in the reference area and in the dumping area (a).

Family and species	Reference area	Dumping area
Coelenterata		
Pleurobrachia pileus Flem.	11,12,1,3,5,6,8,10	12,1,3,5,8,10
Rhizostoma pulmo Ag.	10	
Aurelia aurita L.	5,7	6
Actinia equina L.	11,12,1,3,5,6,7,10	12,1,3,5,6
Echinodermata		
Asterias rubens L.	11,12,1,3,5,6,7,8,9	11,12,1,3,5,6,7,8,9,10
Ophiura texturata Lam.	11,12,1,3,5,6,7,8,10	11,12,1,3,5,6,8,10
Ophiotrix fragilis Abildg.		6
Psammechinus milliaris Gmel.	5	3
Mollusca		
Buccinum undatum L.	12,3,9	12,3,6
Mactra corralina atlantica B.	7	3,5
Ensis ensis L.	12	3
Albra alba W. Wood	12	
Mytilus edulis L.	8,10	
Sepia officinalis L.	5,6,7	5,7
Sepolia atlantica d'Orb.	12,5,6,8	5,9
Loligo vulgaris L.	5,6,7,10	5,7
Vermes		
Pectinaria auricoma Müll.	12,1,8	5,6
Aphrodite aculeata L.	12,7,8,9	3,6,10
Crustacea		
Maeropodia rostrata L.	12,1,7	11,12,9
Macropipus holsatus Fabr.	11,12,1,3,5,6,7,8,9,10	11,12,1,3,5,6,7,8,9,10

Eupagurus bernhardus L.	11,12,1,3,5,6,7 8,9,10	11,12,1,$\overline{3}$,5,6,7, 8,9
Talitrus saltator Mont.	1,3,5,8	
Palaemon serratus L.	5,6,8	
Pisces		
Agonus cataphractus L.	11,12,1,3,5,6,8, 9	11,12,3,6,8,9
Gobius minutus Pallas	11,12,1,3,5,6,7, 8,9,10	11,12,1,3,5,6,7, 8,9,10
Liparis liparis L.	11,3,6,8,9	11,3
Callionymus lyra L.	11,12,5,6,7,9	5,6,7
Motella mustela L.	5,9	
Ammodytes lanceolatus Lesauv.	12,5,7	9
Osmerus eperlanus L.	6,8	
Stolephorus encrasicholus L.	6,8	
Syngnathus acus L.	1,3,6,9	3,5
Cyclopterus lumpus L.		3
Cottus scorpius L.	11	
Belone bellone L.	6	
Ammodytes tobianus L.	12	

(a) 1 - 12 : months during which the organisms were present.

density :

x = few specimens

x = many specimens

$\overline{x}$ = abundant specimens

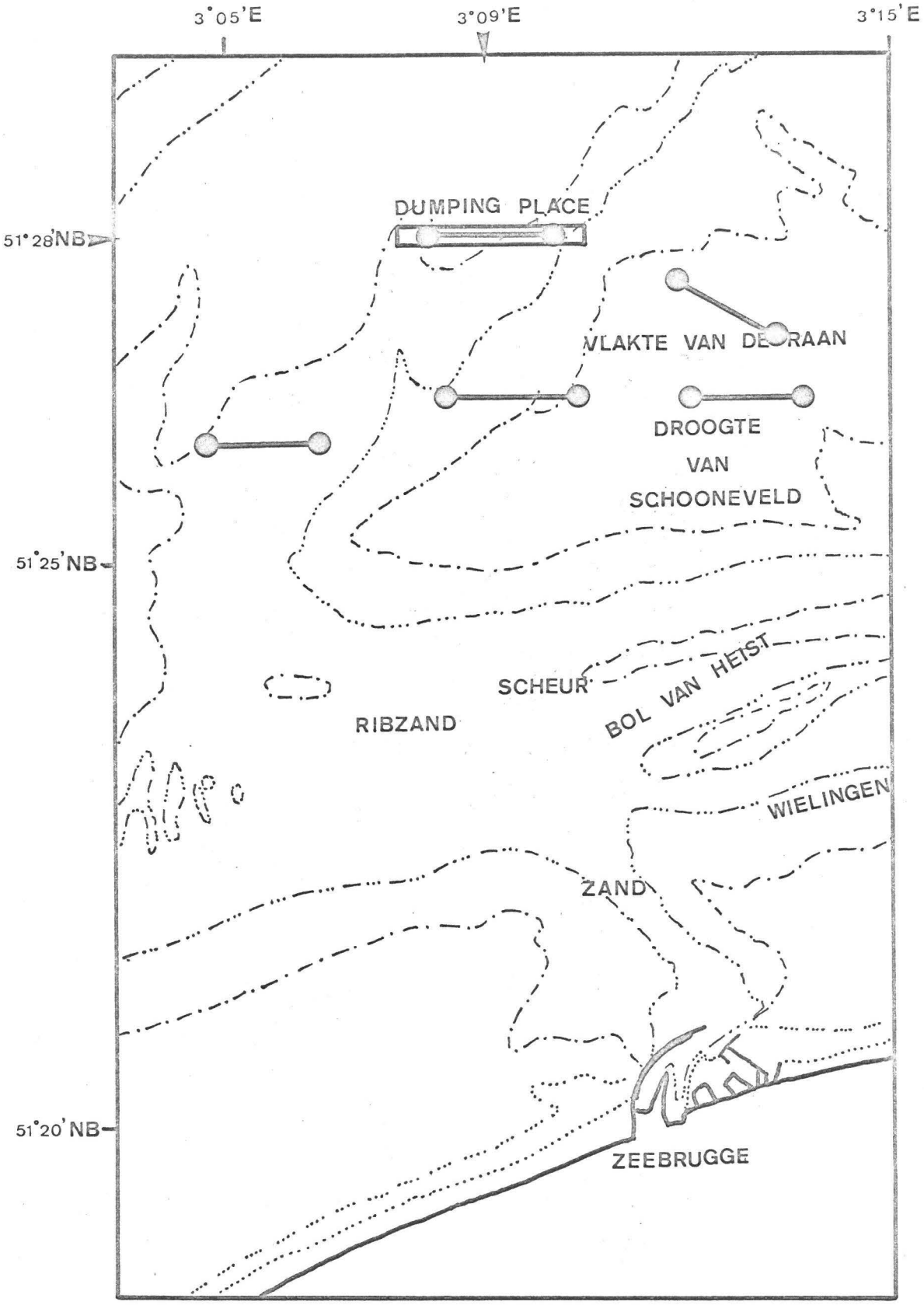

Figure 1 - Position of the dumping place and the 5 sampledstations.

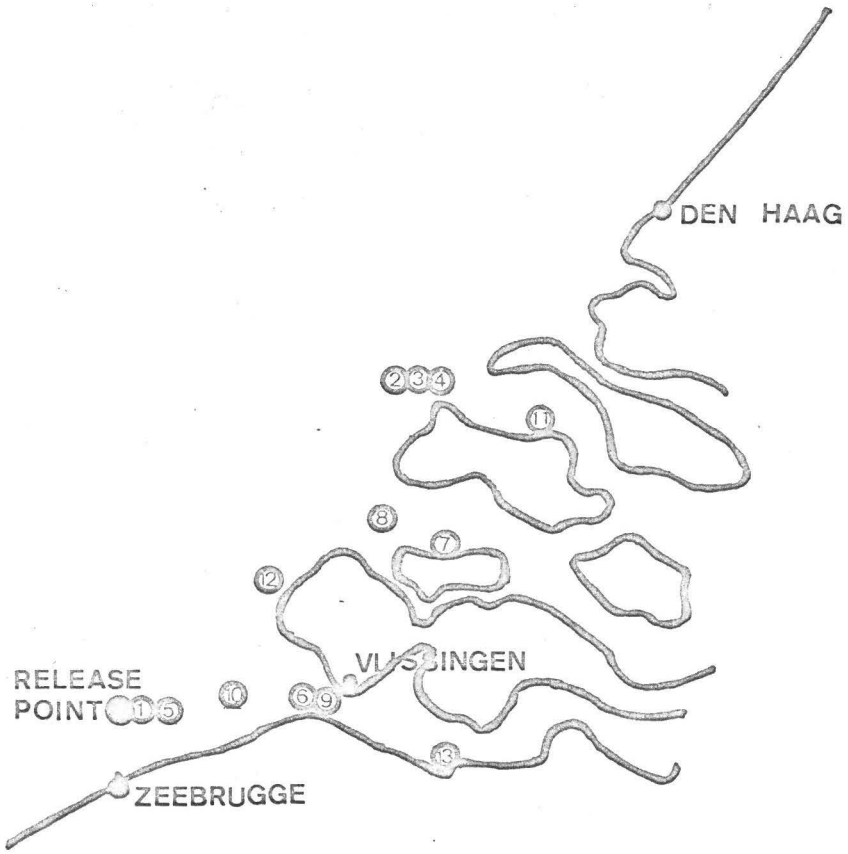

Figure 2 - Position of the recovered sea-bed drifters.

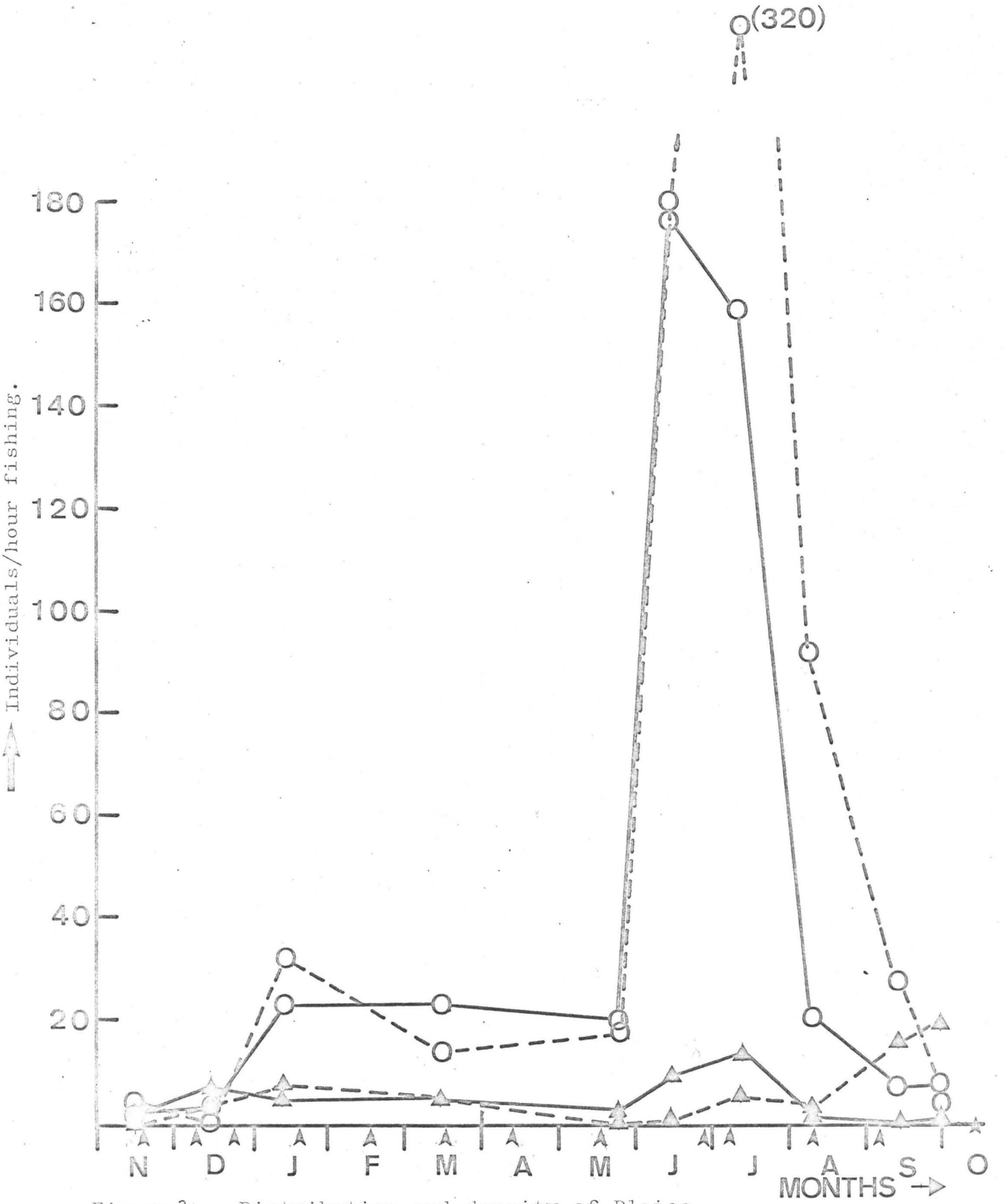

Figure 3 - Distribution and density of Plaice.

dumping area — undersized ○----○ / sized △----△ — reference area — undersized ○——○ / sized △——△

▲ dates of dumping

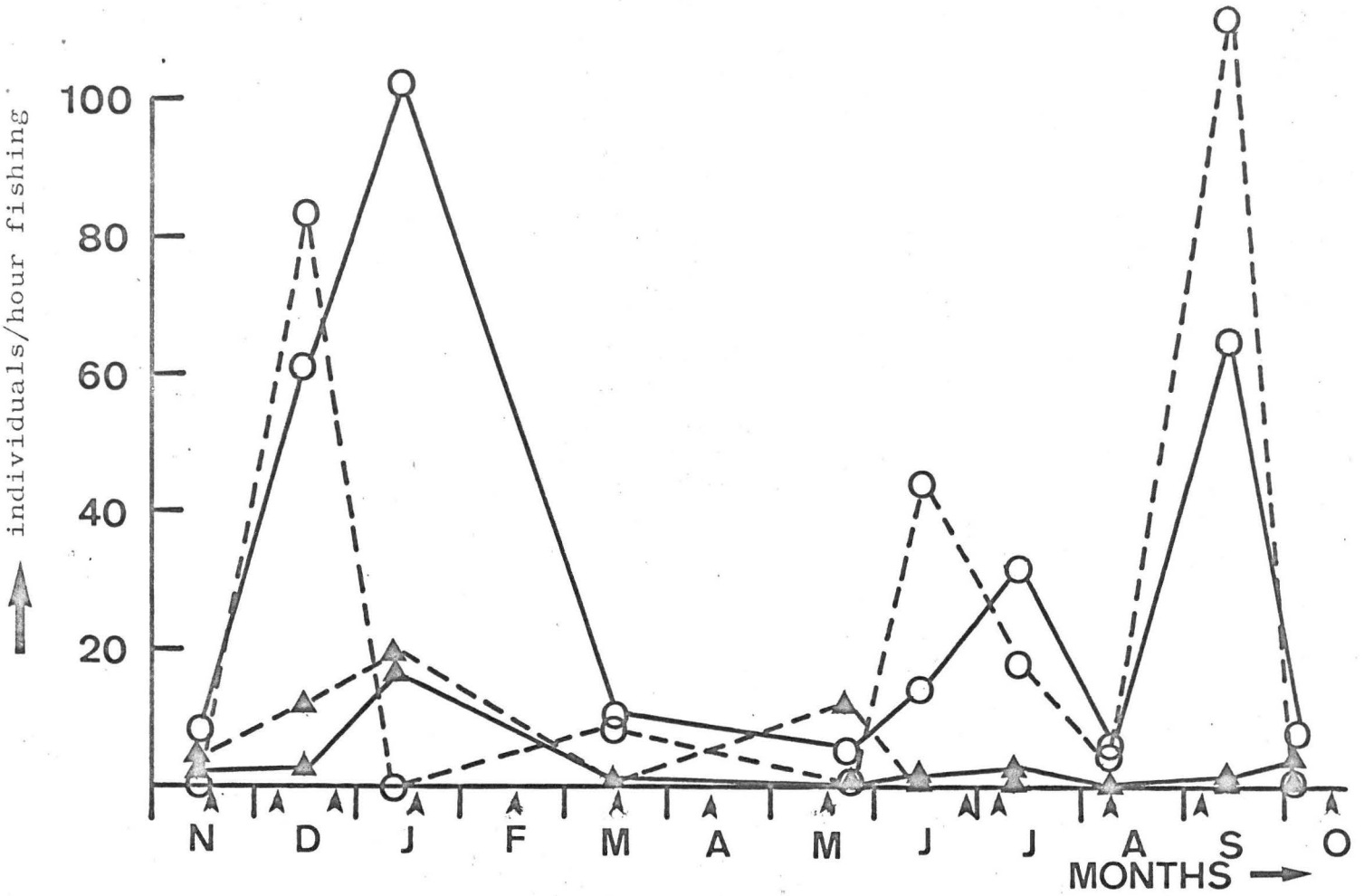

Figure 4 - Distribution and density of Dab.

dumping area — undersized O---O, sized ▲---▲

reference area — undersized O—O, sized ▲—▲

▲ dates of dumping

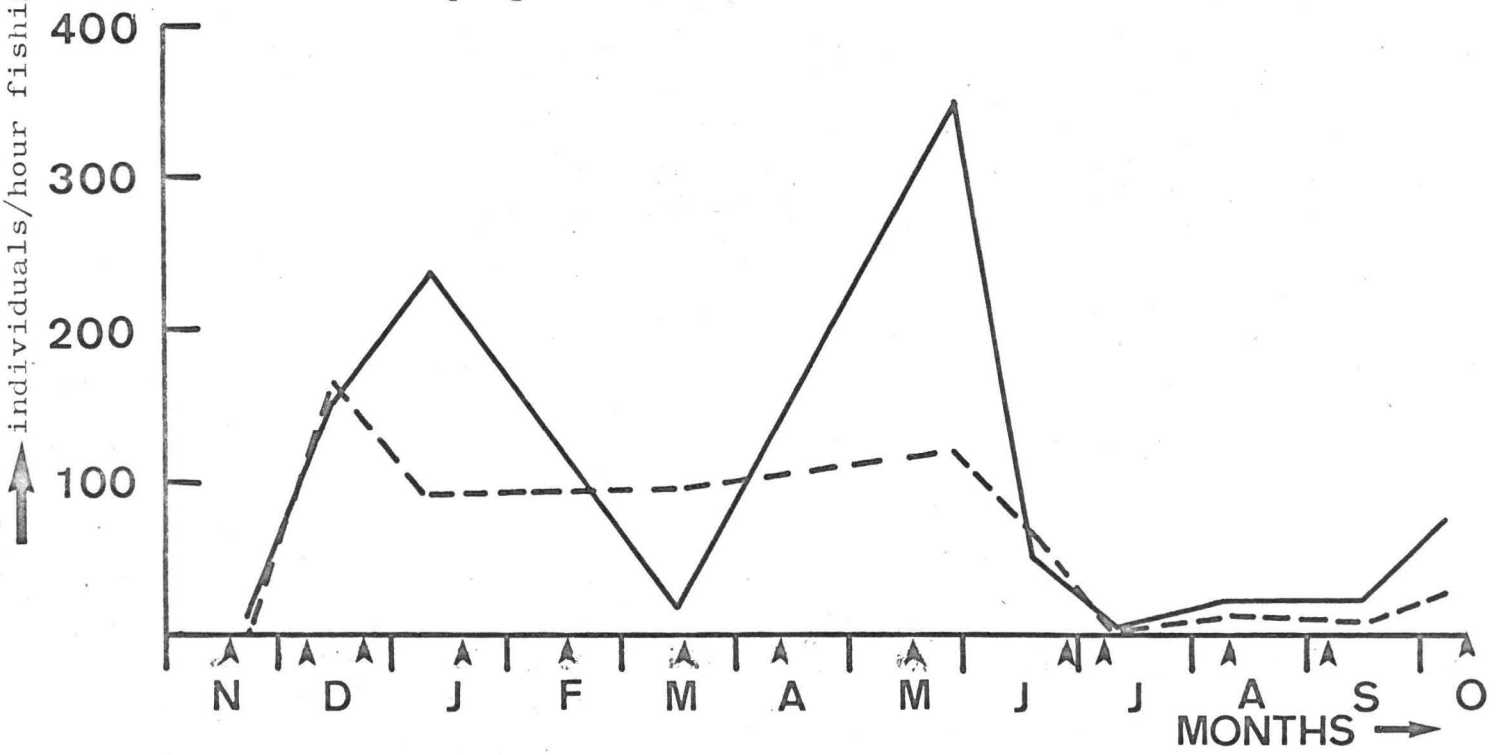

Figure 5 - Distribution and density of Sprat.

dumping area — undersized O---O, sized ▲---▲

reference area — undersized O—O, sized ▲—▲

▲ dates of dumping

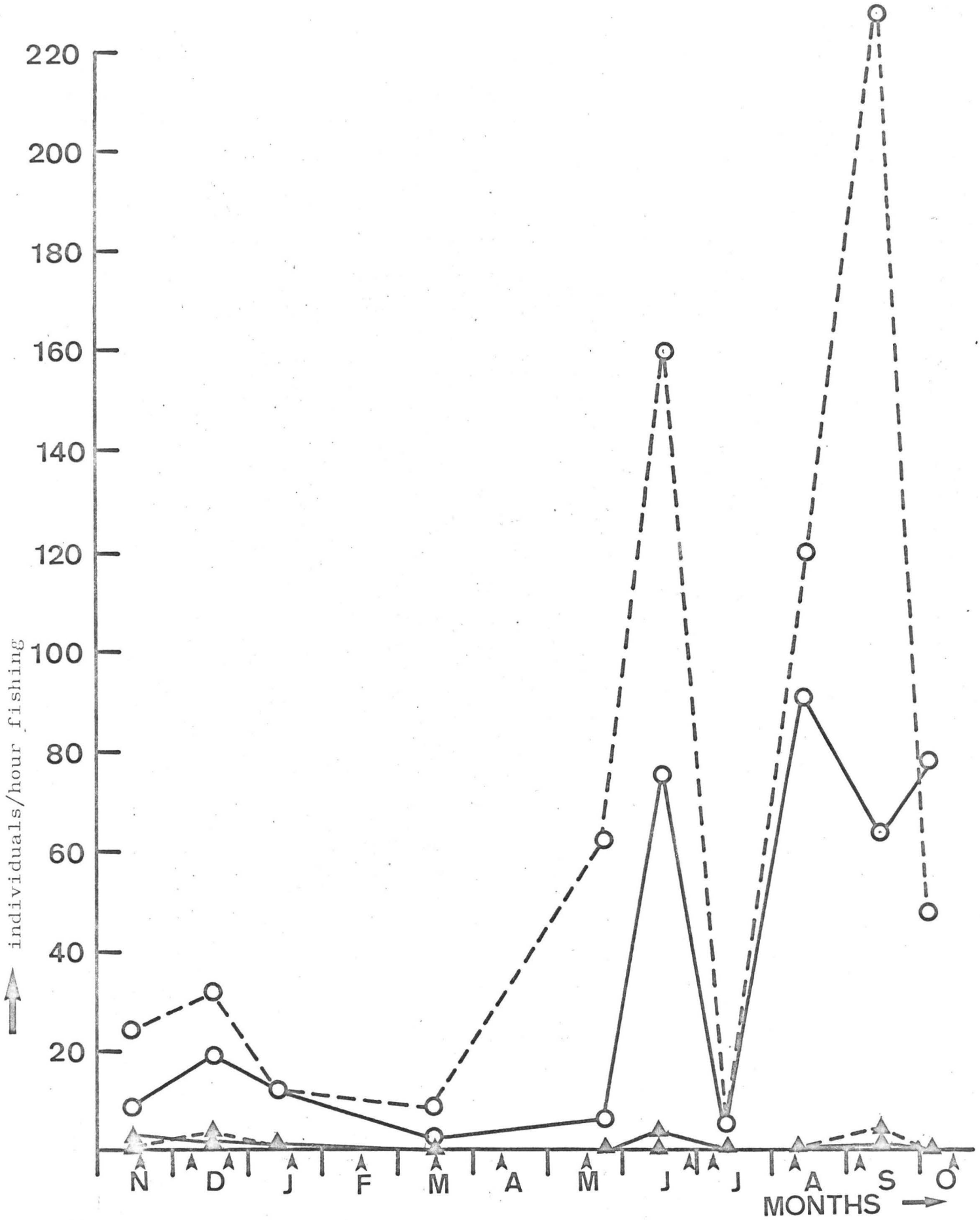

Figure 6 - Distribution and density of Whiting.

dumping area — undersized ○---○ sized △---△

reference area — undersized ○——○ sized △——△

▲ dates of dumping

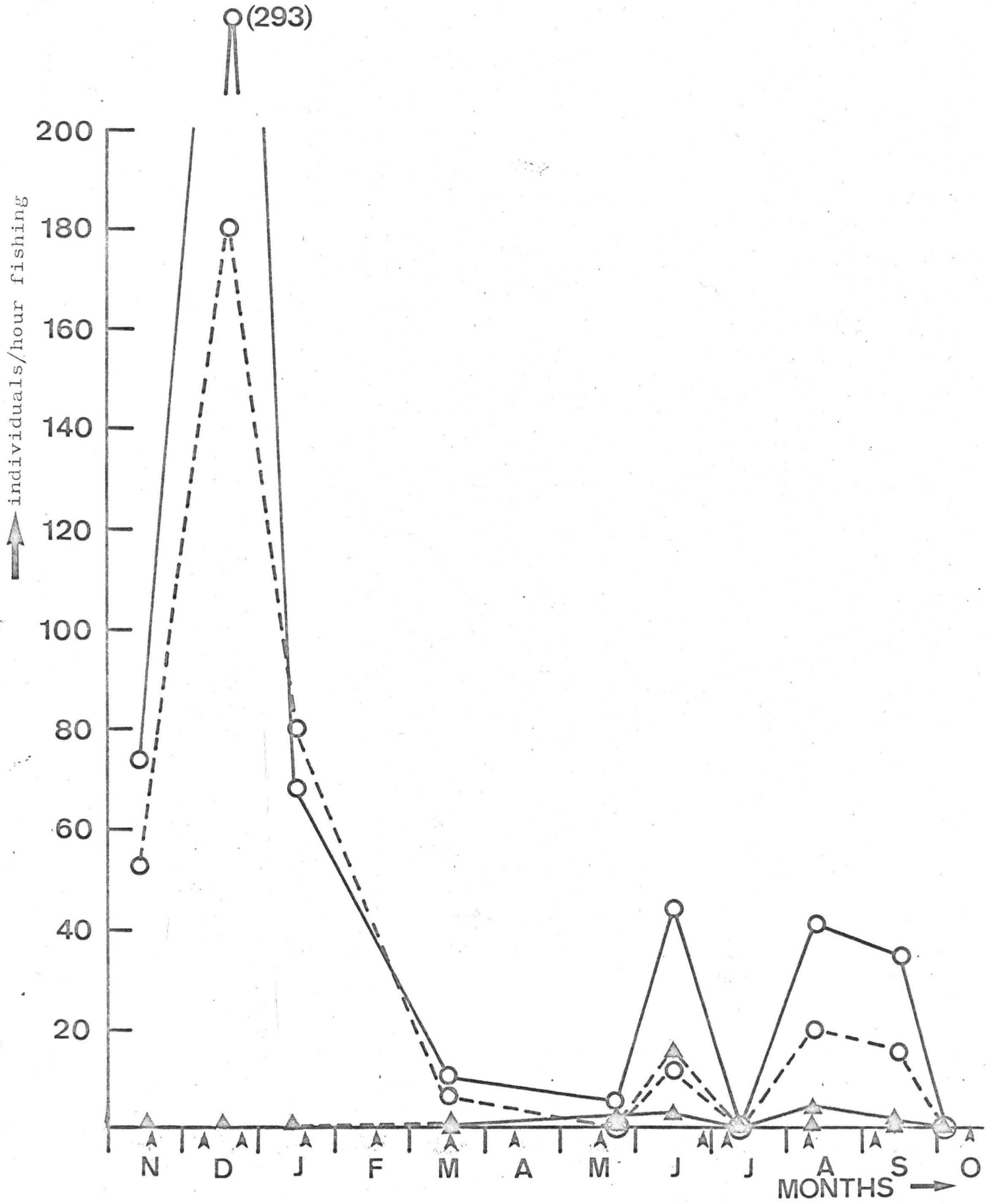

Figure 7 - Distribution and density of Sole.

dumping area — undersized ○---○ — sized △---△ — reference area — undersized ○——— — sized △———

▲ dates of dumping

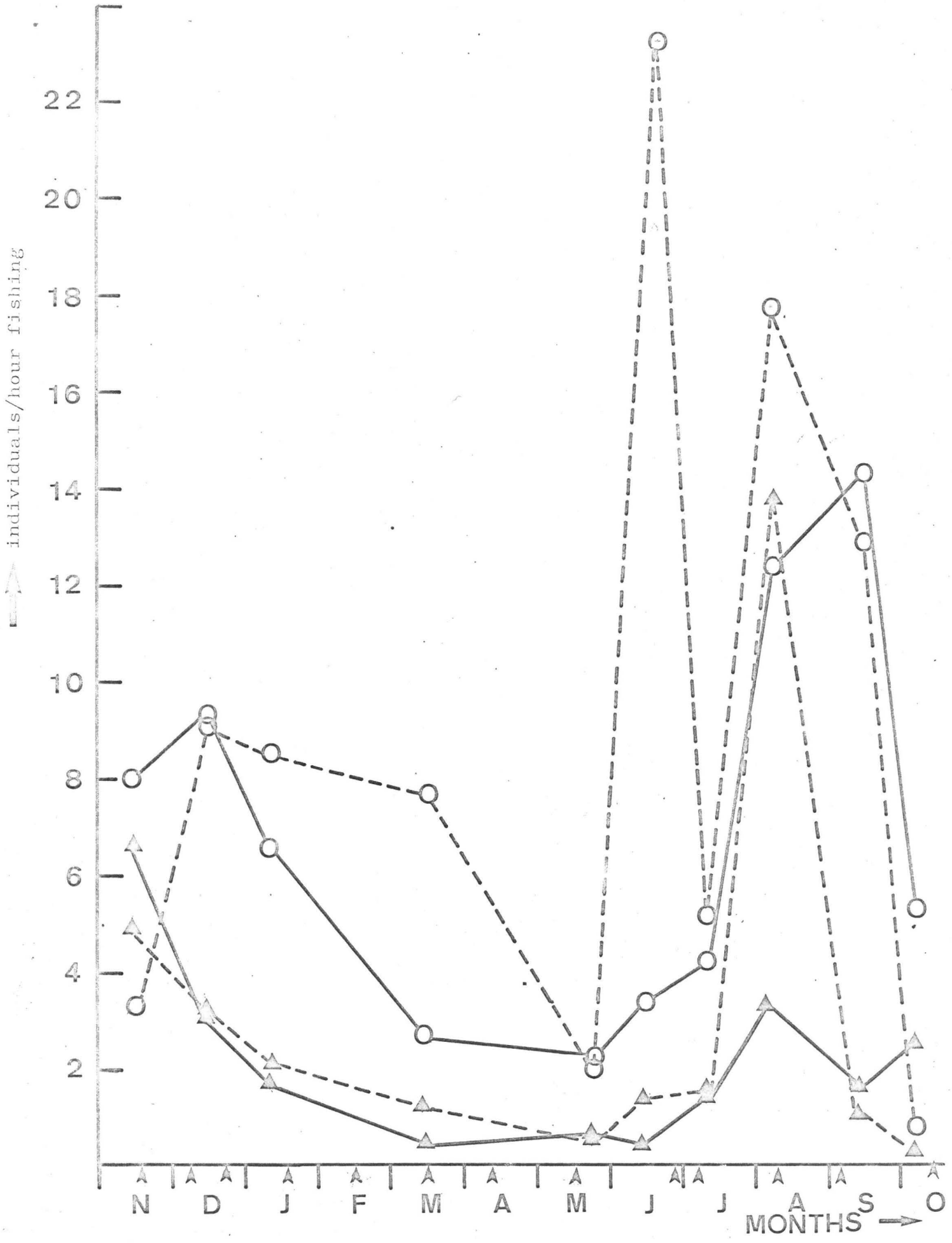

Figure 8 - Distribution and density of Shrimps.

dumping area — undersized ○---○ sized △---△ reference area — undersized ○——○ sized △——△

▲ dates of dumping

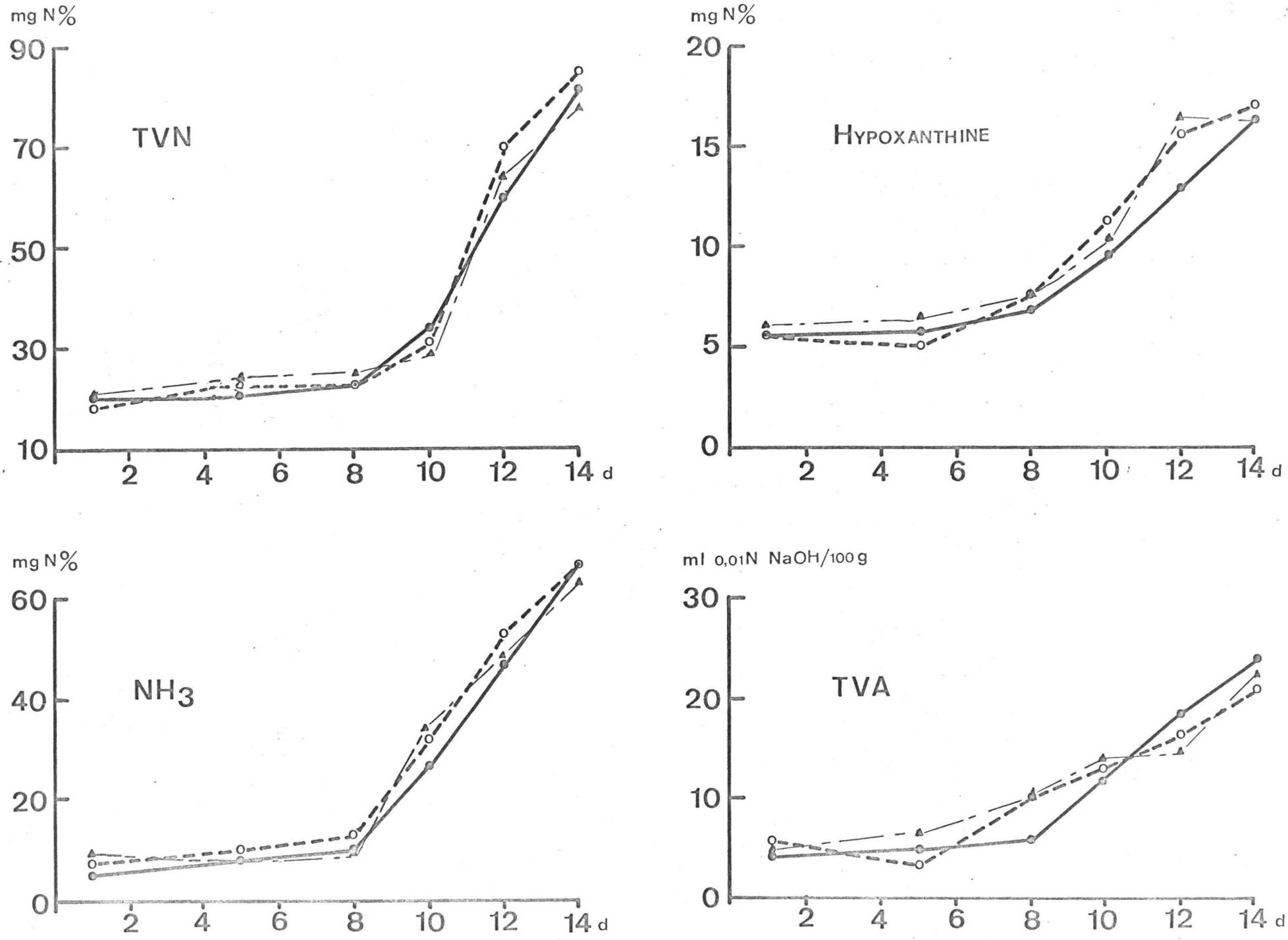

Figure 9 - Spoilage curves of shrimps from the dumping ---- reference area ——— and distant area's ——— ——