

SURVEY OF THE BENTHIC MACRO-INVERTEBRATE COMMUNITIES AT

ESTUARINE SITES AT HAYLE, CORNWALL. JANUARY 1989.

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1. SUMMARY

The benthic macro-invertebrate fauna at all of the estuarine sites surveyed in Hayle was less diverse than expected. The molluscan fauna was especially restricted, and this is thought to be largely due to metal pollution (copper and zinc) in the waters and sediments. Although non-molluscan taxa may also be affected by metal pollution, other explanations for their low diversity and abundance seem more likely. These include excessive accretion in the intertidal areas (especially in Copperhouse Pool), changes in physical properties of the sediments, and unusually large salinity variations in Copperhouse Pool. These three physical factors are linked, and it would appear that their effects on estuarine macro-invertebrates could be significantly decreased by ecologically sensitive engineering.

This study has shown a clear link between the height of the mudflats in Copperhouse Pool and the number of taxa present. At most of the highest sites only one taxon was found, and this is believed to have little importance as a prey item for birds.

The removal of the most contaminated sediments in Copperhouse Pool would be beneficial to most estuarine invertebrates for four main reasons:

- 1 reduction in sediment toxicity;
- 2 increase in the volume of seawater entering Copperhouse Pool, and therefore a decrease in the average concentrations of metals in the water and a decrease in water toxicity;
- 3 increased average salinities due to the greater volume of seawater would increase the number of taxa;
- 4 decrease in the height of the higher mudflats would reduce the effects of desiccation and therefore increase the number of taxa that could colonise those areas.

In the short term the lowering of the intertidal areas of Copperhouse Pool would reduce their importance as feeding grounds for waders, due to the removal of the most productive surface layers. There is also the danger of mobilising metals from the sediments into the water column, but this could be minimised by carefully controlled operations.

The recovery period will be critically dependent on the time of year that the surface layers are removed, the percentage of the surface affected, and the physical and chemical properties of the new surface.

2. DESCRIPTION OF SURVEY METHODS

2.1 ROCK-ASSOCIATED FAUNA

Fauna living on and underneath rocks were assessed using a semi-quantitative timed survey on 18th January 1989. At 11 sites rocks were examined carefully for 10 minutes, and fauna were counted. Most species could be counted reasonably accurately, the main exceptions were the gammarid crustaceans (sand-hoppers) Orchestia mediterranea and Orchestia gammarellus, and the estuarine woodlouse (Ligia oceanica). These three species were often present in uncountable numbers, and moved very rapidly when disturbed. When they were present at very high densities, numbers were recorded as more than 100. Despite the limitations of this technique, it is an extremely useful method for rapidly assessing rock-associated fauna.

2.2 MUD AND SANDFLAT FAUNA

Two 7 cm diameter by 10 cm deep core samples were obtained at 44 sites in Copperhouse Pool, North Quay, Carnsew and Lelant Water on the 19-20th January 1989. Most of the sites (40) were intertidal and easily sampled, but one of the Carnsew transects (4 sites) was subtidal and required a diver to obtain the samples.

Samples were placed in labelled plastic bags and brought back to the laboratory for processing. Each sample was carefully sieved through a 1.0 mm mesh, and all of the material retained by the sieve was preserved in alcohol. Specimens were identified to species level wherever possible, using the latest available keys. The only specimens which were not identified to species level were the enchytraeid oligochaetes. The number of individuals of each taxon was counted, and the results for both cores were summed. The detection limit for this method is approximately 150 individuals of a taxon per square metre. For each taxon results were expressed as the average number per square metre at each site. The estimated total number of individuals per square metre and number of taxa at each site were also calculated.

Sites were located along transects, and were chosen to represent the range of heights present. The highest parts of the intertidal mudflats at Copperhouse Pool were usually avoided, especially when covered with the alga Enteromorpha, as a previous survey had shown them to be colonised only by enchytraeid oligochaetes. At each site the position and height were accurately surveyed, and the results transferred to 1:2500 scale maps. Copies of these maps are available separately. These maps were then photo-reduced to A4 size (Figures 3 - 32), and the ratio scale replaced by a scale bar. The maps for Lelant Water are at a slightly smaller scale than the remaining three areas.

Heights were assessed relative to nearby bench marks, and expressed as metres above or below Ordnance Datum Newlyn (ODN). Measurements were taken to the nearest 0.5 cm, and have an absolute accuracy of approximately ± 2 cm.

Distances were obtained using a laser range-finder, and the results expressed to the nearest metre.

Substrate types were assessed by visual inspection before and during sieving. The following substrate code was used:

Mud	6
Mud/Muddy Sand	5
Muddy Sand	4
Muddy Sand/Sand	3
Sand	2
Clay	1

Although the clays have the smallest particle size they were deliberately placed after the sand category since the compacted nature of clays increases their effective particle size. Many estuarine organisms would find it physically impossible to burrow through the clays found in the higher parts of Copperhouse Pool.

3. RESULTS

3.1 ESTUARINE INVERTEBRATES

Appendix 1 lists all the estuarine invertebrates that have been identified by David Bellamy Associates at locations in Hayle. Most of these were identified during the intensive surveys on the 18-20th January 1989, but a few identifications are from previous surveys. Some taxa may have been missed by the survey techniques used, but it is believed that Appendix 1 is a good representation of all but the rarest estuarine invertebrates at sites in Hayle.

Considering the sampling effort and the range of habitats surveyed, the list of estuarine invertebrates is quite short; 41 taxa were identified, approximately 2/3 of the number that might have been anticipated.

3.2 ROCK-ASSOCIATED FAUNA

Figure 1 shows the location of the sampling sites and the number of taxa recorded at each site. Appendix 2 summarises the taxa found in the five main areas (Copperhouse, North Quay, Penpol, Carnsew and Lelant Water). Detailed results for each site are presented in Appendix 3.

The number of taxa recorded ranged from 4 (site 1) to 11 (site 9). Some taxa which would be expected to occur in this habitat were not seen during the survey, for example the mud-snail Hydrobia ulvae and the isopod crustaceans of the genus Jaera. Other taxa occurred in unusually low numbers at certain sites, for example Littorina saxatilis in Copperhouse Pool.

The ragworm Hediste diversicolor was either absent or present in only low numbers under rocks. The burrows of this worm were seen at most sites, however, so it was probably underestimated in these surveys.

3.3 FAUNA PRESENT IN CORE SAMPLES FROM MUDFLATS AND SANDFLATS.

Appendix 4 summarises the macroinvertebrate fauna present in the four main areas (Copperhouse, North Quay, Carnsew and Lelant Water). Detailed results for each site are presented in Appendix 5 (in order of site number) and Appendix 6 (in order of increasing height on the shore).

Figures 3 - 6 show the number of taxa at each of the 44 sites, this ranged from 0 at site 9.3 to 7 at site 9.1.

The estimated number per square metre of the common taxa are plotted in Figures 7 - 32.

4. INTERPRETATION

4.1 ROCK-ASSOCIATED FAUNA

Several taxa were found at all five of the areas surveyed (Appendix 2), but not necessarily at all the sites within that area. The most ubiquitous taxa are listed below.

	Number of sites (max = 11)
<u>Littorina saxatilis</u>	10
<u>Carcinus maenas</u>	10
<u>Orchestia gammarellus</u>	9
<u>Ligia oceanica</u>	9
<u>Orchestia mediterranea</u>	7
<u>Chaetogammarus marinus</u>	6
Enchytraeid Oligochaetes	6

All of the taxa recorded during the survey are typical of this habitat, and no rare species were found. The greatest number of rock-associated fauna occurred at site 8, at the north-east end of Carnsew. Relatively high numbers of taxa were also recorded at site 9 (SW end of Carnsew) and site 4 (near the slipway at Copperhouse Pool).

Although Littorina saxatilis was found at almost every site, the numbers at sites in Copperhouse Pool were unusually low. It is not clear whether this is due to lack of suitable algae, low salinities or metal pollution. At site 5, near the Copperhouse sluice gates, only 8 L. saxatilis were found despite the abundance of furoid seaweeds, higher salinities, and presumably better water quality than other sites in Copperhouse.

The absence of the mud-snail Hydrobia ulvae, and the crustacean isopod genus Jaera were surprising. There is a possibility that they are absent due to metal pollution (for example by copper) but confirmation would require toxicity tests using waters and sediments.

4.2 FAUNA PRESENT IN CORE SAMPLES FROM MUDFLATS AND SANDFLATS.

The number of taxa present in the cores was exceptionally low, ranging from 0 to 7, with a mean value of 2.75. The reasons for the low number of taxa are discussed in sections 4.3 to 4.6.

Several estuarine species were not recorded in this survey, or were present at very low densities (eg Cerastoderma edule). The molluscs Hydrobia ulvae, Scrobicularia plana, Mya arenaria, and Macoma balthica were not seen, but may have been present at some sites at densities below the detection limit of 150 per square metre. In the case of Scrobicularia plana adults may have been present below the 10 cm depth taken by the core, but juveniles could only survive in the surface layer due to their shorter siphons. Large numbers of broken Scrobicularia shells were seen at some sites, especially in the intertidal part of Carnsew. Scrobicularia plana has been recorded from Hayle in the recent past (Bryan et al, 1980) but the exact locations were not reported.

Other species which would be expected to occur in the Hayle estuarine sites include the polychaetes Arenicola marina (intertidal) and Nephtys hombergii (lower intertidal and subtidal). Although the 10 cm deep cores may have missed adults of these species, it would be sufficient to collect juveniles. It seems likely that these species are present at some sites at low densities (<150 per square metre).

4.3 EFFECT OF HEIGHT ON THE SHORE ON MACROINVERTEBRATE COMMUNITIES

The height on the shore is important for benthic invertebrates because it is directly related to the length of inundation by overlying water. This in turn affects factors such as the microclimate of the site, predation pressure, and exposure to pollutants. These effects are summarised below, with special reference to estuarine intertidal sites, where the main sources of pollution are likely to be from freshwater.

	LOWER SHORE	UPPER SHORE
Period of inundation	Longer	Shorter
Salinity range	Greater	Smaller
Max. summer temperature	Lower	Higher
Min. winter temperature	Higher	Lower
Current velocities	Higher	Lower
Exposure to pollutants:		
concentrations	Higher	Lower
period of exposure	Longer	Shorter
Predation by flatfish	Longer	Shorter
Predation by waders	Shorter	Longer

The above list is not exhaustive, but does give an indication of the complexities of life in the intertidal zone. Many species have evolved which can tolerate this harsh estuarine intertidal environment. Each one has slightly different preferences in terms of particle size, salinity regime, food items etc. The species which have adapted often occur at very high densities, populations in the range 10,000 to 100,000 per square metre are commonplace for intertidal macro-invertebrates in estuaries.

The fauna of rocky shores has frequently been monitored in relation to the precise height on the shore. Most studies of intertidal mudflats and sandflats have simply described the results in terms of upper, middle and lower shore. This present study is therefore somewhat unusual, and the results clearly indicate the importance of accurately measuring height in this type of survey.

In Appendix 6 the sites have been listed in order of increasing heights relative to ODN. Some taxa show clear preferences for a particular height, even within the very narrow range of approximately 3.5 metres.

> + 1.6 metres ODN Enchytraeid oligochaetes
 > + 0.9 metres ODN Corophium volutator and Hediste diversicolor
 <+ 1.3 metres ODN Pygospio elegans
 <+ 1.0 metres ODN Streblospio shrubsolii and Capitella capitata
 <+ 0.2 metres ODN Tharyx sp.

The oligochaete Tubifex costatus appears to have a very narrow height preference of + 1.0 to + 1.4 metres, but six of the seven sites it was recorded from were in Copperhouse Pool, so it may also have been responding to other factors.

It is clear from Appendix 6 that few taxa can survive at the highest sites in this survey. Above + 1.4 metres ODN in Copperhouse Pool the only taxa recorded were Hediste, Corophium and enchytraeid oligochaetes. In Lelant Water some sites in this zone also had Pygospio and Capitella present.

Linear regressions of number of taxa on height were calculated for the 40 intertidal sites (accurate depth data were not obtained for the Carnsew subtidal sites). The regression line was significant at $P < 0.01$. When the results for Copperhouse Pool were excluded, however, the regression line was no longer significant at $P < 0.05$. Results for Copperhouse Pool were then analysed separately, and the regression was significant at $P < 0.01$. The regression for the Copperhouse Pool sites is shown in Figure 2; it should be noted that this regression should not be extrapolated beyond the limits of the graph. Under the conditions present at the time of sampling, an average of 1 extra taxon could be expected in Copperhouse Pool with each 0.35 metre decrease in height.

The highest points surveyed within Copperhouse Pool were the base of the seawall on the northern bank (generally +2.3 - 2.4 m ODN, rising to +2.8 at the junction with Black Road).

4.4 EFFECT OF SUBSTRATE ON MACROINVERTEBRATE COMMUNITIES

Although there is a strong relationship between height on the shore and the taxa present, this factor alone is insufficient to explain all the data. This is particularly true at the higher parts of the shore, above approximately +1.7 metres ODN. These sites are usually very well drained, with a clay substrate often covered with the alga Enteromorpha. In Copperhouse Pool these sites are easily recognised as the main bird roosts. The macro-invertebrate fauna at such sites is very restricted, and usually comprises only enchytraeid oligochaetes. The exceptions to this general rule are the poorly drained muddy saltmarsh areas to the north of Copperhouse Pool near Black Road. Only one such site was sampled in this survey (site 4.5); although this site had the second highest elevation in the entire survey, it had very good populations of the ragworm Hediste diversicolor and the gammarid crustacean Corophium volutator. This is almost certainly due to the muddy, poorly drained sediments at this site, which always have a surface veneer of water. Despite the height at this site (+1.99 m ODN) it had the highest densities of ragworm recorded during this survey. These saltmarsh areas attract wading birds due to the high prey densities and availability at most tidal states.

4.5 EFFECT OF METAL POLLUTION ON MACROINVERTEBRATE COMMUNITIES.

Previous studies by David Bellamy Associates have shown that the sediments in Copperhouse Pool are among the most contaminated of any UK estuaries, especially for copper, arsenic and zinc (Smith, 1988). The only UK estuary which has comparable or higher concentrations of these metals is Restronguet Creek, part of the Fal estuary complex. The chemistry, biology and toxicity of Restronguet Creek sediments and waters have been intensively studied by the Marine Biological Association (Bryan and Gibbs, 1983). They concluded that the macroinvertebrate fauna (especially the molluscan fauna) was restricted by metal toxicity. Comparisons of concentrations of metals in the sediments and waters of Restronguet Creek with laboratory toxicity data showed that copper and zinc were the most likely to exert toxic effects. Metals such as arsenic, lead and tin were thought to be less important. Sediment from the upper part of Restronguet Creek was lethal to juvenile bivalves (Scrobicularia plana and Macoma balthica) in laboratory tests. Although adult Scrobicularia plana were present in Restronguet Creek they were not found within 150 metres of the river channel. Large specimens predominated, suggesting that successful spawning was rare (Bryan and Gibbs, 1983). This may explain the apparent disappearance of Scrobicularia plana from Copperhouse Pool, as the older population may have died out. Recruitment may only occur rarely in such conditions, for example when metal inputs are low at the time of spawning and settlement.

There are interesting similarities between the faunas of Copperhouse Pool and Restronguet Creek. In Restronguet Creek the most metal-tolerant organisms were Hediste diversicolor, Carcinus maenas, Nephtys hombergii, Corophium volutator and Pygospio elegans (Bryan and Gibbs, 1983). With the exception of Nephtys hombergii (which prefers lower sediment heights than those found in Copperhouse Pool) all these taxa are present in Copperhouse Pool. The absence of Pygospio elegans from the freshwater end of Copperhouse Pool is probably due to low salinities rather than metal toxicity. The list of 'missing' taxa is also similar for the two sites. The absence of Cerastoderma edule (cockle) Mytilus edulis, Littorina littorea, L. littoralis and Hydrobia ulvae from the main part of Restronguet Creek was considered significant, as was the lack of juvenile Scrobicularia plana.

4.6 EFFECT OF ORGANIC POLLUTION ON MACROINVERTEBRATE COMMUNITIES

Organic pollution is usually caused by sewage or other biodegradable wastes. The effects on macroinvertebrates are well documented, and range from almost complete elimination of the fauna at the most polluted sites, to a decrease in the number of species but increase in population densities and biomass of tolerant species.

The results of this survey show little evidence of organic pollution in the sites around Hayle. The main exceptions were the Carnsew subtidal sites, two of which supported only Tharyx sp (known to be tolerant of organic pollution).

5. CONCLUSIONS

- 5.1 The macroinvertebrate fauna at estuarine sites around Hayle is sparse, and the molluscan fauna is especially restricted.
- 5.2 The distribution of the macroinvertebrates in Copperhouse Pool can be explained in terms of sediment height, substrate type, and tolerance to metal pollution.
- 5.3 In Copperhouse Pool an average of one extra taxon can be expected for each 0.35 metre decrease in height.
- 5.4 The absence of several species of molluscs (Scrobicularia plana, Macoma balthica, Hydrobia ulvae and Littorina littorea) from Copperhouse Pool and absence or low numbers at other sites around Hayle is probably due to metal pollution of the waters and sediments.
- 5.5 All of the factors which adversely affect macroinvertebrates in Copperhouse Pool could be ameliorated by ecologically sensitive engineering.
- 5.6 There is evidence that the subtidal sediments in Carnsew are affected by organic pollution, but the waters in Carnsew are probably of better quality than other estuarine sites around Hayle.
- 5.7 The morphology of Copperhouse Pool, particularly at the freshwater end, has apparently changed considerably since the 1983 bathymetric survey by Sea Sediments Ltd.

6. RECOMMENDATIONS

Please note that these recommendations only consider the macro-invertebrate communities, and different criteria may apply to other fauna, eg birds. In particular, the higher parts of Copperhouse Pool are used as roost sites by many species of birds, and support dense growths of the alga Enteromorpha which is eaten by wigeon.

COPPERHOUSE POOL.

- 6.1 Provided that there is a suitable method of disposing of the removed material, the higher parts of the intertidal areas in Copperhouse Pool should be lowered.
- 6.2 At some sites the concentrations of metals increase with depth, so it will be important to analyse the new surface to ensure that metal concentrations are significantly lower than at present.
- 6.3 The new surface should be in the range +0.5 - +1.5 metres ODN.
- 6.4 Most estuarine organisms living in the sediment rely on organic matter as a source of food. The recolonisation rate should be improved by increasing the organic content of the new surface, perhaps by incorporating small quantities of peat into the top 10 cm.

CARNSEW.

- 6.5 Maintain existing water quality.
- 6.6 Re-create rocky shore environment.

LELANT WATER.

- 6.7 Discuss with NCC and RSPB whether there are ways to reduce the rate of accretion of the intertidal areas.

GENERAL

- 6.8 Organise toxicity tests using waters and sediments from various sites around Hayle and a range of estuarine invertebrates.

REFERENCES.

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Bryan, G W, Langston, W J and Hummerstone, L G (1980). The use of biological indicators of heavy metal contamination in estuaries. Marine Biological Association Occasional Publication Number 1.

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7. APPENDICES

APPENDIX 1. LIST OF ALL ESTUARINE INVERTEBRATES IDENTIFIED BY DAVID BELLAMY ASSOCIATES AT LOCATIONS IN HAYLE.

PHYLUM	CLASS	TAXON	AUTHORITY
COELENTERATA	ANTHOZOA	ORDER ACTINIARIA <u>Anemonia viridis</u>	(Forsk.)
NEMERTEA	ENOPLA	ORDER HOPLONEMERTEA <u>Tetrastemma (flavidum?)</u>	Ehrenberg
ANNELIDA	OLIGOCHAETA	ORDER HAPLOTAXIDA Family Enchytraeidae <u>Tubificoides benedeni</u> <u>Tubificoides pseudogaster</u> <u>Tubifex costatus</u>	(Udekem) (Dahl) Claparede
	POLYCHAETA	ORDER ERRANTIA <u>Hediste diversicolor</u> <u>Neanthes virens</u> <u>Eumida sanguinea</u> Family Syllidae (juvenile)	O F Muller Sars (Oersted)
		ORDER SEDENTARIA <u>Capitella capitata</u> <u>Mediomastus fragilis</u> <u>Tharyx</u> sp <u>Cirriformia tentaculata</u> <u>Streblospio shrubsolii</u> <u>Pygospio elegans</u> <u>Polydora ciliata/ligni</u> <u>Laonice cirrata</u> <u>Manayunkia aestuarina</u> <u>Spirorbis spirorbis</u>	(Fabricius) Rasmussen (Montagu) (Buchanan) Claparede (M Sars) (Borne) (Linnaeus)
MOLLUSCA	BIVALVIA	ORDER LAMELLIBRANCHIA <u>Cerastoderma edule</u> <u>(Epilepton clarkiae?)</u> <u>Mytilus edulis</u>	(Linnaeus) (Clark) Linnaeus
	GASTROPODA	ORDER PROSOBRANCHIA <u>Littorina saxatilis</u> <u>Littorina littorea</u> <u>Littorina littoralis</u>	(Oliv) (Linnaeus) (Linnaeus)

CRUSTACEA	MALACOSTRACA	ORDER DECAPODA	
		<u>Carcinus maenas</u>	(Linnaeus)
		<u>Crangon crangon</u>	(Linnaeus)
		ORDER MYSIDACEA	
		1 juvenile mysid	
		ORDER ISOPODA	
		<u>Ligia oceanica</u>	(Linnaeus)
		ORDER AMPHIPODA	
		<u>Corophium volutator</u>	(Pallas)
		<u>Bathyporeia pilosa</u>	Lindstrom
		<u>Aora typica</u>	Kroyer
		<u>Microdeutopus anomalus</u>	(Rathke)
		<u>Orchestia gammarellus</u>	(Pallas)
		<u>Orchestia mediterranea</u>	Costa
		<u>Chaetogammarus marinus</u>	(Leach)
		<u>Chaetogammarus stoerensis</u>	(Reid)
		<u>Gammarus duebeni</u>	Liljeborg
		<u>Calliopius laevisculus</u>	(Kroyer)
	CIRRIPIEDIA	ORDER THORACICA	
		<u>Balanus balanoides</u>	(Linnaeus)

The following taxa were found in some intertidal cores, but not identified:

Nematoda
 Chilopoda (centipedes)
 Coleoptera (beetles)
 Diptera larvae (fly larvae)

APPENDIX 2 SUMMARY OF ROCK-ASSOCIATED FAUNA FOUND IN THE INTERTIDAL ZONE,
JANUARY 1989.

	COPPER- HOUSE POOL	PENPOL DOCK	CARNSEW	LELANT WATER	NORTH QUAY TO MOUTH
<hr/>					
OLIGOCHAETE WORMS					
<u>Enchytraeidae</u>	X		X	X	X
<hr/>					
POLYCHAETE WORMS					
<u>Hediste diversicolor</u>	X		X		
<u>Spirorbis spirorbis</u>			X		
<hr/>					
GASTROPOD MOLLUSCS					
<u>Littorina saxatilis</u>	X	X	X	X	X
<u>Littorina littorea</u>			X		
<u>Littorina littoralis</u>			X		
<hr/>					
BIVALVE MOLLUSCS					
<u>Mytilus edulis</u>	X		X		
<hr/>					
CRUSTACEANS					
<u>Carcinus maenas</u>	X	X	X	X	X
<u>Ligia oceanica</u>	X	X	X	X	X
<u>Orchestia gammarellus</u>	X	X	X	X	X
<u>Orchestia mediterranea</u>	X	X	X	X	X
<u>Chaetogammarus marinus</u>	X		X	X	X
<u>Chaetogammarus stoerensis</u>	X				
<u>Calliopius laevisculus</u>			X		
<u>Balanus balanoides</u>	X		X		
<hr/>					

APPENDIX 3 ROCK-ASSOCIATED FAUNA IN THE INTERTIDAL ZONE OF COPPERHOUSE POOL.
(NUMBER COUNTED IN A 10 MINUTE SEARCH)

	S I T E S				
	1	2	3	4	5
<hr/>					
OLIGOCHAETE WORMS					
<u>Enchytraeidae</u>		8	4	1	
<hr/>					
POLYCHAETE WORMS					
<u>Hediste diversicolor</u>	1		3	1	
<hr/>					
GASTROPOD MOLLUSCS					
<u>Littorina saxatilis</u>		1	14	2	8
<hr/>					
BIVALVE MOLLUSCS					
<u>Mytilus edulis</u>					1
<hr/>					
CRUSTACEANS					
<u>Carcinus maenas</u>	70	40	26	31	6
<u>Ligia oceanica</u>	8	4	>100	60	
<u>Orchestia gammarellus</u>	>100	50	>100	>100	
<u>Orchestia mediterranea</u>		>100			
<u>Chaetogammarus marinus</u>				1	13
<u>Chaetogammarus stoerensis</u>				1	
<u>Balanus balanoides</u>					Present
<hr/>					
TOTAL NUMBER OF TAXA	4	6	6	8	5
<hr/>					

APPENDIX 3
(CONTINUED)

ROCK-ASSOCIATED FAUNA IN THE INTERTIDAL ZONE OF PENPOL DOCK,
NORTH QUAY AND NEAR MOUTH OF THE HAYLE.
(NUMBER COUNTED IN A 10 MINUTE SEARCH)

	S I T E S		
	PENPOL DOCK 6	NORTH QUAY 7	NEAR MOUTH OF THE HAYLE 8
<hr/>			
OLIGOCHAETE WORMS			
<i>Enchytraeidae</i>			10
<hr/>			
GASTROPOD MOLLUSCS			
<i>Littorina saxatilis</i>	>100	50	4
<hr/>			
CRUSTACEANS			
<i>Carcinus maenas</i>	2	4	
<i>Ligia oceanica</i>	80	110	
<i>Orchestia gammarellus</i>	>100		50
<i>Orchestia mediterranea</i>	20	>100	10
<i>Chaetogammarus marinus</i>		4	1
<hr/>			
TOTAL NUMBER OF TAXA	5	5	5
<hr/>			

APPENDIX 3
(CONTINUED)

ROCK-ASSOCIATED FAUNA IN THE INTERTIDAL ZONE OF CARNSEW AND
LELANT WATER.
(NUMBER COUNTED IN A 10 MINUTE SEARCH)

	S I T E S		
	CARNSEW N.E. END 9	CARNSEW S.W. END 10	LELANT WATER 11
<hr/>			
OLIGOCHAETE WORMS			
<u>Enchytraeidae</u>	12		1
<hr/>			
POLYCHAETE WORMS			
<u>Spirorbis spirorbis</u>	>100		
<hr/>			
GASTROPOD MOLLUSCS			
<u>Littorina saxatilis</u>	90	120	150
<u>Littorina littorea</u>		2	
<u>Littorina littoralis</u>	>100?	1	
<hr/>			
BIVALVE MOLLUSCS			
<u>Mytilus edulis</u>	4		
<hr/>			
CRUSTACEANS			
<u>Carcinus maenas</u>	2	6	2
<u>Ligia oceanica</u>	>10	6	8
<u>Orchestia gammarellus</u>	>100	>100	>100
<u>Orchestia mediterranea</u>	>100	>100	>100?
<u>Chaetogammarus marinus</u>		7	6
<u>Calliopius laeviusculus</u>	1		
<u>Balanus balanoides</u>	Present		
<hr/>			
TOTAL NUMBER OF TAXA	11	8	7
<hr/>			

APPENDIX 4. SUMMARY OF DATA FROM CORE SAMPLES.

COPPERHOUSE POOL. TAXA FOUND IN CORE SAMPLES FROM ALL SITES.

Enchytraeidae
Tubificoides pseudogaster
Tubifex costatus
Hediste diversicolor
Capitella capitata
Streblospio shrubsolii
Pygospio elegans
Corophium volutator

Total number of taxa in core samples = 8

NORTH QUAY. TAXA FOUND IN CORE SAMPLES FROM ALL SITES.

Enchytraeidae
Tubificoides benedeni
Hediste diversicolor
Capitella capitata
Tharyx sp.
Streblospio shrubsolii
Pygospio elegans
Cerastoderma edule

Total number of taxa in core samples = 8

CARNSEW. TAXA FOUND IN CORE SAMPLES FROM ALL SITES.

Enchytraeidae
Tubificoides benedeni
Hediste diversicolor
Neanthes virens
Eumida sanguinea
Capitella capitata
Mediomastus fragilis
Tharyx sp
Cirriiformia tentaculata
Streblospio shrubsolii
Pygospio elegans
Polydora ciliata/ligni
Laonice cirrata
(Epilepton clarkiae?)

Total number of taxa in core samples = 14

APPENDIX 4 (CONTINUED)

LELANT WATER. TAXA FOUND IN CORE SAMPLES FROM ALL SITES.

Tetrastemma (flavidum?)

Enchytraeidae

Tubifex costatus

Hediste diversicolor

Capitella capitata

Pygospio elegans

Cerastoderma edule

Corophium volutator

Bathyporeia pilosa

Total number of taxa in core samples = 9

APPENDIX 5. DATA FROM CORE SAMPLES.

Site Number	Height Above ODN (metres)	Number of Taxa	Number of Individuals (per sq metre)	Substrate Code
COPPERHOUSE				
1.1	0.97	6	2550	3
1.2	1.36	1	450	4
1.3	0.80	5	5500	3
1.4	1.15	3	1200	6
2.1	1.93	1	150	4
2.2	1.14	4	4350	4
2.3	1.23	3	10050	4
2.4	1.71	2	3450	4
3.1	1.94	1	1050	1
3.2	1.07	3	2400	5
3.3	1.88	1	1050	1
3.4	1.55	2	1950	4
3.5	1.68	2	2100	4
4.1	1.64	2	2700	4
4.2	1.34	4	4800	5
4.3	2.19	1	84000	1
4.4	1.93	2	900	5
4.5	1.99	2	5100	6
NORTH QUAY				
5.1	0.75	2	450	4
5.2	-1.42	1	600	2
5.3	-1.00	6	2700	3
5.4	-1.06	5	5500	3
5.5	-0.88	3	1450	3
CARNSEW				
6.1	NA	6	3000	4
6.2	NA	1	4500	4
6.3	NA	3	450	6
6.4	NA	1	150	6
7.1	-0.21	5	4500	6
7.2	0.12	6	900	6
7.3	1.13	1	150	1.5
7.4	1.14	2	750	6
LELANT WATER				
8.1	0.26	2	1200	3
8.2	0.38	3	2550	2
9.1	0.93	7	47850	3
9.2	1.97	3	9900	3
9.3	1.61	0	0	4
9.4	1.22	4	10950	4
10.1	1.17	3	1200	4
10.2	1.68	2	4050	5
10.3	1.85	2	1500	5
10.4	1.95	3	6450	4
11.1	1.79	2	450	5
11.2	1.81	1	1650	5
11.3	1.94	2	1350	5

APPENDIX 5 (CONTINUED)

NUMBER PER SQUARE METRE

Site Number	<u>Hediste</u> <u>diversicolor</u>	<u>Corophium</u> <u>volutator</u>	Enchy- traeidae	<u>Pygospio</u> <u>elegans</u>	<u>Streblospio</u> <u>shrubsolii</u>	<u>Capitella</u> <u>capitata</u>
COPPERHOUSE						
1.1	300	450	150	300	150	0
1.2	0	0	450	0	0	0
1.3	450	0	0	1200	300	1050
1.4	900	0	0	0	0	150
2.1	0	0	150	0	0	0
2.2	0	3000	750	150	0	0
2.3	600	8550	0	900	0	0
2.4	300	3150	0	0	0	0
3.1	0	0	1050	0	0	0
3.2	1200	1050	0	0	0	0
3.3	0	0	1050	0	0	0
3.4	900	1050	0	0	0	0
3.5	600	1500	0	0	0	0
4.1	150	2550	0	0	0	0
4.2	2250	1500	150	0	0	0
4.3	0	0	84000	0	0	0
4.4	600	300	0	0	0	0
4.5	3300	1800	0	0	0	0
NORTH QUAY						
5.1	0	0	300	0	150	0
5.2	0	0	0	600	0	0
5.3	150	0	0	600	300	1200
5.4	0	0	0	300	3000	1050
5.5	0	0	0	1050	150	0
CARNSEW						
6.1	0	0	0	0	0	0
6.2	0	0	0	0	0	0
6.3	0	0	0	0	0	0
6.4	0	0	0	0	0	0
7.1	300	0	0	0	150	150
7.2	450	0	0	0	0	0
7.3	0	0	0	150	0	0
7.4	600	0	0	150	0	0
LELANT WATER						
8.1	0	300	0	0	0	900
8.2	0	0	0	0	0	150
9.1	1200	750	150	34200	0	11250
9.2	0	0	450	7950	0	1500
9.3	0	0	0	0	0	0
9.4	2100	7050	0	750	0	0
10.1	0	450	600	150	0	0
10.2	0	450	3600	0	0	0
10.3	0	1350	150	0	0	0
10.4	150	6150	0	150	0	0
11.1	0	300	150	0	0	0
11.2	0	0	1650	0	0	0
11.3	450	0	900	0	0	0

APPENDIX 5 (CONTINUED)

NUMBER PER SQUARE METRE

Site	<u>Tharyx</u>	<u>Tubifex</u>	<u>Tubificoides</u>	<u>Tubificoides</u>	<u>Cerastoderma</u>	<u>Bathyporeia</u>	<u>Tetra-</u>
Number sp.		<u>costatus</u>	<u>pseudogaster</u>	<u>benedeni</u>	<u>edule</u>	<u>pilosa</u>	<u>stemma</u>
COPPERHOUSE							
1.1	0	1200	0	0	0	0	0
1.2	0	0	0	0	0	0	0
1.3	0	0	2550	0	0	0	0
1.4	0	150	0	0	0	0	0
2.1	0	0	0	0	0	0	0
2.2	0	450	0	0	0	0	0
2.3	0	0	0	0	0	0	0
2.4	0	0	0	0	0	0	0
3.1	0	0	0	0	0	0	0
3.2	0	150	0	0	0	0	0
3.3	0	0	0	0	0	0	0
3.4	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0
4.1	0	0	0	0	0	0	0
4.2	0	900	0	0	0	0	0
4.3	0	0	0	0	0	0	0
4.4	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0
NORTH QUAY							
5.1	0	0	0	0	0	0	0
5.2	0	0	0	0	0	0	0
5.3	300	0	0	150	0	0	0
5.4	1050	0	0	0	150	0	0
5.5	0	0	0	0	150	0	0
CARNSEW							
6.1	0	0	0	1950	0	0	0
6.2	4500	0	0	0	0	0	0
6.3	150	0	0	0	0	0	0
6.4	150	0	0	0	0	0	0
7.1	3750	0	0	150	0	0	0
7.2	450	0	0	0	0	0	0
7.3	0	0	0	0	0	0	0
7.4	0	0	0	0	0	0	0
LELANT WATER							
8.1	0	0	0	0	0	0	0
8.2	0	0	0	0	0	2250	150
9.1	0	0	0	0	150	150	0
9.2	0	0	0	0	0	0	0
9.3	0	0	0	0	0	0	0
9.4	0	1050	0	0	0	0	0
10.1	0	0	0	0	0	0	0
10.2	0	0	0	0	0	0	0
10.3	0	0	0	0	0	0	0
10.4	0	0	0	0	0	0	0
11.1	0	0	0	0	0	0	0
11.2	0	0	0	0	0	0	0
11.3	0	0	0	0	0	0	0

APPENDIX 5 (CONTINUED)

NUMBER PER SQUARE METRE

The following taxa were only found in sediment cores from the Carnsew subtidal sites (6.1 - 6.4).

Site No.	<u>Neanthes virens</u>	<u>Eumida sanguinea</u>	<u>Mediomastus fragilis</u>	<u>Cirriformia tentaculata</u>	<u>Polydora ciliata/ ligni</u>	<u>Laonice cirrata</u>	<u>Epilepton clarkiae?</u>
6.1	0	150	450	150	150	150	0
6.2	0	0	0	0	0	0	0
6.3	150	0	0	0	0	0	150
6.4	0	0	0	0	0	0	0

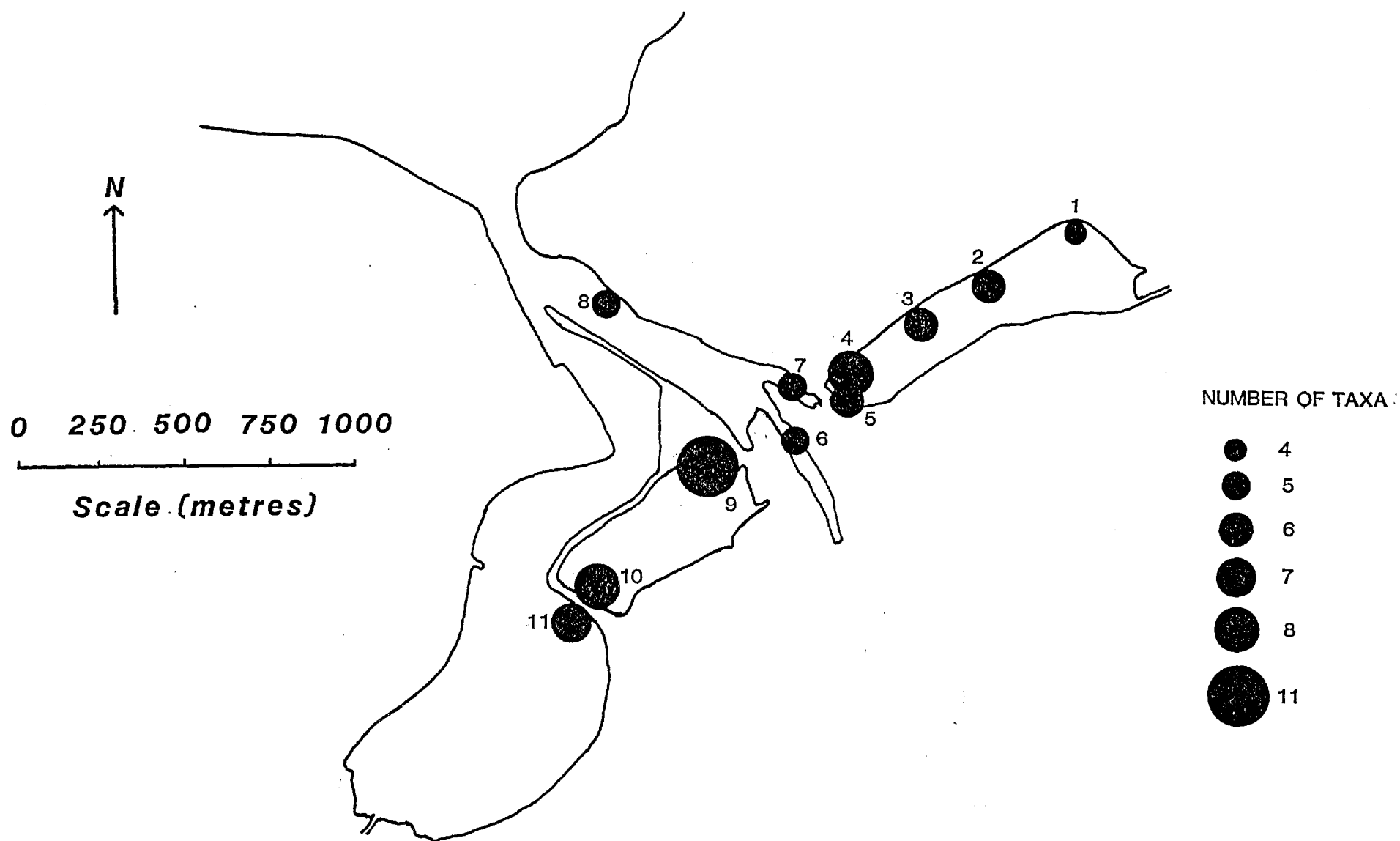
In addition, the following species were identified from a non-quantitative sample of algae obtained by diver from site 6.3:

Anemonia viridis
Tubificoides benedeni
Capitella capitata
Tharyx sp. (possibly I. vivipara)
Manayunkia aestuarina
Syllidae (juv)
Aora typica
Microdeutopus anomalus

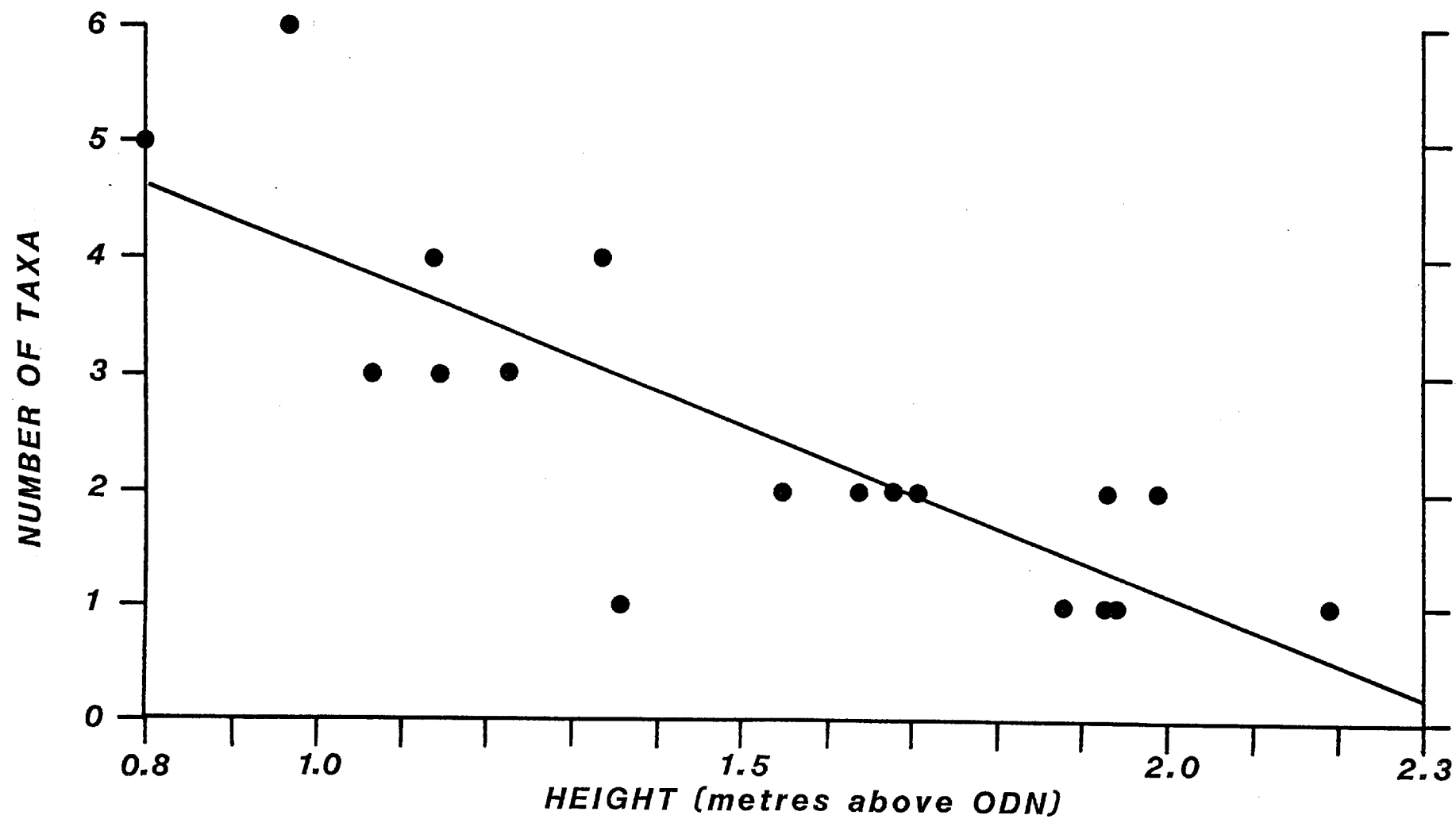
APPENDIX 7. DATA FROM CORE SAMPLES; SORTED BY HEIGHT.

Site Number	Height Above ODN (metres)	Number of Taxa	Number of Individuals (per sq metre)	Substrate Code	<u>Hediste diversicolor</u>	<u>Corophium volutator</u>	Enchytraeidae	<u>Pygospio elegans</u>	<u>Streblospio shrubsolii</u>	<u>Capitella capitata</u>	<u>Tharyx sp.</u>	<u>Tubifex costatus</u>	<u>Tubificoides pseudogaster</u>	<u>Tubificoides benedini</u>	<u>Cerastoderma edule</u>	<u>Bathyporeia pilosa</u>	<u>Tetrastrea</u>
5.2	-1.42	1	600	4	0	0	0	600	0	0	0	0	0	0	0	0	0
5.4	-1.06	5	5500	4	0	0	0	300	3000	1050	1050	0	0	0	150	0	0
5.3	-1	6	2700	5	150	0	0	600	300	1200	300	0	0	150	0	0	0
5.5	-0.88	3	1450	4	0	0	0	1050	150	0	0	0	0	0	150	0	0
7.1	-0.21	5	4500	4	300	0	0	0	150	150	3750	0	0	150	0	0	0
7.2	0.12	6	900	4	450	0	0	0	0	0	450	0	0	0	0	0	0
8.1	0.26	2	1200	4	0	300	0	0	0	900	0	0	0	0	0	0	0
8.2	0.38	3	2550	5	0	0	0	0	0	150	0	0	0	0	0	2250	150
5.1	0.75	2	450	4	0	0	300	0	150	0	0	0	0	0	0	0	0
1.3	0.8	5	5500	3	450	0	0	1200	300	1050	0	0	2550	0	0	0	0
9.1	0.93	7	47850	5	1200	750	150	34200	0	11250	0	0	0	0	150	150	0
1.1	0.97	6	2550	2	300	450	150	300	150	0	0	1200	0	0	0	0	0
3.2	1.07	3	2400	3	1200	1050	0	0	0	0	0	150	0	0	0	0	0
7.3	1.13	1	150	4	0	0	0	150	0	0	0	0	0	0	0	0	0
2.2	1.14	4	4350	6	0	3000	750	150	0	0	0	450	0	0	0	0	0
7.4	1.14	2	750	5	600	0	0	150	0	0	0	0	0	0	0	0	0
1.4	1.15	3	1200	3	900	0	0	0	0	150	0	150	0	0	0	0	0
10.1	1.17	3	1200	5	0	450	600	150	0	0	0	0	0	0	0	0	0
9.4	1.22	4	10950	4	2100	7050	0	750	0	0	0	1050	0	0	0	0	0
2.3	1.23	3	10050	3	600	8550	0	900	0	0	0	0	0	0	0	0	0
4.2	1.34	4	4800	4	2250	1500	150	0	0	0	0	900	0	0	0	0	0
1.2	1.36	1	450	3	0	0	450	0	0	0	0	0	0	0	0	0	0
3.4	1.55	2	1950	3	900	1050	0	0	0	0	0	0	0	0	0	0	0
9.3	1.61	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
4.1	1.64	2	2700	1.5	150	2550	0	0	0	0	0	0	0	0	0	0	0
3.5	1.68	2	2100	5	600	1500	0	0	0	0	0	0	0	0	0	0	0
10.2	1.68	2	4050	1	0	450	3600	0	0	0	0	0	0	0	0	0	0
2.4	1.71	2	3450	2	300	3150	0	0	0	0	0	0	0	0	0	0	0
11.1	1.79	2	450	3	0	300	150	0	0	0	0	0	0	0	0	0	0
11.2	1.81	1	1650	6	0	0	1650	0	0	0	0	0	0	0	0	0	0
10.3	1.85	2	1500	5	0	1350	150	0	0	0	0	0	0	0	0	0	0
3.3	1.88	1	1050	3	0	0	1050	0	0	0	0	0	0	0	0	0	0
2.1	1.93	1	150	6	0	0	150	0	0	0	0	0	0	0	0	0	0
4.4	1.93	2	900	6	600	300	0	0	0	0	0	0	0	0	0	0	0
3.1	1.94	1	1050	4	0	0	1050	0	0	0	0	0	0	0	0	0	0
11.3	1.94	2	1350	1	450	0	900	0	0	0	0	0	0	0	0	0	0
10.4	1.95	3	6450	4	150	6150	0	150	0	0	0	0	0	0	0	0	0
9.2	1.97	3	9900	5	0	0	450	7950	0	1500	0	0	0	0	0	0	0
4.5	1.99	2	5100	4	3300	1800	0	0	0	0	0	0	0	0	0	0	0
4.3	2.19	1	84000	6	0	0	84000	0	0	0	0	0	0	0	0	0	0

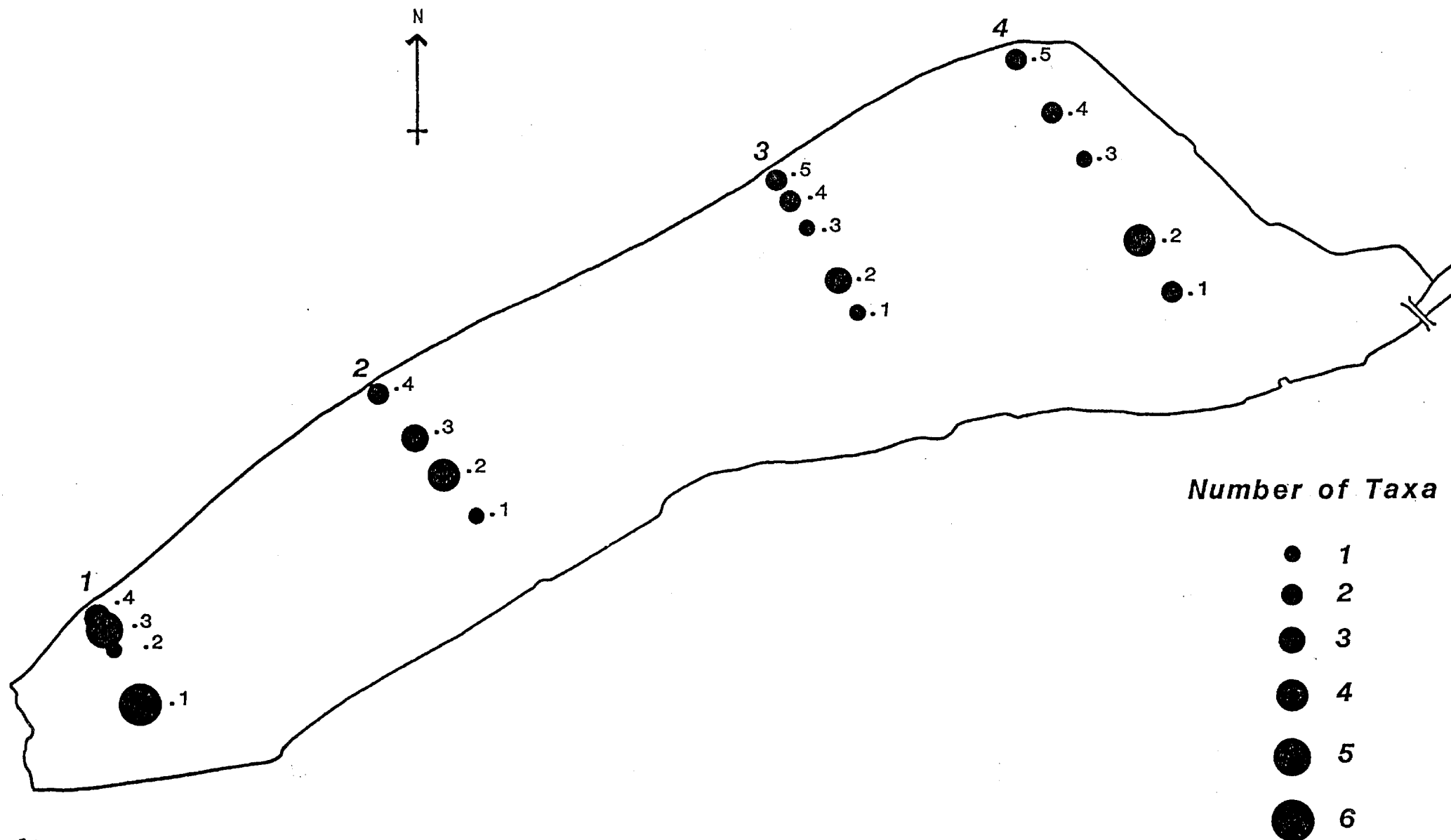
ROCK-ASSOCIATED FAUNA. SITES AND NUMBER OF TAXA.



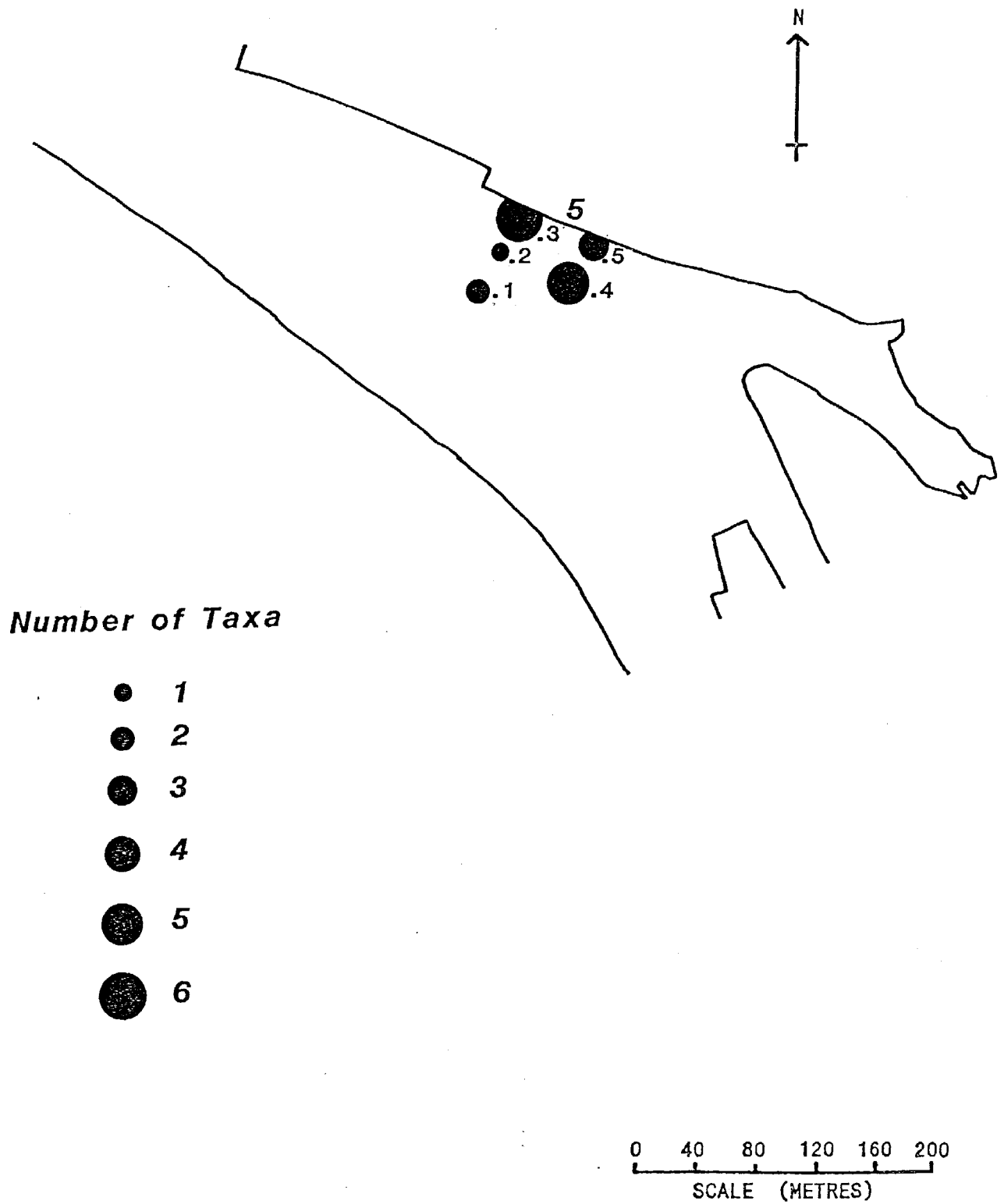
COPPERHOUSE POOL . REGRESSION OF NUMBER OF TAXA ON HEIGHT.



COPPERHOUSE POOL. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.

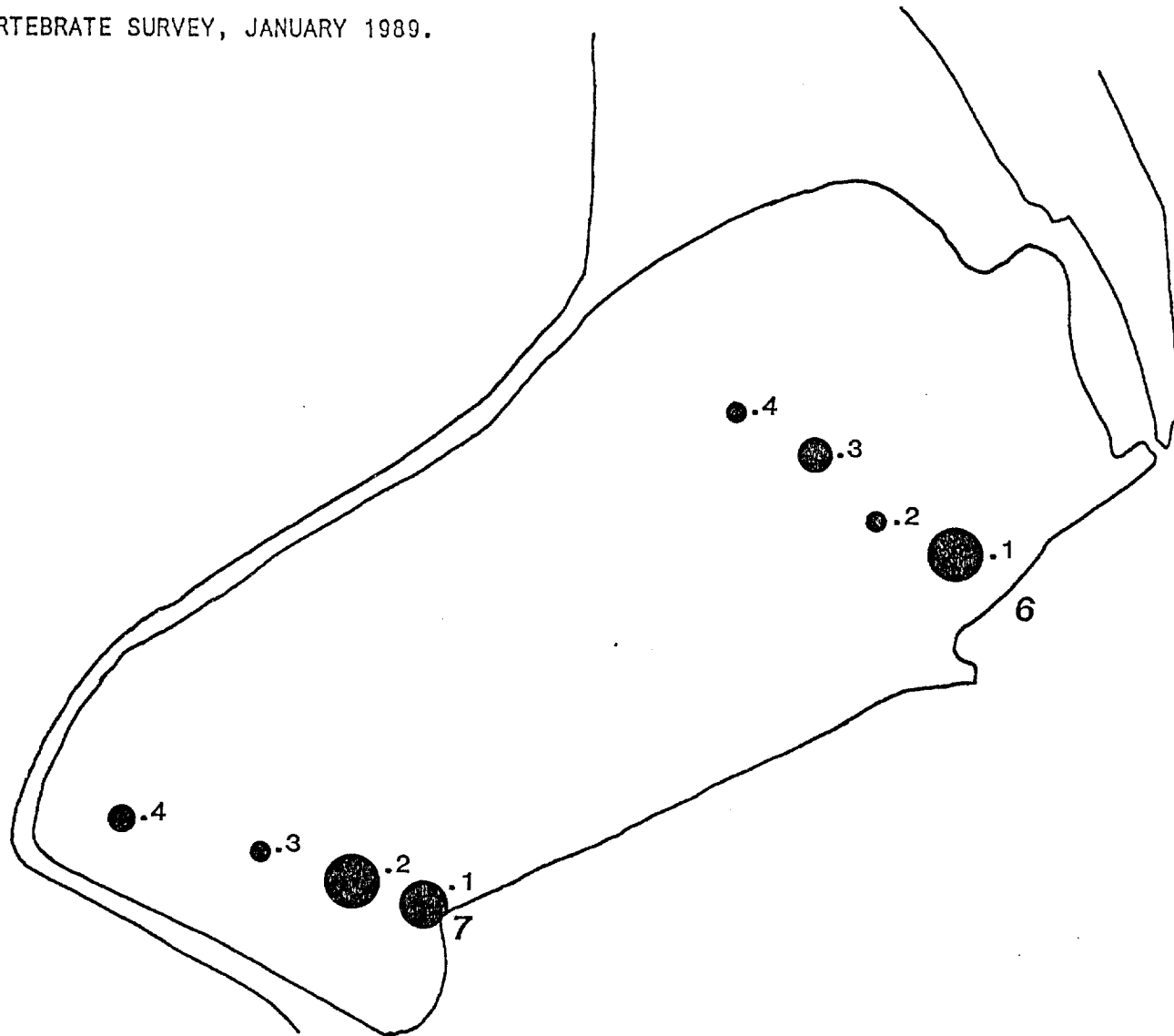
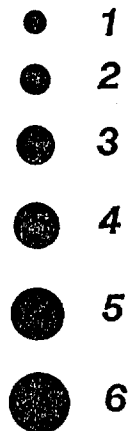


NORTH QUAY. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.



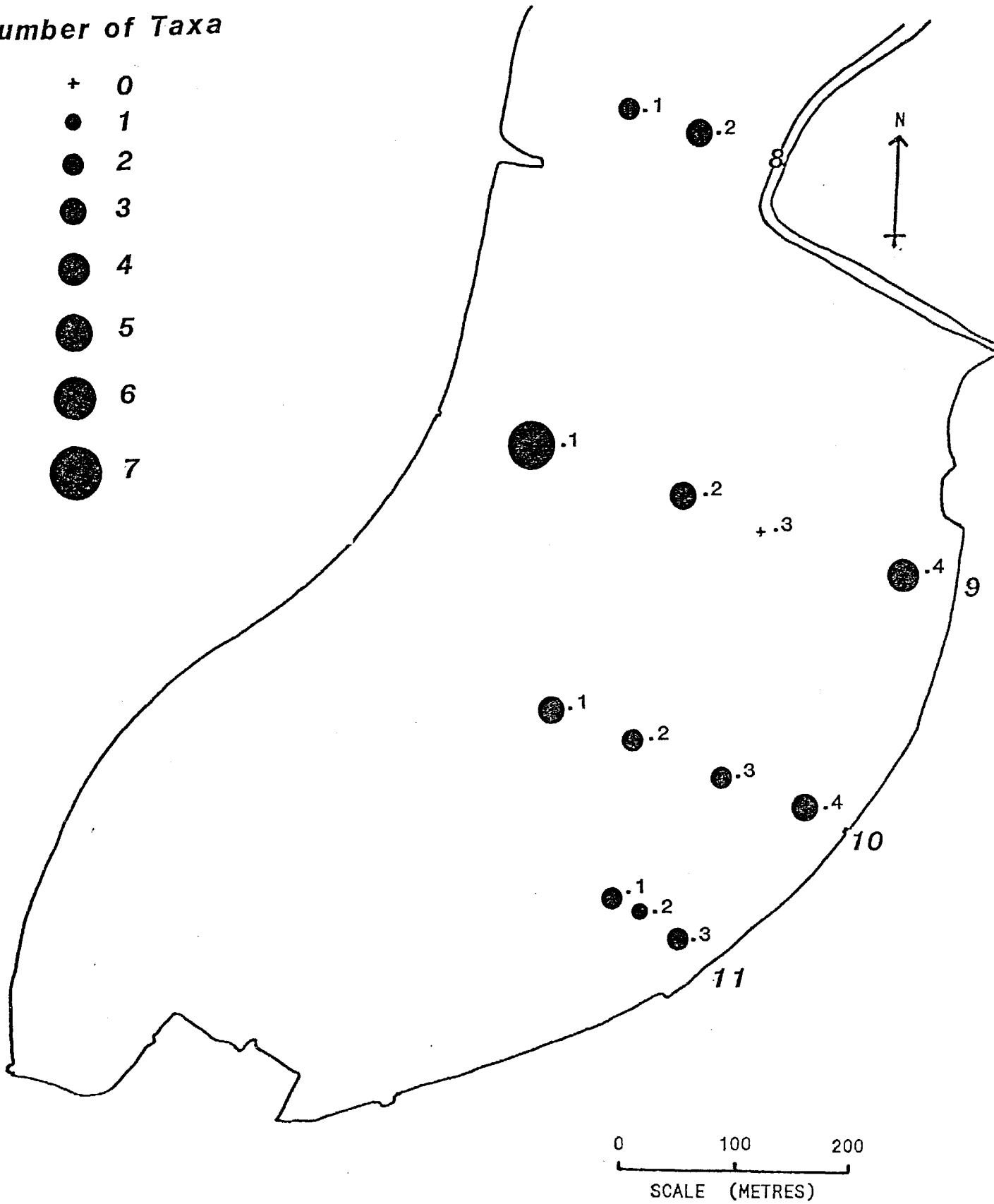
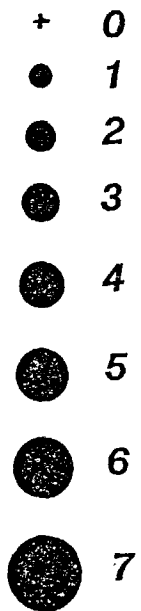
CARNSEW. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.

Number of Taxa

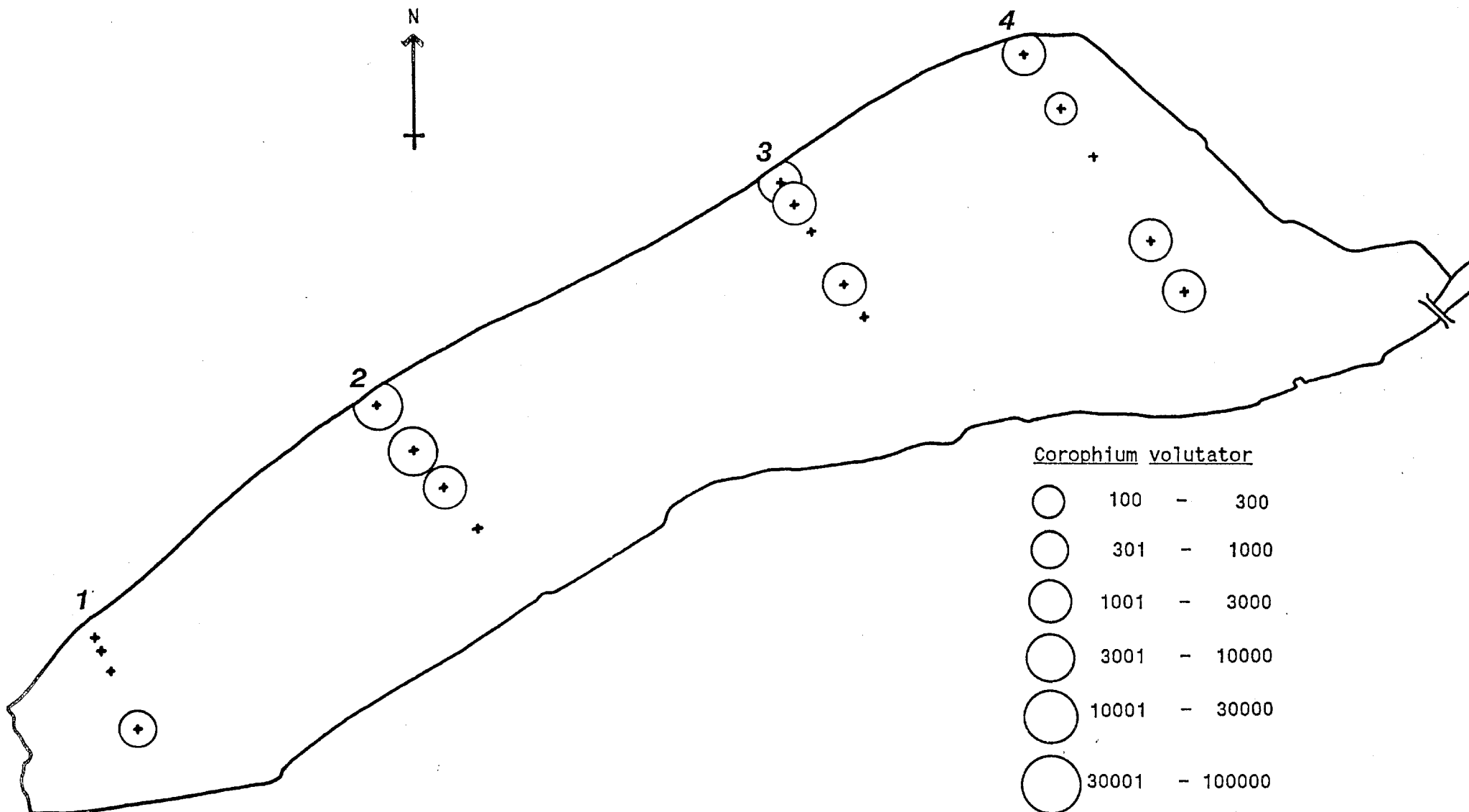


LELANT WATER. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.

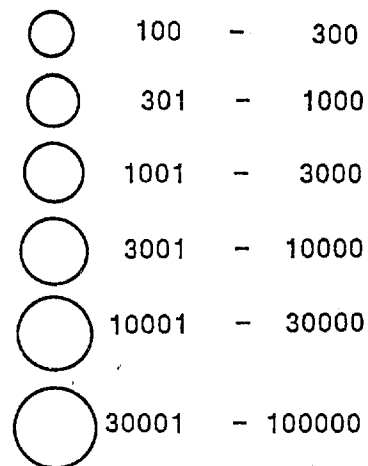
Number of Taxa



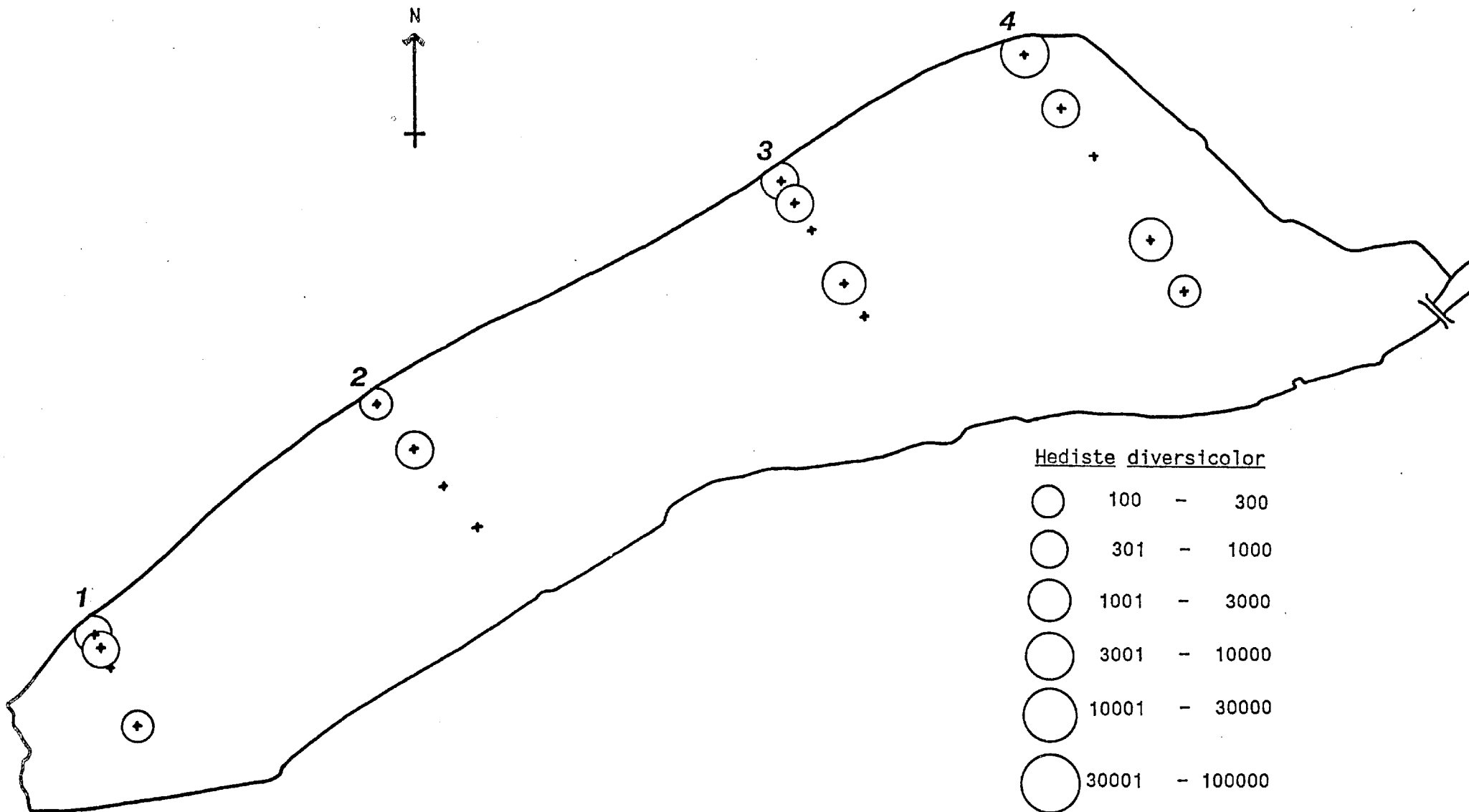
COPPERHOUSE POOL. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.



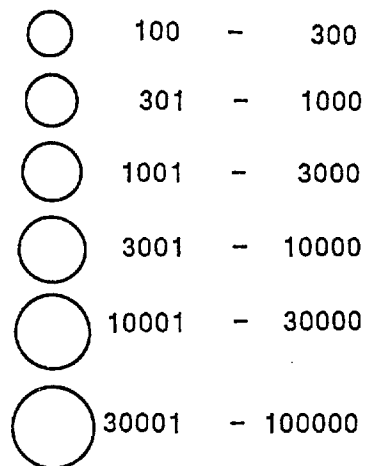
Corophium volutator



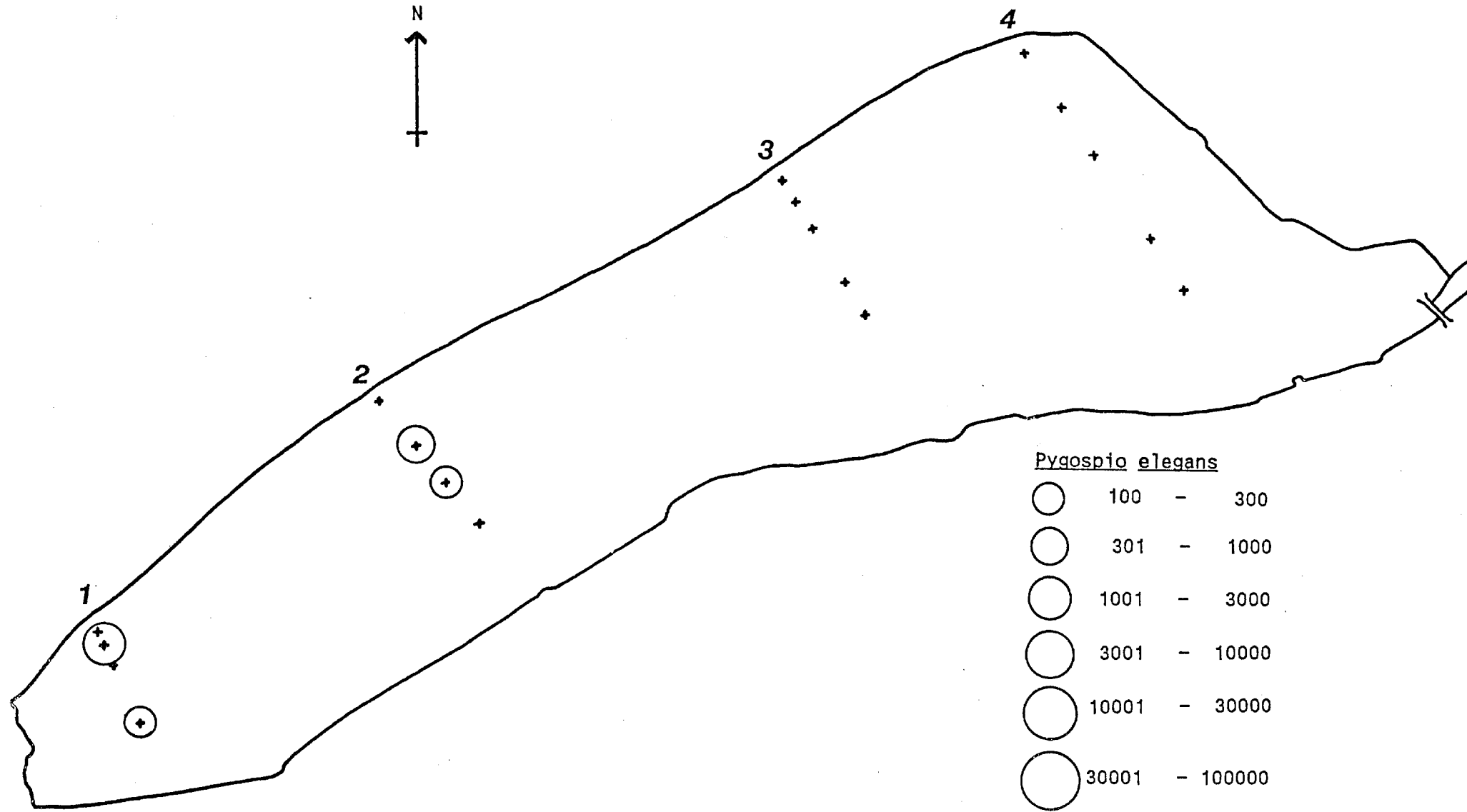
COPPERHOUSE POOL. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.



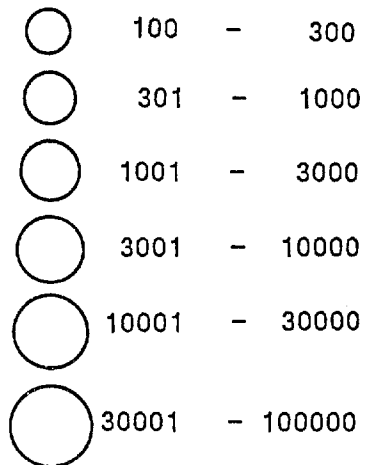
Hediste diversicolor



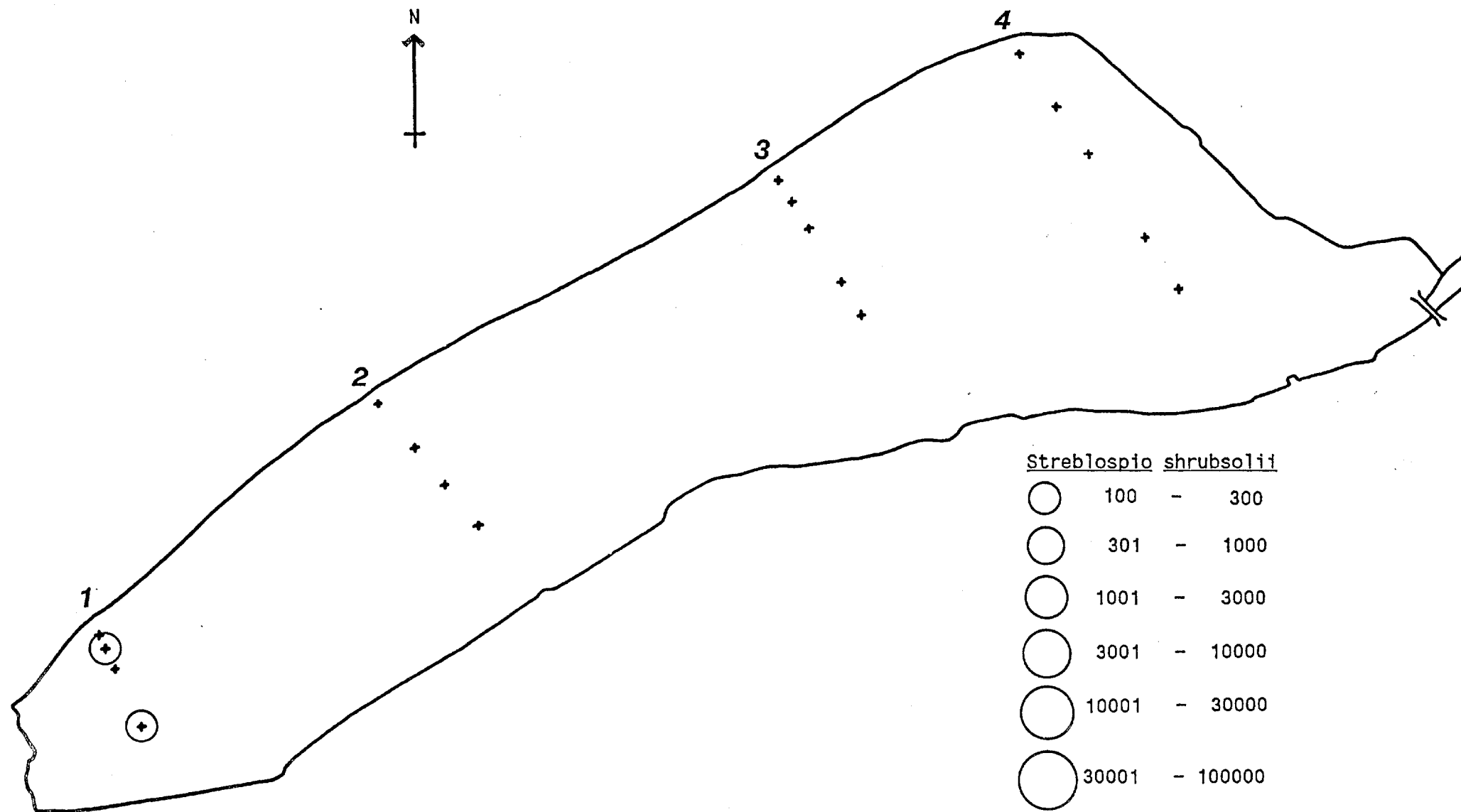
COPPERHOUSE POOL. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.



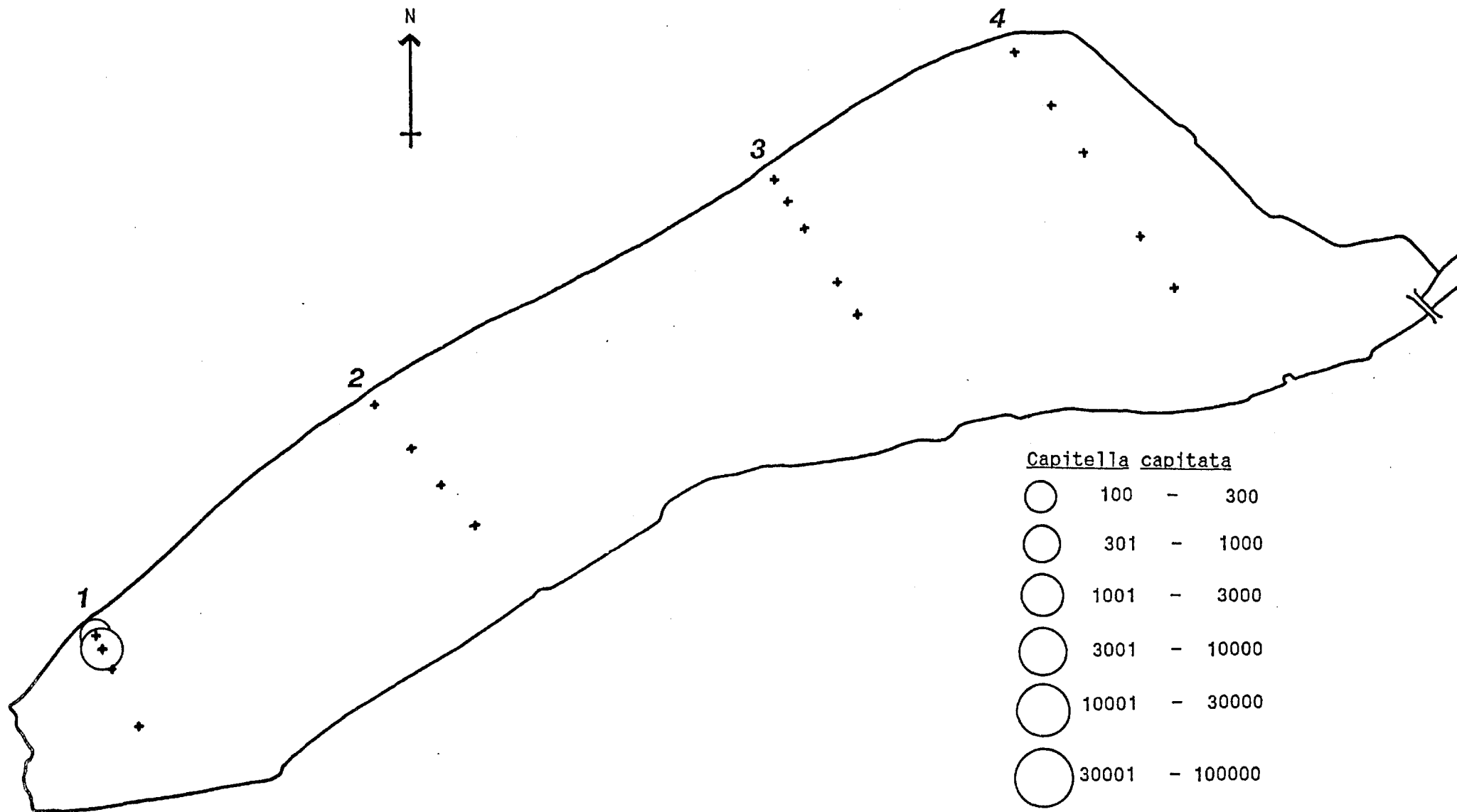
Pygospio elegans



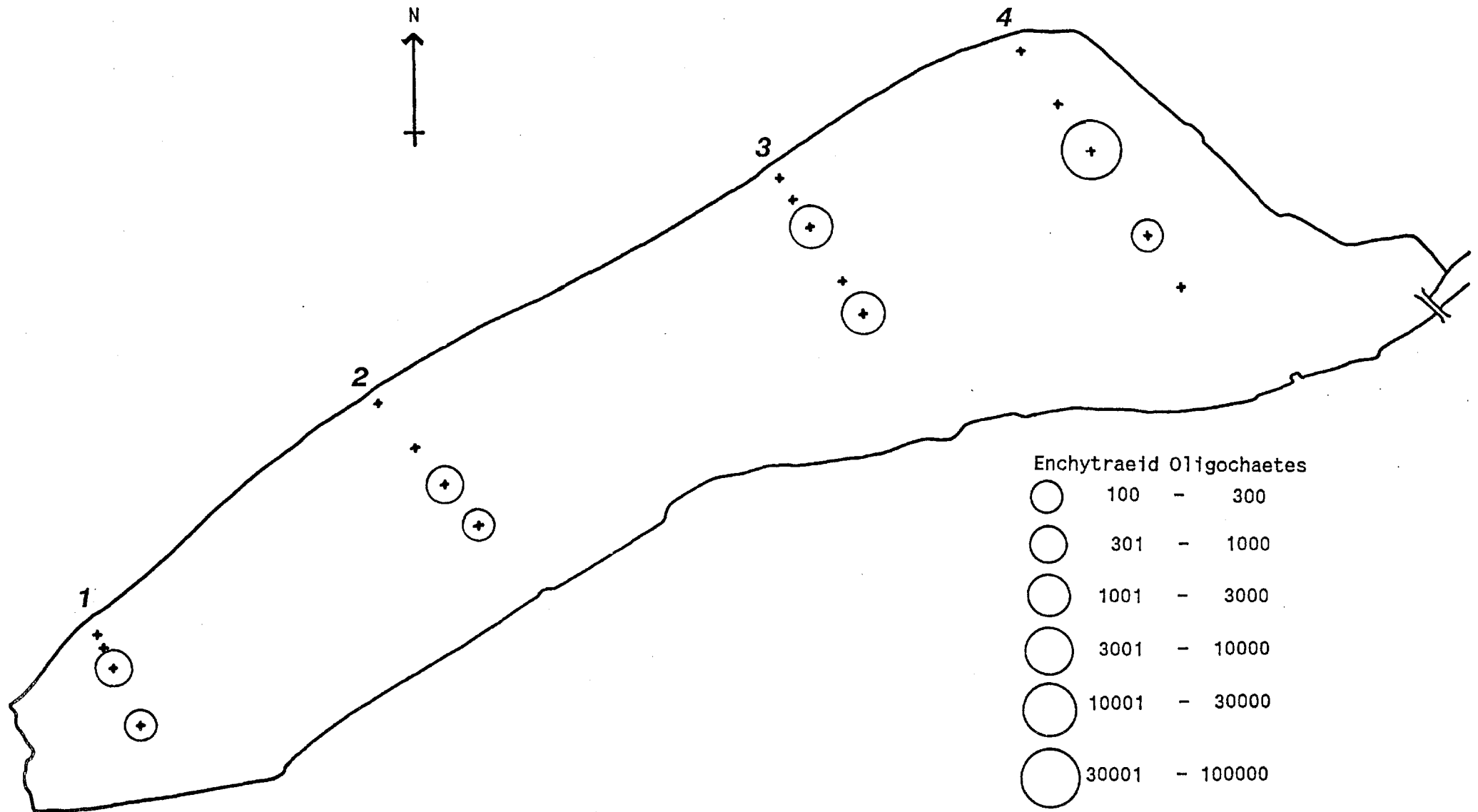
COPPERHOUSE POOL. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.



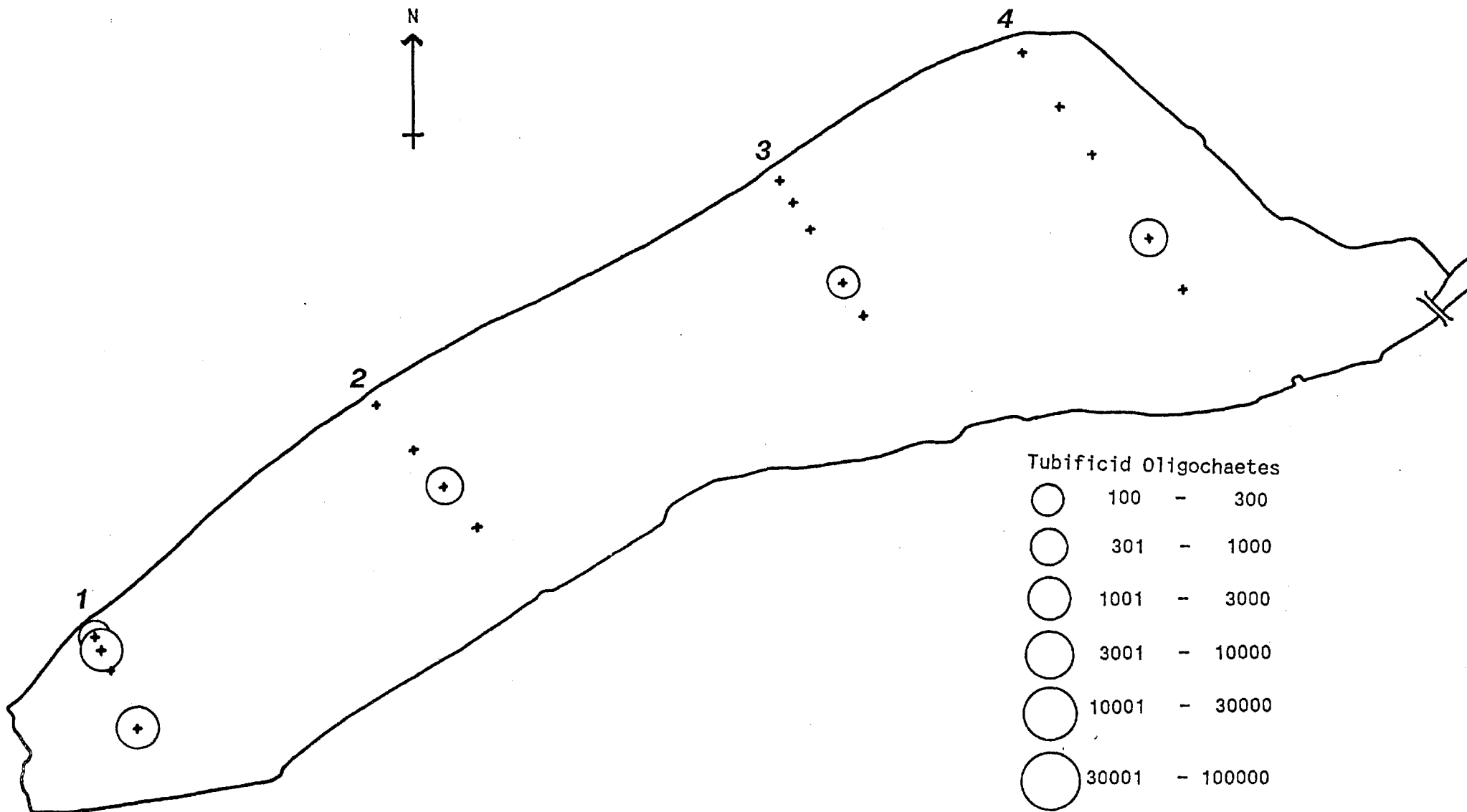
COPPERHOUSE POOL. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.



COPPERHOUSE POOL. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.



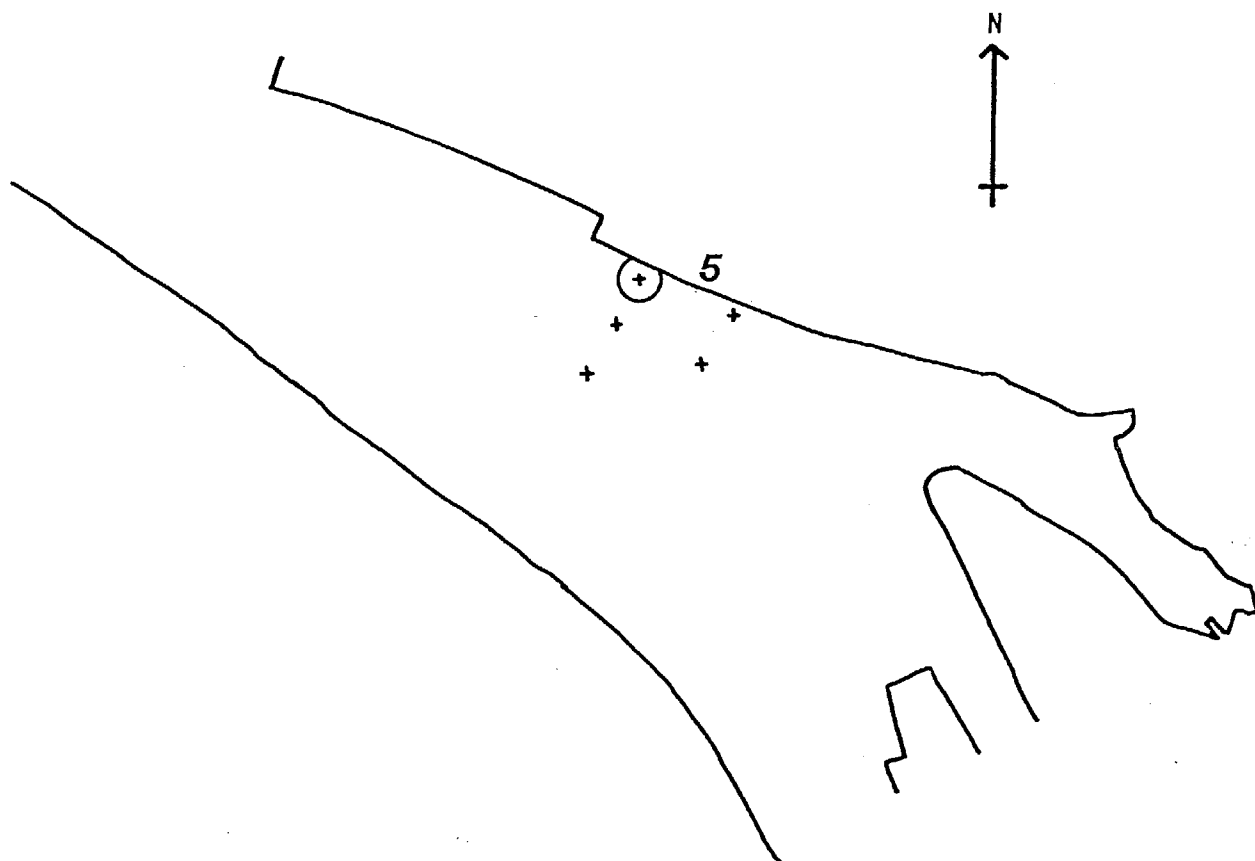
COPPERHOUSE POOL. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.



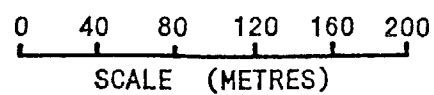
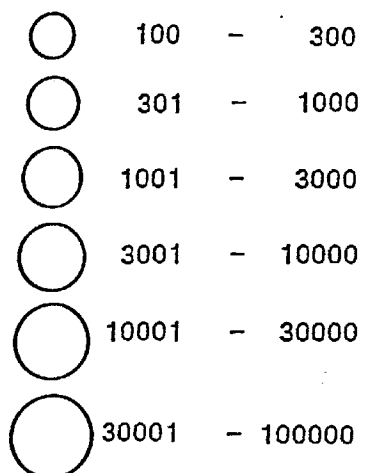
Tubificid Oligochaetes

○	100	-	300
○	301	-	1000
○	1001	-	3000
○	3001	-	10000
○	10001	-	30000
○	30001	-	100000

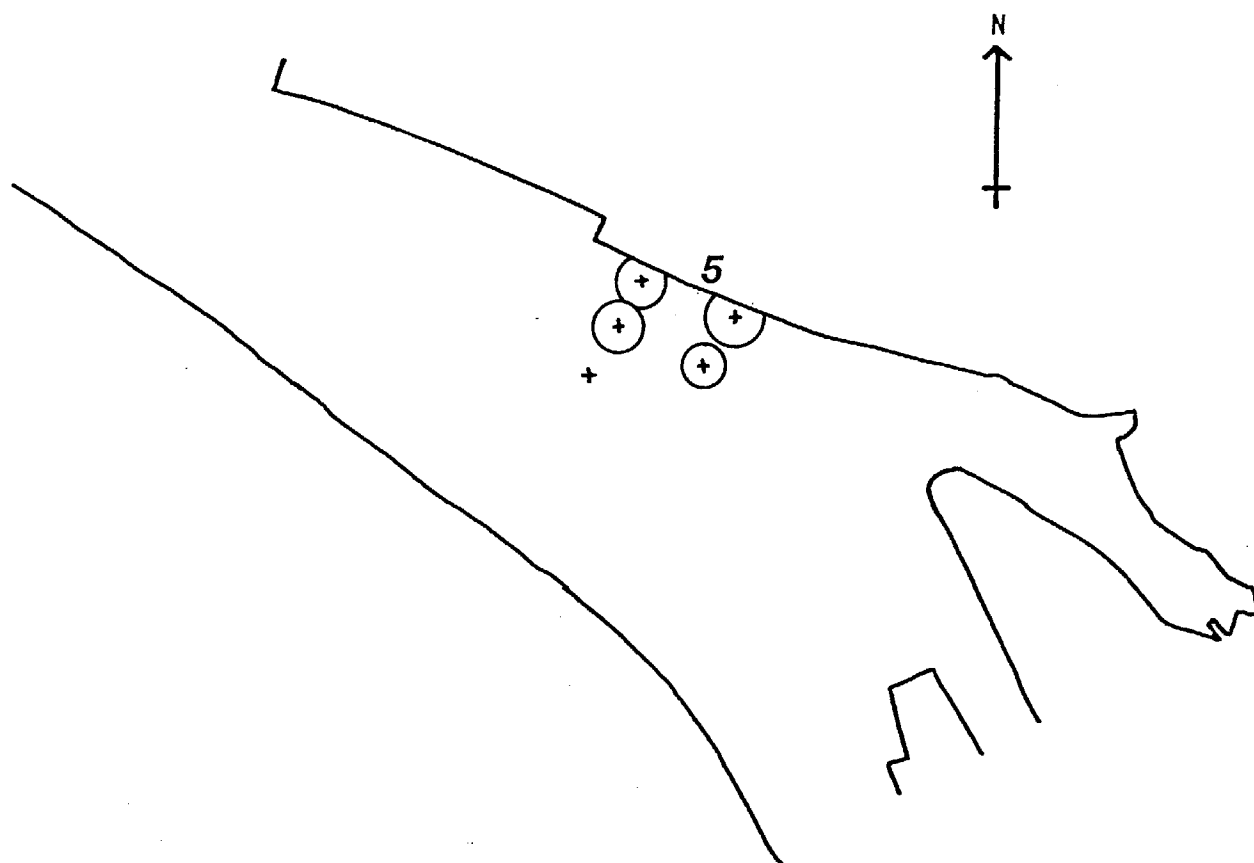
NORTH QUAY. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.



Hediste diversicolor



NORTH QUAY. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.

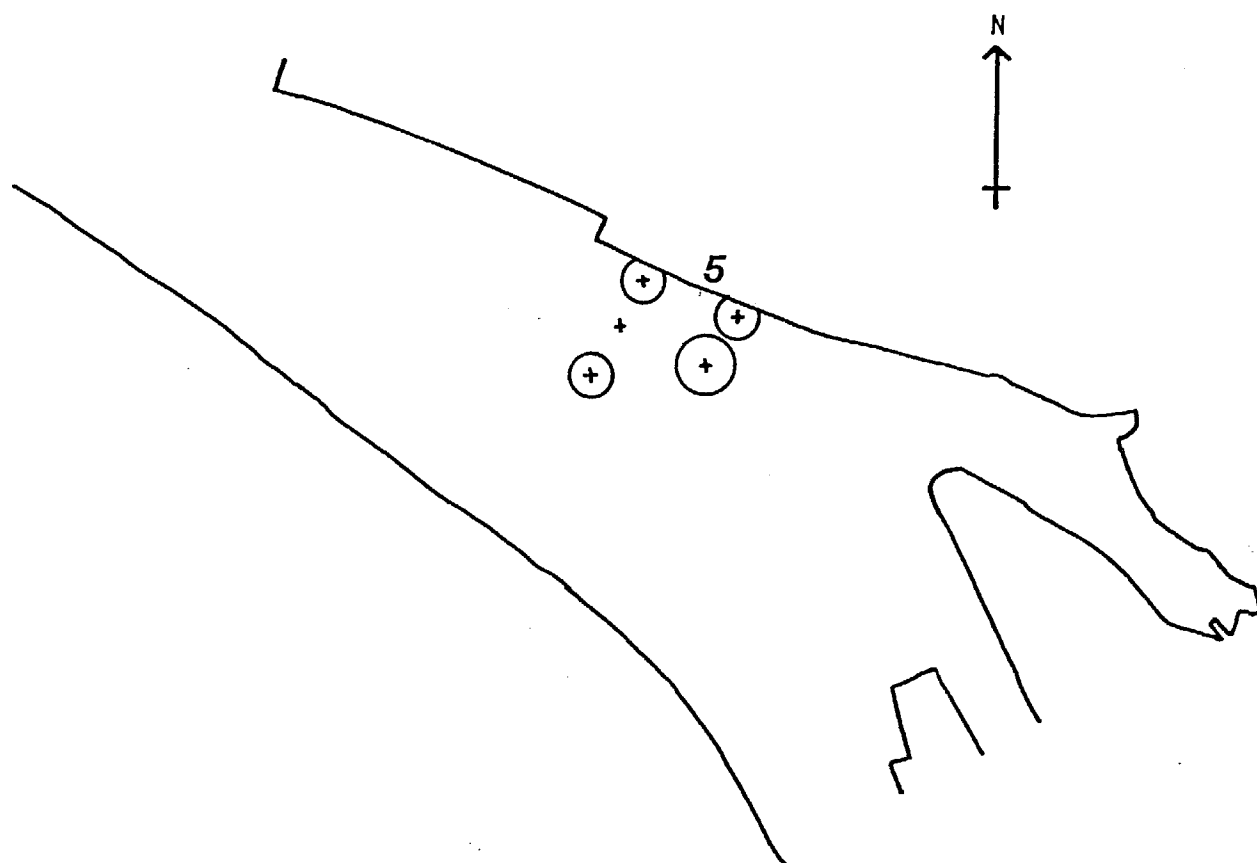


Pygospio elegans

○	100	-	300
○	301	-	1000
○	1001	-	3000
○	3001	-	10000
○	10001	-	30000
○	30001	-	100000

0 40 80 120 160 200
SCALE (METRES)

NORTH QUAY. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.

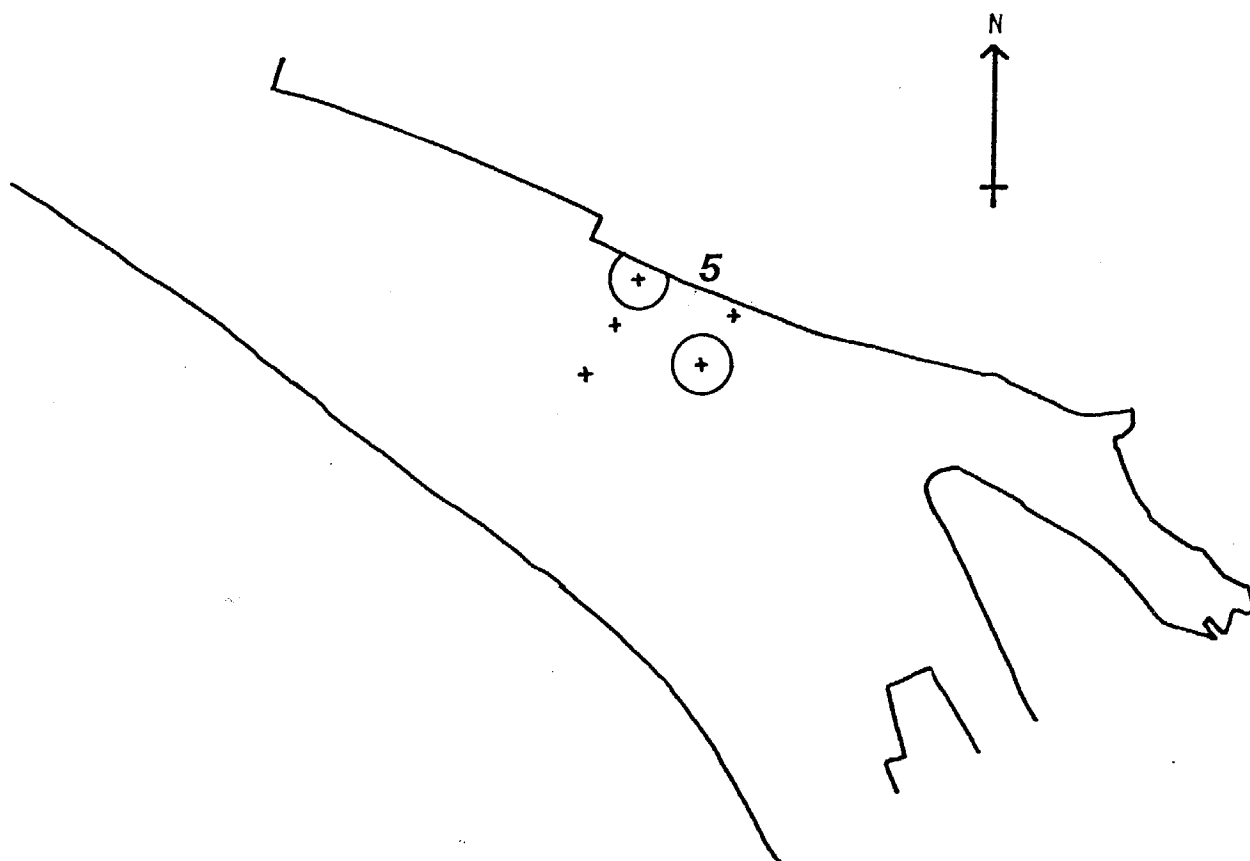


Streptosia shrubsolii

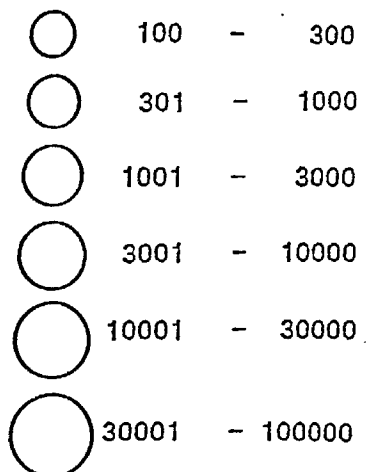
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○	3001	-	10000
○	10001	-	30000
○	30001	-	100000

0 40 80 120 160 200
SCALE (METRES)

NORTH QUAY. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.

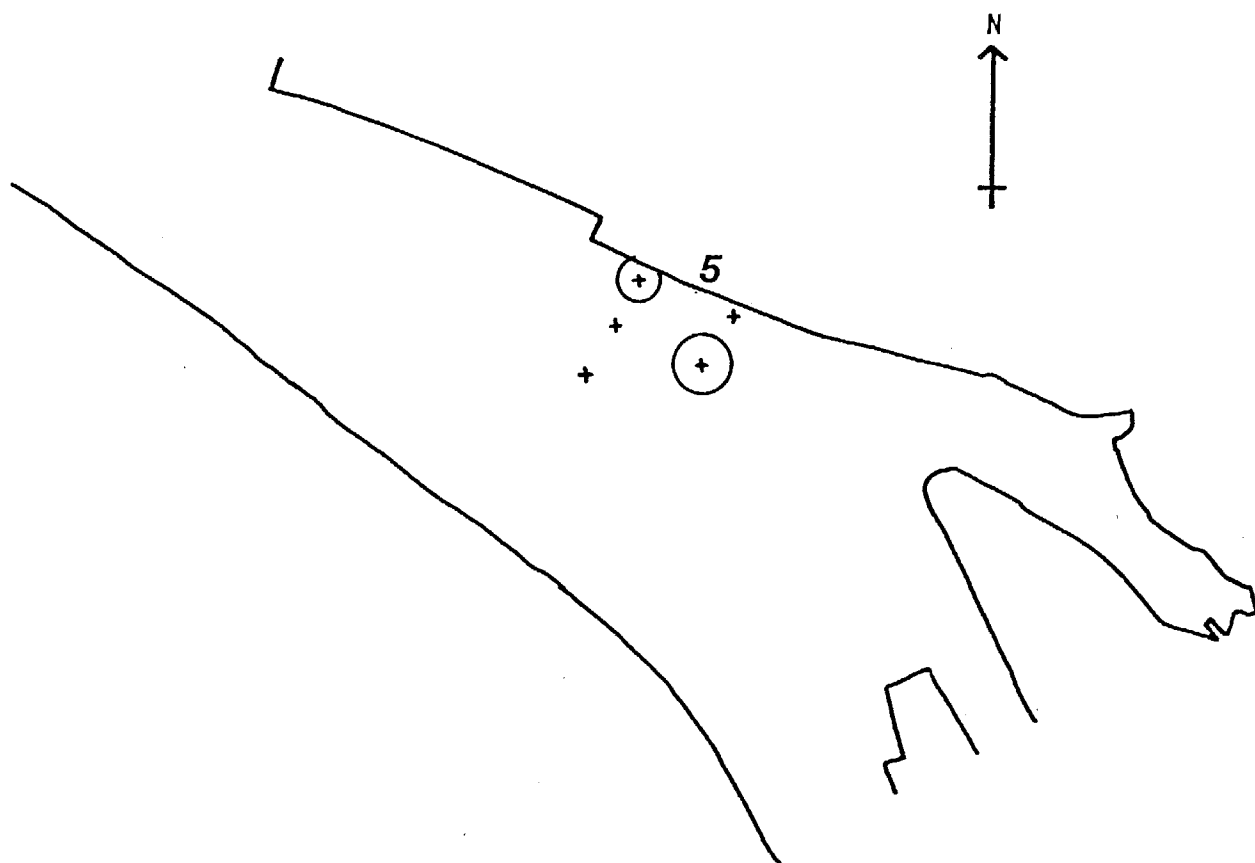


Capitella capitata



0 40 80 120 160 200
SCALE (METRES)

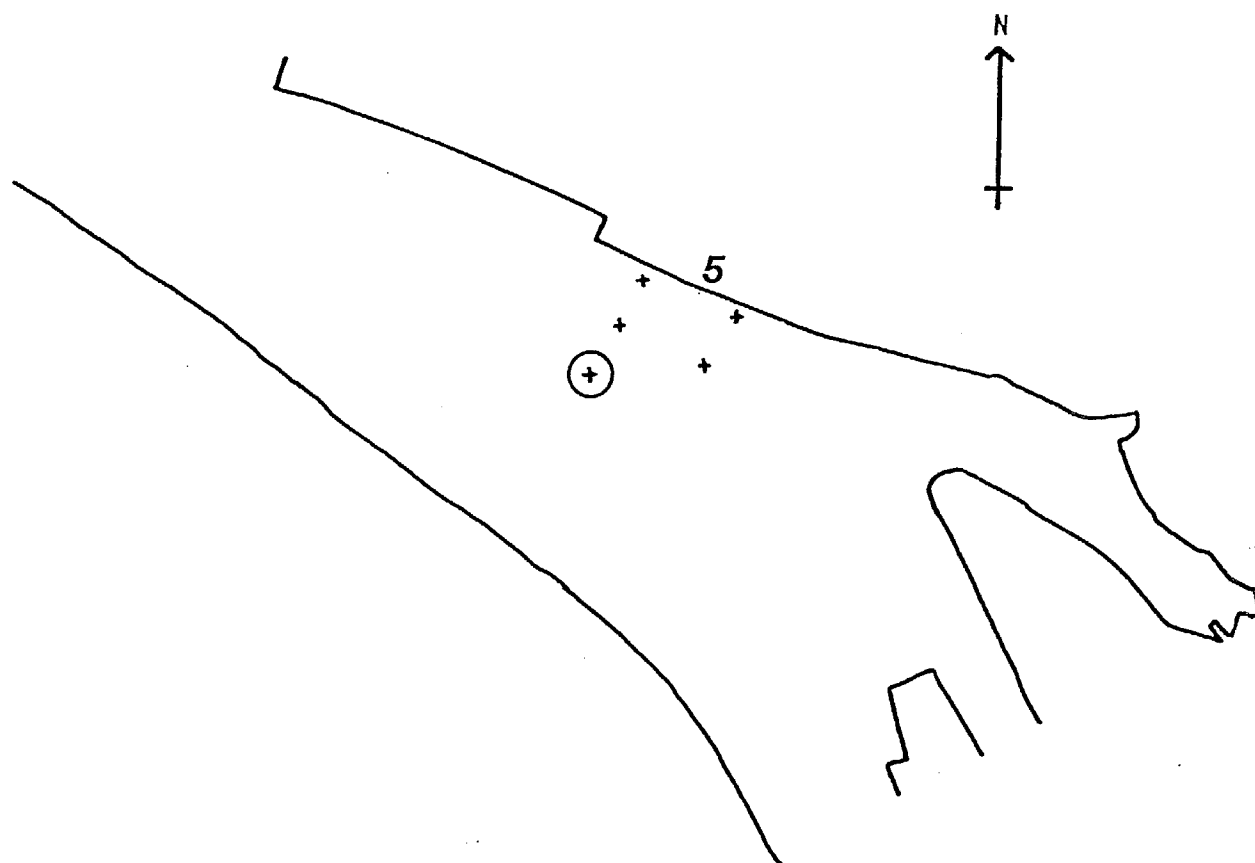
NORTH QUAY. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.



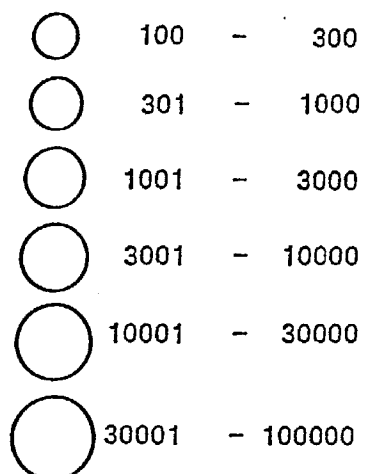
<u>Tharyx</u> sp			
○	100	-	300
○	301	-	1000
○	1001	-	3000
○	3001	-	10000
○	10001	-	30000
○	30001	-	100000

0 40 80 120 160 200
SCALE (METRES)

NORTH QUAY. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.

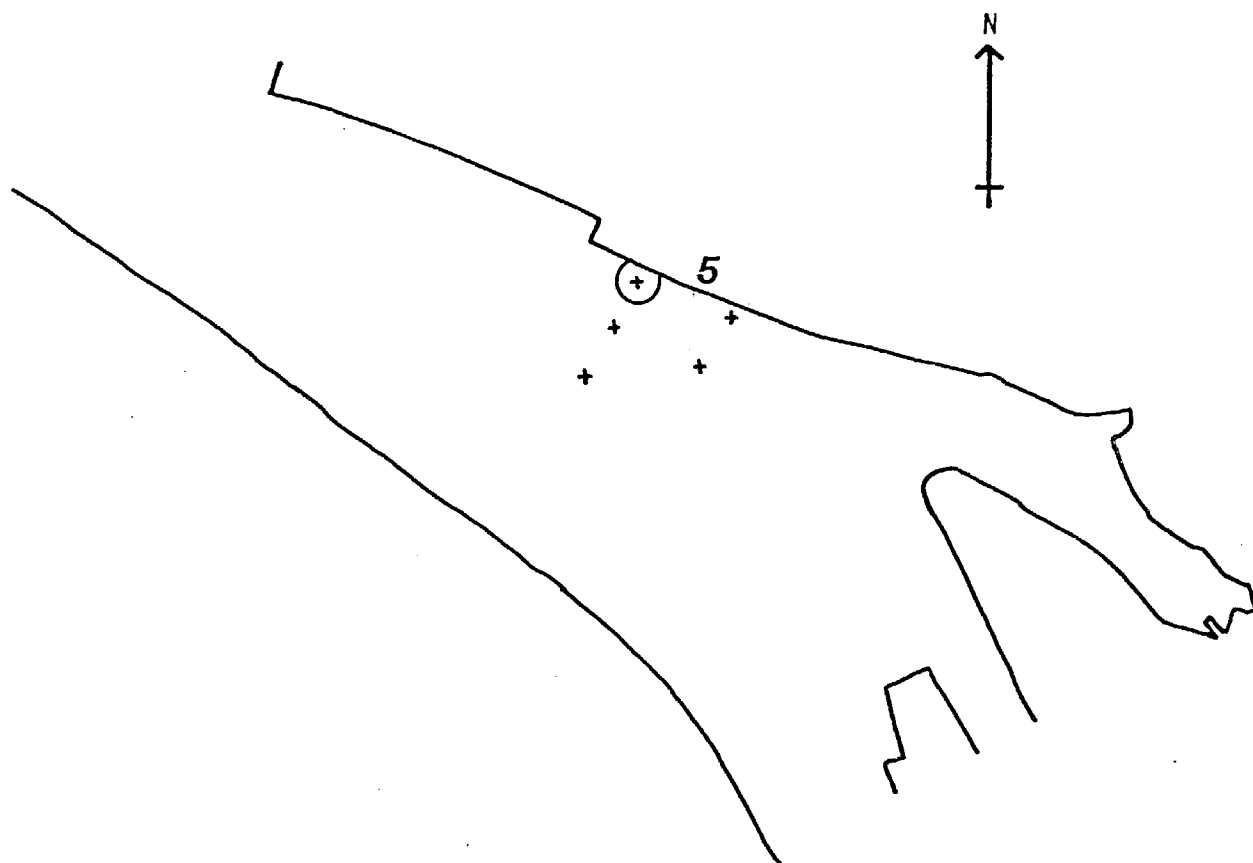


Enchytraeid Oligochaetes

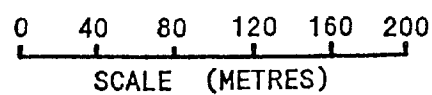
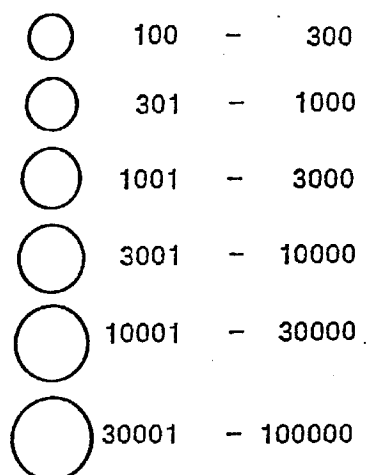


0 40 80 120 160 200
SCALE (METRES)

NORTH QUAY. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.

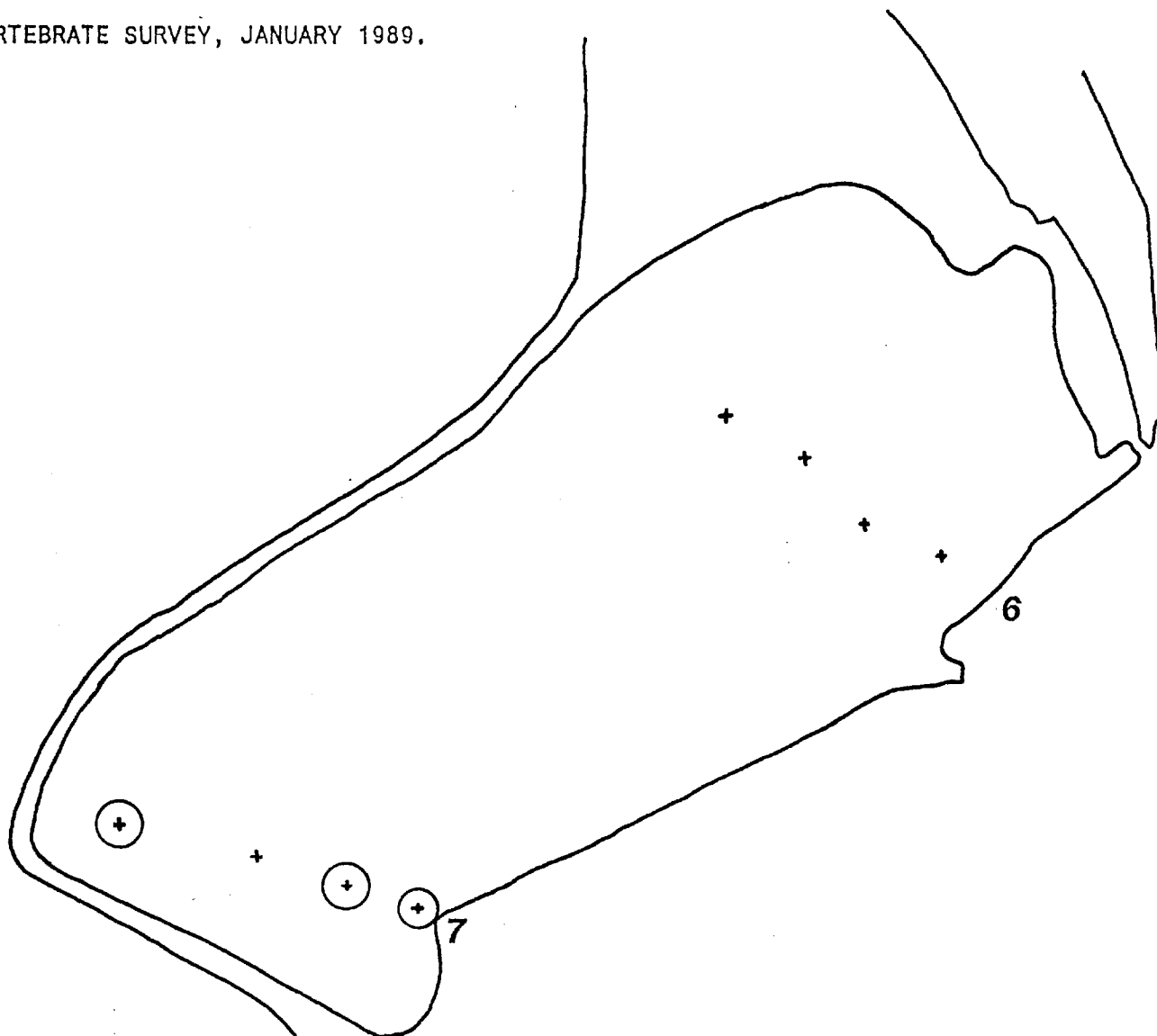
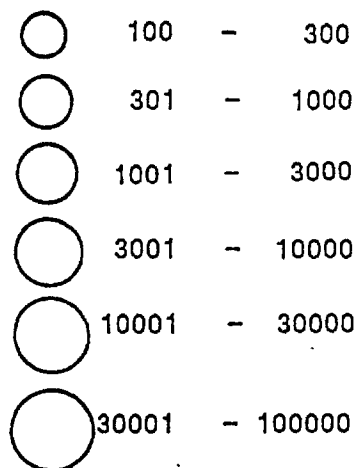


Tubificid Oligochaetes



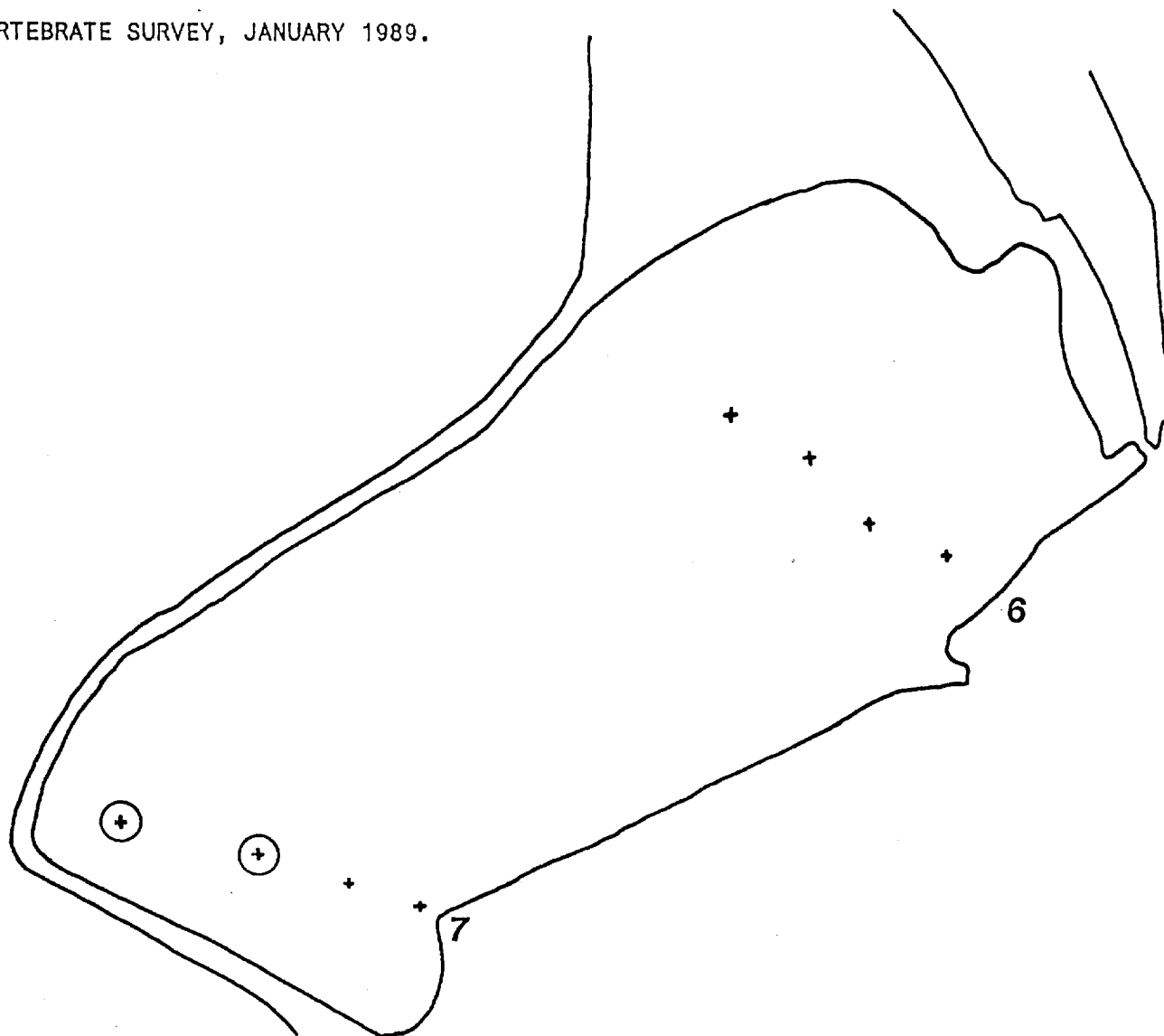
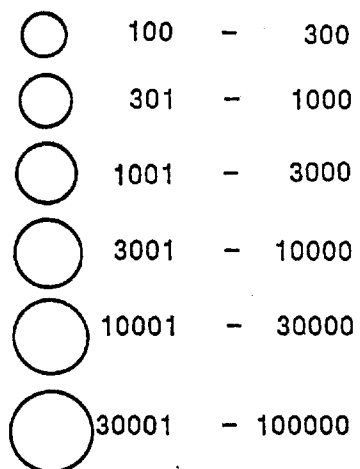
CARNSEW. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.

Hediste diversicolor



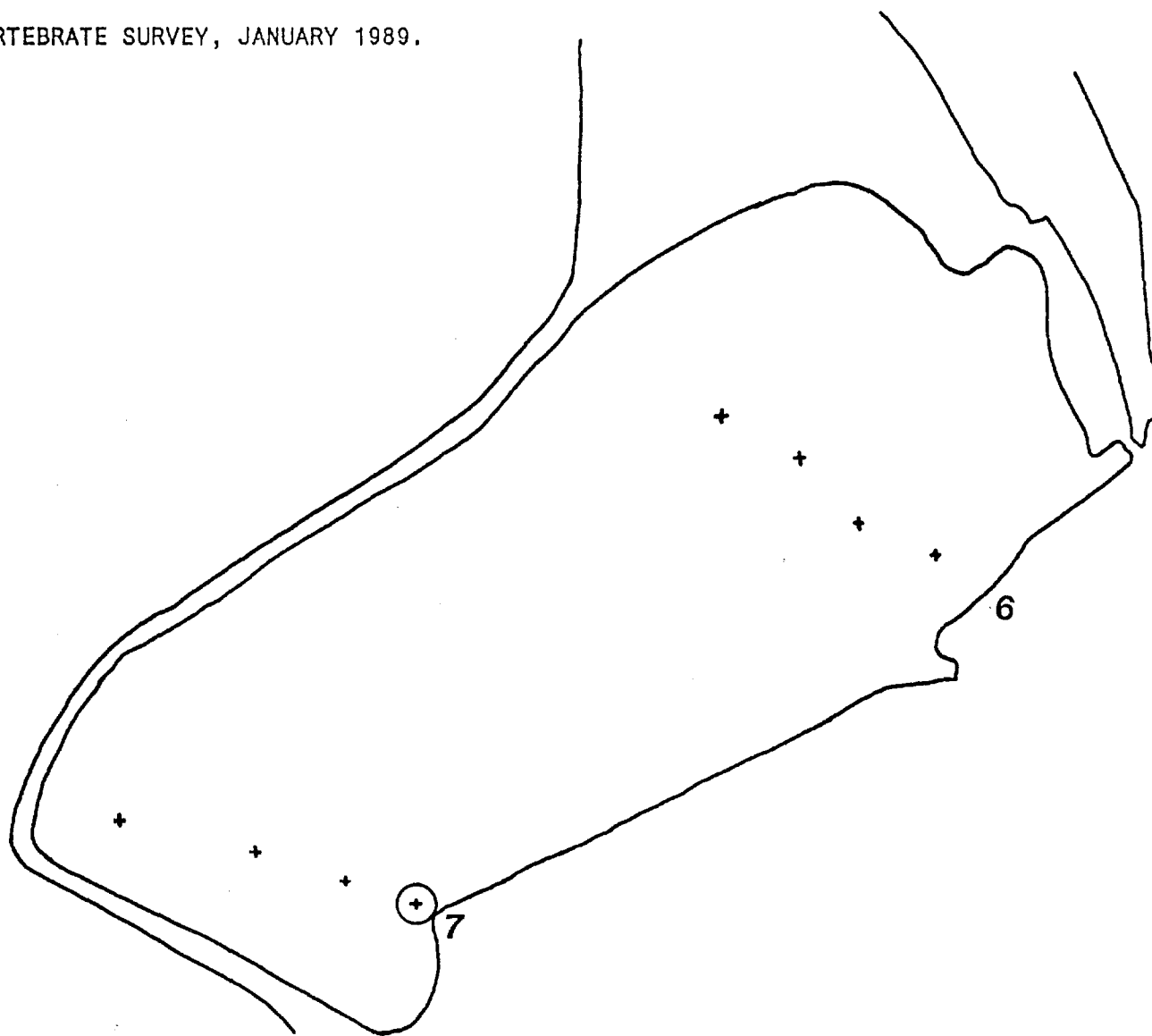
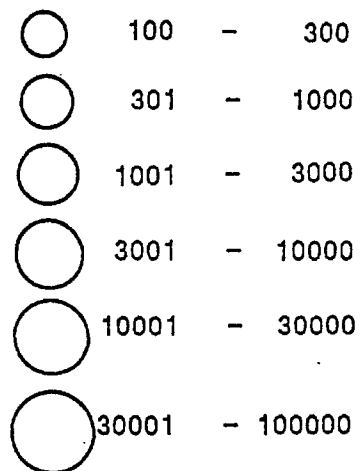
CARNSEW. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.

Pygospio elegans



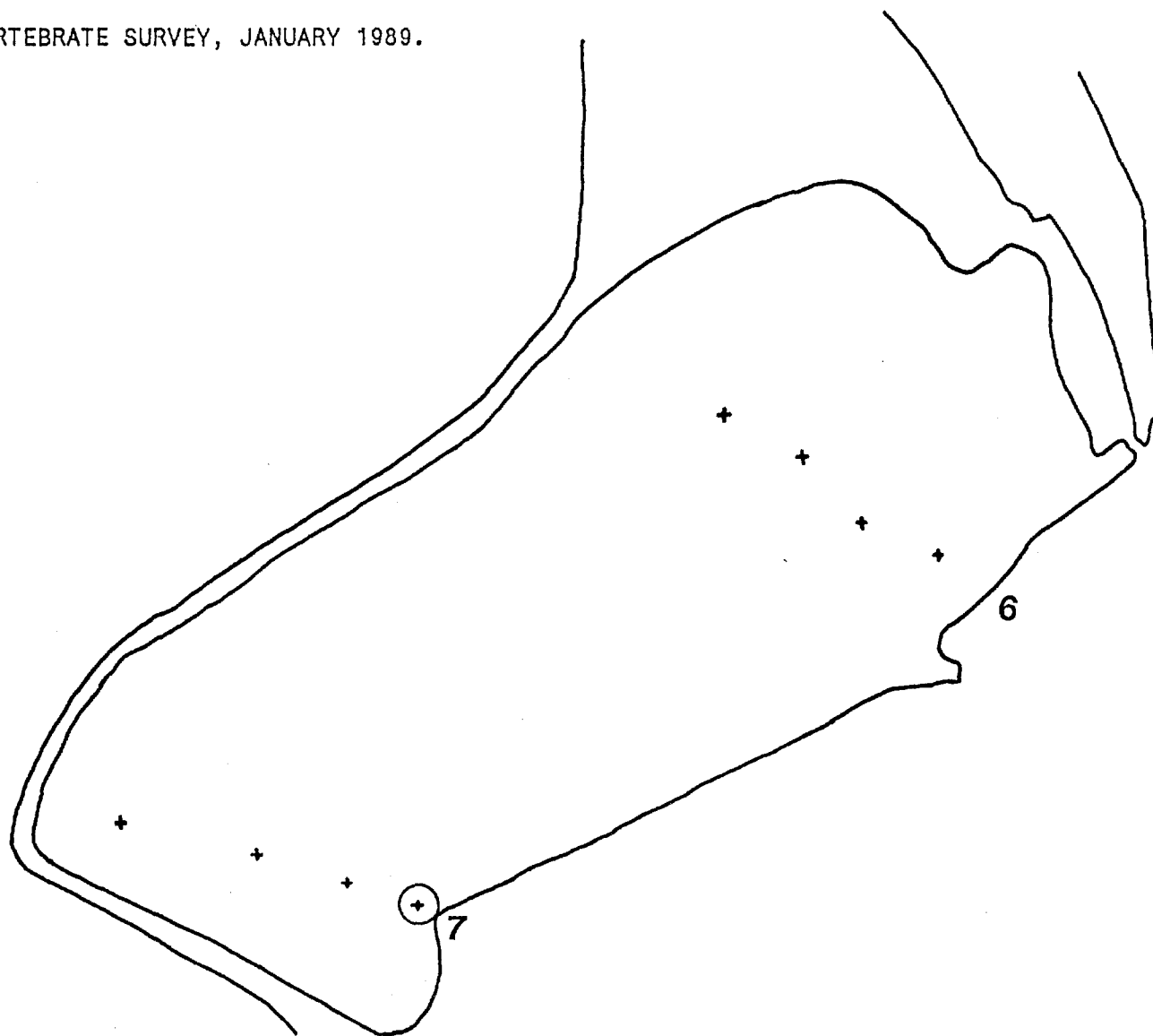
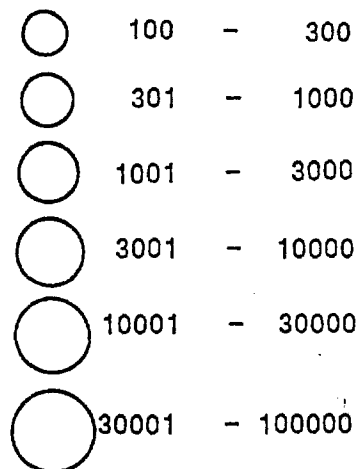
CARNSEW. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.

Streblospio shrubsolii



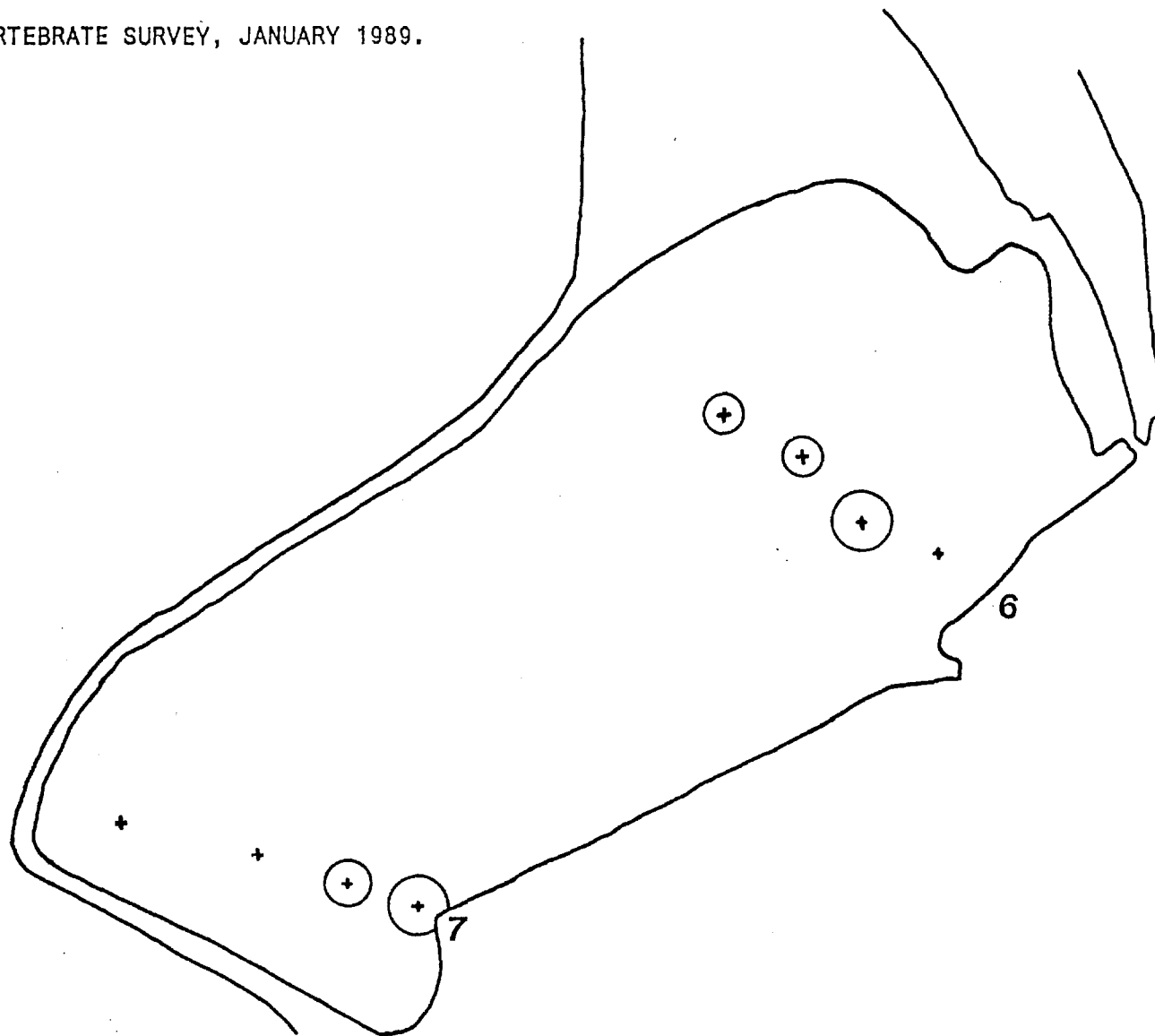
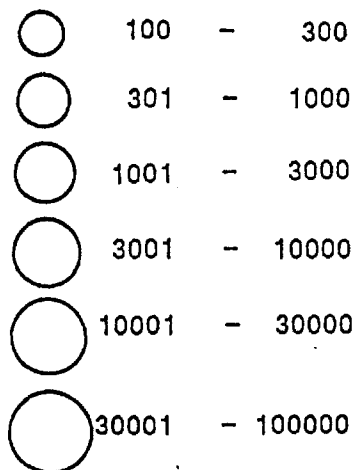
CARNSEW. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.

Capitella capitata



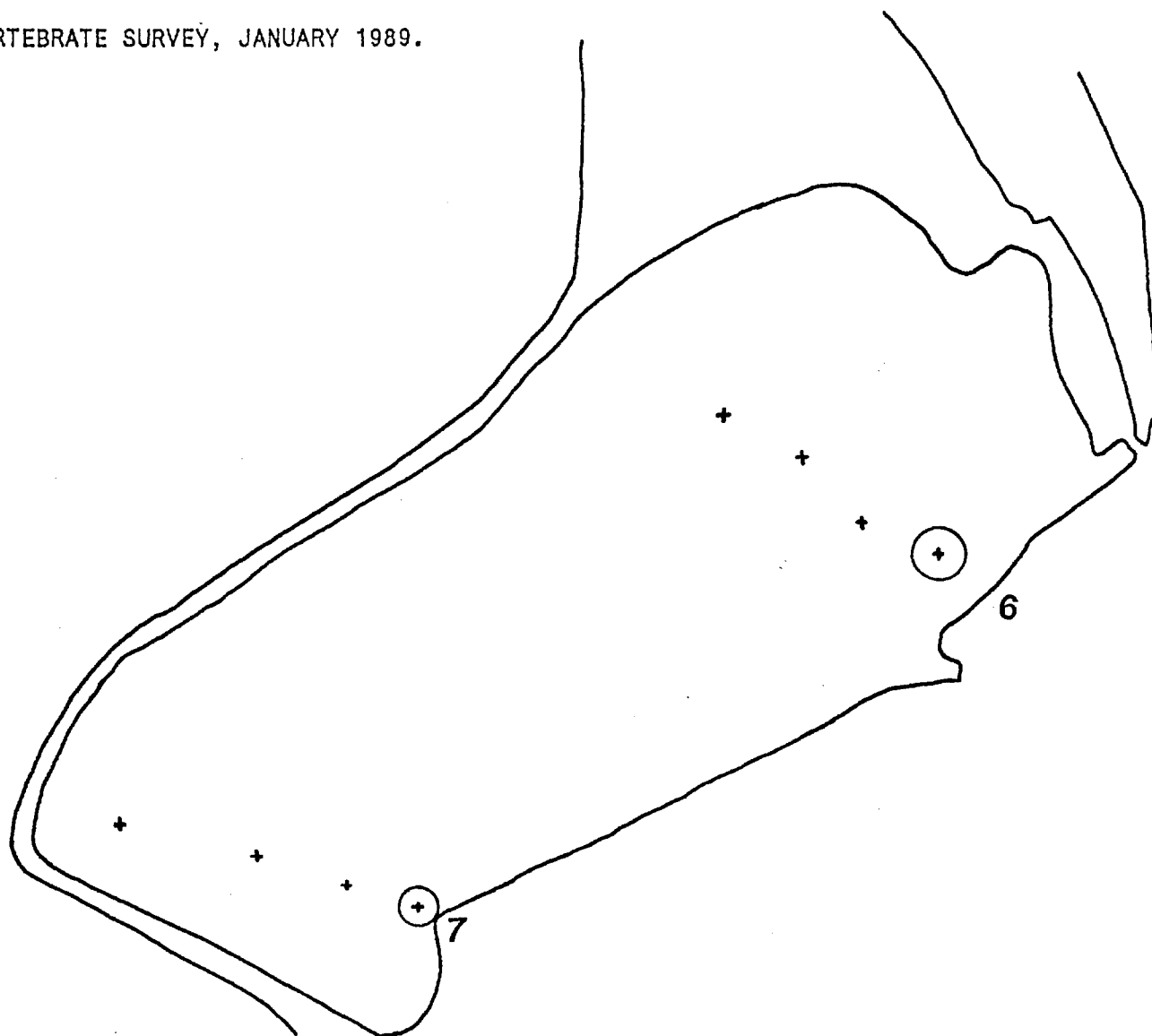
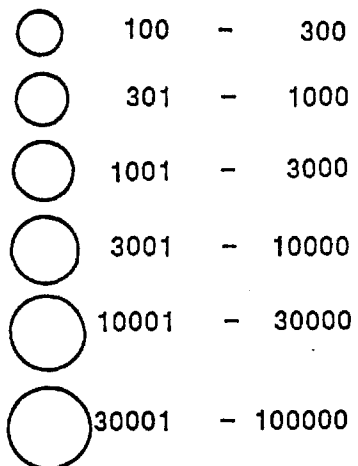
CARNSEW. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.

Tharyx sp

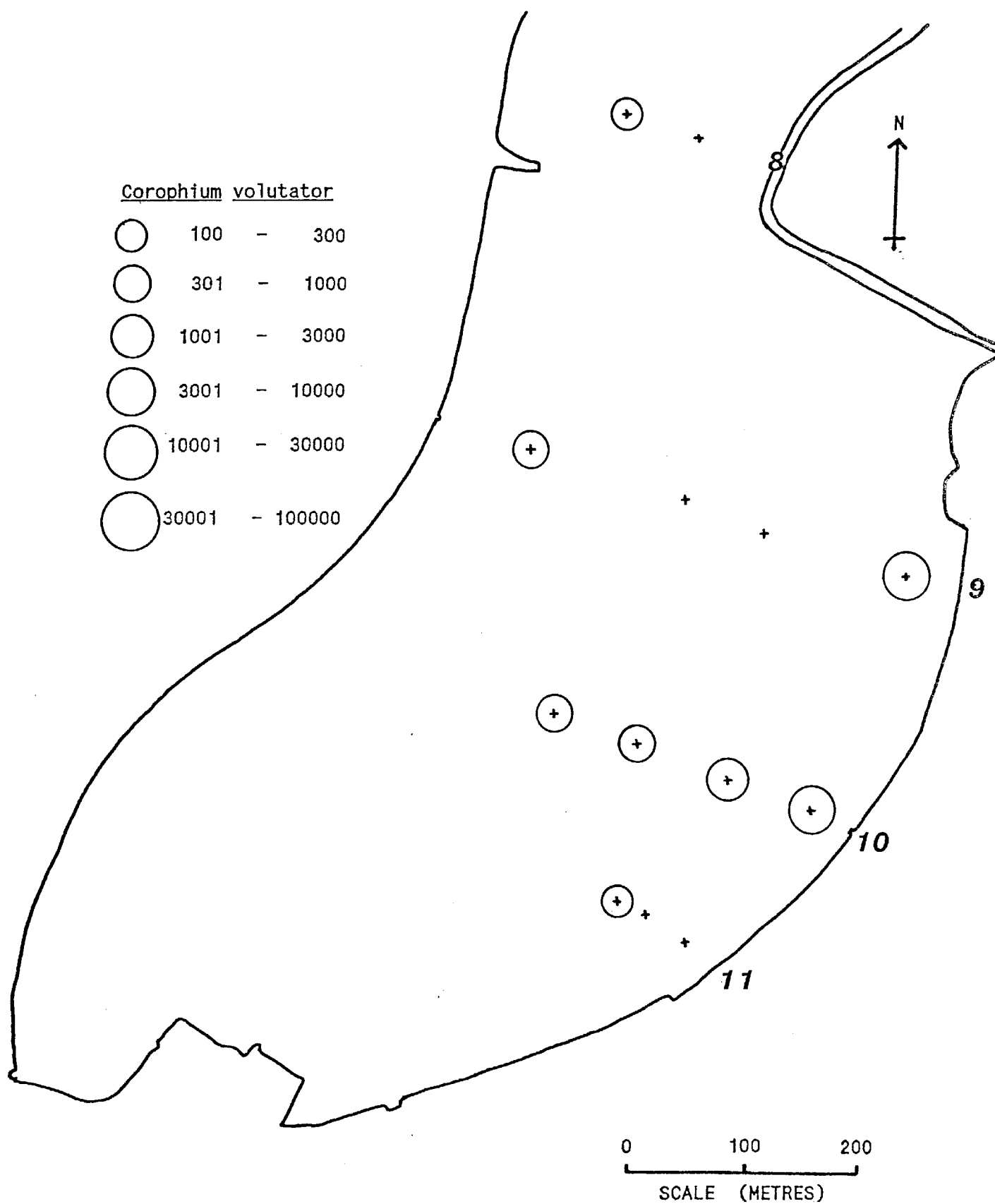


CARNSEW. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.

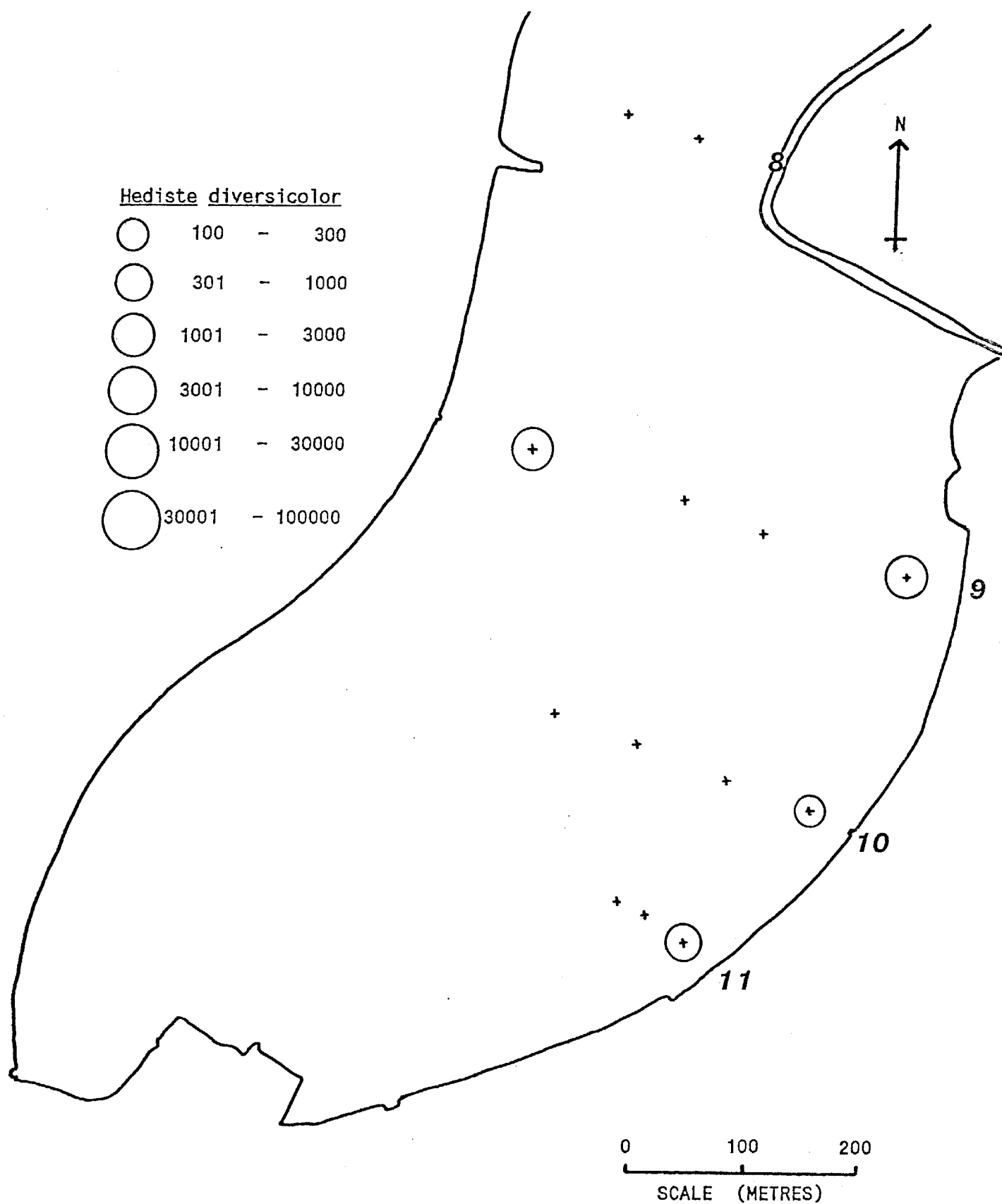
Tubificid Oligochaetes



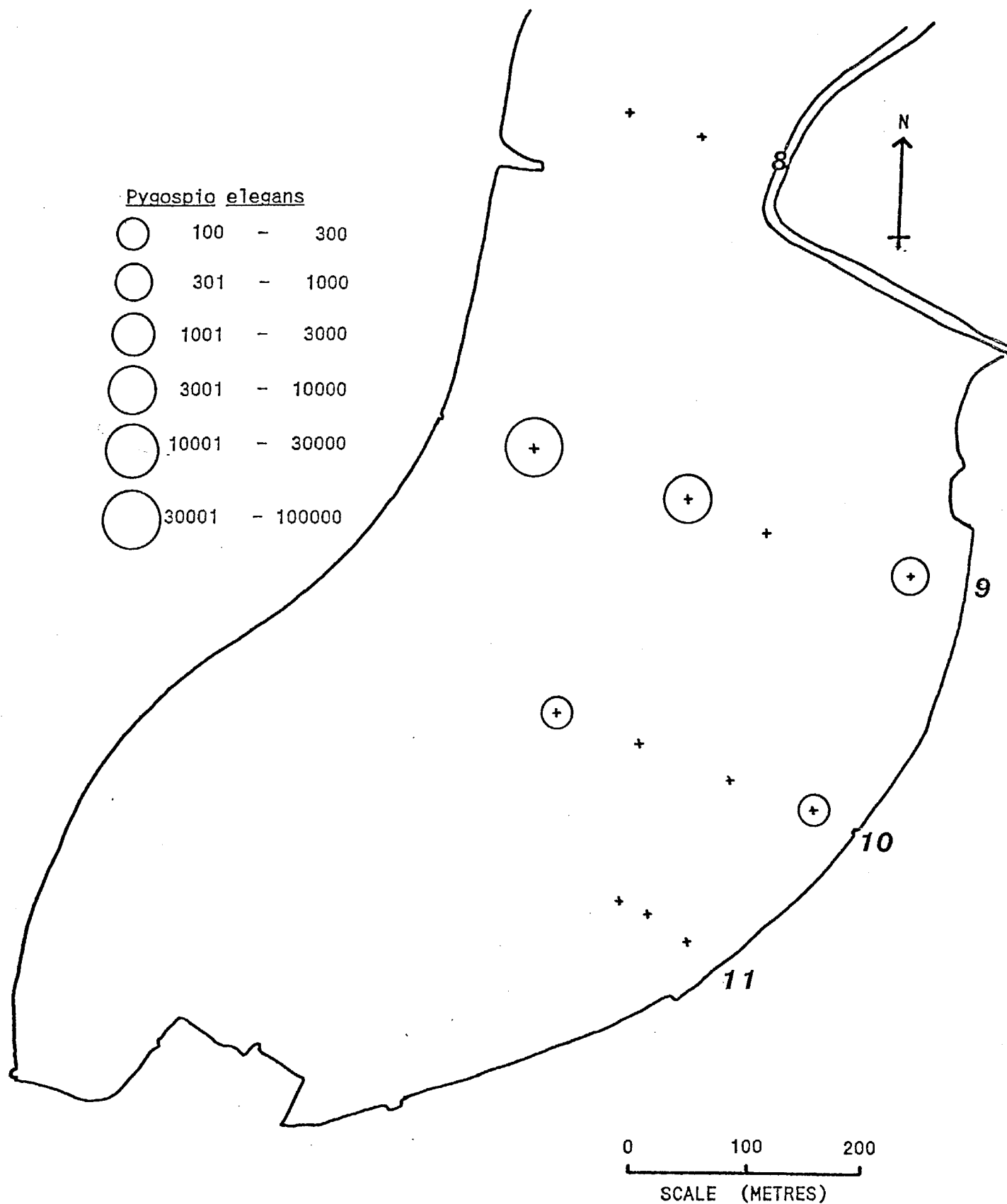
LELANT WATER. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.



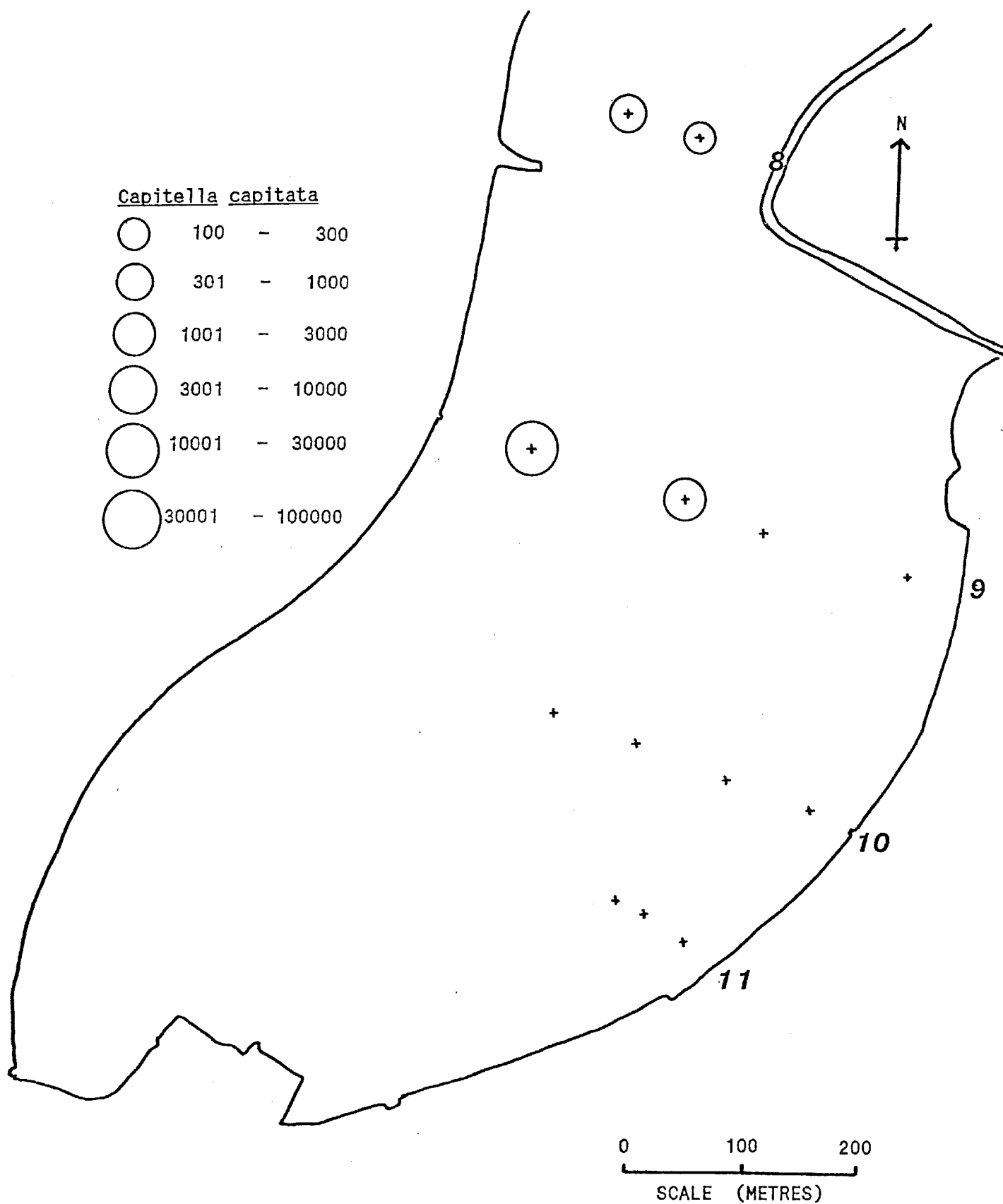
LELANT WATER. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.



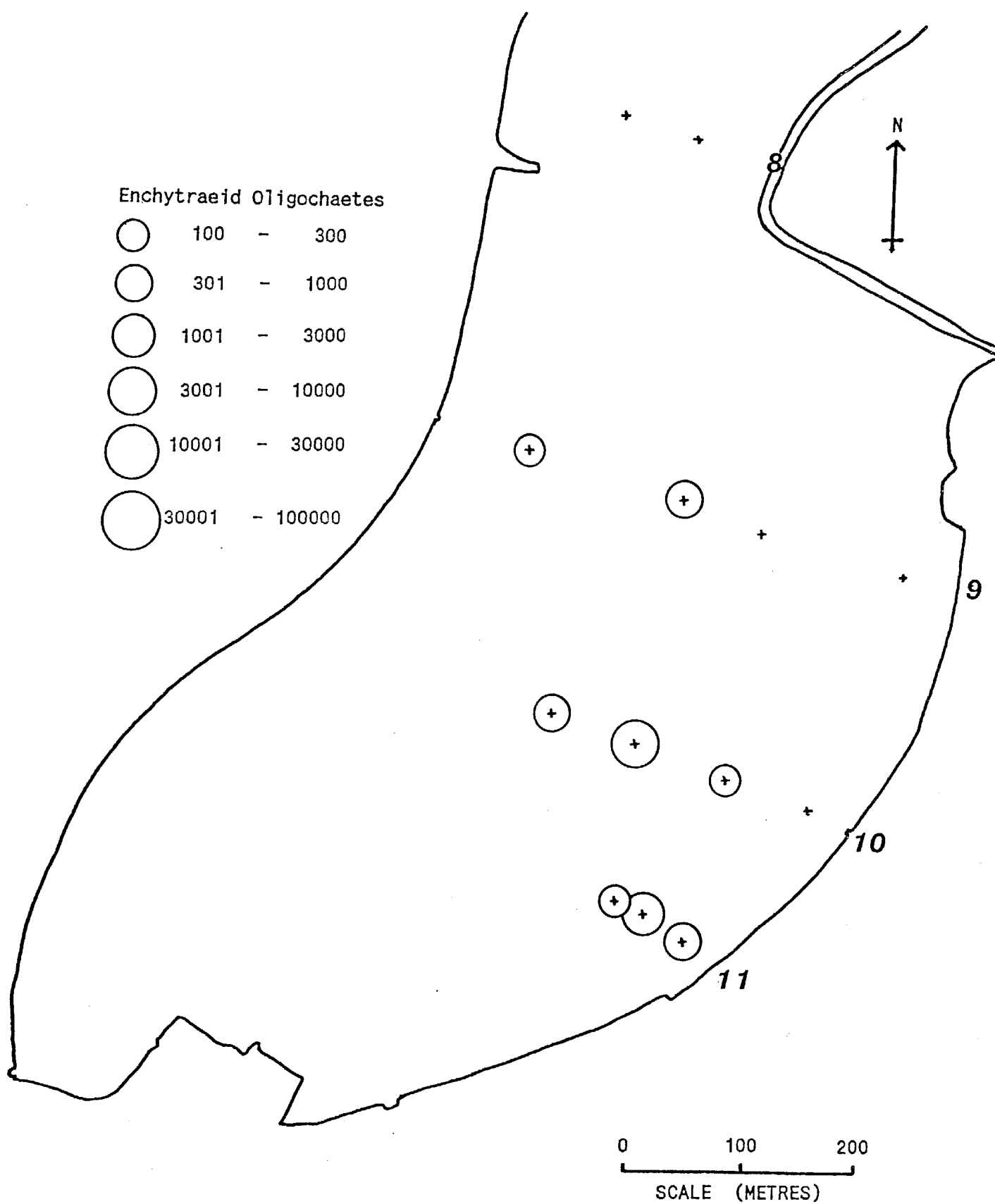
LELANT WATER. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.



LELANT WATER. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.



LELANT WATER. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.



LELANT WATER. BENTHIC INVERTEBRATE SURVEY, JANUARY 1989.

