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FISH REMAINS FROM THE UPPER 63 M OF BOREHOLE ZUURLAND-2 AT BRIELLE (PROVINCE OF ZUID-HOLLAND, THE NETHERLANDS)

by

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A large variety of bony fish remains was found: otoliths, pharyngeal teeth, incisor and molar teeth, vertebrae, spines and other bones, and scales. Also some elasmobranch teeth were collected. Fourteen different fish assemblages are distinguished on the basis of the species composition and the kind of elements represented.

The Pleistocene deposits almost exclusively contain freshwater fishes, the Holocene sediments are characterized by marine and brackish water species. Most fish remains were transported over shorter or longer distances. Therefore, detailed palaeoecological conclusions are difficult to draw.

One important biostratigraphical boundary was recognized on the basis of pharyngeal teeth: it is situated at -43.75 m, separating an older, warmer fauna from a younger, colder one.

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CONTENTS

SAMENVATTING

Visresten uit de bovenste 63 m van boring Zuurland-2 te Brielle (provincie Zuid-Holland, Nederland).

Er is een groot scala van verschillende resten van beenvissen gevonden: otolieten, keeltanden, snij- en maaltanden, wervels, stekels en andere botten, en schubben; ook enkele haaie- en roggetanden

komen voor. Er worden veertien verschillende gezelschappen onderscheiden op grond van de soortensamenstelling en de aangetroffen soorten onderdelen van vissen.

De otolieten behoren tot negen mariene en/of brakwatersoorten en twee zoetwatersoorten. Keeltanden van minstens negen soorten karperachtigen (Cyprinidae) werden aangetroffen. De beenvistanden behoren tot vier verschillende taxa. Drie soorten konden worden herkend bij de visbotten en één familie bij de schubben. De tanden van elasmobranchen zijn van minstens drie verschillende soorten afkomstig (zie tabel 1).

De pleistocene afzettingen bevatten bijna uitsluitend zoetwatervissen, de holocene worden gedomineerd door mariene en brakwatersoorten. De meeste visresten zijn over kortere of langere afstanden getransporteerd, waardoor het moeilijk is om paleo-oecologische conclusies te trekken. Met behulp van keeltanden van karperachtigen is n belangrijke biostratigrafische grens gevonden, en wel op -43,75 m. Onder deze grens komt een warmere fauna voor, erboven een koudere.

INTRODUCTION

The fish material described in this paper comes from borehole Zuurland-2 (RGD file number 37C/554), made by Mr Leen W. Hordijk (Brielle), in whose collection all material is kept. For an introduction and a brief lithological description of the borehole the reader is referred to Hordijk (1988) and Burger, Hordijk & Meijer (1988). Other papers on this borehole by A.W. Burger, J. de Jong, T. van Kolfschoten, W.J. Kuijper and T. Meijer are published in the present issue of this periodical, together with a paper on mammal remains from the nearby Maasvlakte area by Y. Vervoort-Kerkhoff & T. van Kolfschoten.

All depths given in this paper are in metres below surface, which is 0.40 m below Normal Amsterdam Ordnance Level (N.A.P.).

SYSTEMATIC REMARKS

Gadus parallelus was described as a new species by Gaemers (1976) on the basis of otoliths from the Pliocene of Antwerp. Subsequently, Recent otoliths of *Eleginus* became available, displaying a much closer affinity to the fossil species. *Gadus parallelus* is very similar to the Recent *Eleginus gracilis* (Tilesius, 1810), nowadays occurring in boreal Pacific waters of Alaska and NE Asia (Svetovidov, 1962). Therefore, the fossil species must be regarded as the immediate forerunner of *Eleginus gracilis* and should be named *Eleginus parallelus* (Gaemers, 1976). *Eleginus* can easily be distinguished from *Gadus* by its flat otoliths which are not or only very slightly curved along the long axis.

A considerable part of the fish remains of borehole Zuurland-2 comprises pharyngeal teeth of the carp family (Cyprinidae). They are the most resistant parts of carps and have therefore the best chance to become fossilized. Another reason for their relative abundance is that cyprinids can shed their pharyngeal teeth several times during their life, so one individual produces many of these teeth. They have often a very characteristic shape so that genera and in many cases even species can be recognized.

The most accurate identifications are possible when complete pharyngeal jaws are available which are however rare in the fossil record. The hindmost three pharyngeal teeth are usually the most

differentiated ones (Rutte, 1962), and are consequently best suited for identification. Each pharyngeal jaw is provided with four, five or more teeth which often differ strongly in shape. When studying my own small reference collection of Recent pharyngeal jaws and a somewhat larger collection at the Institute for Pre- and Protohistory in Amsterdam it became evident that the intraspecific variability of each type of tooth can be considerable. A left tooth may even differ markedly from the same tooth in the right jaw of the same individual. Various degrees of wear by mastication also give the teeth a different appearance. The forming of hybrids in natural circumstances between many species of cyprinids, frequently even belonging to different genera, may cause even larger difficulties with identification, but I deliberately have not taken this possibility into account, the more so as a hybrid usually resembles one of the parent species much more than the other.

The foregoing demonstrates that identification of isolated pharyngeal teeth of cyprinids is not very easy, which might explain the limited number of papers on this subject. Biologists, having the complete animal available, usually hardly paid any attention to these teeth. Palaeontologists, being much more dependent on identifications of cyprinids by means of pharyngeal teeth, usually give good illustrations, especially of isolated teeth (*e.g.* Rutte, 1962, still the most comprehensive paper on this subject). Other publications consulted are Wheeler (1978), Gaudant (1979) and Sibbing (1984), but identifications presented in this paper are mainly based on direct comparison with Recent material. There are indications of changes in shape in teeth of at least some species in the Pleistocene of boring Zuurland-2. The available number of well-preserved teeth is not large enough for the introduction of fossil species. Moreover, the knowledge of Recent teeth and my experience with them are hardly sufficient in this respect. It is for instance not yet clear whether Cyprinidae sp. 1 found in the Kedichem Formation is a fossil species or not.

Identifications of incisor and molar teeth of bony fish are based primarily on comparison with Recent material in my own collection. The spines of two species of sticklebacks and the preoperculum of the perch were identified using Libois et al. (1987) and Gaudant (1979).

THE SUCCESSIVE FISH ASSEMBLAGES AND THEIR PALAEOECOLOGY

In the uppermost 63 m of borehole Zuurland-2 fourteen different fish assemblages can be distinguished. Eleven of these contain identifiable fish remains which could be used for an interpretation of the local environment in case of (more or less) *in situ* elements or, more frequently, of the original environment in case of transported elements. Wheeler (1978) and Muus & Dahlstr/om (1968) provided detailed data on the habitat of Recent representatives of the species encountered.

Two clearly different fish assemblages occur in the lowermost formation, the Early Pleistocene Kedichem/Tegelen Formation (-55.60 to -63 m):

1. The oldest assemblage is confined to the lowermost 15 cm, between -62.85 and -63 m, and yields a varied fish fauna. The following species are considered to be more or less *in situ*: the ruffe (*Gymnocephalus cernuus*), the roach (*Rutilus rutilus*), the tench (*Tinca tinca*) and the three-spined or common stickleback (*Gasterosteus aculeatus*). A pharyngeal tooth of *Rutilus* is very well preserved, whereas those of *Tinca* all have a remarkably worn occlusal surface and show signs of transportation over a short distance. The presence of one pharyngeal jaw and one fragment of a pharyngeal jaw, both with the teeth partly preserved and only slightly eroded, belonging to the carp family (Cyprinidae), is the best proof of nearly *in situ* preservation. Unfortunately it is impossible to identify them as yet. Such jaws

	FORMATIONS	WESTLAND FORMATION																	*	KREF-	
	DEPTH IN METRES BELOW SURFACE	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26
OTOLITHS	*Pomatoschistus minutus* (Pallas, 1770)	2	1	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-
	Dicentrarchus labrax (Linnaeus, 1758)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Clupea harengus Linnaeus, 1758	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
	Osmerus eperlanus (Linnaeus, 1758)	-	-	-	-	-	-	-	-	4	-	-	-	-	-	1	-	-	-	-	-
	Pomatoschistus microps (Krøyer, 1838)	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
	Platichthys flesus (Linnaeus, 1758)	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
	Scomber scombrus (Linnaeus, 1758)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
	Melanogrammus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Gymnocephalus cernuus (Linaeus, 1758)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Stizostedion lucioperca (Linnaeus, 1758)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Eleginus parallelus (Gaemers, 1976)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CYPRINID PHARYNGEAL TEETH	*Rutilus rutilus* (Linnaeus, 1758)	-	-	-	*1*	-	-	-	-	-	-	-	-	-	-	-	-	*1*	-	1	-
	Leuciscus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
	Scardinius erythrophthalmus (Linnaeus, 1758)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
	Tinca tinca (Linnaeus, 1758)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Leuciscus idus (Linnaeus, 1758)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Abramis brama (Linnaeus, 1758)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Blicca bjoerkna (Linnaeus, 1758)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Cyprinidae sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Barbus barbus (Linnaeus, 1758)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Chondrostoma nasus (Linnaeus, 1758)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Cyprinidae sp. indet.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
	pharyngeal jaws with teeth	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BONY FISH TEETH	*Esox lucius* Linnaeus, 1758	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*1*	-	-	-	-	1
	Sparinae sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lophius sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Gadinae sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BONY FISH BONES	vertebrae	2	7	8	-	-	-	1	8	-	37	19	23	17	25	-	-	-	-	-	1
	dentale (lower jaw)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	pre-operculum of *Perca fluviatilis* L., 1758	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	spines of *Gasterosteus aculeatus* (L., 1758)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	spines of *Pungitius pungitius* (L., 1758)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	other bones	-	4	4	-	-	-	-	-	-	1	-	4	3	5	-	-	-	-	-	-
SCALES	ctenoid scale (fragm.) of Percidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
	oval cycloid scale	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	ctenoid scale fragments	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	irregular cycloid scale	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	scale fragments indet.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ELASMO-BRANCH TEETH	*Raja clavata* Linnaeus, 1758	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
	Odontaspidae sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Raja batis Linaeus, 1758	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	shark teeth fragments indet.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 1. Distribution of fish remains in borehole Zuurland-2. Numbers of specimens or fragments are indicated. Numbers in italics indicate clearly reworked fossils from older deposits. Samples are

TENHEIJE/EEM FORMATION										KEDICHEM FORMATION																			KEDICHEM/TEGELEN FM.							
26-27	27-28	28-29	29-30	30-31	31-32	32-33	33-34	34-35	35-36	36-37	37-38	38-39	39-40	40-41	41-42	42-43	43-44	44-45	45-46	46-47	47-48	48-49	49-50	50-51	51-52	52-53	53-54	54-55	55-56	56-57	57-58	58-59	59-60	60-61	61-62	62-63
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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-	*1*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	8	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*1*
-	-	-	-	1	3	1	1	-	2	-	2	1	-	-	-	4	8	13	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	2	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-
-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	3	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	1	1	2	1	-	-	-	1	-	-	-	5	3	6	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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1	-	-	-	1	1	-	2	-	1	-	-	-	-	-	-	-	8	-	2	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	4
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-	-	-	-	-	2	2	2	-	-	1	-	-	-	-	-	3	9	5	3	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
-	*1*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*1*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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-	3	-	-	1	3	2	-	2	-	3	1	-	-	-	-	-	-	-	1	-	1	-	-	-	14	13	8	16	-	5	-	1	-	-	-	-
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-	3	4	1	-	3	1	1	-	3	2	-	-	-	-	1	1	3	2	-	-	-	-	-	-	-	4	3	11	1	-	-	-	-	-	-	3
-	-	-	-	-	-	1	-	-	1	-	1	-	-	-	-	1	2	3	-	-	-	-	-	1	5	-	-	2	-	-	-	-	-	-	-	-
-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	3	-	-	-	-	1	-	2	4	5	13	11	1	2	-	-	-	-	-	-
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1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*1*	*1*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

presented as whole metre intervals, but the samples were taken by Mr L.W. Hordijk at more accurate depths, which are mentioned in the text. The * indicates the Twente Formation.

have not been found in higher levels of the boring. The strongly worn otolith of *Eleginus parallelus* and the somewhat worn teeth of *Raja* species must have been reworked from the marine Maassluis Formation ('Icenian') in which these fully marine species are known to occur *in situ* (unpublished data). The autochthonous fossils point to a freshwater environment with some sort of connection with the sea (*Gasterosteus*). The well-preserved otolith of the ruffe must come from an *in situ* fish, indicating one-time waterplant vegetation of low density. Dense underwater vegetation must have been nearby, however, considering the presence of *Tinca*.

2. Fish remains are rather rare to absent in the interval between -55.60 and -62.85 m. Only some unidentified scale fragments, vertebrae and one further bone occur above -59 m. From these no conclusions can be drawn.

The Early Pleistocene Kedichem Formation (-36.25 to -55.60 m) contains a series of different fish remain assemblages:

3. The oldest assemblage of this formation occurs between c. -51 and -55.60 m and is characterized by large numbers of scales and scale fragments, vertebrae, and other fish bones; cyprinid pharyngeal teeth are more or less common, bony fish teeth are rare. All vertebrae are clearly rounded by transportation, the fish teeth and most pharyngeal teeth and bones are at least somewhat eroded. Thus it is concluded that most remains are from fishes which lived at probably not too great a distance. The only identifiable fossils which are perhaps indigenous are some fresh looking spines of the nine-spined stickleback (*Pungitius pungitius*), some scales belonging to the perch (*Perca fluviatilis*) or to the zander (*Stizostedion lucioperca*), and some pharyngeal teeth of the roach (*Rutilus rutilus*), the bream (*Abramis brama*), and an unknown species with thin but wide teeth having a rather round outline with a distinct hook at the top (Cyprinidae sp. 1). Apart from the nine-spined stickleback which can also live in slightly brackish conditions all are pure freshwater species. The presence of a tooth of the cod family (Gadidae, subfamily Gadinae) might indicate a distinct marine influence; however, it is not possible to say if this somewhat eroded tooth has undergone only horizontal transport or also reworking from older deposits.

4. The interval between -45.30 and c. -51 m is poor in fish remains. The only well-preserved fossil is a small tooth of the pike (*Esox lucius*). The single vertebra and most scale fragments show clear signs of transportation.

5. A rich fish assemblage is present between -43.75 and -45.30 m. Pharyngeal teeth of cyprinids, teeth of the pike (*Esox lucius*), and otoliths of freshwater fishes are most abundant in this interval. The upper part of this interval from which most fish remains come consists of very coarse sands which are indicative of strong currents. These currents must have been able to transport most, if not all, fish remains over shorter or longer distances. Worn Tertiary shark and bony fish teeth are good evidence of erosion of older deposits in the hinterland. A sea- bream tooth belonging to the subfamily Sparinae must come from fully marine Late Oligocene to Middle Miocene deposits. All other fish remains are probably from fishes which lived during or shortly before deposition of the sediment in which they were found. A wide variety of freshwater environments is covered by the fish species encountered, giving further evidence for large-scale allochthony: the tench (*Tinca tinca*) is a fish preferring stagnant waters, lakes and ponds with dense vegetation, and it is able to endure extreme circumstances such as a low oxygen content. The rudd (*Scardinius erythrophthalmus*) lives among dense vegetation in clear, shallow water of lakes and also in slow- flowing rivers; the bream (*Abramis brama*) is common in slow-flowing rivers and lakes (habitats of the bream zone), and needs a muddy or clayey bottom; the roach (*Rutilus rutilus*) is another species of the bream zone, but is less fastidious in its choice of food and

way of living. The pike (*Esox lucius*) needs clear water and many water plants in lakes and slow-flowing rivers. The zander or pikeperch (*Stizostedion lucioperca*) prefers troubled open water or larger lakes and lower reaches of rivers; the ruffe (*Gymnocephalus cernuus*) is a bottom dweller in the bream zone, living in places without vegetation. The barbel (*Barbus barbus*) is a bottom-living fish found in the middle reaches of clear lowland rivers with moderate to strong currents (habitats of the barbel zone). Finally, the nase (*Chondrostoma nasus*) is also a fish from the barbel zone requiring flows which are at least temporarily turbulent. The presence of barbel and nase is also good evidence of a relatively warm climate. Judging from the coarseness of the sediment one would say that the barbel and the nase are the most characteristic species of this habitat, but the ruffe and the pikeperch are also good candidates. It is true that the otoliths of these species are poorly preserved, but this is due to partial dissolution by ground water chemistry in the coarse sediment after deposition. From the size of the otoliths it is possible to calculate the total length of the fishes which varies between 32 and 155 mm for the ruffe and between 155 and 350 mm for the pikeperch. The otoliths of the ruffe are from a whole range of sizes between the given values. The absence of size selection, the presence of very small individuals and the good preservation of the sculpture of many otoliths rule out the possibility of substantial transport.

6. A much more uniform fish fauna was found between -42.20 and -43.75 m. The pharyngeal teeth of the silver bream (*Blicca bjoerkna*), some of the pharyngeal teeth of the roach and the bream, and one tooth of the pike look fresh and could only have been transported over short distances. These species are all known to live in slow-flowing rivers or lowland lakes and other still waters (bream zone). All species need dense vegetation at least during part of their life. The other identifiable fish remains, including a pharyngeal tooth of the tench and a pre- operculum of the perch are clearly transported in spite of their being inhabitants of the bream zone too. All fishes found are widely distributed nowadays, having their northern limits in rather cold to cold areas.

7. The interval between -39.35 and -42.20 m yielded only one unidentified fish bone.

8. The youngest assemblage assigned to the Kedichem Formation occurs between -36.25 and -39.35 m. Pharyngeal teeth of cyprinids, and vertebrae and other bones are very common; otoliths, teeth and scales are very rare (see table 1). All species encountered are inhabitants of slow-flowing rivers and lakes (bream zone) with fine-grained bottom sediments. All remains, however, actually do occur in very coarse sediments, implying that they must have been transported. Therefore they cannot provide information on the local environment. The original habitat of the fishes from the lower samples shows a more riverine character and that of the topmost sample a more lacustrine one. The occurrence of the rudd (*Scardinius erythrophthalmus*) points to relatively warm conditions.

The Kreftenheye/Eem Formation consists nearly completely of very coarse sand with some gravel and can be divided into two parts with rather different fish assemblages separated from one another by a thin bed of fine sand:

9. The lower part, comprising the interval between -28.70 and -36.25 m contains a somewhat richer fauna than the upper part. Pharyngeal teeth of cyprinids, pike teeth, vertebrae and other bones are common, scales are rather rare. All fish remains show one or several signs of transportation: detrition, polishing, fragmentation and/or blackening. Consequently, all these fossils are considered allochthonous. Most of them stem from animals that originally lived in slow-flowing rivers and lakes of the bream zone, viz. the roach, rudd, bream, silver bream, pike, and members of the perch family. The presence of the ide (*Leuciscus idus*) in this interval only is interesting: this species is not confined to the lower reaches of large rivers and lowland lakes, but is found also in brackish estuaries of rivers.

The nine-spined stickleback (*Pungitius pungitius*) is found in fresh or slightly brackish waters, and the three-spined stickleback (*Gasterosteus aculeatus*) has an even bigger tolerance for salt water; the latter is frequently found in brackish estuaries. The assemblage as a whole seems to be somewhat more riverine than lacustrine in character.

10. The upper part of the Kreftenheye/Eem Formation comprises the interval between -23.80 and -28.70 m. Pharyngeal teeth of cyprinids are (rather) common, especially in the topmost part. Vertebrae and other bones are common in the lowermost two samples which also contain relatively many fish remains reworked from older deposits. The worn fragment of a haddock otolith (*Melanogrammus* sp.) most likely comes from the Early Pleistocene Maassluis Formation, an eroded sea-bream tooth (subfamily Sparinae) from the Late Oligocene to Middle Miocene, and at least one of the two eroded shark-teeth, an odontaspid, is of Eocene age. The presence of these fossils is good evidence of erosion of older deposits. All other fish remains, apart from one cycloid scale, are more or less worn like those in the lower part of the Kreftenheye/Eem Formation, but it is reasonable to suppose that they lived somewhere in the neighbourhood during deposition of the coarse sediment. Species preferring a densely vegetated lacustrine environment, viz. the rudd and the tench, are relatively well-represented. Mr N.C. Kerkhoff kindly presented me with an impressive collection of pharyngeal teeth from the nearby Maasvlakte area, which were washed ashore after being washed out of artificially supplied sediment. Apparently, a considerable part of this material comes from the upper part of the Kreftenheye/Eem Formation judging from the large number of teeth of the rudd and relatively many teeth of the tench. To a lesser degree also material from the lower part of this formation is involved, seeing the rather large numbers of teeth of the roach and the bream. It is worth mentioning that Mr Kerkhoff found at least one pharyngeal tooth of the bleak, *Alburnus alburnus* (Linnaeus, 1758). This species has not been found in the Zuurland-2 borehole, but it is very likely that this fossil tooth comes from the Kreftenheye/Eem Formation.

No fish remains were found in the Twente Formation ranging from -22.30 to -23.80 m. This is not surprising, since this unit is interpreted as a wind-blown terrestrial sand deposit which formed during the Weichselian.

The uppermost 22.30 m of the borehole belong to the Westland Formation, which is Holocene (Flandrian) in age. Fish remains were found between -6 and -22.30 m. This entire interval belongs to the Calais Deposits (Hordijk, 1985, 1986), which were formed during the Atlanticum and the Early Subboreal.

11. The interval between -20.90 and -22.30 m was deposited during part of the Atlanticum. Only few fish remains occur in the moderately coarse sands. One perfectly preserved, cream-coloured otolith of the mackerel (*Scomber scombrus*), of which only the fragile rostrum is missing, clearly indicates marine conditions. This is a fully marine pelagic fish living near the surface in the North Sea and the North Atlantic. In summer it comes close inshore. Transportation of this fossil can be excluded. One other otolith was found; it is a somewhat worn, light bluish specimen of the smelt (*Osmerus eperlanus*). Its preservation indicates some post-mortem transport. This species is a shallow marine and estuarine fish, living in freshwater (rivers and lakes) part of the year. The otoliths give evidence of the Holocene transgression and must have been deposited in a shallow marine, near-shore environment. A fragile, unfossilized scale of the family Percidae, probably belonging to the perch (*Perca fluviatilis*), must have been washed in by a river. The tooth of a pike is very worn and one pharyngeal tooth of a roach is worn; both teeth are clearly polished and are obviously reworked from Pleistocene deposits. The same applies to the roach tooth found higher in the borehole in the sample -9 to -10 m.

12. The most numerous fish remains in the interval between -7.75 and -20.90 m are small vertebrae; other fish bones are also common. The vast majority of these fossils still has its original gloss and transparency in contrast with the Pleistocene fish bones which are always opaque and usually dull. These still unidentified bones occur in very fine sands which according to Hordijk (1985) were deposited behind a beach barrier in a wadden- like environment, usually not far from a river mouth. Other fish remains are usually absent in these sediments.

13. A very fossiliferous, coarser sand with gravel occurs between -14.25 and -14.75 m. No less than five species are represented by otoliths: juveniles of the herring (*Clupea harengus*), a marine pelagic fish which in its first year is particularly common inshore; smaller specimens and a large one of the sand goby (*Pomatoschistus minutus*), a marine species living inshore in normal euhaline waters; a small otolith of the common goby (*Pomatoschistus microps*), a brackish water species; a rather small otolith of the flounder (*Platichthys flesus*), a mainly shallow marine fish, that also penetrates into freshwater connected with the sea; and otoliths of various sizes of the smelt (*Osmerus eperlanus*). In addition, a tooth of the roker (*Raja clavata*) occurs in this horizon, a marine species which is most common at depths between 10 and 60 m. This assemblage is in good agreement with the environmental interpretation of a marine ingression: a breaking through a beach barrier (Hordijk, 1985). Another relatively coarse interval is found between c. -10 and c. -12 m and may have formed in the same way, but it has not yielded any fish remains.

14. In the interval between -4.90 and -7.75 m an interesting combination of fish bones and otoliths was found in extremely fine greenish-grey sands. Some more or less worn otoliths of the sand goby and a well-preserved one of the bass (*Dicentrarchus labrax*) were collected. The latter is a rather unexpected find and comes from a small juvenile fish. The bass is an inshore marine fish commonly entering estuaries, and penetrating into almost freshwater especially when young. It prefers rather warm temperate waters and is usually found near rocky shores. The most likely environment deducible from the presence of these two species and from the type of sediment is a protected lagoon with a normal or slightly lowered salinity because of a direct connection with the sea which was not too close by.

CONCLUSIONS

From a palaeoecological point of view the fourteen different fish assemblages can be divided into two main groups. The Pleistocene assemblages consist nearly entirely of freshwater species when the fish remains which are clearly reworked from older deposits are left out of consideration. The Holocene assemblages with exclusion of reworked Pleistocene material are strongly dominated by marine and brackish water fishes. This contrasts with the molluscs which always constitute mixed assemblages of various marine, brackish water, freshwater and terrestrial environments (Meijer, 1988). The latter author found a more or less gradual shift from assemblages dominated by non-marine species in the older beds to assemblages dominated by marine molluscs towards the top. Apparently, most of the sequence formed in environments close to the coast. The presence of many thin clay beds alternating with usually much thicker sand beds in the intervals between -36.28 and -43.75 m and between -54.15 and -62.65 m indicates repeated great changes in the velocities of water currents as they occur in tidally-dominated environments like estuaries and wadden. Estuarine environments seem to be most likely for the bulk of the Pleistocene deposits. Most of the fossil fish remains encountered must have been transported to some degree, and usually give a distorted picture of the original environment.

A biozonation based on freshwater fish remains does not yet exist and conclusive marine otoliths are missing so that none of the assemblages can be assigned to a known biozone. Cyprinid pharyngeal teeth are the only fish remains indicating an important biostratigraphical boundary. This boundary is situated at -43.75 m, below which an unknown species occurs which is presumably absent in the present freshwater fish fauna of the region. This boundary coincides with a boundary between two different faunas of small mammals. Van Kolfschoten (1988) found teeth of lemmings in the sample -42 to -43 m pointing to a more continental climate. All identifiable fish remains in the same sample are from species which can endure fairly cold conditions. The stratigraphical position of this horizon is poorly understood (van Kolfschoten, 1988). According to that author the mammals from the samples between -43 and -46 m give evidence of a warmer climate. This is in agreement with the cyprinid assemblage of the upper two samples containing three species which require warmer conditions.

The Kedichem Formation to which both above intervals belong actually contains six often clearly different fish assemblages. Several of these assemblages are confined to characteristic lithologies (compare Burger, Hordijk & Meijer, 1988). The succession of a number of distinctly different lithological units (with different faunas) implies that it must be possible to recognize at least several different members within this formation. Even it might be useful to subdivide the present Kedichem Formation into a number of more uniform, smaller formations.

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