The ecology of the Mersey Estuary: a polluted estuary in northwest England

M. PUGH THOMAS AND R. B. GHOSE

Department of Biology, The University of Salford, Greater Manchester M5 4WT, UK

ABSTRACT

This paper demonstrates that high levels of domestic and industrial pollution have adversely effected the ecology of the Mersey Estuary. The paper indicates that improving water quality has probably already led to an improvement of biological conditions. A scheme for the future biological monitoring of the Estuary is proposed which could easily be adapted for use in other estuaries and coastal waters. It is suggested that the destruction of the littoral habitat plays as large a part as pollution in adversely effecting species composition and occurrence in the Mersey Estuary. It is further suggested that as the areas of damaged habitat will not be restored in the future, pollution control will only partially restore the ecological health of the Mersey Estuary.

INTRODUCTION

The Mersey Estuary is situated on the northwest coast of England between the estuaries of the Ribble and the Dee (Fig. 1). Unlike the Estuary of the neighbouring Dee, which is relatively unpolluted, that of the Mersey has been substantially polluted by domestic and industrial effluent for more than 150 years. Changes in the water quality and ecology of the Mersey Estuary have been closely linked to development of the Merseyside area. A brief history of this development and its relation to the Estuary is therefore a relevant introduction to this paper.

The River Mersey is formed by the confluence of the rivers Tame and Goyt at Stockport. It then flows through the southern outskirts of the Greater Manchester conurbation and enters the Manchester Ship Canal near Irlam. After leaving the Ship Canal at Bollin Point it flows through Warrington and over the normally accepted tidal limit of Howley Weir. From Howley Weir the Mersey Estuary extends some 47 km to its mouth between Seaforth and New Brighton, at the tip of the Wirral Peninsula. For the first 8 km of its course the Estuary occupies a narrow channel through predominantly open country. Then, above Widnes, the channel opens into a small, shallow basin before again contracting to pass through a gap in the bed rock between Widnes on the Lancashire bank and Runcorn on the Cheshire bank. Below Runcorn the Estuary suddenly widens into the main tidal basin, which is broad and shallow, with sand and mud banks exposed at low tide. At Ince, the Estuary reaches its maximum width of about 5·0 km. At low water, the drainage channels are only a few feet deep and almost the whole of the floor of the basin is exposed. The tidal banks on

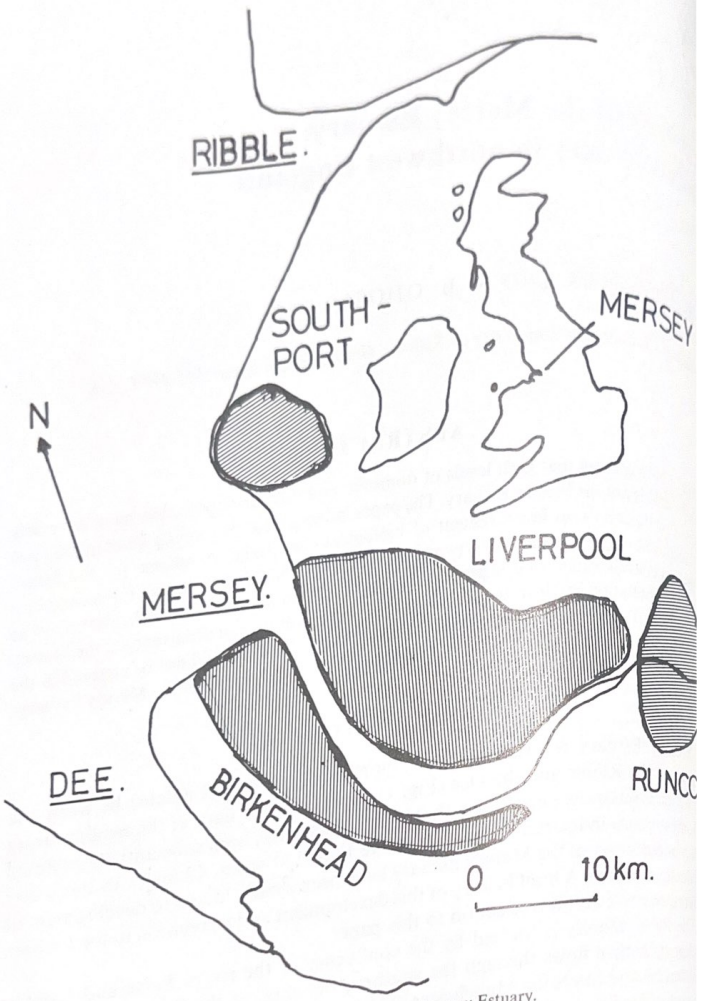


Fig 1. The location of the Mersey Estuary.

the northern side consist mainly of muddy sand, but on the Cheshire side there is extensive mud bank and salt marsh adjoining the shore and stretching for 11 km fr just below Runcorn almost to Eastham. Below Eastham the Estuary contracts ag into a straight deep channel, known as The Narrows, separating Liverpool and Boc on one bank from Bebington, Birkenhead and Wallasey on the other. Beyond N Brighton the Estuary opens into Liverpool Bay which consists for a considera distance off-shore of a shallow area of sand banks interspersed with occasion deposits of silt and other mud formations through which shipping channels maintained by regular dredging. The configuration of the Estuary is shown in Fig.

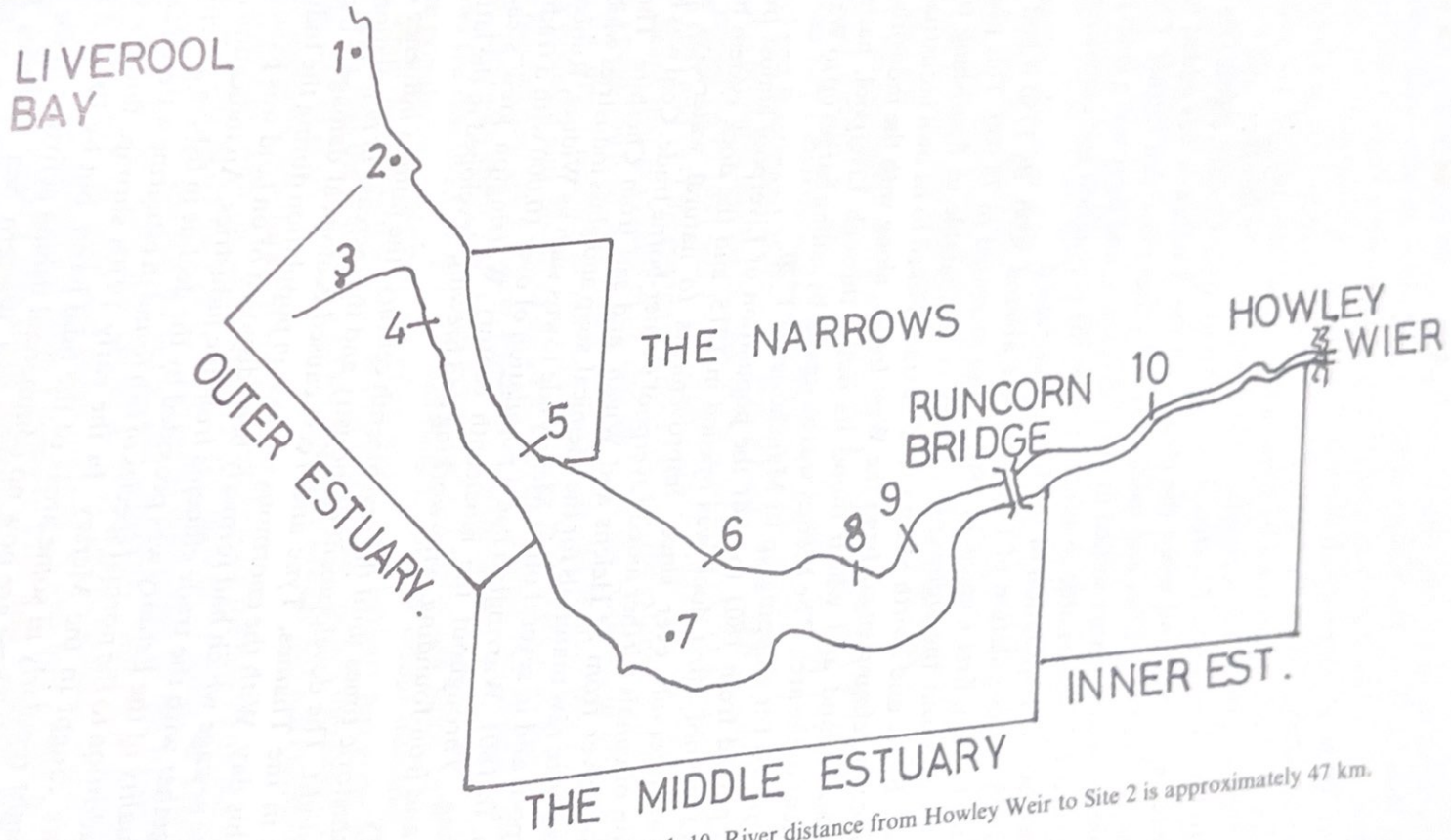


Fig. 2. The Mersey Estuary. The location of the sampling points 1–10. River distance from Howley Weir to Site 2 is approximately 47 km.

The whole of Liverpool Bay and the Estuary are subject to a very large (greater than 9·5 m for spring tides) and the interaction of the tidal and flows result in an average time within the Estuary of about 30 days for over Howley Weir. The history of human settlements on Merseyside date Bronze Age when there was considerable trade between England and Ire about 700 BC greater rainfall and wetter conditions prevailed and it is believ area was deserted from then until Roman times. Liverpool became a borou and the Port was again used by ships sailing to and from Ireland. The popul only 3000 and the main occupation was fishing from the foreshore and hand with Ireland. Gradually Liverpool captured trade from Chester, on the Dee E the latter silted up, and when the trade with the Americans was added to th Ireland, the port facilities and associated industries expanded further. Chesh Lancashire became more settled in the 16th century, and there was a great pro agriculture. It is reasonable to assume that as the population and commercial ac increased so the population of the Estuary increased.

In 1698 the population of Liverpool was around 5000. By 1750 it had gro 20,000 and at the first Census in 1801 it had increased to 78,000. This phenom growth throughout the eighteenth century is attributable to flourishing trade w American, Baltic and North Sea ports. This trade linked to its own industrial grow for instance in refining sugar from the West Indies, along with the industrial grow taking place inland and which found its outlet through Liverpool, hastened th development of the area. The Mersey was navigable by sailing barges up to Warrington and was opened for shipping up to Manchester in 1720.

In the period from 1801 to 1841 the population of Liverpool almost trebled to 223,000. Liverpool's first dock was opened in 1715, and the dock system has been extended at intervals ever since. Improvements to natural waterways and the construction of canals further aided Liverpool's water-borne trade. Coal was brought by canal and river from St Helens and Wigan, and salt from Cheshire. These two commodities were raw materials for the chemical, soap and glass industries which grew up in Liverpool and in several other Merseyside towns such as Widnes, Runcorn and Warrington. In 1801, Warrington had a population of over 10,000 with a tradition of manufacturing. Throughout the nineteenth century Warrington grew steadily in population, and iron-founding, wire-working and brewing developed in the latter half of the century.

From prehistoric times until the seventeenth century, the human influence on the Estuary was slight. The development of industry and the increase in population since then have, as in the Thames, Tyne and Tees, caused ecological damage which has continued to this day. With the enormous increase in population during the Industrial Revolution, the sewage which had formerly been disposed of on land was passed into the Estuary together with the trade effluents from the industries. An indication of the deteriorating quality of the Estuary was provided by the decline in fishing activities. A century ago, in addition to the normal species of fish found in estuarine waters, sole and pink shrimp were caught in the Mersey. In the early 1930s shrimp, flounders and whiting were caught regularly in some areas of the tidal basin, but by 1948 all these fisheries had disappeared. There are now no commercial fishing activities in the tidal basin. Between 1951 and 1961 the Lancashire and Western Sea Fisheries Joint Committee conducted surveys which demonstrated that, at low water in the summer, the Estuary was unsuitable for fish due mainly to lack of dissolved oxygen and an

abundance of suspended matter which has always been present. Even at high water the Estuary was unsuitable for a demersal fishery, but some pelagic fish were able to tolerate conditions over the high water period at least as far upstream as the landward end of The Narrows. In the earlier years of this century, concern for the environment was not as widespread as it is today, but there was nevertheless considerable apprehension that the pollution of the Mersey might affect commercial interests. This led, in 1930, to a detailed and comprehensive report by an expert scientific Committee appointed by the Mersey Docks and Harbour Board to investigate whether the discharge of crude sewage into the River Mersey increased the rate of sedimentation of solid matter and altered the character of the deposits in such a way that they were more difficult to remove by dredging. Their report indicated that the silting and consequent reduction in tidal capacity of the Upper Estuary was a direct result of the discharge of crude sewage to the Estuary. A subsequent investigation by the Water Pollution Research Laboratory carried out between 1933 and 1935 failed to confirm these findings and concluded that the rate of sedimentation and the composition of the mud were not appreciably altered by the discharge of sewage, and in a minor way the debate continues to this day (Alexander *et al.* 1935). It was not until 1971 that the Mersey and Weaver River Authority were able to present a comprehensive report on the condition of the Mersey Estuary and adjacent coastline, which showed how serious the pollution problem then was.

In 1931 the population of the surrounding Estuary was 1,474,000. Most of the area was sewered directly to the Estuary. Crude sewage entered the Estuary or the Manchester Ship Canal through eighty-three outfalls, twenty-four of which were from Liverpool and Bootle and 25 from the Wirral bank. Although detailed information is lacking, it is probable that the increase in the quantities of sewage discharged over the 70-year period up to 1931 was considerably greater than the increase in population. Between 1861 and 1931 the population doubled, and the extension of water carriage for sewage meant that gradually more and more of the population contributed to the Estuary's pollution load. According to the Mersey and Weaver River Authority's 1971 report, the upper reaches of the estuary from Warrington to below Widnes were severely polluted and devoid of dissolved oxygen during the summer months; in the middle reaches near the Stanlow, Ellesmere Port area, dissolved oxygen was normally present, although there had been some marked reduction since 1938; and in The Narrows the dissolved oxygen was sufficient to obviate odour nuisance.

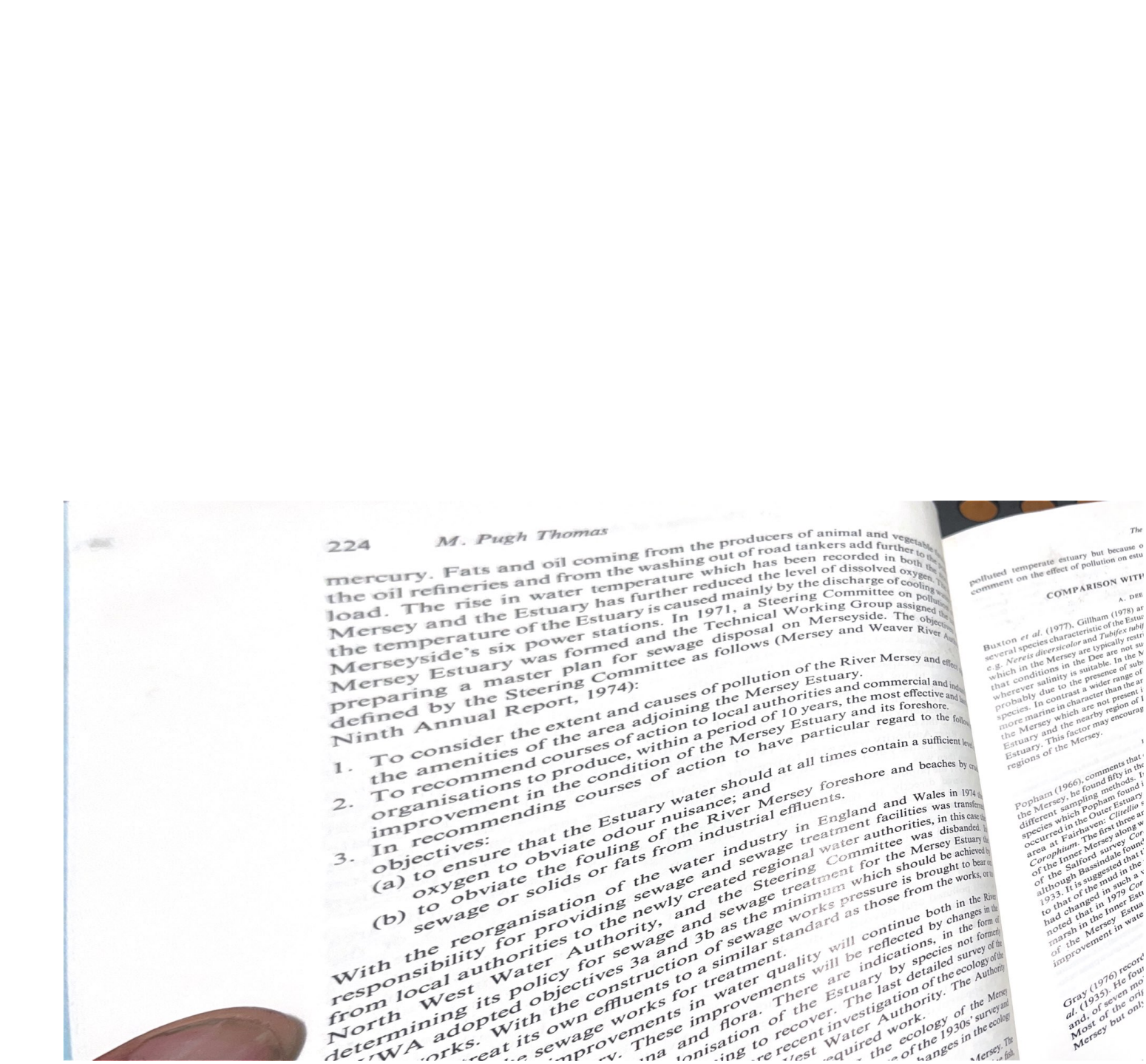
The population contributing crude sewage to the Estuary has gone down since the 1930s, while the population contributing treated sewage has increased. On balance, it seems likely that the polluting load for domestic sewage has not changed significantly over the last 40 years.

The apparent deterioration in water quality since the late 1930s exhibits a temporal correspondence with the establishment and growth of some of Merseyside's larger industries. The BOD load of the industrial discharges to the Estuary has increased substantially over the last 40 years, and especially important among these organic wastes are those from the chemical and petrochemical industries; from food processing; and from pulp and paper making. About half of the polluting load from industry is now discharged from Ellesmere Port and Stanlow, whereas in the early 1930s this area made a very small contribution. In addition to the BOD load, other indications of pollution deserve brief consideration. Chlorine occurs in some of the discharges from Widnes and Runcorn, together with traces of copper, lead and

mercury. Fats and oil coming from the producers of animal and vegetable
the oil refineries and from the washing out of road tankers add further to
load. The rise in water temperature which has been recorded in both the
Mersey and the Estuary has further reduced the level of dissolved oxygen.
the temperature of the Estuary is caused mainly by the discharge of cooling
Merseyside's six power stations. In 1971, a Steering Committee on pollution
Mersey Estuary was formed and the Technical Working Group assigned the
preparing a master plan for sewage disposal on Merseyside. The objectives
defined by the Steering Committee as follows (Mersey and Weaver River Au
Ninth Annual Report, 1974):

1. To consider the extent and causes of pollution of the River Mersey and effec
the amenities of the area adjoining the Mersey Estuary.
2. To recommend courses of action to local authorities and commercial and ind
organisations to produce, within a period of 10 years, the most effective and
improvement in the condition of the Mersey Estuary and its foreshore.
3. In recommending courses of action to have particular regard to the follow
objectives:
(a) to ensure that the Estuary water should at all times contain a sufficient leve
oxygen to obviate odour nuisance; and
(b) to obviate the fouling of the River Mersey foreshore and beaches by org
sewage or solids or fats from industrial effluents.

With the reorganisation of the water industry in England and Wales in 1974
responsibility for providing sewage and sewage treatment facilities was transferre
from local authorities to the newly created regional water authorities, in this case t
North West Water Authority, and the Steering Committee was disbanded.
determining its policy for sewage and sewage treatment for the Mersey Estuary th
NWWA adopted objectives 3a and 3b as the minimum which should be achieved by
works. With the construction of sewage works to a similar standard as those from the works, or
reat its own effluents to 3a and 3b as the minimum for the Mersey Estuary
e sewage works for a similar standard as those from the works, or to bear
mprovements in water quality will continue both in the River
ry. These improvements will be reflected by changes in the
na and flora. There are indications, in the form of
onisation of the Estuary by species not formerly
ing to recover. The last detailed survey of the
re recent investigation of the ecology of the
Vest Water Authority. The Authority
equired work.
the ecology of the Mersey
s of the 1930s' survey and
anges in the ecology
Mersey. The
of fish



polluted temperate estuary but because of the present lack of comparative data comment on the effect of pollution on estuarine diatoms is difficult to make.

COMPARISON WITH OTHER ESTUARIES

A. DEE ESTUARY

Buxton *et al.* (1977), Gillham (1978) and Parsons and Pugh Thomas (1979), found several species characteristic of the Estuary of the Mersey which were found in the Dee, e.g. *Nereis diversicolor* and *Tubifex tubifex*. Inner estuarine species in the Dee are those which in the Mersey are typically restricted to the Outer Estuary. This would suggest that conditions in the Dee are not such as to limit the spread of euryhaline species wherever salinity is suitable. In the Mersey, however, the drop in fauna upstream is probably due to the presence of substances which are inimical to the more sensitive species. In contrast a wider range of species was found in the Outer Estuary which is more marine in character than the area studied in the Dee, thus marine species occur in the Mersey which are not present in the Dee. The temperature of the Outer Mersey Estuary and the nearby region of Liverpol Bay is 1–2°C higher than that of the Dee Estuary. This factor may encourage the greater diversity of species in the less polluted regions of the Mersey.

B. RIBBLE ESTUARY

Popham (1966), comments that of the seventy species recorded by Bassindale (1938) in the Mersey, he found fifty in the Ribble and most of the difference can be explained by different sampling methods. In comparison with the present Mersey survey all the species which Popham found in the Outer Estuary of the Ribble or in sandy mud also occurred in the Outer Estuary of the Mersey. Popham, however, lists species in the mud area at Fairhaven: *Clitellio* sp., *Nereis diversicolor*, *Pygospio*, *Eteone*, *Hydrobia* and *Corophium*. The first three and some *Hydrobia* are characteristic members of the fauna of the Inner Mersey along with *Macoma* and several species of oligochaete. At the time of the Salford survey *Corophium* and *Eteone* were not found in the Inner Mersey although Bassindale found the former to be a regular inhabitant of the Mersey mud in 1933. It is suggested that the condition of the Mersey mud banks in 1933 corresponded to that of the mud in the middle reaches of the Ribble in the 1950s and since then they had changed in such a way to lead to the disappearance of *Corophium*. It should be noted that in 1979 *Corophium* was again found to be abundant in the banks of salt marsh in the Inner Estuary of the Mersey. The process of improving the water quality of the Mersey Estuary continues and the return of *Corophium* may reflect this improvement in water quality.

C. TEES ESTUARY

Gray (1976) records a great change in species diversity since the study of Alexander *et al.* (1935). He found a reduction from fourteen to seven polychaete species since 1935 and, of seven molluscs only small numbers of *Macoma* and *Mytilus* are now present. Most of the original twenty-one species are still found in the Outer Estuary of the Mersey but only two of the polychaetes, *Nereis diversicolor* and *Polydora*, have been

found in the Inner Estuary with *Macoma* and *Hydrobia* also [illegible] current population of the Seel Sands area of the Tees is given as [illegible] *Streblospio* and *Manayunkia* with *Pelescolex* and *Tubifex*. This [illegible] similar to that found at Hale Head and Speke where there is also a [illegible] colony, but with *Pygospio* instead of *Streblospio*. The Estuary of the [illegible] the Mersey, is heavily polluted with industrial and domestic effluent. A [illegible] faunal composition is to be expected.

D. MORECAMBE BAY

Apart from *Nereis diversicolor*, none of the species characteristic of the [illegible] polluted regions of the Mersey Estuary occurred in the much cleaner [illegible] Morecambe Bay (Anderson 1972). Species from the outer regions of the Mersey [illegible] occur in Morecambe Bay, for instance *Macoma balthica*, but the number of [illegible] per square metre (2000–3000/m^2) was much lower than in Morecambe [illegible] phenomenon which was shared with other species such as *Hydrobia* and *Corophium*. The pollution load of the Mersey probably contributes to the differences in [illegible] species' composition and abundance.

E. SUMMARY OF ESTUARINE COMPARISONS

Several species, *Arenicola marina*, *Eteone longa*, *Eurydice pulchra*, *Bathyporeia pelagica* and *Corophium volutator* did not occur in parts of the Estuary where natural physical and chemical conditions were suitable. Their distribution was probably restricted by pollution. Similarly, the numbers of several species were markedly smaller when compared, for instance, to the neighbouring relatively unpolluted Dee Estuary. Again this may be due to pollution.

COMPARISON OF 1976/78 AND 1933 MERSEY ESTUARY SURVEYS

In 1933 Bassindale found less than eighty species in the Mersey Estuary. The 1976 Salford University survey listed over 135 species of macro-invertebrates. The Sal survey encompassed a slightly larger area and was extended over a longer peri time. It is, therefore, difficult to say whether the macrobenthic fauna has increa variety since 1933. A subjective interpretation of the species lists would indicat has. (Full species lists are available in the Report of the Salford University, which can be obtained from the author of this paper.) Nevertheless, it is diffi whether this indicates an improvement or otherwise in the condition of t For instance, *Arenicola marina* has been lost since 1933 but, conversel *capitata* has undoubtedly entered the Outer Estuary and Scrobicularia pla be gaining a foothold (Table 1).

It is possible that the Salford survey was completed just as the wat Mersey was reaching a level which allowed species not present in the E start to recolonise the area. The species lost since 1933 could have b period up to the late 1960s–early 1970s when pollution loads wer pertaining in the Estuary now.

Table 1. Summary of the species changes between 1933 and 1978

1933 Survey	1976/78 Survey
Over 75 species present	135 species present
Over 20 species lost since 1933, 15 from the Inner Estuary, 6 from the Outer Estuary.	50 gained since 1933, 18 of which were oligochaetes not collected in 1933.

SOURCE: Bassindale 1938; Fraser 1932.

Table 2. Indications of changing conditions in the Mersey Estuary as revealed by the littoral macrobenthos

Beneficial changes	Adverse changes
Spread of *Arenicola marina, Eteone longa, Eurydice pulchra, Bathyporeia pelagica*	Decrease of the spread of these species
Return of *Corophium volutator* to Inner Estuary	Loss of this species from Outer Estuary
Increase in numbers of *Macoma balthica* levels similar to that of nearby unpolluted estuaries	Decrease from 1976/78 population densities
Increase in species diversity index	Decrease in species diversity index
Increase in size of species such as *Pygospio elegans* at present small in size compared to species in neighbouring estuaries	Decrease in size of such species
Return of lost species from 1933. Additional colonisations	Loss of species from 1976/78 Survey

A detailed examination of the data arising from the University of Salford study makes it possible to propose a table of biological indicators for monitoring future changes in water quality in the Mersey Estuary and this is presented as Table 2.

LOSS OF NATURAL HABITATS

Since the early years of the last century poor water quality has undoubtedly effected the ecology of the Mersey Estuary. In addition, destruction of the littoral habitat has also probably effected the occurrence and distribution of species within the Mersey Estuary. Table 3 summarises numbers of species at different sites within the Estuary. Sites 1–3 are in the Outer Estuary where water quality is good and where the commercial development of the littoral zone is least. Nevertheless, it is interesting to note that the number of species present decreases from site 1 to sites 2 and 3 and that this reflects the increased level of habitat interference at sites 2 and 3.

Sites 4–7 are in the most commercially developed region of the Estuary. For much of this region the littoral zone has been destroyed by docks and retaining walls. This has undoubtedly influenced the number of species present. It is not the only factor, however, as the littoral region continues to exist at New Brighton, where there is a heavy pollution load typified by the occurrence of floating human faeces, a similar

Table 3. Species numbers at littoral benthic sampling sites

Site no.	Site name	No. of species	Distances from Howley Weir (km)	Remarks
1	Formby	96	58	Marine epi- and benthic fauna, including polychaetes, bivalves, amphiopods, isopods, gastropods, echinoderms and oligochaetes
2	Crosby	65	49	Marine epi- and benthic fauna, including polychaetes, bivalves, amphiopods, isopods, echinoderms and oligochaetes
3	Wallasey	78	48	Marine species polychaetes, several species of bivalves, gastropods, amphiopods, isopods and oligochaetes
4	New Brighton	10	46	Benthic littoral fauna including polychaetes, one species of bivalve, and one species of gastropod. Other species on rocks or stones
	Pluckington Bank	9	39	One bivalve, three gastropods, five polychaetes
	Speke	15	36	One gastropod, one bivalve. Rest of fauna oligochaetes and polychaetes
	Eastham Bank	26	30	Oligochaetes and polychaetes were main elements with one gastropod, one bivalve and one copepod
	'ale Head	15	20	Oligochaetes, polychaetes, plus one bivalve and one gastropod
	ıcorn	8	18	Oligochaetes and polychaetes plus one bivalve and one gastropod.
	ers Ferry	12	7	'Salt-tolerant' freshwater oligochaetes and nematodes

'luckington Bank, and the reduced fauna at Speke and Eastham Bank. eavily contaminated by domestic effluent. (The species list at Eastham han indicated, tidal currents and difficulty of access made this site very ple.) Pluckington Bank is in the middle of the most intensively f the estuary, the extent of the littoral region is approximately 500 nd the species list more restricted than elsewhere in this part of the

ent the natural zone of changes in the Mersey Estuary where the nd although the tidal rise is still considerable the Estu come is noticeable, however, that the species lists uncorn where the habitat destruction nt is most intense.

SUBSIDIARY

ed on the macr ior
ects of the uar

Such is the local reputation for the pollution believed on Merseyside that there are no fish species were recorded from the Estuary and far upstream as Runcorn sand gobies were was concentrated on sand gobies, *Gobio platessa*. (Both these fish could be sam regular investigations.) Differences be Brighton were probably due to the difference would indicate reduction of the marine species upstream toward

B. HEAVY

At the time of writing this pap estuarine benthic organisms w organisms such as the cockle heavy metal contamination of metals acquired from algae a

A short duration survey area both for feeding an indicated by the large n quality of the water imp to expect the number a habitat due to land re tric power stations co

This paper demo adversely effect improving wate conditions. A which could destruction c contributor Although w occurring quali

A. FISH

Such is the local reputation for the pollution of the Mersey Estuary that it is widely believed on Merseyside that there are no fish in the Mersey Estuary. In fact twenty-two species were recorded from the Estuary and from the Manchester Ship Canal. Even as far upstream as Runcorn sand gobies were found although in small numbers. Research was concentrated on sand gobies, *Gobio minutus*, and O group plaice, *Pleuronectes platessa*. (Both these fish could be sampled from the shore and thus were ideal for regular investigations.) Differences between the populations at Wallasey and New Brighton were probably due to the pollution at the latter site. Reduction of the difference would indicate reduction of the pollution in the Mersey as would a spread of the marine species upstream towards Runcorn Bridge.

B. HEAVY METAL ACCUMULATION

At the time of writing this paper, work on the accumulation of heavy metals in estuarine benthic organisms was still in progress. The technique of using benthic organisms such as the cockle and mussel has considerable potential for estimating heavy metal contamination of estuaries as filter feeding organisms tend to accumulate metals acquired from algae and detritus.

C. ORNITHOLOGY

A short duration survey of the Estuary indicates that large numbers of birds use the area both for feeding and for roosting. That these birds are at risk from pollution is indicated by the large number of inexplicable deaths that occurred in 1981. As the quality of the water improves and the number of invertebrates increases it is reasonable to expect the number and variety of gulls, waders and wild fowl also to increase. Loss of habitat due to land reclamation, amenity development and the building of hydroelectric power stations could all adversely effect the future of the estuarine bird population.

CONCLUSION

This paper demonstrates that high levels of domestic and industrial pollution have adversely effected the ecology of the Mersey Estuary. The paper indicates that improving water quality has probably already led to an improvement in the biological conditions. A scheme for the future biological monitoring of the Estuary is proposed which could easily be adapted for use in other estuarine and coastal waters. The destruction of the littoral habitat by commercial development is suggested as a major contributor to the restricted species composition of many sites within the Estuary. Although water quality is improving, the restoration of lost habitats cannot be seen as occurring in the foreseeable future. It is therefore unlikely that improvement of water quality will wholely restore the ecological health of the Estuary.

At present proposals are being made for the building of a hydroelectric scheme in the Mersey Estuary. The author believes that although the water quality is improving the habitat change produced by such a scheme could well stop the return of the Mersey Estuary conditions similar to that of neighbouring estuaries.

REFERENCES

Alexander, W. B., W. A. Southgate and R. Bassindale. 1935. *DSIR, Water pollution*, Technical Paper No. 5: *Survey of the River Tees, Part II. Chemical and biological.* London: H.M.S.O.

Anderson, S. S. 1972. The ecology of Morecambe Bay. II. Intertidal invertebrates and factors affecting their distribution. *Journal of Applied Ecology* **9**:161–178.

Bassindale, R. 1938. The intertidal fauna of the Mersey Estuary. *Journal of the Marine Biological Association of the UK* **23**:83–98.

Buxton, N. E., R. M. Gillham and M. Pugh Thomas. 1977. Some aspects of the Dee Estuary. In *Problems of a small estuary*. Swansea: Institute of Marine Sciences. University College of Wales.

Fraser, J. H. 1932. Observations on the fauna and constituents of an estuarine mud in a polluted area. *Journal of the Marine Biological Association of the UK* **18**:69–85.

Gillham, R. M. 1978. *An investigation of the intertidal benthic invertebrates of the Dee Estuary*. Ph.D. Thesis, University of Salford.

Gray, J. S. 1976. The fauna of the polluted Tees Estuary. *Estuarine and Coastal Marine Science* **4**:653–676.

Mersey and Weaver River Authority. 1971. Technical Report No. 48. *A preliminary survey of the macro-fauna of the Mersey Estuary*. Warrington, UK: Mersey and Weaver River Authority.

Mersey and Weaver River Authority. 1974. *Annual Report for 1974*. Warrington, UK: Mersey and Weaver River Authority.

Parsons, N. and M. Pugh Thomas. 1979. The Biology of the Clwyd Estuary. *Journal of Natural History* **13**:725–734.

Popham, E. J. 1966. The littoral fauna of the Ribble Estuary, Lancashire, England. *Oikos* **17**:19–32.