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THE ECOLOGY OF THE ESTUARY OF RIVER WANSBECK, U.K.

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INTRODUCTION

SINCE the beginning of twentieth century a good deal of attention has been paid to the study of flora and fauna of brackish waters, lagoons, salt marshes and estuaries. Important contributions in the field of estuarine studies are those of Allen and Todd (1900 and 1902), Percival (1929), Lambert (1930), Fisher-Piette (1931), Reid (1930 and 1932), Alexander *et al.* (1932 and 1935), Fraser (1932), MacGinitie (1935) Milne (1940), Bassindale (1938, 1942, 1943 and 1943a), Hartley (1940), Beanland (1940), Spooner and Moore (1940), Goodhart (1941), Spooner (1947), Sexton (1912 and 1942), Holme (1949), Day (1951), Day, Millard and Harrison (1952), Scott, Harrison and Macnae (1952), Capstick (1957) and Swain and Newman (1962). The estuary of river Wansbeck is comparatively small and shallow. It was, therefore, considered desirable to study the ecological conditions of such an estuary of which nothing is known, and the results are presented here.

MATERIAL AND METHODS

To study the salinity conditions, pH and oxygen concentration the estuary of the river Wansbeck was visited (i) once a month for horizontal survey, (ii) twice in the month of November, to ascertain turbulence, (iii) and four times a year for vertical salinity gradient. Tidal predictions were obtained from the Admiralty Tide Tables for the river Tyne and nine minutes were subtracted from it for Wansbeck. The water samples were collected by means of a Casella water sampler in the mid stream from the surface, middle and bottom region, from a dinghy fitted with an outboard engine. As far as possible the samples were collected from the fixed points at each salinity station. Vertical salinity gradient was studied by collecting water samples every half an hour in a twelve-hour cycle for every quarter from the Stakeford bridge. The days selected were either on or near Summer and Winter Solstice, Autumnal and Vernal Equinox. These water samples were brought to the laboratory, titrated for chlorinity and their corresponding value of the salinity ‰ was obtained from Knudsen's Tables (1901) to the nearest of 0.1 ‰. For dissolved oxygen, Winkler's (1901) modified method was used. The value of dissolved oxygen absorbed by 100,000 cc. of water of known chlorine value and temperature was found from Fox's Tables (1907). pH was determined on the spot by the comparator method.

For the ecological study of benthic flora and macrofauna, preliminary field investigations were carried out from October, 1961 to March 1962. The quantitative sampling of the benthic and epifauna was done from 1st April, 1962 to 31st March, 1963. Only a rough count was made in case of *Neomysis*, *Crangon*, verte-

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brates and plants. Nine traverses were selected for the purpose of this study. As these covered the whole length of the estuary a true picture of the distribution of the flora and fauna inhabiting various areas was obtained. Further different stations were set in these traverses. These stations, as far as possible, were located at different tidal levels but if the substratum of a particular level showed some reasonable difference, two stations were established at the same tidal level. This gave a good picture of the distribution of fauna in different substrata but with the same salinity conditions. A profile of each station was determined by means of a dumpy level and surveying staff. In order to ascertain the absolute heights in relation to the Ordnance Datum, various bench marks were made use of. Once a point of absolute height in a traverse was established it was found easier to fix the Ordnance Datum of respective stations. Following are the Ordnance Datum heights of various stations.

Traverse	Stations						
	1	2	3	4	5	6	7
A	4.6	4.9	4.0	4.9	X	X	X
B	4.0	3.8	3.8	4.0	X	X	X
C	4.5	4.5	4.5	4.0	5.0	6.0	7.0
D	5.0	4.0	3.0	-1.0	3.0	3.8	6.0
E	4.8	3.0	3.0	2.9	2.0	4.6	X
F	4.8	3.0	2.9	2.6	2.6	4.0	X
G	5.8	4.2	2.9	3.0	-0.75	2.6	X
H	4.2	3.0	0.0	1.0	2.0	4.0	X
I	1.0	-2.0	-1.0	X	X	X	X

For the collection, low tide was found very satisfactory. Near the mouth, however, extreme low tides were found to be the best. Animals were collected by the following method :

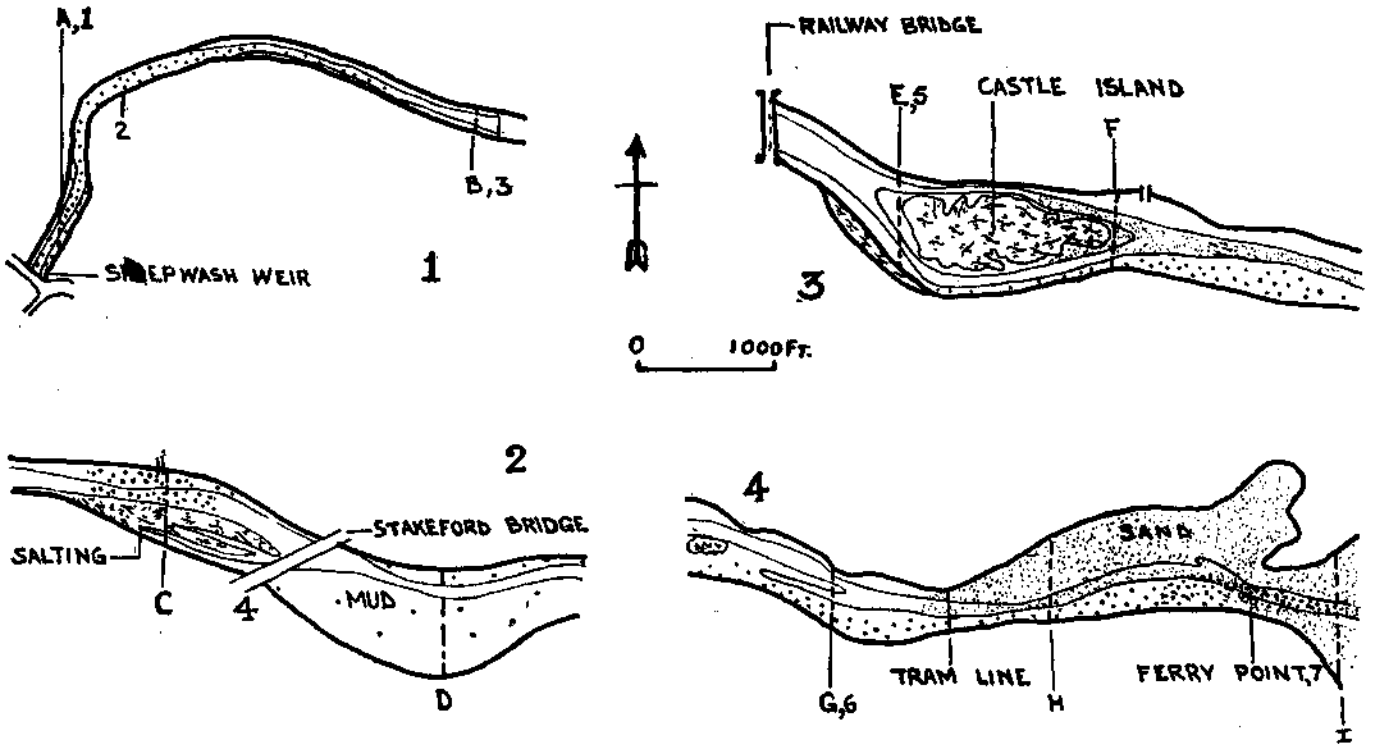
A. *Fauna and Flora of the Intertidal Mud :* In the exposed region, at each station, a quarter square meter area was marked with an iron frame. At first, the surface (1″-2″) was scraped and sieved and then digging was done by showel or fork upto 1½′. In the water, Allen's (1952) modified grab was used. Its measurements were changed to 25×16 cm. to give a sample of 400 sq. cm. Sieving was done on the spot, the animals removed, bottled and brought back to the laboratory, counted and studied. 1 mm. mesh sieve was used. A great deal of difficulty was encountered for sieving the clayey mud which was done by sieving small quantities of mud for a number of times.

B. *Epifauna : Jaera* spp. and *Gammarus* spp. were collected by Surber's (1937) bottom sampler. Albert's Wydler's No. 0000, extra heavy bolting silk cloth was used as a net for this sampler. The sampler was put in the required area with the mouth facing the incoming stream. Its frame was pushed a bit in the ground. The stones from the enclosed area of the frame were picked up and were placed in an enamel dish. All the animals were removed by a brush. The trailing net caught whatever tried to escape. It was searched for animals later on. These animals were collected in a bottle and preserved in 70% alcohol or 4% formalin.

Description of the Estuary

A few small streams in the west part of Morpeth rural district combine together to form the river Wansbeck. Further running down eastwards this river becomes estuarine from Sheepwash weir and runs almost perpendicular to the North Sea. The estuary of river Wansbeck lies between Lat. 55° 09′ 44″ N and 55° 10′ 16″ N, and Long. 1° 31′ 19″ W and 1° 35′ 58″ W. It is presumably a drowned valley in origin and is of single channel system. Its length between the latitudes is approximately three miles. The total area of the estuary under study at mean low water is 0.071 square miles and it is 0.21 square mile at mean high water, thus the exposed area at low water is 0.140 square mile. The intertidal volume is 13.8×105 c. ft. and the tidal range amplitude is 3.7 ft. Major part of this estuary remains exposed at low tide and the water even in the main channel, with the exception of deep pit and Ferry point, is less than two feet deep (Figs. 1-4).

The weir at Sheepwash is made up of concrete and is about 5 feet high. It is followed by an area of sandy bottom with stones here and there. This is soon replaced by stones of various sizes which are covered with algae (Tr. A). The flow of the water at low tide is on the left side, the right being exposed. The gradient is smooth. Travelling down another thousand feet one comes across a deep pit. The depth of this pit varies from 6 to 15 feet. The bottom of this pit has got boulders and soft mud. This pit is followed by the Tr. B. whose sides consist of soft mud but the mid bottom is very hard. Further down stream the bottom of the estuary is stony for the greater part but its left side and the two off shoots (stations 1 and 2 of Tr. C) are muddy. Between Sts. 2 and 3 of Tr. C is a big patch of land. This is covered with *Plantago maritima* and *Obione portulacoides*. C 3 (means Tr. C. station 3) has sandy clay type of substratum, C 4 and C 5 are stony with little mud and sand. *Fucus ceranoides* is found to grow on these stones. C 6 is more muddy and there is no plant growth on it. C 7 is the left bank of transect C and is covered with *Plantago maritima*. As we proceed from Tr. C to D in fact upto Tr. F we find that mud becomes more prominent. From Tr. C to Stakeford bridge it is muddy in the middle but firm and clayey on the sides. Little down Stakeford bridge is a very soft muddy area, full of pebbles. One can easily sink down to 3 feet in this region. D7 is like C7, D5 and D6 have got black mud. From D 5 to D 4 the surface of mud becomes more gray. Though D 4 is muddy, it has got sand mixed with it. D 3 has got gray sandy mud with a few pebbles. D 1 and D 2 have got sticky dark mud and has a slippery surface. From Tr. D to Tr. E it is as described for Tr. D. Trs. E and F present different substrata though they are only 500 feet apart. E 1 and F 1 are alike with muddy surface and *Fucus vesiculosus* growing on the stones. E 2 and E 3 are very muddy, soft at the surface but becoming firm 6″ to 9″ deep. E 4 has got a firm bottom with gray mud at the top. Between E 4 and E 5 is the main channel. The channel has a sandy bottom. E 5 is like E 4. E 6 is again muddy. As we travel from E to F we find that in the middle of the estuary there is a big patch of land called the Castle Island. On this island *Plantago* and *Obione* grow. The right side of this island is more muddy than the left. Tr. F is more sandy than Tr. E. F 2 has got a mixture of sand and mud. F 3 and F 4, though appear to be sandy at the surface, have got firm muddy bottom. F 5 is sandy with little mud and F 6 is like E 6. The right bank of Tr. G has got clayey mud with stones scattered here and there, whereas the middle part and left bank are purely sandy. Tr. H is almost like Tr. G, with the exception that H3 has got clayey mud. From H to I the right surface shows more stones and pebbles while the middle and left are purely sandy. Near the Ferry point this estuary becomes deep again. At low water it is 17 feet deep. This is perhaps due to the presence of small hillock which



FIGS. 1-4. Map of the estuary of the river Wansbeck, showing the salinity stations 1-7 used in horizontal surveys and the position of the traverses A to I.

causes whorlly movements of water in this region. From Ferry point to Tr. I it is sandy on both sides and stony in the middle. From Tr. I to sea it is stony in the middle with sandy sides making the seashore. There is a sudden fall in the slope from Tr. I to sea.

Study of Soil Sediments

The soil was analysed by sieving method and the grading was done according to Wentworth's scale (1926). Necessary precautions were taken against the flying away of the dry clay. The results of the soil analyses are as follows :

Sediment Analysis (Wentworth Grade Scale in %)

Stations	2 mm.	2-1 mm.	1-500 μ	500-250 μ	250-125 μ	125-62 μ	62 μ
Tr.A. 1	0	0	21	36	23	20	0
2							
3							
Tr.B. 1 & 3	0	0	20	4	16	26	34
2 & 3	0	0	15	6	13	16	50
Tr.C. 1	6	8	0	22	28	22	14
2	6	8	0	22	28	22	14
3	0	0	10	32	38	10	10
4	54	6	5	11	13	2	9
5	56	6	10	10	6	1	11
6	0	6	4	22	24	24	20
7			Left Bank				
Tr.D. 1	0	0	7	17	18	28	30
2	0	8	7	19	8	18	40
3	16	0	9	10	30	20	15
4	0	0	5	9	41	20	25
5	2	2	6	6	21	27	36
6	2	2	4	4	10	14	64
7				Left Bank			
Tr.E. 1	6	8	14	9	15	32	16
2	0	4	12	14	12	34	24
3	1	1	5	6	10	29	48
4	1	1	5	6	10	29	48
5	0	0	3	9	24	26	38
6	23	8	14	9	18	22	6
Tr.F. 1	0	8	14	9	18	35	16
2	0	8	14	9	24	20	25
3	0	3	2	5	80	10	0
4	0	3	2	5	80	10	0
5	0	0	10	20	60	10	0
6	23	8	14	9	18	22	6
Tr.G. 1				Stones with very little sand			
2	20	6	4	26	24	10	10
3	1	0	3	60	36	0	0
4	3	2	3	28	64	0	0
5	4	4	10	64	18	0	0
Tr.H. 1	30	20	12	8	20	6	4
2	30	7	4	19	31	1	8
3	20	18	10	14	22	6	10
4	0	0	0	76	24	0	0
5	0	0	0	76	24	0	0
Tr. I. 1	0	0	0	80	20	0	0
2	0	0	24	34	18	24	0
3	0	0	0	80	20	0	0

pH : The pH of the estuary was tested both at high and low tides. At low tide it was usually 7.6 but at high tide it varied according to the position of the station, from 7.6 at the head to 8.2 near the mouth, the variation being directly proportional to salinity.

Oxygen : Oxygen saturation was found to vary from 70% to 90%.

Light : Since the major part of this estuary is exposed at low water for a good length of time the organisms are exposed to the radiant energy or what is called ' normal sunlight '. Even at high tide as the turbidity is very low, it does not interfere with the penetration of light which is essential to carry out photo-synthesis.

Turbidity : The water of river Wansbeck is clear for a greater part of the year at low tide but becomes a bit turbid at high tide. The turbidity increases a little during the floods due to the presence of suspended matter which gets eroded from the land upstream. However, even during the floods it never exceeded enough to have any adverse effect on the organisms.

Horizontal Salinity : The results of the earlier workers have shown that the tongue of less saline water extends over the surface of the estuary at high tide, but how far this tongue extends down any estuary is different in different cases. To collect this information regular horizontal hydrographic surveys were undertaken. For this purpose data were collected for a period of one year (April 1962 to March 1963) and the sampling was done once a month at high tide. The position of isohalines shown in Figure 5 were calculated from the results obtained from mid stream samples by interpolation. From the data (Fig. 5) it becomes apparent that though there was a regular salinity gradient at high tide, yet due to shorter length and the abnormal height of this estuary bed there was an unusual flood tide. Therefore salinity gradient was not very much marked and the isohalines appeared to be nearly oblique. It may be pointed out here that the base of the Ferry point is equal to zero of ordnance datum or mid-tide level. So the sea water does not enter the estuary for a considerable time at high tide but about 2½ hours after the predicted time. The result of this is that the sea water when starts coming in, rushes in with great force thus exerting a damming effect on the river water and results in the oblique isohalines.

As these surveys were always completed at high tide and presuming that the sea water entering at that time was usually of the same force, the position of the isohaline depended on the river water entering the estuary. Therefore, from these figures (Fig. 5) it becomes evident that April to November 1962 were rather dry months as compared to December 1962 to March 1963. Further it may be observed that maximum amount of fresh water entered the estuary in December and the least in the month of June. The results of October survey are slightly abnormal in as much as the isohalines are pushed more towards the head of the estuary than normally expected. This was because of the strong northerly winds encountered at that time.

Vertical distribution of salinity : The results of these surveys show that this estuary has a vertical salinity gradient at high tide and indicates the amount of fresh water that enters the estuary (Fig. 6).

In June, 1962 the flow of the incoming freshwater was perhaps the minimum.

So much so that even at low tide the stream was a bit saline. During flood tide the mixing of fresh water was gradual for a short while but became abrupt with

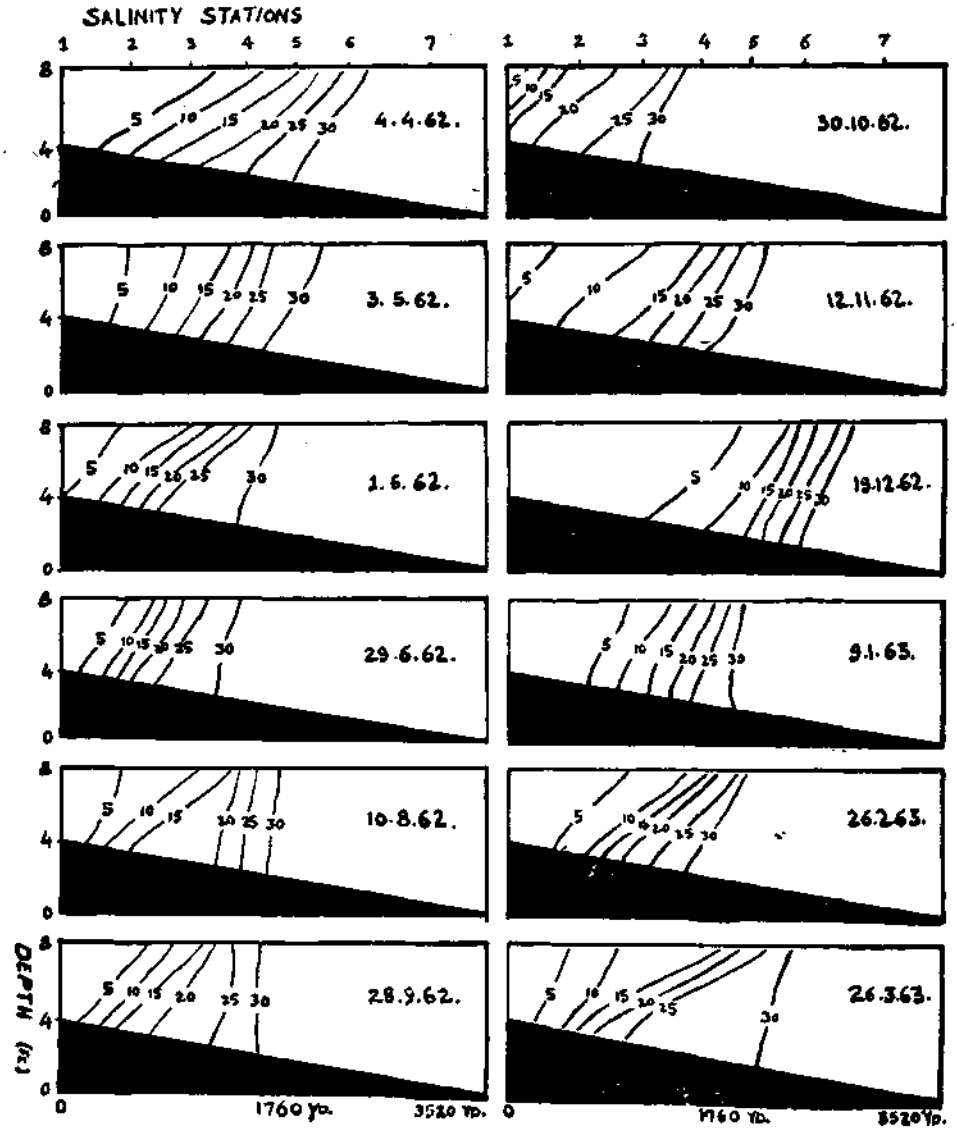


FIG. 5. The salinity condition in the estuary at high tide during horizontal survey.

the increase in tide. In September, 1962 more freshwater entered the estuary than in June. The result of this was that at low tide the surface water was fresh. Also it was noticed that the mixing was a gradual process rather than abrupt as in June. In December, 1962 the amount of fresh water entering the estuary was maximum. Consequently even at high tide the surface water remained fresh. In March, 1963

at the time of the survey, it showed slightly lesser amount of freshwater coming in than in December but more than in June and September, 1962.

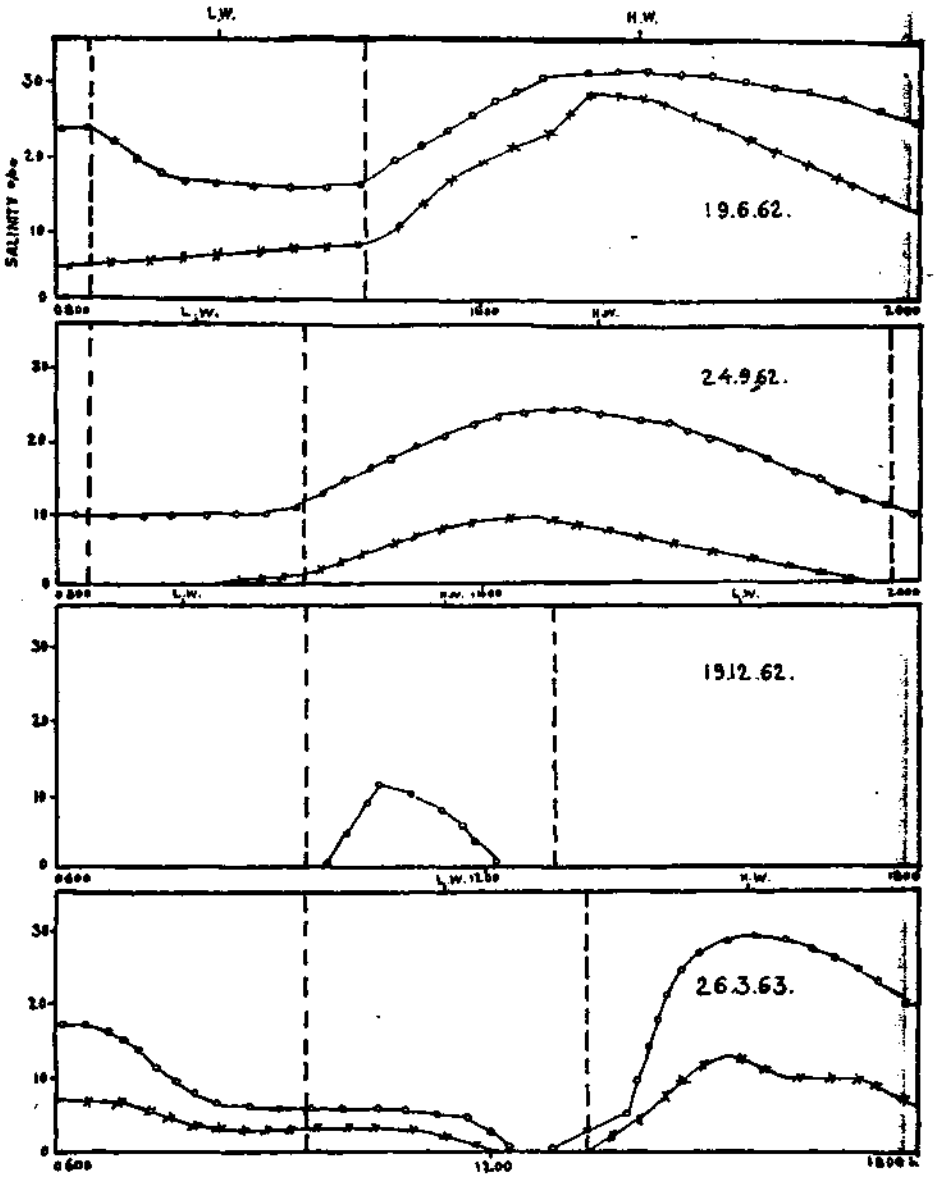


FIG. 6. Shows the result of the twelve hour cycle and the salinity conditions of the surface and the bottom water; surface water x—x—x, bottom water o—o—o. Dashed lines show the time when the estuary at Stakeford bridge was drained off the tidal water and the estuary maintained a constant depth of 1½ feet. L.W. means low water and H.W. means high water.

Deep pit : Two special surveys were made on 16.8. 62 (Fig. 7 A, Spring tide) and 25-8-62 (Fig. 7B, Neap tide) to study the salinity conditions of the deep pit,

situated between salinity stations 2 and 3. This pit is about 15′ deep at places. Salinities at various points were tested both at low and high spring and neap tides. It was seen that during spring tide period at low tide, the surface water was fresh and the bottom water showed salinity upto 20‰ whereas at high tide the surface salinity varied from 3 to 5‰. At neap tide period, however, the surface water remained fresh both at high and low tides but the bottom salinity showed some difference in concentration. At low tide it was 15‰, but at high tide it varied from 20‰ to 23‰.

From this study three things have come to light (i) the salinity varies at different levels with the minimum at the surface and maximum at the bottom (ii) some mixing of saline water and fresh water was always going on in the region of deep pit, (iii) that whereas in the normal course perhaps the water at Stakeford Bridge at low tide would have been fresh it was always a bit saline for majority of months. This is due to some of the bottom water of the deep pit being pushed out at low tide, making the river water beyond station 3 partly saline.

Turbulence : To ascertain the exact phenomenon of mixing of fresh and sea water two special surveys were made, one at high spring tide and one at high neap tide in the month of November, 1962. These studies revealed that the area of turbulence lies in between salinity stations 2 and 3 ; in other words the maximum mixing takes place in the region of deep pit.

Fauna and Flora, with Biological Notes

Traverses A, B, C and D were visited for collection on 18.4 ; 29.6 ; 17.8 ; 30.10 ; 12.11 ; 19-12-1962 ; 11.1 ; 8.2 and 26-3-1963 and traverses E.F.G.H and I were visited on 25.4 ; 22.5 ; 16.6 ; 3.7 ; 2.8 ; 23.8 ; 13.9 ; 17.10 ; 27.11 ; 27-12-1962 ; 25.1 ; 25.2 and 29-3-1963. Unless otherwise mentioned the average number of animals is per square meter. In order to avoid unnecessary repetition of the words station and no., it has been preferred to write number of the animals followed by dash and then the no. of the station *e.g.* 112-3 be read 112 animals p.sq. m. at station 3. H.W.S.T. means high water spring tide and H.W.N.T. means high water neap tide. For easy reference, the horizontal distribution of different species have been shown in Table 1.

Platyhelminthyes

Dugesia lugubris (Schmidt)
Polycelis nigra (Muller)
Polycelis tenuis (Ijima)

These triclads were found near the head of the estuary very near the Sheepwash weir, under the stones. Like *Asellus aquaticus* these were commonly found above the weir and some of them were washed down during floods.

Annelida

Arenicola marina Linn.

This annelid was found from Castle Island down to the Ferry point. Its presence at various places with different type of substratum revealed that it could live in different substrata. The minimum requirement, however, was long exposure, moist sandy bottom with little mud and high salinity (15‰ to 33‰). Their

no. at Tr. F from 25.4.1962 to 29-3-1963 were 32 at stations 2 and 3, and 48 at St. 4 and at Tr. H during the same period 16 to 32 at St. 2.

It was observed that during early November of 1962 a large number of small castings appeared on the surface. Digging showed the presence of tiny Arenicolids which indicated that they breed near about that period. Newell (1948) found it to breed in October ; Holme (1949) also came across small *Arenicolids* in Salthouse Lake area in the month of November.

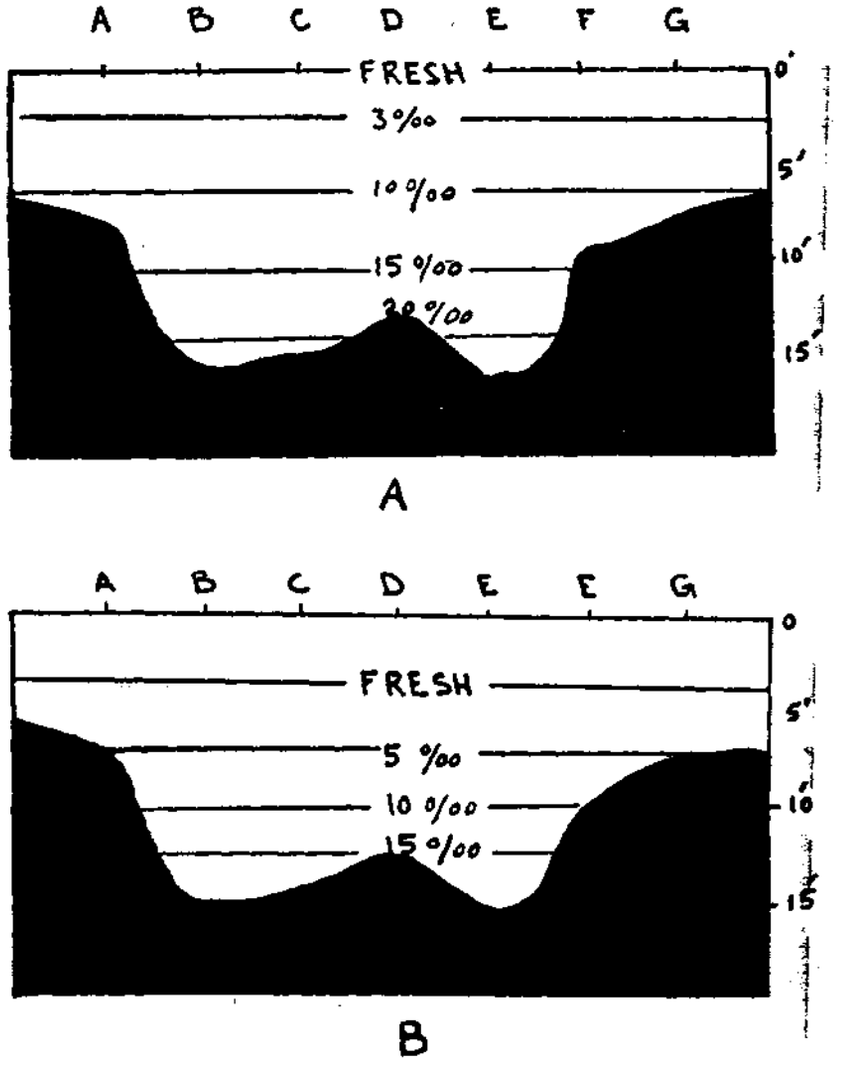


FIG. 7. Shows salinity conditions of deep pit (situated between salinity stations 2 and 3) at different levels, during (A) high spring tide, and (B) high neap tide.

Nereis diversicolor Muller

It forms a major burrowing faunal element of this estuary. It has neither been found in fresh water zone nor beyond Ferry point. The largest no. of 320 per square meter was met with at stations 4 and 5 of traverse C.*N. diversicolor* can stand fairly large range of salinity (5‰ to 30‰). Their no. from 18-4-1962 to 19-12-1962, at Tr. B are 176-1, 96-2, 80-3, 112-4 at Tr. C. 224-1, 208-2, 240-4, 320-5, 160-6 and at Tr. D 64-1, 80-2, 128-3, 32-4, 96-5, 80-6. From 25-4-1962 to 29-3-1963, their no. at Tr. E are 96-1, 64-2, 80-3, 48-4, 64-5, 32-6, at Tr. F 64-1, 32-2, 48-3, 32-3, 96-4, 32-6 and at Tr. G. 80-1.

CRUSTACEA

Jaera spp.

This isopod is represented by two species namely, *J. nordmanni* (Rathke) and *J. albifrons* (Leach). Their distribution is directly related to the presence of stones though a few were also found on *Fucus* spp. *J. nordmanni* is found in large numbers at Tr.C., from 18-4-1962 to 19-12-1962, it is 128-4, 80-5 and from 11-1-1962 to 26-3-1963 it is 112-4, 80-5 whereas *J. albifrons* was present more near the mouth. At Tr. H from 25-4-1962 to 29-3-1963, it is 112-2, 320-3 and a Tr.I from 25-4-1962 to 27-12-1962, 160-1, 112-3, and from 25-1-1962 to 29-3-1963, their no. is 112-1, 80-3. They have been found to breed throughout the year, the peak breeding period being the months of July and August.

Sphaeroma rugicorda (Leach)

In Wansbeck this isopod has not been found in any appreciable number though occasional specimens were found in small pools present in the saltings situated between Traverses B and E. These pools were situated between H.W.S.T. and H.W.N.T. The average salinity at H.W.S.T., here was about 25‰.

Asellus aquaticus Linn.

This isopod, is in reality the inhabitant of the non-estuarine part of the river Wansbeck and is commonly found above Sheepwash weir. This was ascertained by making a survey of the river above the weir where it could be collected in an appreciable number. However, it was washed down to Tr. A by accidental displacement during floods. They were usually found in a large number (about 100 in a square meter) if the collection was made within a few days of rain or flood, otherwise only 1 or 2 were present in a square meter on the left side of the stream and never in the mud stream.

Neomysis integer (Leach)=(*Neomysis vulgaris*)

Neomysis integer appears in the estuary of the river Wansbeck sometimes in April, disappearing in late November or early December. In winter these schizopods move down to sea making a come back in April. From April to September, 1962 it has been observed to live in millions between salinity stations 1 and 2. One minute catch could bring in as many as 10,000 of these. During low tides, at salinity station 1 it has been seen both in the mid stream and edges but at salinity station 2 a large number of these inhabit the sides alone, which may be due to the presence of detritus near the edges. Further it has also been observed that during flood tide, as the water rises from Traverse B to A or salinity stations 3 to 1 this mysid starts travelling towards Stakeford bridge but still remaining near the surface. This migration appears to be due to change in salinity conditions. As the bottom salinity at salinity station 1 and 2 rises at high tide, the fresh water flows

on the surface and they start moving down stream but not going further down than traverse C because of the high surface salinity. The average water temperature is 12°C.

Nearly during the whole period of observations a few of *Neomysis integer* have always been found to be full of eggs. In May and June the females became very conspicuous due to the well developed brood pouch full of ripe eggs. In addition, it has been observed that stages of various sizes have been found from time to time which means that the breeding is not confined to a particular month but is spread over the whole period of summer.

Gammarus spp.

Various species of *Gammarus* have been described from the estuaries. Their distribution has been found to be more or less related to different salinity conditions. The remarkable work in this connection are those of Sexton (1912 and 1942), Crawford (1936), Goodhart (1941), Bassindale (1942), and Spooner (1947).

In the estuary of river Wansbeck two species e.g. *Gammarus duebeni* Lilljeborg and *G. locusta* (Fabricius) have been found and their distribution seems to be more or less restricted to different areas. This is due to salinity conditions and the substratum. Like *Jaera* spp. they have also been found from under the stones. But unlike *Jaera* they do not inhabit stones of smaller size. *G. duebeni* is confined to the head of the estuary and is found in abundance underneath the stones. The number of *G. duebeni* varies from stone to stone but an average count shows that it is about 112 per square meter. Their no. from 18-4-1962 to 19-12-1962 are, at Tr. A 112-1, 32-2, 320-3, 96-4 and from 11-1-1962 to 26-3-1963, 80-1, 96-4 and at Tr. C. from 18-4-1962 to 19-12-1962, 112-4, 32-5. *G. locusta*, on the other hand occurs from Tr. C to right upto the sea. It is also found under the stones. Their average number is about 112-128 per square meter. Their no. is from 18-4-1962 to 19-12-1962, at Tr. C. 112-4, 32-5 and on 26-3-1963, 160-4, 96-5, at Tr. G from 25-4-1962 to 29-5-1963 80-1, at Tr. H 25-4-1962 to 27-12-1962, 96-1, 80-2, 32-3, 25-1-1963 to 29-3-1963, 96-1, 64-2, 16-3, and at Tr. I 25-4-1962 to 27-12-1962, 320-1, 224-3 and 25-1-1963 to 29-3-1963, 160-1, 128-3.

Corophium volutator (Pallas)

It usually lives in U-shaped tubes and is found burrowing in grayish mud of the estuary. Their average no. is from 18-4-1962 to 19-12-1962, at Tr. D 8-3, 112-5, from 25-4-1962 to 27-12-1962, at Tr. E 110-4, and Tr. F 80-2, 96-3, 160-4, 64-5. During the summer months it is often found moving on the surface but in winter it was always found in burrows. The tubes may be as deep as 3″ and are open at both ends. A careful survey of the ground reveals these openings as small apertures. These holes are slightly smaller than those of *Nereis*. The most suitable substratum seems to be soft gray sandy mud. It has never been found in black mud. This may be, as explained by Hart (1930), due to the presence of high organic contents.

Talitrus saltator (Montagu)

It is confined only from Tr. C to F at places which are touched by H.W.S.T. It is usually found amongst the roots of grass *e.g.*, *Plantago maritima*, where the high water salinity is 25‰. There is more of sand than mud at these places. It breeds during the month of July. Many young ones can be seen during the ensuing months.

Crangon vulgaris Linn.

This shrimp prefers sandy beds and fairly high salinity *i.e.* 15-33‰ and is a summer visitor to the estuary, often seen during the months of May to October. They were not recorded after October 1962, which may be explained due to their offshore migration during the colder months. They reappear in the estuary in late April or early May depending on the temperature conditions.

Carcinus maenas (Pennant)

This shore crab has been found from Traverse E to Ferry point, at all the places wherever there was a stone or some other object to provide it with shelter. They have been usually found burrowed between the tide marks. Their burrows may vary from 2″ to 4″, the larger forms preferring to live deeper. Specimens of very big size could not be found in this estuary. The largest crab caught had a carapace of 4 mm. length and smallest 1.5 mm. Juveniles of *Carcinus* have also been recorded all the year round at sts. 1 and 2 of Traverses G and H and near the Ferry point.

Balanus balanoides (Linn.)

This cirripede is found encrusting the stones from Traverse G to I and on the Stakeford bridge pillars where it is situated at high level.

MOLLUSCA

Cardium edule Linn.

This common cockle is plentiful in Tr. F and is found from 25-4-1962 to 29-3-1963, above 1″ size, 16-2, 48-3, 48-4 and below 1″ size, 48-2, 32-3, 64-4. The substratum is more or less a mixture of sand and mud up to 2″-3″ deep. The salinity at high water is above 30‰. Traverse F is its upper limit the lower being the Ferry point. Specimens of large size 3-4 mm. are found more near the surface on the right side of the estuary, near low water level and their number is about 16 in a square meter.

Mya arenaria Linn.

This bivalve has been found buried in two altogether different substrata, one is sandy gravel with little mud between Tram Pier and Ferry point at mid-tide level, and the other in muddy sand in Traverse E at station 3. But there is a notable difference between the sizes of shells of both these places. The former are almost double the size (8 mm.) of the latter (3 to 4 mm.). Their average no. p. sq. m., however, varies between 16-32 at both these places.

Scrobicularia plana (da Costa)

This mollusc, though has been described by Sponer and Moore (1940) as the common bivalve of the estuaries, is very much limited in its distribution in the estuary of river Wansbeck. Out of all the Traverses studied it could only be found at station 3 of Tr. G. It lies deep in the mud from 6″ to 13″. Their number 32-48 per sq. meter is also not very large even at this station. The salinity at high tide at this place is 30‰.

Mytilus edulis Linn.

Mytilus edulis, the common edible mussel, is very abundant at all places where there is stony surface for its attachment. Its largest number (500 per square meter) was found near the Tram Pier on the right hand side where it is spread into mussel

beds. At Tr. H. its no. is 112 p.sq.m. at station 2. It is found between mid-tide level and high water neap tide in Wansbeck.

The young ones of *M. edulis* have been seen from Tr. H to I in the months of July to September. It appears from the distribution of young ones that it breeds at intervals.

Macoma balthica Linn.

This bivalve prefers firm mud of black colour with a bit of mixture of sand. It is found from Tr. D to F. In other words it occurs both in estuarine as well as marine zones. The salinity at high tide at these places is above 25‰ but at low tide is 5‰ during dry months and 0‰ during rainy months. Its no. at Tr. D from 18-4-1962 to 19-12-1962 is, 32-2, 16-3 and 4 and from 25-4-1962 to 29-3-1963, at Tr. E, 16-1, 3 & 5, 48-4 and Tr. F 32-1, 16-2, 48-3, 64-4.

Hydrobia ulvae (Pennant)

This gastropod is found in a large number in the middle part of the estuary *i.e.*, D to F on the muddy surface. A few were found at Trs. A and C. At Tr. D from 18-4-1962 to 19-12-1962, 640-1, 320-3, 1600-5, 800-6 and from 25-4-1962 to 27-12-1962, at Tr. E 480-1, 1600-2, 900-3 and Tr. F 16-6-1962 to 17-10-1962, 400-1, 500-2, 480-3. Its maximum concentration is near the high water neap tide. The maximum number recorded in the estuary is 1600 per square meter during the summer months. It feeds on diatoms, which form green scum on the surface of mud. *Hydrobia* starts appearing on the surface of mud in the months of April, disappearing in November.

Littorina littorea Linn.

This edible Periwinkle is very common between mid tide level and high water neap from Traverse E to the mouth of the estuary. Its presence is clearly related to the presence of stones, with or without *Fucus vesiculosus*. From Ferry point, as we walk on the right side we find it constantly increasing in number up to Tram Pier, after which it goes on decreasing till it completely disappears above Tr. E.

TELEOSTEI

Gasterosteus aculeatus Linn.

This common stickleback is found both in fresh as well as in brackish waters. In the estuary of the river Wansbeck it was found in a large number from April to November between Traverses A and C. Very seldom it has been seen below the Railway bridge. It was noticed that *G. aculeatus* voraciously feeds on *Neomysis integer*. It can stand a wide range of salinity *i.e.*, 1-30‰. It has been observed that this fish moves offshore during winter.

Anguilla anguilla Linn.

Only the young ones of this fish have been caught from under the stones at low tide. At high tide they have been seen swimming near the surface between salinity stations 1 and 2. They have been caught only during the months of June to September.

Ammodytes lanceolatus Lesanvage

This is found in shoals between Tr. E and G in the right subchannel of the estuary. The bottom of this area is sandy. When an attempt was made to catch them they buried themselves in the sand.

Gobius minutus Pallas

This gobiid has been caught in Wansbeck between Tr. E and F during the months of June to September. This fish has also been described in Tamar estuary by Hartley (1940).

Platichthys flesus Linn.

Various sizes of this flounder have been observed in the estuary of river Wansbeck right from the Head to the Tram Pier (Tr. A to H). Young ones were caught in July-August in between Tr. E and F by a push net.

Pleuronectes platessa Linn.

This plaice is another flat fish that inhabits the Wansbeck estuary. But unlike *Platichthys flesus* it is confined to lower limits of the estuary.

AVES

Larus argentatus (Pallas)

In addition to 4 swans which were often seen swimming in the upper part of this estuary, large number of Herring gulls, *Larus argentatus*, visit the tidal and flats of this estuary at low tide. These flats provide a favourable feeding ground for them. These gulls were seen in their maximum numbers at Traverses D, E and F. They appear to feed on *Nereis diversicolor, Macoma balthica* and *Cardium edule.*

FLORA

Enteromorpha compressa Greville

This alga of the group chlorophyceae is present along with *Fucus vesiculosus* between Tr. H and I above the mid tide level and below mean high water neap. It is found in abundance from May to November.

Ulva lactuca Linn.

This is another alga of the group chlorophyceae and its habitat is more or less the same as that of *Enteromorpha compressa.* Its colour varies according to age, ranging from young greenish to old brownish.

Ascophyllum nodosum LeJol

Only a few specimens of this plant were noticed near Tram Pier at about high water tidal level. This like, *Enteromorpha compressa* and *Ulva lactuca* is inhabitant of marine zone. The reason for its small number can be attributed to the wave action near the mouth which is not very much favourable to it.

Fucus vesiculosus Linn.

This Fucoid is found on stones in a large number from Tr. G. to Ferry point, decreasing in number towards Tr. E and going no further up than E. It is found between high water neap and mid tide level and thus is subjected to exposure for a considerable time.

Fucus ceranoides Linn.

This is the only other species of *Fucus* that is found in the estuary of river Wansbeck. This is found just above and below Tr. C which is in brackish water zone.

Obione portulacoides (Linn.) Moq.

This small angiospermic shrub is found in large number on Castle island and at Tr. C and D. It shares the ground with *Plantago maritima.*

Plantago maritima Linn.

This angiospermic grass is commonly called 'Sea Plantain', and is found near high water spring tide mark. This is found in plenty on saltings from Tr. B to E on the right side and on left bank.

TABLE I

Showing Horizontal Distribution of Fauna and Flora

Fauna and Flora	Traverses								
	A	B	C	D	E	F	G	H	I
FAUNA									
Dugesia lugubris	—								
Polycelis nigra	—								
P. tenuis	—								
Nereis diversicolor		—	—	—	—	—	—	—	
Arenicola marina						—	—	—	
Jaera albifrons				—	—	—	—	—	—
J. nordmanni				—	—	—			
Sphaeroma rugicorda				—	—	—			
Gammarus locusta				—	—	—	—	—	—
G. duebeni	—	—	—						
Corophium volutator				—	—	—			
Talitrus saltator				—	—	—			
Carcinus maenas				—	—	—			
Balanus balanoides			—	—	—	—	—	—	—
Cardium edule						—	—	—	
Mya arenaria					—	—	—	—	
Scrobicularia plana						—	—		
Mytilus edulis						—	—		—
Macoma balthica				—	—	—			
Hydrobia ulvae				—	—	—			
Littorina littorea					—	—	—	—	—
FLORA									
Ascophyllum nodosum								—	—
Enteromorpha compressa								—	—
Fucus vesiculosus								—	—
F. ceranoides		—	—	—					
Ulva lactuca								—	—

Discussion

The earlier work (refer to introduction and literature cited), with the exception of Milne's (1940) on Aberdeenshire Dee and Capstick's (1957) on Blyth have been conducted on estuaries of great dimensions. Even these two (Dee and Blyth) are comparatively deeper as compared to Wansbeck.

Hydrography

The study of the hydrography of the estuary of river Wansbeck shows a few points of interest. For instance like other estuaries, with the exception of Severn (Bassindale, 1943a), this estuary has a vertical salinity gradient. In Wansbeck, as also in Tees, Tamar, Blyth and Tyne, the whole bulk of the water from the bottom to the surface is forced up the estuary by the flood tide but in Aberdeenshire Dee there is only an up estuary movement of the sub-surface water. The result of this is that fresh water flows on the surface right through even at high tide. This is a point of great interest because the estuary of river Wansbeck is almost of the same length as Aberdeenshire Dee but behaves like bigger estuaries. However, in winter during floods the fresh water does reach the sea, travelling on the surface, at high tide. Another important difference between Tamar, Blyth, Tees and Wansbeck on one hand and Aberdeenshire Dee on the other is that the surface salinity changes due to high and low water are much less in Dee *i.e.*, 3‰ than the other estuaries. At one point the surface salinity at low water has a difference with high water in Tees from 1-14‰, Tamar 2-14‰, Blyth 0-30‰ and Wansbeck 0-25‰. This again takes the estuary of river Wansbeck more near the longer estuaries than the smaller one like Aberdeenshire Dee.

Salinity and Biota

The broad divisions of estuarine faunas suggested by Day (1951) has been adopted here as it has been found more suitable for the estuaries than those of Ekman 1953) and other workers. Day (1951-pp. 86-87) divides an estuary into 4 hypothetical parts according to salinity conditions the head, upper reaches, middle reaches and the mouth. The estuary of river Wansbeck presents a little different pattern. Its salinity conditions are in agreement with Day's observations so far as the head and the mouth of the estuary are concerned but it is found difficult to divide the estuary in upper and middle reaches. This is because the salinity is very high (more than 25‰) at high tide right up to salinity station 3 but at low tide it is usually 5‰. Now if we divide this estuary purely on salinity conditions then the marine zone will extend right upto Tr. B but the presence of fauna from Tr. B to E contradicts this. The fauna is mostly estuarine from Tr. B to E. The only explanation for the presence of estuarine fauna seems to be the shorter duration of high salinity conditions at these places, which is due to the delayed entry of sea water at flood tide and quick flushing at low tide. It is, therefore, preferred to call it an estuarine zone rather than upper and middle reaches. Dividing the estuary of river Wansbeck on the basis of the distribution of fauna and flora as recorded by the present author and by others (in other estuaries) it may be summarized that Tr. A is a freshwater zone, from Tr. B to Tr. F is an estuarine zone and from Tr. E to Tr. I, it is a marine zone.

From the present investigations it has been found that Day's (1951 pp. 80-81) groupings of estuarine fauna also suits very well to the distribution of fauna in Wansbeck estuary.

A. The freshwater component.

Animals belonging to this group are restricted to fresh water or very low salinity (5‰) ; Tr. A is a very good example of this. Here we usually find *Asellus aquaticus, Dugesia lugubris, Polycelis nigra, P. tenuis, Jaera nordmanni, Gammarus duebeni,* water beetles and caddis larvae.

B. The stenohaline marine component.

This does not exist in Wansbeck because of the abnormal height of the mouth of the estuary.

C. The euryhaline marine component.

Traverses E, F, G and H are very good examples of this. One finds *Gammarus locusta, Jaera albifrons, Arenicola marina, Cardium edule, Mytilus edulis, Mya arenaria* and *Littorina littorea* in large number in these traverses. *Fucus vesiculosus, Ascophyllum nodosum* and *Ulva lactuca* are the plant that are found here.

D. The estuarine component.

It comprises a few species which are commonly restricted to estuaries and is represented by Traverses B, C and D. In these traverses we find *Corophium volutator, Gammarus duebeni, G. locusta, Jaera nordmanni, J. albifrons, Nereis diversicolor, Hydrobia ulvae.* Out of the plants we only find *Fucus ceranoides.*

E. The migratory component.

Neomysis integer, Crangon vulgaris, Gasterosteus aculeatus, Anguilla anguilla, Gobius minutus, Platichthys flesus, Pleuronectes platessa, Ammodytes lanceolatus.

It is noted that the animals inhabiting the estuaries have found various means to face the change in salinity conditions. The animals either have the capacity to osmoregulate (*Gammarus, Jaera,* and *Hydrobia*) or close themselves from the outer unfavourable conditions (*Mytilus* and *Balanus*) or burrow down in the mud (*Macoma, Cardium, Scrobicularia, Mya* and *Arenicola*).

The mud burrowing animals are quite at home in the mud because the salinity of the interstitial mud is always higher than the fresh water flowing over it at low tide and lower than the sea water at high tide and also because the salinity variations are less with the increasing depth (Reid 1930, 1932 ; Alexander et al. 1932, Nicol 1935, Smith 1956 and Capstick, 1957).

Correlation of the fauna with the type of substratum

Like salinity, substratum is also an important factor in controlling the distribution of the bottom fauna of the estuaries. Beanland (1940) and Holme (1949) have even gone into the detailed analysis of the different soils in relation to the fauna and showed that there was a close relation between the infauna and the grade of soil. Hereunder is given the list of fauna found in the estuary of river Wansbeck vis-a-vis the substratum :

1. Stony area—*Asellus, Jaera* and *Gammarus* are found under stones. *Mytilus, Balanus, Littorina* and plants are on the stones.
2. Thick mud—*Mya, Nereis, Macoma, Scrobicularia* and *Hydrobia.*
3. Muddy sand—*Corophium.*
4. Sandy mud—*Arenicola* and *Cardium.*

5. Thin mud—A few *Nereis* could be found. However, on the surface large number of *Hydrobia* were found.
6. Muddy sand gravel—*Carcinus, Mya* and *Arenicola.*
7. Pure sand—No macro-fauna was found in this.

This by no means is a rigid limit but only the optimum condition of substratum. Salinity becomes of secondary importance when we consider the wide range of salinities that the animals can tolerate.

With the exception of *Hydrobia Asellus, Jaera* and *Gammarus*, the present observations are in conformity with the findings of previous workers. *Hydrobia ulvae* has usually been recorded at places where *Zostera* grows in large numbers (Spooner and Moore, 1940). In Wansbeck, however, it is found only in muddy areas. This may be due to the absence of *Zostera* in this estuary. For *Asellus, Jaera* and *Gammarus* it is said that the substratum could possibly have no importance in their distribution. Spooner (1947) has gone as far as to say about *Gammarus* spp. that they are indifferent to the nature of substratum. The present observations have revealed that to these animals the under surface of the stone serves as a substratum. They have never been found from under the stones which lie on pure mud which means that pure mud is not liked by them. On the other hand they have been found in large number from under the stones, which were lying on semi-sandy muddy substratum more so with plants growing on them.

Summary

The results of the study of ecology of the fauna and flora of the estuary of river Wansbeck are presented in this paper and the distribution of these in relation to the salinity and substratum has been discussed.

The estuary of river Wansbeck is approximately three miles long. It is almost emptied at low tide, thus exposing large areas of intertidal mud. Horizontal surveys showed that the isohalines appear obliquely and the twelve hour cycle (studied during or near about summer and winter Solstice, and autumnal and Vernal Equinox) showed that it has a vertical salinity gradient and the quantity of the inflow of fresh water into the estuary during the period under study.

Distribution of the fauna and flora has revealed that (1) *Dugesia lugubris, Polycelis nigra, P. tenuis, Asellus aquaticus,* and *Gammarus duebeni* occupy fresh water zone ; (2) *Nereis diversicolor, Jaera albifrons, J. nordamnni, Gammarus locusta, Corophium volutator, Hydrobia ulvae, Macoma balthica* and *Fucus ceranoides* are found in estuarine zone ; (3) *Arenicola marina, Gammarus locusta, Jaera albifrons, Cardium edule, Mytilus edulis, Scrobicularia plana, Mya arenaria, Littorina littorea, Fucus vesiculosus, Ascophyllum nodosum, Enteromorpha compressa* and *Ulva lactuca* inhabit marine zone and, (4) some of the animals, *e.g. Nereis diversicolor, Jaera albifrons, Gammarus locusta,* and *Macoma balthica* occupy both the estuarine and marine zones.

The fauna was found rather scarce because of (1) an abnormal height of the estuary above sea level, (2) its short length, (3) shorter duration of the stay of sea water in the estuary, (4) too much exposure and, (5) wide range of salinity changes.

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