Helgoländer wiss. Meeresunters. 17, 216–223 (1968)

The fauna of a polluted shore in the Firth of Forth

JOHN C. SMYTH

Paisley College of Technology, Paisley, Renfrewshire, Scotland

KURZFASSUNG: **Die Fauna einer verunreinigten Küstenstrecke im Firth of Forth.** Bei einer Untersuchung der Küstenfauna an den Ufern in der Nähe der Stadt Edinburgh, die bis zu einem gewissen Grade von Kloakenwasser-Verunreinigung betroffen ist, wurde festgestellt, daß eine Strecke von ungefähr 1½ km westlich des Hafens von Granton bemerkenswert arm an Arten ist. Dies scheint in Beziehung zu stehen zur Bewegung der Abwässer auf diese Küste hin während der Flutzeit; sie wird durch lokale Strömungen hervorgerufen. Die Untersuchungen beschränken sich hauptsächlich auf Organismen, die auf einer Reihe von Sandsteinklippen leben, welche voneinander durch Strecken von Schlick oder schlammigem Sand getrennt sind. Die am häufigsten vorkommenden Tiere sind – genau wie an den benachbarten Strecken der Küste – Balaniden, *Mytilus edulis* und *Littorina littorea.* Größere Algen sind verhältnismäßig selten, doch treten Grünalgen zahlreicher auf als in den anliegenden Gebieten. Wie an anderen verunreinigten Fundorten weist die Fauna eine Verringerung an Arten, zugleich jedoch eine sehr große Individuenzahl an widerstandsfähigen Arten auf. Vergleiche, die zwischen diesen Klippen und anderen ähnlichen Fundorten östlich und westlich davon angestellt wurden, zeigen, daß mehrere häufig auftretende Spezies in diesem Gebiet selten oder gar nicht vorhanden sind, darunter *Halichondria panicea, Actinia equina, Pomatoceros triqueter, Patella vulgata, Thais lapillus,* und gewisse Polyzoen. *Fabricia sabella, Polydora ciliata* und andere mit ihnen assoziierten Tiere sind weit verbreitet, scheinen aber nur in schlickigen Substraten in dichten Beständen vorzukommen.

INTRODUCTION

The boundaries of the City of Edinburgh enclose some fifteen kilometres of coastline on the southern shore of the Firth of Forth. All of it is to some degree polluted by domestic and industrial wastes, discharged untreated mostly below low water mark. Both the flora and fauna are notably poorer in species than those of unpolluted shores elsewhere in the Firth.

During a survey of the fauna, it became evident that a stretch of shore extending approximately one and a half kilometres to the west of Granton Harbour was even poorer in species than similar neighbouring areas, although some animals were abundant. This appeared to be related to an onshore movement of effluents from the Caroline Park and Granton Gas Works sewers which occurred during flood tides, making the shore noticeably dirtier than adjacent areas. The situation thus seemed to provide an opportunity for investigating effects of pollution on a marine littoral fauna.

It was also thought that an investigation might help to identify faunal indicators of polluted shores. Much less is known of the species indicative of pollution intensity in marine habitats than in freshwater, and with the wider variety of species and habitats the difficulties are likely to be greater. Nevertheless, the accessibility of the shore to the investigator and its special importance as a public amenity seem to make further investigation worthwhile in spite of the difficulties.

RESULTS

The stretch of shore which was studied is relatively sheltered and consists of mud or muddy sand crossed by a series of sandstone outcrops extending below low water mark. Beyond the westernmost of these the sand extends to Cramond Island, a

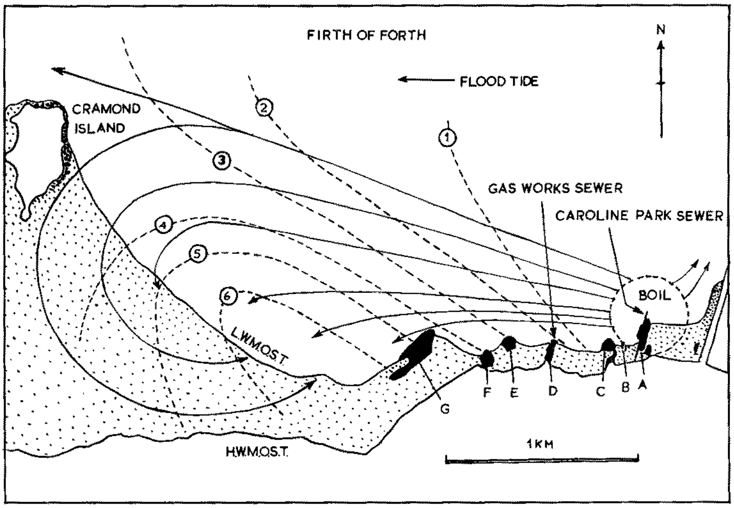

Fig. 1: Map of the shore west of Granton Harbour showing stations A–G and Cramond Island. Solid lines show movement of surface pollution; broken lines show extent of slick in hours after low tide, in average conditions. (Re-drawn from Lothians River Purification Board 1967)

teschenite outcrop connected to the mainland only during low water. The present study was largely confined to the fauna of the rock surfaces, and a similar rocky shore at Trinity about 1½ km to the east was also used for comparison.

The movement of sewage in surface waters over this shore has been studied by the staff of the LOTHIANS RIVER PURIFICATION BOARD (1967) and the results of float tests are incorporated in Figure 1. During the flood tide, westward-moving tidal currents are swung shorewards by the shelving coastline and carry sewage onto the shore, as indicated. Effluent from a sewer off Cramond Island crosses the area on the ebb tide but does not appear to affect the shore except with a northerly wind. Effluent from another sewer about $1^1/_2$ km to the east does, however, reach the area during the latter part of the flood tide and increases the pollution.

Algal vegetation is relatively poor. A sparse growth of *Fucus vesiculosus* is present on some rocks and *F. serratus* is better developed but still uneven. This contrasts with Cramond Island where a full series of fucoid algae is found. To the east, however, fucoids are also relatively sparse. *Gigartina stellata* occurs in patches at lower levels of rocks and under *Fucus; Porphyra umbilicalis* is common, especially with mussels. Green algae, particularly *Ulva lactuca* and *Enteromorpha* spp., are more evident on this stretch of shore than on adjacent ones to the east, a feature which might be related to the "fertilizing" effect of sewage (FØYN 1965). On some rock surfaces, particularly damp and sheltered rocks on the upper shore and in places associated with *Fucus,* a felt layer is formed by various small algae, including *Rhodochorton rothii* and *Enteromorpha,* which provides an important habitat for small animals.

The most conspicuous members of the shore fauna are *Mytilus edulis,* balanids and the spionid worm *Polydora ciliata. Mytilus* occurs in characteristic beds and in damper cracks of the steeper rocks. *Balanus balanoides,* with occasional patches of *Elminius modestus,* and *B. crenatus* at low levels on the shore, are found on all the reefs and dominate most of those not covered by mussels or *Polydora.* Large numbers of *Littorina littorea* are found everywhere except where *Polydora* is dominant or on some rocks where the growth of fucoids is denser. *Polydora ciliata* forms dense mats on low-level rocks and on sheltered parts of the middle shore.

Intervening mud and sand faunas include vast numbers of nematode worms in the muddier parts close to the sewer; high densities of *Scolelepis fuliginosa* also occur in this region. The cleaner sand towards Cramond Island contains a rather sparse population including *Tellina tenuis* and *T. fabula, Nephtys hombergi* and *Spio filicornis,* with *Cerastoderma edule, Macoma balthica* and *Pygospio elegans* in muddier patches.

All these animals are abundant in comparable habitats to the west and to the

Table 1

Larger invertebrates recorded regularly on similar shores from the Edinburgh shore as a whole and from the Granton shore

Animal groups	Number of species taken regularly within city boundaries	Number of species taken regularly on Granton shore	Percentage scarce or absent at Granton
Porifera	6	1	83
Coelenterata	13	4	69
Polychaeta	32	13	60
Crustacea	18	8	56
Mollusca	32	8	75
Polyzoa	10	4	60
Echinodermata	5	1	80
Tunicata	4	1	75
Total	120	40	67

east, although not always in such densities. Many other animals found regularly elsewhere are very scarce on this stretch. Table 1 is compiled from records of 120 species of littoral animals found regularly over a period of five years within the city boundaries.

Further observations were made of the distribution of a more limited number of animals along the Granton shore. For this purpose the reefs were lettered A–G (from east to west) and the shores at Trinity and Cramond Island added for comparison. At A and C the rocks are relatively steep and covered with balanids; the Caroline Park sewer runs over A to below low water mark. At B the rocks are lower and largely confined to the region below mid-tidal level. The Granton Gas Works sewer runs down D and some of its effluent escapes through cracks in the pipe above low water mark; these rocks are again steeper. Rocks E and G are low-lying and largely covered by dense mussel beds, while F is steeper and carries a mixture of *Mytilus* and fucoid algae. Mussel beds are a major feature of the shore at Trinity to the east, and fringe the lower shore at Cramond Island where there are also large boulders and a good growth of fucoid algae.

The animals selected for this study were sedentary or sessile species sufficiently prominent to be seen and identified without special searching during a walk across the rocks. Several visits were paid to each reef during low water and the results summarized in Table 2. Animals were scored 1 to 4 as follows: (4) Abundant; dominant in suitable situations. (3) Common; visible in suitable places at a glance. (2) Scattered; only a few seen, some searching needed. (1) Occasional; only one or two seen, possibly casual.

All the animals shown in the table were scored 3 in at least one locality. Other animals found regularly at Trinity and Cramond Island but scarce or absent in-between include *Tealia felina, Pagurus bernhardus, Gibbula cineraria, Littorina*

Table 2

Distribution of selected invertebrates between Cramond Island and Trinity
(See text for explanation of figures)

Station	Cramond Island	G	F	E	D	C	B	A	Trinity
Halichondria panicea	3	2	–	–	–	–	–	–	3
Dynamena pumila	3	–	2	–	–	–	1	–	3
Laomedea flexuosa	3	3	3	4	3	4	3	4	3
Actinia equina	3	1	1	–	–	–	–	–	3
Polydora ciliata "mat"	2	2	2	2	4	4	4	4	2
Pomatoceros triqueter	2	–	2	–	–	–	–	–	3
Balanus spp.	4	4	4	4	4	4	3	4	4
Patella vulgata	3	3	–	2	–	–	1	2	3
Littorina littorea	3	4	3	4	1	4	2	4	4
Buccinum undatum	2	3	–	–	–	–	–	–	3
Thais lapillus	3	–	–	–	–	–	–	–	3
Mytilus edulis	4	4	4	4	3	4	3	4	4
Alcyonidium polyoum	2	–	–	–	–	–	–	2	3
Total present	13	9	8	6	5	5	7	7	13

obtusata, Flustrellidra hispida, Asterias rubens, Dendrodoa grossularia and *Botryllus schlosseri.*

A striking feature of the Granton shore in comparison with neighbouring areas is the success of mat-forming organisms, which are far more numerous there. The most abundant are *Fabricia sabella* and *Polydora ciliata. Fabricia* occurs higher on the shore than *Polydora,* especially in the algal felt already referred to, but is found on similar surfaces on the lower shore and intermingling in many places with *Polydora. Polydora* is the dominant organism on rock surfaces near low water and on the more sheltered surfaces up to approximately mid-tidal level. Both also occur among balanids on muddier surfaces, where they do not form a mat but are still numerous.

Mat formations were sampled by means of a cork borer which removed a core from approximately 2.54 cm^2 of rock surface.

The *Polydora* mat is a dominant feature of the lower shore on reefs A–D where it covers the upper surfaces and sides of rocks, boulders and stable stones. It may be over 3 cm thick, although less than this is more usual. When thick, the mat appears to smother balanids and small algae. The elimination of the latter can make the mat less stable so that patches of it are more readily washed away. Where the mat is well developed the density of worms (irrespective of the thickness of the mat) averages 2,600 per 100 cm^2. Maxima are in the order of 5,500 representing a wet weight of approximately 6 gm per 100 cm^2. The mat appears to remain generally stable throughout the year. Higher on the shore it becomes more restricted to sheltered surfaces, particularly those facing west; this may be related to the fact that the lowest tides occur in the morning, resulting in maximum exposure on south-east-facing surfaces.

Fabricia is much more variable in density of colonization. The maximum recorded on this shore was approximately 11,500 per 100 cm^2, in an algal felt, but much lower figures are more usual. In places where it mingles with *Polydora* it shows a marked preference for the upper parts of reefs and boulders where, for example, up to 5,000 per 100 cm^2 may be found along with similar numbers of *Polydora.* A few centimetres lower on the same vertical face, with no obvious change in the appearance of the mat, the numbers of *Fabricia* may drop below 10 per 100 cm^2.

Apart from *Fabricia,* the mat also contains variable numbers of *Clitellio arenarius* and nematodes. *Phyllodoce maculata* and *Eteone longa* are often present, the latter seemingly favouring the more exposed surfaces. Amphipods are often present in relatively small numbers. Harpacticoid copepods, halacarid mites and dipteran larvae also occur regularly, especially where algae are growing.

These mat formations do not extend to the undersides of crevices, boulders and stones, although *Fabricia* may be frequent along with other animals. Here a more varied fauna develops, even in the muddiest areas, provided water circulates beneath the surfaces. The hydroid *Laomedea flexuosa* becomes a dominant organism, its dense growths sometimes covered with a further growth of colonial ciliate protozoans. The polyzoan *Bowerbankia gracilis* may form a continuous carpet, with occasional tufts of *B. imbricata.* Others regularly present include *Electra pilosa, Balanus crenatus, Phyllodoce maculata, Sagartia troglodytes* and, in places, *Ascidiella scabra.*

These animals all occur commonly in similar situations elsewhere on the coastline, but the distribution of mat-forming organisms becomes more restricted. Although

Polydora still occurs in smaller numbers to the west of reef D, mat formation is found only in sheltered corners of the lower shore and it does not generally appear to compete successfully with other sessile organisms. The same is true of shores to the east, although patches have been found in muddy corners of quite unpolluted shores at the mouth of the Firth.

DISCUSSION

The fauna of the Granton shore clearly exhibits two features which have been widely recognized as characteristic of moderately polluted conditions. These are, a reduction in the number of species present by the elimination of intolerant species, and an increase in the number of individuals of species tolerant of the conditions (see, for example, BLEGVAD 1932, FILICE 1954, 1959).

The reduction in number of species is evident from comparisons between rock faunas within the study area (Table 2). This becomes more obvious when boundaries are extended eastwards to include the whole shore of the City (Table 1), and could be extended further by comparison with shores at South Queensferry to the west and cleaner shores to the east approaching the mouth of the Firth.

Assessment of the degree of pollution could be made here not so much by the presence of indicator species as by the scarcity or absence of species whose presence would otherwise be expected. This of course requires a reliable estimate to be made of the "normal" fauna. On the Granton shore the scarcity or absence of, for example, *Pomatoceros triqueter, Patella vulgata* and *Thais lapillus,* which are very common on adjacent shores, is probably significant. Observations made elsewhere on the Firth of Forth coastline tend to confirm that their distribution may be a useful guide to pollution. The distribution of polyzoans might also be a productive study from this point of view.

The growth of the *Polydora* population into an exclusive mat formation is a striking example of increase in the number of individuals of a tolerant species. The fauna of which it is a part resembles one described by SMIDT (1944) in Copenhagen harbour, where also *Polydora* became dominant in places. FULLER (1946) described *Polydora* mats of similar thickness to the Granton ones developing on the upper surfaces of experimental plates and eliminating other sessile organisms. Similar mat formations produced by different organisms occur in other similar localities. For example, thick mats produced solely by *Fabricia* and small algae have been found on the lower shore in parts of the Clyde estuary, and D. B. LEWIS (personal communication) has studied similar mats on the Northumberland coast. BARNARD (1958) described mats formed mainly by several species of amphipods although a species of *Polydora* was also abundant. Thus it seems that the development of such mats may be characteristic of some types of pollution. The frequent presence within the mats of *Capitella capitata,* a recognized indicator of pollution (e. g. REISH 1959), is also noteworthy.

The main value of faunal composition as an indicator of pollution is that it represents the product of all the factors which have influenced it during the life-time of its component members. To identify the separate effects of these factors much more information would be needed than is now available on the chemical and physical properties of the water and a more detailed knowledge of their effects on the different animals. Some contribution to this may come from studies which have been commenced on the mat-forming animals. Present indications are that salinity, which is usually in the range 28 to 33 ‰, does not account for differences between Granton and adjacent shores, nor apparently does oxygen saturation since Granton and Trinity shores seem to be similar in this respect also. Industrial discharges from the Gas Works sewer may have a local toxic effect: where it spills over reef D there is a bare area but *Balanus* and green algae survive on the edge of it and *Polydora* flourishes nearby.

Suspended matter in the water appears to be the main influence on the fauna. Its density is greatest in the parts where the species composition of the fauna is poorest. Many animals, especially filter-feeders, are probably excluded through inability to keep gills or other surfaces sufficiently free of particles. Others may be excluded indirectly through the competitive advantages conferred by the suspended matter on the mat-forming animals.

The sediment consists of both organic matter and silt. Both of these are used by *Polydora* and *Fabricia*, the organic matter as a source of food and the silt for tube-building. *Polydora* is constantly adding to its tube to maintain its opening at the surface of the mat, and where suspended matter is dense this gives rise to the thick mats particularly common on the lowest parts of the shore where exposure to the sediment is most prolonged. BARNARD (1958) similarly relates the development of amphipod mats to turbidity.

What other factors besides turbidity may affect the distribution of animals on the Granton shore is still largely undetermined. The absence of animals such as *Thais* and *Pomatoceros*, the scarcity of *Patella* and the development of the *Polydora* mat all appear, however, to be related to sewage discharges, and the ease with which the distribution of such animals can be assessed at least justifies the extension of observations to other localities.

SUMMARY

1. During a survey of the Edinburgh shore fauna it was found that on one stretch, similar to neighbouring areas in the habitats available, there occurred only about 33 % of the larger invertebrates found regularly elsewhere. This can be related to the onshore movement of sewage by local currents to a greater degree than in neighbouring areas.
2. A more detailed survey of selected common animals and rock surfaces made by a simple method which avoids detailed searching and sampling, has shown that several animals which would normally be present are scarce or absent. These include *Actinia equina*, *Pomatoceros triqueter*, *Patella vulgata* and *Thais lapillus*.
3. *Balanus* spp., *Mytilus edulis* and *Littorina littorea* are common in most suitable places, but the lower shore is dominated by dense populations of *Polydora ciliata* forming in some places a thick mat of tubes which excludes many other sessile organisms. This mat blends with, and on higher rocks is replaced by, a mat of small

algae with *Fabricia sabella* also present in high densities. Both of these mat-forming worms also occur among barnacles and *Fabricia* is common in the more varied association living under stones and boulders not bedded in mud.

4. The density of suspended matter in the water is thought to be the main factor causing the scarcity of some animals and the abundance of others, notably the mat-forming species. The effect may be direct, e. g. on feeding and respiratory mechanisms, or by provision of food and tube-building materials, or it may be indirect through its influence on other species.
5. The absence of certain common species and the abundance of mat-forming organisms are regarded as possible indicators of the degree of shore pollution.

Acknowledgements: I am grateful to Mr. R. W. COVILL and his staff of the Lothians River Purification Board for helpful discussion, data and permission to use the map in their report, to Dr. J. D. GEORGE for confirming two identifications, and to Miss A. E. GILLIES for carrying out most of the work of treating and sorting samples.

LITERATURE CITED

BARNARD, J. L., 1958. Amphipod crustaceans as fouling organisms in Los Angeles-Long Beach Harbors, with reference to the influence of seawater turbidity. *Calif. Fish Game* **44**, 161–170.

BLEGVAD, H., 1932. Investigations of the bottom fauna at outfalls of drains in the Sound. *Rep. Dan. biol. Stn.* **37**, 1–120.

FILICE, F. P., 1954. An ecological survey of the Castro Creek area in San Pablo Bay. *Wasmann J. Biol.* **12**, 1–24.

— 1959. The effect of wastes on the distribution of bottom invertebrates in the San Francisco Bay Estuary. *Wasmann J. Biol.* **17**, 1–17.

FULLER, J. L., 1946. Season of attachment and growth of sedentary marine organisms at Lamoine, Maine. *Ecology* **27**, 150–158.

FØYN, E., 1965. Disposal of waste in the marine environment and the pollution of the sea. *Oceanogr. mar. Biol. A. Rev.* **3**, 95–114.

LOTHIANS RIVER PURIFICATION BOARD, 1967. Annual Report for the year ended 15th May 1966. City Chambers, Edinburgh, 26 pp. *(Rep. Lothians River Purif. Bd)*

REISH, D. J., 1959. An ecological study of pollution in Los Angeles-Long Beach Harbors, California. *Occ. Pap. Allan Hancock Fdn* **22**, 1–119.

SMIDT, E. L. B., 1944. Biological studies of the invertebrate fauna of the harbour of Copenhagen. *Vidensk. Meddr fra dansk naturh. Foren.* **107**, 235–316.