WATER QUALITY IN THE FORTH ESTUARY

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The Forth estuary extends approximately 55 km from the tidal limit at Stirling to the Rail Bridge at Queensferry. It is narrow and winding from Stirling to Kincardine then widens and straightens between Kincardine and Queensferry. The varied topography provides a range of habitats which host a variety of wildlife, ranging from saltmarshes in the upper estuary to mudflats in the lower estuary.

The estuary has been used for centuries by man for food, transport and the disposal of waste. In the mid 20th century uncontrolled disposal of waste into the estuary led to the degradation of water quality which threatened wildlife. By the middle of the 20th century the salmon and sea trout fishery in the estuary was in danger of being wiped out by extensive mortalities of smolts and adult fish (Collett, 1972).

The introduction of the Control of Pollution Act in 1974 helped the regulatory agencies to impose standards on waste water discharges to reduce pollution and further legislation (e.g. the Urban Waste Water Treatment Directive 91/271/EEC) tightened these standards. The introduction of the Water Framework Directive (200/60/EC) in 2000 widened the focus of environmental legislation from protecting water quality to encompass the protection of wildlife. The ultimate aim of the Water Framework Directive (WFD) is achieving at least 'Good Ecological Status'. Good Ecological Status is described as a low level of disturbance to the ecosystem resulting from man's activities compared to undisturbed conditions. Unlike previous legislation the WFD takes account of the impact on wildlife of the physical modification of the estuary in addition to water quality.

The WFD classifies water bodies into five classes: High, Good, Moderate, Poor and Bad. The classification is based on measurements of water quality and various aspects of ecology including assessments of phytoplankton, macroalgae, fish and benthic invertebrates. The overall class defaults to the lowest class for each measurement.

Under the Water Framework Directive the Forth estuary is sub divided into three water bodies (Figure 1) which are based on their physical, ecological and chemical differences:

1) The upper estuary extends from the tidal limit at Stirling to Kincardine Bridge. This section of the estuary is predominantly narrow and meandering. Salinity is relatively low as a result of freshwater input from the rivers Forth, Teith, Allan, Devon and Black Devon. Much of the shore

line of the upper estuary has been claimed for agricultural land with a subsequent loss of the natural saltmarsh habitat.

2) The middle estuary extends from Kincardine Bridge to a line between Carriden and the eastern edge of Torry Bay. The estuary is wider and straighter here and the water is more saline although there are freshwater inputs from the Rivers Carron and Avon at Grangemouth. The middle estuary is fringed with mudflats, which are important feeding grounds for fish and wading birds. However, much of the intertidal land in the middle estuary has been lost to industrial land claim at Bo'ness, Grangemouth and Longannet. Intertidal land has also been lost to agriculture, especially along the banks of the Carron and Skinflats mudflats (Figure 1).

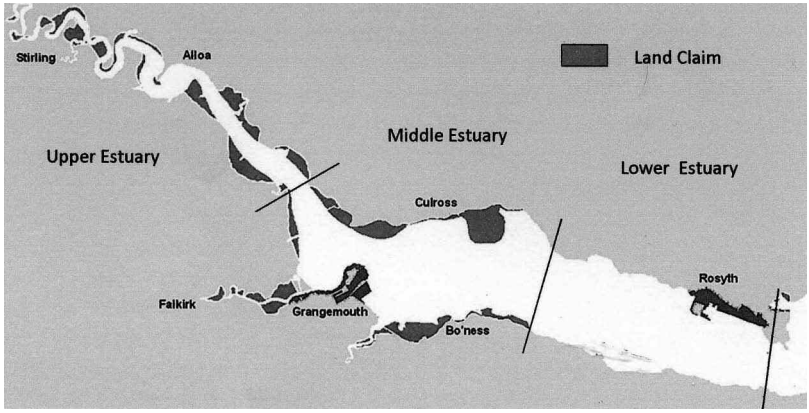

Figure 1. Assessment and land claim areas (dark grey) along the Forth estuary.

3) The lower estuary extends from the middle estuary to the seaward limit just downstream of the rail bridge at Queensferry. This part of the estuary is wide and deep with a strong marine influence. The shoreline has been modified by ports and the large harbour at Rosyth.

The loss of natural habitat in both the upper and middle estuary means that they are designated as heavily modified. Heavily modified water bodies cannot reach Good Ecological Status, therefore the aim is for them to reach Good Ecological Potential. The lower estuary is less impacted by land claim so it can be expected to achieve Good Ecological Status.

The upper Forth estuary is currently classed as Poor Ecological Potential due low dissolved oxygen concentrations which develop during the summer months when the water is warm and freshwater input is low. Lowest dissolved oxygen concentrations typically occur on Spring tides when there are high levels of suspended particulate matter in the water. The high levels of

suspended particulate matter result from turbulent mixing between the flooding tide and freshwater flow in the narrow upper estuary. This mixing causes the muddy bed of the estuary to be mixed into the water column. This zone of muddy water, called the turbidity maximum, extends for 10 km and moves up and down the estuary from Stirling to Kincardine with the tide. Oxygen entering the estuary from the rivers is consumed by bacteria attached to the particulate matter as they metabolise organic matter. As a result water passing through the turbidity maximum becomes increasingly depleted in oxygen resulting in the characteristic oxygen sag.

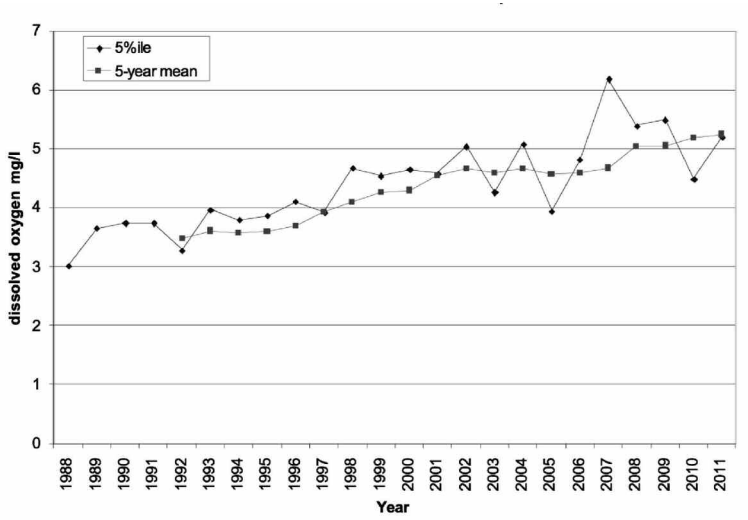

Figure 2. Long term trend in dissolved oxygen (mg/l) in the upper Forth estuary, 1988-2011. The 5 percentile is the value exceeded by 95 percent of the data. It represents the lowest values recorded.

Dissolved oxygen has been monitored at 30 minute intervals throughout the year by in situ monitoring equipment since 1988. The 5 percentile value of this data has increased from 3 mg/l to 5 mg/l although there has been substantial interannual variation in recent years (Figure 2). This interannual variation is a result of changes in climate, dissolved oxygen concentrations are higher in wet summers as the supply of oxygen is increased by higher river flows. The 5 year mean of this data smooths out the interannual variation.

Oxygen is also removed from the water by the decomposition of organic waste discharged to the estuary. The oxygen consumed by organic waste is estimated from the biological oxygen demand (BOD) of the discharges. The BOD is defined as the oxygen removed from a waste water sample incubated at 20°C for 5 days. Dissolved oxygen concentrations in the upper estuary have

increased (Figure 2) as the BOD of waste water discharges to the estuary have decreased (Figure 3).

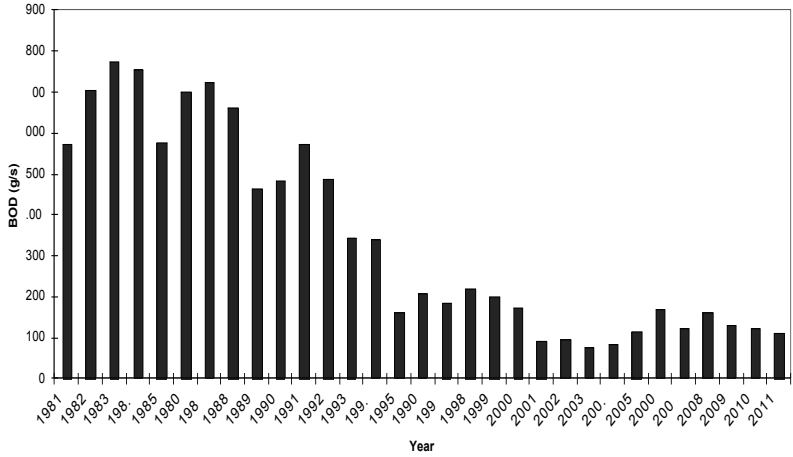

Figure 3. Long term trend in average BOD g/s (Biological Oxygen Demand) of inputs to the Forth estuary from 1981 to 2011.

Despite the reduction in discharges of organic waste, the upper estuary has not achieved good ecological potential because there are sufficient organic residues present in the turbidity maximum to continue to consume oxygen. However, as water quality has improved the number of fish found in the estuary has increased (Figure 4). The return of the sparling to the estuary in 1989 was a significant indicator of the improvement in water quality because it is an oxygen sensitive fish which lives in the estuary and migrates to freshwater to spawn (Maitland, 2010).

The middle Forth estuary is classed as Moderate Ecological Potential. Although water quality in the middle estuary is good, the benthic invertebrate population of the subtidal sediments is impacted by historical discharges of industrial waste. The sediments of the middle Forth estuary were contaminated by a discharge of mercury in the 1970s. This was substantially reduced in 1985 and has now ceased however it was estimated that 90 % of the mercury discharged was retained in the sediments. Mercury binds to organic matter in preference to remaining in solution so the concentration of dissolved mercury was always relatively low, despite the volume of the discharge. Annual monitoring of mercury in sediments, fish and mussels show that the concentrations have decreased, however they are still elevated compared to background levels (Figure 5).

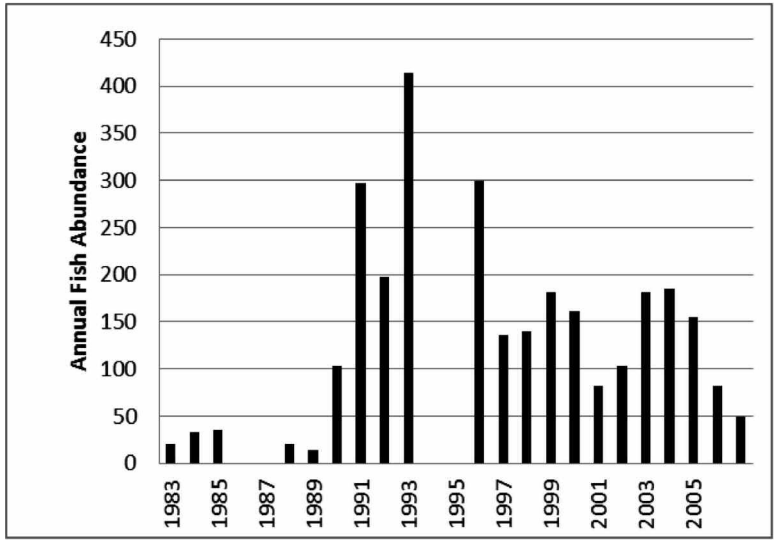

Figure 4. Annual fish abundance (number of fish caught in beam trawls) in the upper Forth estuary 1983 to 2007 of the eight most common species. These in approximate order of abundance are: flounder, goby, sprat, smelt, place, herring, whiting, cod. Data have been normalised for number of trawls per year. Surveys were not carried out in years 1986-7 and 1994-5.

The benthic invertebrate population of subtidal sediments of the middle Forth estuary are showing recovery from pollution following the Species-Abundance-Biomass model of macrobenthic succession described by Pearson and Rosenberg (1978). Sediments impacted by pollution are populated by a high abundance of opportunistic species, typically oligocheate worms. As the sediments recover these opportunistic species are replaced by a variety of larger longer lived species so the abundance drops but the number of species and biomass increases. The benthic invertebrate population in the middle Forth estuary is at different stages of recovery depending on the distance from discharge sites. The sites closest to the discharges are still more impacted than the sites furthest from them.

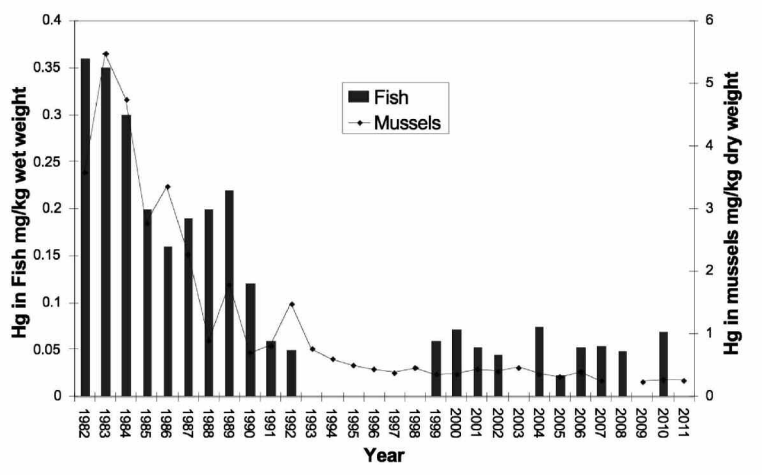

Figure 5. Long term trends in mercury in fish and mussels from the middle Forth estuary.

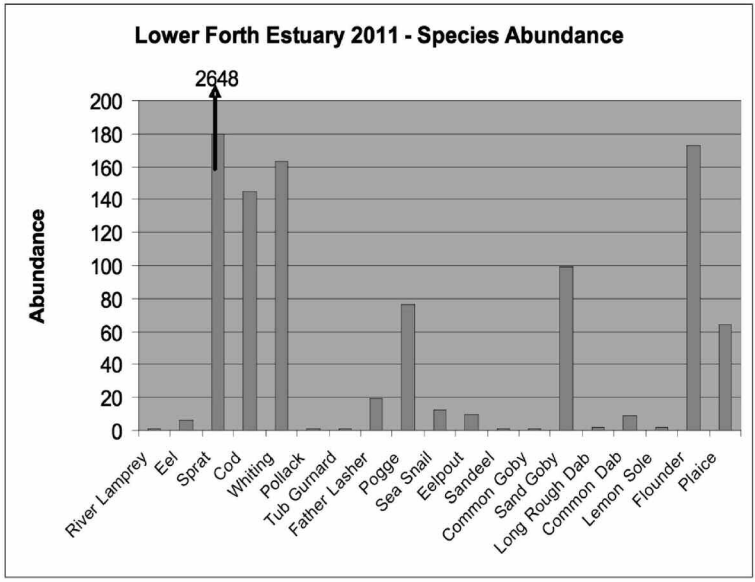

Figure 6. Species and number of fish caught in the lower Forth estuary in 2011.

The lower Forth estuary, which extends from the middle Forth estuary to the estuarine limit just downstream of the rail bridge, is Good Ecological Status. This water body is less influenced by freshwater input and is more marine in nature. Water quality is good and the benthic invertebrate population is less impacted by discharges than in the middle estuary. Fish population studies have revealed that the lower Forth estuary supports a good variety of fish with representatives from different functional groups and feeding guilds (Figure 6).

Summary:

- The upper and middle Forth estuary from Stirling to Torry Bay cannot achieve Good Ecological Status as defined by the Water Framework Directive because the shoreline has been extensively modified by agricultural and industrial land claim. The best that can be achieved is Good Ecological Potential.

- Currently the upper estuary is classified as Poor Ecological Potential. The efforts to control waste discharge have had a beneficial effect on the dissolved oxygen concentrations but there is still sufficient organic matter in the river bed to produce an depletion of oxygen particularly when the turbidity increases during the summer spring tides.

- The middle estuary from Kincardine Bridge to Torry Bay is classified as Moderate Ecological Potential but is still impacted by historical discharges of mercury. The subtidal benthic invertebrate populations are at different stages of recovery dependent on their distance from discharge sites.

- The lower estuary from Torry Bay to downstream of the rail bridge is classified as Good Ecological Status and supports a variety of fish.

References

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