IAEA-SM-354/70

AN INTERGRATED STRATEGY FOR BIOLOGICAL EFFECTS MONITORING IN SCOTTISH COASTAL WATERS

PARK R. A., J. DOBSON, L. RICHARDSON, A. HILL
Scottish Environment Protection Agency, East Region, Edinburgh, Scotland, UK

Abstract

The paper summarises SEPA's current programme of water quality and biological effects monitoring and, using recent examples, discusses the current environmental issues affecting the condition of our coastal waters.

1. INTRODUCTION

The Scottish Environment Protection Agency (SEPA) is one of the main administrative bodies charged with statutory responsibility for protecting Scotland's natural environment. SEPA's principal aim is an efficient and integrated environmental protection system for Scotland which will both improve the environment and contribute to the British Government's aim of sustainable development. This is provided mainly by careful regulation of emissions to the atmosphere and aquatic environment, the management and disposal of wastes and the control of radioactive substances. Our statutory powers stem from the Environment Act 1995, a range of EC Directives and other internationally agreed obligations.

An example of SEPA's integrated approach to environmental protection is seen in the monitoring and research carried out in the tidal waters of south eastern Scotland (Fig. 1). Tidal Waters Section is a team of scientists with expertise in marine chemistry, oceanography, modelling and marine biology. The monitoring programme is achieved using a vessel " Forth Ranger", surveying most of the controlled waters of south eastern Scotland. This comprises a 600km length of coastline to a three mile limit which represents 4.5% of the total coastline of Scotland and 2.8% of that of Great Britain.

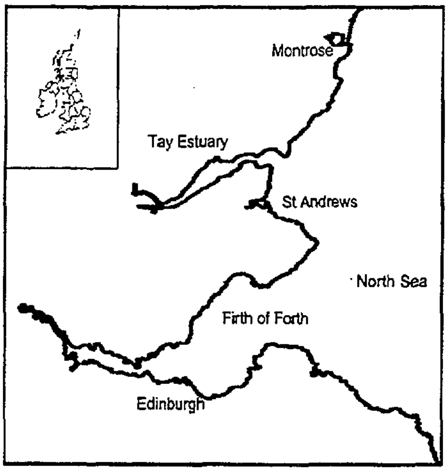

Figure 1. Map of south eastern Scotland in relation to the UK

2. BIO-DIVERSITY AND BIOLOGICAL EFFECTS

The measurement of biodiversity and habitat diversity play a central role in SEPA's assessment of environmental quality, evaluating the quality of the environment. An integrated approach to biological monitoring studies most of the key habitats and biological communities, including pelagic and demersal fish, plankton, benthic micro- and macro-algae, subtidal and intertidal macro- and meio-fauna.

2.1 Fish Communities

The fish community studies of the Forth estuary have produced one of the best and most valuable datasets for any European estuary. Since 1979 the pelagic and demersal fish populations have been monitored in detail in relation to feeding relationships [1] effects of habitat loss [2] changes in relation to water quality [3] and the importance of the estuary as an overwintering and nursery area [4]. Fish monitoring is designed to determine the effects of general water quality, persistent pollutants and the degree of food-web and habitat perturbation. SEPA currently uses a variety of trawling (benthic and pelagic) methods alongside routine examination of fish captured on the intake screens of a power station to estimate fish abundance and community structure in the Forth.

SEPA's monitoring of both fish and water chemistry in the upper Forth estuary exemplifies our integrated approach to environmental studies. In the upper Forth estuary (Fig. 7) a well documented [5] dissolved oxygen minimum develops during the summer (June-September) months when water temperatures are relatively high and river flows are generally at a minimum. The depletion of dissolved oxygen (DO) in the water column results from the degradation of organic matter, derived from both natural and anthropogenic inputs (e.g. sewage effluent) resulting in a high biochemical oxygen demand (BOD). Fig. 2 shows how an area of high suspended solids concentration develops in the upper reaches of the estuary (upstream of the freshwater/saltwater interface). Organic degradation is enhanced in this turbidity maximum leading to a sag in dissolved oxygen levels within a defined area of the estuary (Fig. 3). When concentration falls to less than 5.5 mg/l DO, the resident and migratory estuarine fish can be affected. The fish are therefore monitored throughout the summer months to estimate diversity and abundance and determine their distribution is compared with observations in previous years.

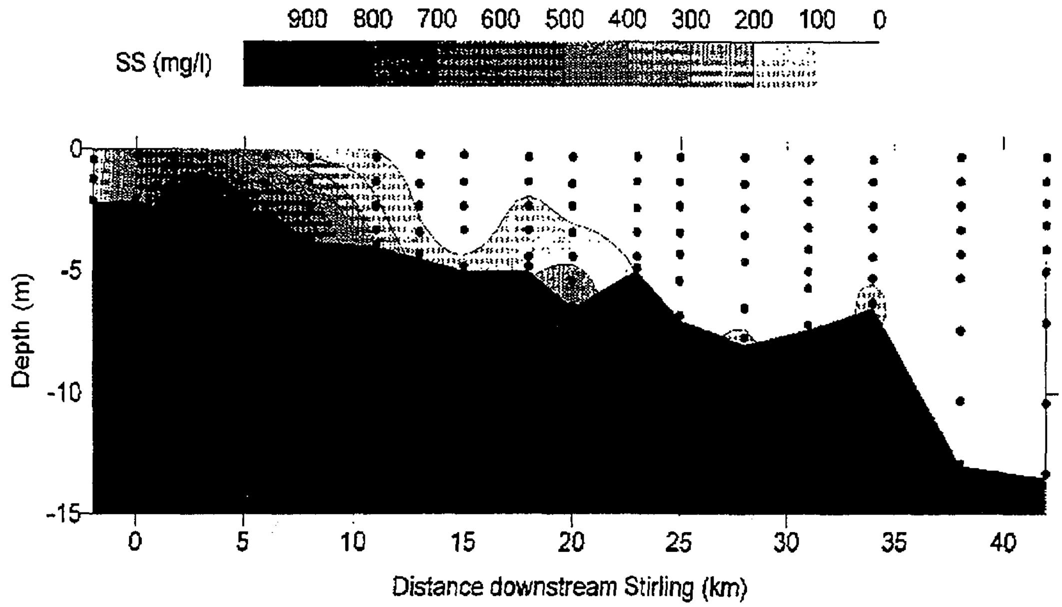

Figure 2. Distribution of suspended solids (mg/l) in the Forth Estuary on 22 July 1998 (dots represent sampling sites and depths).

Fig. 4 shows an example of these data summarised for Alloa (approximately 20 km downstream from Stirling) over the period 1996-98 (Fig.s 3 & 7). Reductions in organic inputs to the upper Forth estuary over the past decade have resulted in a general improvement in BOD and DO [6]. This improvement in water quality has been seen as the primary reason for the return of the cucumber smelt (*Osmerus eperlanus*) to the estuary following a period absence from the whole catchment.

2.2 Phytoplankton and eutrophication

Phytoplankton growth is monitored using a combination of automatic sensors (moored sub-surface and towed) and ship-based sampling. This provides detailed information on the spatial and temporal distributions of phytoplankton species and blooms in relation to major point and diffuse sources of inorganic nitrogen. This approach ensures an effective base-line of information on the dynamics of phytoplankton and nutrients, against which current and future eutrophication effects

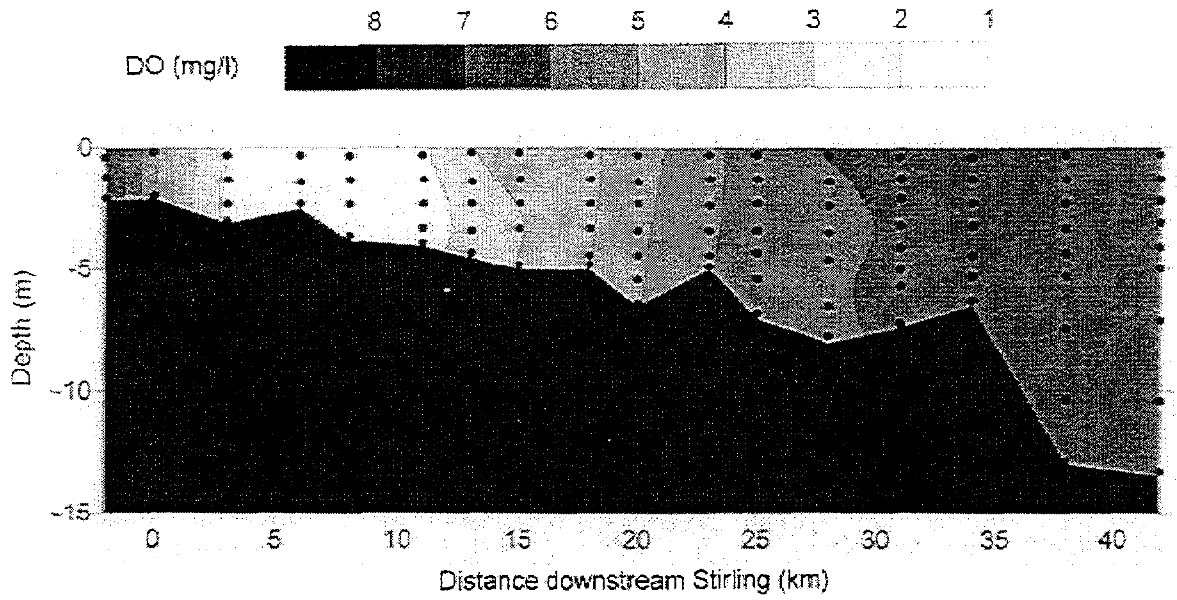

Figure 3. Dissolved Oxygen Distribution (mg/l) in the Forth Estuary 22 July 1997 (dots represent sampling sites and depths).

may be seen [7]. Other potential effects of nutrient enrichment are monitored, including the occurrence of abnormal toxic phytoplankton blooms and excessive growth of opportunistic macroalgae on beaches and intertidal mudflats.

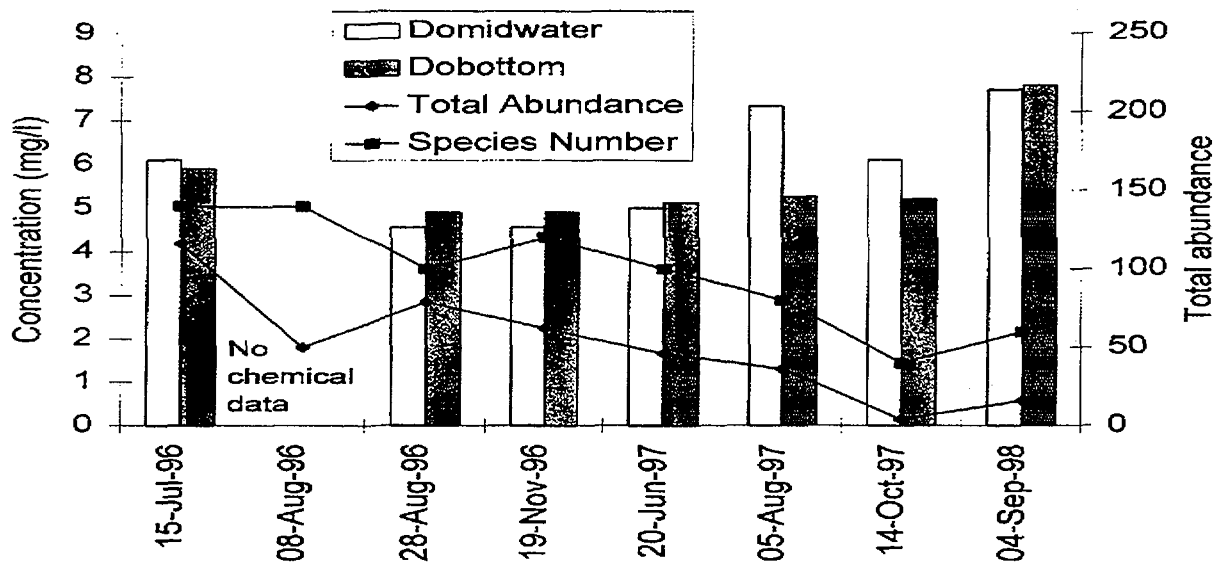

Figure 4. Fish abundance and species number with midwater and bottom water dissolved oxygen concentrations. Alloa in the upper Forth estuary, 1996-98.

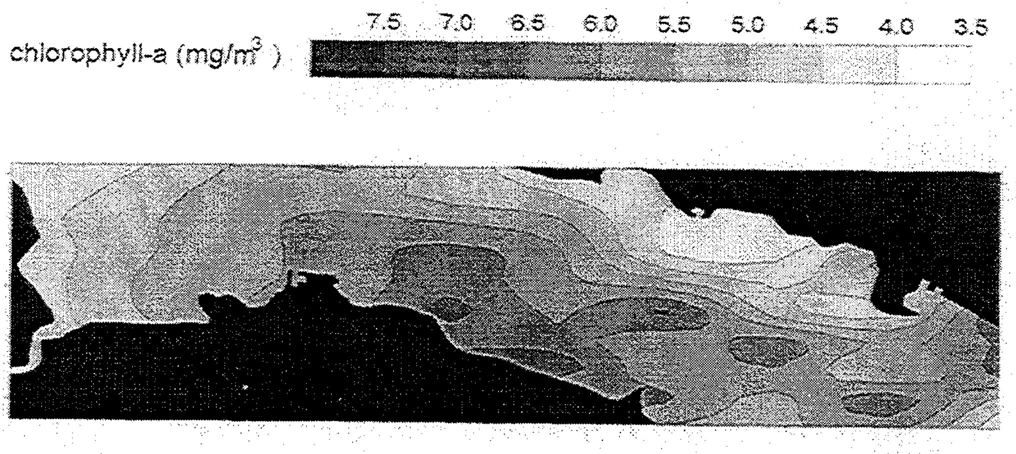

Figure 5. The spatial distribution of phytoplankton chlorophyll-a (1m depth) in the lower Forth Estuary, 12th May 1997. For location see figure7.

Fig. 5 shows the results of an investigation of the trophic status of the lower Forth estuary in the spring of 1997. The spatial distribution of phytoplankton chlorophyll-a was determined using a towed fluorometer, with additional sensors measuring salinity, temperature, turbidity as well as a continuous plankton recorder. This rapid mapping technique is always verified through the collection of spot samples (for salinity, temperature, suspended solids and chlorophyll-a) which also provide samples for micronutrient analysis. The distribution of phytoplankton chlorophyll-a, seen in Fig. 5, reflects the riverine input of fresh turbid water to the West (inhibiting phytoplankton production) and the tidal intrusion of phytoplankton-rich (approximately 22 mg m^{-3} chl.-a) and relatively saline water from the Firth of Forth.

Although the estuaries and coastal waters of south eastern Scotland are generally free from serious eutrophication, SEPA is tackling the underlying causes of hypernutrification. SEPA's powers of regulation allow control of the nutrient content of discharges to controlled coastal waters. Nitrogenous emissions from diffuse sources are also limited at their source by promoting Best Management Practices to the agricultural community. This initiative includes the promotion of multi-purpose buffer zones to reduce the run-off of pesticides as well as fertilisers into streams and groundwater [8].

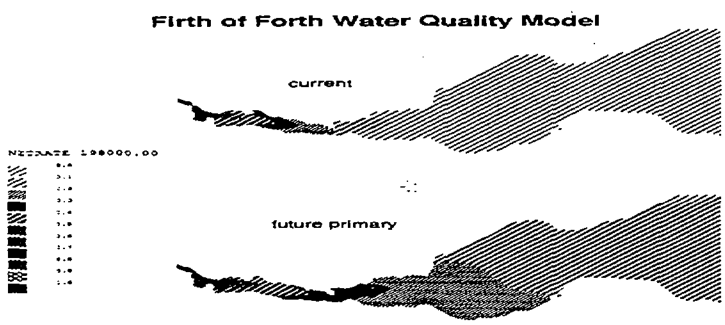

Figure 6.
Predicted nitrate levels for 50%ile current and future loads at Edinburgh and Levenmouth

SEPA also utilises a two- dimensional hydrodynamic and water quality model (TELEMAC) to investigate and predict the impact of treated effluent on the tidal waters of the Forth estuary. This model is based on both fine and coarse triangular grids enabling fine and coarse resolution to tackle both small-scale and large scale (or far-field) effects. The model is capable of simulating tidal flows and water quality processes over its domain using finite element techniques. Fig. 6 illustrates the use of TELEMAC in predicting the effect of improved sewage treatment at Edinburgh and Levenmouth Sewage Treatment Works (serving the equivalent of 1.6 million people) on the loading of nitrate within the Firth of Forth in the year 2006. These and other model runs are used as sound management tools for recommending sewage treatment levels and predicting possible biological impacts.

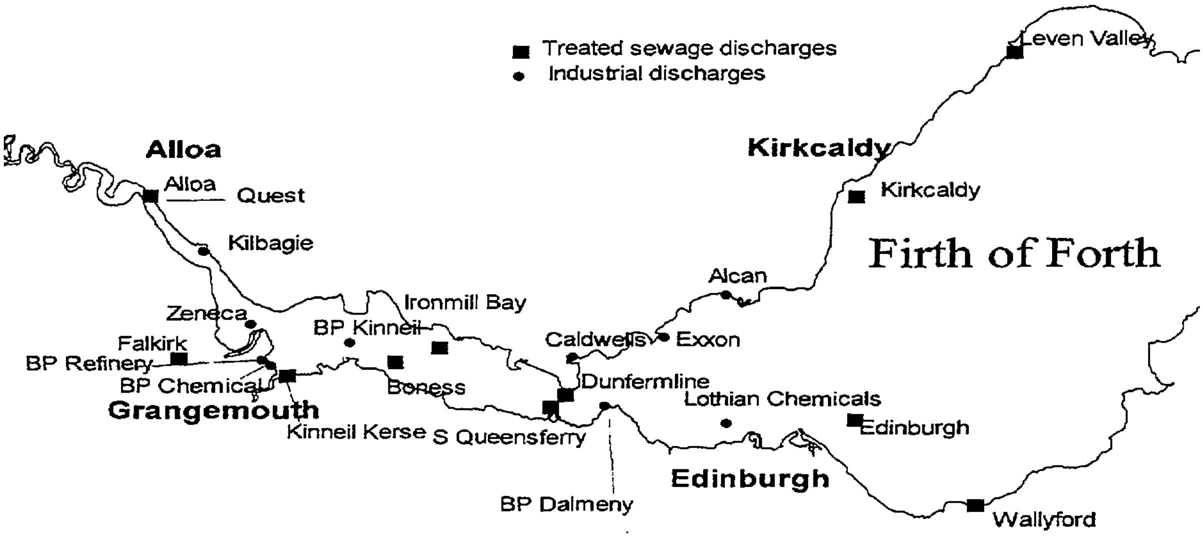

Figure 7. Major discharges in the Forth estuary and the Firth of Forth.

2.3. Benthic faunal communities

The intertidal and subtidal soft-sediment fauna are routinely examined in relation to sediment chemistry and particle size. Large spatial and temporal variations in macrofaunal abundance and species composition occur in response to natural gradients in salinity, suspended solids and sediment stability [9]. Subtle community changes are used particularly to evaluate the impact of organic waste from both sewage and industrial discharges. Fig. 7 summarises the major treated sewage and industrial discharges in the Forth estuary. The biological impact of some of these major discharges is assessed directly whereas large sampling grids are used to examine the combined impact of discharges on the health of the whole catchment. A numerical model of the settling of organic material througha moving and turbulent sea has been developed [10] to predict the effect of orgainc detritus on benthic faunal communities.

3. CONCLUSION

A long-term programme of biological and water quality monitoring has centred effort on the Forth and Tay estuaries and the coastal embayment of the Firth of Forth. The monitoring aims to assess the quality of tidal waters against quality standards set both by SEPA and EC Directives.

Sea water quality is generally defined in terms of bacterial, persistent and dangerous substances (organochlorine pesticides and heavy metals), DO, nutrient status, organic load (BOD) and suspended solids. The last three are considered the most important ecological factors, related to sewage pollution, affecting our coastal waters [11].

The measurement of contamination of sea water, sediments and marine organisms is integrated with a programme of biological effects monitoring of invertebrates, fish, macroalgae and plankton. This approach enables detailed environmental impact assessments to be made relating to both point and diffuse sources of pollution.

References

[1] COSTA, M. J. & M. ELLIOTT., Fish usage and feeding in two industrialised estuaries - the Tagus, Portugal, and the Forth, Scotland. In: Elliott, M & J-P Ducrotoy (Ed.). Coasts and Estuaries: spatial and temporal comparisons. Olsen & Olsen, Fredenborg, Denmark. (1991) 289-297.

[2] MCLUSKY, D. S., D. M. BRYANT & M. ELLIOTT., The impact of land-claim on the invertebrates, fish and birds of the Froth estuary. Aquatic Conservation: Marine and Freshwater Ecosystems **2** (1992) 211-222.

[3] POMFRET, J. R., M. ELLIOTT, M. G. O'REILLY & S. PHILLIPS., Temporal and spatial patterns in the fish communities of two North Sea Estuaries. In: Elliott, M & J-P Ducrotoy (Ed.), Coasts and Estuaries: spatial and temporal comparisons. Olsen & Olsen, Fredenborg, Denmark. (1991) 277-274.

[4] ELLIOTT, M., M. G O'REILLY & C. J. L. TAYLOR., The Forth Estuary: a nursery and overwintering area for the North Sea fish species. Hydrobiologia, **195** (1990) 89-103.

[5] GRIFFITHS, A. H., Water quality of the estuary and Firth of Forth, Scotland. Proc. Roy. Soc. Edin., 93B (1987) 303-314.

[6] BALLS, P. W., N. BROCKIE, J. DOBSON & W. JOHNSTONE., Dissolved oxygen and nitrification in the upper Forth Estuary during summer (1982-1992): patterns and trends. Estuarine Coastal Shelf Science **42**(1), (1996) 117-134.

[7] PARK, R. A., Phytoplankton of the Firth of Forth. Coastal Zones Topics: Process, Ecology & Management. **1** (1995) 105-109.

[8] D'ARCY, B. J., I. M. RIDGEWAY, M. W. MARSDEN & R. J. SARGENT., Diffuse Pollution and Agriculture in the Forth Catchment (1996). Proceedings of Diffuse Pollution in Agriculture Conference, Edinburgh, 12-14th April 1995.

[9] MCLUSKY, D. S., S. C. HULL & M. ELLIOTT., Variations in the intertidal and subtidal macrofauna and sediments along a salinity gradient in the upper Forth estuary. Neth. J Aquat. Ecol. **27** (1993) 101-109.

[10] BENOSS version 2., Forecasting the deposition and biological effects of excess carbon from sewage discharges. Biological effects and organic solids sedimentation. UK Water Industry Research Ltd. Report Ref. 97/WW/03/2 (1997).

[11] READ, P. A., K. J. ANDERSON, J. E. MATTHEWS, P. G. WATSON, M. C. HALLIDAY & G. M. SHIELLS., Water Quality in the Firth of Forth. Marine Pollution Bulletin **13 (12),** (1982) 421-425.