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Effects of Reductions in Organic and Nutrient Loading on Bird Populations in Estuaries and Coastal Waters of England and Wales Phase 1 Report March 2002

Authors

N.H.K. Burton, E. Paipai, M.J.S. Armitage, J.M. Maskell, E.T. Jones, J. Struve, C.J. Hutchings & M.M. Rehfisch

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The National Centre for Ornithology, The Nunnery, Thetford, Norfolk IP24 2PU
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EXECUTIVE SUMMARY

1. This report investigates the potential impacts of the European Community's Urban Waste Water Treatment Directive (UWWTD) and Bathing Water Directive (BWD) upon coastal waterbird populations. The first part of the report presents an overview of the directives and a literature review summarising how waste water discharges and changes to their treatment may affect waterbird populations. The second summarises data collated for a companion Geographical Information System (GIS) Project relating to coastal waterbird numbers, particularly within sites designated as Special Protection Areas (SPAs), and waste water outfalls within these areas. The first aim of the collation of these data was to determine how many SPAs important for waterbirds have already been affected by changes in the treatment of discharges. The second aim was to identify those sites for which the relationships between improvements in water quality and changes in bird numbers could be analysed. The report also provides preliminary analyses of these data. This report should be read in conjunction with the GIS Project, which is supplied separately on a CD-ROM.

2. The two directives aim to protect coastal and freshwater environments from the adverse effects of urban waste water (i.e. domestic waste water - sewage - and industrial waste water). Their main focus has been to end the discharge of such effluents onto intertidal areas and into coastal waters, usually by providing 'secondary treatment'. The impact of these directives on waterbirds has raised some concern as in many areas discharges may provide considerable food for birds, either as directly edible matter or by enhancing concentrations of invertebrates.

3. The literature review details studies that have described how organic and nutrient loading influences the Biochemical Oxygen Demand (BOD) in sediments and how as a result invertebrate diversity, abundance and biomass change in zones of increasing distance from outfalls. Highly-enriched sediments close to outfalls are occupied by an abundance of a small number of opportunistic species, e.g. *Capitella capitata*, that are able to tolerate a depletion of Dissolved Oxygen. Species that benefit from more moderate enrichment include *Corophium*, *Eteone longa*, *Macoma balthica* and *Scolelepsis fuliginosa* and *Mytilus edulis.*

4. The increased invertebrate food supply found near outfalls may benefit some pelagic fish species, though benthic species may be restricted due to the toxic effects of sewage. The effects of improved treatment depend upon the degree of past loading and the fish species. Thus, whilst reductions in gross pollution can be of benefit to fish, reductions in moderate loading can decrease invertebrate food resources. Fish may act as competitors to birds for these food resources, though their increased abundance at outfalls may attract species such as grebes, cormorants, gannets, sawbill ducks and terns.

5. A number of bird species feed directly on waste matter released in the discharge. Gulls are particularly opportunistic and because they may act as carriers of Salmonella, have been the focus of a number of studies. Grain and other matter from food factories, breweries and distilleries may also provide considerable food for ducks. Invertebrate populations enhanced by the nutrient and organic enrichment may provide food for wildfowl and waders.

6. Although a number of studies have reported changes in waterbird numbers following improved waste water treatment, comparatively few have offered quantitative information that has linked such changes to alteration of the birds' food supply. However, by assessing which species may benefit from the food associated with outfalls, it is possible to identify species which are potentially at risk from the implementation of the UWWTD.

7. Reductions in the food discharged directly from waste water outfalls have been associated with declines in Common and Great Black-backed Gulls and, notably in Scotland, duck species such as Scaup, Goldeneye, Pochard and Tufted Duck. Little evidence exists of a change to the national populations of these species, however. More maritime species of duck (Eider, Common Scoter, Velvet Scoter and Long-tailed Duck) that usually gather around more natural food concentrations are potentially less at risk.

8. Improvements to discharges, except on the most grossly polluted sites, have the potential to lead to reductions in the numbers of waders and certain wildfowl due to reductions in invertebrate

abundance, biomass and diversity. However, there is only limited evidence from the literature that this has already occurred. Species of waders and wildfowl that prey upon intertidal invertebrates that have been identified as potentially at risk from the implementation of the UWWTD include Brent Goose, Shelduck, Wigeon, Teal, Pintail, Oystercatcher, Avocet, Grey Plover, Lapwing, Knot, Purple Sandpiper, Dunlin, Black-tailed Godwit, Bar-tailed Godwit, Curlew, Spotted Redshank, Redshank and Turnstone.

9. The second part of the report summarises the collation of waterbird count data and information concerning the locations of outfalls, the dates of changes in treatment to discharges from these outfalls and the quality of the waste water discharged. These data are shown on the GIS Project on CD.

10. Data concerning waterbird numbers were obtained from the Wetland Bird Survey (WeBS) Core Count and Low Tide Count Schemes, the Winter Shorebird Count and Non-Estuarine Waterfowl Survey of non-estuarine coasts and from the BTO's own surveys. The locations of sites for which data have been collected are shown on the GIS Project. Core Count Data have been collected for all estuarine SPAs and for the Northumbria Coast SPA. Low Tide Count Data are presented on the GIS for 58 sites, of which 43 are protected as SPAs.

11. The GIS Project indicated that outfalls where there had been recent changes to discharges were present in or adjacent to a minimum of 17 of 54 SPAs important for waterbirds and seabirds. Details of these changes are also tabulated. It was apparent from the GIS Project that outfalls may have influenced the distribution of some species on some estuaries. The GIS was also invaluable in identifying sites where the relationships between improvements in water quality and changes in bird numbers could be analysed.

12. Box modelling indicated how the BOD fell on four of these estuaries following improved treatment to discharges. Comparative analysis of WeBS Core Count information indicated that, on two of the estuaries – the Orwell and Mersey – species have declined in 10 of 17 cases (and increased in only one) since improvements to discharges

13. An Annex to this report (published separately) contains information concerning outfalls where changes to discharges have not yet occurred, an analysis of the degree of change or proposed change in loading from the sewage treatment works into each SPA and the implications of these changes for waterbirds within each SPA, and identifies SPAs where further investigation is required.

14. In conclusion, both the literature review and the data collation and analysis demonstrated that improvements to waste water discharges may have a negative impact on waterbirds. The literature review highlighted the species that exploit the food resources associated with outfalls and which are thus at risk from the implementation of the UWWTD. However, few studies were found that offered quantitative information linking changes in discharge treatment to alteration of the birds' food supply. The collation of data onto GIS successfully helped to identify those SPAs where there had been recent changes to discharges and was invaluable in identifying those sites where data existed to further investigate the effects of the UWWTD. Preliminary data analysis indicated that waterbirds had declined on two estuaries following changes to waste water treatment.

15. Two further areas of work are recommended. Firstly, it is recommended that box modelling be expanded to a wider range of sites in order to assess how changes to discharges relate to change in bird numbers at a whole estuary scale. Further sites where it would be possible to relate changes in BOD concentrations to changes in bird numbers, include the Humber Flats, Marshes & Coast SPA, Ribble Estuary SPA, Duddon Estuary SPA, Camel Estuary, Thanet Coast & Sandwich Bay SPA and Teesmouth & Cleveland Coast SPA.

16. Secondly, it is recommended that work be undertaken to quantitatively assess how the distribution of organic matter from discharges determines the distribution of waterbirds and further, to investigate the effects of change in the quantity of organic matter discharged. Suggested sites for these analyses, identified using the GIS Project, are the Orwell Estuary, Mersey Estuary, Barrow and Southampton Water.

1. INTRODUCTION

This report presents a study investigating the importance of waste water outfalls in providing food for waterbirds and is the result of concern over the impacts of two European Community (EC) Directives – the Urban Waste Water Treatment Directive and the Bathing Water Directive –, which have aimed to improve the levels of treatment to waste water discharges. The first part of the report (sections 2-6) aims to provide an overview of the directives and summarise how waste water discharges and changes to their treatment may affect bird populations. Section 2 of this report introduces these directives and Section 3 describes how waste water discharges may cause organic and nutrient enrichment. Sections 4-6 present the results of a literature review that look at the relationships between discharges, invertebrates, fish and waterbirds and the proven and theoretical impacts of improved treatment or cessation of discharges to these fauna.

The second part of the report, Section 7, details the collation of data concerning the distribution and numbers of waterbirds on coastal sites and related information concerning the location of outfalls and their discharges. These data are presented on a Geographical Information System (GIS) Project so that relationships between the distribution of waterbirds and outfall locations can be discerned. This section of the report should be read in conjunction with the GIS Project. The first aim of the collation of these data was to determine how many SPAs important for waterbirds have already been affected by changes in the treatment of discharges. The second aim was to identify those sites for which the relationships between improvements in water quality and changes in bird numbers could be analysed. This section provides a preliminary analysis of the impacts of improved treatment to discharges upon waterbirds at two estuaries – the Orwell and the Mersey.

An Annex to this report (published separately) contains information concerning outfalls where changes to discharges have not yet occurred, an analysis of the degree of change or proposed change in loading from the sewage treatment works into each SPA and the implications of these changes for waterbirds within each SPA, and identifies SPAs where further investigation is required.

Section 8 concludes the study and provides recommendations for further work.

2. IMPROVEMENTS TO WASTE WATER TREATMENT DRIVEN BY THE URBAN WASTE WATER TREATMENT DIRECTIVE (UWWTD) AND THE BATHING WATER DIRECTIVE (BWD)

The Urban Waste Water Treatment Directive (UWWTD) (Directive 91/271/EEC and its Amending Directive 98/15/EEC) (Anon 1991a, 1998a) aims to protect the environment from the adverse effects of urban waste water (*i.e.* 'domestic waste water' - hereafter referred to as 'sewage' - and 'industrial waste water' e.g. from agri-foodstuff sectors) by requiring Member States to ensure that such water is collected and treated. Untreated water may adversely affect human health and the environment due to the following forms of 'pollution' (Anon 1999):

- discharges of nitrogen in its various forms: organic nitrogen, ammoniacal nitrogen, nitrites and nitrates from urban water and agricultural activities. Nitrates may pollute drinking water, cause eutrophication in certain waters, resulting in an ecological imbalance due to excessive algae growth, Ammoniacal nitrogen is particularly toxic to the aquatic fauna.
- discharges of phosphorus which, in spite of the reduction in the use of phosphates in detergents and washing powders, are responsible for cases of eutrophication, particularly in fresh waters or estuaries.
- a reduction in the amount of oxygen in water as a result of the decomposition of the organic matter contained in waste water, endangering aquatic life through asphyxiation and disrupting the ecological balance of the water.
- discharges of pathogenic micro-organisms of faecal origin (bacteria, viruses, parasites) contained in urban waste water which could pose a health risk through contamination of drinking water supplies, waters used for bathing or other water sports and shellfish waters.
- discharges of hazardous, toxic and bioaccumulable substances (chemical compounds, heavy metals, hydrocarbons, etc.) from connected industries but also domestic activities (detergents, paints, solvents, etc.) posing a potential risk to aquatic life and human health.
- the adverse effects of waste water on the Special Protection Areas (SPAs) under the amended Council Directive 79/409/EECof 2 April 1979 on the conservation of wild birds and on the natural habitats and species referred to in Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.
- loss of value in terms of appearance and appeal to tourists of freshwater areas or coastal waters polluted by urban waste water.

Sources of industrial waste water have been summarised by Pounder (1976a) and include food factory discharges, chemical effluents from the pharmaceutical and oil industries, mine water, pulp mill and cooling water discharges. Pollution problems may also come from sludge dumping.

The Bathing Water Directive (BWD) (Directive 76/160/EEC and its proposed revision COM(94)0036-94/00006SYN) (Anon 1976) aims to reduce the pollution of bathing water and to protect such water against further deterioration. (Bathing water is defined as all running or still fresh waters or parts thereof and seawater in which bathing is authorised or not prohibited and traditionally practised). The Directive requires Member States to identify bathing areas, to monitor them during the bathing season and to report the results of the monitoring to the Commission. Measures detailed in the UWWTD and BWD, together with measures in the Nitrates Directive (Directive 91/676/EEC) (Anon 1991b), concerning the protection of waters against pollution caused by nitrates from agricultural sources, the Drinking Water Directive (Directive 98/83/EC) (Anon 1998b) and others have been included within a new Water Framework Directive (Anon 2000) (see Appendix 1).

The main focus of these directives in coastal areas has been to end the discharge of raw sewage and industrial waste water effluents, whether from urban waste water treatment plants or other sources, directly onto intertidal areas and into coastal waters. Treatment may take three forms (Anon 1999). 'Primary treatment' entails treatment of urban waste water by a physical and/or chemical process involving settlement of suspended solids, or other processes in which the BOD5 (five-day biochemical oxygen demand) of the incoming waste water is reduced by at least 30-40% before discharge and the total suspended solids of the incoming waste water are reduced by at least 50-65%. 'Secondary treatment' generally involves biological treatment with a secondary settlement or equivalent process and removes

65-95% of the BOD and 60-90% of the suspended solids in the waste water. 'Tertiary treatment' entails treatment (additional to secondary treatment) or removal of the nitrogen (nitrification-denitrification) and/or phosphorus and/or of any other pollutant affecting the quality or a specific use of the water (see also Section 3). The Directives usually require secondary treatment, but may be more stringent (secondary plus tertiary treatment) for discharges in areas identified as sensitive by the Member States and in the relevant catchment areas. The treatment may be less stringent (primary treatment) under certain conditions and agreed to by the Commission or the Council for discharges in coastal waters or estuaries identified by the Member States as being less sensitive. No such sites have been designated in England or Wales, however.

Appendices 2a and 2b details the requirements of the UWWTD, which vary according to the location, rather than the discharges themselves. The requirements need to be fulfilled at the latest by 31 December 2005 for discharges to fresh-water and estuaries. Details of those discharges where improvements have been made are given in Section 7. Appendix 3 lists the quality requirements set out by the BWD in 1976.

The impact of these directives on coastal waterbirds has raised some concern as in many areas waste water discharges from outfalls may provide considerable supplies of food for bird species, either as directly edible matter or by artificially enhancing concentrations of invertebrate food (Pearce 1998, Rehfisch 1998a, 1998b, Spray 1998). Pearce (1998) reported how sewage improvements may result in a decline in organic matter and thus the invertebrate life dependent upon it. Each of these articles has highlighted cases where declines in bird numbers have followed improvement programmes. The Ramsar Convention Bureau made reference to this dichotomy in its 1994 mission report for the Dee Estuary and recommended that a monitoring project should be set up at Heswall where a primary treatment plant was due to be upgraded to provide full treatment, including ultra-violet sterilization. This new treatment plant was completed during 1998. The area was particularly important for Redshank *Tringa totanus* that reportedly fed on sewage-enriched mudflats (though the importance of these areas to the species was not determined). However, it was the view of the bureau's Monitoring Procedure team that the potential value for birds of locally sewage-enriched areas should not prevent the upgrading of treatment in the interests of the wider environment (Ramsar Convention Bureau 1994). There is no evidence that monitoring was undertaken.

3. ORGANIC AND NUTRIENT ENRICHMENT DUE TO SEWAGE AND INDUSTRIAL WASTE WATER DISPOSAL

Organic loads from outfalls may influence the estuarine food chain and, eventually bird populations, in several direct and indirect ways. Some of these effects will be observed in the vicinity of outfalls but others will affect an estuary at some distance from the discharge. Negative effects on biological communities may be observed where organic discharges result in gross pollution, but positive effects on biological communities may be observed where organic loads are moderate.

Near field effects

The heaviest discharged organic matter will fall close to outfalls and may be consumed directly by invertebrates and birds (see Section 6). Settlement of such particulate matter may blanket sediments close to outfalls and cause local depletion of Dissolved Oxygen (DO) and thus result in reduced invertebrate biomass, diversity and abundance (see Chapter 4). The boundary between the upper aerobic sediments and the anaerobic sediments below is referred to as the Redox Potential Discontinuity (RPD). Anaerobic bacteria below the RPD produce Hydrogen Sulphide, metal sulphides associated with this process causing the sediments to turn black.

Far field effects

Discharged suspended solids will be diluted and transported by currents. Transport of such material will depend on the location of the outfall and the hydrodynamic environment, especially local currents, water levels and tides. Eventually, it will settle and become a direct food source to invertebrates, or be degraded by bacteria and enter the food chain through this pathway. Nutrients released directly from outfalls or indirectly during the degradation or consumption of discharged loads will enrich the water and possibly enhance algae growth. The dilution and dispersion of nutrients will again depend on the location of the discharge and hydrodynamic environment, but effluent discharges may cause nutrient enrichment and algae growth several kilometres away from the actual outfall. By settling and being consumed by bacteria and invertebrates, nutrients may also serve as an indirect food source for birds.

As noted in the previous chapter, the BWD and UWWTD have resulted in or will lead to improvements in treatment levels at most coastal outfalls, removing most raw and primary treated discharges and replacing them with secondary or tertiary treated discharges. The main changes in effluent characteristics as a result of increased treatment are a decrease in suspended solids, and Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) loads. BOD5 and COD are indirect measures of organic loads (see Box 1). The situation for nutrients is a little more complicated, as total nutrients are reduced during primary and secondary treatment due to the removal of total organic material, but also released in the process of degradation. The overall reduction in nutrients therefore occurs mainly in the tertiary treatment stage.

Typical loads per capita and reductions in organic and nutrient loads during various treatments are listed in Table 3.1. As this table indicates, changes in organic loads to estuaries could change dramatically due to implementation of primary and secondary treatment of effluent. However, the relative importance of these changes in individual estuaries depends on the size of populations around estuaries and the magnitude of other sources. Continuous discharges from outfalls are not the only sources of organic material and nutrients in estuaries. Diffuse inputs from agricultural, urban run-off and storm overflows could mask the effects of the UWWTD and BWD locally (Carpenter *et al.* 1998).

BOX 1

BOD5 is an indirect measure of easily degradable organic material. Large and small solids and dissolved organic material all contribute to total BOD5. Standard BOD5 measures the oxygen consumption in a water sample over a 5-day period and therefore does not capture all organic material discharged.

COD is a measure of the total organic material that can be degraded theoretically, but will also contain organic material that is not available as a food source in practice.

Hence both measures have weaknesses. Some of the organic material captured in the measured BOD5 will be available as a food source to invertebrates rather than to birds and therefore enter the food chain through this pathway.

Total Nitrogen and Total Phosphorus refer to the total amount of Nitrogen and Phosphorus in the water from inorganic sources and as nutrients bound in organic material. Nutrients bound in organic material degrade and eventually become available in the food chain. These are better indicators of nutrient availability, therefore, than inorganic Nitrogen or Phosphorus, and of the general trophic status of a water body.

The response of estuarine communities to changes in organic loading will depend upon the scale of past enrichment. In previously moderately enriched estuaries, effluent treatment will generally reduce the total amount of organic matter directly available as food and reduce the estuary's productivity. This could result in reduced invertebrate and bird numbers (see Sections 4.2 and 6.2.2). If an estuary was previously grossly polluted then the implementation of wastewater treatment may result in enhanced biological communities (see Sections 4.2.1 and 6.2.1). The effect of the removal or improved treatment of individual discharges on the populations of individual bird species will also depend on a number of other factors. The change from no treatment to primary treatment or the closure of crude discharges may have the greatest effect on bird species which feed on the matter directly available from outfalls (see Section 6.2.2). Changes from primary to secondary treatment may have a more noticeable effect on bird species which feed on invertebrates, which may decrease as a consequence of decreased organic inputs (see Sections 4.2 and 6.2.3). This could happen at some distance from the outfall. A reduction in nutrient inputs may reduce eutrophication, and this in turn affect invertebrate populations (see Section 4.1.1), but only if algae growth is limited by nutrient availability. If the tidal range and suspended sediment loads are high and the hydraulic residence time is low, algae growth may be limited by other factors. Reductions in nutrient loads discharged from outfalls may thus have reduced effects in such areas.

4. WASTE WATER OUTFALLS AND INVERTEBRATE POPULATIONS

The effects of nutrient and organic loading from waste water outfalls and other sources on invertebrate populations have been well-documented and are summarised in Section 4.1 below. Section 4.2 summarises studies that have investigated changes in invertebrate abundance following improved waste water treatment.

Invertebrates form a major food resource for fish (see Section 5) and both are preyed upon by a variety of waterbirds (Section 6). The invertebrate prey species utilised by intertidal waders and wildfowl are detailed in section 6.1.2. In addition an assessment is made in that section of how wader and wildfowl numbers might vary according to distance from outfalls as a result of the variation in invertebrate diversity, abundance and biomass described below.

If improved waste water treatment does affect invertebrate populations, there are likely to be important implications for these bird species. The potential effects of changes to invertebrate populations, resultant from the implementation of the UWWTD, on the bird species that prey upon them are discussed in section 6.2.3.

4.1 Effects of Waste Water Discharges on Invertebrate Populations

4.1.1 Effects on Species Composition, Abundance and Biomass

The consequences of the increased organic and nutrient loading to coastal sediments due to sewage and industrial waste water have been classically described by Pearson and Rosenberg (1978). Their theoretical model, describing the variation in the effects of such loading on invertebrate species diversity, abundance and biomass in zones (A to D) of increasing distance from the source, is summarised in Figure 4.1.1.1 and below. Within this description, examples are given of studies which have investigated these relationships and demonstrated how these relationships vary from that proposed in the model. The effects on invertebrate species composition, abundance and biomass described are important in determining which bird species may be affected by the increased organic and nutrient loading to coastal sediments (see sections 6.1.2 and 6.1.4).

The extent of the zones described depends greatly upon the size of discharges, but also surrounding currents and habitats, and can range from only a few 100 m to over 1,000 m. Several large outfalls within a single estuary can cause gross pollution to all the sediments within the site. The effects of scale and habitat are discussed in section 4.1.2.

Zone A

In Pearson and Rosenberg's model, sediments close to sources of nutrient and organic enrichment become anaerobic due to the high BOD and may in the most extreme cases become completely unsuitable for invertebrate life due to a depletion of DO and the high concentrations of hydrogen sulphide produced by anaerobic bacteria. The high nutrient loading may encourage algae to flourish (Perkins & Abbott 1972, Tubbs 1977, Smith 1996, Soltan *et al.* 2001) and this will add to the organic matter originating from the discharge itself and further increase the BOD. Mats of algae, such as *Enteromorpha* and *Ulva lactuca*, may support moderate numbers of the Laver Spire Shell *Hydrobia ulvae*, amphipods such as *Gammarus locusta*, Common Shore Crabs *Carcinus maenas* and if the RPD is not too near the surface, ragworms *Nereis diversicolor* (Tubbs 1977). In a study using stable isotope analysis, Waldron *et al.* (2001) found that organic matter derived from sewage in the Firth of Forth could be traced, in decreasing quantities, in the polychaete *Nereis virens* at distances of 0, 300 and 600 m from an outfall.

Zone B

In the next zone, the RPD begins to get deeper and sediments are occupied by an abundance of a small number of opportunistic species, notably the polychaete complex *Capitella capitata*, that are able to tolerate the depletion of DO (Pearson & Rosenberg 1978, Pearson *et al.* 1983). Despite the limited diversity of species that are able to tolerate these conditions, their numbers are such that overall abundance usually peaks in this zone. These polychaetes were characteristic of formerly highly polluted estuaries, such as the Tees (Gray 1976, 1979), and have been used as an indicator in a number of pollution related benthic studies (*e.g.* Gray *et al.* 1992, Grassle & Grassle 1976, Marine Pollution Monitoring Management Group 1998). *Capitella* are commonly found in sediments close to outfalls (Player 1970, Swartz *et al.* 1986).

Capitella and other pollution-tolerant species may help to aerate and detoxify organically enriched sediments through their mass action (Aller 1982) and thus make sediments suitable for some other species. Lugworms *Arenicola marina*, for example, may colonise such areas (Pounder 1976a), though McLusky (1968) found that sewage polluted sediments could not support the amphipod *Corophium volutator*.

Studies of an area of sewage discharge on the Fraser River in British Columbia have found that sediments (of Zone B) beyond the most severe pollution may also be colonised by the polychaetes *Manayunkia aestuarina* and *Eteone longa*, the Baltic Tellin *Macoma balthica* (with a biomass of up to 10.7 g/m^2) the amphipods *Corophium salmonis* (biomass of up to 2.9 g/m^2) and *C. insidiosum* and copepods (Levings & Coustalin 1975, McGreer 1979, Harrison *et al.* 1999). In comparison to other studies, densities of *Capitella capitella* were low, reaching only 2,200 individuals/m^2 at a distance of 1,500 m from the outfall.

Zone C

As the DO level in sediments increases and the RPD becomes even deeper, a transitory zone exists containing species characteristic of both polluted and unpolluted sediments. Species diversity and overall biomass may peak in this zone (Otte & Levings 1975, Pearson & Rosenberg 1978). Invertebrate community composition and activity in these sediments may also be affected by reduced salinity levels and by the moisture given to the mudflats when the tide is out (Yates *et al*. 1993).

Zone D

Beyond this zone the influence of organic enrichment diminishes and species diversity, abundance and biomass reduce to levels that would be expected in the absence of the outfall.

4.1.2 Effects of Scale and Habitat

The distances to which invertebrate communities are affected by waste water outfalls depend upon the volume and nature of the discharge, the depth of water into which it flows (Otway *et al.* 1996) and coastal and other currents (Sherwin 2000). Smith (1996) found that the impact of poorly treated domestic sewage effluent (i.e. the total extent of zones A-C) was restricted to within 300 m of the discharge point for most species of invertebrates found living in a kelp bed in Australia. Anderlin and Wear (1992) similarly found that the abundance and biomass of invertebrates were affected within a 500 m radius of an outfall in New Zealand. Taylor *et al.* (1998) reported a typical response in the benthic infaunal community in a study of untreated sewage discharging from two deep water outfalls in British Columbia. Zone B, where overall abundance was increased and species diversity reduced, stretched to 100 m from the outfalls. Toxins from the sewage were still apparent in sediments 400 m away. Harrison *et al.* (1999), studying a much larger discharge in British Columbia (which served a population of approximately half a million people and which together with two other outfalls discharged 22 tonnes of nitrogen per day into the estuary), found that the area beyond the most severe pollution (i.e. zone B) stretched to at least 1,500 from the outfall.

On rocky shores, rapid removal of the effluent by waves may reduce the impacts of discharges on invertebrates (Underwood & Chapman 1997). However, Eaton (2000a, 2001), in a study using stable isotope analysis in Northumberland, suggested that up to 61% of organic matter in the immediate vicinity of five open coast outfalls may have originated from the discharges and that this may have been an important food source for filter-feeding molluscs such as mussels *Mytilus edulis*. The percentage of organic matter originating from the discharges decreased to 11% at a site 3 km up an estuary from one outfall and 14% at a site 8 km down the coast from another. Tucker *et al.* (1999) used a similar approach to trace sewage through Boston Harbour and Massachusetts Bay.

Whilst the effects of individual waste water outfalls may be restricted to within a few hundred metres, the combined effects of several outfalls and nutrient enrichment from farmland may affect whole estuaries. In both the Rogerstown Estuary in Ireland (Fahy *et al.* 1975) and the Lillo-Rilland area of Holland's Delta Region (van Impe 1985), for example, increases in algae and invertebrates such as *Hydrobia ulvae*, *Corophium volutator* and *Nereis diversicolor* have been linked to increases in both organic and nutrient inputs, from domestic sewage and from industrial and agricultural wastes. Eutrophication of the Ythan Estuary in Scotland (primarily due to nutrient inputs from farmland) has led to increased algal cover of mudflats and this has had deleterious effects on the distribution and abundance of benthic invertebrates, notably *Corophium volutator* (Raffaelli *et al.* 1999). The estuary is now designated as a Nutrient Vulnerable Zone under the 1991 Nitrates Directive (Directive 91/676/EEC; Anon 1991b).

The effects of organic inputs from waste water discharges are thus likely to vary widely between sites due to the varying background nutrient and organic loading of estuaries and this needs to be taken into account in any investigation of the impacts of changing treatment. The box-modelling described in section 7 of this report, which is used to estimate the change in BOD concentration at an estuary scale after improvements to waste water treatment, takes into account the background BOD concentration at each site. As stated in that section, the impact of a particular outfall on a body of water will depend on the relative magnitude of the effluent in question relevant to all the other inputs, the background concentration of BOD in surrounding waters and the rate of exchange between the zone of interest and the surrounding water bodies.

4.2 Effects of Improved Waste Water Treatment on Invertebrate Populations

A number of studies have investigated how invertebrate (and algae) communities have changed following improved waste water treatment and have shown that both the direction and degree of change in species composition and abundance depends upon the level of nutrient and organic loading. Comparatively few of these studies come from the UK, however, reflecting a failure, perhaps, to implement research programmes into the effects of clean-ups. Results of the most relevant studies are described briefly below, where possible giving data on the scale of change in invertebrate abundance and biomass. It should be noted, however, that it is inadvisable to estimate changes in bird numbers directly from known reductions in invertebrate biomass (i.e. through knowing species' daily energy requirements). Goss-Custard *et al.* (2001), demonstrated that some Oystercatchers could still starve even though adequate food resources still existed for the entire population present on an estuary, due to the effects of interference competition.

4.2.1 Estuarine Mudflats

Recovery from Gross Pollution

In the Fraser River Estuary in British Columbia, primary treated sewage was formerly discharged directly onto the mudflats of Sturgeon Bank. Diversion of this sewage in 1998 resulted in a gradual colonisation of previously grossly polluted and empty sediments (i.e. those found within zone A of the Pearson-Rosenberg model) by the sewage tolerant polychaete *Manayunkia aestuarina, Corophium* spp. and *Macoma balthica* (which are more typical of zones B and C) (Rebele 1994). Harrison *et al.* (1999) though noted that the recolonisation of such mudflats may be affected by several interacting factors, including the organic carbon, metal and nutrient contents of the water and sediments as well as the sediment particle size. Recovery of the health of the estuarine environment in this study was monitored using two indicator species, *Corophium salmonis* and *Macoma balthica*.

Decreases in Invertebrate Abundance in Enriched Mudflats

In less polluted areas where waste water discharges have enriched sediments, improvements to treatment may result in a decrease in invertebrate abundance as communities return to those more typical of unenriched mudflats. On the Clyde Estuary, improvements to four sewage treatment works have been linked to a decline in the abundance of *Corophium volutator* and *Nereis diversicolor* (Curtis & Smyth 1982, Thompson *et al.* 1986). Overall densities of these species recorded in 1980 and 1981 (2,500-2,575 individuals/m^2) were apparently only about 65% of those found in 1974 and 1975 (by inference, c.3,850-3,960 individuals/m^2), prior to improvements to waste water treatment (Curtis & Smyth 1982). Species diversity at two study sites increased from 1-3 species in 1967-69 to 8-12 in 1976-77.

On the Firth of Forth, Read (1987) studied changes in invertebrate populations through the introduction of the Edinburgh Sewage Scheme in 1978. Here, eight discharges of crude or screened sewage were transferred to a new primary treatment works at Seafield and an 2,800 m long outfall discharging offshore. The sewage treatment works were designed to accommodate the previous dry weather flow of 250,000 m^3 of sewage per day and remove approximately 60% of the suspended solids. At a study site just west of the new treatment works and close to two of the closed outfalls, Read found that invertebrate abundance and biomass both fell following the introduction of the scheme (mean abundance from 59,952 individuals/m^2 between 1974 and 1977 to 10,608 between 1979 and 1981, and mean biomass from 873.6 to 153.6 g/m^2), whilst species diversity increased (from 6 to 16 species). The changes in abundance and biomass were primarily due to declines in *Capitella capitata* and *Scolelepis fuliginosa*. The abundance of these two species fell from peaks of over 8,000 and 192,000 individuals/m^2 respectively to almost zero in 1980. The latter species was particularly associated with the finer sediments formerly found close to the outfalls (Read & Renshaw 1977). Species that colonised the site included *Microphthalamus* sp., *Ophiodromus flexuosus*, *Eulalia viridis*, *Eurydice pulchra* and *monoculodes* sp. The invertebrates in the sediments thus changed from those typical of zone B of the Pearson-Rosenberg model to those more typical of zones C or D. The size of the area formerly affected by the discharge was not specified by the study.

In Boston Harbor, which was formerly grossly polluted, cessation of sewage sludge discharges in 1991 initially resulted in a general increase in invertebrate abundance and diversity over the following three years, with a particularly dramatic increase in the abundance and spread of the amphipod *Ampelisca* (Kropp *et al.* 2000). More recently, however, as the influence of organic and nutrient loading has waned further following the implementation of firstly primary treatment and then secondary treatment, there has been a gradual decline in the abundance and diversity of the infaunal community as it has reverted to one more typical of less-polluted environments.

4.2.2 Rocky Coasts

As mentioned above, invertebrates and algae on rocky shores may be less influenced by discharges of sewage than those inhabiting softer sediments. Reductions or cessation of discharges, therefore, may have correspondingly smaller impacts on communities in these habitats. Underwood and Chapman (1997), for example, looked at changes in a community of filter-feeding species, including sponges, ascidians, bryozoans and sea anemones, following the closure of an outfall by Sydney Harbour, Australia. Their study found that, despite years of discharge of first raw and then primarily treated sewage, there was little evidence that the assemblages by the outfall were originally significantly different from those found in control locations or that there had been any recovery since the closure of the outfall. Soltan *et al.* (2001) similarly showed that the diversity of algal taxa only increased marginally at a rocky shore site close to an outfall following the setting up of a waste water treatment plant.

4.3 Summary

- Sediments close to outfalls often become anaerobic due to a high Biochemical Oxygen Demand (BOD) and may in the most extreme cases become completely unsuitable for invertebrate life.

High nutrient loading encourages algae, which will add to the organic matter originating from the discharge itself and further increase the BOD.

- Beyond this zone, sediments are occupied by an abundance of a small number of opportunistic species, notably the polychaete *Capitella capitata*, that are able to tolerate a depletion of Dissolved Oxygen (DO). In the next zone, more moderate enrichment allows species characteristic of both polluted and unpolluted sediments to flourish and here the overall invertebrate biomass and diversity may peak. Species that may benefit from the enrichment in these zones include *Corophium*, *Eteone longa*, *Macoma balthica* and *Scolelepsis fuliginosa* and on rocky substrates *Mytilus edulis*. Beyond this, the influence of organic enrichment diminishes.
- The impact of a particular outfall on a body of water depends on the relative magnitude and treatment level of the discharge in question relevant to all the other inputs, the background concentrations of organic and nutrient inputs in the surrounding water and the rate of exchange between the zone of interest and the surrounding water bodies. The extent of the area impacted by individual discharges may range from only a few 100 m to over 1,000 m. Several large outfalls within a single estuary can cause gross pollution to all the sediments within the site.
- Inputs from farmland, in particular, may lead to high background levels of nutrients, and may themselves cause eutrophication of the estuaries.
- Improvements to discharges, except on the most grossly polluted sites, typically lead to reductions in invertebrate abundance, biomass and diversity. Species which may be reduced in abundance by the implementation of the UWWTD include *Capitella capitata*, *Corophium*, *Eteone longa*, *Macoma balthica*, *Scolelepsis fuliginosa* and *Mytilus edulis*.
- The potential effects of such changes to invertebrate populations on the bird species that prey upon them are discussed in section 6.2.3.

5. WASTE WATER OUTFALLS AND FISH POPULATIONS

A number of fish species feed on the invertebrates that are associated with sediments close to waste water outfalls. Whether they are able to benefit from these food resources, however, depends upon their ability to withstand the toxic effects of the effluent. As predators of these invertebrates, some species may act as competitors to birds (Furness *et al.* 1986). Others, though, may themselves provide an important resource for fish-eating birds such as grebes, cormorants, gannets, sawbill ducks and terns. This chapter looks firstly at the effects of nutrient and organic loading from waste water discharges on fish populations and secondly summarises studies that have investigated changes in fish populations following improved waste water treatment. The importance to birds of the fish populations associated with outfalls and the significance to them of the changes in fish populations associated with improved treatment are discussed in sections 6.1.3 and 6.2.4 respectively.

5.1 Effects of Waste Water Discharges on Fish Populations

A number of studies have looked at the effects of waste water discharges on fish, particularly in terms of their growth, immune responses and reproductive health (Costello & Gamble 1992, Secombes *et al.* 1992, Costello & Read 1993, Houlihan *et al.* 1994, Waring *et al.* 1996, Lye *et al.* 1997, 1998). Lye *et al.* (1998), for example, showed that sewage effluent could cause testicular abnormalities in male Flounder *Platichthys flesus* and result in an increased proportion of degenerating oocytes in females. As a result of this, the study found some limited evidence that wild populations of Flounder were suffering disturbances during their reproductive cycle.

Studies on the River Tyne have shown how fish populations may be associated with food sources associated with the outfalls. At sampling sites by a new outfall on this estuary, pelagic species such as Whiting *Merlangius merlangus* were high in number, probably due to the food resources within the effluent (Hall *et al.* 1997). However, benthic fish species, including Plaice *Pleuronectes platessa*, Flounder and Dab *Limanda limanda*, were comparatively low in number (Gill & Frid 1995, Hall *et al.* 1997), perhaps due to a lack of food, such as the amphipod *Corophium volutator* (Hall *et al.* 1997) Alternatively, the toxic effects of the effluent may have resulted in increased mortality or health problems in species associated with the estuary floor and thereby have affected their populations close to outfalls (Elliott *et al.* 1988). These species were more numerous at more moderately enriched sampling sites 1.5-2.5 km away.

Waldron *et al.* (2001) demonstrated, using stable isotope analysis, that organic matter derived from sewage in the Firth of Forth was utilised by the polychaete *Nereis virens*. Similar studies have analysed stable isotopes to determine how much of the diet of fish may stem from the organic matter discharged from outfalls. Spies *et al.* (1989), for example, found that 15-20% of the diet of species such as Dover Sole *Microstomus pacificus* near a Californian outfall was derived from sewage particulates. Moore *et al.* (1996) likewise found that the diet of Flounder off the coast of Massachusetts was in part derived from matter originating from outfalls.

5.2 Effects of Improved Waste Water Treatment on Fish Populations

Effects of improved waste water treatment upon fish populations vary according to the degree of past organic and nutrient loading and between fish species. A study on the formerly grossly polluted Tyne, for example, noted an overall increase in fish abundance and diversity, and the return of migratory salmonids, following the diversion since 1974 of raw sewage discharges to the Howdon Treatment Works, where they receive primary treatment (Pomfret *et al.* 1988). Whilst the bringing together of these discharges to one treatment site has improved overall estuary quality, however, there has been an increased impact at Howdon due to the resultant increase in the size of the discharge there (Hall *et al.* 1997). An increase in the BOD load of from 33.5 to 35 t/day between April 1993 and April 1994 coincided with a reduction of c.20% in the abundance of five invertebrate taxa (*Ophryotrocha hartmanni*, *Parathalestris clausi*, *Tubificoides* spp., *Eteone longa* and Nemotodes), but an increase of 300% in the total numbers of fish, largely due to a rise in the numbers of small pelagic species such as Whiting. Benthic fish species – Plaice, Flounder and Dab did not benefit in the immediate vicinity of the outfall in these studies and were more numerous 1.5-2.5 km upstream of the treatment works, where there was comparatively less deposition of particulate organic matter (Gill & Frid 1995, Hall *et al.* 1997) – see above.

The clean up of waste water discharges on the Thames also resulted in the return of species such as salmonids (Harrison & Grant 1976) and increases in DO on the Clyde have been linked in theory to increased numbers of Flounder (McKay *et al.* 1978, Henderson & Hamilton 1986). Likewise, in British Columbia, cessation of sewage discharges resulted in an increase in fish numbers, particularly in the area closest to the former outfall (Piercey *et al.* 1996).

In contrast, in areas of more moderate organic and nutrient loading, where invertebrate populations were formerly able to prosper, improved treatment may result in a decrease in fish numbers. In Australia, for example, Smith *et al.* (1999) found that improvements to sewage discharges reduced the relative abundance of several common species in the fish community and thus also the total abundance of fish.

5.3 Summary

- Although a number of fish species may benefit from the increased invertebrate food supply found near outfalls, benefits are likely to vary between species. Pelagic species such as Whiting have been shown to occur in increased numbers in the immediate vicinity of outfalls, whilst benthic species such as Plaice, Flounder and Dab avoid these areas, perhaps due to the toxic effects of the sewage. These benthic species may benefit in more moderately enriched areas.
- The effects of improved treatment depend upon the degree of past organic and nutrient loading and vary between fish species. Reductions in gross pollution may benefit many species, but reductions in moderate loading may decrease invertebrate food resources and potentially reduce the numbers of benthic species in particular.
- The potential effects of these changes to fish populations on the bird species that prey upon them or act as their competitors are discussed in section 6.2.4.

6. WASTE WATER OUTFALLS AND BIRD POPULATIONS

The food available directly from sewage and industrial discharges and the changes in invertebrate and fish densities resultant from organic inputs (as described in Sections 4 and 5) may have a large influence on the populations of waterbirds that the local coastal areas are able to support. Many bird species benefit directly from food resources found within the discharges. Further species prey upon the invertebrates found in the sediments close to outfalls or on the fish that also exploit these food resources. Fish may also act as competitors to birds feeding on invertebrates, however.

The links between waste water discharges and birds are described in a flow diagram in Figure 6.1 and are discussed below in section 6.1. Table 6.1.1 summarises the most important case studies on the association between waterbirds and outfalls. Section 6.2 and Table 6.2.1 summarise studies that have investigated changes in waterbird numbers following improved waste water treatment.

6.1 Avian Food Resources Associated with Waste Water Outfalls

6.1.1 Food Discharged Directly from Waste Water Outfalls

Gulls

A number of species feed directly on waste matter released in the effluent discharge from outfalls. Gulls are particularly opportunistic feeders and may feed on whatever food items are available in the discharge (Vernon 1970, Cramp & Simmons 1983). Ferns and Mudge (2000) in their study on the south Wales and Dorset coasts found that Black-headed Gulls *Larus ridibundus* took a range of vegetable matter, including plant seeds and potato peelings, as well as bread, meat and a variety of indigestible items, including pieces of plastic and string. Their study also found that the abundance of both Black-headed Gulls and Herring Gulls *L. argentatus* was positively correlated to the volume of sewage discharged and that numbers were reduced by over half during periods of infrequent intermittent discharge. Sewage outfalls only supported a small proportion of the local population of each species (11% and 3% respectively), and each was also found in large numbers at refuse tips and on fields. The outfalls in the Dorset study area also supported fewer gulls than those in Wales, partly because they discharged into deeper waters and consequently less food was made available from them. Black-headed Gull was the most numerous species at outfalls in both study sites and Ferns and Mudge suggested that the average particle size of food items available at the sewers was perhaps too small to provide an adequate return for larger species. Outfalls were particularly favoured by juveniles of each of these two gull species. Other gull species recorded included Common Gull *L. canus* and Lesser Black-backed Gull *L. fuscus* and, very occasionally, Great Black-backed Gull *L. marinus*, Little Gull *L. minutus* and Mediterranean Gull *L. melanocephalus*. One other study has also quantified the degree to which outfalls are frequented by gulls. Fitzgerald and Coulson (1973), looking at gull populations along the Tyne and Wear estuaries, found that outfalls were particularly frequented by Black-headed and Herring Gulls, but to a lesser extent by Lesser Black-backed Gulls, Common Gulls and Kittiwakes *Rissa tridactyla*. A number of other studies have looked at the possible human health risk that may result from gulls feeding at waste water outfalls and refuse tips (MacDonald & Brown 1974, Fenlon 1981, 1983, Butterfield *et al.* 1983, Fricker 1984, Monaghan *et al.* 1985). In particular, there is a worry that gulls may act as carriers of Salmonella between these sources and the inland water reservoirs that they roost on at night. Gulls and other coastal waterbirds, which feed at waste water outfalls, may also excrete large numbers of faecal coliforms and streptococci and thus affect the quality of bathing waters in a much larger area (Jones & Obiri-Danso 1999).

Wildfowl

The importance of sewage and some industrial outfalls in maintaining duck populations has been well documented. Studies in Scotland have described how flocks of Scaup *Aythya marila* and Goldeneye *Bucephala clangula*, in particular, were in the past concentrated near sewage outfalls or outfalls discharging waste from food factories, breweries and distilleries (Thom 1969, Player 1970, 1971, Milne & Campbell 1973, Pounder 1974, 1976a, 1976b, Campbell & Milne 1977, Campbell 1977, 1978, 1984, Barrett & Barrett 1985, Campbell *et al.* 1986). The diet of duck in the vicinity of outfalls at Leith and

Seafield in Edinburgh was described by Player (1970, 1971) and Campbell (1978). Their studies emphasized the importance of barley and maize grain and husk, directly discharged from distilleries, in the diet of Scaup and Goldeneye, and also of nematodes, nereid worms and gammarids, which would have been abundant in the nutrient, enriched sediments. Eiders *Somateria mollissima*, in contrast, fed primarily on mussels, which were less dependent upon discharges. Campbell (1978) reinforced the distinction made by previous studies in eastern Scotland (Thom 1969, Milne & Campbell 1973) between Scaup, Goldeneye, Pochard *Aythya ferina* and Tufted Duck *A. fuligula* that congregated in areas of artificially concentrated food and more marine seaducks – Eider, Common Scoter *Melanitta nigra*, Velvet Scoter *M. fusca* and Long-tailed Duck *Clangula hyemalis* – that usually gathered around more natural food concentrations. These latter species would be at less risk to changes in discharges than Scaup, Goldeneye, Pochard and Tufted Duck.

6.1.2 Invertebrate Food and Algae

Waders and Wildfowl

The changes in invertebrate and algal biomass found in the vicinity of outfalls are also likely to affect the densities of a number of other surface-feeding ducks and waders. The potential benefits to birds, however, will vary due to the degree of nutrient and organic enrichment and the possibility of pollution to mudflats and according to the variation in invertebrate abundance, biomass and diversity in zones away from the outfall (see Section 4.1 and Figure 4.1.1.1). The following paragraphs summarise studies that have shown how the densities of these birds are affected by the densities of their prey and indicate the favoured prey of some of the most widespread species. Following this, an assessment is made of how wader and wildfowl numbers might vary in zones (A to C) of increasing distance from waste water outfalls.

A number of studies have investigated how wader and wildfowl densities vary according to the dispersion of their prey. Goss-Custard (1970) and Goss-Custard *et al.* (1977), for example, demonstrated that Curlew *Numenius arquata* and Redshank tended to concentrate in those areas with the highest densities of their preferred prey – *Nereis diversicolor* and *Corophium volutator* respectively. Both these invertebrate species are also favoured by intertidally-feeding Lapwing *Vanellus vanellus* (Metcalfe 1985). Studies in The Netherlands have found that the densities of Knot *Calidris canutus* are related to the biomass of the most prevalent prey species, either *Macoma balthica* or *Cerastoderma edule* (Piersma *et al.* 1993) and those of Dunlin *Calidris alpina* greatest on muddier sediments where their favoured polychaete and shrimp *Crangon crangon* prey are most available (Nehls & Tiedemann 1993). Likewise, Goss-Custard *et al.* (1992) related the densities of foraging Oystercatcher *Haematopus ostralegus* to the densities of the favoured prey, mussels.

Yates *et al.* (1993) provided a more thorough analysis, relating the densities of waders and Shelduck *Tadorna tadorna* on the Wash to the densities or biomass of appropriate prey species. Their study found that, accounting for variation in sediment characteristics, Shelduck densities were positively related to densities of Oligochaetes and *Corophium arenarium*. Oystercatcher densities were positively related to *C. edule* densities and the area of mussel beds. Grey Plover densities were positively related to densities of Cirratulids and *Spio filicornis*. Knot densities were positively related to densities of *Macoma balthica* and those of both Dunlin and Curlew to densities of *Nephtys* spp. and *Scoloplos armiger*. Bar-tailed Godwit *Limosa lapponica* densities were positively related to densities of *Arenicola marina* and *Macoma balthica* and those of Redshank to *Nephtys* spp., *Scoloplos armiger* and Oligochaetes.

Goss-Custard *et al.* (1991) similarly looked at relationships between wader and prey densities on estuaries in the south-west of the UK, in order to be able to predict their densities following the possible barraging of the Severn Estuary. Taking into account variables relating to the estuary itself, sediment and year, their study found that Oystercatcher densities were positively related to those of mussels and *Scrobicularia plana*. Grey Plover and Curlew densities were both related to those of *Nereis diversicolor* and *Nephtys hombergii*. Dunlin densities were related to those of Bar-tailed Godwit densities were related to those of *Nereis diversicolor* and Cirratulidae and those of Bar-tailed Godwit to those of *Nereis*

diversicolor and *Scoloplos armiger*. Redshank densities were those of *Nereis diversicolor* and *Corophium voluator*.
Zone A

Close to outfalls, the extreme levels of nutrient and organic enrichment cause sediments to become deoxygenated and unsuitable for all but a few species of polychaetes, notably *Capitella capitata*, which due to their small size, provide relatively little benefit to birds. Over-enrichment in this zone may also lead to particularly dense mats of algae forming and their decay further depletes the sediments below of oxygen. Pounder (1976a) postulated that this may provide a short-term food bonanza for some species, such as Oystercatcher, as due to the lack of oxygen, shellfish such as Common Cockles *Cerastoderma edule* and *Macoma balthica* may be forced up to the surface. In the long-term, however, the sediments beneath the algal mats may become particularly impoverished of invertebrate food and this could in theory lead to local declines in bird numbers (Tubbs 1977, summarizing the conclusions of Dunn 1972, Southgate 1972 and Portsmouth Polytechnic 1976). McLusky (1968), for example, found that sewage polluted anaerobic sediments on the Ythan Estuary in north-east Scotland did not support *Corophium volutator* and thus were particularly poor areas for feeding Redshank (see above comments on the distribution of Redshank on intertidal mudflats). Such areas may still hold lugworms *Arenicola marina*, however, and thus could support the Curlew, Black-tailed Godwit *Limosa limosa* and Bar-tailed Godwit that feed upon them (Pounder 1976a). Although they may lead to an impoverished infaunal community, mats of algae, may themselves support moderate numbers of amphipods such as *Gammarus locusta*, Common Shore Crabs *Carcinus maenas* and *Hydrobia ulvae* (Tubbs 1977), the latter being an important food source for Shelduck, Pintail *Anas acuta* and Dunlin (Olney 1965, Cramp 1977, Cramp & Simmons 1983). *Enteromorpha* is also itself grazed by Wigeon *Anas penelope* (Cramp 1977).

Zones B and C

Beyond this polluted zone, oxygen levels rise and invertebrates may proliferate in the more moderately enriched organic levels (Pearson & Rosenberg 1978). This enrichment increases the overall abundance and diversity of invertebrates and may benefit a number of bird species (Pounder 1976a). In estuarine sediments, increases in the densities of *Nereis diversicolor* and *Corophium volutator* (particularly in zone C), for example, may benefit Lapwing, Curlew and Redshank (Goss-Custard 1969, 1970, Goss-Custard *et al.* 1977, Metcalfe 1985). On rocky shores, nutrient inputs from sewage outfalls may promote the growth of mussel beds and benefit Turnstones *Arenaria interpres* and Purple Sandpipers *Calidris maritima* (Eaton 2000b).

Insectivores

Studies using stable isotope analysis have shown that nutrients derived from the organic matter originating from discharges can pass up the food chain to invertebrates such as *Nereis virens* (Waldron *et al.* 2001) and fish, such as Flounder and Dover Sole (Spies *et al.* 1989, Moore *et al.* 1996). Using this approach, Wayland & Hobson (2001) similarly found that sewage-derived nitrogen could be detected in the body tissue of Tree Swallow *Tachycineta bicolor* nestlings raised adjacent to a municipal sewage treatment plant in Canada (using tertiary treatment) as well as the aquatic insects that formed 50-60% of their diet and occurred in greater numbers by discharges (Wayland *et al.* 1998). Likewise sewage-derived sulphur could be detected in the body-tissue of swallows raised by a pulp-mill effluent discharge. In this case, 19% of the sulphur in the swallows’ body-tissue could be attributed to the effluent.

Whilst this study looked at a species associated with freshwater habitats, such an approach could also be used to detect the importance of effluent-derived material in the diet of waterbirds at coastal outfalls.

6.1.3 Fish

In addition to the food available directly from outfalls and the invertebrates associated with them, the fish found around outfalls are also preyed upon by birds. Cormorants, for example, may benefit from the abundance of flatfish, such as Flounder, that feed upon the invertebrates found in moderately enriched sediments (Furness *et al.* 1986). In New Zealand, Australasian Gannets *Morus serrator* have been found to associate with outfalls (Robertson 1992). Other species that may benefit from these food resources include grebes, sawbill ducks and terns.

6.1.4 Studies of Relationships between Organic and Nutrient Loading and Bird Populations

A number of studies have investigated associations between bird populations and organic and nutrient loading at the estuary scale. These have recognised the importance of both point source inputs, such as those from waste water outfalls, and non-point sources, such as the run-off in river systems from agricultural wastes and nutrient inputs.

Tubbs (1977) found that nine of 13 waterbird species (Dark-bellied Brent Goose *Branta bernicla bernicla*, Wigeon, Teal *Anas crecca*, Oystercatcher, Grey Plover *Pluvialis squatarola*, Knot, Dunlin, Black-tailed Godwit and Bar-tailed Godwit) had increased in Langstone Harbour between 1952/53 and 1974/75 and attributed this partly to the increased local input of sewage effluent. (The main reason for change was a reduction in hunting pressure). Numbers of Ringed Plover *Charadrius hiaticula* fluctuated over this period, whilst those of Shelduck, Curlew and Redshank declined, perhaps, Tubbs speculated, due to decreasing prey densities and biomass in areas blanketed by *Enteromorpha* algal mats. Aerial photographs indicated that there was comparatively little algae in 1961, but that it spread to cover 75% of 264 ha of mudflats surveyed in 1974. No data were provided on changes in invertebrate densities, however.

Studies of the Rogerstown Estuary in Ireland (Fahy *et al.* 1975) and the Lillo-Rilland area of Holland's Delta Region (van Impe 1985) have also linked increases in organic and nutrient inputs (from sewage and industrial and agricultural wastes) to increases in algae and invertebrates and thus to increased bird populations. In the Lillo-Rilland area, the abundance of polychaetes increased significantly at two of three sites (by 80% and 220%) and the abundance *Corophium volutator* at all three (by between 1260 and 9180%) over the period between 1953/53 to 1983. Over this time the maximum numbers of Black-headed Gull and seven of nine species of wader (Oystercatcher, Avocet *Recurvirostra avosetta*, Grey Plover, Bar-tailed Godwit, Curlew, Spotted Redshank *Tringa erythropus* and Redshank) increased (by between 20 and 790%). Only numbers of Ringed Plover declined, whilst those of Common Sandpiper *Actitis hypoleucos* showed no apparent change.

On the Ythan Estuary, an increase in algal cover (from c.20 ha in 1954 to c.45 ha in 1995: Raffaelli *et al.* 1999) resultant from increased nutrient inputs from farmland, has reduced the abundance of *Corophium volutator* (Raffaelli *et al.* 1991, Raffaelli 2000) Possibly as a result, numbers of Oystercatcher, Dunlin, Bar-tailed Godwit, Curlew and Redshank declined between the early 1980s and the mid-1990s (Raffaelli *et al.* 1999). There was no direct evidence from this study that the decline in bird numbers was a result of the algal mats making prey less available.

Green *et al.* (1990) and Hill *et al.* (1993) investigated whether, in addition to physical, climatic and geographic variables, wader communities on British estuaries could be determined directly by water quality variables. Their studies found that the composition of wader communities was associated with salinity, ammoniacal nitrogen concentration in the water, percentage dissolved oxygen and the biochemical oxygen demand. In spite of these relationships, changes in the wader communities recorded over their 16 year study period were not related to any aspect of the nutrient status of estuaries. This was perhaps because their study investigated these relationships only prior to the implementation of the UWWTD, when the nutrient status of estuaries may have been such that food resources for waterbirds were less limited than they perhaps have been since. The fact that the study did find links between the composition of wader communities and water quality variables would suggest, however, that large changes in the nutrient status of estuaries, such as those resultant from the implementation of the UWWTD, could affect the numbers of some species.

Rehfisch and Austin (in press) presented similar preliminary work on the relationships between water quality variables and waterbird numbers in the UK. They found that total wader biomass and numbers of Redshank and Curlew could, to a limited degree, be related directly to variables such as ammoniacal nitrogen and percentage dissolved oxygen. Total wader biomass was positively related to the BOD of estuaries and thus might be expected to decrease as a result of the decreases in BOD associated the implementation of the UWWTD.

Ravenscroft (1998) studied the association between wintering waterbirds and freshwater inputs on the mudflats of East Anglian estuaries. Inputs included natural flows from streams and ditches as well as discharges from storm-drains and pipes. On the Orwell, Stour and Blackwater, he found that Shelduck, Wigeon, Pintail, Dunlin, Curlew and Redshank all used such stream corridors in greater numbers than would have been expected if birds were distributed evenly across the estuaries. Densities of Shelduck, Grey Plover, Dunlin, Curlew and Redshank were also positively related to the rate of discharge of flows into the Orwell. These associations were attributed to the increased nutrient and freshwater flow into the mudflats.

The wildfowl and wader species that these studies (and those in section 6.1.2) thus suggest might decline as a result of the implementation of the UWWTD include Brent Goose, Shelduck, Wigeon, Teal, Pintail, Oystercatcher, Avocet, Grey Plover, Lapwing, Knot, Purple Sandpiper, Dunlin, Black-tailed Godwit, Bar-tailed Godwit, Curlew, Spotted Redshank, Redshank and Turnstone.

6.2 Effects of Improved Waste Water Treatment

A number of studies have reported changes in waterbird numbers following improved waste water treatment, though comparatively few have offered quantitative information that has linked such changes to alteration of the birds' food supply. Table 6.2.1 summarise the results of the most important of these studies.

6.2.1 Recovery from Gross Pollution

In some cases it is probable that improved waste water treatment may benefit birds. Some British estuaries, such as the Thames and Mersey, were formerly so grossly polluted by sewage and other effluent that many mudflats had become anaerobic and had a relatively impoverished invertebrate fauna (as is typical of mudflats within zone A of the Pearson-Rosenberg model). Recent increases in bird numbers on these estuaries (Atkinson *et al.* 2000) have been attributed to a re-establishment of a variety of invertebrates following improvements to sewage works and a change to the more moderately enriched sediments characteristic of zones B and C in the Pearson-Rosenberg model (Harrison & Grant 1976, Head & Jones 1991, National Rivers Authority 1995). No studies have been undertaken to determine whether this has actually been the case, however. Other studies have focussed upon the problems that contaminants in sewage and other effluents may cause and how improved waste water treatment may reduce the incidence of toxins in birds' tissues (Harrison *et al.* 1999, Wilson *et al.* 1999).

6.2.2 Reductions in Food Discharged Directly from Waste Water Outfalls

Gulls

In areas where waste water discharges provide large quantities of food directly into coastal ecosystems or where they have enriched the invertebrate biomass, improvements to treatment have the potential to seriously deplete bird populations. The following studies have monitored gull numbers during changes in sewage treatment.

On the Tyne Estuary, where five of six species of gull formerly used untreated sewage as a food source (Fitzgerald & Coulson 1973), declines of 93% and 91% in the numbers of Common Gulls and Great Black-backed Gulls respectively were recorded between 1969/70 and 1993/94 following improved treatment and an 86% decrease in the volume of untreated waste discharged into the river (Raven & Coulson 2001). In the former case at least, there was no evidence that numbers had changed elsewhere within the region. Numbers of Black-headed and Herring Gulls, the two species most linked with sewage outfalls (Fitzgerald & Coulson 1973), did not change significantly, however, whilst those of Lesser Black-backed Gull and Kittiwake rose due to increases in the sizes of breeding colonies nearby (by 468% and 195% respectively).

A similar study in New Zealand, found that following improved treatment of waste discharges into Wellington Harbour, numbers of Dominican Gulls *Larus dominicanus* declined, whilst the population of Red-billed Gulls *L. novaehollandiae* became concentrated around the one outfall where sewage remained untreated (Robertson 1992). The changes in the volumes of the discharges, and thus in the likely food supply, were not recorded, however.

Wildfowl

Studies in Scotland have demonstrated how dependent internationally important populations of duck formerly were on effluent discharges (Thom 1969, Player 1970, 1971, Milne & Campbell 1973, Pounder 1974, 1976a, 1976b, Campbell & Milne 1977, Campbell 1977, 1978, 1984, Barrett & Barrett 1985, Campbell *et al.* 1986). Pounder (1976a) expressed the concern felt by many about changes in sewage disposal and highlighted several areas where the introduction of primary treatment, settlement systems or the combination of separate short outfalls into single outfalls discharging into deeper water, could affect birds.

The impact of changes at Leith and Seafield was reported by Campbell (1984). Here untreated sewage from Edinburgh was formerly discharged directly into the Firth of Forth via eight main outfalls (Anderson *et al.* 1981), but this system began to be replaced in February 1978 when a primary treatment plant came into operation. In the two winters following the plant's implementation, Campbell (1984) found that there had been considerable declines in the local numbers of both Scaup and Goldeneye between Leith and Levenhall – from peaks of 10280 and 2334 in 1975/76 respectively to 675 and 608 respectively in 1979/80 – and that the remaining birds preferentially used those outfalls least affected by the changes (see also Bryant 1987 for a summary). It was unclear, however, whether the fall in numbers was due to a redistribution of birds to other coastal sites or whether the changes had actually affected the species' populations. Waterfowl counts carried out since the late 1960s suggest that Goldeneye populations have in fact risen in Great Britain since the late 1970s (Musgrove *et al.* 2001b). No comparable data are available for Scaup.

Similar declines have been reported on the Moray Firth. The closure of a maltings, improvements to a distillery's effluent and the creation of a new deep water outfall for sewage have been linked to dramatic falls (i.e. of over 50%) in the numbers of Goldeneye in the Invergordon-Dalmore and Burghead areas and the closure of an outfall at Carn Arc to the disappearance of Tufted Duck and a small flock of Goldeneye there (Barrett & Barrett 1985). Similarly, Thom (1969) linked declines in Mallard *Anas platyrhynchos* and Teal numbers (from peaks of 1554 and 4390 respectively in 1962/63 to 416 and 1294 respectively in 1967/68) on the Tullibody Island – Kennet Pans stretch of the Firth of Forth to a cessation of distillery wash. Musgrove *et al.* (2001a), likewise, reported a decline in Mute Swan *Cygnus olor* numbers on the Stour Estuary following closure of a brewery. More recently Marsh (2000) noted a decline in the numbers of Goldeneye following the clean up of the Sandylands outfall in Lancashire.

6.2.3 Reductions in Invertebrate Food Associated with Waste Water Outfalls

Species of invertebrates which may be reduced in abundance by the implementation of the UWWTD include *Capitella capitata*, *Corophium*, *Eteone longa*, *Macoma balthica*, *Scolelepsis fuliginosa* and *Mytilus edulis*. Bird species associated with these invertebrate prey and areas enriched by organic and nutrient loading (as identified in sections 6.1.2 and 6.1.4) and thus also potentially at risk include Brent Goose, Shelduck, Wigeon, Teal, Pintail, Oystercatcher, Avocet, Grey Plover, Lapwing, Knot, Purple Sandpiper, Dunlin, Black-tailed Godwit, Bar-tailed Godwit, Curlew, Spotted Redshank, Redshank and Turnstone.

Previous changes in waste water treatment and disposal have been linked to changes in the numbers of several of these species. Comparative data on food supply have seldom been presented in these studies, however, and where they have, have had to be drawn from elsewhere.

Estuarine Waterbirds

On the Clyde Estuary, changes in waste water treatment have been linked to changes in the numbers of both wintering waders and wildfowl. Prior to the 1970s, the estuary had been recovering from high pollution levels and over-enrichment of its mudflats and the initial reduction in pollution levels was speculatively linked to a concurrent increase in the numbers of waders (McKay *et al.* 1978, van Impe 1985). More recent study has shown that between 1972-77 and 1978-85 numbers of Oystercatcher, Lapwing, Dunlin and Redshank declined by 19%, 59%, 85% and 60% respectively. These declines by far exceeded the changes in the national midwinter index over the same period (+15%, -1%, -24% and -11% respectively) (Furness *et al.* 1986). Numbers of Shelduck and Pintail also declined significantly, though, in contrast, the numbers of Curlew fell by only 3% - in line with the national trend. Though data on changes in the densities of invertebrates in the estuary over this period were difficult to obtain, Furness *et al.* (1986) believed that the declines in the bird populations were due to a shortage of food, particularly of *Corophium volutator* and *Nereis diversicolor*. Densities of these species recorded in 1980 and 1981 were apparently only about 65% of those found in 1974 and 1975 (Curtis & Smyth 1982). This, Furness *et al.* (1986) suggested, was due either to the reduced nutrient enrichment of the mudflats or increased consumption of these invertebrates by fish. The latter theory was supported by the increase in numbers of Cormorants *Phalacrocorax carbo*, which feed mainly on flatfish. Flounders, in particular, are important predators of *Corophium volutator* (Summers 1980) and apparently benefited on the Clyde from reduced waste water pollution and resultant increases in DO (McKay *et al.* 1978, Henderson & Hamilton 1986) (see also Section 6).

Similar changes in organic pollution were also linked to declines of over 50% in Knot and Dunlin numbers at Kinneil on the Firth of Forth between 1971/72 and 1985/86 (Bryant 1987). These declines were also influenced by the loss of intertidal habitat during the same period, however. No information was given in this study on the changes in invertebrate densities at the site.

At Heswall on the Dee Estuary, where the Ramsar Convention Bureau recommended that a monitoring project should be set up to monitor changes resultant from upgrading sewage treatment, Wetland Bird Survey (WeBS) counts have indicated a decline (of over 50%) in the numbers of Redshank in the two winters since improvements began (Smith 2000). A similar sewage improvement programme has been implicated in a decline of Knot at Cleethorpes, though precise details of the scale of this decline were not given (Pearce 1998). In neither of the latter two cases were other species discussed, nor information given on invertebrate densities.

Waterbirds of Rocky Shores

A more recent study investigated whether Purple Sandpipers and Turnstones had been affected by the cessation of the discharge of untreated sewage from short outfall pipes off the rocky coast of Hartlepool Headland in April 1998 (Eaton 2000b). A major improvement programme during the mid-1990s resulted in all sewage from the town being discharged further south having first received secondary treatment. Comparison of counts of birds between September 1999 and June 2000 and those undertaken between 1991 and 1994 showed no significant differences in bird numbers that could be attributed to the removal of sewage inputs. Furthermore, survival rates did not differ between the two periods and the diet of Purple Sandpipers appeared superficially similar to that recorded in an area at Blyth still enriched by sewage discharges. Food availability was not compared between the two study periods, however.

The study at Hartlepool was limited because data were collected for only one year after the cessation of sewage discharge and it is possible that the impacts of this on invertebrates and thus bird populations may not have become apparent until later. As a result it is difficult to draw firm conclusions from the results. As suggested in section 4.2, however, rocky shores may theoretically be less enriched by sewage discharges than the soft sediments found in estuaries. Any reduction in discharges, therefore, may be less likely to affect the invertebrates and algal communities of rocky shores (Underwood & Chapman 1997, Soltan *et al.* 2001) and thus the birds that are associated with them. Until more firm comparisons are made, however, it would be negligent to disregard the potential impacts in these habitats.

6.2.4 Changes in Fish Populations

Fish-eating Seabirds

As noted in Section 5, waste water discharges have been linked with both increase and decreases in the abundance of fish populations. Benthic fish species were noted to be low in abundance close to outfalls, partially due to low food supplies and partially due to toxins in the discharges. Pelagic species such as Whiting, in contrast, have been shown to increase in number close to outfalls.

Improvements to waste water treatment may thus benefit some fish species and be disadvantageous to others and therefore, in turn could be either of benefit or disbenefit the bird species that prey upon them. As noted above, an increase in the numbers of Cormorants on the Clyde Estuary following improved water treatment was linked to an increase in numbers of Flounder (Furness *et al.* 1986). The latter had probably benefited from increased numbers of *Corophium volutator.*

In contrast, bird species that prey upon the more pelagic fish species that benefit from waste water discharges, may decline following improved treatment. Such an effect has been recorded in New Zealand, where numbers of Australasian Gannets fell around a sewage outfall as less waste was discharged, probably because of a decline in fish stocks (Robertson 1992).

Improved treatment may thus potentially also be a problem in the UK for species such as Common Terns *Sterna hirundo* and Arctic Terns *Sterna paradisaea*, which include fish species such as Whiting in their diet (Cramp 1985). However, whilst there have been many studies on the impacts that the accumulation of various pollutants may have upon tern breeding biology (e.g. Becker 1991, Becker *et al.* 1993, Hoffman *et al.* 1993, Thompson *et al.* 1993, Bosveld *et al.* 1995), there is little understanding of the influence that waste water outfalls may have upon tern food supplies. Current research at Durham University (undertaken by Kathryn Fletcher under Keith Hamer and funded by Northumbrian Water PLC) aims in part to investigate the link between food supplies associated with outfalls and food provisioning and parental investment in Common and Arctic terns.

6.3 Summary

- Many bird species benefit from the food resources associated with the discharges.
- Gulls are particularly opportunistic and take a range of food items directly from discharges. Grain and other matter from food factories, breweries and distilleries may also provide considerable food for ducks.
- Invertebrate populations enhanced by the nutrient and organic enrichment may provide food for wildfowl and waders, but also fish that may act as competitors.
- Further species may prey upon the fish that also exploit these food resources.
- Reductions in the food discharged directly from waste water outfalls have been associated with declines in Common Gulls and Great Black-backed Gulls and, notably in Scotland, duck species such as Scaup, Goldeneye, Pochard and Tufted Duck. Little evidence exists of a change to the national populations of these species, however. More maritime species of duck (Eider, Common Scoter, Velvet Scoter and Long-tailed Duck) that usually gather around more natural food concentrations are potentially less at risk.
- Improvements to discharges, except on the most grossly polluted sites, have the potential to lead to reductions in the numbers of waders and certain wildfowl, at least within sites, due to reductions in invertebrate abundance, biomass and diversity. There is only limited evidence that this has already occurred, however. Species of waders and wildfowl that prey upon intertidal invertebrates that are potentially at risk from the implementation of the UWWTD include Brent Goose, Shelduck, Wigeon, Teal, Pintail, Oystercatcher, Avocet, Grey Plover, Lapwing, Knot, Purple Sandpiper, Dunlin, Black-tailed Godwit, Bar-tailed Godwit, Curlew, Spotted Redshank, Redshank and Turnstone.

7. DATA COLLECTION AND ANALYSIS

7.1 Introduction

This section summarises the collation of waterbird count data and information concerning the locations of outfalls, the dates of changes in treatment to discharges from these outfalls and the quality of the waste water discharged. These data are collated on an Arc View Geographical Information System (GIS) Project, which should be read in conjunction with this report and which is supplied separately on a CD-ROM. The section also contains an initial simple analysis of trends in bird populations on two estuaries, the Orwell and Mersey, in relation to changes in BOD following waste water treatment, as revealed by box modelling.

The first aim of the collation of the data was to determine how many SPAs important for waterbirds have already been affected by changes in the treatment of discharges. The second aim was to identify those sites for which the relationships between improvements in water quality and changes in bird numbers could be analysed.

An Annex to this report (published separately) contains information concerning outfalls where changes to discharges have not yet occurred, an analysis of the degree of change or proposed change in loading from the sewage treatment works into each SPA and the implications of these changes for waterbirds within each SPA, and identifies SPAs where further investigation is required.

7.2 Methods

7.2.1 Waterbird Count Data

Data concerning waterbird numbers have been collected primarily from the Wetland Bird Survey (WeBS) Core Count and Low Tide Count Schemes. The Core Count Scheme collects information for most waterbird species on a monthly basis on examples of each wetland habitat across the UK, including most estuarine and many freshwater sites, as well as a relatively few non-estuarine coastal sites. Coastal sites are mostly counted at high tide. Data have been collected annually for all major estuaries since the 1970s. The data are primarily used to provide winter population estimates for species at national and site levels and thus to indicate long-term changes in numbers (Musgrove *et al.* 2001b).

Collation of data for this project concentrates upon the bird numbers recorded within Special Protection Areas (SPAs). A list of these sites is given in Table 7.2.1.1, together with the species for which they are notified. For estuarine sites, analysis of Core Count data may determine whether long-term changes in water quality have affected bird numbers within a whole estuary / SPA. For the one non-estuarine Core Count site – the Northumbria Coast SPA – data analysis would be undertaken at a sector (individual count section) level.

The Low Tide Count Scheme provides data on the numbers of waterbirds present on subdivisions of the intertidal habitat within each estuary. Counts are undertaken by volunteers monthly from November to February within the period two hours either side of low tide (Musgrove *et al.* 2001b). Sites for which counts have been undertaken are summarised in Table 7.2.1.2. As this table shows, few sites are counted every year. For those sites with more than one year's counts, however, these data provide the best means for analysing the responses of waterbirds to changes in water quality as they are able to accurately show changes in species' feeding distributions. The major determinant of the presence of a species on a site is the availability of good feeding conditions.

In addition to these two main sources, data have also been collated for non-estuarine habitats from two one-off waterbird surveys – the January 1985 Winter Shorebird Count (WSC) and the Non-Estuarine Waterfowl Survey (NEWS) of January 1998. Both surveys recorded birds during the low tide period on intertidal areas on stretches of non-estuarine coast, usually less than 4 km long. The WSC covered 78% of the UK's non-estuarine coastline and NEWS 38% (Rehfisch *et al.* submitted). Non-estuarine coastal habitats hold a high proportion of the UK populations of Ringed Plover, Sanderling *Calidris alba*, Purple Sandpiper and Turnstone.

Further data concerning waterbird distributions are available from the BTO's own project work for the Mersey Estuary and intertidal areas at Barrow at the northern edge of Morecambe Bay. These projects recorded bird numbers and their distributions not only at low tide, but also at hourly intervals through the tidal cycle ('Through-The-Tide-Counts' – TTTCs).

Information concerning each of these sets of data have been collated on the GIS Project. Locations of all coastal WeBS Core Count Sites in England and Wales are shown, together with the stretches of coast surveyed for the WSC and NEWS, and count sections used in BTO surveys of the Mersey and Barrow mudflats. The GIS Project also contains all Low Tide Count information data collected up to and including the winter of 2000/01.

7.2.2 Receiving Water Quality and Effluent Quality Data

In parallel with the collation of data concerning the numbers and distribution of waterbirds, appropriate water quality data have been collated from two principle sources: the Water and Sewerage Companies (WSCs) and the Environment Agency (EA). The EA holds a national database of water quality measurements covering the whole of the coastline of England and Wales, including significant parts of the major estuaries. The EA also holds effluent discharge consents (which it issues to WSCs) for all licensed waste water discharges to all waters and substantial effluent sample data which it uses to monitor the compliance of effluent discharges with the consent conditions. The WSCs also hold copies of the consent conditions and asset databases detailing the location of their outfalls.

In order to focus the collection of relevant data, we used two approaches. Firstly, we recognise that the WSCs have, over the past 10 years, been operating according to two Asset Management Plans (AMPs), known as AMP1 and AMP2. These defined the sewerage /sewage treatment improvements (amongst other things) which would be provided during the periods 1990-1994 and 1995 to 1999 respectively and thus can be used as a guide to changes in treatment levels and flows from coastal and estuarine outfalls. AMP1 dealt mainly with discharge to bathing waters, while AMP 2 picked up the remaining discharges to bathing waters and dealt with some early schemes required to meet the UWWTD. Although, the AMP1 and AMP2 programmes for each WSC were published, the publicly available versions did not provide sufficient detail for this project. However, the EA (and before it, the NRA) did keep a record of the proposed changes to treatment levels. Information on discharge consents before and after the year in which the treatment of waste water was upgraded was received from EA regional offices, namely Anglian, North West, South West, Southern, Severn Trust and North East. These data will be most useful in Phase II of the Project, when it will be used, together with the AMP3 (2000-2005) data (already obtained), to assist in predicting the future impacts of the UWWTD on organic loading to estuaries and coastal waters. In addition to the consent data, the EA regions mentioned above provided us with annual effluent quality data for the period 1990 to 2000 for BOD, COD, ammonia, total nitrogen, suspended solids, nitrate and orthophosphate. The EA also provided water quality data from their National Monitoring Programme, Baseline Data sites and from a survey specifically focussing on the Severn Estuary.

Data from WSCs were collated to identify the locations of outfalls where there have been major changes to coastal/estuarine discharges in the last ten years. In addition, WSCs provided information on consented flows and effluent quality and the required treatment level for these discharges, before and after the improvements. These data have been provided by Anglian Water, Southern Water, South West Water, Severn Trent Water, Welsh Water and United Utilities (formerly North West Water). Data were not obtained for parts of Wales, or from Wessex Water or Northumbrian Water.

The information concerning the locations of outfalls where there have been major changes to coastal/estuarine discharges in the last ten years, dates of changes to discharges and data concerning the water quality of discharges have been collated on the GIS Project, for cross reference with information concerning the distribution of bird populations and the locations of SPAs. Subsequent analyses look at the correlation between waterbird numbers and BOD concentrations – estimated using box modelling – within two estuaries, the Orwell and Mersey. The EA effluent data provided in the GIS Project also provide a good indication of changes subsequent to improved treatment. Sample water quality data obtained from the EA for points within estuaries were more limited temporally and were not used in subsequent analyses, although the locations of sample points are shown on the GIS Project.

Information concerning outfalls where changes to discharges have not yet occurred is contained in the Annex to this report.

7.2.3 Box Modelling

The box modelling aims to give an indication of the average concentration of BOD within a whole or part of an estuary or a segment of near-coastal water. The impact of a particular outfall on the body of water will depend on:

- The relative magnitude of the effluent in question relevant to all the other inputs to the body of water
- The typical concentration of BOD in surrounding waters (the background value)
- The rate of exchange between the zone of interest and the surrounding water bodies.

The method described here is similar to that used in determining the potential for eutrophication during comprehensive studies of outfalls under Article 6 of the EU Urban Waste Water Treatment Directive (CSTT 1994).

In general, the reduction in the BOD load from the waste water treatment works is of the order of 5 to 100 times. Often, the Waste water Treatment Works (WwTW) is the largest source of organic effluent. If there is a high concentration of organic material in the surrounding waters then the relative impact of the treatment works effluent is reduced.

The rate of exchange depends on the hydrodynamics of the study area. In an estuary where the tidal volume is a large fraction of the total volume, the exchange rate will be large. For coastal waters, especially for deeper waters, the exchange rate could be very small.

The box model is a mass balance over the zone of interest :

MASS IN = MASS OUT + ACCUMULATION

For an estuary such as the Orwell, where the discharge of effluent is near the tidal limit, the zone of interest can be considered to be a box with only one open side, the open side being the mouth of the estuary.

Over a tide the individual terms can be replaced by :

MASS IN = $S_{outfall} + \Sigma S_i + V_t C_{back}$

MASS OUT = $V_t C_{box}$

ACCUMULATION= 0

Where

$S_{outfall}$ is the load from the outfall of interest (mass per tide)

S_i is the load from a discharge into the box (a treatment works, a river or an industrial input)

V_t is the tidal volume – the amount by which the box volume changes over a tide

C_{back} is the concentration of BOD in the surrounding body of water

C_{box} is the average concentration of BOD in the box

The accumulation term is set to zero, as it is assumed that the system is in a steady state, and that the mass of pollutant in the box is the same at the beginning of each tide as it is at the end.

$C_{box} = C_{back} + (S_{outfall} + \Sigma S_i)/ V_t$

In an open body of water, the exchange of water is more complicated and the tidal volume is replaced by EV, where E is an exchange coefficient and V is the average volume of the box below the mean tidal level. In estuaries, E can be estimated as

$E = V_t/V$

E lies between 0 (for a non tidal area) and 1 per tide (where there is no low tide volume). For the estuaries of interest in this study, E lies between 0.5 and 1 per tide. For outfalls discharging to coastal waters values of E as low as 0.05 per tide have been used. In the case studies that follow, E is used in units of per day.

7.2.4 Analysis of Trends in Bird Populations on the Orwell and Mersey in Relation to the Results of Box Modelling

Trends in bird populations on the Orwell and Mersey Estuaries were investigated in relation to the results of box modelling using WeBS Core Count data for those species present in nationally important numbers on the sites (see Musgrove *et al.* 2001b). Data were already analysed for these estuaries, unlike the sites at Barrow and Southampton Water. The Mersey Estuary is a relatively enclosed site and there is restricted movement of birds in or out of the site between low and high water. It is thus safe to assume that changes in the numbers of birds feeding on intertidal mudflats, such as those potentially caused by changes to waste water discharges, would be reflected in the numbers recorded at high tide by WeBS Core Counts. The Orwell Estuary is less enclosed, being adjacent to and part of a single SPA with the Stour Estuary. Movements between these estuaries are limited enough, however, to assume also that WeBS Core Counts accurately monitor the numbers of birds that feed in the estuary (R. Leavett, N. Ravenscroft, M. Wright pers. comm.).

Data were analysed using General Additive Models to produce indices of the population for each species each winter (relative to that in the last winter, usually 1999/2000, which was set to 100). For each species, there are a recommended series of months, which are traditionally used to index that population (Musgrove *et al.* 2001b). These are December, January and February for waders but different months are used for wildfowl, ranging between one to seven months for each species. Data were extracted from the WeBS database and the Fortran program GAIM used to smooth the count data. Models used a maximum number of degrees of freedom (number of years minus 1) so as to fit indices unconstrained by data from other years (Atkinson *et al.* 2000, 2001).

Trends in these indices are compared graphically with estimates of the BOD load to each estuary obtained through box modelling. For the Orwell, the primary source of effluent was the Ipswich – Cliff Quay outfall. For the Mersey, three main areas were considered in calculating overall BOD Load – Liverpool, Widnes and Warrington, these covering the major outfalls at Liverpool WwTW, Widnes (formerly Halewood) WwTW, and Warrington North respectively.

For both estuaries, the degrees of correlation between the estimated average BOD concentration in the estuary and waterbird indices for the subsequent winter were also calculated. (BOD concentration was assumed to be stable at the pre-treatment level for the years 1991 to 1995 for the Orwell – see Table 7.3.2.1 – and for 1991 to 1997 for the Mersey – see Table 7.3.2.3).

These comparisons make two assumptions. Firstly, that the BOD in the water column estimated by box modelling is reflected by that in the sediments. Secondly, that BOD reflects organic and nutrient loading and thus is related to waterbird numbers through their influence on invertebrate abundance, biomass and diversity. As shown by Green *et al.* (1990) and Hill *et al.* (1993), these assumptions have some validity.

7.3 Results

7.3.1 Overview of the GIS Project (supplied on CD-ROM)

The GIS Project holds information on the locations of coastal WeBS Core Counts, WeBS Low Tide Counts, stretches of coast covered by the WSC and NEWS, relevant BTO count sites, SPAs, the locations of outfalls where there have been major changes to coastal/estuarine discharges in the last ten years, data concerning dates of change to discharge treatment and the quality of water discharged and the locations of EA water quality sampling. Information concerning outfalls where changes to discharges have not yet occurred is contained in the Annex to this report.

Dot-density maps indicate the distribution of birds on WeBS Low Tide Count Sites for each year for which data were collected. Focussing in on individual sites also reveals the boundaries of SPAs. Subdivided areas surveyed for two specific BTO projects – on the Mersey and at Barrow on the northern edge of Morecambe Bay – are also shown.

Within the GIS, information is provided on the name and grid reference of each outfall, a description of any change in discharge at the site (including information on the size of consented flows) and the date of any such change. Additionally, Excel spreadsheets of data concerning the quality of the discharges are provided for a high proportion of the outfalls. Data concerning outfalls are not complete. Limited data were received from Welsh Water or Northumbrian Water. It should also be noted that the locations provided for some outfalls may be those of the treatment plant, not the end of the outfall itself.

Outfalls where there had been recent changes to discharges were present in or adjacent to a minimum of 17 of 54 coastal SPAs (Appendix 4). Discharges have changed at all of these sites in the last ten years. Outfalls where major changes have occurred in the last ten years are listed in Table 7.3.1.1.

An examination of WeBS Low Tide data also indicates that, in many cases, waterbirds are apparently concentrated on mudflats around the locations of waste water outfalls. An example of the low tide feeding distribution of Dunlin in the Stour and Orwell Estuaries produced from the GIS is shown in Figure 7.3.1.1, together with the boundary of the SPA. On the Orwell Estuary, the greatest density of Dunlin was found on mudflat count sections adjacent to the Ipswich – Cliff Quay outfall. Other species that were found in this area of the estuary include Shelduck, Pintail, Black-tailed Godwit and Redshank – all species that would be expected to benefit from organic enrichment of mudflats (see section 6). Discharges of crude sewage at this outfall were terminated in June 1995 and waste water from the outfall now receives primary treatment. Examination of the GIS Project reveals similar associations between the distributions of waterbird species and the locations of outfalls on several other estuaries.

7.3.2 Case Studies of Box Modelling

Orwell Estuary

The largest source of effluent into the Orwell Estuary is the discharge from the Cliff Quay WwTW, which is about 1km from the tidal limit. The BOD load from this discharge was significantly reduced in 1995 from 9900kg/day to 340kg/day. Results of modelling are shown in Table 7.3.2.1.

The Orwell Estuary is represented as three boxes:

- Box 1 – approximately 1 tidal excursion from the outfall
- Box 2 – approximately 2 tidal excursions from the outfall
- Box 3 – approximately 3 tidal excursions from the outfall

The length of the tidal excursion is proportional to the mean velocity. In the Orwell, the mean velocity is about 0.5 m/s at the mouth and about 0.2 m/s near the outfall. Thus, the length of the tidal excursion increases down the estuary. The tidal excursion based on the mean velocity at the mouth is 11km, while based on the upper estuary velocity it is 4.5km. As the length of the Orwell from the confluence with the Stour to its tidal limit is about 15km, we have assumed that Box 3 represents the whole estuary, Box 2 about 2/3^{rds} of the estuary and Box 1 about 1/3rd of the estuary. Data on the hydrodynamic characteristics of the Orwell was obtained from a number undertaken by HR Wallingford over the last 10 years in the vicinity of Ipswich and Harwich (HR Wallingford 1995a; HR Wallingford 1996; HR Wallingford 1997; HR Wallingford 2000).

The Orwell has a large ratio of tidal volume to total volume (65%). There is a dredged navigational channel, which maintains a sub-tidal volume. As the data on the volume changes used to calculate the exchange ratio was limited to the whole estuary, it was assumed that the volume of the boxes would be determined from the whole estuary volume and scaled according to their length. Although this approach may underestimate the volumes of Boxes 1 and 2, the resulting predictions in the relative change in concentration are representative of the impacts of the change in the effluent loading.
There are two other significant discharges to the Orwell (Metoc 1996)

- Shotley WwTW
- BSC Sproughton

Before the improvements to Cliff Quay WwTW, these two outfalls discharged only about 4% of the total BOD load to the estuary. After the changes to Cliff Quay, this proportion rose to about 40%. The total input of BOD from these two discharges is 430 kg/day.

In addition, the River Gipping also carries about 430 kg/day of BOD into the Orwell.

The background concentration was set to 1 mg/l, as this is typical of coastal waters in the UK (HR Wallingford 1995b). It is doubtful whether BOD can be measured accurately at concentrations lower than this.

Data relating to the effluent sources and receiving water quality was supplied by Anglian Water and the Environment Agency.

Mersey Estuary

There are three significant WwTWs on the Mersey that have had reductions in BOD load under the UWWTD – Liverpool, Warrington North and Widnes. As the Mersey is a large estuary, three boxes were defined, one for each of the WwTWs at which there had been significant changes in organic load. Each box is one tidal excursion from the outfall. The Liverpool WwTW outfall is within the narrows of the Mersey and the outer limit of its box was set at the mouth of the narrows. For Warrington WwTW the landward limit of its box is set at the tidal limit. The estimates of the tidal excursions were based on data form numerical models developed by HR Wallingford (HR Wallingford 1991; HR Wallingford 1992; HR Wallingford 1993). Results of modelling are shown in Tables 7.3.2.2 and 7.3.2.3.

The volumes of the boxes used for the purposes of the box modelling exercise were based on the analysis of the inter-tidal and sub tidal volumes made by HR in 1999 (HR Wallingford 1999). In that analysis the estuary was divided into six compartments. Box 1 was assumed to cover two of these compartments in the outer estuary (Rock Light to Dingle) into which Liverpool WwTW discharges. Box 2 was assumed to cover one compartment between Hale Head and Runcorn Gap into which Widnes WwTW discharges. Box 3 was based on the single compartment between Fiddler's Ferry to the tidal limit at Warrington, which included the discharge from Warrington North WwTW. Only three of the six estuarine compartments are being considered for the modelling exercise and they are those within a tidal excursion of a significant outfall with significant changes in the treatment of the waste water. The remaining compartments are not within a tidal excursion of a significant outfall at which there had been significant changes in organic load, and are therefore not included in any of the three boxes. Box 2 also includes the input from the River Weaver and Box 3 receives the input from the River Mersey.

From the HR analysis of the Mersey estuarine volume, it is clear that above Dingle the volume at low water is only a small fraction of the total volume (< 6%). Using the tidal prism approach to determine the exchange coefficient leads to values of the order of 1.8 per day. Below Dingle, the sub-tidal volume is about 40-50% of the total volume.

There are significant crude effluent discharges to the Mersey. Most of those on the Liverpool Bank were removed by 1998, although significant discharges from the Wirral Bank have remained unchanged. Most of these effluents are discharged in the lower estuary between Eastham and Perch Rock, and for the purposes of this box modelling exercise are assumed to be discharged in Box 1. Crude effluent from Garston and Speke is assumed to discharge into Box 2. The estimated changes in BOD load from the crude discharges were provided by North West Water.

There are a number of industrial inputs to the Mersey. The significant direct industrial inputs are mostly confined to the upper Mersey and are largely within Box 3. Other indirect discharges from industrial sources and from both untreated and treated sewage come via the tidal section of the Manchester Ship Canal. There are two major rivers – the Mersey itself and the Weaver, which discharge into the Mersey Estuary via the Manchester Ship Canal. The data for the industrial inputs and the rivers are largely based on historical data (pre-1990).

A background value of 2.5 mg/l was used for BOD concentration as this was the value measured in Liverpool Bay during surveys undertaken for North West Water plc and the then National Rivers Authority to support a detailed water quality study in 1989 (HR Wallingford 1992).

The same exercise was carried out by treating the whole estuary as a single box. The modelling was carried out to determine the impact of changes to the treatment of sewage for each of the three years from1997 to 1999. During those years, the bulk of the changes to discharges occurred.

Data relating to the effluent sources and receiving water quality of the Mersey was supplied by both the North West Water Company (recently renamed to United Utilities) and the Environment Agency.

Barrow-in-Furness

The outfall from Barrow-in-Furness WwTW discharges into an intertidal area between Walney Island and the mainland. This intertidal area is crossed by the Walney Channel, which has a bottom level of about –1 to –2 m CD (although there is a deeper section, Piel channel, which has a depth of –6 to –10 m CD), which allows access to the shipyards at Barrow. There is a large tidal range (8m spring, 4.4 m neap). Current speeds are only available at points along the navigation channel, and are therefore not representative of the large inter-tidal zone. However, it could be assumed that the peak speed at the outfall will be of the order of 0.4-0.5 m/s, in which case the tidal excursion is likely to be of the order of 10km from the outfall. For the purposes of this analysis, the area between Walney Island and the mainland and east of the bridge/causeway (at the narrowest point between the two) is treated as a bay. This bay is approximately 6km long and 3.5km wide, and the bed level is typical +4 to +6 m CD except in the Walney Channel where it is between –0.5 to –7 m CD . The box for the modelling exercise for Barrow is 'extended' beyond Walney Channel into Morecambe Bay for one tidal excursion from the outfall. Estimating the exchange coefficient in this box is less straightforward than for an estuary site as there will be exchange through three sides of the box outside of the confines of the bay around Walney Channel. The calculations below are presented for two values of E. The upper value is based on the estimated ratio of the intertidal volume to the total volume, and the lower value is set at 0.5 per day, approximately one third of the upper value. This was done in order to provide a range for the change in concentration, allowing for the uncertainties in determining the exchange coefficient. (The main source of hydrodynamic information on the Barrow are was obtained from Admiralty Charts 3164 and 2010). Results of modelling are shown in Table 7.3.2.4.

The BOD load from the Barrow-in-Furness works was reduced from 4250kg/d to 73kg/d in 1996. There are a number of other discharges to the 'bay' between Walney Island and the mainland. The load from crude outfalls is 1200kg/d with an additional 300kg/d from other treatment works. The total load therefore used in the box modelling calculation is 1500kg/d.

The background concentration was set at 1mg/l, as a typical value for UK coastal waters (HR Wallingford 1995b).

Data relating to the effluent sources and receiving water quality was supplied by North West Water Company (United Utilities) and the Environment Agency.

West Solent

The only significant discharge from a WwTWs that has been modified in the last ten years in the West Solent is at Pennington. The outfall is located about 2km North-east of Hurst Point, at the western entrance to the Solent. Before 1997, the outfall discharged an average of 6204kg/day of BOD. Secondary treatment was introduced at Pennington to deal with the crude sewage previously discharged via the Pennington outfall and that discharged via the Barton-On-Sea outfall to Christchurch Bay. The current consent conditions allow a BOD load of 475kg/day. Thus the BOD load from the Pennington outfall has been reduced by at least 92%. It is possible that the actual present BOD load is significantly less than the consent value. Results of modelling are shown in Table 7.3.2.5.

The outfall is about 1km long and is discharged at about 2m below low water. Peak currents in the Solent are of the order of 1.5m/s. From model results, the peak currents in the shallower water on the northern edge of the Solent are probably less than 0.5 m/s (HR Wallingford 1995c). From this it can be estimated that the tidal excursion in the vicinity of the outfall is of the order of 7km. Assuming that the effluent is confined to about 3km from the coast, the area of the box extends from Hurst Point to about 7km North-east of the outfall. The volume of the box has been estimated by assuming a uniform depth below mean tidal level of 6m (based on data from Admiralty Chart 2040). Estimating the exchange coefficient in this box is less straight forward than for an estuary site because there will be exchange through three sides of the box. The calculations below are presented for two values of E. The upper value is based on the ratio of the intertidal volume to the total volume, and the lower value is set at 0.1 per day , which is the default value used in similar modelling for comprehensive studies (CSTT 1994).

There are no other significant discharges into the area, which the box represents, apart from the Lymington River. From data from previous modelling studies, the BOD from this river has been estimated as 195kg/day.

The background concentration was set at 1mg/l, again as a typical value for UK coastal waters.

Data relating to the effluent sources and receiving water quality was supplied by Southern Water and the Environment Agency.

7.3.3 Analysis of Trends in Bird Populations on the Orwell and Mersey in Relation to the Results of Box Modelling

Figures 7.3.3.1 and 7.3.3.2 show the trends in winter indices for those species of waterbird recorded in nationally important numbers on the Orwell and Mersey Estuaries and trends in annual mean values for BOD concentration (in mg/l) estimated by box modelling.

On the Orwell, four of seven nationally important species – Dark-bellied Brent Goose, Shelduck, Pintail and Dunlin – have apparently declined since the change from crude discharges to primary treatment in 1995. Only Gadwall *Anas strepera* have increased in number. As the bottom graph shows, the BOD concentration in the estuary's water has fallen to a fraction of its pre-treatment level. BOD concentration within the estuary each year was positively correlated with the subsequent winter indices of Shelduck (r_8 = 0.800, $P < 0.001$) and Pintail (r_8 = 0.848, $P < 0.001$), negatively correlated with those of Gadwall (r_8 = -

0.782, P = 0.013), but not significantly correlated with those of any other species (Dark-bellied Brent Goose: r_8 = 0.628, P < 0.10; Dunlin: r_8 = 0.595, P < 0.10; Black-tailed Godwit: r_8 = 0.227, ns; Redshank: r_8 = -0.029, ns).

On the Mersey, improvements to the discharges from three of six outfalls (Warrington North, Widnes and Halewood) in 1997 and 1998 have led to a dramatic overall decrease in the BOD concentration in the estuary. There are indications of declines since then for six of the ten nationally important species - Great Crested Grebe *Podiceps cristatus*, Shelduck, Grey Plover, Dunlin, Black-tailed Godwit and Redshank. These results should be treated with caution, however, as only two years data were available for the period after improvements and thus it is not yet known whether the decreases observed will be sustained. It should be noted also that the decline in Black-tailed Godwit numbers followed a recent large increase in population size. BOD concentration within the estuary each year was only correlated with the subsequent winter indices of Great Crested Grebe, however (Great Crested Grebe: r_8 = 0.679, P = 0.044; Shelduck: r_8 = 0.039, ns; Wigeon: r_8 = 0.426, ns; Teal: r_7 = 0.150, ns; Pintail: r_8 = 0.459, ns; Grey Plover: r_8 = 0.300, ns; Dunlin: r_8 = 0.218, ns; Black-tailed Godwit: r_8 = -0.474, ns; Curlew: r_8 = -0.090, ns; Redshank: r_8 = 0.473, ns).

7.4 Discussion

7.4.1 Box Modelling

Simple box models were applied to determine the impact on tide-averaged BOD concentrations of reductions in organic loads from waste water treatment works in four areas:

- Orwell
- Mersey
- Barrow-in-Furness
- West Solent

The hydrodynamic properties of these areas were assessed for a variety of sources including admiralty charts and studies carried out by HR Wallingford.

In the Orwell, the model suggests that the reduction in the discharge from Cliff Quay works would have resulted in a 38% reduction in BOD concentration within one tidal excursion of the outfall. While over the estuary as a whole (within three tidal excursions), the reduction is 21%.

In the Mersey, there have been reductions to three large works and the removal of some crude discharges. The model suggests that close to the works the improvement in treatment will have reduced BOD concentrations by 4% in the narrows, by 29% near Runcorn and by 19% in the upper estuary near Warrington. Looking at the estuary as a whole, the model suggests that the BOD concentration will have been reduced by about 1-2% a year between 1997 and 1999.

At Barrow, lack of detailed information on hydrodynamic characteristics made the determination of the exchange coefficient more difficult. The model suggests that the BOD concentration in the vicinity of Barrow will have been reduced by between 9 and 22% following the reduction to the organic load from the Barrow WwTW depending on the assumption made about the residence time. The reduction in BOD concentration was determined for a high and a low value of the exchange coefficient to allow for uncertainties in the effect of the local hydrodynamics.

At West Solent, there was also difficulty in determining the exchange coefficient. The model suggests that the BOD concentration in the vicinity of the Pennington outfall will have been reduced by between 4 and 16% following the reduction to the organic load from the WwTW depending on the assumption made about the residence time. The reduction in BOD concentration was determined for a high and a low value of the exchange coefficient to allow for uncertainties in the effect of the local hydrodynamics.

These estimates of the impacts of the changes in organic loads from WwTW are sensitive to all the main driving factors listed below:

- The accuracy of data describing the works load before and after any improvement in treatment
- Background concentrations
- Estimates of exchange coefficients
- Size of modelled water body

7.4.2 Impacts of Improved Treatment to Waste Water Discharges on Waterbird Populations

Mapping of outfalls on the GIS has shown that, potentially, improvements to waste water discharges may have had a negative impact on the numbers of waterbirds on several SPAs. It is also apparent that the distribution of some species on some estuaries may have been influenced by outfalls – for example, Dunlin on the Orwell.

Examining the trends in waterbird indices on the Orwell and Mersey revealed that species have declined in 10 of 17 cases (and increased in only one) since improvements to discharges. Three of the four species (Shelduck, Pintail and Dunlin) that showed declines on the Orwell are predominantly found on the upper estuary, i.e. near the Ipswich – Cliff Quay outfall. All four species that declined were amongst those identified as potentially at risk from the implementation of the UWWTD in section 6. Those that did not decline were Gadwall, Black-tailed Godwit and Redshank. Gadwall tend to be concentrated on Trimley Marshes and Loonpit Lake, freshwater areas at the lower end of the estuary (Pollitt *et al.* 2000) unaffected by the outfall. Black-tailed Godwits, in contrast, tend to be concentrated at the upper end of the estuary, close to the outfall. However, any impact of reduced nutrient and organic loading upon the numbers of godwits found on the Orwell will have been tempered by the continuing increase in the size of the regional wintering population (Gill *et al.* 2001). Redshank also tend to concentrate on the upper estuary and would have been expected to decline following the improvement to the discharge at Cliff Quay given that they were identified in section 6 as one of those species potentially vulnerable to reductions in organic loading.

On the Mersey, declines were noted for all species, with the exception of Wigeon and Teal, whose numbers have shown very high fluctuations from year to year, Pintail, which have declined to very low numbers in recent years and Curlew, which have been increasing on the estuary and in this region over the last two decades (Austin *et al.* 2000). As with those species that did decline, these four species of wildfowl and wader were identified in section 6 as potentially vulnerable to reductions in organic loading.

Although it seems probable that the changes in the treatment of the discharges at these sites could have affected bird numbers, these initial analyses do not reveal how. Box modelling confirmed that improved treatment has led to dramatic declines in BOD concentrations at both sites and clearly the associated changes in organic and nutrient inputs to the estuaries will have affected invertebrate populations in the intertidal sediments. Reductions in these food resources could have led to declines in the numbers of Shelduck, Pintail, Grey Plover, Dunlin, Black-tailed Godwit and Redshank. Great Crested Grebes, in contrast, could have been affected on the Mersey by reduced numbers of fish associated with the outfalls.

8. CONCLUSIONS AND RECOMMENDATIONS

This report, both through the literature review and the preliminary analysis of relationships between water quality data and waterbird numbers, has demonstrated how improvements to waste water discharges may have a negative impact on waterbirds. The literature review highlighted the range of birds that exploit the food resources associated with outfalls. Gulls and wildfowl, for example, benefit directly from the food resources found within the discharges. Wildfowl and waders also prey upon the invertebrates found in the sediments close to outfalls and other species on the fish that also exploit these food resources. Improvements to discharges, except on the most grossly polluted sites, have been demonstrated to lead to reductions in these food resources, particularly in invertebrate populations, through changes not just in nutrient and organic inputs, but also in DO. Such changes could affect a range of bird species.

The GIS Project indicated that outfalls where there had been recent changes to discharges were present in a number of coastal SPAs important for waterbirds. Furthermore, it was apparent from the project that outfalls may have influenced the distribution of some species on some estuaries. Box modelling confirmed that improvements to treatment resulted in a decline in BOD (a variable that indicates the amount of oxygen required by aerobic bacteria to help in the decomposition of the organic matter, and is reflective of the amount of organic and nutrient loading). Preliminary analysis indicated that the numbers of several species had declined on two estuaries, the Orwell and Mersey, following changes to waste water treatment and at the same time as the decline in BOD. Although no information was available on changes in food supply, it seems likely that these declines were a result of the changes to treatment.

Two elements to further work are recommended.

Firstly it is suggested that box modelling be applied to a larger number and range of estuarine SPAs. Changes in the BOD concentration estimates obtained from these models could then be statistically related to changes in waterbird numbers on the estuaries as indicated by WeBS Core Counts. Likewise, changes in the BOD load and other water quality variables within the discharges themselves could also be statistically related to changes in the numbers of waterbirds on these sites. Sites where major changes in waste water treatment have occurred in the last ten years, and where it would be possible to relate changes in BOD concentrations to changes in bird numbers, include the Humber Flats, Marshes and Coast SPA, Ribble Estuary SPA, Duddon Estuary SPA, Camel Estuary, Thanet Coast and Sandwich Bay SPA and Teesmouth and Cleveland Coast SPA.

Such studies are purely correlative and assume, as mentioned in Section 7, that BOD can be related to waterbird numbers. Similarly, previous studies highlighted by the literature review (Section 6), have only recorded the degree of change in waterbird numbers following improvements, and have not attempted to discern the factors that drives these changes.

To better understand the relationships between waterbird numbers and discharges, therefore a second approach is thus needed. The first part of this would involve the modelling of the dispersal of organic matter from discharges on the sediments of a small, but varied, sample of estuarine SPAs, according to effluent characteristics and the hydrodynamics of these estuaries. It would then be possible to determine whether the distribution of organic matter and its depth were determinants of the distributions of waterbirds - as indicated by WeBS Low Tide Counts or the BTO's own 'Through-The-Tide-Count' survey data. It is suggested that, if possible, correlations also be made with available invertebrate data, as changes in invertebrate populations driven by changes in the discharges may be a major driver of change in the waterbird community.

It is also suggested that if possible those estuaries studied should be ones where discharges have changed over the period of collection of waterbird count data. Suggested sites for these analyses, identified using the GIS Project, are the Orwell Estuary (Figure 8.1), Mersey Estuary (Figure 8.2), Barrow (Figure 8.3) and Southampton Water (Figure 8.4). For each of these sites, Low Tide Count or Through-The-Tide-Count data are available for several years either side of known changes to waste water treatment. Such analyses would allow a quantitative assessment of how known decreases in organic input relate to changes in waterbird numbers on intertidal mudflats within a site.

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	SS	BOD5	COD	Total N	Total P
Load (g/head/day)	91	82	140	12	4
Mean loads from a town of 50,000 (t/day)	4.5	4.1	7.0	0.6	0.2
% Reduction during Primary Treatment	50-65	30-40	30-40	5-10	10-20
% Reduction during Secondary Treatment	60-90	65-95	60-85	10-30	8-25
% Reduction during Tertiary Treatment	N/A	N/A	N/A	50-90	70-90

Table 3.1 Typical wastewater loads and percentage reductions during various treatments.

Figures modified from Metcalf & Eddy (1991) p.170.
SS = Suspended Solids, BOD% = 5-day Biochemical Oxygen Demand, COD = Chemical Oxygen Demand.

The figures for mass loads and changes during different treatment stages should only serve as indicators. Estimates for loads are based on the concentration measured before treatment, the population in the catchment and the water consumption per head per day. There is usually considerable uncertainty in all the figures that contribute to the final estimate of the mass load per person. The changes during different treatment stages are dependent on the type of treatment (e.g. trickling filter or activated sludge) and, in some cases, on the size of the works, which affects efficiency. It is also uncertain whether percentage reductions quoted in the literature relate to the concentrations entering the treatment stage, or to the initial concentrations in untreated wastewater. Therefore, these figures, too, should only serve as indicators.

Changes in mass loads into rivers since 1990 are currently being calculated by the Environment Agency from measured effluent concentrations. This approach to estimating changes in loads is different from the method used in this study (see Section 7), because it is based on real effluent concentrations and not on changes in consents. These results (expected to be available in April 2002) would give an indication of changes due to the UWWTD and BWD in rivers and also indicate how river loads into estuaries have changed. It is possible that estimates of total loads into estuaries will also be calculated by the Environment Agency using this method. The figures could be used to complement the figures we have derived from changes in consented discharges over two AMP periods (see Section 7.2.2).

Studies	Site	Habitats	Food Source	Bird Species	Results
Ferns & Mudge 2000	S Wales & Dorset	Estuary and open coast	Waste matter	Gulls	Black-headed and Herring Gull numbers correlated with volume of sewage discharged at outfalls
Fitzgerald & Coulson 1973	Tyne Estuary	Estuary	Waste matter	Gulls	Outfalls favoured by Black-headed and Herring Gulls and to a lesser extent by Common, Lesser Black-backed and Great Black-backed Gulls
Barrett & Barrett 1985 Campbell 1977, 1978, 1984 Campbell *et al.* 1986 Campbell & Milne 1977 Milne & Campbell 1973 Player 1970, 1971 Pounder 1974, 1976a, 1976b Thom 1969	Scotland (principally the Firth of Forth, Moray Firth and East Coast)	Estuary and open coast	Brewery, distillery and food factory waste	Seaduck	Outfalls favoured by Scaup and Goldeneye and in some locations, Pochard and Tufted Duck
Tubbs 1977	Langstone Harbour	Estuary	Invertebrates / algae	Wildfowl & waders	Nutrient enrichment from waste water discharges and other sources led to increased algal cover, which particularly benefited Wigeon
van Impe 1985	Scheldt Estuary, Holland	Estuary	Invertebrates	Wildfowl & waders	Nutrient enrichment from waste water discharges resulted in increased invertebrate abundance and thus probably numbers of waders, including: Oystercatcher, Avocet, Grey plover, Ringed Plover, Bar-tailed Godwit, Curlew, Spotted Redshank, Redshank and Common Sandpiper
Eaton 2000b	Hartlepool	Rocky coast	Invertebrates	Waders	Nutrient inputs from sewage outfalls promoted the growth of mussel beds utilised by Purple Sandpipers and Turnstones

Table 6.1.1 Principal studies relating the presence of waterbirds to food resources associated with waste water outfalls.

Studies are sorted according to the type of food that discharges provided and thus by bird species group.

Study	Site	Habitats	Food Source	Bird Species	Results
Raven & Coulson 2001	Tyne Estuary	Estuary	Waste matter	Gulls	**Large declines** of Common and Great Black-backed Gulls following decreases in the discharge of untreated sewage **No change** in Black-headed Gull or Herring Gull **Increases** in Lesser Black-backed Gull and Kittiwake
Robertson 1992	Wellington, New Zealand	Harbour	Waste matter	Gulls & seabirds	**Large declines** of Dominican and Red-billed Gulls and Australasian Gannets following decreases in the discharge of untreated sewage
Campbell 1984 Bryant 1987	Firth of Forth	Estuary	Brewery, distillery and food factory waste	Seaduck	**Large declines** of Scaup and Goldeneye following cessation of untreated sewage discharges and introduction of primary treatment
Barrett & Barrett 1985	Moray Firth	Estuary	Brewery, distillery and domestic waste	Seaduck	**Large declines** of Tufted Duck and Goldeneye
Furness *et al.* 1986	Clyde Estuary	Estuary	Invertebrates / fish	Wildfowl, waders & Cormorants	**Large declines** of Shelduck, Pintail, Lapwing, Dunlin and Redshank following improvements to waste water discharges, due to decreased invertebrates and perhaps competition from fish. **Moderate decline** of Oystercatcher **No change** of Curlew **Increases** of Cormorant, probably due to increased fish population
Bryant 1987	Firth of Forth	Estuary	Invertebrates	Waders	**Large declines** of Knot and Dunlin following improvements to waste water discharges
Eaton 2000b	Hartlepool	Rocky Coast	Invertebrates	Waders	**No change** of Purple Sandpiper and Turnstone following cessation of untreated sewage discharges

Table 6.2.1 Principal studies investigating the effects of improvements to waste water treatment on waterbird populations.

Studies are sorted according to the type of food that discharges provided and thus by bird species group.

Large decline – a decline of 50% or more over the period in which changes in water treatment were studied
Moderate decline – a decline of less than 50% over the period in which changes in water treatment were studied
No change – no significant change recorded over the period in which changes in water treatment were studied
Increase – any significant increase recorded over the period in which changes in water treatment were studied

Site Name	Species
Alde-Ore Estuary	AF, AV, BH, BW, DN, EW, HG, L., LB, RK, SU, SV, T., TE, WN
Benacre to Easton Bavents	AF, BI
Benfleet and Southend Marshes	DB, DN, GV, KN, OC, RP
Blackwater Estuary (Mid-Essex Coast Phase 4)	AF, AV, BW, CA, CU, DB, DN, GG, GP, GN, GV, L., PT, RK, RM, RP, RU, SU, SV, T., WN
Breydon Water	AV, BS, BW, CA, CN, DN, EW, GP, L., SV, WN
Burry Inlet	BW, CU, DN, KN, OC, PT, SU, SV, WM
Chesil Beach and The Fleet	AF, DB
Chichester and Langstone Harbours	AF, BA, BW, CA, CU, DB, DN, ET, GV, KN, L., LG, OC, PT, RK, RM, RP, SS, SU, SV, T., TE, WM, WN
Colne Estuary (Mid-Essex Coast Phase 2)	AF, AV, BW, CA, DB, DN, GG, GP, GV, L., RK, RP, SU
Coquet Island	AE, BH, CN, ET, PU, RS
Crouch and Roach Estuaries (Mid-Essex Coast Phase 3)	DB
Deben Estuary	AV
Dengie (Mid-Essex Coast Phase 1)	BA, BW, CA, DB, DN, GG, GV, KN, L., OC
Duddon Estuary	CU, DN, KN, OC, PT, RK, RM, RP, SS, SU, TE

Table 7.2.1.1 Coastal English and Welsh Special Protection Areas (SPAs) and waterbird (grebe, cormorant, heron, wildfowl and wader) and seabird (petrel, gannet, tern, gull and auk) species for which they are notified. Sites for which Wetland Bird Survey (WeBS) Core Count data have been collected recently are highlighted in bold.

AE = Arctic Tern *Sterna paradisaea*, AF = Little Tern *Sterna albifrons*, AV = Avocet *Recurvirostra avosetta*, BA = Bar-tailed Godwit *Limosa lapponica*, BH = Black-headed Gull *Larus ridibundus*, BI = Bittern *Botaurus stellaris*, BS = Bewick's Swan *Cygnus columbianus*, BW = Black-tailed Godwit *Limosa limosa*, BY = Barnacle Goose *Branta leucopsis*, CA = Cormorant *Phalacrocorax carbo*, CN = Common Tern *Sterna hirundo*, CO = Coot *Fulica atra*, CU = Curlew *Numenius arquata*, CX = Common Scoter *Melanitta nigra*, DB = Dark-bellied Brent Goose *Branta bernicla bernicla*, DN = Dunlin *Calidris alpina*, E. = Eider *Somateria mollissima*, ET = Little Egret *Egretta garzetta*, EW = European White-fronted Goose *Anser albifrons*, GA = Gadwall *Anas strepera*, GB = Great Black-backed Gull *Larus marinus*, GD = Goosander *Mergus merganser*, GG = Great Crested Grebe *Podiceps cristatus*, GJ = Greylag Goose *Anser anser*, GN = Goldeneye *Bucephala clangula*, GP = Golden Plover *Pluvialis apricaria*, GU = Guillemot *Uria aalge*, GV = Grey Plover *Pluvialis squatarola*, GX = Gannet *Morus bassanus*, HG = Herring Gull *Larus argentatus*, KI = Kittiwake *Rissa tridactyla*, KN = Knot *Calidris canutus*, L. = Lapwing *Vanellus vanellus*, LB = Lesser Black-backed Gull *Larus fuscus*, LG = Little Grebe *Tachybaptus ruficollis*, MA= Mallard *Anas platyrhynchos*, MS = Mute Swan *Cygnus olor*, MU = Mediterranean Gull *Larus melanocephalus*, MX = Manx Shearwater *Puffinus puffinus*, OC = Oystercatcher *Haematopus ostralegus*, PB = Light-bellied Brent Goose *Branta bernicla hrota*, PG = Pink-footed Goose *Anser brachyryhnchus*, PO = Pochard *Aythya ferina*, PS = Purple Sandpiper *Calidris maritima*, PT = Pintail *Anas acuta*, PU = Puffin *Fratercula arctica*, RA = Razorbill *Alca torda*, RK = Redshank *Tringa totanus*, RM = Red-breasted Merganser *Mergus serrator*, RP = Ringed Plover *Charadrius hiaticula*, RS = Roseate Tern *Sterna dougallii*, RU = Ruff *Philomachus pugnax*, SA = Shag *Phalacrocorax aristotelis*, SP = Scaup *Aythya marila*, SS = Sanderling *Calidris alba*, SU = Shelduck *Tadorna tadorna*, SV = Shoveler *Anas clypeata*, SZ = Slavonian Grebe *Podiceps auritus*, T. = Teal *Anas crecca*, TE = Sandwich Tern *Sterna sandvicensis*, TM = Storm Petrel *Hydrobates pelagicus*, TT = Turnstone *Arenaria interpres*, TU= Tufted Duck *Aythya fuligula*, VS = Velvet Scoter *Melanitta fusca*, WM = Whimbrel *Numenius phaeopus*, WN = Wigeon *Anas penelope*, WS = Whooper Swan *Cygnus cygnus*.

Site Name	Species
Dungeness to Pett Level	AF, BS, CN, MU
Dyfi Estuary	EW
Exe Estuary	AV, BW, CA, DB, DN, GV, L., OC, RM, SZ, WM, WN
Farne Islands	AE, CA, CN, GU, KI, PU, RS, SA, TE
Flamborough Head and Bempton Cliffs	GU, GX, HG, KI, PU, RA
Foulness (Mid-Essex Coast Phase 5)	AF, AV, BA, BW, CN, CU, DB, DN, GP, GV, KN, L., LG, OC, RK, SU, TE, WN
Gibraltar Point	AF, BA, GV, KN, OC
Glannau Aberdaron and Ynys Enlli / Aberdaron Coast and Bardsey Island	MX
Grassholm	GX
Great Yarmouth North Denes	AF
Hamford Water	AF, AV, BW, DB, DN, GP, GV, L., RK, RP, RU, SU, T., WN
Humber Flats, Marshes and Coast (Phase 1)	AF, BA, BI, BW, CA, CU, DB, DN, GN, GP, GV, KN, L., MA, OC, PO, RK, RP, SS, SU, T., WM, WN
Isles of Scilly	GB, LB, SA, TM
Lindisfarne	AF, BA, CX, DN, E., GJ, GP, GV, KN, L., PB, PG, RK, RM, RP, SU, WN, WS
Medway Estuary and Marshes	AF, AV, BW, CA, CU, DB, DN, GG, GV, L., LG, OC, PT, RK, RP, SU, T., WM, WN
Mersey Estuary	BW, CU, DN, GG, GP, GV, L., PT, RK, RP, SU, T., WN
Mersey Narrows and North Wirral Foreshore	CA, DN, GV, KN, OC, RK, TT
Minsmere – Walberswick	AF, AV, BI
Morecambe Bay	AF, BA, BW, CA, CU, DN, E., GG, GN, GP, GV, HG, KN, L., LB, MA, OC, PG, PT, RK, RM, RP, SS, SU, T., TE, TT, WM, WN
North Norfolk Coast	AF, AV, BA, BI, CA, CN, CX, DB, DN, EW, GA, GP, GV, KN, L., MU, OC, PG, PT, RK, RP, RS, RU, SS, SU, SV, T., TE, VS, WM, WN
Northumbria Coast (Northumberland Shore and Durham Coast)	AF, PS, TT
Pagham Harbour	AF, PT, RU
Poole Harbour	AV, BW, CA, CN, CU, DB, DN, ET, GN, L., MU, PO, RK, RM, SU, SV
Portsmouth Harbour	DB
Ribble and Alt Estuaries (Phase 2)	BA, BH, BS, BW, CA, CN, CU, CX, DN, GP, GV, KN, L., LB, OC, PG, PT, RK, RP, RU, SS, SU, T., WN, WS

Table 7.2.1.1 Continued.

Site Name	Species
Severn Estuary	BS, CU, DN, EW, GA, GV, L., MA, PO, PT, RK, RP, SU, SV, T., TU, WM, WN
Skokholm and Skomer	LB, MX, TM
Solent and Southampton Water	AF, BW, CA, CN, CU, DB, DN, GA, GG, GV, L., LG, MU, PT, RK, RM, RP, RS, SU, SV, T., TE, WN
Stour and Orwell Estuaries	BW, CA, CU, DB, DN, GG, GN, GV, KN, L., OC, PT, RK, RP, SU, TT, WN
Tamar Estuaries Complex	AV, ET
Teesmouth and Cleveland Coast	AF, CA, KN, L., RK, RP, SU, SS, TE
Thames Estuary and Marshes	AV, BW, DN, EW, GA, GV, L., LG, PT, RK, RP, SU, SV, WM
Thanet Coast and Sandwich Bay	TT
The Dee Estuary	AF, BA, BW, CA, CN, CU, DN, GV, KN, L., MA, OC, PT, RK, SS, SU, T., TE, WN
The Swale	AV, BA, BW, CA, CU, DB, DN, EW, GA, GP, GV, KN, L., LG, MU, OC, PT, RK, RP, SU, SV, T., WN
The Wash	AF, AV, BA, BS, BW, CA, CN, CU, DB, DN, EW, GN, GP, GV, KN, L., LG, MA, OC, PG, PT, RK, RP, SS, SU, TT, WM, WN, WS
Traeth Lafan/Lavan Sands, Conway Bay	OC
Upper Solway Flats and Marshes	BA, BY, CA, CU, DN, GG, GN, GP, GV, KN, L., MA, OC, PG, PT, RK, RP, SP, SU, WS
Ynys Feurig, Cemlyn Bay and The Skerries	AF, CN, RS, TE
Ynys Seiriol / Puffin Island	CA

Table 7.2.1.1 Continued.

Site Name	SPA Status	92/93	93/94	94/95	95/96	96/97	97/98	98/99	99/00	00/01
Adur Estuary								✓		
Alt Estuary	SPA					✓	✓	✓		
Blackwater Estuary (Mid-Essex Coast Phase 4)	SPA			✓						
Breydon Water	SPA							✓	✓	✓
Burry Inlet	SPA			✓		✓				
Camel Estuary		✓								
Carmarthen Bay								✓	✓	
(Chichester and Langstone Harbours) - Chichester Harbour	SPA	✓	✓			✓	✓	✓		
(Chichester and Langstone Harbours) - Langstone Harbour	SPA		✓			✓		✓		
Cleddau Estuary							✓			
Clwyd Estuary		✓								
Colne Estuary (Mid-Essex Coast Phase 2)	SPA			✓						
Conwy Estuary						✓				
Crouch and Roach Estuaries (Mid Essex Coast Phase 3)	SPA				✓					
Deben Estuary	SPA							✓		
Dengie (Mid-Essex Coast Phase 1)	SPA	✓								
Duddon Estuary	SPA	✓	✓	✓						
Exe Estuary	SPA		✓							
Fal Estuary					✓					
Fowey Estuary					✓					
Hamford Water	SPA	✓					✓			
Hayle Estuary								✓		
Humber Flats, Marshes and Coast (Phase 1)	SPA							✓		
Inland Sea					✓					
Kingsbridge Estuary			✓							
Lindisfarne	SPA	✓								✓
Medway Estuary and Marshes	SPA					✓	✓			
Mersey Estuary	SPA					✓	✓	✓	✓	

Table 7.2.1.2 Estuary sites and years for which WeBS Low Tide Count data have been collected, together with their SPA status.

Data for Breydon Water, Lindisfarne, Morecambe Bay, Severn Estuary and Upper Solway Flats and Marshes had not been added to the WeBS Low Tide Count database at the time of writing and are not included in the GIS.

Site Name	SPA Status	92/93	93/94	94/95	95/96	96/97	97/98	98/99	99/00	00/01
(Minsmere – Walberswick) - Blyth Estuary	SPA						✓			
Morecambe Bay	SPA								✓	✓
North Norfolk Coast	SPA						✓			
Pagham Harbour	SPA				✓	✓	✓	✓	✓	
Pegwell Bay				✓						
Poole Harbour	SPA		✓							
Portsmouth Harbour	SPA	✓					✓	✓		
Ribble Estuary	SPA						✓			
Severn Estuary	SPA							✓	✓	✓
(Solent and Southampton Water) - Beaulieu Estuary	SPA					✓		✓		
(Solent and Southampton Water) - Bembridge Estuary	SPA					✓		✓		
(Solent and Southampton Water) - Greater Solent	SPA					✓		✓		
(Solent and Southampton Water) - Medina Estuary	SPA				✓	✓		✓		
(Solent and Southampton Water) - Newtown Harbour	SPA					✓		✓	✓	
(Solent and Southampton Water) - NW Solent	SPA	✓				✓	✓	✓		
(Solent and Southampton Water) - Southampton Water	SPA			✓	✓	✓	✓	✓	✓	✓
(Solent and Southampton Water) - Western Yar	SPA					✓		✓		
(Solent and Southampton Water) - Wootton Creek	SPA					✓		✓		
(Stour and Orwell Estuaries) - Orwell Estuary	SPA			✓	✓	✓	✓	✓	✓	✓
(Stour and Orwell Estuaries) - Stour Estuary	SPA					✓			✓	✓
Tamar Estuaries Complex	SPA						✓			
Taw and Torridge Complex				✓						
Teesmouth and Cleveland Coast	SPA					✓				
Thames Estuary and Marshes	SPA		✓					✓	✓	
The Dee Estuary	SPA					✓	✓	✓		
The Swale	SPA	✓								
Traeth Lafan / Lavan Sands, Conway Bay	SPA				✓					
Tyne Estuary								✓		
Upper Solway Flats and Marshes	SPA							✓	✓	✓
Wear Estuary					✓					

Table 7.2.1.2 Continued.

Company	Location	Outfall	Comment on Changes
Anglian Water	Humber Flats, Marshes and Coast (Phase 1) SPA	Grimsby – Pyewipe	Crude to Secondary 1999
	Humber Flats, Marshes and Coast (Phase 1) SPA	Cleethorpes – Newton Marsh	Crude to Secondary 1995
	Stour and Orwell Estuaries SPA	Ipswich – Cliff-Quay	Crude to Secondary 1995
	North Sea	Felixstowe	Crude to Primary 1995
	Hamford Water SPA	Harwich and Dovercourt	Crude discharge abandoned at Dovercourt. Primary discharge begun on Stour Estuary
United Utilities (North West Water)	Mersey Estuary SPA / Mersey Narrows & North Wirral Foreshore SPA	Liverpool	Crude to Primary 1999
	Mersey Estuary SPA	Halewood	Closed 1998
	Mersey Estuary SPA	Widnes	Crude to Primary 1997
	Mersey Estuary SPA	Warrington North	Crude to Primary 1998
	Ribble and Alt Estuaries SPA (Phase 2)	Hesketh Bank	1997
	Ribble and Alt Estuaries SPA (Phase 2)	Preston	1996
	Ribble and Alt Estuaries SPA (Phase 2)	Southport	1996
	Morecambe Bay SPA	Burrow-in-Furness	Primary to Secondary 1996
	Morecambe Bay SPA	Lancaster	Unknown to Secondary 1999
	Morecambe Bay SPA	Morecambe	Unknown to Secondary 1997
	Morecambe Bay SPA	Milnthorp	Unknown to Secondary 1995
	Morecambe Bay SPA	Pilling WwTW	Unknown to Secondary 1995
	Morecambe Bay SPA	Preesall WwTW	Unknown to Secondary 1995
	Morecambe Bay SPA	Fleetwood	Unknown to Secondary 1996
	Morecambe Bay SPA	Poulton	Closed
	Morecambe Bay SPA	Vickerstown South	Unknown to Secondary 1995
	Morecambe Bay SPA	Tummerhill	Unknown to Secondary 1995
	Morecambe Bay SPA	Ulverston	2000
	Duddon Estuary SPA	Vickerstown North	Unknown to Secondary 1995
	Duddon Estuary SPA	Barrow North Scale	Unknown to Secondary 1995
	Duddon Estuary SPA	North Walney	Unknown to Secondary 1995
	Duddon Estuary SPA	Millom	1995
Northumbrian Water	Tyne Estuary		

Table 7.3.1.1 Sites of major changes in sewage treatment within the last 10 years.

Company	Location	Outfall	Comment on Changes
Northumbrian Water cont.	Teesmouth and Cleveland Coast SPA		
Severn Trent Water	Severn Estuary SPA	Gloucester	Crude to Primary 1991 to Secondary 1995
South West Water	Exe Estuary SPA	Exmouth	Primary to Secondary 1995
	Teign Estuary	Various	New LSO 1994
	Kingsbridge Estuary	Salcombe	Crude to Secondary 1994
	Kingsbridge Estuary	Kingsbridge	Secondary 1995
	Tamar Estuaries Complex SPA	Plymouth - Ernessettle & Saltash	Crude to Secondary and UV 2000
	Tamar Estuaries Complex SPA	Plymouth - Camels Head	Crude to Secondary 2000
	Tamar Estuaries Complex SPA	Plymouth - St Levans Road	Closed 2001
	Tamar Estuaries Complex SPA	Plymouth - Eastern Kings	Closed 2000
	Tamar Estuaries Complex SPA	Plymouth - Carpenters Rock	Closed 2000
	Tamar Estuaries Complex SPA	Plymouth - West Hoe	Closed 2000
	Tamar Estuaries Complex SPA	Plymouth Central	New Secondary and UV 2000
	Fowey Estuary		Crude to Secondary 1997
	Fal Estuary	Falmouth	Crude to Secondary and UV 2000
	Camel Estuary	Porthilly & St Minver	Crude to Secondary and UV 1996/97
	Camel Estuary	Polzeath	Closed 1996/97
	Camel Estuary	Padstow	Closed 1996/97
	Camel Estuary	Little Petherick	Crude to Secondary and UV 1992
	Camel Estuary	Wadebridge	Crude to Secondary 1990
	Taw and Torridge Estuaries	Barnstable	Crude to Secondary 1995
Southern Water	Thames Estuary and Marshes SPA	Gravesend	Primary to Secondary 2000
	Medway Estuary and Marshes SPA	Queenborough	Primary to Secondary 1998
	Medway Estuary and Marshes SPA	Motney Hill	Primary to Secondary 2000
	Thanet Coast and Sandwich Bay SPA	Swalecliffe	Crude to Primary 1998
	Thanet Coast and Sandwich Bay SPA	Swalecliffe	Primary to Secondary 2001
	Thanet Coast and Sandwich Bay SPA	Herne Bay	Transfer to May Street – Inland WwTW 1995
	Thanet Coast and Sandwich Bay SPA	Ramsgate	Transfer to Weatherlees WwTW 1995
	Thanet Coast and Sandwich Bay SPA	Sandwich	Transfer to Weatherlees WwTW 1995
	Thanet Coast and Sandwich Bay SPA	Deal	Transfer to Weatherlees WwTW 1995
	South Coast	Dover	Transfer to Bloomfield Bank WwTW 1999

Table 7.3.1.1 Continued.

Company	Location	Outfall	Comment on Changes
Southern Water Cont.	South Coast	Folkestone	Transfer to Bloomfield Bank WwTW 1999
	South Coast	Hythe	Crude to Primary 1998
	South Coast	Hythe	Primary to Secondary 2001
	South Coast	Eastbourne	Crude to Primary 1996
	South Coast	Newhaven	Crude to Secondary 2000
	South Coast	Shoreham	Crude to Primary 1996
	South Coast	West Worthing	Transfer to East Worthing
	South Coast	East Worthing	Crude to Primary 1998
	South Coast	Littlehampton	Transfer to Ford WwTW 2000
	South Coast	Bognor	Transfer to Ford WwTW 2000
	Solent and Southampton Water SPA	Pennington	Crude to Secondary 1996
	Solent and Southampton Water SPA	Barton-on-Sea	Transferred to Pennington 1996
	Solent and Southampton Water SPA	Ashlett Creek	Closed 1999
	Solent and Southampton Water SPA	Southampton Water	New Secondary 1999
	Isle of White	Sandown	Flows transferred to new outfall by 2000
Thames Water	None		
Welsh Water	Severn Estuary SPA	Various	
	The Dee Estuary SPA	Chester	2000
	The Dee Estuary SPA	Queensferry	2000
	The Dee Estuary SPA	Connahs Quay	2000
	The Dee Estuary SPA	Flint	2000
	The Dee Estuary SPA	Bagillt (East)	2000
	The Dee Estuary SPA	Bagillt (West)	2000
	The Dee Estuary SPA	Greenfield	2000
	The Dee Estuary SPA	Mostyn	1982
	The Dee Estuary SPA	Llanasa	2000
	The Dee Estuary SPA	Neston	2000
	The Dee Estuary SPA	Heswall	Primary to Secondary/UV
Wessex Water	Severn Estuary SPA		
Yorkshire Water	Humber Flats, Marshes and Coast (Phase 1) SPA		

Table 7.3.1.1 Continued.

	Box 1		Box 2		Box 3	
	Before 1995	After 1995	Before 1995	After 1995	Before 1995	After 1995
E /day	1.92	1.18	1.46	1.05	1.31	1.04
V Mm^3	9.2	9.2	18.4	18.4	27.6	27.6
C_{back} mg/l	1	1	1	1	1	1
ΣS_I kg/day	719	719	719	719	874	874
$S_{outfall}$	9900	341	9900	341	9900	341
C_{box} mg/l	2.32	1.58	1.66	1.25	1.31	1.04
% Change in concentration	-38%		-28%		-21%	
% Change in total load	-90%		-90%		-89%	

Table 7.3.2.1 Results of box modelling for the Orwell Estuary.

	Box 1 Liverpool		Box 2 Widnes		Box 3 Warrington	
	1998	After 1999	1996	After 1997	1996	After 1997
E /day	1.00	1.00	1.90	1.90	1.85	1.85
V Mm^3	176	176	12.4	12.4	8.4	8.4
C_{back} mg/l	2.5	2.5	2.5	2.5	2.5	2.5
ΣS_I kg/day	21500	21500	17833	2073	11912	11912
$S_{outfall}$ kg/day	24658	6849	7945	274	12329	192
C_{box} mg/l	2.76	2.66	3.66	2.60	4.06	3.28
% Change	-4%		-29%		-19%	
% Change in total load	-39%		-91%		-50%	

Table 7.3.2.2 Results of box modelling for sections within the Mersey Estuary.

	Before 1997	1997	1998	1999
E /day	1.53	1.53	1.53	1.53
V Mm^3	416	416	416	416
C_{back} mg/l	2.5	2.5	2.5	2.5
ΣS_I kg/day	54800	36700	21500	21500
$S_{outfall}$ kg/day	46630	26820	25200	7670
C_{box} mg/l	2.67	2.61	2.58	2.56
% annual change		-2 %	-1%	-1%
% Change in total load		-25%	-24%	-33%
% change in concentration over 1997-99				-4%

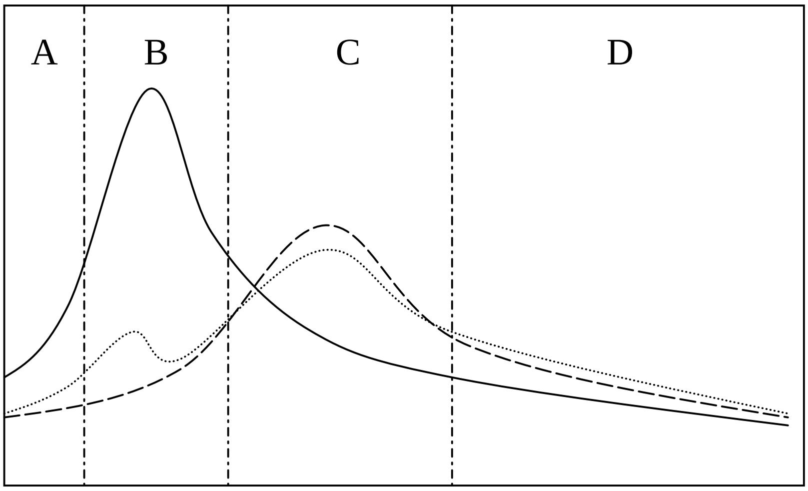
Table 7.3.2.3 Results of box modelling for the whole Mersey Estuary.

	Low exchange		High exchange	
	Before 1996	After 1996	Before 1996	After 1996
E /day	0.5	0.5	1.55	1.55
V Mm^3	27.8	27.8	27.8	27.8
C_{back} mg/l	1	1	1	1
Σ S_I kg/day	1500	1500	1500	1500
$S_{outfall}$ kg/day	4500	73	4500	73
C_{box} mg/l	1.43	1.11	1.14	1.04
% Change in total load	-74%		-74%	
% Change	-22%		-9%	

Table 7.3.2.4 Results of box modelling for Barrow-in-Furness.

	Low Exchange		High Exchange	
	Before 1997	After 1997	Before 1997	After 1997
E /day	0.1	0.1	0.42	0.42
V Mm^3	29.6	29.6	29.6	29.6
C_{back} mg/l	1	1	1	1
ΣS_I kg/day	194.4	194.4	194.4	194.4
$S_{outfall}$ kg/day	6204	474.3	6204	474.3
C_{box} mg/l	1.2162	1.0226	1.05	1.005
% Change in total load	-90%		-90%	
% Change	-16%		-4%	

Table 7.3.2.5 Results of box modelling for the West Solent.



Gradient of Organic Enrichment away from Outfall

Figure 4.1.1.1 Examples of species diversity (dashed line), abundance (solid line) and biomass (dotted line) curves through zones A-D along a gradient of organic enrichment away from a waste water outfall (after Pearson & Rosenberg 1978).

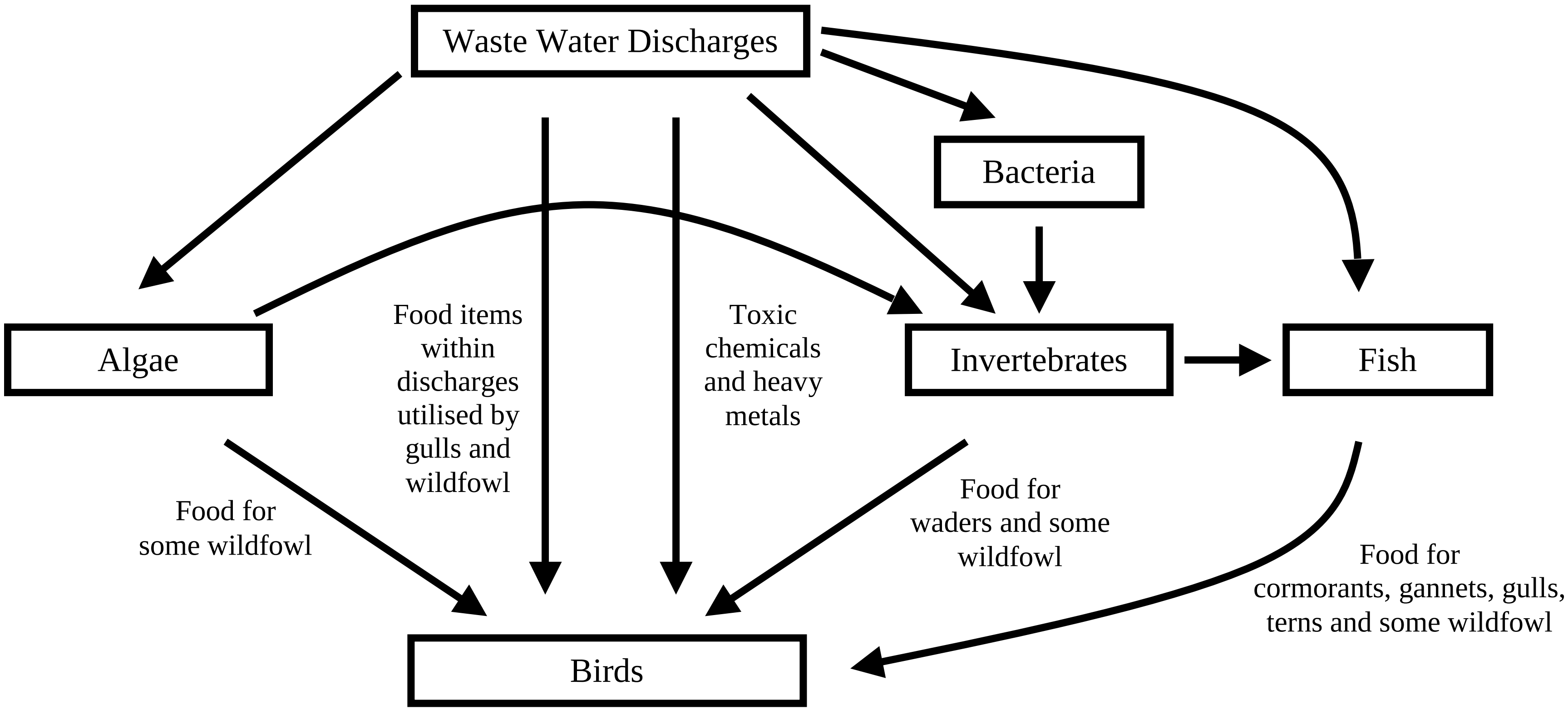


Figure 6.1 The effects of organic and nutrient loading from waste water discharges on bird populations.

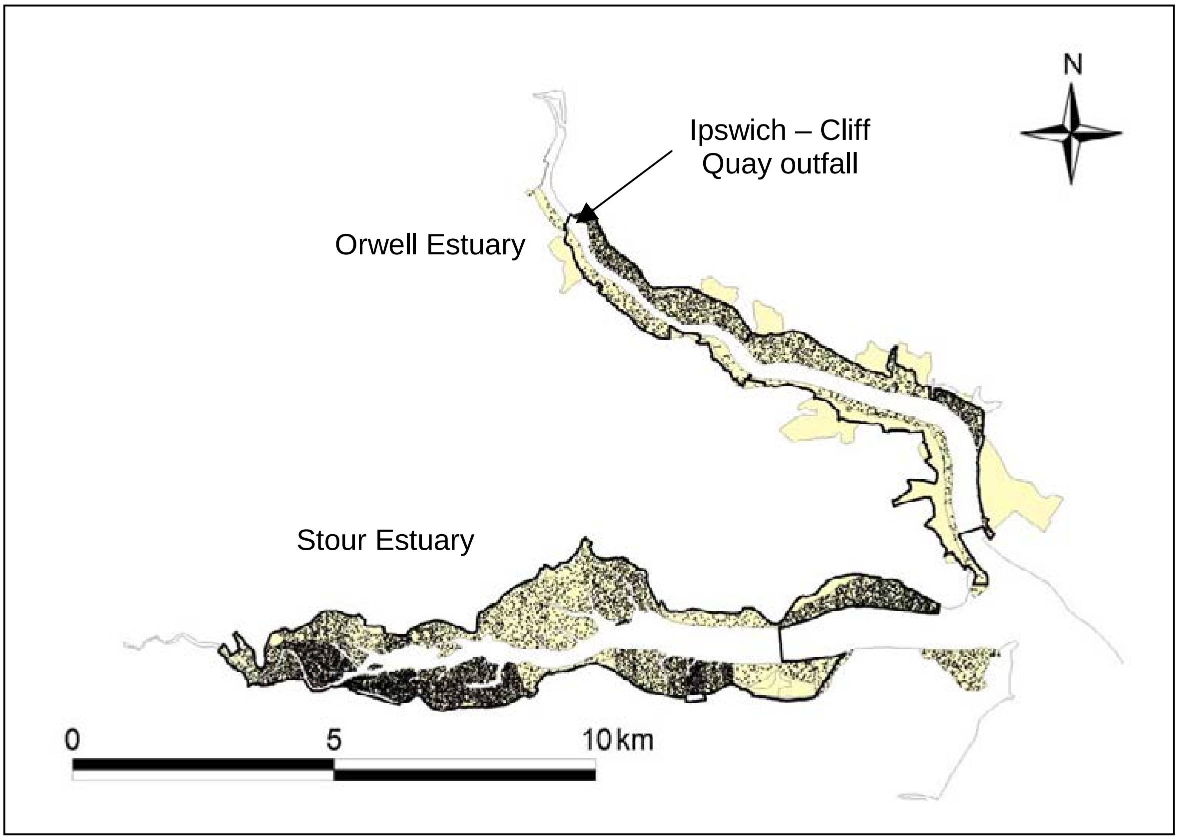


Figure 7.3.1.1 The low tide distribution of Dunlin on the Stour and Orwell Estuaries in East Anglia, showing the 'Stour and Orwell Estuaries' SPA boundary in bold.

One dot equals ten birds.

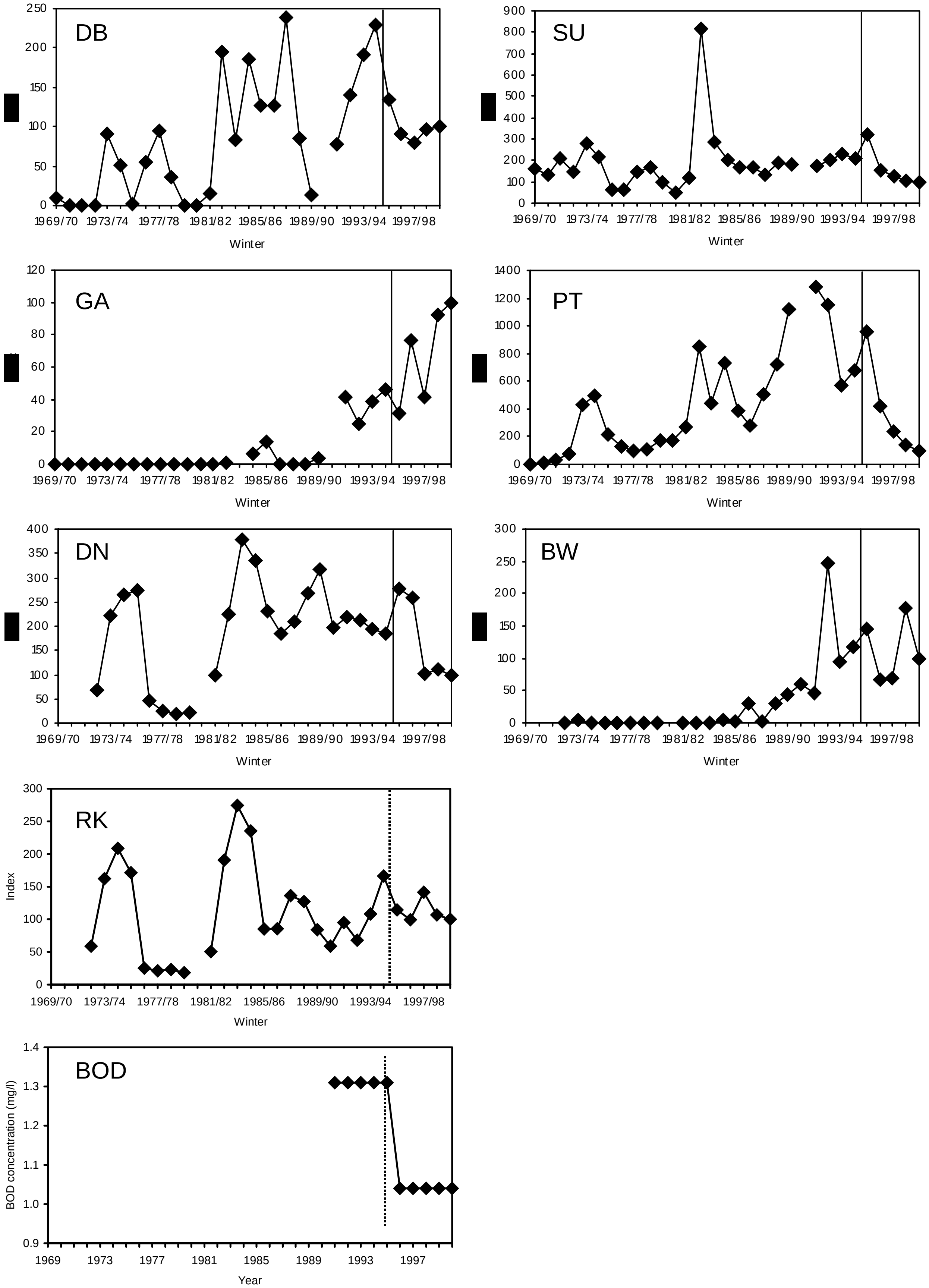


Figure 7.3.3.1 Annual indices derived from WeBS Core Count data for Dark-bellied Brent Goose (DB), Shelduck (SU), Gadwall (GA), Pintail (PT), Dunlin (DN), Black-tailed Godwit (BW) and Redshank (RK) on the Orwell Estuary and variation in overall BOD concentration (mg/l) in the estuary as estimated by box modelling. The dotted lines indicates the change from crude discharges to primary treatment.

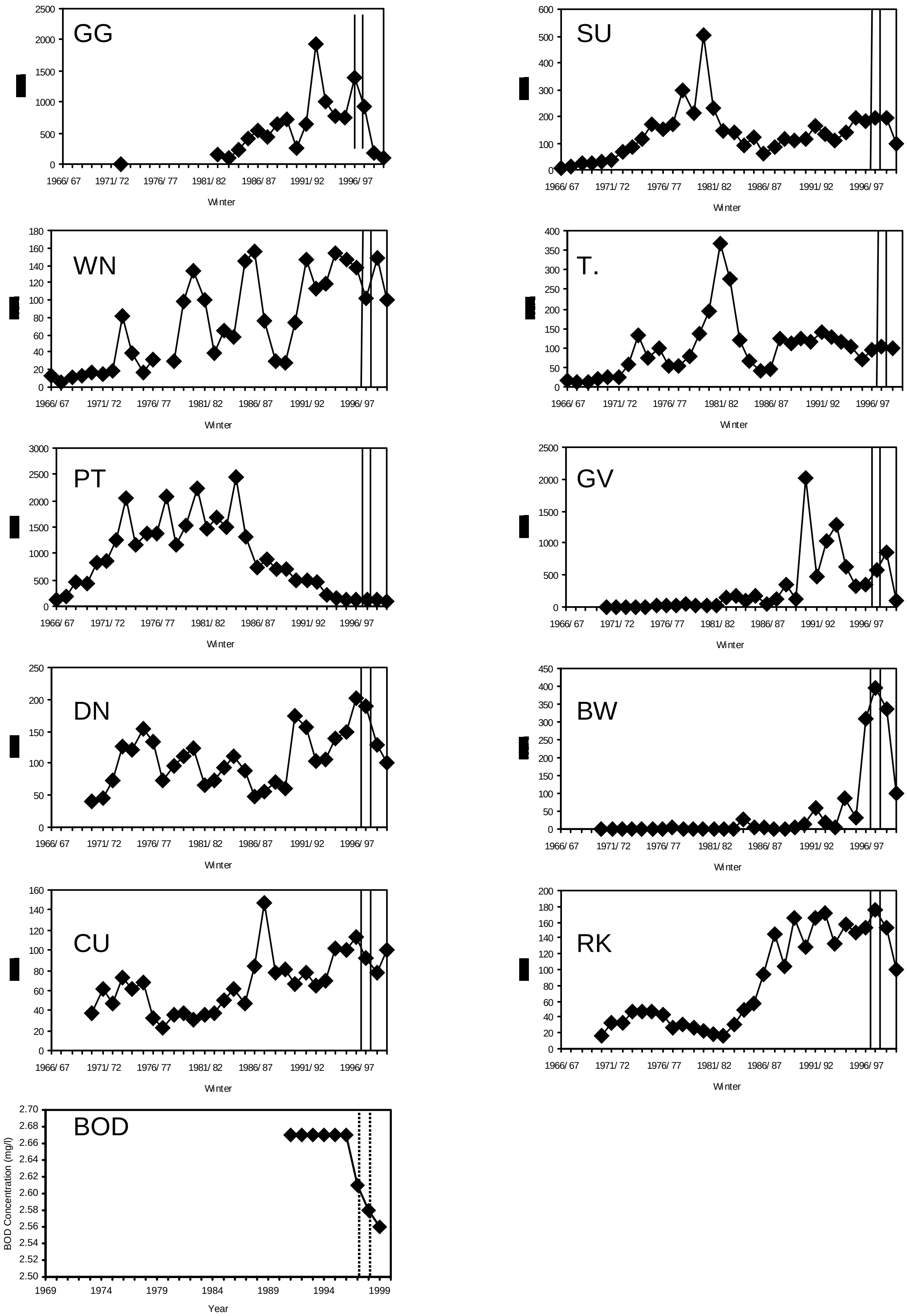


Figure 7.3.3.2 Annual indices derived from WeBS Core Count data for Great Crested Grebe (GG), Shelduck (SU), Wigeon (WN), Teal (T.), Pintail (PT), Grey Plover (GV), Dunlin (DN), Black-tailed Godwit (BW), Curlew (CU) and Redshank (RK) on the Mersey Estuary and variation in overall BOD concentration (mg/l) in the estuary as estimated by box modelling. Dotted lines indicate dates of improvements to discharges.

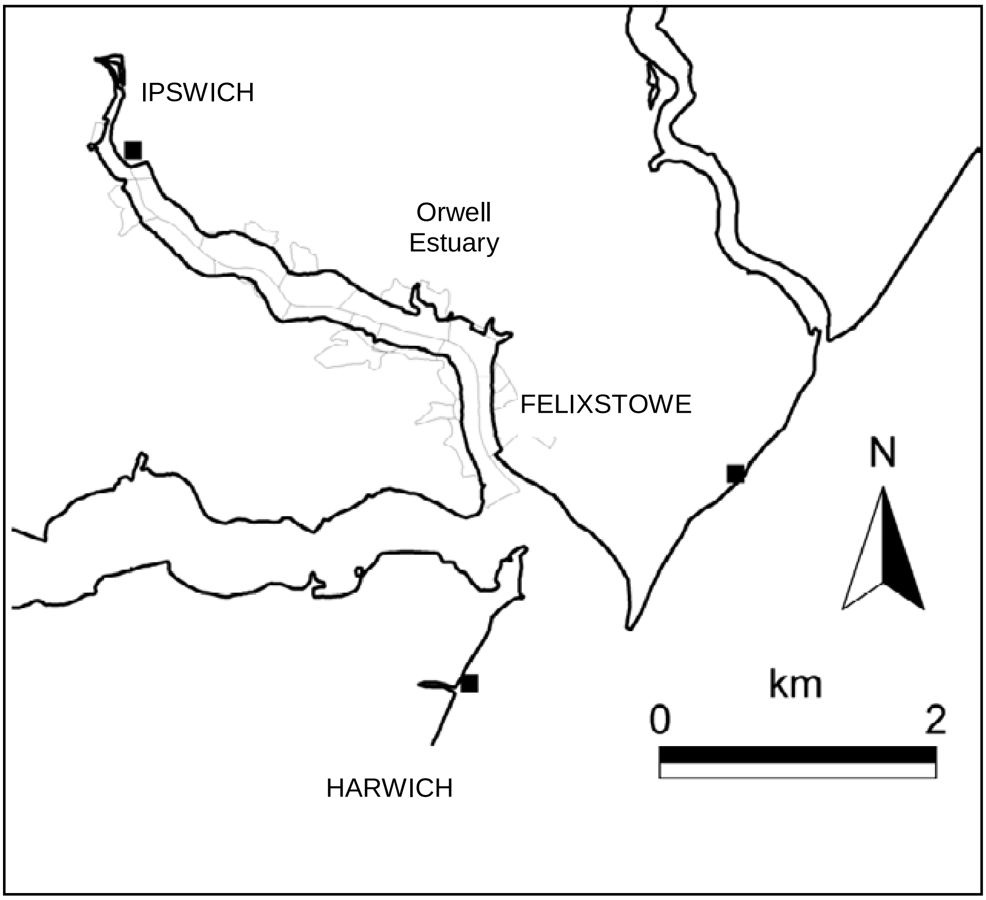


Figure 8.1 The Orwell study site, showing outfall locations (as squares) and intertidal mudflat sections used by WeBS Low Tide Count surveys.

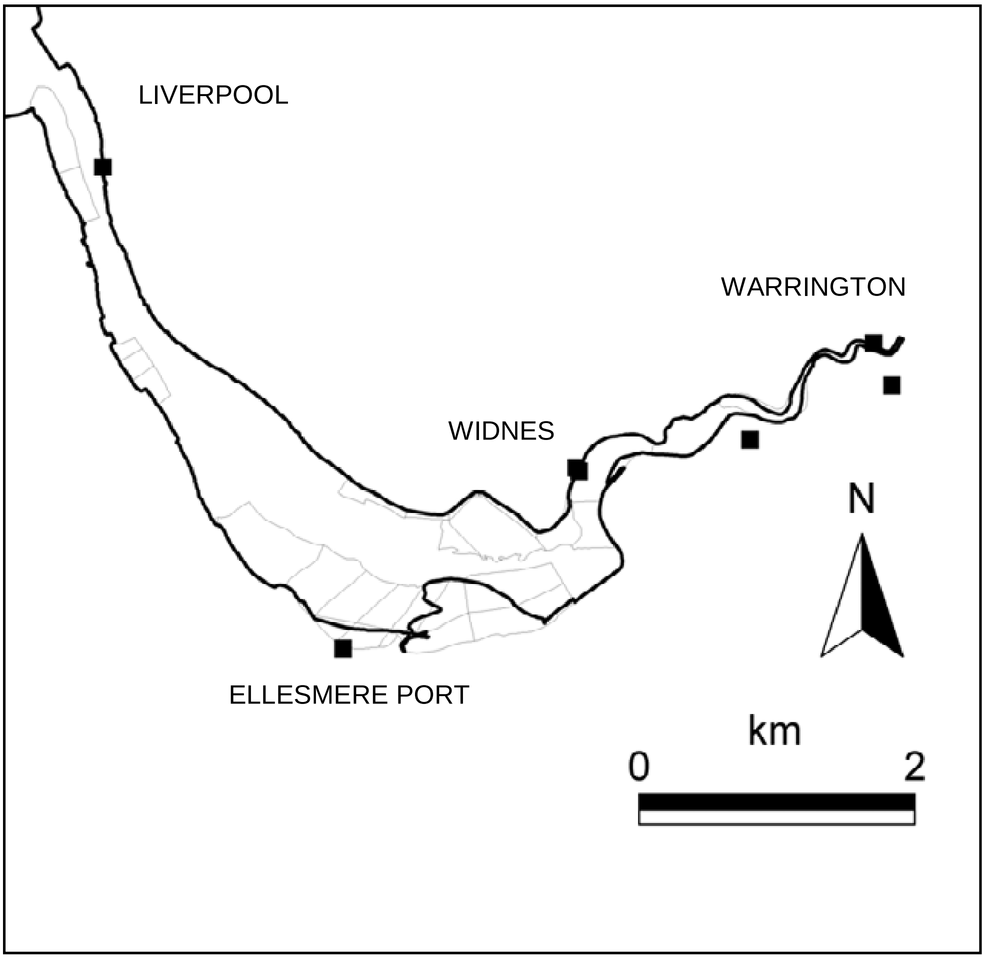


Figure 8.2 The Mersey Estuary study site, showing outfall locations (as squares) and intertidal mudflat sections used by WeBS Low Tide Count surveys.

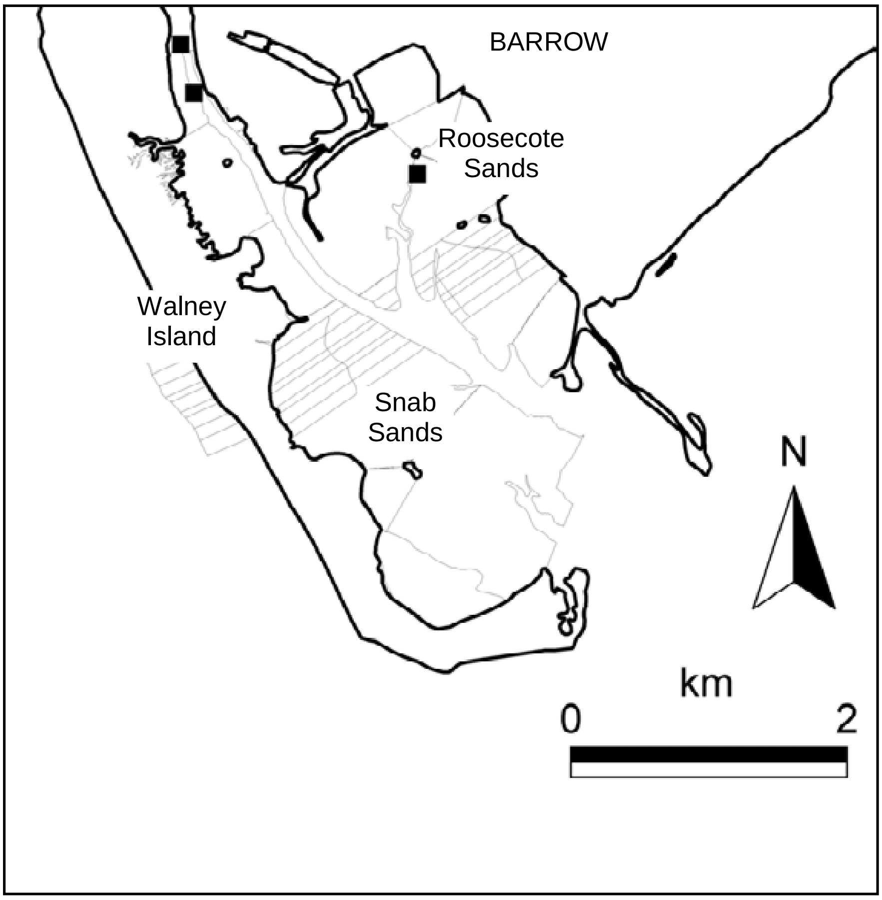


Figure 8.3 The Barrow study site, showing outfall locations (as squares) and intertidal mudflat sections used by BTO surveys.

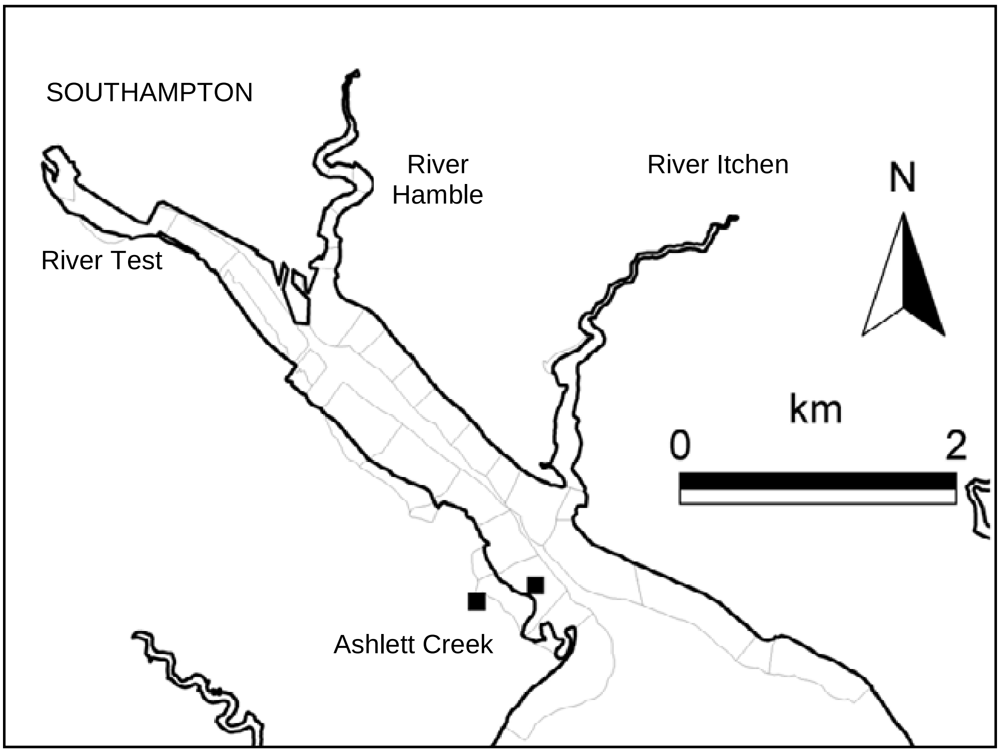


Figure 8.4 The Southampton Water study site, showing outfall locations (as squares) and intertidal mudflat sections used by WeBS Low Tide Count surveys.

Directives whose measures needed to be included in implementing the Water Framework Directive:

The Bathing Water Directive (76/160/EEC)
The Birds Directive (79/409/EEC)
The Drinking Water Directive (80/778/EEC) as amended by Directive (98/83/EC)
The Major Accidents (Seveso) Directive (96/82/EC)
The Environmental Impact Assessment Directive (85/337/EEC)
The Sewage Sludge Directive (86/278/EEC)
The Urban Waste-water Treatment Directive (91/271/EEC)
The Plant Protection Products Directive (91/414/EEC)
The Nitrates Directive (91/676/EEC)
The Habitats Directive (92/43/EEC)
The Integrated Pollution Prevention Control Directive (96/61/EC)

Those to be repealed:

Directive 75/440/EEC of 16 June 1975 concerning the quality required of surface water intended for the abstraction of drinking water in the Member States
Decision 77/795/EEC of 12 December 1977 establishing a common procedure for the exchange of information on the quality of surface freshwater in the Community
Directive 79/869/EEC of 9 October 1979 concerning the methods of measurement and frequencies of sampling and analysis of surface water intended for the abstraction of drinking waters in the Member States
Directive 78/659/EEC of 18 July 1978 on the quality of freshwaters needing protection or improvement in order to support fish life
Directive 79/923/EEC of 30 October 1979 on the quality required of shellfish waters
Directive 80/68/EEC of 17 December 1979 on the protection of groundwater against pollution caused by certain dangerous substances
Directive 76/464/EEC, with the exception of Article 6, which shall be repealed with effect from the entry into force of this Directive.

Appendix 1 Directives whose measures needed to be included in implementing the Water Framework Directive and those which will be repealed as a result of its implementation (Anon 2000).

Parameters	Concentration	Minimum percentage of reduction
Biochemical Oxygen Demand (BOD5 at 20 °C) without nitrification	25 mg/l O^2	70-90 40 under Article 4
Chemical Oxygen Demand (COD)	125 mg/l O^2	75
Total Suspended Solids	35 mg/l 35 under Article 4 (> 10,000 p.e.) 60 under Article 4 (2,000-10,000 p.e.)	90 (3) 90 under Article 4 (more than 10 000 p.e.) 70 under Article 4 (2 000-10 000 p.e.)

Appendix 2a Requirements for discharges from urban waste water treatment plants subject to Articles 4 and 5 of the Urban Waste Water Treatment Directive. (Directive 91/271/EEC and its Amending Directive 98/15/EEC) (Anon 1991a, 1998a). The values for concentration or for the percentage of reduction apply.

Parameters	Concentration	Minimum percentage of reduction
Total phosphorus	2 mg/l P (10,000 – 100,000 p.e.) 1 mg/l P (> 100,000 p.e.)	80
Total nitrogen	15 mg/l N (10,000 – 100,000 p.e.) 10 mg/l N (> 100,000 p.e.)	70-80

Appendix 2b Requirements for discharges from urban waste water treatment plants to sensitive areas which are subject to eutrophication as identified in Annex II.A (a) of the Urban Waste Water Treatment Directive. (Directive 91/271/EEC and its Amending Directive 98/15/EEC) (Anon 1991a, 1998a). One or both parameters may be applied depending on the local situation. The values for concentration or for the percentage of reduction apply.

Article 4 states that "Member States shall ensure that urban waste water entering collecting systems shall before discharge be subject to secondary treatment or an equivalent treatment as follows:
at the latest by 31 December 2000 for all discharges from agglomerations of more than 15 000 p.e.,
at the latest by 31 December 2005 for all discharges from agglomerations of between 10 000 and 15 000 p.e.,
at the latest by 31 December 2005 for discharges to fresh-water and estuaries from agglomerations of between 2 000 and 10 000 p.e."

Article 5 states that "Member States shall ensure that urban waste water entering collecting systems shall before discharge into sensitive areas be subject to more stringent treatment than that described in Article 4, by 31 December 1998 at the latest for all discharges from agglomerations of more than 10 000 p.e." Sensitive areas are defined according to criteria set out in the Directive.

Article 6 states that "Urban waste water discharges from agglomerations of between 10,000 and 150,000 p.e. to coastal waters and those from agglomerations of between 2,000 and 10,000 p.e. to estuaries situated in areas described as less sensitive may be subjected to treatment less stringent than that prescribed in Article 4 providing that such discharges receive at least primary treatment and comprehensive studies indicate that such discharges will not adversely affect the environment."

An Agglomeration is defined as "an area where the population and/or economic activities are sufficiently concentrated for urban waste water to be collected and conducted to an urban waste water treatment plant or to a final discharge point."

p.e. = the organic biodegradable load having a five-day Biochemical Oxygen Demand (BOD5) of 60 g of oxygen per day.

	Guide	Mandatory
Microbiological parameters		
Total coliforms/100 ml	500	10,000
Faecal coliforms/100 ml	100	2,000
Faecal streptococci/100 ml [1]	100	-
Salmonella/l [1]	-	0
Enteroviruses PFU/10 l [1]	-	0
Physico-chemical parameters		
PH [1]	-	6-9
Colour [1]	-	No abnormal change in colour
Mineral oils mg/l [1]	≤ 0.3	No film visible on the surface of the water & no odour
Surface-active substances reacting with methylene blue mg/l (Lauryl sulphate) [1]	≤ 0.3	No lasting foam
Phenols mg/l (phenol indices) $C_6 H_5 OH$ [1]	≤ 0.005	No specific odour ≤ 0.05
Transparency	2	1 (Secchi's disc measure)
Dissolved Oxygen – % saturation O_2 [1]	80 to 120	-
Tarry residues & floating materials such as wood, plastic articles, bottles, containers of glass, plastic, rubber or any other substance. Waste or splinters	Absence	-
Ammonia [2]	-	-
Nitrogen Kjeldahl [2]	-	-
Other substances regarded as indications of pollution		
Pesticides (parathion, HCH, dieldrin) [1]	-	-
Heavy metals such as: arsenic, cadmium, chrome, lead & mercury [1]	-	-
Cyanides [1]	-	-
Nitrates & phosphates [1]	-	-

Appendix 3 Quality requirements set out by the Bathing Water Directive (Directive 76/160/EEC and its proposed revision COM(94)0036-94/00006SYN) (Anon 1976).

[1] Concentration to be checked when an inspection in the bathing area shows that the substance may be present or that the quality of the water has deteriorated.
[2] These parameters must be checked when there is a tendency towards eutrophication of the water.

Duddon Estuary
Exe Estuary
Hamford Water
Humber Flats, Marshes and Coast (Phase 1)
Medway Estuaries and Marshes
Mersey Estuary
Mersey Narrows and North Wirral Shore
Morecambe Bay
Ribble and Alt Estuaries (Phase 2)
Severn Estuary
Solent and Southampton Water
Stour and Orwell Estuaries
Tamar Estuaries Complex
Teesmouth and Cleveland Coast
Thames Estuary & Marshes
Thanet Coast and Sandwich Bay
The Dee Estuary

Appendix 4 Coastal SPAs in or close to which there have been recent changes to discharges from waste water outfalls