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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 2 report

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Phase 2 report

N.H.K. Burton, T.E. Jones, G.E. Austin, G.A. Watt, M.M. Rehfisch & C.J. Hutchins

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Executive summary

1. This report presents the second phase of a study investigating the impacts on coastal waterbirds of the EC's Urban Waste Water Treatment Directive (UWWTD) and Bathing Water Directive (BWD), which have aimed to improve the levels of treatment to waste water discharges.

2. The first phase of the work (Burton and others 2002) reviewed the importance of waste water discharges in providing food for waterbirds and identified species most likely to be at risk from changes to these discharges and sites where waterbirds may have been or may still be affected by the implementation of the directives.

3. Twelve Special Protection Areas (SPAs) or parts of SPAs were identified where past changes in waste water treatment over the period 1990 to 2000 could have impacted upon waterbird populations. These were the Humber Flats, Marshes and Coast SPA, Orwell Estuary (part of the Stour and Orwell Estuaries SPA), Medway Estuary and Marshes SPA, Thanet Coast, Sandwich Bay (parts of the Thanet Coast and Sandwich Bay SPA), North-west Solent (part of the Solent and Southampton Water SPA), Tamar Estuary, Mersey Narrows and North Wirral Foreshore pSPA, Mersey Estuary SPA, Ribble and Alt Estuaries SPA, Morecambe Bay SPA and Barrow-in-Furness (part of the Morecambe Bay SPA). No changes to waste water treatment occurred within four other sites investigated – the Northumbria Coast SPA, Thames Estuary and Marshes SPA, Exe Estuary SPA or Severn Estuary SPA – within this period.

4. Waterbird count data were obtained from the Wetland Bird Survey (WeBS) Core Count Scheme, for each of the 12 sites, as well as for the regions in which these sites were located.

5. Box-modelling was undertaken for each of the 12 sites (and in addition for the Northumbria Coast SPA where change was predicted to occur in the period 2000-2005) in order to give an indication of the average Biochemical Oxygen Demand (BOD) concentration in the receiving water before and after changes in waste water treatment. BOD provides a measure of the organic and nutrient loading and thus may be related to waterbird numbers through their influence on invertebrate abundance, biomass and diversity.

6. Plots indicated that there were declines in waterbird indices on all of the study sites, but that there was no consistent pattern of decline following improvements to waste water discharges. In a number of cases, declines began prior to the implementation of improved treatment or matched regional trends in the species' populations. Only for Shelduck and Grey Plover did the number of sites where declines were noted significantly outnumber those where there were increases (though small samples limited the likelihood of detecting significant probabilities).

7. Initial analyses investigated whether waterbird indices might be positively related to the concentrations of BOD and other variables in the effluent at sites only affected by one main discharge. Results for the three sites where analysis was possible indicated no consistent relationships between waterbird numbers and these variables.

8. The main analyses investigated whether, for individual species, the scale of change in their numbers following improvements to waste water treatment was related to the scale of change in BOD concentration for each site. Again, there were no significant relationships for any species, either using site indices or when taking into account regional change (so as to account for factors not operating at the site-level).

The analyses did indicate, however, that on the sites with the greatest decreases in BOD concentration – the Orwell Estuary, the Medway Estuary and Marshes SPA and the Tamar Estuary – a significantly greater proportion of species declined following improvements to waste water discharges (Fig. 3.2.3.17c).

9. There are a number of reasons why, with the approach used in these analyses, it has not been and would not be possible to clearly link changes in waterbird populations to the changes in water quality resultant from the implementation of the UWWTD (and BWD).

Firstly, it is possible that, at some sites, some species might have benefited from the improvements in water quality – though as none of the sites in the present study were grossly polluted, this seems unlikely.

Importantly, it is likely that even in cases where improvements to waste water discharges do have an impact on waterbird numbers, it might not be possible to see these impacts at the estuary or SPA level, perhaps because other factors operating at the site-level are masking them. Evidence of the impacts on waterbirds of improvements to waste water discharges is likely to be most apparent at a finer, within-site scale.

Significantly, many of the improvements to waste water treatment have only occurred relatively recently and it is possible that there has not been sufficient time since for the impacts of these changes to become apparent. It should be noted, though, that while improved waste water treatment may cause little impact to the majority of species over the short-term, over the longer-term impacts may be more difficult to discern as they may be hidden by other factors affecting waterbird numbers, eg disturbance or climate change.

Lastly, it should be noted that the impacts of the changes to waste water treatment would have been reduced if sites were below their carrying capacity for individual species.

10. The correlative analyses used in this study could not prove a causal link between waterbird numbers and waste water discharges. To be able to prove this link and fully investigate the impact of the directives, it would be necessary to look at changes in the distributions and numbers of waterbirds within sites and to be able to relate these to changes in food resources and preferably also the distribution of organic matter discharged from outfalls. Additional ringing studies would help to determine any impacts on waterbird survival rates. A study that provides baseline data on food resources and waterbird populations in Northumbria is discussed.

Such within-site studies provide the best means of determining the impact of the directives on waterbirds. Without such specifically designed research programmes, investigation of these impacts will be limited to those sites where data on the numbers and distributions of feeding waterbirds have been collected, at a relatively fine scale, over periods where changes to local discharges have occurred. Possible English sites for these analyses include the Orwell Estuary, the Mersey Estuary and Barrow-in-Furness.

Contents

1. Introduction

This report presents the second phase of a study investigating the impacts on coastal waterbirds of two European Community (EC) Directives – the Urban Waste Water Treatment Directive (UWWTD) (Directive 91/271/EEC and its Amending Directive 98/15/EEC) (Anon 1991, 1998) and the Bathing Water Directive (BWD) (Directive 76/160/EEC and its proposed revision COM(94)0036-94/00006SYN) (Anon 1976) – which have aimed to improve the levels of treatment to waste water discharges. Under the UWWTD, all coastal discharges above a certain size must have secondary treatment installed, with the aim of reducing organic loading and to a lesser extent the nutrient loading to the receiving water. For outfalls affecting bathing beaches, the BWD requires further treatment to be implemented.

The implications of these directives on coastal waterbirds, in particular at sites classified as Special Protection Areas (SPAs), led to the implementation of the current work. The first phase of the work (see Burton and others 2002) reviewed the importance of waste water discharges in providing food for waterbirds and assessed how changes to their treatment might affect bird populations. Outfalls may provide food for birds either as directly edible matter or by organic-enriching sediments and thus increasing the invertebrate (and algal) biomass. The first phase work also identified species most likely to be at risk and sites where waterbirds may have been or may still be affected by the implementation of the directives.

To assess whether the implementation of the directives may have already impacted waterbird populations, this report investigates whether the numbers of waterbirds at individual sites may be related to the quality of effluent from individual discharges or whether the scale of change in species' populations may be related to the scale of change in the quality of the receiving water of the site as a whole.

The report considers 16 SPAs or parts of SPAs (identified in the Phase 1 work) where past changes in waste water treatment over the period 1990 to 2000 could have impacted upon waterbird populations or where changes to treatment were planned to occur between 2000 and 2005. These were the Northumbria Coast SPA, Humber Flats, Marshes and Coast SPA, Orwell Estuary (part of the Stour and Orwell Estuaries SPA), Thames Estuary and Marshes SPA, Medway Estuary and Marshes SPA, Thanet Coast, Sandwich Bay (parts of the Thanet Coast and Sandwich Bay SPA), North-west Solent (part of the Solent and Southampton Water SPA), Exe Estuary SPA, Tamar Estuary (part of the Tamar Estuaries Complex SPA), Severn Estuary SPA, Mersey Estuary SPA, Mersey Narrows and North Wirral Foreshore pSPA, Ribble and Alt Estuaries SPA, Morecambe Bay SPA and Barrow-in-Furness (part of the Morecambe Bay SPA).

2. Methods

2.1 Waterbird count data

Data concerning waterbird numbers were collected from the Wetland Bird Survey (WeBS) Core Count Scheme. This 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 and others 2001).

For the purposes of this project, data were collated for the 12 SPAs/parts of SPAs where it was identified that changes in waste water treatment had occurred during the period 1990-2000 and for which it was possible to undertake box modelling (see section 2.3 below). These were the Humber Flats, Marshes and Coast SPA, Orwell Estuary (part of the Stour and Orwell Estuaries SPA), Medway Estuary and Marshes SPA, Thanet Coast, Sandwich Bay (parts of the Thanet Coast and Sandwich Bay SPA), North-west Solent (part of the Solent and Southampton Water SPA), Tamar Estuary, Mersey Narrows and North Wirral Foreshore pSPA, Mersey Estuary SPA, Ribble and Alt Estuaries SPA, Morecambe Bay SPA and Barrow-in-Furness (part of the Morecambe Bay SPA). No changes to waste water treatment occurred within the Northumbria Coast SPA, Thames Estuary and Marshes SPA, Exe Estuary SPA or Severn Estuary SPA within this period (see sections 3.1.1, 3.1.4, 3.1.9 & 3.1.11 of the results).

In addition for each of the 12 sites for which waterbird count data were obtained, data were also obtained at the regional level (the regions used match those of the Environment Agency). A list of all the SPAs and the species for which they are notified is given in Appendix 1.

For the majority of cases, waterbird count data were obtained from WeBS at the site-level (it is assumed that these sites match the SPAs/parts of SPAs being studied) and were mostly available from the winter of 1974/75 to 2000/01. In five cases, the areas where changes to waste water treatment had taken place only formed parts of defined WeBS sites and it was necessary to obtain data for individual sectors within the WeBS site to match against the sites for which box modelling was undertaken (see section 2.3). In these cases – the Humber Flats, Marshes and Coast SPA, North-west Solent, Tamar Estuary, Mersey Narrows and North Wirral Foreshore pSPA and Barrow-in-Furness – data were available from the winter of 1993/94 to 2000/01.

2.2 Water quality and effluent quality data

Water quality and effluent quality data were 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 additionally 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 1995-1999 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 AMP2 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, Midlands, Northeast, Northwest, Southern and Southwest, and from EA Headquarters in Bristol. Data for planned changes during the current AMP3 phase (2000-2005) were also obtained. Initially, this was in the form of a table of which works are being improved. Additional data were provided by EA staff.

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 Biochemical Oxygen Demand (BOD), Ammonia (as N) and Suspended Solids.

Data from WSCs indicated the locations of outfalls where there were major changes to coastal/estuarine discharges between 1990 and 2000. In addition, WSCs provided information on consented flows and effluent quality and the required treatment level for these discharges, before and after the improvements. Data were provided by Anglian Water, Southern Water, South West Water, Severn Trent Water and United Utilities (formerly North West Water).

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. BOD provides a measure of the organic and nutrient loading and thus may be (positively) related to waterbird numbers through their influence on invertebrate abundance, biomass and diversity.

The impact of a particular outfall on the body of water will depend on:

- the relative magnitude of the effluent in question in relation 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 UWWTD (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 Sewage Treatment Works (STW) is the largest source of organic effluent into a site. 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.

Modelling was undertaken for all 12 sites where it was identified that change had occurred in the period 1990-2000 and also for the Northumbria Coast SPA, where change was predicted to occur in the period 2000-2005. No modelling was undertaken for the Thames Estuary and Marshes SPA, the Exe Estuary SPA or the Severn Estuary SPA (see sections 3.1.4, 3.1.9 & 3.1.11 of the results).

Results of a validation of the box-modelling approach, using actual BOD data collected at the Tamar Estuary and Medway Estuary and Marshes, are shown in Appendix 2.

2.4 Analysis of waterbird count data in relation to changes in effluent and water quality

The WeBS count data for each site and region were initially analysed to provide annual indices of the numbers of each species present. Missing counts are inevitable with this kind of data. In addition, waterbird numbers may fluctuate naturally from year to year, for example, due to variation in winter weather conditions. In order to overcome these factors and thus to be able to determine whether changes to the organic and nutrient inputs to a site have had an impact on waterbirds, it was thus necessary to fit smoothed curves to the count data using General Additive Models (GAMs). The models relate the count data to site, year and month factors and use estimates in place of poor quality or missing counts. For each species certain months are used to index the population. These are chosen to be the months in which the population of that species is most stable. For waders these are December through to February but the months used vary for different species of wildfowl (see Leech and others 2002).

Data were smoothed by reducing the number of degrees of freedom available to the GAMs. As the number of degrees of freedom is decreased from (n-1) the trend becomes- increasingly smooth until ultimately with one degree of freedom the smoothed curve becomes a linear fit. Following previous analysis of WeBS data (Austin and others 2003), we adopted a standard (n/3) degrees of freedom to produce a level of smoothing that, while removing temporary fluctuations not likely to be representative of long term trends, captured those aspects of the trends that may be considered to be important. Changes in population size calculated using smoothed values produced by GAMs are less likely to be due to the effects of short-term fluctuations in population size, or to errors when sampling, than results produced using raw data plots. With (n-1) degrees of freedom, the index for the most recent winter for which data are available is set to 100. This value will be affected by the smoothing produced by using (n/3) degrees of freedom.

GAMs were fitted to provide smoothed annual indices of the numbers of each species at both site and regional levels. Data for the region were analysed in order to take into account population changes that were not related to factors operating solely at the site-level – climate change, for example. These regional analyses excluded data from the site in question. It should be noted, though, that other sites included in the regional indexing might have also been affected by improvements to waste water discharges at the same time as the particular site being studied. Dates over which improvements to coastal waste water discharges are known to have been made within each (Environment Agency) region under the Water Companies' first two Asset Management Plans are shown in Table 2.4.1.

In addition to the species-specific indices, a Total Wader Index was also calculated for each site. The index was initially calculated as the sum of the numbers of birds of each species, having first weighted these figures by species-specific Basal Metabolic Rate (BMR) and body weight (following Quesenberry and others 1989). These indices were then also smoothed using GAMs. It was not possible to calculate Total Wader Indices for the North-west Solent as data were missing for a number of species. It was not possible to calculate a wildfowl or overall waterbird index from the data available.

Trends in the smoothed indices were initially compared graphically with estimates of BOD concentrations for each site obtained through box modelling. It was predicted that following improvements to waste water treatment, and thus a reduction in BOD concentrations, there would be declines in bird populations. Plots are provided for every (estuarine) species numerous enough to be able to index (ie those which occur on a site in numbers greater than 0.2% of the national population). All those for which the site is important in winter (see Appendix 1) are thus included, with the exception of species that predominantly use freshwater habitats, ie Bewick's swan *Cygnus columbianus*, whooper swan *C. cygnus*, pink-footed goose *Anser brachyrhynchus*, European white fronted goose *Anser albifrons* and gadwall *Anas strepera*, and species that are poorly monitored by WeBS counts, ie Slavonian grebe *Podiceps auritus*, little egret *Egretta garzetta*, eider *Somateria mollissima*, common scoter *Melanitta nigra*, golden plover *Pluvialis apricaria*, lapwing *Vanellus vanellus* and purple sandpiper *Calidris maritima*.

Following this initial appraisal, regression analysis was used to determine whether the smoothed waterbird indices (for individual species and the Total Wader Index) each winter were related to the average levels of BOD, Ammonia (as N) and Suspended Solids in the effluent in the preceding year. It was only appropriate to undertake these analyses at three sites – the Orwell Estuary, North-west Solent and Barrow-in-Furness – as other sites were affected by more than one main discharge. As only a few years' water quality data were available from these sites and because the water quality variables were highly correlated with one another, the relationships between each of these variables and waterbird indices were considered in separate analyses. The analyses were repeated with the site indices also regressed against the regional indices, so as to allow for factors not operating at the site-level. (For the purposes of these analyses, the regional indices were calculated excluding waterbird count data from the WeBS site in question).

The main analysis uses the results of box modelling to assess whether, for individual species (and the Total Wader Index), the scale of change in their numbers following improvements to waste water treatment was related to the scale of change in BOD concentration for each site. Plots are shown using the change in waterbird indices at each site and using the residuals from the relationship between the changes in site and regional indices. Change is evaluated as the proportional increase or decline in these values one winter after the changes to waste water treatment in relation to the value in a base winter immediately preceding the changes to treatment. As the effects of these improvements may have taken time to become apparent, however, we have also investigated the effects of change between the index in the base winter and that two winters after the changes to waste water treatment. Most improvements to waste water treatment were too recent to investigate any greater time lag than this. (In those instances where no data were available for the winter immediately preceding improvements to waste water treatment, the winter preceding that was used as the base winter). Regression analysis was used to determine whether the change in site index was significantly (and positively) related to the change in BOD concentration. The analyses were then repeated with the change in regional index also taken into account.

Analysis was only undertaken for those instances where change in waterbird indices could be determined for six or more of the 12 sites where change in waste water treatment had occurred during the period 1990-2000. It was thus only possible to undertake analysis for 15 species that occurred commonly at a number of the sites. These were: great crested grebe *Podiceps cristatus*, cormorant *Phalacrocorax carbo,* shelduck *Tadorna tadorna*, wigeon *Anas penelope*, pintail *Anas acuta*, oystercatcher *Haematopus ostralegus*, ringed plover *Charadrius dubius,* grey plover *Pluvialis squatarola*, knot *Calidris canutus,* sanderling *C. alba*, dunlin *C. alpina,* black-tailed godwit *Limosa limosa*, curlew *Numenius arquata,* redshank *Tringa totanus* and turnstone *Arenaria interpres*.

These analyses thus aimed to determine whether changes in waterbird numbers may be affected by changes in water quality as indicated by BOD concentrations and thus whether this factor could be used to predict future changes in bird populations at sites yet to be affected by the UWWTD. Thus, the results for Turnstone, if significant, could be used to predict the impact to this species of the future changes to waste water discharges on the Northumbria Coast SPA (as determined by box-modelling).

It is important to note that the analyses are purely correlative and make two fundamental 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 and others (1990) and Hill and others (1993), these assumptions have some validity.

3. Results

3.1 Box modelling

3.1.1 The Northumbria Coast SPA

The Northumbria Coast SPA extends from the River Tweed in the north to Hartlepool Headland in the south. The SPA is characterised by a rocky foreshore. During AMP3, the period from 2000 to 2005, there will have been a large improvement in sewage treatment with all sewage treatment works being upgraded to secondary treatment. Many small crude or preliminary outfalls will have been closed with the effluent diverted to new or existing works. The principal changes will be at Amble, Cambois, Newbiggin, Seaham, Howdon and Hendon. The changes to be carried out were identified from the Environment Agency's 'Achieving the Quality' (Environment Agency 2000). Actual effluent data were confirmed by personal communication with local Agency staff. The largest input is from Howdon sewage works on the Tyne Estuary (actually outwith the SPA), which is to receive improved treatment levels that will reduce the BOD load by a factor of six, from 32 t/day to 5 t/day, although how effluent from Howdon impacts on the SPA is unknown without carrying out detailed modelling.

As the numerous outfalls involved are spread along the whole length of the SPA, the box model was set up for the whole of this stretch of coast and extending offshore by 1 km. The model area has been based on the overall domain of the SPA rather than in terms of tidal excursions from a specific outfall. (Note the box also includes the Lindisfarne SPA). Therefore, the exchange coefficient has been determined as if the SPA is closed on three sides and the exchange coefficient can be determined solely by the ratio of the tidal volume to the total volume. The coastline for most of the length of the SPA is relatively uniform, so a typical depth is applied to the whole box area of -7.5 m CD. Data were obtained from Admiralty Chart 109 and from the Northumbrian Coastal Modelling System developed by HR Wallingford for Northumbrian Water (HR Wallingford 1996a).

The results of the box model are shown in Table 3.1.1.1. The overall effect of the reductions in BOD by the end of AMP3 will be to reduce the total BOD load to the SPA by 52%. However, the reduction in concentration is predicted to be only 0.07 mg/l (6%).

3.1.2 The Humber Flats, Marshes and Coast SPA

Box modelling was undertaken for the part of the Humber Flats, Marshes and Coast SPA at the mouth of the estuary from Immingham in the west to Tetney and Spurn Head in the east. The two discharges that have been changed under the UWWTD, Pyewipe and Cleethorpes are located within the SPA. The load from Pyewipe was reduced by 65% in 1995. The load at Cleethorpes was reduced by 93% in 1999.

The size and hydrodynamic properties of the box were determined from the ACMS model (HR Wallingford 1997) and Admiralty Chart 1191. The longitudinal extent of the box was centred about half way between the two outfalls at Immingham and the size determined from the tidal excursion. The mean current speeds locally are relatively high leading to a large tidal excursion (~15 km), and hence the volume of the box is high.

All other discharges to the Humber are considered to be included in the background figure, as the westward edge of the box does not extend as far as Hull. The easternmost part of the model is at the narrow entrance of the Humber at Spurn Head. Results of modelling are shown in Table 3.1.2.1.

This combination of a large box with and a high exchange coefficient gives rise to a relatively small change in net concentration – 0.03 mg/l (2%) – despite a 71% reduction in BOD load.

3.1.3 The Orwell Estuary

The Orwell Estuary forms part of the Stour and Orwell Estuaries SPA.

The largest source of effluent into the Orwell Estuary is the discharge from the Cliff Quay STW, which is about 1 km from the tidal limit. The BOD load from this discharge was significantly reduced in 1995 from 9900 kg/day to 340 kg/day. Results of modelling are shown in Table 3.1.3.1.

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 11 km, while based on the upper estuary velocity it is 4.5 km. As the length of the Orwell from the confluence with the Stour to its tidal limit is about 15 km, we have assumed that Box 3 represents the whole estuary, Box 2 about two thirds of the estuary and Box 1 about one third of the estuary. Data on the hydrodynamic characteristics of the Orwell were 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 1996b; 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 were 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 STW
- BSC Sproughton

Before the improvements to Cliff Quay STW, 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.

The results of the box modelling indicate that the overall BOD load to the whole estuary (Box 3) decreased by 89% following the improvements at Cliff Quay and the BOD concentration by 0.27 mg/l (21%). The change in concentration for Box 3 is used for the analyses with the waterbird data.

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

3.1.4 The Thames Estuary and Marshes SPA

No outfalls that have been or are to be upgraded have been identified that may impact on this SPA. Consequently, no meaningful box modelling can be carried out. More remote outfalls, such as those in the middle Thames Estuary may have an impact on the SPA in terms of nutrients, but the impact of the UWWTD on nutrient loads is generally not as significant as the impact on BOD loads. In any case, something of the order of 80% of the organic carbon discharged to the upper Thames Estuary is re-mineralised by the time it reaches Southend (Trimmer and others 2000).

3.1.5 The Medway Estuary and Marshes SPA

The Medway Estuary and Marshes SPA covers all the inter-tidal areas in the outer Medway Estuary and Long Reach (the northern arm of the Swale Estuary). The impact of the two major discharges is represented by two separate boxes, one for the outer Medway Estuary and the other for Long Reach. All the hydrodynamic data were derived from a model being developed by HR Wallingford for the Environment Agency of the Outer Thames Estuary with specific focus being placed on the Medway and Swale. This work is yet to be reported. Admiralty chart 1834 was also used.

Medway

The first box is located relative to the STW at Motney Hill in the southern Medway. The size of the box is derived from the tidal excursion centred about this outfall (4 km). The box is constrained in a lateral direction by the sides of the estuary and contains a large area of tidal flats (> 50% of the total area).

Motney Hill was upgraded from primary to secondary treatment in 2000, leading to a 93% reduction in BOD load. The hydrodynamics of the area produce a relatively small box but there are a number of other discharges (including small treatment works and industry) to the area. Also included are the numerous discharges to the upper part of the Medway Estuary, which are technically outside of the box. These additional loads have not changed over the period of the analysis to the best of our knowledge. As that part of the estuary has a small volume it seems logical to include these as direct inputs to the box. In 2000 the load to this area reduced by 49% giving a 17% reduction in concentration. The results for the Medway box are shown in Table 3.1.5.1.

Long Reach

The Long Reach box represents a tidal excursion relative to Queenborough STW (6.5 km). The width of this narrow tidal channel, which is less than 500m wide at Queenborough, limits the lateral extent of the box. The works was improved from primary and secondary treatment in March 1998, leading to a 95% reduction in BOD. Seventy-five percent of the additional BOD load to Long Reach is from two paper mills. The remaining load is from four small sewage treatment works. After 1998, the load to the area was reduced by 68% leading a 6% reduction in the box concentration. The results for the Long Reach box are shown in Table 3.1.5.2.

The results for the boxes have been combined as a single box to more representative of the whole SPA. These combined results are shown in Table 3.1.5.3. The overall load was reduced by 51% and the box concentration reduced by 0.18 mg/l (12%) between 1998 and 2000, the changes at the Motney Hill works being the major factor.

3.1.6 The Thanet Coast

The Thanet Coast forms part of the Thanet Coast and Sandwich Bay SPA and stretches along the north coast of Kent from the eastern edge of The Swale SPA to the Isle of Thanet.

Hydrodynamic data were derived from the model being developed for the Environment Agency, as used for the Medway Estuary and Marshes SPA and the ACMS developed for Anglian Water (HR Wallingford 1997) and from Admiralty Chart 1607. The size of the box was deduced from the tidal excursion at Swalecliffe (6-7 km) and confined to 5 km offshore.

Only two discharges are included in this box. Swalecliffe STW was upgraded from crude to primary in 1998 and from primary to secondary in 2001. The crude discharge at Herne Bay was closed in 1995. This effluent is now treated at a secondary plant and is discharged from Wetherlees on the Stour Estuary. Results of modelling are shown in Table 3.1.6.1. The overall load was reduced by 68% by the changes between 1995 and 1998 and the box concentration reduced by 0.003 mg/l (0.21%). The change in concentration between 1995 and 1998 is used for the analyses with the waterbird data.

3.1.7 Sandwich Bay

Sandwich Bay forms part of the Thanet Coast and Sandwich Bay SPA and covers the intertidal areas at the mouth of the Stour Estuary to the south of the Isle of Thanet.

Hydrodynamic data were derived from the ACMS developed for Anglian Water (HR Wallingford 1997), that includes part of the Kent coast, and from Admiralty Chart 1828. The size of the box was deduced from the tidal excursion at Ramsgate (8-9 km), and confined to 7 km offshore. Pegwell Bay is included in the box, but not the riverine stretches of the Stour Estuary.

Crude discharges via long sea outfalls at Deal, Ramsgate and Sandwich were all closed in 1995. The effluent is now treated in a secondary treatment plant at Wetherlees in the Stour Estuary. Results of modelling are shown in Table 3.1.7.1. The overall load was reduced by 90% after 1995 and the box concentration reduced by 0.0035 mg/l (0.05%).

3.1.8 North-west Solent

The North-west Solent forms part of the Solent and Southampton Water SPA.

The only significant discharge from a STW that has been modified in the last ten years in this area is at Pennington. The outfall is located about 2 km north-east of Hurst Point, at the western entrance to the Solent. Before 1997, the outfall discharged an average of 6204 kg/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 475 kg/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 3.1.8.1.

The outfall is about 1 km long and is discharged at about 2 m below low water. Peak currents in the Solent are of the order of 1.5 m/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 7 km. Assuming that the effluent is confined to about 3 km from the coast, the area of the box extends from Hurst Point to about 7 km north-east of the outfall. The volume of the box has been estimated by assuming a uniform depth below mean tidal level of 6 m (based on data from Admiralty Chart 2040). Estimating the exchange coefficient in this box is less straightforward 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 195 kg/day.

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

The results of the box-modelling (assuming a high exchange coefficient) indicate that the overall BOD load to the site decreased by 90% following the improvements in 1997 and the BOD concentration by 0.045 mg/l (4%). The change in concentration from the model that assumes a high exchange coefficient is used for the analyses with the waterbird data.

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

3.1.9 The Exe Estuary SPA

There were no changes to the treatment to the two outfalls – Countess Wear at Exeter and Kenton-Starcross – that discharge into the Exe Estuary SPA during the periods covered by AMP1 and AMP2. The Exmouth STW, which was upgraded in 1995 to provide secondary treatment in 1995, discharges into the English Channel outwith the SPA and is therefore unlikely to affect the SPA's bird populations. Consequently, no box modelling was carried out for this site.

3.1.10 The Tamar Estuary

Box modelling was undertaken for the intertidal areas of the Tamar Estuary upstream of Devonport. The Tamar Estuaries Complex SPA also includes the Lynher Estuary and St. John's Lake. The box size was base on the tidal excursion in the upper estuary estimated from data on the Admiralty chart 871. This gave a tidal excursion of 4 km.

Ernesettle & Saltash and Camel's Head STWs were upgraded from crude to secondary treatment in 2000. Only consent data were available for the Camel's Head load, and therefore calculations have been carried out for two cases: using these data and omitting the discharge altogether, in order to provide a range of variation.

The box model results for the Tamar Estuary are shown in Table 3.1.10.1. The reductions in load are significant (54% using the data for Ernesettle & Saltash only) and have lead to reasonably large reductions in average BOD concentration – 0.22 mg/l (15%) (again using the data for Ernesettle & Saltash only). The change in concentration from the model that only uses the data for Ernesettle & Saltash is used for the analyses with the waterbird data. (The Camel's Head outfall discharges into Weston Mill Lake which lies outwith the SPA).

3.1.11 The Severn Estuary SPA

No changes to waste water treatment at outfalls discharging into the Severn Estuary SPA were identified for the periods covered by AMP1 and AMP2. Changes have been implemented at Cardiff since 2000, though it was not possible to obtain data for this site and, thus, no box modelling was carried out.

3.1.12 The Mersey Estuary SPA

There are three significant STWs on the Mersey Estuary SPA 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 STWs at which there had been significant change in organic load. Each box is one tidal excursion from the outfall. The Liverpool STW 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 STW the landward limit of its box is set at the tidal limit. The estimates of the tidal excursions were based on data from numerical models developed by HR Wallingford (HR Wallingford 1991; HR Wallingford 1992; HR Wallingford 1993). Results of modelling are shown in Tables 3.1.12.1 and 3.1.12.2.

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 STW discharges. Box 2 was assumed to cover one compartment between Hale Head and Runcorn Gap into which Widnes STW 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 STW. 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 from 1997 to 1999. During those years, the bulk of the changes to discharges occurred. These results suggest that the BOD load was reduced by 71% by these changes and the BOD concentration by 0.11 mg/l (4%).

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

3.1.13 The Mersey Narrows and North Wirral Foreshore pSPA

The impacts of the changes due to sewage loads on this pSPA are assumed to be already covered by the calculations for the Mersey Narrows in 3.1.12. The results for Box 1 in Table 3.1.12.1 for the Mersey give the indicative changes of the area of the pSPA likely to be affected by discharges in the Mersey, in particular from central Liverpool. These results suggest that the BOD load was reduced by 39% by the changes in 1999 and the BOD concentration by 0.10 mg/l (4%).

3.1.14 The Ribble and Alt Estuaries SPA

The box for the Ribble and Alt Estuaries SPA includes the mudflats of the River Ribble and the coast from Blackpool Airport to Queen's Channel, just south of Formby and the Alt Estuary. The dominant outfall in this area is Preston STW, which was upgraded from crude to secondary treatment in 1996/97, leading to a 98% reduction in BOD load. The outfalls from Hesketh Bank on the south bank of the Ribble Estuary and at Southport, although smaller, were also upgraded about the same time. Four large untreated discharges on the Fylde coast and Blackpool were also closed at this time.

The bathymetry of the box was derived from Admiralty Chart 1981. In total, 80% of the area of the box is inter-tidal. The exchange coefficient was calculated based on the ratio of the tidal prism to the total volume. It gives a high exchange coefficient as the tidal range is of the order of 6 m in this area.

Apart from the outfalls mentioned above, the only other significant loading that was considered was that due to the Rivers Ribble and Darwen at Preston. These contribute a total of 7516 kg/day. This load was derived from river flow data available from River Archive on the CEH web site and from summary of water quality data available on the Environment Agency web site. The data on the sewage works loads were provided by United Utilities.

The comparatively large box volume and efficient flushing, means that even though the sewage loads have reduced dramatically (by 82%), the overall concentration has changed only by 0.03 mg/l (3%). The results for the Ribble and Alt box model are shown in Table 3.1.14.1.

3.1.15 The Morecambe Bay SPA

The Morecambe Bay SPA covers most of the inter-tidal area of the bay. Treatment levels in at least 10 significant sewage works that discharge to the bay have been improved since 1995. As a result of the distribution and hence the interaction between these discharges, a single box covering the whole of Morecambe Bay was used.

The Morecambe Bay box covers a large area (~850 km^2), two thirds of which is inter-tidal. The bathymetry of the bay was derived from Admiralty Chart 2010. The exchange coefficient for the box was derived on the simple ratio of the tidal prism to the total volume rather than based on the tidal excursion about a particular outfall. This choice was made because of the large number of outfalls spread over the whole of the bay, from Barrow-in-Furness in the north to Fleetwood in the south-west. The exchange coefficient for the bay is relatively large (1.2/day).

A number of changes to treatment works have been made since 1995. The following discharges have been upgraded or closed:

1995 – Milnthorp, Pilling, Preesall, Poulton and Tummerhill
1996 – Barrow-in-Furness, Grange-over-Sands and Fleetwood
1997 – Morecambe
2000 – Lancaster, Ulverston, Barrow-in-Furness (crude discharges)

Most of these are sewage works that were upgraded from primary to secondary treatment. The data on the sewage works loads were provided by United Utilities.

The other major discharge is the river Lune. The data for this river were obtained from the river archive at CEH Wallingford and the Environment Agency web site.

Due to the large box volume and large exchange coefficient, the outfalls contribute very little to the overall box BOD concentration. Although the BOD load has reduced by 71%, the BOD concentration has reduced by just 0.005 mg/l (0.5%).

Results of modelling are shown in Tables 3.1.15.1.

3.1.16 Barrow-in-Furness

The Barrow-in-Furness site forms part of the Morecambe Bay SPA.

The outfall from Barrow-in-Furness STW 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-in-Furness. There is a large tidal range (8 m 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 10 km 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 6 km long and 3.5 km 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-in-Furness 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 sources of hydrodynamic information on Barrow-in-Furness were Admiralty Charts 3164 and 2010). The higher value of the E is probably more realistic given the large inter-tidal area. Results of modelling are shown in Table 3.1.16.1.

The BOD load from the Barrow-in-Furness works was reduced from 4250 kg/d to 73 kg/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 1200 kg/day with an additional 300 kg/d from other treatment works. The total load therefore used in the box modelling calculation is 1500 kg/day.

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

The results of the box-modelling (assuming a high exchange coefficient) indicate that the overall BOD load at Barrow-in-Furness decreased by 74% following the improvements in 1996 and the BOD concentration by 0.10 mg/l (9%). The change in concentration from the model that assumes a high exchange coefficient is used for the analyses with the waterbird data.

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

3.2 Trends in waterbird numbers in relation to changes in effluent and receiving water quality

3.2.1 Trends in waterbird numbers

Trends in waterbird indices are plotted for those 12 sites where there have been improvements to waste water treatment following the implementation of AMP1 in 1990 and prior to the winter of 2000/01. The following site accounts indicate those species which have shown obvious declines following improvements to waste water treatment (the size of the change in BOD concentration for each site is indicated in the header line). As waterbird data were only available for one or two years following some of the changes in treatment and for five sites were only available from 1993/94, results for some sites should be treated with caution. The apparent changes are summarised in Table 3.2.1.1. Most species showed a larger number of declines than increases at the sites where they were indexed, though only for shelduck and grey plover was this difference significant (it should be noted, however, that small samples limited the likelihood of detecting significant probabilities).

The Humber Flats, Marshes and Coast SPA -0.030 mg/l

Indices were plotted for 15 species for the area at the mouth of the Humber Flats, Marshes and Coast SPA affected by changes to waste water treatment (Figure 3.2.1.1). Numbers of three designated species – oystercatcher, grey plover and sanderling – and, in addition, turnstone, appear to have declined following the period (1995 to 1999) that improvements to waste water treatment took place. Each of these declines was contrary to the regional trend for the species.

The Orwell Estuary -0.270 mg/l

Indices were plotted for 18 species for the Orwell Estuary (Figure 3.2.1.2). Numbers of 11 designated species – great crested grebe, cormorant, dark-bellied brent goose *branta bernicla*, shelduck, wigeon, pintail, goldeneye *Bucephala clangula*, ringed plover, grey plover, dunlin and black-tailed godwit – appear to have declined since the change from crude discharges to primary treatment in 1995. With the exception of cormorant, these declines have been contrary to or in excess of regional trends. The declines of pintail, ringed plover, grey plover and black-tailed godwit began prior to the improvements to waste water treatment in 1995.

The Medway Estuary and Marshes SPA -0.180 mg/l

Indices were plotted for 18 species for the Medway Estuary and Marshes SPA (Figure 3.2.1.3). The treatment to two discharges at this site was improved from primary to secondary in 1998 and 2000. With only one year's data following the changes, it is difficult to draw firm conclusions as to their impacts on bird populations.

Numbers of 12 designated species – little grebe *Tachybaptus ruficollis*, great crested grebe, cormorant, dark-bellied brent goose, shelduck, wigeon, pintail, oystercatcher, ringed plover, dunlin, curlew and redshank – have apparently declined following the changes. With the exception of Pintail, these declines have been contrary to or in excess of regional trends. However, with the exception of little grebe and oystercatcher, all these declines began in the late 1980s or early 1990s prior to the recorded improvements to waste water treatment.

The Thanet Coast -0.003 mg/l

Indices were plotted for four species for the Thanet Coast section of the Thanet Coast and Sandwich Bay SPA (Figure 3.2.1.4). The numbers of grey plover declined slightly following the period (1995 to 1998) that improvements to waste water treatment took place, though this reflected a regional decline. Numbers of the other three species increased over this period, the increase in sSanderling numbers mirroring the regional trend.

Sandwich Bay -0.004 mg/l

Indices were plotted for three species for the Sandwich Bay section of the Thanet Coast and Sandwich Bay SPA (Figure 3.2.1.5). The numbers of Turnstone declined following the change from crude discharges to secondary treatment in 1995, before then recovering. This pattern reflects the regional trend for the species.

North-west Solent -0.045 mg/l

Indices were plotted for 16 species for the North-west Solent section of the Solent and Southampton Water SPA (Figure 3.2.1.6). Numbers of six designated species – cormorant, dark-bellied Brent goose, shelduck, grey plover, dunlin and black-tailed godwit – appear to have declined since the changes from crude to secondary treatment in 1997. However, with the exception of cormorant, these declines matched regional trends.

The Tamar Estuary -0.220 mg/l

Indices were plotted for four species for the area of the Tamar Estuary affected by changes to waste water treatment (Figure 3.2.1.7). As only one year's data were available for the period following the change from crude to secondary treatment in 2000, it is difficult to draw firm conclusions as to the impact of the change on bird populations.

The plots suggest that numbers of Cormorant and Black-tailed Godwit have declined following the improvements to treatment, though also show that both these declines began prior to 2000. In the latter case, the decline also mirrors the regional trend.

The Mersey Estuary SPA -0.110 mg/l

Indices were plotted for 11 species for the Mersey Narrows and North Wirral Foreshore pSPA (Figure 3.2.1.8). Numbers of eight designated species – great crested grebe, shelduck, wigeon, teal *Anas crecca*, pintail, grey plover, black-tailed godwit and redshank – and, in addition, cormorant, have apparently declined in the two winters since the improvements to the discharge at Liverpool. The declines of great crested grebe, teal, pintail and grey plover began prior to the improvements to treatment. The decline in wigeon numbers reflects that seen at the regional level.

The Mersey Narrows and North Wirral Foreshore pSPA -0.100 mg/l

Indices were plotted for eight species for the Mersey Narrows and North Wirral Foreshore pSPA (Figure 3.2.1.9). Numbers of three designated species – oystercatcher, grey plover and knot – and, in addition, bar-tailed godwit *Limosa lapponica*, appear to have declined since the improvements to treatment in 1999. The declines of oystercatcher, grey plover and bar-tailed godwit are contrary to or in excess of regional trends. However, all the declines began in the mid-1990s, prior to the changes to sewage improvements in 1999.

The Ribble and Alt Estuaries SPA -0.030 mg/l

Indices were plotted for 17 species for the Ribble and Alt Estuaries SPA (Figure 3.2.1.10). Numbers of eight designated species – shelduck, wigeon, pintail, ringed plover, grey plover, knot, dunlin and bar-tailed godwit – and, in addition, turnstone, appear to have declined since the changes from crude to secondary treatment in 1996 and 1997. The declines of ringed plover, knot, bar-tailed godwit and turnstone began prior to the improvements to treatment. Those of knot, dunlin and turnstone are contrary to or in excess of the trends at regional level.

The Morecambe Bay SPA -0.005 mg/l

Indices were plotted for 22 species for the Morecambe Bay SPA (Figure 3.2.1.11). Six designated species – mallard *Anas platyrhynchos*, goldeneye, ringed plover, grey plover, dunlin and turnstone – appear to have shown declines since improvements to waste water treatment began in 1995. The declines of goldeneye, grey plover, dunlin and turnstone began prior to 1995. For all but goldeneye, declines were also noted at the regional level.

Barrow-in-Furness -0.100 mg/l

Indices were plotted for 22 species for the Barrow-in-Furness part of the Morecambe Bay SPA (Figure 3.2.1.12). The numbers of seven designated species – great crested grebe, shelduck, pintail, knot, dunlin, black-tailed godwit and bar-tailed godwit – and, in addition, little grebe, have declined since the improvements to the Barrow-in-Furness discharge in 1996. The declines of little grebe, great crested grebe and black-tailed godwit have not been matched by declines at the regional level.

3.2.2 Trends in waterbird numbers in relation to effluent quality

Regression analysis was used to determine whether the smoothed waterbird indices were related to the concentrations of BOD, Ammonia (as N) and Suspended Solids in the effluent at sites affected by one main discharge. For the Orwell Estuary, data were available for the period 1991-2000 for the Cliff Quay STW outfall at Ipswich – this discharge was upgraded from crude to primary treatment in 1995. For the North-west Solent, data were available for the period 1990-2000 for the Pennington outfall, which was upgraded from crude to secondary treatment in 1997. Data were available, for BOD only, for the Barrow-in-Furness discharge for 1991-1999. Treatment at this outfall was upgraded from primary to secondary in 1996; a number of smaller discharges also affect the Barrow mudflats.

Tables 3.2.2.1 to 3.2.2.3 provide the results of regression analyses between the smoothed bird indices and the mean annual concentrations of BOD, Ammonia (as N) and Suspended Solids in the effluent at each site. Tables 3.2.2.4 to 3.2.2.6 repeat these analyses with the smoothed regional bird indices considered as an extra independent variable. As annual flow data were not available for most of the discharges, it was not possible to calculate the loads for each of the variables. At Barrow-in-Furness, however, the data provided suggest that the flow remained constant over time and thus that the BOD concentration could be used as a surrogate for the BOD load.

The results of the regression analyses using the different water quality variables were similar as in most cases there was a high degree of correlation between them (see Table 3.2.2.7). Smoothed species-specific indices were significantly positively related to BOD concentrations in 14 cases, but negatively related to them in seven cases (Table 3.2.2.1), an insignificant difference (Sign Test, $P = 0.190$). Similarly, waterbird indices were significantly positively related to Ammonia (as N) concentrations in six cases, but negatively related to them in three cases (Table 3.2.2.2) (Sign Test, $P = 0.508$). The indices were also positively related to Suspended Solids concentrations in 10 cases, but negatively related to them in four cases (Table 3.2.2.3) (Sign Test, $P = 0.180$). Similar results were obtained if the sites were looked at separately (see Tables). No relationships were found between the Total Wader Index and any of the three water quality variables.

Taking into account the regional indices, smoothed species-specific indices were significantly positively related to BOD concentrations in eight cases, but negatively related to them in six cases (Table 3.2.2.4), again an insignificant difference (Sign Test, $P = 0.790$). Similarly, having taken into account the regional indices, waterbird indices were significantly positively related to Ammonia (as N) concentrations in six cases, but negatively related to them in three cases (Table 3.2.2.5) (Sign Test, $P = 0.508$). The indices were also positively related to Suspended Solids concentrations in eight cases, but negatively related to them in five cases (Table 3.2.2.6) (Sign Test, $P = 0.582$). Similar results were also obtained if the sites were looked at separately (see Tables). Again, no relationships were found between the Total Wader Index and any of the three water quality variables.

3.2.3 Trends in waterbird numbers between sites in relation to box modelling results

Plots indicating the scale of change in bird numbers in relation to the scale of change in BOD concentration for each site (as estimated by box-modelling) are shown for 15 species and the Total Wader Index in Figures 3.2.3.1 to 3.2.3.16. The results of regression analyses investigating these relationships are shown in Tables 3.2.3.1a and 3.2.3.1b. Plots are shown using both the change in waterbird indices at each site and using the residuals from the relationship between the changes in site and regional indices. Change is evaluated as the proportional increase or decline in these values one or two winters after the changes to waste water treatment in relation to the value in a base winter immediately preceding the changes to treatment.

All but four (cormorant, sanderling, curlew and redshank) of the 15 species showed declines at over 50% of the sites where they were indexed in the winter immediately following improvements to waste water treatment. Likewise, all but three (cormorant, curlew and redshank) of nine species investigated showed declines at over 50% of sites two winters after improvements to waste water treatment.

As the tables indicate, however, no significant relationships were found between the scale of change in waterbird indices and the scale of change in BOD concentrations, either using site indices or when also taking into account regional trends in numbers. The lack of significant relationships meant that it was not possible to use BOD to predict the impact to waterbirds of the predicted changes to waste water discharges on the Northumbria Coast SPA.

The proportions of species that showed declines between the base winter and the first and second winters following the completion of improvements tended to be greater at the sites where there had been the greatest decreases in BOD concentration, though these trends were not significant (Figs. 3.2.3.17a & 3.2.3.17b) (for the winter following improvements: G^2_1 = 2.44, P = 0.1180; for the second winter following improvements: G^2_1 = 1.42, P = 0.2333). The relationship was significant if the more subjective appraisal of which species had shown declines (provided in the site accounts in section 3.2.1) was used (Fig. 3.2.3.17c) (G^2_1 = 8.17, P = 0.0043).

4. Discussion

Declines in waterbird indices were recorded at all the study sites. In a number of cases, however, declines matched regional trends in the species' populations or began prior to the implementation of improved treatment. Our study only considered changes to waste water improvements that took place during the 1990s (the period covered by the Water Companies' first two Asset Management Plans). It should be noted, therefore, that declines in waterbird populations that began prior to the recorded improvements, such as those on the Medway Estuary, may possibly have been the result of earlier, less well-documented changes to waste water treatment.

Only for shelduck and grey plover did the number of sites where declines were noted significantly outnumber those where there were increases (though small samples limited the likelihood of detecting significant probabilities). It was also not possible to clearly link waterbird numbers to water quality in the correlations between the waterbird indices and BOD and other concentrations in the discharges on the Orwell Estuary, the North-west Solent and at Barrow-in-Furness.

There were no significant ($P < 0.05$) relationships for any species between the scale of change in indices and the scale of change in BOD concentrations, either using site indices or when also taking into account regional trends in numbers (although, again, small samples limited the likelihood of detecting significant probabilities).

Significantly, though, our analyses did show that on the sites with the greatest decreases in BOD concentration (0.18 to 0.27 mg/l) – the Orwell Estuary, the Medway Estuary and Marshes SPA and the Tamar Estuary – a greater proportion of species declined following improvements to waste water discharges (Fig. 3.2.3.17c). Eleven of 18 species on the Orwell Estuary, 12 of 18 on the Medway and two of four on the Tamar showed obvious declines following improvements at these sites. In contrast, at the three sites with the smallest decreases in BOD concentration (0.003 to 0.005 mg/l) – the Thanet Coast, Sandwich Bay and Morecambe Bay – declines were only noted for one of four, one of three and six of 22 species respectively.

The Phase 1 work (Burton and others 2002) reported a number of studies that had shown how waterbirds benefited from the presence of waste water discharges and how their distributions within sites were influenced by the locations of outfalls. Studies in Scotland, for example, have described how flocks of scaup *Aythya marila* and goldeneye, in particular, were in the past concentrated near sewage outfalls or outfalls discharging waste from food factories, breweries and distilleries (eg Player 1971, Milne & Campbell 1973, Pounder 1976a, 1976b, Campbell & Milne 1977, Campbell 1978, Campbell and others 1986). As Campbell (1984) reported, improvements to waste water discharges at Leith and Seafield on the Firth of Forth had a clear detrimental impact on the numbers of seaduck at these locations. However, there are a number of reasons why, with the approach used in these analyses, it has not been and would not be possible to clearly link changes in waterbird populations to the changes in water quality resultant from the implementation of the UWWTD (and BWD).

Firstly, it is possible that some species might have benefited from the improvements in water quality, for example, if their favoured prey was reduced in abundance by the organic and nutrient enrichment near outfalls. Additionally, as noted in the Phase 1 work (Burton and others 2002), at previously grossly polluted sites, reductions in organic and nutrient loading actually may increase the abundance, biomass and diversity of many invertebrates and thus benefit some species of estuarine waterbirds. It is not thought, however, that any of the sites in the present study were this grossly polluted and thus it was not expected that improvements to waste water treatment would have benefited waterbirds.

Secondly and most importantly, it is likely that even in cases where improvements to waste water discharges do have an impact on waterbird numbers, it might not be possible to see these impacts at the estuary or SPA level. This is not to say that there have not been impacts at this level, but that they may be hidden by natural population fluctuations and other factors operating within the site – changes in disturbance, for example. It was not possible to account for such factors in our analyses, though by considering regional indices, it was possible to take into account factors operating over a larger scale, such as climate change. It should be noted, though, that other sites included in the regional indexing might have also been affected by improvements to waste water discharges at the same time as the particular site being studied (see Table 2.4.1 for a summary of the dates of regional changes). Given these confounding factors, it is likely that evidence of the impacts on waterbirds of improvements to waste water discharges would be most apparent at a finer, within-site scale.

Thirdly, many of the improvements to waste water treatment have only occurred relatively recently and it is possible that there has not been sufficient time since for the impacts of these changes to become apparent. Indeed, in our study, it was only possible to consider the change up to two winters following the completion of improvements. A previous study investigated the effects of the cessation in April 1998 of the discharge of untreated sewage from short outfall pipes off the rocky coast of Hartlepool Headland (Eaton 2000). Comparison of counts of turnstones and purple sandpipers between September 1999 and June 2000 and those undertaken between 1991 and 1994 showed no significant differences that could be attributed to the removal of sewage inputs. The study concluded that the impacts of the cessation of the discharges were unlikely to be seen until greater time had passed. In part, such delayed impacts could arise if shores remain enriched for sometime after the changes to or cessation of discharges. Additionally, as individuals of a number of waterbird species may be very faithful to their wintering sites (Metcalfe & Furness 1985, Burton & Evans 1997, Burton 2000), they may be reluctant to leave previously favoured areas (or be unable due to intraspecific competition at alternative sites). Any declines in waterbird numbers would therefore be the result of reduced recruitment of juveniles and thus take time to become apparent. It should be noted, though, that while improved waste water treatment may cause little impact to the majority of species over the short-term, over the longer-term impacts may be more difficult to discern as they may be hidden by other factors affecting waterbird numbers, eg disturbance or climate change, as mentioned above.

Fourthly, it should be noted that the impacts of the changes to waste water treatment would have been reduced if sites were below their carrying capacity for individual species, ie if there were sufficient food supplies elsewhere within the sites for birds affected by the waste water improvements. In such instances only localised declines would be expected.

The correlative analyses used in this study could not prove a causal link between waterbird numbers and waste water discharges. To be able to prove this link and fully investigate the impact of the UWWTD (and BWD), it would be necessary to look at changes in the distributions and numbers of waterbirds within sites (preferably using data for some years before and after improvements to the discharges) and to be able to relate these to changes in invertebrate populations and preferably also the distribution of organic matter discharged from outfalls. Additional ringing studies would help to determine any impacts on waterbird survival rates. In a unique ongoing study commissioned by Northumbrian Water PLC, an attempt is being made to use this approach in an experimental 'before and after' study of the impacts of the directives at outfalls within the Northumbria Coast SPA.

The Northumbrian Water PLC study, undertaken by Durham University (Hamer and others 2002), has provided five years of baseline data on invertebrates, inshore fish populations and the numbers, breeding success and feeding ecology of breeding terns, and the behaviour and numbers of wintering waders. This work has concentrated on changes to the Amble treatment works which lies within the SPA, where major improvements to waste water treatment were completed in 2001. In addition, work indicated the spread of particulate organic matter from five outfalls along this coast (Eaton 2001). Ongoing study aims to look over the four years following the improvements at the impact on the terns at Coquet Island. Further funding is now also in place to continue the work on wintering waders.

Such within-site studies provide the best means of determining the impact of the directives on waterbirds. Without such specifically designed research programmes, investigation of these impacts will be limited to those sites where data on the numbers and distributions of feeding waterbirds have been collected, at a relatively fine scale, over periods where changes to local discharges have occurred. Possible English sites for these analyses, identified using the GIS project from the first phase of this work (Burton and others 2002), include the Orwell Estuary, the Mersey Estuary and Barrow-in-Furness. For the former site, WeBS Low Tide Count data and similar data collected by Suffolk Wildlife Trust are available for several years before and after 1995, when primary treatment was introduced to the Cliff Quay STW which discharges into the estuary. At Barrow-in-Furness and the Mersey Estuary a combination of WeBS Low Tide Count data and 'through-the-tide' data collected for other BTO projects provide similar (though less complete) datasets with a temporal match to changes in waste water treatment at these sites. For these sites, it would thus be possible to assess how changes in waterbird numbers on intertidal mudflats within a site correlate to known decreases in organic inputs.

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Appendix 1 English and Welsh Special Protection Areas (SPAs) investigated in this report and the waterbird species for which they are notified.

SPA	Species
Exe Estuary	AV, BW, CA, DB, DN, GV, L., OC, RM, SZ, WM, WN
Humber Flats, Marshes and Coast	AF, BA, BW, CA, CU, DB, DN, GN, GP, GV, KN, L., MA, OC, PO, RK, RP, SS, SU, T., WM, WN
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 & North Wirral Foreshore	CA, DN, GV, KN, OC, RK, TT
Morecambe Bay	AF, BA, BW, CA, CU, DN, E., GB, GG, GN, GP, GV, KN, L., LB, MA, OC, PG, PT, RK, RM, RP, SS, SU, T., TE, TT, WM, WN
Northumbria Coast	AF, PS, TT
Ribble and Alt Estuaries	BA, BH, BS, BW, CA, CN, CU, CX, DN, GP, GV, KN, LB, OC, PG, PT, RK, RP, RU, SS, SU, T., WN, WS
Severn Estuary	BS, CU, DN, EW, GA, GV, L., MA, PO, PT, RK, RP, SU, SV, T., TU, WM, WN
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
Thames Estuary and Marshes	AV, BW, DN, EW, GA, GV, L., LG, PT, RK, RP, SU, SV, WM
Thanet Coast and Sandwich Bay	TT

AF = little tern *Sterna albifrons*, AV = avocet *Recurvirostra avosetta*, BA = bar-tailed godwit *Limosa lapponica*, BH = black-headed gull *Larus ridibundus*, BS = Bewick’s swan *Cygnus columbianus*, BW = black-tailed godwit *Limosa limosa*, CA = cormorant *Phalacrocorax carbo*, CN = common tern *Sterna hirundo*, 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*, GG = great crested grebe *Podiceps cristatus*, GN = goldeneye *Bucephala clangula*, GP = golden plover *Pluvialis apricaria*, GV = grey plover *Pluvialis squatarola*, KN = knot *Calidris canutus*, L. = lapwing *Vanellus vanellus*, LB = lesser black-backed gull *Larus fuscus*, LG = little grebe *Tachybaptus ruficollis*, MA= mallard *Anas platyrhynchos*, MU = Mediterranean gull *Larus melanocephalus*, OC = oystercatcher *Haematopus ostralegus*, PG = pink-footed goose *Anser brachyryhnchus*, PO = pochard *Aythya ferina*, PS = purple sandpiper *Calidris maritima*, PT = pintail *Anas acuta*, RK = redshank *Tringa totanus*, RM = red-breasted merganser *Mergus serrator*, RP = ringed plover *Charadrius hiaticula*, RS = roseate tern *Sterna dougallii*, RU = ruff *Philomachus pugnax*, 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*, TT = turnstone *Arenaria interpres*, TU = tufted duck *Aythya fuligula*, WM = whimbrel *Numenius phaeopus*, WN = wigeon *Anas penelope*, WS = whooper swan *Cygnus cygnus*.

Appendix 2 Validation of box model approach

Validation of the box model approach depends on the quantity of comparable water quality data. Of the areas studied, there were only two sites where sufficiently large sets of sampling data were available – the Tamar Estuary and the Medway Estuary and Marshes.

The Tamar Estuary box model was confined to the area of the Tamar Estuaries Complex SPA to the north of Devonport and included the Tamar and Tavy Estuaries and the lowest part of the Lynher Estuary. The water quality data set provided cover the period for 1992 to early 2003. However, the number of samples collected each year in the area of the box model dropped from 100+ before 1998 to less than 50 thereafter. After 1998, no results were available for sites within the Tamar Estuary.

The observed data within the box area was averaged for each year in two ways:

∉ using all the data;

∉ using only sites for which there were data after 2000.

Mean BOD values are summarised in the following table:

	All sites		Subset of sites	
	Mean BOD mg/l	Number of samples	Mean BOD mg/l	Number of samples
1992	1.75	190	1.41	122
1993	1.71	304	1.50	144
1994	1.75	277	1.58	118
1995	1.78	114	1.84	82
1996	1.57	110	1.46	82
1997	2.27	104	2.28	72
1998	1.31	49	1.31	49
1999	1.36	47	1.36	47
2000	1.30	48	1.30	48
2001	1.24	27	1.24	27
2002	1.28	37	1.28	37

This set of observations suggests that there was a reduction in BOD after 1997, with a further slight reduction in 2001. The changes to the sewage works discharging directly to the SPA occurred in 2000.

For comparison with the box model, the observed values were averaged over the 'before 2000' and 'after 2000' periods.

	All sites	Subset of sites	Box model A	Box model B
Before 2000	1.69	1.59	1.40	1.57
After 2000	1.27	1.27	1.18	1.20
Change	-0.42	-0.32	-0.22	-0.37
% change	-25%	-20%	-16%	-23%

Box Model A includes only the Ernesettle STW effluent, while Box Model B contains both Ernesettle and Camel's Head works. The results from Box Model A were used for the correlation with the waterbird data. This comparison suggests that the box model is slightly conservative in terms of the prediction of change over the last 10 years. However, the box model does predict the change of concentration to be within 30% of the observed value. Considering the scope for uncertainty in defining all the input parameters to the box model, this is a satisfactory validation of the box modelling.

For the Medway Estuary and Marshes, five years of data were available (1997-2001). There were two sampling sites in the Southern Medway box and six sites in Long Reach box. At some of the sites, data was collected at both high and low water. There was also considerable variation in the reported BOD concentrations at these sites. Thus, the averages below are based on the median values. This reduces the contribution of the occasional high values in the data set.

	Southern Medway	Long Reach	Combined
1997	1.60	1.75	1.70
1998	1.40	1.40	1.40
1999	1.10	1.20	1.10
2000	1.20	1.00	1.00
2001	1.20	1.00	1.10

Comparison with box model of the combined area:

	Observations	Box Model
Pre 1998	1.70	1.36
1998-1999 (average)	1.40	1.33
2000+	1.05	1.18
Change after 1998	-26%	-2%
Change after 2000	-26%	-11%
Overall change	-38%	-13%

The observations show higher pre-1998 BOD concentrations than the model, while the post 2000 concentrations in the two sets are much closer. This could be due to reductions to other inputs to the box area not accounted for in the model. The reported change to the total sewage works loads in 1998 is relatively small (7%) yet the observations show a reduction of more than 25% in the mean concentration. Thus, this change in the observed concentration after 1998 cannot be attributed to the changes to the Queenborough STW effluent alone.

The results of this validation exercise suggest that the box modelling tends to give a conservative interpretation of the change compared to the observed data. However, the observed data sets are neither evenly distributed spatially across the domain nor uniformly distributed temporally throughout the periods.

Appendix 3 Tables

Table 2.4.1 Dates over which improvements to coastal waste water discharges are known to have been made within each (Environment Agency) region under the Water Companies' first two Asset Management Plans

Region	Earliest known change	Latest known change
Northeast	2000	ongoing
Anglian	1995	1999
(Thames)	2000	2000
Southern	1995	2001
Southwest	1990	2001
(Midlands)	1995	1995
Northwest	1995	2000

Information for the Thames and Midlands regions come from the Gravesend and Gloucester STWs respectively. Only limited data were obtained for the Welsh region.

Table 3.1.1.1 Results of box modelling for the Northumbria Coast SPA

	Before 2005	After 2005
E /day	0.90	0.90
V Mm^3	677	677
C_{back} mg/l	1	1
$S_{outfall}$ (all outfalls) kg/day	62536	22805
C_{box} mg/l	1.13	1.06
% change in total load		-52%
Change in concentration		-0.07

Table 3.1.2.1 Results of box modelling for the Humber Flats, Marshes and Coast SPA

	Before 1995	1995 to 1999	After 1999
E /day	0.94	0.94	0.94
V Mm^3	1160	1160	1160
C_{back} mg/l	1	1	1
ΣS_i kg/day		None significant	
$S_{outfall}$ (Pyewipe) kg/day	36400	36400	12830
$S_{outfall}$ (Cleethorpes) kg/day	9547	716	716
C_{box} mg/l	1.04	1.03	1.01
% change in total load		-19%	-64%
% change in load since 1995		-19%	-71%
Change in concentration		-0.01	-0.02

Table 3.1.3.1 Results of box modelling for the Orwell Estuary

	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
Ɇ S_i kg/day	719	719	719	719	874	874
$S_{outfall}$ (Cliff Quay) kg/day	9900	341	9900	341	9900	341
C_{box} mg/l	2.32	1.58	1.66	1.25	1.31	1.04
% change in total load		-90%		-90%		-89%
Change in concentration		-0.74		-0.41		-0.27

Table 3.1.5.1 Results of box modelling for the southern Medway (part of the Medway Estuary and Marshes SPA)

	Before 2000	After 2000
E /day	0.53	0.53
V Mm^3	57	57
C_{back} mg/l	1	1
Ɇ S_i kg/day	14462	14462
$S_{outfall}$ (Motney Hill) kg/day	17096	1587
C_{box} mg/l	1.54	1.28
% change in total load		-49%
Change in concentration		-0.26

Table 3.1.5.2 Results of box modelling for Long Reach (part of the Medway Estuary and Marshes SPA)

	Before 1998	After 1998
E /day	0.45	0.45
V Mm^3	80	80
C_{back} mg/l	1	1
Ɇ S_i kg/day	1000	1000
$S_{outfall}$ (Queenborough) kg/day	2403	91
C_{box} mg/l	1.10	1.03
% change in total load		-68%
Change in concentration		-0.07

Table 3.1.5.3 Combined results of box modelling for the whole Medway Estuary and Marshes SPA

	Before 1998	1998-2000	After 2000
E /day	0.71	0.71	0.71
V Mm^3	137	137	137
C_{back} mg/l	1	1	1
Ɇ S_i kg/day	15462	15462	15462
$S_{outfall}$ (both outfalls) kg/day	19499	17161	1678
C_{box} mg/l	1.36	1.33	1.18
% change in total load		-7%	-48%
% change in load since 1998		-7%	-51%
Change in concentration		-0.03	-0.15

Table 3.1.6.1 Results of box modelling for the Thanet Coast

	Before 1995	1995 to 1998	1998 to 2001	After 2001
E /day	1.44	1.44	1.44	1.44
V Mm^3	305	305	305	305
C_{back} mg/l	1	1	1	1
Ɇ S_i kg/day	None significant			
$S_{outfall}$ (Herne Bay) kg/day	2940	0	0	0
$S_{outfall}$ (Swalecliffe) kg/day	2780	2780	1840	690
C_{box} mg/l	1.007	1.006	1.004	1.002
% change in total load		-51%	-34%	-63%
% change in load since 1995		-51%	-68%	-88%
Change in concentration		-0.001	-0.002	-0.002

Table 3.1.7.1 Results of box modelling for Sandwich Bay

	Before 1995	After 1995
E /day	0.39	0.39
V Mm^3	2710	2710
C_{back} mg/l	1	1
Ɇ S_i kg/day	906	977
$S_{outfall}$ (Ramsgate, Sandwich & Deal) kg/day	8574	0
C_{box} mg/l	1.0040	1.0005
% change in total load		-90%
Change in concentration		-0.0035

Table 3.1.8.1 Results of box modelling for the North-west Solent

	Low Exchange		High Exchange	
	Before 1997	After 1997	Before 1997	After 1997
E /day	0.10	0.10	0.42	0.42
V Mm^3	29.6	29.6	29.6	29.6
C_{back} mg/l	1	1	1	1
Ɇ S_i kg/day	194	194	194	194
$S_{outfall}$ (Pennington) kg/day	6204	474	6204	474
C_{box} mg/l	1.2162	1.0226	1.0500	1.0050
% change in total load		-90%		-90%
Change in concentration		-0.1936		-0.0450

Table 3.1.10.1Results of box modelling for the Tamar Estuary

	Case A		Case B	
	Before 2000	After 2000	Before 2000	After 2000
E /day	1.07	1.07	1.07	1.07
V Mm^3	26.5	26.5	26.5	26.6
C_{back} mg/l	1	1	1	1
Ɇ S_i kg/day	4147	4147	4147	4147
$S_{outfall}$ (Camel's Head) kg/day	0	0	4800	388
$S_{outfall}$ (Ernesettle) kg/day	7180	1077	7180	1077
C_{box} mg/l	1.40	1.18	1.57	1.20
% change in total load		-54%		-65%
Change in concentration		-0.22		-0.37

Case A – includes only the Ernesettle & Saltash discharge.
Case B – includes both Ernesettle & Saltash discharge and the Camel's Head STW.

Table 3.1.12.1Results of box modelling for sections within the Mersey Estuary SPA

	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
Ɇ S_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 in total load		-39%		-91%		-50%
Change in concentration		-0.10		-1.06		-0.78

Box 1 provides results for the Mersey Narrows and North Wirral Shore SPA.

Table 3.1.12.2Results of box modelling for the whole Mersey Estuary SPA

	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
Ɇ S_i kg/day	54800	36700	21500	21500
$S_{outfall}$ (all outfalls) kg/day	46630	26820	25200	7670
C_{box} mg/l	2.67	2.61	2.58	2.56
% change in total load		-37%	-26%	-38%
% change in load since 1997		-37%	-54%	-71%
Change in concentration		-0.06	-0.03	-0.02

Table 3.1.14.1Results of box modelling for the Ribble and Alt Estuaries SPA

	Before 1996	After 1997
E /day	1.51	1.51
V Mm^3	735	735
C_{back} mg/l	1	1
Ɇ S_i kg/day	7516	7516
$S_{outfall}$ (Preston) kg/day	15526	382
$S_{outfall}$ (other works & crude) kg/day	21859	379
C_{box} mg/l	1.04	1.01
% change in total load		-82%
Change in concentration		-0.03

Table 3.1.15.1Results of box modelling for the Morecambe Bay SPA

	Before 1995	1995-1996	1996 1997	1997-2000	After 2000
E /day	1.22	1.22	1.22	1.22	1.22
V Mm^3	3820	3820	3820	3820	3820
C_{back} mg/l	1	1	1	1	1
Ɇ S_i kg/day	5926	5926	5926	5926	5926
$S_{outfall}$ (various STW) kg/day	33561	32159	15787	12620	5660
C_{box} mg/l	1.008	1.008	1.005	1.004	1.003
% change in total load		-4%	-43%	-15%	-38%
% change in load since 1995		-4%	-45%	-53%	-71%
Change in concentration		0	-0.003	-0.001	-0.001

Table 3.1.16.1Results of box modelling for Barrow-in-Furness

	Low exchange		High exchange	
	Before 1996	After 1996	Before 1996	After 1996
E /day	0.50	0.50	1.55	1.55
V Mm^3	27.8	27.8	27.8	27.8
C_{back} mg/l	1	1	1	1
Ɇ S_i kg/day	1500	1500	1500	1500
$S_{outfall}$ (Barrow) 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 in concentration		-0.32		-0.10

Table 3.2.1.1 Apparent change in species' site indices following the completion of improvements to waste water discharges. A '-' sign indicates a decrease following waste water improvements, a '+' sign indicates an increase, and an '=' that there was no clear trend. *P* values show the results of sign tests indicating whether, for particular sites or species, there were significantly more decreases or increases

Site	7	10	3	4	1	12	6	2	8	5	9	11	P
BOD change (mg/l)	-0.270	-0.220	-0.180	-0.110	-0.100	-0.100	-0.045	-0.030	-0.030	-0.005	-0.004	-0.003	
LG	+		-		-		+	=		+			1.000
GG	-		-	-	-		+			=			0.376
CA	-	-	-	-	=	=	-		+	+			0.454
MS	=												
DB	-		-				-	=					
SU	-		-	-	-		-	=	-	=			0.032
WN	-		-	-	=		=		-	=			0.124
T.			=	-	+		=		+	+			0.624
MA					=			=	+	-			
PT	-		-	-	-		=		-	=			0.062
SV			+				+			=			
PO					=								
GN	-				=					-			
RM					+		+			+			
OC	=		-		+	-		-	+	+			1.000
AV		=	+										
RP	-		-		+		=	+	-	-		+	1.000
GV	-		=	-	=	-	-	-	-	-	+	-	0.040
KN	+		+		-	-		=	-	+			1.000
SS					+			-	+	+	=	+	0.376
DN	-		-	=	-	+	-	=	-	-			0.124
BW	-	-		-	-		-	+	+	+			0.726
BA					-	-		+	-	=			0.624
CU	=		-	+	+		=	+	+	+			0.218
RK	=	=	-	-	=	=	=	+	=	=			
TT	=		+		=	=		-	-	-	-	+	0.688
P	0.022		0.076	0.022	0.790	0.376	0.754	1.000	0.804	0.608		0.624	
Total Wader Index	=	=	-	+	+	-		+	+	+	-	+	0.508

Sites are ordered according to the degree of change in BOD concentration: 1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA. It was not possible to calculate Total Wader Indices for the North-west Solent.

AV = avocet *Recurvirostra avosetta*, BA = bar-tailed godwit *Limosa lapponica*, BW = black-tailed godwit *Limosa limosa*, CA = cormorant *Phalacrocorax carbo*, CU = curlew *Numenius arquata*, DB = dark-bellied Brent goose *Branta bernicla bernicla*, DN = dunlin *Calidris alpina*, GG = Great crested grebe *Podiceps cristatus*, GN = goldeneye *Bucephala clangula*, GV = grey plover *Pluvialis squatarola*, KN = knot *Calidris canutus*, LG = little grebe *Tachybaptus ruficollis*, MA= mallard *Anas platyrhynchos*, MS = mute swan *Cygnus olor*, OC = oystercatcher *Haematopus ostralegus*, PO = pochard *Aythya ferina*, PT = pintail *Anas acuta*, RK = redshank *Tringa totanus*, RM = Red-breasted merganser *Mergus serrator*, RP = ringed plover *Charadrius hiaticula*, SS = sanderling *Calidris alba*, SU = shelduck *Tadorna tadorna*, SV = shoveler *Anas clypeata*, T. = teal *Anas crecca*, TT = turnstone *Arenaria interpres*, WN = wigeon *Anas penelope*.

Table 3.2.2.1 The direction and significance of the relationship between the smoothed indices of waterbird abundance and concentrations of Biochemical Oxygen Demand (BOD) (mg/l) from individual discharges

Site	Orwell			NW Solent			Barrow-in-Furness		
	+/-	***P***	*n*	+/-	*P*	*n*	+/-	*P*	*n*
LG	**-**	**0.0199**	**(8)**	-	0.1878	(7)	**+**	**0.0142**	**(6)**
GG	-	0.3053	(8)	-	0.5226	(7)	**+**	**0.0494**	**(6)**
CA	+	0.2707	(8)	**+**	**0.0286**	**(7)**	-	0.0922	(6)
MS	**+**	**0.0057**	**(8)**						
DB	+	0.1786	(8)	**+**	**0.0449**	**(7)**			
SU	**+**	**0.0127**	**(8)**	**+**	**0.0315**	**(7)**	+	0.8093	(6)
WN	+	0.3000	(8)	-	0.2103	(7)	**+**	**0.0393**	**(6)**
T.				-	0.1662	(7)	-	0.0517	(6)
MA							-	0.0916	(6)
PT	**+**	**0.0003**	**(8)**	-	0.2285	(7)	+	0.1874	(6)
SV				-	0.1439	(7)			
PO							+	0.0965	(6)
GN	+	0.9374	(8)				**+**	**0.0480**	**(6)**
RM				**-**	**0.0075**	**(7)**	+	0.9918	(6)
OC	-	0.4112	(8)				-	0.5569	(7)
AV									
RP	**+**	**0.0015**	**(8)**	+	0.4138	(7)	**-**	**0.0018**	**(7)**
GV	+	**0.0034**	(8)	+	0.0723	(7)	+	0.3980	(7)
KN	**-**	**0.0045**	**(8)**				**+**	**0.0139**	**(7)**
SS							**-**	**0.0247**	**(7)**
DN	**+**	**0.0076**	**(8)**	+	0.0505	(7)	-	0.3588	(7)
BW	+	0.7553	(8)	+	0.5705	(7)	+	0.9208	(7)
BA							-	0.9016	(7)
CU	**-**	**<0.0001**	**(8)**	+	0.5650	(7)	**-**	**0.0179**	**(7)**
RK	-	0.0786	(8)	+	0.2326	(7)	-	0.0829	(7)
TT	+	0.0680	(8)				-	0.0741	(7)
P		0.508			0.624			0.726	
Total Wader Index	-	0.5571	(7)				-	0.1682	(6)

Significant results are shown in bold and the numbers of years for which data were available are in parentheses. *P* values indicate whether, for particular sites, there were significantly more positive or negative relationships.

AV = avocet *Recurvirostra avosetta*, BA = bar-tailed godwit *Limosa lapponica*, BW = black-tailed godwit *Limosa limosa*, CA = cormorant *Phalacrocorax carbo*, CU = curlew *Numenius arquata*, DB = dark-bellied Brent goose *Branta bernicla bernicla*, DN = dunlin *Calidris alpina*, GG = great crested grebe *Podiceps cristatus*, GN = goldeneye *Bucephala clangula*, GV = grey plover *Pluvialis squatarola*, KN = knot *Calidris canutus*, LG = little grebe *Tachybaptus ruficollis*, MA= mallard *Anas platyrhynchos*, MS = mute swan *Cygnus olor*, OC = oystercatcher *Haematopus ostralegus*, PO = pochard *Aythya ferina*, PT = pintail *Anas acuta*, RK = redshank *Tringa totanus*, RM = red-breasted merganser *Mergus serrator*, RP = ringed plover *Charadrius hiaticula*, SS = sanderling *Calidris alba*, SU = shelduck *Tadorna tadorna*, SV = shoveler *Anas clypeata*, T. = teal *Anas crecca*, TT = turnstone *Arenaria interpres*, WN = wigeon *Anas penelope*.

Table 3.2.2.2 The direction and significance of the relationship between the smoothed indices of waterbird abundance and concentrations of Ammonia (as N) (mg/l) from individual discharges

Site	Orwell			NW Solent		
	+/-	*P*	*n*	+/-	*P*	*n*
LG	**-**	**0.0196**	**(10)**	-	0.6206	(7)
GG	+	0.2436	(10)	+	0.9254	(7)
CA	**+**	**0.0234**	**(10)**	+	0.0715	(7)
MS	-	0.3402	(10)			
DB	**+**	**0.0451**	**(10)**	+	0.0997	(7)
SU	**+**	**0.0148**	**(10)**	+	0.1571	(7)
WN	+	0.0631	(10)	-	0.0892	(7)
T.				-	0.1469	(7)
PT	+	0.0659	(10)	-	0.2703	(7)
SV				-	0.3202	(7)
GN	+	0.1638	(10)			
RM				-	0.0784	(7)
OC	**-**	**0.0426**	**(10)**			
AV						
RP	**+**	**0.0240**	**(10)**	+	0.1887	(7)
GV	+	0.5017	(10)	+	0.0502	(7)
KN	**-**	**0.0141**	**(10)**			
DN	**+**	**0.0093**	**(10)**	**+**	**0.0470**	**(7)**
BW	+	0.0668	(10)	-	0.9434	(7)
BA						
CU	-	0.5140	(10)	-	0.9827	(7)
RK	+	0.9530	(10)	+	0.1304	(7)
TT	+	0.7782	(10)			
P		0.736			-	
Total Wader Index	-	0.3406	(9)			

Significant results are shown in bold and the numbers of years for which data were available are in parentheses. *P* values indicate whether, for particular sites, there were significantly more positive or negative relationships.

Table 3.2.2.3 The direction and significance of the relationship between the smoothed indices of waterbird abundance and concentrations of Suspended Solids (mg/l) from individual discharges

Site	Orwell			NW Solent		
	+/-	*P*	*n*	+/-	*P*	*n*
LG	**-**	**0.0061**	**(10)**	-	0.1932	(7)
GG	-	0.9066	(10)	-	0.5131	(7)
CA	+	0.0590	(10)	**+**	**0.0246**	**(7)**
MS	+	0.2362	(10)			
DB	**+**	**0.0250**	**(10)**	**+**	**0.0392**	**(7)**
SU	**+**	**0.0016**	**(10)**	**+**	**0.0266**	**(7)**
WN	+	0.0691	(10)	-	0.2179	(7)
T.				-	0.1591	(7)
PT	**+**	**<0.0001**	**(10)**	-	0.1924	(7)
SV				-	0.1127	(7)
GN	+	0.4688	(10)			
RM				**-**	**0.0073**	**(7)**
OC	-	0.1049	(10)			
AV						
RP	**+**	**0.0002**	**(10)**	+	0.3969	(7)
GV	**+**	**0.0012**	**(10)**	+	0.0691	(7)
KN	**-**	**0.0023**	**(10)**			
DN	**+**	**0.0030**	**(10)**	**+**	**0.0464**	**(7)**
BW	+	0.1348	(10)	+	0.5726	(7)
BA						
CU	**-**	**0.0026**	**(10)**	+	0.5119	(7)
RK	-	0.1063	(10)	+	0.2147	(7)
TT	+	0.0747	(10)			
P		0.508			0.376	
Total Wader Index	-	0.2547	(9)			

Significant results are shown in bold and the numbers of years for which data were available are in parentheses. *P* values indicate whether, for particular sites, there were significantly more positive or negative relationships.

Table 3.2.2.4 The direction and significance of the relationship between the smoothed indices of waterbird abundance and concentrations of Biochemical Oxygen Demand (BOD) (mg/l) from individual discharges, having also taken into account regional indices

Site	Orwell			NW Solent			Barrow-in-Furness		
	+/-	*P*	*n*	+/-	*P*	*n*	+/-	*P*	*n*
LG	-	0.4195	(8)	-	0.2455	(7)	+	0.5054	(6)
GG	-	0.3426	(8)	+	0.9237	(7)	+	0.1176	(6)
CA	+	0.8607	(8)	+	0.0592	(7)	-	0.7461	(6)
MS	+	0.9980	(8)						
DB	+	0.0526	(8)	+	0.2186	(7)			
SU	+	0.3953	(8)	-	0.5944	(7)	-	0.5014	(6)
WN	-	0.3330	(8)	**-**	**0.0006**	**(7)**	+	0.0958	(6)
T.				-	0.0533	(7)	-	0.1624	(6)
MA							-	0.1835	(6)
PT	**+**	**0.0007**	**(8)**	+	0.6203	(7)	+	0.4829	(6)
SV				-	0.4364	(7)			
PO							**+**	**0.0278**	**(6)**
GN	**+**	**0.0491**	**(8)**				+	0.0590	(6)
RM				**-**	**0.0309**	**(7)**	-	0.1153	(6)
OC	+	0.8352	(8)				-	0.6558	(7)
AV									
RP	**+**	**0.0050**	**(8)**	-	0.4176	(7)	**-**	**0.0269**	**(7)**
GV	**+**	**0.0033**	**(8)**	+	0.2372	(7)	-	0.2238	(7)
KN	-	0.2713	(8)				+	0.3972	(7)
SS							**-**	**0.0362**	**(7)**
DN	**+**	**0.0007**	**(8)**	+	0.6485	(7)	**-**	**0.0156**	**(7)**
BW	-	0.3590	(8)	+	0.0877	(7)	-	0.7989	(7)
BA							-	0.2674	(7)
CU	**-**	**0.0053**	**(8)**	+	0.5015	(7)	-	0.1467	(7)
RK	**+**	**0.0075**	**(8)**	-	0.4624	(7)	+	0.5307	(7)
TT	**+**	**0.0024**	**(8)**				+	0.6081	(7)
P		0.070			-			0.624	
Total Wader Index	+	0.7127	(7)				-	0.3213	(6)

Significant results are shown in bold and the numbers of years for which data were available are in parentheses. *P* values indicate whether, for particular sites, there were significantly more positive or negative relationships.

Table 3.2.2.5 The direction and significance of the relationship between the smoothed indices of waterbird abundance and concentrations of Ammonia (as N) (mg/l) from individual discharges, having also taken into account regional indices

Site	Orwell			NW Solent		
	+/-	*P*	*N*	+/-	*P*	*n*
LG	-	0.0844	(10)	-	0.6837	(7)
GG	-	0.9288	(10)	+	0.4524	(7)
CA	+	0.3498	(10)	+	0.1317	(7)
MS	**-**	**0.0255**	**(10)**			
DB	+	0.1344	(10)	+	0.8579	(7)
SU	+	0.1704	(10)	-	0.1680	(7)
WN	**+**	**0.0345**	**(10)**	**-**	**0.0170**	**(7)**
T.				-	0.0706	(7)
PT	**+**	**0.0225**	**(10)**	-	0.9381	(7)
SV				-	0.9894	(7)
GN	**+**	**0.0357**	**(10)**			
RM				-	0.0504	(7)
OC	-	0.0742	(10)			
AV						
RP	**+**	**0.0169**	**(10)**	+	0.8615	(7)
GV	+	0.4348	(10)	+	0.0737	(7)
KN	**-**	**0.0082**	**(10)**			
DN	**+**	**0.0168**	**(10)**	+	0.1731	(7)
BW	+	0.3005	(10)	+	0.2819	(7)
BA						
CU	+	0.4738	(10)	+	0.8898	(7)
RK	**+**	**0.0207**	**(10)**	+	0.9705	(7)
TT	+	0.0894	(10)			
P		0.290			-	
Total Wader Index	-	0.2558	(9)			

Significant results are shown in bold and the numbers of years for which data were available are in parentheses. *P* values indicate whether, for particular sites, there were significantly more positive or negative relationships.

Table 3.2.2.6 The direction and significance of the relationship between the smoothed indices of waterbird abundance and concentrations of Suspended Solids (mg/l) from individual discharges, having also taken into account regional indices

Site	Orwell			NW Solent		
	+/-	*P*	*n*	+/-	*P*	*n*
LG	-	0.7683	(10)	-	0.2477	(7)
GG	-	0.2937	(10)	+	0.9086	(7)
CA	+	0.9439	(10)	+	0.0502	(7)
MS	+	0.5566	(10)			
DB	**+**	**0.0236**	**(10)**	+	0.2112	(7)
SU	+	0.7815	(10)	-	0.4646	(7)
WN	+	0.0907	(10)	**-**	**0.0016**	**(7)**
T.				**-**	**0.0490**	**(7)**
PT	**+**	**<0.0001**	**(10)**	+	0.7352	(7)
SV				-	0.3481	(7)
GN	**+**	**0.0253**	**(10)**			
RM				**-**	**0.0264**	**(7)**
OC	-	0.4721	(10)			
AV						
RP	**+**	**<0.0001**	**(10)**	-	0.4506	(7)
GV	**+**	**0.0010**	**(10)**	+	0.2979	(7)
KN	**-**	**0.0168**	**(10)**			
DN	**+**	**<0.0001**	**(10)**	+	0.7165	(7)
BW	-	0.6217	(10)	+	0.0956	(7)
BA						
CU	**-**	**0.0175**	**(10)**	+	0.4491	(7)
RK	**+**	**0.0048**	**(10)**	-	0.4791	(7)
TT	**+**	**0.0001**	**(10)**			
P		0.110			-	
Total Wader Index	-	0.7208	(9)			

Significant results are shown in bold and the numbers of years for which data were available are in parentheses. *P* values indicate whether, for particular sites, there were significantly more positive or negative relationships.

Table 3.2.2.7 Pearson correlation coefficients for concentrations of BOD, Ammonia (as N) and Suspended Solids in discharges at Cliff Quay on the Orwell Estuary and Pennington on the North-west Solent

	BOD v Ammonia (as N)	BOD v Suspended Solids	Ammonia (as N) v Suspended Solids
Cliff Quay	0.873, n = 11, P = 0.0004	0.959, n = 11, P < 0.0001	0.940, n = 11, P < 0.0001
Pennington	0.352, n = 8, P = 0.3922	0.990, n = 8, P < 0.0001	0.594, n = 10, P = 0.0701

Table 3.2.3.1 Results of regression analyses relating proportional changes in waterbird indices to changes in BOD concentrations (mg/l) resultant from improved treatment to waste water discharges. 1 – change from a base-winter immediately prior to waste water improvements to the first winter following improvements. 2 – change from a base-winter immediately prior to waste water improvements to the second winter following improvements. The parameter estimate indicates the scale and direction of the relationship between the change in waterbird indices and change in BOD concentrations

a.

Species	1			2		
	Parameter estimate	*n*	*P*	Parameter estimate	*n*	*P*
Great Crested Grebe	-0.342	6	0.8686	-	-	-
Cormorant	0.543	10	0.5384	0.399	7	0.7479
Shelduck	0.854	8	0.3080	0.319	6	0.6160
Wigeon	1.489	7	0.1428	-	-	-
Pintail	0.278	7	0.6937	-	-	-
Oystercatcher	0.741	7	0.3161	-	-	-
Ringed Plover	1.554	8	0.2808	2.465	6	0.1720
Grey Plover	0.398	11	0.6608	1.651	9	0.2545
Knot	0.066	7	0.9854	-	-	-
Sanderling	4.177	6	0.6159	-	-	-
Dunlin	-0.276	9	0.7989	-0.462	7	0.7309
Black-tailed Godwit	10.026	8	0.2248	11.047	6	0.2903
Curlew	1.485	8	0.1074	1.969	6	0.2971
Redshank	0.627	10	0.3928	0.358	7	0.7197
Turnstone	-0.791	9	0.3404	-0.463	7	0.7447
Total Wader Index	0.515	10	0.3561	0.605	7	0.6716

b.

Species	1			2		
	Parameter estimate	n	*P*	Parameter estimate	*n*	*P*
Great Crested Grebe	-0.975	6	0.4993	-	-	-
Cormorant	0.546	10	0.5681	0.576	7	0.6783
Shelduck	0.994	8	0.2854	0.256	6	0.7440
Wigeon	1.947	7	0.0653	-	-	-
Pintail	0.758	7	0.3724	-	-	-
Oystercatcher	0.731	7	0.3850	-	-	-
Ringed Plover	3.056	8	0.1951	1.234	6	0.7994
Grey Plover	1.247	11	0.1281	1.907	9	0.0550
Knot	0.101	7	0.9813	-	-	-
Sanderling	3.600	6	0.6989	-	-	-
Dunlin	-0.159	9	0.8910	-0.618	7	0.6935
Black-tailed Godwit	13.585	8	0.1578	11.521	6	0.3182
Curlew	1.687	8	0.1022	1.949	6	0.3824
Redshank	0.643	10	0.4304	0.607	7	0.6039
Turnstone	-0.859	9	0.3855	-0.654	7	0.6587
Total Wader Index	0.484	10	0.4084	1.304	7	0.2914

a. Results using smoothed indices of bird abundance.
b. Results taking into account regional changes in bird abundance.

Appendix 4 Figures

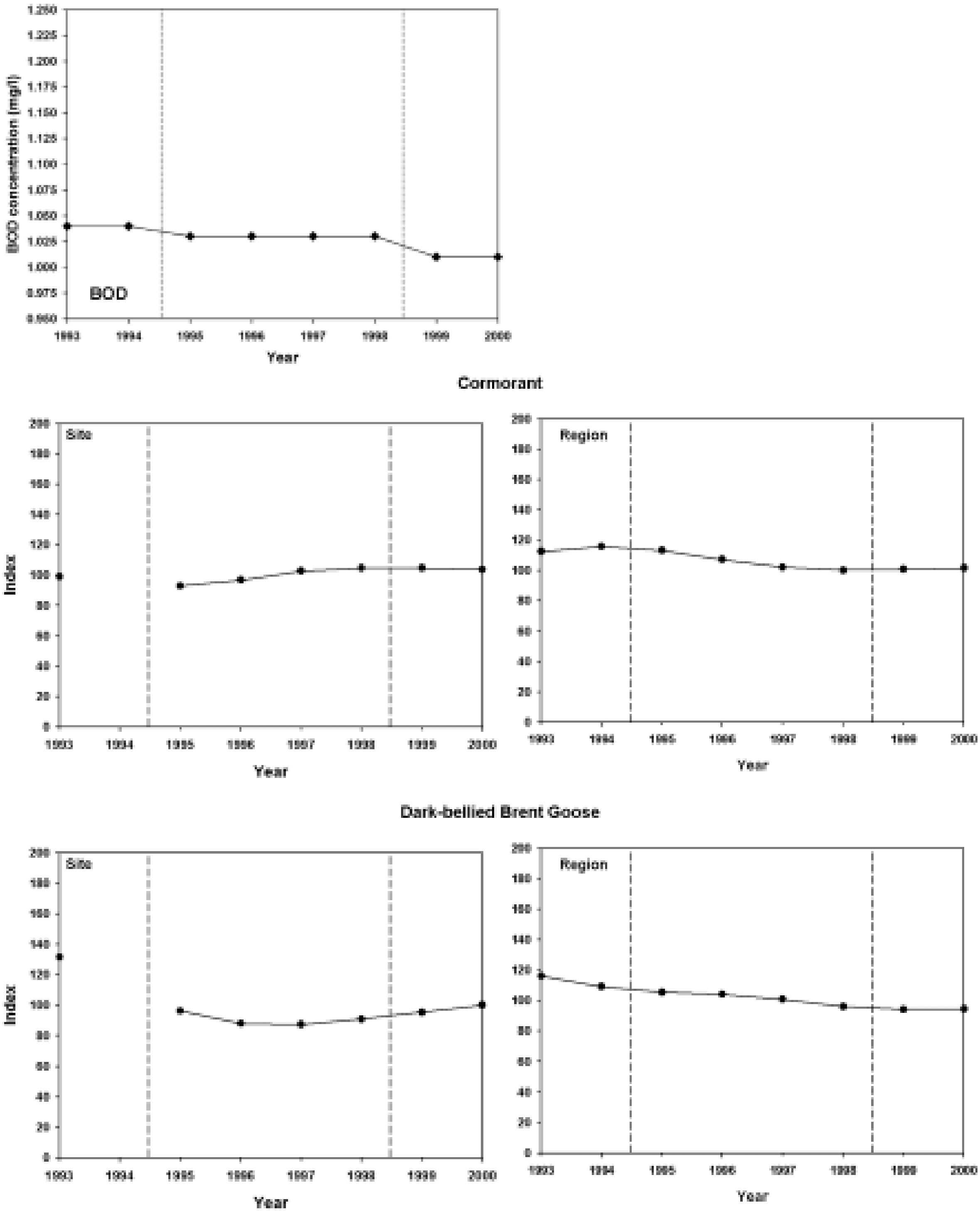
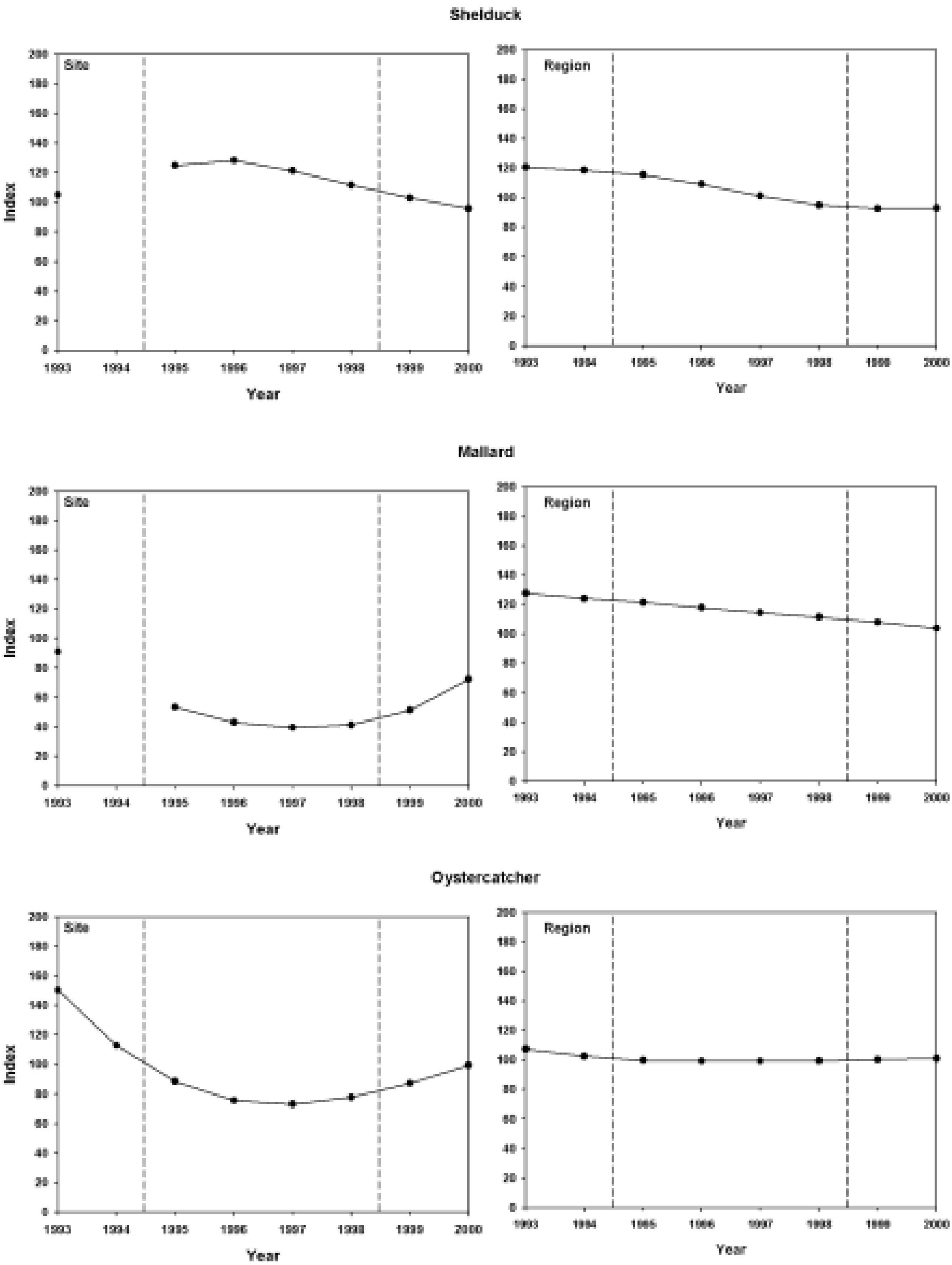


Figure 3.2.1.1 Smoothed waterbird indices derived from WeBS Core Count data for 15 species at The Humber Flats, Marshes and Coast SPA and variation in the overall BOD concentration (mg/l) on the site as estimated by box-modelling. The dotted lines indicate the first and last years of improvements to waste water treatment. 1993 = the winter of 1993/94 etc.



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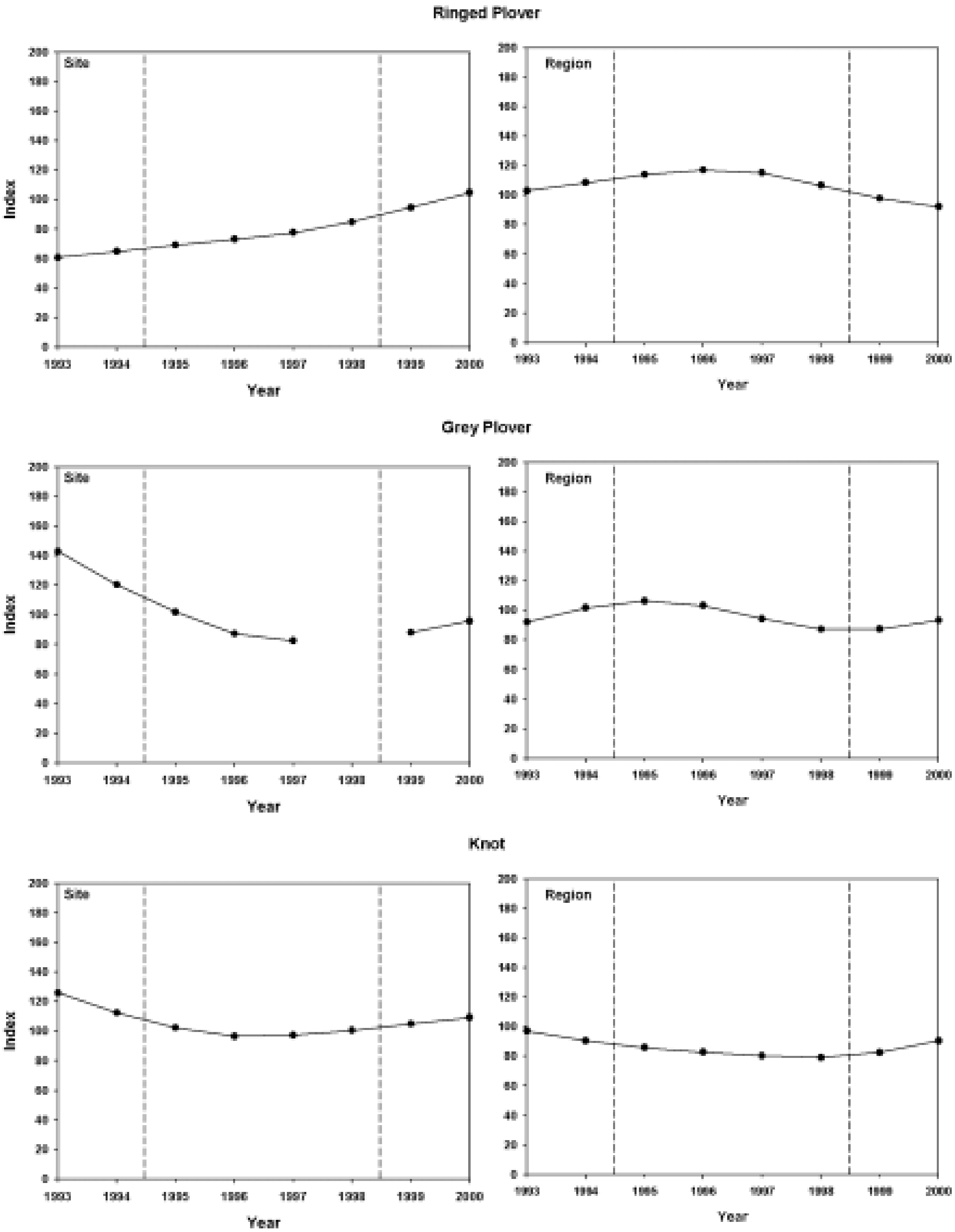

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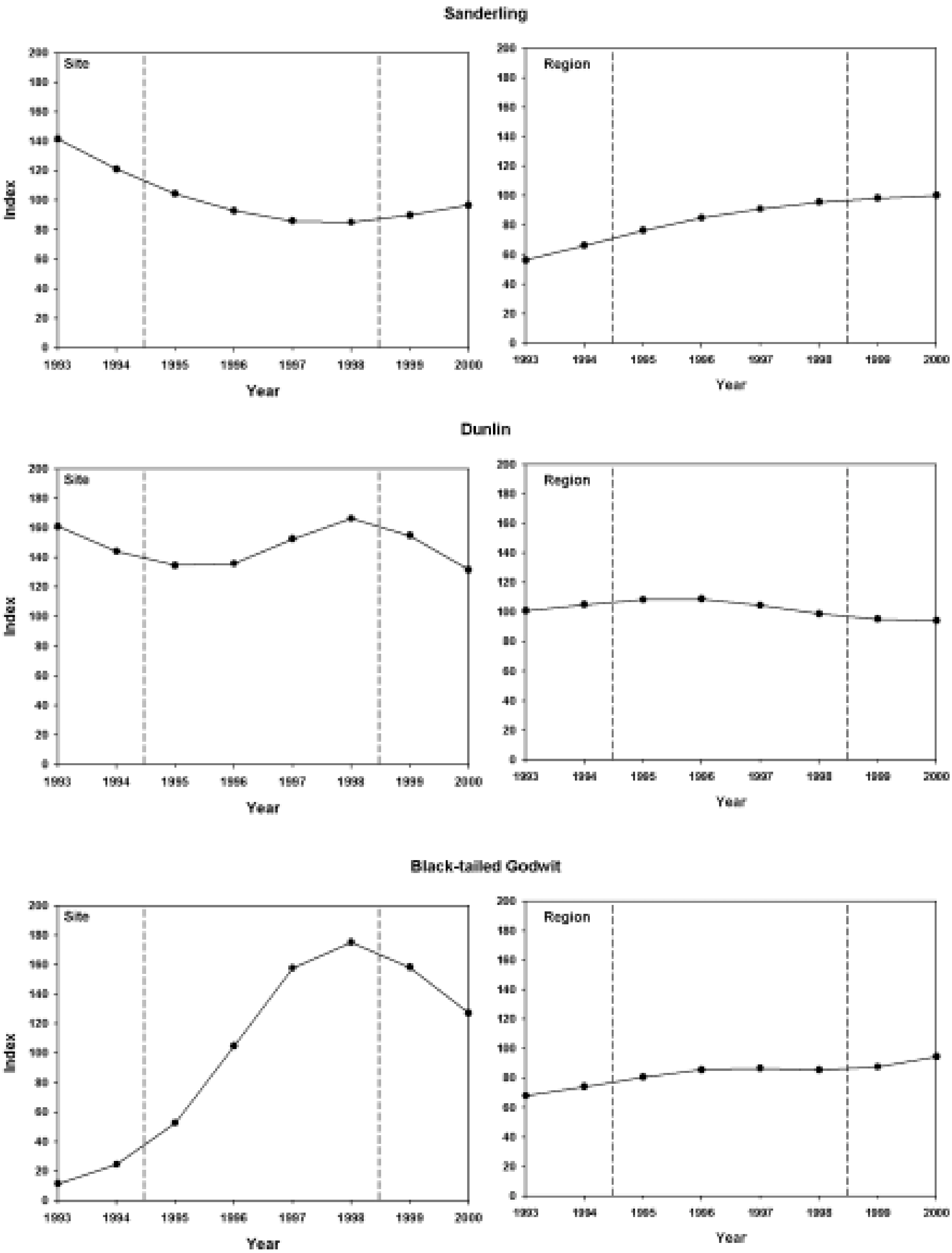

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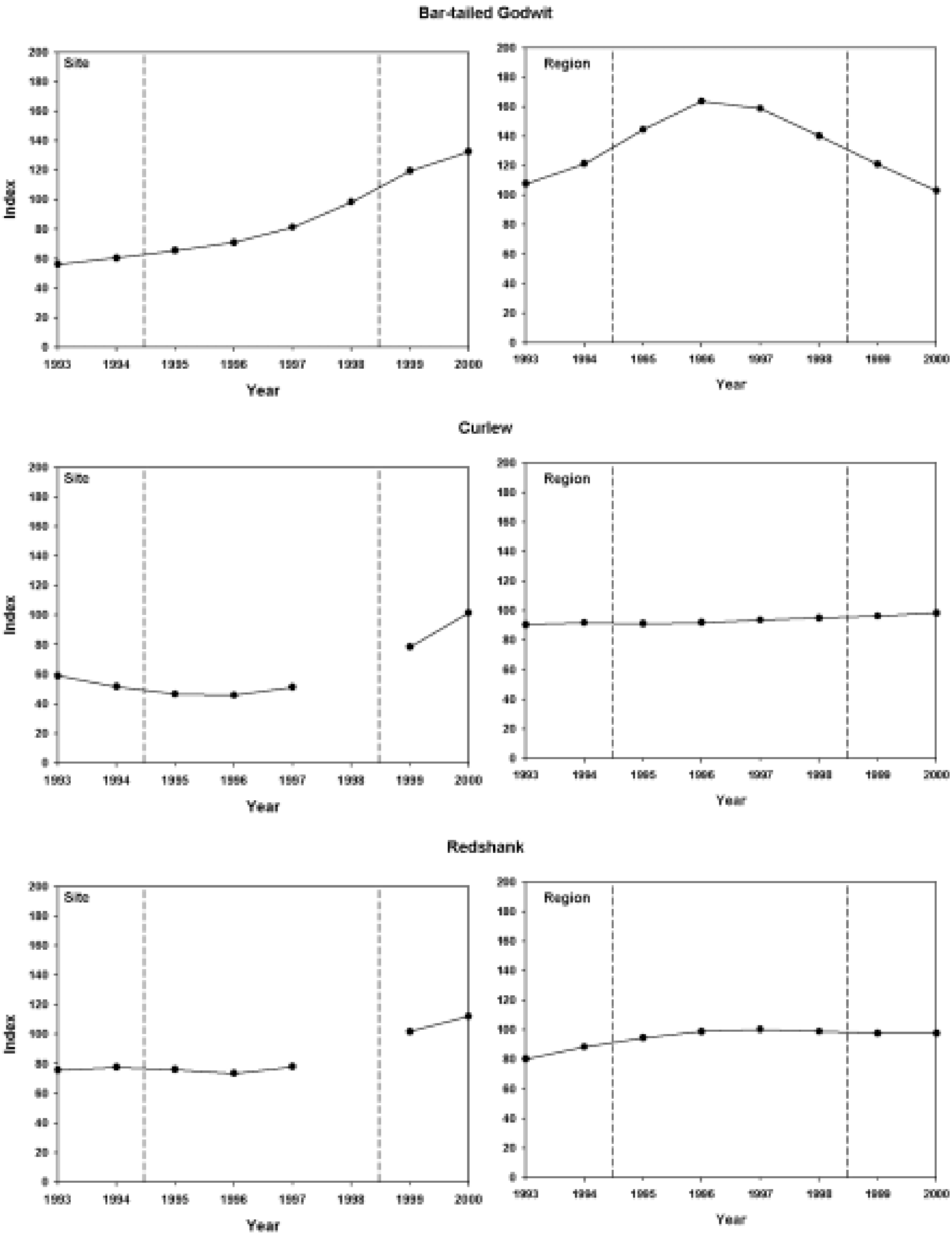

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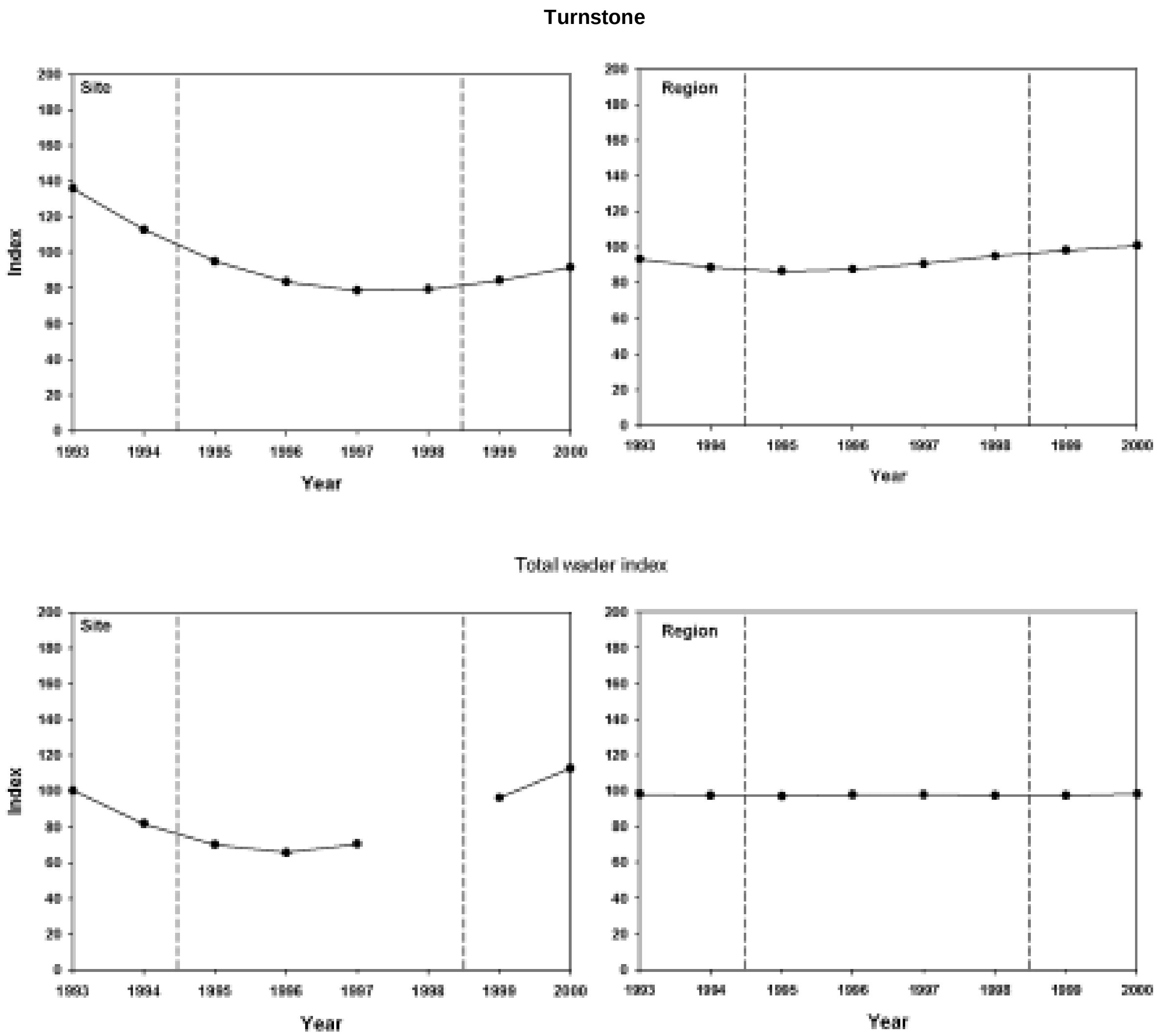

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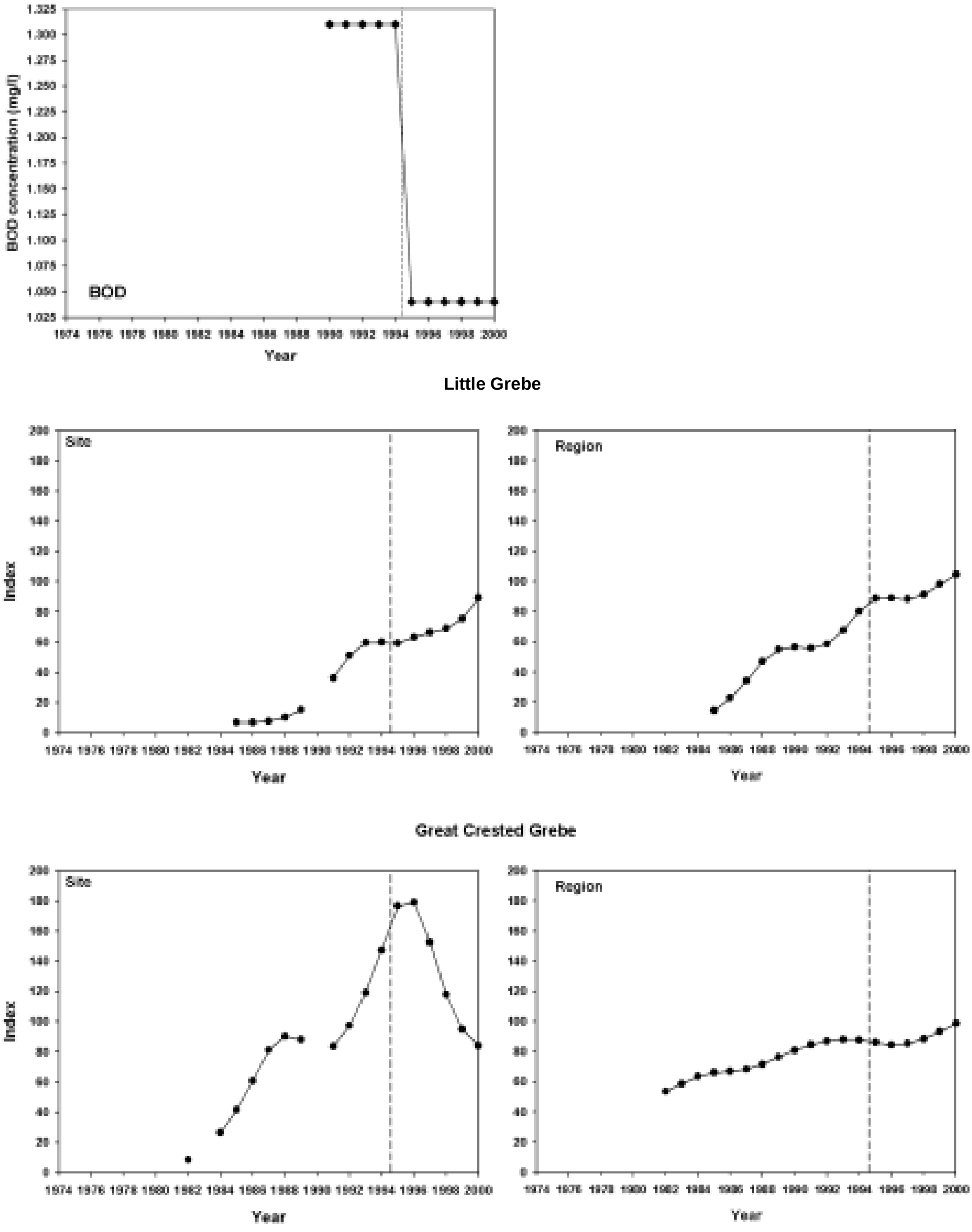
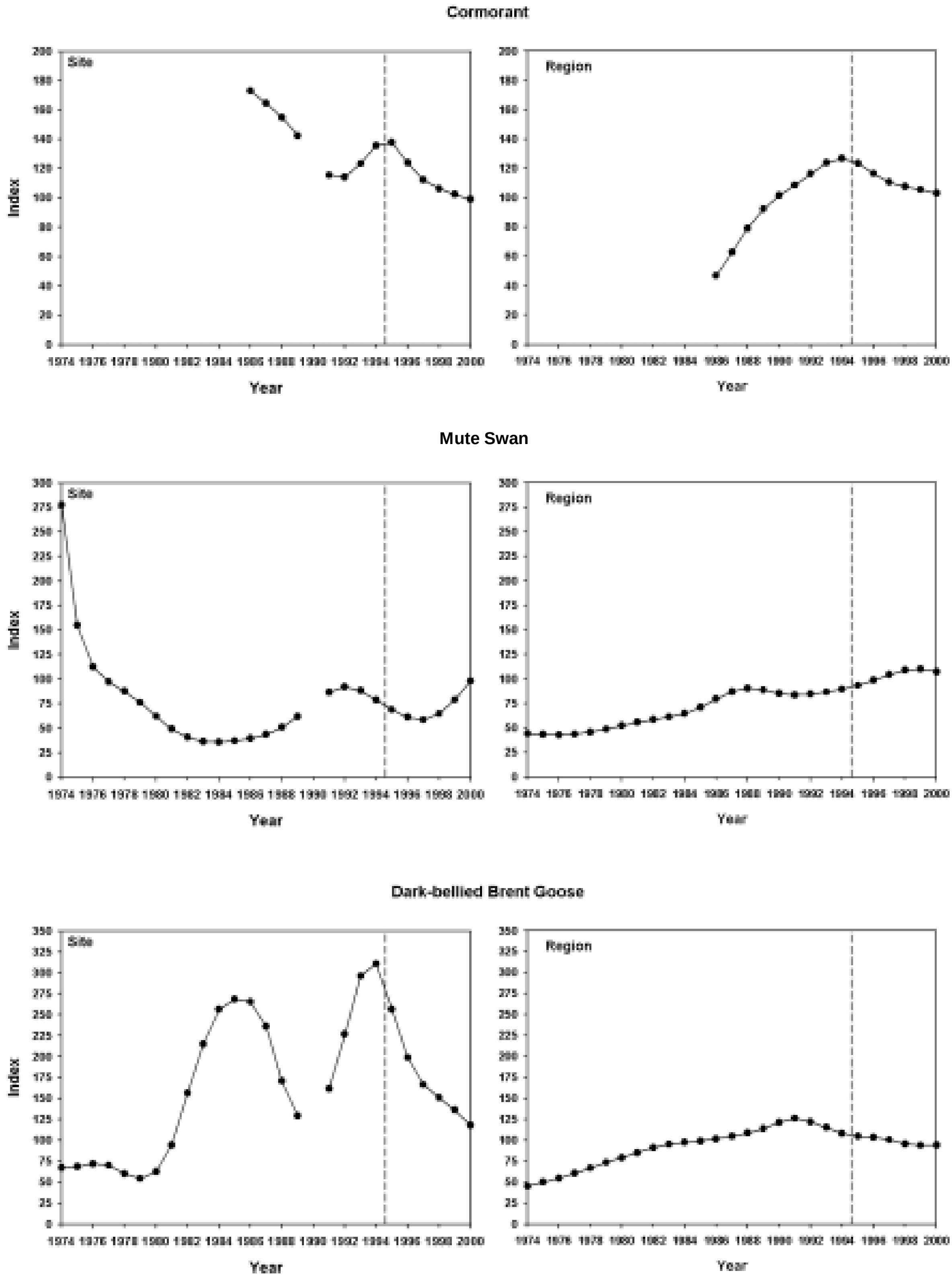


Figure 3.2.1.2 Smoothed waterbird indices derived from WeBS Core Count data for 18 species at the Orwell Estuary and variation in the overall BOD concentration (mg/l) on the site as estimated by box-modelling. The dotted line indicates the date of the improvement to waste water treatment. 1974 = the winter of 1974/75 etc.



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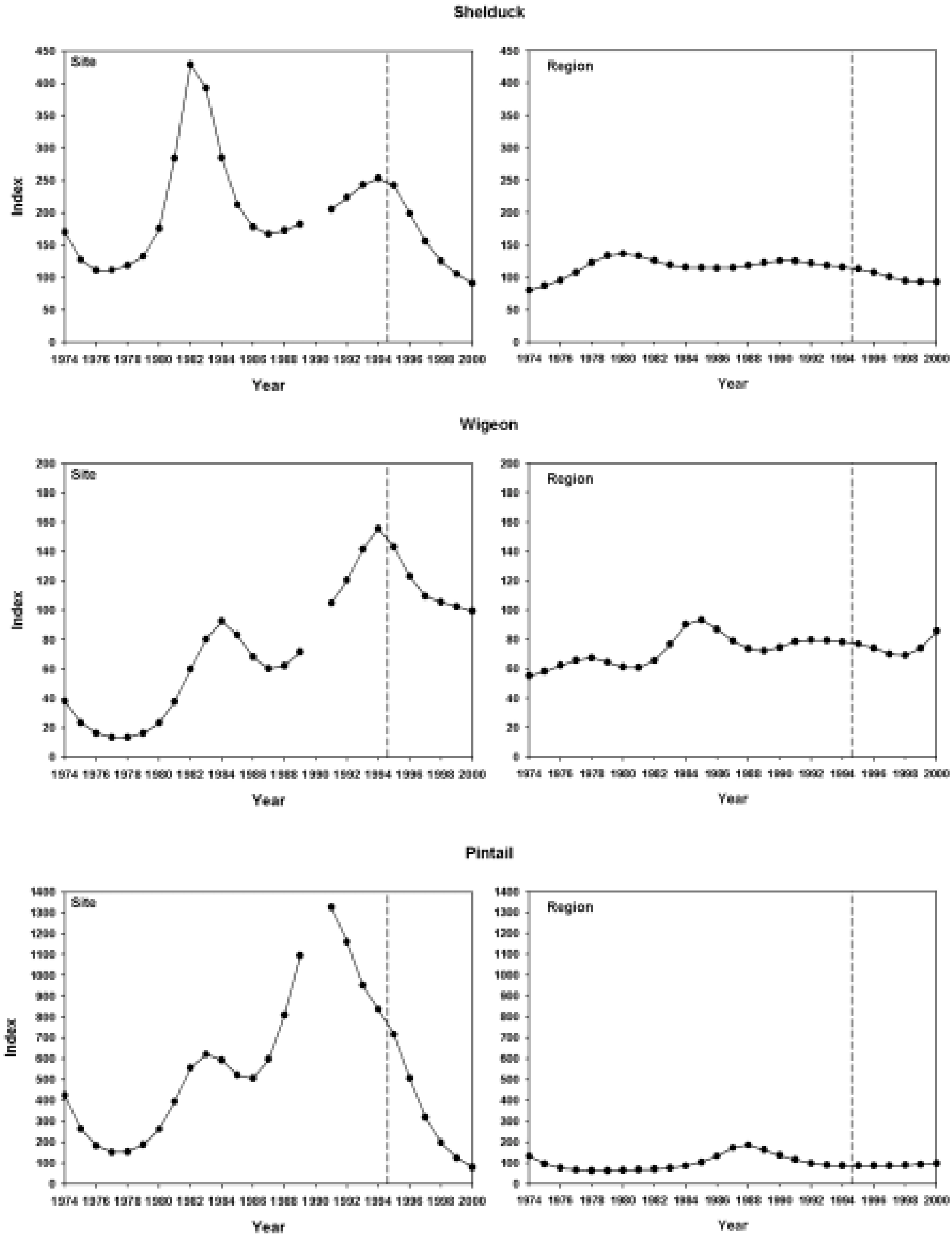

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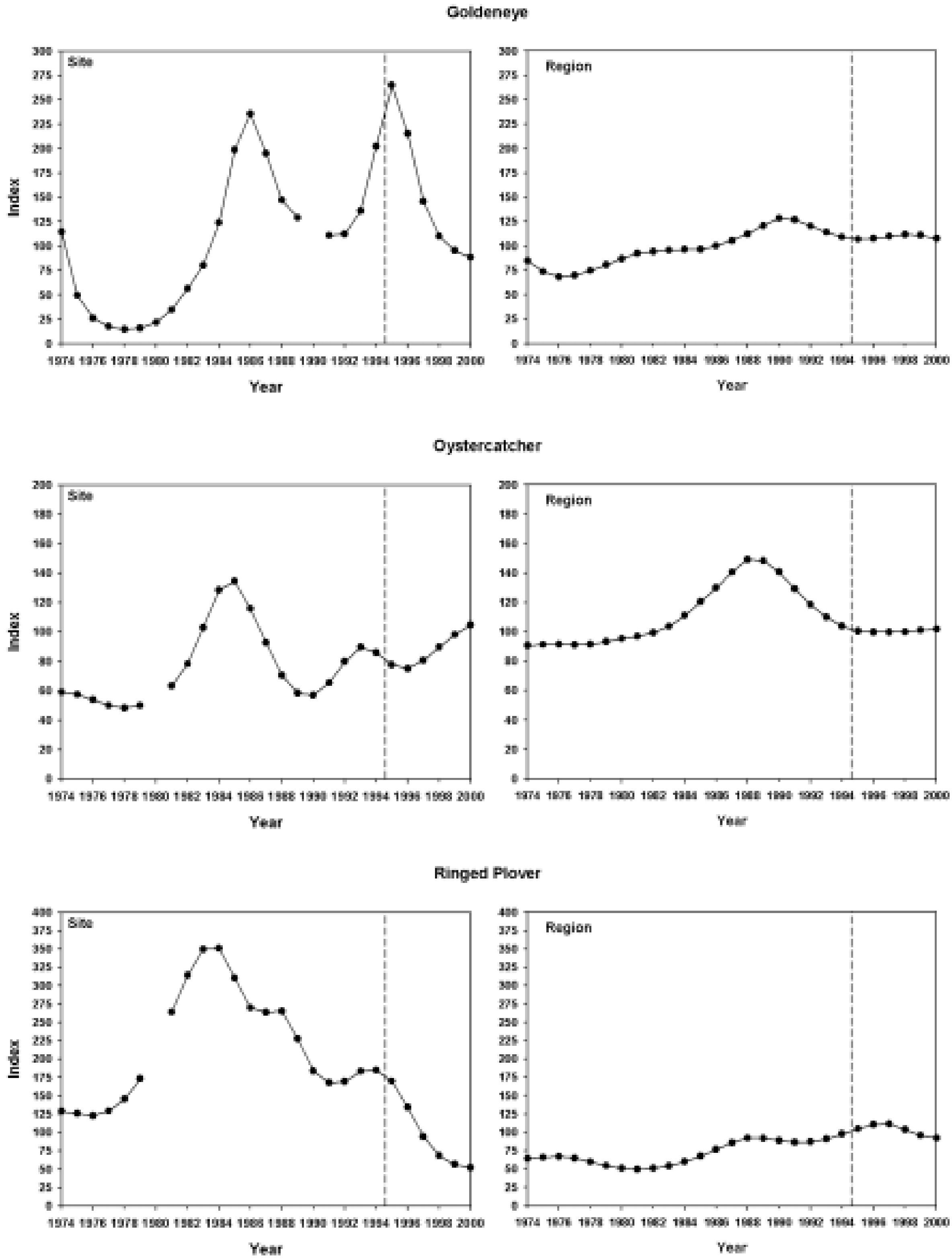

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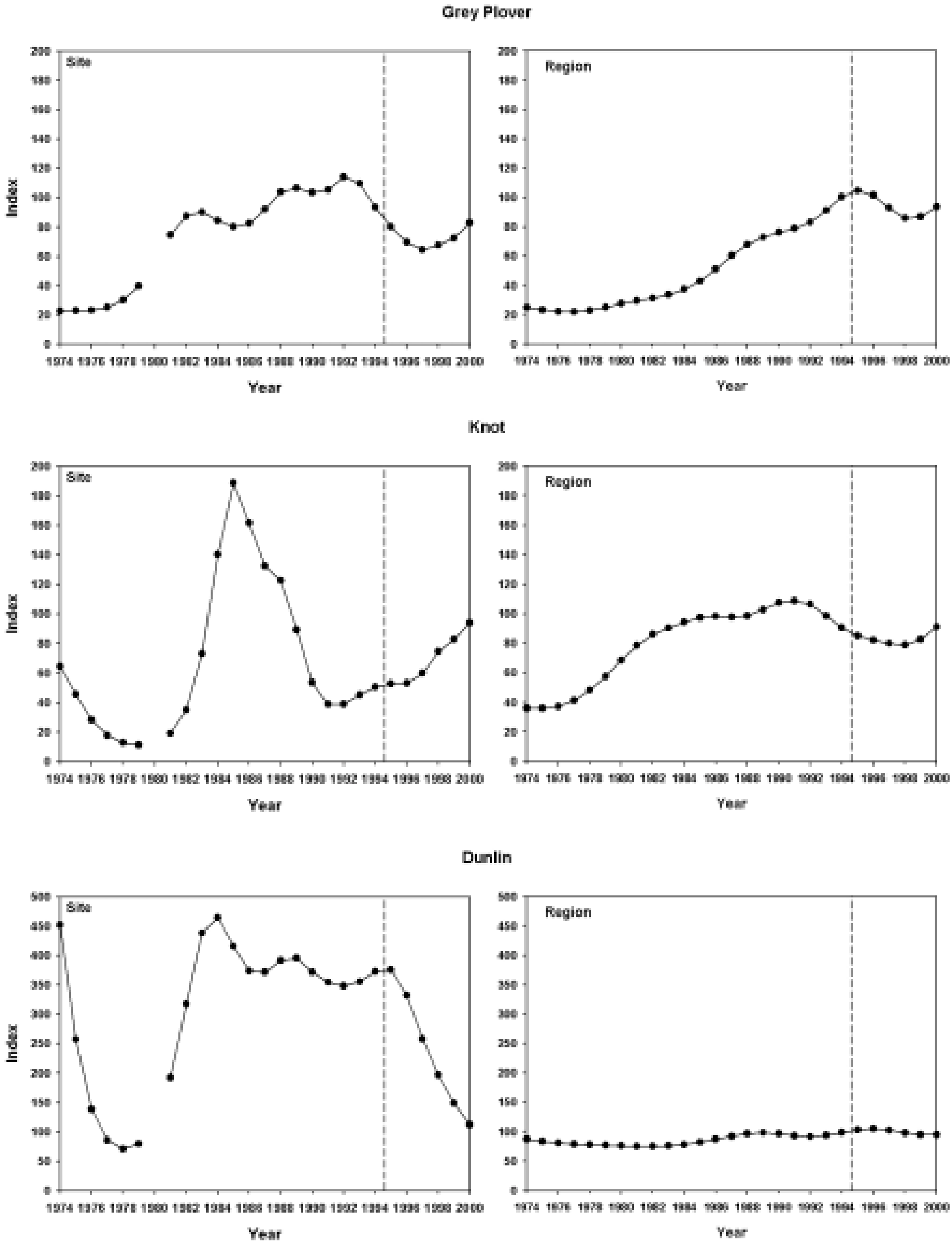

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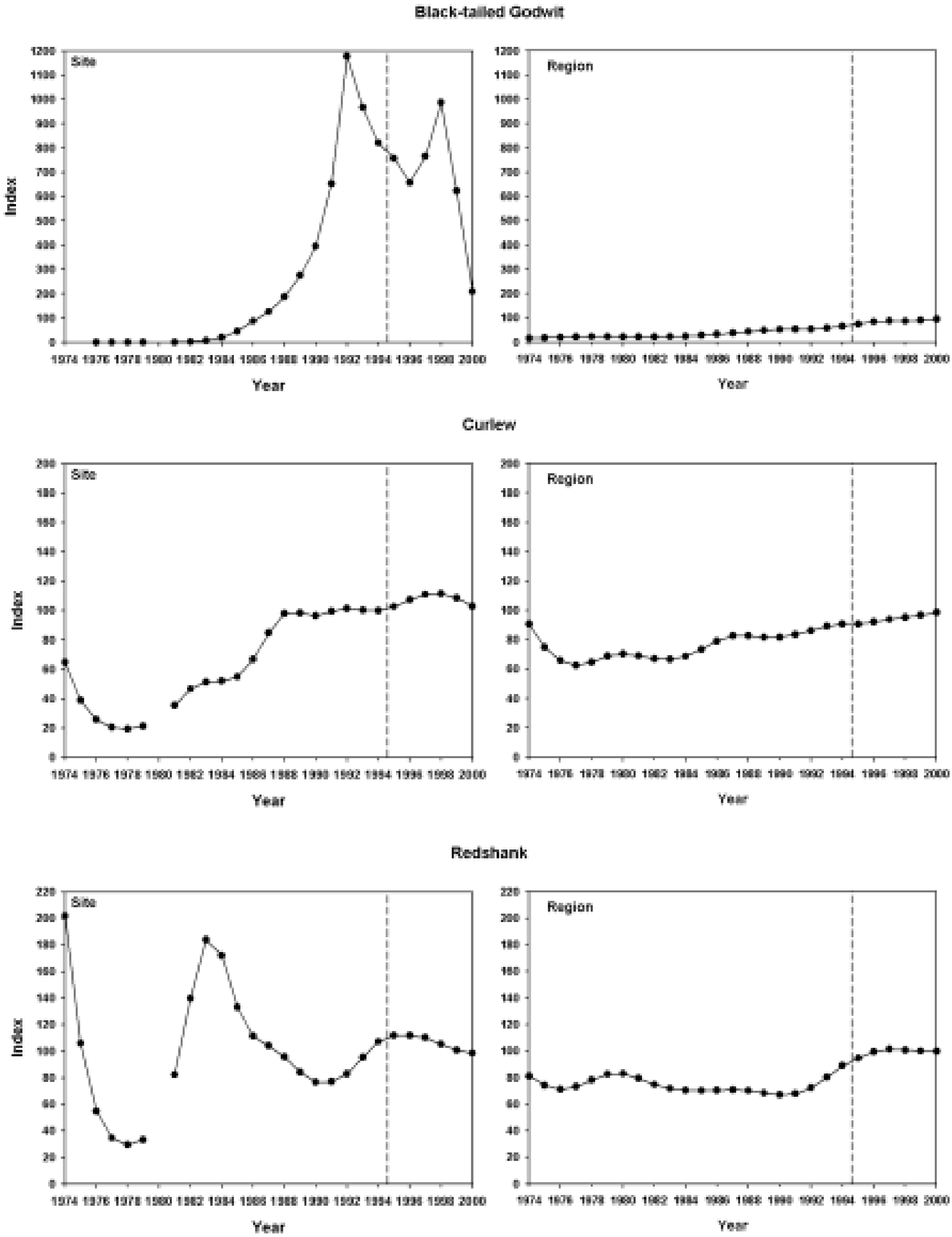

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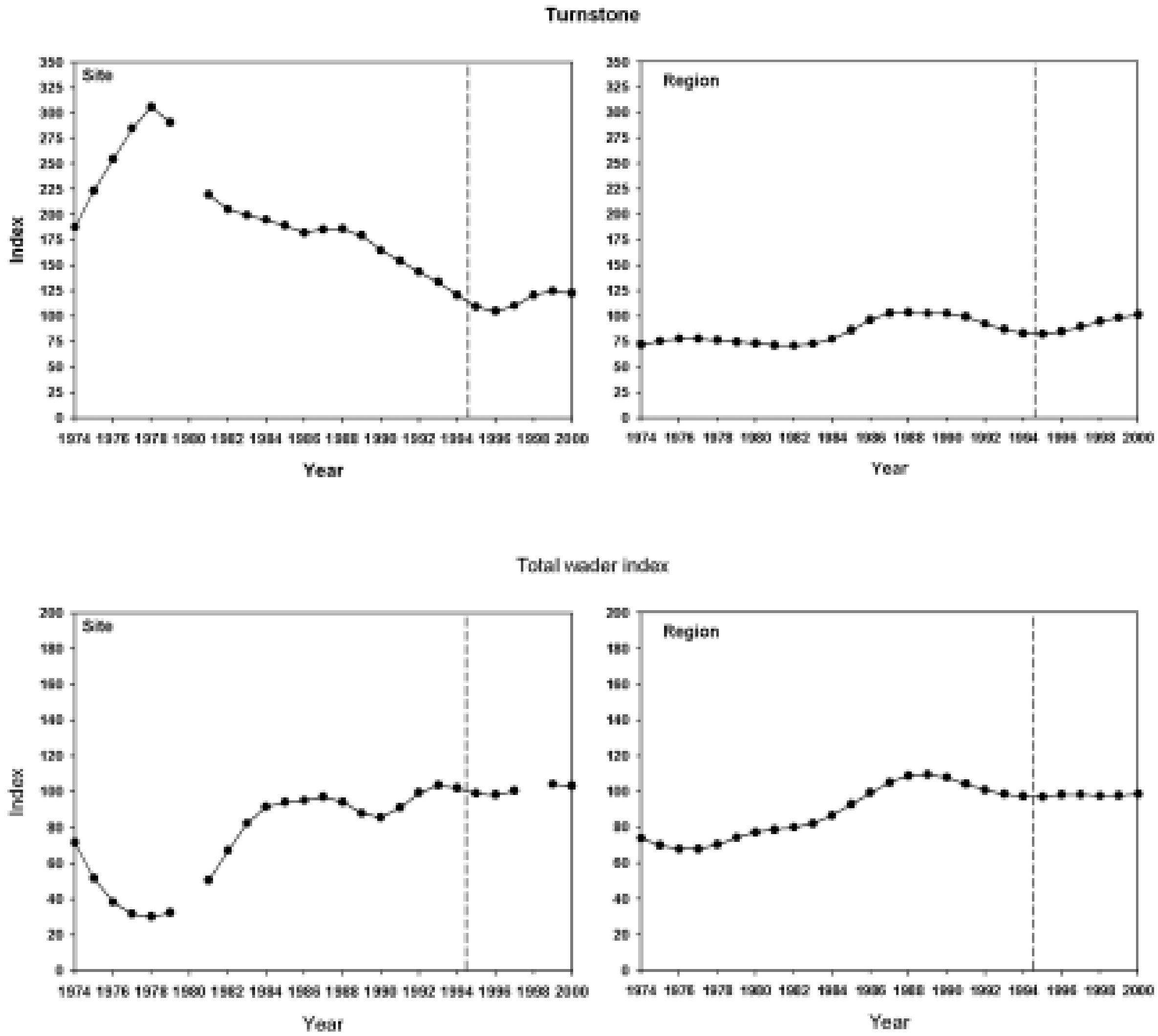

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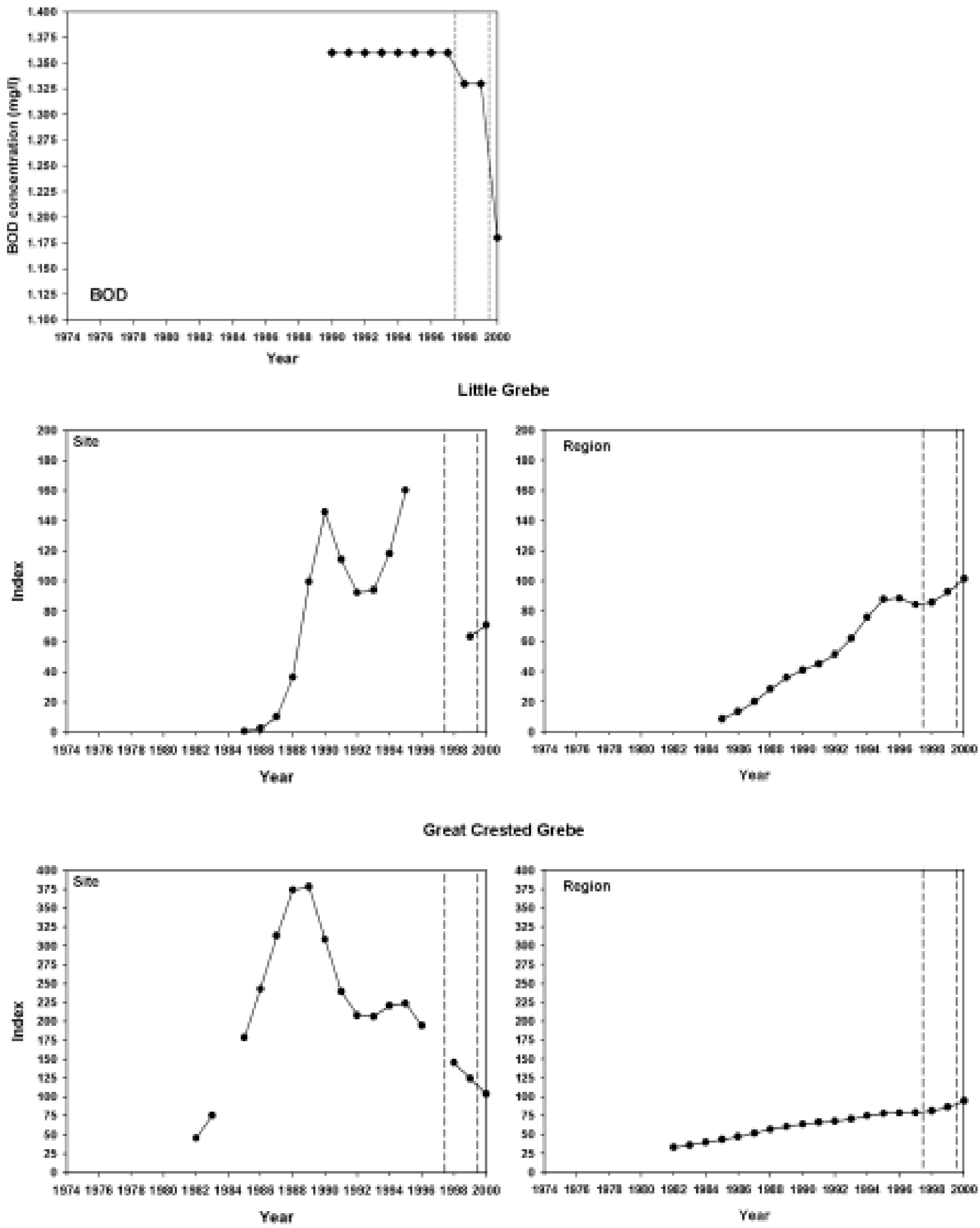
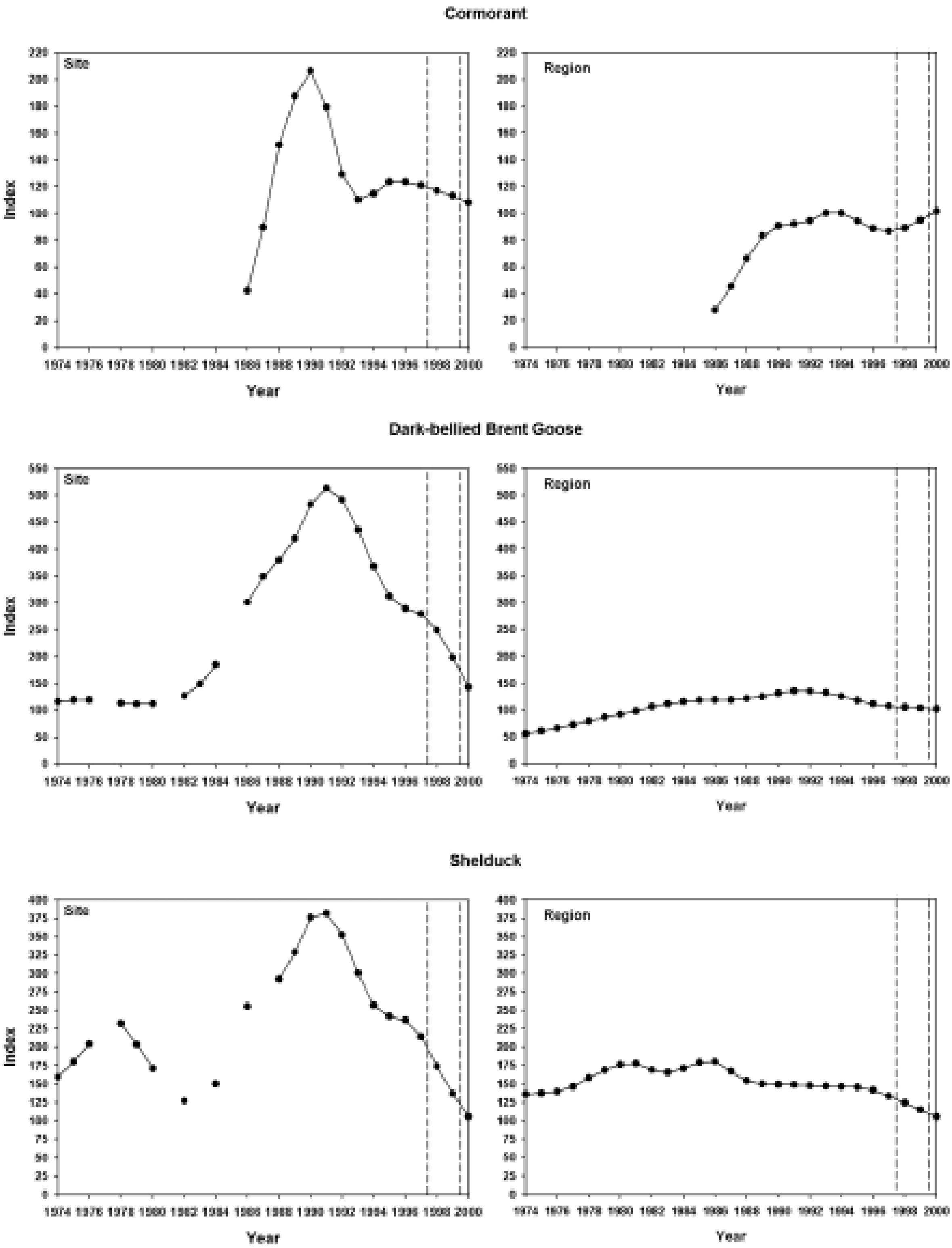


Figure 3.2.1.3 Smoothed waterbird indices derived from WeBS Core Count data for 18 species at The Medway Estuary and Marshes SPA and variation in the overall BOD concentration (mg/l) on the site as estimated by box-modelling. The dotted lines indicate the first and last years of improvements to waste water treatment. 1974 = the winter of 1974/75 etc.



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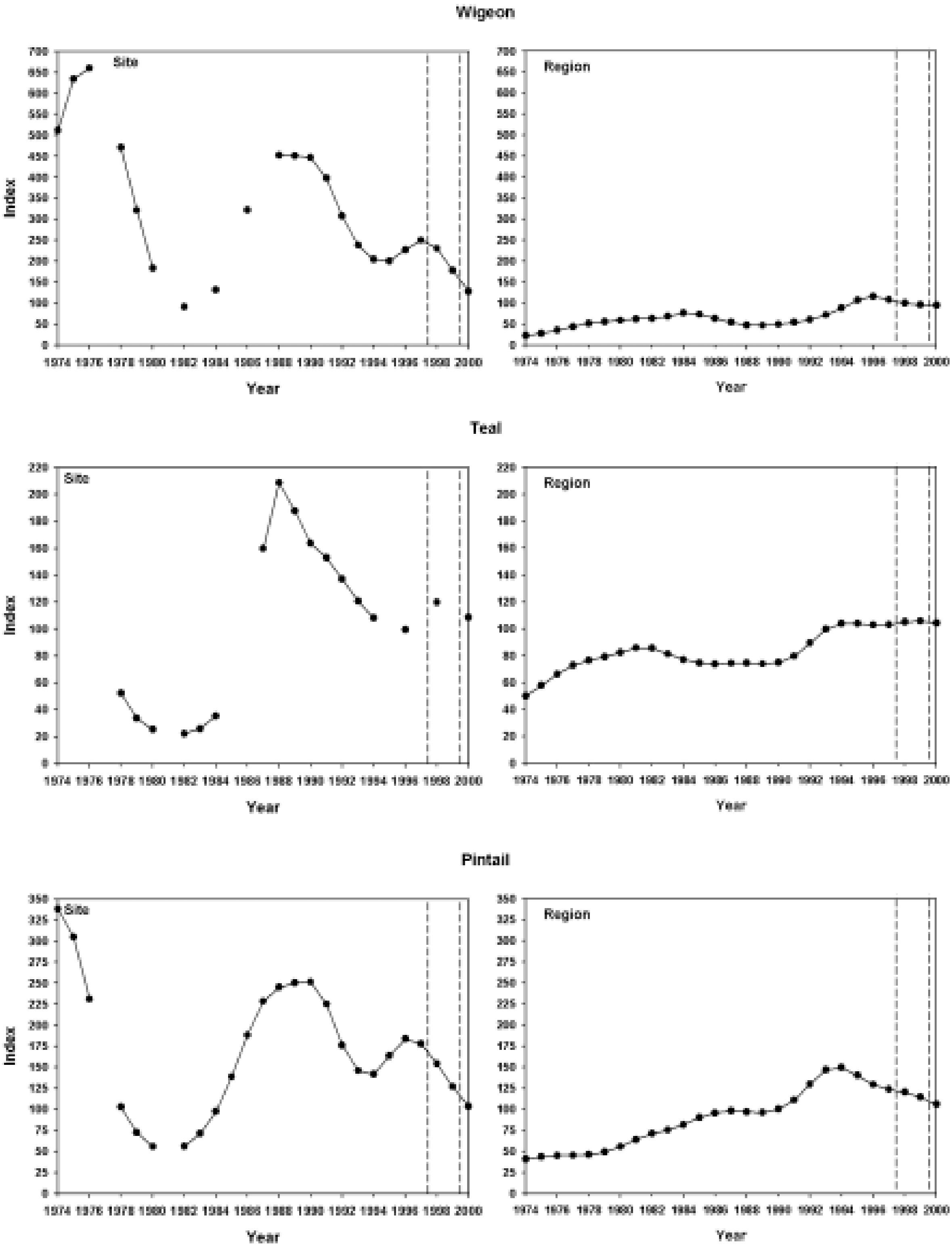

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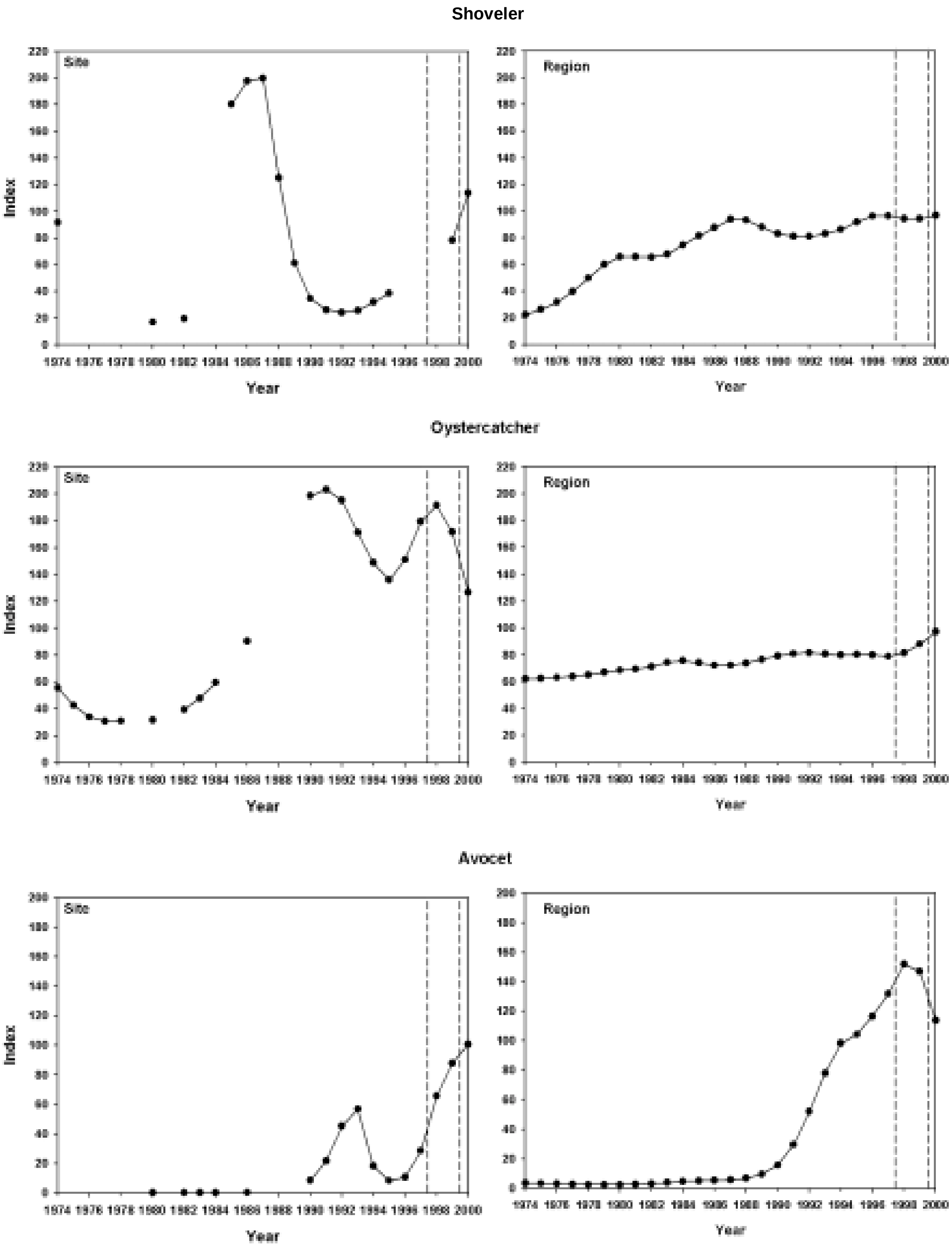

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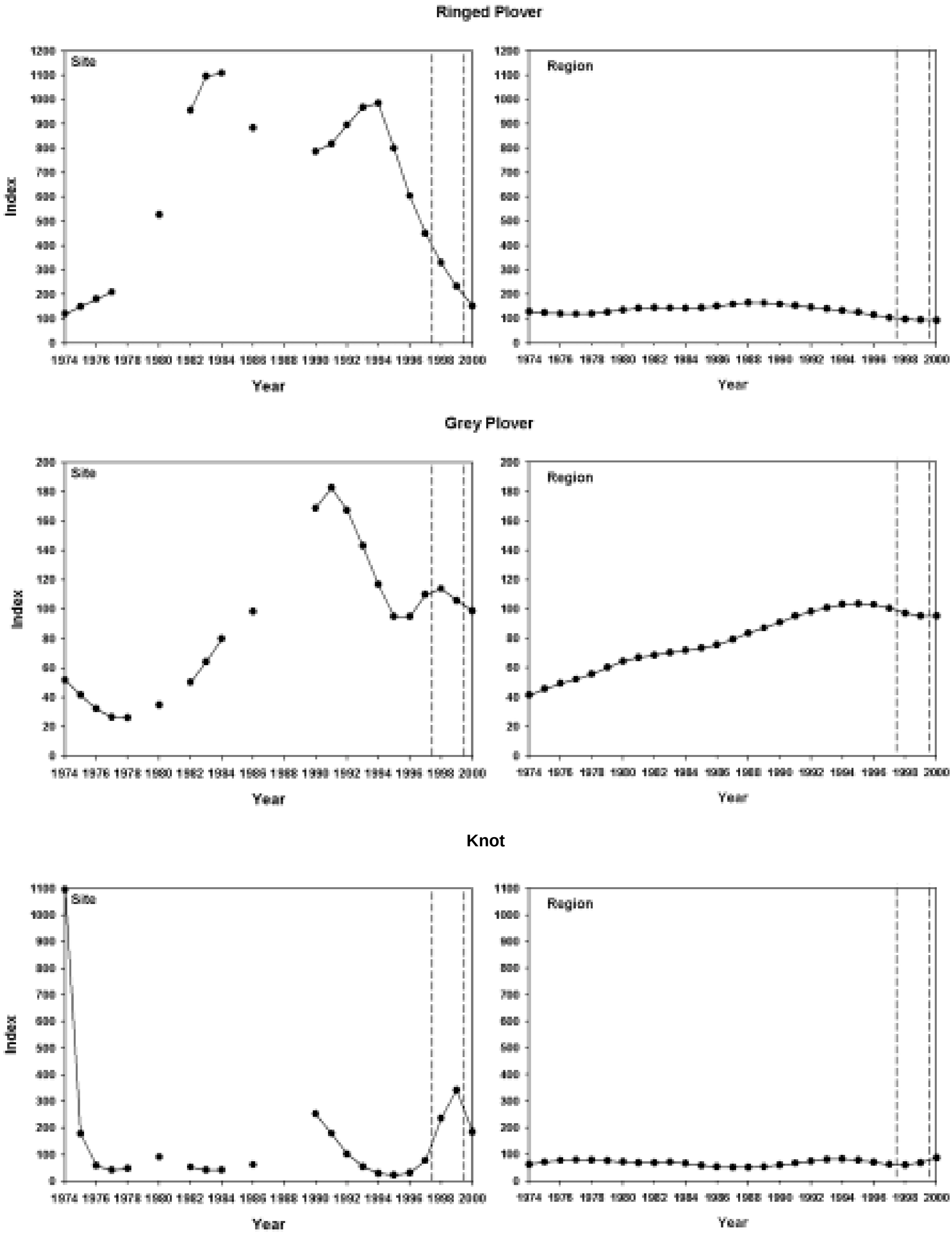

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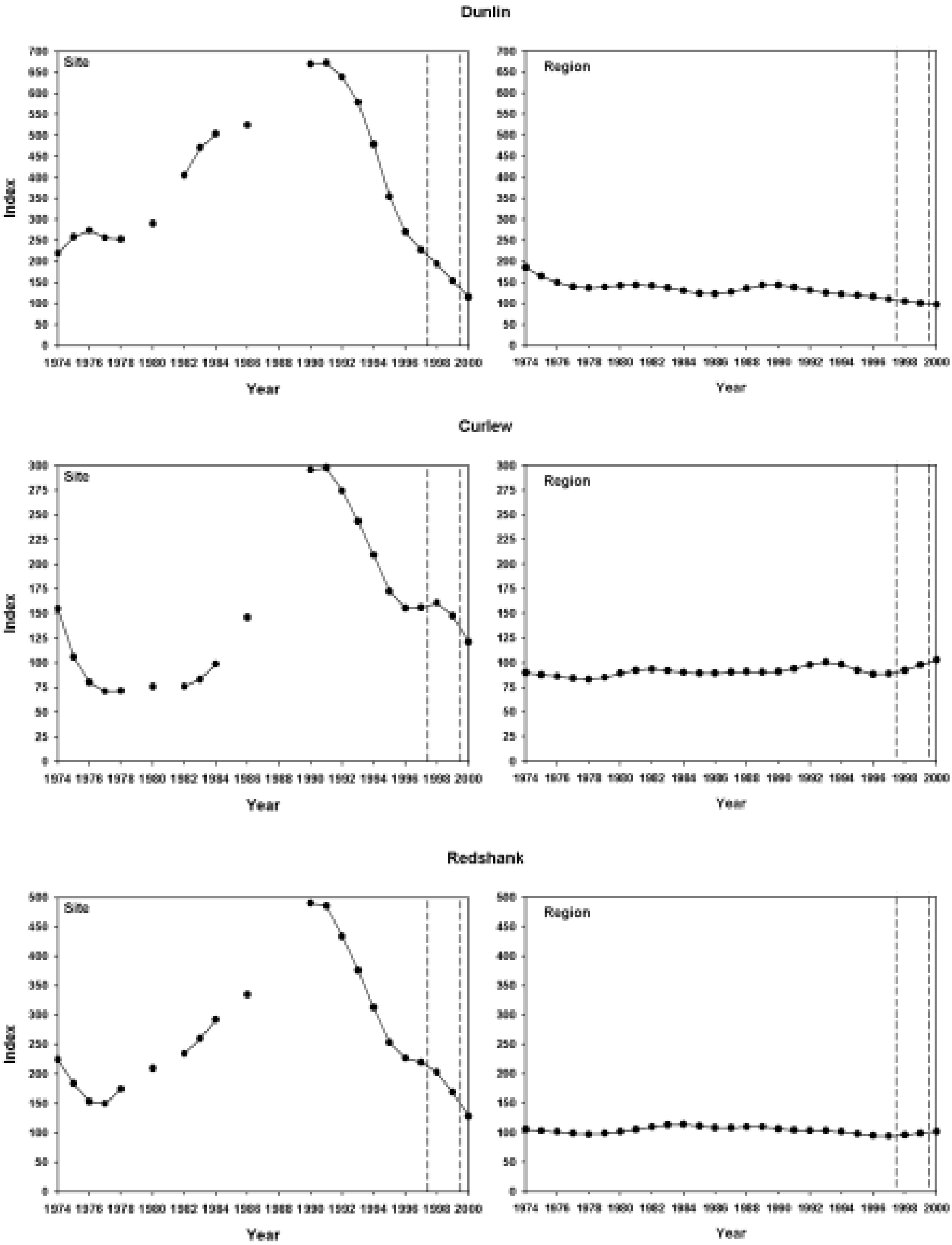

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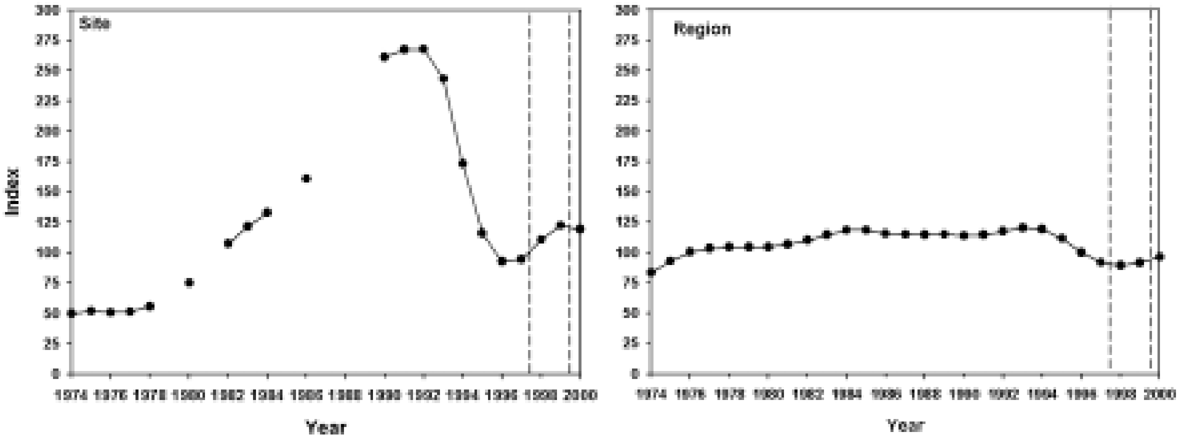
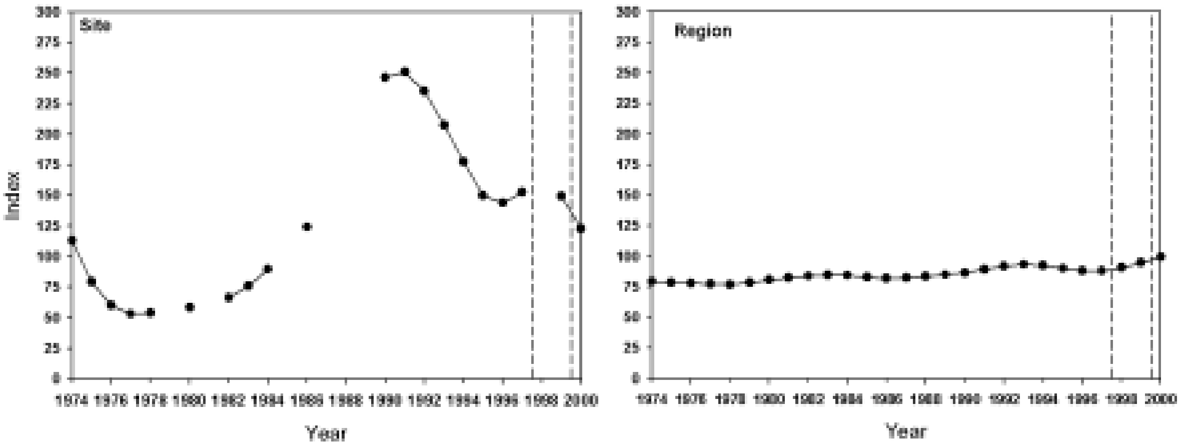
Turnstone



Total wader index



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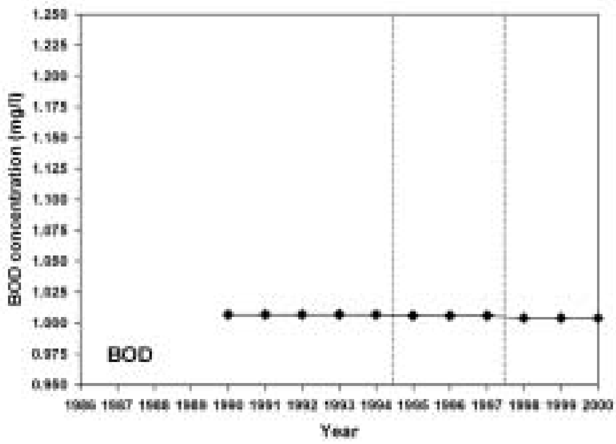
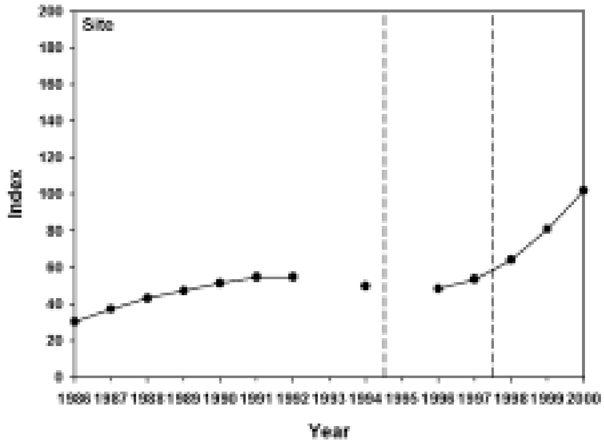
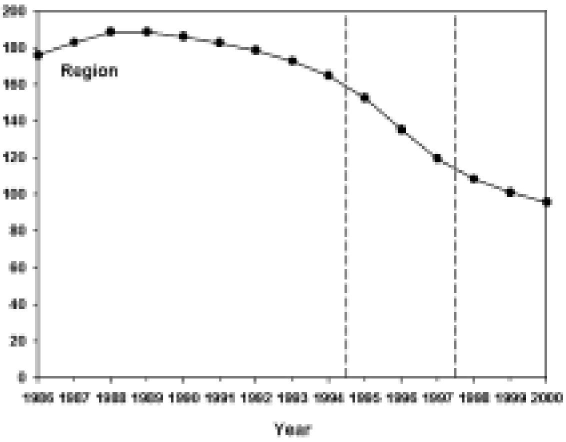
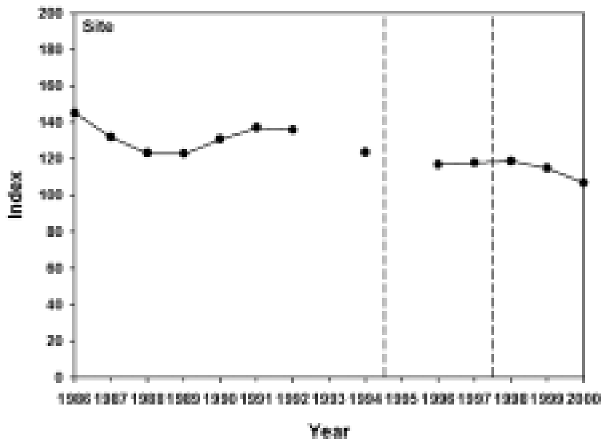


Ringed Plover





Grey Plover



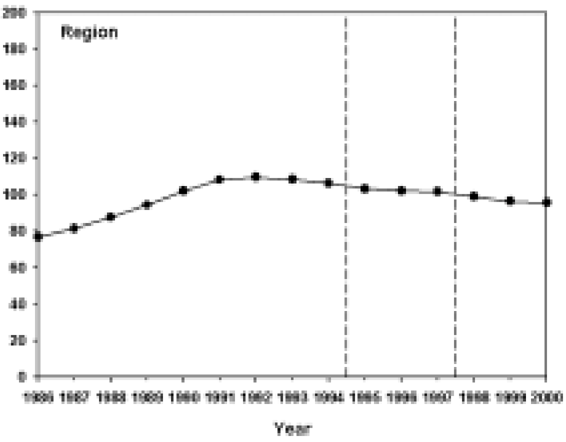
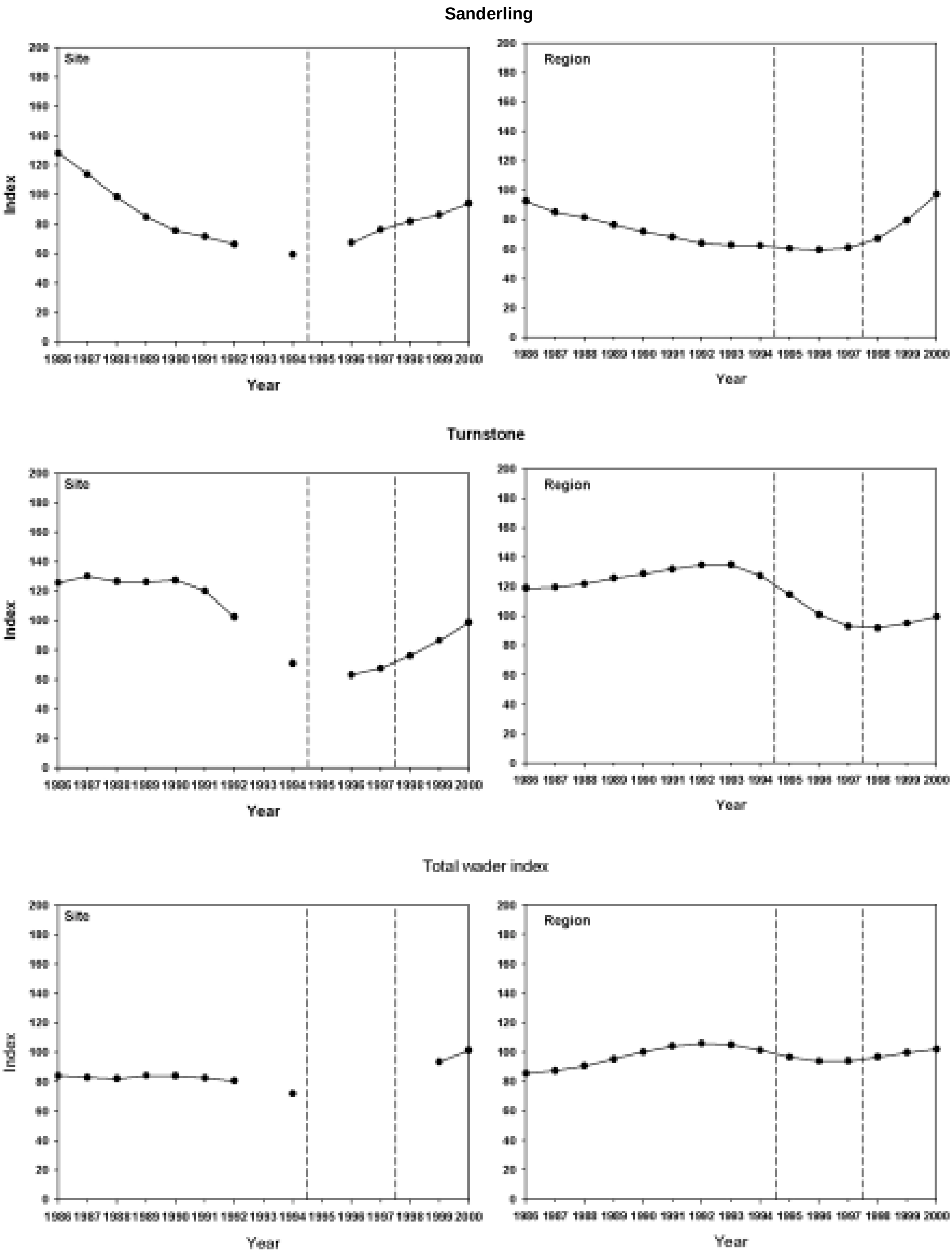


Figure 3.2.1.4 Smoothed waterbird indices derived from WeBS Core Count data for four species at The Thanet Coast and variation in the overall BOD concentration (mg/l) on the site as estimated by box-modelling. The dotted lines indicate the first and last years of improvements to waste water treatment. 1986 = the winter of 1986/87 etc.



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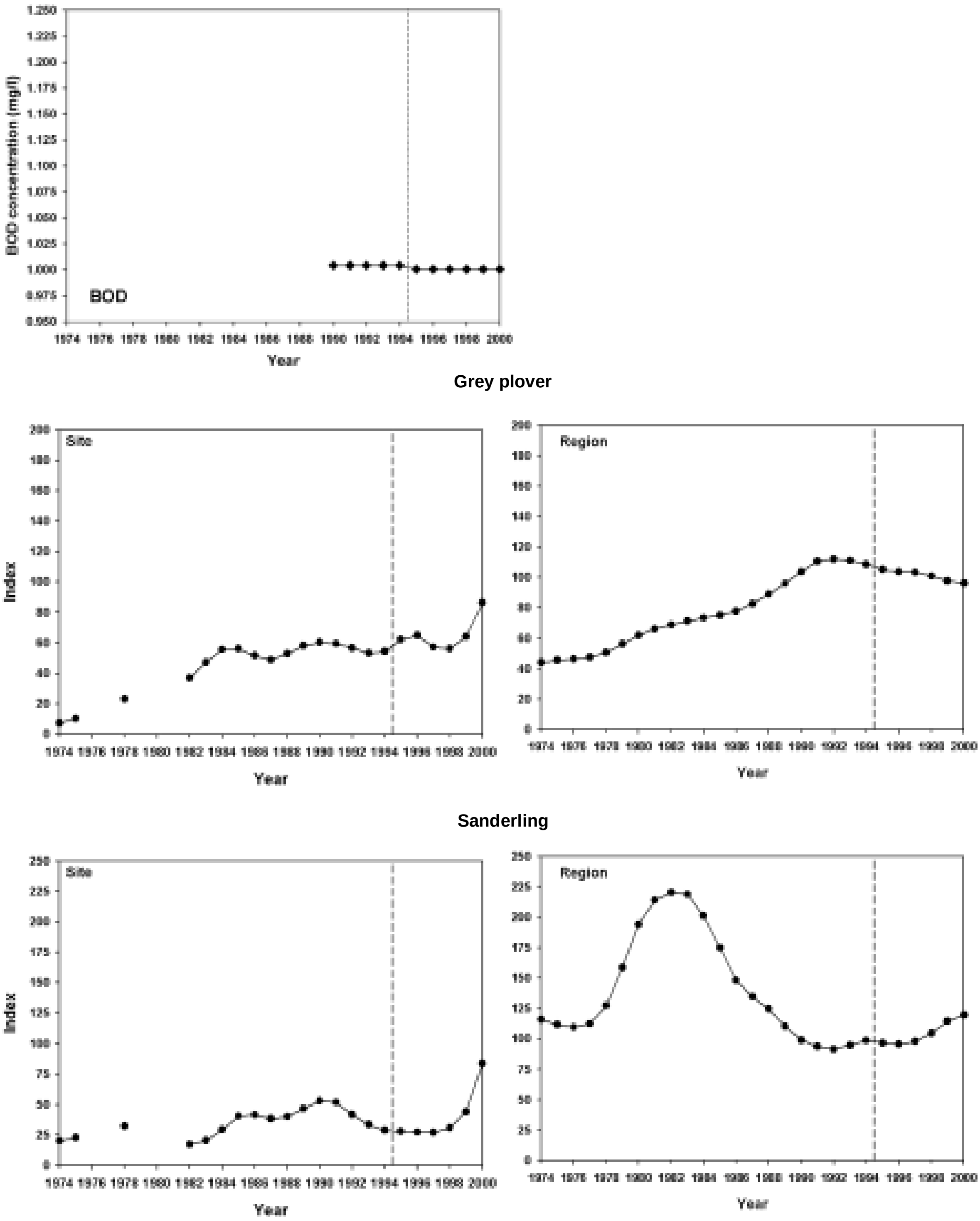
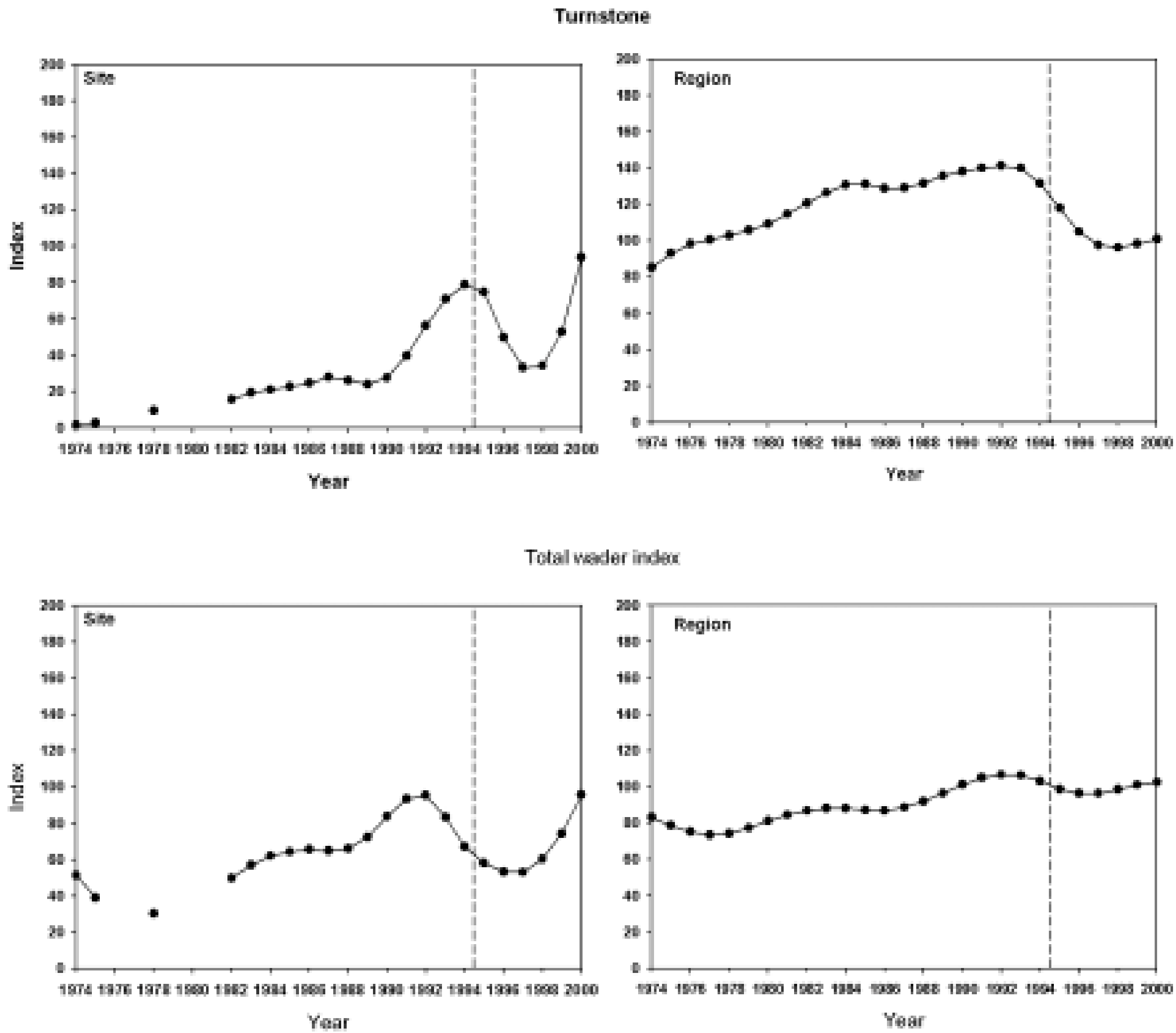


Figure 3.2.1.5 Smoothed waterbird indices derived from WeBS Core Count data for three species at Sandwich Bay and variation in the overall BOD concentration (mg/l) on the site as estimated by box-modelling. The dotted line indicates the date of the improvement to waste water treatment. 1974 = the winter of 1974/75 etc.



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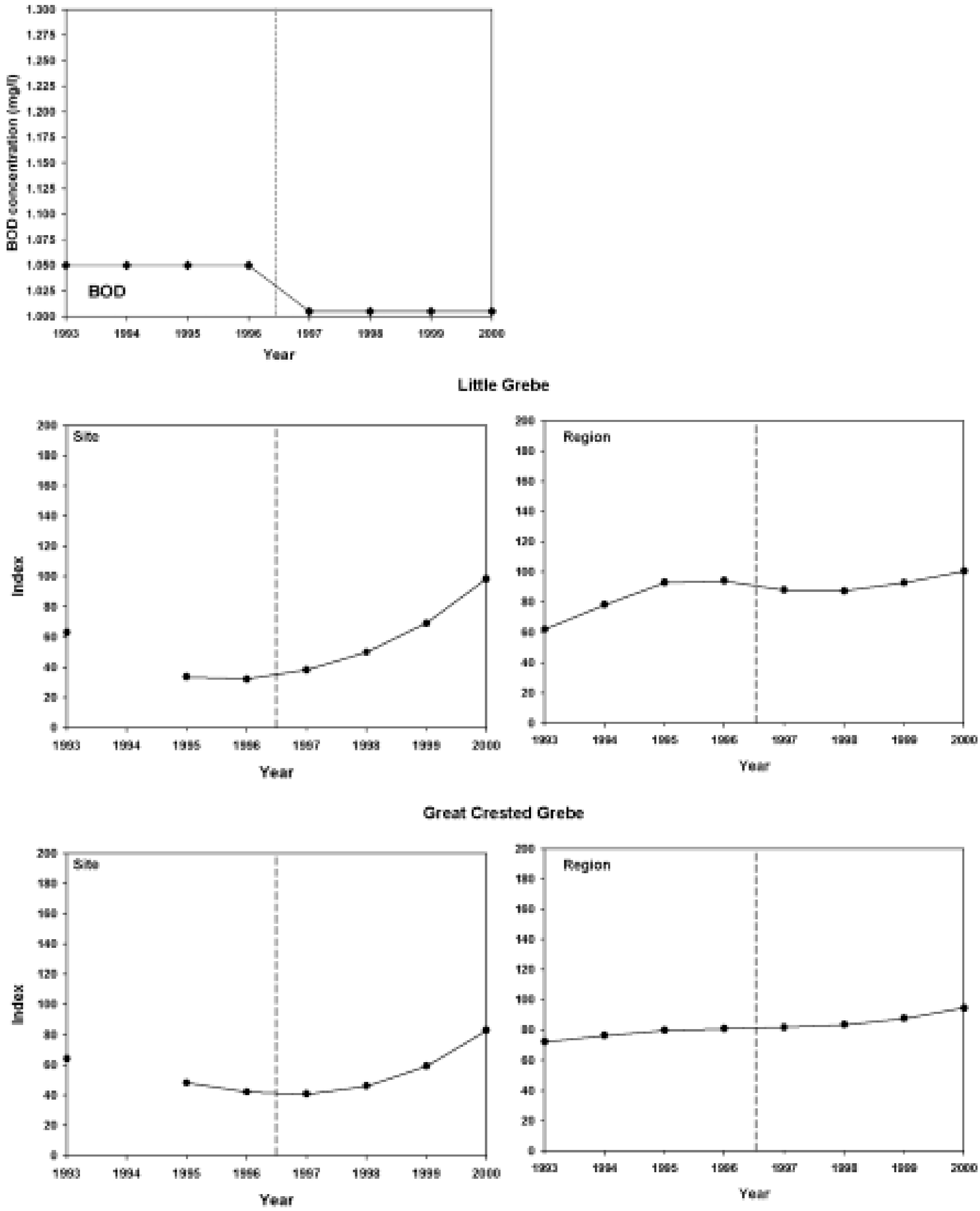
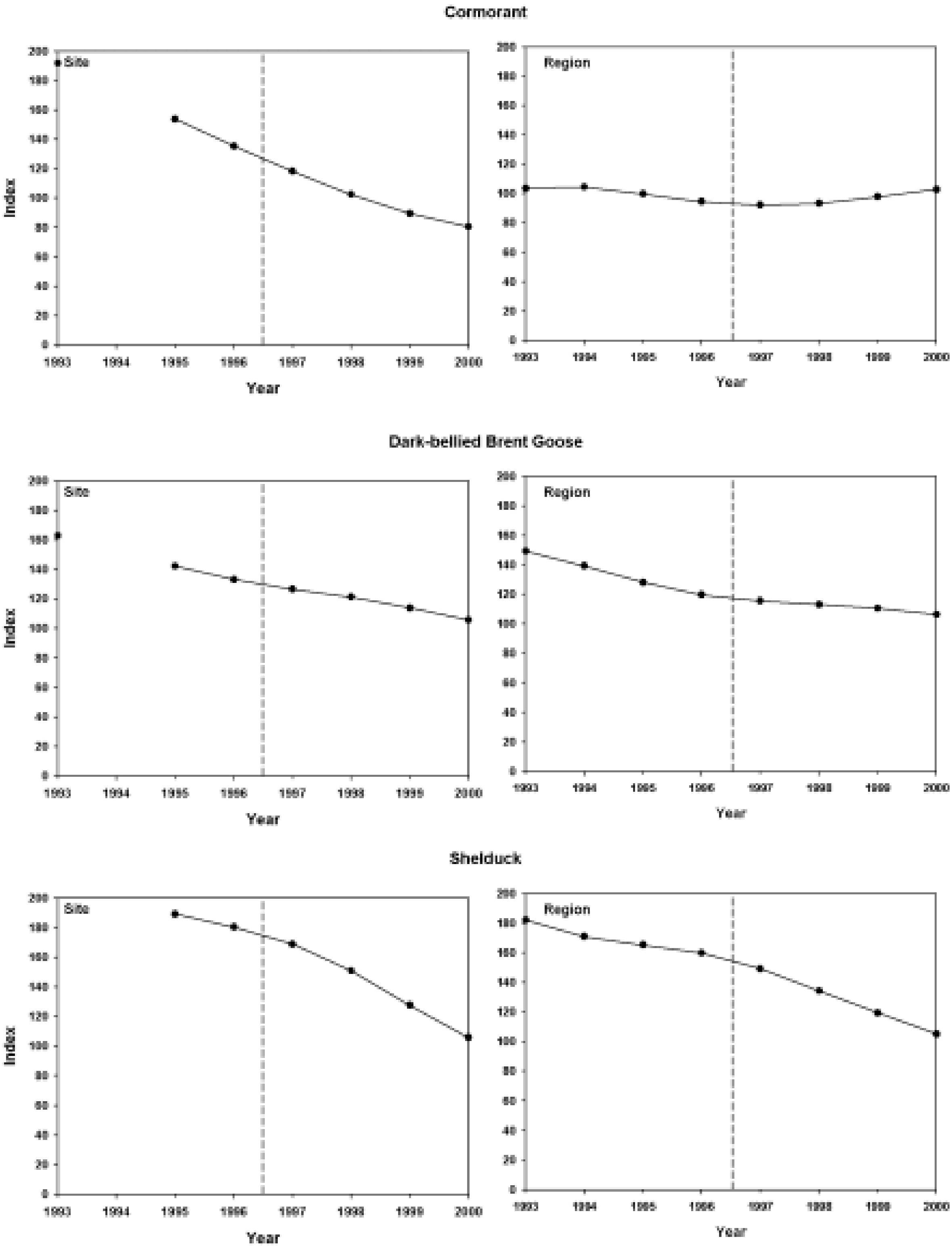


Figure 3.2.1.6 Smoothed waterbird indices derived from WeBS Core Count data for 16 species at the North-west Solent and variation in the overall BOD concentration (mg/l) on the site as estimated by box-modelling. The dotted line indicates the date of the improvement to waste water treatment. 1993 = the winter of 1993/94 etc.



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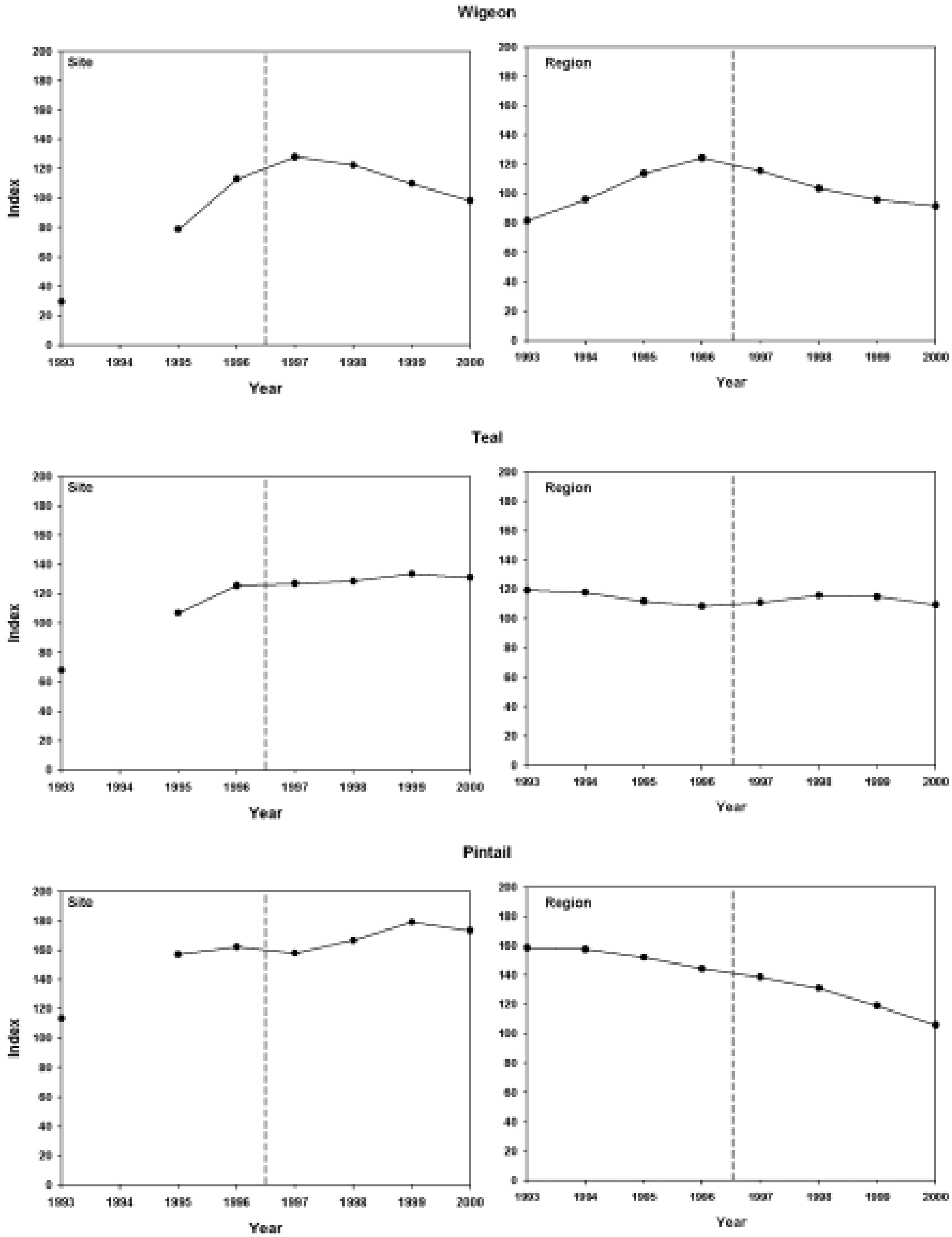

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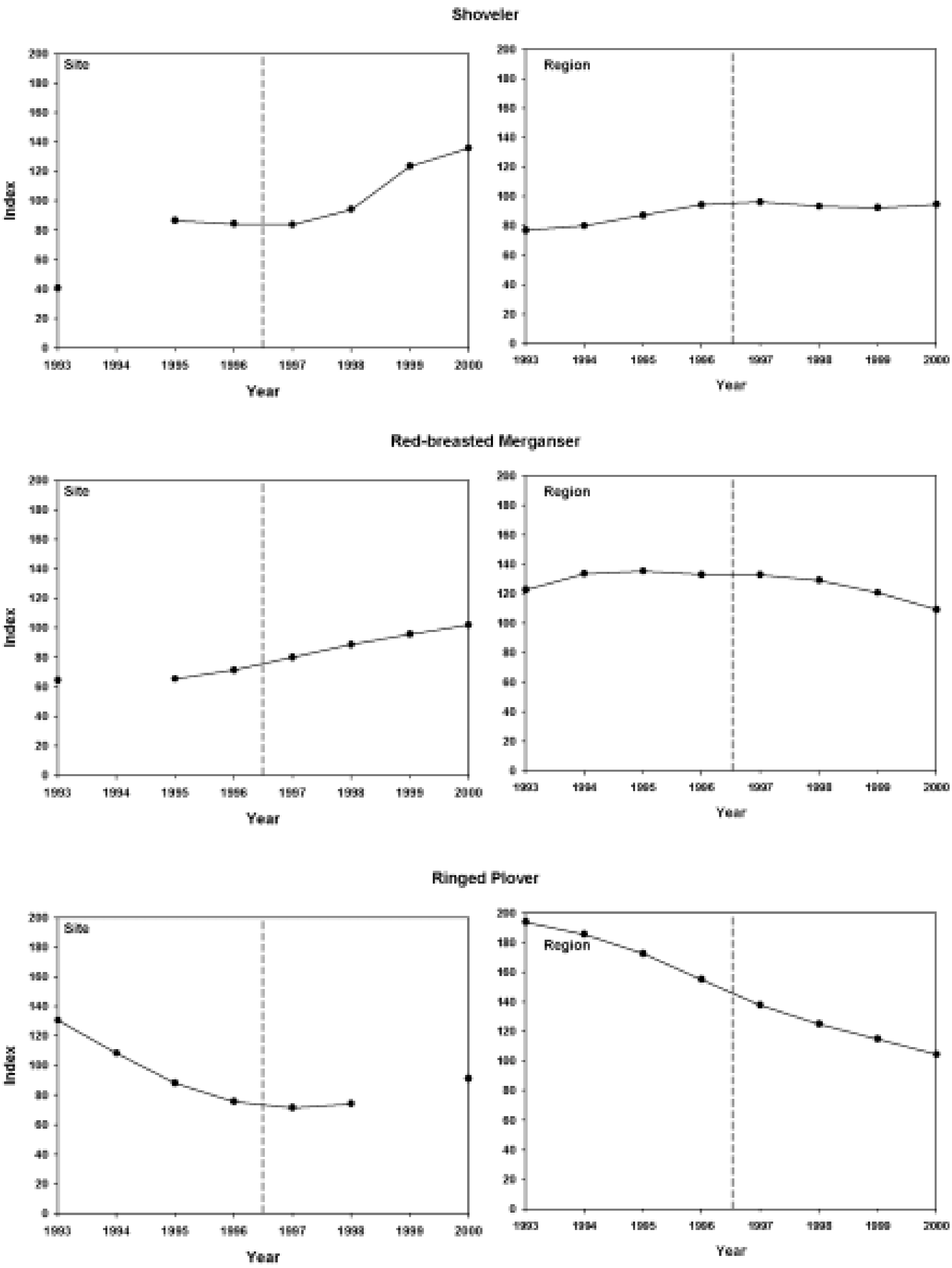

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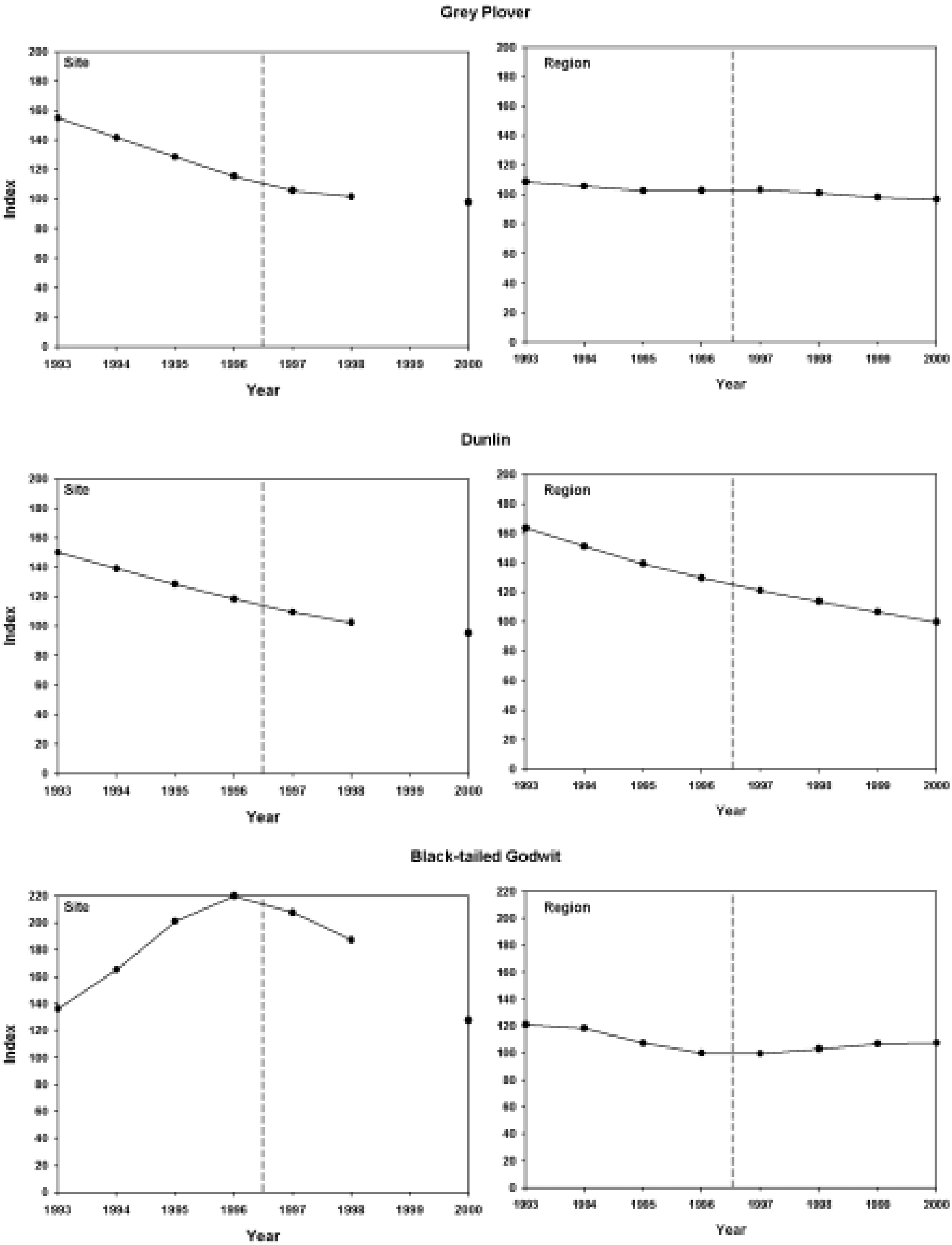

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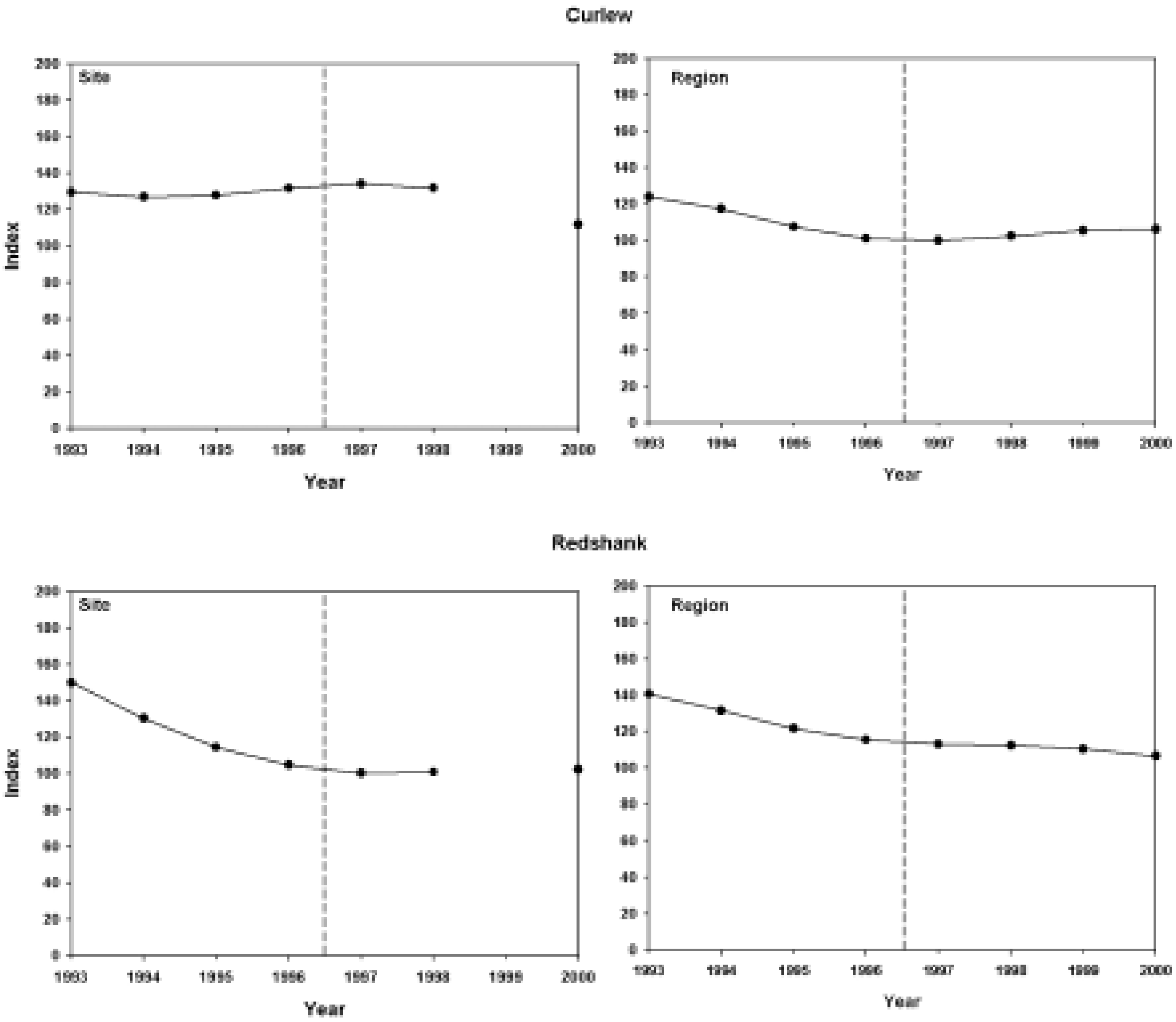

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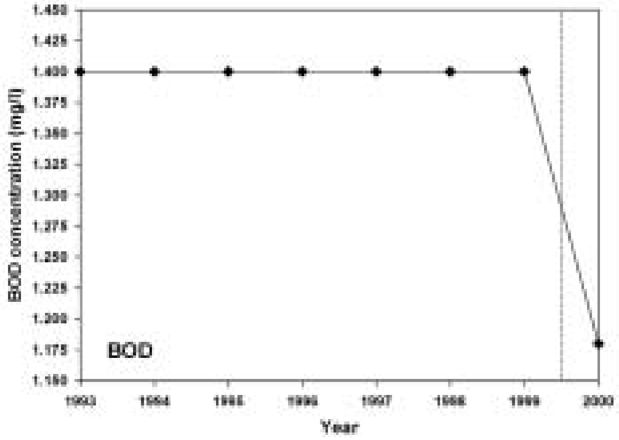
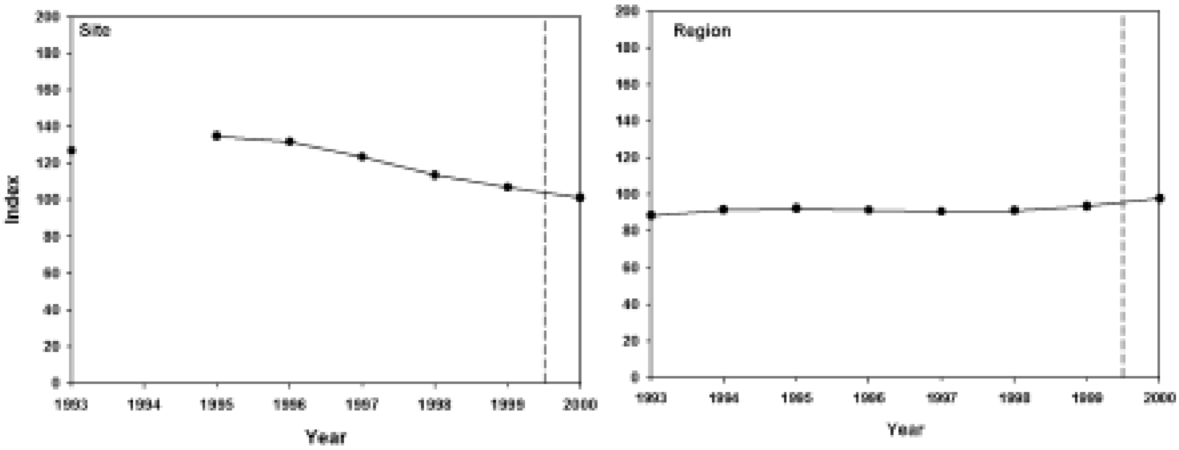


Cormorant



Avocet

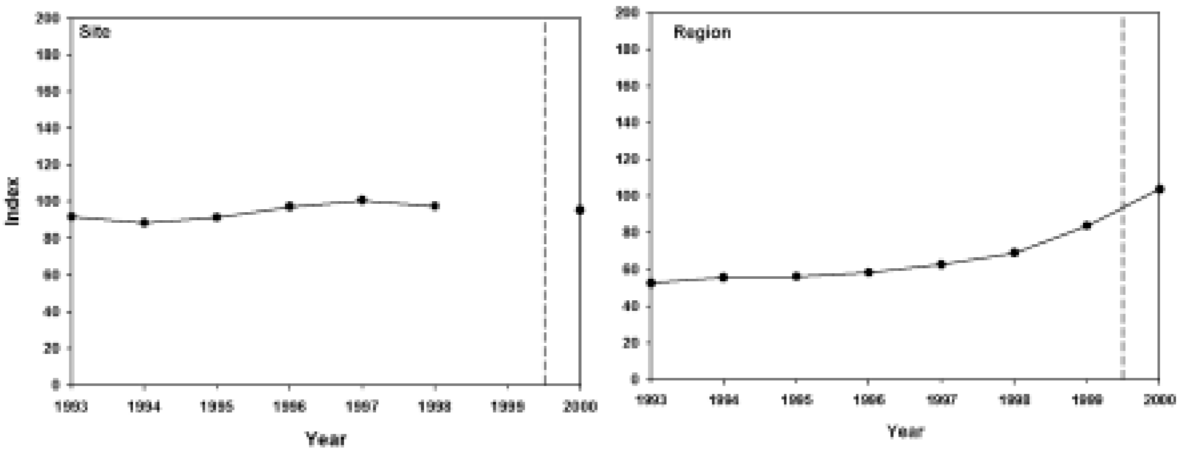
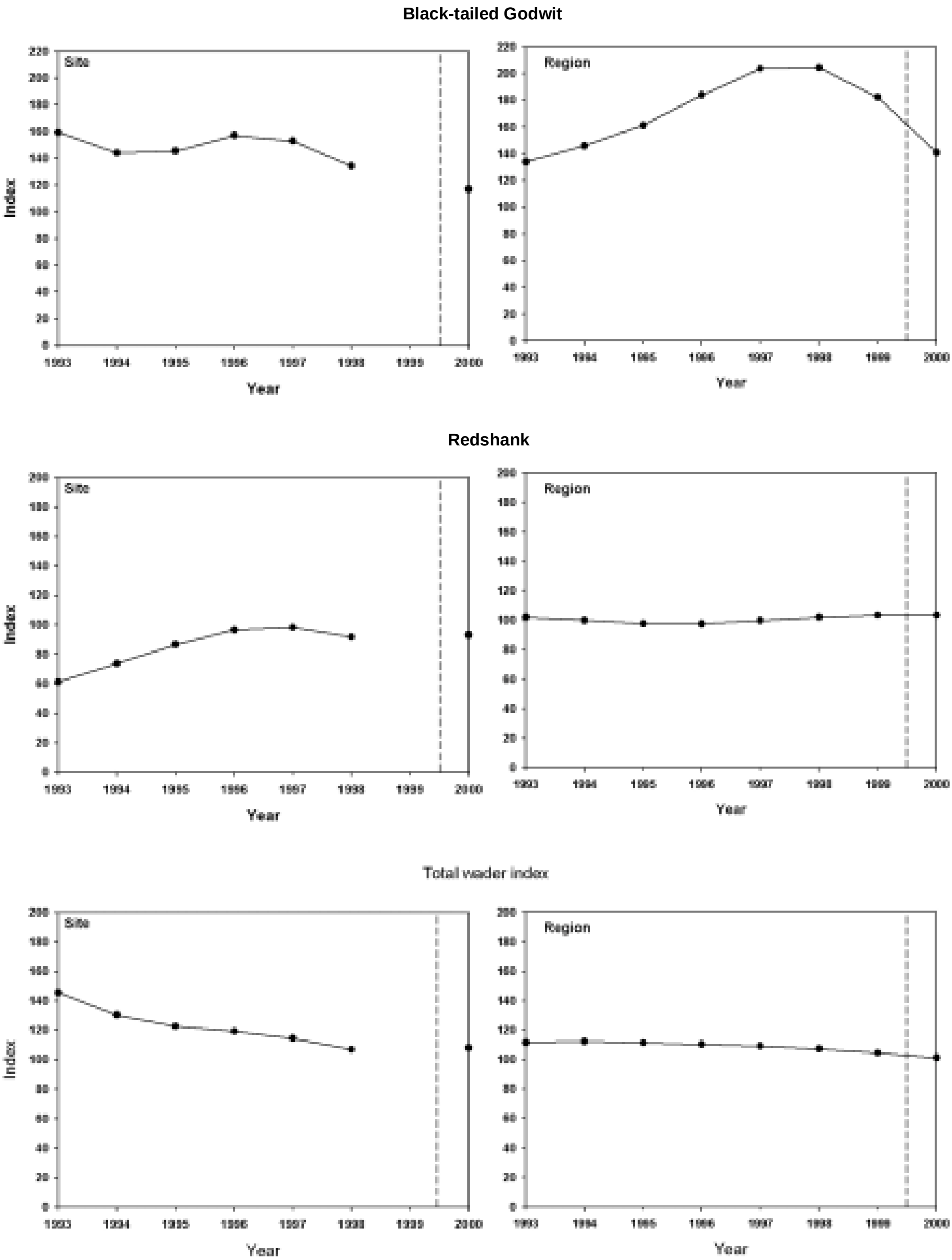


Figure 3.2.1.7 Smoothed waterbird indices derived from WeBS Core Count data for four species at The Tamar Estuary and variation in the overall BOD concentration (mg/l) on the site as estimated by box-modelling. The dotted line indicates the date of the improvement to waste water treatment. 1993 = the winter of 1993/94 etc.



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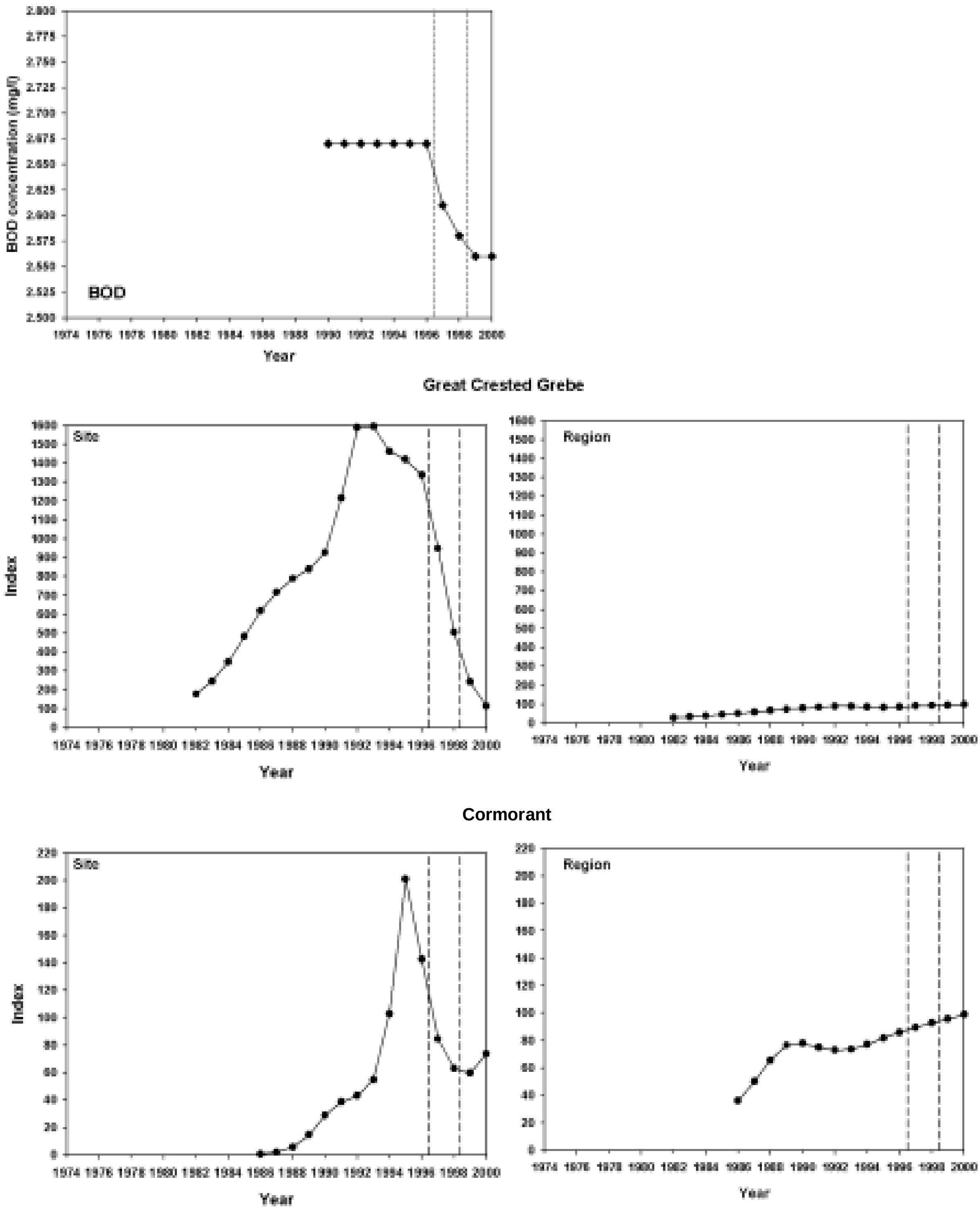
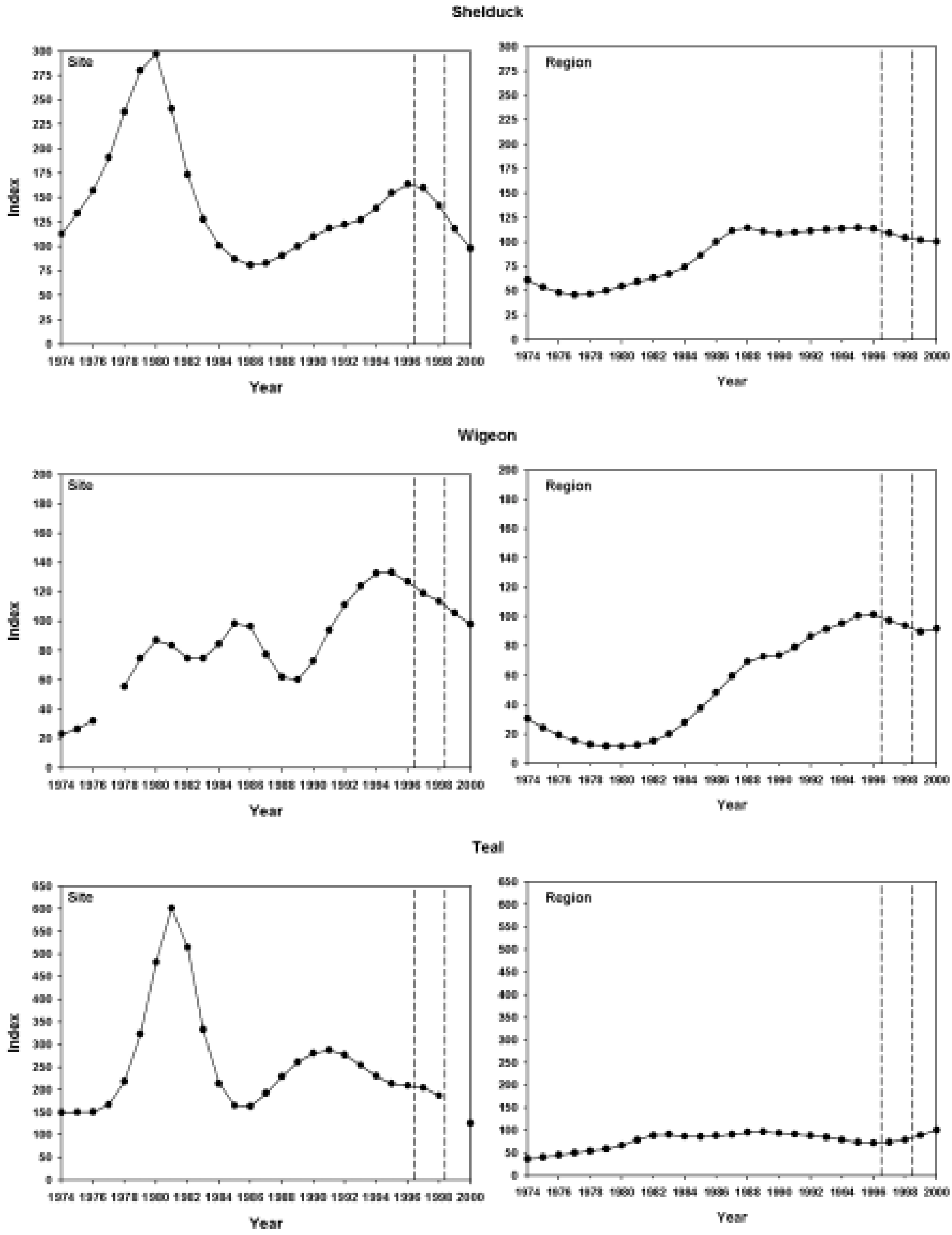


Figure 3.2.1.8 Smoothed waterbird indices derived from WeBS Core Count data for 11 species at The Mersey Estuary SPA and variation in the overall BOD concentration (mg/l) on the site as estimated by box-modelling. The dotted lines indicate the first and last years of improvements to waste water treatment. 1974 = the winter of 1974/75 etc.



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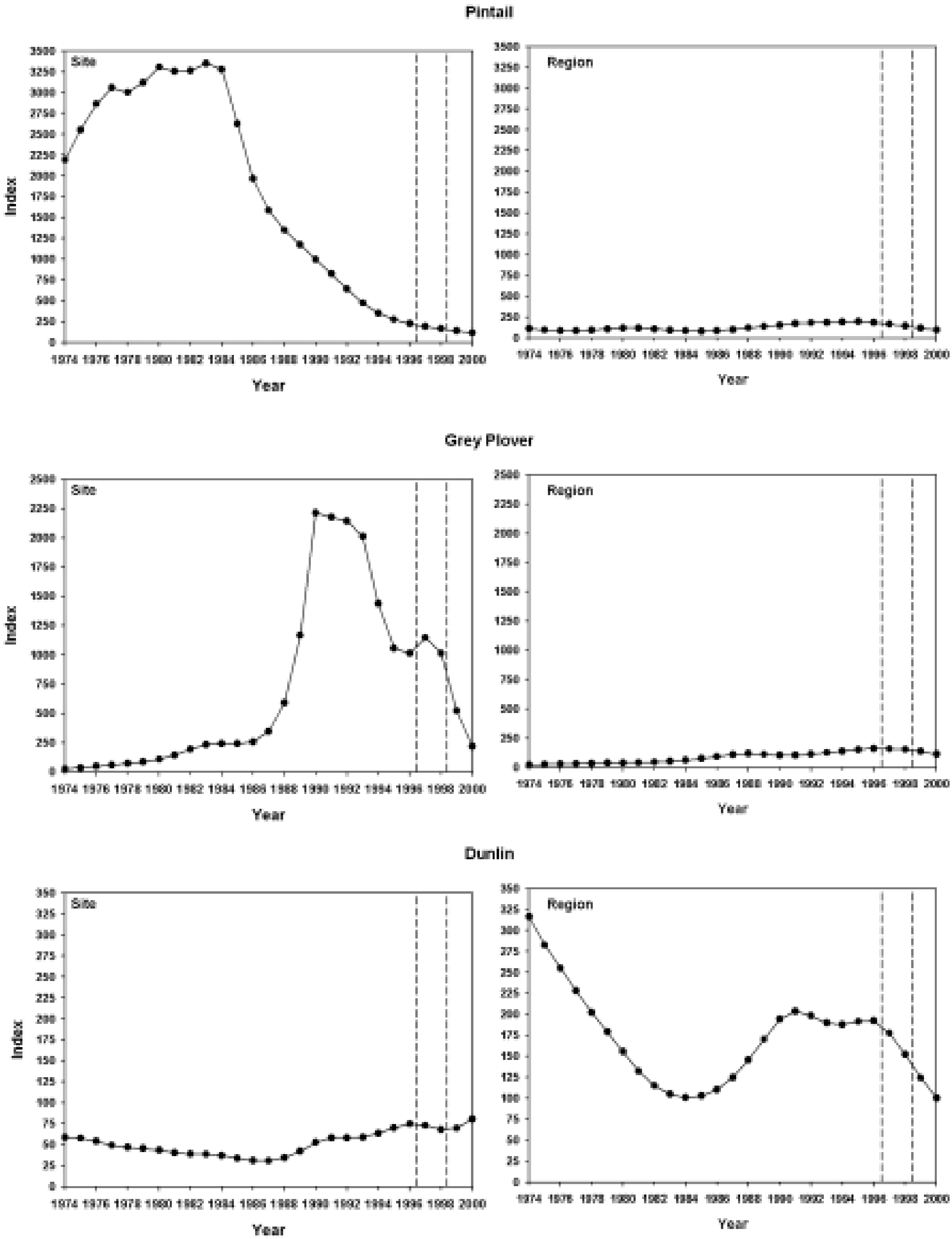

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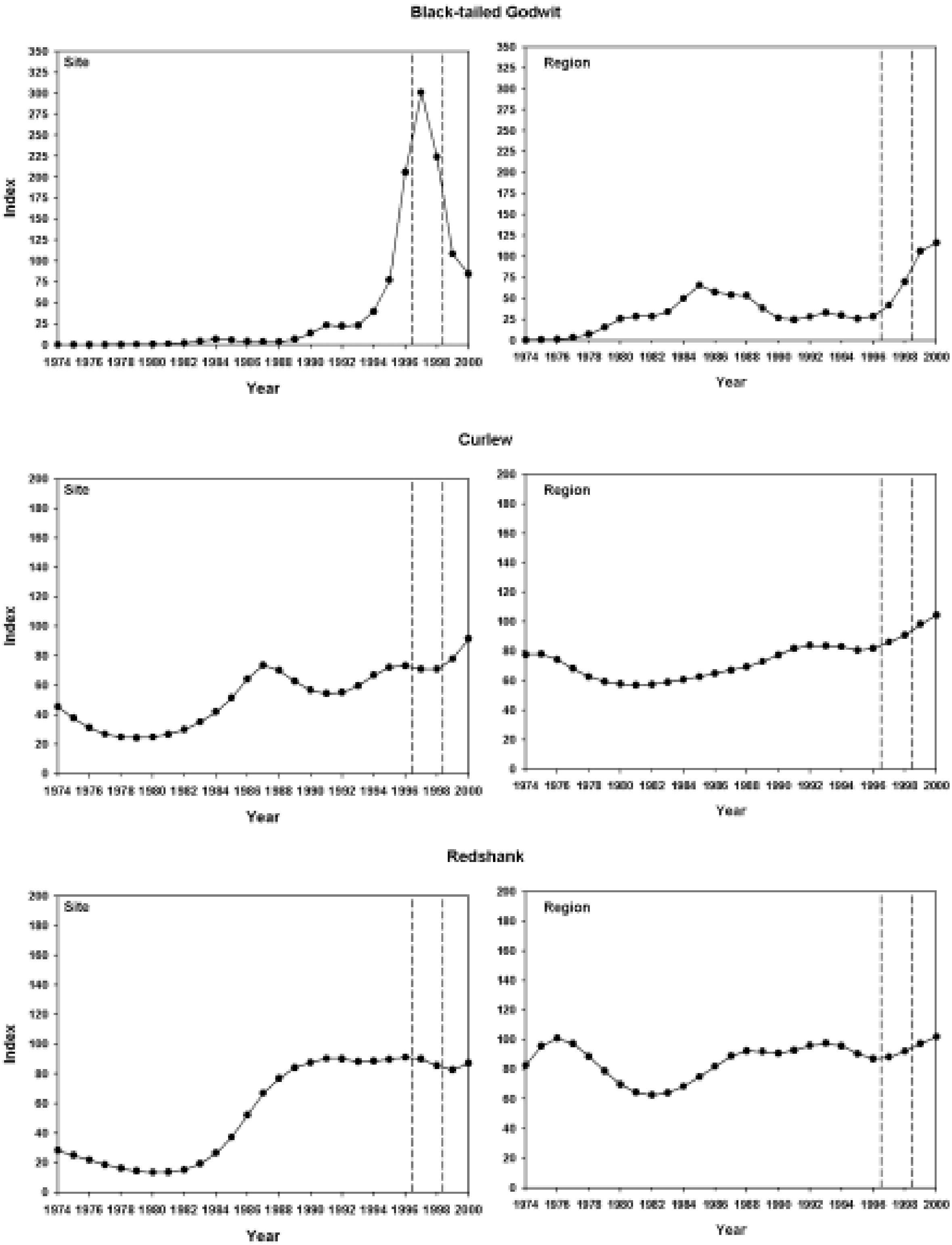

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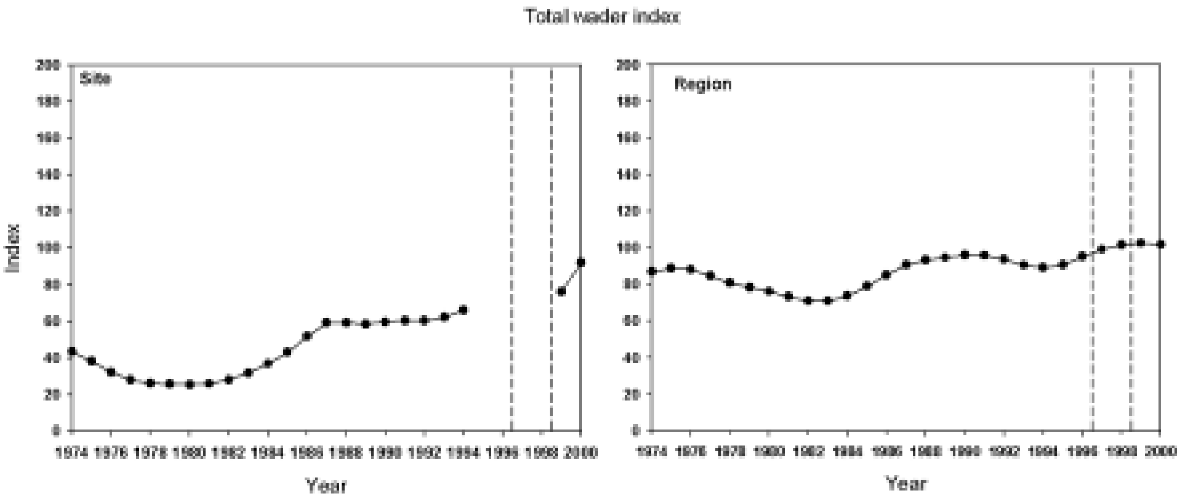

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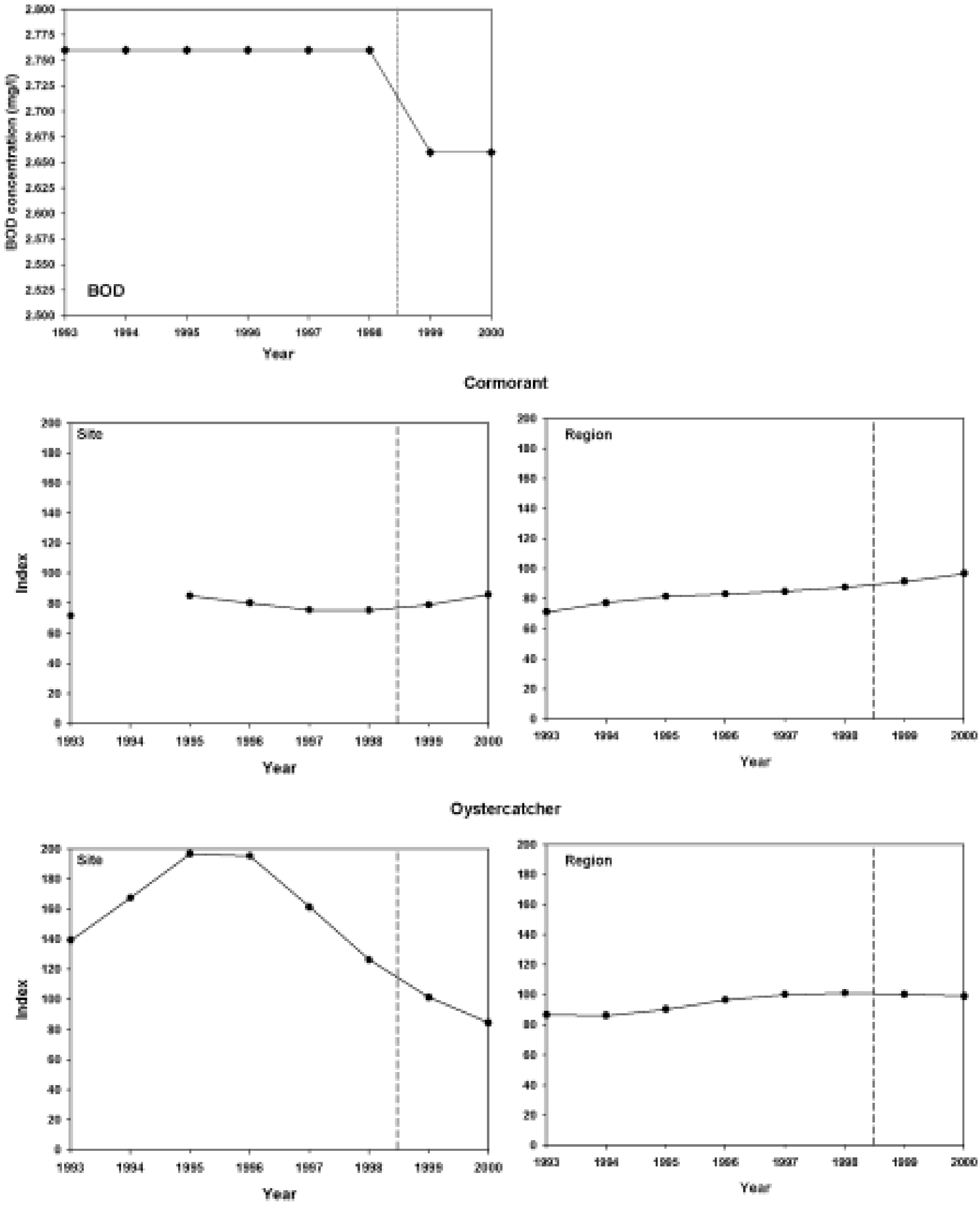
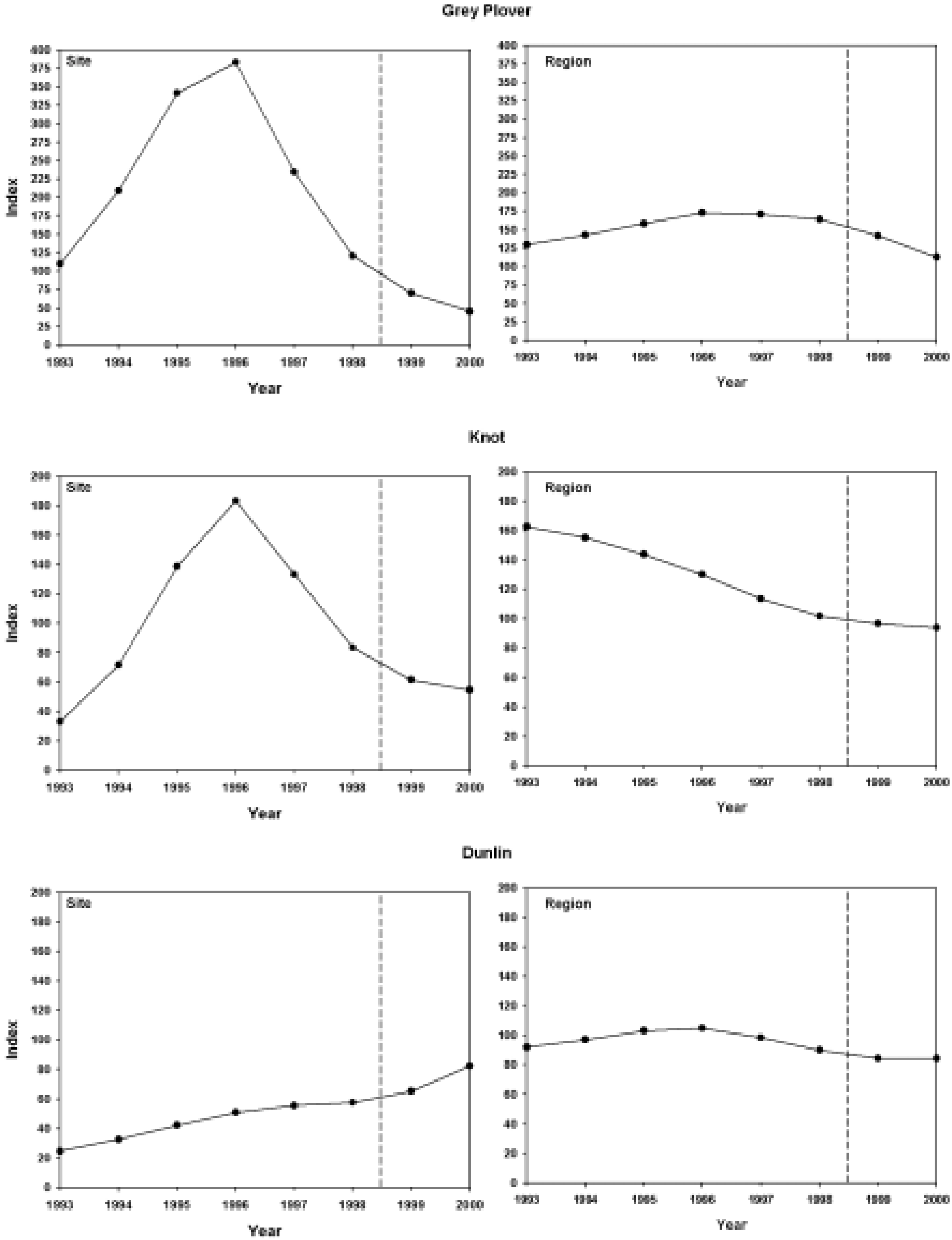


Figure 3.2.1.9 Smoothed waterbird indices derived from WeBS Core Count data for eight species at The Mersey Narrows and North Wirral Foreshore pSPA and variation in the overall BOD concentration (mg/l) on the site as estimated by box-modelling. The dotted line indicates the date of the improvement to waste water treatment. 1993 = the winter of 1993/94 etc.



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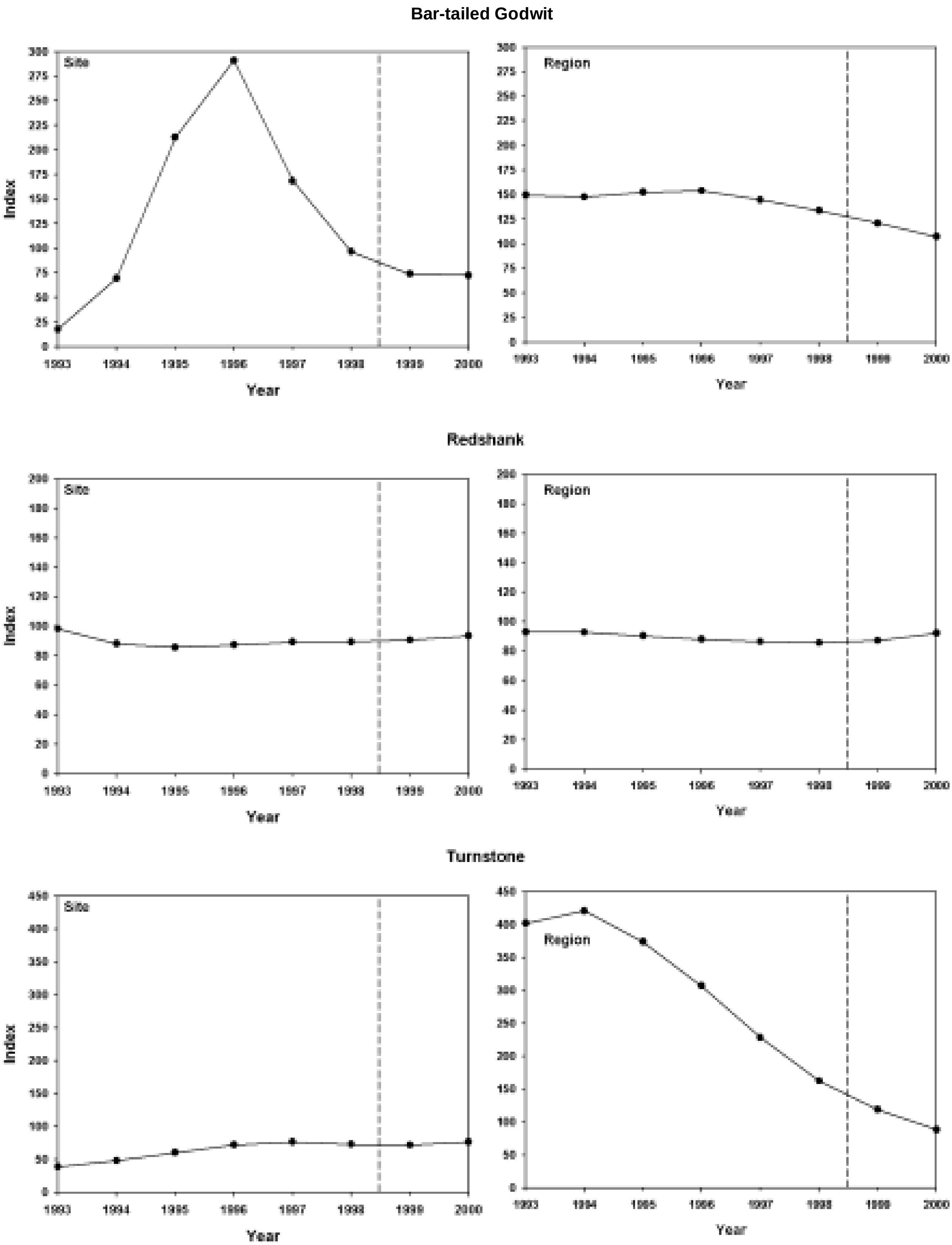

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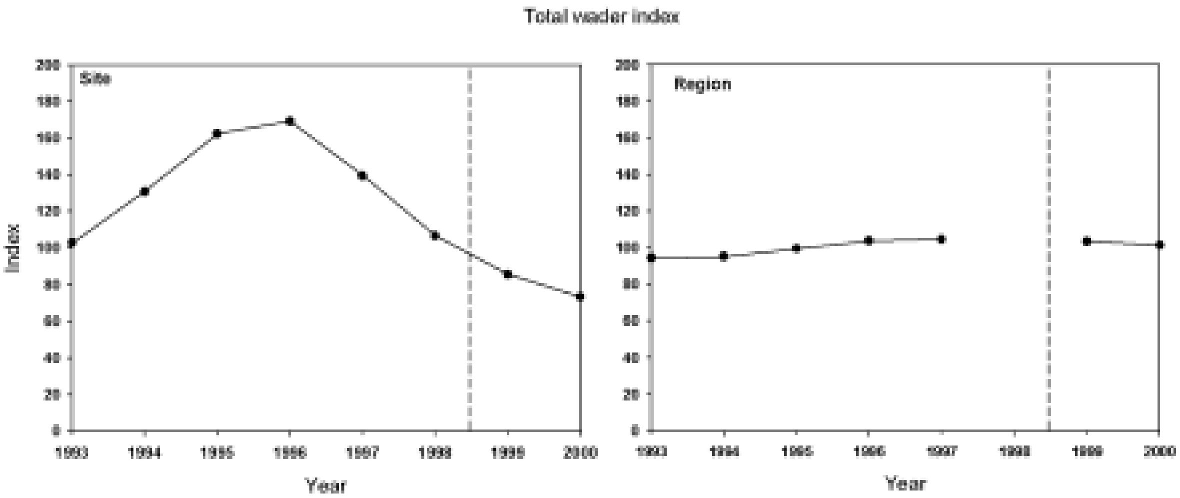

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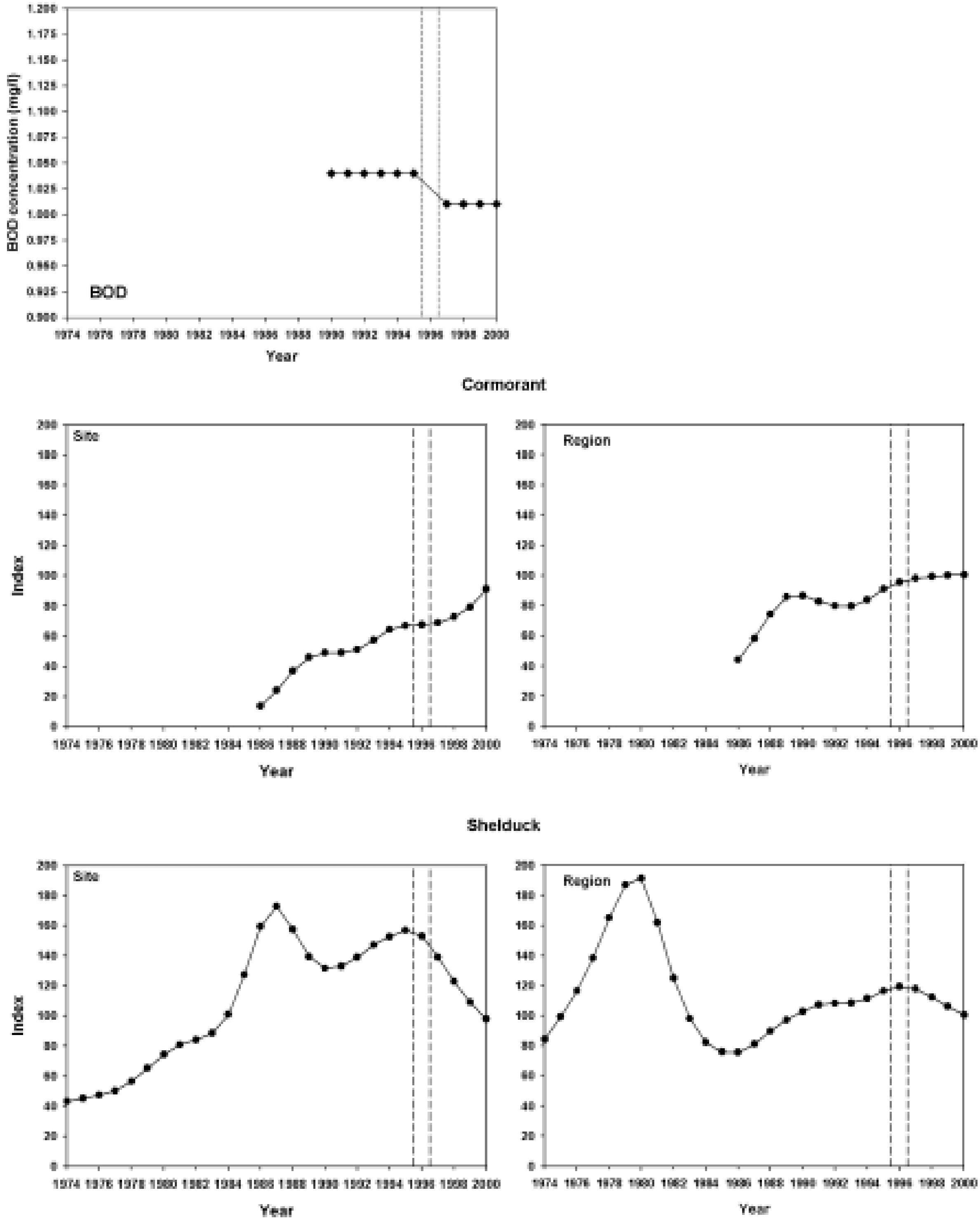
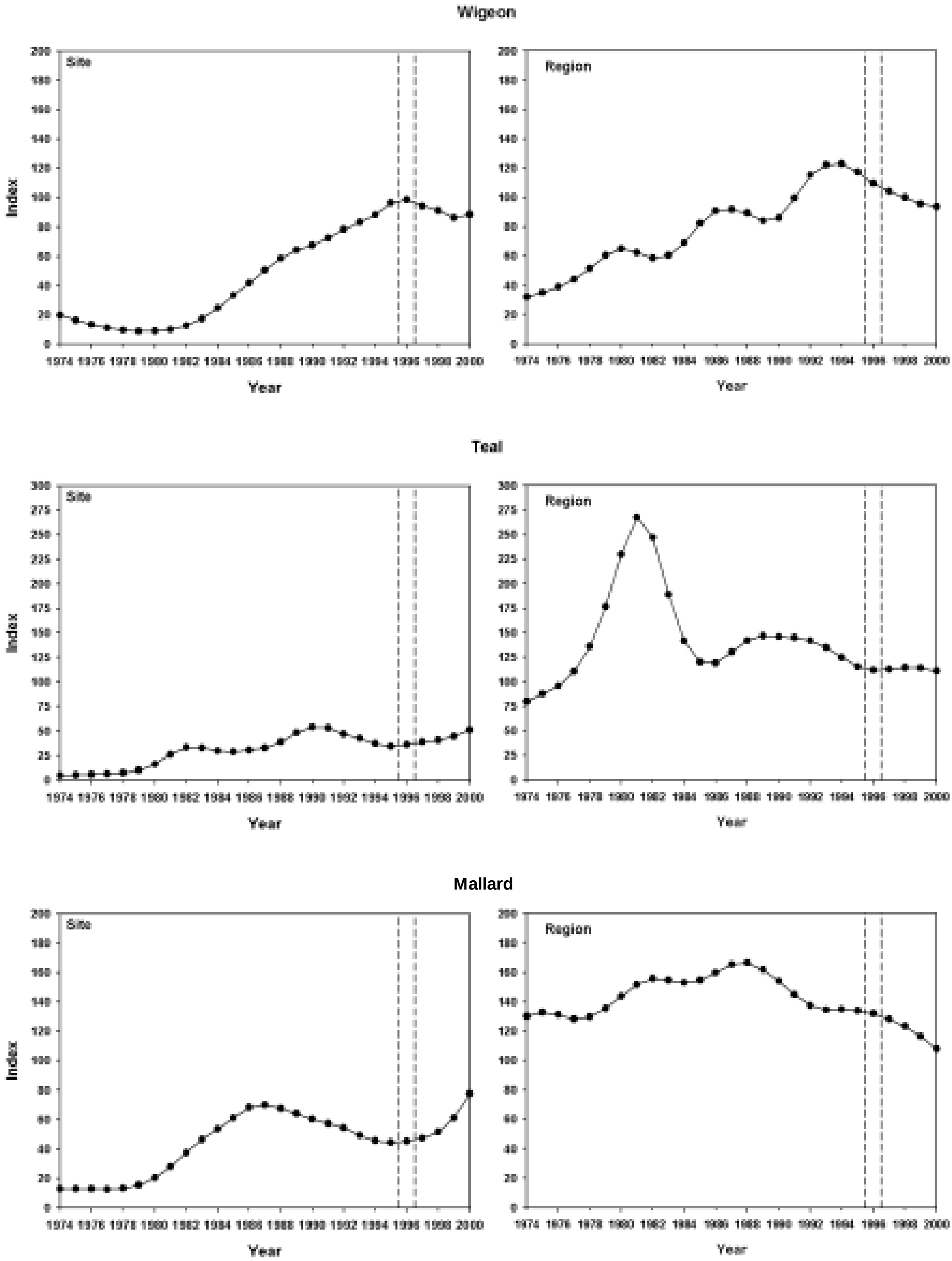


Figure 3.2.1.10 Smoothed waterbird indices derived from WeBS Core Count data for 17 species at The Ribble and Alt Estuaries SPA and variation in the overall BOD concentration (mg/l) on the site as estimated by box-modelling. The dotted lines indicate the first and last years of improvements to waste water treatment. 1974 = the winter of 1974/75 etc.



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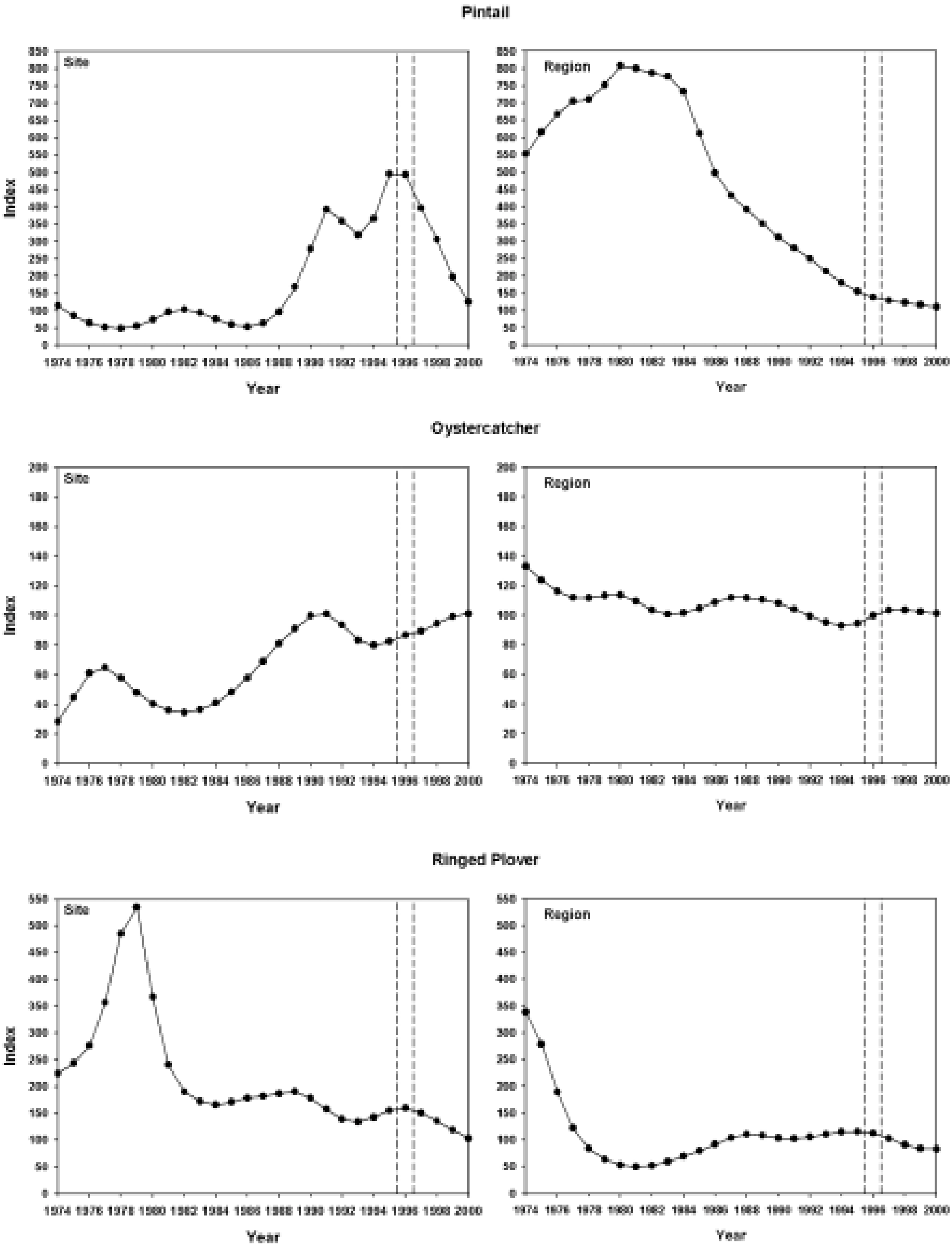

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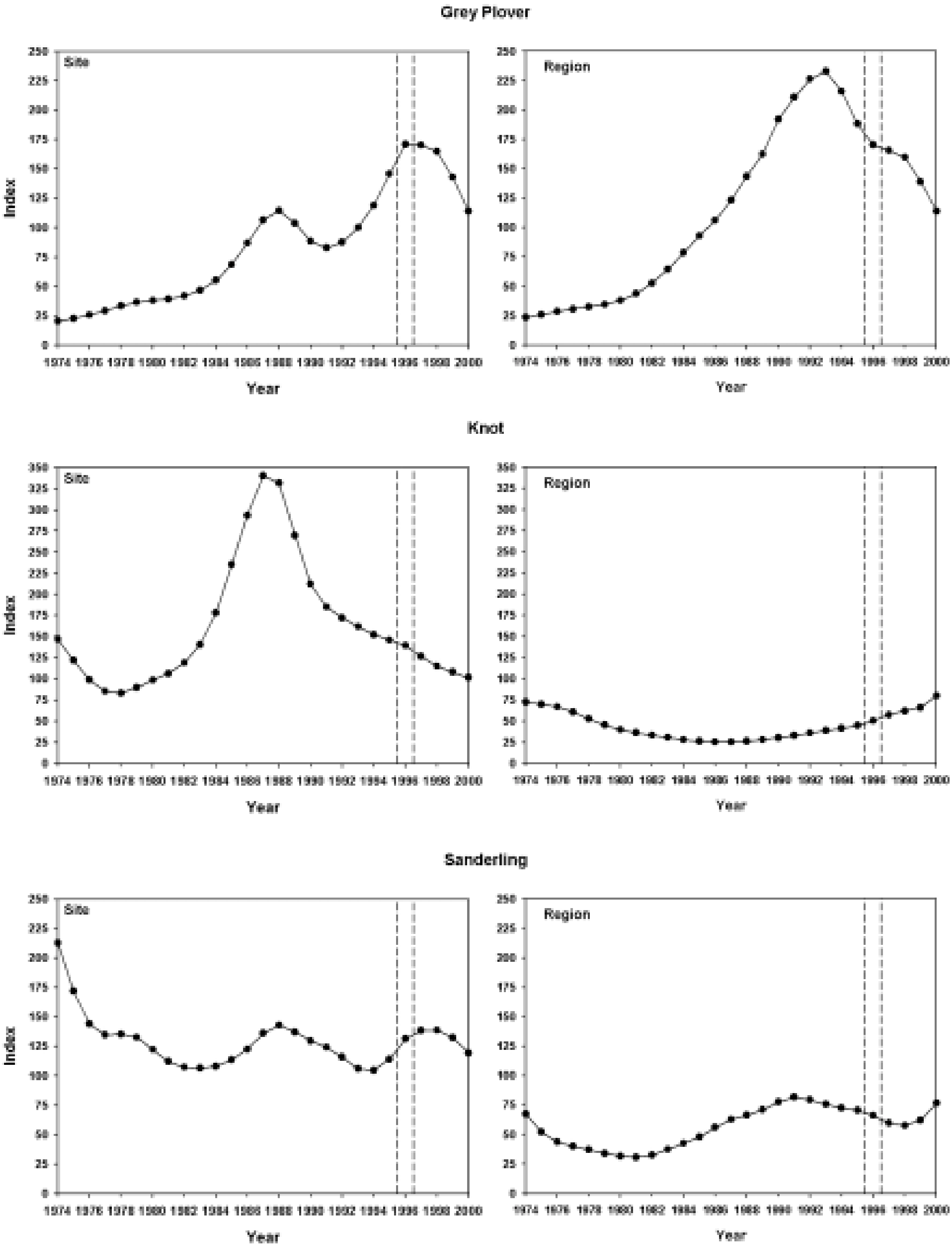

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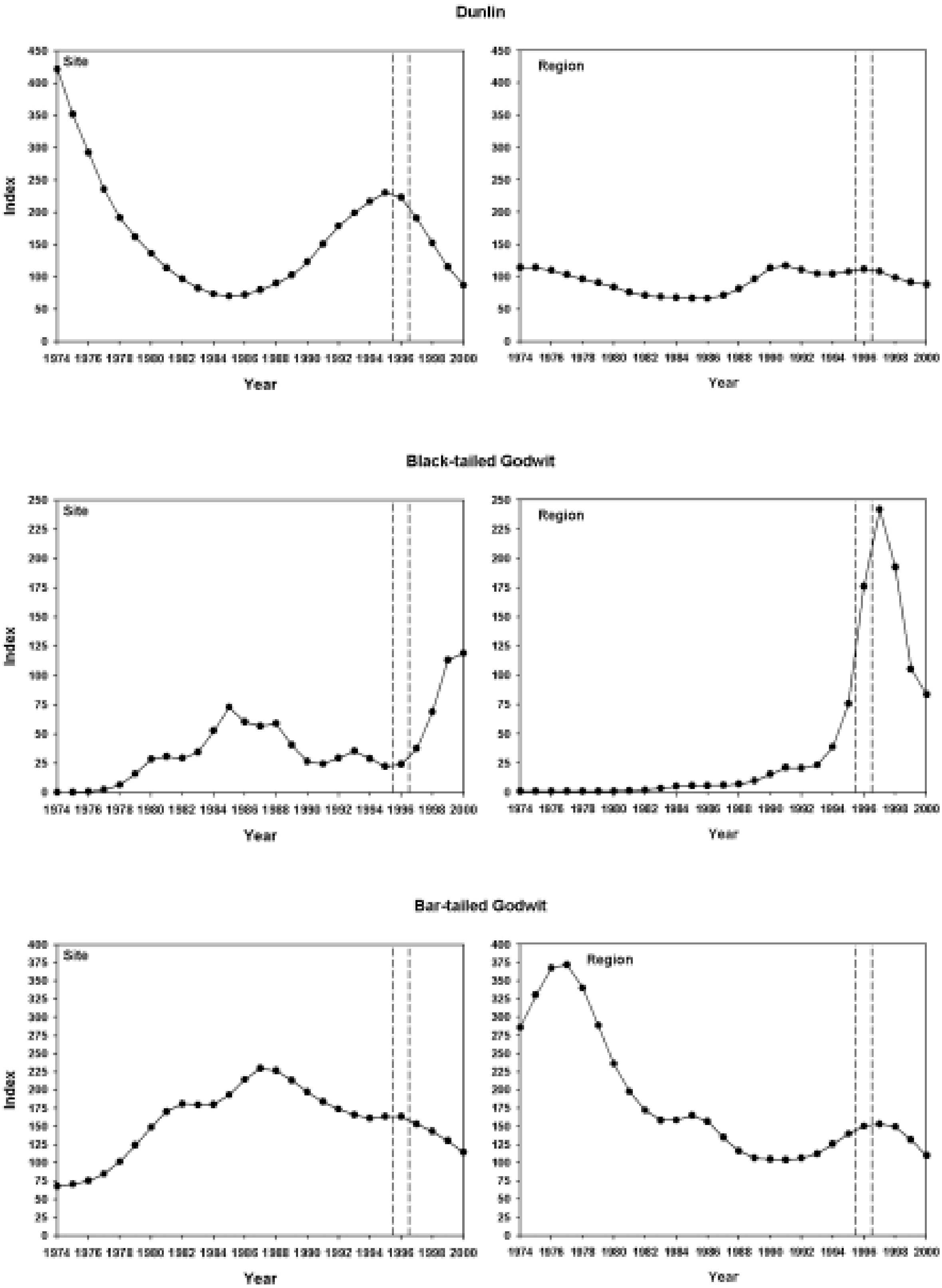

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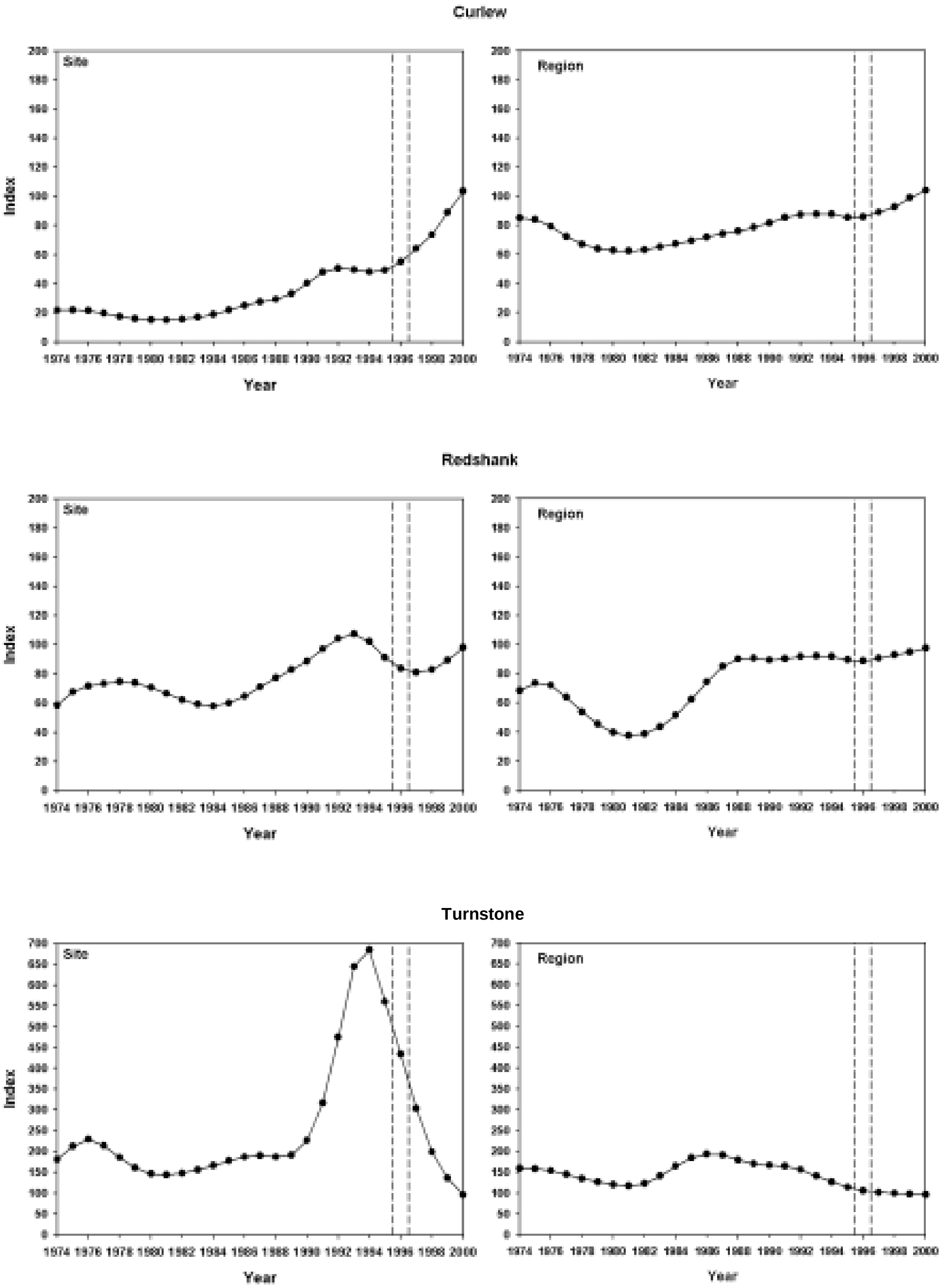

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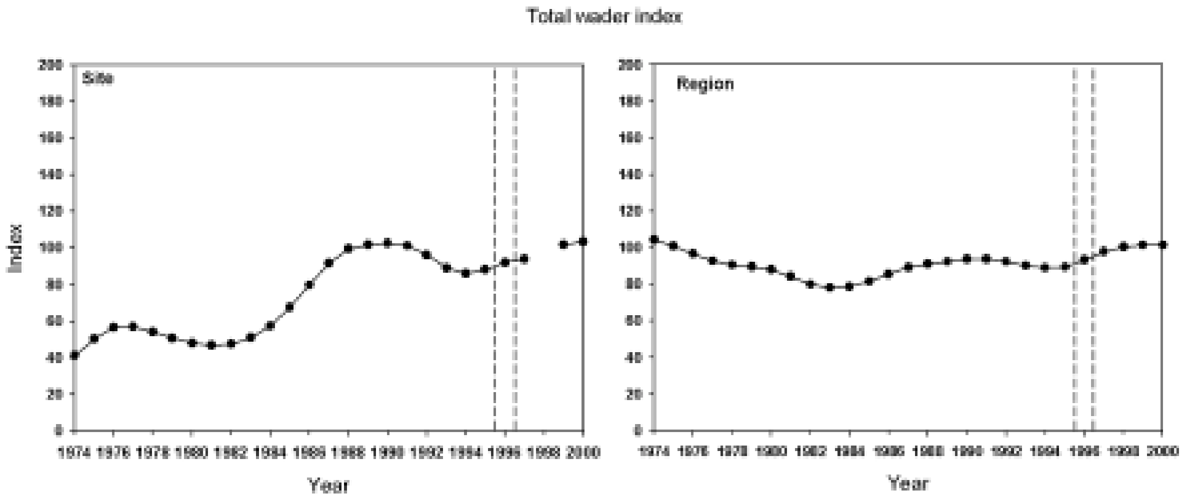

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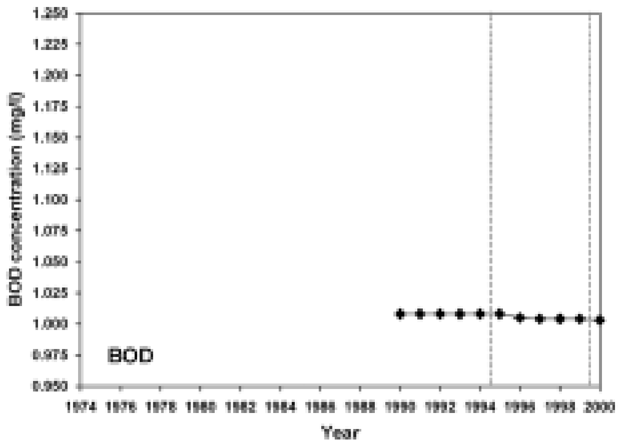
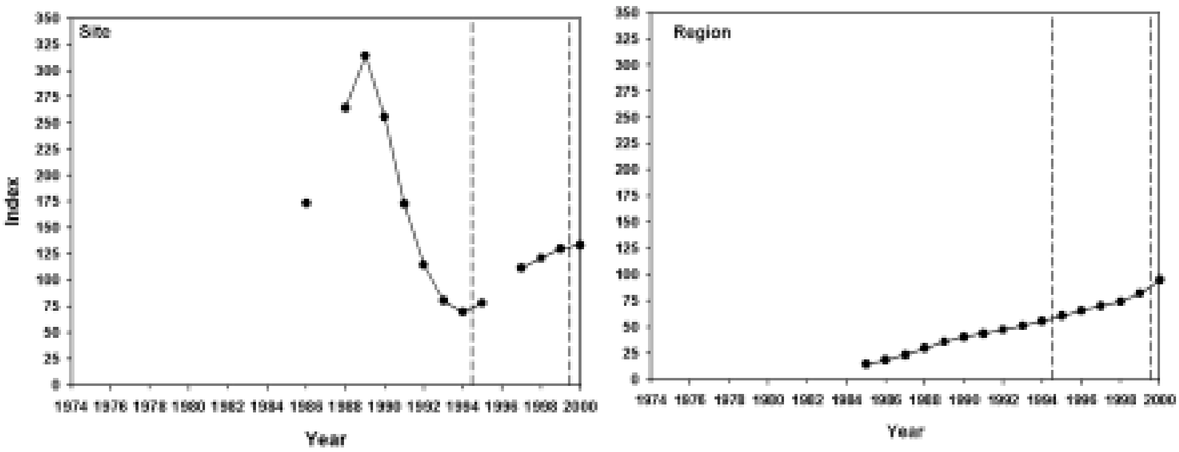


Little Grebe



Great Crested Grebe

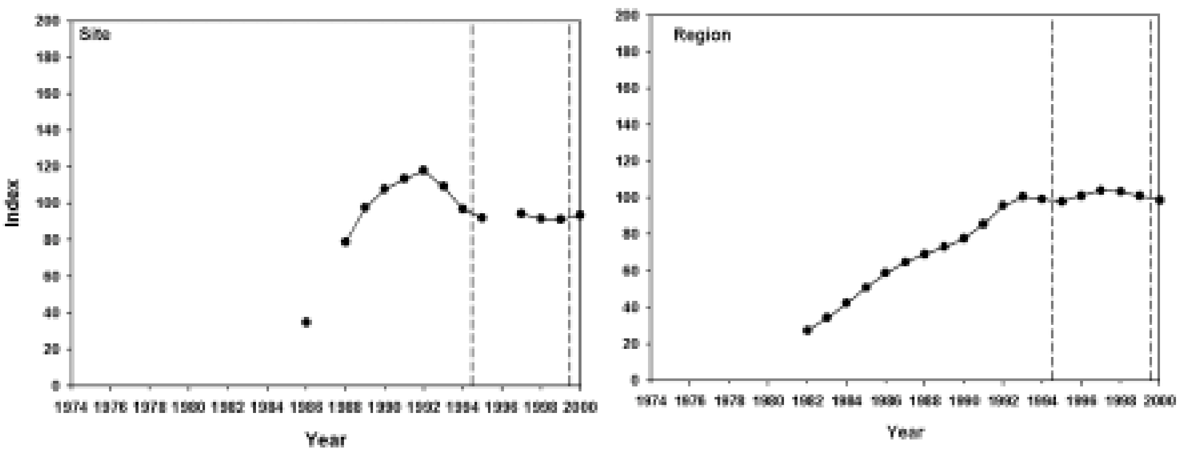
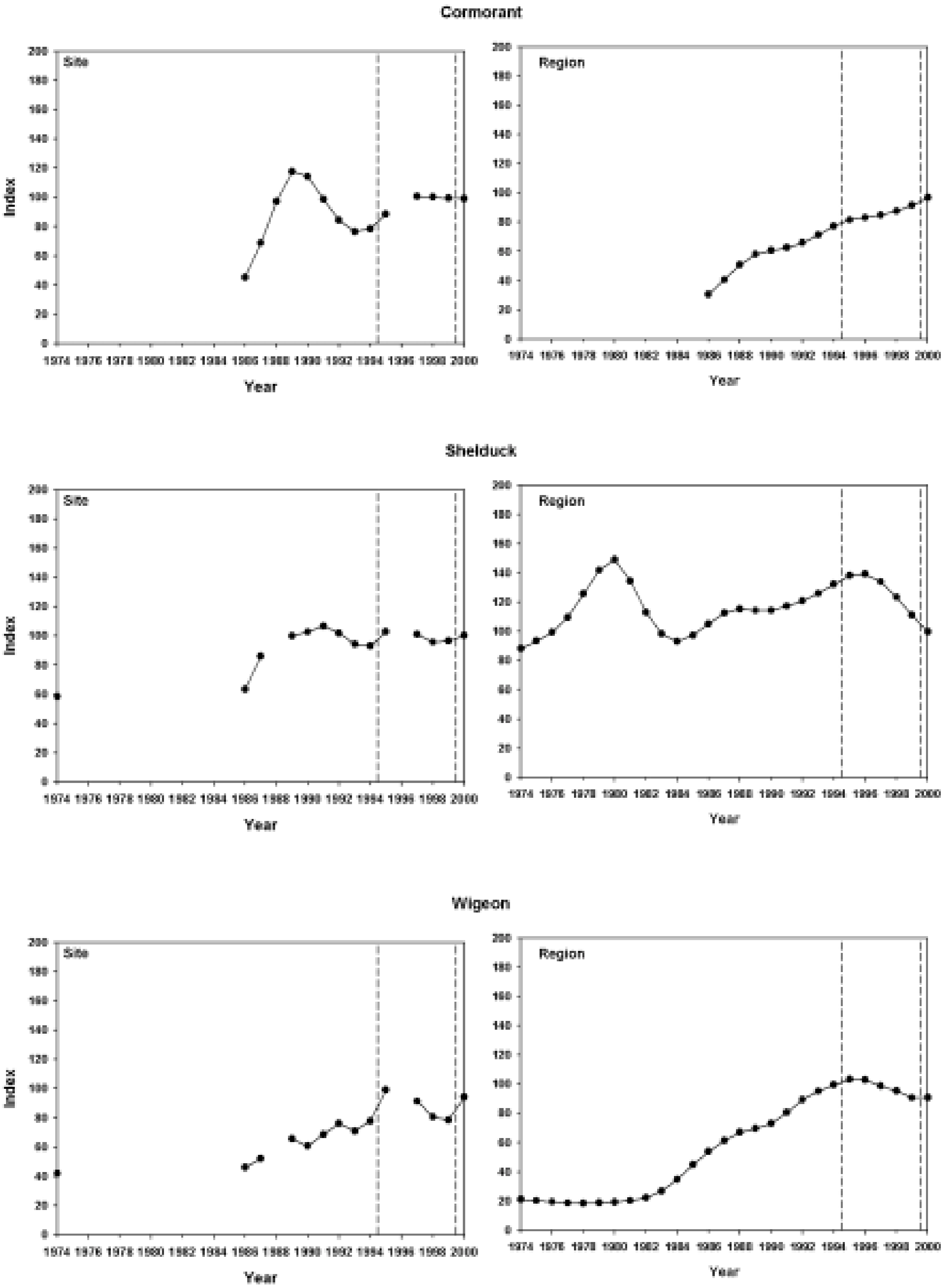


Figure 3.2.1.11 Smoothed waterbird indices derived from WeBS Core Count data for 22 species at The Morecambe Bay SPA and variation in the overall BOD concentration (mg/l) on the site as estimated by box-modelling. The dotted lines indicate the first and last years of improvements to waste water treatment. 1974 = the winter of 1974/75 etc.



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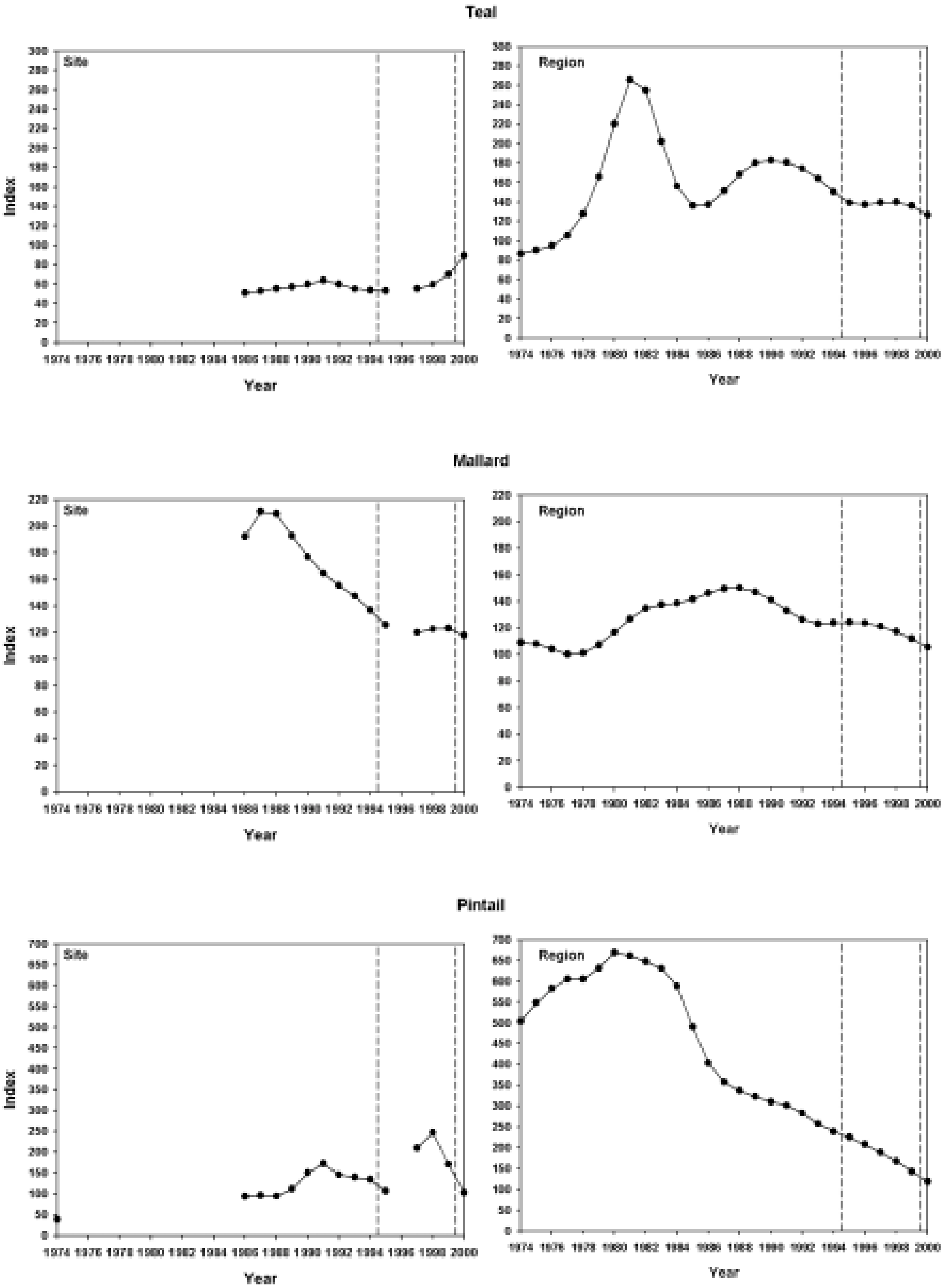

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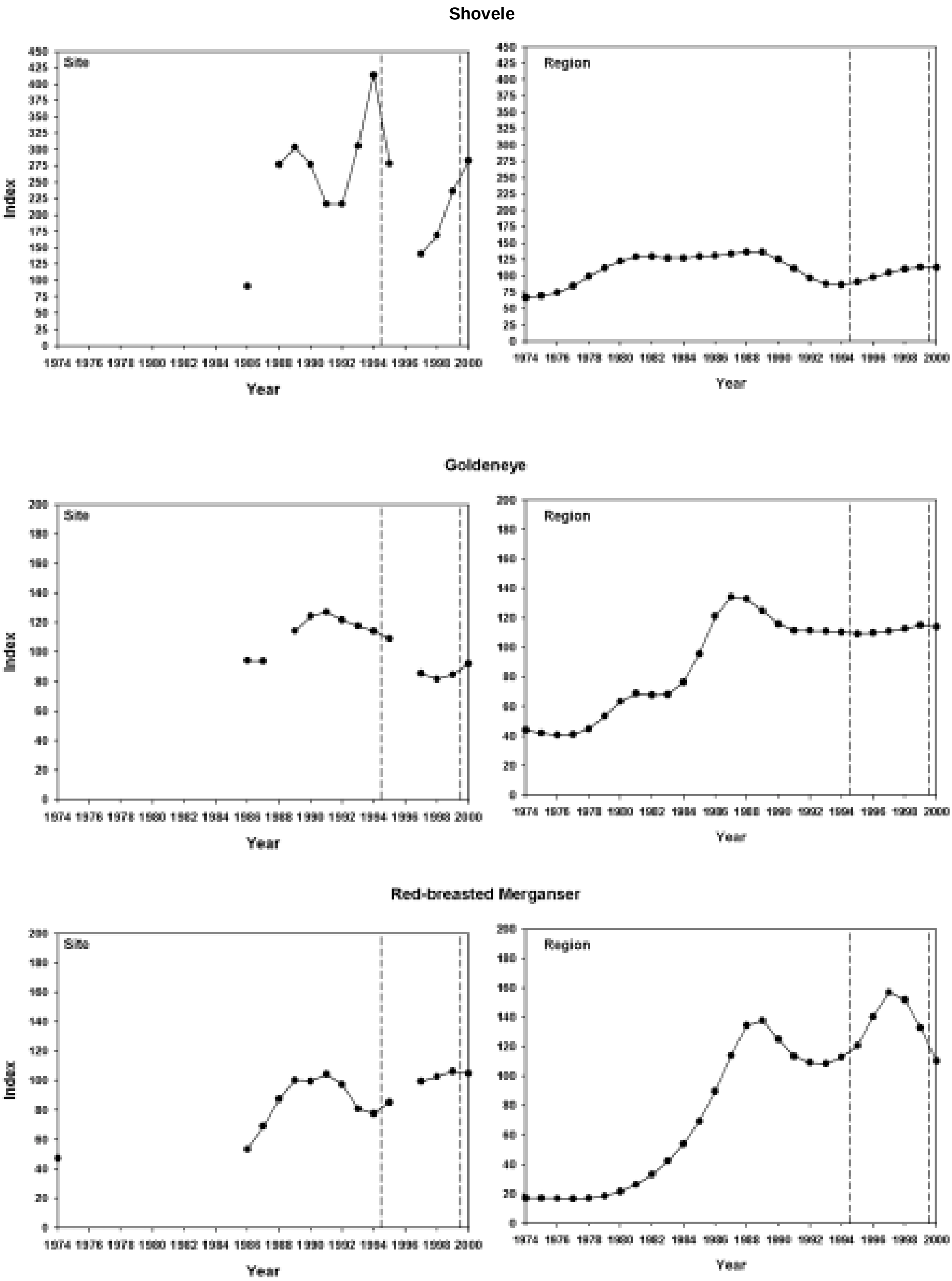

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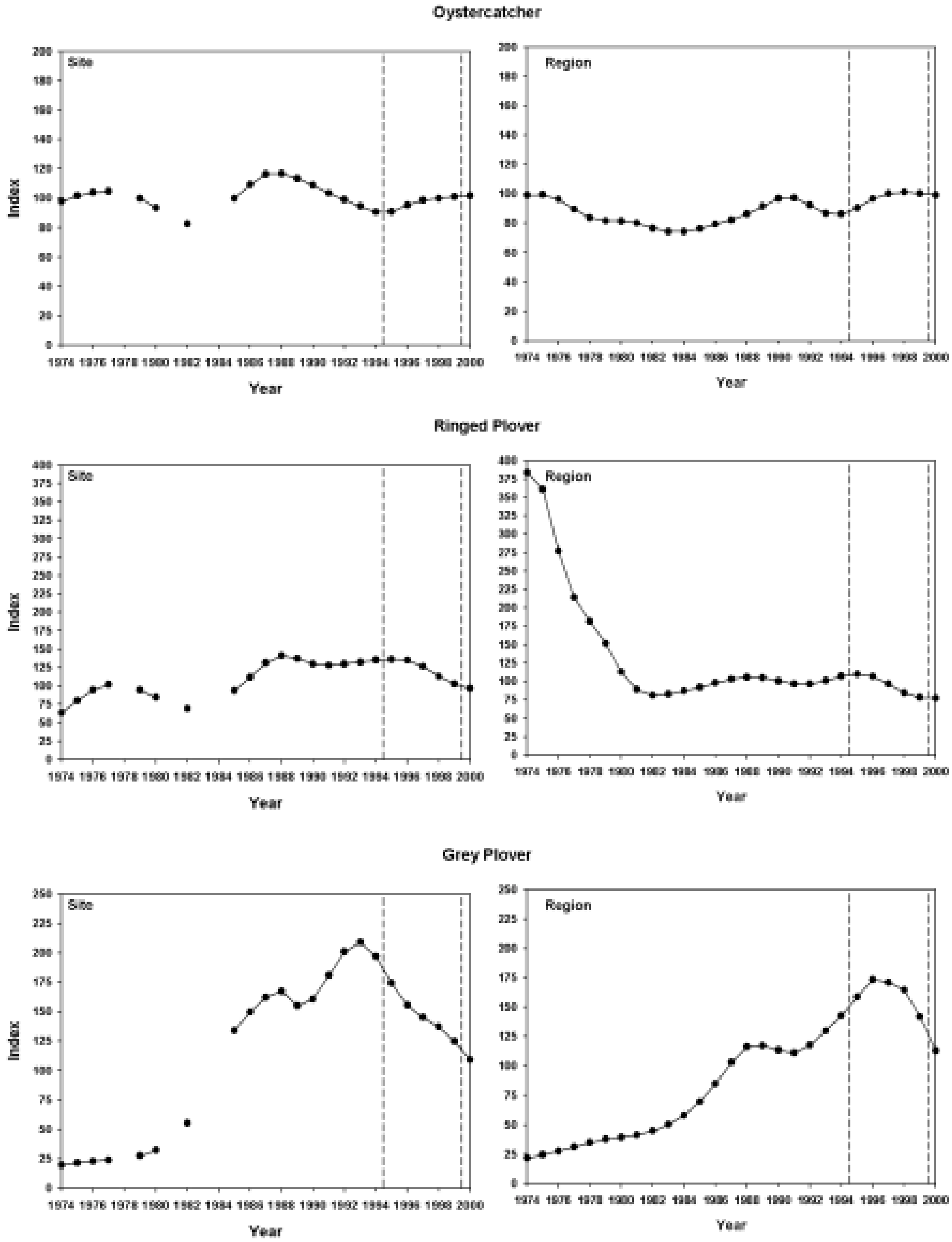

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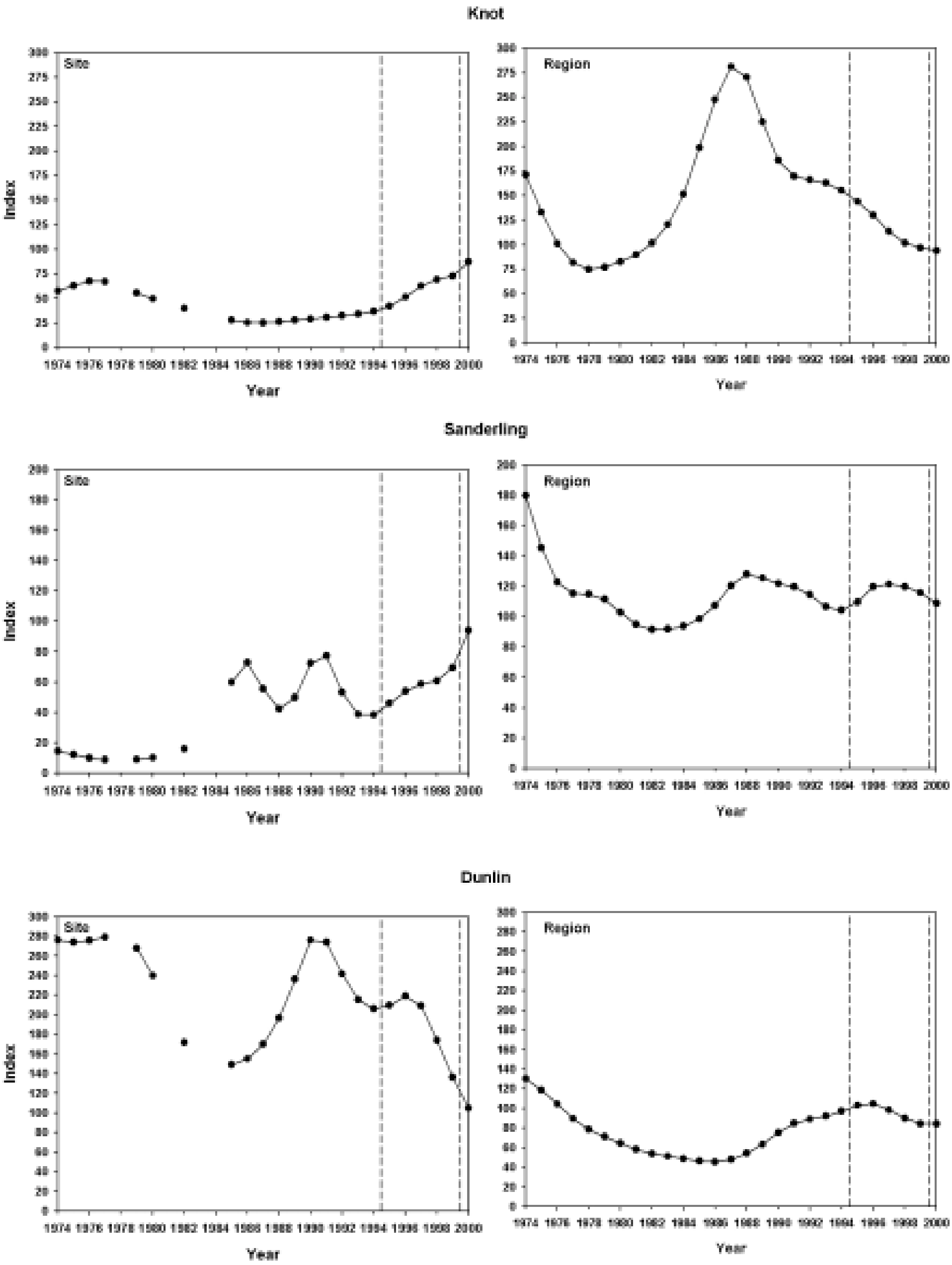

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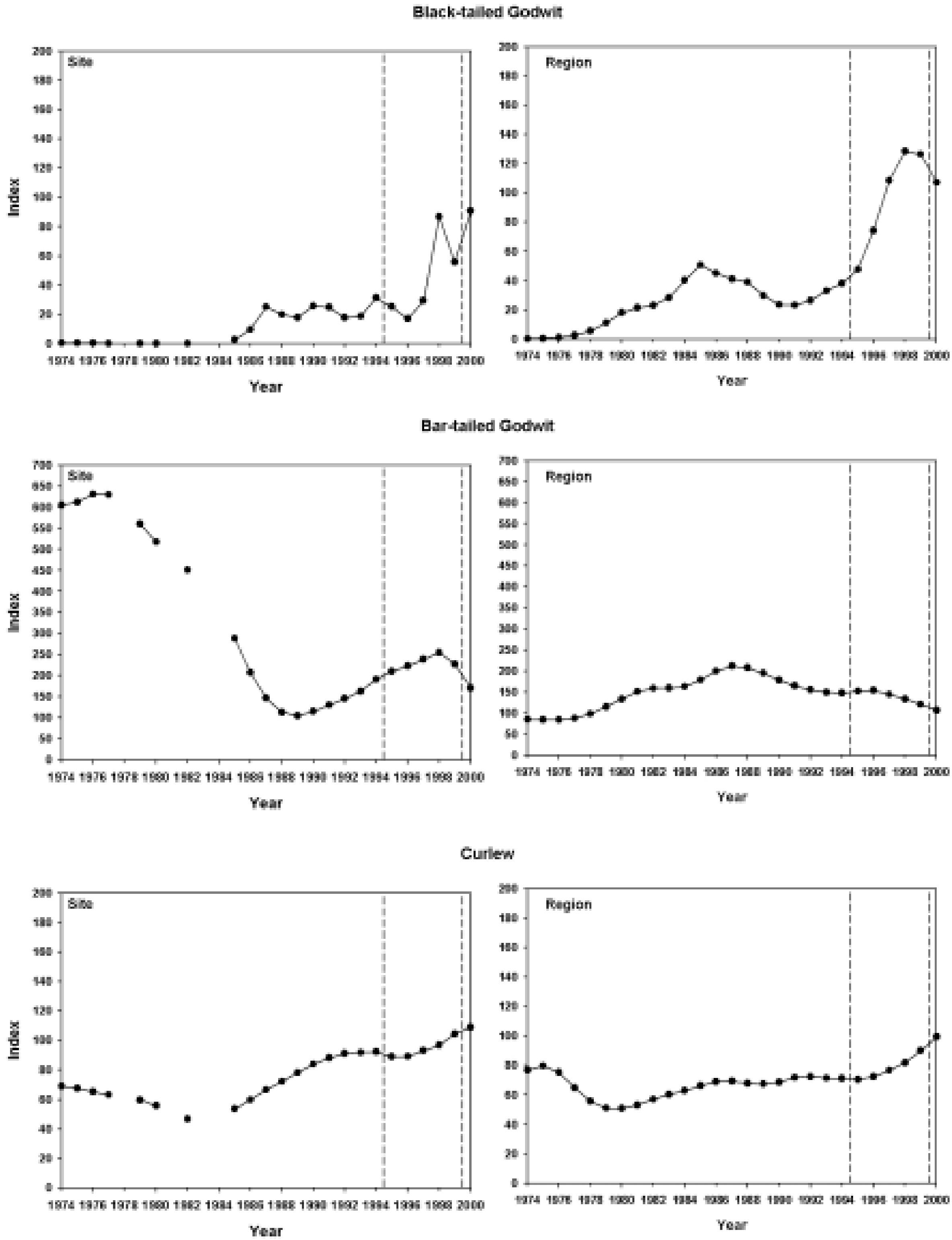

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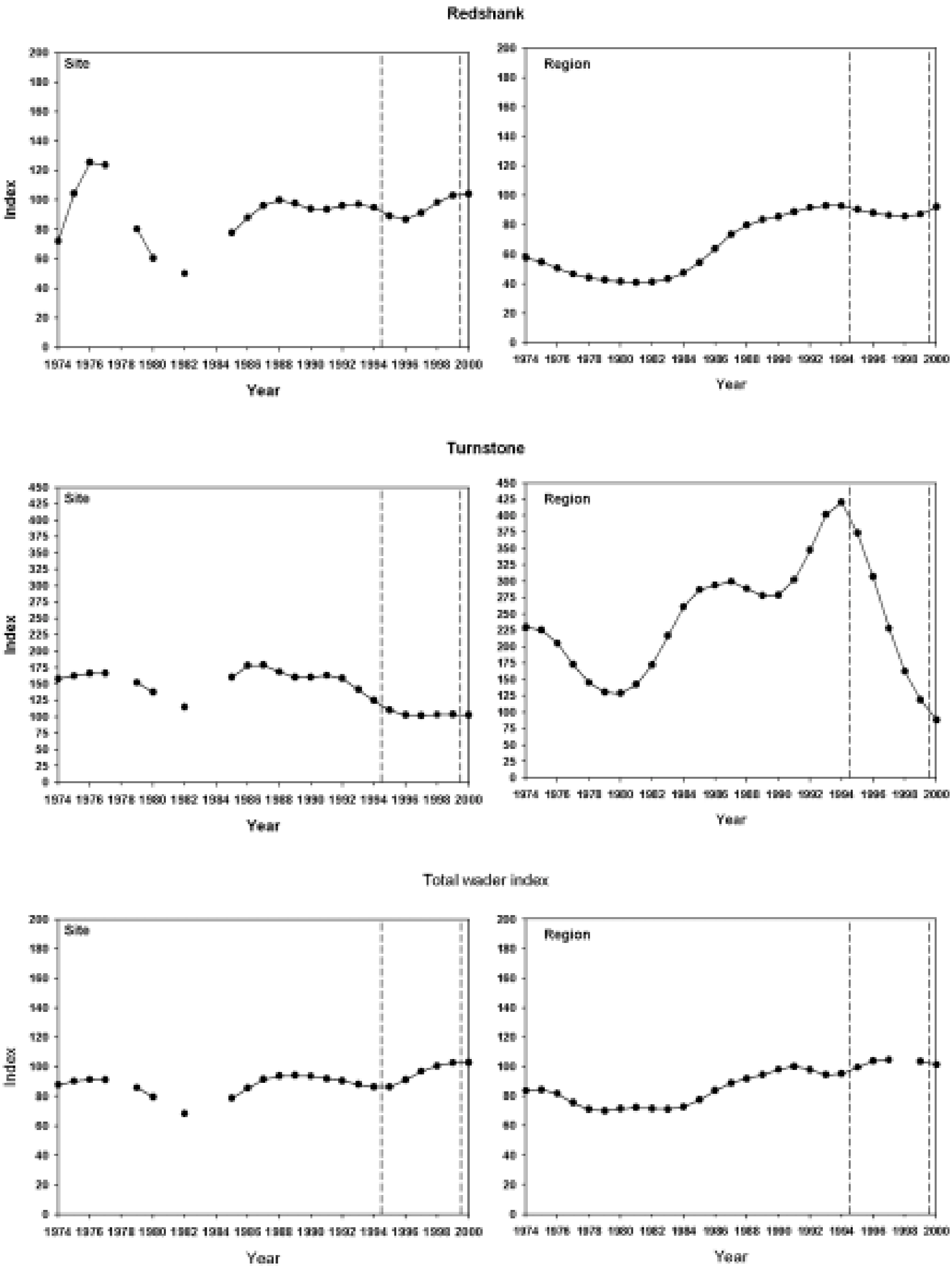

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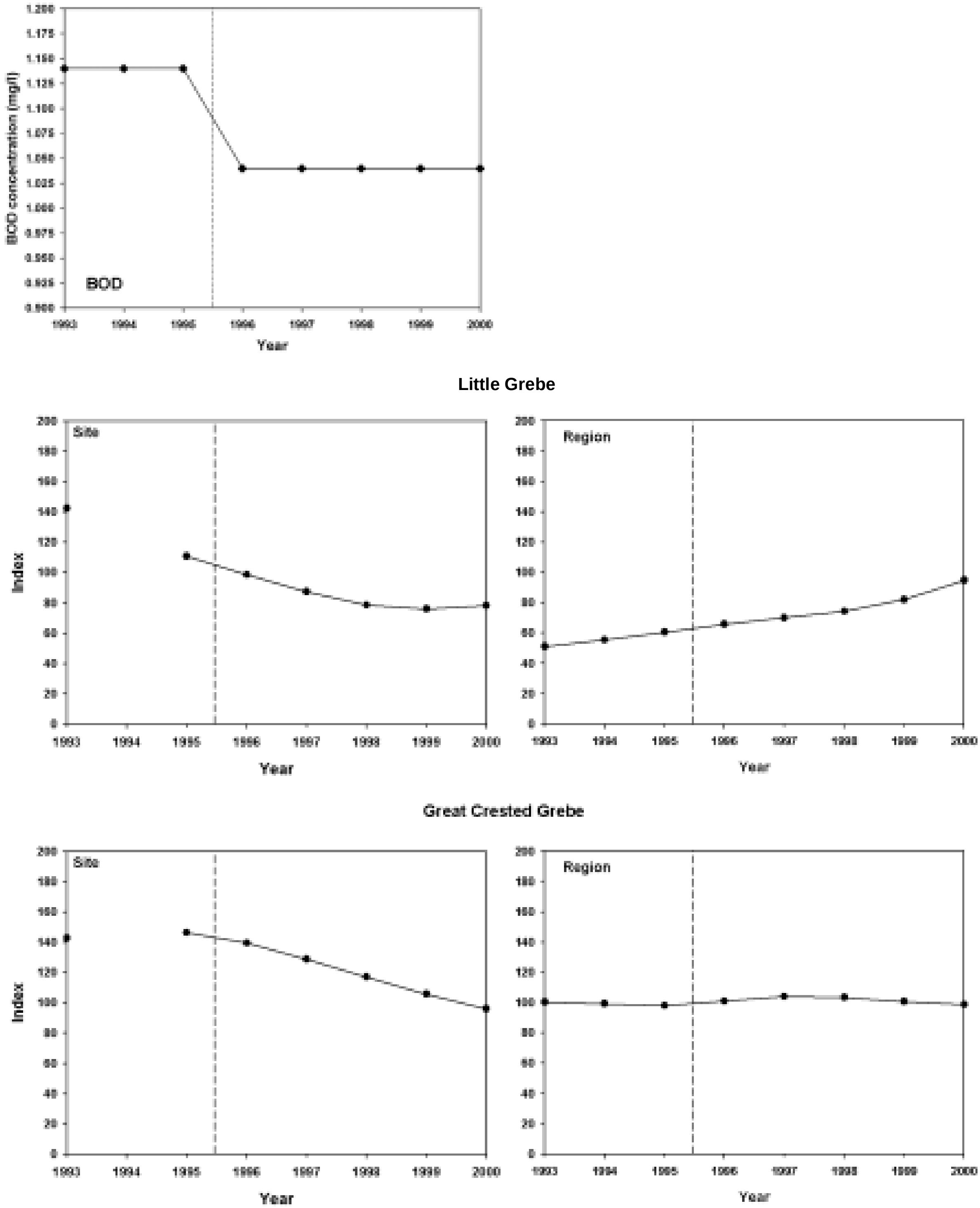
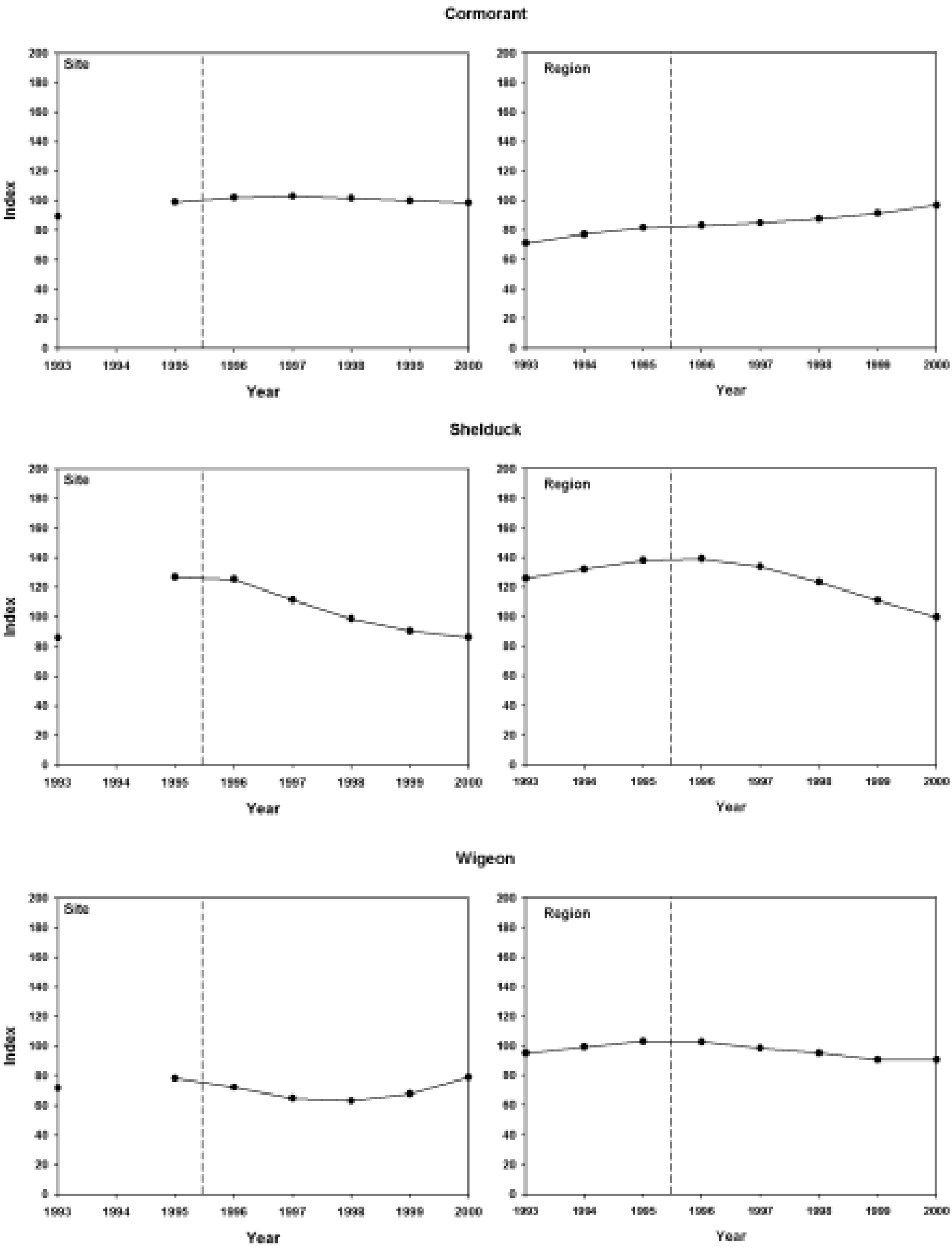


Figure 3.2.1.12 Smoothed waterbird indices derived from WeBS Core Count data for 22 species at Barrow-in-Furness and variation in the overall BOD concentration (mg/l) on the site as estimated by box-modelling. The dotted line indicates the date of the improvement to waste water treatment. 1993 = the winter of 1993/94 etc.



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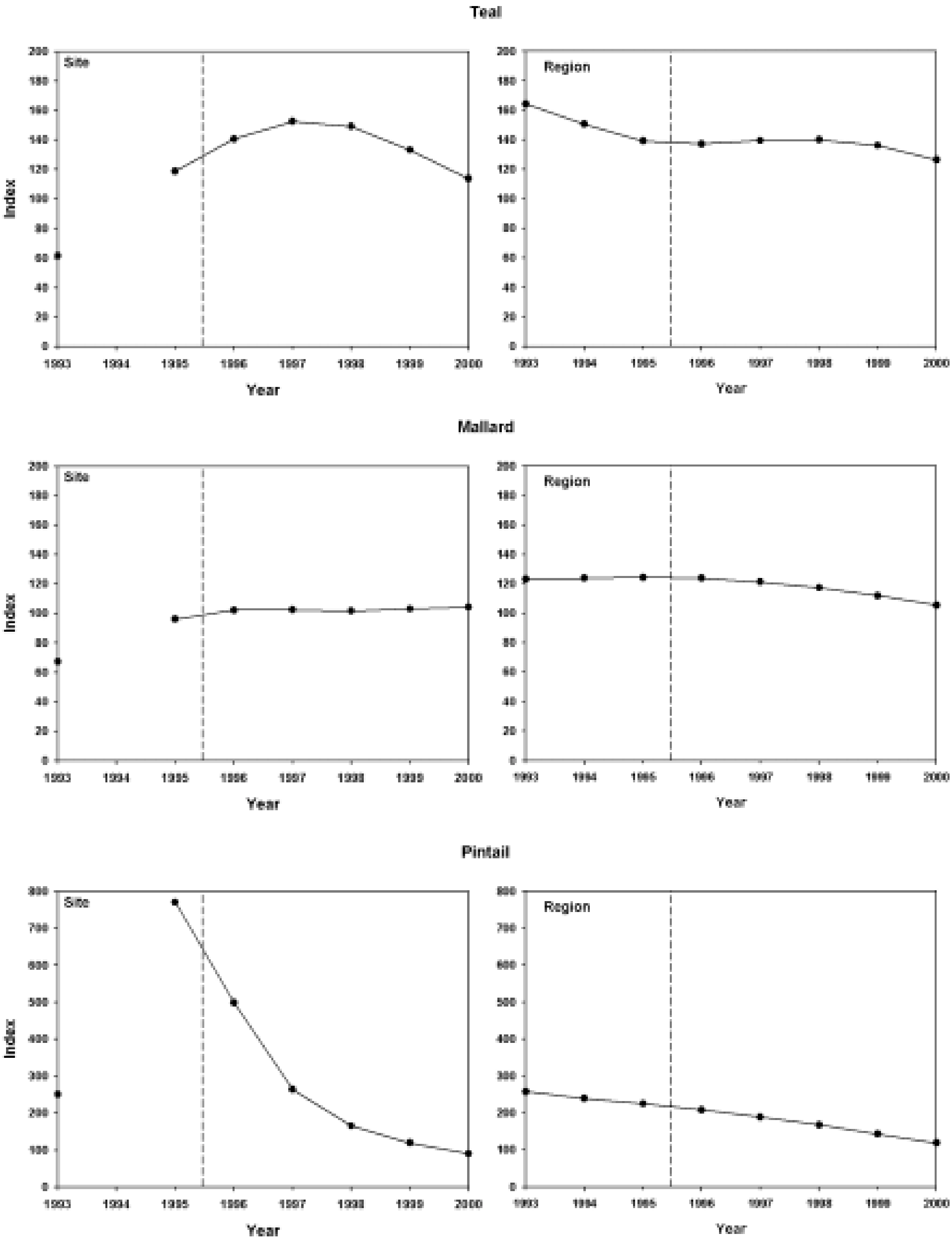

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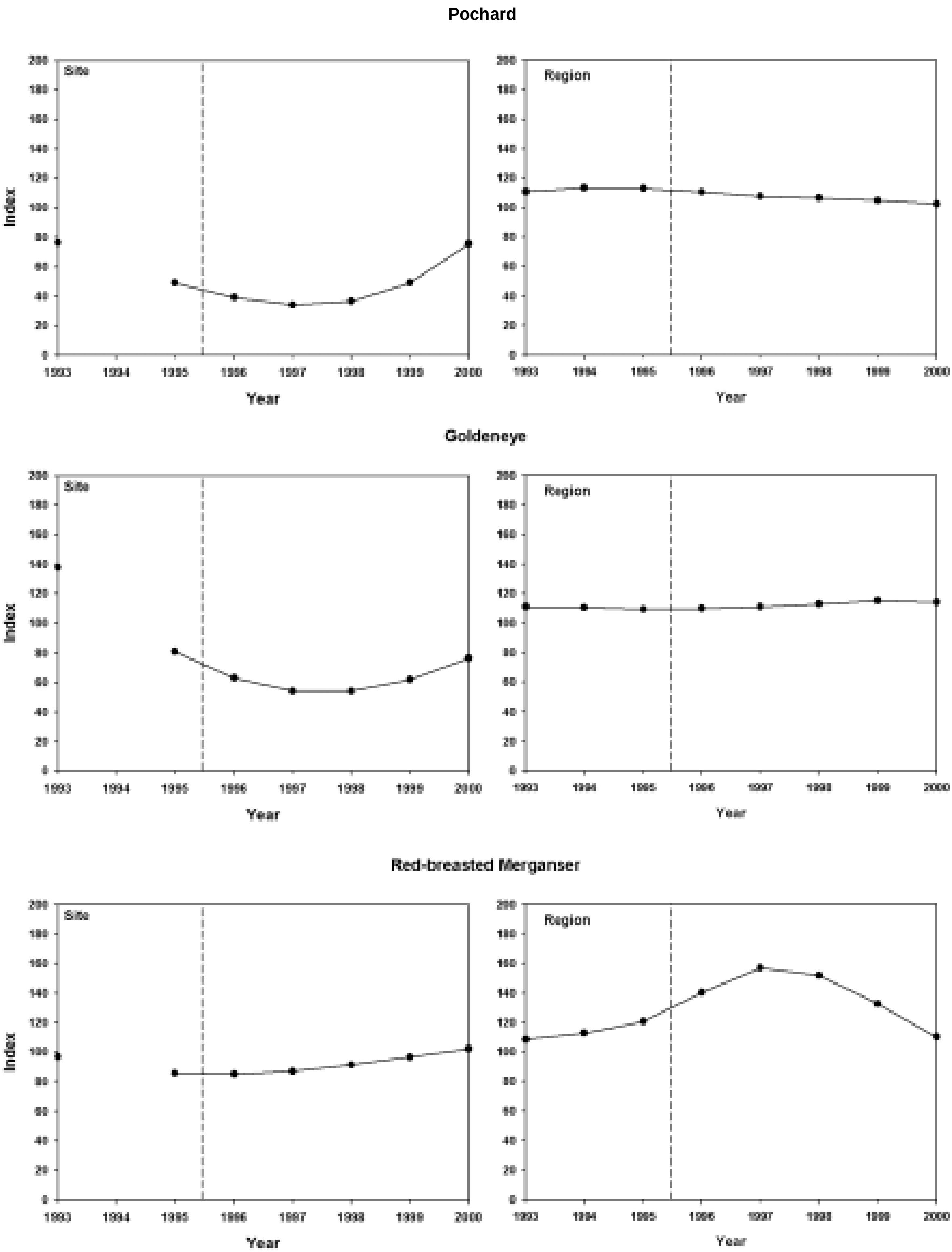

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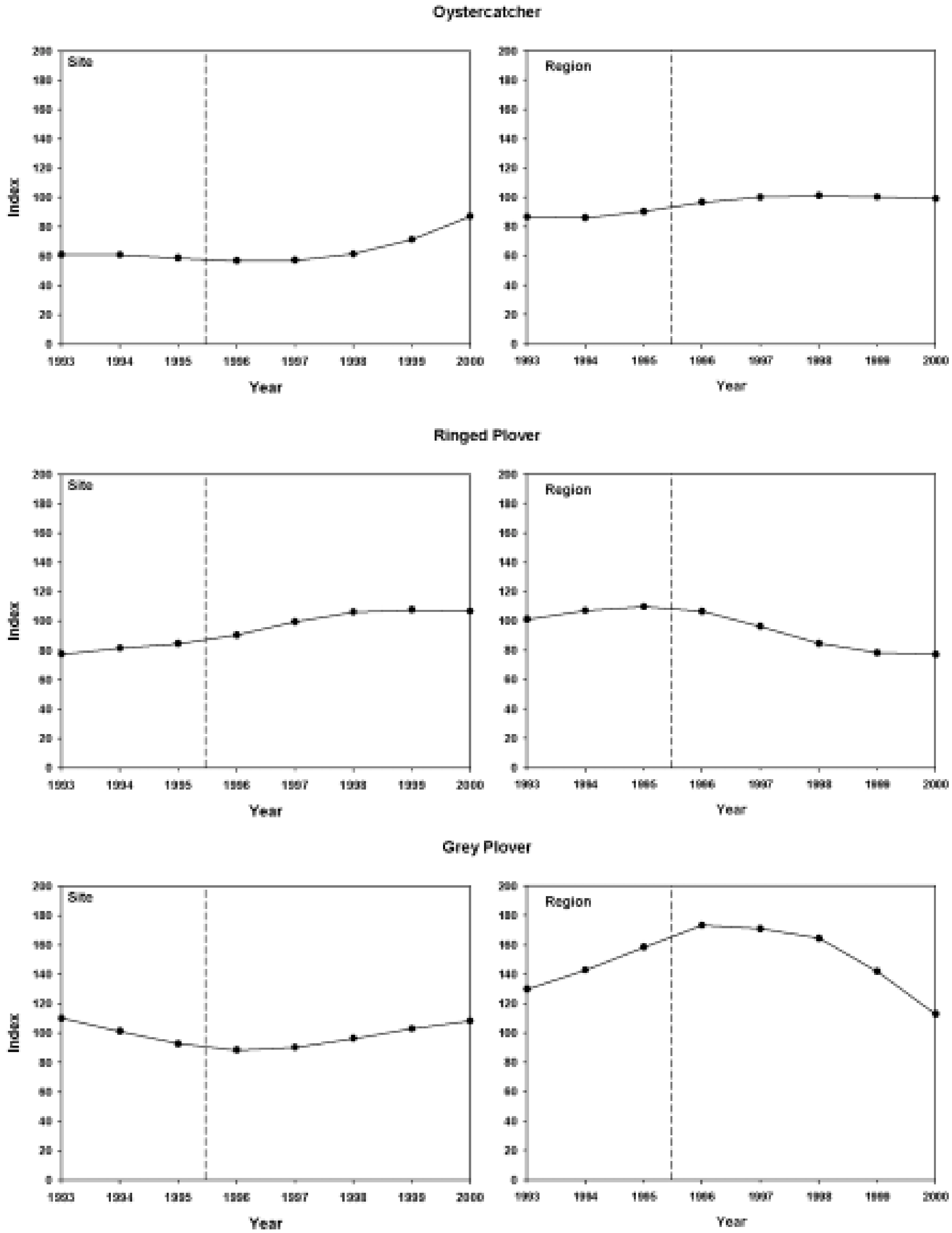

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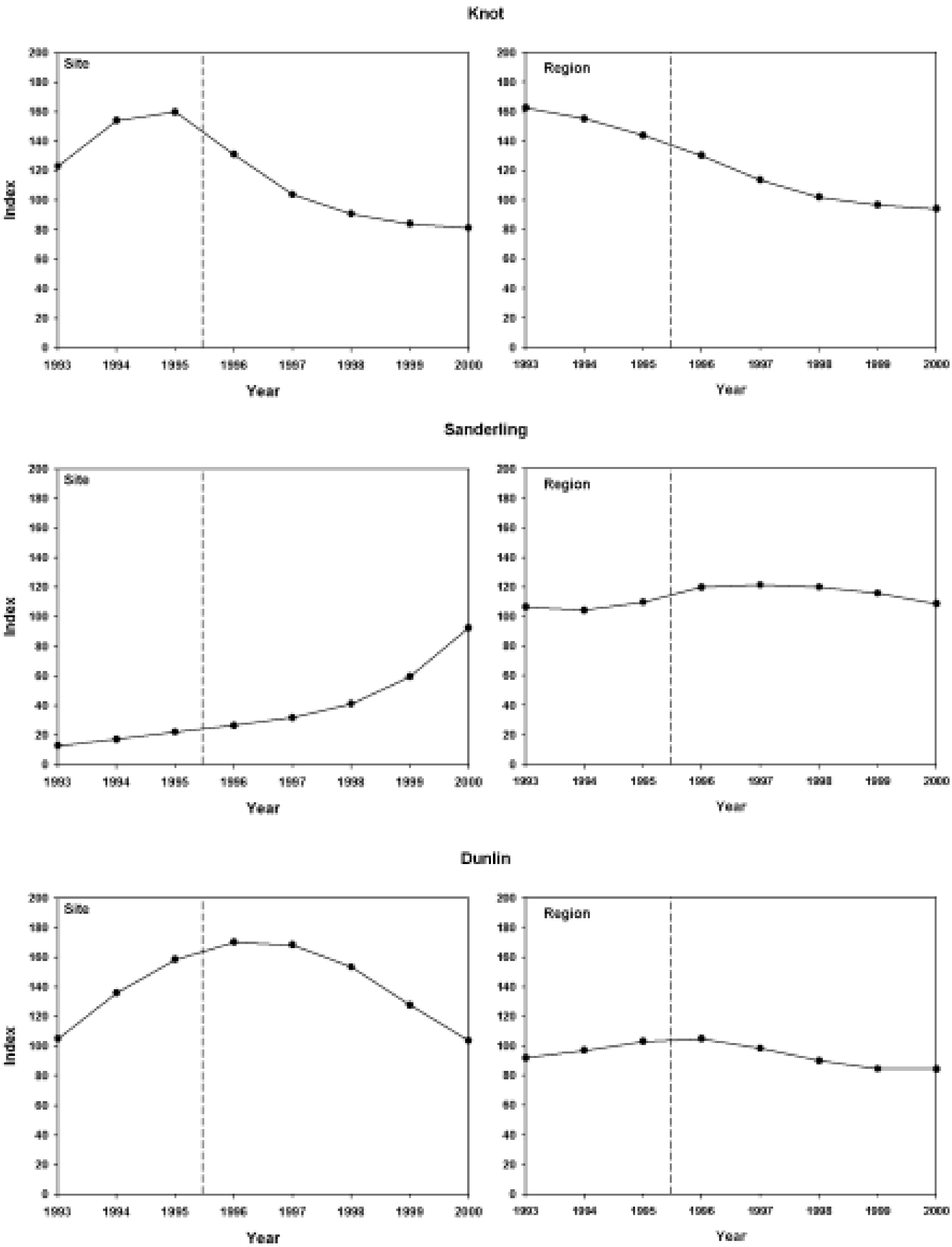

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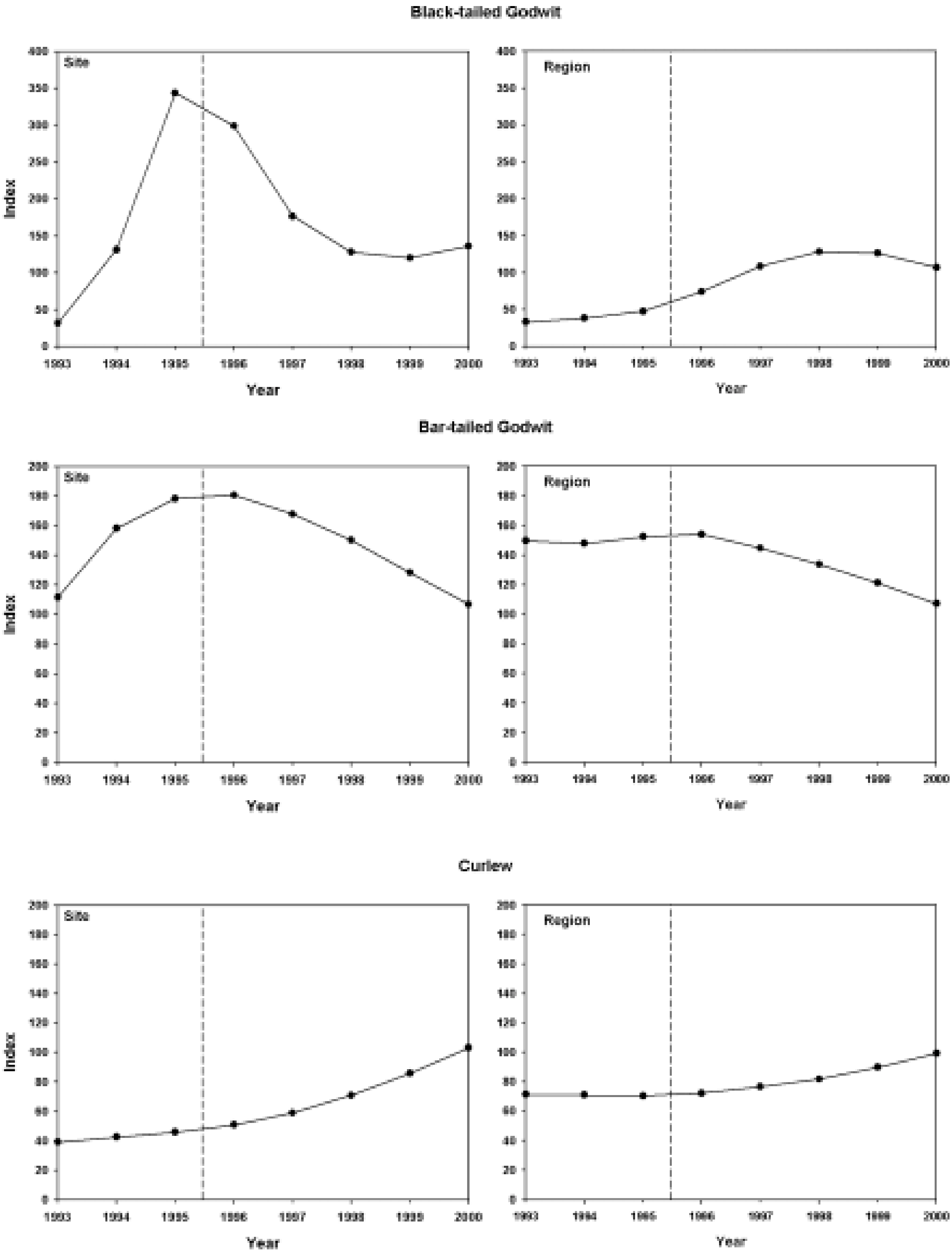

Figure 3.2.1.12 Continued.

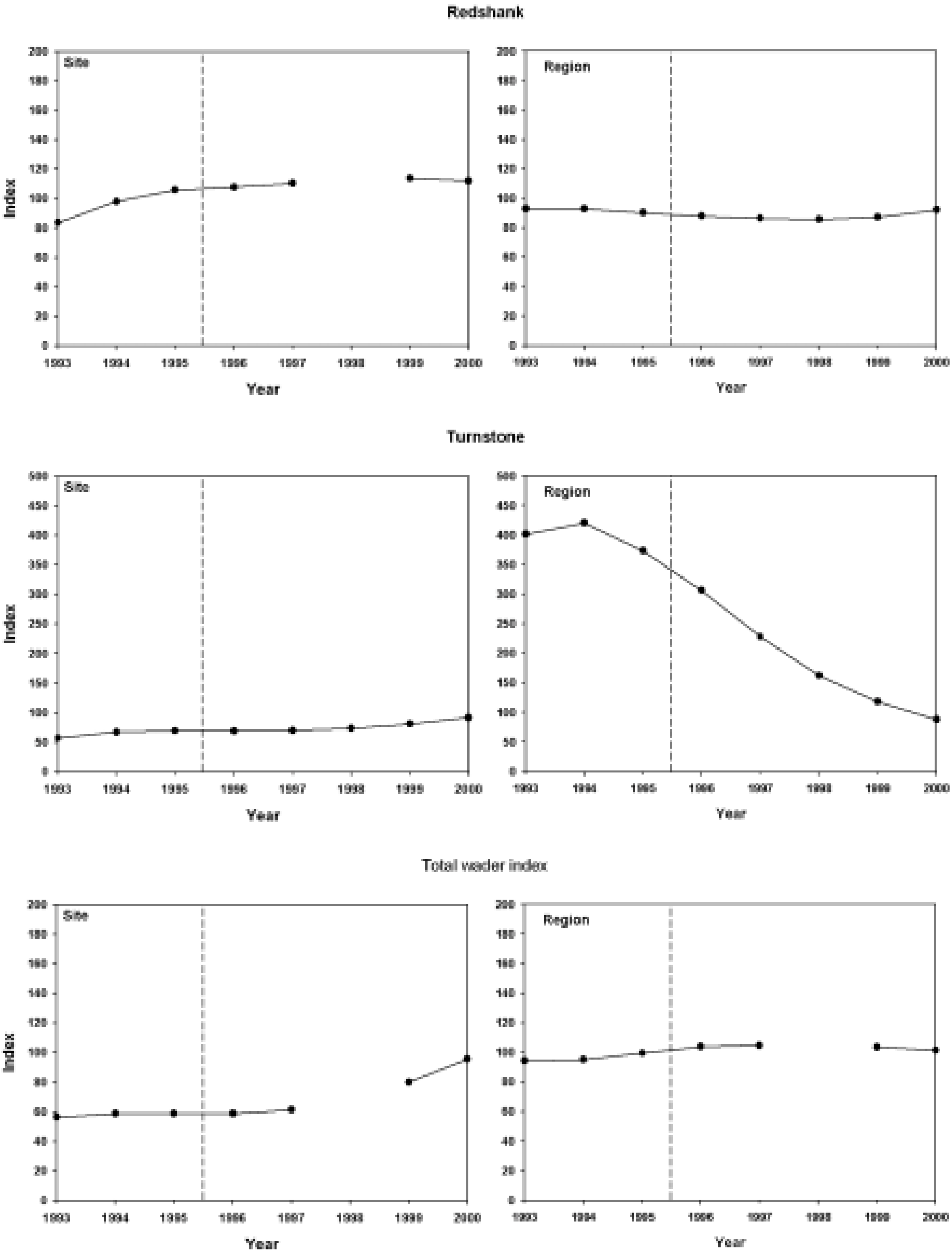

Figure 3.2.1.12 Continued.

Great Crested Grebe

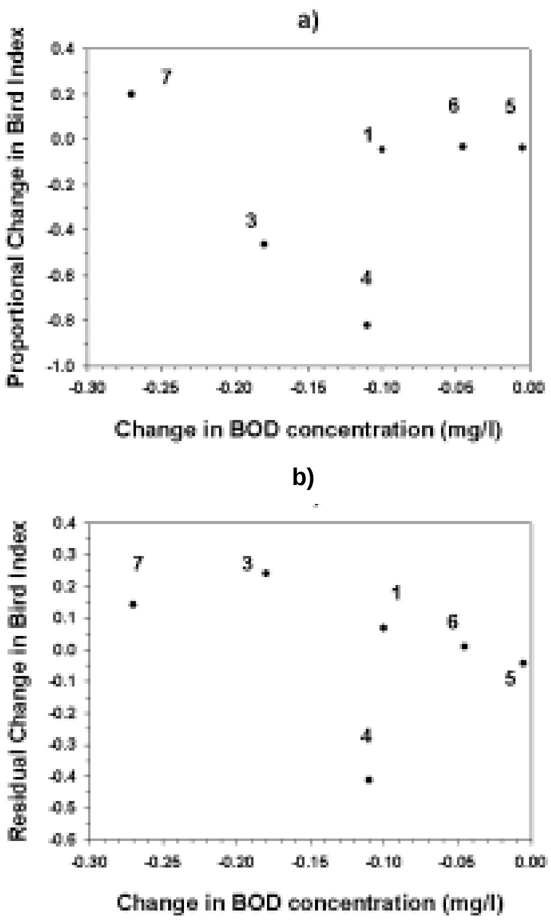

Figure 3.2.3.1 The relationship between the scale of change in site indices for Great Crested Grebe and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed. Data were available from too few sites to investigae the relationship between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

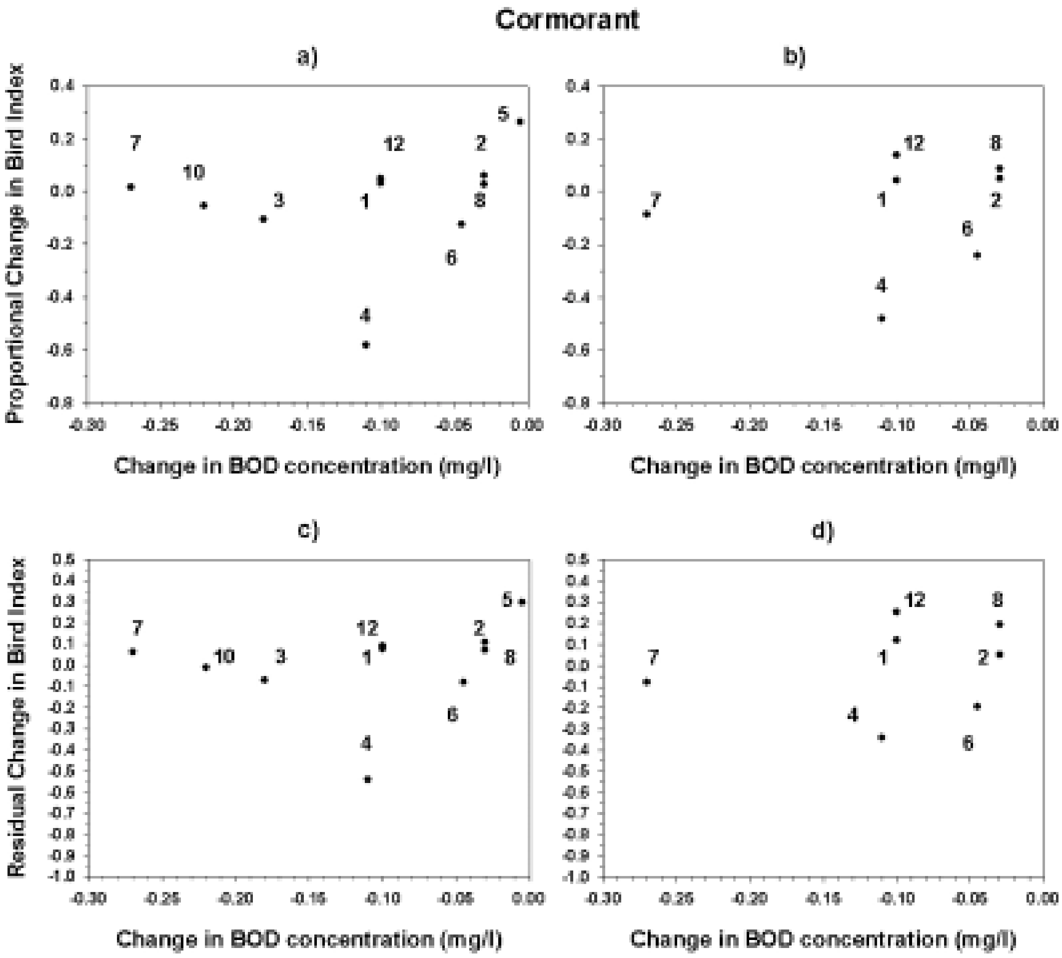

Figure 3.2.3.2 The relationship between the scale of change in site indices for Cormorant and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The change in index between the base winter and the second winter after improvements were completed.

c. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed.

d. The change in the residuals, from the relationship between site and regional indices, between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

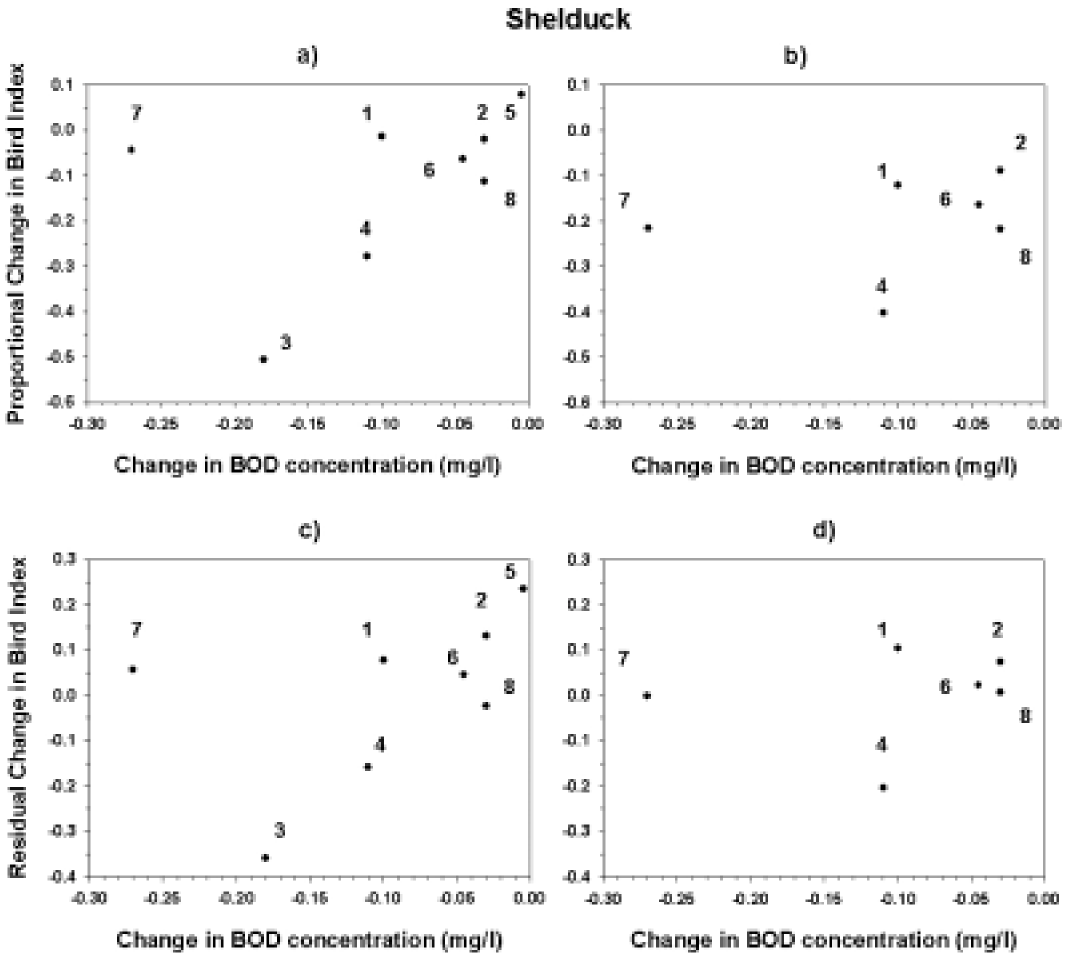

Figure 3.2.3.3 The relationship between the scale of change in site indices for Shelduck and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The change in index between the base winter and the second winter after improvements were completed.

c. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed.

d. The change in the residuals, from the relationship between site and regional indices, between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

Wigeon

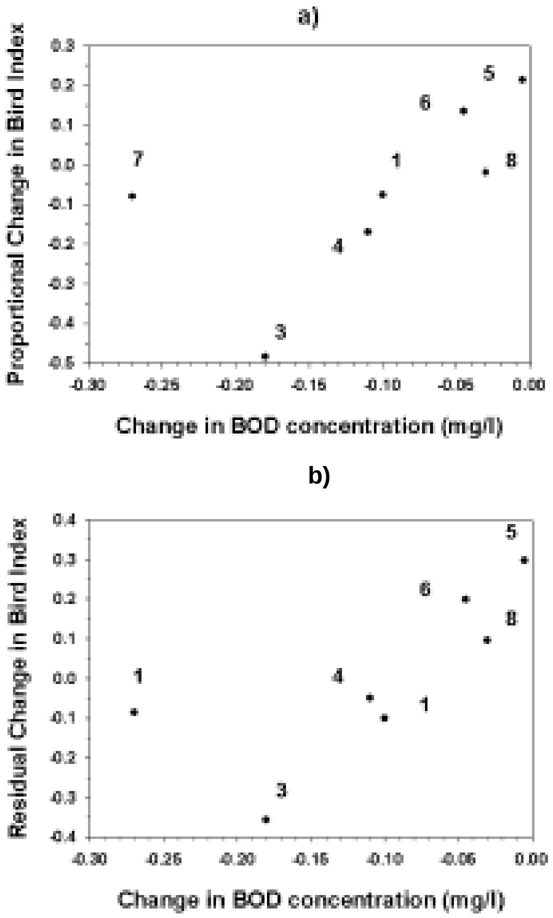

Figure 3.2.3.4 The relationship between the scale of change in site indices for Wigeon and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed. Data were available from too few sites to investigae the relationship between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

Pintail

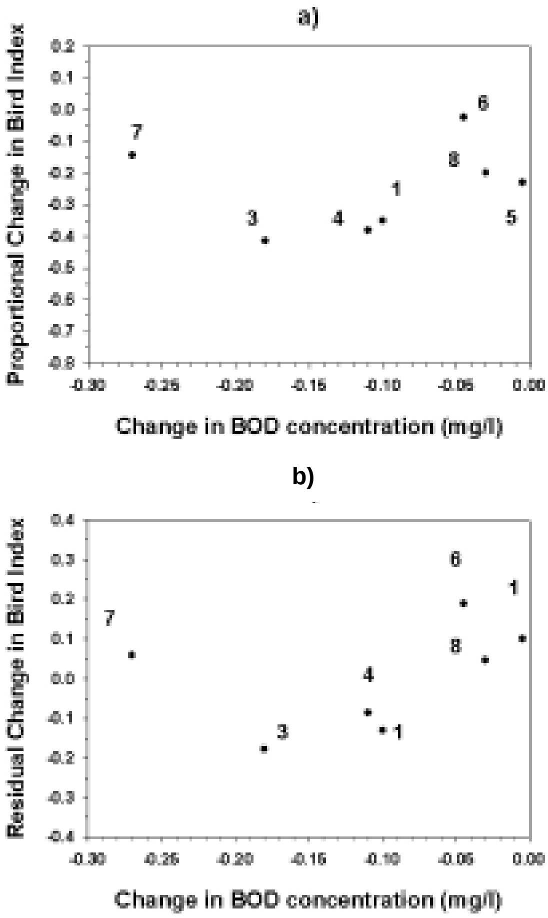

Figure 3.2.3.5 The relationship between the scale of change in site indices for Pintail and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed. Data were available from too few sites to investigae the relationship between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

Oystercatcher

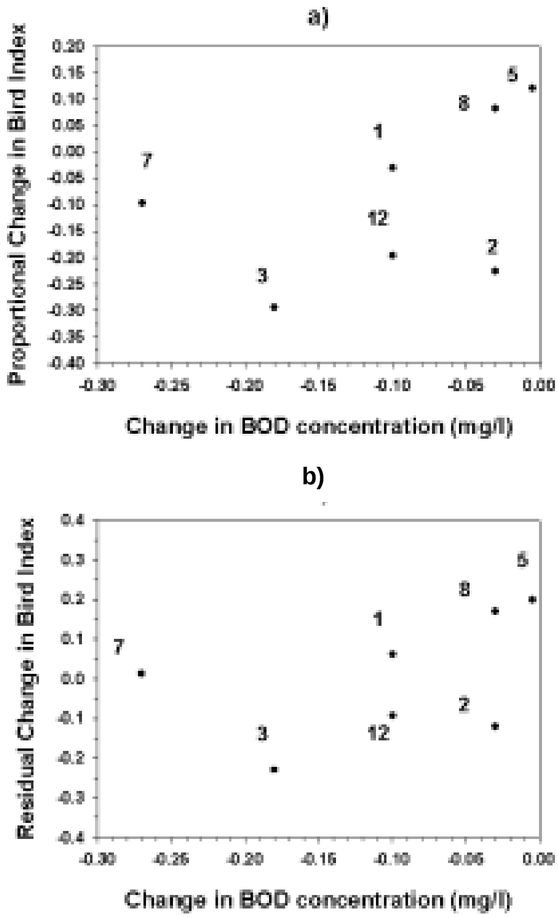

Figure 3.2.3.6 The relationship between the scale of change in site indices for Oystercatcher and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed. Data were available from too few sites to investigate the relationship between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

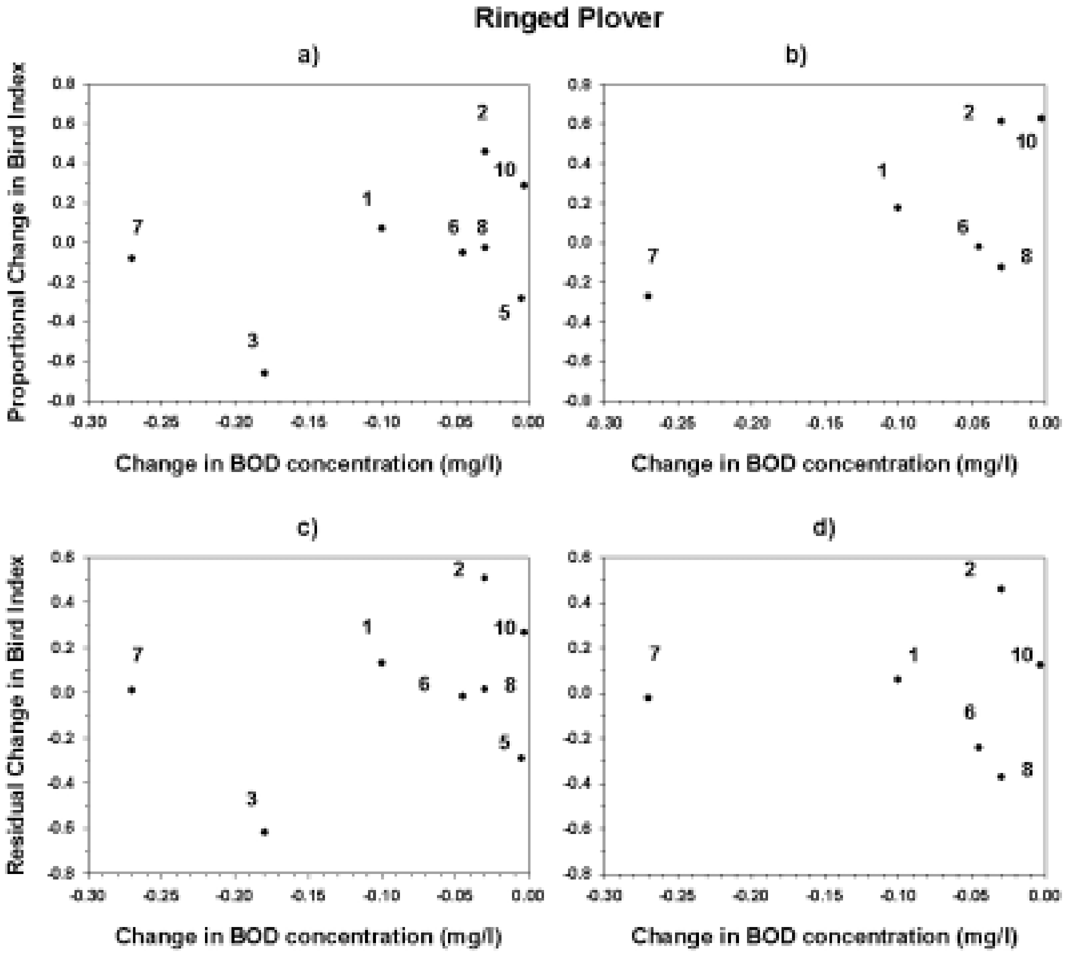

Figure 3.2.3.7 The relationship between the scale of change in site indices for Ringed Plover and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The change in index between the base winter and the second winter after improvements were completed.

c. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed.

d. The change in the residuals, from the relationship between site and regional indices, between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

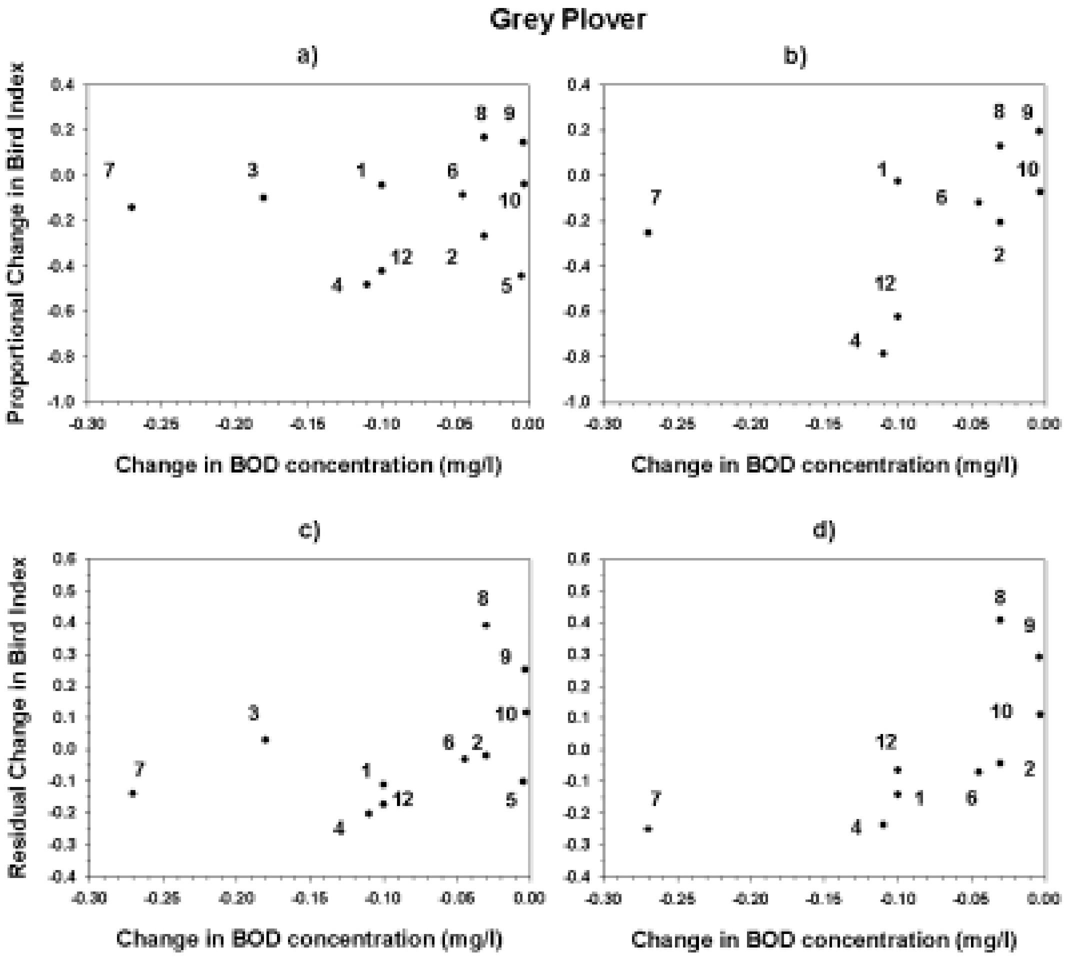

Figure 3.2.3.8 The relationship between the scale of change in site indices for Grey Plover and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The change in index between the base winter and the second winter after improvements were completed.

c. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed.

d. The change in the residuals, from the relationship between site and regional indices, between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

Knot

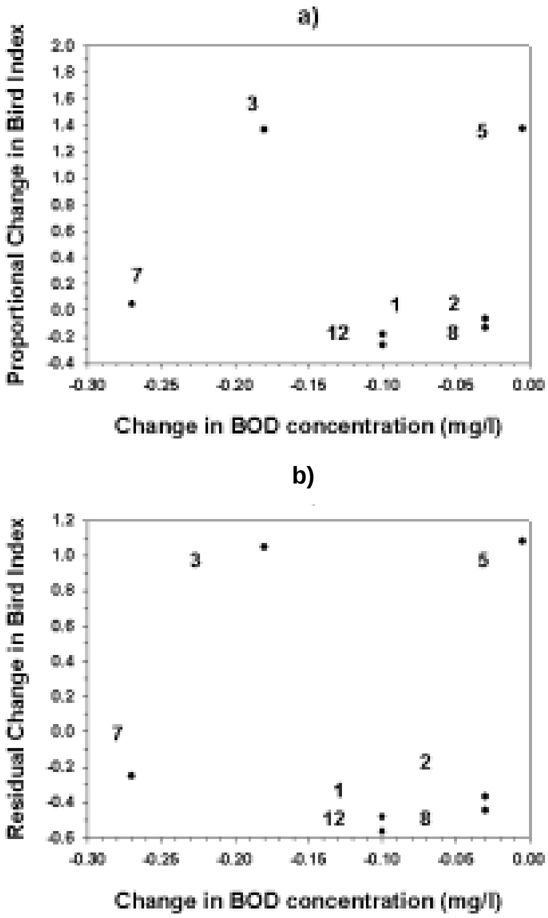

Figure 3.2.3.9 The relationship between the scale of change in site indices for Knot and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed. Data were available from too few sites to investigae the relationship between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

Sanderling

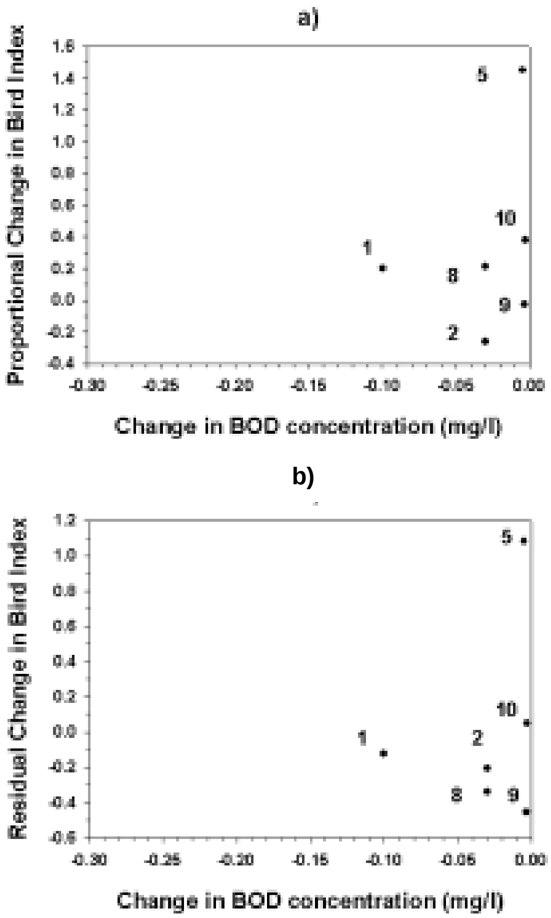

Figure 3.2.3.10 The relationship between the scale of change in site indices for Sanderling and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed. Data were available from too few sites to investigae the relationship between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

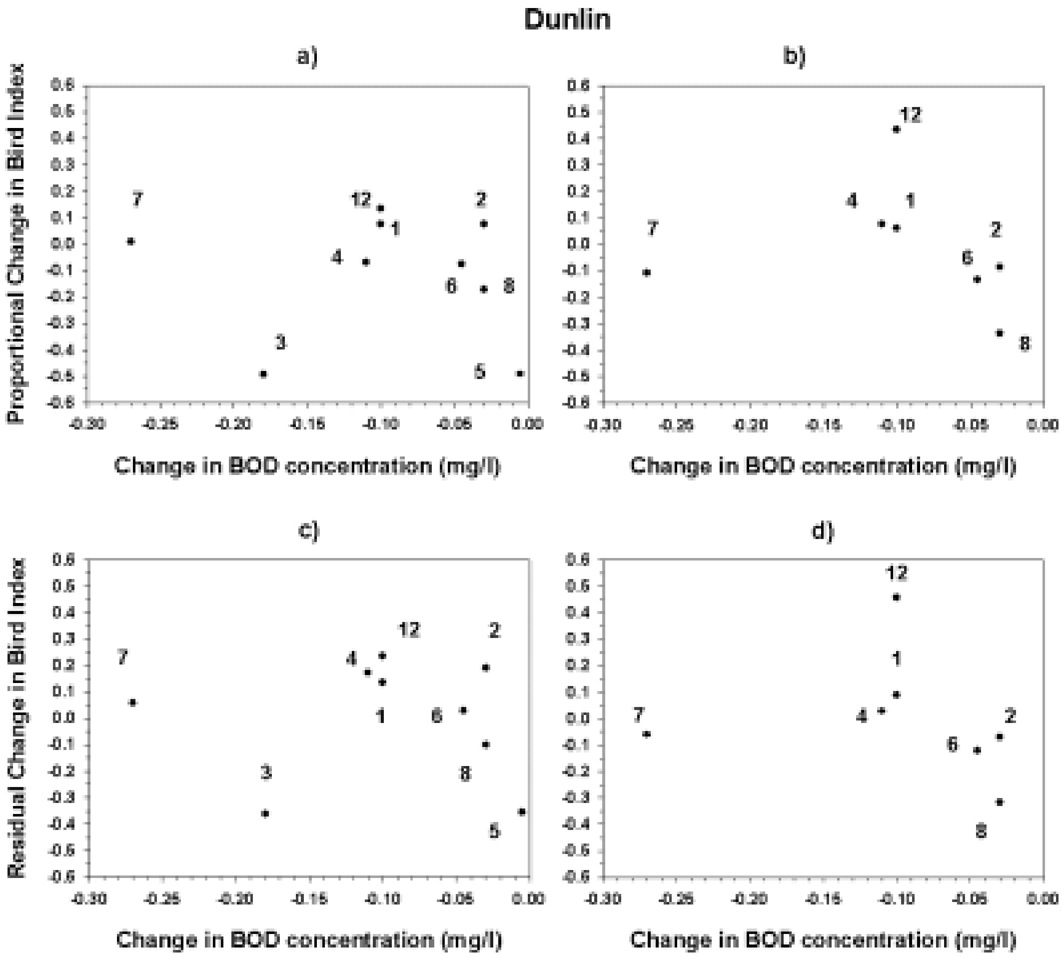

Figure 3.2.3.11 The relationship between the scale of change in site indices for Dunlin and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The change in index between the base winter and the second winter after improvements were completed.

c. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed.

d. The change in the residuals, from the relationship between site and regional indices, between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

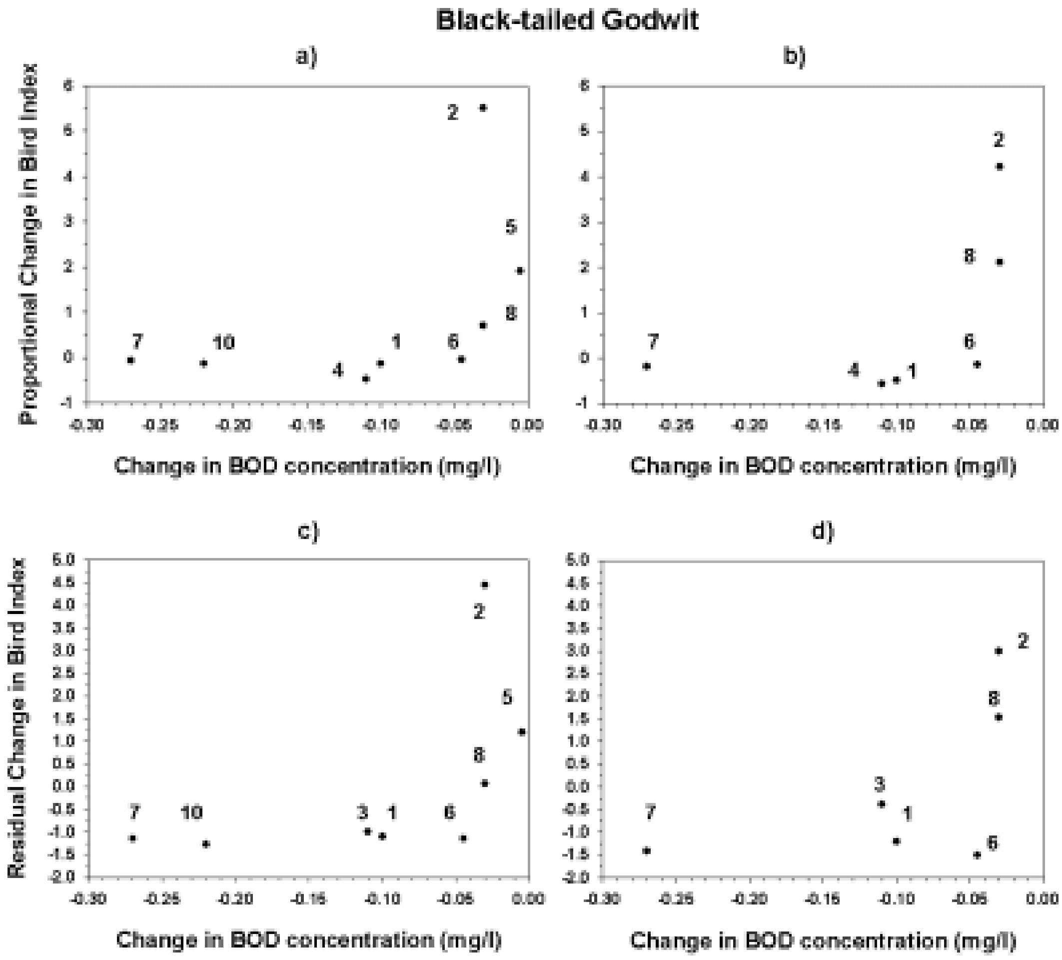

Figure 3.2.3.12 The relationship between the scale of change in site indices for Black-tailed Godwit and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The change in index between the base winter and the second winter after improvements were completed.

c. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed.

d. The change in the residuals, from the relationship between site and regional indices, between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

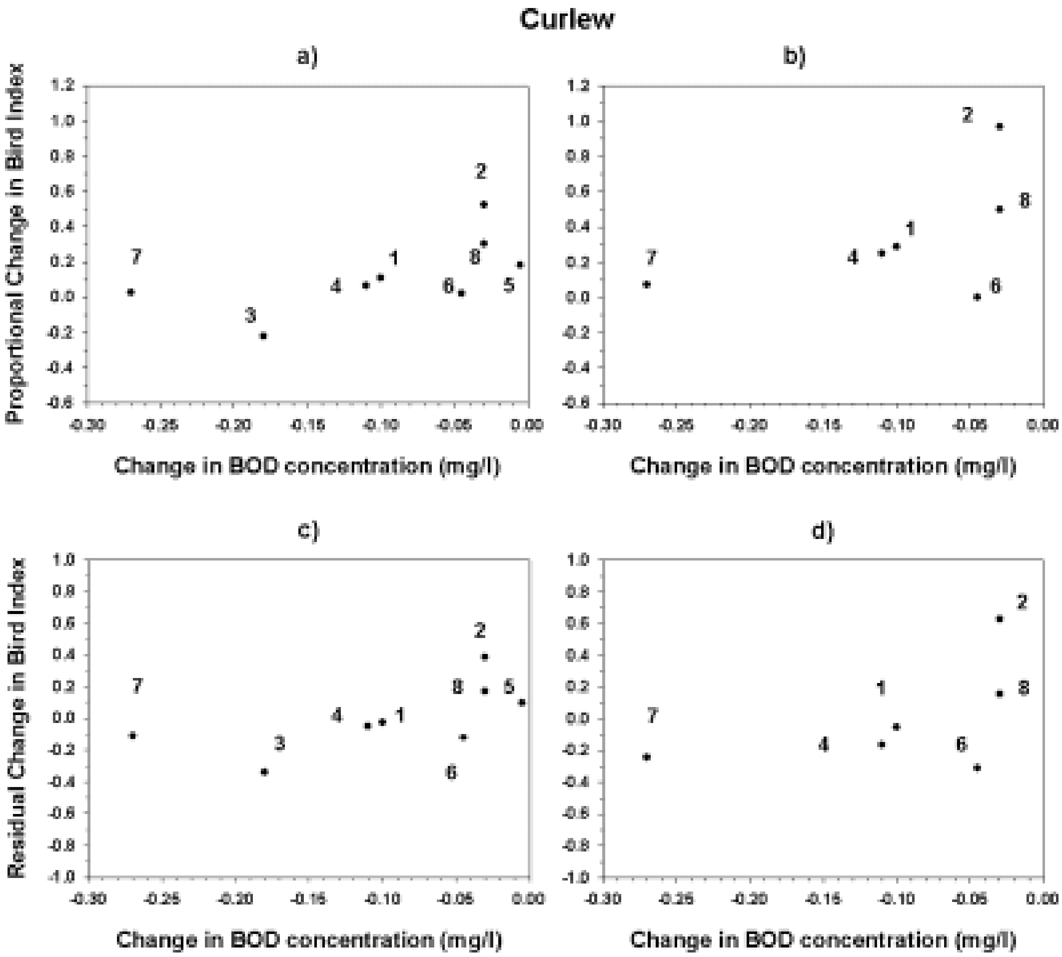

Figure 3.2.3.13 The relationship between the scale of change in site indices for Curlew and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The change in index between the base winter and the second winter after improvements were completed.

c. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed.

d. The change in the residuals, from the relationship between site and regional indices, between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

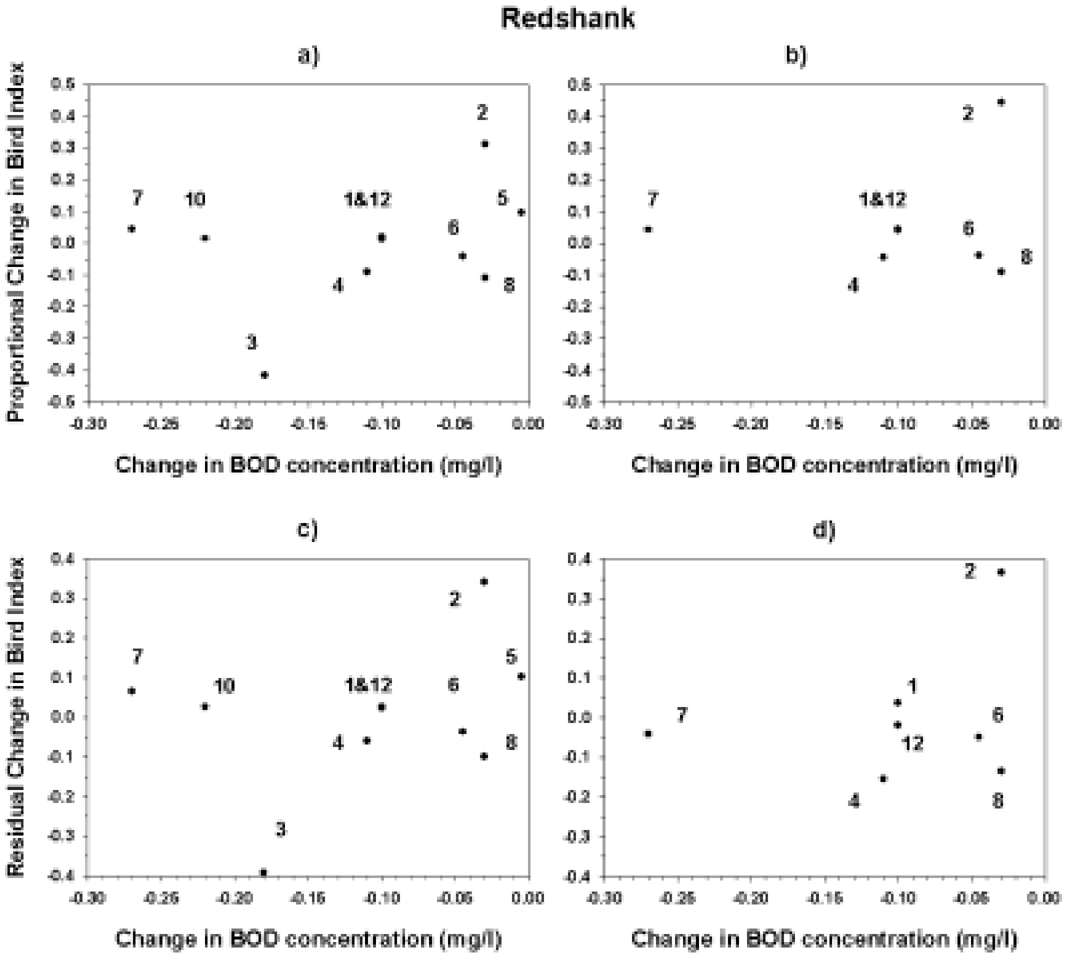

Figure 3.2.3.14 The relationship between the scale of change in site indices for Redshank and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The change in index between the base winter and the second winter after improvements were completed.

c. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed.

d. The change in the residuals, from the relationship between site and regional indices, between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

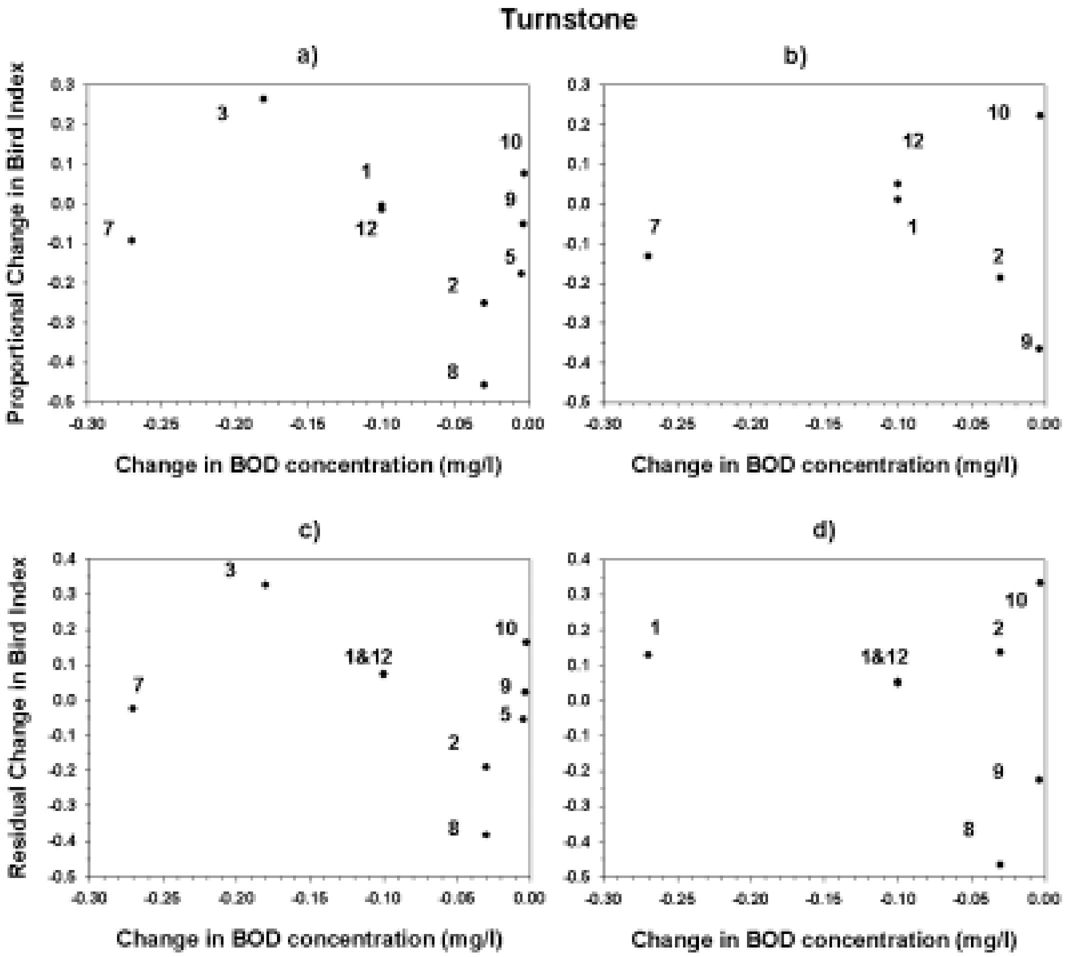

Figure 3.2.3.15 The relationship between the scale of change in site indices for Turnstone and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The change in index between the base winter and the second winter after improvements were completed.

c. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed.

d. The change in the residuals, from the relationship between site and regional indices, between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

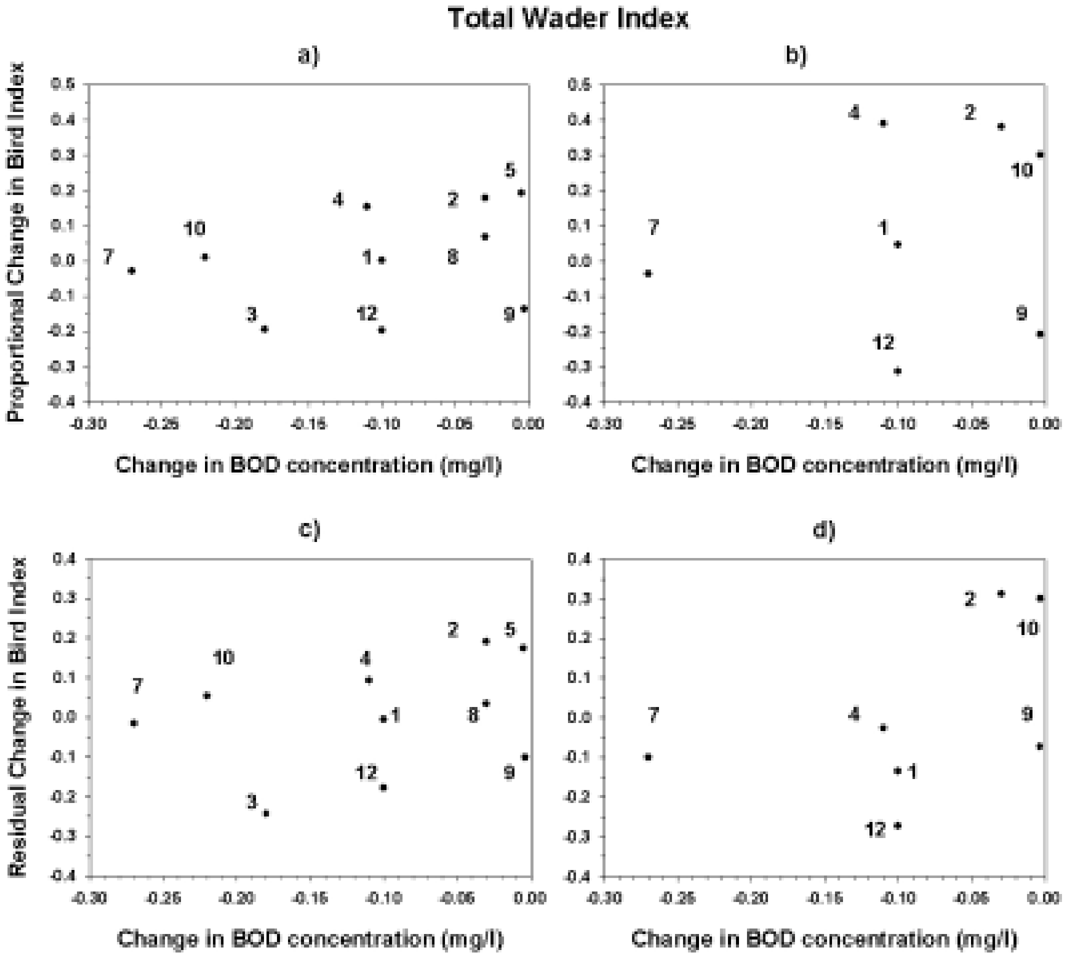

Figure 3.2.3.16 The relationship between the scale of change in site indices for the Total Wader index and the scale of change in BOD concentration (mg/l) resultant from improvements to waste water treatment.

a. The change in index between the base winter and the first winter after improvements were completed.

b. The change in index between the base winter and the second winter after improvements were completed.

c. The residuals, from the relationship between the changes in site and regional indices, between the base winter and the first winter after improvements were completed.

d. The change in the residuals, from the relationship between site and regional indices, between the base winter and the second winter after improvements were completed.

1 = Barrow-in-Furness; 2 = The Humber Flats, Marshes and Coast SPA; 3 = The Medway Estuary and Marshes SPA; 4 = The Mersey Estuary SPA; 5 = The Morecambe Bay SPA; 6 = North-west Solent; 7 = The Orwell Estuary; 8 = The Ribble and Alt Estuaries SPA; 9 = Sandwich Bay; 10 = The Tamar Estuary; 11 = The Thanet Coast; 12 = The Mersey Narrows and North Wirral Foreshore pSPA.

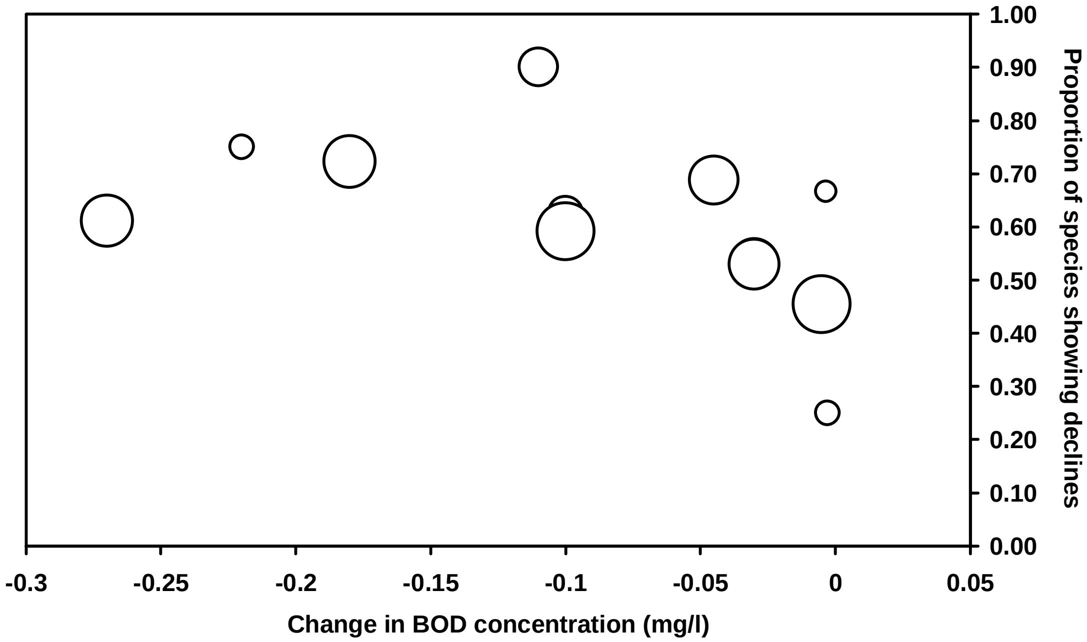

Figure 3.2.3.17a The proportion of species showing declines between the base winter and the first winter after improvements to waste water treatment were completed in relation to the change in BOD concentration (mg/l) at each site.

Dots are scaled in size according to the number of species for which data were analysed.

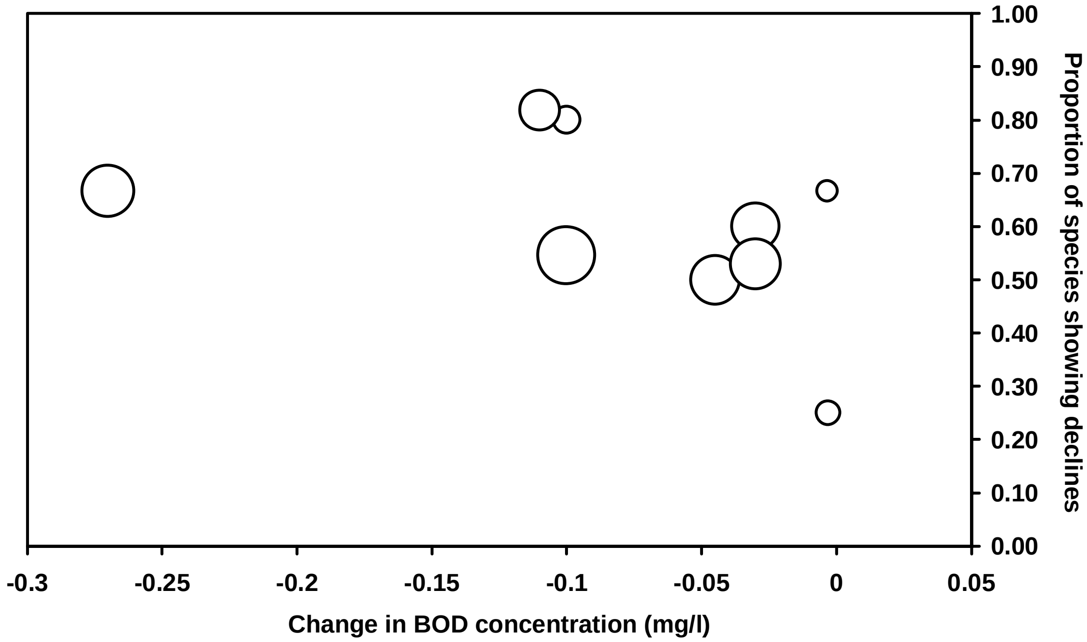

Figure 3.2.3.17b The proportion of species showing declines between the base winter and the second winter after improvements to waste water treatment were completed in relation to the change in BOD concentration (mg/l) at each site.

Dots are scaled in size according to the number of species for which data were analysed.

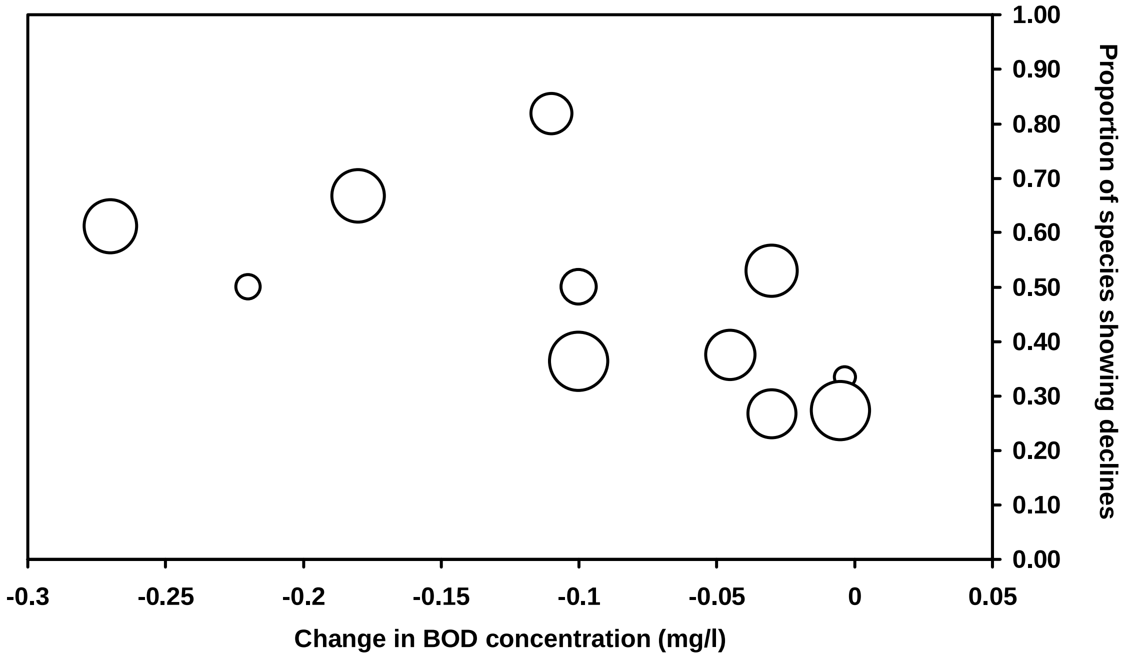

Figure 3.2.3.17c The proportion of species showing clear declines following the completion of improvements to waste water treatment in relation to the change in BOD concentration (mg/l) at each site.

Dots are scaled in size according to the number of species for which data were analysed.

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