Avian Population Dynamics and Human Induced Change in an Urban Environment

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Abstract

The predominantly urban boroughs of Warrington and Halton straddle the river Mersey in northwest England. Since the 1970s there has been a major change in land-use associated with both innovative town design and the decline of manufacturing and chemical industries in the boroughs. Also, co-ordinated programmes have directly addressed air and water pollution. The breeding birds of the two boroughs were surveyed in 1978-84 and 2004-06 as part of the bird atlases of Cheshire and Wirral, based on tetrads (2x2 km squares). We divided the breeding species into eight guilds based on broad ecological characteristics of habitat or food, omitting the generalists and colonial species, and compared the change between our two atlases in the number of occupied tetrads in Halton and Warrington and in the rest of the county. Four of our eight guilds have fared significantly better within our study area: waterbirds (24 species), those feeding on invertebrates (16 species), woodland specialists (21 species) and the two species that decorate their nests with lichens. The remaining four guilds showed no difference between Halton and Warrington and the rest of Cheshire and Wirral: raptors (5 species) have increased throughout, while breeding waders (7 species), farmland seedeaters (7 species) and aerial insectivores (5 species) have declined throughout. We interpret these results in relation to improved quality of water and air and changing patterns of land-use in the urban greenspace, especially an increase in woodland cover and connectivity.

Keyword: Urban birds . Greenspace . Environmental quality . Urban design

Introduction

The predominantly urban boroughs of Warrington and Halton in northwest England are crossed by the river Mersey, which rises in the Pennines and flows 110km, westward to the Irish Sea. Warrington and Halton, the latter incorporating the towns of Runcorn and Widnes, were created as unitary authorities in 1998 as part of a re-organisation of local government.

The River Mersey is of particular significance as it was central to the industrial revolution of the eighteenth century and the post-industrial economy of the later twentieth and early twenty-first centuries (Handley and Wood 1999; Langston *et al*. 2006). After many years of pollution and neglect the Mersey was dubbed the most polluted river system in Europe and in 1982 the Secretary of State for the Environment (Michael Heseltine MP) declared:

"… today the river is an affront to the standards a civilised society should demand of its environment. Untreated sewage, pollutants, noxious discharge all contribute to water conditions and environmental standards that are perhaps the single most deplorable feature of this critical part of England" (DoE 1982 p. 1).

Of course, this was not always the case. In 1795 John Aiken (quoted in Fox and Guest 2003) wrote that Runcorn "has of late become a place of some resort for salt-water bathing…; and the agreeable situation and good air of the place and its neighbourhood are useful auxiliaries to the effects of the bath." Within eight years (1803) of Aiken.s observations the first local chemical works making soap with alkalis were established in Halton. The chemical industry expanded after 1850s. By 1903 the landscape of the Mersey valley had been drastically affected. Coward (1903) (quoted in Fox and Guest 2003) wrote of a visit to Keckwick Hill near Warrington "[h]as there been a forest fire here? What is the meaning of the long line of bare trunks and blasted trees, that crowns the ridge…? 'Here' said Bagshaw, writing in 1850, 'is a thriving plantation of fir trees, extending for about a mile in length.' And this is the thriving plantation! thriving no longer, for Widnes fumes have done their deadly work ... . Wherever high land catches the vapour laden breezes from Widnes the trees have suffered, even at High Legh and Dunham [a distance of 16-20km] the effect may be seen on the western edge of the woodlands."

In 1956 a survey recorded 52 major factories in Halton, successors to the original industry, making heavy chemicals, metals, soap, gelatine glue, bone meal, animal feed, fertilisers, asbestos cement, cement, insulating materials, furniture and light engineering (Halton Borough Council 2001 p39–40). Now (2006) manufacturing accounts for only 14% of the jobs in Halton and the biggest employment sectors in the borough are the knowledge economy and public services (Halton Borough Council 2008).

The industrial development and decline of Warrington mirrored that of Halton. In the eighteenth century Warrington was a centre for the manufacture of sailcloth, and the making of pins, locks, hinges, cast iron and other branches of hardware. There was a very large works for refining copper as well as developed glass and sugar refining industries. Whilst the glassmaking industry declined in the early 19th century, due to competition from St Helens, other industries boomed. Metalworking was the mainstay and there were many ironworks as well as manufacturers adding value to the iron. There was also a considerable textile industry and a large soap making industry. Now, following the decline of manufacturing, the local economy of Warrington is mainly in service industries such as retail, education and local government (Lambert n.d.).

Following the Second World War the national awareness of pollution increased greatly and legislative and regulatory measures were introduced to reduce industrial and household emissions. The 1956 Clear Air Act did much to lower the level of air pollution and the subsequent decline, mainly during the 1980s, in the chemical and other heavy industries considerably reduced the burden of industrial discharges in the region. Also, over the last twenty to thirty years, considerable effort has been made by the public, private and voluntary sectors to transform the area. The principal players have been the Local Authorities, the Mersey Basin Campaign (a Government-backed partnership aiming to improve the rivers, streams, and canals of the Mersey Basin), the Mersey Forest, United Utilities (a private company that owns, operates and maintains utility assets, including water and wastewater), and numerous voluntary organisations, who have all been involved in addressing the air, water and land pollution in and around Halton and Warrington.

From the 1960s there were major changes in land use, mostly connected with the development of two New Towns in Runcorn (designated 10 April 1964) and Warrington (designated 26 April 1968), adding 100,000 to the local population. The towns are different in character and design but a key feature is the emphasis on green and open space. The preponderance of private gardens, alongside larger public realm open spaces provides the space in which a potentially rich mosaic of habitats might be developed. Runcorn was developed around a large (ca. 100 ha) „Town Park. providing informal wooded recreation, and a number of areas of urban greenspace and small woods.

Warrington New Town was designed around linked woodland belts and parks, creating structural diversity, with complex patterns used to emulate natural mosaics of trees, shrubs and meadows.

Warrington and Halton also fall within the area covered by the Mersey Forest, one of 10 Community Forests established by the 1990 Community Forest Programme of the then Countryside Commission. As with other community Forests the Mersey Forest has a 30-year vision, in this case to transform the landscape of The Mersey Forest through woodland planting and the creation of associated habitats, to produce long term, sustainable benefits for the economy, people and wildlife. Whilst much of the work of the Mersey Forest is outside Halton and Warrington the guiding principles within these two boroughs are to:

- Provide a woodland buffer around the urban edge and create a wooded edge to the Mersey Estuary.
- Extend planting into the urban area using all appropriate and available open land, including derelict land.
- Provide a new woodland structure for surrounding agricultural areas.
- Protect and manage the existing resource of urban trees and woodlands in a sustainable manner.
- Create two green wedges of woodland running from the east and west along the Mersey into Bridgefoot, Warrington. This will provide a new landscape for the Mersey, mitigating past damage and taking the Forest to the centre of the town.
- Create a chain of woodlands around the periphery of the urban area, forming a green edge to the town.
- Plant smaller sites within the town and create access routes, acting like the spokes of a wheel leading from the town centre to the green edge.
- Maintain and reconstruct the surrounding agricultural landscape (Mersey Forest 2001).

These principles clearly demonstrate a thrust towards creating more woodland and associated habitats and along with the New Towns in Runcorn and Warrington should result in increased habitat diversity and hence species diversity in the Mersey Valley.

The figures for land use in Halton and Warrington, compared to those for the rest of Cheshire and Wirral (Table 1) show clearly the urban nature of the former, with developed land taking two-and-a-half times the proportion of land area. The dominance of agriculture in Cheshire is reflected in the much higher percentage for „greenspace. in the rest of the county, whilst the area of domestic gardens in Halton and Warrington is almost double that for the rest of the county. The figures for the proportion of water are distorted by the inclusion of estuarine and marine areas in the definitions of some local authority boundaries.

Table 1 Land use in 2005, derived from Office of National Statistics data.

	Halton & Warrington	Remainder of Cheshire and Wirral
Total area (ha)	27 307.2	236 254.0
% Developed[1] area	13.4	5.5
% Domestic gardens	10.2	5.8
% Greenspace[2]	64.2	81.8
% Water[3]	7.6	5.1
% Other land use	4.5	1.8

[1]'Developed' land includes domestic, industrial and other uses

[2]'Greenspace' includes urban parks, municipal gardens and agricultural land

[3]'Water' includes freshwater and estuarine/ marine areas within the defined local authority boundaries.

All these changes in land use and quality of air and water are likely to impact on the wildlife of the area. One would expect that as pollution levels fell and as remediation programmes bore fruit that biodiversity levels ought to increase (Furness and Greenwood 1993). This paper examines this premise from data relating to avian distribution as recorded in two atlases covering the same geographic area but surveyed approximately 20 years apart (Guest *et al*. 1992; Norman 2008). This study differs from those conducted in other European cities (e.g. Dinetti, 2005; Luniak, 2005 and Witt, 2005) by being focused on an area which was subject to the adverse environmental effects of industrialisation and which, in the past 20 years or so, has been the subject of a number of environmental interventions aimed at improving water quality, air quality and woodland cover. The second survey was conducted at a time when environmental improvements had taken place and pollution levels were lower. In the preparation of the second atlas it was noted that some species were displaying possibly significant changes in their distribution between the two surveys. This observation was tested by testing hypotheses that differences in the distribution of eight guides of birds (birds associated with water, those feeding on invertebrates, woodland specialists, nests built with lichens, raptors, waders, farmland seedeaters and aerial insectivores) were statistically significant between the two atlas dates. Where statistically significant differences were observed those changes were examined in the context of the environmental interventions occurring in the study area.

Methods

In this paper we identify changes in avian distribution as recorded in two bird atlases separated by some 20 years and then build explanations to account for the changes observed. Similar methods have been used in other European cities (e.g. Luniak, 1996; Nowakowski, 1996; Witt, 1996), however, in those papers the authors concentrated on the effects of urbanization and synurbanization. The difference here is that the area under study was once heavily industrialised but is now much less so. The Cheshire Ornithological Association (COA) organized an atlas survey to record the breeding birds within a geographic area comprising the county of Cheshire (from 1st April 2009 the Unitary Authorities of East Cheshire, and West Cheshire and Chester), the Unitary Authorities of Warrington and Halton and the Metropolitan Borough of Wirral in Merseyside over a seven year period from 1978 to 1984 (Guest *et al*. 1992). A survey following the same methodology and covering the same geographical area was conducted by the Cheshire and Wirral Ornithological Society (CAWOS), the COA.s successor, over three years 2004 to 2006 with the results being published by Norman (2008).

In both atlas surveys volunteers, more than 350 in each period, recorded the birds present in 670 tetrads, 2km x 2km squares set out following the grid used by the Ordinance Survey. Seventy-seven of these tetrads lie within Halton and Warrington, and 593 in the rest of Cheshire and Wirral. In the breeding season, the subject of this paper, species were observed and their behaviour recorded according to a hierarchy of 16 codes indicating different levels of breeding status.

These were then translated into three categories: possible, probable and confirmed breeding status (Guest *et al*. 1992; Norman 2008). Some of the differences between these levels of breeding status result from varying levels of observer competence and familiarity with the species, inevitably so with a volunteer-based, „citizen science. project, so the analyses in this paper lump together all three categories and thus deal with any level of presence in suitable habitat in the breeding season. Tetrads are larger in area than the grids used in other studies, e.g. 500m grid used by Nowakowski (1996) or 100ha (Witt, 1996). The use of tetrads reflects the larger total area covered by the Cheshire Atlases and means that the data collected is on a coarser scale compared to the other two studies cited. Within each tetrad there may be considerable variation in habitat and hence this precludes the examination of relationships between changes in species distribution and specific habitats as was possible in the work of other authors (e.g. Luniak, 1996; Nowakowski, 1996; Witt, 1996).

The species recorded in the two Cheshire atlases were assigned to different guilds (Table 2), with birds grouped according to broad general characteristics of habitat use, food or other aspects of their breeding behaviour. This approach allows relationships between broad groupings and broad habitat changes to be examined. Not every breeding species has been included in these guilds, with the main exclusions comprising:

1) the locally-distributed colonial species (Grey Heron (*Ardea cinerea*), Cormorant (*Phalacrocorax carbo*), gulls (Laridae) and Rook (*Corvus frugilegus*)). These are omitted because an odd single nesting bird or a small shift in the breeding site can give an unrealistic apparent change in distribution; and also the first atlas survey, covering seven years, was

more likely to record a greater number of transient sites than the second atlas which was completed in three years.

2) the generalist species that use a wide range of habitats, thus often not being useful as indicators of changed environmental variables; many of these are almost ubiquitous, therefore having little scope for change in distribution (including Wren (*Troglodytes troglodytes*), Dunnock (*Prunella modularis*), Robin (*Erithacus rubecula*), Blackbird (*Turdus merula*), Song Thrush (*Turdus philomelos*), Mistle Thrush (*Turdus viscivorus*), Magpie (*Pica pica*), Carrion Crow (*Corvus corone*), Starling (*Sturnus vulgaris*), House Sparrow (*Passer domesticus*), and Greenfinch (*Carduelis chloris*)).

3) highly-specialised birds that occur elsewhere in the county, but not in Halton and Warrington because of lack of suitable habitat (such as Red Grouse (*Lagopus lagopus*), Golden Plover (*Pluvialis apricaria*), Dipper (*Cinclus cinclus*), Ring Ouzel (*Turdus torquatus*), Crossbill (*Loxia curvirostra*)).

Within a guild, each species is likely to be sensitive to different particular factors, described in more detail in the Discussion section below.

The number of tetrads occupied by each breeding species was counted in each of the atlases and these numbers compared in order to ascertain if a particular species had expanded, stayed the same or decreased in its range. This is a measure of the birds' distribution, not abundance, but for all except the most colonial species, the number of tetrads occupied is reasonably well correlated with their population (Gaston and Lawton 1990; Fuller *et al*. 1995).

It is well known that there have been considerable changes in bird population and distribution in Britain, caused by a variety of factors including habitat change (Fuller and Ausden 2008), agricultural practices (Shrubb 2003), climate change (Crick 2004), and the conditions in Africa encountered by the long-distance migrants (Sanderson *et al*. 2006). These large-scale changes have affected birds everywhere, so to isolate and analyse the effects of the local changes within Halton and Warrington, we compare the changes in bird distribution in the 77 tetrads in our study area with the changes in the 593 tetrads in the rest of Cheshire and Wirral. The remainder of the county contains a variety of habitat types including agricultural areas, some other conurbations and the uplands at the edge of the Peak District, and we, therefore, use the changes in bird distribution in these tetrads as a general indicator of population change. To establish the level of significance in the comparison between Halton and Warrington and the rest of Cheshire and Wirral, a simple 2x2 contingency table was established and a chi-squared test (with Yates' correction for continuity because there is only one degree of freedom) was used (Zar 1998).

In addition to these data on the avian fauna of the area, historic and contemporary data recording air quality, water quality and land use were collated from local authorities, government agencies, voluntary organisations and peer-reviewed research papers. These disparate sources cover different time periods but we do not regard this as a serious flaw because there is expected to be a time-lag, and differing levels of sensitivity for different species, rather than a direct and immediate link between bird distributions and measures of air quality, water quality, land use/ habitat structure. These data were then used to build a themed, chronological narrative of environmental quality change in the Mersey Valley. Comparison of the avian and environmental data allows for explanations for changes in avian distributions to be advanced.

Table 2: Guilds of breeding birds

Guild	Species
Birds associated with water 24 species	Mute Swan (*Cygnus olor*), Greylag Goose (*Anser anser*), Canada Goose (*Branta canadensis*), Shelduck (*Tadorna tadorna*), Wigeon (*Anas penelope*), Gadwall (*Anas strepera*), Teal (*Anas crecca*), Shoveler (*Anas clypeata*), Mallard (*Anas platyrhynchos*), Pintail (*Anas acuta*), Garganey (*Anas querquedula*), Pochard (*Aythya ferina*), Tufted Duck (*Aythya fuligula*), Ruddy Duck (*Oxyura jamaicensis*), Water Rail (*Rallus aquaticus*), Moorhen (*Gallinula chloropus*), Coot (*Fulica atra*), Little Grebe (*Tachybaptus ruficollis*), Great Crested Grebe (*Podiceps cristatus*), Black-necked Grebe (*Podiceps nigricollis*), Kingfisher (*Alcedo atthis*), Grey Wagtail (*Motacilla cinerea*), Reed Warbler (*Acrocephalus scirpaceus*), Reed Bunting (*Emberiza schoeniclus*)
Feeding on invertebrates (Tits and warblers) 16 species	Grasshopper Warbler (*Locustella naevia*), Sedge Warbler (*Acrocephalus schoenobaenus*), Reed Warbler (*Acrocephalus scirpaceus*), Blackcap (*Sylvia atricapilla*), Garden Warbler (*Sylvia borin*), Lesser Whitethroat (*Sylvia curruca*), Whitethroat (*Sylvia communis*), Wood Warbler (*Phylloscopus sibilatrix*), Chiffchaff (*Phylloscopus collybita*), Willow Warbler (*Phylloscopus trochilus*), Long-tailed Tit (*Aegithalos caudatus*), Blue Tit (*Cyanistes caeruleus*), Great Tit (*Parus major*), Coal Tit (*Periparus ater*), Willow Tit (*Poecile montana*), Marsh Tit (*Poecile palustris*)
Woodland specialists 21 species	Sparrowhawk (*Accipiter nisus*), Buzzard (*Buteo buteo*), Woodcock (*Scolopax rusticola*), Stock Dove (*Columba oenas*), Tawny Owl (*Strix aluco*), Green Woodpecker (*Picus viridis*), Great Spotted Woodpecker (*Dendrocopos major*), Lesser Spotted Woodpecker (*Dendrocopos minor*), Blackcap (*Sylvia atricapilla*), Garden Warbler (*Sylvia borin*) Wood Warbler (*Phylloscopus sibilatrix*), Chiffchaff (*Phylloscopus collybita*), Willow Warbler (*Phylloscopus trochilus*), Goldcrest (*Regulus regulus*), Coal Tit (*Periparus ater*), Willow Tit (*Poecile montana*), Marsh Tit (*Poecile palustris*), Nuthatch (*Sitta europaea*), Treecreeper (*Certhia familiaris*), Jay (*Garrulus glandarius*), Lesser Redpoll (*Carduelis cabaret*)
Nests built with lichens 2 species	Long-tailed Tit (*Aegithalos caudatus*), Chaffinch (*Fringilla coelebs*)
Raptors 5 species	Sparrowhawk (*Accipiter nisus*), Buzzard (*Buteo buteo*), Kestrel (*Falco tinnunculus*), Hobby (*Falco subbuteo*), Peregrine (*Falco peregrinus*)
Waders 7 species	Oystercatcher (*Haematopus ostralegus*), Avocet (*Recurvirostra avosetta*), Little Ringed Plover (*Charadrius dubius*), Ringed Plover (*Charadrius hiaticula*), Lapwing (*Vanellus vanellus*), Curlew (*Numenius arquata*), Redshank (*Tringa totanus*)
Farmland seedeaters 7 species	Grey Partridge (*Perdix perdix*), Turtle Dove (*Streptopelia turtur*), Skylark (*Alauda arvensis*), Tree Sparrow (*Passer montanus*), Linnet (*Carduelis cannabina*), Yellowhammer (*Emberiza citrinella*), Corn Bunting (*Miliaria calandra*)
Aerial insectivores 5 species	Swift (*Apus apus*), Sand Martin (*Riparia riparia*), Swallow (*Hirundo rustica*), House Martin (*Delichon urbicum*), Spotted Flycatcher (*Muscicapa striata*)

Results

Avian Distributions

The analysis of the changes in distributions of the various guilds of birds is presented in Table 3, showing the trend for the change in Halton and Warrington compared to the rest of Cheshire and Wirral and its statistical significance. The occupancy of tetrads in Halton and Warrington four guilds (birds associated with water, those feeding on invertebrates, woodland specialists and those building nests with lichens) increased more than in Cheshire and Wirral; indicating the extent of the colonisation by these guilds into areas that were heavily industrialized.

Table 3: Changes in the occurrence of eight guilds of birds between the first and second Cheshire breeding bird atlases.

Guild	Trend Birds in Warrington and Halton have:	Chi-squared value	P
Birds associated with water	done better than in the rest of the county	6.92	<0.01
Feeding on invertebrates	done better than in the rest of the county	5.21	<0.025
Woodland specialists	done better than in the rest of the county	10.27	<0.005
Builds nests with lichens	done better than in the rest of the county	4.98	<0.05
Raptors	increased in line with the rest of the county	0.07	NS
Breeding waders	decreased in line with the rest of the county	0.64	NS
Farmland seedeaters	decreased in line with the rest of the county	1.12	NS
Aerial insectivores	decreased in line with the rest of the county	1.25	NS

To ensure that the results are not distorted by just a few species, we checked for heterogeneity by comparing the total of the chi-squared values for the species in each guild (without continuity correction for this calculation) with the chi-squared value of the guild (Zar 1998 p.471). As a few species are new to the whole area covered by the atlas in the last twenty years, their individual chi-squared contributions are indefinable, so they are omitted from their guild for this test. The results given in Table 4 show that four of our guilds are statistically homogeneous but four are significantly heterogeneous (where the data could be distorted by one species which for example increased much more than other members of that guild) between the two atlas dates. Inspection of the chi-squared values for individual species showed that in each case just one or two species accounted for the heterogeneity.

Table 4: Testing for heterogeneity within guilds for the direction and value of temporal changes in the occupation of tetrads

Guild	Heterogeneity chi-squared	Df	P
Birds associated with water [1]	40.32	22	<0.01
Feeding on invertebrates	20.51	15	NS
Woodland specialists	37.03	20	<0.02
Builds nests with lichens	2.70	1	NS
Raptors [2]	5.63	2	NS
Breeding waders [3]	15.19	5	<0.01
Farmland seedeaters	27.02	7	<0.001
Aerial insectivores	8.58	4	NS

[1] Omitting Black-necked Grebe

[2] Omitting Hobby, Peregrine

[3] Omitting Avocet

In the guild of "woodland specialists", the Willow Tit provides the dominant contribution to the heterogeneity. This species has declined substantially across the UK to become one of the red-listed Birds of Conservation Concern (Eaton *et al*. 2009) but they are still widely distributed in the Mersey valley, which is now one of their national strongholds. Excluding Willow Tit from the original guild (Table 2) results in a guild of woodland specialists whose trend between our two atlas periods (Table 3) is still significantly better than in the rest of the county (chi-squared = 9.89, $p<0.005$), and is now statistically homogeneous (heterogeneity chi-squared = 24.69, NS).

The "birds associated with water" also contains one outlier, Mute Swan. This species had suffered badly in the 1970s and 1980s from lead poisoning caused by ingestion of fishing weights discarded or lost by amateur anglers. There are disproportionately high densities of anglers in the urban areas such as Halton and Warrington, and during the first bird atlas period (1978-84) the Mute Swan population, and distribution, was depressed much more in the Mersey valley than in the rest of the county. The anglers' voluntary ban on lead weights, and legislation effective from 1987, allowed the Mute Swan to recover and indeed to exceed by far its previous distribution in Halton and Warrington. Exclusion of Mute Swan from the original list (Table 2) results in a guild of birds associated with water whose trend (Table 3) is still significantly better than in the rest of the county (chi-squared = 4.00, $p<0.05$) and that is now statistically homogeneous (heterogeneity chi-squared = 29.00, NS).

Because the other statistically heterogeneous guilds ("breeding waders" and "farmland seed-eaters") exhibit a trend in distribution not significantly different from that for the rest of the county (Table 3), and this conclusion is not changed by removing the species that dominate the statistics, we do not consider these guilds further in this analysis.

On the basis that two of our guilds were statistically homogeneous and another other two became so by excluding just one species each, we feel confident in proceeding to use the guilds as defined in Table 2.

Air Quality

According to the UK National Air Quality Information Archive and data obtained from both Halton and Warrington Borough Councils annual mean sulphur dioxide levels have been falling over the period 1960 to 2008. At the time of data collection for the first atlas, sulphur dioxide levels were typically between 100 μgm^{-3} and 50 μgm^{-3}. This followed a period when values were considerably higher. At the time of the second atlas the sulphur dioxide levels were typically below 10 μgm^{-3} (Figure 1). There was also a substantial reduction in the mean smoke levels over the same period (Figure 2).

Figure 1: Annual mean Sulphur dioxide levels (μgm^{-3}). From 1962 the results are from SO_2 'bubbler' samples. This was replaced in 2002 by a real time analyser.

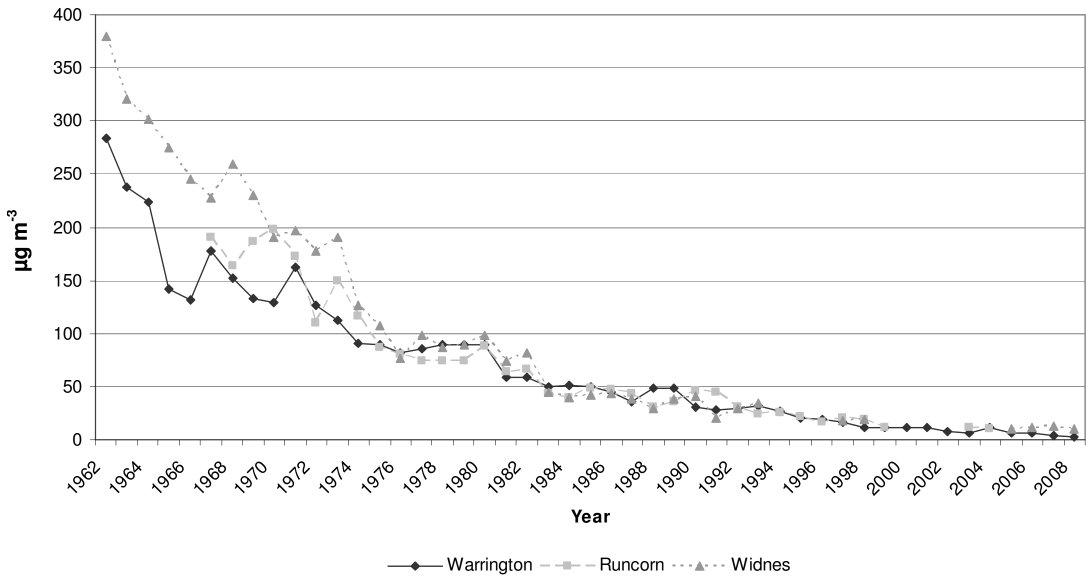
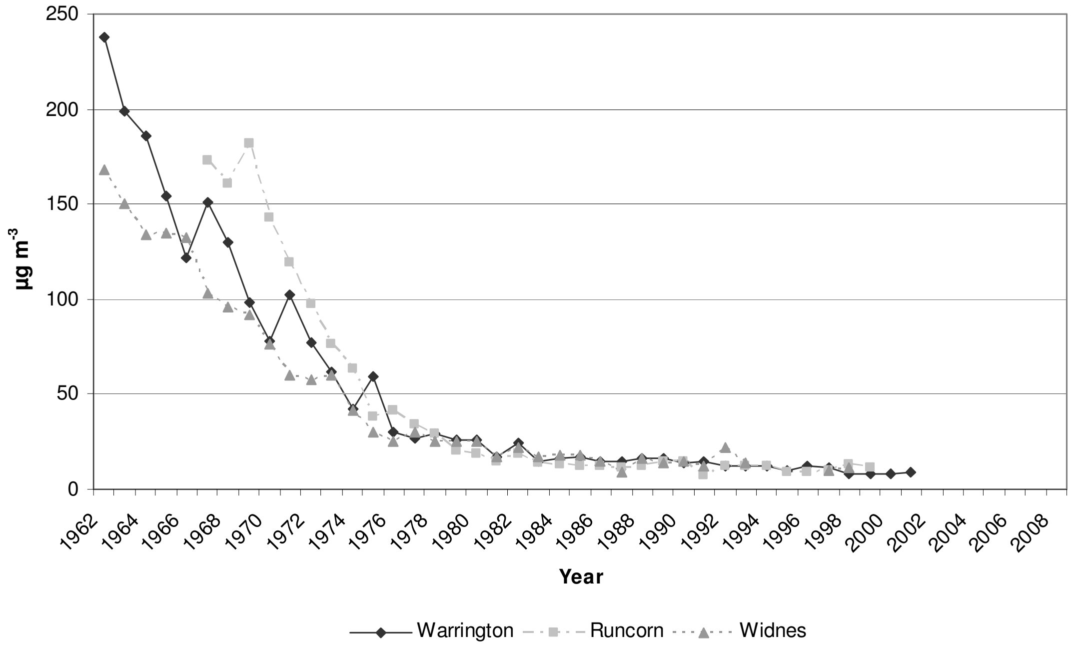


Figure 2: Annual mean smoke levels (µgm^{-3}). Smoke measurements were stopped in 2002 because of the low levels.

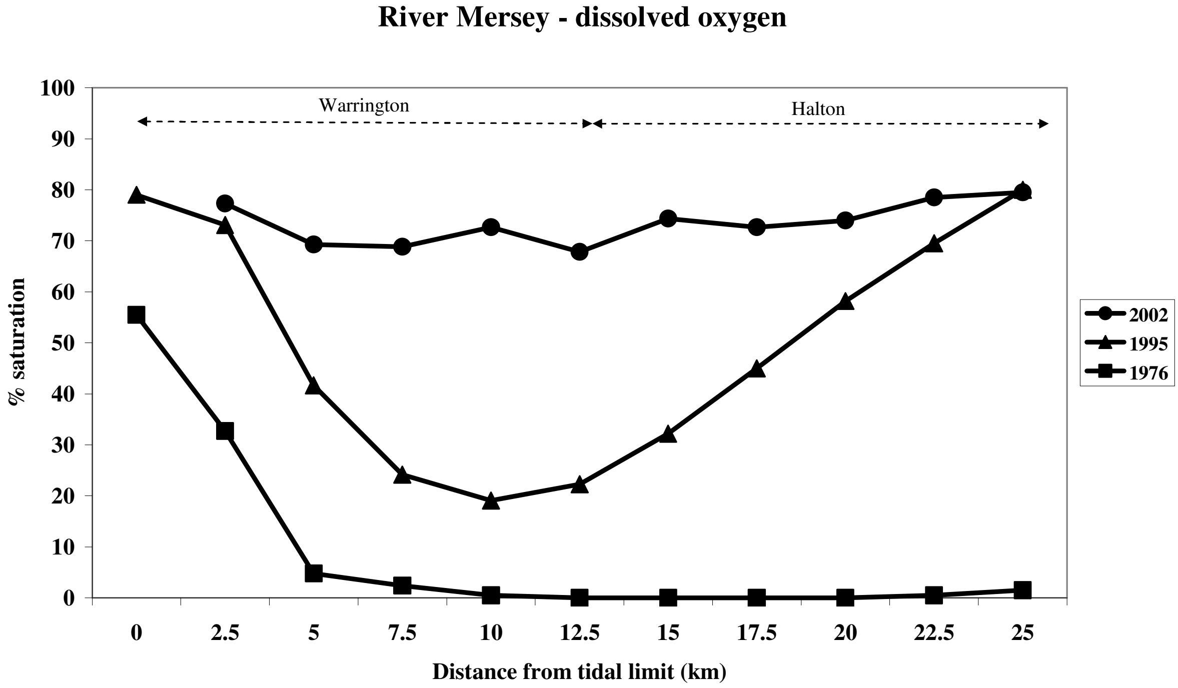


Water quality

Water quality shows a similar improving trend over the period of interest whereby high pollution levels, associated with a lack of sewage treatment and the chemical and manufacturing industries, have been ameliorated through concerted environmental improvement programmes and a decline in those industries. Pollution of the River Mersey was probably at its worst during the 1950–1960s (Burton 2003). Since 1985, there has been a substantial improvement in water quality: data presented by Jones (2006) indicate that there was little or no discharge of crude or treated sewage and a much reduced level of discharge from industry into the river from around 2000.

Measurements in the River Mersey in 1976 showed that throughout the majority of its passage through Warrington and Halton the river was essentially devoid of oxygen. A dissolved oxygen level of 60% was found at the weir in Warrington, owing to the mixing of oxygen that occurs at that point, but within 5km of the weir oxygen had fallen to almost zero and remained at that level for the next 20 or so kilometres (Figure 3). By the mid-1990s the river showed some improvement, but it was not until 2002 that a more or less stable level of 75% was recorded (Langston *et al*. 2006). A cleanup scheme was initiated in the early 1970s which aimed to improve water quality at the tidal-limit, construct interceptors and effluent treatment works providing primary sewage treatment and impose stringent control on industrial discharge (Jones 2006). In the 1990s there came the need to comply with the EU Wastewater Treatment Directive (91/271/EEC) which required secondary treatment for all estuarine discharges, a process that was introduced in 2000. The cleanup of the 1970s and the work to comply with the EU Wastewater Treatment Directive both led to marked improvements in the water quality of the estuary.

Figure 3: Typical levels of dissolved oxygen in the tidal River Mersey on its passage through the boroughs of Warrington and Halton in 1976, 1995 and 2002. (Data from the Environment Agency, adapted from Langston et al. 2006)



Data taken from core samples of the sediment in the river Mersey suggest that, in accordance with surface sediment samples, metal contamination in the river has decreased over time (Langston *et al*., 2006). These data point to reduced inorganic pollution entering the river and a general amelioration of the water and sediment quality. Over £1000 million has been spent to address the poor water quality in the River Mersey and the evidence of the effect is now clear in terms of water quality improvement (Jones, 2006).

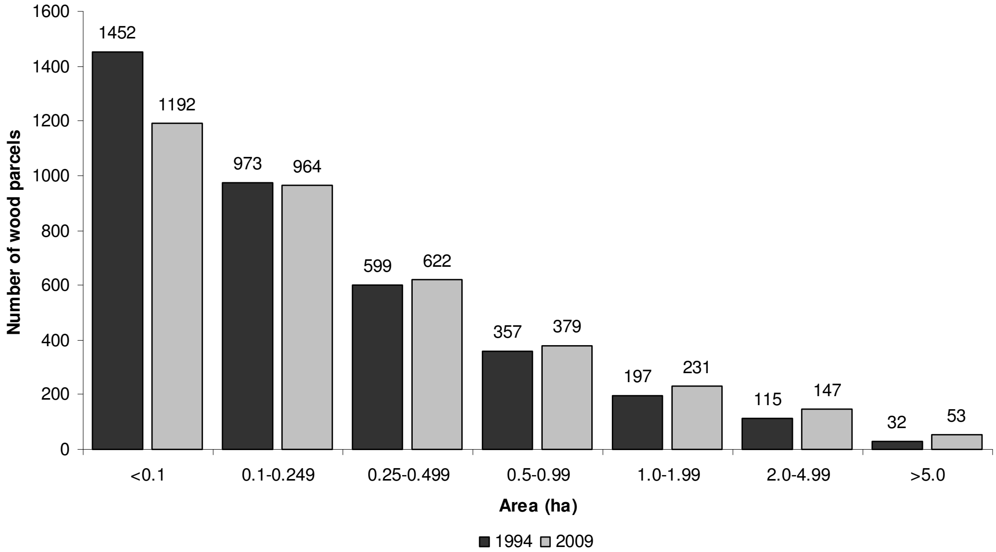
Land use

Woodland habitats in the two boroughs have changed considerably over the fifteen years existence of the Mersey Forest (Table 5 and Figure 4). During the period covered in Table 5 the area of woodland increased by 493ha (31%), the mean size of a woodland parcel increased by 0.153ha (36%) and the largest woodland had increased in size by 36%, all measures indicating that there was more woodland and that, due to actions to improve woodland connectivity, woodland parcels were larger (Figure 4).

Table 5: The change in woodland parcel number and size in Halton and Warrington between 1994 and 2009. 'Woodland' is identified as areas marked on Ordnance Survey maps as having trees present. The Mersey Forest database does not contain figures for woodland cover before 1994.

Year	1994	2009
Area of woodland (ha)	1611	2104
Number of parcels of woodland	3725	3588
Mean area of a woodland parcel (ha)	0.43	0.59
Median area of a woodland parcel (ha)	0.14	0.16
Largest woodland parcel (ha)	31.0	42.2

Figure 4: Distribution of woodland parcel areas in Halton and Warrington in 1994 and 2009.



The Results presented in this section thus show, from the 1970s onwards, major changes in air quality, water quality, land use including woodland cover and the distributions of some groups of birds. The following section discusses the likely reasons linking the avian distributions to the environmental data.

Discussion

There are clear positive relationships between four of our guilds of birds (birds associated with water, those feeding on invertebrates, woodland specialists and those building nests with lichens) and the improving environment in Halton and Warrington (Table 3). As commented earlier, there is not expected to be a direct and immediate connection between bird distributions and measures of air quality, water quality and land use, so the links are not exact, but we now explore and discuss the likely causal basis for the correlations for these four ecological groups of birds. Some of the differences, we postulate, are due to habitat composition and structure, and others to the species. food. Birds are recorded much more thoroughly than almost any other wildlife taxon, so we usually do not have direct measures of the abundance or distribution of the birds' food species, be they fish, mammals, invertebrates, vegetation or seeds. We thus make plausible connections between the environmental variables and their effect on birds.

The guild of "birds associated with water" lumps together species of a wide range of sizes that nest on flowing or static water, on ponds/ lakes of varying sizes; and have varied diets including fish, aquatic invertebrates and submerged or floating vegetation or waterside vegetation. They are thus likely to be susceptible to different aspects of water quality but the effects are widespread across different genera: for Waterways Bird Survey data of the British Trust for Ornithology, 23 species showed significant relationships with water quality (Rushton *et al*. 1994). Although the water quality assessments are from flowing water, while many of the species in the guild nest on standing water, it seems likely that the general quality of the subterranean water, and thus the ponds and lakes, will have improved as well.

Two of the smallest species in this guild of birds associated with water are widely cited as vulnerable to pollution. Kingfisher has long been regarded as a key indicator of healthy rivers (Meadows 1972) while Grey Wagtail is reportedly amongst the species most sensitive to water quality (Rushton *et al*. 1994). It is, therefore, not surprising that they have spread within Halton and Warrington between the two atlas census dates in response to improving waterways. These two species feed mainly along the area's streams and canals; results from Italy show that stream quality and richness of the riparian bird community are closely related (Sorace *et al*. 1999).

Birds are at the top of the aquatic food chain and their responses to sewage effluent discharge have been widely investigated (Furness 1993; Cao *et al*. 1996; Abel 2007). In an urban lagoon in Spain, Great Crested Grebes were found to be the most sensitive species to nitrogen enrichment, with Black-necked Grebes less so, but the abundance of the two species of grebes closely tracked the nitrogen load curve (Fernández *et al*. 2005). In Australia in late winter the highest densities and diversity of birds associated with water, and of zooplankton, were found in the ponds towards the (cleanest) end of a series of sewage treatment lagoons. Filter-feeding waterfowl (Anatidae) probably used these ponds because of the availability of zooplankton as a food-source (Hamilton *et al*. 2005). These results from elsewhere support our hypothesis that improving water quality, especially reduced sewage input and higher dissolved oxygen, underlies the spread of a suite of birds associated with water within our study area.

The birds comprising the guild of "tits and warblers" nest in a wide variety of habitats – including swamp, grassland, reeds, hedges, scrub, woodland and gardens – but the common factor is that they are all exclusively insectivorous during the breeding season; adults may take occasional fruits, nuts and seeds for themselves, but deliver entirely live food to their chicks. Their invertebrate prey is expected to be sensitive to air quality and thus to have increased since the 1980s. There are, however, no direct measures of invertebrate diversity or abundance in our area, but there is likely to be a complex variety of species of unpredictable occurrence, as in studies of Sheffield gardens (Smith *et al*. 2006a; 2006b). As well as probably reducing the availability of invertebrate prey, aerial pollution may have other impacts on birds including reduced calcium, thus affecting egg quality. This might be severe enough to deter some birds from breeding. Species may well show differing sensitivity to these factors; in the vicinity of a copper smelter in Finland, for instance, Great Tits proved to be more robust than Pied Flycatchers (*Ficedula hypoleuca*) (Eeva and Lehikoinen 1995).

Supporting circumstantial evidence for the increase in insectivorous birds comes from observations in inner London, where the total of eight species breeding regularly in 1956 had risen to eleven in 1973, along with another six species either nesting occasionally or becoming established (Cramp 1973). By 2002 all eleven of the regular breeders were present and all but one (Coal Tit) had expanded their range, with little change in the other six occasional nesters (Hewlett 2002). It is not possible, however, to identify how much of this increase is attributable to the improved air quality rather than other factors such as, for example, improved habitat management (Montier 2009).

We might have expected the guild of aerial insectivores similarly to have benefited from an increase in prey, but their change in breeding distribution was not significantly different in Halton and Warrington from the rest of the county (Table 3). This is determined probably by factors other than food supply, including reduced availability of nest sites. Turner (1982) reported no impact of "moderate" (~100 µgm-3) levels of smoke and sulphur dioxide on the breeding density of Swallows, martins and Swifts, although higher levels of pollution probably depressed House Martin numbers in Manchester (Tatner 1978).

Amongst the "woodland specialists" guild there are likely to be different factors affecting different species, including the types of tree, their maturity and density. Most of them nest in trees, especially in holes (Stock Dove, Tawny Owl, Green Woodpecker, Great Spotted Woodpecker, Lesser Spotted Woodpecker, Coal Tit, Willow Tit, Marsh Tit, Nuthatch), but this broad category also includes species that nest within woodlands on the ground (Woodcock, Wood Warbler, Willow Warbler) or in the shrub layer (Blackcap, Garden Warbler, Chiffchaff), and some of the "woodland" birds will occasionally nest in hedgerow trees (e.g. Buzzard, Great Spotted Woodpecker, Treecreeper). Many of them spend the whole of the breeding season within woodland, and some indeed pass their entire lives in this habitat, while others (such as Sparrowhawk, Buzzard and Woodcock) may find much of their food away from trees.

In general, larger woods hold more of the „woodland specialist. species (Hinsley *et al*. 1996; Mörtberg 2001), and the area of trees within urban and suburban parks in Belgium was a good predictor of biodiversity (Cornelis and Hermy 2004). Woodland bird species richness in London parks was positively correlated with the site area and the area of rough grassland present, but not with the extent of tree cover, perhaps because deciduous trees were almost ubiquitous (Chamberlain *et al*. 2007), while in the suburbs of Paris, species richness was found to be mainly related to patch size and to the diversity of trees and shrubs (Husté *et al*. 2006). Analysis of the British Trust for Ornithology's Breeding Bird Survey data for urban areas shows complicated relationships between species and habitats, but the most important were the area and number of trees and bushes (Evans *et al*. 2009).

Nuthatch is often regarded as a key indicator species for a woodland landscape. They have a strong preference for broadleaved woods, especially oak trees; their main nest sites are old woodpecker holes, especially those made by Great Spotted Woodpecker, and snags where branches have broken off. Although there are no absolute thresholds, the species is rarely found breeding in woodlands smaller than 1 ha and younger than 20 years (Matthysen 1998). In Halton and Warrington some of the woodland planted in the early years of the New Towns (1960s-1980s) is now reaching maturity: from the figures given in Table 5 and Figure 5, it is likely that there are now enough large areas of woodland in the area, and also that there are some trees sufficiently old to hold breeding Nuthatches.

Most of the woodland guild requires mature trees but some of them depend on early-stage scrub (such as Garden Warbler, Willow Warbler and Lesser Redpoll). The two warbler species have both declined, but by proportionately less in Halton and Warrington than in the rest of Cheshire and Wirral: they have probably benefited from a succession of new plantings in the twenty years between the two bird atlases. Lesser Redpoll had its Cheshire stronghold in Halton and Warrington around the time of the first atlas (1978-84) but their distribution has contracted substantially as the national population has crashed.

The proportion of the land area taken up by domestic gardens in Halton and Warrington is almost twice that of the rest of the county (Table 1), and domestic gardens are often associated with high levels of diversity, of habitats and species (Gaston *et al*. 2005), so it might be expected that this would influence the numbers of bird species. But analysis of the habitat data submitted by fieldworkers in the second bird atlas shows that only five of the species in our guilds were recorded nesting in gardens in more than four tetrads in Halton and Warrington (Long-tailed Tit, Blue Tit, Great Tit, Coal Tit and Chaffinch). Domestic gardens are thus unlikely to have been significant for the species considered here, and there is no evidence that they have changed in their attractiveness to birds over the period covered by the two atlas projects, so we do not explore this relationship further in this paper. Also, the increase in birds breeding in urban parks in Montreal, Canada, was accompanied by an increase in cover by large trees, and a reduction in shrubs, but attributed mostly to installation of bird feeding stations (Morneau *et al*. 1999): there has also been a substantial rise in the provision of food for birds in the UK (Cannon 1999) but we doubt that there has been a differential increase between Halton and Warrington and the rest of the county.

Moreover, only seven of the species in our defined guilds make significant use of bird feeders (Great Spotted Woodpecker, Long-tailed Tit, Blue Tit, Great Tit, Coal Tit, Nuthatch and Chaffinch) so we reject this as a significant contributor to our results.

Perhaps the best-studied link between air quality and the natural world has been the presence or absence of lichens. As sulphur dioxide levels rise, lichens are lost according to a scale described by Hawksworth and Rose (1970). In the 1960s sulphur dioxide levels in Halton and Warrington were greater than the highest point of this scale (Figure 1) and hence it is likely that no lichens would be present in the area. As sulphur dioxide levels fall lichens begin to recolonise the area but the pattern of recolonisation is not a direct reversal of the pattern in which they are lost, as demonstrated in London (Hawksworth and McManus 1989). A tranche of six indicator species of epiphytic lichens recolonised the once polluted industrial areas of Halton and Warrington in the period between 1992 and 2002 (Fox and Guest 2003). It is these lichens that are used by Long-tailed Tits and Chaffinches to bind and camouflage their nests, and the surprising lack of these two very widespread species as breeding birds in 1978-84 had been attributed to the absence of lichens in our area (Guest *et al*. 1992). Although they are both insectivores during the breeding season, and there may be some influence of increased invertebrate numbers, it seems highly likely that the dominant factor is lichens and that, as suggested previously (Norman 2008), the improved air quality accordingly explains the increase in distribution of these two bird species in Halton and Warrington between 1978-84 and 2004-06.

Thus, in summary, we have shown that the increase of several ecological guilds of breeding birds in Halton and Warrington is linked to improvements in air quality, water quality and land use, especially the extent and maturity of woodland. It has recently been shown that site area is the most consistent and significant predictor of bird species richness in public green spaces, with a consequent recommendation that, to maximise the number of urban bird species, urban greenspace in the UK should be at least 10 ha in extent, and left without intensive management (Chamberlain *et al*. 2007). Now that aerial or aquatic pollution appears to present little constraint on breeding bird species in Halton and Warrington, habitat structure and area will probably be the most important factors in promoting further increases in avian diversity, and should be the focus of future urban planning and site management.

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