THE IMPACT OF BIRD POPULATIONS ON THE MICROBIOLOGICAL QUALITY OF BATHING WATERS

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ABSTRACT

To ensure optimum quality at Bathing Waters, the control of diffuse sources of bacterial contamination is receiving increasing attention. As part of an initiative to improve the quality of the EU designated bathing waters on the Fylde Coast (North West England), a project was undertaken to quantify the faecal indicator load from birds and assess the significance on water quality. High bird counts are encountered on the Fylde Coast with gulls, feral pigeons and starlings being prominent. The piers at Blackpool make an attractive roost for starlings with numbers peaking at over 30 000 in late summer. Systematic recording of bird numbers and locations was undertaken during 2001/2. Estimates were also made of the daily faecal organism production by the different species. The spatial distribution of faecal organisms from the bird population was statistically linked to synoptic water quality data. This allowed estimates to be made of the contribution from birds to the faecal pollution load at the bathing waters. The work confirmed a statistically significant link between bird populations and water quality with a marked seasonal bias.

Keywords: Bathing Waters, Birds, Diffuse Pollution, Faecal indicators

INTRODUCTION

European Directive 76/160/EEC, the 'Bathing Waters Directive', lays down, *inter alia*, minimum standards for faecal indicators in the water at bathing sites. In marked contrast to the majority of directives, which have been greeted by the UK public with either indifference or hostility, there has been considerable interest in bathing water quality, and achievement of the optional higher guideline standards is commonly used by coastal resorts as a marketing tool.

The Fylde coast of North West England (fig 1) has long been a major tourist destination and includes the resorts of St Annes, Blackpool and Fleetwood. During the 1990s some £400m was spent by the Water Utility on upgrading the sewerage infrastructure and providing secondary treatment at a new regional treatment plant. Despite this investment, the bathing waters continued to fail the European 'Imperative' standard, giving rise to considerable public concern, as well as prompting the European Commission to threaten infraction proceedings against the U.K. The response was a major programme of investigations into possible causes with an emphasis on diffuse inputs.

Whilst birds are an ever-present feature of any coastal resort, the Fylde coast presents an attractive environment for several species. Blackpool is blessed with three fine Victorian Piers and the intricate iron work presents an attractive roost, attested to by the build up of guano deposits under the decking. Feral pigeons and, principally, starlings (*Sturnus vulgaris*) are seasonally present in large numbers. The dusk sky blacked with thousands of starlings wheeling above the beach as they approach the roosts is a characteristic and memorable sight.

Anecdotal reports suggested that starling numbers exceeded 20 000 in late summer, whilst the production of faecal indicator organisms from avian species is not dissimilar to many mammals including humans (table1) (Kay 1998). Bird faeces may be deposited directly onto the beach and, unlike domestic sewage, bird faeces do not receive any treatment prior to discharge! This lead to a realisation that birds had the potential to be a significant contributor to the faecal indicator input to Fylde coastal waters.

Table 1

	E. Coli load (per day)
Chicken	2.4×10^{8}
Human	1.9×10^{9}
Gull	2×10^{9}
Duck	1.1×10^{10}
Sheep	1.8×10^{10}

The Environment Agency (EA) is the statutory body charged with ensuring good water quality, and this paper describes work undertaken during the summers of 2001 and 2002 to quantify the impact of bird populations.

OBJECTIVES

The programme had three main objectives:

- To evaluate the bird populations associated with Fylde beaches including their spatial and temporal variation.
- To determine if there was a statistically significant link between bird numbers and bathing water quality.

- To improve our understanding of the faecal load produced by birds in their natural habitat.

STUDY AREA

The survey area comprised an 8.5 km stretch of the Blackpool seafront, and included a 5 km stretch of coast between Bispham to the north and South Pier to the south incorporating Blackpool bathing waters and the adjacent piers. The extent of the study area was defined so as to encompass areas of high and low levels of faecal coliforms and *streptococci* and expected to contain high and low densities of intertidal birds. The inclusion of the Bispham area provided a control remote from any Starling roosts.

BIRD OBSERVATIONS

Methodology

To ensure adequate temporal coverage, 24 weekly surveys, each lasting two days and covering the four stages of the tidal cycle - high, ebb, low and flood tides, were conducted weekly on the site between early May and late October 2001. Each of these surveys was conducted within the 48 hour period prior to the scheduled bathing water compliance sample. Additionally, to determine whether there were any differences in the distribution and numbers of birds present between weekdays and weekends, the project also included two intensive four-day monitoring periods that included a Saturday and Sunday as well as two weekdays.

During the weekly bird surveys, bird species within the intertidal area were counted and mapped on 1:10 000 scale maps. These data were reinforced by additional weekly counts of the Pigeons breeding and roosting on the three piers. It was apparent that, even from the beginning of May, Starlings regularly roosted on each of Blackpool's three piers. As the three piers are widely spaced along the seafront, it was not possible to accurately count roosting Starlings on more than one pier at a time. Initially a different pier roost was counted each week on a regular rota, but from July to October, each of the piers was counted on successive nights. Observations commenced well before the first birds began to arrive and continued to dusk. The observation times were adjusted on a daily basis to allow for the changing of the seasons as well as the weather. The first Starlings began to arrive at roost earlier if the weather was poor (overcast and/or wet) and flights into the roosts finished earlier during very dull conditions.

To improve the overall data set, and gain some knowledge of inter annual variation, a similar series of observations was made during the summer of 2002 but restricted to the area of most interest, the 4km between Pleasure Beach and the Metropole Hotel that delineates Blackpool's tourist centre.

Results

Wading birds

Waders were present in only small numbers in the early part of the season, and although by late August numbers had increased, they were still low both in absolute terms and also in comparison with adjacent areas in the Ribble Estuary and Morecambe Bay.

Gulls

Five species of gull were noted with peak numbers in mid August. Most common were Herring Gulls (2000) and the Lesser Black-backed gull (220), with the remaining species present only in small numbers. Gulls were perhaps less common than anticipated given the opportunities for scavenging at a busy resort, and the highest numbers tended to be between North and South piers where visitor density is highest. It is possible that a selection of domestic refuse sites in the hinterland prove an irresistible counter attraction.

Feral pigeons

Like gulls, feral pigeons were omnipresent with the greatest concentration always centred around the three piers. Accurate quantification proved difficult as many pairs may remain hidden amongst the under-pier superstructure. Fewer than 50 birds were present in general on the intertidal substrate, although more than 400 were counted on or under the three piers on several occasions. During the busiest holiday period (July to September), pigeons were commonly fed scraps along the promenade, and flocks of between 40 and 50 birds were not unusual. Many pigeons were noted flying further inland and there was evidence that some of these birds roosted on the piers.

Starlings

Actual numbers changed with the seasons, with the expected post-breeding build up from July onwards, with an apparent peak during the last week of August. By far the largest numbers were recorded on North Pier, where the roost was an estimated 25,208 birds at its height. The largest count on Central Pier was of 9,193 birds at the end of August, and that on South Pier, 2,601 birds at the beginning of September. The largest number of Starlings was counted on the piers during the period 29st August to 1st September, when the grand total recorded on the three piers amounted to approximately 37,000 individuals.

It was presumed that the roosts would begin at the end of the breeding season (probably during August), and gradually build up during the autumn and early winter, as continental birds, principally from North-west Europe, arrived in the country and joined resident post-breeding birds. With this established pattern in mind, it was a surprise to find that there were varying numbers of Starlings roosting on all three of the piers throughout the survey period .

STATISTICAL MODELLING

Relationships between microbiological data from compliance sampling and the bird and environmental data were explored using generalized linear models (GLMs; McCullagh and Nelder, 1989). Statistical models were constructed using a "bottom-up" approach whereby relationships between water compliance data and each of the avian and available environmental measures were considered first using separate exploratory models and then combined using stepwise methods into the all-factor models.

A hierarchical approach was used to develop relationships between bird distributions, other environmental variables, and observed water quality:

- consider potential relationships between microbiological contaminants (MC) - faecal coliforms (FC), faecal *streptococci* (FS) or total coliforms (TC) - and the physical aspects of the environment. Values for microbiological contaminants were $\log_{10}$ transformed.
- consider potential relationships between microbiological contaminants and Starling numbers, with sampling location included as a class variable -again represented by the estimable factor location
- consider potential relationships between microbiological contaminants and the number and distribution of birds on the intertidal areas. Unlike gulls, the numbers of waders and pigeons recorded on the intertidal areas were insufficient to implicate either as the sole source of the microbiological contamination but were included in estimates of the overall microbiological contamination.
- consider potential relationships between microbiological contaminants and the overall number of birds across the entire study area.

These steps were used to develop combined (all factor) models. This was achieved by seeking the minimum allowable set of predictor variables from the suite of physical environmental variables and then seeking to explain residual variation by the inclusion of avian factors. The ultimate models for microbiological contaminants therefore included physical aspects of the environment, intertidal bird variables and Starling numbers (or the latter combined) as explanatory variables, with only those variables that significantly improved the model included.

Microbiological Data

Microbiological data from the compliance sampling were collected as part of the routine bathing waters monitoring programme. Three different measurements were supplied for the analysis, these being faecal coliforms (CFU/100ml), total coliforms (CFU/100ml) and faecal *streptococci* (CFU/100ml). Values of microbiological contaminant measurements were $\log_{10}$ transformed and averaged, using geometric means, across all samples within each compliance sampling period. These averages were either calculated separately for each sampling location (Bispham, North Pier, Central Pier and South Pier), across all piers or across all locations as appropriate for each analysis. Each sampling event collected data over a three day period for various heights of the tide.

Physical Environmental Data

In addition to the numbers and distributions of birds, which may have been related to values of faecal contaminants, a number of other factors are known to affect observed values of water compliance measurements, and it was important that these were taken into consideration during the modelling process. Sunlight, and in particular ultra-violet (UVB) radiation are known to kill the bacteria. Rain would lead to increased quantities of land surface runoff which could bring contaminants into the site from outside. Wind speed and direction are largely responsible for wave action and long-shore currents.

Intertidal Bird Distributions

The statistical approach adopted sought to relate bird numbers and distribution to measured levels of faecal contaminants. The bird data collected on the intertidal habitat could be considered using several options. Models could be derived based on the total bird numbers across the entire study area. Summing together birds of different species can be simplistic because the amount of faecal material an individual bird can be expected to produce will be related to its energy requirements, which in turn will be largely dependent on its size and also its taxonomic group. This was addressed by deriving indices based not on numbers but on energy requirements as described below. The other option, the proximity indices, also described below, takes this further by considering not only numbers but also the distribution of birds.

BMR indices

A bird's output of faecal material is related to its food intake, which in turn is related to its metabolic rate. The latter will differ on average between species and also with changes in environmental conditions, but the metabolic rate of a bird of a particular species would be expected to be closely related to its Basal Metabolic Rate (table 2) By weighting numbers of each species by BMR, numbers of different species were quantified on a common scale of measurement that facilitated summing by species group and across all species.

Table 2 Basic Metabolic Rate (BMR)

Species	BMR (Kcal/day)	Species	BMR (Kcal/day)
Oystercatcher	46	Black-headed Gull	29
Ringed Plover	9	Common Gull	41
Knot	18	Lesser Black backed Gull	67
Sanderling	9	Herring Gull	79
Dunlin	8	Yellow legged Gull	79
Curlew	64	Great Black backed Gull	116
Redshank	17	Feral Pigeon	38
Turnstone	15	Starling	19

Proximity Indices

While the BMR indices can be readily incorporated into statistical models, they fail to capture information regarding the distribution of birds within the site, and thus the way in which concentrations of birds may be related spatially to observed values of water compliance measurements. This was addressed by modelling the bird distributions within a Geographic Information System (GIS). The bird numbers and distribution data were digitally captured and incorporated into the GIS as geo-referenced polygons with boundaries corresponding to the limits of flocks recorded on the field maps and with associated attributes. For each species the numbers contained within each flock were reallocated to overlapping 100 m x 100 m grid cells in proportion to the area of overlap (between the grid cell and the flock polygon), and then, the values within each grid cell summed over the four surveys representing the complete tidal cycle. The values were then multiplied by the BMR of the species concerned. Bird values were thus represented on a common scale. This facilitated summing them across species whilst allowing for size differentials to give a measure of the overall bird distribution across the grid matrix. To capture the aspect of faecal contaminant input from the birds extending beyond the flock limits due both to being spread out from source by the water and flocks movement, flocks were observed through a complete tidal cycle. In areas where no flocks had been recorded it would be expected that levels of faecal contaminants would be related to their proximity to areas where birds had been recorded. Geostatistical interpolation (ESRI 2001) was used to derive *Group Proximity Indices* for gulls, waders, and Feral Pigeons and *an Intertidal Proximity Index* for all species combined. For Starlings data was collected simply as point counts. A process, known as Kriging, (a feature of most GIS software), uses statistical models that include auto-correlation (the statistical relationship between the measured points) to interpolate a smoothed surface between the measured points. Kriging weights the surrounding measured values to derive a prediction for an unmeasured location. These were the values that were spatially matched to water compliance sampling locations to provide inputs into the statistical modelling that followed (figure 2).

MODELLING RESULTS

The aim of this analysis was to model possible relationships between microbiological contaminants and a set of avian factors, having first controlled for physical aspects of the environment. Thus, models based on physical environmental variables, Starling roost counts and intertidal bird numbers and distributions were first explored separately and then combined for the all-factor analysis. By first considering separate models, either derived using physical variables only, or particular methods for quantifying bird numbers and distribution, it is possible to gain insight that may be obscured in the ultimate models. Once models had been controlled for external variables a set of models was constructed based on bird numbers and distributions. Some key results are summarised in table 3.

Table 3

variable	% explanation		
	total coliforms	faecal coliforms	faecal streptococci
No. of starlings roosting on North Pier (fit for all piers)	27	30	33
No. of starlings roosting on North Pier (fit for North Pier)	34	40	42
Gull Proximity Index	7		
Gull Basal Metabolic Rate	-	25	23
Intertidal Bird Index	18	26	25

The final stage was to create appropriate combined model in which all factors (physical and avian) are combined. Ultimately, different models were found to optimise the explanation for the numbers of the three indicator organisms.

Total coliforms: rain (22%) and northerly wind (40%) dominate; bird numbers did not increase model fit.
Faecal coliforms: rain, northerly wind and Gull BMR index overall explanation 70% with, gull BMR contributing 9%
Faecal Streptococci: rain, northerly wind, north pier starling numbers. Rain alone can explain up to 64% variation, but starlings numbers can explain up to 15% of the variation

FAECAL INDICATOR ORGANISM PRODUCTION BY STARLINGS

Methodology

The importance of starling roosts became evident early in the study. The only quantification for starling Faecal Indicator Organisms production available was based on gulls (table 1) factored according to BMR. The gull figures were subject to error as the measurements were made on caged captured birds which would be under some stress. Starlings represent numerically the majority of the birds present, and being largely confined to defined roosts on the piers there seemed to be the potential for making a realistic estimate of production of faecal indicators, data that was not otherwise available.

Plastic crates with a surface area of approximately $0.7m^2$ were covered by plastic sheets dished to a plastic funnel in the centre of the crate draining to a sterile container. These crates were placed beneath the piers. Faecal deposits collected onto the plastic sheeting were washed via the funnel into the sample bottle. By scaling up the area of the plastic sheeting to the total area under the piers and with a knowledge of the roost size an estimate of the faecal production per bird per night was made. Predictably the quantity of material collected by each crate was highly variable. However by placing multiple crates under each pier for a series of nights a reasonable estimate was made.

Results

As might be expected the results were highly variable, the levels and ranges of the key parameters measured are summarised in Table 4.

TABLE 4

4a. approximate area of starling roosts

site	area m^2
south pier	40
central pier	2 000
north pier	5 595

4b ratio wet:dry weights

	ratio
minimum	1.5
maximum	17.1
mean	5.5

4c production of faecal material

	gm faecal material x m^{-2} (dry weight)
minimum	0.036
maximum	12
geometric mean	5

4d faecal indicator levels

	E.coli cfu gm^{-1}
minimum	6.0×10^6
maximum	2.4×10^9
geometric mean	4.6×10^7

From these figures the following estimates were made of the starling contribution to the bathing waters:
mean load of faecal material = 210 kg per night
mean number of E-*coli* produced = 9.6×10^{12} cfu per night

DISCUSSION

Any experiment of this nature is constrained by the large number of variables to be considered, and it is critical that the interpretation of the data avoids making conclusions that are not statistically robust. It would be unrealistic to expect a limited experiment to describe the impact of the bird population with great accuracy, particularly as the variable nature of both environmental variables and other sources (e.g. storm sewage) will have an important influence. The more modest aim is to decide if control of bird populations is a necessary precursor to the consistent achievement of bathing water quality targets. The production of faecal indicators from Starlings varies according to diet, but on the Fylde is estimated at 40gm/bird/day wet weight (Feare 2002). Using values from table 4 the total production per bird per day = 3.4×10^8 *E coli*. This agrees remarkably well with that derived from the gull figure (table 1) factored by the BMR (table 2) = 4.8×10^8.
A interesting comparison is to compare the nocturnal roost load of 9.6×10^{12} cfu with the 4.9×10^{13} cfu from a typical secondary sewage treatment plant serving a population equivalent of 75 000. Feare also suggest a figure of approximately 10% of this matter being deposited under a roost making an estimate of 4 grams per bird per night. If this figure is multiplied by the peak starling numbers of 37,000 individuals an estimate of 148kg of faeces deposited per night can be obtained. This estimate also agrees well with the calculated weight of 210kg/night given the inherent errors of both estimates. These loads are significant and support the levels of explanation produced by the modelling.

Despite the uncertainties it does now appear that bird populations should be considered as potential contributors to lapses in bathing water quality, particularly in locations where diffuse sources dominate

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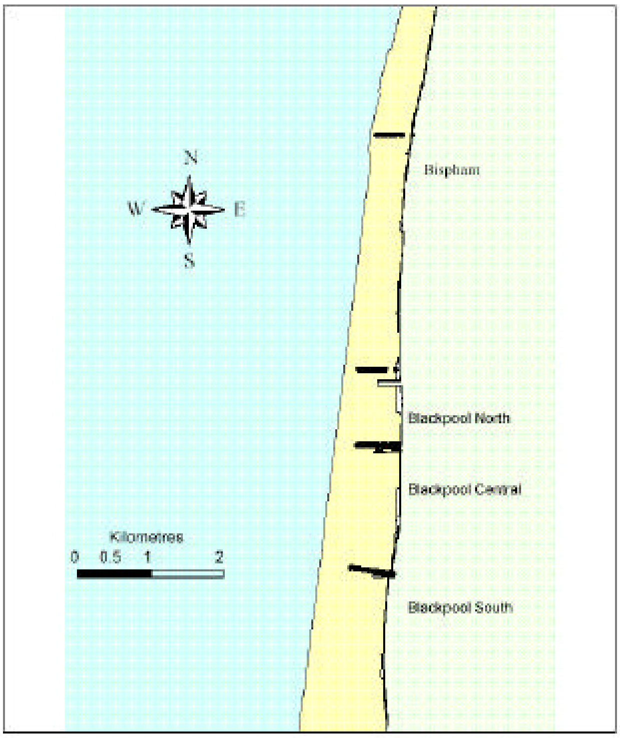

Figure 1 Blackpool and the Fylde Coast. (sampling points)

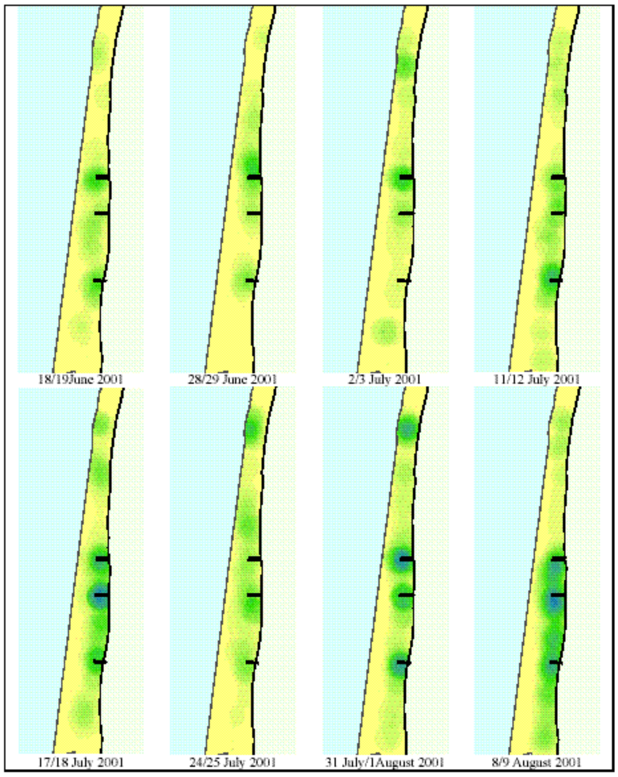

Figure 2 Distribution of starlings on the Blackpool. shoreline during 2002 depicted using the Bird Proximity Index