Associations of wintering waterfowl with freshwater on the mudflats of East Anglian estuaries

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Summary

1. The associations of wintering waterfowl with freshwater that flows over the intertidal mudflats of four East Anglian estuaries were studied between 1996 and 1998. The research was initiated in response to concerns over the impact of further reduction in freshwater inputs to these estuaries through abstraction. The wintering bird populations of these estuaries contribute to internationally recognised and designated conservation sites.

2. The numbers and densities of some waterfowl in corridors around freshwater flows were consistently greater than those on the remaining mudflats of all the estuaries studied. Shelduck, wigeon, pintail, grey plover and redshank showed the strongest relationships overall, and large proportions of the estuary populations of these species occurred around flows.

3. Defined flows were favoured over areas of freshwater seepage across broad fronts (from the base of a cliff and a reedbed). Birds occurred on the latter in similar densities to remaining mudflats. There was no overall preference of waterfowl for a particular type of channel or length of flow, nor were bird densities on individual mudflats and their flows correlated. Greater proportions of individual mudflat populations of some species actually occurred around flows when bird density was low.

4. At low tide, waders and shelduck were usually feeding on the lower shore around flows, especially where these fanned out, and other wildfowl roosting or preening. Counts through the tide revealed that the turnover of waterfowl around flows was often high and that land birds also used the flows to drink and preen. High densities of waterfowl remained in and around flows even as the tide covered them.

5. The densities of several species on one estuary were correlated with the volume of freshwater being discharged. Low densities of all waterfowl occurred around the smallest flows. Favoured flows on the estuaries studied had discharges of 1 litre/sec or more but the minimum required may vary according to estuary and width of mudflats. The density of only one species was correlated with discharge on the other estuaries, and this discrepancy may be caused by surrounding geology which affects the consistency of discharge as well as water temperature. There were no indications from the data that an upper limit of freshwater flow existed, but if it does it is likely that this will also vary according to width of mudflats.

6. The potential influence of freshwater on the distribution of waterfowl is discussed. Among possibilities are its effect on local microclimate, prey density or availability, as well as the shelter provided by channels. Little is known about impact of reducing the discharge of flows, although its effects on remaining mudflats may be similar to the displacement of birds from other intertidal grounds. It is also possible that loss of freshwater sources on mudflats could affect birds from other estuaries as well as on surrounding land.

Contents

1. Introduction

As in many parts of the UK, increasing demand for freshwater has led to the licensing of many small streams and creeks that flow over the mudflats of East Anglian estuaries for storage in reservoirs on neighbouring land, as well as straightforward abstraction for summer irrigation. Little is known about the role this freshwater plays in the ecology of the intertidal zones of estuaries other than inferences that can be drawn from studies of the variations in salinity, nutrients and sediment on mudflats which may affect local invertebrate populations (*e.g.* Hill *et al* 1993, Yates *et al* 1993). Currently, primarily owing to the large reduction in freshwater from river catchments, mudflat flows and creeks are often major contributors to the remaining freshwater inputs to estuaries. For example, they currently form about 35% of the freshwater component of the Orwell estuary during periods of low flow (Environment Agency), but no data exists on the range of discharge that needs to be maintained to minimise impact on the wildlife of estuaries.

The estuaries of East Anglia are important wildlife sites and are variously scheduled as Special Areas of Conservation (EC Habitats Directive), Special Protection Areas (EC Directive on Wild Birds and their Habitats), Ramsar sites (Ramsar Convention on Wetlands of International Importance) and Sites of Special Scientific Interest (Wildlife and Countryside Act 1981), usually for their wintering waterfowl populations (waders and wildfowl) (Table 1). They are also part of wider designations for their landscapes.

Table 1. The statutory landscape and conservation designations for the study estuaries and the species of waterfowl (that use mudflats) for which they are important (** internationally important, * nationally important) (the Stour and Orwell estuaries form a single SPA/Ramsar site). Source of data: English Nature citations and Cranswick *et al* (1997).

	Orwell	Stour	Blackwater	Alde
cSAC			*	
SPA	*	*	*	*
Ramsar	*	*	*	*
SSSI	*	*	*	*
AONB	*			*
Heritage Coast				*
Brent goose	*	*	**	
Shelduck	*	*	**	*
Wigeon		*		*
Teal			*	*
Pintail	*	*	*	
Ringed plover	*	*	*	
Grey plover		**	**	
Dunlin	*	**	**	
Black-tailed godwit	*	**	**	*
Curlew		*	*	
Redshank	**	**	**	**
Mean waterfowl population 1991/92-1995/96	24,445	50,219	77,252	25,137

In 1996, the Environment Agency commissioned a preliminary study on the importance of freshwater flows on three East Anglian estuaries using data from previous low water waterfowl counts. This suggested a broad relationship between the distribution of flows and high densities of some species of waterfowl (Ravenscroft 1996). In response to the requirement for more specific data, the Agency and English Nature initiated research to investigate the importance of flows to the wintering waterfowl populations for which these and other East Anglian estuaries are internationally and nationally recognised.

2. Objectives

1. Compare the numbers and densities of waterfowl at low water on the mudflats of four East Anglian estuaries with numbers around freshwater flows over the mudflats of these estuaries.

2. Investigate any preferences of waterfowl for particular characteristics of flows, in particular the range of freshwater discharge.

3. Methods

3.1 Study sites

Over the winters of 1996/97 and 1997/98 the study focused primarily on two estuaries, the Orwell and Stour. Both are SPA, Ramsar and SSSI for the majority of their lengths and support important wintering populations of several species of waterfowl (Table 1). Both have also been the subject of a series of previous studies and low water waterfowl counts. Over the second winter, the study was extended to parts of the Alde and Blackwater estuaries.

3.2 Freshwater flows

The distribution of freshwater flows was mapped along both shores of the Orwell and Stour estuaries and the north shore of the Blackwater. Flows varied from deep creeks to smaller surface flows that fanned out on the shore at low tide. Those that were temporary or extremely minor (ditch run-off or flows that disappeared on the upper shore) were not studied further. Around the Orwell and north Stour, these flows are comprised of groundwater that issues from a crag aquifer beneath the surrounding sandy soils. Around the south shore of the Stour and north shore of the Blackwater flows are primarily run-off from surrounding London Clay.

Twenty-seven flows and two areas of freshwater seepage across broad fronts (from a cliff and reed bed respectively) occurred on the Orwell, 12 flows on the Stour and 15 on the north shore of the Blackwater (appendix 4). The discharges (litres/second) of major freshwater flows in the centre of the channel and close to the high tide mark were measured using an OTT impeller type current meter with an accuracy of ±7%. It was not possible to measure the discharges of all flows that were counted as some (especially on the Orwell) had minimal and shallow discharges (<1litre/sec) and others were large, deep and muddy (Stour and Blackwater). Measurements were taken during the winter on the Orwell (16 in February 1997 and 18 in March 1998), Stour and Blackwater (9 and 12 flows respectively, both March/April 1998). To test any differences caused by variations in flows in summer, 12 discharges into the Orwell were also measured in August 1996.

In March 1997, the topography and other physical aspects of the Orwell flows were recorded where possible, such as channel depth, flow depth, channel width, steepness of banks and substrate. Analysis of bird distribution indicated that the middle and lower thirds of mudflats and flows were usually frequented at low tide and data was measured for these parts of flows.

3.2 *Whole estuary counts of birds*

Winter low water numbers of waterfowl (up to two hours either side of low tide) were counted on the entire estuaries in sections by teams of experienced waterfowl counters. Six counts were made on the Orwell in 1996/97 and six in 1997/98 (organised by the Suffolk Wildlife Trust, SWT), four on the Stour in 1996/97, and three along the north shore of the Blackwater in 1997/98 (both organised by the Royal Society for the Protection of Birds, RSPB). The Orwell, Stour and Blackwater were counted in the low water sections used in previous low water counts for the Wetland Bird Survey (WEBS) organised by the British Trust for Ornithology (BTO). Counts affected by poor weather were omitted from analyses (one each for the Orwell and Stour in 1996/97).

Winter means of bird numbers and densities were affected by small sample size (the number of counts) and by large variations in populations during the winter of 1996/97 when counts were made monthly from October to March. In 1997/98, counts of the Orwell and Blackwater were made only during the midwinter period (December to February) when bird populations were largest and more stable.

3.3 *Counts of flows*

During the whole estuary counts of the Orwell and Blackwater, observers counted the number of each species of waterfowl that occurred at low tide within an estimated band 10m either side of each freshwater flow being studied (i.e. a corridor of 20m). During the counts of the Stour estuary in 1996/97, birds were counted in a corridor 50m either side of flows (100m wide overall).

Six counts were also made in demarcated 20m and 400m corridors around nine flows of the Stour and two of the Alde in midwinter 1997/98. These counts used landmarks and compass bearings to re-locate measured corridors. On the Orwell in 1997/98, similar counts were made at hourly intervals around two flows through the tidal cycle from low to high tide.

During all counts on the Orwell in both winters, the behaviour of each bird or flock of birds within the flow corridor was recorded. During the counts on the Alde in 1997/98 the behaviour of all birds in both corridors around flows was recorded.

3.4 *Analysis of data*

Bird densities

The mudflat area of estuaries was measured from O.S. 1:10000 maps or obtained from previous measurements made by the RSPB, SWT or BTO. The total areas of the Orwell, Stour and north shore of the Blackwater were 602.4ha, 1584.2ha and 1087ha respectively. Areas of flow count corridors or seepages were calculated using the dimensions of count corridors and lengths of flows measured from O.S. maps. The total flow areas were 10.8ha (and 28.9ha of seepages) on the Orwell, 38.5ha on the Stour and 8.4ha on the Blackwater. Owing to weather and time constraints around low tide, it was not always possible to count all flows within a single estuary count. During such counts, numbers of birds around uncounted flows were included in the estuary count. Relative areas of flows and remaining mudflats were adjusted accordingly when calculating and comparing the densities of species (birds per ha).

Comparisons of counts

The mean winter densities of species around the flows and on remaining seepages and mudflats of the Orwell were compared with the Kruskal-Wallis test (non-parametric analysis of variance). However, as sample size for all estuaries (the number of winter counts) was small and fluctuating bird populations caused high variation in means, the raw population data for each count on each estuary, separated into counted flows and remaining mudflats (including uncounted flows), was also compared. Expected numbers were extrapolated from the relative areas of the estuary represented by flows and mudflats on that count. As numerous tests were performed on the data, a significance level of 1% is used for Chi-square tests.

Count error

Flow corridors were estimated by eye during whole estuary counts. It was not feasible to mark out corridors during these counts and observers trialled the technique beforehand against measured corridors. To account for possible error arising from difficulties in estimating the count corridor at large distances, comparisons were made between bird count data calculated for an assumed double corridor width around flows (40m for the Orwell and Blackwater and 200m for the Stour) and remaining mudflats, in addition to the intended count corridor.

4. Results

4.1 Bird densities around flows

The mean proportions of waterfowl occurring in flow corridors were large given the areas flows represented of each estuary (Table 2). In particular, the proportions of shelduck, wigeon, pintail and redshank around flows were notably high, although in general these trends were less pronounced on the Stour. On occasions, over 10% of most species studied occurred around the flows of each estuary.

Several species (shelduck, wigeon, pintail, grey plover and redshank) occurred in significantly greater densities around the flows of the Orwell compared with mudflats and seepages (Table 3). Densities of other species, such as dunlin, curlew and brent goose, were usually greater around flows but means were highly variable. None of the species studied occurred in significantly greater densities on mudflats or seepages and densities of most species were similar on these two parts of the Orwell. Sample size was too small for similar comparisons using the whole estuary counts of the Stour and Blackwater.

Counts of individual mudflats revealed that the same five species also occurred at greater densities around flows on the Stour and Alde (Table 4). Brent goose, curlew and dunlin were also present in greater densities on one or other estuary.

Table 4. The mean densities (birds per ha) recorded in marked 20m and 400m corridors around nine freshwater flows of the Stour estuary and two flows of the Alde estuary over the midwinter period of 1997/98. Means of the two corridors were compared with the paired Mann-Whitney test (* $P<0.05$, ** $P<0.01$). There were no brent goose, plovers and black-tailed godwit on the parts of the Alde studied.

	Stour (n=51)			Alde (n=12)		
	20m	400m	U	20m	400m	U
Brent goose	34.4±14.8	0.5±0.2	2.8**	-	-	-
Shelduck	3.3±0.9	0.3±0.06	3.1**	13.7±3.4	1.4±0.4	2.9**
Wigeon	10.4±3.3	0.9±0.2	4.1**	87.2±22.1	5.2±1.6	2.8**
Pintail	1.4±0.5	0.02±0.01	2.9**	13.5±2.3	0.9±0.4	3.0**
Ringed plover	0.1±0.04	0.1±0.04	0.2	-	-	-
Grey plover	1.7±0.4	0.6±0.1	2.4*	-	-	-
Dunlin	6.9±2.0	6.4±1.2	0.7	25.4±8.9	5.8±1.8	2.3*
Curlew	1.4±0.3	0.4±0.1	3.3**	2.8±1.0	0.4±0.1	1.9
Redshank	3.5±0.6	0.6±0.2	4.7**	7.1±2.0	1.2±0.3	2.2*
Black-tailed godwit	0.3±0.2	0.1±0.06	1.2	-	-	-

4.2 Comparisons of counts

Chi-square analysis of the observed and expected distributions of birds around flows and on mudflats for each whole estuary count also indicated that some species favoured the vicinity of flows (Table 5 and appendix 2). These differences were also apparent in the larger count corridors used on the Stour. Shelduck, wigeon, pintail and redshank, as well as dunlin and curlew, were consistently present in significantly greater numbers than expected around flows and the differences were consistent across all three estuaries (appendix 2). Grey plover showed fewer positive associations with flows (primarily owing to the low numbers expected as flows represented such small areas of each

Table 2. The mean and maximum proportions of the wintering populations of waterfowl recorded around the freshwater flows of three East Anglian estuaries. Figures in brackets are the count areas around flows as a mean percentage of the estuary area (data for Orwell does not include seepages).

	Orwell 1996/97 (1.88%)		Orwell 1997/98 (1.86%)		Stour 1996/97 (1.99%)		Blackwater 1997/98 (0.57%)	
	Mean ± SE (n=5)	*Max*	*Mean±SE (n=6)*	*Max*	*Mean±SE (n=3)*	*Max*	*Mean±SE (n=3)*	*Max*
Brent goose	2.8±1.3	7.5	2.6±1.8	11.1	2.6±1	7.6	2.2±2.2	6.6
Shelduck	13.9±3.8	24.8	14.5±2.1	19.0	4.0±1.4	5.6	2.8±0.7	4.1
Wigeon	17.2±3.7	27.7	13.9±1.7	19.8	20.1±10.2	39.9	5.4±5.4	16.1
Pintail	43.5±15.2	100	23.9±5.2	34.8	2.6±1.4	4.9	1.2±1.2	3.6
Ringed plover	16.7±10	61.1	3.1±2.4	15.2	2.0±1.4	4.7	5.6±3.5	11.9
Grey plover	9.9±4.5	29.8	5.4±1.5	11.9	4.5±3.4	11.2	1.2±0.9	2.9
Dunlin	12.9±6.2	39.8	4.0±1.8	12.7	1.3±0.6	2.4	1.4±0.4	1.9
Curlew	3.5±0.7	6.1	2.5±0.8	5.5	4.2±0.5	4.8	0.7±0.04	0.8
Redshank	11.8±0.4	13.1	7.9±1.7	15	4.9±2.9	10.7	7.2±1.9	11.0
Black-tailed godwit	5.2±1.7	10.6	3.1±1.4	9.7	3.3±1.1	4.9	12.0±6.4	21.8

Table 3. The mean (& SE) densities (birds per ha) of waterfowl around freshwater flows, on freshwater seepages and on the remaining areas of mudflat of the Orwell estuary over the winters of 1996/97 and 1997/98 compared with the Kruskal-Wallis test (non-parametric ANOVA).

	1996/97 (*n*=5)			Kruskal-Wallis	1997/98 (*n*=6)			Kruskal-Wallis
	Flows	Seepages	Mudflats		Flows	Seepages	Mudflats	
Brent goose	1.7±1.3	0	0.9±0.3	8.3*	0.7±0.5	0	0.9±0.3	9.7**
Shelduck	9.3±3.4	1.7±0.8	0.8±0.2	3.8	10.2±2.1	0.9±0.1	1.1±0.1	11.8**
Wigeon	16.9±8.1	0.1±0.1	1.6±0.4	12.1**	14.5±3.8	0.5±0.3	1.7±0.4	13.8**
Pintail	2.6±1.1	0.2±0.2	0.1±0.1	9.5**	3.6±1.5	0	0.2±0.06	10.6**
Ringed plover	3.3±2.6	0.3±0.2	0.2±0.02	3.8	0.4±0.3	0.03±0.03	0.5±0.2	7.9*
Grey plover	0.8±0.2	0.05±0.04	0.2±0.04	9.3**	1.0±0.2	0.02±0.01	0.4±0.1	14.5**
Dunlin	29.1±12.3	7.7±5.2	6.6±2.6	3.3	14.9±5.8	18.3±6.0	7.1±0.8	1.3
Curlew	1.6±0.3	0.5±0.2	0.9±0.1	6.1*	1.4±0.5	0.3±0.1	1.0±0.1	7.4*
Redshank	17.8±1.7	8.7±3.7	2.5±0.2	6.9*	11.4±1.5	6.1±2.4	2.8±0.3	7.6*
Black-tailed godwit	1.2±0.5	0.3±0.1	0.4±0.2	1.8	1.0±0.5	1.2±0.5	0.5±0.1	0.1

estuary; similar problems were encountered with brent goose, ringed plover and black-tailed godwit). Assuming an error of 100% in the estimation of count corridors by observers, the distribution of shelduck, wigeon, pintail and redshank was still biased towards flows on most counts on all three estuaries (Table 5 and appendix 2), although in these analyses dunlin and curlew showed more even distributions across the mudflats.

4.3 *Bird behaviour*

Most wigeon and pintail were usually loafing or preening in the close vicinity of flows (Table 6). Most waders, shelduck and brent goose in flow corridors were usually feeding, and all brent goose, 69% of shelduck, 33% of curlew and 12% of redshank were feeding in the flow itself (41% of brent goose and 10% of shelduck were drinking). Virtually all non-feeding waders and brent goose in flow count corridors were washing or preening in the flows (91-100%), while most feeding wigeon and pintail were doing so in the flows (67% and 100% resp.).

On the Alde estuary, comparisons of numbers of birds loafing, preening or feeding around flows with those on the surrounding mudflat revealed that fewer shelduck than expected were feeding close to flows and greater numbers preening ($\chi^2 = 42.2$, *d.f.* 2, $P<0.01$). Wigeon and pintail showed similar differences in behaviour close to flows ($\chi^2 = 251.1$, *d.f.* 2, $P<0.01$ and $\chi^2 = 539.4$, *d.f.* 2, $P<0.01$ respectively). Expected numbers of waders were too small for analysis although a relatively high proportion of redshank were preening in flows.

Table 6. The behaviour of waterfowl in freshwater flow count corridors. Pooled data from the Orwell and Alde estuaries.

	Feeding		Non-feeding	
	n	%	*n*	%
Brent goose	1098	81	253	19
Shelduck	1063	68	510	32
Wigeon	436	14	2763	86
Pintail	87	13	581	87
Ringed plover	213	97	6	3
Grey plover	175	95	9	5
Dunlin	3118	99	35	1
Curlew	245	94	17	6
Redshank	1873	96	78	4
Black-tailed godwit	149	98	3	2

Counts through the tide revealed that most species occurred at higher densities around flows for most of the tidal cycle. They also indicated that numbers were highly variable and that there were large turnovers of birds using flow corridors. Some species such as the wildfowl, grey plover and curlew vacated mudflats 2-3 hours after low water (Table 7) and wildfowl would gather in large numbers on the water at the mouth of flows. Some species, such as ringed plover, seemed to use flows more as high water approached, when they would be joined by other species such as lapwing and gulls.

Table 7. The mean densities of birds (no. per ha) in 20m and 400m corridors around two flows on the Orwell in 1997/98 through the tidal cycle. Number of counts in brackets.

		Hours after low water				
		1hr (4)	2hrs (6)	3hrs (6)	4hrs (6)	5hrs (5)
Shelduck	20m	12.4±3.7	10.2±4.7	7.4±4.3	0	0
	400m	1.1±0.4	0.3±0.1	0.5±0.3	3.1±2.4	0.1±0.1
Pintail	20m	7.9±6.8	9.5±6.3	0	0	0
	400m	0.9±0.6	0.1±0.1	0	0.4±0.4	0
Ringed plover	20m	0.8±0.8	4.0±2.3	0.4±0.4	9.3±0.2	3.2±3.2
	400m	0	0.1±0.1	0.1±0.1	1.3±0.2	0.9±.9
Grey plover	20m	3.5±1.5	3.7±1.5	0	0	1.6±1.6
	400m	1.3±0.3	1.5±0.6	0.2±0.1	0.3±0.3	0
Dunlin	20m	49.0±28.3	56.3±17.1	0.8±0.8	37.8±14.9	8.0±8.0
	400m	26.0±8.8	21.1±3.5	23.5±7.9	30.6±9.7	2.9±2.1
Curlew	20m	8.3±4.7	0.8±0.8	0	0	0
	400m	3.2±1.1	0.1±0.1	0	0	0
Redshank	20m	9.9±2.2	13.9±5.6	18.0±13.3	10.9±4.2	1.5±1.5
	400m	6.1±2.6	5.6±1.3	7±1.4	7.6±3.0	2.3±2.3

4.4 *Favoured flow characteristics*

There was no consistent affinity of all waterfowl with any particular type of channel (i.e. deep, shallow, wide, narrow). There were, however, some indications of species-specific preferences, particularly for the plovers (Table 8).

Table 8. Significant associations of waterfowl with particular types of channel (* P<0.05, ** P<0.01, sample sizes in brackets). All channel categories (including channel width) were tested on all species and those species and categories not tabulated showed no relationships.

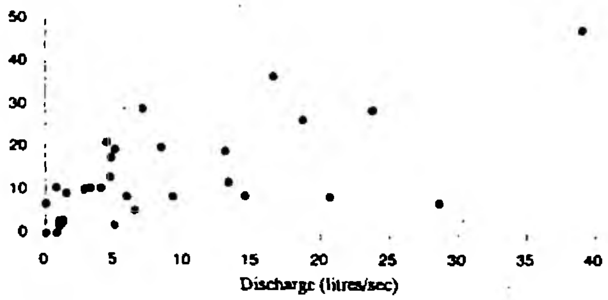
	Mean density (birds per ha)			Kruskal-Wallis
1. Bank slope	*Flat (45)*	*Gentle (15)*	*Steep (15)*	
Ringed plover	0.3±0.2	1.5±1.5	22.7±18.1	10.6**
Grey plover	0.2±0.1	2.3±1.3	2.5±1.0	8.3*
2. Channel depth	*0-0.1m (35)*	*0.1-0.5m (25)*	*>0.5m (15)*	
Pintail	11.1±7.7	1.9±1.9	1.6±0.8	6.6*
Ringed plover	0	0.5±0.3	14.5±10.9	8.0*
Grey plover	0.6±0.3	0.2±0.2	2.5±0.9	8.4*
3. Water depth	*0-0.04m(35)*	*0.05-0.1m (25)*	*>0.1m (15)*	
Wigeon	6.4±2.7	62.1±35.9	11.5±6.8	8.7*
Ringed plover	0.4±0.3	14.5±10.9	0	7.8*
Dunlin	19.8±7.5	77.4±27.4	22.5±15.8	8.0*
Curlew	2.6±1.5	3.3±1.2	0.3±0.3	7.2*
4. Channel substrate	*Mud(30)*	*Sand/gravel(25)*	*Mixture(20)*	
Shelduck	15.3±5.6	39.0±14.9	5.4±2.0	7.2*
Ringed plover	12.1±9.1	0.7±0.5	0	6.0*
Grey plover	2.3±0.8	0.2±0.2	0.4±0.2	6.1*

There was also no indication of any preference of waterfowl for particular length of flows. There were positive relationships for pintail (Spearman's r= 0.43, n=27, P<0.05) and grey plover (r=0.44, n=27, P<0.02) on the Orwell in 1996/97 and a negative relationship for dunlin on the Blackwater (r= -0.73, n=12, P<0.01), but none for all other species on all estuaries.

A more consistent relationship resulted from comparisons of mean bird densities around flows with flow discharges (Table 9). Generally, low densities of most species occurred around small flows, but the analysis was hampered by the difficulty of measuring the discharges of the numerous small flows that occurred generally and those of deeper, muddy flows on the Stour and Blackwater. Despite this, several species showed positive relationships on the Orwell, in particular shelduck and redshank (Fig. 1). Only redshank were correlated with discharge on the other estuaries.

Table 9. Spearman correlation coefficients of mean winter waterfowl density and rate of discharge of flows (litres/sec). Discharges of some flows on the Orwell were measured in the summer of 1996 as well as the winter of 1996/97. (* $P<0.05$, ** $P<0.01$).

	Orwell 1996/97			Orwell	Stour	Blackwater
	Summer	Winter	Mean	1997/98	1997/98	1997/98
	n=12	n=16	n=16	n=18	n=9	n=12
Brent Goose	0.22	0.14	0.14	0.23	0.37	-
Shelduck	0.69*	0.7**	0.67**	0.63**	0.31	-0.1
Wigeon	0.05	-0.05	0.04	0.28	0.65	-
Pintail	0.48	0.36	0.38	0.34	0.43	-
Ringed Plover	0.53	0.32	0.35	0.15	0.57	-
Grey Plover	0.68*	0.45	0.52*	0.57*	0.25	0.03
Dunlin	0.16	0.1	0.12	0.65**	0.3	0.47
Curlew	0.59*	0.54*	0.57*	0.31	0.2	0.01
Redshank	0.76*	0.68**	0.72**	0.13	0.82*	0.59*
Black-tailed godwit	0.16	0.02	0.02	-0.01	-0.06	0.57



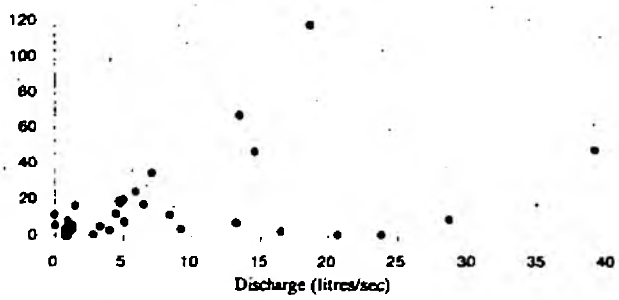


Fig. 1. The densities (birds per ha, y axis) of two species (left, shelduck and right, redshank) on the flows of the Orwell estuary (pooled 1996/97 and 1997/98 data) compared with mean freshwater discharge (correlation coefficient: shelduck r=0.68, n=34, $P<0.001$, $y = 1.29 + 0.55x$; redshank r=0.4, n=34, $P<0.02$, $y = 5.47 + 0.15x$).

5. Discussion

5.1 The attraction of flows

Freshwater flows over mudflats appeared to be an important feature for overwintering waterfowl on all four estuaries studied. This preference was evident in comparisons between numbers around flows with whole estuaries and with surrounding mudflats. Generally, there was no preference for length of flow, nor a single type of flow or channel, but the densities of several species increased with greater freshwater discharge on one estuary. Birds occurred in normal densities on freshwater seepage over large areas of mudflat and around small flows which generally petered out on the upper shore.

With birds that occurred in tight flocks, such as brent goose, pintail and wigeon, this preference was obvious and it was often easy to distinguish the presence and course of freshwater by the line of birds around it. These species primarily used the freshwater for washing and preening, and an added benefit may be the shelter and/or protection provided by deeper channels during severe weather. Reducing heat loss on exposed mudflats is important to waterfowl (Kersten & Piersma 1987). On the Alde, large flocks of wildfowl (including teal and mallard) would gather in the channel of one deep flow during periods of high winds.

At low tide, most feeding birds occurred on the lower shore and this is presumably because of higher densities of prey (Yates *et al* 1993). This may account for the observed preference for larger flows as these will reach this part of the mudflat. Birds particularly favoured the parts of flows that fanned out on the lower shore and on an incoming tide larger waders such as curlew and redshank would remain in these areas and feed in shallow water. Ducks would gather in large numbers on the water in the same areas. There were indications that flows that petered out mid-shore were used more as the tide came in, especially by feeding birds such as dunlin and shelduck.

There was also a high turnover of birds around flows and flocks of waders and wildfowl would alight in flows for short periods to preen and drink before dispersing to neighbouring mudflats and elsewhere to feed. Flocks of birds from surrounding land also used flows *e.g.* black-headed gulls and lapwing. It seems likely, therefore, that flows may service birds in a larger area of the estuary than is obvious from this study.

There are a number of potential reasons why freshwater flows are attractive to feeding birds, although it is well established that waders tend to concentrate on mudflats where prey density or feeding rate is high (Bryant 1979; Goss-Custard 1980, 1985; Goss-Custard *et al* 1977, 1991; Yates *et al* 1993). The most relevant are listed below.

1. Freshwater run-off from surrounding land may increase local nutrient input to mudflats. Possible benefactors would be algae and invertebrates such as *Hydrobia* which are algal grazers. These are one of the main prey items of shelduck and dunlin. In areas of organic enrichment on mudflats, the few invertebrates that are able to exploit these conditions are found in high densities around the source. Normal mudflat communities are also enhanced close to these sources (Hill *et al* 1993).

2. The flows may carry food items in the form of detritus for invertebrates such as surface-feeding polychaetes and filter-feeding molluscs, or even larger matter for birds (although birds were rarely witnessed feeding in flows). Larger prey items of waders, such as ragworm *Nereis diversicolor* and the amphipod *C. volutator*, prefer organically rich areas (Yates *et al* 1993). The size or quality of prey items also influences bird distribution on mudflats (Sutherland 1982).

3. Waders prefer the lower shore for feeding because of higher invertebrate densities, but also because the mudflat surface remains wet, maintaining the activity of invertebrates and hence their availability (Yates *et al* 1993). Flows over mudflats, especially where they fan out over the lower and middle shores, may have a similar effect.

4. There will be a local effect of freshwater on the salinity of the surrounding mudflats. Euryhaline invertebrates may occur in greater densities, such as ragworm *Nereis diversicolor*, lugworm *Arenicola marina* and *C. volutator*, all favoured prey items of wintering waders.

Birds are also known to favour certain parts of estuaries according to estuarine effects of salinity and sediment on prey distribution (Goss-Custard *et al* 1977, Bryant 1979). Wigeon and pintail, for example, are mid-estuary species. It is therefore possible that freshwater flows occurred in the parts of estuaries that were favoured by waterfowl anyway. This seems unlikely as flows were distributed along the entire lengths of the estuaries. Anyway, bird density around the flows of 12 sections of the Orwell was independent of bird density on the mudflats of each section (Table 10). If flows occurred in favoured parts of the estuary a positive relationship might be expected between the densities on each (densities were negatively correlated in one comparison). Greater proportions of redshank and shelduck actually occurred around flows when section bird density was low, a pattern which strengthens the overall conclusion that flows are favoured and that they remain favoured even when a mudflat provides otherwise relatively poor conditions.

Table 10. Comparisons of the mean winter waterfowl density (birds per ha) on the mudflats of each of the 12 count sections of the Orwell estuary with 1) the mean density around the flows within those sections and 2) the mean percentage of the section population occurring around its flows (n=12, Spearman's r, * P<0.05). Also shown is the maximum proportion of a section population occurring around its flows. Species selected are those distributed along the entire length of the Orwell.

Species	(1) r	(2) r	Maximum proportion of section population around flows %
Shelduck 1996/97	-0.31	-0.69*	52.2
Shelduck 1997/98	-0.46	-0.71*	54.9
Dunlin 1996/97	0.19	0.25	38.9
Dunlin 1997/98	0.49	-0.42	42.3
Redshank 1996/97	-0.60*	-0.73*	82.0
Redshank 1997/98	-0.38	-0.37	78.5

5.2 *Thresholds of freshwater discharge*

Although it is clear that waterfowl favoured flows, not all species showed positive relationships with discharge. This suggests that the amount of freshwater within flows may not be critical to all species, such as those that use flows primarily for shelter. Nevertheless, it is clear that the presence of freshwater is still essential, if only to maintain channels for shelter. Identification of the range of discharges necessary would provide information that would assist licensing decisions without impacting on the estuarine environment.

Redshank showed the most consistent relationship with discharge, being positively correlated on all three estuaries. All other correlations were confined to the Orwell. Data analysis was hindered by the difficulty of measuring some flows and by the small sample sizes on the Stour and Blackwater. It is also likely that other factors may influence the choice of flows in the same way as mudflats, such as disturbance and vulnerability to predators as well as the proximity to favoured roosts (Prater 1981). This would produce a non-consistent relationship with discharge despite a consistent preference for flows compared with surrounding mudflats. These factors may have had less influence on the Orwell which has mudflats of more or less consistent width along its length.

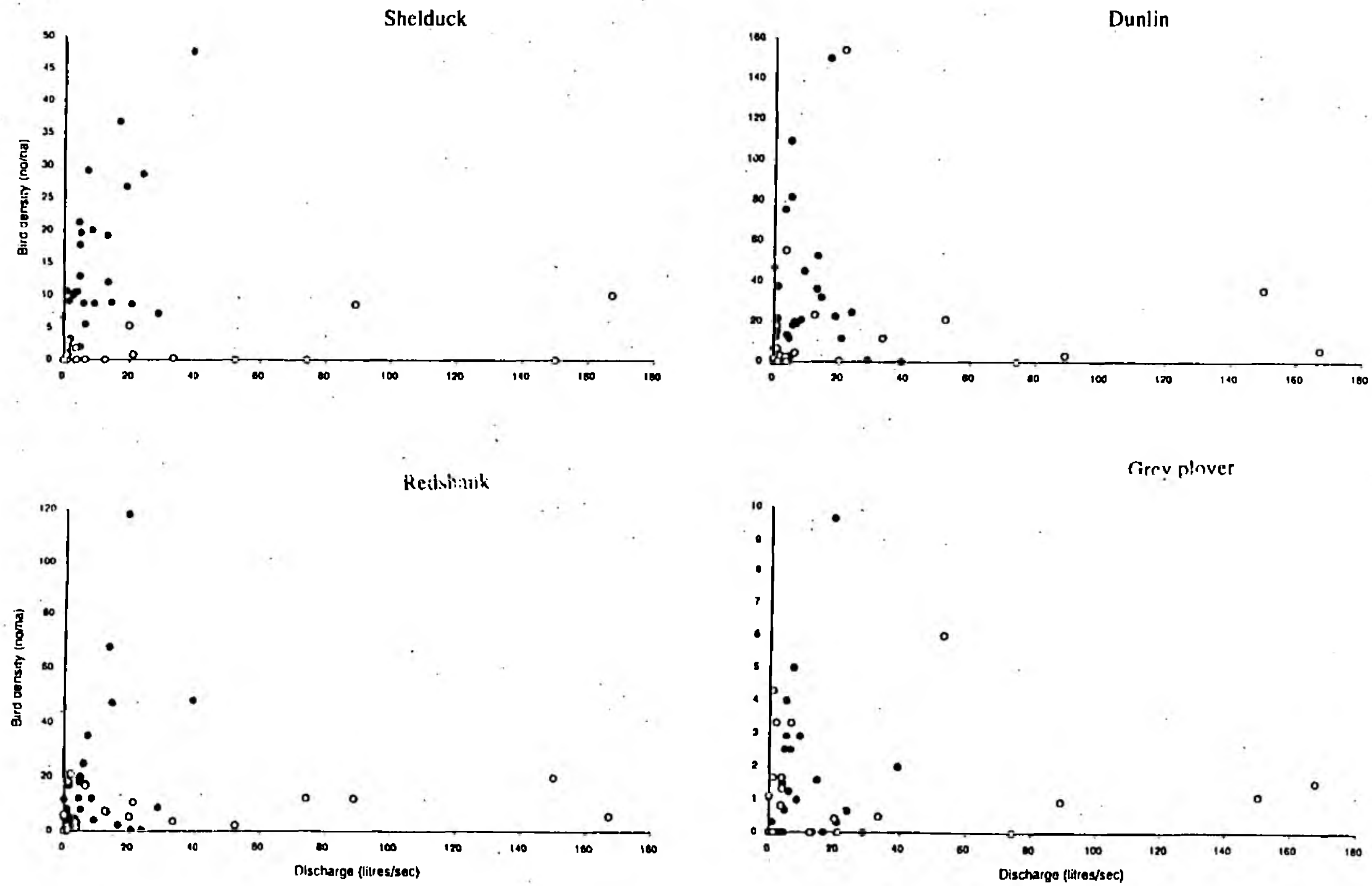
It seems probable that the discharge necessary to produce attractive features for waterfowl may vary according to mudflat size if a pre-requisite is the ability of a flows to reach the middle and lower shores at low tide. Large flows across small mudflats and *vice-versa* may not be suitable. It is possible to identify the lower threshold of flow necessary for the relatively small mudflats of the Orwell. The smallest flows had a discharge of 0.75 litre/sec. If smaller flows with unmeasurable discharges are added to the analysis at this rate, more species show strong relationships with discharge (Table 11). This also reinforces the conclusion that lower densities of waterfowl occurred around smaller flows.

Table 11. Spearman correlation coefficients of mean winter waterfowl density around the freshwater flows of the Orwell compared with water discharge after smaller, unmeasured flows have been included at the rate of 0.75 litres/sec, the smallest measured on the Orwell (such flows were not counted on the Stour and Blackwater). * P<0.05, ** P<0.01, *** P<0.001.

Species	1996/97 *n*=25	1997/98 *n*=26
Shelduck	0.77***	0.80***
Wigeon	0.50*	0.51*
Pintail	0.47*	0.33
Grey plover	0.67**	0.69***
Dunlin	0.33	0.61**
Curlew	0.70***	0.45*
Redshank	0.75***	0.3

The relationships on the Orwell are linear (Fig. 1), but the largest flow on this estuary was a modest 48 litres/sec. If the data for the Stour and Blackwater, which had larger flows to 170 litres/sec, is included, the plots suggest thresholds of about 60 litres/sec beyond which the densities of most species do not really increase (Fig. 2). However, overall densities of wintering birds varied between the estuaries. Redshank, for

Fig. 2. The mean winter densities of four species of waterfowl around the freshwater flows of the Orwell (both winters, closed circles), Stour and Blackwater (open circles) compared with flow discharge. Clockwise from top left are shelduck, dunlin, grey plover and redshank.



example, occurred at mean densities of 2.7 and 2.8 birds/ha on the Orwell in the two winters studied, but only 1 and 1.3 birds/ha on the Blackwater and Stour respectively. The densities around flows on the Stour and Blackwater were also generally lower than the Orwell (Fig. 2).

It therefore seems that if an upper limit of discharges does exist beyond which water can be licensed safely it will vary from estuary to estuary. It remains possible that there is no upper limit although flows that are deep and channelled may hold little attraction to waterfowl. On the Orwell, it appears that none of the discharges can be reduced safely, but this range may not be appropriate on larger estuaries with larger mudflats. Given more data, it may be possible to construct a model to predict what minium rates of discharge are required for flows to reach the middle and lower parts of differing sizes mudflats at low tide.

5.3 *The nature of flows*

Other factors may account for the differences in the strength of correlations between bird density and water discharge on the estuaries. There are differences in the geology of the estuaries which affect the nature of freshwater discharge. The flows of the Orwell (and the north shore of the Stour) are derived from groundwater in a crag aquifer around the estuaries, and emerge at a relatively constant 7-8C (Environment Agency). There was little variation in freshwater discharge in flows between the seasons (apart from that caused by abstraction) and bird density was related to summer as well as winter discharges (Table 9). Those of the Blackwater (and the south shore of the Stour) are largely over London Clay and are subject to large variation in discharge and temperature as they consist primarily of run-off.

The effects of these differences may be two-fold. Firstly, the elevated temperature of groundwater compared with surface and estuarine waters may produce a rise in local microclimate on mudflats, especially in the coldest winter months, and may be attractive to roosting and feeding birds alike. Flows will remain ice-free during freezes and mudflats around groundwater-fed flows may remain ice-free for longer. These effects will also be greatest around the largest flows. Freshwater may also benefit local invertebrate populations through raised body temperatures or through maintaining suitable feeding conditions. This may increase prey availability to birds during severe weather. Low temperatures reduce the activity of invertebrates and some, such as the amphipod *Corophium volutator* (a favoured prey item of redshank), cease to emerge from burrows below about 4C (Goss-Custard 1969).

Secondly, if a freshwater component on mudflats contributes to better feeding conditions for some birds, the consistent discharge of groundwater-fed flows may be preferable to those which are fed by run-off. There will be discharge during spring and summer months during the period that invertebrate stocks are recovering after winter depletion. Run-off flows will be much reduced or dry in summer. It must be remembered, however, that erratic flows such as those on the Stour and Blackwater are still attractive to waterfowl (appendix 2). One of the flows studied on the Alde estuary results from pumping of water from behind the sea wall and this suggests that some interest may be maintained through artificial and occasional discharges of water.

5.4 *Impact of altered discharges*

What remains unclear is whether seasonal reductions in flows are relevant and whether flows may be safely reduced at specific times of year. Most existing licenses in the Orwell catchment are for summer abstraction. Shelduck and redshank are summer breeders around East Anglian estuaries and their use of estuaries at these times has yet to be investigated.

What is also unclear is the actual impact of reduced freshwater flow on waterfowl and whether this has knock-on effects on feeding birds similar to the loss of intertidal areas to development, which may increase food competition and winter mortality among displaced birds and those on remaining feeding grounds (Goss-Custard *et al.* 1995). Presumably, the loss of freshwater for washing and preening so close to feeding grounds would have a pronounced impact on wintering waterfowl, as well as the land birds that use the flows, necessitating long journeys to other mudflats, estuaries or areas of shallow (unfrozen) water on neighbouring land. On the Orwell at least, substantial proportions of the estuary populations of some birds could be involved and changes in freshwater availability on mudflats could affect birds on other estuaries as well as on surrounding land.

6. Conclusions

1. Several species of wintering waterfowl were consistently present in greater densities around the flows of all four estuaries studied.

2. The benefit of freshwater to feeding birds is unknown but may be increased invertebrate prey densities or availability, or the effects of raised microclimate during poor weather. Many birds also sheltered in channels and preened and drank in flows.

3. The amount of freshwater in flows was important to several species on the Orwell (shelduck, wigeon, pintail, grey plover, dunlin, curlew and redshank), but given current data apparently to only redshank on the Stour and Blackwater. The relationship between birds and flows will be complicated by other factors and differences between the estuaries may result from variation in the sizes of mudflats, and the proximity of flows to roosts, disturbance and predators.

4. Surrounding geology also produces consistent flows on the Orwell and erratic flows on the remaining estuaries. The latter may be less attractive to birds, although they still appear to be favoured compared with mudflats. Pumped flows can also produce suitable conditions for waterfowl.

5. At this stage it is difficult to determine whether upper thresholds of freshwater discharge exist beyond which freshwater can be licensed without impact on bird populations. Currently, there is no upper limit on the Orwell. If thresholds exist on other estuaries, they will vary according to width of mudflats.

7. Further study

1. The association between wintering waterfowl and freshwater flows has been established on two whole estuaries and parts of two others in East Anglia. Data gathered on other estuaries in different parts of the UK will help establish the national

(and international) significance of these associations. It is hoped that the study will be extended to the Thames estuary and parts of north Norfolk over the winter of 1998/99.

2. The relationship between bird densities and flow discharge is well established on the Orwell but further data is required on other estuaries, including the Stour and Blackwater. Of particular relevance to licensing issues is the discharge range required on different sizes of mudflat. Further data may clarify this relationship. Little is also known of the seasonal effects of varying discharge.

8. Acknowledgements

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Appendix 1.

The dates of counts and areas (ha) of freshwater flows and mudflats counted on the Orwell, Stour and Blackwater used in chi-square analyses.

	Flows	Seepages	Mudflats	Total ha
Orwell 1996/97				
1: 21.10.96	10.8	28.9	562.7	602.4
2: 19.12.96	10.8	28.9	562.7	602.4
3: 16.1.97	10.8	28.9	562.7	602.4
4: 14.2.97	10.8	28.9	562.7	602.4
5: 18.3.97	10.8	28.9	562.7	602.4
Orwell 1997/98				
1: 9.12.97	7.6	21.2	408.7	437.5
2: 22.12.97	10.8	28.9	562.7	602.4
3: 8.1.98	10.8	28.9	562.7	602.4
4: 22.1.98	10.8	28.9	562.7	602.4
5: 5.2.98	10.8	28.9	562.7	602.4
6: 20.2.98	7.6	21.2	408.7	437.5
Stour 1996/97				
1: 3.11.96	37	-	1547.2	1584.2
2: 5.1.97	27.3	-	1556.9	1584.2
3: 2.2.97	30.3	-	1553.9	1584.2
Blackwater 1997/98				
1: 22.12.97	8.4	-	1078.6	1087
2: 18.1.98	8.4	-	1078.6	1087
3: 21.2.98	8.4	-	1078.6	1087

Appendix 2.

The numbers of birds observed during the winters of 1996/97 and 1997/98 around freshwater flows and on the remainder of the Orwell (not including seepages), during 1996/97 on Stour and during 1997/98 on the Blackwater compared with numbers expected when a) observers correctly counted birds within 20m flow corridors, and b) when it is assumed that they actually counted in a 40m corridor (* P< 0.01, highlighted values are those where birds appear to favour flows).

Orwell 1996/97

Species	Count	Observed numbers		Expected numbers					
				a) 20m corridor			b) 40m corridor		
		Flows	Mudflats	Flows	Mudflats	χ^2	Flows	Mudflats	χ^2
Brent goose	1	7	137	3	141	-	5	139	0.8
	2	0	137	3	134	-	5	132	-
	3	5	995	19	981	10.4*	38	962	29.4*
	4	74	918	19	973	167*	37	955	37.3*
	5	5	507	10	502	2.3	19	493	11*
Shelduck	1	0	16	0	16	-	1	15	-
	2	40	333	7	366	157.8*	14	359	49.8*
	3	206	626	16	816	2356.5*	31	801	1011.7*
	4	123	774	17	880	679.3*	34	863	244.8*
	5	135	534	13	656	1212*	25	644	497.2*
Wigeon	1	117	1017	21	1113	436.6*	43	1091	134.3*
	2	89	1237	25	1301	167.3*	50	1276	31.7*
	3	529	1507	38	1998	6399.5*	77	1959	2772.4*
	4	131	723	16	838	836.9*	32	822	315.6*
	5	46	120	3	163	-	6	160	276.7*
Pintail	1	14	37	1	50	-	2	49	-
	2	16	162	3	175	-	7	171	12.1*
	3	33	167	4	196	-	8	192	81.4*
	4	71	39	2	108	-	4	106	-
	5	5	0	0	5	-	0	5	-
Ringed plover	1	146	93	5	234	4533.9*	9	230	2166.6*
	2	11	139	3	147	-	6	144	4.3
	3	8	158	3	163	-	6	160	0.7
	4	0	99	2	97	-	4	95	-
	5	12	103	2	113	-	4	111	-
Grey plover	1	14	33	1	46	-	2	45	-
	2	6	138	3	141	-	5	139	0.2
	3	16	161	3	174	-	7	170	12*
	4	7	154	3	158	-	6	155	0.2
	5	2	79	1	80	-	3	78	-
Dunlin	1	40	758	15	783	42.3*	30	768	3.4
	2	768	5115	111	5772	3973.6*	222	5661	1400.3*
	3	429	8377	166	8640	425.7*	332	8474	29.7*
	4	73	3932	75	3930	0.1	151	3854	41.7*
	5	260	393	12	641	5085.3*	25	628	2341.4*
Curlew	1	19	458	9	468	11.4*	18	459	0.1
	2	26	399	8	417	41.2*	16	409	6.5
	3	19	607	12	614	4.5	24	602	0.9
	4	16	487	9	494	4.6	19	484	0.5
	5	6	530	10	526	1.7	20	513	15.1*
Redshank	1	261	1728	37	1952	1359.7*	75	1914	480.3*
	2	180	1397	30	1547	775.3*	59	1518	254.5*
	3	154	1260	27	1387	621*	53	1361	198*
	4	189	1535	32	1692	7769.2*	65	1659	246.3*
	5	180	1228	27	1381	905.5*	53	1355	315.9*
Black-tailed godwit	1	29	554	11	572	30*	22	561	2.3
	2	3	141	3	141	-	5	139	-
	3	21	177	4	194	-	7	191	29*
	4	13	141	3	151	-	6	148	8.5*
	5	0	65	1	64	-	2	63	-

Orwell 1997/98

Species	Count	Observed numbers		Expected numbers					
				a) 20m corridor			b) 40m corridor		
		Flows	Mudflats	Flows	Mudflats	χ^2	Flows	Mudflats	χ^2
Brent goose	1	25	538	10	543	22.5*	21	542	0.8
	2	8	64	1	71	-	3	69	-
	3	0	60	1	59	-	2	58	-
	4	0	603	11	592	-	23	580	-
	5	0	875	16	859	-	33	842	-
	6	0	600	11	589	-	22	578	-
Shelduck	1	27	267	5	289	98.5*	11	283	24.2*
	2	53	675	14	714	110.8*	27	701	26*
	3	131	559	13	677	1091.6*	26	664	440.6*
	4	109	677	15	771	600.5*	30	756	216.3*
	5	162	696	16	842	1357.6*	32	826	548.6*
	6	117	512	11	618	936.6*	23	606	398.7*
Wigeon	1	243	1480	31	1692	1417.6*	63	1660	533.8*
	2	107	1050	22	1135	334.8*	44	1113	93.8*
	3	92	640	14	718	443*	28	704	152.1*
	4	77	710	15	772	261.2*	30	757	76.5*
	5	186	751	18	919	1598.7*	35	902	676.7*
	6	94	434	10	518	719.2*	19	509	307.1*
Pintail	1	6	32	1	37	-	1	37	-
	2	16	200	4	212	-	8	208	8.3*
	3	67	155	4	218	-	8	214	451.4*
	4	101	189	5	285	1875.5*	11	279	765.4*
	5	43	94	3	134	-	5	132	299.7*
	6	0	0	0	0	-	0	0	-
Ringed plover	1	0	131	2	129	-	5	126	-
	2	2	150	3	149	-	6	146	-
	3	3	202	4	201	-	8	197	-
	4	20	112	2	130	-	5	127	46.8*
	5	3	952	18	937	-	36	919	-
	6	0	94	2	92	-	3	91	-
Grey plover	1	5	77	2	80	-	3	79	-
	2	19	141	3	157	-	6	154	29.3*
	3	9	139	3	145	-	6	142	1.6
	4	8	395	8	395	0	15	388	3.4
	5	11	375	7	379	2.3	15	371	1.1
	6	8	218	4	222	-	8	218	0
Dunlin	1	287	1972	41	2218	1503.3*	82	2177	531.8*
	2	70	3089	59	3100	2.1	119	3040	20.9*
	3	124	4715	91	4748	12.2*	182	4657	19.2*
	4	78	4476	86	4468	0.7	172	4382	53.4*
	5	280	5745	113	5912	251.5*	227	5798	12.8*
	6	2	2410	44	2368	-	88	2324	-
Curlew	1	1	228	4	225	-	8	221	-
	2	26	593	12	607	16.6*	23	596	0.4
	3	13	581	11	583	0.4	22	572	3.8
	4	36	614	12	638	48.9*	25	625	5.0
	5	5	768	15	758	6.8*	29	744	20.6*
	6	7	365	7	365	0	14	358	3.6
Redshank	1	101	1010	20	1091	334.1*	41	1070	91.2*
	2	138	1881	38	1981	268.2*	76	1943	52.5*
	3	139	1479	30	1588	403.5*	61	1557	103.6*
	4	47	1929	37	1939	2.7	74	1902	10.2*
	5	151	858	19	990	934.6*	38	971	349.2*
	6	82	1429	28	1483	106.1*	55	1456	13.7*
Black-tailed godwit	1	1	125	2	124	-	5	121	-
	2	4	220	4	220	-	8	216	-
	3	34	318	7	345	106.2*	13	339	35.2*
	4	18	462	9	471	9.2*	18	462	0
	5	9	323	6	326	1.5	12	320	0.8
	6	0	148	3	145	-	6	142	-

Stour 1996/97 (too few data for ringed plover)

Species	Count	Observed numbers		Expected numbers					
				a) 100m corridor			b) 200m corridor		
		Flows	Mudflats	Flows	Mudflats	χ^2	Flows	Mudflats	χ^2
Brent goose	1	36	1231	29	1238	1.7	59	1208	9.4*
	2	1	142	2	141	-	5	138	-
	3	43	989	20	1012	27*	39	993	0.4
Shelduck	1	26	440	11	455	20.9*	22	444	0.8
	2	28	2219	39	2208	3.1	77	2170	32.3*
	3	115	2079	42	2152	129.4*	84	2110	11.9*
Wigeon	1	763	1147	44	1866	12026.2*	89	1821	5353.7*
	2	212	3102	57	3257	428.9*	114	3200	87.2*
	3	536	3311	73	3774	2993.4*	147	3700	1070.3*
Pintail	1	0	118	3	115	-	5	113	-
	2	22	696	12	706	8.5*	25	693	0.4
	3	29	563	11	581	30*	23	569	1.6
Grey plover	1	106	838	22	922	328.4*	44	900	91.6*
	2	9	597	10	596	0.1	21	585	7.1*
	3	25	3477	67	3435	26.8*	134	3368	92.1*
Dunlin	1	10	6800	159	6651	142.9*	318	6492	312.9*
	2	361	14754	260	14855	39.9*	521	14594	50.9*
	3	204	16472	319	16357	41.7*	637	16039	306*
Curlew	1	42	825	20	847	24.7*	40	827	0.1
	2	23	702	12	713	10.3*	25	700	0.2
	3	31	666	13	684	25.4*	27	670	0.6
Redshank	1	23	1759	41	1741	8.1*	83	1699	45.5*
	2	206	1725	33	1898	922.8*	67	1864	298.7*
	3	66	2352	46	2372	8.9*	92	2326	7.6*
Black-tailed godwit	1	46	1173	28	1191	11.8*	57	1162	2.2
	2	60	1160	21	1199	73.7*	42	1178	8*
	3	26	1967	38	1955	3.9	76	1917	34.2*

Blackwater 1997/98 (too few data for wigeon, pintail and ringed plover).

Species	Count	Observed numbers		Expected numbers					
				a) 20m corridor			b) 40m corridor		
		Flows	Mudflats	Flows	Mudflats	χ^2	Flows	Mudflats	χ^2
Brent goose	1	0	1200	9	1191	-	18	1182	-
	2	0	1201	9	1192	-	18	1183	-
	3	54	767	6	815	386.8*	13	808	131.4*
Shelduck	1	33	766	6	793	122.4*	12	787	37.3*
	2	11	652	5	658	7.2*	10	653	0.1
	3	16	569	4	581	-	9	576	5.5*
Grey plover	1	2	1437	11	1428	-	22	1417	-
	2	5	1018	8	1015	1.1	16	1007	7.7*
	3	19	638	5	652	39.5*	10	647	8.2*
Dunlin	1	106	10651	83	10674	6.4*	166	10591	22.1*
	2	125	11702	91	11736	12.8*	182	11645	18.1*
	3	179	9457	74	9562	150.1*	148	9488	6.6*
Curlew	1	3	454	3	454	-	7	450	-
	2	3	426	3	426	-	7	422	-
	3	5	623	5	623	0	10	618	2.5
Redshank	1	53	947	8	992	255.2*	15	985	97.7*
	2	68	1223	10	1281	339*	20	1271	117*
	3	143	1156	10	1289	1782.6*	20	1279	768.3*
Black-tailed godwit	1	0	12	1	11	-	1	11	-
	2	6	36	1	41	-	1	41	-
	3	22	79	1	100	-	1	100	-

Appendix 3.

The areas around flows counted on the estuaries studied, the discharges recorded and the mean densities of birds in the flow corridors.

Orwell 1996/97

Flow no.	Area ha.	Discharge litres/sec		Mean bird densities (n=5 counts) no./ha									
		Summer	Winter	BG	SH	WN	PT	RP	GV	DN	CU	RK	BW
1	0.15	0	0	0	6.7	18.7	0	0	0	46.7	0	11.7	1.33
2	0.15	0.75	0.75	0	0	0	0	0	0	0	0	4	0
3	0.25	1	1	0	1.6	20.8	0	0	0	0	0	0	0
4	0.25		28.7	0	7.2	4.8	11.2	0	0	0.8	0.8	8.8	0
5	0.4			0	0	0	0	0	0	0	0	0.5	0
6	0.4	1	1.25	0	3	5	0	0	0	37.5	0.5	6	2.5
7	0.4			0	0	8.5	0	0.5	0	15	0	0.5	1.5
8	0.4			0	0	0	0	0	0	9.5	0	2.5	0
9	0.4			0	0	0	0	0	0	3.5	1.5	2.5	0
10	0.4	3.5	3.25	0	10.5	15.5	31	0	0	75.5	0.5	5	0.5
11	0.4			0	1	0	2	0	0	0	0	0	0
12	0.5	0	0.75	0	0	0	0	0	0	0	0	0	0
13	0.5	11.2	13.3	0	12	8.8	0	2.8	0	52.4	4	67.6	13.2
14	0.4	4	4	0	10.5	18	0	7.5	1.5	13.5	2	3.5	0
15	0.4			0	0	0	0	2.5	0	1.5	0	0	0
16	0.4	6	5	0	2	50	0	60.5	4	81.5	6	20	2.5
17	0.4	7.5	6.5	36.5	5.5	5.5	0	8.5	2.5	20	2	17.5	5.6
18	0.5			7.2	11.6	223	0.8	4.4	5.2	107.6	6.8	80.4	0.4
19	0.2		8.4	0	20	12	0	0	1	21	1	12	0
20	0.5	42.9	39.1	0	47.6	4	7.2	0	2	0	0	48	0
21	0.2			0	116	0	0	0	0	45	10	25	0
22	0.4			0	3.6	0	0	0	0	0	0	0	0
23	0.6		1	0	2.7	0	4.7	0	0.33	15.3	0.3	8.3	0
24	0.9	14	14.5	0	8.9	10.4	1.6	0.7	1.6	32.2	2.7	47.1	0
25	0.3			0	0	0	0	0	0	37.3	0	3.3	0
26	0.3			0	0	0	0	0	0	0	0	0	0
27	0.6		4.8	0	17.7	4	3.7	0	0.7	109	1	18	0.33

Orwell 1997/98

Flow no.	Area ha.	Discharge litres/sec		Mean bird densities (n=6 counts) no./ha									
		Summer	Winter	BG	SH	WN	PT	RP	GV	DN	CU	RK	BW
1	0.15		0	0	0	0	0	0	0	6.67	0	5.55	0
2	0.15		0.75	0	0	0	0	0	0	0	0	3.33	0
3	0.25		2.8	0.83	10	24.7	0	0	0	0	0	0.67	0
4	0.25		23.8	0	28.7	0	7.33	8	0.67	24.7	0	0.67	0
5	0.4			0	0	0	2.5	0	0	0.83	0	6.25	15.4
6	0.4		1.25	0	2.5	2.5	1.67	0.83	0	21.7	0.83	3.33	1.7
7	0.4			0	5.42	0	3.33	3.75	0	24.2	0.42	11.3	2.1
8	0.4			0	0.83	6.25	0	0	0	10.4	0.42	9.17	2.5
9	0.4			0	5.41	0.42	0.83	0	0	0	0	2.5	0
10	0.4		4.5	0	21.3	2.92	29.6	0	0	0	1.25	12.1	0.42
11	0.4		1.5	0	9.17	7.1	0.83	0	0	1.25	0	16.7	0.83
12	0.5		0.75	0	10.7	0	0	0	0	0	0	0	0
13	0.5		20.7	0	8.7	0	0	0	0.33	11.7	0.33	0.67	0.33

14	0.4		4.7	0	12.9	86.7	0	0.83	2.5	11.7	5.83	19.6	2.5
15	0.4			0	0	0	0	0	0	0	0	0	0
16	0.4		5.9	0	8.75	46.7	0	0	1.25	18.3	3.33	24.6	0
17	0.4		5.1	4.6	19.6	13.7	0	1.25	2.92	2.92	5.42	7.92	1.67
18	0.5			0	3.33	0	0	0	0	0	0	0	0
19	0.2		16.6	10	36.7	38.3	0	0	0	150	5	2.5	0
20	0.5		18.8	0	26.7	90.3	18	0	9.67	22.7	2.33	118	0
21	0.2		7.1	0	29.2	0	0	0	5	19.2	0	35	0
22	0.4			0	0	0	0	0	0	0	0	0	0
23	0.6		0.75	0	0	0	0	0	0	12.5	0.42	1.25	0
24	0.9		13.1	1.5	19.2	1.67	11.7	0	0	36.1	8.61	7.22	0
25	0.3			0	5.83	0	0	0	0	4.2	0	1.67	0
26	0.3			0	0	0	0	0	0	0	0	0	0
27	0.6		9.2	0	8.75	9.2	12.9	0	2.92	45	0	4.17	0

Stour 1997/98

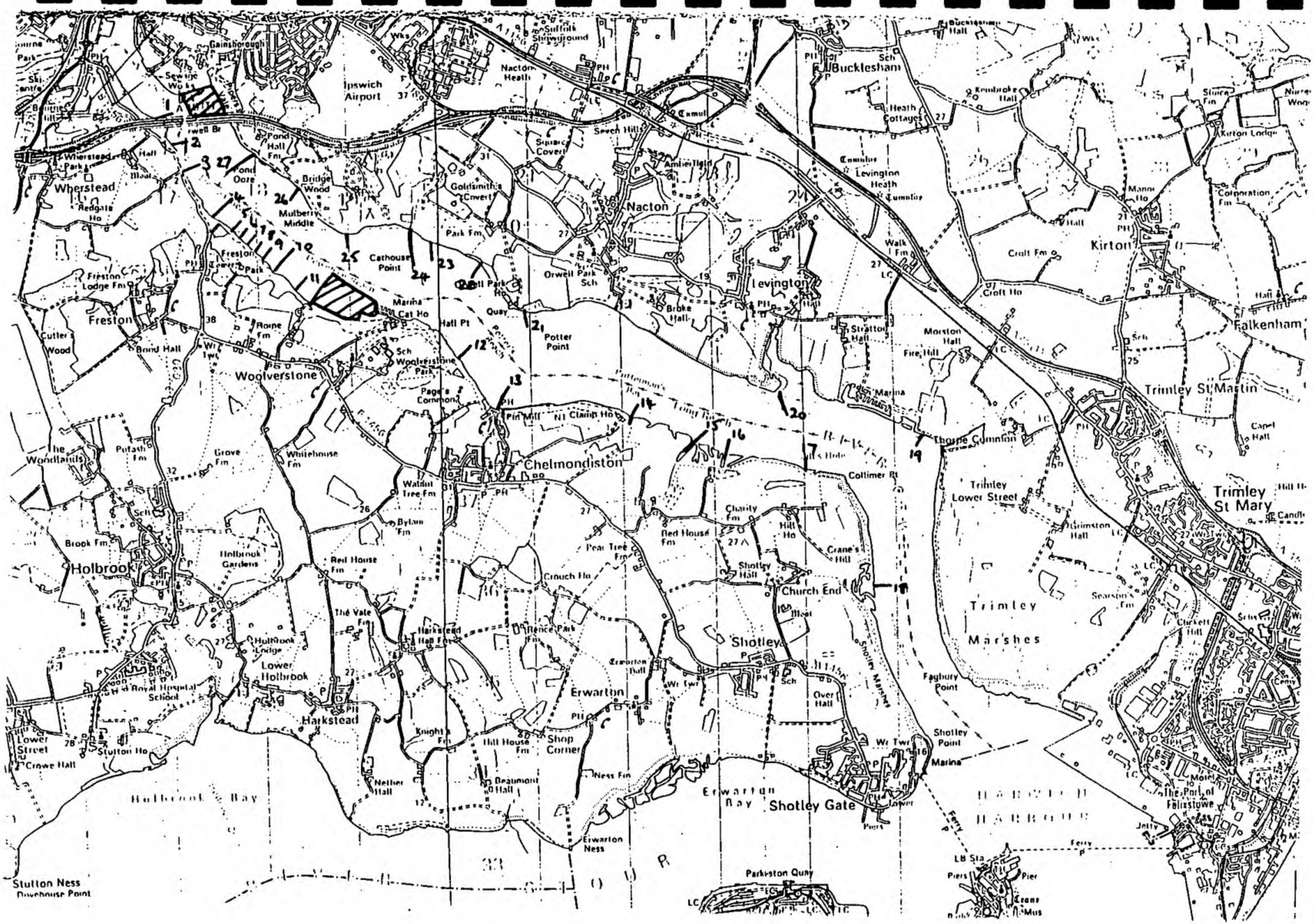
Flow no.	Area ha.	Discharge litres/sec		Mean bird densities (n=6 counts) no./ha									
		Summer	Winter	BG	SH	WN	PT	RP	GV	DN	CU	RK	BW
1	0.65		33.3	0	0.26	0.26	8.7	0	0.51	11.8	1.03	3.8	0
2	0.65		167	4.1	10	39.7	0	0.26	1.54	5.9	3.8	5.9	0
3	1.5		1	0	2.1	4.7	0	0	4.3	18.2	2.2	1.8	0.33
4	0.8		3.6	128	1.87	4.58	0.31	0	0.83	2.5	0.63	0.83	0
5	2.35		89	38.2	8.6	7	2.9	0	0.96	3.2	0.95	12.2	0
6	0.25		3.9	0	0	0	0	0	1.33	0	1.33	1.33	0
7	0.75		20	134	5.33	10.4	0.22	0.22	0.44	0.44	1.11	5.56	0.67
8	1.2		52.5	0.33	0	28.3	1.17	0.33	6	21.3	1	2.33	1.8
9	0.6		1.3	0	3.05	0	0	0	0	0	0.28	0.55	0

Blackwater 1997/98

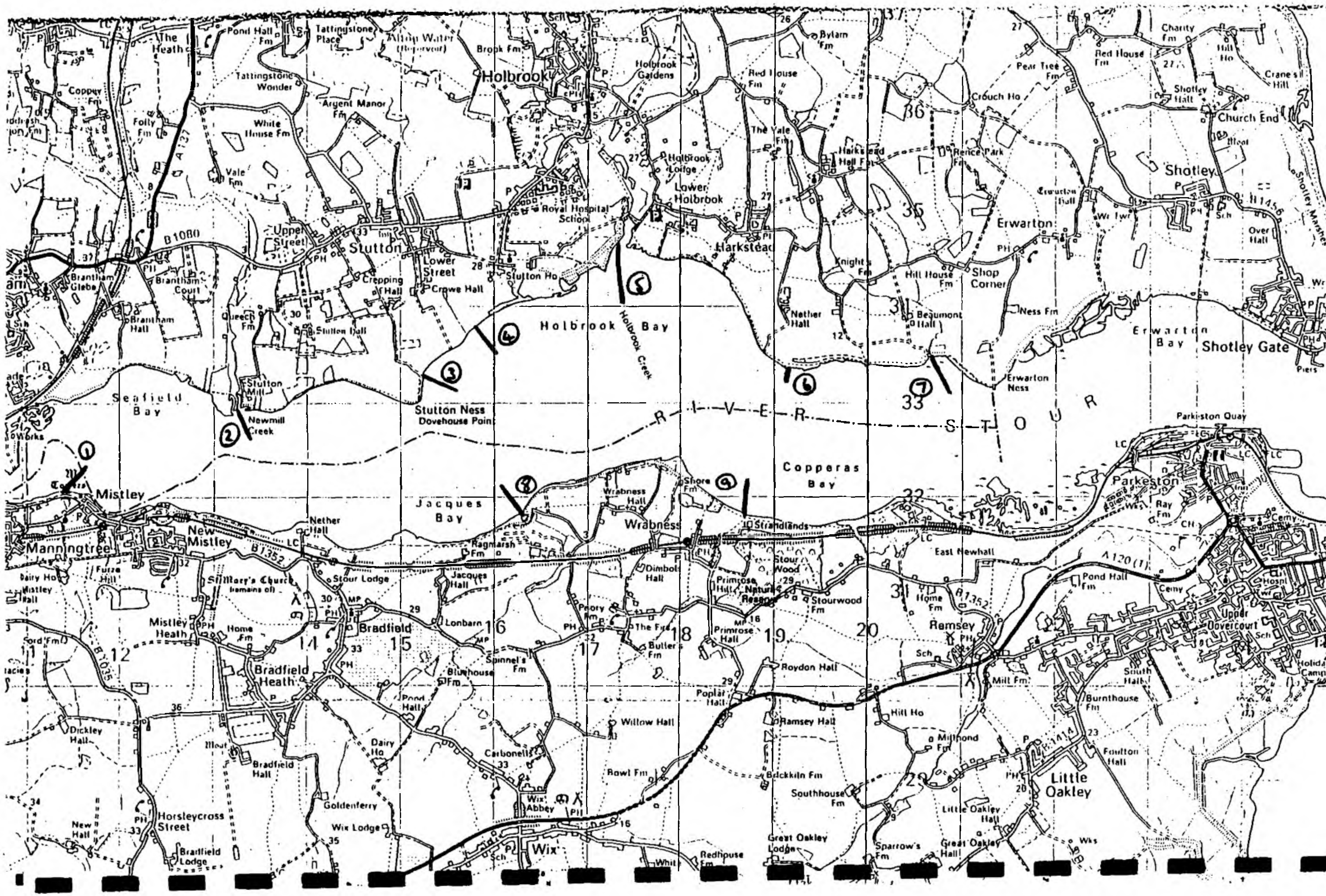
Flow no.	Area ha.	Discharge litres/sec		Mean bird densities (n=3 counts) no./ha									
		Summer	Winter	BG	SH	WN	PT	RP	GV	DN	CU	RK	BW
1	1.6		0	0	0	0	0	0	0	0	0	0	0
2	0.8		1.1	0	0	0	0	0	0	0	0	0	0
3	0.6		6.5	0	0	0	0	0	3.33	4.44	0	16.7	0
4	0.4		1.2	0	0.83	0	0	0	1.67	5.83	0	18.3	0
5	0.9		2	0	3.33	0	0	0	3.33	2.96	1.11	21.1	1.85
6	1		74.3	0	0	0	0	0	0	0	0	12.3	5.33
7	0.6		0	0	0	0	0	0	1.11	1.67	0	6.11	0
8	0.4		12.6	0	0	0	0	0	0	23.3	0	7.5	0
9	0.4		1	0	0.83	0	0	0	0	6.67	1.67	1.67	0
10	0.4		21.1	0	0.83	0	0	0	0	154.2	2.5	10.8	0
11	0.2		3.7	0	0	0	0	0	1.67	55	0	3.33	0
12	0.3		150	0	0	0	0	0	1.11	35.6	0	20	2.22

Appendix 4

The location of freshwater flows studied on the Orwell, Stour and Blackwater estuaries. The hatched areas on the Orwell are freshwater seepage zones. The Blackwater shows the study area on the north shore, flows measured (numbered) and others counted (arrowed).



Suffolk Showground
Gainsborough
Ipswich Airport
Nacton Heath
Bucklesham
Buckleshan Hall
Kembroke Hall
Heath Cottages
Kirton Lodge
Corporation Fm
Wherstead Park
Wherstead
Redgate Ho
Pond Hall Fm
Pond Ooze
Bridge Wood
Mulberry Middle
Goldsmith's Covert
Seven Hills
Amberfield
Levington Heath
Nacton
Park Fm
Cathouse Point
Orwell Park Sch
Broke Hall
Levington
Walk Fm
Croft Fm
Croft Ho
Kirton
Falkenham
Freston Lodge Fm
Freston
Freston Tower
Freston Park
Cutler's Wood
Bond Hall
Marina
Cat Ho
Hall Pt
Quay
Potter Point
Stratton Hall
Morston Hall
Fire Hill
Woolverstone
Woolverstone Park
Page's Common
Pin Mill
Clamp Ho
Trimley St Martin
Capel Hall
Thorpe Common
The Woodlands
Potash Fm
Grove Fm
Whitehouse Fm
Chelmondiston
Collimer Pt
Trimley Lower Street
Trimley St Mary
Walnut Tree Fm
Bylam Fm
Charity Fm
Hill Ho
Brook Fm
Holbrook
Holbrook Gardens
Red House Fm
Pear Tree Fm
Red House Fm
Crane's Hill
Grimston Hall
Shotley Hall
Church End
Crouch Ho
The Vale Fm
Harkstead Hall Fm
Rence Park
Trimley Marshes
Seaston's Fm
Holbrook Lodge
Lower Holbrook
Erwarton Hall
Shotley
Shotley Marshes
Royal Hospital School
Harkstead
Erwarton
Over Hall
Fagbury Point
Knight's Fm
Hill House Fm
Shop Corner
Shotley Point
Lower Street
Stutton Ho
Crowe Hall
Ness Fm
Nether Hall
Beaumont Hall
Marina
Holbrook Bay
Erwarton Bay
Shotley Gate
The Port of Felixstowe
Jetty
Erwarton Ness
Ferry
LB Sta
Piers
Pier
Parkeston Quay
Stutton Ness
Dovehouse Point



Holbrook
Holbrook Gardens
Tattingstone Place
Tattingstone Wonder
Argent Manor Fm
White House Fm
Pond Hall Fm
Brook Fm
The Heath
Coppuy Fm
Folly Fm
Vale Fm
Royal Hospital School
Upper Street
Stutton
Lower Street
Crowe Hall
Cropping Hall
Stutton Ho
Stutton Hall
Queech Fm
Brantham Glebe
Brantham Court
Brantham Hall
Stutton Mill
Newmill Creek
Stutton Ness
Dovehouse Point
Seafield Bay
Holbrook Bay
Holbrook Creek
Holbrook Lodge
Lower Holbrook
Harkstead
Harkstead Hall Fm
The Vale Fm
Red House Fm
Bylam Fm
Nether Hall
Knight's Fm
Hill House Fm
Beaumont Hall
Shop Corner
Ness Fm
Erwarton
Erwarton Hall
Erwarton Ness
Erwarton Bay
Crouch Ho
Pear Tree Fm
Rence Park Fm
Red House Fm
Charity Fm
Hill Ho
Crane's Hill
Shotley Hall
Church End
Shotley
Shotley Marshes
Over Hall
Shotley Gate
Piers
B1080
B1456
A137
RIVER STOUR
Parkeston Quay
Parkeston
Ray Fm
Copperas Bay
Jacques Bay
Shore Fm
Strandlands
Wrabness
Wrabness Hall
Nether Hall
Ragmarsh Fm
Mistley
New Mistley
Manningtree
B1352
St Mary's Church (remains of)
Stour Lodge
Jacques Hall
Dimbols Hall
Stour Wood
Primrose Hill
Nature Reserve
Stourwood Fm
East Newhall
A120 (T)
Pond Hall Fm
Home Fm
Ramsey
Mill Fm
Upper Dovercourt
South Hall
Burnthouse Fm
Holiday Camp
Furze Hill
Mistley Hall
Dairy Ho
Mistley Heath
Home Fm
Bradfield
Bradfield Heath
Lonbarn
Spinnel's Fm
Priory Fm
The Firs
Butlers Fm
Primrose Hall
Roydon Hall
Poplar Hall
Bluehouse Fm
Pond Hall
Dairy Ho
Carbonells
Willow Hall
Ramsey Hall
Hill Ho
Millpond Fm
Foulton Hall
Little Oakley
Little Oakley Hall
Great Oakley Hall
Sparrow's Fm
Southhouse Fm
Brickkiln Fm
Bowl Fm
Great Oakley Lodge
Redhouse Fm
Wix
Wix Abbey
Wix Lodge
Goldenferry
Bradfield Hall
Moat
Dickley Hall
Horsleycross Street
New Hall
Bradfield Lodge
B1035
B1414
1
2
3
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5
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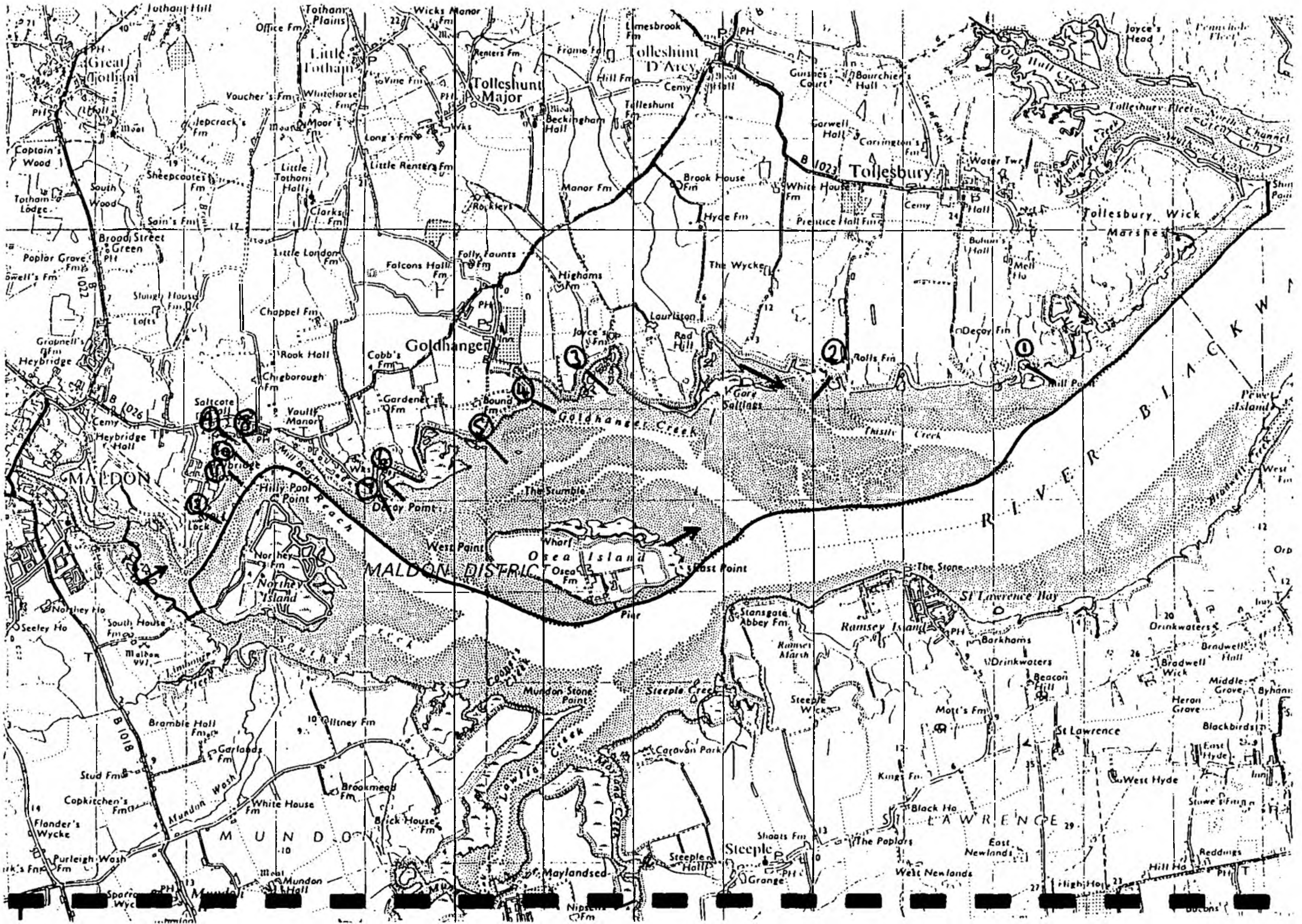
8
9



Tolleshunt D'Arcy
Tolleshunt Major
Little Totham
Great Totham
Tollesbury
Tollesbury Wick Marshes
Goldhanger
Goldhanger Creek
Heybridge
MALDON
Northey Island
Osea Island
MALDON DISTRICT
RIVER BLACKWATER
Decoy Point
Hilly Pool Point
The Stumble
West Point
East Point
Mill Point
Thistle Creek
Gore Saltings
Joyce's Head
Tollesbury Fleet
St Lawrence Bay
Ramsey Island
Steeple
Steeple Creek
Mundon Stone Point
Lawling Creek
Maylandsea
Mundon
ST LAWRENCE
Bradwell Creek