APPENDIX 14

LOGIE AND BRYANT 1994 REPORT UNDERTAKEN FOR THE 1995 STAGE 2 COMPARATIVE ASSESSMENT

SHOREBIRD USAGE OF MUD AND SAND FLATS IN THE VICINITY OF ESTUARINE BRIDGE CROSSINGS.

A study of the potential impact of a new road crossing at Kincardine-on-Forth.

Avian Ecology Unit,
University Of Stirling.

1994

Up a level Home

INTRODUCTION

Background

The impact of road crossings on the usage of nearby intertidal mudflats by shorebirds has not been researched previously (Davidson et al. 1991, Davidson & Rothwell 1993). If it is assumed that the area of exposed mudflats and their sediment characteristics are not altered by the presence of a bridge, two questions arise in relation to planned estuarine bridge crossings: 1. Is the passage of birds across the line of the bridge likely to be impeded, such that the usage of peripheral sites near a bridge is reduced, and 2. Is the area underneath, or within the immediate vicinity of a bridge crossing, likely to be shunned or little used by shorebirds?

While it is inherently unlikely that a bridge with a high span, such as the Forth Road Bridge at Queensferry, has any significant effect on bird movements below it, a lower structure, especially if it is massive, might be perceived by birds as providing sufficient cover for aerial or ground predators, or as a source of danger, such as a risk of collision, or disturbance by humans, for it to deter feeding and flight movements beneath and nearby. If this is the case, then mudflats upstream of the present bridge at Kincardine-on-Forth might have their value to feeding shorebirds reduced by the construction of a second bridge. Furthermore, a bridge may affect the abundance or availability of mud-dwelling invertebrates beneath the span, which would reduce the food supply for shorebirds. If so, a new bridge could in the extreme case have an impact on Skinflats SSSI which is analogous to the loss of a considerable area of intertidal mudflat. If the present study demonstrated that no impact was likely, based on inferences from similar structures elsewhere, then attention could be focused on other possible effects, such as those relating to construction itself, or to changes in human access which might arise incidentally.

The possible routes of the planned Forth crossing at Kincardine-on-Forth all lie within or close by the Skinflats SSSI. Skinflats is notable as a wintering ground for large numbers of geese, ducks and waders. During recent years, 7 species of waterbird have occurred in numbers which qualifies them as Nationally or Internationally important (Newton and Bryant 1991). Developments affecting the mudflats in the vicinity of the present Kincardine Bridge are likely to have the greatest impact on Dunlin *Calidris alpina* (Newton and Bryant 1991).

Aims

The aim of this study was to assess the effect of estuarine bridges on the usage of adjacent intertidal mud and sand flats by feeding shorebirds and their impacts, if any, on local movements of birds across the line of estuarine bridge crossings. Implicit in the study is that the effects of bridges includes the direct effects of the physical presence of a bridge as well as any motorised, mechanical, pedestrian and other disturbance due to the bridge.

METHODS

Distribution counts

Studies were carried out in the vicinity of eight major estuarine crossings in the north, west and east of Scotland (Table 1). Observations were made in December, late January and early February 1994, to assess the distribution of both feeding and roosting shorebirds and waterbirds, specifically, waders, ducks, and diving species such as grebes and cormorants, and the local movements of these birds across the line of each bridge crossing. At each site, counts were undertaken throughout the tide cycle (so-called 'through the tide counts' or TTTC) for ten, 100 metre sections on the north and south shores of each estuary, east and west of the bridges (all bridges studied coincidentally ran North-South), in order to record all birds using the shore, or the waters immediately offshore, within 1000m of the bridges. Counts were repeated on a second visit to each site, and the means of all daily low and high tide counts (low water $\pm$ 2 hours), made at similar distances from a single bridge (i.e. the mean of all shorelines), duly calculated. At the Tay Road Bridge, Erskine Bridge and the South Esk crossings at the mouth of Montrose Basin, however, where the presence of near-vertical embankments on one or more shorelines limited the available intertidal foraging areas, only data from suitable shores was considered in the calculation of mean site abundances. The principal substrate types of each 100m section, classified to the level of 'mud', 'sand' and 'rocky shore', were recorded on site, and later quantified in terms of area from 10 000 Ordnance Survey maps.

In addition to the census counts undertaken at all sites, visits were made to Kincardine Bridge, Kessock Bridge and Montrose Basin on three further days (making five in total), to examine the use of intertidal areas between and beneath bridge crossings. Studies at Kincardine Bridge eventually proved unproductive in this respect (see below), but served to refine field data collection methods, and yielded data on feeding and movements. Kessock Bridge was selected as the only crossing having sufficient shorebird densities and potential intertidal foraging areas extending directly below the bridge, to allow detection of possible avoidance behaviours. At sites with lower wader densities or smaller foraging areas, birds may not have been recorded below the bridges even if distributed randomly, so making them unsuitable for study. So, while studies at Kincardine Bridge would in theory have been ideal, there was insufficient intertidal mud underneath the bridge for it to be a suitable site. All the additional data from Kessock Bridge were collected on the south shore, as the bridge is relatively low above the water only on the south side of the estuary.

Montrose Basin bridges provided an opportunity to study usage of intertidal habitats between bridges, with approximately 140 metres of the estuary being enclosed between the road and rail bridges at this site. This disposition of bridges was analogous to some of the options proposed for the Kincardine crossing on the Forth. Even so, it was not an ideal location, since no shoreline similar to that between the bridges was available for direct comparison, because beyond the rail bridge to the west the shoreline opens into the extensive sandflats of Montrose Basin, and eastwards beyond the road bridge, embankments and docks offer little suitable intertidal habitat. Nevertheless, avoidance of the inter-bridge area by foraging shorebirds should have been detectable had it occurred.

Monitoring movements of birds across bridge crossings.

At all sites the passage of birds across the line of the crossings was recorded, noting the route taken, whether flying above or below the bridge, and if any change in the direction of flight was evident that would indicate disruption of local movements. Observations of movements were made on an *ad hoc* basis during the census counts. At Kincardine Bridge, Montrose Basin and Kessock Bridge, additional data were collected from four, one hour periods of continual recording, 1-2 hours either side of high tide. At this time birds were generally either entering or leaving roost sites and movement of birds was at its greatest. To avoid bias, all observations have been given equal weighting during data analysis, with individual birds and flocks each being considered as single samples.

Table 1. Locations of the sites studied for assessment of shorebird and waterfowl movements and distributions in the vicinity of estuarine bridge crossings.

Bridge	Route	Grid square
Dornoch Bridge	A9 Dornoch-Tain	NH 78
Cromarty Bridge	A9 Alness-Inverness	NH 55/56
Kessock Bridge	A9 North Kessock-Inverness	NH 64
Montrose Road Br.	A92 Arbroath-Montrose	NO 75
Montrose Rail Br.	East coast line, Perth-Aberdeen	
Tay Road Bridge	A92 Dundee-St Andrews	NO 42
Forth Road Bridge	A90 North Q'ferry-South Q'ferry	NT 17/18
Kincardine Bridge	A876 Kincardine-Grangemouth	NS 98
Erskine Bridge	A726 Erskine-Duntocher	NS 47

Analysis - feeding shorebirds.

Preliminary analyses of the low tide counts combined data from both east and west of all bridges and compared the mean abundance of birds within 100m sections against distances from the bridges. It is possible, however, that any effect of the bridge crossing was confounded by differences in substrate area or character, both of which are known to influence shorebird abundance (Prater 1981, Bryant 1979). Abundance differences between estuaries may also result in undue bias being placed on counts from only one or a few of the bridges studied. For these reasons all abundance figures were converted to bird densities to correct for differences in intertidal area. Density indices were then calculated for all distances from the bridge, expressing the densities of shorebirds relative to the mean density of that species on each estuary over all sections with the same substrate. The use of density indices allowed relative 'densities' of all species to be examined within a site irrespective of substrate, and also standardised for density differences between sites. At all estuaries except the Cromarty Firth, where only counts made on the uniformly sandy south-west shoreline were included in the analyses, substrate type was found to be independent of distance from the bridge (Oneway ANOVA $F_{2,40} \geq 2.77$, $p \geq 0.104$ across all cases). The mean local density of birds on any single substrate was calculated from between 11 and 40 counts at each site. These could be treated as independent data points, even though several counts were made on the same day, since movements about the estuary were continual, in association with the ebb and flow of the tides.

Analysis - feeding waterfowl

The abundances of waterfowl (i.e. ducks, grebes, cormorants and other species, but excluding waders) were assumed to be unrelated to local differences in the character and area of the intertidal flats. This was because only a minority relied directly on intertidal flats for feeding. The means of counts per 100 metres of shoreline, therefore, have been used during analyses without correction for substrate or intertidal area. All results have, however, been expressed as abundance index values, where numbers were expressed relative to the mean local abundance, to account for differences in density between estuarine sites.

For all species, least squares regression analysis has been used in the first instance to identify trends in density with distance from bridges. All counts and density and abundance indices were transformed ($\ln x+1$) prior to analysis to achieve near-normality within the data.

It remains possible, that the impact of a bridge may be restricted only to the immediate vicinity of the crossing and that these effects may have been overlooked in regression analyses examining the full 1000m of shoreline sections. Therefore, three further tests were undertaken for each species, examining only differences in local densities. The mean densities of birds in 100m sections for the first 500 metres from the bridge were compared with those from 500 to 1000 metres, densities from 0-200m were compared with 200-1000m and 0-100m with 100-1000m. These comparisons were undertaken using Students t-tests, with density indices alone included in the analyses. Similar techniques were also used to examine the densities of birds directly below Kessock Bridge, comparing the density of birds beneath the bridge with the mean of the 1000m sections surveyed.

Roosting birds

Although resting birds were recorded throughout the tidal cycle, the principal roosts were generally identified only during the high tide counts. At this time birds gathered into a number of large roosting flocks, with only a few birds elsewhere along the shorelines. Analysis was restricted to the distribution of roost sites, rather than the numbers of roosting birds. Due to the limitations of the data available and the assumptions of the statistics used (Chi-square), data from all sites have been pooled for analysis, with only the presence or absence of roosts in 200m sections extending from the bridge, being examined.

RESULTS

Feeding birds.

Considering only the means of the crude counts for each estuary, significant negative relationships for the total number of ducks (all ducks combined, ANOVA $F_{1,80}$=5.12, r^2=0.02, p=0.027) and the total number of birds (all species combined, $F_{1,80}$=8.32, r^2=0.12, p=0.005) in relation to distance from bridges were recorded. No relationship with distance was apparent for all wader species combined, although the results from this analyses must be treated with caution in view of the problems highlighted earlier, about conducting analyses without first accounting for within-site substrate effects and between-site differences in abundance. No analyses were conducted on individual species counts, due to these difficulties.

Amongst the analyses based on density and abundance indices, no significant relationships were identified for any of the following classes: all waders (Figure 1), all ducks (Figure 2) and all birds. From Oystercatcher *Haematopus ostralegus*, Curlew *Numenius arquata*, Redshank *Tringa totanus*, and Lapwing *Vanellus vanellus*, the only waders recorded in sufficient numbers for specific analysis, Redshank alone revealed a relationship with distance (Figure 3). Again significantly fewer birds were recorded with increasing distance from the bridge crossing (ANOVA $F_{1,80}$=5.60, r^2=0.09, p=0.017). No significant relationships were recorded for any other species, although negative trends for density with distance, significant at only $p \leq 0.1$ (ANOVA $F_{1,80} \geq 3.40$), were recorded for Tufted Duck *Aythya fuligula*, Goldeneye *Bucephala clangula*, and all ducks combined. Hence, no evidence was found for any species which suggested avoidance of the intertidal areas within 1000m of the bridges.

Comparisons of mean densities, based only on local counts, revealed significantly more Redshank within 100m sections in the first 500m from the bridge than in those at 500-1000m distance (Students t-test, t=3.13, p=0.02, n=8). This was, however, the only statistically significant result from all analyses of single species or combined species classes. Again no significant, or near significant results were found to indicate an avoidance of the foraging areas adjacent to the bridge crossings.

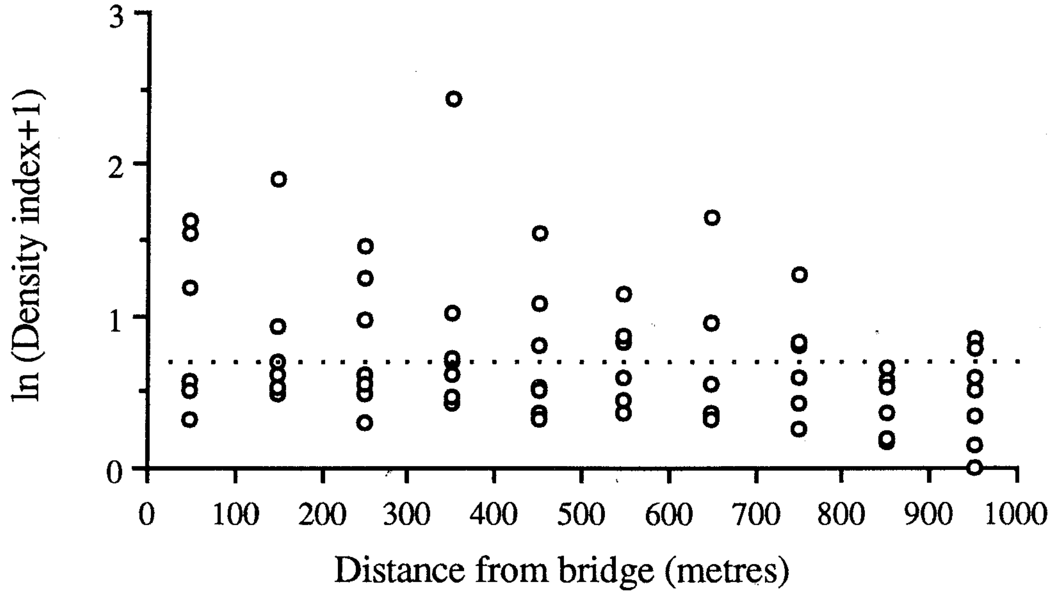

Figure 1. The density of wading birds (all species combined) within 100 metre sections in relation to distance from bridge crossings.

Density indices express the numbers of shorebirds at each distance interval from the bridge relative to the mean density of each species over all sections of a similar substrate within an estuary. The dotted line shows the mean standardised density index value of all species combined (i.e. ln 1+1 = 0.69)

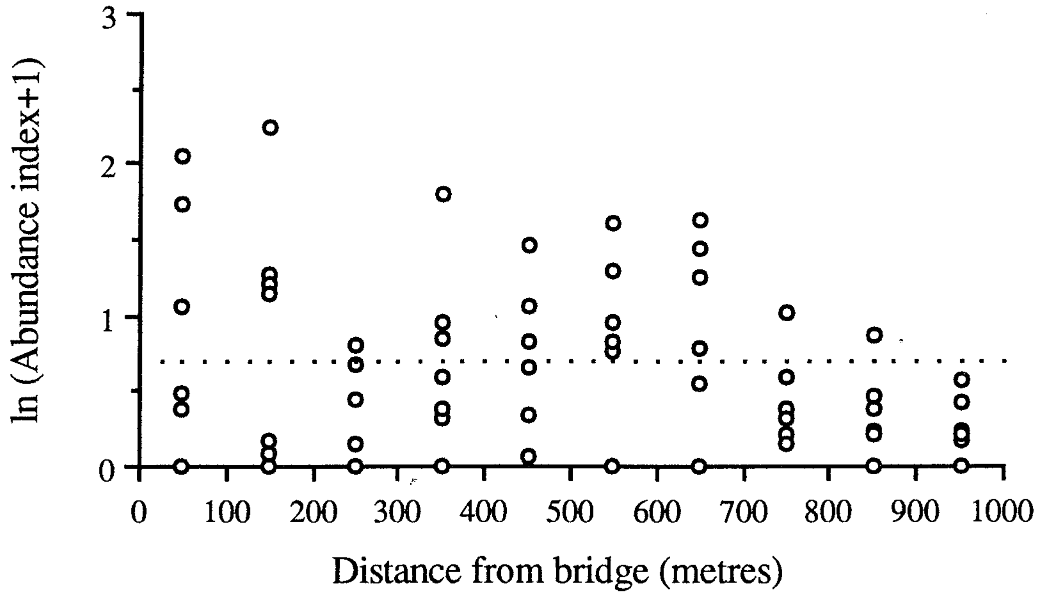

Figure 2. The abundance of ducks (all species combined) within 100 metre sections in relation to distance from bridge crossings.

Abundance indices express numbers of shorebirds at each distance interval from the bridge relative to the mean numbers of each species for each site. Hence, unlike the density indices, they do not adjust for differences in substrate type or intertidal area.

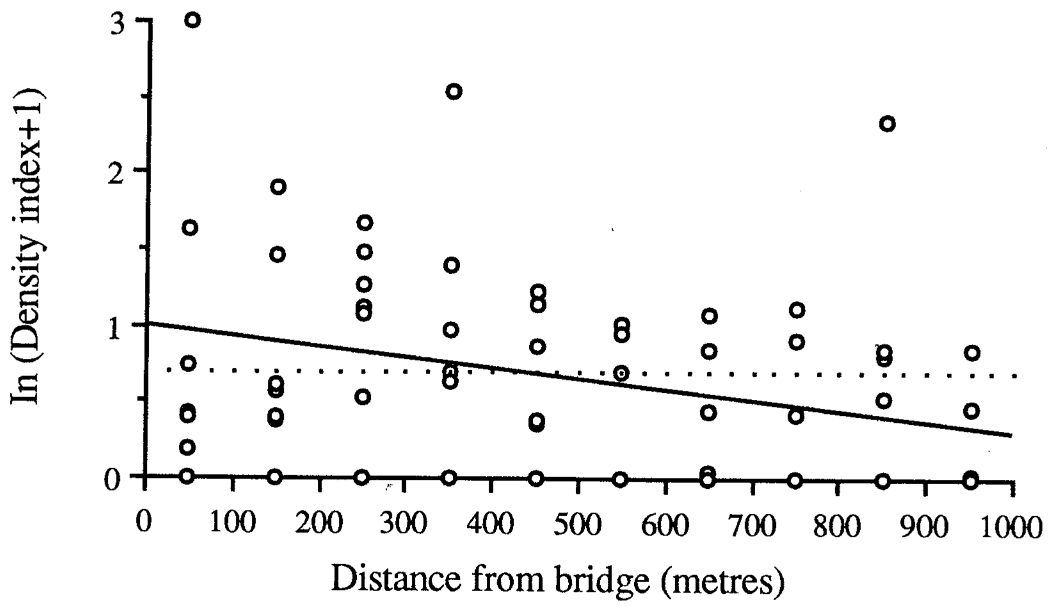

Figure 3. The density of Redshank *Tringa totanus* within 100 metre sections in relation to distance from bridge crossings.

(See Figure 1 and text for an explanation of density indices).

Use of feeding areas underneath bridges.

The highest mean densities of shorebirds were recorded 300 metres from Kessock Bridge (Figure 4). No significant differences were found, however, between densities of birds foraging directly below the bridge crossing (defined to include all substrates within 10m of the bridge) and the mean density of birds across all the remaining 100 metre sections counted (Students t-test: $t=1.63$ NS, $n=5$). This result is based only on 5 samples (from the five days of counting), however, and so the analysis has little statistical power. In contrast, there did appear to be a temporal change through the tide cycle in the numbers of birds feeding directly below the bridge. The mud beneath the crossing was amongst the first to be exposed by the receding tide and was used extensively 1-2 hours after high water (Figure 5); a time when little other substrate was available for feeding. Later, as more extensive mudflats elsewhere on the shoreline were exposed, birds tended to move away from the bridge. Although, during the five days of study at Kessock, densities under the bridge of up to 15 times the local mean were noted on the receding tide, on two days no birds were recorded feeding below the bridge during one or more of the counts around low water, when other birds were present nearby. This suggests that feeding below Kessock Bridge is not preferred, and is chosen when access to other feeding areas is denied. Nevertheless, it does not preclude the possibility that it is avoided at low water simply because its character, irrespective of its position under the bridge, make it unfavourable for feeding.

Use of feeding areas between bridges.

Only one site was available where two bridges ran side by side across an estuary. Comparisons of shorebird abundances within this site at the mouth of the South Esk by Montrose have been problematic as the foraging areas available between the bridges (0.42 ha) were not on a comparable scale to those available within 1000m of the bridge in Montrose Basin (itself 890 ha). Nevertheless, over the five days of study at Montrose, the mean density of birds feeding between the bridges was calculated as 13.80 waders ha^{-1} compared to only 9.42 waders ha^{-1} on the adjacent mudflats of Montrose Basin. Although it would be unwise to assume that the area between the bridges was being particularly favoured by foraging shorebirds, especially as the calculations of densities between the bridges were sensitive to movements of even a small number of birds, the results appear to suggest that at this site the abundance of birds feeding between the bridges was around that expected from a knowledge of local wader densities. These densities are also consistent with data from earlier analyses of waders at Montrose Basin (Bryant & McLusky 1976), which showed 'peak winter count' densities of 16.30 waders ha^{-1} for the Basin as a whole.

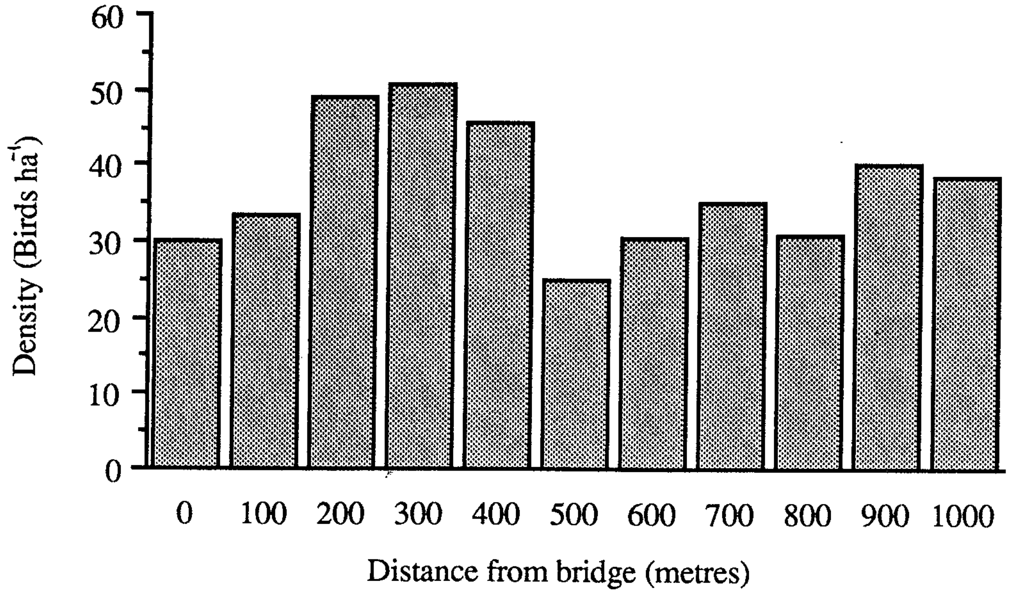

Figure 4. The density of wading birds (all species combined) relative to distance from Kessock Bridge.

Data based on five, mean daily low tide counts (low water ± 2 hours) for the South shore only.

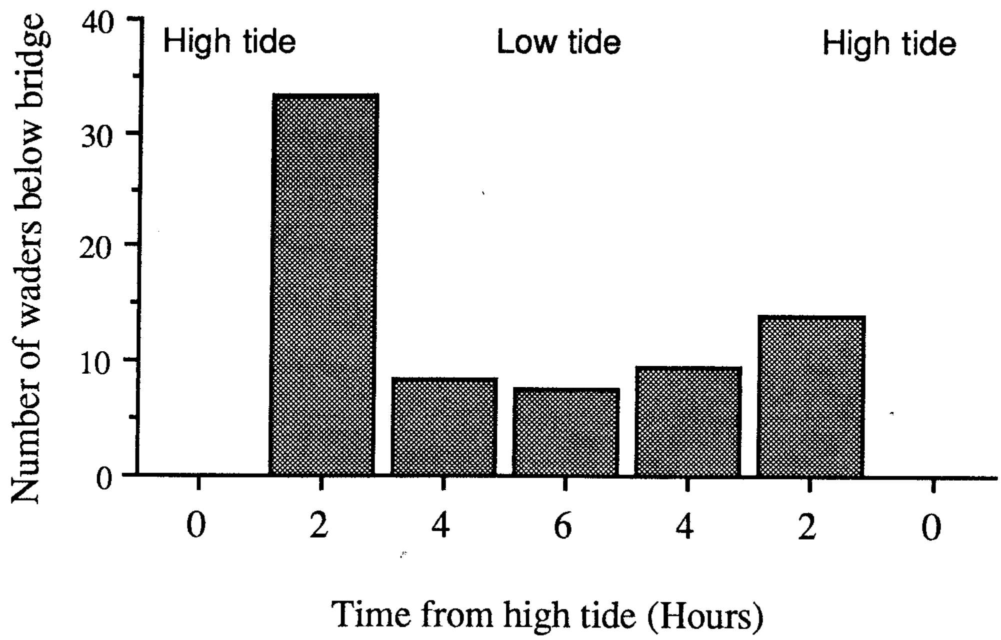

Figure 5. Numbers of wading birds (all species combined) feeding directly below Kessock Bridge, relative to the state of the tide.

Data based on five, mean daily low tide counts (low water ± 2 hours) for the South shore only.

Up a level Home

Distribution of roosting birds.

No significant differences were recorded between presence and absence of roost sites in 200 metre sections with distance from the bridges (Chi square=0.31 NS, n=30, Figure 6). Although, rigorous testing has not been possible due to limitations of the data, Redshank, Oystercatcher and Lapwing were all recorded roosting within 100m of the crossing on one or more of the estuaries visited. Dunlin *Calidris alpina* and Curlew were recorded within 200 metres of the crossings. All waterbirds recorded in sufficient numbers for analysis (Mallard *Anas platyrhynchos*, Teal *Anas crecca*, Wigeon *Anas penelope*, Tufted Duck, Goldeneye, Red-breasted Merganser *Mergus serrator* and Cormorant *Phalacrocorax phalacrocorax*) were also noted roosting within 100 metres of the bridge at one or more of the sites visited.

Movements of birds underneath bridges.

With the exception of soaring Gulls (Laridae), no species was recorded flying above the Forth, Erskine or Tay Bridges, the highest structures visited, although the heights of these bridges probably precludes most birds from making trivial or regular flights above them. Nevertheless, although the proportion of all birds and all waders flying below the bridges increased with bridge height (Figures 7 and 8), even at Montrose Road Bridge, the lowest crossing, 72% of all birds and 71% of all waders passed under the bridge.

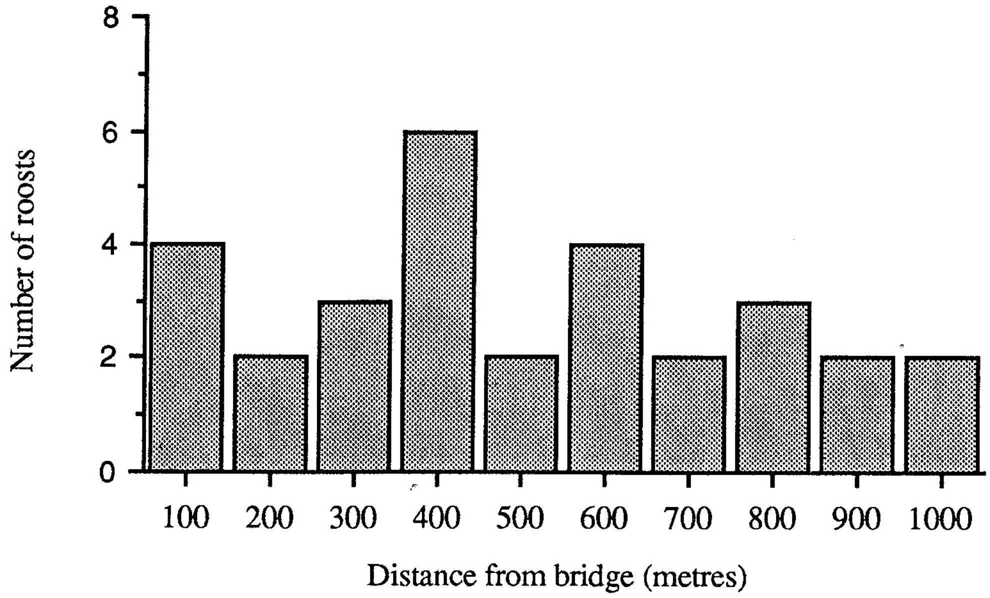

Figure 6. The distribution of major roost sites in the vicinity of eight estuarine bridge crossings (all sites combined), January and early February, 1994.

Up a level Home

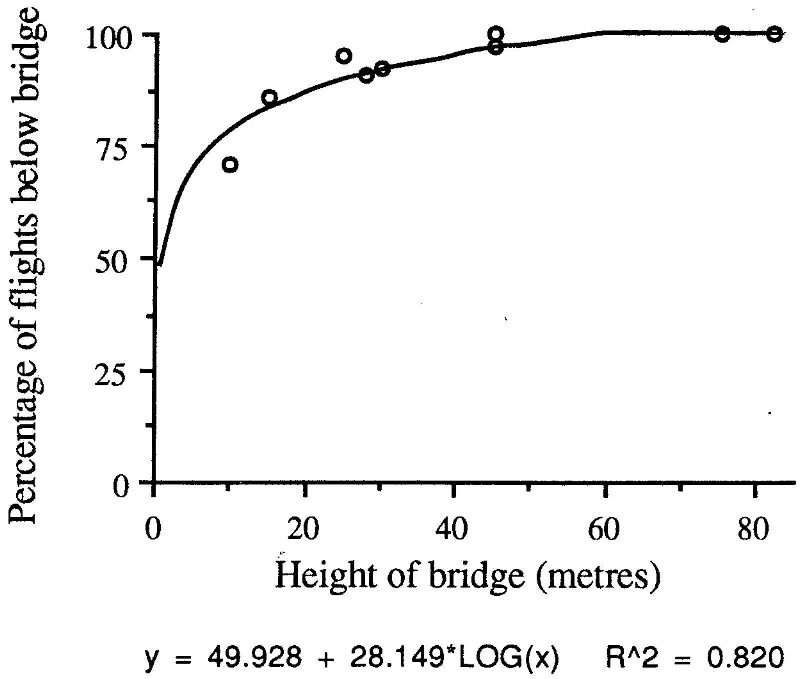

Figure 7. The proportions of all birds flying below bridge crossings in relation to bridge height (Figures exclude gulls).

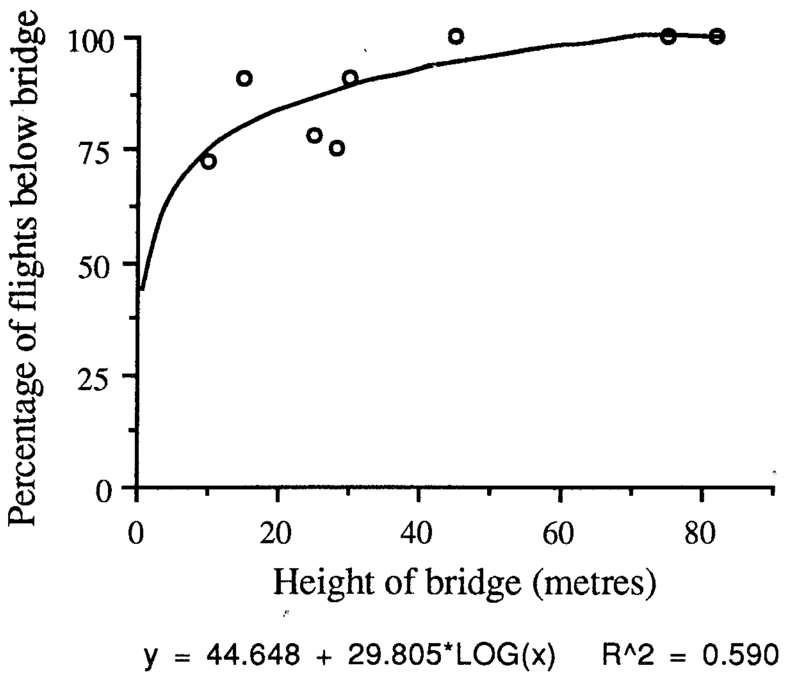

Figure 8. The proportions of all wading birds flying below bridge crossings in relation to bridge height.

DISCUSSION

Potential effects of bridge construction.

The results of this study are considered in the light of several hypotheses concerned with the impact of bridge construction on estuarine birds. All four hypotheses imply deterrence or exclusion of birds from nearby shores and are outlined below.

1. The presence of a bridge may cause sufficient traffic and associated **disturbance** to discourage birds from roosting and feeding nearby.

Reduced densities of some breeding songbirds have been recorded along the edges of Dutch motorways (Reijnen and Foppen 1994a,b), showing that at least some bird species may be directly or indirectly, and adversely affected by motor traffic. Although, Cayford (1993) suggests that birds, being highly motile, may be less susceptible to disturbance effects than many other groups of organisms, such an assumption relies on his definition of disturbance as a *discrete* event. The effects of prolonged disturbance, such as that associated with road traffic, or the presence of a (perceived) potentially hazardous structure such as a bridge, could lead to the long-term loss of feeding opportunities. This might be particularly important with estuarine bridge crossings, since they carry the potential for disturbance directly into the intertidal area rather than alongside it.

2. Bridge structures may be perceived by birds as providing cover for waiting **predators**, thereby discouraging use of the surrounding intertidal flats.

Sparrowhawks *Accipiter nisus* were identified by Whitfield (1985) as the principal predator of wader species at two sites on the Midlothian coast, and are known to favour attacks from cover (Tinbergen, 1946; Newton and Marquiss, 1982). For this reason, adult Redshank attempt to avoid feeding near cover suitable for predators, although behaviourally subordinate juveniles may not have this option (W. Cresswell unpublished). The Sparrowhawk is a common predator of shorebirds at Skinflats and other sites on the Forth Estuary, while other aerial and ground predators are also frequent. A reduction in use of mudflats in the vicinity of bridges is therefore feasible.

3. Bridges may deter some trivial flight **movements** and thereby restrict access to adjacent mudflats.

This view was based on theory and heresay, but found some support from preliminary studies at Kincardine Bridge, where a substantial proportion of wading birds chose to overfly the bridge rather than pass beneath it (Appendix 3). Since flying is costly of energy for birds, it may be deduced that the frequency of such flights could be reduced because the net benefit would be less following a long as opposed to a short flight.

4. The character of mud or sand flats may be changed **beneath and near** bridges, leading to

less favourable feeding conditions and lower shorebird densities (In this case an improvement in local conditions is a feasible but less likely outcome of bridge construction).

Construction and development on estuaries is commonly associated with land-claim (Davidson et al. 1991). Even when loss of intertidal flats is not involved, however, minor changes in hydrology and sedimentation, or in shelter from the elements, may affect shorebirds via an effect on their food supply. If, on the other hand, bridge construction or its presence has a substantial effect on the habitat, leading to losses or gains of mudflats, or marked accretion or erosion of silts, then this would fall outside the scope of this report since the likely scale of these changes would need to be known.

Bridges as sources of disturbance.

During this study, no evidence was found to suggest important disturbance effects on either roosting or foraging shorebirds. Of the species recorded in sufficient numbers for their distributions to be adequately assessed, all ducks, and the wader species, Oystercatcher, Lapwing and Redshank, were recorded roosting within 100 metres of the crossings at one or more of the sites visited. Indeed, at Dornoch, on each day of counting more than 110 Redshank roosted on the causeway leading to the bridge. Roosts of Curlew and Dunlin were noted within 200 metres of bridge crossings, and individual Curlew were recorded as roosting to within 20 metres of Montrose Rail Bridge. Birds of all species were recorded feeding within 100 metres of the bridges at one or more of the sites covered.

The potential for disturbance will obviously differ between sites. Traffic on large, high spans, such as the Forth Road Bridge (Queensferry) and the Erskine Bridge, may be less evident on surrounding shores, than on low profile crossings such as the present Kincardine Bridge or the Cromarty and Dornoch Bridges. Yet at Dornoch, although birds would certainly have been aware of passing vehicles, Redshank were recorded roosting to within 20 metres of the traffic. It appears that the secure and sheltered site on the causeway embankment, rather than proximity to the roadside, determined the choice of roost at this site. As no significant differences in the distribution of roost sites were apparent with increasing distance from the bridges (all sites combined), the suitability of roosts, rather than their position relative to the road, appears to be of principal importance. These results suggest that any disturbance impacts due to the presence of an estuarine crossing may be minimal or only of very local importance.

Evidence from a number of wader species has suggested that disturbance may be greatest in response to infrequent events, and that birds are apparently less affected by potentially disturbing occurrences that are either predictable or have been encountered before (Glimmerven and Went, 1984; Smit and Visser, 1993; Goss-Custard and Verboven, 1993). In many cases, habituation, facilitated by repeated encounters with similar disturbance sources, appears to occur, associated with greater tolerance to even high levels of disturbance. Many waders will tolerate people approaching to even short distances (<20 metres) where human activity is generally high, whereas birds feeding on the same estuary but in undisturbed sites take flight at significantly greater distances (Goss-Custard and Verboven 1993, Smit and Visser 1993, Davidson and Rothwell 1993).

Familiarisation with high intensity noise, such as aircraft and helicopter movements has been noted without substantial effects on feeding and roosting birds, whereas unusual or infrequent disturbances still elicited a strong response (Smit and Visser 1993). Smit and Visser (1993) also quote an example of Lapwing, Starlings *Sturnus vulgaris* and gulls breeding on airfields where, although the disturbance was of a high intensity, the movements of aircraft were highly predictable. Anecdotal evidence suggests that Lapwings and Oystercatchers may forage on motorway roundabouts and verges, attracted by the availability of earthworms, encouraged to the surface by the vibrations of passing vehicles. At one site in central Scotland, both Lapwing and Oystercatcher nest within a few metres of passing vehicles on a motorway, confirming a remarkable tolerance of moving traffic.

Consistency and predictability of "disturbance", as exhibited by road traffic, appears to result in the least detriment to roosting and feeding birds. Although, responses may differ between species (Tensen and van Zoest, 1993), it may be that these factors, together with the high degree of winter, site fidelity shown by many waders in Scotland (Furnace and Galbraith, 1980; Symonds *et al*, 1984), that allows birds to roost and feed in the vicinity of bridge crossings without apparent distress.

Bridges as sites of increased risks from predators.

There appeared to be no evidence that an increased risk of predation, either real or perceived, reduced the value of habitats adjacent to the bridges studied. Of the species found in sufficient numbers for analysis, no significant relationships with distance were recorded for Oystercatcher, Curlew, Lapwing or any waterbirds. Whitfield (1985) could attribute no deaths of any of these species to predatory attacks, however, and it would appear unlikely that avoidance effects associated with the risk of predation would be evident for these, or other large birds. Indeed, Cormorants are known to roost on a disused rail-bridge on the Forth at South Alloa (Bryant et al. 1994), illustrating that the structure itself is unlikely to be avoided by this species. However, for Redshank and smaller waders such as Turnstone *Arenaria interpres*, Dunlin and Ringed Plover *Charadrius hiaticula*, predation was recorded as a principal source of winter mortality in Whitfield's study (1985) and they are known as frequent prey of raptors at Skinflats (Bryant et al. 1994).

Since Redshank were ubiquitous and the most abundant small wader at all sites, they would appear to be the best candidate for identification of an avoidance response; yet within this study significantly more Redshank were recorded in the vicinity of bridge crossings than elsewhere on the shore. As no evidence of avoidance was found for any other small wader species, it appears unlikely that bridge crossings are perceived as sources of any additional danger, relative to surrounding shorelines. Redshank are, however, known to favour sheltered foraging sites on the Forth (Bryant *pers obs*). If bridges provide the shelter favoured by Redshank, this might explain the observed distribution of this species, even if they only exploit shelter intermittently.

The only evidence to suggest avoidance of estuarine crossings comes from counts made directly beneath Kessock Bridge. Although, density differences were not rigorously tested and conclusions cannot, therefore, be not presented with certainty, it appeared that when they exercised choice, waders were less inclined to forage directly below the bridge than on habitats close by (within 100 metres). Birds foraged below the crossing at high densities only in the hours immediately following high tide, and then moved to feed elsewhere on the shoreline as other substrate became available. If these effects are general, they appear to be limited. Had areas adjacent to bridges been consistently avoided, the density of birds within these 100 metre sections would be expected to be significantly reduced and this did not appear to be the case. It should be noted that these and other conclusions are based on density data and more subtle behavioural responses, such as increased vigilance or reduced foraging activities may also be important, but remain undetected. It is possible that long term survival is impaired by subtle but persistent effects which reduce foraging success but have no short term effect on numbers. This avenue of research was beyond the scope of the present study.

None of the sites visited was ideal for studying the effect of cover provided by a bridge span similar to that planned for Kincardine, either because the span was too high or some critical species were not present in sufficient numbers for study. It seems most likely, for example, that a low span (5-10m high) would deter most birds from feeding beneath it, with the possible exception of solitary small waders such as Redshank, which have been noted elsewhere on the Forth occasionally feeding beneath solid structures (Bryant *pers obs*). Large shorebird species and flocks of smaller waders such as Knot and Dunlin would seem to be inherently unlikely to use the shaded area beneath a span of low or medium elevation. So while firm evidence did not emerge from this study, low bridge spans seem likely to have an effect not dissimilar to the loss of mudflats equal to the area covered by the bridge carriageways.

Bridges as barriers to local movements.

Local movements of birds within estuaries did not appear to be significantly affected by the presence of bridge crossings. Although the proportion of birds flying over bridges declined with greater bridge height, at no site did less than 72% of all birds and 71% of all waders fly below the bridges. While Common Sandpipers *Actitus hypoleucos* breeding near upland streams, are known to fly below bridges only a few metres high (Bryant *Pers obs*), evidence from work at Kincardine Bridge in December and a number of other sites, suggested that some species, particularly Lapwing and perhaps Dunlin (both species passed the line of bridges only infrequently but few data were available for assessment), may dislike flying beneath the lowest bridges. However, the fact that Dunlin were subsequently noted roosting within 140 metres of Kincardine Bridge and Lapwing roosted directly below Kessock Bridge suggested that even for these species bridges are not routinely avoided. From the data available here (Figure 7), it was calculated that a bridge of less than 5 metres height would be required to force more than 50% of birds to fly above it. Yet it appears unlikely that a structure of this height would, at the same time, significantly impede movements of birds overhead, so overall effects would be slight.

One factor determining the flight paths of birds past the line of a bridge crossing may be the amount of visual information available on circumstances the other side of the structure. This appears to be partly determined by the bridge height, with lower spans leading to reduced visibility for low flying birds and therefore an increased potential for danger. However, the complexity of the structure may also be important in this respect, perhaps explaining the relatively high proportion of birds recorded flying above the present Kincardine

Bridge, which has a complex superstructure, during the preliminary December studies. Complex structures may obstruct visibility or be perceived as providing additional cover for lurking predations. It appears, therefore, that high spans do not restrict the natural flights of birds and that lower bridges may act only as an obstacle, rather than a barrier, to local movements.

Shorebird densities underneath and near bridge crossings.

No evidence was available from this study to show if mudflat characteristics beneath bridges differed systematically from those elsewhere. A direct study of sediments and their infauna, and possibly bridge related micro-climates, would clarify this issue, since it is unclear if the apparent avoidance of intertidal flats under Kessock Bridge, and by implication other bridges too, was related to reduced food availability or other factors, such as those discussed above.

Redshank on estuaries were found to be commoner adjacent to bridges than elsewhere. What caused these elevated densities? They may be the result of an effect of bridges, more particularly their supports, on water movements, with consequences in turn for sediment deposition, detrital food supplies, invertebrate prey and hence shorebird predator densities (Bryant 1979). Alternatively, shelter from the elements near (and underneath) bridges may make prey easier to detect. Traffic induced vibrations making prey more available is inherently unlikely, however, since surface movements usually cause intertidal invertebrates to retreat rather than rise to the surface. Equally, since bridges are normally constructed across narrow sections of estuaries, it could be that such narrows themselves provide more favourable conditions for certain shorebirds and that an association with bridges is coincidental. Another possibility has been mentioned previously; bridges and their approach roads may provide shelter from winds, reducing windchill amongst feeding and roosting birds. Finally, bridges may incidentally be a focus of estuarine pollution, ultimately with positive effects on some shorebirds which rely on invertebrates tolerant of, or benefitting from, eutrophication. Agricultural run-off, for example, may be concentrated near bridges because drainage channels are more likely to run towards rivers than cross beneath roads, potentially increasing local food supplies and bird densities (Raffaelli et al. 1989, Gillon 1992).

Parallel bridge crossings.

This study has shown that single bridge crossings have only a limited effect on shorebird densities, yet it remains possible that any effects would be compounded where two bridges lie close together. While observations at Montrose Basin showed no adverse consequences with bridges 140m apart, direct comparison with some crossing options at Kincardine faces several problems: bridges closer than 140m were not examined; Montrose's bridges carry one rail and one road crossing and differ in associated disturbance, structure and height from those planned for Kincardine, and the mudflats between the bridges at Montrose are narrower than most of those near Kincardine Bridge. Hence bridges of different structure, placed less than c.200m apart could have effects not detected during the present study. The chance of such an effect presumably increases with bridge proximity. Hence a crossing placed close to the present Kincardine Bridge, runs some risk of creating an intertidal area little frequented by shorebirds. If this occurred to the east of the present Kincardine Bridge it would affect an area at present exploited intensively by feeding shorebirds (Newton and Bryant 1991), as well as having possibly damaging shading or other effects on nearby saltmarshes. The alternative outcome, that a particularly favourable enclave would be created, offering sheltered feeding conditions, cannot be wholly dismissed, but given the anticipated traffic volume and the proximity of human activity and associated secondary developments, this presents itself as a less likely outcome.

SUMMARY AND CONCLUSIONS

Numbers of waterbirds were counted in the vicinity of eight estuarine bridge crossings in Scotland during December 1993 to February 1994. The bridges included in the study carried road and rail across the following estuaries and firths: Cromarty, Dornoch, Beauly, South Esk, Tay, Forth and Clyde. Counts were made of waders, ducks and other waterfowl up to a distance of 1000 metres on both sides of bridges to determine if densities of birds using the intertidal flats were reduced by the proximity of bridges. A negative effect of bridges might have been due to four factors: increased disturbance, increased predation risk, deterence of local movements and alteration of mudflat characteristics. If an effect of bridges was demonstrated it would suggest that the construction of new estuarine crossings, such as that proposed for Kincardine-on-Forth, would result in comparable changes in its vicinity.

No evidence was found to suggest reduced densities of estuarine waterbirds in the areas surrounding bridges. Indeed, the only significant, or near significant relationships identified, showed increased densities of Redshank *Tringa totanus* and possibly a number of duck species, in the vicinity of bridges. Although intertidal areas directly beneath bridges may be partially or wholly avoided, these effects, if general, appear to be limited to the area immediately around the bridge. Movements of birds across the line of the bridge were not hindered by the presence of bridge crossings. It appears, therefore, that estuarine bridges do not normally comprise a sufficient source of disturbance or danger to reduce the usage of nearby intertidal areas by shorebirds, or waterfowl more generally, although a low bridge is likely to reduce usage of mudflats within the limited area beneath its span and parallel bridges less than 200m apart may have effects which were not identified in this study.

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APPENDIX 1. Mean low tide counts of shore and wader birds within 1000 metres of eight bridge sites in Scotland. Figures based on mean of counts for two days (five for Montrose Basin and the south shores at Kessock bridge), daily means from between five and eleven counts of each section.

Forth Road Bridge, Queensferry. South.
South east section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.5	0.0
Curlew	0.0	1.0	0.0	0.5	0.0	0.0	0.0	0.5	0.5	0.0
Oystercatcher	0.5	13.0	4.0	2.5	1.0	13.0	5.0	12.5	11.5	9.0
Ring. Plover	0.0	0.0	2.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0
Turnstone	0.0	0.5	0.5	0.0	0.0	1.5	1.0	0.0	0.5	1.0
Goldeneye	0.5	1.0	0.0	0.0	0.0	1.0	2.0	0.0	1.0	1.0
Merganser	0.0	0.5	0.0	0.0	0.5	0.0	0.0	0.5	0.0	0.5

South west section

Redshank	0.0	0.0	0.0	5.5	2.0	0.0	0.5	1.5	1.5	0.0
Curlew	0.0	0.0	0.0	1.5	0.5	1.0	17.0	3.0	23.5	2.0
Oystercatcher	0.5	0.0	0.0	0.5	1.0	3.5	2.0	1.5	3.0	0.5
Dunlin	0.0	0.0	0.0	113.5	63.5	0.0	0.0	0.0	0.0	0.0
Turnstone	0.0	0.0	0.0	0.0	1.0	0.0	0.5	0.0	0.0	0.0
Mallard	0.0	2.0	0.0	0.0	0.0	2.5	3.0	1.5	3.0	1.0
Merganser	0.5	0.5	0.0	0.0	0.0	0.0	1.0	0.0	0.5	0.0
G C Grebe	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0

Forth Road Bridge, Queensferry. North.
North east section

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	0.0	0.0	2.5	9.5	5.5	0.0	0.0	0.0	---	---
Curlew	1.0	1.0	0.0	1.5	1.5	1.0	0.5	1.0	---	---
Oystercatcher	2.0	1.0	1.0	1.5	0.5	0.5	1.5	2.5	---	---
Dunlin	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	---	---
Ring. Plover	0.0	0.0	0.5	2.0	0.0	0.0	0.0	0.0	---	---
Mute Swan	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	---	---
Mallard	25.0	40.5	3.5	3.5	0.5	0.0	2.5	0.5	---	---
Teal	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	---	---
Shelduck	0.0	0.0	1.5	1.5	0.0	0.0	0.0	0.0	---	---
Eider	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0.5	---	---
Goldeneye	2.5	6.5	0.0	0.0	0.0	0.0	0.0	0.0	---	---
Cormorant	0.0	0.0	0.0	0.0	3.0	1.0	1.0	0.0	---	---

North west section.

Oystercatcher	0.0	0.0	1.0	0.5	0.5	0.0	1.0	0.5	0.0	0.0
Mallard	0.0	5.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0
Eider	16.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
Cormorant	21.5	1.0	6.5	0.0	1.0	0.0	0.5	0.5	0.0	0.0
Merganser	0.0	0.0	0.5	0.5	0.5	0.0	0.0	0.5	0.0	0.0

Kincardine Road Bridge. South.

South east section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Curlew	0.0	0.5	1.5	0.5	0.0	4.0	1.5	5.5	0.5	0.5
Oystercatcher	0.5	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Lapwing	3.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mallard	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0
Wigeon	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Guillemot	43.0	34.0	8.0	2.0	2.0	5.0	2.0	7.0	8.0	6.0
Cormorant	0.0	0.0	0.5	1.0	3.0	0.0	0.5	0.5	0.5	0.0

South west section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	0.0	0.0	0.0	1.0	6.0	1.0	0.0	3.5	4.0	2.5
Curlew	0.0	0.0	0.0	1.0	0.0	3.0	0.0	2.0	4.0	4.0
Oystercatcher	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Lapwing	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dunlin	0.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0
Mallard	0.0	0.0	0.0	4.0	2.0	12.5	0.0	4.0	5.0	0.0
Wigeon	0.0	0.0	0.0	0.0	34.0	0.0	27.0	0.0	0.0	0.0
Shelduck	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
Cormorant	0.0	0.0	0.0	0.0	0.0	8.5	6.5	1.5	3.5	2.5

Kincardine Road Bridge. North.

North east section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	0.0	0.0	0.5	0.5	0.5	2.0	0.5	1.0	0.0	1.0
Curlew	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	1.0
Shelduck	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	9.0
Guillemot	53.0	50.0	6.0	40.0	0.0	2.0	0.0	0.0	0.0	0.0
Cormorant	0.0	0.0	0.5	0.0	11.0	0.5	0.0	0.0	1.0	0.0

North west section

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	1.0	1.0	9.0	2.5	1.0	0.5	0.5	0.0	0.5	0.0
Curlew	0.5	0.0	1.5	0.5	0.5	1.0	0.5	0.5	0.5	0.0
Oystercatcher	1.5	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.5
Guillemot	29.0	0.0	0.0	0.0	3.0	0.0	1.0	0.0	0.0	0.0
Grey Heron	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Merganser	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0

Tay Road Bridge. South.

South east section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	3.5	1.5	1.0	1.0	10.5	8.5	3.0	0.0	1.0	2.0
Curlew	2.0	0.5	1.5	1.5	1.0	3.5	0.5	1.0	2.0	2.0
Oystercatcher	2.5	1.0	0.0	0.0	0.0	4.0	5.5	1.0	1.0	0.0
Lapwing	0.0	0.0	0.0	0.0	0.0	5.0	19.5	5.5	1.0	0.0
Mallard	4.0	0.0	0.0	2.0	0.0	13.0	0.0	0.0	0.0	0.0
Cormorant	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
Grey Heron	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
Merganser	3.0	1.0	2.5	0.0	0.0	0.0	0.0	0.5	0.0	0.0

South west section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	3.0	1.0	3.5	3.0	1.5	1.5	2.0	4.0	1.0	1.0
Curlew	2.0	2.5	3.0	0.5	0.0	0.0	1.0	1.5	0.5	1.0
Oystercatcher	2.0	0.0	3.0	2.5	2.5	1.5	3.0	1.5	0.0	0.5
Mallard	0.5	3.0	1.0	0.0	2.0	0.0	0.0	1.0	0.0	0.0
Goldeneye	0.5	3.5	1.5	2.0	0.0	2.0	0.0	0.0	0.0	1.0
Cormorant	0.5	0.5	0.5	0.0	2.5	0.0	0.5	0.0	0.0	0.0
Merganser	4.0	6.0	1.5	4.0	3.0	0.0	0.0	0.5	0.0	0.0

Montrose Basin. South & North.

South west section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	2.0	2.5	4.8	7.8	17.6	1.9	15.0	7.7	13.0	20.2
Curlew	2.0	11.0	4.5	3.8	21.4	17.6	46.3	36.2	42.0	51.5
Oystercatcher	17.8	12.4	21.2	7.6	6.0	14.5	37.4	49.0	58.6	36.8
Dunlin	0.0	0.0	0.0	.4	0.0	0.0	0.0	0.0	24.0	18.4
Knot	0.0	0.0	0.0	0.0	39.4	0.0	0.0	0.0	0.0	0.0
Bar Godwit	0.0	.4	0.0	3.9	.4	0.0	6.4	3.9	8.9	7.4
Turnstone	0.0	0.0	.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mallard	2.4	5.8	2.5	4.5	2.5	4.0	.2	2.3	0.0	0.0
Teal	0.0	11.6	3.2	0.0	0.0	.4	0.0	0.0	0.0	0.0
Merganser	3.6	.3	.3	0.0	0.0	.2	0.0	0.0	0.0	0.0
Eider	99.4	46.5	20.1	10.4	57.2	63.0	54.4	18.8	34.4	8.9
Cormorant	17.2	3.6	1.2	0.0	2.1	0.0	0.0	.2	0.0	0.0
Goldeneye	0.0	0.0	0.0	0.0	2.0	1.2	.6	0.0	.4	0.0

North west section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	5.4	7.4	9.3	21.0	17.2	14.4	19.4	27.5	21.6	22.7
Curlew	4.3	3.2	7.4	6.7	8.4	12.5	11.8	14.7	7.8	9.8
Oystercatcher	20.3	7.7	12.4	12.6	7.9	14.2	18.4	18.2	26.0	31.2
Dunlin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	54.6	22.0	0.0
Bar Godwit	0.0	.4	2.4	.4	4.4	6.5	4.4	8.7	6.5	5.4
Mute Swan	2.0	.3	.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mallard	2.0	7.5	9.8	35.8	59.0	75.0	34.6	45.3	60.4	22.0
Teal	0.0	0.0	0.0	2.0	2.6	0.0	0.0	0.0	0.0	.6
Wigeon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eider	102.3	46.0	52.0	12.0	4.5	7.8	5.3	2.4	2.4	4.6
Cormorant	3.4	.2	0.0	0.0	.2	0.0	0.0	0.0	0.0	0.0

Kessock Road Bridge. South.
South east section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	0.0	0.0	73.0	81.0	0.0	26.0	15.5	21.0	38.5	14.5
Oystercatcher	0.0	0.0	7.0	7.0	2.0	3.5	2.0	3.5	1.5	1.5
Ring. Plover	0.0	0.0	7.0	39.0	0.0	1.5	4.5	0.0	1.5	0.5
Mute Swan	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wigeon	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	3.5	0.0
Goldeneye	0.0	5.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Cormorant	0.0	1.0	0.0	2.0	0.0	0.0	0.0	0.0	0.5	0.0

South west section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	40.5	105.5	106.5	100.0	26.5	---	---	---	---	---
Curlew	3.0	7.0	14.5	2.0	2.0	---	---	---	---	---
Oystercatcher	30.0	40.5	28.0	25.0	8.0	---	---	---	---	---
Lapwing	0.0	0.0	0.0	25.0	23.5	---	---	---	---	---
Dunlin	0.0	0.0	12.5	43.0	10.0	---	---	---	---	---
Bar Godwit	0.0	0.0	0.0	0.0	1.0	---	---	---	---	---
Ring. Plover	0.0	11.5	6.0	5.0	0.0	---	---	---	---	---
Mute Swan	12.5	12.5	0.0	0.5	0.0	---	---	---	---	---
Mallard	0.0	4.0	6.5	4.0	4.5	---	---	---	---	---
Teal	0.5	9.0	10.5	19.0	2.5	---	---	---	---	---
Wigeon	0.0	3.5	1.0	0.0	0.0	---	---	---	---	---
Goldeneye	6.0	9.0	1.5	0.0	0.0	---	---	---	---	---
Tufted Duck	15.0	52.0	0.0	0.5	0.0	---	---	---	---	---
Cormorant	29.5	0.0	0.5	0.5	1.0	---	---	---	---	---
Grey Heron	0.0	0.0	1.0	0.0	0.0	---	---	---	---	---

Kessock Road Bridge. North.
North east section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Oystercatcher	3.5	5.5	0.5	0.0	0.0	0.0	0.5	0.0	0.5	0.5
Mallard	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1.5	1.5	0.0
Cormorant	10.5	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

North west section.

Oystercatcher	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.5	0.5	0.0
Cormorant	28.0	12.0	3.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0

Cromarty Road Bridge. South.

South east section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Curlew	0.5	2.0	0.0	0.0	1.0	1.5	0.5	0.5	1.5	0.0
Oystercatcher	1.0	1.5	2.0	0.5	1.0	0.0	0.0	0.5	0.0	0.0
Bar Godwit	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Mute Swan	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
Grey Heron	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Merganser	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.0	1.5

South west section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Curlew	20.0	8.0	6.0	6.0	4.5	7.0	6.5	6.5	4.0	3.5
Oystercatcher	25.5	9.5	4.0	2.5	5.0	3.0	4.5	6.5	5.0	3.0
Mute Swan	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mallard	101.5	5.5	5.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0
Teal	107.5	0.0	0.0	0.0	0.0	0.0	15.0	0.0	0.0	0.0
Shelduck	7.5	0.0	0.0	0.0	2.0	0.0	1.0	6.5	1.0	0.0
Merganser	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	1.0

Cromarty Road Bridge. North.

North east section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Curlew	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	1.5	0.0
Oystercatcher	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	1.5	1.5
Mute Swan	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
Mallard	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.0
Teal	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grey Heron	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

North west section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	10.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oystercatcher	0.0	0.0	0.0	1.0	0.0	0.5	0.0	0.0	0.0	1.0
Mute Swan	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Teal	0.0	0.0	0.0	0.0	0.0	0.0	21.5	14.5	11.5	1.5
Tufted Duck	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
Grey Heron	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Dornoch Road Bridge. South.
South east section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	98.5	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.5	1.0
Curlew	1.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0
Oystercatcher	0.0	0.0	0.0	0.0	0.0	0.5	1.0	0.0	0.0	1.0
Shelduck	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0
Cormorant	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Merganser	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0

South west section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	38.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Curlew	7.5	6.5	5.0	5.0	0.0	0.5	6.0	0.5	1.5	1.5
Oystercatcher	1.5	1.5	2.0	1.5	0.5	0.5	2.0	1.5	1.5	1.5
Mute Swan	4.0	3.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0
Shelduck	0.0	4.5	0.0	1.0	7.0	0.0	0.0	0.0	0.0	0.0

Dornoch Road Bridge. North.
North east section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	8.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Curlew	0.0	0.0	0.0	0.0	0.0	2.5	0.5	8.5	1.5	5.5
Oystercatcher	0.0	0.0	0.0	1.0	12.0	4.0	0.5	3.5	3.0	7.0
Mallard	0.0	0.0	0.0	0.0	0.0	5.5	0.0	0.0	0.5	0.5

North west section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	26.5	9.0	10.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0
Curlew	0.0	0.0	0.0	0.0	0.0	0.5	1.0	2.0	1.0	1.5
Oystercatcher	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.5	1.5	4.0

Erskine Road Bridge. South.
South east section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	0.0	0.5	0.0	2.0	1.5	2.5	0.0	0.0	0.0	0.0
Curlew	0.0	0.0	0.0	1.0	0.5	1.0	1.0	0.0	0.0	0.0
Oystercatcher	0.5	4.5	2.5	1.0	0.0	1.0	0.0	0.0	0.0	0.0
Lapwing	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0
Mallard	0.0	0.0	0.0	4.0	6.0	1.0	0.0	0.0	1.0	0.0
Cormorant	0.5	0.0	2.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
Grey Heron	0.0	0.0	0.0	0.0	0.0	0.0	1.5	2.5	0.0	0.0
Merganser	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.5	0.0

South west section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Redshank	0.5	2.5	2.0	1.5	2.5	0.0	0.0	0.0	0.0	0.0
Curlew	0.5	0.0	0.0	0.5	1.0	0.0	1.5	0.0	1.0	1.0
Oystercatcher	2.0	2.5	5.0	4.5	2.5	7.0	8.0	10.0	6.5	7.0
Lapwing	0.0	0.0	0.0	1.0	0.5	14.5	14.5	17.5	13.5	21.0
Goldeneye	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
Cormorant	0.5	0.5	0.0	0.0	0.0	0.0	1.5	1.0	1.0	1.5
Grey Heron	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Merganser	1.5	0.0	0.0	0.0	0.0	0.5	2.0	0.5	0.0	0.0

Erskine Road Bridge. North.
North east section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Mallard	0.0	0.0	3.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Cormorant	0.5	0.0	0.0	0.0	0.0	0.5	2.5	0.5	1.0	0.5
Merganser	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0

North west section.

Species	100m	200m	300m	400m	500m	600m	700m	800m	900m	1000m
Cormorant	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0
Merganser	0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0

APPENDIX 2. Distribution of major shorebird roost sites in the vicinity of eight estuarine crossings in Scotland, January 1994. (All sites combined)

Bridge	**100m**	**200m**	**300m**	**400m**	**500m**	**600m**	**700m**	**800m**	**900m**	**1000m**
Kincardine	RS	DN	--	OC	LP	--	--	--	DN	--
Forth Road	OC	--	--	DN	--	CU	--	OC	--	--
Tay Road	--	--	--	--	CU	LP	OC	LP,OC	--	--
Dornoch	RS	--	CU	--	--	--	OC,CU	--	--	OC,CU
Cromarty	--	--	--	--	--	CU	--	--	--	OC,CU
Kessock	--	CU	LP	--	--	OC,RS	--	--	--	--
Erskine	LP	--	RS	--	--	--	--	--	--	--
Montrose	--	--	--	CU,KT OC,DN	--	--	--	--	RS	--

RS Redshank
CU Curlew
OC Oystercatcher
LP Lapwing
KT Knot
DN Dunlin

APPENDIX 3. Report on shorebird studies at Kincardine Bridge carried out during Decemeber 1993.

APPENDIX 15

SUMMARY OF HISTORICAL ESTUARINE BIRD SURVEYS IN THE FORTH

Summary of historical bird studies on the Forth

Information on the birds of the Forth Estuary dates back to the uniquely detailed observations for the 19thC made by Brotherston (1875)(Table 1). A comparison of ranked wading bird abundances between his observations and those of the BOEE (Prater 1981), showed that largely the same species predominated (Bryant unpublished). There were a few exceptions amongst the scarcer species, however, such as the much lower frequency of passage Whimbrel at present. Nevertheless, such differences can be accounted for by known changes in migratory habits or flyway population sizes. The picture that emerges, therefore, is of a largely stable community composition amongst wintering waders, bridging a period of well over 100 years. Because detailed counts are only available since the 1950s, however, changes in the absolute, as opposed to the relative abundance of most species, are not known. Harvie-Brown made many observations on the Forth but unfortunately it was one of the few parts of Scotland that he did not document in detail. Nevertheless, the Vertebrate Fauna of Forth by Rintoul and Baxter (1935) brought together many earlier observations on the birds of the Forth, including those of Harvie-Brown. They had a coverage bias towards the Outer Firth of Forth, and quantitative data for the Inner Forth remained scarce. Hence, while a general decline in the abundance of waterfowl might be presumed to have occurred as a result of loss of mudflat feeding areas, intensification of agriculture and industrialisation of the area (McLusky et al. 1982), there is no firm evidence of such changes due to lack of detailed census work. It was not until systematic counts of wildfowl began on the Forth after WWII that population sizes were assessed quantitatively (Table 1).

Table 1 Sources of data on which a long-term perspective of waterfowl populations is based

Source	Groups included	Data type
Brotherston (1875)	Waders	Descriptive
Rintoul & Baxter (1935)	Wildfowl and waders	Descriptive
Atkinson-Willes (1963) (NWC)	Wildfowl	Total counts
Patterson, T. (unpubl. notes)	Wildfowl	Total counts
Campbell (1975) FOWP	Wildfowl and waders	Roost counts
Bryant (1976) TTTC	Wildfowl and waders	Feeding and roosting birds
Prater (1981) BOEE	Wildfowl and waders	Roost counts
Warnes (1981) (Thesis)	4 species	Feeding birds
Owen (1983) (NWC)	Wildfowl	Total counts
Bryant (1987)	Wildfowl and waders	Total counts
Newton & Bryant (1991)	Wildfowl & waders	Feeding birds
Bryant (1994) LTC survey	Wildfowl and waders	Feeding and roosting birds
Bryant & McLusky (1997)	Waders	Total counts
Present study (2000) LTCs	Wildfowl and waders	Feeding and roosting birds
Musgrove et al. (2001) WeBS	Waterbirds	Roost counts

The revival of studies of waterfowl on the Forth occurred in 1947, as a result of the IWC initiating surveys across Europe. After 1952 the (then) Wildfowl Trust coordinated counts across the UK. The earliest systematic records from the Forth were in 1947, with counts in the Grangemouth-Kincardine area (including Skinflats) from 1952, and west of Kincardine Bridge from 1958. Unfortunately the main published account of these populations (Atkinson-Willes 1963, Table 2) aggregates data from Grangemouth to Alloa, so they cannot be used to assess populations in the Kincardine Bridge area alone, mainly referring to populations near Grangemouth and Alloa.

Table 2. Wildfowl populations in the Grangemouth-Alloa area from 1947-1960

Species	Regular	Peak
Mallard	1560	2600
Teal	2030	5500
Wigeon	885	1600
Pintail	170	490
Tufted duck	535	1500
Pochard	40	160
Goldeneye	540	825
Goosander	10	20
Merganser	85	230
Shelduck	790	1670
Greylag	250	500
Pinkfoot	1100	1700
Mute swan	345	390
Whooper swan	155	345

'Regular' refers to the mean of the 3 highest counts in the census period. 'Peak' to the highest single. The NWCs extended from September to March. From Atkinson-Willes (1963).

Nevertheless, they do allow some useful comparisions, because information from counters and other sources allows some detailed interpretation. When compared with current populations, they show that since that time mallard and teal, tufted duck, mute swan and whooper swan have declined, whereas shelduck and pink footed goose have increased. Some of these declines follow removal of an artificial food source (distillery waste) at Cambus, near Alloa (Thom 1969). In November 1962, for example, peaks of 1554 Mallard and 4390 Teal were recorded near Alloa, but these populations declined after discharges were reduced in 1963. Teal in particular had their major Scottish haunt near Alloa, and this would have inevitably boosted counts at nearly Kincardine, for example when they were disturbed by wildfowling, or though 'population overspill', when numbers were high (Moser 1988). Other changes in wildfowl numbers, such as those amongst the diving ducks, are also likely to reflect the withdrawal of artificial food supplies. There will be an additional factor, however; the recent scarcity of hard winters, which previously caused diving ducks to resort to the Forth in the Kincardine area in large numbers. While it is not known where these flocks originated, they likely included many birds from the surrounding Scottish lowlands moving from frozen freshwaters onto the open estuary. Counts made by T. Patterson who (with J. Potter), was mainly responsible for monitoring wildfowl in the area until the start of the BOEE, noted the general downturn of all wildfowl species after about 1963 (Table 3). While, the 1962/1963 peaks for the 3 main species of diving ducks were due to the exceptional winter weather, subsequent declines are notable. It can be concluded, that the high numbers of wildfowl counted up to the early 1960s in the Kennet Pans area depended in large part on the supply of distillery waste at Cambus, and that its withdrawal led to progressive population declines. Comparable declines affecting diving ducks occurred on the Outer Forth, following cessation of effluent discharges from Edinburgh in the 1970s (Campbell 1980). The more 'natural' wildfowl population sizes, mostly dependent on local resources, therefore, were those occurring after artificial supplies had been withdrawn. This period was covered by the BOEE, and more recently by WeBS.

Table 3. Peak winter counts made by T. Paterson for Kennet Pans (i.e. Kincardine Bridge to Alloa)

	58/9	59/60	60/61	61/62	62/63	63/64	64/65	65/66	66/67	67/68	68/69
Mallard	511	1072	1500	680	1200	669	610	545	603	330	NC
Teal	450	642	400	300	690	42	1500	52	10	36	
Wigeon	950	896	1000	750	1000	513	384	325	117	172	
Pochard	40	82	19	160	300	10	66	95	40	20	
Tufted Duck	900	1200	1500	86	3500	6	720	2300	850	390	
Goldeneye	600	600	700	700	800	33	122	544	190	280	
Merganser	2	5	17	2		33					
Shelduck	50	135	137	103	134	83	46	186	44	51	

Unpublished data from T. Patterson's notebooks.

The report of the Forth Ornithological Working Party (Campbell 1975) summarised the situation during the BOEE at the level of individual sites. However, since it was based on numbers present at roosts within each count zone, and did not allow for movements to other zones for feeding, the extent to which it was able to rank the conservation importance of sites is questionable. Nevertheless, the FOWP report notes Regular peaks of 1363 wildfowl and 1197 waders for Kincardine to Dunmore, and 403 and 1173 respectively for the now reclaimed Black Devon Mouth (the site was adjacent to the recently re-established Black Devon Marsh, and had a tidal mudflat).

The results of the NWCs for wildfowl were summarised by Owen et al. (1986). They drew attention to the decline in numbers of wildfowl in the area between the 1960s and 1970s. However, as noted above, the principal contrast is between the period when food supplies were available from the Cambus distillery (pre-1963), and the following period. Indeed, the counts between the latter half of the 1960s and the 1970s do not differ markedly (compare Tables 3 and 4).

Table 4. Numbers of wildfowl counted in Kincardine Bridge to Alloa area (i.e. excludes Alloa Inches). From Owen et al 1986. (note that these data overlap the BOEE and the unpublished data of T. Patterson, Table 3).

Species	1960-68	Regular 1969-77	Maximum 1969-77
Mallard	519 (1500)	163	365
Teal	121 (640)	29	320
Wigeon	380 (1000)	53	207
Pintail	-	0	1
Pochard	45 (615)	10	233
Tufted duck	620 (2300)	25	638
Goldeneye	274 (760)	234	748
R b merganser	-	1	8
Shelduck	-	40	150
Mute swan	17 (89)	2	13
Whooper swan	-	2	10

Counts under 1960-69 show 'regular' and 'maximum' counts (in brackets).

Detailed counts of usage of mudflats by feeding birds became available in Bryant (1976) (Table 5). While earlier counts of wildfowl would have included both loafing and feeding ducks, the 1976 counts were the first to record usage of the area by wading birds and to separate feeding waterbirds from others. They showed that the small areas of mudflat at Kennet Pans and by the Pow Burn mouth were favoured by redshank and dunlin, in particular. Equally, wildfowl numbers recorded were low because birds loafing offshore were not included in counts, even though they may have fed in these areas outside the observation period (i.e. at night).

Table 5. Mean number of waterbirds feeding on mudflats during January 1976

	Kennet Pans	**Kincardine Bridge to Dunmore**
Cormorant	0	92
Mallard	87	68
Teal	0	0
Wigeon	0	2
Goldeneye	27	0
Red breasted merganser	0	0
Shelduck	0	11
Oystercatcher	0	2
Ringed plover	0	2
Curlew	3	24
Redshank	32	67
Knot	0	0
Dunlin	280	300

Means obtained from daily peak numbers at each site during study period.

To allow comparisons between sites, the numbers of certain birds feeding at Kennet Pans, Kincardine Bridge to Dunmore and Skinflats during through-the-tide counts were compared (Table 6). The data or North Skinflats have been extracted from the original 1976 data and are presented here for the first time. They show that all three sites in the vicinity of Kincardine Bridge were ranked highly within the Inner Forth, in terms of bird densities, with North Skinflats the most heavily used.

Table 6 Feeding usage by shorebirds in January 1976. Species included were shelduck, redshank, knot and dunlin; identified as 'key species' due to their internationally and nationally important populations on the Inner Forth (Bryant 1989).

Sites	**FH/12.5hr tide**	**% Inner Forth (FI)**	**FH/km^2**
Kennet Pans	2,239	1.5	15,879
Kinc Br - Dunmore	1,673	1.1	4,686
North Skinflats only	17,388	11.8	21,735
Skinflats (whole site)	58,938	40.2	15,416
Inner Forth	14,6743	100%	6,551 (=mean)

FH/12.5 hr tide = bird feeding hours per 12.5 hour tidal cycle, based on Through-the-tide counts. % Inner Forth = % of feeding hours on Inner Forth occurring at this site during study period. FH/km^2 = bird feeding hours related to area of intertidal mudflat.

This study was repeated in 1996/1977, but only maps of relative shorebird densities were available for comparison (Warnes 1981). The next detailed study was in 1991, and allowed direct comparisons with earlier data. This study confirmed that the North Skinflats was as important for key species in terms of densities of feeding birds as Skinflats was as a whole (Table 7). It also showed that feeding usage had lessened by 1991 (Tables 6, 7), but this was to be expected from the reduction in numbers using the Inner Forth as a whole (Bryant & McLusky 1997).

Table 7. Feeding usage by shorebirds at North Skinflats during January 1991

Sites	**FH/12.5hr tide**	**FH/km^2**
North Skinflats	10394	12992
Skinflats	43772	11459

This study was followed by a LTC survey of the Firth of Forth as a whole in the winter period 1993/94 (Tables 1, 8). Data from these Low-tide counts in the area of Kincardine Bridge are presented in Table 8. They provide the most recent information for comparison with that obtained in the present study (1999-2000). They cannot provide for an assessment of the conservation status of the area because they cover a period of less than five years. Instead, especially when considered in parallel with equivalent data collected in earlier years, however, they demonstrate the relative value of each sub-site for feeding waterbirds. Summary statistics based on these data are discussed in the main text. The raw data also demonstrate the level of variation found in low tide counts, which ranges from rather constant numbers of mallard at Kennet Pans, to several case of single records (i.e Pink-footed Goose at Kennet Pans). As with WeBs and comparable count data, a high level of variation of this kind, even within sites, makes detection of changes through time a difficult task. Inevitably therefore, because the ability to statistically detect change reliably is low, due to variability and limited data, fewer short and long-term changes can be demonstrated than are likely to have occurred.

Table 8. Summary of Low tide counts (LTCs) in winter 1993/94 for 3 sites in the vicinity of Kincardine Bridge. The table shows NS = North Skinflats; KP = Kennet Pans (Black Devon Mouth to Kincardine Bridge) and PB = Pow Burn (Dunmore to Kincardine Bridge)

1994 (Dates)	**KP 6/1**	**PB 6/1**	**NS 6/1**	**NS 16/1**	**KP 30/1**	**PB 30/1**	**NS 30/1**	**KP 13/2**	**PB 13/2**	**NS 13/2**
Heron						5	9		2	
Cormorant		120			6	40		8	13	7
PF goose	1200									
Greylag							4			
Shelduck	87	50	12	102	194	106	18	158	65	1
Teal	20				25			47	25	
Mallard	70	10	15		52			86	2	6
Dunlin	20	25		48		1	140			
Redshank	75	15	13	76	25	104	43	102	22	10
Goldeneye	8	5						15		
Oystercat'r		60		5	82	5		47		2
Lapwing		40		143				27	1	
Curlew		14	8	15	210	15	68	170	6	50
Knot				104		73	71			
Red b merg					18			2		
Bar-t god				36						

Bryant (1987) and Bryant & McLusky (1997) examined population trends amongst waterbirds on the Forth based on up to 21 years of data from WeBS (1973/74 to 1993/94). They detected changes on the Inner Forth that were likely to be due to fluctuations in the size of the flyway populations of waders, notably amongst dunlin, black-tailed godwit, curlew and redshank. A similar pattern was found amongst knot by Bryant (1987) in a subset of these data. Local variations in food supplies and loss of habitat to land claim were also considered to be important for some species, leading respectively to changes in numbers of knot and oystercatcher at Skinflats, and dunlin at Kinneil, for example. As a result of these and other factors, which operate both from within and outside the Forth, several waterbird populations on the Inner Forth have fluctuated in abundance. The declines amongst knot in the early 80s, for example, have persisted to the present time, whereas dunlin have recovered from a low point in the mid-80s to levels found during the early 1970s. The rise of black-tailed godwits has been the most striking recent example of a population increase rather than a recovery.

Conclusion

It is clear from this summary of long term data for waterbirds in the vicinity of Kincardine Bridge that the species represented in the area have been largely consistent, as confirmed by examination of descriptive data stretching back over 100 years. Hence, the waterbird species recorded in the earliest surveys of the area are still present today. This suggests that the habitat available to waterbirds on the Inner Forth has retained the same character and provides similar types of resources, even though about half of the intertidal estuary has been lost to land-claim and other factors (McLusky et al. 1992). In contrast, loss of habitat is likely to have an effect on the sizes of populations which are present (Yates et al. 1996).

The extent to which the abundances of waterbirds have changed over the long term, are not clear because systematic counts of sites are available for only 50 years or less and detailed counts of feeding birds are even more recent. Amongst wildfowl, for which data are available from the 1950s, it appears that the principal changes on the Inner Forth have been amongst dabbling and diving duck species that depended on distillery waste from Cambus. After this food supply ceased to be available in the 1960s, fewer ducks were present, although the possibility of large numbers returning during an extended period of winter cold remains. Hence, during the last exceptional cold spell, in January-February 1979, a peak count of over 11000 ducks was made on the Inner Forth, including many diving ducks between Grangemouth and Cambus. Amongst other waterbird species, for which data are available only from the 1970s, the changes in populations were generally more modest in scale (Bryant & McLusky 1997). No more recent analysis of waterfowl population trends on the Inner Forth has been undertaken, although from unpublished information from WeBS counts, it seems likely that amongst those waders showing significant declines up to the mid-90s (Bryant & McLusky 1997), these have persisted to the present day for grey plover, knot and turnstone. In contrast, dunlin and oystercatcher have recovered their former status and black-tailed godwits have increased. The recent changes in status of wildfowl have not been analysed, but it is nevertheless clear that the number of wintering shelduck has declined while the moulting flock has increased (Bryant unpublished data). The causes of these changes lie within and outside the Forth Estuary and some remain speculative. Changes in flyway populations, land-claim, climate and localised pollution have all been implicated (Bryant 1987, Bryant & McLusky 1997).

The data available for feeding waterbirds show that the mudflats in the Kincardine Bridge area are of high quality, as judged from the consistently high densities of shorebirds feeding there, and that this pattern has been evident over the period of nearly 30 years for which detailed counts have been available. It follows that loss of a unit-area of habitat in the vicinity of Kincardine Bridge will, in general terms, be as damaging as equivalent losses elsewhere. Equally, predicted impacts must consider the total number of waterbirds likely to be affected. These and other points are considered in detail in the main body of the report.

APPENDIX 16

TABLES OF MONTHLY BIRD NUMBERS FROM THE RTTC ESTUARINE BIRD SURVEY, 1999-2000

Monthly estuarine bird numbers, Random Through The Tide Count December 1999 – February 2000

1. December counts (no in-channel counts made)

Section 1 - Dunmore to Kennet Pans

	all waders	all waterfowl	Redshank	Shelduck
Mean	64.09	114.36	12.75	18.43
Mean peak	112.00	144.50	21.00	38.25
Peak	379.00	512.00	64.00	48.00

Section 2 - Kennet Pans to Kincardine Bridge

	all waders	all waterfowl	Redshank	Shelduck
Mean	119.37	81.69	48.78	15.14
Mean peak	223.50	173.50	94.50	27.50
Peak	427.00	377.00	222.00	65.00

Section 3 - North Skinflats

	all waders	all waterfowl	Redshank	Shelduck	Dunlin
Mean	185.32	17.76	57.37	14.64	56.51
mean peak	412.50	37.50	119.75	25.00	186.00
Peak	1,087.00	133.50	358.00	85.00	500.00

2. January Counts

Section 1 - Dunmore to Kennet Pans

	all waders	all waterfowl	Redshank	Shelduck
Mean	43.67	80.10	12.71	8.41
Mean peak	90.25	162.75	21.50	18.25
Peak	219.00	535.00	84.00	69.00

Section 2 - Kennet Pans to Kincardine Bridge

	all waders	all waterfowl	Redshank	Shelduck
Mean	58.40	107.63	51.27	7.37
Mean peak	179.65	306.25	98.25	20.50
Peak	425.00	953.00	290.00	59.00

Section 3 - North Skinflats

	all waders	all waterfowl	Redshank	Shelduck	Dunlin
Mean	141.29	38.14	69.78	40.16	11.32
Mean peak	524.00	141.90	226.75	135.00	56.50
Peak	1,290.00	435.00	564.00	410.00	219.00

3. February Counts

Section 1 - Dunmore to Kennet Pans

	all waders	all waterfowl	Redshank	Shelduck
mean	108.85	90.30	18.83	50.31
mean peak	181.25	197.50	46.50	108.80
Peak	649.00	403.25	146.00	320.00

Section 2 - Kennet Pans to Kincardine Bridge

	all waders	all waterfowl	Redshank	Shelduck
Mean	66.62	116.30	13.02	13.19
mean peak	154.25	399.75	37.75	44.00
Peak	540.00	1,506.00	120.00	120.00

Section 3 - North Skinflats

	all waders	all waterfowl	Redshank	Shelduck	Dunlin
Mean	112.06	30.23	32.16	25.53	19.58
mean peak	355.25	100.25	107.25	81.25	93.25
Peak	987.00	295.00	311.00	228.00	363.00

Monthly estuarine bird numbers, Random Through The Tide Count, May, August and September 2000

May

Kennet Pans

	All waders	All waterfowl	Redshank	Shelduck	Dunlin
Mean	5.47	10.49	0.18	8.70	0.00
Mean peak	17.50	25.00	0.75	19.00	0.00
Peak	53	60	3	39	0

North Skinflats

	All waders	All waterfowl	Redshank	Shelduck	Dunlin
Mean	3.01	3.94	0.00	3.53	0.00
Mean peak	9.75	11.00	0.00	11.75	0.00
Peak	31	23	0	22	0

Dunmore

	All waders	All waterfowl	Redshank	Shelduck	Dunlin
Mean	3.90	2.45	0.12	1.06	0.00
Mean peak	11.25	6.25	1.00	2.75	0.00
Peak	41	22	2	9	0

Aug

Kennet Pans

	All waders	All waterfowl	Redshank	Shelduck	Dunlin
Mean	39.85	16.42	2.93	11.04	0.00
Mean peak	75.00	36.49	9.25	22.50	0.00
Peak	203	99	37	61	0

North Skinflats

	All waders	All waterfowl	Redshank	Shelduck	Dunlin
Mean	73.97	29.77	0.37	29.63	0.00
Mean peak	145.45	60.25	1.50	59.00	0.00
Peak	450	153	4	149	0

Dunmore

	All waders	All waterfowl	Redshank	Shelduck	Dunlin
Mean	15.79	1.05	1.50	0.00	0.00
Mean peak	41.50	2.75	2.00	0.00	0.00
Peak	149	9	8	0	0

Sept

Kennet Pans

	All waders	All waterfowl	Redshank	Shelduck	Dunlin
Mean	111.34	33.96	7.16	16.47	0.12
Mean peak	263.25	70.00	15.50	36.25	0.5
Peak	816	154	39	70	2

North Skinflats

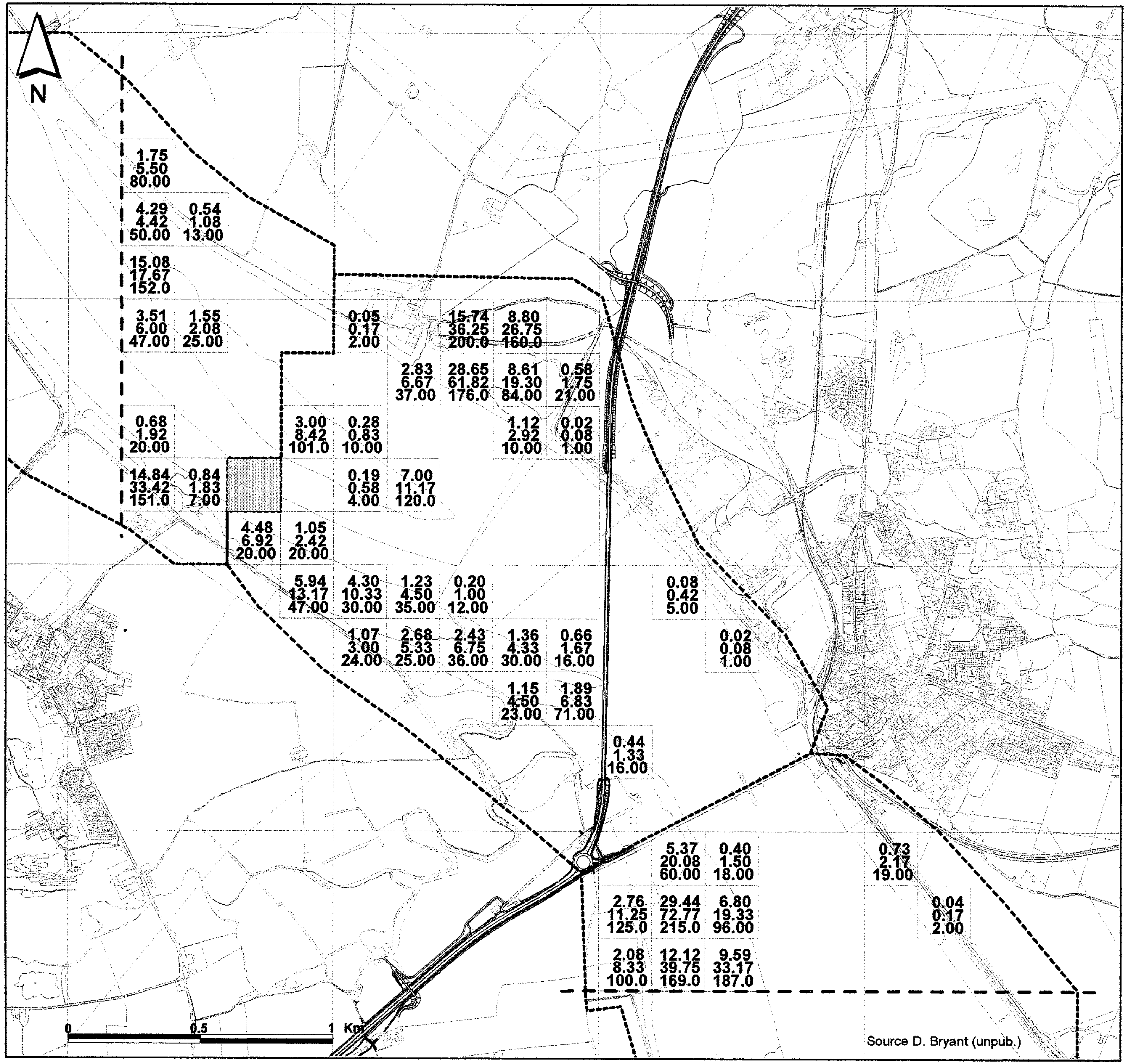
	All waders	All waterfowl	Redshank	Shelduck	Dunlin
Mean	406.10	106.99	0.43	94.24	0.87
Mean peak	724.20	280.00	1.50	185.50	3.50
Peak	1081	547	5	342	14

Dunmore

	All waders	All waterfowl	Redshank	Shelduck	Dunlin
Mean	26.05	82.82	1.23	0.00	0.00
Mean peak	46.50	212.00	3.00	0.00	0.00
Peak	141	597	10	0	0

APPENDIX 17

1999-2000 RTTTC ESTUARINE BIRD SURVEY DATA MAPS



LEGEND

Winter 1999/2000 - All Waders

Figures in each count square represent mean (upper), mean peak (middle) and peak (lower) bird numbers respectively

No data

Bird count boundaries:

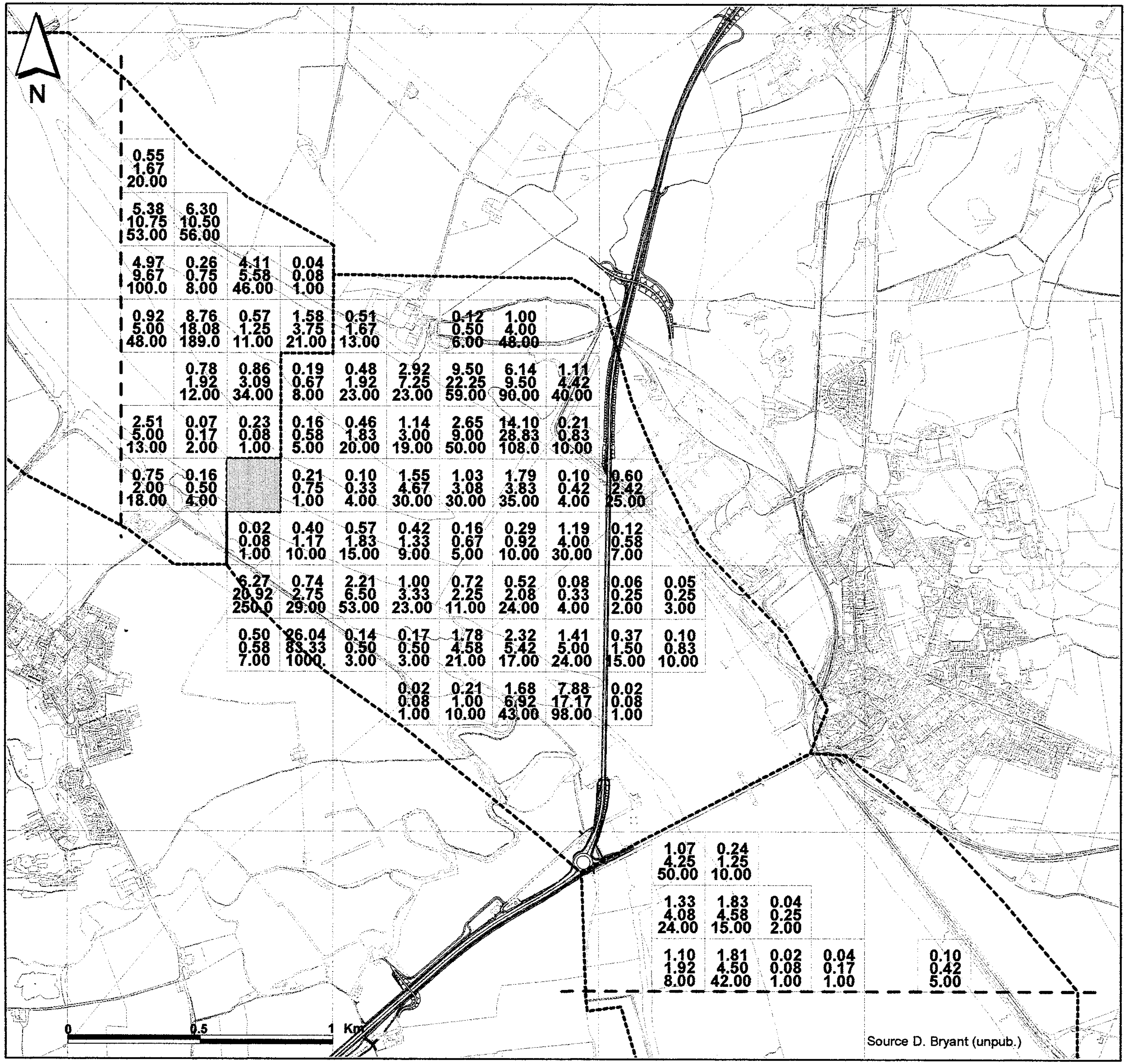
Limits of count areas

Limit of mapped data

Preferred route

NES

CLIENT	Babtie
PROJECT	Upper Forth Crossing at Kincardine, Stage 3 Ecological Impact Assessment
TITLE	Estuarine bird feeding distribution. Overall Autumn mean, mean peak and peak bird numbers - All waders
SCALE	1:20 000
DATE	July 2003



LEGEND

Winter 1999/2000 - All Waterfowl

Figures in each count square represent mean (upper), mean peak (middle) and peak (lower) bird numbers respectively

No data

Bird count boundaries:

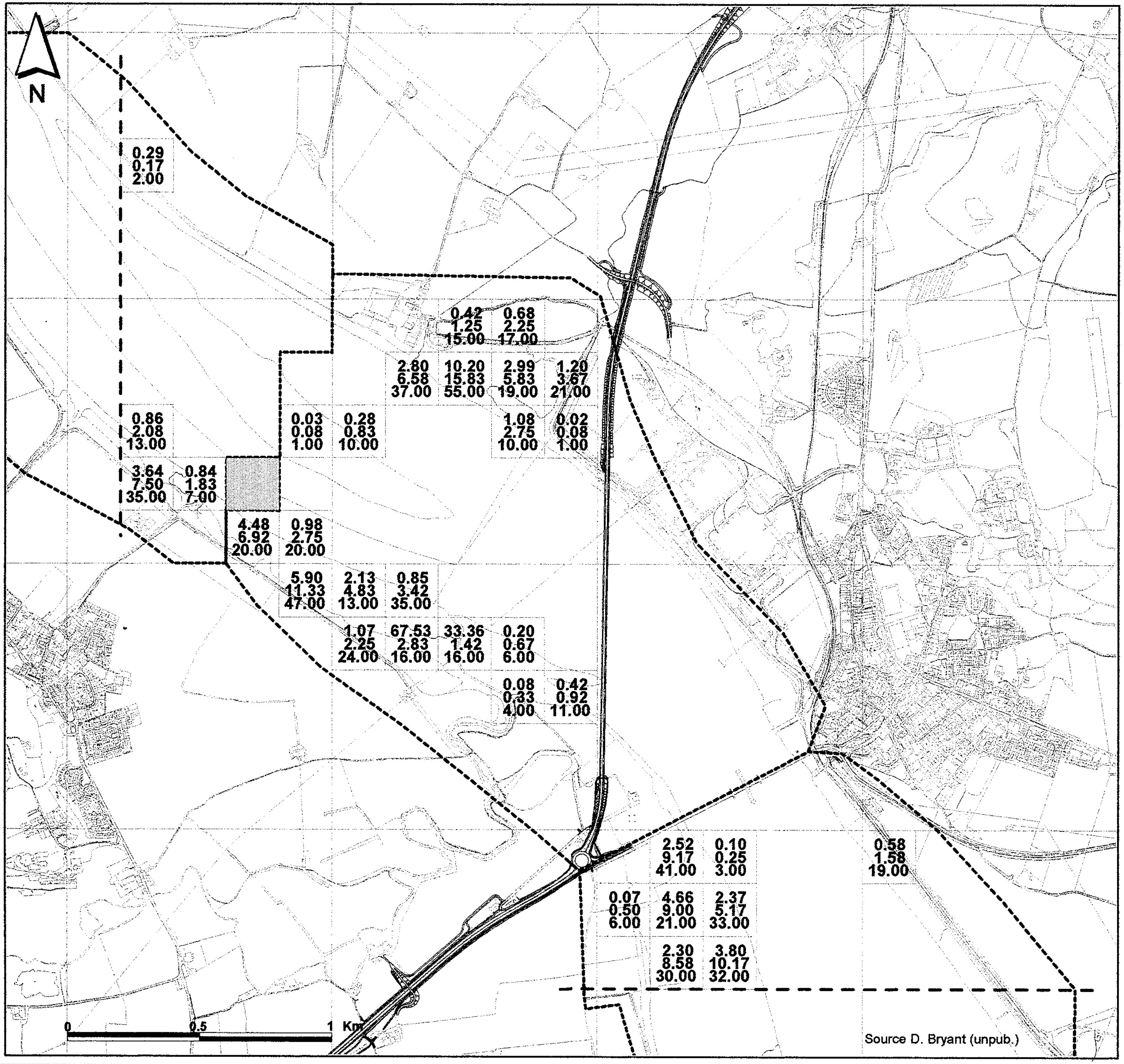
Limits of count areas

Limit of mapped data

Preferred route

NES

CLIENT	Babtie
PROJECT	Upper Forth Crossing at Kincardine, Stage 3 Ecological Impact Assessment
TITLE	Estuarine bird feeding distribution. Overall Autumn mean, mean peak and peak bird numbers - All waterfowl
SCALE	1:20 000
DATE	July 2003



LEGEND

Winter 1999/2000 - Redshank

Figures in each count square represent mean (upper), mean peak (middle) and peak (lower) bird numbers respectively

No data

Bird count boundaries:

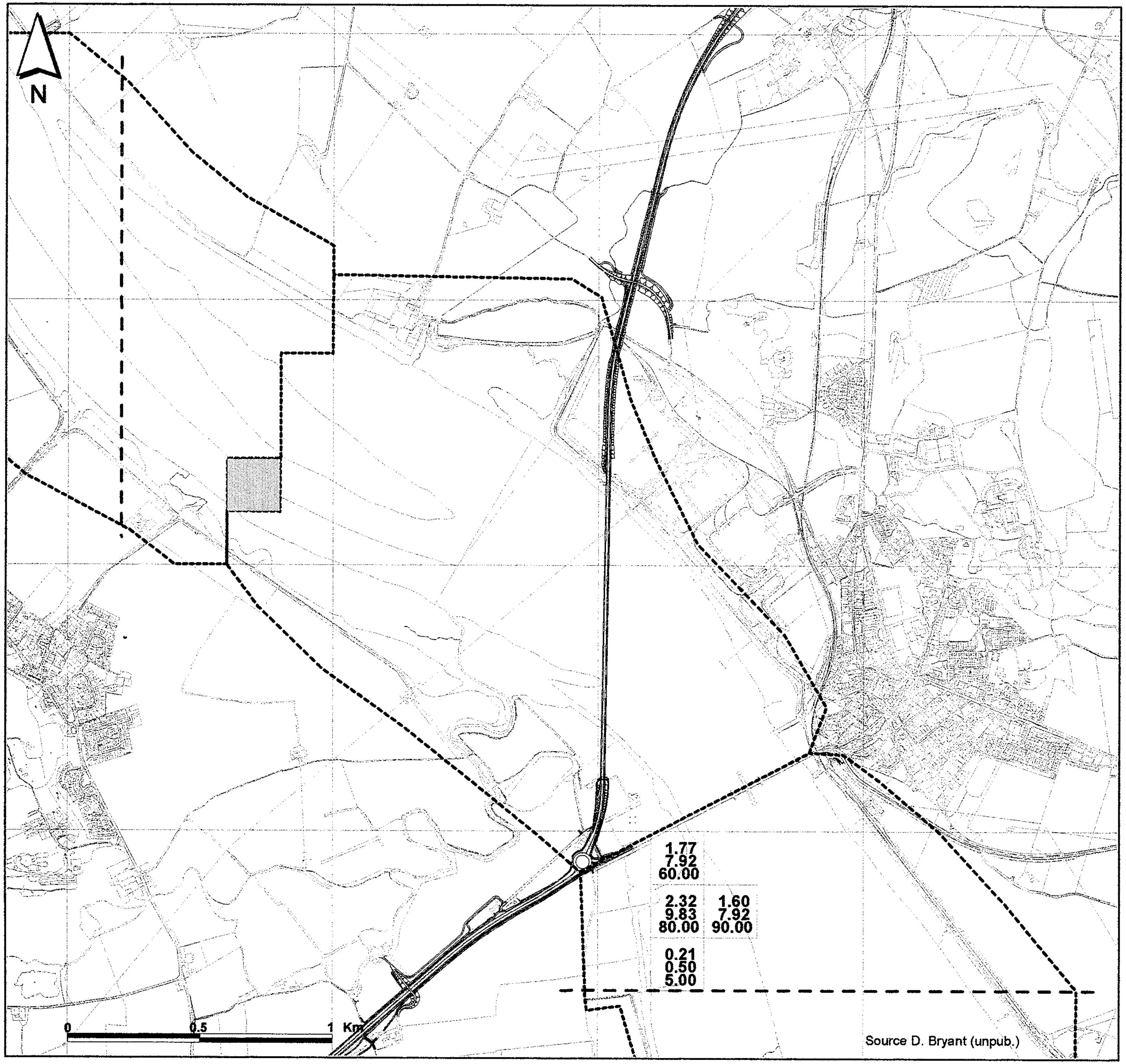
Limits of count areas

Limit of mapped data

Preferred route

NES

CLIENT	Babtie
PROJECT	Upper Forth Crossing at Kincardine, Stage 3 Ecological Impact Assessment
TITLE	Estuarine bird feeding distribution. Overall Autumn mean, mean peak and peak bird numbers - Redshank
SCALE	1:20 000
DATE	July 2003



LEGEND

Winter 1999/2000 - Dunlin

Figures in each count square represent mean (upper), mean peak (middle) and peak (lower) bird numbers respectively

No data

Bird count boundaries:

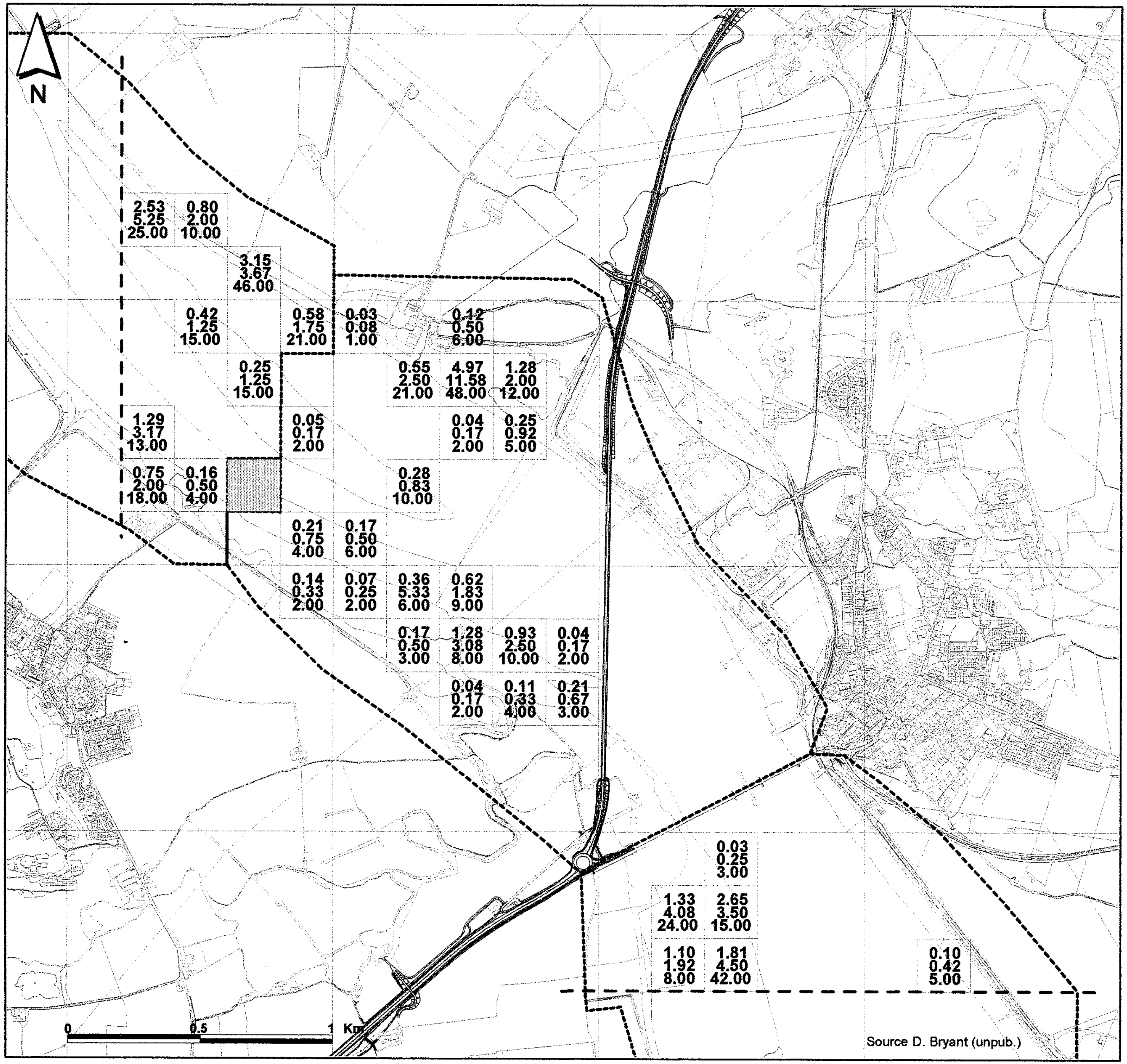
Limits of count areas

Limit of mapped data

Preferred route

NES

CLIENT	Babtie
PROJECT	Upper Forth Crossing at Kincardine, Stage 3 Ecological Impact Assessment
TITLE	Estuarine bird feeding distribution. Overall Autumn mean, mean peak and peak bird numbers - Dunlin
SCALE	1:20 000
DATE	July 2003



LEGEND

Winter 1999/2000 - Shelduck

Figures in each count square represent mean (upper), mean peak (middle) and peak (lower) bird numbers respectively

No data

Bird count boundaries:

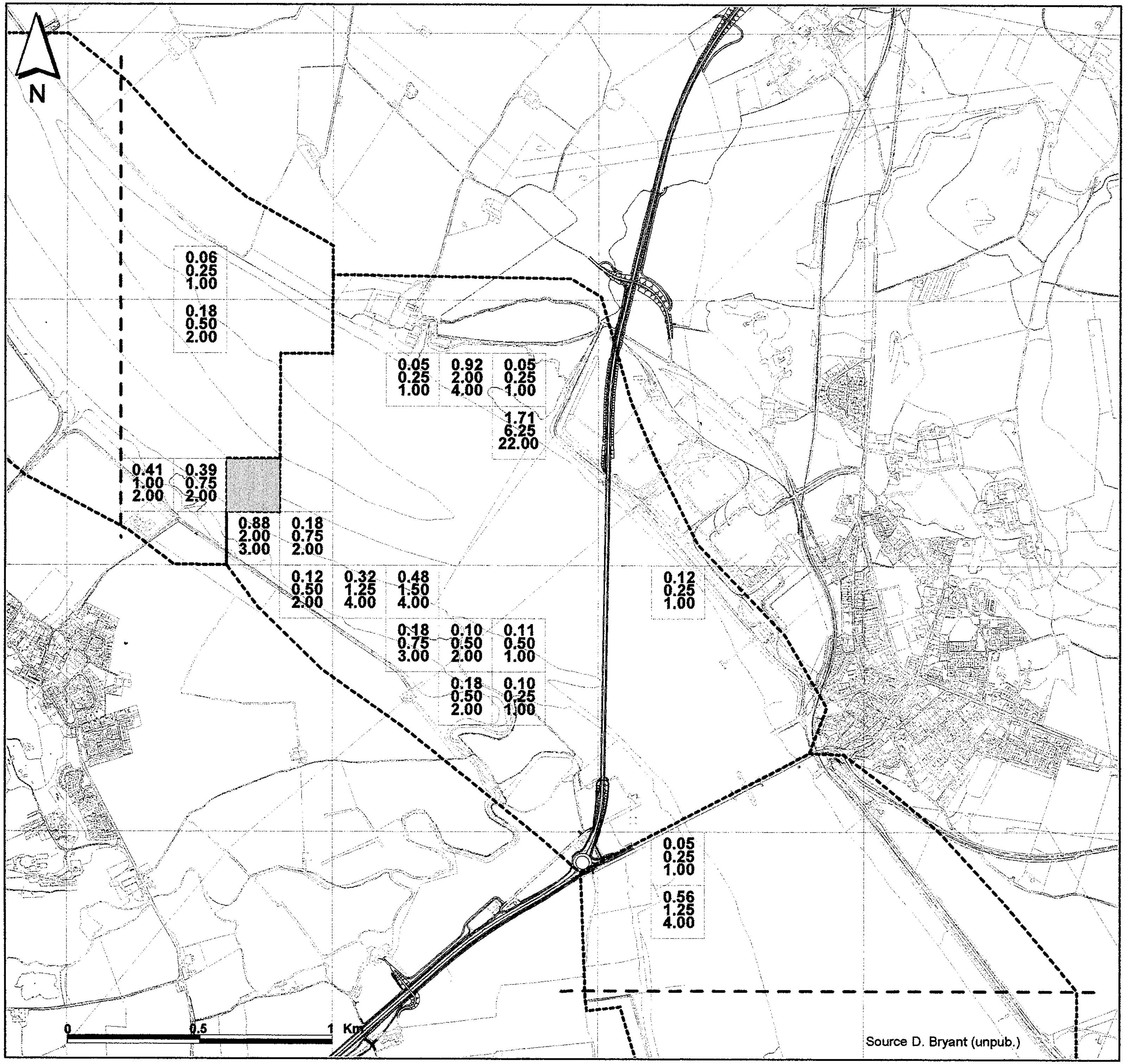
Limits of count areas

Limit of mapped data

Preferred route

NES

CLIENT	Babtie
PROJECT	Upper Forth Crossing at Kincardine, Stage 3 Ecological Impact Assessment
TITLE	Estuarine bird feeding distribution. Overall Autumn mean, mean peak and peak bird numbers - Shelduck
SCALE	1:20 000
DATE	July 2003



LEGEND

May 2000 - All Waders

Figures in each count square represent mean (upper), mean peak (middle) and peak (lower) bird numbers respectively

No data

Bird count boundaries:

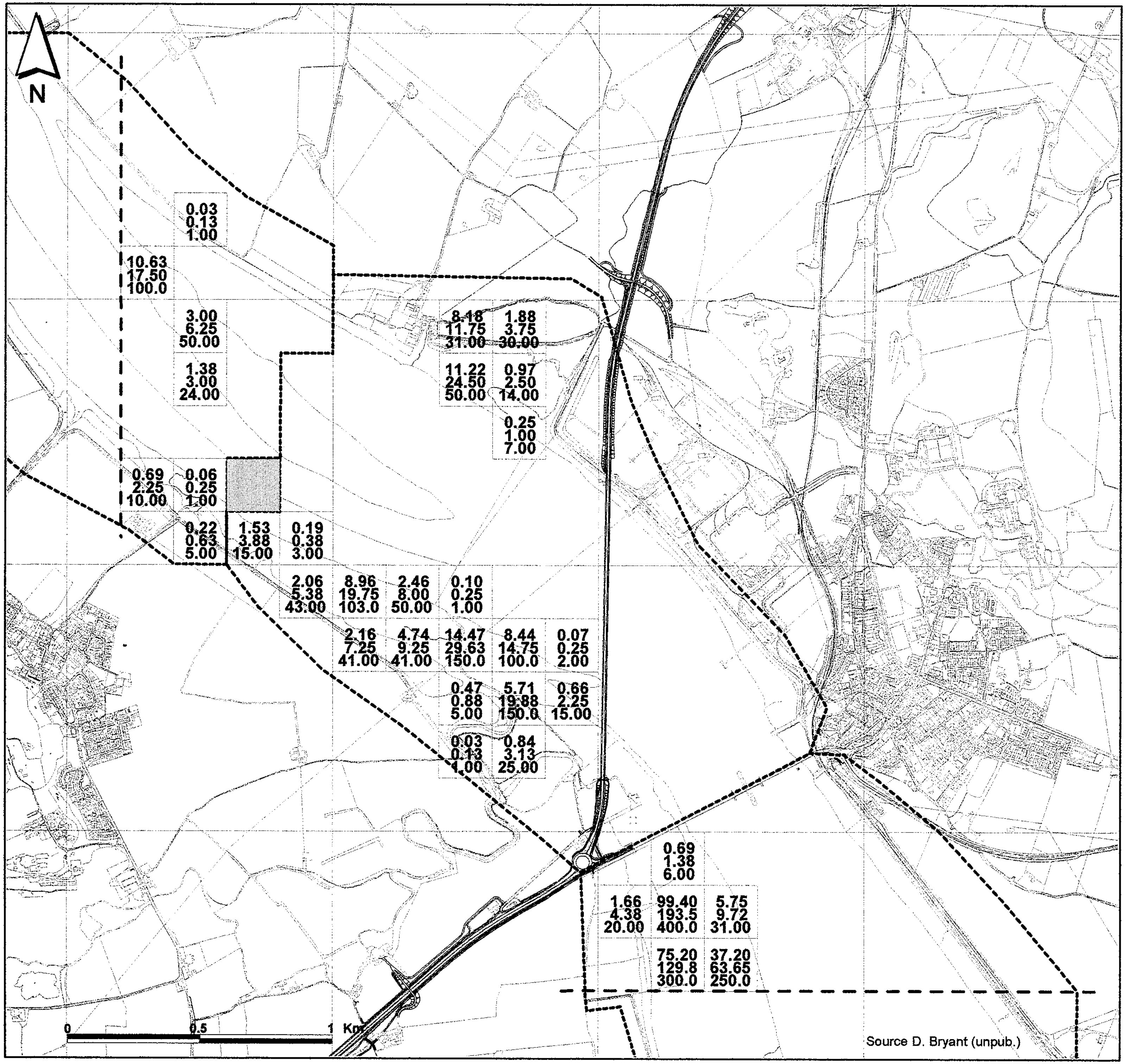
Limits of count areas

Limit of mapped data

Preferred route

NES

CLIENT	Babtie
PROJECT	Upper Forth Crossing at Kincardine, Stage 3 Ecological Impact Assessment
TITLE	Estuarine bird feeding distribution. May mean, mean peak and peak bird numbers - All waders
SCALE	1:20 000
DATE	July 2003



LEGEND

Autumn 2000 - All Waders

Figures in each count square represent mean (upper), mean peak (middle) and peak (lower) bird numbers respectively

No data

Bird count boundaries:

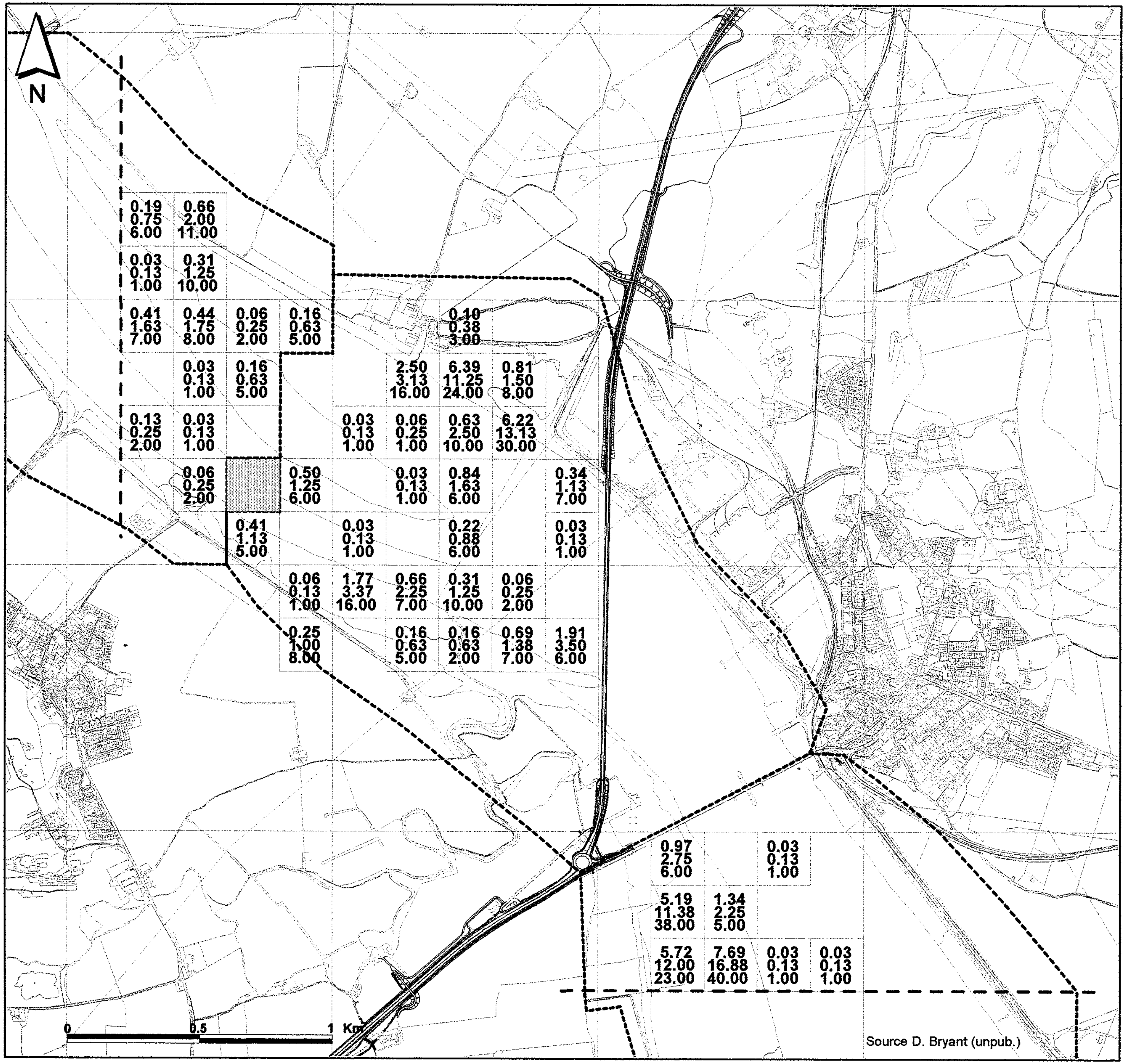
Limits of count areas

Limit of mapped data

Preferred route

NES

CLIENT	Babtie
PROJECT	Upper Forth Crossing at Kincardine, Stage 3 Ecological Impact Assessment
TITLE	Estuarine bird feeding distribution. Overall Autumn mean, mean peak and peak bird numbers - All waders
SCALE	1:20 000
DATE	July 2003



LEGEND

Autumn 2000 - All Waterfowl

Figures in each count square represent mean (upper), mean peak (middle) and peak (lower) bird numbers respectively

No data

Bird count boundaries:

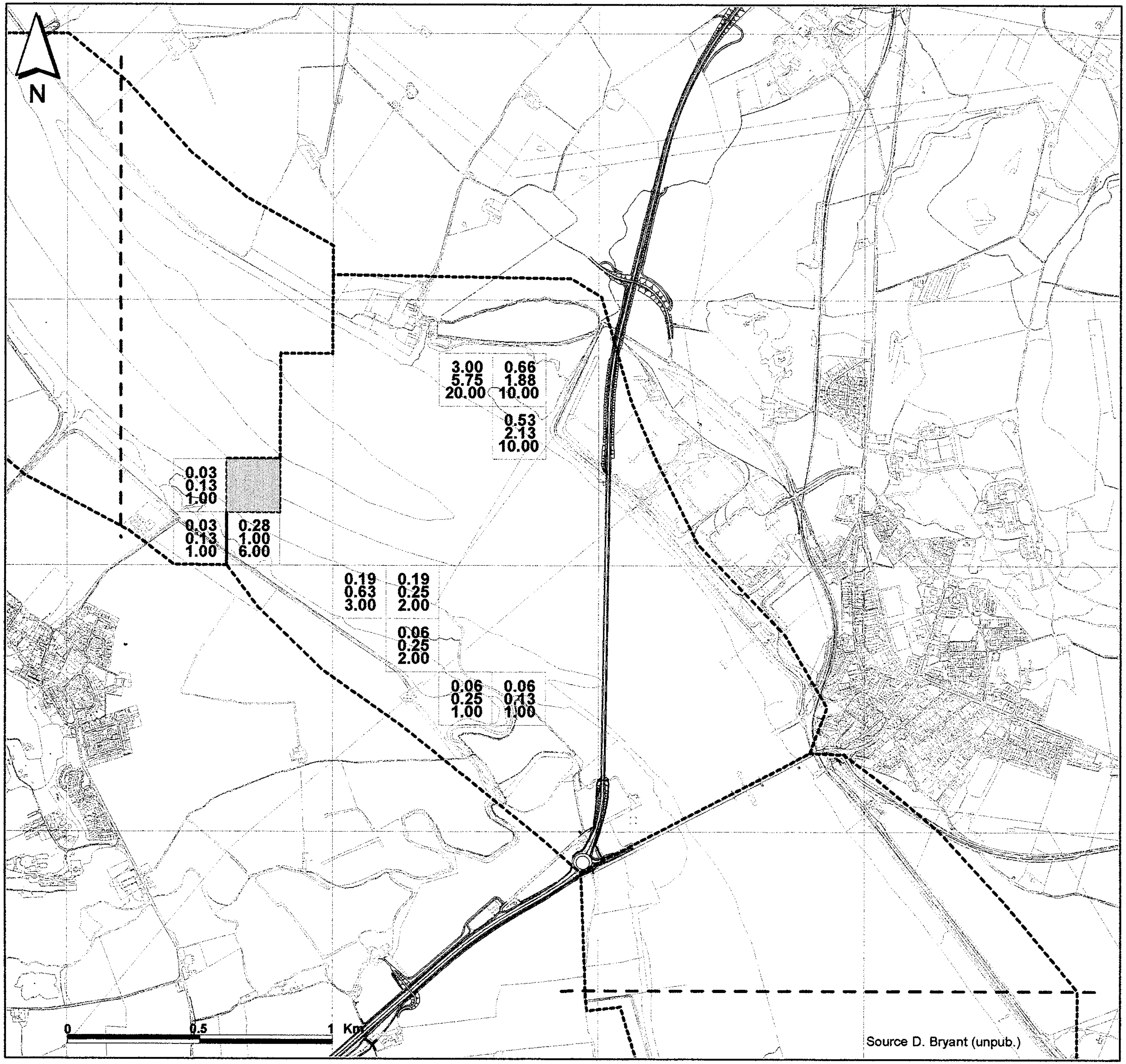
Limits of count areas

Limit of mapped data

Preferred route

NES

CLIENT	Babtie
PROJECT	Upper Forth Crossing at Kincardine, Stage 3 Ecological Impact Assessment
TITLE	Estuarine bird feeding distribution. Overall Autumn mean, mean peak and peak bird numbers - All waterfowl
SCALE	1:20 000
DATE	July 2003



LEGEND

Autumn 2000 - Redshank

Figures in each count square represent mean (upper), mean peak (middle) and peak (lower) bird numbers respectively

No data

Bird count boundaries:

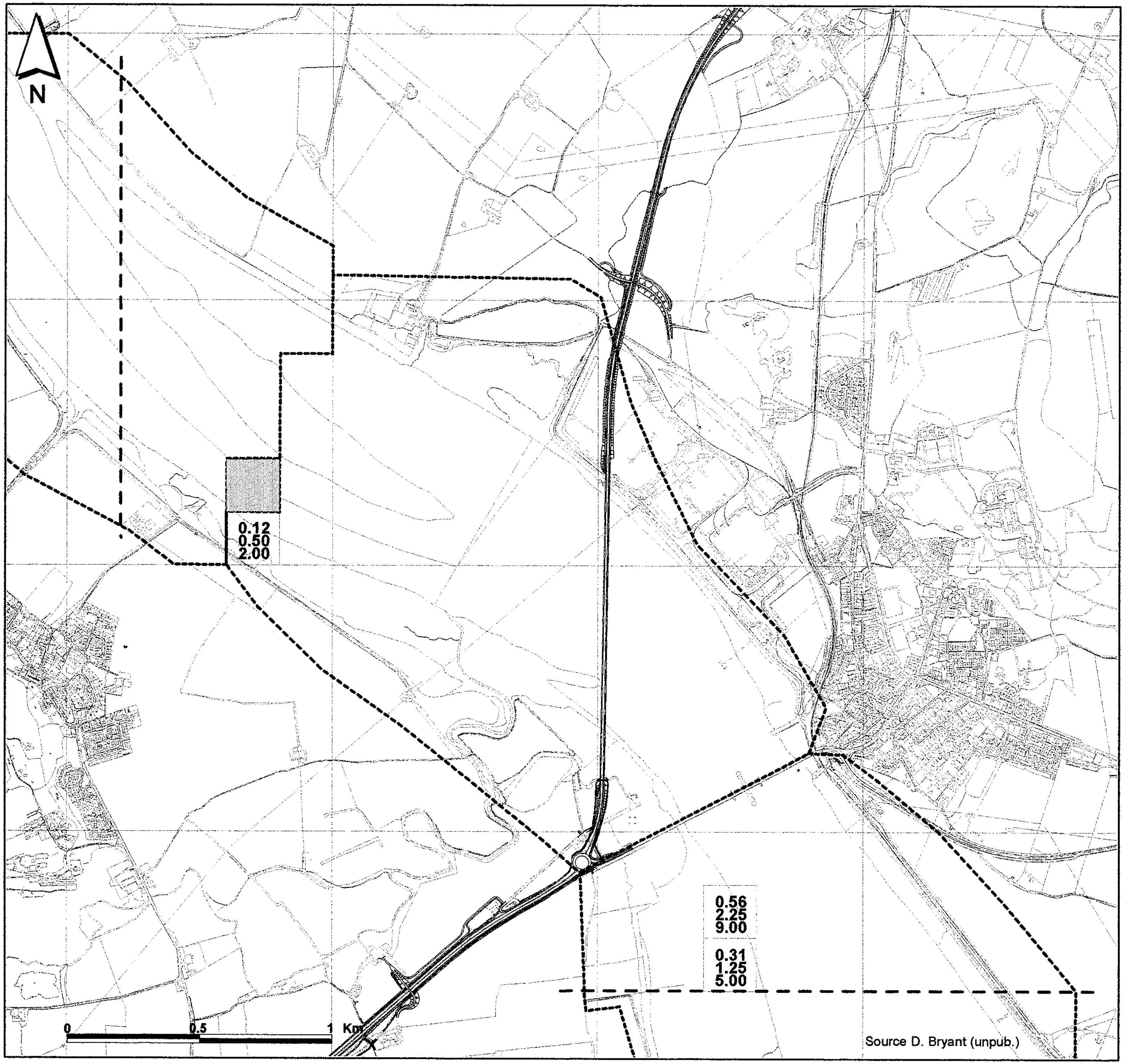
Limits of count areas

Limit of mapped data

Preferred route

NES

CLIENT	Babtie
PROJECT	Upper Forth Crossing at Kincardine, Stage 3 Ecological Impact Assessment
TITLE	Estuarine bird feeding distribution. Overall Autumn mean, mean peak and peak bird numbers - Redshank
SCALE	1:20 000
DATE	July 2003



LEGEND

Autumn 2000 - Dunlin

Figures in each count square represent mean (upper), mean peak (middle) and peak (lower) bird numbers respectively

No data

Bird count boundaries:

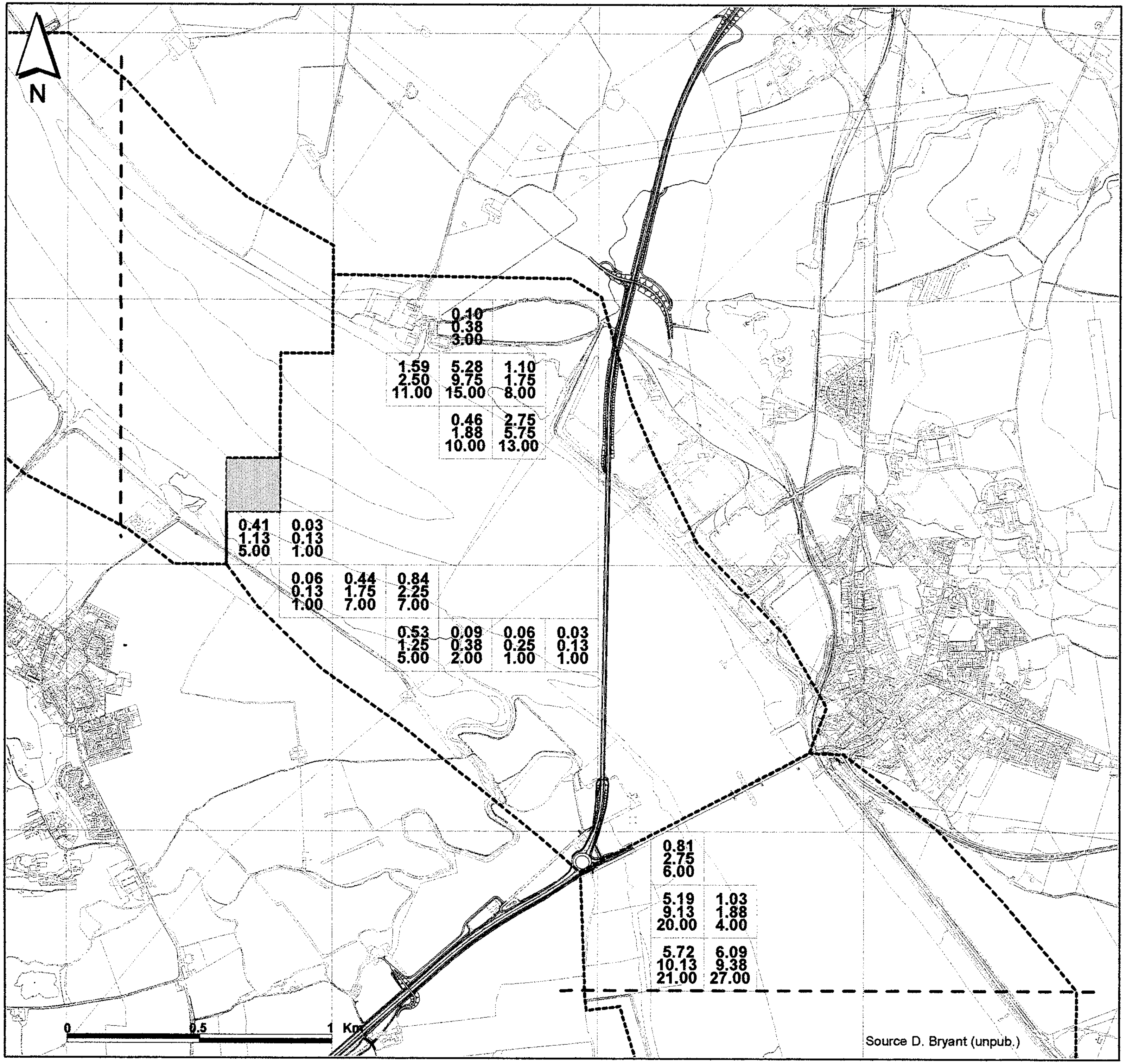
Limits of count areas

Limit of mapped data

Preferred route

NES

CLIENT	Babtie
PROJECT	Upper Forth Crossing at Kincardine, Stage 3 Ecological Impact Assessment
TITLE	Estuarine bird feeding distribution. Overall Autumn mean, mean peak and peak bird numbers - Dunlin
SCALE	1:20 000
DATE	July 2003



LEGEND

Autumn 2000 - Shelduck

Figures in each count square represent mean (upper), mean peak (middle) and peak (lower) bird numbers respectively

No data

Bird count boundaries:

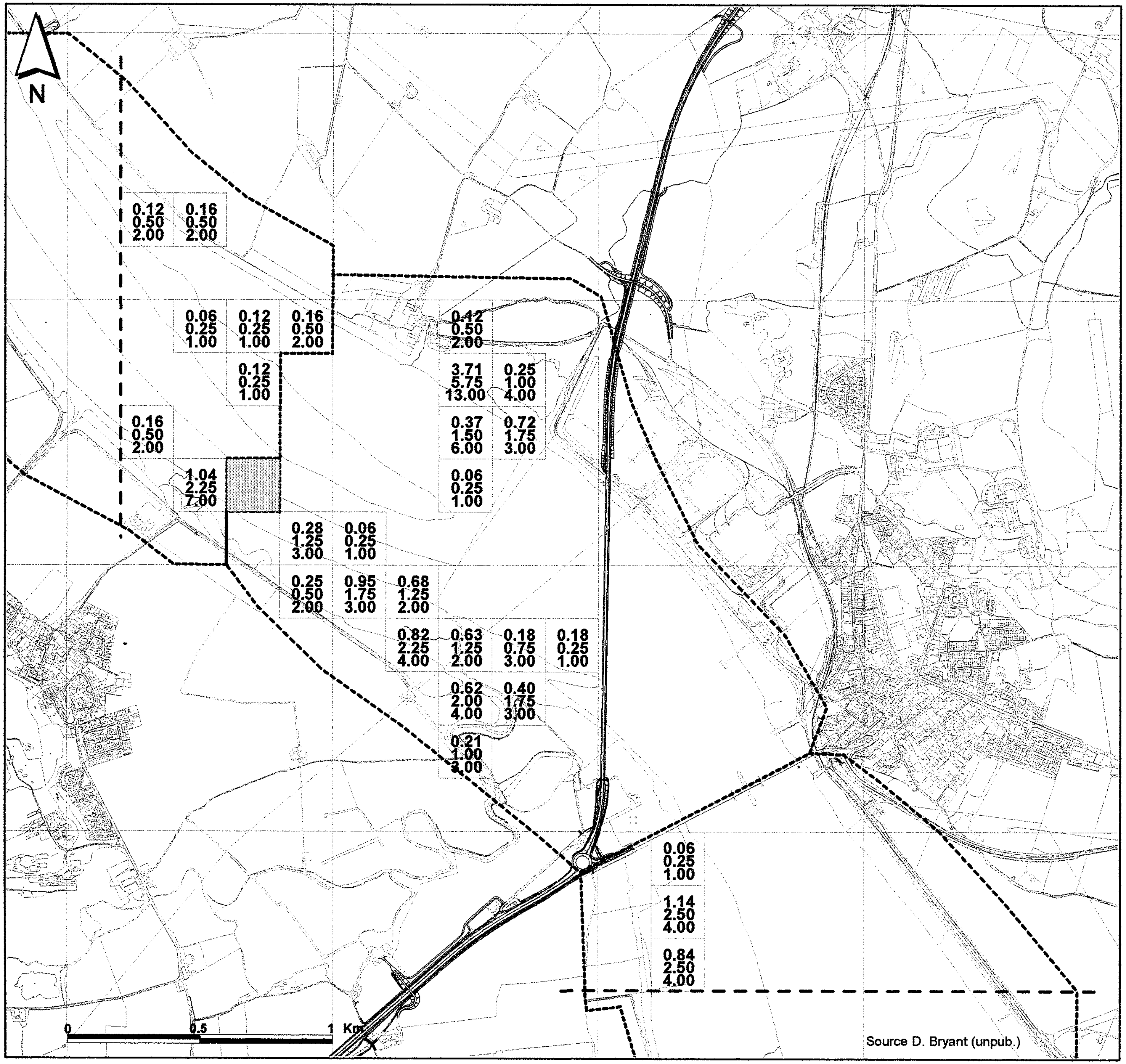
Limits of count areas

Limit of mapped data

Preferred route

NES

CLIENT	Babtie
PROJECT	Upper Forth Crossing at Kincardine, Stage 3 Ecological Impact Assessment
TITLE	Estuarine bird feeding distribution. Overall Autumn mean, mean peak and peak bird numbers - Shelduck
SCALE	1:20 000
DATE	July 2003



LEGEND

May 2000 - All Waterfowl

Figures in each count square represent mean (upper), mean peak (middle) and peak (lower) bird numbers respectively

No data

Bird count boundaries:

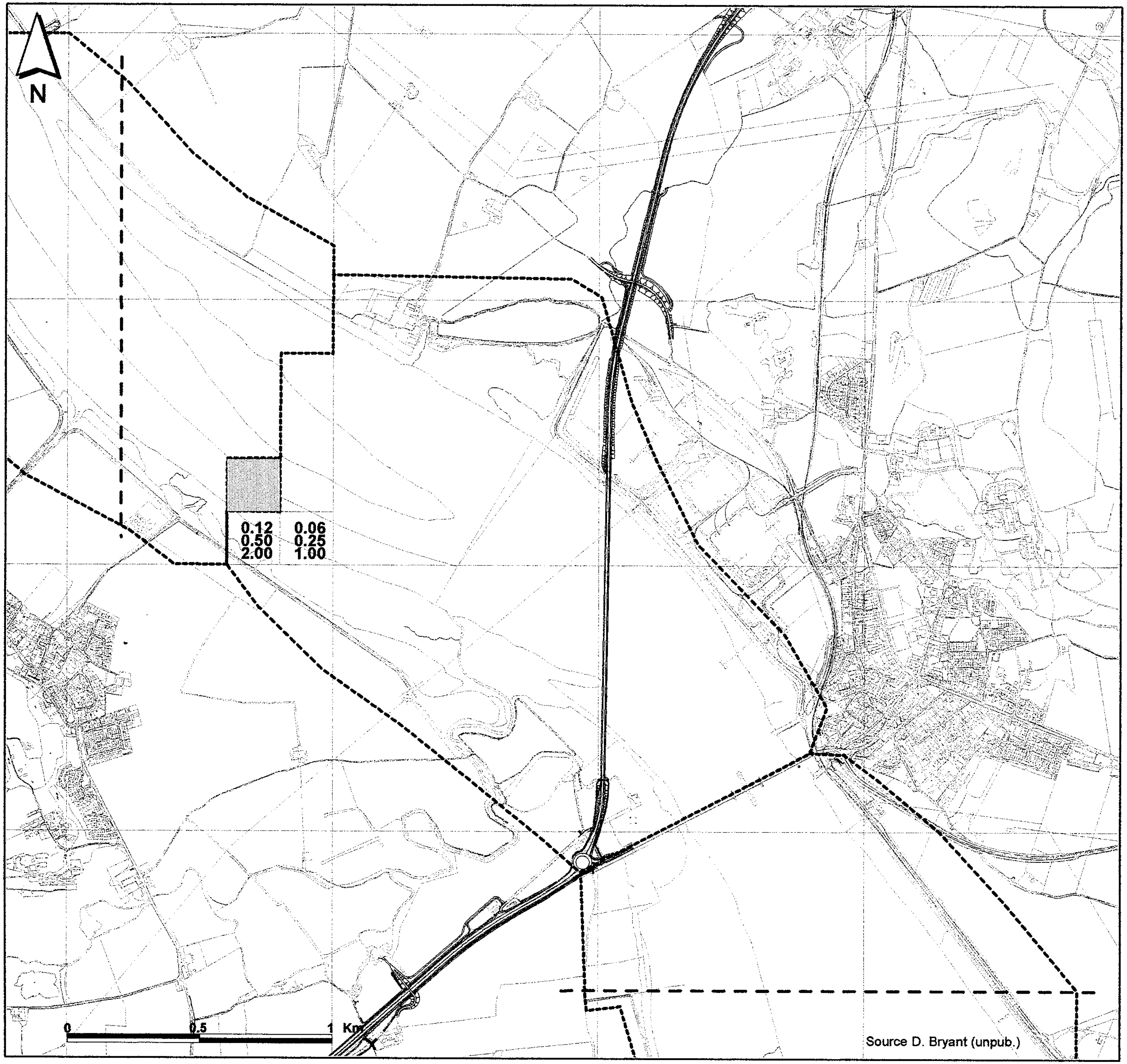
Limits of count areas

Limit of mapped data

Preferred route

NES

CLIENT	Babtie
PROJECT	Upper Forth Crossing at Kincardine, Stage 3 Ecological Impact Assessment
TITLE	Estuarine bird feeding distribution. May mean, mean peak and peak bird numbers - All waterfowl
SCALE	1:20 000
DATE	July 2003



LEGEND

May 2000 - Redshank

Figures in each count square represent mean (upper), mean peak (middle) and peak (lower) bird numbers respectively

No data

Bird count boundaries:

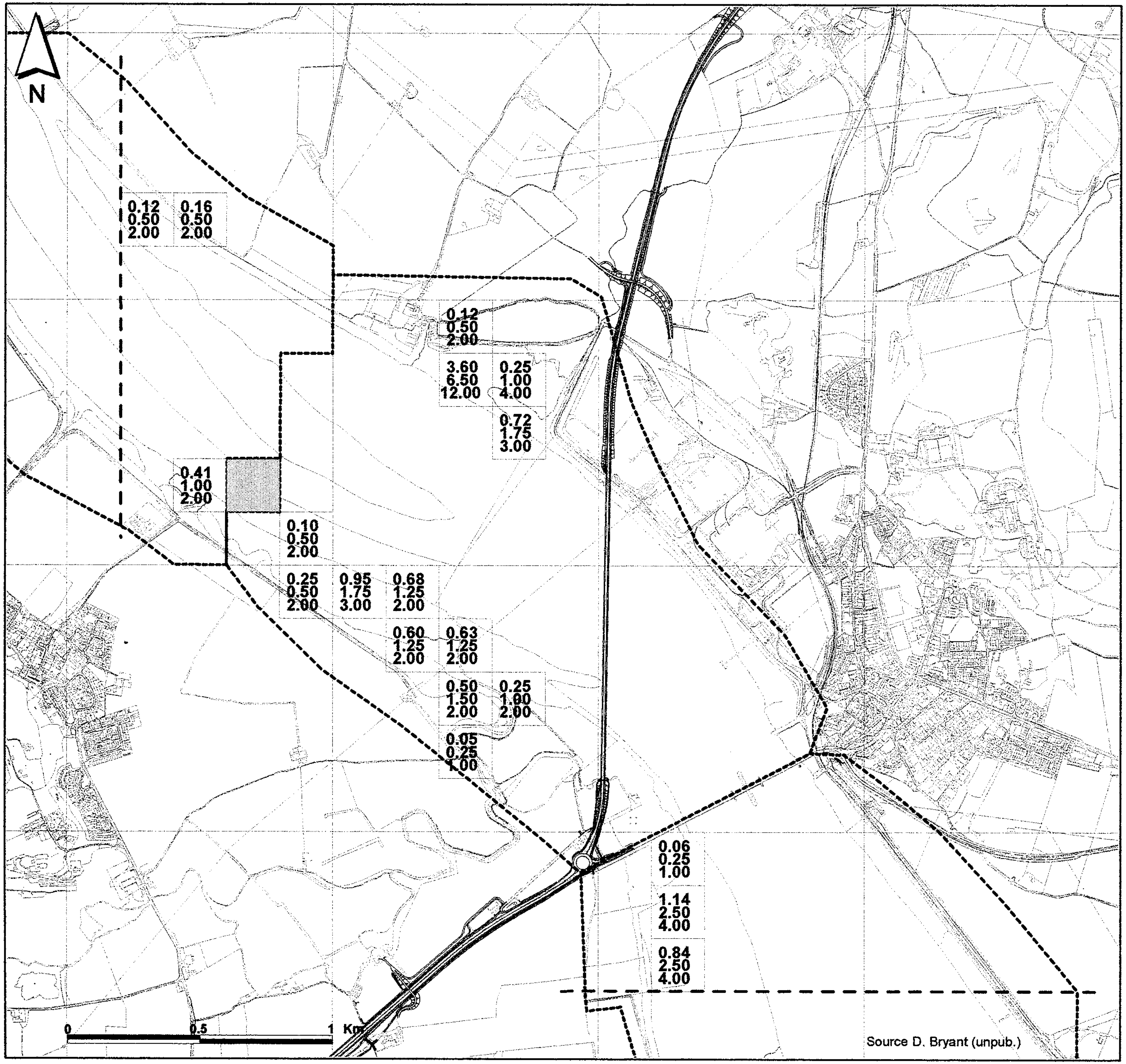
Limits of count areas

Limit of mapped data

Preferred route

NES

CLIENT	Babtie
PROJECT	Upper Forth Crossing at Kincardine, Stage 3 Ecological Impact Assessment
TITLE	Estuarine bird feeding distribution. May mean, mean peak and peak bird numbers - Redshank
SCALE	1:20 000
DATE	July 2003



LEGEND

May 2000 - Shelduck

Figures in each count square represent mean (upper), mean peak (middle) and peak (lower) bird numbers respectively

No data

Bird count boundaries:

Limits of count areas

Limit of mapped data

Preferred route

NES

CLIENT	Babtie
PROJECT	Upper Forth Crossing at Kincardine, Stage 3 Ecological Impact Assessment
TITLE	Estuarine bird feeding distribution. May mean, mean peak and peak bird numbers - Shelduck
SCALE	1:20 000
DATE	July 2003

APPENDIX 18

SEPA TRAWL DATA FOR THE FORTH ESTUARY, 1996-2000

Annexe 1. High water Agassiz trawl catch data from the the lower Forth estuary between January 1994 and ~~April 1999~~. Jan 2000
Abundances are per 20 min. tow.

	Jan-94	Apr-94	Jul-94	Oct-94	Dec-94	Jan-95	Apr-95	Jul-95	Oct-95	Dec-95	Jan-96	Apr-96	Jul-96	Oct-96	Dec-96	Jan-97	Apr-97	Jul-97	Oct-97	Dec-97	Jan-98	Apr-98	Jun-98	Oct-98	Dec-98	Jan-99	Apr-99	Jul-99	Sep-99	Dec-99	Jan-00
Port Edgar																															
Butterfish		3							1									5													
Cod	7	9	1		5	2	4			1	26		Abiotic	15	2	3	10	3	2		12		1			2			29	19	2
Dab		4	2		1			1		9					2			2			2			1		1		1			
Dover Sole																					2										
Dragonet																						1									
Eelpout	1	10	3			1	4							6			20	1	6	1	7	24	1		2	5		1	2	1	3
Fatherlasher		2				2		1	1	1								1	1	4	10	1	1	1					1	1	2
Flounder		4			1	1	1			2				4		3				1	2	2	1		1			3		2	1
Great Pipefish																															
Herring									2			1				32		1		5	1	1		1							1
Lemon Sole																	1						3								
Lesser Sandeel						1										1															
Long Rough Dab														2				1													1
Plaice			3	1		1		2							1			1	2	1		1		1	1	1		6	2	5	3
Pogge	6	10	1		1	12	4			3	7			1	1	3	2	2	7	5	6	1	4	2	2	20		1		3	5
Red Gurnard																	1														
Sea Snail						1			1	2				3					1	1	1			5	2				1		
Sprat		1		11		1	1	1	4	1		3		1	3	5			1	5	1	13			1	1					
Whiting	44	22	9		295	9	3	8	3	32	33			8	4	1	21		60	1	20	8			2	13				3	3
Lesser Pipefish																						1									
Pollack											1																				2
Eel																															
Smelt																															
Grey Gurnard																															
Sand Goby (indet)		1			1	1	1		1	12	7			1	6	1			5	1	20	6		7	2						1
River Lamprey (indet?)				1														1	1												
Lesser Spotted Dogfish																															
Species Number	4	10	6	3	6	11	7	5	7	9	5	2	0	9	7	8	6	10	10	10	12	11	6	7	8	7	-	5	5	7	11
Total Abundance	58	66	19	13	304	32	18	13	13	63	74	4	0	41	19	49	55	18	86	25	84	59	11	18	13	43	-	12	35	34	24
Tancred																															
Butterfish																															
Cod															6	6														3	6
Dab					1				3	16	4				12					7	1			1							
Dover Sole																															
Dragonet																															
Eelpout		5	1				2	4				1				1	12					1									
Fatherlasher																					1					1					1
Flounder			1					3					4	4			2	1	8	2	1		4	2				2	4	1	1
Great Pipefish																				3	1										
Herring	1			1											1	4				3	1										
Lemon Sole																	1														
Lesser Sandeel																															
Long Rough Dab							1								1																
Plaice		3	12			1	2	4					7	5	1		3	3	2	2	1		3		1	2		8	30	2	3
Pogge		1	9	3				2	3	3	3		1	4	5	4	1	41	18	7	19		3	1	1					2	2
Red Gurnard																															
Sea Snail							10						1	1					3					1	6				1		
Sprat	1			2						1			1		1	16				12											
Whiting	1	55	9		2	2	8	10	6	6	14	8		4	6	1	18	8	15	3	3				4	2			1	2	3
Lesser Pipefish									1																						
Pollack																															3
Eel																															
Smelt																															
Grey Gurnard																															
Sand Goby (indet)		1			1	2			1	9				1	17				7	1	6	1		1		1					1
River Lamprey (indet?)														1				1		1										1	
Lesser Spotted Dogfish										1																					
Species Number	3	5	5	3	3	3	5	5	5	5	3	2	5	7	9	6	6	5	6	10	9	2	3	5	4	4	-	2	4	6	8
Total Abundance	3	65	32	6	4	5	23	23	14	35	21	9	14	20	50	32	37	54	53	41	34	2	10	6	12	6	-	10	36	11	20
Longannet																															
Butterfish			1																			2									
Cod					1			1						1		4		1													1
Dab		1			19	6	1	1	5	14	2				21					38	3										
Dover Sole								1										1			1										
Dragonet																															
Eelpout		3	37	3	2	1	1	9	1	1	5		7	3	3		1	1	2	1	2	2									
Fatherlasher		2							2					1			1		1	2	1	1		1							1
Flounder	4	7	9		5	7	1	3	2		2	3	1	5	4		2	2	10		3	16		2		1		1	5	2	1
Great Pipefish																															
Herring	11					1					1					1															
Lemon Sole																															
Lesser Sandeel					4																										
Long Rough Dab														1		3															1
Plaice	2	3	4		3	4		2	1			1				4	1			3				3	1					1	2
Pogge		11	10	7	4	1	2	1			5		6	7	4	1		3	6	4	2	4	1	5	1	5		2	1	2	6
Red Gurnard																															
Sea Snail				2	1						1		4	6		1		2		1						1					1
Sprat	3	1		4		3			1													1									
Whiting	10	10	8	1	22	5	1	1	6		35	2	1	5	1	12	2	6	2		2	2				1				1	1
Lesser Pipefish																															
Pollack																															
Eel																															
Smelt																															
Grey Gurnard																															
Sand Goby (indet)					1			1		1	2		2	3	4				5	4		4									
River Lamprey (indet?)				1														3				1			2					1	
Lesser Spotted Dogfish																															
Species Number	5	8	6	6	10	8	5	9	7	3	8	3	6	9	6	7	5	8	6	7	7	9	1	4	3	4	-	2	2	5	8
Total Abundance	30	38	69	18	62	28	6	20	18	16	53	6	21	32	37	26	7	19	26	53	14	33	1	11	4	8	-	3	6	7	14

Annexe 3. Pelagic catch data from the lower Forth estuary between 1998 - 2000.

	Port Edgar									Tancred									Longannet								
	Jun-98	Oct-98	Dec-98	Jan-99	Apr-99	Jul-99	Sep-99	Dec-99	Jan-00	Jun-98	Oct-98	Dec-98	Jan-99	Apr-99	Jul-99	Sep-99	Dec-99	Jan-00	Jun-98	Oct-98	Dec-98	Jan-99	Apr-99	Jul-99	Sep-99	Dec-99	Jan-00
High Water																											
Sprat	1	121	133	Abiotic		3	284	18	808	Abiotic	200	136	Abiotic		11	19	19	150	1	Abiotic	3	23		7	4	22	12
Whiting		23				1	1				2	3				20	1				8			1	11	2	
Herring		4	5			80	181	39	99		1	14			10	52	38	2			10			3	49	57	
Sand Goby			1									1														2	
River Lamprey						1					1					2					1				4	1	
Cod						1																					
Lesser Sandeel							2																				
Lesser Pipefish																	1	1									1
Pogge																		1									
Number of Species	1	3	3	0	-	5	4	2	2	0	4	4	0	-	2	4	4	4	1	0	4	1	-	3	4	5	2
Total Abundance	1	148	139	0	-	86	468	57	907	0	204	154	0	-	21	93	59	154	1	0	22	23	-	11	68	84	13
Low Water																											
Sprat	19	143	37	Abiotic	60	6	906	105	252	2	126	Abiotic	1	62	52	40	14	108	5	9	200	Abiotic	7	37	41	23	103
Whiting			69			5	1		29	9	9			5	12	42		11	11	4	70		12	11	111		5
Herring		9	126		3	3	113		65		13				4	75	8	25	9	5	159			4	48	19	172
Sand Goby									1		1			1	1	8		3	1					2	1		6
Lesser Pipefish																			5								
Smelt															4				3	1				40	2		
Flounder					1						1			1	5	1					2		1	18	5		
Lesser Sandeel			1				1														2						
Pogge									1												1				1		1
Plaice							1								12	6		2			5			8	6		
Cod																	3				1						
River Lamprey					3	2	1								1	8		1						2	5		1
Sea Snail																1											
3 Spine Stickleback																1											
Eelpout									1																1		
Pollack									1																1		
Number of Species	1	2	4	0	3	3	5	1	5	2	5	0	1	4	7	6	3	5	6	4	8	0	3	7	8	2	5
Total Abundance	19	152	233	0	64	14	1022	105	348	11	150	0	1	69	90	172	25	149	34	19	440	0	20	120	215	42	287

no data

Table 4. Continued

		Station																																						
		UE4													UE5													UE6													
		15-Jul-96	8-Aug-96	28-Aug-96	19-Nov-96	3-Jun-97	20-Jun-97	5-Aug-97	14-Oct-97	4-Sep-98	14-Jun-99	9-Jul-99	10-Aug-99	6-Sep-99	15-Jul-96	8-Aug-96	28-Aug-96	19-Nov-96	3-Jun-97	20-Jun-97	5-Aug-97	14-Oct-97	4-Sep-98	14-Jun-99	9-Jul-99	10-Aug-99	6-Sep-99	15-Jul-96	8-Aug-96	28-Aug-96	19-Nov-96	3-Jun-97	20-Jun-97	5-Aug-97	14-Oct-97	4-Sep-98	14-Jun-99	9-Jul-99	10-Aug-99	6-Sep-99	
Sand Goby	*Pomatoschistus minutus*		1	4	2		8	200		93		17	65	188	11	232	148						nd			7	11	2	38	2									7	2	1117
Flounder	*Platicthyes flesus*	2	3	8	6	7			1	1	1	2	1	2	13	2	1	34	1	8		1	nd	3	2	12		10	74		38	1			3	1	6	13	1	31	507
Smelt	*Osmerus eperlanus*		1	1	149	4	2	19	2	21	2	16	63	19		6	14	15	4	22	12		nd		1	27	9		10	1	2				45			7	9	19	542
Sprat	*Sprattus sprattus*								14	3				17									nd																		170
Cod	*Gadus morhua*																						nd																		42
Herring	*Clupea harengus*										11		1										nd	1																	70
Plaice	*Pleuronectes platessa*				9																		nd												3						48
Whiting	*Merlangius merlangus*																						nd																		40
Lesser Pipefish	*Synagnathus rostellatus*																						nd																		5
River Lamprey	*Lampetra fluviatilis*									1													nd																		6
Pogge	*Agonus cataphractus*																						nd																		4
Eelpout	*Zoarces viviparus*																						nd																		4
Eel	*Anguilla anguilla*										1												nd																		3
Stickleback	*Gasterosteus aculeatus*				1																		nd																		1
Father Lasher	*Myoxocephalus scorpius*																						nd																		1
Total abundance		2	5	13	167	11	10	219	17	119	15	35	130	226	24	240	163	49	5	30	12	1	nd	4	3	46	20	12	122	3	40	1	0	0	51	1	6	20	17	52	
Total spp no		1	3	3	5	2	2	2	3	5	4	3	4	4	2	3	3	2	2	2	1	1	nd	2	2	3	2	2	3	2	2	1	0	0	3	1	1	2	3	3	
		UE4													UE5													UE6													
		15-Jul-96	8-Aug-96	28-Aug-96	19-Nov-96	3-Jun-97	20-Jun-97	5-Aug-97	14-Oct-97	4-Sep-98	14-Jun-99	9-Jul-99	10-Aug-99	6-Sep-99	15-Jul-96	8-Aug-96	28-Aug-96	19-Nov-96	3-Jun-97	20-Jun-97	5-Aug-97	14-Oct-97	4-Sep-98	14-Jun-99	9-Jul-99	10-Aug-99	6-Sep-99	15-Jul-96	8-Aug-96	28-Aug-96	19-Nov-96	3-Jun-97	20-Jun-97	5-Aug-97	14-Oct-97	4-Sep-98	14-Jun-99	9-Jul-99	10-Aug-99	6-Sep-99	

APPENDIX 19

GENERIC REVIEW OF TERRESTRIAL IMPACTS OF ROADS

Generic review of terrestrial impacts of roads

1. Loss, fragmentation and isolation of habitats, communities and species

<u>1.1 Introduction</u>
The following impacts can result from habitat loss, fragmentation and isolation:

- a decline in species number as the habitat patch is reduced in size. This is most likely to be seen in species that exist as metapopulations (mostly animals) in the surrounding habitat mosaic, and in specialist species for which the reduced patch area can no longer support a viable population
- a loss of core or characteristic species and invasion of edge and more catholic species
- increased predation by edge or invasive species
- changes in community composition as a product of the loss of species which were an integral part of the foodchain or ecosystem
- nutrient enrichment as an edge effect (as identified for nitrogen in section 6.1.4)

Fragmentation is thought to be most significant in habitats that were formerly more widespread and are now reduced to variable sized patches within a landscape of other uses (English Nature 1994). The habitats most affected are woodland, heathland and species-rich grassland. Plant and animal populations affected most severely by fragmentation are those species that maintain genetic diversity and avoid interbreeding by moving between habitats. Many of these species have been found to exist in metapopulations in a fragmented landscape, such as bank vole and possibly badger. Where sub-populations die out in small populations, they are regularly replaced by immigration, but this process is hindered or prevented where roads are introduced. This reduction in connectiveness of the patches may cause loss of sub-populations, and if this takes place in several places within a short time period, metapopulations without a 'mainland' habitat can become extinct.

Research suggests that fragmentation may have a greater impact than isolation (English Nature 1994). Some species readily cross gaps in habitat and may meet their area requirements by using habitat clusters, such as groups of small woods used by the great spotted woodpecker. The ability to cross-habitat gaps, however, varies with species and those less able to cross become isolated more readily by fragmentation.

Isolation may result in a reduced population size and an increased risk of extinction (Bennett 1995). However, the long-term effects of isolation on the viability of populations are largely unknown. Research on amphibian populations isolated by road and railways for three decades has revealed a reduction in genetic heterogeneity, and in genetic variation between populations, as a result of reduced gene flow between them (reported in English Nature 1994). In theory, this reduced diversity would hasten the demise of the population due to a reduced adaptive ability in the event of environmental change.

The barrier and disturbance effects of roads, as well as the high death rates incurred for some species, increases isolation effects. The busier and wider the road, the more it is effective as a barrier to movements. Some species cannot, or rarely, cross such obstacles, whilst others venture out and are frequently killed. Other species will not settle even within a few hundred metres of a road (English Nature 1994). Barrier effects have been recorded for small mammals, certain species of invertebrates, reptiles and amphibians (reported in English Nature 1996). Where road densities are currently low and the extent of semi-natural habitat is high, the disturbance from infrastructure development may be relatively small and only the most sensitive species are likely to be affected (English Nature 1996).

The effects from roads and road vehicles favour edge, generalist and exotic species over specialist species (Forman 1995). Increased predation by edge or invasive species can occur along edges, with effects recorded up to 600m into woodlands (English Nature 1994). The importance of a buffer zone to absorb edge effects from land use adjacent to protected habitats is widely recognised.

In summary, the greatest impacts on nature conservation interests resulting from habitat fragmentation by roads are likely to be in the intermediate situation:

- in landscapes where sufficient natural and semi-natural habitat exists that all routes are likely to involve some damage to sites
- where fragmentation has already put many species close to their limits; but where the relative benefits from mitigation are likely to be small (English Nature 1996).

1.2 Loss, fragmentation and isolation of plant communities and habitats

Habitat loss and fragmentation has greatest impact on long established, semi-natural habitats that show a high degree of naturalness, such as ancient woodland and old, unimproved grassland. Such habitats often support plant species that do not colonise easily, and are therefore not usually found in recently established habitat. This means that even temporary habitat loss will usually result in loss of these species, while fragmentation would make the remaining populations more vulnerable to extinction.

1.3 Loss, fragmentation and isolation of faunal habitat

The crucial issue for habitat loss is whether it reduces the effective carrying capacity of a site through a reduction in food accessibility, leading to movements of animals to other sites where there is increased density. This, in turn, results in food depletion and/or mutual interference so that food intake rate is affected, reducing the optimality of the habitat and, therefore, its carrying capacity (Hill et al 1997). The magnitude of this impact will determine whether the population is reduced on a local or national scale. There may be no effect on numbers until a threshold density is reached, at which point there would be increased local emigration rates, but if the resulting redistribution also increased mortality or decreased breeding success in the wider population, the national population size would also decrease. In considering fragmentation and isolation effects, the minimum area requirements and dispersal ability of individual species need to be considered.

Birds

Except in a few cases, most studies have been habitat orientated and have concentrated on woodland birds, many species of which are less able to cope with habitat fragmentation than more mobile species of open ground and edge habitat. These studies found that, in highly fragmented woodlands, larger woods were more species rich, with factors such as length of nearby hedgerows and the woodland composition being significant factors to variations in numbers of breeding species (Hinsley et al 1992 and 1994). Local species extinctions and the relative turnover rate were higher for smaller woods. No similar studies have been found for scrub and associated open ground habitat. However, by the nature of the habitat, it can be generally supposed that birds of open scrub habitat are less affected by habitat fragmentation than woodland birds.

It is thought that birds fly less easily across wide, busy roads than narrower, quieter roads (Mead 1997). For some species this is possibly related to the territory size of the small birds using the adjacent areas, with territory size of small hedgerow birds in good habitat being typically of 30-40m radii, and therefore birds may hold territory on both sides along narrower roads (Mead 1997).

Amphibians
In densely populated countries, amphibians often depend on small habitat patches separated by intensively used agricultural landscapes, as found in the Kincardine area. Such fragmentation has been found to result in frequent absence of species in small or isolated habitat patches (e.g. Sjogren 1988, 1991, Loman 1988). The isolating impact of roads may significantly add to this effect, for example, a significant effect of road density was demonstrated on the occupation probability of ponds by moor frogs (*Rana arvalis*) in the Netherlands (Vos & Chardon 1998).

Amphibians are particularly affected by fragmentation of their habitats where a road divides breeding, terrestrial and home range habitat, in which situation the animals often still try to migrate between them, resulting in very high mortality. A Dutch study concluded that the highways and most secondary roads of the Dutch road network must be considered as absolute barriers to toad movement (Vos 1995).

2.0 Disturbance to birds

Many studies and reviews of disturbance impacts on birds have focused on water based recreation on inland waters, and a number of others have looked at a range of disturbance impacts on estuary shorebirds. In many cases, results of the immediate effect of disturbance, such as flight tolerance distances and escape flight distances, has been recorded. However, these are very variable, being different across species and within species, across habitat types and between sites where exposure to disturbance causes varying amounts of habituation by birds. Furthermore, these do not, on their own, allow prediction of impacts on a population level, as birds may be displaced from disturbed sites in the short term but may return at a later date, with the overall use of these sites possibly being unaffected over the course of a season.

As with habitat loss, the crucial issue is whether disturbance reduces the effective carrying capacity of a site, with a reduction in food accessibility and bird density. Disturbance studies that have calculated reduced habitat usage in relation to the available resource are therefore the most useful. For example, territory use and consequent productivity of ringed plovers were shown to be markedly affected by human disturbance, resulting in significant reductions in local population size (Liley 1999, reported in Gill et al 2001).

The magnitude of this impact will determine whether the bird population is reduced on a local or national scale. There may be no effect on bird numbers until a threshold density is reached, at which point there would be increased local emigration rates, but if the resulting redistribution also increased mortality or decreased breeding success in the wider population, the national population size would also decrease.

In estimating the severity and likely impact of disturbance to birds, the following factors have to be taken into account:

- intensity of disturbance

- duration and frequency (continuous, infrequent, regular, variable)
- proximity of source
- seasonal variation in sensitivity of affected species
- presence of people associated with source
- whether birds move away, but return after disturbance ceases
- whether regional numbers are affected
- whether there are alternative habitats available nearby
- whether rare, scarce or especially shy species are affected

However, data on the last three points are rarely available, making cumulative impacts impossible to predict accurately.

In general, birds appear to habituate to continual noises so long as there is no large amplitude ‘startling’ component (Hockin et al 1992). Vehicles and vehicle movements are much more tolerated than are people at the source of disturbance (e.g. Smit and Visser 1993, Henderson & Clark 1993). In general, larger bird species, those higher up the food chain, or those which feed in flocks in the open, tend to be more vulnerable to disturbance than small birds living in structurally complex or ‘closed’ habitats such as woodland (Hill et al 1997). Waders and wildfowl are thought to be particularly sensitive. For example, pink-footed geese are highly responsive to disturbance from surrounding roads, with exploitation of fields increasing linearly with distance from road (Gill et al 1996). Density of breeding waders on shore meadows in Finland was observed to decrease near the road after the construction of a main highway (Hirvonen 1995). As an exception to this trend, human disturbance was found to have no effect on the number of black-tailed godwits in relation to the existing the food supply (Gill et al 2001). In open ground habitats, passerines have been found to be less vulnerable to disturbance than waders (Hirvonen 1995).

Visual disturbance from roads on sensitive species is thought to be greatest in open landscapes (Reijnen et al 1995), particularly if the road is raised on an embankment, reducing the visibility of predators (English Nature 1994). In contrast, species that utilise both open ground and scrub, such as yellow hammer, may benefit from the provision of scrub along roadsides in otherwise very open landscapes.

Research on woodland and woodland edge species has shown reduced densities of 60% of the species surveyed in woodland and locations close to busy roads in the Netherlands. It was estimated that effects on density with distance varied between species from 70-2800m for a road with 60,000 cars per day and with 70% woodland along the road. The effect distance was found to increase with greater traffic intensity and speed and with smaller woodland areas (Reijnen et al 1995). Maximum effect distance distances were found to be between 100m and 1500m. For a zone of 250m from the road the reduction of the density varied from 20 to 98%. For willow warbler, at distances of less than 200m from the road, this is thought to be due to the drowning out of courting bird song and consequent inability to attract a mate (Reijnen & Foppen 1994). However, it is thought that stress caused by traffic noise, rather than disturbance of communication pattern is likely to be the more general mechanism of disturbance, the latter effect probably only being pertinent for those species producing songs and calls with a frequency band similar to the highest sound pressure levels of traffic noise (Reijnen et al 1995).

Noise, rather than visual, disturbance from roads is thought to be most pertinent to birds of woodland and scrub, particularly at distances greater than 200m from the road (Reijnen et al 1995). However, disturbance from nearby human presence in woodland can be a significant impact on some species, with, in general, larger woodland birds being more vulnerable to disturbance than smaller birds, particularly at breeding time when nest desertion can occur (Smart & Andrews 1985).

3.0 Road casualties

Large numbers of animal casualties are recorded on British roads, but the significance is still undetermined in all but a few cases (English Nature 1994). The exceptions arise when such deaths are concentrated at certain locations, and result in the near loss of a local population. Three main animal groups are considered pertinent to this impact type in the study area, namely otters, birds and amphibians. Birds are reviewed below.

<u>Birds</u>

There is believed to be considerable variation between species as to the degree and effect of road mortality and much would also appear to depend on the road type and adjacent habitat. Recorded road deaths show that the most vulnerable species are those which:

- use roads for feeding (such as corvids)
- are nocturnal (such as owls)
- skulk about in heavy cover making sudden breaks of cover
- are flock feeders.

(Hill & Hockin 1992).

Maximum published casualty rates in Britain are one bird per 1.5 miles per year. The greatest number of deaths of birds appears to be along roads bordered by trees and shrubs. Most mortality occurs at ‘hot spots’; gaps in hedges, walls and open gates used by birds as crossing points, particularly for low flying birds that suddenly break cover (Hill & Hocken 1992). However, mortality of birds of edge and scrub habitat is thought to be lower on bigger and busy roads than smaller and quieter roads, as birds cross the former less readily (Mead 1997). This is possibly related to the territory size of the small birds using the adjacent areas, with territory size of small hedgerow birds in good habitat being typically of 30-40m radii, and therefore birds may hold territory on both sides along narrower roads (Mead 1997). This is supported by the studies on the effect of traffic noise on bird density in woodlands adjacent to busy roads, in which road mortality was found to be an insignificant factor (Reijnen et al 1995).

For some species, such as finches, greatest mortality occurs when a crop is on one side of the road and cover on the other, with birds moving backwards and forwards across the road, apparently unable to learn to avoid the potential danger (Hill & Hocken 1992).