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Severn Estuary Bird Food Monitoring. Phase 1

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Executive summary

1. The purpose of this report was to assess the current state of knowledge about the Severn Estuary SPA and determine whether the methods for monitoring bird species described by West et al. (2001) would be suitable for use there. Methods for monitoring bird food and disturbance on the Severn Estuary were also to be developed and described in detail. It was anticipated that the approach could be applied to dunlin, redshank, curlew, shelduck and pintail.

2. A literature review found that although some areas of the Severn are highly dynamic, these areas tend not to contain prey for the target bird species so could be excluded from a monitoring program. Outside these areas the extent of feeding habitat and the benthic communities contained within it seem to have remained broadly the same over a number of years. The data required to predict the tidal exposure of feeding areas was found to be available and there was also good data on the population sizes of key bird species.

3. The diets of curlew, dunlin, redshank and shelduck on the Severn estuary are known from previous studies. Although pintail generally feed on vegetation, in estuaries they feed on *Hydrobia* and small crustaceans so a vegetation survey would not be required. Functional responses for the three wader species can be predicted using recently-developed equations that predict functional response parameters over a wide range of wader and prey combinations. Much less is known about intake rates and functional responses in shelduck and pintail. The closest examples of measured functional responses are in teal and mallard. It may be possible to use these as a guide to shelduck and pintail intake rates, but confidence in the model's predictions for these species would be lower than for species where the functional response is known.

4. Four of the five target bird species fed mainly on muddy areas with biotopes characterised by the presence of the ragworm *Hediste diversicolor* and the clam *Macoma balthica*. The exception to this, curlew, also fed on sandy areas likely to contain the lugworm *Arenicola marina*. None of the five target species made use of the impoverished mobile sandbanks in the middle and upper reaches of the Severn. This strengthens the case for not monitoring these banks.

5. It is recommended that intertidal core survey is the best way to determine prey distribution and density in the Severn estuary. The data from such a survey can either be used in an individual-based model or to develop empirical relationships between environmental factors, prey distribution and bird densities. As there is a background of current changes in human inputs to the Severn and the possibility of a barrage across the Severn in future cannot be ruled out, such empirical relationships may very well change. In this case, an individual-based modelling approach is preferable.

6. There is currently a lack of information about disturbance to birds on the Severn SPA. It is recommended that a comprehensive survey of disturbance to birds be undertaken. The survey should measure the type and frequency of disturbances to birds both on mudflats and roosts, as the latter is though to be a

particular problem. To provide data for modelling the impacts of disturbance the survey should also measure flushing distances and the time costs associated with disturbance.

7. Overall, most of the data required for monitoring the Severn using the bird:food biomass approach described by West et al. (2005a) is already available or can be collected by survey. The lack of published functional responses for shelduck and pintail mean that confidence in model predictions for these species would be lower. For dunlin, redshank and curlew confidence would be much higher, indeed, all three species have been successfully modelled at other sites using this approach. Present and possible future changes on the Severn mean that empirical relationships between environmental variables, prey and shorebird densities are likely to change. An individual-based modelling approach designed to predict to new circumstances is therefore recommended as the best way to monitor the Severn.

Crynodeb Gweithredol

1. Diben yr adroddiad hwn oedd asesu'r wybodaeth gyfredol a geir am Ardal Gwarchodaeth Arbennig Aber Afon Hafren, a phenderfynu p'un a fyddai'r dulliau a ddisgrifiwyd gan West et al (2001) ar gyfer monitro rhywogaethau adar yn addas i'w defnyddio yno. Yn ogystal, roedd angen i'r adroddiad ddatblygu dulliau ar gyfer monitro bwyd adar a ffactorau sy'n aflonyddu ar adar yn Aber Afon Hafren a'u disgrifio'n fanwl hefyd. Rhagwelwyd y gellid defnyddio'r dull gweithredu hwn mewn perthynas â phibydd y mawn, y pibydd coesgoch, y gylfinir, hwyaden yr eithin a'r hwyaden lostfain.

2. Er bod rhai ardaloedd o afon Hafren yn hynod ddeinamig, dangosodd adolygiad o lenyddiaeth nad yw'r ardaloedd hyn yn tueddu i gynnwys ysglyfaethau ar gyfer y rhywogaethau o adar a dargedir, sy'n golygu y gellid hepgor yr ardaloedd o raglen fonitro. Y tu hwnt i'r ardaloedd hynny, mae'n ymddangos bod y cynefin bwydo a'r cymunedau benthig sy'n rhan o'r cynefin hwnnw wedi aros fwy neu lai yr un fath dros nifer o flynyddoedd. Gwelwyd bod y data sy'n angenrheidiol i broffwydo'r graddau y mae'r llanw'n effeithio ar ardaloedd bwydo ar gael, ac roedd data da ar gael hefyd mewn perthynas â maint poblogaethau o rywogaethau adar allweddol.

3. Mae deiet y gylfinir, pibydd y mawn, y pibydd coesgoch a hwyaden yr eithin yn Aber Afon Hafren yn hysbys o astudiaethau blaenorol. Mae'r hwyaden lostfain yn bwyta llystyfiant yn gyffredinol, ond mae'n bwyta hydrobia a chramenogion bach mewn aberoedd, sy'n golygu na fyddai angen cynnal arolwg o lystyfiant. Gellir proffwydo ymatebion gweithrediadol ar gyfer y tair rhywogaeth o adar hirgoes gan ddefnyddio hafaliadau a ddatblygwyd yn ddiweddar sy'n proffwydo paramedrau ymatebion gweithrediadol ar draws ystod eang o gyfuniadau o adar hirgoes ac ysglyfaethau. Ceir llawer llai o wybodaeth am gyfraddau porthiant ac ymatebion gweithrediadol hwyaden yr eithin a'r hwyaden lostfain. Mae'r enghreifftiau tebycaf o ymatebion gweithrediadol a fesurwyd yn perthyn i'r gorhwyaden a'r hwyaden wyllt. Gellid defnyddio'r rhain i roi amcan o gyfraddau porthiant hwyaden yr eithin a'r hwyaden lostfain, ond byddai proffwydoliaethau'r model ar gyfer y rhywogaethau hyn yn llai sicr nag yn achos y rhywogaethau hynny y mae eu hymateb gweithrediadol yn hysbys.

4. Roedd pedair o'r pum rhywogaeth a dargedir yn cael eu bwyd yn bennaf o ardaloedd lleidiog sy'n cynnwys biotopau a gaiff eu nodweddu gan bresenoldeb abwydyn y môr *Hediste Diversicolor* a'r gragen fylchog *Macoma Balthica*. Roedd y rhywogaeth a oedd yn eithriad yn hyn o beth - sef y gylfinir - yn cael ei bwyd o ardaloedd tywodlyd hefyd sy'n debygol o gynnwys yr abwydyn tywod *Arenicola Marina*. Nid oedd unrhyw un o'r pum rhywogaeth a dargedir yn defnyddio'r ponciau tywod dirywiedig a geir yn rhan ganol a rhan uchaf afon Hafren. Mae hynny'n cryfhau'r ddadl dros beidio â monitro'r ponciau hyn.

5. Argymhellir mai cynnal arolwg craidd rhynglanwol yw'r ffordd orau o bennu dosbarthiad a dwysedd ysglyfaethau yn Aber Afon Hafren. Gellir defnyddio data o arolwg o'r fath mewn model sydd wedi'i seilio ar un rhywogaeth, neu gellir ei ddefnyddio i ddatblygu cysylltiadau empeiraidd rhwng ffactorau amgylcheddol, dosbarthiad ysglyfaethau a dwyseddau poblogaethau adar. Gan fod dylanwad

pobl ar afon Hafren yn newid ar hyn o bryd ac na ellir diystyru'r posibilrwydd y bydd argae'n cael ei godi ar draws afon Hafren yn y dyfodol, mae'n debygol iawn y bydd cysylltiadau empeiraidd o'r fath yn newid. Os felly, y dull modelu sydd wedi'i seilio ar un rhywogaeth sydd orau.

6. Ar hyn o bryd, nid oes digon o wybodaeth ar gael am y ffactorau sy'n aflonyddu ar adar yn Ardal Gwarchodaeth Arbennig Aber Afon Hafren. Argymhellir bod arolwg cynhwysfawr yn cael ei gynnal o'r ffactorau hyn. Dylai'r arolwg fesur y math o ffactorau sy'n aflonyddu ar adar ac amlder yr achosion o aflonyddu ar adar ar wastadeddau mwd ac mewn mannau clwydo, oherwydd ystyrir bod achosion o aflonyddu ar fannau clwydo yn broblem benodol. Dylai'r arolwg fesur pellteroedd codi adar o'u mannau clwydo a'r effaith o ran amser sy'n gysylltiedig ag achosion o aflonyddu, fel y gellir darparu data ar gyfer modelu effaith achosion o aflonyddu.

7. Yn gyffredinol, mae'r rhan fwyaf o'r data sydd ei angen ar gyfer monitro afon Hafren gan ddefnyddio'r dull gweithredu adar:bio-màs bwyd a ddisgrifiwyd gan West et al (2005a) ar gael eisoes, neu gellir ei gasglu trwy gynnal arolwg. Mae'r ffaith bod diffyg ymatebion gweithrediadol a gyhoeddwyd ar gael mewn perthynas â hwyaden yr eithin a'r hwyaden lostfain yn golygu y byddai proffwydoliaethau'r model ar gyfer y rhywogaethau hyn yn llai sicr. Byddai proffwydoliaethau'r model ar gyfer pibydd y mawn, y pibydd coesgoch a'r gylfinir yn fwy sicr - yn wir, mae pob un o'r tair rhywogaeth hon wedi'u modelu'n llwyddiannus ar safleoedd eraill gan ddefnyddio'r dull gweithredu hwn. Mae newidiadau presennol a newidiadau posibl yn y dyfodol i afon Hafren yn golygu bod cysylltiadau empeiraidd rhwng newidynnau amgylcheddol a dwyseddau poblogaethau o ysglyfaethau ac adar y glannau yn debygol o newid. Felly, argymhellir mai defnyddio dull modelu sydd wedi'i seilio ar un rhywogaeth ac sydd wedi'i gynllunio i broffwydo amgylchiadau newydd yw'r ffordd orau o fonitro afon Hafren.

1. INTRODUCTION

The Countryside Council for Wales (CCW) and English Nature (EN) have a statutory duty to report on the condition of Special Protection Areas (SPAs). Monitoring bird numbers alone is not always a reliable indicator of site condition for two reasons. First, birds may be slow to respond to changes in habitat quality because they are reluctant to take the risk of moving to another site or are unable to do so. Second, bird numbers can be influenced by the quality of neighbouring sites, by large scale changes like climate change, or, in the case of wintering birds, by conditions on the breeding grounds. It is therefore better to measure habitat quality in an SPA in terms of its ability, or inability, to support a particular number of birds based on measured attributes of the habitat.

Five estuaries in Wales are SPAs for wintering waders and wildfowl. On three of these sites, the Burry Inlet, Traeth Lafan and the Dee Estuary work carried out as part of CCW's Marine Monitoring programme (West and McGrorty, 2003; West et al., 2005b) assessed the quality of these SPAs for oystercatchers and knot, which feed primarily on cockles in those sites. Similar work is now required for species that are more generalist predators and feed on more widely dispersed prey. A report to English Nature by the Centre for Ecology and Hydrology made recommendations for monitoring these species by assessing the relationship between bird biomass and prey biomass (West et al., 2001). The report also considered the effects of disturbance, which can prevent birds from feeding and may affect their survival, especially when combined with low food supplies. Increasing public use of coastal areas means that disturbance to birds may increase, so it important to be able to assess disturbance in terms of its impact on fitness, rather than just behavioural impacts.

The purpose of this project is to build on the work in West et al.'s (2001) report and develop detailed methods for monitoring bird food and disturbance on the Severn Estuary.

The Severn is a large and very dynamic estuary on the border between England and Wales with the second highest tidal range in the world. Of the five bird species included in this report (dunlin, redshank, curlew, shelduck and pintail), dunlin and curlew numbers are declining on the Severn in contrast to national and regional trends (Austin et al., 2004). Food supply is one possible cause of the declines and needs further investigation. One of the important questions to be addressed in this report is whether it is possible to apply a monitoring approach based on a knowledge of prey biomass to such a dynamic estuary.

Disturbance is also an important issue on the Severn. Public access to the Severn coast is increasing and needs to be managed to avoid adverse impacts on feeding and roosting birds. Open Access, long-distance coastal paths and new paths on sea defences all need to be assessed against the conservation objectives of the SPA, in combination with existing activities such as angling and wildfowling.

The overall aim of Phase 1 of the project, detailed in this report, is to review relevant literature on the Severn Estuary and the birds for which it is anticipated the methods will be used, then, assuming a bird:food biomass approach is considered to be suitable for use on the Severn to develop methods for monitoring two aspects of habitat quality on the Severn: food supply and disturbance.

2. SEVERN LITERATURE REVIEW

The literature review uncovered 238 journal papers of possible relevance to the Severn. The majority of these were concerned with sediments, fish and pollution (Table 1) and of little relevance to the present study. Most research that could inform a Severn estuary waterbird model has been conducted in response to plans to build a power-generating tidal barrage across the estuary in the 1980's. A co-ordinated set of studies, focused on engineering issues but including some environmental appraisal, was published by the Department of Energy in 1981 (Department of Energy, 1981). This was followed by a series of studies with more emphasis on environmental impacts, published in 1989 (Department of Energy et al., 1989). Also in 1989 the Estuarine and Coastal Sciences Association, the British Ecological Society and the Linnean Society of London held a workshop to discuss the then current understanding of the Severn Estuary ecosystem. Proceedings of this workshop were published in 1994 (Crothers et al., 1994). Few, if any, papers of direct relevance to this study have been published since then, although there are some studies from other estuaries which may help to explain the bird distributions on the Severn.

Subject	Number of ISI refereed journal papers
Barrage	5
Birds	13
Chemistry	7
Crustacea	3
Diatoms	4
Engineering	7
Fish	51
Hydrology	12
Invertebrates	12
Management	2
Geology/Palaeogeology	23
Plankton	4
Pollution	39
Sediments	53
Other	3

Table 1. Numbers and subjects of Severn-related refereed journal papers indexed by the Institute for Scientific Information (ISI) (see Appendix 1 for bibliography).

In addition to the literature in refereed journals, there are a number of reports related to the Severn. Again, many report the results of studies into the possible effects of constructing a Severn barrage. Perhaps the most useful of these for the current study is that of Goss-Custard *et al.* (1989), which looked at the diets and distributions of birds on the Severn, the latter with reference to environmental variables and prey densities. The high and low tide distributions of waterbirds have also been mapped and the low tide distributions compared to historical data in reports to CCW recently (Burton et al., 2003; Goodger, 2005). Data of possible relevance to applying CEH's bird:food biomass approach to the Severn estuary are summarised in tables 2 and 3 below.

2.1 Intertidal data

Data type	Source	Description
Biotope map of Welsh side	CCW Phase 1 monitoring biotope survey.	GIS-based maps of biotope distributions on the Welsh side of the Severn. No quantitative information.
Biotope map of English side	English Nature biotope survey	GIS-based maps of biotope distributions on the English side of the Severn. No quantitative information.
Exposure times at different parts of the estuary	Ferns et al. (1984)	Graphical data sufficient to calculate duration of exposure and proportion of mudflats exposed on different tides
Distribution of sediments and faunal groups	Mettam et al. (1994)	Point samples of sediment types and invertebrate communities throughout the Severn. Cluster analysis of invertebrate data.
Benthic ecology of Severn tributaries	Morrisey et al. (1994)	Fauna of tributaries. Maximum densities of dominant species.
Benthic fauna 1972/3 & 73/4	Little & Boyden (1976)	Semi-quantitative sediment and faunal data from 4 transects at various point in the Severn sampled at 4 different times of year
Faunal changes in 30 years preceding 1979	Mettam (1979)	Mostly qualitative. Not to species level.
Invertebrate densities at 6 sites in the Severn	CEH records. Raw data from Dept. of Energy study (1987)	Densities of important bird prey species at sampling sites used in 1989 Dept. of Energy report.
Community structure in relation to environmental factors	Warwick et al. (1991)	Average densities of a number of species.

Table 2. Sources of intertidal data on the Severn Estuary relevant to shorebird modelling.

2.2 Bird data

Data type	Source	Description
Bird counts for winter 1987/88	Clark (1994)	Mean low-tide distribution and numbers through winter for all study species except pintail
Historic wader populations	Ferns (1994)	Wader population sizes 1970-1987
Wildfowl populations	Salmon & Fox (1994)	Mean distributions of wildfowl species 1983-87
High tide roost locations	Goodger (2005)	Maps. Also includes low tide distribution data for 2002/03

Low tide counts	BTO GIS files	Low tide counts by sector in GIS format for species of interest for winter 98/99 and 02/03. Includes monthly counts as well as means.
Low tide distribution	BTO Research report no. 335	2002/03 low tide counts and historical analysis
Redshank habitat use	Burton & Armitage (2005)	Day/night site use of radio-tagged redshanks
Correlation between bird densities and environmental variables. Prey densities. Bird diets.	Goss-Custard et al (1991) 1991 ETSU report	Bird densities (waders and shelduck) correlated with environmental variables, including prey densities. Also information on the diets of dunlin, redshank, curlew and shelduck in the Severn

Table 3. Sources of shorebird data on the Severn Estuary relevant to shorebird modelling

3. BIRD FOOD REQUIREMENTS

3.1 Diets

The birds included in this study are those that were identified in the SPA Review (Stroud et al., 2001) as qualifying features of the SPA. These are three species of shorebird: dunlin *Calidris alpina*, redshank *Tringa totanus* and curlew *Numenius arquata* (currently in nationally important numbers), and two species of wildfowl: shelduck *Tadorna tadorna* and pintail *Anas acuta*. All three shorebird species and shelduck feed on benthic invertebrates in the intertidal area when they are exposed by the tide, although shelduck also feed in shallow water. Pintail usually feed in shallow water – generally 20 – 30 cm, but up to 53cm deep (Cramp and Simmons, 1977).

Prey size classes taken by these birds are shown in Fig. 1. Dunlin on the Severn estuary feed on the smaller size classes of polychaete worms, particularly *Hediste diversicolor*, the small bivalve *Macoma balthica*, and the gastropod mollusc *Hydrobia ulvae*, all of which are found in muddy intertidal flats (Worrall, 1984; Goss-Custard et al., 1988). Redshank feed on small and middle-sized polychaete worms and the crustaceans *Corophium volutator* and *Cyathura carinata* (Goss-Custard and Durell, 1986; Goss-Custard et al., 1988). Curlew mainly feed on larger size classes of polychaete worms, primarily *Hediste diversicolor*, but also *Nephtys spp*. and *Arenicola marina* (Goss-Custard et al., 1988). Curlew also take the larger size classes of *Macoma balthica*.

All three shorebird species are known to feed in fields around the Severn estuary, with curlew, in particular, feeding throughout the winter on the Gwent Levels (P. Ferns, D. Worrall & N. Burton pers. comm.). Earthworms *Lumbricus spp*., therefore, form a part of the diets of all three shorebirds.

Over 80% of the shelduck diet is known to consist of *Hydrobia* (Stroud et al., 2001), but they also eat small worms, both polychaetes and oligochaetes, and small bivalves (Goss-Custard et al., 1988). Pintail generally feed on vegetative material, particularly rhizomes, tubers and seeds, and also on insects, crustacea and molluscs (Cramp and Simmons, 1977). However, in estuaries, they feed mostly on *Hydrobia* and crustaceans such as *Corophium volutator* and *Cyathura carinata.*

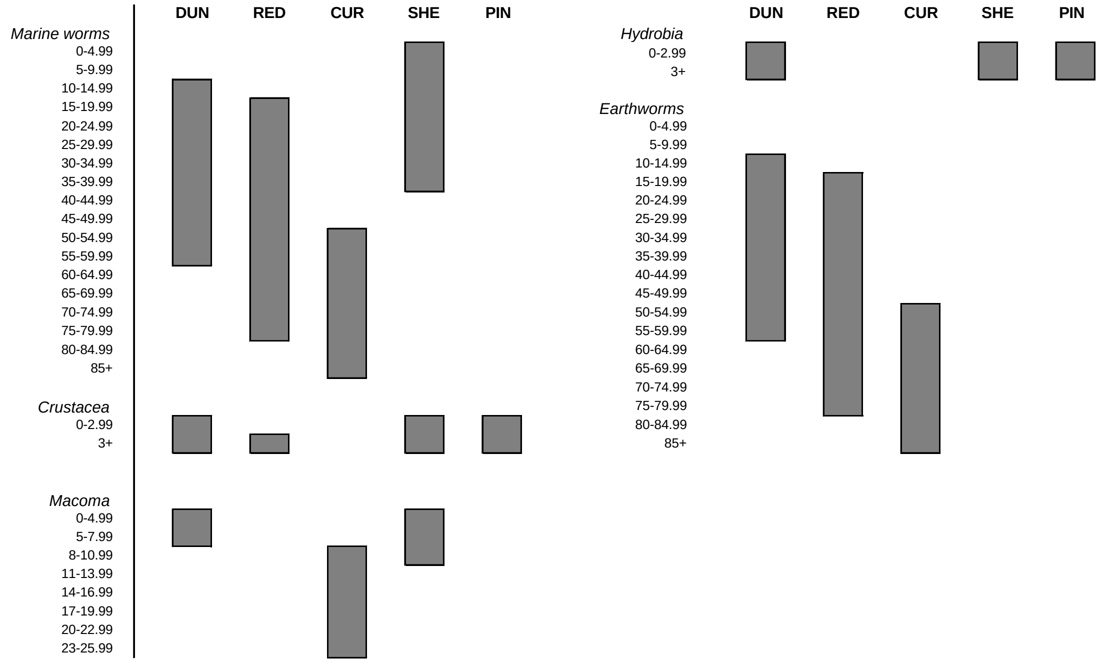

Figure 1 Prey species taken and size (mm) class selection. The bars show the size classes consumed by each species. Bars are missing if a prey species is not consumed by a shorebird.

3.2 Intake rates and functional responses

Shorebird intake rates and functional responses have been well researched and parameterised for previous models (Stillman et al., 2005a). All three shorebirds in this study were included in our models of the Humber (Stillman et al., 2005c), the Wash (Stillman et al., 2005b) and Poole Harbour (Goss-Custard et al., In press), whilst dunlin and curlew were included in models of the Seine (Durell et al., 2005c) and the Exe estuary (Stillman et al., 2005a).

The rate at which shorebirds feed in the model is determined by the abundance of food in a patch and the strength of interference from other competitors. Intake rate in the absence of competitors is initially calculated from the following equation:

$$IFIR = f\,\frac{IFIR_{\max} B}{B_{50} + B} \qquad \text{(eqn. 1)}$$

where $IFIR$ = Interference-free intake rate (mg s^{-1}), f = foraging efficiency of focal individual, B = patch biomass density of prey within the size range consumed (mg m^{-2}), $IFIR_{max}$ = maximum intake rate when prey are superabundant and B_{50} = prey biomass density at which intake rate is 50% of its maximum. This produces a hyperbolic asymptotic curve of the form shown in Figure 2.

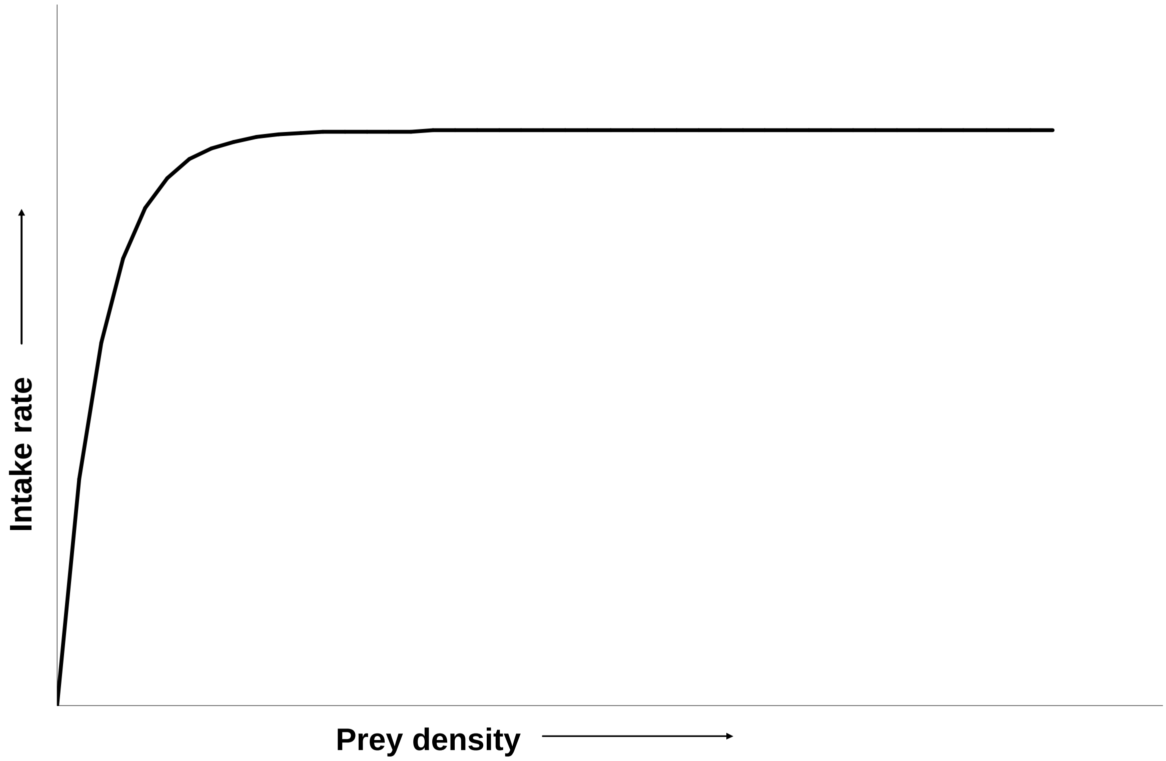

Figure 2 Example of a shorebird functional response produced by eqn. 1

A literature review was used to estimate the values $IFIR_{max}$ and B_{50} *(Goss-Custard et al., In press)*. $IFIR_{max}$ is related to shorebird body mass and prey mass by the following equation:

$$\log_e(IFIR_{\max}) = -2.802 + 0.245\log_e(M_{spec}) + 0.365\log_e(rM_{prey}) \qquad \text{(eqn. 2)}$$

where M_{spec} = average body mass (g) of the shorebird species in September, M_{prey} = mean ash-free dry mass (mg) of prey within the size range consumed and r = ratio of size of prey consumed to size in patch. A literature review showed that birds select the larger-sized prey within the size range consumed, giving a value of r of 1.05 (Goss-Custard et al., In press). $IFIR_{max}$ was greater in larger birds and when larger prey were consumed. B_{50} was unrelated to either bird or prey mass, with a mean value of 0.761 g ash-free dry mass m^{-2}.

The shorebird functional response parameters that will be used in the Severn model are shown in Table 4.

	Dunlin	Redshank	Curlew
B_{50} (g AFDM m^{-2})	0.761	0.761	0.761
Forager coefficient (0.245$\log_e(M_{spec})$)	-1.71232	-1.53300	-1.03936
Prey coefficient	0.36542	0.36542	0.36542

Table 4. Wader functional response co-efficients for dunlin, redshank and curlew.

Much less is known about intake rates of shelduck and pintail, and no data were found on their functional responses. Functional responses have been calculated for mallard *Anas platyrhynchos* eating poultry pellets (Fritz et al., 2001) and teal *Anas crecca* filter-feeding on millet seeds (Van Eerden and Munsterman, 1997) and rice grains (M. Guillemain pers. comm.). These functional responses could be compared predictions from the equations we use for calculating shorebird functional responses from body mass and prey size data (Goss-Custard et al., In press). If the equations also predict wildfowl intake rates with reasonable accuracy they could be used to predict the intake rates of shelduck and pintail on the Severn for modelling purposes.

3.3 Occurrence, distribution and biomass of prey in the Severn Estuary

Figure 3 shows the distribution in the Severn Estuary of the main biotopes likely to contain one or more prey species of the birds included in this scoping study. Although other relevant biotopes were present on the Severn, they were in areas so small as to be invisible on the scale of Fig. 3 and so were excluded from the legend for the sake of clarity.

The main biotopes of interest constitute approximately 59% of the intertidal area of the Severn (Table 5), with a further 20% consisting of mobile coarse sand shores containing burrowing amphipods and *Eurydice pulchra* (biotope LGS.S.AEur). The remainder consists of rocky biotopes (11%), barren sands and shells (2%) and small amounts of other muddy biotopes (7%). The most important biotope for shorebirds on the Severn, both in terms of size and of the prey species it supports, is sandy mud containing a mixture of the clam *Macoma balthica* and the ragworm *Hediste diversicolor* (LMU.SMu.HedMac). It is used by all 5 bird species under consideration in this study, although shelduck and pintail do not prey on *Macoma* or *Hediste* but will be attracted to this biotope by the presence of the gastropod *Hydrobia*, which is widespread on muddy sediments throughout the Severn estuary. This particular sandy mud biotope occurs along the northern and southern banks of the Severn throughout the length of the SPA. The second most important biotope, in terms of size, is clean sand shores with burrowing amphipods and polychaetes, often with *Arenicola marina*. This biotope is confined to the middle and upper reaches of the estuary opposite Avonmouth and Chepstow and may attract dunlin and redshank to feed on polychaetes and particularly curlew if *Arenicola* is present. The remaining three biotopes are relatively limited in distribution, with the *Zostera* biotope (LMS.Zos.ZNol) limited to one area near Caldicot. Muddy sands containing *Macoma* and *Arenicola* occur mainly on the Welsh side of the Severn at Magor and on the English side in a strip along the shore from Sand Bay down to Bridgewater Bay in the lower reaches of the estuary. The latter may represent nursery areas for juvenile *Arenicola*, which tend to occur in a fairly narrow strip at the top of the beach before moving further down as they grow larger.

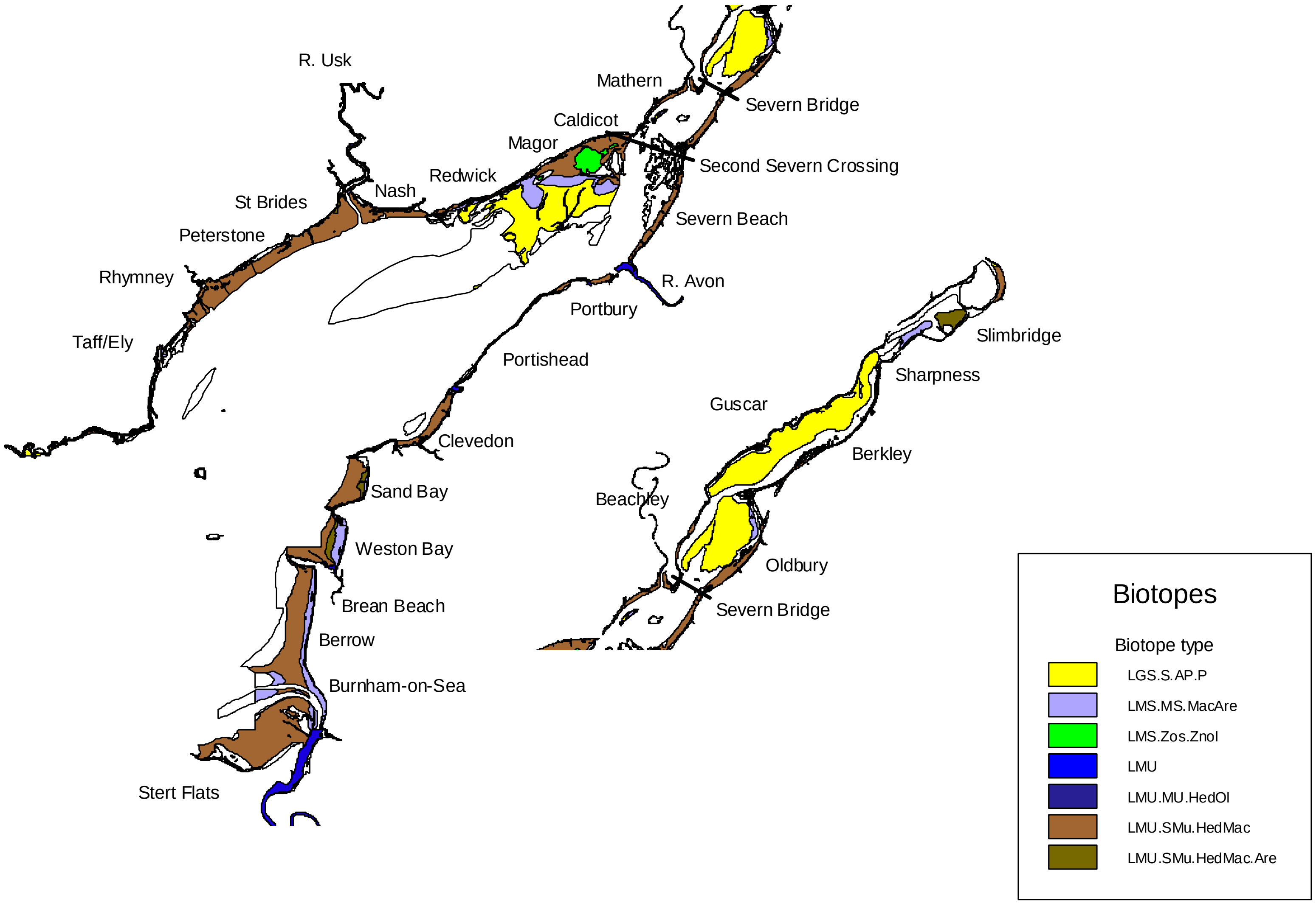

Figure 3. Biotopes likely to contain prey suitable for dunlin, redshank, curlew, pintail and shelduck on the Severn Estuary. Site names after Clark and Prys-Jones (1994). See Table 5 for biotope descriptions.

Biotope name	Description	% of total area	Relevant bird species
LGS.S.AP.P	Burrowing amphipods and polychaetes (often with *Arenicola marina*) in clean sand shores	18	Dunlin, redshank, curlew
LMS.MS.MacAre	*Macoma balthica* and *Arenicola marina* in muddy sand shores	6	Dunlin, curlew
LMS.Zos.Znol	*Zostera noltii* beds in upper to mid shore muddy sand.	1	Dunlin, redshank, curlew, shelduck, pintail
LMU.Mu.HedOl	*Hediste diversicolor* and oligochaetes in low salinity mud shores	4	Dunlin, redshank, curlew, shelduck, pintail
LMU.SMu.HedMac	*Hediste diversicolor* and *Macoma balthica* in sandy mud shores	29	Dunlin, redshank, curlew, shelduck, pintail
LMU.SMu.HedMac.Are	*Hediste diversicolor*, *Macoma balthica* and *Arenicola marina* in muddy sand or sandy mud shores	1	Dunlin, redshank, curlew, shelduck, pintail

Table 5. Descriptions of biotope types in Fig. 3 and bird species of relevance to this study that may feed on them.

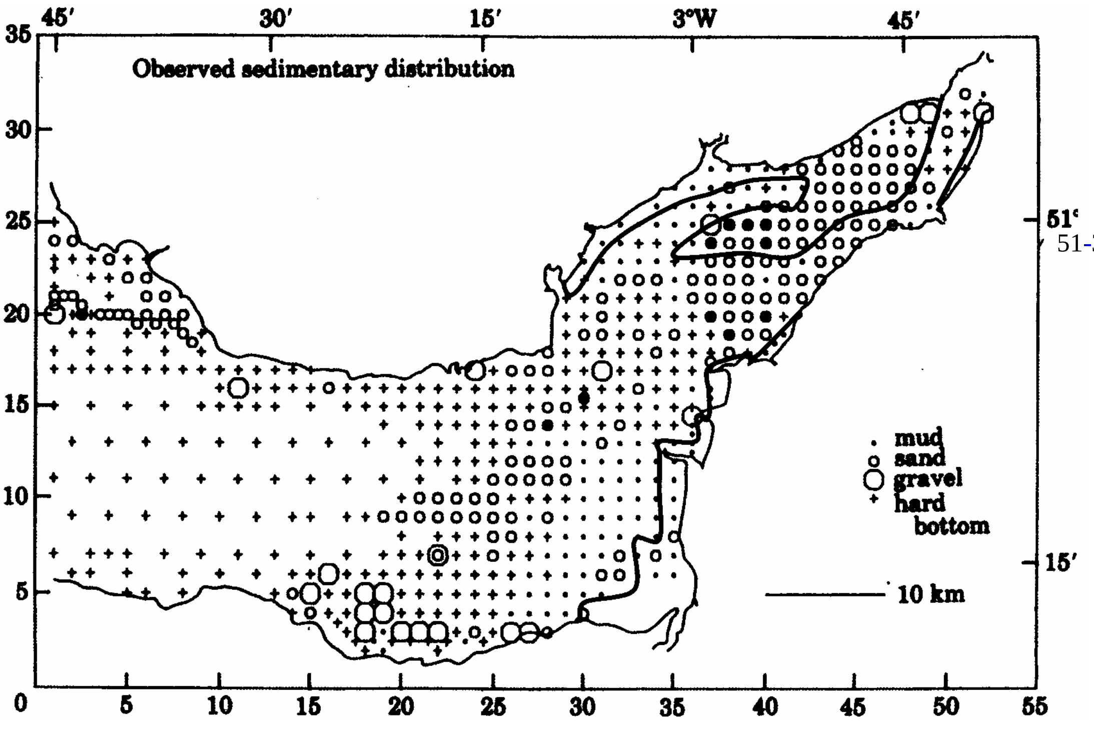

Figure 1. Distribution of sediment* determined by visual inspection of samples into mud, sand, gravel and hard bottom, or combinations of these categories.

Figure 4. Distribution of sediments in the Severn estuary from a survey in spring 1988 (after Mettam et al. (1994)). Thick black lines show approximate the extent of the intertidal zone in 2003. Reproduced with permission.

Despite the highly dynamic nature of the Severn Estuary, the distribution of sandy and muddy biotopes in Fig. 3 matches well with the distribution of sediment types found by a survey in the spring of 1988, as described by Mettam *et al.* (1994) (Fig. 4). Muddy sediments dominate in the lower reaches of the estuary on both northern and southern sides. In the

middle reaches, there is a large sandbank with a mixture of muddy and sandy sediments closer to shore. One noticeable change is that in 1988 the large mid-channel sandbank below the River Usk contained some muddy sands, but now consists entirely of a sandy biotope. Although Mettam et al. *'s* (1994) definitions are likely to be slightly different from those used for biotopes, it is clear that the general distribution of the sediments in the estuary has not changed dramatically in the last 15 years.
Similarly, the faunal groups identified by Mettam *et al.* (1994) (Fig. 5) are a good fit for the biotopes observed in recent surveys.

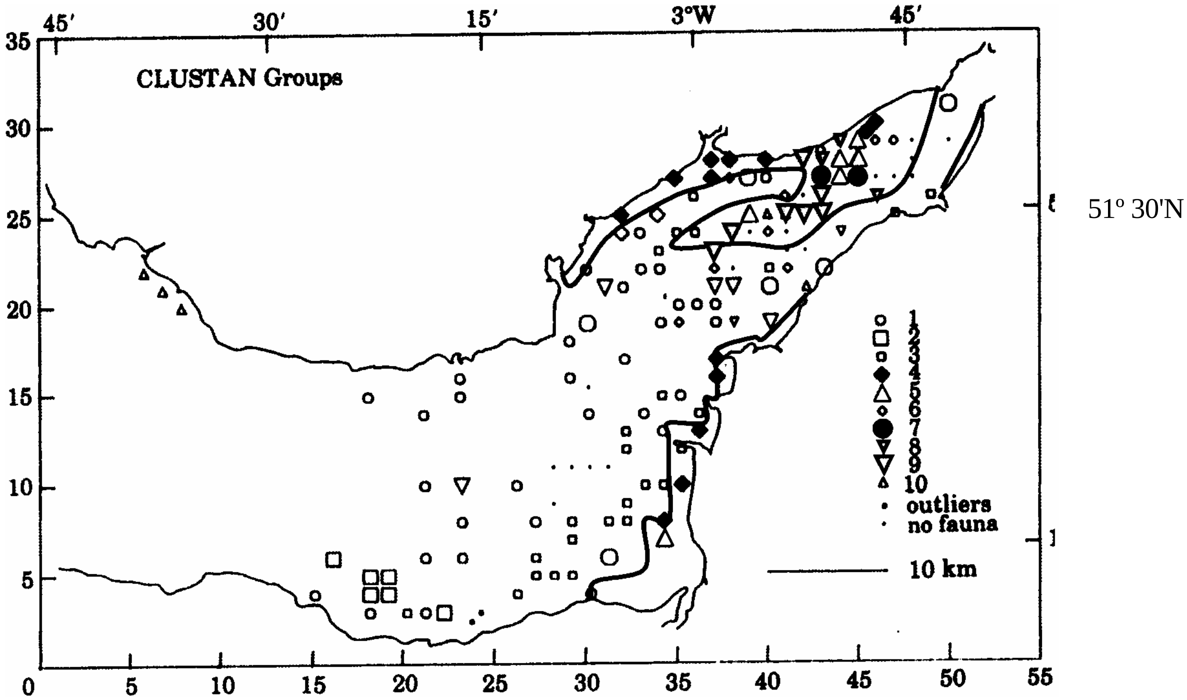

Figure 6. Distribution of 10 faunal groups determined by CLUSTAN.

Figure 5. Distribution of faunal groups in the Severn Estuary from a spring survey in 1988 (after Mettam *et al.* (1994) . See Table 6 for key to groups.) Thick black lines show approximate the extent of the intertidal zone in 2003. Symbols in the intertidal zone have been colourised to show which of the biotopes in Fig. 4 they most closely resemble. Grey symbols represent the equivalent of the biotope LGS.S.AEur - the biotope of the large uncoloured mid-channel sandbank in Fig. 3. Reproduced with permission.

In 1988 both northern and southern banks in the lower half of the estuary were dominated by group 4 (Fig. 5), which contains *Macoma balthica, Hediste diversicolor* and *Hydrobia ulvae* (Table 6) and as a result would be potential feeding habitat for all five bird species being considered in this study. The large mid-channel sandbank below the R. Usk consisted mainly of clean sand containing various crustacean species, frequently including *Eurydice pulchra,* although there is evidence of some muddiness (as seen in Fig. 4) in that one of the samples contained *Hydrobia ulvae* (Group 5), which is typically associated with muddy sediments.

Group	Characteristic species
1	*Sabellaria alveolata* (Honeycomb worm), various other polychaetes/oligochaetes
2	*Exogone naidina*
3	*Nephtys hombergii, Tubificoides amplivasatus*

4	*Macoma balthica, Hydrobia ulvae,* polychaetes, including *Hediste diversicolor*, oligochaetes
5	*Bathyporeia* spp., *Hydrobia ulvae*, other crustacea, *Nephtys cirrosa*
6	*Capitella capitata, Mesopodopsis slabberi*
7	*Gammarus salinus*
8	*Mesopodopsis slabberi*
9	*Euridyce pulchra*
10	*Nephtys cirrosa*

Table 6. Characteristic species of the 10 CLUSTAN groups identified by Mettam *et al.* (1994). Adapted from Table 1 of that paper.

We have not been able to trace any comprehensive survey of invertebrate densities on the Severn Estuary but there are two sources of data which give some idea of the densities of several common invertebrates, including the major components of the diets of birds included in this scoping study. The first is Little and Boyden's (1976) paper 'Variations in the fauna of particulate shores in the Severn Estuary'. They took transects down the shore at four sites on four occasions from 1972 to 1974. Three of those sites fall within the SPA; Weston-super-Mare, Portishead and Sharpness, all on the southern side of the estuary. The data is presented as graphs showing, to the nearest order of magnitude, the densities of a number of common species at different levels down the shore at each site. Species presented include *Hediste diversicolor*, *Corophium volutator*, *Corophium arenarium*, *Hydrobia ulvae* and *Macoma balthica*. The original data from the 1989 Dept. of Energy report (Great Britain Department of Energy et al., 1989) contains mean densities of a larger range of invertebrates at twelve sites along both sides of the lower half of the estuary, from Bridgewater Bay to the River Usk. For some species the data is also sub-divided by size-class in order to better understand the numbers of prey available to particular bird species, each of which has a preferred size-range of prey. However, while these data sources may provide useful background information neither is sufficient to parameterise an individuals-based waterbird model of the Severn Estuary, especially in view of their age.

3.4 Bird distribution in relation to prey

Figures 6-10 below show mean bird distributions from the BTO low tide survey of the Severn from winter 2002-03 overlaid on the biotope data from CCW and EN biotope surveys. Curlew occur in relatively low densities along the whole of the northern side of the estuary, and to some extent along the southern side as well (Fig. 6), but there are two main concentrations. One occurs on the sandbanks above the Severn Bridge at Oldbury and Guscar, where the birds may be able to feed on *Arenicola marina*, a preferred prey of curlew, and the other occurs on the muddy *Hediste* and *Macoma*-dominated biotope at Stert Flats, around the mouth of the River Parrett.

The majority of dunlin occur in the lower half of the estuary, below the bridge. Again, some birds are scattered across the mudflats on the northern side of the estuary from Cardiff to Newport, but the greatest concentration of birds is on Stert Flats and the mudflats north of there (Fig. 7). There are also small concentrations near the mouth of the River Avon at Caldicot and on the opposite bank at Magor.

Pintail are relatively restricted in their distribution and are mainly to be found on the mudflats between Cardiff and Newport, although a few were also seen at the top of the estuary near the WWT's Slimbridge wetlands reserve (Fig. 8).

As noted by Burton *et al.*(2003) redshank are widely distributed throughout the estuary on *Hediste* and *Macoma*-dominated muddy biotopes with some degree of clustering around freshwater inputs, although this pattern is by no means universal (Fig. 8).

Shelduck are also distributed throughout the estuary, again on *Hediste* and *Macoma* dominated biotopes, but the majority of the population occurs in the lower third of the estuary. On the southern side there is a particular concentration around the mouth of the River Parrett and significant numbers of birds feeding along most of the beach up to Sand Bay above Weston-super-Mare. There is also a concentration around the mouth of the River Avon and, as with dunlin, on the opposite shore at Magor. Significant numbers of shelduck were also observed on the mudflats between Cardiff and Newport, particularly around the mouth of the River Rhymney.

Notably, not one of the 5 species under consideration in this report fed on the flats at Burnham-on-Sea to the north of the outlet of the River Parret. The large mobile mid-estuary sandbank below the River Usk was also absent of birds. In fact with the exception of curlew, which favoured sandy areas likely to contain *Arenicola*, the species under consideration for modelling preferred to feed on the apparently relatively stable muddy *Arenicola* and *Hediste* dominated biotopes. In the case of shelduck and pintail the attraction is likely to be the presence of *Hydrobia* rather than the primary species by which the biotope is defined.

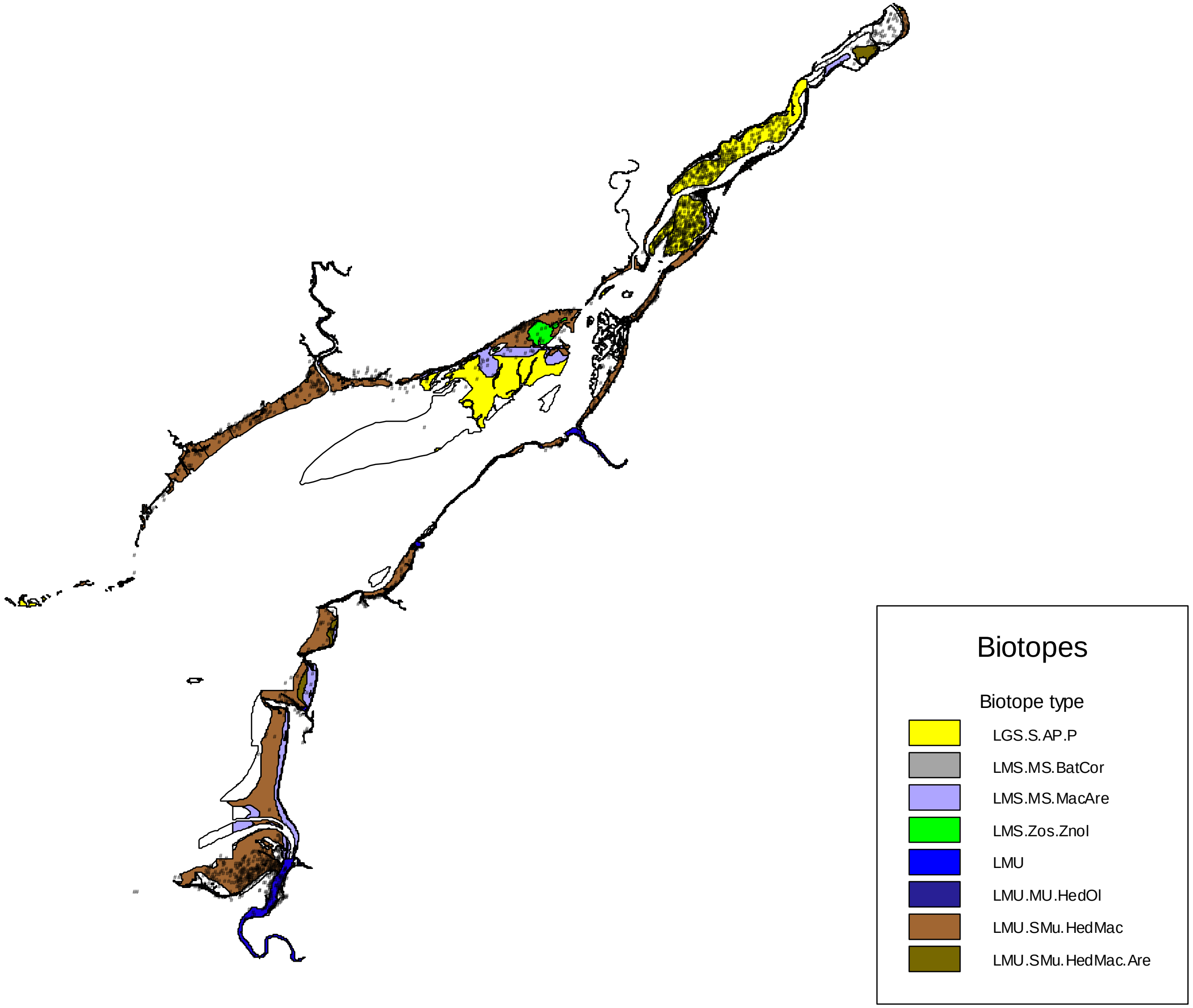

Figure 6. Mean overwinter distribution of curlew on the Severn Estuary in 2002-03 in relation to biotopes. 1 dot = 2 birds.

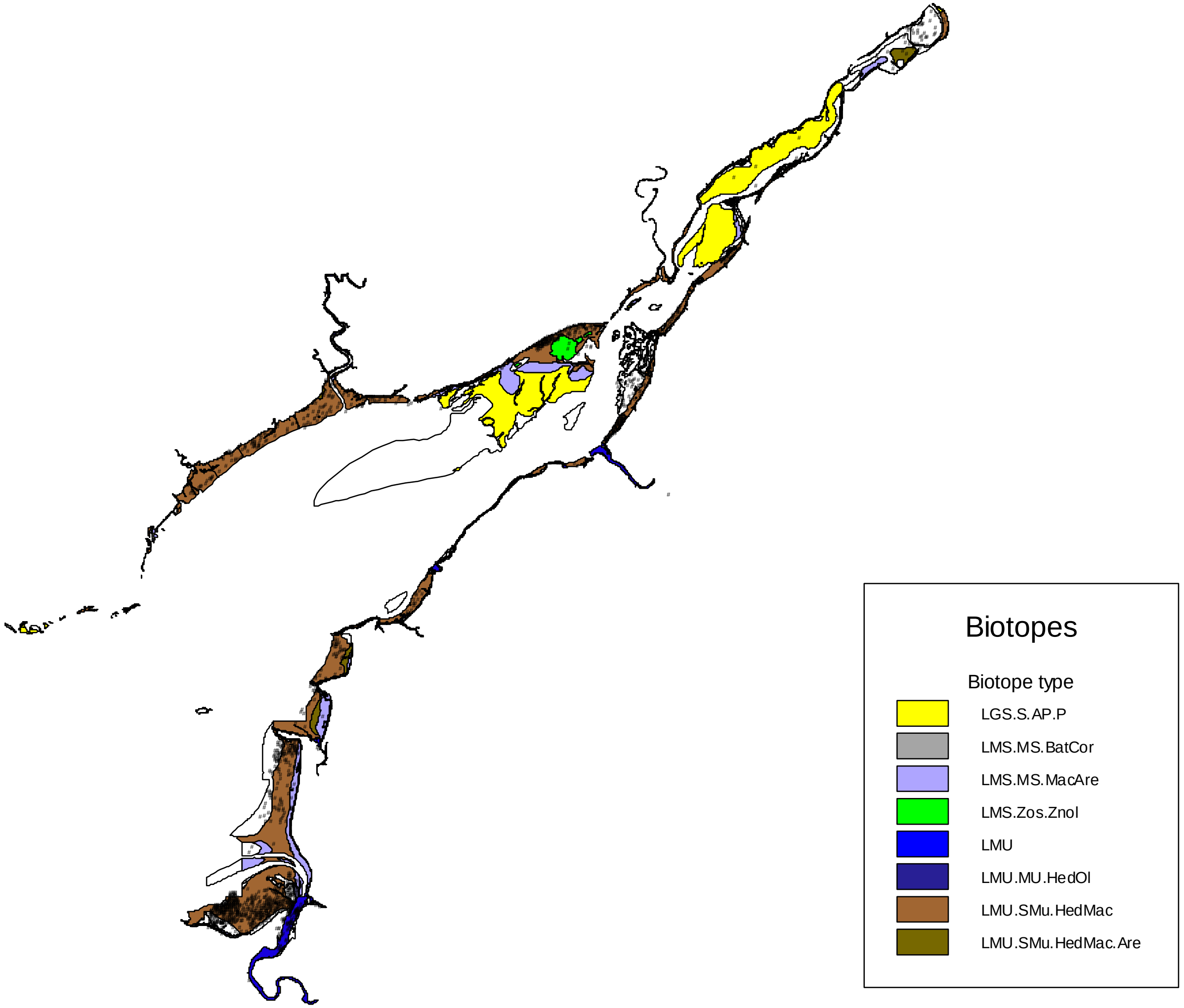

Figure 7. Mean overwinter distribution of dunlin on the Severn Estuary in 2002-03 in relation to biotopes. 1 dot = 2 birds.

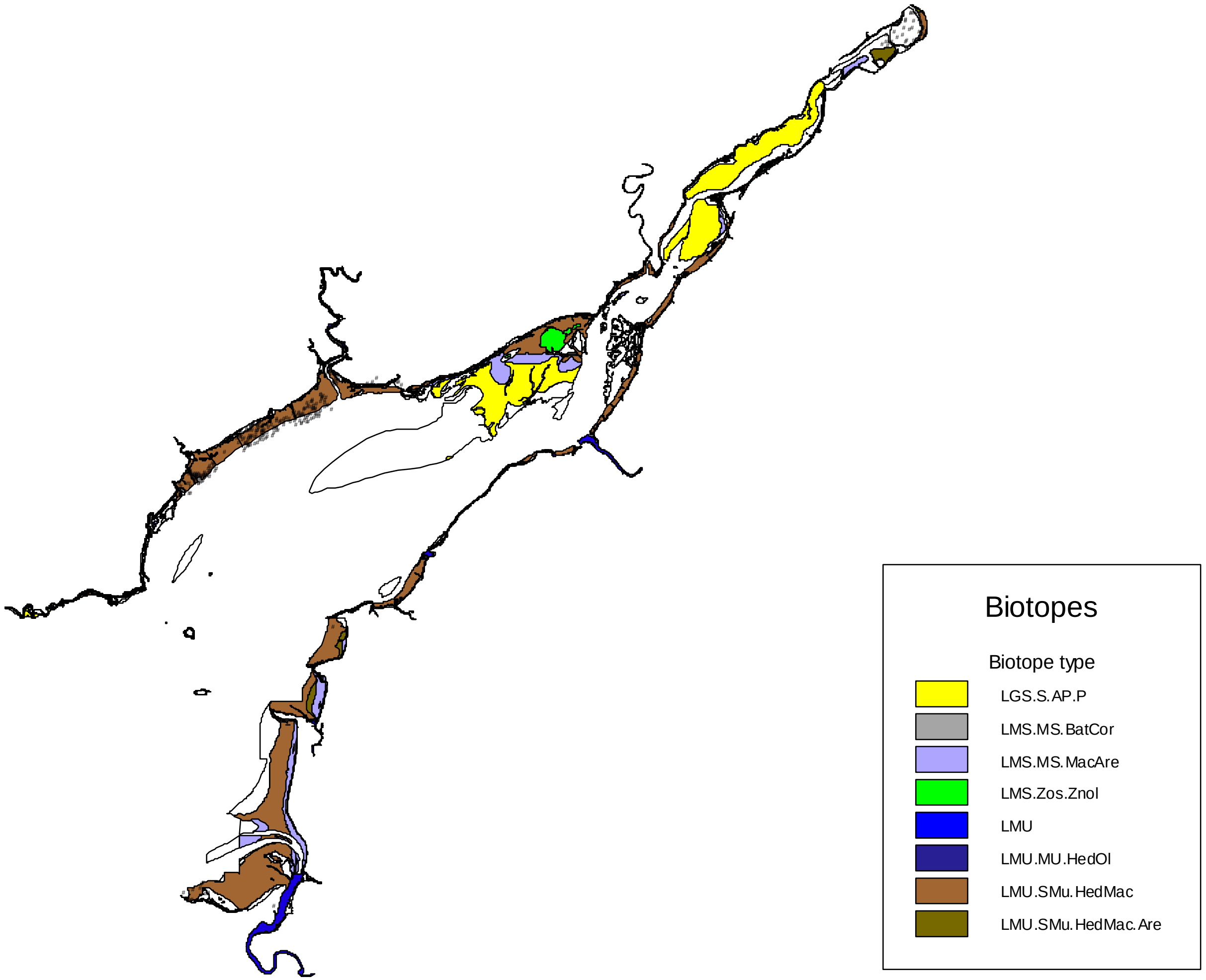

Figure 8. Mean overwinter distribution of pintail on the Severn Estuary in 2002-03 in relation to biotopes. 1 dot = 1 bird.

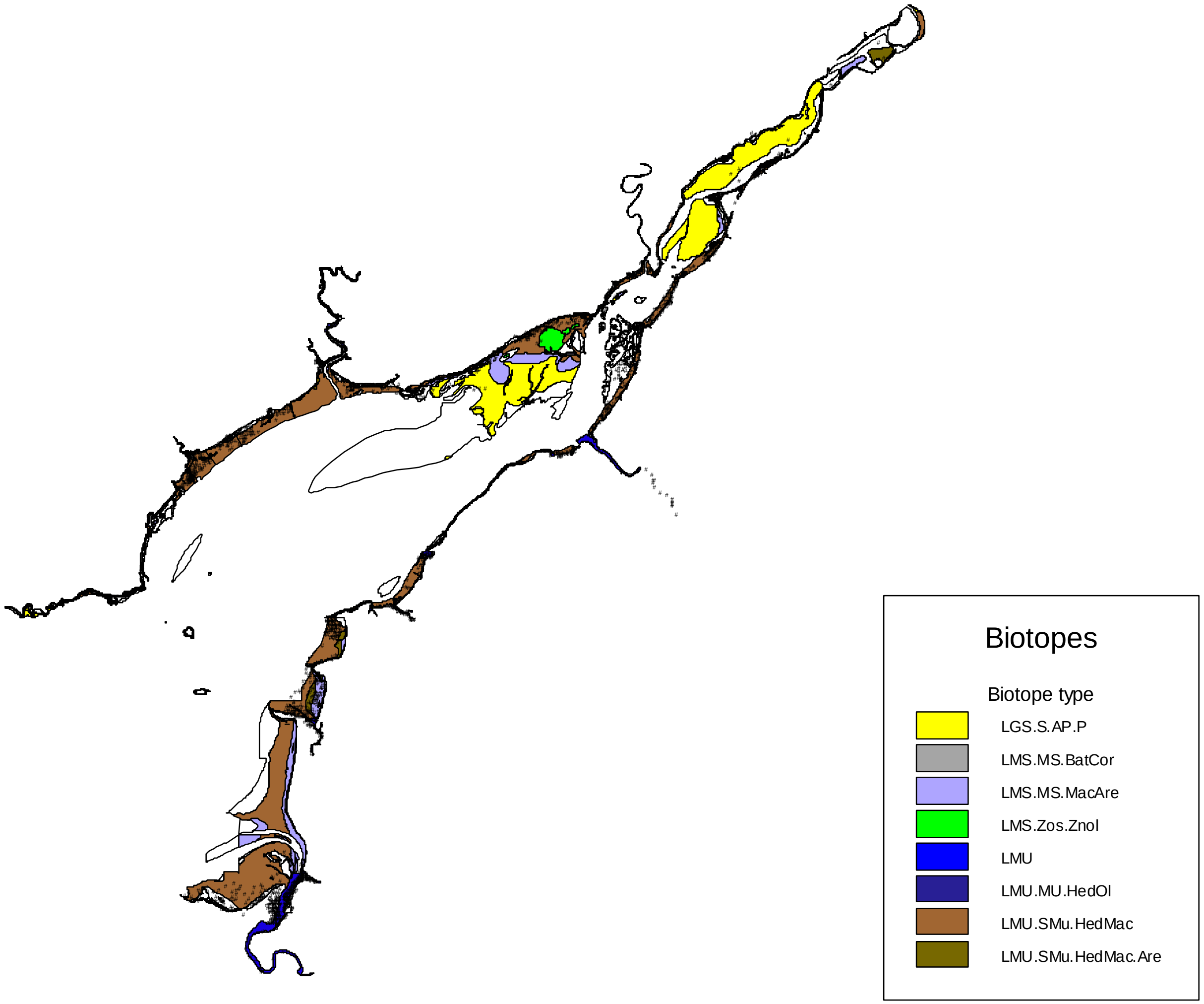

Figure 9. Mean overwinter distribution of redshank on the Severn Estuary in 2002-03 in relation to biotopes. 1 dot = 1 bird.

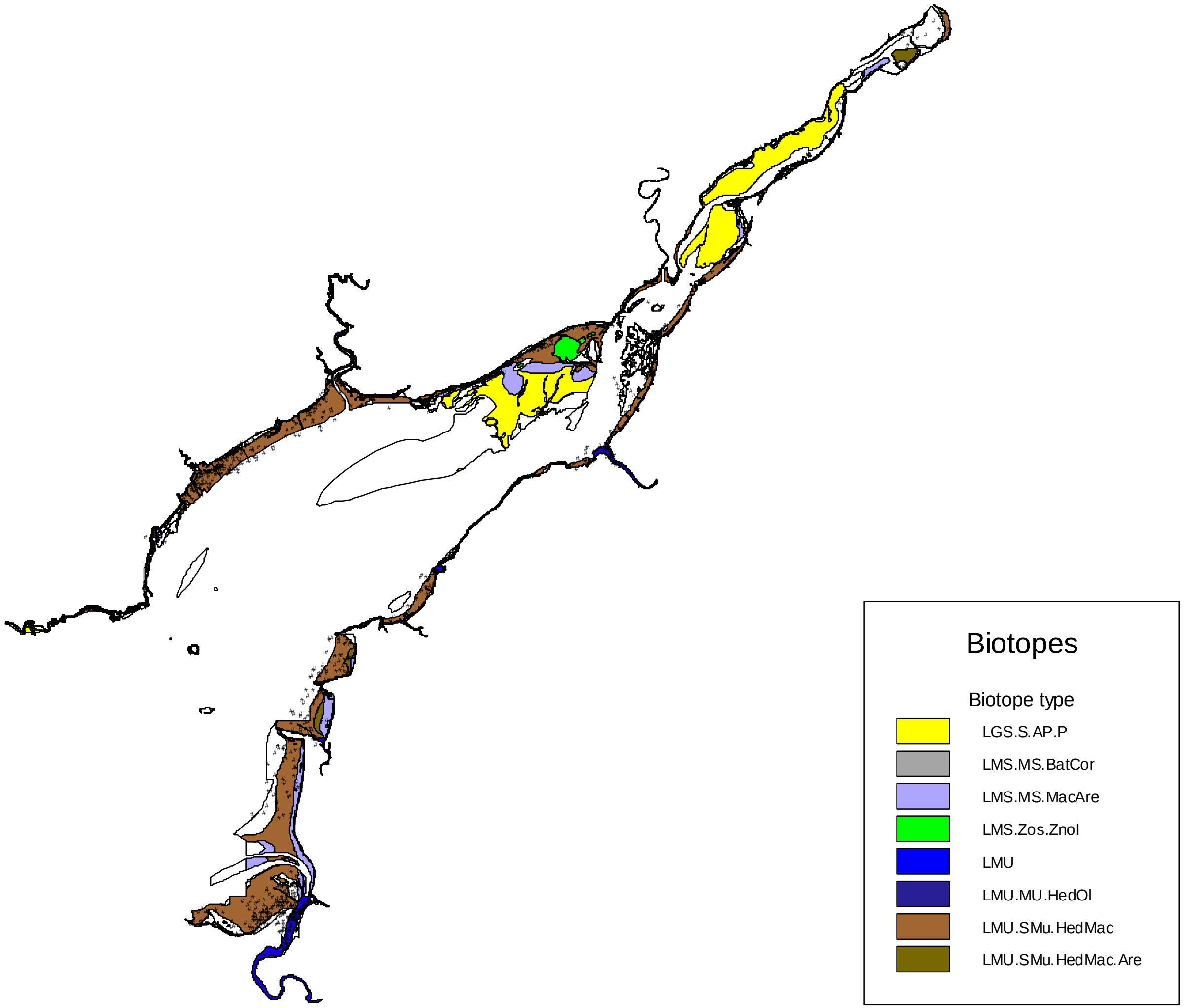

Figure 10. Mean overwinter distribution of shelduck on the Severn Estuary in 2002-03 in relation to biotopes. 1 dot = 4 birds.

4. INTERTIDAL SURVEY TECHNIQUES

4.1 Techniques

The purpose of surveying the intertidal areas of the Severn Estuary would be to measure their quality in terms of food supply for the birds that live there. The crudest way to measure this is simply to monitor the area of each of the biotopes on the Severn that are likely to provide suitable feeding habitat for waterbirds. However, there is evidence that whilst the distribution of different biotopes around the Severn has remained broadly stable over the past 10 years at least (see section 3.3), bird numbers have fluctuated in different areas (Burton et al., 2003). Given that, and the likelihood that changes to waste water inputs will lead to changes in the invertebrate community within biotopes at various places on the Severn (Burton et al., 2002a), it is essential that any assessment of SPA quality for shorebirds include some quantitative element. Techniques for obtaining quantitative data on intertidal macroinvertebrates are well established (Holme and McIntyre, 1984; Dalkin and Barnett, 2001). Currently, core sampling is still the only practical way in which the abundance of most intertidal macroinvertebrate species can be determined. The JNCC procedural guideline on the sampling of intertidal sediment species (Dalkin and Barnett, 2001) provides a detailed protocol for conducting such surveys with reference to establishing species composition and abundance within a biotope. However, when surveying a whole SPA with the aim of providing data suitable for use in spatially-explicit adaptive individual-based models (SAIBMs) some modifications of the JNCC protocol are appropriate. The bird group at CEH has developed protocols specifically optimised for this purpose (West et al., 2004) included in this report as Appendix 2. The main difference between CEH's protocol and JNCC's guidelines is that the former emphasises broad coverage of the estuary over detailed examination at each sampling site. The reason for this is that our experience of modelling different estuaries has shown that, given limited time and resources for survey, a good estimate of the distribution of different species and the overall area of mudflat they occupy is more important than a high degree of accuracy in point estimates of abundance. The accuracy of individual estimates of abundance can accorded less importance because of the general nature of shorebird functional responses. In most cases the intake rates of shorebirds rise rapidly with increasing prey densities and reach a plateau well below the upper end of the range of prey densities seen in the wild (Goss-Custard et al., In press), so prey densities can be depleted to low levels before intake rate is affected.

CEH's protocol differs from JNCC's in several respects. Most notably, we recommend taking only a single core at each sampling site as opposed to the 5 cores recommended by JNCC. Whilst this reduces the accuracy of the estimate at one particular sampling site, it allows for many more sites to be sampled and thus gives a better estimate of the distribution of particular species. This helps to determine boundaries for patches in spatially explicit models and the issue of lower point sample accuracy is mitigated to some extent by aggregating samples into coherent feeding patches. JNCC's protocol also advises against field-sieving of samples on the grounds that it is 'regarded as unproven' (Dalkin and Barnett, 2001 p. 255), but in our experience field sieving can produce good results providing it is conducted gently, in particular by avoiding the use of water jets to force sediment through the sieve which can damage delicate specimens. The advantages of field sieving are threefold; 1) it is done soon after samples are collected so minimises the probability of mortality of specimens between collection and sieving 2) it is usually easy to use seawater when sieving samples on site and thus avoid damaging specimens by exposing them to fresh water, and 3) it greatly reduces the weight and bulk of material that needs to be transported to and stored at the laboratory.

4.2 Sampling Schemes

There are four basic sampling designs that could, in theory, be used to survey intertidal infauna: random, stratified, systematic and adaptive sampling. It has been shown that adaptive sampling, in which spatially contiguous quadrats are sampled whenever the number of individuals of a particular taxon in a quadrat exceed a critical value, tends to produced biased estimates of abundance (Cabral and Murta, 2004). More importantly, the need to determine abundances *in situ* makes this method unsuitable in practice for the sort of whole estuary survey required for this project. The three other designs produce similar unbiased results for abundance, albeit with higher variances than adaptive sampling.

CEH have tended to use systematic sampling designs for intertidal survey for a number of reasons. First, it greatly simplifies the process of finding sampling sites if they are located on a systematic scheme, although this is less of an issue with increasing availability of GPS receivers equipped with waypoint capabilities. Second, it ensures maximum spatial coverage of the area to be sampled, which is important if large areas of visually homogeneous mudflat are to be divided into feeding patches based on their invertebrate infauna. Third, there is often little information on which to base any stratification, other than a broad categorisation of the muddiness or sandiness of particular areas. Finally, intertidal areas tend to show downshore zonation so, depending on shore width and slope, a systematic grid or transect survey is an effective way to capture this variation. There are, of course, potential pitfalls to systematic sampling, mainly the possibility that the sampling grid will coincide with some regular natural environmental variation and thus provide a biased estimate. In practice this is not common. The most likely pattern of this sort in intertidal areas would be a regular pattern of drainage channels running down the shore and this is would easily be picked up by surveyors in the field.

Random sampling avoids any risk of coinciding with regular environmental patterns but has its own drawbacks in the context of surveying for the prey of waterbirds or, indeed, for SPA quality. The random nature of such sampling means that some parts of the SPA will be undersampled or missed altogether whilst other parts will be oversampled. The risk of this can be reduced by increasing the number of samples taken, but in practice the number of samples is usually determined by logistics and it is not usually possible to increase it to any great extent. Another drawback to random sampling in this context is the issue of repeatability. Given that the samples will be distributed randomly across the SPA one is faced with the choice of repeat sampling at the same sites each time, which means that some areas will always be under-represented, or generating a new set of random samples each time, making it harder to differentiate between genuine changes and artefacts caused by sampling a different set of sites.

In the case of the Severn, although there is no quantitative information with which to stratify sampling, some of the available data indicates that a systematic sampling scheme would benefit from some stratification. It is clear that some biotopes on the Severn are not suitable feeding habitat for the birds of concern in this study (see section 3.4) so there would be little point in taking samples that fall in these biotopes. Although there is evidence that some species are attracted to the vicinity of freshwater flows across the mudflats, both in the Severn (Burton et al., 2003) and elsewhere (Ravenscroft and Beardall, 2003; Lourenco et al., 2005),the zone of this influence is small (as little as 10m according to Lourenco et al. (2005)) in comparison to the wider Severn and it is therefore probably not worth including this as a stratifying factor.

4.3 Remote methods

In the last two decades there has been increasing interest in the use of remote sensing methods, i.e. satellite imagery and aerial photography, to monitor terrestrial and intertidal habitats. For remote sensing to be of use in determining habitat quality for waterbirds there are several stages through which the raw data must be transformed into invertebrate biomass or densities (Fig. 11).

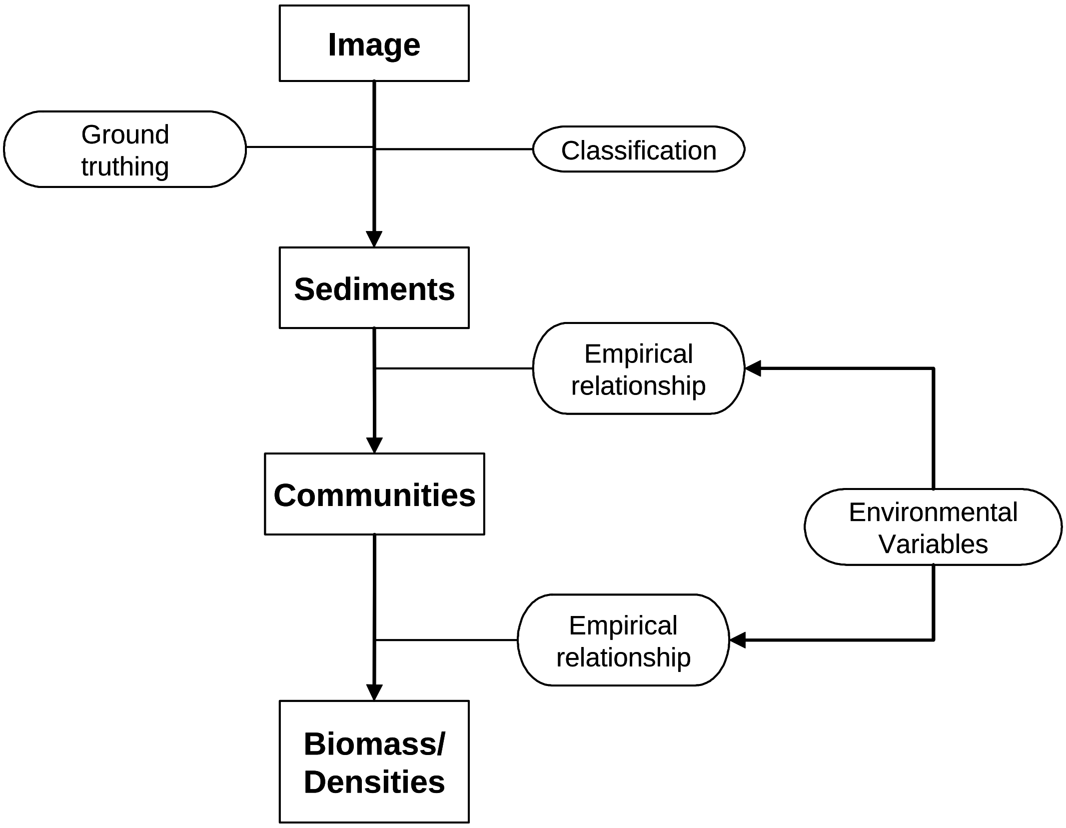

Figure 11. Stages of interpretation from remotely-sensed image to invertebrate biomass or densities.

The first issue to consider is the type of image to be used. Satellite images have the advantage that they typically collect data from several spectral bands and an analysis can therefore be made on the basis of the spectral signature of different habitat types of interest. An example of this is Yates et al's (1993) use of satellite imagery to determine sediment distributions in the Wash. Recent commentators have taken the view that aerial photographs are preferable to satellite images when engaging in habitat mapping at an estuary scale, because the resolution of aerial photographs is currently higher (c. 1m pixel size compared to 20-30m from satellites) (Higinbotham et al., 2004; Zharikov et al., 2005), although this is not necessarily a big disadvantage on a large site like the Severn. The other potential drawback of using satellite imagery for intertidal work is that a good image requires that the satellite is over a particular estuary at low tide on a spring tide in daylight on a relatively cloud-free day in a particular season, limiting the availability of images (Thompson et al., 2003). With aerial photography is that it is possible to commission custom surveys if necessary, although the associated expense may make this impractical in many cases. Satellite imagery has been available for over 30 years (e.g. LANDSAT) but comparable aerial photography datasets now exist as well (e.g. Infoterra Ltd.).

Once suitable images have been obtained they are classified into habitats. For satellite images this involves use of a classification scheme based on known reference sites within the study area (e.g.Yates et al., 1993) whereas for aerial photography a more labour-intensive interpretation and digitising process may be involved (e.g. Zharikov et al., 2005). In either case some element of ground-truthing is needed and, in the absence of recent sediment data, field visits would be required. For example, Zharikov et al's (2005) photography-based characterisation of Moreton Bay, Australia (100x35km) used 329 intertidal ground control points and 173 intertidal reference points for accuracy assessment. Typically, the accuracy with which pixels or features are classified is around 70-80% although it varies depending on habitat type and classification method.

Sediment type is a strong influence on intertidal invertebrate communities, so the next stage is to predict the distribution and composition of invertebrate communities from the sediment distribution. Analyses of macrobenthic invertebrate communities in relation to environmental factors for the Severn and other estuaries were carried out during the original round of pre-barrage studies in the early 1990s (Warwick et al., 1991). Warwick et al (1991) analysed invertebrate community structure in relation to sediment shear-strength, granulometry, organic content, spring tidal range and estuary width. They found that faunal communities in the Severn differed from those in other estuaries because of the Severn's high tidal range and width, but they were nonetheless confident that the composition of faunal communities in the Severn could be predicted, even after such a drastic event as the building of a barrage. Numerous other studies have successfully explored relationships between macrobenthic invertebrate communities and environmental factors (e.g. Rainer and Fitzhardinge, 1981; Warwick et al., 1990; Rosenberg et al., 1992; Gonzalez-Oreja and Saiz-Salinas, 1998)

Whilst the prediction of intertidal invertebrate communities from sediments and environmental factors is well-established and tractable, the prediction of biomass or densities is subject to many more influences and thus much greater uncertainty. As part of the pre-barrage studies of the Severn an attempt was made to derive equations that could predict prey densities from easily measured static environmental variables (Goss-Custard et al., 1991). Whilst the densities of various invertebrates could be related to environmental factors, the R^2 values were relatively low, ranging from 0 to 53.3%

The justification for using remote-sensing to derive estimated invertebrate abundances and/or distributions is that it avoids the need for costly and time-consuming field surveying. Given that there is a relatively recent biotope survey of the Severn available it could be considered, with some justification, that the transition from image to invertebrate communities has already been bypassed. There remains however the stage of converting those communities, or other environmental factors, into invertebrate densities and biomasses. This conversion is necessarily based on empirical relationships and is likely to be specific to a particular estuary, especially in the case of the Severn with its unusually dynamic nature. Goss-Custard et al's (1991) regressions could form the basis of such a conversion, but this would not be an ideal solution because Goss-Custard et al. (1991) were comparing the Severn to a number of other estuaries and they sampled relatively few sites within the Severn itself (12). In addition, it is likely that some environmental factors within the Severn, not included in the regressions, have changed since 1991, or are still changing, e.g. pollution levels and sewage inputs (Burton et al., 2003). If such an approach were chosen it would be necessary to take samples throughout the Severn and repeat the regression analysis relating them to environmental factors, including granulometry. In fact, an intertidal survey designed to measure the food availability for waterbirds could also serve as a source of data for such an analysis.

5. DISTURBANCE

5.1 Existing information and approach

The literature on human disturbance to birds in the Severn estuary is very sparse. Burton et al. (2002b) studied the effects of construction work around Cardiff Bay in terms of bird distribution and feeding activity, showing that construction work related to the enclosure of the Bay and associated projects reduced the density of some shorebirds on adjacent mudflats. Of the activities currently carried out on the Severn (JNCC, 1995) the most likely to cause disturbance to birds on the Severn are wildfowling, shellfish gathering, bait collection and recreation. Shellfish gathering and bait collection are restricted to low tide and likely to have a relatively localised impact, with birds avoiding the area immediately around the activity. Wildfowling and recreational activities also have the potential to disturb birds at high tide and over wider areas. For example, on the Somme estuary in northern France birds at risk from hunting, oystercatchers and curlew, avoid hunted areas altogether unless they are at risk of starving (Durell et al., 2005b). There are paths running close to the banks of the Severn along much of its length so there is potential for recreational disturbance of birds in many places, although activity is likely to be greatest near easy access points.

For the impacts of disturbance on the bird populations of the Severn to be estimated a program of data collection and modelling would need to be carried out. Several different aspects of disturbance need to be surveyed if the impacts on fitness are to be determined (Hockin et al., 1992; Hill et al., 1997; West et al., 2002). First, the type, location and frequency of occurrence of disturbances on the Severn must be established. Although this can then be correlated with bird distributions (e.g. Gill et al., 2001a; Bright et al., 2004) and this in turn can provide estimates of under-use of resources (Gill et al., 1996) it cannot be used to predict what effect the disturbance is having on the fitness of birds in terms of mortality and maintaining the necessary weight for spring migration.

Many studies record the behavioural responses of birds to disturbance, most commonly flushing distance, in addition to the causes of disturbance (Draulans and van Vessem, 1985; Fernandez-Juricic and Telleria, 2000; FernandezJuricic et al., 2004; Laursen et al., 2005). Measuring these responses is useful for practical aspects of managing disturbance, for example flushing distance can be used to set buffer zones to avoid disturbance to birds (Rodgers Jr. and Schwikert, 2002), but such responses cannot be used as indicators of the impacts of disturbance on birds. It is often assumed that birds which respond to disturbance at long distances are the most sensitive to disturbance (e.g. Burger, 1981), but the opposite may be true – those birds that respond first may be the ones that can most easily compensate for the time and energy costs involved and therefore incur less risk in doing so (Hill et al., 1997; Gill et al., 2001b). The only way in which the true impacts of disturbance at a population level can be measured is by measuring its effects on mortality rates and, for migratory birds, accumulation of fat reserves for migration, which affect a birds chances of reaching the breeding grounds and reproducing successfully. As this is almost impossible in practice without enormous expenditure of time and effort the next best option is to predict the impacts of disturbance using individuals-based models (West et al., 2002; Goss-Custard et al., 2006; Stillman et al., In press). In addition to predicting the impacts of current disturbance levels, a Severn model could be used to explore possible future disturbance scenarios and options for mitigating the impacts of disturbance. For this approach to give good results, disturbance surveys would need to measure the disturbance events and behavioural responses as described above. This would not be limited to recording human disturbance as other sources of disturbance, such as raptors, impose similar penalties on the birds in terms of lost feeding time and increased energetic costs. Suggested techniques for surveying disturbance are described in section 5.2

5.2 Techniques for surveying disturbance

The best way to survey disturbance is by direct observation on a number of occasions throughout the winter. On the Welsh side of the Severn common roost locations have been mapped (Goodger, 2005) so surveying for roost disturbance can be concentrated at these sites. A similar mapping exercise should be undertaken for the English side. On a site the size of the Severn it will be very difficult to survey disturbance of feeding birds throughout the whole site. A number of locations along the Severn should be chosen to provide views across as much of the mudflats as possible, especially in areas containing large concentrations of birds, for example Bridgewater Bay. Disturbance can be surveyed by observing birds from a fixed position through the tidal cycle, recording any incidents that cause birds to flush. Things to record are:

- type of disturbance
    - walker
    - dog
    - vehicle
    - aircraft
    - raptor
    - hunter
- bird species being disturbed
- estimated flushing distance
- time for which birds are in the air
- time taken for birds to resume feeding.

In many cases it will be difficult or impossible to measure the last three items, so it may be necessary to address these in a separate behavioural study.

Disturbance sources that might lead birds to avoid areas altogether should also be noted, for example if there are particular wildfowling areas or areas designated for waterskiing. In the case of wildfowling, which tends to take place at dawn or dusk, birds may avoid commonly hunted areas altogether once they have learnt where these areas are, as happens on the Somme estuary in France (Durell et al., 2005b), but this should initially be determined by the disturbance survey.

It may also be useful to note weather conditions, especially temperature and wind as these will influence the energy balance of the birds which may in turn influence their responses to disturbance.

Surveys should be conducted both on weekdays and at weekends as recreational disturbance might be more frequent at weekends. They should be carried out several times during the course of the winter, at least in September, December and February to account for changing responses in the birds' behaviour as conditions change. In particular, birds tend to flush at shorter distances towards the end of winter when food supplies are depleted and cold weather and the need to store fat for migration increase the birds' energy demands (McGowan et al., 2002; Stillman and Goss-Custard, 2002).

Disturbance surveys will provide some data about the extent and nature of disturbance on the Severn but will not in themselves measure impacts on the birds. For modelling the impacts of disturbance on fitness some behavioural data would need to be collected. If sufficient data on flushing distance and flight time could be collected during the surveys of disturbance type and intensity then a separate behavioural study might be unnecessary. This would require 5-10 flushing distances being recorded for each species being studied responding to the most common forms of disturbance on the Severn at the very least at the start and end of winter. If this is unlikely to be achieved a separate experimental disturbance study would need to be carried out. The commonly-used technique for this (e.g. Blumstein et al., 2003) is very simple and is illustrated in Figure 12. An observer (large circle) looks for foraging or resting birds (small circle) of the species required and walks towards them at a steady pace (Fig. 12a). They note the point at which the bird flies away (Fig. 12b) and continue walking until they reach the position the bird was at (Fig. 12c).

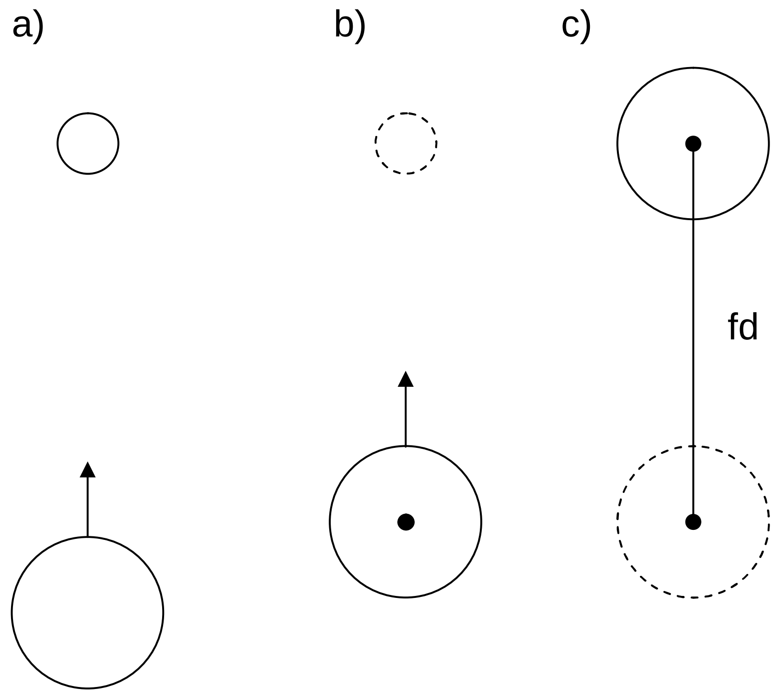

Figure 12. Procedure for measuring flushing distance in birds

The flushing distance (fd) can be determined in one of several ways: a GPS can be used to mark the observer's position when the bird flew and then the position of the bird on flying; the observer can use a pacing stick whilst walking to measure the distance; the observer's stride can be measured and the number of paces between observer's position and bird's position can be counted; or a range-finder can be used to measure distance to the bird at intervals until it flies away. The observer should also if possible record the amount of time the bird spends in the air before landing and, again this may not always be possible, the time taken for the bird to return to its previous activity (e.g. Stillman and Goss-Custard, 2002). The latter two measurements are used in individuals-based models to assess the impact of disturbance as they are measures of the time and energy costs of disturbance to the birds (West et al., 2002). As with disturbance surveys, the experimental disturbance should be carried out at least at the start and end of winter to assess the amount of change through the season.

6. USING THE BIRD:FOOD BIOMASS RATIO APPROACH ON THE SEVERN

6.1 Recommended survey methods

6.1.1 Sampling scheme

We recommend that the survey be conducted using the procedures contained in Appendix 2 with some modifications to take account of the nature of the Severn and existing information about the site.

Normally we recommend using a grid system to ensure coverage of the whole estuary when surveying for bird food. This can be a regular grid, as in the case of the Exe (Durell et al., 2005a), or an uneven grid with a greater frequency of points downshore (effectively a series of regularly spaced transects), e.g. in the Wash (Yates et al., 2002). However, the dynamic nature of the Severn means that there are some areas which contain no prey at all for birds or prey of no interest to the bird species covered by this study. As these areas have been defined and mapped in the Phase 1 biotope surveys it would be sensible to avoid placing any samples in them. It is therefore recommended that these areas, shown in white in Fig. 3 (principally the large area of barren sand mid-estuary and mid-river), are treated as other non-feeding habitats for the purpose of allocating sampling points.

Based on the total area of biotopes likely to contain shorebird prey (14367 ha), Figure 13 shows the approximate number of sampling point that would be generated by different sizes of grid.

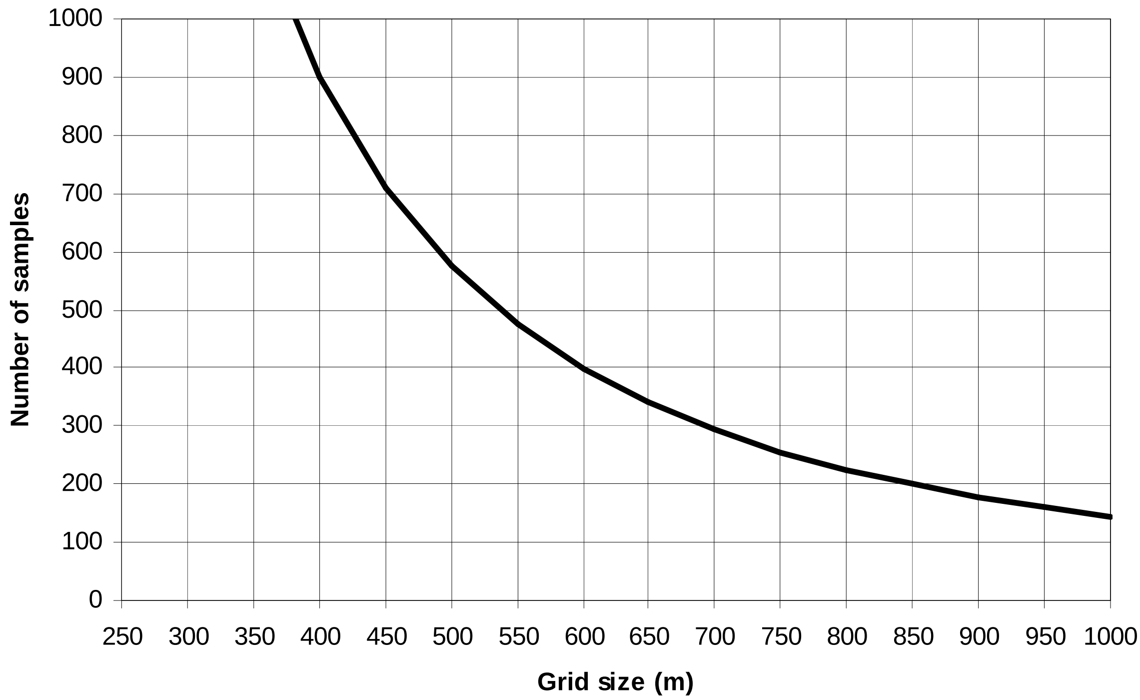

Figure 13. Sampling grid size vs. approximate number of samples expected to fall within biotopes suitable for shorebirds. See text for explanation of shaded area.

For the Severn, the best balance between coverage and practicality can be achieved with a grid size of between 500m and 750m. Figs. 14 & 15 illustrate sampling points at these grid sizes based on the Ordnance Survey (OS) grid; both grid sizes show coverage across the relevant biotopes. The advantage of a 500m grid size would be improved accuracy of biomass estimates, the disadvantage being more than double the number of samples to process - c. 475 vs. 225 at a 750m grid size. Based on a study of cockle surveys from three Welsh estuaries (West and McGrorty, 2003), 95% confidence intervals around estimates of prey density would increase in accuracy from ±19% of the mean to ±13% of the mean with this level of increase in sampling effort. Although the figures will differ for different prey types the majority of the improvement in accuracy to be gained by increasing sample numbers is seen at relatively low numbers of samples. However, a 500m grid would provide a more accurate representation of prey distribution. The 750m grid does lead to relatively few samples being placed in certain biotopes as they represent a relatively small fraction of the intertidal area. Whether this is a problem for the survey largely depends on the variance in prey densities in those biotopes and their importance for birds. This is most likely to be a concern with *Arenicola* in LMS.MS.MacAre as they provide a source of large prey for curlew. However, the survey technique for *Arenicola* is rapid and simple so if the survey results for this biotope show an unacceptable level of variance it would be feasible to go back and increase the number of samples.

Biotope	**Description**	**750m grid**	**500m grid**
LGS.S.AP.P	Burrowing amphipods and polychaetes (often with *Arenicola marina*) in clean sand shores	66	168
LMS.MS.MacAre	*Macoma balthica* and *Arenicola marina* in muddy sand shores	23	75
LMS.Zos.Znol	*Zostera noltii* beds in upper to mid shore muddy sand	6	12
LMU.Smu.HedMac	*Hediste diversicolor* and *Macoma balthica* in sandy mud shores	130	220
LMU.Smu.HedMac.Are	*Hediste diversicolor*, *Macoma balthica* and *Arenicola marina* in muddy sand or sandy mud shores	4	12

Table 7. Approximate numbers of sampling sites in each target biotope on the Severn at 750m and 500m grid sizes.

We recommend that a symmetric grid of between 500m and 750m, depending on available resources, is used to survey the Severn. We also recommend that the grid is based on the Ordnance Survey grid. Three other possibilities were considered and rejected in making this recommendation. The first was to use and asymmetric grid (i.e. regularly spaced transects) based on the OS grid. This was rejected because the shape of the Severn means that in many places the transects would be running alongshore instead of downshore, regardless of whether the asymmetry was east-west or north-south. A second option is to use transects but to run them perpendicular to the shore at any particular point. Given the irregular nature of the Severn estuary’s coastline it was felt that a survey conducted in this way would present serious statistical problems in the data analysis stage. The final option considered was to simply divide up the estuary into a number of units based on geography and biotope and sample randomly within these units. The difficulty with this is that any division is likely to be arbitrary in biological terms. One possibility would be to use the Wetland Bird Survey (WeBS) count sectors, allowing survey data to be matched up with bird densities, but there would have to be considerable amalgamation of count sectors for a meaningful number of sampling sites to be placed in each one. A further disadvantage of random sampling is that it would become much harder to distinguish genuine between-survey variation from stochastic variation caused by changes in sampling site. With those factors in mind, the simplest survey system to set up and to carry out will be a regular grid based on the OSGB National Grid and the results of such a survey would prove at least as useful, if not more so, than those from other schemes.

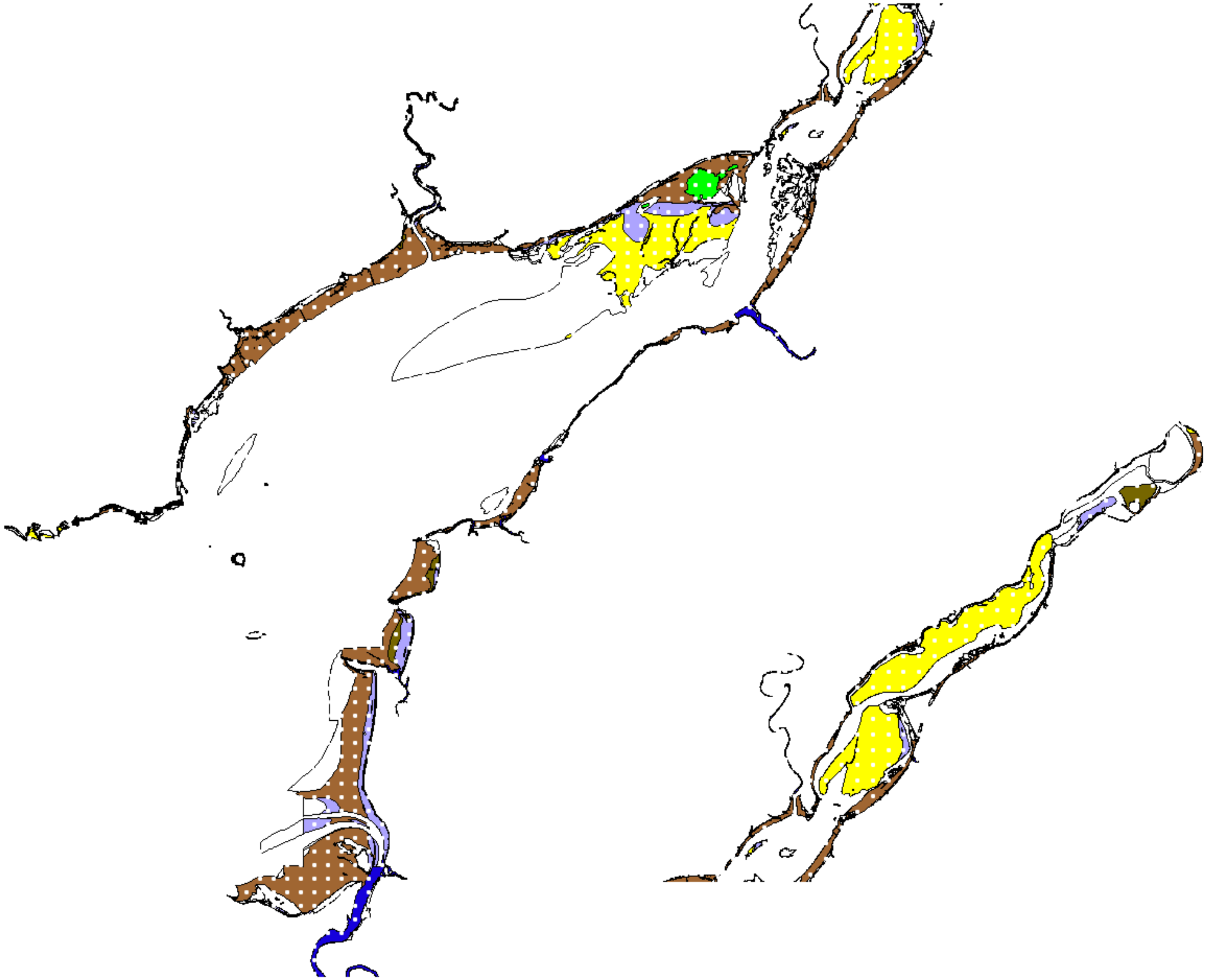

Figure 14. 750m square grid overlaid on the Severn estuary

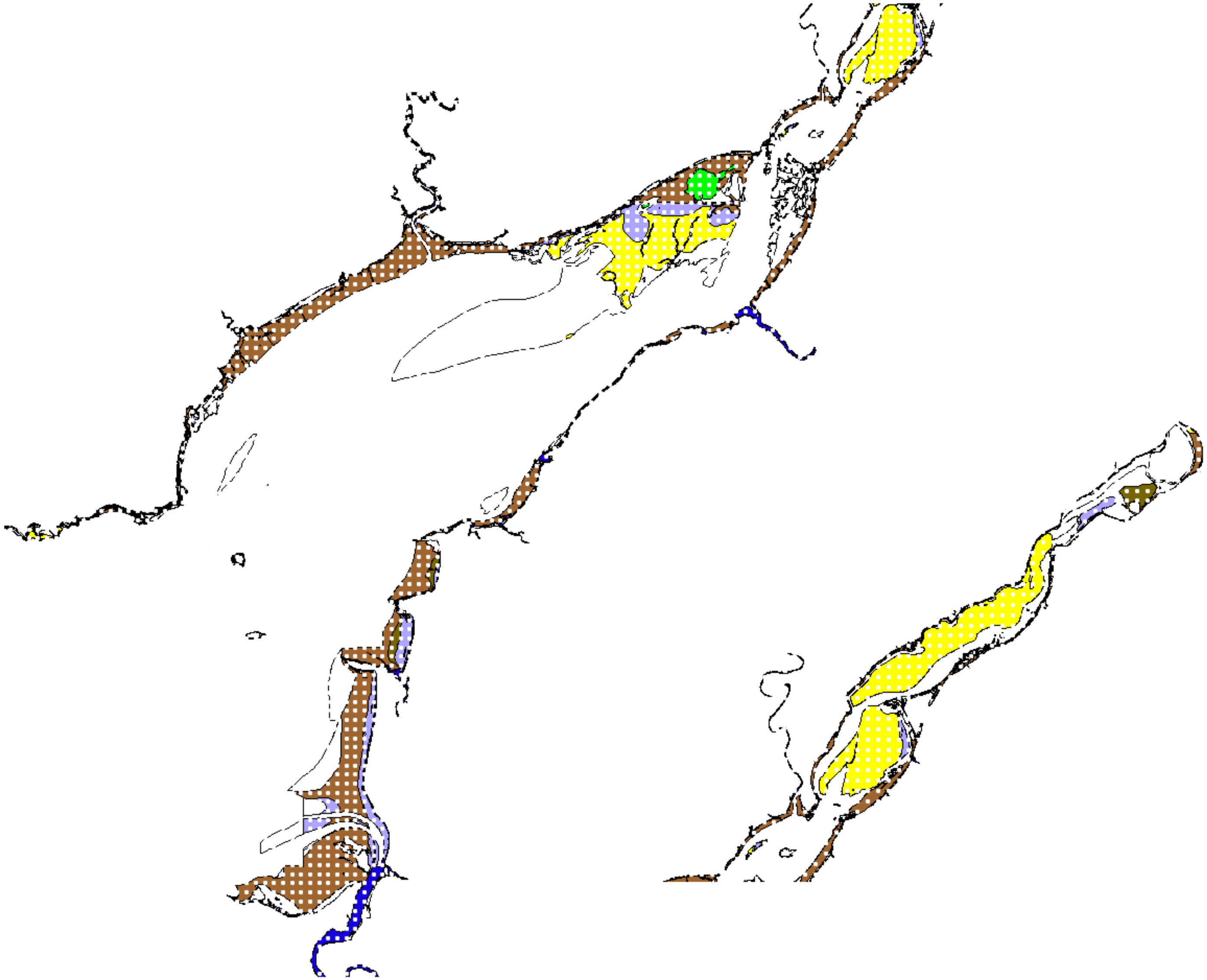

Figure 15. 500m square grid overlaid on the Severn estuary.

6.1.2 Sampling Techniques

For the most part the survey techniques described in Appendix 2 (which in part are very similar to JNCC's intertidal core sampling guidelines (Dalkin and Barnett, 2001), although developed independently) are applicable to the Severn estuary, but some minor modifications are appropriate. These are described below.

1. For surveying the mud and muddy sand biotopes of the Severn, the techniques contained in Appendix 2 should be used. However, on the sandy biotopes above the Severn bridge at Oldbury and Guscar a different technique might be more useful. These sands appear to be extensively used by curlew but not by the other four species in this study. It is likely that the prey there consist mostly of *Arenicola marina* and if that is the case then sediment cores are unnecessary. In these areas sampling should thus exclude point 1 of the general sampling procedure in Appendix 2 (sediment cores) and if no large bivalves are present point 3 (hand-raking surface sediment) could also be excluded.
2. Given the muddy nature of many parts of the Severn and the highly dynamic tides it is recommended that the survey be conducted with the aid of a small hovercraft to transport surveyors rather than attempting to reach sampling sites on foot. This may not be necessary in areas where the mudflats are known to be firm underfoot, but in any case use of a hovercraft has proven an effective way of increasing the rate at which samples can be taken in surveys that CEH has conducted.
3. As *Hydrobia* are likely to be a major prey item for Shelduck and Pintail on the Severn it is worth noting that it is important to distinguish between intact snails and dead shells when counting the *Hydrobia* in the samples. Often the difference is easily observable, with dead shells being damaged or lighter in colour, but in borderline cases shells should be crushed

Apart from these three modifications the standard core sampling procedures described in Appendix 2 are applicable to the Severn estuary. It might also be desirable to collect a small sediment sample (teaspoon-sized) at each sampling site, leaving open the possibility of exploring the empirical relationships between environmental factors, prey and shorebird distribution at some time in the future.

7. MODEL DATA REQUIREMENTS

Data required for the model falls into four broad categories divided according to the way in which the estuary is translated into model terms. Those categories are environmental parameters, prey parameters, bird parameters and disturbance parameters. Many of the parameters required are already available from the literature but others, principally those specific to the Severn estuary, would need to be measured before a modelling exercise could be undertaken. The parameters required for an individual-based model of shorebirds on the Severn are listed by category below. Those parameters which require further research or survey work to be undertaken are highlighted in bold.

Environmental parameters

Parameter	**Description**	**Source**
Tidal cycle	Tide heights at selected points along the Severn at intervals (e.g. hourly) throughout the winter.	Basic tide heights can be obtain from tidal prediction software using UK Hydrographic Office data. Data from Ferns et al. can be used to adjust the timing of these for distance along the Severn
Temperature	Daily mean temperatures for the Severn area	UK Meteorological Office
Day length	Length of longest and shortest day at the latitude of the Severn	Literature
Exposure time	Time for which mudflats are exposed	Calculate for different shore levels from tidal cycle.

Prey parameters

Parameter	**Description**	**Source**
Distribution	Distribution of shorebird prey species across the mudflats	Survey
Density	Density of shorebird prey species across the mudflats	Survey
Size distribution	Size distribution of shorebird prey species	Survey
Mass	Relationship between length and wet weight or ash-free dry weight for shorebird prey species in the Severn	Survey
Overwinter decline in mass	Change in length-weight relationship of shorebird prey species, particularly bivalves, over winter.	Survey

Bird parameters

Parameter	Description	Source
Bird numbers	Number of birds of each target species on the Severn through the winter	WeBS counts
Energetics	Daily energy requirements of each target species	Literature
Target weights	Average winter weights of target species on the Severn or other locations in southern Britain	Literature
Diets	Diet of each target species based on the prey species available in the Severn	This study
Functional responses	Relationships between prey density and intake rate for the target species	This study for wader species. Literature or further study for wildfowl.
Interference functions	Relationships between bird density and intake rate for target species	Literature for waders. Less likely to apply to wildfowl
Assimilation efficiency	Proportion of ingested energy absorbed through the gut	Literature

Disturbance parameters

Parameter	Description	Source
Types of disturbance	Sources of disturbance to birds. Each source to which birds respond differently, e.g. person, raptor, should be distinguished	Disturbance survey
Frequency of disturbance	Frequency with which different types of disturbance occur. Only includes occurrences that actually disturb birds.	Disturbance survey
Disturbance distances	Distance at which different bird species respond to different types of disturbance. For some types of disturbance, e.g. raptors, this cannot be measured.	Disturbance survey or experimental disturbance.
Disturbance costs	Time spent in flight in response to disturbance. Time taken to resume feeding after a disturbance.	Disturbance survey or experimental disturbance.

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Appendix 2. Sampling procedures

SAMPLING MACRO-INVERTEBRATES ON INTERTIDAL FLATS TO DETERMINE THE POTENTIAL FOOD SUPPLY FOR WADERS

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Introduction

The main purpose of this document is to describe procedures developed over the last 30 years (McGrorty, 1973) by members of the behaviour-based modelling group (BBMG) at CEH Dorset, for sampling different components of the invertebrate macro-fauna of intertidal flats.

These consist of

1) A 'General Intertidal Survey Procedure' used to survey the abundance and distribution of all the main macro-invertebrate groups and/or species present on an intertidal flat.

2) A 'Cockle Survey Procedure' used to survey the abundance and distribution of cockles, or any other near-surface dwelling bivalve.

3) A 'Mussel Survey Procedure' used to survey the extent of, and mussel density and percentage cover within, mussel beds.

These procedures are used by the BBMG to supply the information needed to characterise the food supply in our individuals-based wader models, but as they provide information about the overall amount of biomass of different species present and its spatial distribution, they are of value in their own right.

Health and Safety

The responsible person for any team using the following guidelines to sample intertidal or wetland invertebrates should assess the risks of local circumstances and put in place procedures to minimise them. In European Union member states you should follow local regulations based on EU Health and Safety directives. Elsewhere, the current laws, regulations and procedures should be strictly followed to assess and minimise potential risks.

General Intertidal Survey Procedure

Survey design

This procedure is designed to produce estimates of the population size, spatial distribution and size-structure of important wader prey species within a site. Different wader species feed on different size ranges of different invertebrate prey species (see Table 1, adapted from Goss-Custard (Goss-Custard et al., In press)), so estimates of the size-structure and biomass density of these species are essential for parameterising CEH's individuals-based wader model[1]. Species-level identification of very small and/or rare organisms is not important for this purpose, so this procedure emphasizes the detailed measurement of important bird prey species rather than any need for precise, species-level identification in all cases.

The survey has four main aims

1) To map the distribution of all the main wader prey species in a site

2) To determine the total population of each species or prey type

[1] It should be noted that, although we consider this sampling scheme the most effective way to supply information for CEH's wader models, the models can also be developed using data collected by other sampling methods e.g. (Stillman et al., 2003)

3) To determine the size structure of those populations

4) To determine the biomass of those populations

There are two ways in which these aims could be accomplished. One is to use an initial survey to map the distribution of each species/prey-type, then to use a stratified random sampling scheme to characterise the populations mapped in the initial survey. The other is to combine mapping and sampling in one survey by using a systematic grid-based sampling scheme.

The advantage of the two-stage mapping/sampling approach is that it allows for stratified random sampling of prey populations, which in turn allows statistically unbiased error estimation and thus more precise estimates of the mean population density of each species. There are several disadvantages of this approach. First, it requires two surveys so is more labour-intensive, particularly as the initial survey would require sampling to establish the presence/absence and density of many species that leave no indication of their presence at the surface. As intertidal invertebrate populations are often very variable in their numbers and distribution, it is unlikely that as single initial survey would provide an adequate basis for stratification in repeated subsequent surveys. Finally, it may be difficult to design a stratified sampling scheme suitable for a number of species whose distributions overlap to a greater or lesser extent.

The advantages of using a systematic grid-based approach are i) it can be carried out without pre-survey or extensive prior knowledge about faunal distribution[2] ii) it provides a good map of species distribution iii) it is much easier to carry out in practice and iv) as samples are spread evenly across the whole area, sampling sites do not have to be changed from survey to survey. The main disadvantages of grid-based survey are i) because all subsequent samples are fixed relative to the position of the first sample, estimates of mean density will be biased in the statistical sense, although in practice not likely to be further from the true population mean than a random sampling survey and ii) if there is zonation within the site which matches approximately the size of the grid, there is a danger of missing some species altogether. It is currently unknown how often the latter disadvantage is likely to occur on intertidal flats, but to some extent it can be overcome by using an asymmetric grid based on the most important perceived environmental gradients, e.g. sampling at smaller intervals downshore than alongshore. However the grid is arranged, it is important to remember that one of the main aims is to produce a map of species distribution over the whole site and to ensure the selected sampling scheme can provide this.

Normally, the practical starting point for planning the survey is to estimate how many samples can be taken within the time and budget available, taking into account the considerable time needed for processing each sample after the fieldwork is complete.

In our experience, the average processing rate is approximately 4 samples per day in the lab. Although the time taken for individual samples varies considerably around this figure, the average should remain more-or-less fixed given the protocol.

The rate at which samples can be taken in the field is very variable, depending on how accessible the sample locations are, the mode of transport used to reach them and the timing of low tide in relation to daylight hours at the particular site being surveyed.

[2] This is not to say that knowledge of conditions on the site itself is not required. For safety reasons, as much local knowledge as possible should be sought before surveying and unknown location.

As the best time for surveying is limited to a few weeks in autumn (see next section) the fieldwork is best achieved by bringing together as many people as possible for a concentrated effort over a short period of time.

The size and positioning of the grid depends very much on the nature of the site being surveyed. CEH has used both symmetric and asymmetric grid sampling schemes successfully at a number of sites throughout the UK, ranging from a completely symmetrical 0.25km grid on the Exe estuary (Durell et al., 2005a) to a highly asymmetric grid on the Wash (Yates et al., 2002).

Generally, we base our grid on that on the Ordnance Survey maps. We mark a cross (representing a sampling point) at each 1km grid intersection that falls in the intertidal area, then at each 0.5km intersection (first downshore, then alongshore – See Fig. 1), then each 0.25km intersection and so on, until we reach approximately the number of samples we have estimated can be taken[3]. Grid intersections which are near, but not quite on, the flats are included because OS maps are rarely an up-to-date representation of the intertidal areas. This means that samples are restricted to those sites at or above mean low water. This is adequate for the purpose of model parameterisation as sites below this level are seldom available to waders. If lower levels are required the grid can be based on the extent of banks/flats shown by Admiralty yachting charts which extend down to the lowest astronomical tide.

In large sites, like the Wash, a symmetric grid would not be the best option as the large distances along shore mean little information about downshore variation would be captured. In these cases an asymmetric grid would be preferred. The size of the grid can be arrived at by deciding the appropriate distance between samples required to capture downshore variation, then setting the grid interval along-shore to an appropriate value based on the number of samples that can be taken. This is, in fact, transect sampling, but because distribution maps must be produced it is essential that the transects are evenly-spaced along the shore and *not* concentrated around access points.

[3] 'Filling in' of the grid should be done in blocks, e.g. fill in all the 500m intersections downshore, tally the number of samples and, if insufficient, fill in all the 500m intersections alongshore. Clearly it makes no sense to stop at exactly the required number of samples and leave some parts of the grid at a different resolution to others.

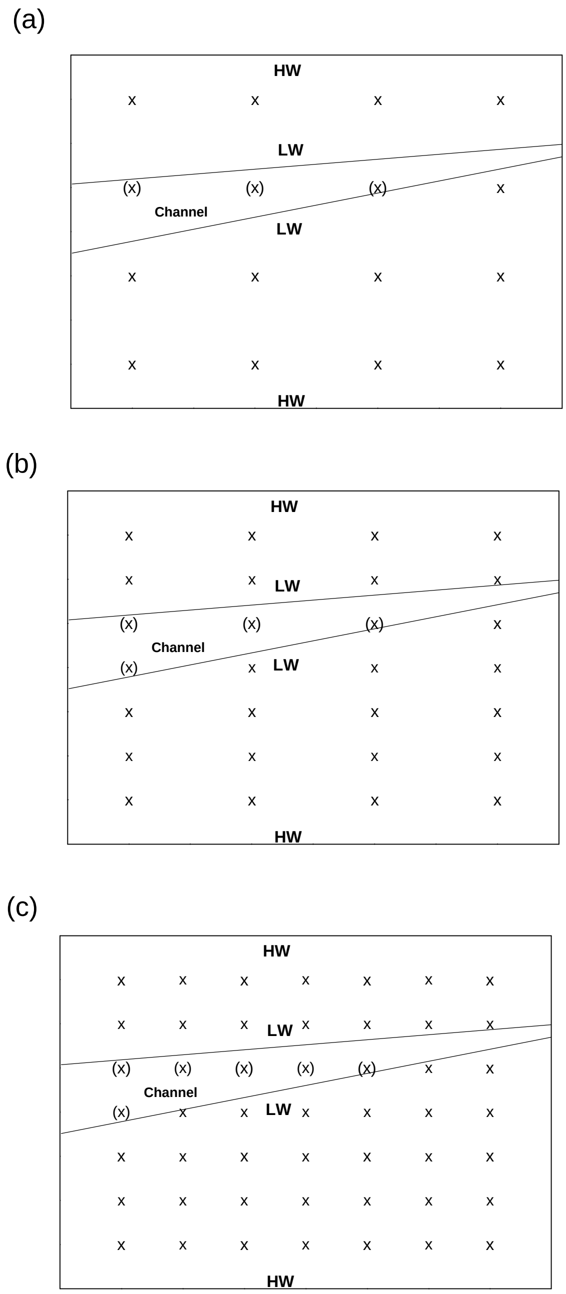

Figure 1. Filling in from a 1km grid. The rectangles represent an estuary with HW and LW representing high and low water marks respectively and the river channel shown by diverging lines just above the middle. Crosses are grid intersections. Those that fall in the channel (in parentheses) are unlikely to be sampling points, but surveyors on the ground should check to ensure the channel has not moved and made these sites available. a) 1km grid. b) Filled in downshore to make a 1km by 500m grid. c) Filled in alongshore to make a 500m grid.

Survey Timing

The survey should be conducted in September, extending into October if necessary. This is the time of year when migratory waders have just returned to their wintering grounds and when prey biomass is at its post-summer maximum, prior to the onset of senescence and depletion. In western Europe, large spring tides also occur in daylight during these months, allowing the best access to the birds' intertidal feeding areas.

Sampling Procedure

Sampling points should be located using a GPS or map, pacing stick & compass. On arrival at the sampling point care should be taken should be taken to avoid conscious or unconscious bias when placing the corer. For example, the sample could be taken at the tip of the toe after the last pace if walking to the site, or 1m in front of the vehicle if travelling by quad-bike.

If you can get close, but not actually to, the exact sampling point, a sample should be taken as close as possible to the correct point and it's position recorded for future reference.

At each sampling point:

1. to sample very small and/or abundant species, a 10cm diameter sediment core is removed to a depth of 30cm. The bottom half of the core is broken up and sorted by hand to locate the large invertebrates that might occur at this depth. If transport is available these are placed with the top half of the core in a labelled plastic bag for further processing later. If on foot, partially sieve the top half of the core by placing in a large polythene bag with sea water, shake gently to liquidise and pour through a 0.5mm mesh. Repeat 2 or 3 times if necessary, then wash the contents to the corner of the sieve and transfer to the labelled bag. This greatly saves on the weight of wet sediment to be transported without any loss of data

2. To sample large burrowing worms such as Arenicola marina, a randomly placed 1 x 1m area is marked out on the surface and the numbers of worm casts, tubes or holes within it counted. If there is any doubt about the identity of these a nearby area should be dug up to check the species[4].

3. To sample large, less abundant species which are unlikely to occur at high enough densities to be sampled effectively by the coring technique, one quarter of the $1m^2$ area is marked off and any larger surface-dwelling molluscs present (e.g. mussels and winkles) within that area counted and collected. This area is then hand-raked or, if water is available nearby, dredge-netted with a 2mm mesh net to count and collect other near-surface dwelling molluscs (e.g. cockles). These samples should be frozen on return to the laboratory.

4. Records are made of any noteworthy features e.g. surface sediment features, depth of aerobic layer, species of plant or alga present, e.g. Zostera, Enteromorpha, Ulva, Fucus and their percent cover if possible in the quadrat and in the general vicinity. Vegetation within the quadrat may help to explain otherwise inexplicable low values of invertebrate abundance (e.g. anoxic conditions under algal mats) and data on the wider presence of vegetation around each sampling station may provide valuable information on the abundance of food supplies of herbivorous wildfowl.

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[4] If there are significant numbers of such worms present in the study area as a whole, some worms should be dug up from a selection of sites and measured to determine the size distribution present.

5. If specimens are being collected at the same time for ash-free dry mass (AFDM) estimation, a few (2-3) of each of the main species present at the sampling point should be placed individually (one specimen per bag) in small Ziploc plastic bags. These should be frozen on return to the laboratory or within 24h of collection, whichever is sooner. Note, worms should be measured before freezing.

As soon as possible after collection, each sample should be sieved through a 0.5mm nylon mesh sieve, nylon being less destructive than brass (see Appendix 1 for the sieve design we use). The contents should then be fixed in a solution of 4% formalin (40% *buffered* formalin diluted with 1:9 seawater). If the samples cannot be sieved on the day of collection, they should be stored at 4ºC and processed within 24 hours.
Once fixed the samples should be washed in fresh water and preserved in industrial methylated spirits (IMS) prior to processing.

Processing

The sieved and preserved samples are washed again in the laboratory through a 0.5mm nylon mesh to remove residual sediment.
All macro-invertebrates in each sample are counted and identified to the level of taxonomic detail that is necessary to quantify the abundance of the various important types of bird food. This is generally species level for all except 'small worms', e.g. oligochaetes, capitellids, spionids etc.
Some worms are likely to be broken either during the coring or sieving process. Only the head end of broken worms should be counted.
The maximum length of all individuals of all species that are above the minimum size taken by any of the bird species of interest are also be measured to the nearest mm. There are two exceptions to this: 1) intrinsically small species, e.g. 'small worms', which it would be too time-consuming to measure and in any case unnecessary for modelling purposes and 2) mussels, which are measured using length parallel to the ventral surface (Fig. 2), usually, but not always, equivalent to maximum length.

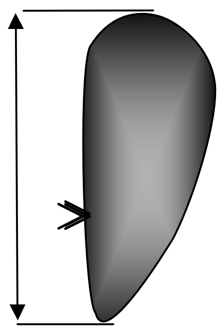

Figure 2. Measuring mussel length
The length of any broken worms should be estimated from jaw length, if present, or roughly from the breadth of the remaining front part in comparison with intact specimens present. If this is not possible, the worm should be recorded as 'broken, length unknown'

If a sample contains excessive numbers of any species, only a sub-sample should be counted. The method of sub-sampling is best judged on a sample-by-sample basis, but details of any sub-sampling methods used should be provided with the data.

Ash-free dry mass estimation

For each of the main prey species an ash-free dry mass (AFDM) length relationship is required to calculate the biomass density at each sampling site[5]. It is also needed to calculate the potential intake rate of the birds in the model as this depends on the mean AFDM of the prey they are eating.

The individual animals used to derive these relationships can be collected during the survey, but should not be extracted from the main set of samples as this can easily lead to confusion. For each species, c. 50 individuals that span the entire range of sizes present should be collected. In the case of molluscs and crustaceans the 50 individuals can be placed together in one bag and the frozen prior to further processing. Worms, however, should be measured while alive and then frozen individually, as they thaw rapidly during processing and leak body fluids. The length of the worm should be written in waterproof marker on the bag in which it is frozen. Worm lengths should be measured when the worms are 'relaxed' being neither concertinaed up nor stretched out. There is an element of subjectivity in this but, in our experience this still produces good AFDM-length relationships with a high R^2 value[6].

To determine the AFDM of each individual, first measure the length as follows:

- Mussels – parallel to the ventral surface, as in Fig. 2
- Other bivalves – maximum length
- Worms (excluding 'small worms') – 'relaxed' body length (see above)
- Crustaceans – body length from tip of rostrum to telson
- Gastropods – spire height

Lengths should be measured while the specimens are still frozen, using suitable gloves or implements to avoid chilblains.

Worms and crustaceans can then be placed into individual crucibles. Any body fluid or flesh remaining in the bag in which a worm was frozen should be washed into the crucible using water and a fine-jet wash-bottle. Small threadlike worms are very difficult to measure accurately and weigh too little to be ashed individually. In this case 50 individuals should be counted into a single crucible, ashed as described below, and the AFDM divided by 50 to calculate the AFDM of an average small worm.

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[5] Although it is preferable to collect AFDM relationships at the time of the survey, the model can be parameterised using values from previous estimations or published estimates from similar sites.

[6] In ragworms, the jaw-length can be measured after freezing and thawing. Although this is, on the face of it, less subjective than measuring body length, in fact measurement error and variation in the curvature and degree of wear of the jaws mean that the AFDM/jaw-length relationships are no more accurate than those obtained by measuring body length.

Bivalves and gastropods (with the exception of Hydrobia, where this is impractical) should be placed in individual crucibles and allowed to thaw partially. Then, a suitable implement should be used to remove all the flesh from the shell, holding the item over the crucible to retain any body fluids that leak from the shell upon opening. Again, any remaining body fluid or flesh should be washed from the shell into the crucible using water and a fine-jet wash-bottle. The shell can be discarded unless required for other measurements.

The number or identifying mark of the crucible, length of the item and, if required, its age, should be noted in a table with additional columns for the weights.

The crucibles plus flesh should be placed in a suitable holder/tray and dried at 90^{o}C to constant weight. Usually 24 hours will suffice, but large 'fat' individuals might need longer. After the initial period of drying, remove the tray from the oven using heat-proof gloves and as quickly as possible transfer the crucibles to a desiccator using large forceps or tongs. Ensure that the silica crystals in the desiccator are blue rather then pink prior to transferring the specimens to cool. Note that the dried flesh (and probably the crucible) is hygroscopic and will quickly absorb moisture and gain weight if exposed to the air.

When cooled to room temperature, weigh the crucibles on a balance accurate to 0.1mg, note the weight (crucible + dry flesh mg) and return to the desiccator. Return to the oven for a further 3-4 hours and repeat the procedure until there is no further weight loss (i.e. the only difference is in the fourth value after the decimal point). The accumulated drying time can be used as a standard for other sets of similar sized samples.

Using gloves and long tongs transfer the crucibles to a muffle furnace and burn at 550^{o}C to constant weight, normally for 4-6 hours. Remove the crucibles and place in a desiccator, allow to cool to room temperature and weigh. Note the weight (crucible + ash mg). Repeat the procedure, burning for periods of 2 hours until there is no further loss of weight. Note that the ash may also be hygroscopic so the use of a desiccator at all stages is very important. It is also important to 'refresh' the silica gel in the desiccator regularly; any sign of pink and the sample might absorb moisture from the crystals.

Note that by drying the crucibles first thoroughly in a muffle furnace at 550^{o}C and weighing empty, then whole fresh weight, flesh weight, dry flesh weight and ash-free dry weight can all be obtained in sequence by subtracting the weight of the crucible from the weight of crucible plus cockle at each stage in turn.

Subtract the crucible + ash weight from the crucible + dry flesh weight for the ash-free dry mass (AFDM) in mg. Regress AFDM (mg) against length (mm) transforming values to natural logarithms (ln or log_e) and adding a quadratic term, if significant, to explain the maximum variance in weight due to length i.e. to maximise R^2. Note that an error is introduced by back-transforming predicted log_e AFDM values. To counter this, half the regression error mean square (EMS) must be added to the logged AFDM value before it is transformed back to a predicted AFDM in mg.

Sample archiving

If archiving is required, all of the contents of each sample processed for the purposes of identification and measuring (including detritus) are stored together in a single pot containing stabilised industrial methylated spirits (IMS), and labelled internally and externally with site and date. These pots are stored in sealed plastic boxes. Separate storage of individual species and of juveniles for each sample requires the unnecessary use of considerably more resources (plastic pots, IMS, storage space).

Sampling procedure for a survey of only cockles or other near-surface dwelling bivalves

Introduction

Fisheries scientists routinely survey cockles to determine stock levels and allowable fishing quotas. These surveys are easily adapted to provide the data for CEH's wader models.

The most important difference between a survey designed purely for fisheries purposes and one suitable for wader modelling is that the former concentrates only on known cockle beds, whereas the latter must encompass the whole of the intertidal area, as patches of cockles which are unprofitable to fish but nonetheless useful to birds often occur outside the main beds.

The sampling procedure described here would replace that described under 'General Intertidal Survey Procedure' above when only cockles and/or other surface-dwelling bivalves are to be sampled.

Sampling procedure

Following the ebbing tide locate the first site using map and compass and /or GPS[7]. If on foot, on arrival at the grid intersection / sample site place the $0.1m^2$ sieve squarely at the tip of the toe after the last pace to mark out an area of $0.1m^2$. This is to avoid any worker bias; consciously or unconsciously the quadrat may always be placed where there are more or less cockles (if they are 'squirting' or 'winking'), or where the sediment is wet rather than dry, smooth rather than rippled etc., which might affect cockle density. If using a vehicle, stop as close as possible to the grid references then take one pace beyond the front of the vehicle and place the sieve as before.

If the exact sampling site cannot be reached, for example for safety reasons, a sample should be taken as close as possible to the correct site and its position recorded for future reference[8].

Using the tool of your choice (hand-rake, trowel, spade) remove the top 5cm of sediment from the area marked out by the sieve and place it into the 2mm sieve. Sieve the sample in water either in the sample hole or a nearby pool or creek. Then place the cockles in a polythene bag labelled with the site number and the date.

Place the sample bags in a large labelled polythene bag and rucksack if on foot or in a cool box if using a vehicle, if the weather is warm, or if the samples will be transported a long distance before being processed.

Record that you have sampled the site (or, if for some reason you are unable to sample a site record the site number and the reason it could not be sampled). Consulting the map and grid references walk/drive to the next site and repeat the sampling procedure.

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[7] Using the OS grid means that after the first sample all subsequent sites will be either north, south, east or west. Even using a GPS it can still help and save time if, using a hand-held sighting compass, landmarks are identified on the horizon in each direction as a guide.

[8] Below the high water mark maps/charts are rarely up to date. Even using boats/vehicles, because sandbanks and channels move about and salt-marsh advances and retreats, some sites may be inaccessible, while others may have become accessible. Either be prepared to sample any site which is unexpectedly exposed or note its presence for the next survey. In either case it is always advisable to carry spare polythene bags (+10%) as it is easy for one to be blown away or ripped by a broken shell.

Where possible, sieves, trowels etc. should be washed in fresh water at the end of the day to delay the onset of rusting.

Storing and processing of samples.

Cockles will not survive much more than 2 days in the back of a car even in a cool box. Treat the samples gently; cockles that are thrown to the ground, or shaken violently in a vehicle, tend to gape and may die sooner. So, either process the samples at high water / in the evening, return them to the laboratory every 1-2 days for processing, or arrange for the use of a freezer close to the field site.

Ideally the length of every cockle should be measured. If this is too time consuming, then sub-sample by measuring all of the cockles from every second, third or fourth bag (i.e. from sites 1, 3, 5 … or 1, 4, 7 …etc); **do not** choose bags with the fewest or the most cockles as this could bias the size (and age) distribution. Measure the length of each cockle along its longest axis using vernier callipers. Close the jaws gently to just touch the cockle, then rotate it slightly to find the maximum length. Read the value (mm) and record it, either on paper or directly into a spread sheet.

Approximately 60 cockles from the samples should be retained to determine cockle weight. If possible, retain three cockles (1 small, 1 medium & 1 large) from every other sample site. This ensures that all areas of the estuary and both high and low-density areas are represented. If there are, for example, no small cockles at a particular site, then only a medium and large specimen will be collected. Place the cockles from each site in a polythene bag and keep cool. At the end of each day's processing, sub-sample the retained cockles by taking a number of small medium and large cockles from the bag and placing each one in an individual Ziploc plastic bag. Freeze as soon as possible (before they begin to gape and die). The number taken each day should be proportionate to the number of samples processed that day, e.g. if the survey contains 400 samples and 100 have been processed in a day, 60*100/400 = 15 cockles should be retained and frozen from that day's samples.

If the age of the cockle is required, count the rings on the shell and record this also. Check that the number of rings is the same on both valves, as damage can result in a clear line on one but not the other.

Sampling procedure for a mussel survey

Introduction

In contrast with most other intertidal invertebrates, mussels are visible at the sediment surface, so a mapping and stratified sampling technique can be used easily and fairly rapidly in a mussel survey.

This field procedure is based on the methods developed by CEH for surveying intertidal mussel beds. It is designed to produce a map of the bed, a value of the percentage cover of mussels on the bed and an estimate of the mussel density and size-distribution. Full details can be found in McGrorty et al.(1990).

If a bed has clearly different, and discrete, areas of mussel density, high and low, these can be treated as two strata for mapping and sampling purposes. This should improve sampling efficiency and reduce variance.

Sampling procedure – Mapping

First, establish a baseline alongside the mussel bed using bamboo canes or find existing markers using a GPS or compass bearing.

If establishing a baseline for the first time, the position will depend on the shape and position of the mussel bed. Generally, the baseline should be established parallel to the longest axis of the bed.

If there are no existing marker posts, insert a crossed pair of bamboo canes at one end of the baseline. Record your position using a GPS. Establish the direction of the baseline by looking along it and taking a bearing on a distant object using a sighting compass. Walk along this bearing inserting bamboo canes at regular intervals (250m or less) until you reach the other end. Record the position of this end using the GPS.

The distance across the mussel bed is measured along a series of regularly spaced transects at right-angles to the baseline, using a 1m pacing stick. To obtain the inter-transect interval, divide the length of the baseline by the number of transects you intend to take *plus one*. The first transect can either be located randomly along the baseline within the first interval or at half the interval width. Starting at this transect, work out the bearing of your transects by adding or subtracting 90^{o} to/from the baseline bearing. Identify a distant object on this transect bearing and walk towards it using a 1m pacing stick. The distances at which the boundaries of the bed were crossed is noted. At each 1m pace across the bed the presence or absence of one or more mussels (>20mm) within a 20x20cm quadrat is noted. These data are used to draw an outline map of the mussel bed, to calculate its area and the percentage cover of mussels within it and hence the actual area of mussels.

When you reach the top of the transect, i.e. the end of the mussel bed, record your position, either in terms of paces of by GPS. Turn parallel to the baseline and walk [X]m to the start of the next transect then repeat the process until you have covered the entire mussel bed. (Fig. 3)

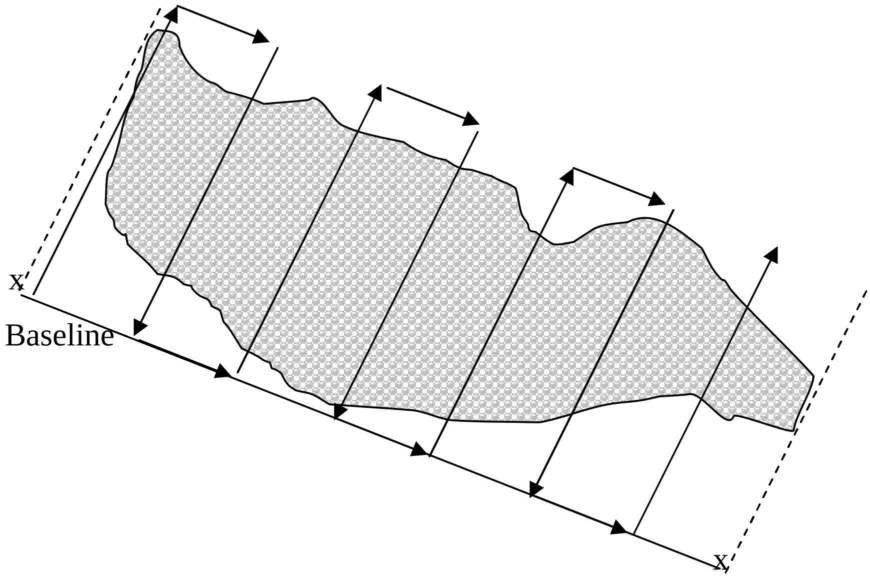

Figure 3. Mapping a mussel bed

Sampling procedure – Estimating density and % cover

To estimate mussel density, a number of samples (20x20cm quadrat) of mussels are taken at random from each bed.
The number taken is determined on site according to the area and the variability of the mussel cover / density within it. Samples are apportioned to mussel beds based on the total number that can be processed and the relative area of the beds.
At each sampling site, place a 20x20cm quadrat at the tip of your toe to avoid subconscious bias in quadrat placement.
Remove all the mussels within the quadrat. Place them in a plastic bag with a waterproof label stating the sample number, the mussel bed and the date on which the sample was taken.
If there are no mussels present, still place a label within an empty bag to record the fact that the sample was taken but contained no mussels.
If the mussels are very dense it may be necessary to remove mussels from only half of the quadrat. If you do this, make sure this is recorded on the label and preferably in a field notebook as well.
A separate sample of 40-50 mussels covering a wide range of sizes (20-70 mm) is also taken at random from each of the main areas to determine the ash-free dry mass of the mussels. Ideally, these should be taken a few at a time from a range of sampling sites to cover any environmental gradients across the bed.

Field procedure – rapid mussel survey

This procedure combines the mapping / %cover and sampling aspects of the above procedure in one set of transects. It is useful for giving a relatively rapid estimate of the extent and density of mussel beds about which there is no prior knowledge.
First, establish a baseline alongside the mussel bed using bamboo canes or existing marker posts. If a baseline has already been established in a previous year, use marker

posts or GPS to relocate it.
If establishing a baseline for the first time, the position will depend on the shape and position of the mussel bed. Generally, the baseline should be established parallel to the longest axis of the bed.
Mark the start of the baseline with a bamboo cane and take a bearing along the baseline to a distant object.
Turn 90^{o} so you are perpendicular to the baseline and identify a distant object on the correct bearing. Walk along the transect towards this object, measuring progress with a 1m pacing stick or a GPS.
At regular intervals stop and take a $0.1m^2$ quadrat sample of the mussels, placing the quadrat at the tip of your toe to avoid bias. Arrange this so that, in effect, samples are taken on a grid across the whole bed.
Remove all the mussels within the quadrat. Place them in a plastic bag with a waterproof label stating the sample number, the mussel bed and the date on which the sample was taken.
If there are no mussels present, still place a label within an empty bag to record the fact that the sample was taken but contained no mussels.
If the mussels are very dense it may be necessary to remove mussels from only half of the quadrat. If you do this, make sure this is recorded on the label and preferably in a field notebook as well.
When you reach the top of the transect, i.e. the end of the mussel bed, record your position, either in terms of paces or by GPS. Turn parallel to the baseline and walk [X]m to the start of the next transect then repeat the process until you have covered the entire mussel bed (Fig. 2)

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Table 1 The size range of prey from which common shorebirds obtain most of their consumption. Values are minimum and maximum using CEH 1mm size classes; *i.e.* 1 - 29 means 1.000 - 29.999mm in terms of actual length. 'max' means the birds take sizes up to the maximum length present in the sediment.

	Mytilus	***Mya***	***Cerastoderma***	***Scrobicularia***	***Macoma***	***Hydrobia***	***Corophium***	***Hediste****	***Arenicola***	***Carcinus***	***Crangon***
Bar-tailed godwit	-	-	-	8-19	8-19	-	-	25-max	25-max	-	-
Black-tailed godwit	-	-	-	8-19	8-19	-	-	25-max	-	-	4-max
Curlew	-	25-max	8-19	20-49	8-max	-	-	50-max	50-max	10-39	-
Curlew-sandpiper /Dunlin	-	-	-	3-6	3-6	1-4	3-max	10-59	-	-	-
Grey plover	-	-	-	8-19	8-19	1-4	-	20-max	20-max	-	-
Knot	5-24	8-16	5-14	8-16	8-16	1-4	-	10-59	-	-	-
Oystercatcher	30-59	16-39	15-max	20-max	12-max	-	-	50-99.9	50-max	10-50	-
Redshank	-	7-13	-	7-13	7-13	1-4	4-max	15-79	-	3-7	4-max
Ringed/Kentish plover	-	-	-	-	-	1-4	3-max	10-49	-	-	-

* = and other worms too, such as *Lanice*, Cirratulids *etc*.

Design for a 'McGrorty' floating sieve.
The sieves used for our surveys are constructed from wood and nylon (general intertidal survey) or heavy-duty stainless steel (near-surface dwelling bivalve survey) mesh. The advantage of this is that the sieves are relatively light and will not sink if accidentally dropped into water.

Materials (per sieve)

- Wood – planed softwood 4 each of 338x100x22mm and 338x22x22mm
- Mesh – Nylon 0.5mm aperture size or stainless steel, plain weave, 1.98mm aperture size, mesh count 10, 0.56 mm wire. Piece approx. 350x350mm
- Tacks – 12 and/or Staple gun
- Stainless steel screws – 20
- Wood glue
- Silicone sealant

Construction

- Glue and screw together the four side pieces, as shown in Fig. 1 to produce a square frame with internal dimensions of 316mm (area of $0.1m^2$). If the timber is not 22mm thick the lengths of the side pieces will have to be adjusted accordingly. Allow the glue to dry before proceeding further
- Metal mesh
    - Lay the mesh over the base of the frame and attach with three tacks per side (as in Fig. 2).
    - To avoid hazards from sharp protruding wires, fold over the edges of the mesh so they are tucked under the sieve. Use protective gloves or pliers for this stage.
- Nylon mesh
    - First soak the nylon mesh in water, or it will stretch and sag in use
    - Lay the mesh over the base of the frame and, starting on one side, staple in place every 2-3cm. Try to pull the mesh as taut as possible without causing distortion of the weave while attaching the staples.
    - When one side is stapled repeat the process on the opposite side, again pulling the mesh as taut as possible, then on the remaining two sides
    - Fold over the edges of the mesh so they are tucked under the sieve and secure with 2-3 more staples on each side.
- Glue and screw the 22x22mm battens to the base of the sieve to hold the mesh in place.
  Use three screws per side, ensuring that they are offset from the tacks or staples used to attach the mesh to the frame (Fig. 3).
  Also note that the joints of the side and base pieces are offset to increase strength (Fig. 1)
- Finally, seal all joints with silicone sealant, paying particular attention to the internal joins so none of the sample can escape around the base of the sieve.

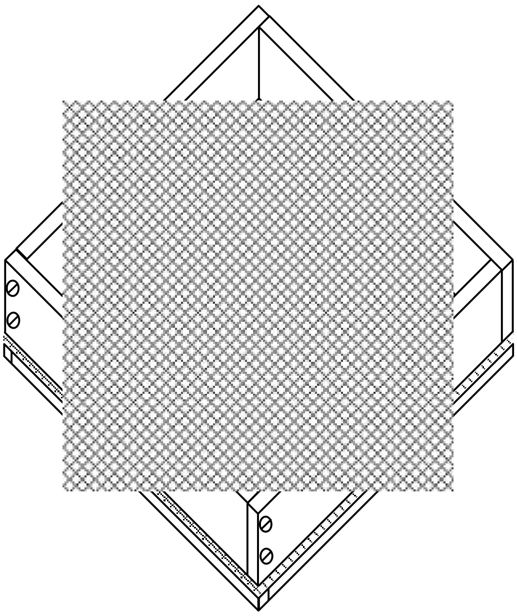

Figure 1. Finished sieve

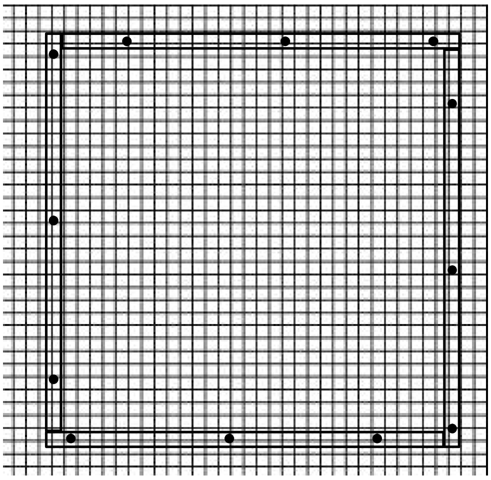

Figure 2. Attaching the mesh to the base

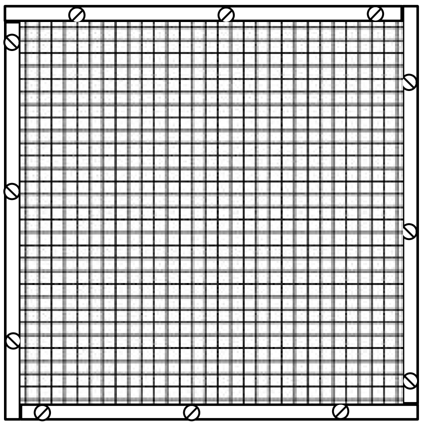

Figure 3. Attaching the base battens. Note offset of the screws from the tacks shown in Fig. 2 and offset of batten joints from main sieve joints.