COWRIE – BEN – 03 – 2002

Predicting the displacement of common scoter *Melanitta nigra* from benthic feeding areas due to offshore windfarms

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Final report

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Executive summary

i Introduction

The environmental impact assessments of most offshore windfarm proposals raise the potential effects on birds as an important issue. Offshore windfarms may affect birds in a number of different ways including mortality due to direct collisions of birds while in flight and mortality induced by habitat loss due to the avoidance by foraging birds of such conspicuous structures. Birds that may be affected by displacement from foraging areas within close proximity to windfarms are likely to be those such as common scoter and common eiders that feed on sedentary or slow-moving bottom-dwelling organisms such as bivalve molluscs and fish-eating birds such as grebes, terns, auks and divers. This present study used field observations and surveys combined with an individuals-based modelling approach to predict the change in over-winter mortality rates of common scoter that would result from the displacement of birds from potential feeding habitat through the avoidance of windfarms in Liverpool Bay. The model code is, however, not specific to Liverpool Bay and can be utilised for other areas provided that suitable data are collected.

ii Project Structure

The project included the following tasks:

A description of the physical habitat utilised by common scoter
Quantification of the spatial and temporal variability in prey
Observation of the behaviour of birds at sea and their response to disturbance
Quantification of other forms of disturbance relevant to common scoter
A review of the diving duck literature
Development of a behavioural model to predict responses to windfarms
Calibration and validation of the behavioural model
Predicting the consequences of offshore windfarm developments
Making recommendations for future research requirements

iii Project findings

The key points relating to each of these tasks are outlined in the following sections

iv A description of the physical habitat utilised by common scoter

A tidal model of the Irish and Celtic Seas was developed with a grid resolution of approximately 3.7 x 3.35 km to simulate the tidal elevations and currents throughout Liverpool Bay. The predictions of this tidal model were used to simulate the spatial and temporal variation in water depth throughout the study area covered by the individuals-based model of common scoter' behaviour.

The tidal model was also used to predict the tidal elevations and currents at the locations and times when common scoter were observed during aerial and land-based surveys. It was then possible to calculate the depth of water beneath each bird at the time of observation and the speed of drift at the sea surface.

A histogram of observed duck numbers as a function of the mean water depth showed an approximately domed distribution with most of the birds concentrated around depths of 10-12m with a range of from 2-22m. When the depths were tidally corrected, however, the histogram became more ramp-like with a relatively rapid decline in numbers where the depth was greater than 18 m. This is consistent with the literature concerning common scoter diving depths and with the diving sub-model within the behavioural model.

The area of habitat that is available to common scoter i.e. water depth les than *circa* 20m can be reduced by approximately a third when comparing low water and high water spring tide conditions. The sea bed stress due to waves was estimated to be an order of magnitude larger than that associated with the tidal motion in the relatively shallow region along the Lancashire coastline and this probably has a strong influence on the depth zone in which the highest biomass of prey types (bivalve molluscs) and hence common scoter are found.

v Quantification of the spatial and temporal variability in prey

An extensive survey of the potential benthic prey of common scoter was conducted in August 2003. This involved sampling 81 stations off the Lancashire coast and a further 88 stations off the North Wales coast. Analysis of the samples was used to define the spatial variation in the abundance of the principle food resources (i.e. benthic bivalves) throughout the study area covered by the individuals-based model of common scoter behaviour.

The highest numbers of common scoter observed on over flights coincided with sites that had a high abundance and biomass of bivalve prey species, and bivalve biomass was among the strongest predictors of numbers of common scoter observed during over flight surveys.

Off the sheltered North Wales coastline the peak in biomass occurred at a shallow depth of 8 m whereas off the Lancashire coastline the peak occurred in deeper water at 14 m. Thus birds that remain to feed off the Lancashire coastline have to dive deeper and expend more energy to acquire their food. If windfarm developments dissipate wave energy this could have implications for the depth zone in which the highest biomass of prey are found (i.e. the peak biomass could move inshore into shallower water).

The distribution of bivalve prey species was extremely patchy even when these were grouped into ‘prey-types’ according to their morphological features i.e. brittle-shelled oval prey, hard-shelled oval prey, elongate prey. One important implication for future Environmental Impact Assessments related to windfarms is that it will not be possible to use an ‘indicator species’ to represent bivalve prey as the distribution of one species on its own has little or no resemblance to the distribution of the entire bivalve assemblage.

Inter-annual variation in bivalve abundance was much lower than spatial variation in their abundance for a four year period between 2001 and 2004. Thus, while the abundance of individual species may vary from one year to the next the number of species of bivalve in Liverpool Bay means that there is usually likely to be a sufficient abundance of some species to meet the energetic requirements of the common scoter.

Repeat surveys of the benthos at 24 sites in December 2003 and April 2004 were used to quantify the seasonal change in the abundance of benthic bivalves. Analysis of the data from stations where common scoter were scarce was used to define the rate of change in the abundance of resources in the individuals-based model of common scoter behaviour

vi Observation of the behaviour of birds at sea and their response to disturbance

A programme of land-based and ship-based observations of the behaviour of over-wintering common scoter were made in Liverpool Bay. These observations included determination of: sex ratios in common scoter flocks, flush distances in response to ships, dive durations, orientation on the sea surface and flight directions and distribution in fair and inclement weather. Little is known of the behaviour of common scoter other than on their breeding grounds. The results reported in the current study are a unique addition to our knowledge of this species.

Differential arrival times were apparent for males and females, with the latter arriving in mid to late winter. Thus, activities in Liverpool Bay will affect different components of the population at different times of the year.

Common scoter tend to face into the current or the wind depending upon which has the greatest influence on their position at any particular time. Severe weather does not appear to change the utilisation of particular areas, and sheltered areas such as Conwy Bay were not used to any greater degree during severe weather conditions.

Common scoter often dive to the seabed in groups and remain submerged for periods of c. 30 – 50 seconds. They spend more time submerged in deeper water. This, coupled with the association between water depth and benthic bivalve abundance means that water depth will clearly be a key factor that influences the energetic costs and benefits of feeding in any given location.

Common scoter are sensitive to disturbance by moving vessels. Observations from a 390 t (35 m long) vessel indicated that large flocks of common scoter were put to flight at a distance of 2 km from the vessel, while smaller flocks were less sensitive and only put to flight at a distance of 1 km. Vessels larger than that used in the study would be expected to have a larger flushing distance. The study did not have a remit to determine disturbance from other boat users (recreational fishing, yachting, jet-skis) or disturbance generated by low flying aircraft.

vii Quantification of other forms of disturbance relevant to common scoter

Commercial shipping activities are considered one of the major forms of disturbance that may affect common scoter distribution. Analysis of a database of commercial shipping activity revealed that there is little seasonal fluctuation in this activity but considerable spatial variation. This information, coupled with data on avoidance distances, was used to characterise the spatial variation in the disturbance caused by shipping throughout the study area covered by the individuals-based model of common scoter behaviour.

The great majority of birds observed in Liverpool Bay do not coincide with the areas of heaviest commercial shipping traffic (vessels > 300 t). Thus, common scoter would appear to be excluded from areas of the seabed that coincide with these activities at present. It is possible that if forced to utilise such areas the birds may be able to habituate or tolerate these activities. This is however entirely subjective.

Direct observations of fishing activities indicate that these are concentrated in areas deeper than 20 m depth and they do not interfere with common scoter in Liverpool Bay other than those encountered on the outbound and inbound journey.

Commercial helicopter activities are another form of disturbance that may affect common scoter distribution. Analysis of a database of commercial helicopter activity revealed that helicopter traffic tends to occur along clearly defined flight paths. There is, therefore, considerable spatial variation in this activity. The frequency of helicopter traffic is, however, very low in comparison with shipping traffic. Nonetheless, this information was used to characterise the spatial variation in the disturbance caused by helicopter traffic throughout the study area covered by the individuals-based model of common scoter behaviour.

viii A review of the diving duck literature

A review of the literature was undertaken to gather information required to parameterise the behavioural ecology model. In the course of the literature review in excess of 100 scientific papers and reports concerning the physiology, diet, energetics, foraging ecology and general behaviour of diving ducks were collated. This served four main purposes: i) to build up knowledge of the way in which diving ducks forage ii) to derive reasonable assumptions on which the model could be based iii) to derive values for the many parameters that the model would need and iv) to derive independent empirical data against which model outputs could be validated.

During the literature review approximately 1,500 notes were made of points or parameter values that may have proven relevant to the final model. These were entered into an Excel database. All of the relevant notes are presented in a series of appendices to this report.

Although many of the entries in the database refer directly to common scoter, the majority do not. This reflects the inaccessible nature of the habitat in which the birds live during the winter months. Thus, in meeting each of the four principal objectives of the literature review it was necessary to utilise information derived from studies of other species of diving duck. Although this is not ideal, it is the only option where data for common scoter did not exist in the literature.

ix Development of a behavioural model to predict responses to windfarms

At the start of the project a computer code existed for an individuals-based model which had, hitherto been applied to predict the response of waders and geese feeding in intertidal and terrestrial habitats to environmental change. It had never been applied in the context of either offshore areas or sea ducks. During this project a new version of the model code was developed which, by virtue of being entirely generic and free of any biological detail, is flexible enough to be applied to a very wide range of consumer-resource systems including sea ducks foraging in offshore habitats.

The model is based on fundamental ecological principles such as fitness maximisation by individual animals which will apply under any change to environmental circumstances. The purpose of the behavioural modelling was to predict the change in the over-winter mortality of the common scoter population of Liverpool Bay that might result from the displacement of birds from feeding grounds in close proximity to offshore wind farms, based on the assumption that common scoter will avoid using areas of sea either within the boundaries of an array of turbines or within some wider area around such arrays.

The model predicts how each individual bird in the population would redistribute its foraging effort in space and time under the novel circumstances and whether these behavioural responses would enable them to survive the winter or not. It is the combination of the survival consequences of each of these individual decisions that enables the model to generate the predicted population-level mortality under any novel environmental circumstance.

In total, one hundred and eighty runs of the model MORPH, exploring 36 different 'scenarios', were conducted in the course of producing the results which are presented here. Principally, these address the consequences for the common scoter population of Liverpool Bay of a number of different windfarm scenarios and whether these consequences might vary depending upon various uncertainties in model parameterisation. Additional simulations explore the consequences of removing what appear in the model to be the most profitable feeding areas within Liverpool Bay and also the sensitivity of model outputs to variation in its key parameters.

x Calibration and validation of the behavioural model

Initial runs with the model to simulate the current day environment, as experienced by common scoter in Liverpool Bay, predicted that the common scoter population would be widely scattered throughout the study area. Most of the areas predicted by the model to be used by common scoter do hold common scoter in reality. However, two areas of the bay that are rich in benthic bivalve resources and were accordingly heavily used by birds in the model are seldom used by birds in daylight in reality. These two areas were excluded from the majority of model runs, although the significance of birds' ability to utilise these areas in response to certain windfarm developments was explored.

The outputs of the model, when run to simulate the current environmental conditions in Liverpool Bay, were compared with independent empirical data concerning: the proportion of daylight hours spent feeding by birds, their daily rate of food consumption, daily rate of energy expenditure, seasonal variation in body mass, distribution (across 99 tidal grid cells) and over-winter mortality. In every case, the model output was in close agreement with independent data. In particular, the range (minimum to maximum) of over-winter mortality predicted by the model was between 5.4% and 8.8% of the common scoter in Liverpool Bay for the baseline conditions (Liverpool Bay with the existing North Hoyle windfarm). This estimate accorded well with the estimated real over-winter mortality (6.4%) of the common scoter population in Liverpool Bay, a value that was computed from published observations of common scoter mortality in the field and the known sex ratio of common scoter in Liverpool Bay (see section 7.2.16 and Appendix 20).

The model did not produce an absolutely perfect fit to the distribution of common scoter across the bay. In particular, several grid cells on Shell Flat that hold birds in reality were seldom or never used by model birds. This reflected the very low quality of the bivalve resources available in these areas and raises the question as to the usefulness of empirical over-flight distribution data in identifying common scoter feeding grounds.

Overall, there was, however, good quantitative agreement between model outputs and a variety of independent empirical data. This provides a basis on which to use the model to predict the likely consequences of novel environmental circumstances following the construction of windfarms in Liverpool Bay.

xi Predicting the consequences of offshore windfarm developments

The model was used to simulate a variety of combinations of existing (North Hoyle), consented (Rhyl Flats and Burbo Bank) and proposed (Gwynt-y-Mor and Shell Flat) windfarms. The model deals only with the predicted effects of the displacement of birds from an area of sea with either a 0km or a 2km radius around these windfarms. It does not deal with any other possible mechanism by which the construction, presence or servicing of offshore windfarms might affect common scoter.

The common scoter population was assumed to number 30,000 birds. Core simulations assumed access to a core of 99 tidal grid cells that encompass all those that are used by common scoter in reality plus twice as many again that are seldom or never used. They also assumed that common scoter only feed during daylight and used the best estimate of benthic resource abundance based on the results of the benthic survey. Additional simulations explored the sensitivity of the model's predictions to varying these baseline conditions/ assumptions.

The following is a summary of the predicted effects of existing/ consented and proposed windfarms.

North Hoyle + Rhyl Flats + Burbo Bank + Gwynt-y-Mor: The displacement of common scoter from areas of the sea around windfarms at Rhyl Flats, Burbo Bank and at Gwynt-y-Mor, in addition to that at North Hoyle, is not predicted to have any significant adverse effects on common scoter mortality. This conclusion holds regardless of the assumed radius of the buffer zone around the physical perimeter of the windfarms (up to a limit of 2km) and regardless of the sampling error inherent in the benthic resource database.

North Hoyle + Rhyl Flats + Burbo Bank + Gwynt-y-Mor + Shell Flat: The displacement of common scoter from areas of the sea around windfarms at Rhyl Flats, Burbo Bank, Gwynt-y-Mor and Shell Flat, in addition to that at North Hoyle, is not predicted to have any significant adverse effects on common scoter mortality if there is no buffer zone around the physical perimeter of the windfarms. This conclusion holds regardless of the sampling error inherent in the benthic resource database.

North Hoyle + Rhyl Flats + Burbo Bank + Gwynt-y-Mor + Shell Flat: The displacement of common scoter from areas of the sea around windfarms at Rhyl Flats, Burbo Bank, Gwynt-y-Mor and at Shell Flat, in addition to that at North Hoyle, is predicted to have a significant adverse effect on common scoter mortality if the buffer zone around the physical perimeter of the windfarms extends to a radius of 2km. In this scenario the median mortality of common scoter increased to 11.7% (range 11% to 12.2%) compared with the baseline condition (Liverpool Bay with North Hoyle) which resulted in a median mortality of 7.3% (range 5.5% to 8.8%). This conclusion holds regardless of the sampling error inherent in the benthic resource database.

It is the presence of a windfarm on Shell Flat which, in combination with the others, and on the assumption that the radius of the buffer zone around them all extends to 2km, leads to increased common scoter mortality. This reflects that the fact that only in the scenarios in which a 2km buffer zone around the Shell Flat windfarm was included did the model predict that common scoter would be excluded from a number of grid cells in which the model predicted they would otherwise feed heavily. The magnitude of this effect may be underestimated by the model, **but nonetheless, a significant effect is predicted.** However, this cumulative adverse effect may be negated if: i) the radius of the buffer zone is smaller than 2km, ii) common scoter redistribute to currently unused but apparently profitable feeding areas within Liverpool Bay such as Burbo Bank or iii) common scoter feed during the hours of darkness as well as during daylight.

xii Recommendations for future research requirements

The following recommendations for future research requirements are made:

- i) Re-examine the validity of over flight data as a means of identifying common scoter preferred feeding grounds
- ii) Conduct direct observations of common scoter foraging/resting activity throughout the tidal cycle,
- iii) Investigate night time movements and feeding activity. Quantify the extent to which common scoter feed during darkness and where they do so and whether this habit varies seasonally.
- iv) Identify the environmental factors that may exclude birds from feeding on areas that are apparently rich in profitable, benthic bivalve food supplies.
- v) Confirm that birds feed at sites off Lancashire.

vi) Investigate the spatial distribution of different age and sex classes within the common scoter population.
vii) Undertake observations of common scoter responses to small ship traffic (e.g. fishing vessels) and recreational boat user activities. Quantify the spatial and temporal variation in these activities across the bay.
viii) Implement more detailed study of disturbance effects of smaller vessels.
ix) Conduct detailed monitoring of the exclusion/ avoidance distances exhibited by sea ducks around all existing offshore windfarms. Establish whether birds habituate to such static structures over time.
x) Run Wave Amplitude Model for higher resolution calculations of physical forcing on the seabed.
xi) Run wave climate change model to predict changes in wave erosion in the future.
xii) Model the effects of windfarm arrays on dissipation of wave energy.
xiii) Fund desk based study to ascertain future risk of prey resource collapse with changes in sea temperature and possible extractive fishing activities.

xiii Project Achievements

Hitherto, one of the principal techniques employed in assessing the potential impact of offshore windfarms on bird populations due to avoidance displacement has been the use of ‘proportional distribution maps’ of aerial survey results. However, this technique leaves the key question of the ecological consequences of such displacement still outstanding. With this approach the corresponding population impact *(of a displacement)* can only be determined by **assigning** an associated mortality rate. In contrast, this project **provides** all of those concerned with predicting the ecological consequences of offshore windfarms in Liverpool Bay with **precisely such quantitative predictions of mortality**. This is the principal achievement of this project. However, the behavioural model is generic and hence, provided that empirical data are available for other areas, it is applicable to other situations.

This project has provided the **first quantitative predictions of the change in overwinter mortality rate of the common scoter population of Liverpool Bay** under various alternative windfarm scenarios. It is predicted that the displacement of common scoter from areas of sea around wind farms at Rhyl Flats, Burbo Bank and Gwynt-y-Mor, in addition to that at North Hoyle, will not cause any increase in over-winter mortality. These predictions hold irrespective of the assumed radius of the exclusion zone, the sampling error inherent in the benthic database and regardless of whether common scoter feed at night or not or whether they can or cannot relocate to currently unused areas of Liverpool Bay. Thus, the project has provided unequivocal quantitative predictions concerning the effect of four of the five existing/ consented/ proposed windfarm locations within Liverpool Bay.

Only in the case of the proposed wind farm at Shell Flat is the predicted change in common scoter mortality subject to uncertainty dependent upon the radius of the exclusion zone and whether common scoter will respond by feeding at night or by redistributing to apparently suitable but currently unused parts of Liverpool Bay. The uncertainty concerning these issues is not a failing of this study. Rather, the uncertainty reflects the current lack of knowledge in the wider scientific community concerning: i) the nocturnal behaviour of sea ducks in general and common scoter in particular, ii) the avoidance of offshore windfarms exhibited by sea ducks in general and common scoter in particular and iii) the total number and relative importance of environmental factors (other than food abundance/ availability/ quality) that influence the distribution of foraging birds. Even so, the ability to make quantitative predictions of mortality under alternative assumptions has allowed exploration of the significance of these areas of uncertainty and highlighting of the key issues that must be the focus of future research in order to increase certainty in the predicted effects of a wind farm on Shell Flat.

All approaches to predicting how populations of animals will respond to environmental change depend upon making assumptions. The individuals-based modelling approach upon which this project is founded is relatively complex and relies upon detailed information about the biology of the species concerned and its environment. The presentation in this report of all the information gathered during this project allows the reader to identify the uncertainties and assumptions. This transparency does not mean that the approach is any less credible than any other. The apparent simplicity of simple models often hides a very complex suite of un-stated assumptions. The open approach adopted has the advantage of making clear where further research should be focussed in order to continually improve the predictive power of such ecological models.

In conclusion, this study has resulted in the development of a new tool which enables the quantitative prediction of the population-level impacts of offshore windfarm development on over-wintering common scoter populations. This is a major advance on any previous approach applied in this field of research. It has indicated that the displacement of common scoter from the areas around four out of five existing/ consented/ proposed windfarms within Liverpool Bay will have no adverse effect on the over-winter mortality of the population. In contrast, it has indicated that the displacement of common scoter from an area around a wind-farm on Shell Flat, given the current best estimates of how these birds behave, will have an adverse effect on the over-winter mortality of the population. However, uncertainty concerning various aspects of the biology of this elusive species means that this prediction may not hold. This highlights the further research that is needed in order to improve the predictive power of future model applications.

1. Introduction

1.1 Context

In December 2003 the UK government increased its commitment to a new target of 15% of electricity to be generated from renewable sources by 2015, to which wind energy is likely to contribute a considerable proportion. Nevertheless, despite the advantages of renewable forms of energy, the construction and placement of windfarms has the potential to interact (positively and negatively) with other stakeholders and biological components of our environment. Environmental concerns have prompted country-based conservation agencies to initiate appropriate research studies to understand the broader ecological consequences of the construction and siting of windfarms in the marine environment. The main concerns relate to the impact upon bird migration patterns and disturbance at bird feeding areas. For example, the Countryside Council of Wales commissioned a study of the distribution of common scoter around Wales and into Liverpool Bay, in order to establish the impact of proposed developments off the north Wales and south Wales coast on this protected species. As a result of this work, Carmarthen Bay has become the first Special Protection Area designated for common scoter. The Crown Estate recognised the value of this research and contributed financially through its Marine Stewardship Fund along with other partners from the offshore wind industry who are hoping to develop projects in the Liverpool Bay area.

The environmental impact assessments (EIAs) of most offshore windfarm proposals raise the potential effects on birds as an important issue. The types of birds which may be displaced feed either on invertebrates (crustaceans, worms, shellfish) that live in or on seabed sediments or on fish. These birds include benthic feeding ducks such as common scoter and eider ducks or fish-eating birds such as terns, auks and divers. This present study addresses the disturbance / displacement of common scoter from the vicinity of the wind turbines and will provide a tool for predicting impacts that are currently uncertain. While the current study is focussed on common scoter in Liverpool Bay, the behavioural model the potential population level responses to windfarm developments is applicable to situations elsewhere.

This study focuses specifically on common scoter because:

1. Most of the proposed sites for offshore windfarm development on the west coast of the U.K. lie within, or close to, significant concentrations of common scoter that occur during the non-breeding season. The impacts on common scoter due to displacement are a key issue and an uncertainty in many emerging EIAs. There is concern that development of offshore windfarms could displace common scoter to less favourable feeding habitats due to both disturbance and/or barrier effects and physical changes in the habitat. A major uncertainty in predicting the impacts of the windfarms is therefore the sensitivity of common scoter populations to habitat loss and change caused by the offshore windfarms.

2. Adverse impacts of offshore windfarms (or other developments and activities) due to displacement / disturbance of birds are potentially more significant for benthic feeders such as common scoter as opposed to fish-eating birds. This is because their prey species (mostly bivalve molluscs) are not mobile, although the settlement of young prey (bivalve spat) will vary with time. This link between the distribution of common scoter and seabed fauna also means that it should be possible to build a model similar to those applied to studies of the interactions between wading birds and shellfish.

1.1.2 Objectives

The project had the following key objectives:

1. To develop a model to assist in predicting the effect of offshore windfarms (individually and cumulatively) on common scoter due to habitat loss and change.

2. To link the non-breeding distribution of common scoter with environmental variables at selected sites.

3. To identify the characteristics of preferred feeding areas for common scoter within these sites. This to include a description of density, species and size classes of prey.

1.1.3 Context – Liverpool Bay

Liverpool Bay is an important non-breeding site for common scoter. Birds are present in Liverpool Bay throughout the year with peak numbers occurring from October to March. The first full census of Liverpool Bay using aerial surveys during the winter of 2000/2001 recorded a peak count of c 16 000 birds (Oliver et al. 2001) with current estimates for 2003 approaching 30 000 birds (A. Webb pers. comm.). At these population levels, Liverpool Bay ranks as one of the most important wintering sites for common scoter. More than 1% of the European population occur in this locality during the overwintering period. Consequently, parts of Liverpool Bay are under consideration for Special Protection Area status (as defined under the provisions of the Birds Directive (Johnston *et al.* 2002)) because of the presence of qualifying numbers of non-breeding common scoter and red throated divers. Following data analysis by the Joint Nature Conservation Committee, English Nature and the Countryside Council for Wales a joint proposal has been submitted to the Department for Environment, Food and Rural Affairs and the Welsh Assembly Government seeking approval to carry out a formal consultation on proposals for selection of Liverpool Bay as a potential Special Protection Area (pSPA). The Welsh Assembly and the U.K. government response to this request is awaited.

1.1.4 Common scoter conservation importance

The common scoter areis a migratory species of sea duck that is protected in Europe through the provisions of the European Commission's Birds Directive (79/409/EEC) and Habitats Directive (92/43/EEC). Within the UK, this species is and is protected under the Wildlife and Countryside Act of 1981 as amended by the Countryside and Rights of Way Act 2000 which controls hunting and provide protection against disturbance to breeding birds. Elsewhere in Europe, common scoter are not protected from hunting. Thus, common scoter are wary of human activity and man-made structures, boats and vehicles (Garthe & Huppop 2004), the presence of which may exclude them from using potential feeding, roosting and breeding sites.

1.1.5 Common scoter

As common scoter are migratory, their survival and population size is affected by different factors at different sites. For example, common scoter have breeding grounds in northern Scandinavia, Iceland and Russia where their breeding success may be influenced by habitat quality factors and the prevalence of predators. Breeding success is also affected by adult body condition (amount of fat reserves) which will depend upon the quality of their feeding grounds. Common scoter migrate from their breeding grounds to moulting and overwintering grounds at more southerly latitudes and arrive in Liverpool Bay in large numbers from October onwards. Male birds arrive first (section 4) followed by females from December onwards. The females also depart for the breeding grounds before males (in February). Some birds remain in Liverpool Bay over the summer period but these tend to be immature or birds that are moulting. Liverpool Bay is an important overwintering site for common scoter due to its abundant bivalve shellfish stocks that occur in shallow waters at depths of less than 20 m. As bivalve shellfish live on the seabed, common scoter resting on the surface of the sea need to dive to the seabed to feed on their shellfish prey. As a result, water depth is an important factor as the deeper the birds are required to dive the more energy they will expend in searching for their food. Common scoter remain at sea for the entire time they are located in Liverpool Bay. As winter sea temperatures are usually warmer and more constant than terrestrial winter temperatures this may help the common scoter conserve energy. Common scoter also have few, if any, natural predators at sea, although they may suffer interference from larger predatory species such as gulls.

1.2 Habitat considerations and disturbance

Observations made from light aircraft indicate that common scoter in Liverpool Bay are located over discrete areas of the seabed. The reasons why common scoter are found in these areas is a key topic of this project. Areas of the sea utilised by common scoter are likely to be those that allow them to maintain a positive energy balance or at least minimise any negative energy balance. Such locations are likely to be those that i) provide a high intake of food, and ii) necessitate a low expenditure of energy. Energetic costs would include energy expended on relocating or maintaining position (by flying or paddling) which may occur due to: strong surface currents (drifting off position), strong winds (blowing birds off position), disturbance from vessels (commercial shipping, fishing vessels, aircraft, recreational boats, jet skiis) or the construction of manmade structures (windfarms, drilling platforms, breakwaters). Birds may also utilise particular areas of the sea for the purpose of moulting and roosting. However, the present study is primarily concerned with the importance of different areas of the seabed in terms of the quality and quantity of food resources that are available for common scoter.

In the context of the proposed and consented windfarm developments in Liverpool Bay (Fig. 1.1), it is necessary to ascertain whether the construction of one or more windfarms would result in a significant increase in the overwinter mortality rate of the common scoter population within Liverpool Bay. in comparison with the current level of mortality It is important to appreciate that the current distribution and mortality of the population occurs against a background of natural variability in prey populations (due to recruitment success and failure from one year to the next) and their other predators (e.g. fish and crabs), and a background of existing sources of disturbance (e.g. commercial shipping activities, fishing, hydrocarbon extractions etc).

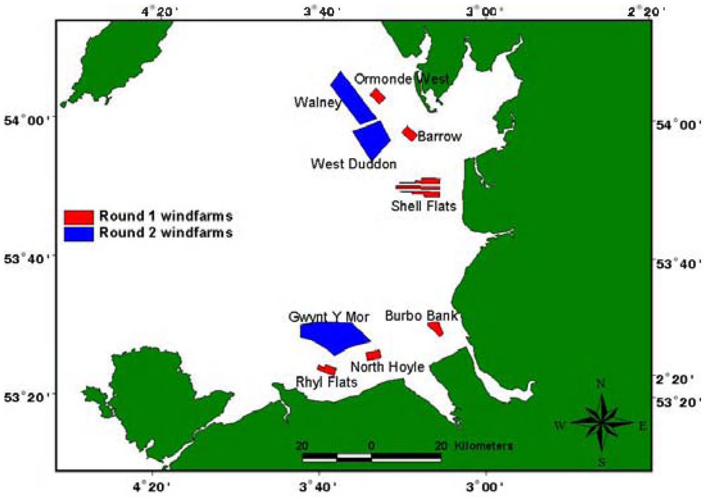


Figure 1.1 The location of round 1 and round 2 consented or proposed windfarms in Liverpool Bay, Irish Sea, UK.

1.2.2 How might windfarms affect common scoter?

It is important to understand the mechanism by which the construction of windfarms might have an effect on populations of common scoter. In contrast to some other types of birds e.g. raptors and vultures, it is unlikely that collision of seaducks with wind turbines is a serious source of mortality. There are no substantive reports in the literature that would, as yet, indicate that this is a problem for common scoter.

The maximum extent of the seabed area that serves as potential foraging habitat is defined by the 20 m mean depth bathymetric contour. This is related to the amount of time and energy that is required to dive to the seabed. Within this maximum area of exploitable seabed the largest amounts of suitable prey (in number and biomass) are found at depths that are shallower than 20 m (section 2), although the depth at which the greatest peak in prey occurs varies according to wave erosion and other physical characteristics at each different locality (section 3). Thus, the extent of the areas that are suitable for feeding in Liverpool Bay are finite. Within this finite area, some parts may be unsuitable because of existing disturbance (e.g. commercial shipping in and out of the River Mersey) while others may hold insufficient prey to make foraging by common scoter energetically efficient. It is assumed that the construction of a windfarm may exclude common scoter from the footprint of that windfarm (i.e. the area over which it extends) probably extending an unknown distance beyond the actual windfarm (i.e. creating a halo of disturbance). The construction and presence of offshore windfarms may, by exclusion of ducks from certain areas, effectively lead to habitat loss

If the windfarm is constructed over a particularly dense bed of suitable prey, these may be made unavailable to the birds. The birds will then need to relocate to other suitable feeding areas. If birds already exist in those areas this will increase the competition for the prey in those areas. This may occur either through interference competition between birds whereby once the density of competitors exceeds a certain value, their ability to forage efficiently is impaired or through depletion competition whereby more birds eat more prey thus leaving fewer for the next day. If, through either process, the rate of prey intake decreases below a certain threshold then birds may begin to lose condition (body fat) or even starve to death. While loss of condition may not lead to the death of birds directly, it may affect their reproductive success later in the year.

Given the constraints of current survey techniques, it appears that extensive prey resources exist that are apparently not utilised by the birds (e.g. Burbo Bank). While this may seem inexplicable, one has to remember that common scoter cannot see the distribution of their prey from the sea surface, they can only gain knowledge of the quantity and type of prey by diving to the seabed. As in many other group living organisms, individuals use social learning to recognise areas that are profitable for feeding. If there are no other common scoter in location X it is unlikely to be an area that holds food. A bird's perception of its available feeding habitat is strongly influenced by the distribution of other individuals. Thus, in the case of Burbo Bank, while it holds abundant prey resources, it may be unavailable to common scoter simply because they have no knowledge regarding the quality or quantity of food in that area. This is an important issue that is brought into clearer light by the bird behavioural model that will be dealt with later in this section.

Furthermore, our model predictions **do not** take into account any possible affects of offshore windfarms due to: **i) collisions ii) increased flight costs iii) changes to the benthos or iv) disturbance by maintenance traffic**. Our predictions are therefore conservative with respect to these additional variables that might impact populations of common scoter. The predictions of the behavioural model developed in the current study are purely based on displacements from feeding areas due to the presence of turbines.However the predictions of the behavioural model based on our current knowledge of the Liverpool Bay situation are probably over-cautious.

1.3 Project structure

The primary source of data regarding habitat use by common scoter in Liverpool Bay is derived from overflight surveys co-ordinated by The Wildfowl & Wetlands Trust. These surveys are conducted using observers in light aircraft that fly a predetermined route over Liverpool Bay. As such, these surveys can only provide a snap-shot of the distribution of the birds and cannot provide information about what the birds are doing at that time (roosting, feeding, relocating) or at night when such surveys cannot be undertaken. Nevertheless, this currently remains the only viable means of gaining an accurate population estimate for a bird that is distributed offshore and that avoids moving vessels. By using all available overflights for the period 2002 – 2004 (n = 12), it is possible to be confident that the distribution observed during daylight overflights is representative of the key areas of sea utilised by common scoter during daylight.

Given that data regarding the distribution of birds is only available for daylight hours, the modelled scenarios outlined in the report have a default assumption that common scoter do not feed at night in line with other diving species of duck. Given that night conditions last up to 16 hours in mid-winter, this assumption precludes common scoter from feeding during the majority of a 24 hour period. Given this fact, scenarios were also run that enabled the birds to feed at night. If this yielded a significantly lower mortality rate for some windfarm scenarios this would indicate that it is important to establish whether common scoter feed at night.

Using the above information as our baseline data, the project was broken down into the following major components:

Description of the physical habitat utilised by common scoter
Spatial and temporal variability in prey
Behaviour of birds at sea and their response to disturbance
Quantification of other forms of disturbance relevant to common scoter
A review of the diving seaduck literature
Development of a predictive behavioural model to predict responses to windfarms.

Description of the physical habitat utilised by common scoter

This was undertaken by using standard oceanographic models to delineate the water depth over which observed birds were recorded, to ascertain the bottom shear stress, surface current speed and mean water depth for each of 99 defined areas of the sea (3.7 x 3.35 km) that were specified within the behavioural ecology model. The output of the oceanographic modelling enables identification of the physical characteristics of areas of the sea over which common scoter occur most frequently.

Spatial and temporal variability in prey

An extensive baseline biological survey of seabed dwelling bivalves and other fauna quantified the prey available to common scoter at the start of the overwintering season. Repeated surveys of a selected number of sites enabled the survival rate (or decline) of prey species to be ascertained. Quantification of prey-type characteristics and energy content enabled the areas of the sea that contained the greatest amount of suitable prey to be identified.

Behaviour of birds at sea and their response to disturbance

Direct behavioural observations at sea and from land enabled quantification of the behaviour of common scoter in response to weather conditions and disturbance to be quantified. Flush distances from a vessel were quantified and used to define those areas of the seabed that are unlikely to be used by common scoter due to disturbance. Additional data enabled interpretation of model outputs for a species for which there is little observational information.

Quantification of other forms of disturbance relevant to common scoter

Other forms of disturbance from shipping and fishing activities were mapped according to available data held by National agencies or consultancies acting on their behalf. Nevertheless, many sources of potential disturbance from smaller vessels remain unquantified as these are not currently recorded.

A review of the diving seaduck literature

A review of the literature was undertaken to aide interpretation of model outputs and to gather information required to parameterise the behavioural ecology model (e.g. the energetic costs of diving). As common scoter are so infrequently studied, data were often gleaned from proxies (similar species or groups of species with similar body mass). The latter is the only option were data for common scoter did not exist in the literature.

Development of a predictive behavioural model to predict responses to windfarms

An existing individuals-based behavioural model (Stillman et al. 2000) was adapted for common scoter. This model was originally devised for oystercatchers and has been applied successfully to other species. The model is widely peer reviewed and well accepted among the ecology and ornithological community. The outputs of the model enable various scenarios of windfarm developments to be explored in terms of their likely effects on common scoter in Liverpool Bay. Once developed the model can be applied to similar situations elsewhere provided the appropriate input data are collected.

2. Common scoter distribution in relation to modelled physical parameters

2.1 Introduction

In Liverpool Bay, aggregations of common scoter are found primarily off Llanddulas (North Wales) and from an area off the mouth of the River Ribble up to Shell Flat, a shallow subtidal area off Blackpool, Lancashire, England (Figure 2.1). The development of offshore wind farms has the potential to influence common scoter duck distribution through two mechanisms. Firstly, the ducks may avoid areas of the sea populated by man-made structures and may thereby be prevented from accessing feeding areas, secondly, the foundation base of the each turbine and associated cable laying activities may alter near-bed hydrography such that the sediment environment changes its suitability for important prey species.

Common scoter are diving ducks that feed on prey that live upon or within the upper few cm of the sea bed. The diet of the common scoter is thought to comprise mainly bivalve molluscs, while other items (e.g. crabs, small fishes and gastropods) are incorporated less frequently. The exact mechanism of feeding is unknown although it is unlikely that they are visual feeders, particularly in Liverpool Bay where the water is particularly turbid due to riverine discharge from the Rivers Dee, Mersey, Ribble and Conwy.

Common scoter feed on benthic prey whose life-history strategies and production are intimately linked to the sedimentary and coastal environment (Snelgrove & Butman 1994). Sedimentary habitats are strongly influenced by near-bed hydrodynamic stress and hence this can be an important determinant of benthic assemblage distribution (Warwick and Uncles, 1980; Yates et al*.,* 1993). Shear bed stress will have both positive and negative effects on benthic communities. At low shear stress values, increasing shear increases the supply of food and hence production of the benthos until a threshold where further increases in shear stress inhibit feeding (Hiddink et al. in press). Increasing levels of wave erosion increase mortality of the benthos (Hiddink et al. in press). These two factors are likely to interact close to the coast and will have a strong influence on the production of the associated benthic communities. In addition, benthic communities are notoriously patchy in their distribution and the population sizes of benthic invertebrates fluctuate greatly from one year to the next (e.g. Rees et al. 1977). Thus food resources available for common scoter are unlikely to be uniformly distributed over the sea bed and certain areas will yield higher rates of energy intake than others. Presumably, common scoter distribute themselves over, or in close proximity to, areas that have a sufficient abundance of prey to maintain their energetic requirements and are able to assess the rate of encounter with suitable prey as they probe through the sediment with their bill. The profitability of prey will also be affected by the depth to which the birds need to dive for feeding, which is a continuously changing variable in tidal areas. The deeper the birds need to dive, the greater the energy expended acquiring prey (Lovvorn & Jones 1991).

A number of environmental and anthropogenic factors are likely to affect the distribution of the birds at the sea surface: the distribution and quality of the prey that may vary interannually and through the year, the depth of the water over the sea bed that fluctuates tidally, the surface current speed which, in Liverpool Bay, will move birds over the ground at speeds of up to 1–2 ms^{-1} at peak tidal flow, diurnal patterns in feeding behaviour and the proximity to human activity and structures. As in other species, the birds probably use visual cues to locate initial feeding sites before sampling other possible food patches. Surface currents may be important if birds are required to continually maintain their position over patches of prey by swimming against currents, or by relocating periodically by flying up-stream.

To answer some of the questions raised above, a tidal model of the Liverpool Bay region was developed as part of a multi-disciplinary study into the potential impact of offshore wind farms on the distribution of the common scoter. This paper presents the main results from the physical study.

2.2 Methods

2.2.1 The tidal model

A two-dimensional finite-difference hydrodynamic model of the Celtic and Irish Sea region was developed using standard techniques (Elliott & Clarke 1998; Tattersall et al. 2003). The depth-averaged shallow water equations of motion were solved on an Arakawa-C grid using centred time and space differences on a latitude/longitude grid. Centred differencing was used in both time and space, and time filtering (Asselin 1972) was used to suppress the computational mode caused by the leap-frog scheme. The grid covered a region from a southern limit in the Celtic Sea at a latitude of 50 18.1’ N to a northern limit in the North Channel at a latitude of 55 2.0’ N (Figure 2.2). The grid spacing was 1/30 of latitude by 1/20 of longitude which corresponds to approximately 3.70 km by 3.35 km and the grid contained 129 142 cells. Results from the Liverpool Bay region (Figure 2.1) were extracted from the main grid and mapped onto a 50×41 array for export to the common scoter related analysis.

The model was forced at the northern and southern open boundaries by specifying the surface elevations using the semi-diurnal tidal constituents M2 and S2 which represent the twice daily tidal signals due to the influence of the moon and sun. It is the beating between these two sinusoidal signals that creates the 14.8 day periodicity of the spring/neap cycle. The amplitudes and phases for the boundary conditions were obtained from the output of a North Atlantic tidal model developed at the Proudman Oceanographic Laboratory (R. Proctor pers. comm.). The east and north components of the tidal currents were interpolated to the centre of each grid cell and then tidally analysed, along with the surface elevation, to produce amplitude and phase constants which could be used in a tidal prediction programme to determine the water depth and current speed at any point within the computational grid.

The simulated values were compared against observational results (Jones 1983; Davies & Jones 1992; Young et al. 2000) using sea level records from both coastal and offshore sites and current data collected at offshore moorings. The modelled surface elevations were accurate to 0.10 m in amplitude and to 5° in phase (which corresponds to a time interval of about 10 minutes). For example, the amplitude and phase of the M2 surface elevation derived for Hilbre Island which is located near the mouth of the River Mersey at 53° 23’ N and 3° 13’ W were 3.27 m and 322°, while the observed values are 3.33 m and 317°. The agreement between the simulated and observed tidal currents displayed greater scatter, with errors of order 0.1 ms^{-1} and 10°. However, part of this discrepancy was due to the difficulty in comparing depth-mean currents derived from the model with the observations which were recorded at a range of depths within the water column.

As an example of the output from the tidal model Figure 2.2 shows a map of tidal vectors and the contoured sea surface elevation for 1500 UTC on August 19 2004. This was close to a time of spring tides and the high water at Liverpool occurred at about 1300 hrs when the sea level reached a height about 4.5 m above mean sea level. At 1500 hrs therefore the sea level was falling in Liverpool Bay as evidenced by the flow vectors which are directed out of the region and which show strong flow towards the south in the central portion of the grid. The right hand portion of Figure 2.2 shows that the tidal elevation was more than 2 m above the mean level in Liverpool Bay, while it was more than 3 m below mean sea level within the Bristol Channel. It is this pronounced slope of the sea surface that is driving the water through the Irish Sea from north to south. (There is also a less pronounced slope near the northern boundary which is driving the tidal flow westwards past the Isle of Man and out of the North Channel.)

Significant surface slopes can also exist within Liverpool Bay. At the time of high water during a period of spring tides, the sea level near Liverpool stands about 1.5 m higher than the water level near Anglesey.

2.2.2 The 1 km depth database

Although the sea surface elevation changes smoothly across a region and its variation can be adequately resolved by a hydrodynamic model with a grid resolution of the order of 3.5 km, water depths can vary on a significantly smaller spatial scale. To resolve such variability a dataset of water depths with a spatial resolution of approximately 1 km was obtained. The depth grid covered the study area with a latitude resolution of 1/120° (~925 m) and a longitude resolution of 1/60° (~1130 m). Figure 2.3 illustrates the spatial resolution of the grid by showing the land cells along with a contour plot of the offshore water depths. In order to estimate the water depth at the location of a duck observation, the tidal elevation with respect to mean sea level was derived from the tidal model and to this was added the water depth at the observed point taken from the 1 km dataset. In this manner an estimate of the instantaneous water depth was obtained.

2.2.3 The wave model

Engineering formulae, based on results from the JONSWAP experiment (Hasselmann et al. 1973) can be used to forecast wave conditions in coastal waters for practical applications. Events when the wind speed was relatively steady and directed offshore were isolated and used by Hasselmann et al. (1973) to determine the dependence of the wave conditions (i.e. wave height and period) as functions of the wind speed, wind duration, and the fetch. Carter (1982) subsequently re-analysed the JONSWAP data and developed empirical formulae that can be used to estimate wave height and period as a function of the wind conditions. For example, in a fetch limited growing sea when the wave conditions are independent of the duration of the storm the significant wave height, H_s, and peak wave period, T_p, can be calculated from:

$$H_s = 0.0163 X^{0.5} W$$

and

$$T_p = 0.566 X^{0.3} W^{0.4}$$

where W is the wind speed in ms^{-1} and X is the fetch in km.

The formulae derived by Carter (1982) parameterise wave conditions as a function of wind speed, wind duration and wave fetch and assume that the wind direction and speed are constant. For most applications, however, the results need to be generalised so that they can be used to simulate conditions when the wind speed and direction are not steady. This was achieved in the following manner:

Radial fetch lines, with an angular separation, , were defined from the target position and the fetch was estimated along each line. (Each grid point of the whole area Irish and Celtic Seas model was taken in turn as the target location. Radial lines were run along the principal compass directions from each point until they reached land or the edge of the grid to define the fetch for each point. A value for θ of 45º was used in the calculations.)

The wind was considered to be from a steady direction if it lay within ± θ /2 of a fetch line. Periods of steady wind direction were used to define each wind 'event'.

A new wind 'event' was defined each time that a new direction sector was entered and the duration of each event was measured from this time.

The JONSWAP formulae were used to estimate significant wave height using the appropriate value of fetch (determined by the wind direction), the duration (determined as the time elapsed since the start of the most recent wind event), and using the mean value of the wind speed during the event.

Wave energy was assumed to decay in an exponential manner at the end of a wind event, thus introducing an element of 'memory' into the wave height forecast. An e-folding time scale of 12 hours was found to give the best agreement with Meteorological Office wave model results as described below. If such a term is omitted the wave energy falls to zero at the start of each new wind event and the wave record shows an unrealistic level of high frequency variability.

Thus the wave model ignores the effects of wave refraction and assumes that the wind field is fixed spatially while varying with time. There are therefore similarities between this approach and the Hydraulics Research HINDWAVE model (Hawkes 1987). The model had previously been validated by comparing its results against both field data and the output from the UK Meteorological Office wave model for sites near the Shetland Islands and near Skomer Island off the coast of West Wales to the north of Milford Haven (Elliott 2001). The model produces realistic wave heights and periods during storm conditions but tends to underestimate the wave energy during light wind conditions. It is therefore suitable for the present application where it was used with wind data from Liverpool Bay covering the period from 1997-2001 (Elliott 2004).

2.3 Results

Figure 2.1 shows the water depth contours with respect to the mean sea level (solid curves) plus the position of the 20 m isobath at the time of high and low water during a period of spring tides (dashed curves). The 20 m isobath moves shoreward at the time of high water and moves offshore at the time of low water. For the Lancashire coastline between Liverpool and Blackpool this displacement is of the order of 10 km. In consequence the area of the sea bed that lies in water depths of less than 20 m (i.e. within the diving depth range of common scoter) increases at the time of a spring tide low water. The statistics of the sea bed area for the region where the water depth is less than 20 m are presented in Table 1. The change in area between the times of high and low water during spring tides equals 1.45×10^9 m^2 which amounts to about 9.3% of the total area of the sea bed in the Liverpool Bay region and to 42.3% of the area shallower than 20 m with respect to the mean sea level. At high water during spring tides 17.4% of the sea bed within the Liverpool bay region would have a depth of less than 20 m, and this percentage would increase to 26.7% at the time of low water. Thus if the common scoter are able to dive to a maximum depth of 20 m to forage for food then the area of the sea bed with this property varies significantly during a tidal cycle at a time of spring tides. (While 20 m has been used as a representative maximum dive depth, the program that computed Table 1 was able to accept any such selected depth as its input parameter). The dashed contours immediately to the north of the Shell Flat near Blackpool mark the position of the Lune Deep where the water depth reaches 50 m (Figure 2.1). In general, the eastern half of Liverpool Bay contains water depths of less than 40 m while depths of up to 80 m occur in the western portion.

An object that drifts on the surface of the sea in the presence of an oscillatory tidal current will be carried a distance of UT/ during each half of the tidal cycle (Elliott et al. 2001). In this expression for the tidal excursion, U is the amplitude of the tidal current (ms^{-1}) and T is the length of the tidal period (s). Figure 2.4 shows the tidal excursions within Liverpool Bay at a time of mean tides (midway between springs and neaps). The depth-mean current obtained from the tidal model was scaled to a surface value using the depth profile derived by Prandle (1982) in which the surface current has a speed of 1.17u and the near-bed flow a speed of 0.70u where u is the speed of the depth-mean current. Along both the North Wales and the Lancashire coastlines the surface displacements are of the order of 10 km at the time of mean tides, and would increase to 13.7 km during spring tides. Knowledge of this factor should therefore be taken into account when analysing bird locations or estimating their energy expenditure if they relocate above a feeding ground by swimming or flying. Thus for a bird to remain in the same location for one complete tidal cycle it would have to swim the equivalent of 13.7 km during a spring tide, unless it chose to reposition by flying.

An estimate of the bottom stress associated with the tidal currents was obtained by computing U_B^2 where U_B is the speed at the bed. This parameter is presented in Figure 2.4d which shows contours of U_B^2. In general, values of 0.5 m^2s^{-2} were obtained along the Lancashire and North Wales coasts with the maximum values occurring around the western and northern shores of Anglesey. This result will be discussed further in the next section.

The wave model was applied to the Liverpool Bay region using 6 hourly wind data from 1997-2001 and a 5 year time series of significant wave height and peak period was computed for each grid point. Parameters such as the mean wave height, the rms wave height and the maximum wave height were then extracted for each grid cell. (In this context, wave height refers to the significant wave height.) In a similar manner, the mean, rms and maximum wave periods were also computed. Figure 2.5a presents a contour plot of the maximum wave heights. The highest waves (up to 7 m) were encountered along the southwest coast of Anglesey due to the increased fetch associated with waves approaching from the southwest. In contrast, the coastline of North Wales where the maximum waves were around 4 m was sheltered by the presence of Anglesey. In the northern portion of the region and near the Blackpool coast the maximum waves reached 6 m. The wave periods displayed a similar pattern, with values of about 9 s along the Lancashire coast and values of 7 s off North Wales (Figure 2.5b).

The near-bed current due to the orbital motion of the waves, u_o, was computed using linear theory (Bowden 1983) after solving the dispersion relationship to determine the wavelength of the wave as a function of water depth. The value of u_o^2 is shown contoured in Figure 2.5c. Maximum values of 5-10 m^2s^{-2} were derived along the Lancashire coastline; this reflects the combination of large waves with relatively shallow water that occurs there. (The orbital velocity of the waves decreases in an exponential manner with increasing water depth). In contrast, values of less than 1 m^2s^{-2} were computed for the central waters of Liverpool Bay and for the sea around Anglesey due to the depth of water in those regions.

Figure 2.4d shows a measure of the bottom stress due to the extreme spring tides that occur in the region. This parameter was obtained from the M2 tidal current results by scaling using a factor of 1.67. This factor was derived by computing the ratio between the offset for chart datum with respect to mean sea level with the amplitude of the M2 surface elevation for all available ports within the Irish Sea. (The chart datum offset, z_o, represents the lowest tidal level likely to be experienced at a location. It can be compared with the M2 amplitude at a port using values that are tabulated in the Admiralty Tide Tables (2005)). Thus the M2 tidal currents were scaled using a factor of 1.67 to derive estimates of the currents that would occur at a time of extreme spring tides.

A comparison of Figures 2.5c and 2.5d suggests that wave action dominates the sea bed stress in the near-shore waters along the Lancashire and North Wales coasts where there is an order of magnitude more energy in the wave associated motions. Tidal stirring is only likely to dominate the sea bed characteristics to the western and northern tips of Anglesey and at the southern tip of the Isle of Man.

Figure 2.6 shows the positions at which common scoter ducks were observed during aerial surveys that were conducted between August 2002 and November 2004. There was a total of 4226 individual data points after error checking had removed positions that were on land. For each of the data points there was information on the time/date and the latitude/longitude of a duck observation. These data were then used with the tidal model to predict the water depth, the depth-mean current (speed and direction) at each duck position. A similar analysis was performed using 1023 land-based observations that were collected from two sites at Anglesey and Llanddulas (Figure 2.1) during December 2003 to March 2004. While fewer in number, this latter data set contained information on the duration of the dive times for the observed ducks that were ascertained by direct observation from land-based sites at Llanddulas and Red Wharf Bay (see section 4).

Figure 2.7a-c presents histograms derived from the aerial survey data. The uncorrected water depth (i.e. the chart value which represents the depth with respect to mean sea level) is displayed in Figure 2.7a and suggests a Gaussian distribution with the greatest number of ducks located in water depths of 10-12 m and with a span from 2 m to 22 m. After correction for the tidal effect, which could add up to ±5 m to the uncorrected value, the distribution became more ramp-like with a steady increase of numbers until the water depth reached a value of 15-17 m followed by a rapid decrease in numbers where the depth was greater than 20 m. A similar trend was shown by the histogram of bird numbers against current speed (Figure 2.7c). This latter characteristic is probably a consequence of the manner in which the current speed generally increases with distance from the shore due to the effect of friction in the shallow water, thus the two physical parameters of depth and current speed are strongly correlated and it is difficult to ascertain which is the more critical determinant of habitat use (see section 3).

Most of the biological parameters showed poor correlation with the physical variables. For example, Figure 2.7d presents a scatter diagram of dive duration against the water depth. While the dive durations varied between 15-55 s there is a weak association between dive duration and depth although this varied with observation site (see section 3).

2.4 Summary

The Liverpool Bay portion of the eastern Irish Sea is a high energy region in terms of its hydrodynamic regime. At the time of spring tides the tidal range between high and low water is around 10 m and the near-shore tidal currents can reach speeds of 1.5 ms^{-1}. The significant change in water depth during the tidal cycle causes the 20 m isobath to migrate on/offshore by approximately 10 km during each tidal cycle at the time of spring tides. This migration causes the area of the sea bed where the water depth is less than 20 m to change from 4.18×10^9 m^2 at the time of low water to a value of 2.73×10^9 m^2 at the time of high water. This variation amounts to a fraction of 45% of the area that is shallower than 20 m with respect to the mean sea level.

In Round One of the programme for the development of offshore wind power, an area of order 7×10^7 m^2 was allocated for turbine sites, with a further 23×10^7 m^2 allocated during the Second Round. In consequence a total of 0.3×10^9 m^2 of the sea bed could eventually be covered by wind farms which are being sited in water depths of typically 15 m with respect to the mean sea level. This amounts to approximately 10% of the area of the sea bed within Liverpool Bay where the depth is less than 20 m. The impact of such farms will therefore depend critically on their location with respect to the regions within which the common scoter forage for food.

Waves from the North Atlantic cannot penetrate into Liverpool Bay due to the sheltering effect of Anglesey on waves from the southwest and the restricted entrance through the North Channel at the northern limit of the region. The wave energy is therefore generated locally by the action of the local wind. A simulation of the wave field using archive winds from the 5 year period 1997-2001 produced maximum wave heights of 6 m with periods of about 9 s along the Lancashire coast. In combination with the relatively shallow water in that region this resulted in a sea bed stress that was an order of magnitude greater than that due to the maximum tidal currents. The wave exposure was less along the North Wales coast, with the simulated waves reaching maximum heights of 4 m with periods of around 7 s. However, in this region the wave associated bed stress was still a factor of 2 stronger than the tidal stress. The differences observed in wave stress at the bed may explain the differing depth distribution of peak bivalve biomass off the Lancashire and North Wales coastline (see section 3).

The tidal model allowed the water depth at the common scoter positions to be corrected for the variation of the sea surface height within the tidal cycle (and during the spring/neap cycle). It also allowed an estimate to be made of the current speed at the site of each duck observation. The corrected water depths suggested that the common scoter were limited to locations where the water depth was less than about 18 m. However, no correlation could be established between the water depth and the dive duration of the ducks.

It is generally accepted that the feeding areas used by common scoter are restricted to water of less than 20 m depth due to the constraints imposed by the energetic costs of diving to the sea bed to consume benthic prey species. Currents and the associated sea bed shear stress can influence food availability for benthic communities (Jenness & Duineveld 1985) and benthic secondary production (Warwick & Uncles 1980; Wildish & Peer 1983). High shear stress results in scouring and high current velocities inhibit feeding activity, while water movement at the sea bed is necessary for the supply of food to the benthos. Below a certain current velocity threshold, food particles transported from other areas may begin to sink to the seabed, where they become available as food to the benthos (Creutzberg 1984). In additional to the natural mortality rates, which relate to body-size, sediment movement due to wave action caused by wind and tides, can be a major cause of mortality among benthic animals and has been shown to affect secondary production (Emerson 1989). Both shear and erosion are likely to interact with depth such that at some distance from the shore it is likely that a critical depth occurs where food supply from shear and mortality from erosion coincide to generate optimal conditions for growth.

The impact of the wind farm developments on the common scoter duck population will depend on the location of the turbine structures in relation to the feeding areas of the ducks. While there may be adequate bivalve biomass on the bed in the deeper offshore waters it may be impossible for the common scoter to feed in such regions due to the limitation on the depth to which they can dive. A budget evaluation of the energy expended by common scoter during diving against the energy gained from their food is the subject of a behavioural modelling component of this multi-disciplinary study and will be reported separately.

	MSL	HWS	LWS	HWN	LWN
No. of grid cells < 20m	277	220	337	244	308
Area < 20m (10^9 m^2)	3.43	2.73	4.18	3.02	3.82
% of total area < 20m	21.9	17.4	26.7	19.3	24.4

Table 1 Sea bed area statistics for the portion of the region where the water depth is less than 20 m. The total area of the sea bed in the Liverpool Bay region (Figure 2.1) is 15.67×10^9 m^2. (MSL = mean sea level, HWS = high water springs, LWS = low water springs, HWN = high water neaps, LWN = low water neaps)

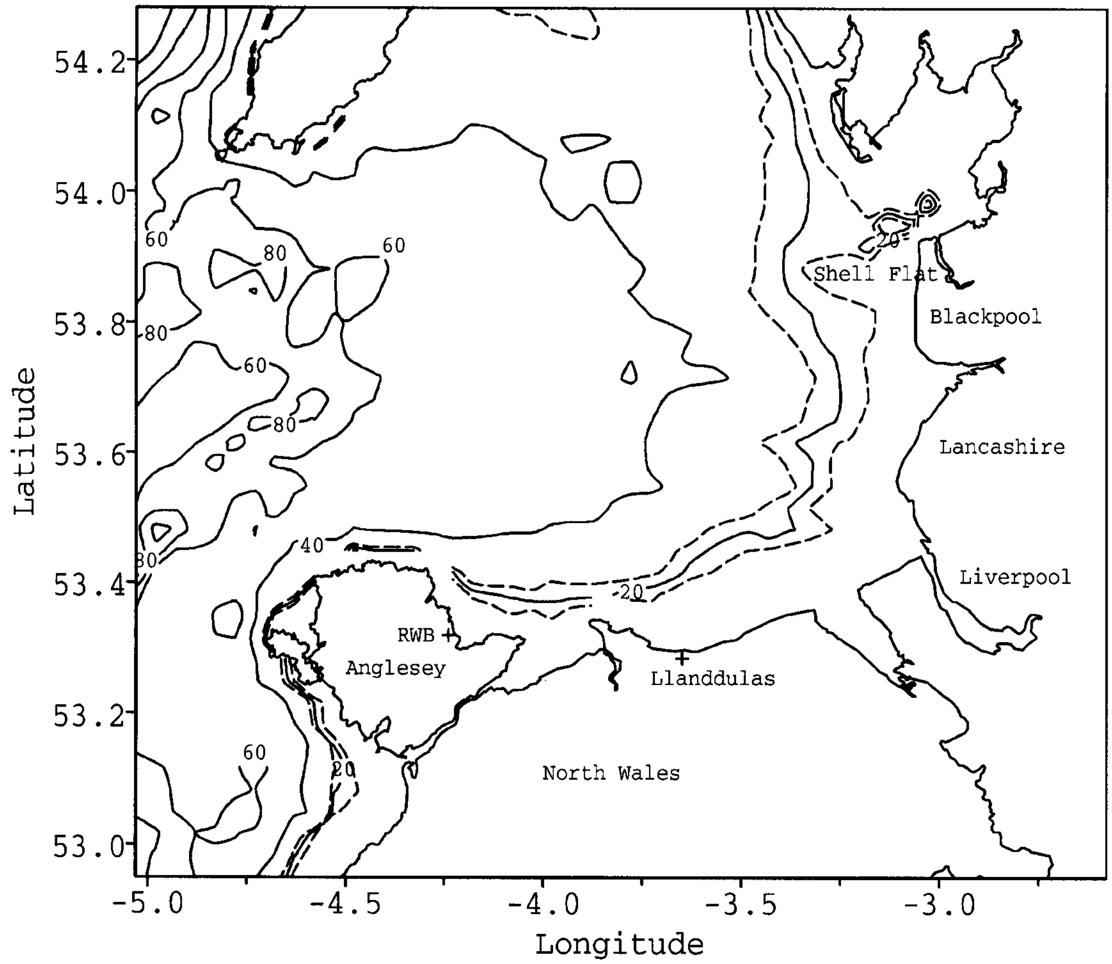


Figure 2.1 Liverpool Bay showing water depth contours (m) with respect to mean sea level (solid curves) and the 20 m isobath (dashed curve) at the time of high and low water during spring tides. The location of the two land-based common scoter surveys are marked by (+) symbols on Anglesey at Red Wharf Bay (RWB) and at Llanddulas on the North Wales coast.

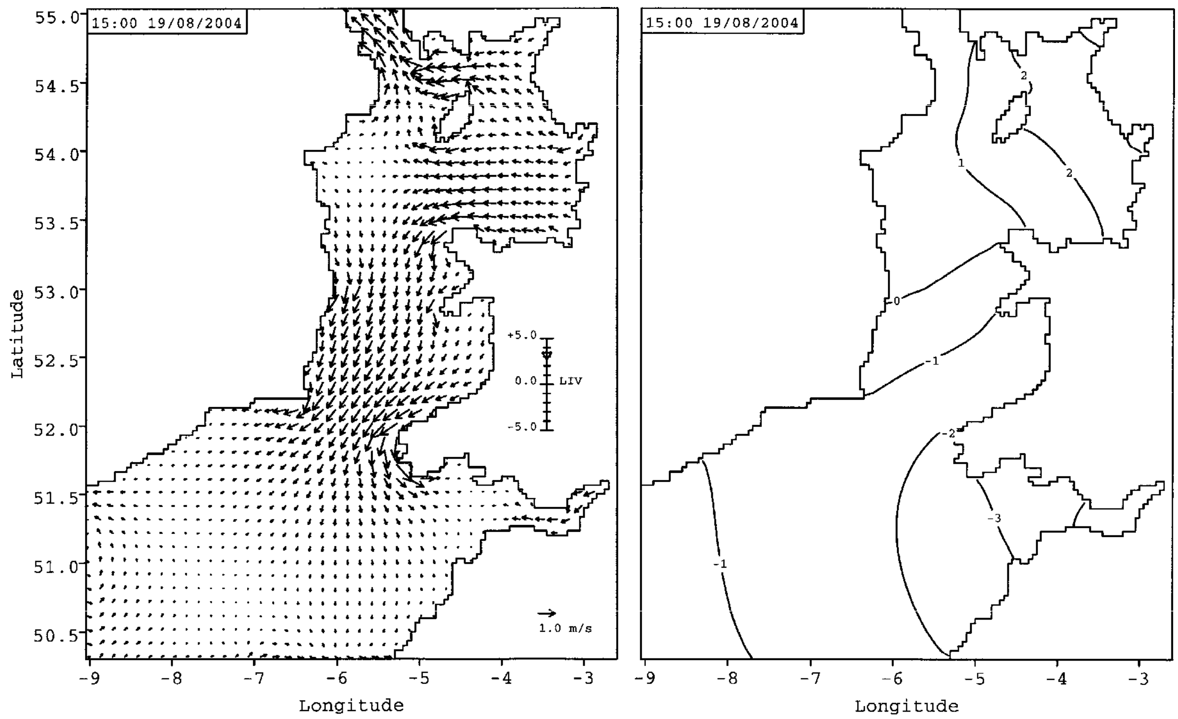


Figure 2.2 An example of the tidal vectors and sea level elevations produced by the tidal model. The tidal staff on the left hand portion of the figure represents the tidal elevation at Liverpool. (For clarity only every 3rd vector in each direction is plotted.)

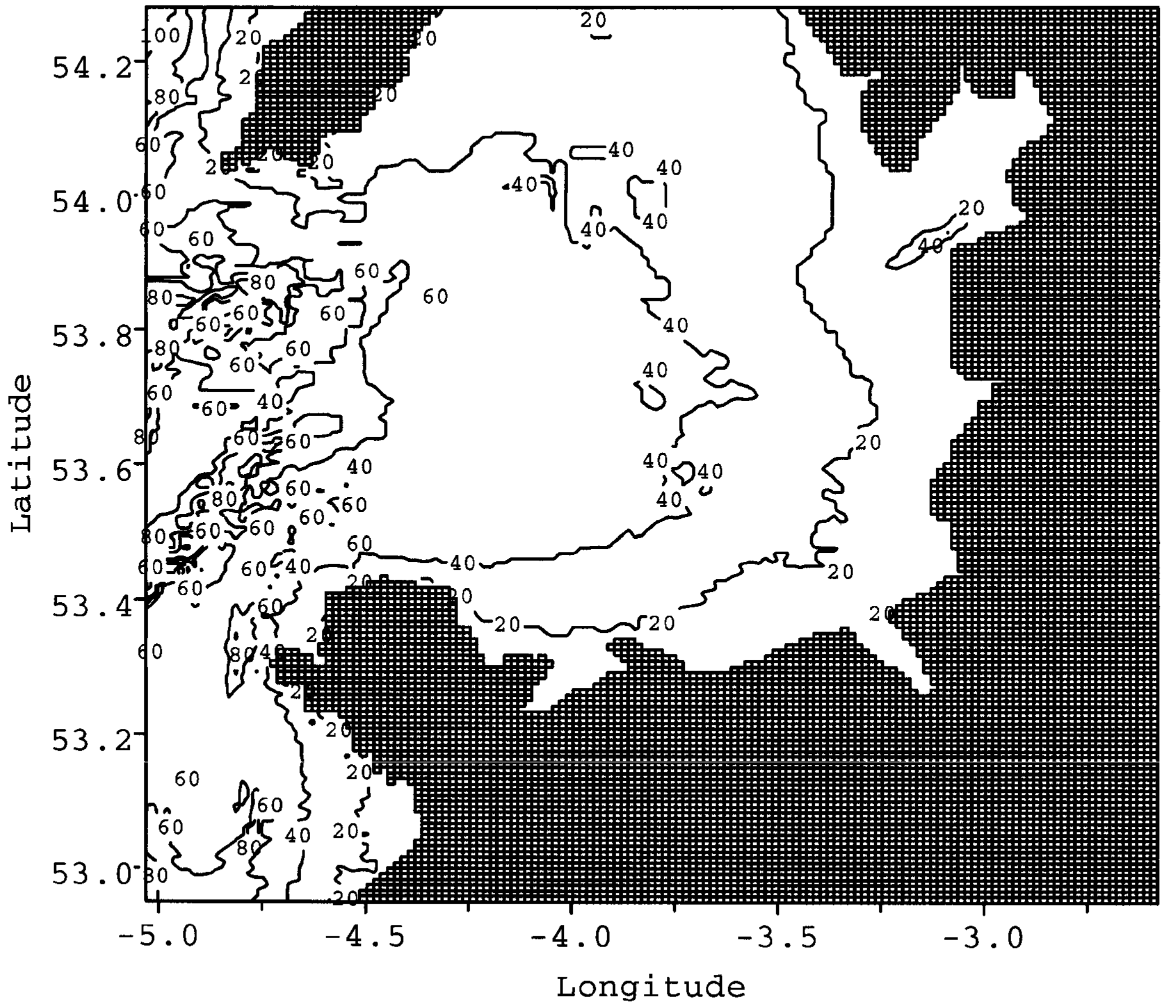


Figure 2.3 Water depths in Liverpool Bay derived from the 1 km database. The spatial resolution of the database is revealed by the cells drawn on the land.

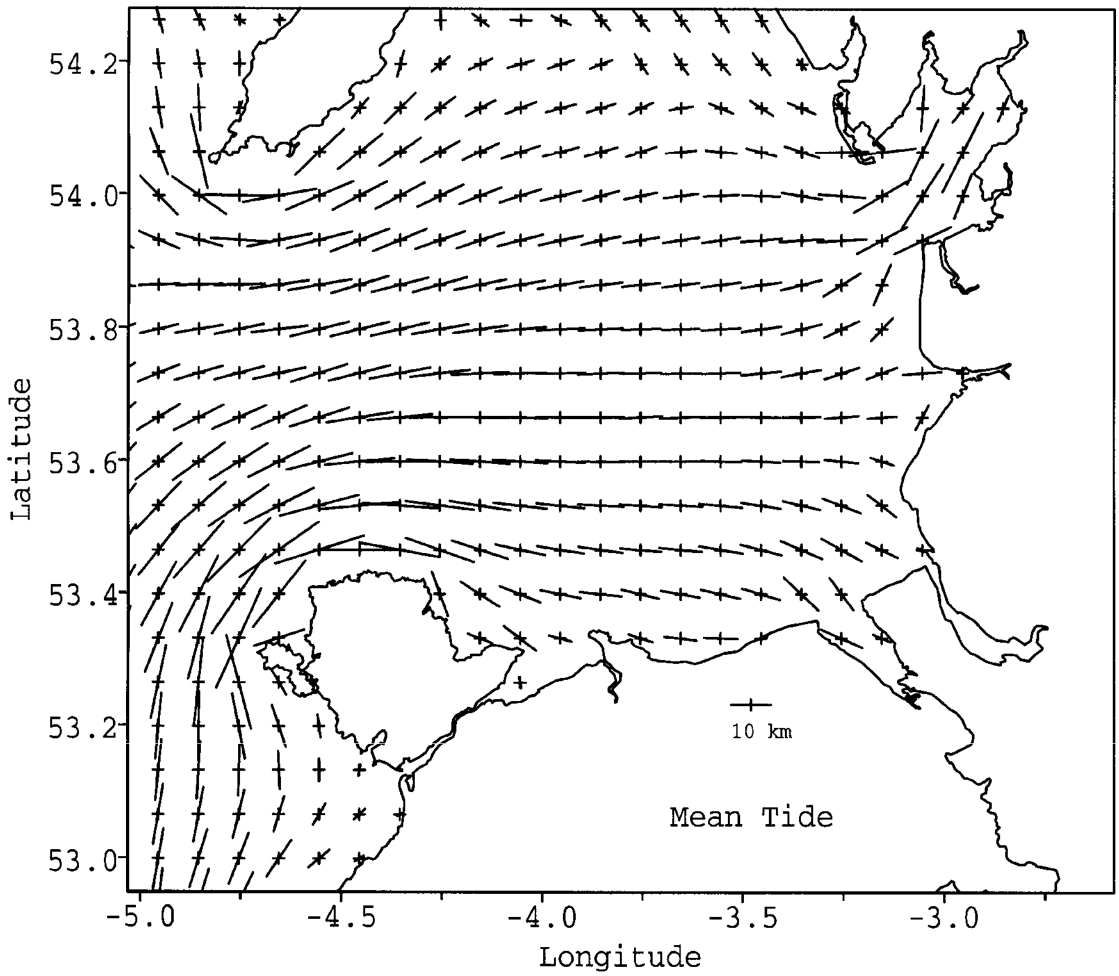


Figure 2.4 Surface tidal excursions during a period of mean tides (mid-way between springs and neaps). (For clarity only every 2nd point has been plotted in each direction.)

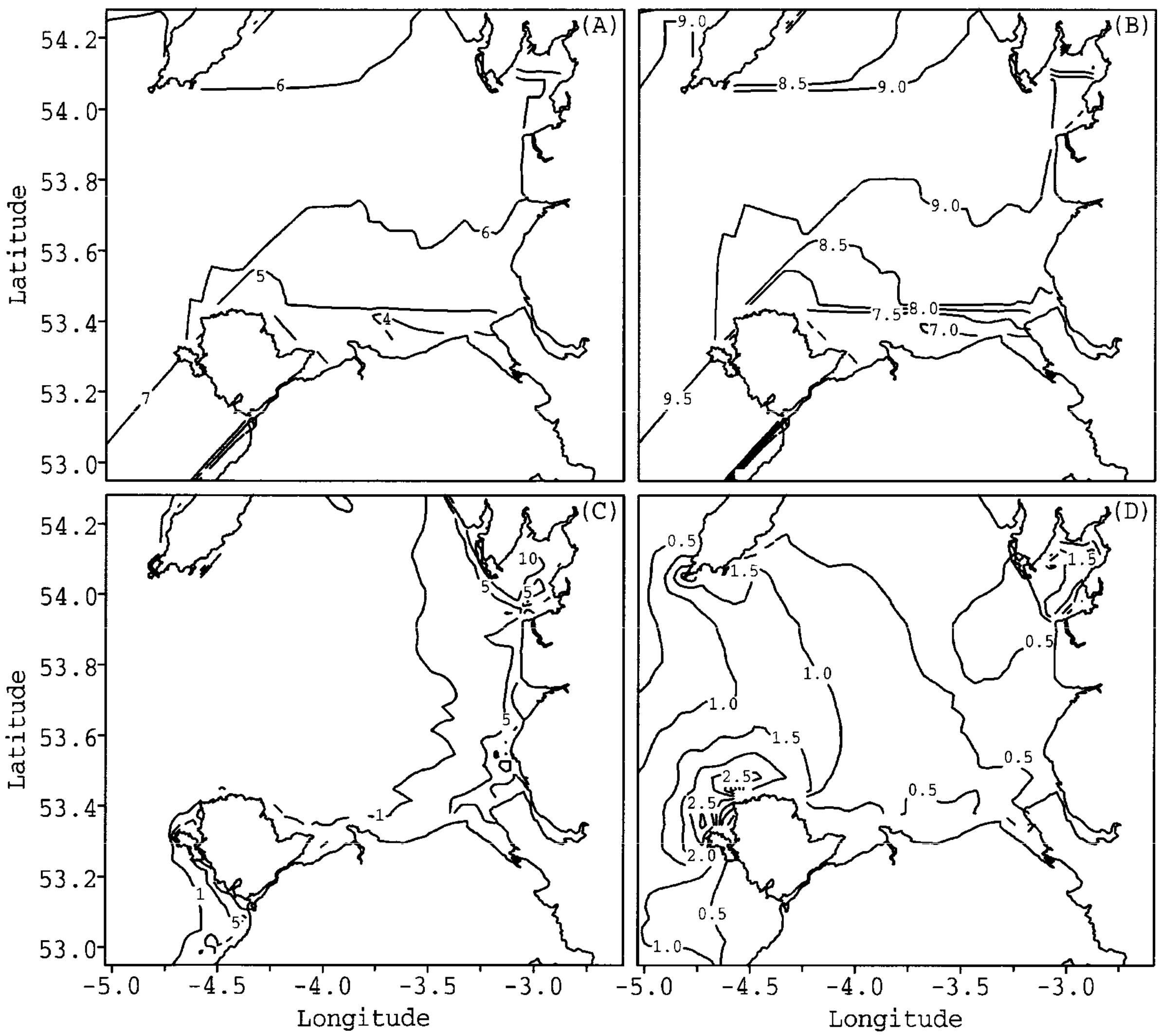


Figure 2.5 (a) Contours of computed maximum significant wave height (m) during 1997-2001. (b) Computed maximum wave period (s) during 1997-2001. (c) Measure of sea bed stress due to the waves (m^2s^{-2}). (d) Measure of sea bed stress due to the tidal currents (m^2s^{-2}).

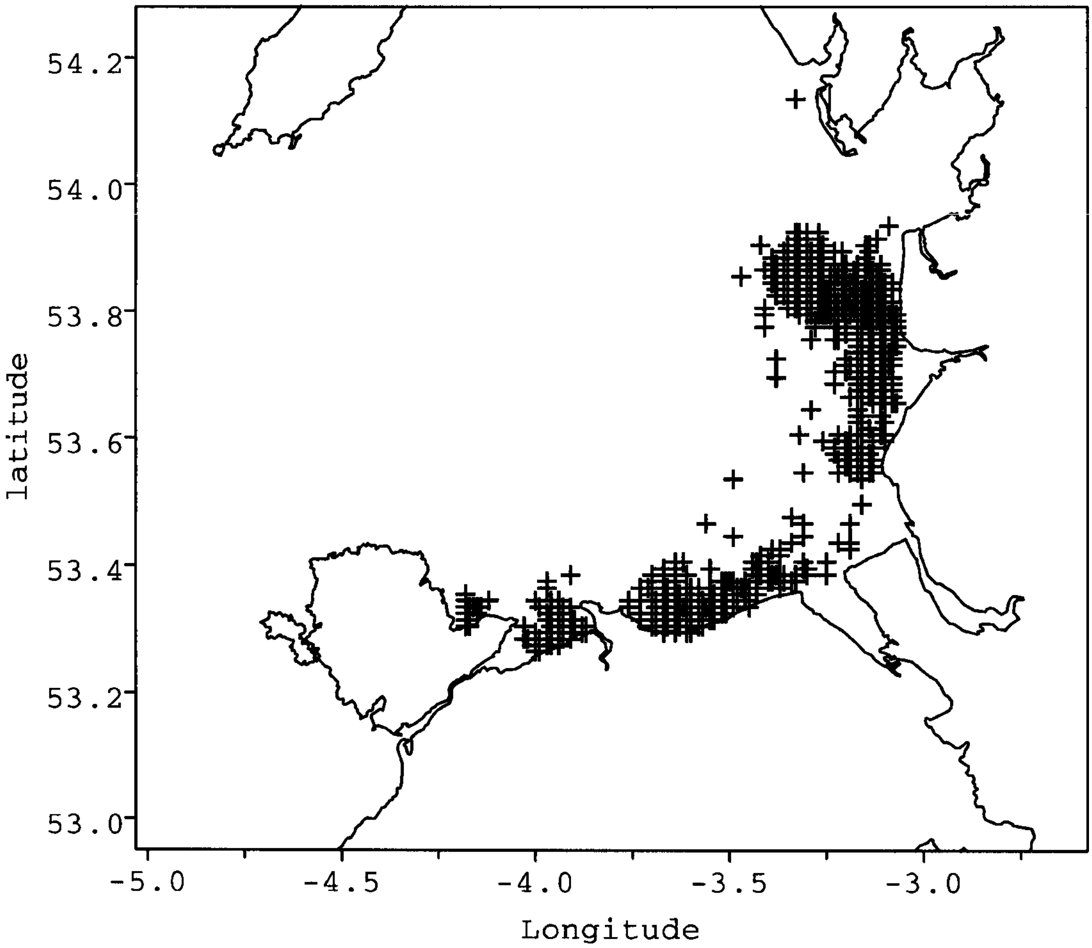


Figure 2.6 Locations at which common scoter were observed during aerial surveys.

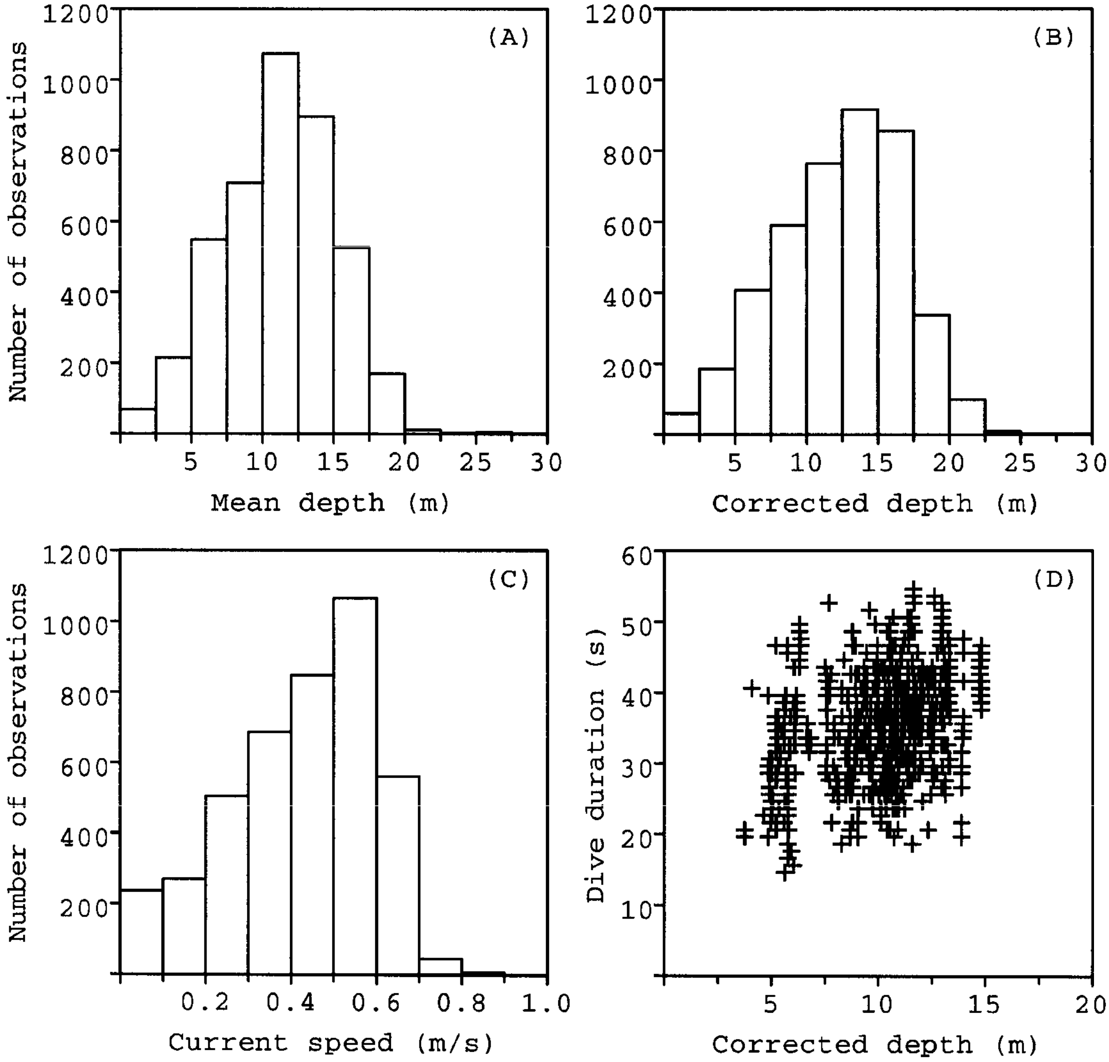


Figure 2.7 (a) Histogram of common scoter numbers versus the water depth with respect to mean sea level. (b) Histogram of common scoter numbers versus the tidally corrected water depth. (c) Histogram of common scoter numbers versus the speed of the tidal current. (d) Scatter plot of dive duration versus the tidally corrected depth.

3. Common scoter distribution in relation to prey-types

3.1 Introduction

Common scoter are diving ducks that feed on prey taxa that live upon or within the upper few cm of the substratum. The diet of common scoter is thought to comprise mainly bivalve molluscs, while other taxa are incorporated less frequently (e.g. crabs, small fishes and gastropods). Echinoderms seem to be included in the diet at such a low frequency that they are presumed to be ingested incidentally (Stott & Olson, 1973; Bourne, 1984; Ferns, 1984; Stempniewicz, 1986; Aulert & Sylvand, 1997; Vaitkus & Bubinas, 2001; present study). Common scoter tend to be highly aggregated and, like other diving ducks, have been reported to severely deplete their food resources over one season (Stempniewicz 1986, Guillemette et al. 1996, Guillemette 1998, Nehls & Ketzenberg 2002 although see Nilsson (1972) for evidence to the contrary). They may, therefore, exert considerable mortality to populations of certain prey-types. The exact mechanism of feeding is unknown although it is unlikely that they are visual feeders, particularly in Liverpool Bay where the water is particularly turbid due to riverine discharge from the Rivers Dee, Mersey, Ribble and Conwy.

Common scoter feed on benthic prey whose life-history strategies and production are intimately linked to the sedimentary and coastal environment that is strongly influenced by near-bed hydrodynamic stress and hence this can be an important determinant of benthic assemblage distribution (Warwick & Uncles 1980; Yates et al. 1993). Shear bed stress will have both positive and negative effects on benthic communities. At low shear stress values, increasing shear increases the supply of food and hence production of the benthos until a threshold where further increases in shear stress inhibit feeding (Hiddink et al. in press). Increasing levels of wave erosion increase mortality of the benthos (Hiddink et al. in press). These two factors are likely to interact close to the coastline and will have a strong influence on the production of the associated benthic communities. In addition, benthic communities are notoriously patchy in their distribution and the population sizes of benthic invertebrates fluctuate greatly from one year to the next (e.g. Rees et al. 1977; Somerfield et al. 2002). Thus food resources available for common scoter are unlikely to be uniformly distributed over the seabed and certain areas will yield higher rates of energy intake than others. Presumably, common scoter, like other diving ducks, distribute themselves over, or in close proximity to, areas that have a sufficient abundance of prey to maintain their energetic requirements and are able to assess the rate of encounter with suitable prey as they probe through the sediment with their bill (Stott & Olson 1973, Phillips 1991). The consistency of the sediment is likely to affect foraging efficiency if selection of prey is by passive sifting through the bill. Sediments that contain a proportion of 'prey-sized' inedible particles may interfere with efficient ingestion such that foraging efficiency is compromised. The profitability of prey will also be affected by the depth to which the birds need to dive for feeding, which is a continuously changing variable in tidal areas. The deeper that benthic feeding birds need to dive, the longer they must take to travel to and from the seabed (Dewar 1924) and the greater the energy that they must expend acquiring prey (Lovvorn & Jones 1991). However, because buoyancy is the predominant force against which ducks have to work during dives (Stephenson et al. 1989), and the uplift generated by air in the lungs decreases as a function of depth and hence increasing pressure, the increasing relationship between depth and energy expenditure may be non-linear (Wilson et al. 1992).

A number of environmental and anthropogenic factors are likely to affect the distribution of the birds at the sea surface: the distribution and quality of the prey that may vary interannually and through the year, the depth of the water over the seabed that fluctuates tidally, the surface current speed which, in Liverpool Bay, will move birds over the ground at speeds of up to 1 – 2 ms^{-1} at peak tidal flow, the distribution and density of conspecifics, diurnal patterns in feeding behaviour and the proximity to human activity and structures. As in other species, the birds probably use visual cues such as the density of conspecifics to locate initial feeding sites before sampling other possible food patches (Nilsson 1972). Because swimming against a current is costly (Woakes & Butler 1983, Hawkins et al 2000), surface currents may be important if birds are required to continually maintain their position over patches of prey by swimming against currents, or by relocating periodically by flying up-stream (see section 2).

Previous studies of the relationship between common scoter and their prey have inferred diet by surveying general areas of seabed in the vicinity of known aggregations of birds (e.g. Degraer et al. 1999). However, in the present study, we were able use aerial surveys of common scoter to generate a more accurate picture of the distribution of a regional population of birds in direct relation to quantitative samples of the benthic assemblage and environmental characteristics of the surveyed area. The specific aims of the present study were to: 1) ascertain whether the distribution of common scoter in Liverpool Bay was related to the distribution of key prey-types, 2) determine environmental factors that may predict either the distribution of common scoter or key prey-types and 3) to ascertain to what extent existing anthropogenic activities influence or constrain the distribution of common scoter. These data provide the basis for predictive modelling of the population effects of likely windfarm construction in Liverpool Bay on the common scoter population (section 8 onwards).

3.2 Methods

3.2.1 Spatial and temporal variation in prey-types

In order to quantify the distribution and quality of food types available in Liverpool Bay it was necessary to undertake an extensive stratified survey that sampled areas of the sea where common scoter had been observed and also areas where common scoter were not observed. For the purposes of the present study, we divided Liverpool Bay into two main areas; the Lancashire coast that extended from just north of Shell Flat to the centre of the entrance to the River Mersey, and the North Wales coast that extended from Red Wharf Bay across to the centre of the entrance of the River Mersey. These two areas held distinct high density aggregations of common scoter. The outer limits of our survey area were set by the reported maximum dive depth for common scoter which is commonly believed to be 20 m (Degraer et al. 1999). As depth directly affects energy expended on travelling to and from the seabed and while foraging on it, we calculated depth bathymetries at 5 m intervals for both spring and neap tides. When possible, a selection of our sample sites coincided with the intersection between these depth bathymetries and the aerial survey flight paths that would enable a direct analysis of the relationship between common scoter abundance and prey abundance at these sites. Additional survey sites were selected to ensure that the full gradient of depth zones was sampled across Liverpool Bay. Three surveys were undertaken from the RV Prince Madog in August and December 2003 and April 2004 to span a full overwintering season of common scoter in Liverpool Bay.

During the initial survey in August 2003, 81 and 88 sites were sampled off the Lancashire and North Wales coast respectively (Fig. 3.1). At each site, three 0.1 m^2 Day grab samples were taken and the contents of the first two were sieved over a 1 mm mesh aboard ship. Bivalves were picked off the mesh by hand and frozen for later biomass analysis. All other residues and biota were preserved in 4% buffered formalin. A sediment sample was collected from the third Day grab and the rest of the sample was discarded. Of these sites, a total of 24 sites (12 in each area) were selected for monitoring purposes (total of 4 Day grabs). These sites were termed monitoring sites and were resampled with the same sampling effort in December 2003 and April 2004 to enable the rate of decline of prey types to be calculated (mortality rate). Seventeen of the 24 monitoring sites occurred in areas over which common scoter were not observed or occurred in low numbers throughout the overflight surveys. These 17 sites provide important information on the natural seasonal changes in potential prey abundance in the absence of common scoter. In addition to these sites, we sampled two transects of 6 sites spaced at an interval of 200 m to gain an estimate of small-scale variability in terms of prey-types and their abundance. Four Day grab samples were collected at each of these sites.

Given the necessity to collect a large number of samples across as wide an area as possible, our ability to analyse all components of the benthos within samples was constrained by time and manpower. As a result, we undertook an extensive search of the literature to ascertain the main recorded prey types of common scoter. Twenty one separate publications that dealt with the diet of common scoter or velvet scoter *Melanitta fusca* were polled. Of 199 records of prey types consumed, c. 75% were bivalves (Table 3.1). As a consequence we have focused our analysis in the present study on the distribution of mollusc prey in Liverpool Bay, although we also quantified seasonal changes in total benthic biomass.

3.2.2. Long-term variation vs spatial variation

Prey resources for common scoter may fluctuate on an annual basis as a result of variation in juvenile recruitment and rates of predation on adult stocks. We investigated the degree of interannual variation from a dataset of bivalve abundance sampled in Liverpool Bay from 2001 to 2004. These samples were collected from Conwy Bay in November 2001 and 2004, from the area off Llanddulas and Shell Flat in March 2002 and August 2003. In all cases sampling was undertaken using the same 0.1 m² Day grab and all bivalves retained on a 1 mm mesh sieve were counted and identified. The mean abundance and standard deviation for each species collected on each sampling occasion was calculated and the coefficient of variation (S.D./mean) ascertained. The mean ± S.D. and C.V. for mean of each species across years (2001 – 2004) was also calculated to enable a comparison of spatial variation (within one year) with the interannual variation.

3.2.3 Bivalve biomass

The literature search yielded a list of in excess of 30 different species of bivalve that have been recorded in the diet of common scoter. We considered that it is unlikely that common scoter are species specific in their choice of prey, but that selection in more likely to be determined by prey morphology, digestibility and energy content. As a result we considered mollusc prey to fall into three main prey morphologies; elongate prey (e.g. *Ensis, Pharus, Phaxas*), ovate brittle shelled (e.g. *Abra, Fabulina, Lutraria*) and ovate hard shelled (e.g. *Nucula, Donax, Chamelea*) (Table 3.2). All of these species are either surface dwelling or are in direct contact with the sediment/water interface and hence all are considered available as potential prey for common scoter. For each sample site, mollusc prey-types were defrosted and their shell dimensions measured to the nearest 0.1mm using Vernier callipers. Maximum length was measured along the anterior-posterior margin axis. Maximum width was measured by placing the callipers on the umbo and sliding them along the ventral margin until the maximum width was reached. For each species, 50-70 individuals were randomly selected from all the samples for each area and season in order to establish Length-Ash Free Dry Weight relationships. Mollusc flesh was removed from the shell and was dried to a constant weight at 90°C for 24 hours in pre-weighed crucibles. Dry flesh was then placed in a muffle furnace set at 550°C for 2 h to determine the ash free dry weight content (AFDW) to the nearest mg. Shells were dried and ashed separately following the same methodology. Elongate bivalves (particularly *Pharus*) were quite commonly broken during sampling and only the anterior part was collected in the samples. For theses species, we established Length-Width relationships with regression analysis (for each area and sampling occasion) in order to calculate their length. Pooling together the data on species for the three prey types, length – AFDW (flesh and shell) equations were calculated for each prey type, area and sampling occasion with regression analysis and these relationships were used to estimate the AFDW of the remaining bivalves.

The relationship of AFDW on depth was modelled as a Gaussian curve according to:

$$G = G_{\min} + (G_{\max} - G_{\min})e^{\frac{(S-S_m)^2}{-V}}$$

where G is the depth dependent bivalve biomass modifier, G_{min} is the minimal biomass, G_{max} is the maximum biomass, S is depth (m), S_m is the depth at which the maximum biomass is attained and V is the variance of the Gaussian curve.

3.2.4 Survival rates

Daily survival rates of the bivalve prey throughout the overwintering period were calculated from monitoring station abundances. Of the 24 monitoring stations, only the 17 that fell outside dense common scoter aggregations were included in the analysis in order to remove the effect of common scoter predation. Since common scoter have different functional responses for different prey sizes, it was decided that the prey type abundances would be divided into 4 size classes for the oval brittle and oval solid bivalves (0-12, 12-24, 24-36 and >36mm) and 6 size classes for the elongate bivalves (0-12, 12-24, 24-36, 36-48, 48-72 and >72mm) and survival rates were calculated accordingly by prey type and size class. Bivalve data were pooled by area and the daily survival rates for the periods of August to December and December to April were calculated from the formula:

$$(final\,abundance / initial\,abundance)^{-number\ of\ days}$$

3.2.5 Infaunal residue

The remaining biota in the formalin preserved benthic samples were stained with rose Bengal, washed over a 0.5mm sieve, sorted into major taxonomic groups (Actiniaria, Bryozoa, Decapoda, Echinodermata, Fish, Gastropoda, Tunicata, small bivalves, small crustaceans and worm-like animals) and preserved in 70% ethanol. Small bivalves include mostly juvenile representatives (<2mm) of the recorded bivalve species, small crustaceans consist of mysids, cumaceans, amphipods and juvenile decapods and worm-like animals include polychaetes, oligochaetes, sipunculids, nemerteans and the anemone Edwardsia by exception to the rest of the Actiniaria because of its resemblance to other representatives of this group. Organisms were blotted dry and the groups were weighed to the nearest mg. (Due to time restrictions, only one out of the two replicate grabs in each station was processed). Dry mass was converted into AFDW using established conversion factors reported by Thomas Brey (electronic reference).

3.2.6 GIS generated data for behavioural model

3.2.6.1 Interpolations

Bivalve data (abundance/0.2m^2) from the sampled stations were used to predict the distribution of the respective bivalve prey type-size class groups, as described above, in areas potentially available to the birds as feeding grounds through spatial interpolation methods. All interpolations were carried out with ArcView GIS and Spatial Analyst and were based on the Inverse Distance Weighted method with a fixed radius of 2.5km. The next step was to bring the bivalve data to the same spatial reference level with the environmental data provided by the tidal model and the common scoter behavioural model which will combine all the available data and will function on the basis of the tidal model grid. Hence, the tidal model grid cells were overlaid on the interpolated abundance grid maps and the average (max and min) bivalve abundance was calculated for each of the relevant grid cells.

3.2.6.2 Proposed windfarms and shipping activity

One of the data requirements of the behavioural model was the estimation of the potential feeding area of the common scoter that would be unavailable to them due to anthropogenic activities such as windfarm developments, shipping traffic and aerial traffic. All spatial data were processed and analysed with ArcView GIS. The positions of the proposed windfarms were entered into ArcView as a map layer together with the tidal grid cells. Shipping intensity data was made available to us by Anatec UK Ltd as number of ships passing from each tidal grid cell per year. The potential effects of disturbance by helicopter flights to and from oil and gas installations were also considered. These potential sources of disturbance are dealt with in more detail in section 5.

3.2.6.3 Environmental parameters

Data on mean water depth, surface current speed (m/sec) and bottom sheer stress (N/m^2) were derived from the tidal model for the central points of the 3.70 x 3.35 km grid cells (section 2). The data were then used to produce interpolated continuous raster grids, from which relevant information could be extracted for any point of the tidal grid surface. Sediment parameters were investigated from samples collected during the benthic surveys.

Sediment samples were defrosted, dried at 90°C to dry weight and 25 g were removed for analysis. Samples were soaked overnight in 250 ml of water with 10ml sodium hexametaphosphate (6.2g/l) to desegregate the sediment particles (Buchanan, 1984). After wet-sieving over a 63 µm mesh sieve to remove the fine particles, the sediment was re-dried and then separated into its component size fractions by dry-sieving with a reciprocating shaker. The different fractions were then weighed. The total organic carbon contents (TOC) of the sediment was determined from sub-samples of the dried sediment, weighed before and after combustion in a muffle furnace for 2 h at 550°C, and hence provided an estimate of the ash-free dry weight of the samples (Buchanan 1984).

3.2.7 Statistical analyses

In order to determine which of the measured suite of variables best explained the observed distribution of common scoter we used a general linear modelling procedure after log10 transformation of observed common scoter numbers. We related each individual recorded geo-referenced sighting of common scoter for the period August 2003 to May 2004 (total of eight overflights) to the associated environmental and biological variables at that location (determined from the GIS layers described in 3.2.5.2). Therefore this analysis relates only to those locations where common scoter were observed. Prior to undertaking the GLM, a correlation matrix for all variables was constructed and strongly auto-correlated variables removed. The variables included were: shear stress, mean surface current velocity, mean depth, sediment type (either sediment with a mud content of < 5% or > 25% derived from British Geological Survey data), bivalve biomass, and number of ships per annum. The correlation matrix gave a coefficient of -0.97 for the relationship between shear stress and surface current velocity, so the former was removed from further analysis. This makes sense as shear stress is the product of the relationship between surface current velocity and depth (see section 2).

As bivalves are key prey for common scoter we investigated which suite of environmental parameters best explained variation in total bivalve biomass at each sample location. For this analysis we were able to utilise sediment characteristics for each site as opposed to interpolated values determined from British Geological Survey data as in the GLM analysis above. General Additive Modelling (GAM) was used as this approach can cope with non-linear relationships among predictor and response (bivalve biomass) variables. The following variables were examined: surface current velocity, shear stress, distance from shore, depth, gravel content (%), sand content (%), mud content (%), organic matter content (%), and median phi.

Generalized additive models extend linear models and generalized linear models by flexibly modelling additive non-linear relationships between the predictors (e.g. environmental variables) and the response (bivalve AFDW). Whereas linear models assume that the response is linear in each predictor, additive models assume only that the response is affected by each predictor in a smooth way. The response is modelled as a sum of smooth functions in the predictors, where the smooth functions are estimated automatically using smoothers.

Smoothing is a non-parametric technique which relies on the data to specify the form of the model and fit a curve to the data locally. With this technique, the curve at any point depends only on the observations at that point and some specified neighbouring points. In locally weighted regression smoothing, the smooth function is built as follows:

1. Take a point. Find its nearest neighbours, which constitute a neighbourhood. The number of neighbours is specified as a percentage of the total number of points. This percentage is called the span.
2. Calculate the largest distance between and another point in the neighbourhood.
3. Assign weights to each point.
4. Calculate the weighted least squares fit of on the neighbourhood. Take the fitted value.
5. Repeat for each predictor value.

As a result of using such a technique, the degrees of freedom (df) generated are may be somewhat unfamiliar to those used to dealing with linear models. Given a linear smoother operator S , we define the degrees of freedom df to be simply df=tr(S). Thus df is the sum of the eigenvalues of S , and gives an indication of the amount of fitting that S does. The number of df is a function of the span and the predictor values in the data set, and is not a function of the response Y. A span of 100% appears to imply a linear regression and thus two df; the use of only 50% of the data, corresponds to about four degrees of freedom (Hastie & Tibshirani, 1990).

3.3 Results

3.3.1 Spatial and temporal variation in prey-types

Benthic samples from Shell Flat were numerically dominated by the small nut shell *Nucula nitidosa* followed by *Pharus legumen* and *Abra alba.* In contrast, samples from Llanddulas were numerically dominated by *Donax vittatus* followed by *Abra alba* and *Pharus legumen* (Table 3.3). *Nucula* contributed most to the similarity among sites sampled off the Lancashire coast, but did not contribute greatly (if at all) to the similarity of sites sampled off the North Wales coastline. *Abra* and *Pharus* contributed most to the similarity among stations off the North Wales coast (Table 3.4).

The median biomasses (AFDW) of bivalves per unit area sampled from the Lancashire and North Wales sites were not significantly different (Fig. 3.2, M-W, U = 7057, d.f. = 167, P = 0.18) although there was some evidence to suggest that there was less variability in bivalve biomass at the sites off Lancashire. Mean AFDW of bivalves was higher than that of other components of the benthos across Liverpool Bay. At the monitoring sites, AFDW of bivalves and other benthic fauna was lower in April 2004 than in August 2003 but this was not a significant decrease for the bivalves (Table 3.5). However, the coefficient of variation of bivalve AFDW increased significantly from August 2003 to April 2004 which indicated that biomass was more patchily distributed across the seabed by the end of winter (Table 3.5). At both locations, the biomass of bivalves was significantly related to depth according to a Gaussian relationship. The Gaussian relationship for each site indicated that a peak in bivalve biomass occurred at a depth of 7.88 m and 13.96 m off the North Wales and the Lancashire coasts respectively (Fig. 3.3, Table 3.6). The use of tidal models to hindcast the depth of water beneath common scoter observed during overflights indicated that most birds occurred more frequently over water between 7 – 15 m deep off North Wales (mean±S.D. 11.12±2.82 m) and between 13 – 18 m (13.95±2.81 m) deep off Lancashire (Fig. 3.4). Thus, birds were observed most frequently over water that was significantly deeper off Lancashire than off the North Wales coastline (Wilcoxon Z = -1.94, P = 0.025) (see also section 2). Further examination of the distribution of common scoter across the different depth zones (based on mean depth) indicated that birds were skewed in their distribution across shallow (8 m) water out to the 20 m depth zone but rarely beyond (Fig. 3.4b, x^2 = 64.4, d.f. = 1,11, P < 0.0001).

The spatial distribution of different prey types was highly aggregated (Fig. 3.5). Small oval hard shelled prey (e.g. *Nucula*) were ubiquitous off Lancashire and to a lesser extent off the North Wales coastline but were particularly abundant on the northern shoulder of Shell Flat off Blackpool (Fig. 3.5a). Very high densities of *Donax* were sampled off the mouth of the River Dee on Chester Flats (Fig. 3.5a). Oval brittle prey types were relatively ubiquitous but were particularly abundant on Burbo Flats off the mouth of the River Mersey and off the North Wales coast and locally at Shell Flat (Fig. 3.5b). Elongate prey such as *Pharus* were locally abundant off the River Ribble and off the North Wales coastline and occurred in very high abundance in Red Wharf Bay (Fig. 3.5c). The interpolated map of total bivalve biomass (all species amalgamated) indicates that the highest concentrations of bivalve biomass occurred on Shell Flat, off the River Mersey and in Red Wharf Bay (Fig. 3.6). Survival rate data for each prey-type were calculated to enable parameterisation of the behavioural ecology model. The data for these calculations can be found in Appendix 3.#. Spatial variation in the abundance of selected species of bivalves and all bivalves pooled together was greater than inter-annual variation in 28 out of 35 occurrences (Fig. 3.7).

3.3.2 Explanatory variables

After the removal of shear stress prior to the GLM analysis, all of the variables contributed significantly to the model that explained best the relationship with the abundance of common scoter. Of these variables bivalve AFDW explained the greatest proportion of the variance, followed in rank order by: depth, sediment type, surface current velocity and finally ship disturbance (Table 3.8). The GAM for bivalve biomass indicated that Log depth (P = 0.01) and Log phi (P = 0.04) were the only variables that explained significantly the variation in bivalve biomass (Table 3.8, Fig. 3.8). Depth is frequently an important explanatory variable of benthic community distribution and composition. In this study depth affects the extent to which wave action influences erosion at the seabed which is a key environmental forcing agent in Liverpool Bay (see section 2). The GAM results suggest declining bivalve AFDW with depth and increasing bivalve AFDW with increasing values of median phi (Fig. 3.8).

3.4 Summary and discussion

Overflight observations of birds at sea have the advantage that they enable large-scale surveys of population density to be undertaken within a short time period (Cranswick et al. 2003). Nevertheless, this approach is problematic for a number of reasons, but particularly for diving ducks found in areas of high tidal amplitude. As water depth is a critical parameter for common scoter that feed on the seabed, the relative position of an aggregation may shift according to tidal state (low to high water) which can vary considerably between the start and end of the survey. Thus we felt using the sum total of two years of overflight observations would eliminate some of the spatial variation of common scoter attributed to tidal fluctuations. In addition, we were able to utilise tidal models to hindcast the depth of water beneath each separately logged record of common scoter. Common scoter located off Lancashire were primarily observed over deeper water than birds observed off the coast of North Wales (Fig. 3.4). Other shore-based studies have indicated that common scoter are found over water depths of between 3 – 20 m which is similar to our shore based observations for Llanddulas and Red Wharf Bay (Dewar 1924; Madsen 1954; Stott & Olson 1973; Cramp & Simmons 1977; Goudie & Ankney 1986; Meissner & Brager 1990; Durinck et al. 1993; Brager et al. 1995). However, seaducks can be found in areas where the water is too deep to dive for food (Degraer et al. 1999). It is clear from the aerial survey that common scoter utilise areas of the sea beyond the range of normal telescopic observations and occur over water up to a maximum depth of 25 m although the majority of birds are found in water shallower than 20 m.

Most authors agree that feeding areas used by common scoter are restricted to water of less than 20 m depth due to the constraints imposed by the energetic costs of diving to the seabed to consume benthic prey species. The present study is to our knowledge the first that has quantified the biomass density of prey across the full range of water depth reported by other authors. The depth distribution of common scoter off Lancashire and North Wales appears to closely coincide with the depth at which the peak in bivalve biomass occurs in both locations. This depth zone of the biomass peak differed for the two localities and was significantly deeper off Lancashire. Currents and the associated seabed shear stress, can influence food availability for benthic communities (Jenness and Duineveld 1985) and benthic secondary production (Warwick and Uncles 1980; Wildish and Peer 1983). High shear stress results in scouring and high current velocities inhibit feeding activity, while water movement at the sea bed is necessary for the supply of food to the benthos. Below a certain current velocity threshold, food particles transported from other areas may begin to sink to the seabed, where they become available as food to the benthos (Creutzberg 1984). In additional to the natural mortality rates, which relate to body-size, sediment movement due to wave action caused by wind and tides, can be a major cause of mortality among benthic animals and has been shown to affect secondary production (Emerson 1989). Both shear and erosion are likely to interact with depth such that at some distance from the shore it is likely that a critical depth occurs where food supply from shear and mortality from erosion coincide to generate optimal conditions for growth. Although the Gaussian model that described the relationship between bivalve biomass and depth was significant for both survey areas there were some sites that had an exceptionally high biomass of bivalve prey, particularly off Lancashire. These exceptional biomass sites occurred in the depth range over which most birds were observed.

Previous studies have attempted to relate the constituents of a benthic community to known large-scale aggregations of common scoter. For example, Degraer et al. (1999) inferred that the benthos found on offshore subtidal sand banks was indicative of common scoter diet given that large aggregations of ducks were observed over these seabed features. Nevertheless, while Degraer et al.'s (1999) findings concur with the assertions of other studies (e.g. Durinck et al. 1993; Leopold et al. 1995; Stempniewicz 1986), their study was not designed to resolve the relationship between the spatial distribution of ducks and the spatial variation in the abundance or biomass of potential prey. Lovvorn & Gillingham (1996) stated that "detailed mapping of benthic foods on a scale relevant to the foraging energetics of highly mobile birds is currently not feasible, despite the importance of food dispersion to their foraging profitability and sustainable population levels". The present study is the first in which it has been possible to discern the relatively fine-scale distribution of common scoter over their feeding grounds in relation to potential prey species. All of the prey species reported in the present study have been reported as prey of common scoter in previous studies. It is clear that individual prey species are highly patchy in terms of their distribution, but when the sum biomass of all species was interpolated it was clear that some of the areas with the highest biomass density of potential prey species did not coincide with observations of common scoter (e.g. off the River Mersey). It is noteworthy that although there was a very high biomass of bivalves in Red Wharf Bay, common scoter were only observed here towards the end of the 2003/2004 winter season. Direct observations of dive times of birds in Red Wharf Bay indicated that dive time was significantly longer than at shallower water sites off Llanddulas North Wales (Fig. 3.9). As common scoter appeared in Red Wharf Bay only towards the end of the season it may be that they preferentially choose shallow sites whenever possible to minimise energy expended on diving.

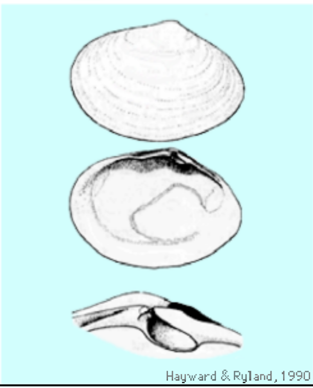
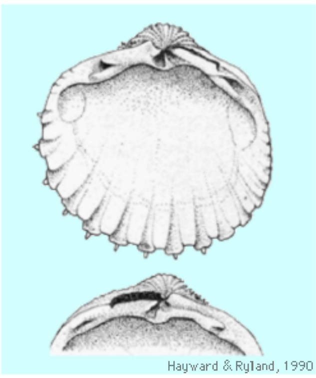
The prey-size categories reported in areas utilised by common scoter concur with previous studies that have reported that common scoter consumed prey of 5 – 40 mm shell length in size (Kube 1996; Meissner & Bräger 1990; Durinck et al. 1993). If length describes the maximum dimension of a prey item this may not be the most relevant parameter with respect to ingestion capability, for example a razor shell (*Ensis* sp.) may be over 50 mm long but only 10 mm wide (MJK personal observations), and the elongate bivalve *Phaus legumen* appeared to be important across Liverpool Bay. Other species such as *Nucula* spp. may be highly abundant but have a small maximum size. They were particularly abundant on the northern shoulder of Shell Flat. Although abundant, consumption of this prey-type may be relatively unprofitable due to the additional energetic costs and dietary constraints associated with processing a high proportion of shell material (Bustnes & Erikstad 1990; Bustnes 1998; Hamilton et al. 1999; Lovvorn et al 2003). The spatial patchiness of the individual species of bivalve prey indicated that it is highly unlikely that common scoter are species-specific in terms of prey choice, hence the decision to amalgamate our consideration of prey distributions in terms of 'prey-types' seems most appropriate.

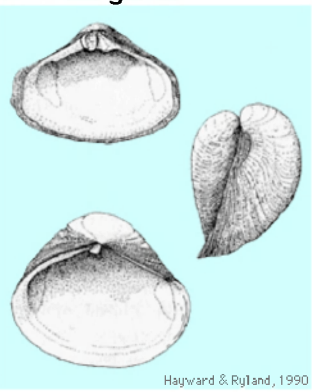
While overflight observations provide useful information on the large-scale distribution of birds at sea, it is infeasible to make detailed observations of birds in situ using such techniques. Birds aligned themselves into the wind when wind speed was force 4 or higher (see section 4). At lower wind speeds the orientation of birds on the water was influenced by sea surface currents. Woakes & Butler (1983) found that the energetic cost incurred by Tufted ducks swimming against a current increased rapidly above current speeds of 0.5 ms^{-1}. No common scoter were observed in areas of the sea with a surface current speed of > 0.6 ms^{-1} (from overflight data). Surface current speed is related to seabed shear and while birds may have to reposition more frequently in areas with high surface current speed, these areas may also have lower bivalve biomass. Common scoter were observed infrequently in Conwy Bay, yet this sheltered site might provide shelter during periods of severe weather. However observations in the present study indicated that common scoter remain at the sites of the main common scoter aggregations and did not utilise sheltered areas even in conditions of force 7/8 onshore winds (see section 4 for further details).

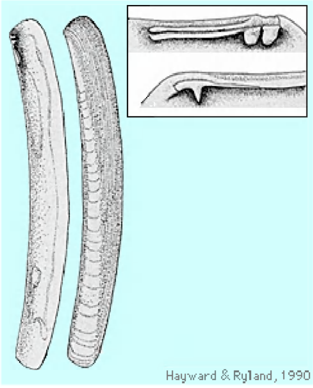
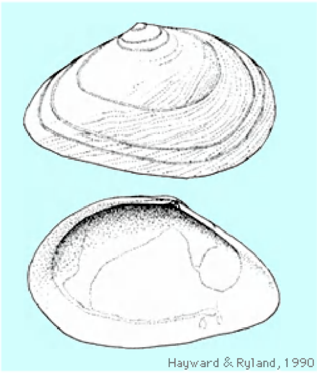
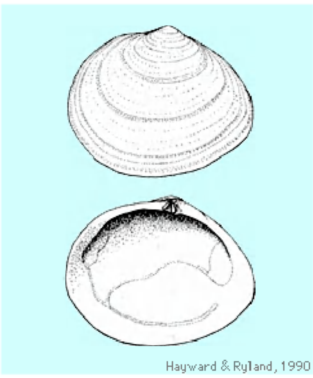
Table 3.1 Number of separate instances of different prey types recorded in the diet of common scoter (n = 199) or velvet scoter (n = 6) from 21 separate publications and shown as a percentage of all recorded instances. The category 'Other' includes chironomids, fish eggs, dragon fly larvae, insects and plants.

	Number	%	%
Bivalves	128	62.4	
Molluscs indet.	11	5.4	
Gastropods	14	6.8	
All molluscs			74.6
Crustaceans	21	10.2	
Other	13	6.3	
Fish	7	3.4	
Annelids	6	2.9	
Echinoderms	5	2.4	
All other prey			25.4

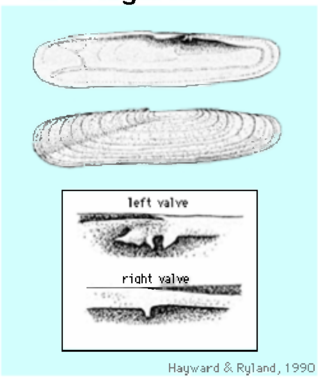
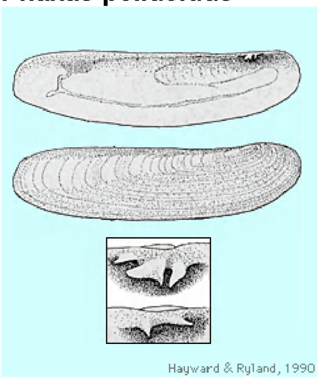
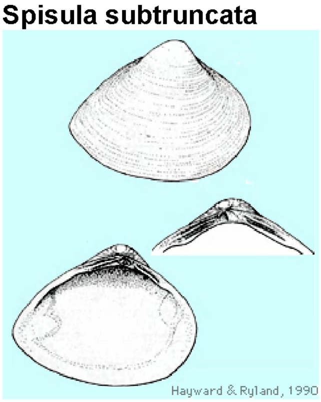
Table 3.2 Bivalve species found in the survey and some key features of their morphology and habitat.

Species	Description	Colour	Size	Habitat
Abra alba 	Shell thin and brittle, broadly oval	White and glossy; periostracum thin	Up to 25 mm long	Burrows in groups in soft substrata; occasionally on the lower shore but most abundant in shallow, offshore waters (to about 60 m) where it may be a dominant member of the benthic infauna.
Acanthocardia tuberculata 	Shell thick and strong, approximately rhombic in shape. Sculpture of 18-20 bold ribs and fine concentric grooves and ridges. Each rib has a central keel, bearing short pointed spines	Off-white, yellow, or light brown, often in concentric bands of different shades. Periostracum thin, yellowish	Up to 90 mm long	On muddy sand and gravel, from the lower shore into the shallow sublittoral

Chamelea gallina  	Shell is solid, thick, equivalve and broadly triangular in outline. Sculpture of numerous concentric ridges	Dirty white, cream or pale yellow, occasionally polished, usually with three red-brown rays of varying width, radiating from the umbones	Up to 4.5 cm long	Inhabits bottoms of clean sand and muddy sand, from above low water-mark to 55 metres
Corbula gibba  	Shell thick, broadly oval to subtriangular, umbones close to midline; right valve convex, enclosing and overlapping left. Sculpture of coarse concentric grooves and ridges	Dull white to cream; periostracum coarse, grey-brown, usually worn at the umbones	Up to 15 mm long	In muddy sand and gravel, occasionally on the lower shore, most abundant offshore
Donax vittatus  	Shell roughly wedge-shaped, umbones posterior to midline, ventral margin distinctly crenulate. Sculpture of fine concentric grooves and numerous fine radiating striations	White, yellowish, light brown, or purple, frequently lighter about the umbones. Periostracum light brown to olive-brown, glossy.	Up to 35 mm long	In sand, from the lower shore into the shallow sublittoral
Dosinia sp.  	Shell almost circular, inequilateral. Anterior hinge line shallowly concave below lunule. Sculpture of numerous fine concentric ridges, shell surface smooth to touch	Off-white, fawn, or light brown, umbones often tinted yellow or pink. Periostracum thin	Up to 40 mm long	In sandy mud, sand, and shell-gravel, from the lower shore to at least 120 m

Ensis ensis 	Shell thin and brittle, dorsal and ventral margins distinctly and symmetrically curved about midline of shell; anterior margin rounded	Dull white or cream, with pale reddish or purplish brown streaks and spots; periostracum glossy, light to dark olive or green	Up to 130 mm long	Burrows in fine sand on the lower shore and in the shallow sublittoral
Fabulina fabula 	Shell is brittle, somewhat flattened, slightly inequivalve. Sculpture of concentric lines with, in the right valve only, diagonal lines superimposed upon them.	White in colour with tinges of yellow or orange	Up to 19 mm long	Clean silty sand, sand, or muddy sand, from the middle or lower regions of the intertidal zone to a depth of about 55 m.
Lutraria sp. 	Shell elongate, somewhat quadrate, anterior hinge line sloping more steeply than posterior. Umbones anterior to midline. Sculpture of numerous fine grooves.	Dull white or yellowish, periostracum pale yellowish brown	Up to 100 mm long	In mixed soft substrata, offshore to about 50 m
Macoma balthica 	Shell broadly oval, umbones more or less on midline. Sculpture of numerous, fine, concentric lines	Colour very variable: white, yellow, pink, or purple, in various shades, unicolorous or banded.	Up to 25 mm long.	Burrows in soft substrata, particularly in estuaries and on tidal flats, where it may be abundant.
Mactra stultorum	Shell thin and brittle, oval, umbones just	White, tinted purple about		

	anterior to midline. Sculpture of very fine concentric lines, growth stages clear. Shell margin prominent at hinge line	the umbones, with light brown rays of varying width radiating from umbones; periostracum light brown, thin	Up to 50 mm long	Burrowing in clean sand, from the lower shore into the shallow sublittoral
Moerella donacina 	Shell is brittle, slightly inequivalve, right valve a little more convex than the left. Inequilateral, beaks in the posterior half. Oval in outline anteriorly	Background colour of dirty white or pale yellow ornamented with pink rays radiating from the beaks. Periostracum is faint, red-brown	Up to 25.4 mm long	Around the British Isles inhabits coarse sand and shell-gravel, offshore to about 45 metres but may occasionally be collected between tide-marks
Mysella bidentata 	Shell thin and fragile, oval, the umbones are posterior to midline. Sculpture of fine, closely spaced, concentric lines; growth stages are clear	White or translucent, periostracum light brown or olive	Up to 3 mm long	From ELWS to about 100 m, in muddy sand or fine gravel, in crevices of dead oyster valves, in the burrows of the sipunculid Golfingia , or associated with the ophiuroid Acrocnida
Nucula nitidosa 	Shell solid, equivalve; inequilateral, beaks behind the midline; triangular in outline. Fine radiating striations and fainter concentric lines	Shell white or grey with bluish growth lines; periostracum very glossy, olive or yellow-olive, often with concentric bands of light yellow	Up to 13 mm long	On silt and fine sand. Down to 100 m

Pharus legumen 	Shell thin and brittle, elongate, about four times as long as deep; anterior and posterior margins rounded, gaping at both ends. Anterior end distinctly tapered.	White or light brown, with a glossy, light olive or yellow periostracum.	Up to 12.7 cm long	Burrowing in sand, from the lower shore into the shallow sublittoral.
Phaxas pellucidus 	Shell thin and brittle, elongate; dorsal margin practically straight, ventral margin curved. Anterior end rounded and upturned, posterior slightly truncate	White or cream, sometimes with dark markings; periostracum glossy, light yellow-brown or olive	Up to 40 mm long	In mixed fine substrata, offshore to about 100 m.
Spisula elliptica 	Shell thin, elongate oval, umbones close to midline. Sculpture of fine concentric lines and grooves, growth stages clear	Dull white with greenish or greyish brown periostracum	Up to 30 mm long	In mixed soft substrata, offshore to about 100 m
Spisula subtruncata 	Shell thick and strong, subtriangular but distinctly asymmetrical; umbones close to midline, posterior end appearing slightly drawn out	Dull white to cream, periostracum greyish brown	Up to 30 mm long	Burrowing in muddy or silty sand, from the lower shore into the shallow sublittoral.

Tellymia feruginosa 	Shell is fragile, equivalve and inequilateral, beaks in the posterior half. Outline is regularly oval	White. Periostracum is thin, often covered by a thick rust-coloured deposit	Up to 7.9 mm long	Particularly in fine muddy sand. A common commensal of Echinocardium cordatum , one of the sand-burrowing echinoderms
Thracia phaseolina 	Shell is brittle and inequivalve. Approximately oval in outline with the dorsal posterior line straight, and the posterior margin truncate. Sculpture of smooth concentric lines and ridges	White	Up to 38 mm long	In sand, muddy sand and sandy gravel from very low in the intertidal zone to about 55 m
Thyasira flexuosa 	Shell thin and fragile, broadly oval, tending to be irregular. Umbones on midline. Each valve marked on either side by distinct groove; lower groove causes deep indentation.	Dull white, with pale yellowish brown periostracum	Up to 18 mm long	Offshore, to the edge of the continental shelf, in muddy sand

Table 3.3 The most common species sampled off Lancashire and in the south of Liverpool Bay in August 2003. Sample size n = 81 stations Lancashire, n = 88 North Wales (two samples at each station, mean abundance of two samples shown).

Lancashire		**North Wales**	
Nucula nitidosa	1204	*Donax vittatus*	699
Pharus legumen	475	*Abra alba*	426
Abra alba	413	*Pharus legumen*	378
Spisula subtruncata	151	*Lutraria*	244
Mactra stultorum	102	*Mactra stultorum*	116
Phaxas pellucidus	87	*Fabulina fabula*	99
Ensis	55	*Echinocardium cordatum*	89
Chamelea gallina	43	*Nucula nitidosa*	86
Echinocardium cordatum	36	*Spisula subtruncata*	79
Mysella bidentata	32	*Phaxas pellucidus*	50
Corbula gibba	23	*Ensis*	47
Polinices pulchellus	20	*Mysella bidentata*	36
Lutraria	19	*Polinices pulchellus*	31
Acanthocardia echinata	18	*Chamelea gallina*	18
Thracia phaseolina	10	*Lutraria siphon*	17
Donax vittatus	10	*Dosinia*	11
Lutraria siphon	8	*Thracia phaseolina*	11
Fabulina fabula	5	*Spisula solida*	10
Philine aperta	4	*Spisula elliptica*	7
Retusa	2	*Tellimya ferruginosa*	5
Dosinia	1	*Acanthocardia echinata*	3
Mya siphon	1	*Acteon tornatilis*	3
Mya truncata	1	*Moerella donacina*	3
Thyasira flexuosa	1	*Thyasira flexuosa*	3
Acteon tornatilis	0	*Pharus legumen siphon*	2

Table 3.4 SIMPER analysis on root-transformed benthic community data for North Wales and Shell Flat. Species are ranked according to their percentage contribution to the overall similarity among samples for either area (North Wales or Lancashire).

North Wales
Average similarity: 21.81

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Abra alba	4.88	4.09	0.57	18.76	18.76
Pharus legumen	8.23	3.91	0.55	17.91	36.67
Ensis ensis	0.95	3.04	0.35	13.96	50.63
Mactra stultorum	1.35	2.79	0.44	12.80	63.43
Fabulina fabula	1.50	1.89	0.37	8.66	72.09
Donax vittatus	13.06	1.54	0.25	7.04	79.14
Phaxas pellucidus	0.64	1.23	0.28	5.64	84.77
Spisula subtruncata	0.93	1.05	0.28	4.84	89.61
Lutraria sp.	1.41	0.53	0.18	2.44	92.05

Lancashire
Average similarity: 43.37

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Nucula nitidosa	27.47	18.58	1.30	42.84	42.84
Abra alba	6.58	6.24	0.78	14.39	57.23
Pharus legumen	10.31	5.68	0.76	13.10	70.33
Phaxas pellucidus	1.89	3.23	0.60	7.45	77.78
Mactra stultorum	1.95	2.98	0.56	6.88	84.66
Spisula subtruncata	3.30	2.85	0.54	6.58	91.23

Table 3.5 Change in mean (± S.D.) AFDW g $0.1m^{-2}$ of bivalves and all other benthic biota for 24 monitoring stations with either low or zero observations of common scoter (within 250 m radius of station). The coefficient of variation (C.V.) for bivalves is also given.

	Aug-03	Apr-04	t	df	P
Bivalves	4.31±6.37	2.85±4.83	0.89	46	0.19
Bivalves C.V.	0.62±0.53	0.93±0.44	-2.16	46	0.017
Other benthos	2.17±2.06	0.69±0.54	3.39	46	0.0007

Table 3.6 Estimates for the Gaussian relationship for biomass with depth giving the mean ± 95% C.I. for each parameter G is the depth dependent bivalve biomass modifier, Gmin is the minimal biomass, Gmax is the maximum biomass, S is depth (m), Sm is the depth at which the maximum biomass is attained and V is the variance of the Gaussian curve.

Parameter	Estimate	Upper C.I.	Lower C.I.	F	d.f.	P
North Wales						
Gmin (Log 10)	-1.2	-1.63	-0.78	15.53	4,84	0.05
G (Log 10)	0.32	0.02	0.63			
S max.	7.88	6.24	9.52			
V	17.7	-5.21	40.6			
Lancashire						
Gmin	0.668	-2.65	3.99	6.59	4,77	0.05
G	3.05	1.41	4.7			
S max.	13.96	12.26	15.66			
V	8.03	-19.93	35.99			

Table 3.7 General Linear Model of environmental factors that best explained variation in the abundance of common scoter.

Variable	df	SS	MS	F	P
bivalve biomass	1	10.09	10.09	38.54	<0.0000000007
depth	1	6.84	6.83	26.08	0.0000003
sediment	2	5.75	2.87	10.97	0.00002
current	1	3.41	3.41	13.03	0.0003
ship disturbance	1	3.17	3.16	12.08	0.0005
error	4245	1112.37	0.26		

Table 3.8 The Generalized Additive Model for the best explanatory factors for the variation in bivalve biomass. The model was estimated with the dispersion factor for a Gaussian type distribution of data set at 35.196. The table gives the predictor variables (Log 10), the d.f. for terms and F-values for non-parametric effects.

	d.f.	non-para d.f.	non-para F	P
Mean surface current velocty	1	3.7	1.08	0.36
Shear stress	1	3.6	0.67	0.59
Distance from shore	1	3.1	2.08	0.11
Depth	1	2.8	4.07	0.01
Gravel content (%)	1	5.2	1.66	0.15
Sand content (%)	1	3.1	0.77	0.51
Mud content (%)	0	3.1	0.91	0.44
Organic content (%)	1	3.9	1.21	0.31
Median phi	1	3.6	2.64	0.04

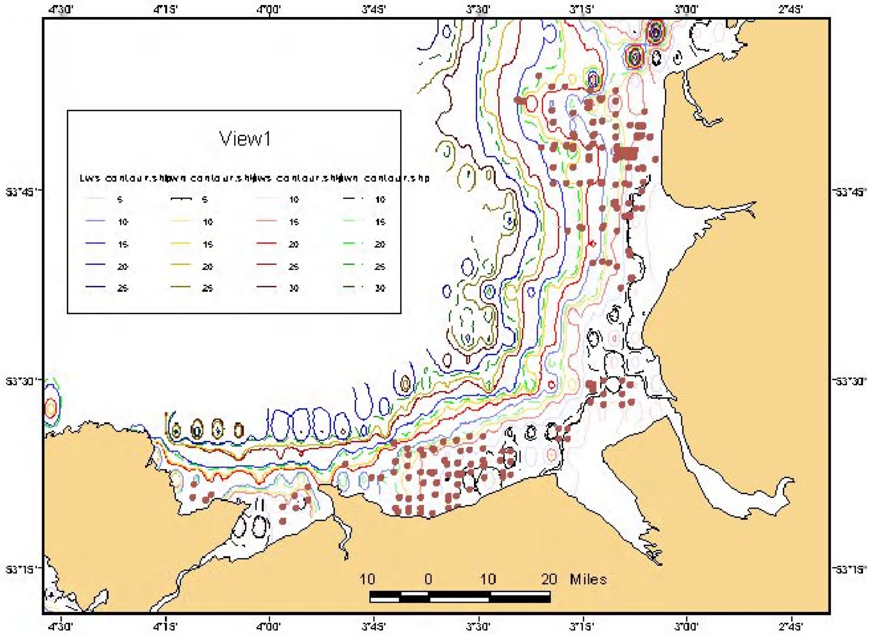


Fig. 3.1 Map indicating the position of Liverpool Bay within the Irish Sea UK, with the modelled bathymetries for spring and neap tides at high and low water at 5 m depth band intervals. Sites sampled for benthic prey species are shown as filled circles.

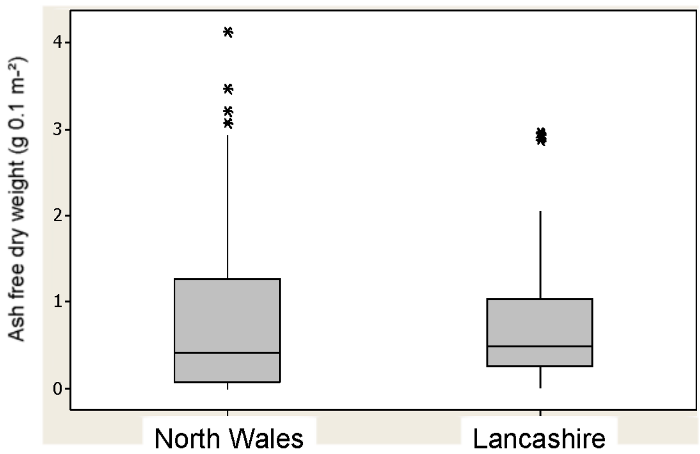


Fig. 3.2 Box and whisker plots of the mean AFDW (g 0.1 m-²) for bivalves sampled off the North Wales and Lancashire coast in August 2003 prior to the arrival of over-wintering common scoter.

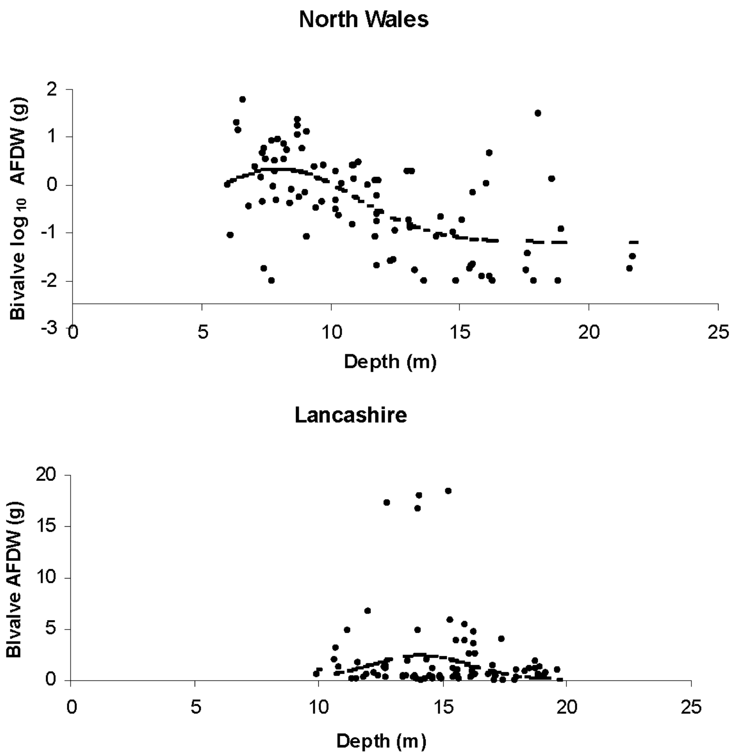


Fig. 3.3 The relationship of bivalve AFDW with depth off North Wales and Lancashire in August 2003. Trend lines are the fit of a Gaussian model (see Table).

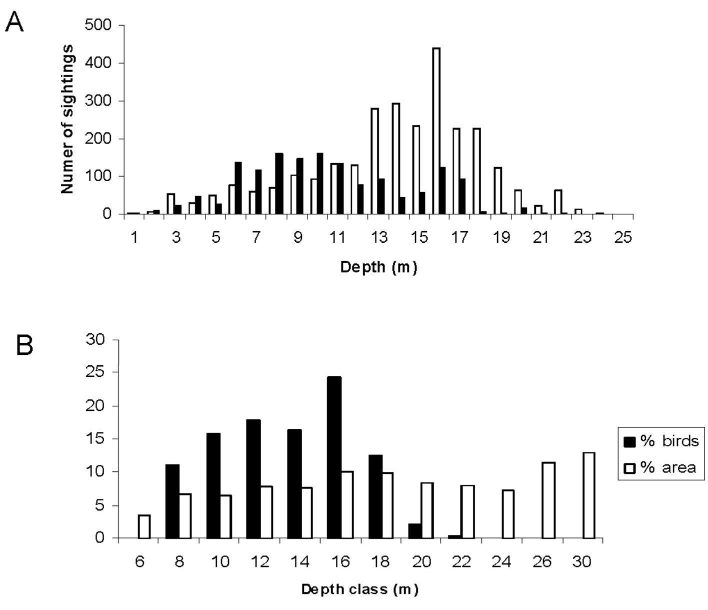


Fig. 3.4 A) The number of sightings of common scoter off North Wales (black bars) and off Lancashire (open bars) in relation to the depth of water over which they were observed. Observations derived from overflights from two over-wintering periods: 2002/2003 and 2003/2004. B) The percentage of the study area (open bars) within each mean depth category and the percentage of all common scoters observed that occurred within each of these mean depth zones.

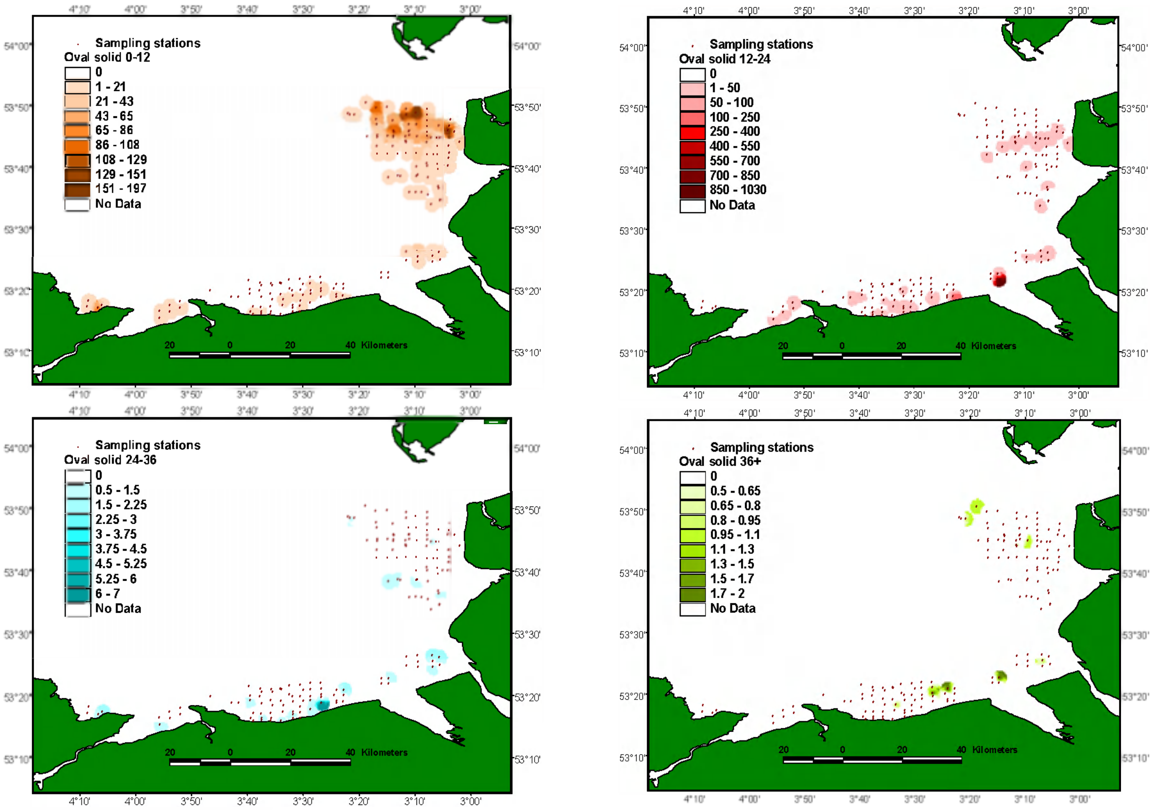


Fig. 3.5a Interpolated grids of oval solid bivalve prey divided into four length classes and expressed as numbers per 0.2 m². For each prey type the distribution of four size (shell length mm) categories are given. Data are interpolated from a total of 169 sample sites across the study area. The interpolation is constrained to within a 2 km radius of each sample site.

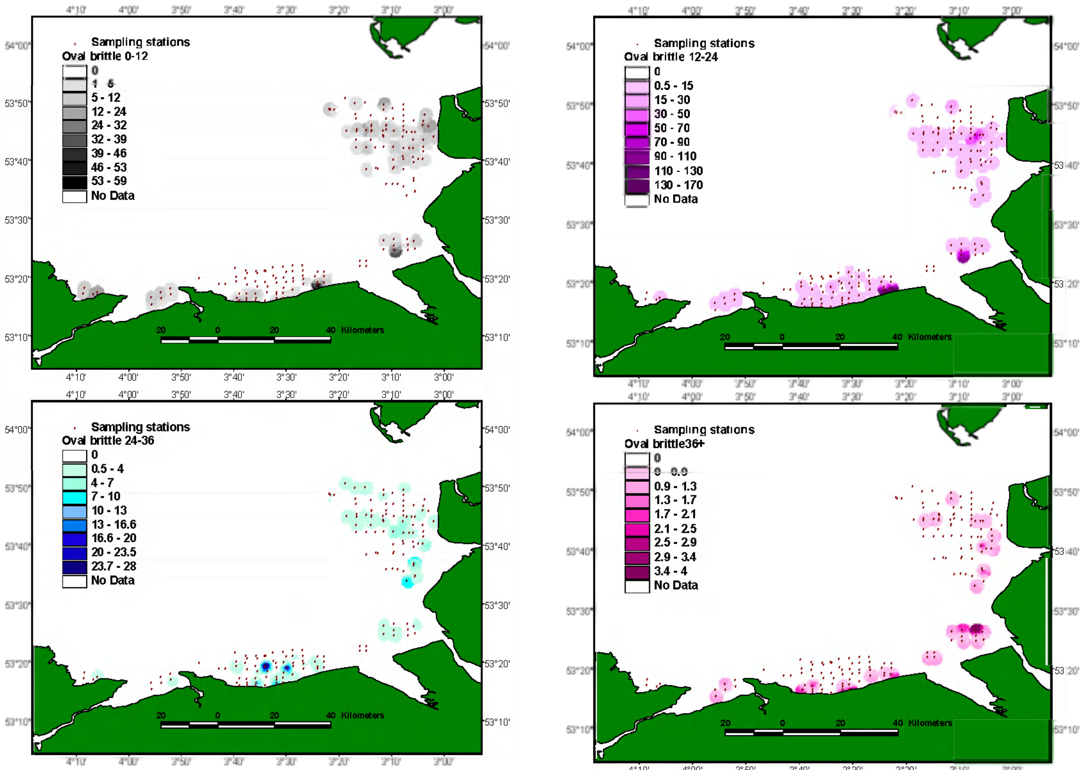


Fig. 3.5b Interpolated grids of oval brittle bivalve prey divided into four length classes and expressed as numbers per 0.2 m². For each prey type the distribution of four size (shell length mm) categories are given. Data are interpolated from a total of 169 sample sites across the study area.

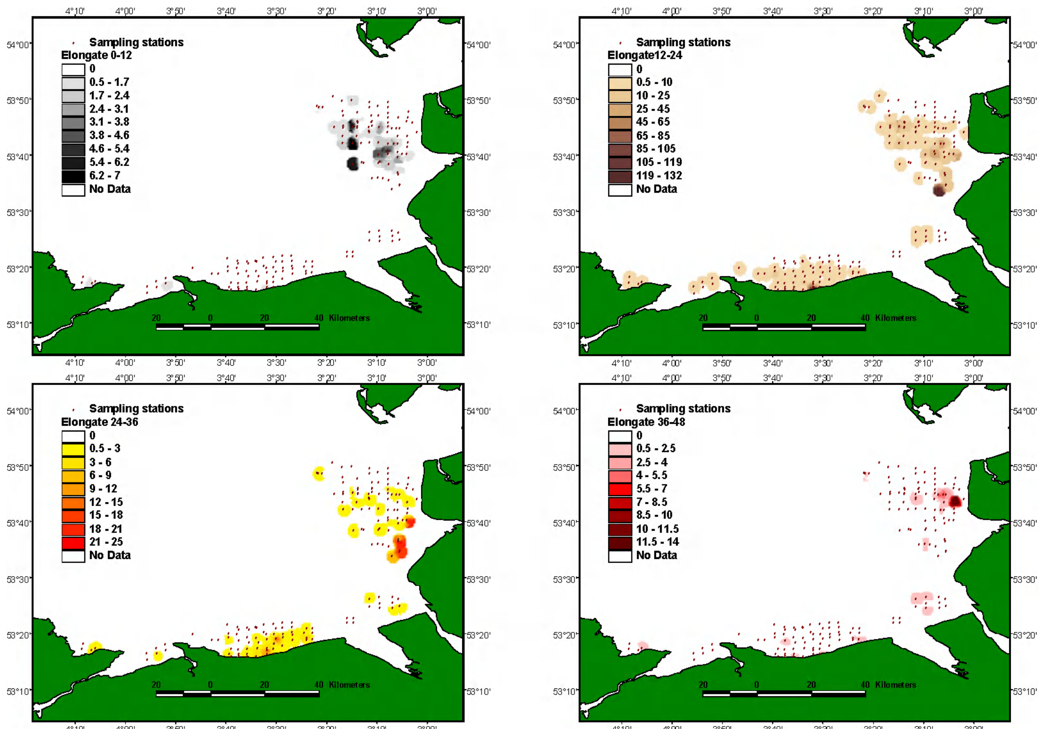


Fig. 3.5c Interpolated grids of elongate bivalve prey divided into four length classes and expressed as numbers per 0.2 m². For each prey type the distribution of four size (shell length mm) categories are given. Data are interpolated from a total of 169 sample sites across the study area.

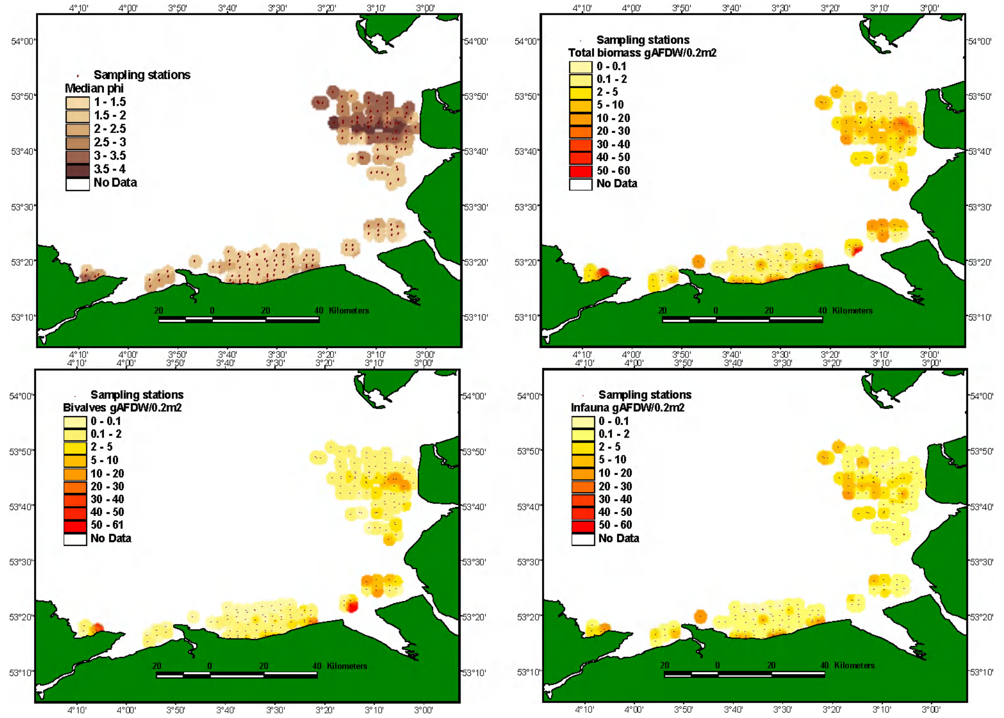


Fig. 3.6 Median phi of the sediments sampled at each sampling station (higher phi = finer sediment), the total biomass of all benthic invertebrates, the total biomass of bivalves only and the total biomass of all invertebrates excluding bivalves (AFDW g/ 0.2 m²)

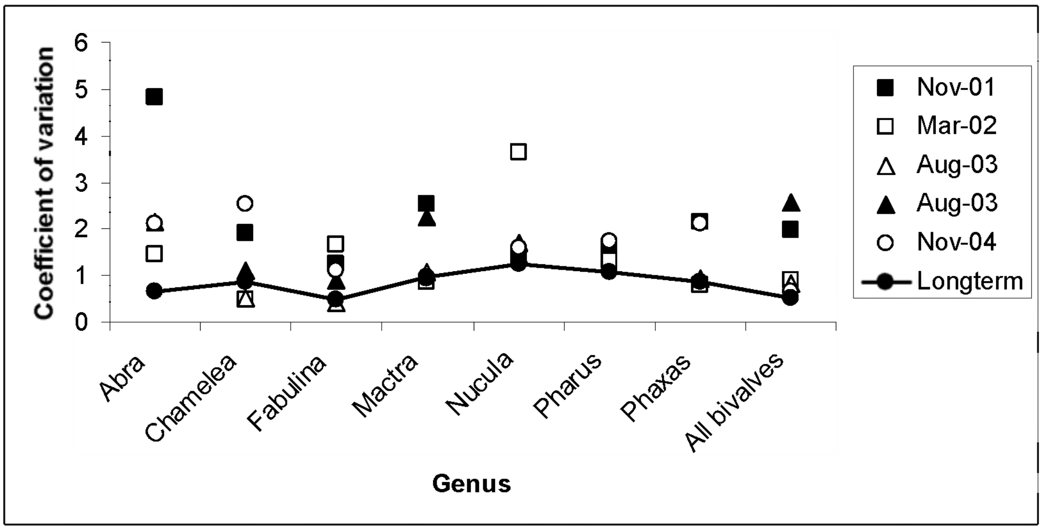


Fig. 3.7 Spatial and interannual variation in bivalve abundance for selected bivalve species and all bivalve species pooled together in Liverpool Bay 2001 -2004. In 28 out of 35 records, spatial variation was greater (i.e. C.V. was higher) than the interannual variability for the same prey species.

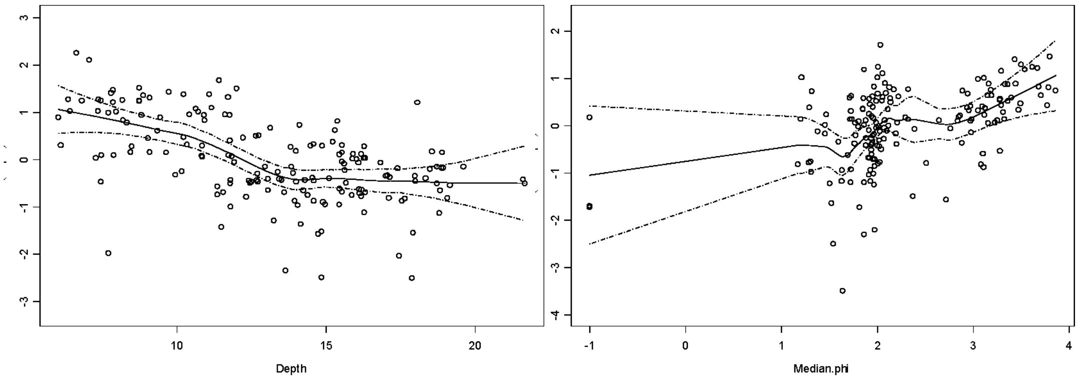


Fig. 3.8 Partial residuals for the Generalized Additive Model for bivalve biomass, showing only the residuals for the two predictors that had significant effects (A) depth (m) and (B) median phi.

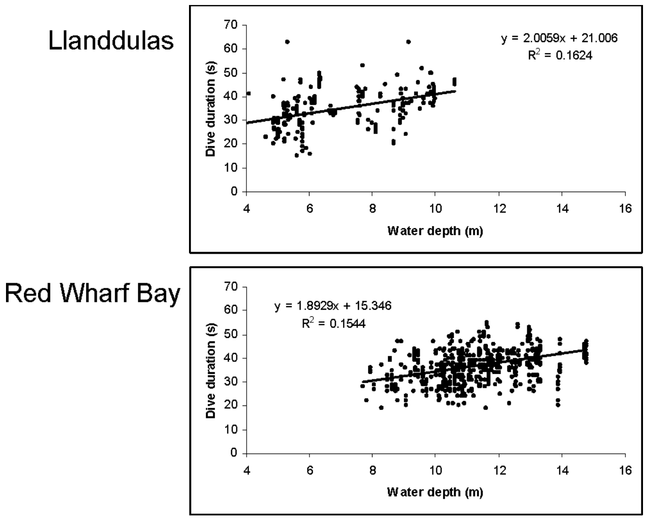


Fig. 3.9 Dive duration (s) of common scoter observed primarily from the shore off (A) Llanddulas and (B) Red Wharf Bay, both North Wales. These observations have been tidally corrected from hindcast modelling. Common scoter were only observed in Red Wharf Bay towards the end of the over-wintering season. The observations of dive time are reported in section 4.

4. Behavioural observations

This section describes the direct behavioural observations that were made to parameterise the behavioural ecology model described later and to elucidate those environmental and human factors that may influence the behaviour of common scoter. Observations were made through the winter period of 2003/2004 to quantify the sex ratio of birds and how this changed through time, to describe flush distances in response to an approaching vessel to ascertain the level of disturbance created by such activities, to quantify whether surface water currents or wind speed affected the orientation of common scoter when sitting on the water, to quantify patterns in flight movements at different times of the day or state of tide, to quantify dive duration in relation to water depth and finally to quantify any change in habitat use during periods of rough sea state.

4.1 Preliminary common scoter surveys

Preliminary land-based surveys were undertaken from 14 to 17 October 2003 and a sea-borne survey on board the RV (research vessel) Prince Madog on 18 October 2003. Suitable land-based observation points were identified and field methodologies tested. During this period observation conditions were good with light winds and calm to moderate seas. A summary of common scoter observations and localities visited during preliminary surveys is presented in Appendix 1.

4.2 Study sites

Study sites were selected initially on the basis of preliminary common scoter surveys undertaken in October. Blackpool was rejected as it was not possible to see birds in sufficient detail for the purposes of data collection. The localities visited (from west to east) comprised; Red Wharf Bay (Anglesey); Conwy Bay observing from Llanfairfechan, Penmaenmawr and Llanddudno West Shore and Great Orme; Colwyn Bay observing from Llanddudno Little Orme, Penmaen Rhôs, Llanddulas and Abergele. Of these localities only in Colwyn Bay between Penmaen Rhôs (SH881788) east to Abergele (SH943788) were large numbers of common scoter visible and close enough inshore to afford data collection opportunities. An especially good locality situated between these two points, Llanddulas (SH906786), was selected as the main survey locality. From Llanddulas it was possible to observe consistently between several hundred and up to 2000 common scoter. Observations were made from the area of the beach car park situated north of the A55 coast road.

Occasional observations during the subsequent two-week survey periods in each of December 2003, February 2004 and March 2004, were made at localities visited in October. This was done to assess for presence/absence of common scoter and to identify any additional survey sites. Of the latter, only at Red Wharf Bay were significant numbers of common scoter located close enough inshore (< 1.5 km) for observations to be undertaken, with an estimated 900-1000 birds present in February. Red Wharf Bay therefore provided an additional study site during the last two survey periods in February and March 2004.

4.3 Common scoter sex/age ratio

Aims: To assess the ratio of male to female/immature common scoter and to identify any changes in sex ratio through the wintering period.

4.3.1 Methods

Sex and age data was collected during the course of direct observations. This was undertaken during each the four survey periods (October and December 2003, February and March 2004) adding to current information regarding arrival dates and proportions of male to female/immature common scoter wintering in Liverpool Bay. Observations were made using binoculars and a telescope mounted on a tripod both from the shore and at sea. During the first two survey periods (October/December) at each locality where common scoter were encountered, at least 100 birds were assigned to one of two age/sex categories:

i) Female/1st autumn
Due to the similarity in plumage of female and juvenile (1st autumn) common scoter in the autumn and early winter (basically brown with pale cheeks) coupled with the observation distance (i.e. common

scoter often >800 m from the observer), it was not possible to distinguish between them. All such birds were thus placed in one category i.e. female/1st autumn.

ii) Adult and sub-adult (2nd winter) male
Adult males are easily identified having all black plumage except for pale undersides to flight feathers. Sub-adult males (approaching their second winter) are black with a pale belly (only visible in flight, when wing-flapping on water's surface with body raised or when roll-preening). Adult and sub-adult males were thus placed together in the second category.

As winter progresses young males (1st autumn entering their 1st winter) gradually attain an adult-like plumage with black feathers that appear from December onwards. During the February/March surveys these could not be distinguished from adult/sub-adult males, except at relatively close range (< c.600 m) in good light when the dark brown wings and brownish black rather than pure black upper parts were apparent. As observation conditions were rarely conducive for such determination, 1st winter males were placed in the 'adult and sub-adult male' category in the post December 2003 surveys.

4.3.2 Results

October
Although only a relatively small number (N=102) of common scoter were sexed/aged in October it was very apparent from *ad hoc* observations of c. 3,500 - 5,000 common scoter (spread over several kilometres from 2 km west of Llanddulas east to Rhyl) that most were adult males. The ratio of 8.3 adult/sub-adult males : 1 female/1st autumn derived from the sample is therefore considered a good estimate.

December
In December a total of 1,744 birds were sexed/aged at four different sites. Sample sizes in excess of 100 birds (the minimum desired sample size) were achieved for all sites except Penmaenmawr (Conwy Bay). Here the sample size (N = 18) was low as these were the only common scoter at the time of observation close enough to be sexed/aged. However, this small sample still reflects the overall situation recorded in December with a sex/age ratio of about one male to one female/1st autumn (1.1:1.0).

February
In February a total of 519 birds were sexed and a sex ratio of 3.3 males:1 female estimated at Llanddulas. Sexing was limited to those birds closer inshore (< c.800 m) due to prevailing poor observation conditions during much of the survey period. This may not have reflected the true sex ratio, the overall impression being that there were probably c.5 males : 1 female present. At Red Wharf Bay an estimated 900-1000 birds where present in February. The vast majority were more than 3 km offshore but several small flocks totalling 80-90 birds came within 1 km of the shore. Those that were sexed/aged (N = 81) resulted in a ratio of 4.1 males to 1 female. Llanfairfechan and Penmaenmawr were each visited once but common scoter were too far offshore to be sexed.

March
In March a total of 163 birds were sexed and a ratio of 5.0 males:1 female estimated at Llanddulas. At Red Wharf Bay 135 birds were sexed and a ratio of 3.2 males:1 female estimated. Llanfairfechan and Penmaenmawr were also visited twice and once respectively but the few common scoter visible were too far offshore to be sexed.

May
From 5-7 May inclusive, seabird surveys onboard the RV Aora were undertaken in the vicinity of the North Hoyle windfarm (situated off the coast north of Rhyl/Abergele) west to almost the Great Orme. Although not within the core common scoter wintering areas, transects passed within c.5 km of where several thousand birds were congregated during the winter months off Llanddulas. Despite good weather and intensive observations, no scoter of any species were observed.

Table 4.1 Sex/age ratio of common scoter observed off the north coast of Wales, winter 2003-2004

Site	Date	Adult & sub-adult males	Adult females + 1st autumn males & females	Ratio
October				
[1]><Llanddulas and Rhyl	18/10/03	91	11	8.27 : 1
December				
Llanddulas	11/12/03	269	374	1 : 1.39
[1]Shell Flat	12/12/03	32	38	1 : 1.18
[1]Rhyl	13/12/03	147	60	2.45 : 1
Penmaenmawr (Conwy Bay)	14/12/03	8	10	1 : 1.25
Llanddulas	14/12/03	88	117	1 : 1.33
[1]Shell Flat	15/12/03	371	230	1.61 : 1
All December observations		915	829	**1.10 : 1**
		All males	**Adult + 1st winter females**	
February				
Llanddulas	20/2/04	178	45	3.96:1
Llanddulas	21/2/04	79	26	3.04:1
Llanddulas	28/2/04	142	49	2.90:1
Red Wharf Bay	25/2/04	65	16	4.06:1
All February observations		464	120	**3.87:1**
March				
Llanddulas	17/3/04	136	27	5.04:1
Red Wharf Bay	8-9/3/04	103	32	3.22:1
All March Observations		239	59	**4.05:1**

[1]observations taken offshore aboard the RV Prince Madog

4.3.3 Discussion

In marked contrast to the adult/sub-adult male : female/1st autumn ratio determined from observations undertaken on 18 October estimated to be 8.3 : 1, the mid-December data reveals a much more balanced ratio, overall approaching 1:1.

This concurs with the expected pattern of arrivals of common scoter in the western seaboard (Cramp & Simmons 1977) where males arrive on the wintering grounds earlier in the autumn with the proportion of females/juveniles rising steadily until passage ends in December. In Britain peak wintering numbers are usually present from December to February (Lack 1986).

In October and December common scoter were placed in one of two categories i.e. females plus 1st autumn males and females; adult and sub-adult males (see Methods above). From December onwards first winter males become mottled with black but do not assume adult plumage until their second autumn (Cramp & Simmons 1977). However, no 1st winter males could be distinguished during the mid-December survey and presumably most of these young males still retained plumage resembling that of females. In contrast, by mid-February first winter males were apparent with blackish-brown upperparts, brown flight feathers and dull yellowish culmen, contrasting with the jet black plumage and bright yellow culmen of adult males.

Unfortunately however, these 1st winter males were difficult to distinguish due to their similarity to adults when viewed at distance, confounded by often overcast conditions. During the February and March surveys, 1st winter males were thus placed with adult and sub-adult males. This therefore prohibits direct comparisons with the earlier surveys but non-the-less it appeared that the proportion of male birds rose later in the winter. It may be that the shift to a higher proportion of males can be simply attributed to the placement of 1st winter males in the 'male' category in the latter two months as opposed prior to this being placed with adult female and 1st autumn females. However, this would imply a disproportionately high number of immature males in the population in an order of magnitude 3-4 times greater than the combined number of adult and immature females. It may be that some movement of birds occurred in the interim period (between the December and February surveys). A higher proportion of female and immature common scoter are present in more southerly wintering areas (Cramp & Simmons 1977) and some females and/or 1st autumn birds present in December may have continued on to more southerly wintering areas after a stop-over in Liverpool Bay. All surveys in February and March were land-based and it is also possible that the majority of certain cohorts e.g. adult females and/or immatures winter further out to sea and could not be observed from land. However, comparing the data collected in December from land (1 male:1.4 female/1st autumn) and sea (1.6 male:1 female/1st autumn) this does not appear to be the case but given the small data set collected at sea over only three days, it is not possible to draw any firm conclusions.

Return common scoter movements occur in late February through to April in the Atlantic and North Sea (Cramp & Simmons 1977). It was hoped that further sex ratio data gathered in April might identify any disparity in return movements between sexes but unfortunately due to inclement weather no data was collected (P. Robinson pers. comm.). Offshore observations in early May yielded no common scoter sightings. By this time most would have migrated to northerly breeding grounds and although surveys in May were not within core wintering areas it was still surprising given the intensive survey effort, that non were seen. This is even more so given that some non-breeding common scoter are reported to summer in Liverpool Bay (E.I.S. Rees pers. comm..).

Environmental impact assessments should take into account the staggered dates of arrivals of M.nigra on their wintering grounds and the higher proportion of females and immatures present in southerly wintering areas. In considerations of the locality of offshore windfarms, regard should be given to the male-biased sex ratio within common scoter populations, numbers of females being lower than males. On the breeding grounds this has been shown to be in the order of 1.2-2.0 males: 1 female (Bengtson 1972). Adult female annual survival is therefore an especially important population parameter in this species (Fox et al. 2003). Disturbance or loss of habitat in southern wintering localities could potentially have a disproportionately high adverse knock-on effect upon the population as a whole. Population declines would be expected if females experienced increased mortality and/or suffered a loss of fitness and hence fecundity due to a loss or decline in the quality of their wintering habitat.

4.4 Flush Distance

Aim: To record the flush distances of common scoter at the approach of the research vessel.

During the construction phase of an offshore wind farm there will inevitably be considerable disturbance from boat traffic travelling to and from the site and in the vicinity of the construction area itself. After the construction phase, as well as the presence of the wind turbines themselves, boats carrying crews to undertake routine maintenance will be an ongoing source of disturbance to common scoter. Potentially other species of seabirds such as other wintering ducks (Anseridae), wintering divers (Gaviidae), auks (Alcidae) and terns (*Sterna* spp.) may also be adversely affected.

There is little empirical data regarding the effects of disturbance from boats on common scoter but it is known that they are intolerant of approaching vessels and are easily flushed from their feeding/loafing areas. Therefore an attempt was made to generate some such data whilst on board the Prince Madog research vessel in December 2003. Some researchers (e.g. P. Cranswick pers. comm. 2003 and during provisional fieldwork during this survey) have highlighted the great problem of estimating distances from an observer to birds out at sea several hundreds metres away and as distances increase. Therefore the ship's (RV Prince Madog) radar was used in combination with field observations to assess flush distances of common scoter flocks at the approach of the research vessel.

4.4.1 Methods

Two observers (using binoculars) positioned on the ship's bridge located and counted the number of common scoter in a flock as they rose from the sea surface at the approach of the research vessel. They alerted a third observer manning the ship's radar to the presence of flushed birds. From the radar, knowing the position of the ship and the point at which the birds rose, a 'flush distance' and bearing was determined. The ship travelled on a steady course at a speed of about 10 knots whilst observations were made. Vessels undertaking maintenance within a windfarm array are likely to traverse at lower speeds for safety, but these vessels are unlikely to cause disturbance to birds that avoid the footprint of a windfarm due to its presence. Vessels en-route from port to a windfarm array are likely to travel at cruising speeds to conserve fuel, which for a vessel of the size of Prince Madog is likely to be in the region of 10 knots.

4.4.2 Results

Simple linear regression analysis was performed on the observations of common scoter flock size and flush distance (N=59). There was no significant relationship between flock size and flush distance (P = 0.508 r^2 = 0.008 df = 57). However, examination of the raw data revealed the presence of a critical flushing distance of c.1000 m, at which flock size increased quite dramatically.

Thus the data set was divided into two samples:

i) those flocks for which flush distances were < 1000 m (N=23)
ii) those flocks for which flush distances were >< 1000 m to 1999 m (N=26)

The remaining flush distances (N = 10) > 2000 m were disregarded for the purpose of this analysis as at this distance it became difficult to be sure if birds were being put up by the approaching research vessel or responding perhaps to another stimulus, although the former appeared to be the case.

A Mann-Whitney Test performed on these samples revealed a highly significant difference between the flock sizes at flush distances of less than 1000 m, as opposed to flock sizes at flush distance between 1000 m to 1999 m. At around a flush distance of c.1000 m, flock size increased quite dramatically. U= 38.5 P = <0.001

4.4.3 Discussion

A number of potential biases should be highlighted in the methodology. In some cases small flocks flushed by the boat in areas of higher concentrations of birds went unrecorded as the observers could not record every flock in such a short space of time. Some smaller flocks (< c.10 birds) were also not apparent on the radar screen as the radar was not sensitive enough to pick them up. At times background interference from wave crests appearing on the radar screen made it impossible to locate flocks - flush distances can only be recorded using this technique in calm weather. The closer birds were to the boat (< c. 500 m) the more difficult it was to get a fix on the rising birds in part because of the wave interference but also as there were usually fewer individuals. Therefore, in combination with the radar, some flushing distance estimates of closer birds were made to the nearest 100 m.

Whilst there was no significant relationship between the flush distance and flock size of the data set as a whole, it was very apparent that the vast majority of larger common scoter flocks took flight at the approach of the research vessel at a distance of greater than c.1 km. Smaller flocks (< c.15 individuals) were less inclined to take flight allowing a closer approach but birds showed signs of alarm with neck up-stretched in an alert posture, before flying away. It was also apparent that there was a 'wave effect' - as birds were flushed and flew, in response ones a little further away would rise, then those behind these would rise and so on. Thus some birds over 2 km from the boat rose from the water's surface in response to those flushed much closer to the research vessel. Other than broadly stating that common scoter wintering in Liverpool Bay are extremely wary of shipping, as noted elsewhere within their European wintering range, it is difficult to make other inferences from this data.

Presumably flush distances vary dependent upon factors such as the prevailing weather conditions, the speed of approach of a vessel, the angle of approach, the size (and even colour) of the vessel, human activity visible on the deck, and the fitness of the birds themselves. It may also be that along regularly used shipping lanes birds might become habituated to the presence of boats. This was beyond the scope of the current project.

The effect of human disturbance is often measured in terms of behavioural changes in response to human presence but from a conservation perspective such disturbance is important only if it affects survival or fecundity and hence a population decline (Gill *et al.* 2001). To demonstrate any such effect on common scoter populations through disturbance on their wintering grounds would be virtually impossible, catching and tagging individuals would be a huge task in itself. However, common scoter as demonstrated, are extremely wary and it has been suggested that species showing the greatest avoidance require the greatest amount of protection (Klein *et al*. 1995). This though may not be true for species where the costs of moving to an alternative site are likely to be small (Gill *et al.* 2001). Wigeon *Anas penelope*, for example show a strong human avoidance (Tuite *et al.* 1984) but for this mainly herbivorous species often grazing on short sward with many nearby alternative feeding sites, costs are probably low. One could argue that this is the case for common scoter as upon disturbance if there are sufficient areas of undisturbed sea to which they could fly and settle presuming that the birds have knowledge that suitable alternative areas exist. On the other hand fitness costs may be high if there are few or no other nearby suitable feeding areas to which they can go.

4.5 Dive duration

Aims: To identify any relationship between dive duration and water depth

4.5.1 Methods

Common scoter dive duration time (in seconds), time of day and location of all field observation points were recorded. Common scoter dive individually, or more often as a group when in a small flock. When in a flock they have a strong tendency to dive almost simultaneously, resurfacing together or staggered over a period of a few seconds (pers. obs..). When staggered, an estimated time ± two seconds was assigned to each individual.

Observations, were made using a telescope mounted on a tripod. The distance of birds offshore was estimated to the nearest 50 m, using known reference points i.e. surface marker buoys, to assist in estimate accuracy. Water depth when on board the RV Prince Madog was recorded using the ship's sonar.

For each land-based observation a water depth estimate will be generated using the tidal model being developed at the Centre for Applied Marine Science, Bangor. The data will subsequently be used in to identify if there is any relationship between dive duration and water depth.

4.5.2 Results

Dive durations and water depths recorded in October and December whilst on board the RV Prince Madog. Other December data from land-based observations (currently lacking water depths) are presented on an Excel spreadsheet. A preliminary analysis of the relationship between dive duration and tidal elevation indicates that common scoter dive time increases with tidal height (i.e. water depth). See also analyses in sections 2 and 3.

4.5.3 Discussion

In total 1103 individual dive times were recorded in the four survey periods as follows: October - 48; December - 111; February - 142; March – 802. Data collected to date provide a broad indication of the dive durations (time spent submerged diving to seabed, foraging for food and resurfacing) of common scoter. It had therefore been proposed to correlate dive durations with water depth but this has proved difficult for a number of reasons. Primarily few common scoter have actually been observed feeding. It may be that feeding activity is mostly nocturnal but this would not appear to be the case from observations of common scoter in other parts of their European wintering ranges [M Leopold pers. comm.]. It may be that the majority of feeding common scoter cannot be seen from land. However, few birds were observed further out to sea from the research vessel feeding perhaps owing to their timid nature, they ceased foraging at the approach of the boat and then did not resume until they were beyond observation range. It was hoped that ship borne observations (using the onboard sonar to calculate the water depth in the vicinity of feeding birds) would enable the gathering of large quantities of such data. However, due to the lack of feeding birds, whether through the wariness of the birds (see Flush Distances, above) or not, and severe constraints of time onboard the research vessel confounded by inclement weather, little data could be gathered. Land-based observations from Llanddulas beach car park yielded little data despite 7 man-days spent undertaking observations, although other data in addition to dive durations, were also being collected. Later surveys could be geared to concentrating on collecting more dive duration data if deemed pertinent.

Apart from in exceptionally calm weather it was difficult to observe common scoter on the water's surface due to their distance offshore (most 800 m distant, stretching well out to sea) and intermittently being obscured by waves. Thus even when diving birds were located, some dive observations had to be abandoned as birds could not be seen at the time of resurfacing. Biases might also be a problem e.g. inevitably it was only the closest birds that could be seen properly to record dive times. In some cases short dives might represent an aborted dive or a quick find of a good prey item/s. Attempts to correlate dive duration with water depth might be confounded by the fact that in shallow water, birds might spend more time feeding on the sea bed as it takes less time to reach it, thus dive times might not necessarily reflect water depth. More data is needed to elucidate this.

An attempt to look at feeding intensity in relation to tide was going to be made but has proved impossible to pursue due to a combination of factors including: birds being very distant and often obscured by waves; the common scoter flock being observed (off Llanddulas) is dispersed over a distance of several kilometres; and most importantly, very few birds could be seen diving.

Table 4.2 Mean (± 95% confidence intervals) dive duration for each observation locality by sample month (December 2003, February and March 2004). Below is an analysis of variance table showing the significant interaction between location and season. This variation may be attributed to tidal height on each observation date.

Location	Month	Mean	Lower 95% CI	Upper 95% CI
Llanddulas	December	36.1	33.75	38.4
	February	33.2	31.7	34.7
	March	35.2	33.7	36.6
Red Wharf Bay	February	45.7	44.5	46.9
	March	36.34	35.8	36.8

Factor	df	ss	F	P
Season	1	37.0	0.68	0.40
Location	1	1926.9	35.77	0.0001
Season * Location	1	3032.5	56.30	0.0001
Residuals	1018	54830.2	53.86	

4.6 Orientation on water

Aims: To identify relationships of orientation of common scoter on the water's surface with wind, tide and current.

Common scoter feed by day drifting along with tide, wind or current, flying back to regain their original station (Cramp & Simmons 1977). Reattainment or maintenance of position can be achieved by swimming against the prevailing breeze and/or current when wind speed and current velocity are low. Orientation and flight direction observations were thus undertaken to examine relationships with wind, tide and current.

The more-or-less east-west running coastline at Llanddulas provided a good locality to undertake observations. Here, on a rising tide water floods from the west and the current flows eastwards, whilst during a receding tide the current direction reverses and flows westwards.

4.6.1 Methods

During land-based observations from Llanddulas, each hour or half hour, a sample of 100 common scoter sitting on the water were assigned one of four orientations (north, south, east or west) dependent upon which direction they were facing. If the required number of birds was not visible in the initial field of view of the telescope (looking out perpendicular to the coastline), the sea was scanned east or west (dependent upon position of the sun and location of birds) until the required number was tallied. Wind direction (N,NE,E,SE etc.) and windspeed (Beaufort Scale) were recorded at the end of each survey.

4.6.2 Results

A total of 45 orientation counts were made. The field data and results of Rayleigh's test for circular uniformity analyses (Zar 1996).. Observations undertaken on a given day in similar weather conditions during either a rising (east-flowing current) or ebbing (west-flowing current) are pooled in the analysis, also all are tested separately. Almost all orientations were not uniformly distributed i.e. there was a significant direction in which the majority of birds were facing ($P < 0.001$ in all non-uniform cases) explained by most birds facing into or at 45^{o} to the prevailing wind.

At wind speeds greater than force 1 (>5 km/h), orientation of common scoter was clearly linked to wind direction, most birds facing into the prevailing wind irrespective of the state of the tide e.g. 10-11/12/03 data. During the first 10 of the 15 survey periods (windspeeds force 3-5) between 67% to 100% of birds were facing either west or north (mean = 81.9, SE = 3.32, SD = 10.51) during prevailing north-westerly winds. During the five remaining periods, with a shift to northerly winds and on a receding tide (i.e. current flow east to west) most birds (48,63,75,89 and 92%) were recorded facing east (mean = 73.4, SE = 8.20, SD = 18.34) with 32,14,26,8 and 10% (mean = 18.0, SE = 4.69, SD = 10.49) facing north. In the latter five periods the current may have also influenced orientation (but also see biases in Discussion, below).

As wind speeds increased there was a tendency towards a higher proportion of birds to face into the wind i.e. greater non-uniform distribution, hence a higher Z-value. The mean Z-value plotted against wind speed displays this trend, although non-significant $P = 0.175$ $r^2 = 0.510$ df = 3 (force 1 mean Z = 25.266; force 2 mean Z = 56.498; force 3 mean Z = 40.906; force 4 = 41.885; force 5 mean Z = 74.561). Care should be taken when interpreting this data as it does not take into account the confounding effects of current direction/speed.

At low wind speeds (force 0-1, 0-5 km/h) there was still a predominant direction in which birds faced, however, orientation patterns were not linked to wind direction and appears explained by the current direction. On a rising tide when the current flow is from west to east, birds face westwards i.e. into the current. On a receding tide when the current flow is reversed, birds face eastwards.

For only one group of three pooled observations on 21 February was there no significant difference in orientation (Z = 0.328, P = >0.5). This coincided with a period of more-or-less slack water either side of high tide with a light (force 2) easterly breeze. At this time common scoter were milling around on the water's surface generally loafing but with many displaying.

Likewise, for observations tested separately almost all were not uniformly distributed (P = <0.001). The five exceptions and explanations for possible non-significance are:

i) one on 17 December (Z = 2.740, P = >0.05); this simply did not conform to the general pattern. During a light (force 1) southerly, with a westerly current the majority of birds were recorded facing east (50%) with fewer (35%) facing west. The pattern at periods of such low wind speeds was for the majority to face into the current.

ii) three on 18 December; the first (Z =1.588 P = >0.20) coincided with low tide (slack water), with the subsequent observations, although non significant (Z=2.900 P = >0.05, Z=2.260 P = >0.10) still conforming to the general pattern during periods of low wind speed with the majority facing into the current. Interestingly, as presumably the current speed increased later in the tidal cycle the proportion of birds facing into the current also increased.

iii) one on 21 February – see explanation above for pooled analysis on this date.

4.6.3 Discussion

It is apparent from the data and general field observations that common scoter, unsurprisingly, like many bird species, orientate themselves into the direction of the prevailing wind. There was also a tendency for a greater proportion of birds to face into the wind as wind speeds increased. In periods of low wind speeds (< 5 km/h) common scoter were often observed engaged in display (male-male aggressive chases, water spraying etc.), some males pursuing females, with many birds loafing and a few birds diving. However, at these times there still appeared a distinct preference to facing in a particular direction, either east or west. Looking at data gathered in such calm periods orientation can be explained by current direction. On a receding tide when the current flows from east to west the birds face east i.e. into the current. On a rising tide when the current flow is reversed the common scoter accordingly re-orientate, rotating 180^{o}. At wind speeds of force 2 (6 to 12 km/h) there were indications that this trend was followed but more data would be required to draw any firm conclusions.

Likewise, more data from periods of higher wind speeds would have been desirable. However, during the last two field periods priority was given to gathering dive duration data. It should be borne in mind that observations become increasingly difficult in progressively rougher weather as wave crests frequently hide birds, thus an elevated observation point, as at the west end of Llanddulas Beach car park, is essential. Also, whilst common scoter could be seen to be facing left (west) or right (east), it was difficult to say if they were facing 'in' (south) as opposed to 'out' (north) as birds were usually very distant. This was a potential source of bias and although care was taken not to ignore such birds it was difficult at times to be sure of their true orientation. Wind was recorded as one of eight directions i.e. north, north east, east, south east etc., but because of observation difficulties it was only possible to afford one of four directions i.e. north, south, east or west, to common scoter orientation, thus making data interpretation more problematic.

Overall the observations suggest that higher wind speeds outweigh the effect of the current (regardless of its direction) and this is the force which governs common scoter orientation. In periods of calm weather however, common scoter orientate themselves towards and presumably swim against the current in order to maintain their position over foraging areas.

4.7 Flight direction

Aims: To examine the influence of wind and current upon common scoter flight direction.

Flight direction observations were undertaken from Llanddulas to look at how flight behaviour was influenced by wind strength and direction, and tidal state hence the direction of the current flow (see also 5.0 Orientation on water).

4.7.1 Methods

From a fixed observation point with telescope mounted on a tripod at a fixed angle looking out perpendicular to the shoreline, for 10 minutes each hour or half hour, the direction of flight of all common scoter flying through the field of view was recorded. A dictaphone was used so that observation was continuous throughout the duration of each survey, thus at no time was it necessary to stop viewing (and potentially miss birds) in order to write down observations.

All flying individuals were counted regardless of the flight distance i.e. a short rise and ditch consisting of tens of metres, or a flight passing from one side of the field of view to the other. The flight direction was recorded as north, south, east or west. Circling birds landing in approximately the same position from which they rose were recorded as 'circling'. Wind direction (N,NE,E,SE etc.) and windspeed (Beaufort Scale) were recorded at the end of each count.

4.7.2 Results

The proportion of common scoter flying into or within 45° of the prevailing wind increased with increasing windspeed ($P = 0.012$ $r^2 = 0.828$ df = 4 (force 1 mean = 27%, force 2 = 65%, force 3 =

71%, force 4 = 63%, force 5 = 91%, force 6 = 100%)). On days with a fairly constant moderate wind there appeared to be a discernable change in flight activity with the change in current direction. e.g. 11 December. On this date a day-long synchronised flight count was undertaken from two points; the west end of Llanddulas beach car park and 3 km to the east. Wind was a fairly constant westerly force 4 (veering NW at 14:00), with a lull at 11:30 to force 2. Due to boat disturbance (cross-sea ferry) during the 13:30 count when many common scoter were flushed, and the midday count during a period of slack water (high tide 12:08 at Llandudno, source: UK Hydrographic Office), these data are excluded from the analysis. With wind and current acting together, a greater proportion of birds flew in the opposing direction; west Llanddulas: 74.2% (SE = 7.41 SD = 16.57); east Llanddulas: 75.2% (SE = 8.22 SD = 18.39) in comparison with when wind and current countered each other when the proportion of birds flying into the wind reduced; west Llanddulas: 55.4% (SE = 5.45 SD = 12.18) east Llanddulas: 47% (SE = 5.51 SD = 12.32).

4.7.3 Discussion

Wind direction and strength would appear to be the driving force behind flight patterns in the dispersed common scoter flock off Llanddulas. As they are blown downwind they re-position themselves by periodically flying back. A significantly higher proportion of common scoter flew into or within 45° of the prevailing wind as windspeeds increased, presumably in order to maintain their position close to or over foraging areas.

Day-long observations also suggested that in periods of moderate windspeed, when the current flow was against the prevailing wind the proportion of birds flying against the wind was reduced in comparison to those periods when wind and current were in the same direction. Logically, a current direction opposing the prevailing wind negates to some extent the effect of the prevailing wind thus accounting for these observations.

In combination with the observations of the orientation of birds on the water, during days of exceptionally calm weather when wind speeds remained below 5 km/h, common scoter could probably mostly maintain there position by swimming rather than needing to fly, the latter presumably being more energy demanding. Unfortunately however, no direct comparison of actual numbers of birds flying at different windspeeds could be made as this would require a constant number of birds to be present during each survey. One would expect reduced activity on calmer days as it would take fewer flights to maintain position.

No regular dawn/dusk movements for common scoter are described and it is assumed that they roost in or close to daytime feeding areas (Cramp & Simmons 1977). No large scale movements of common scoter at dawn or dusk were noted during any land-based observation, however, it is possible that nocturnal movements occur. Night-time radar observations in December in the vicinity of Shell Flat from the RV Prince Madog hinted at a northerly movement after dark but it may simply have been birds being flushed and repositioning themselves behind the vessel as it made its way southward. Early morning observations before dawn when anchored off Llanddulas suggested a movement of birds southwards. Only with more intensive night-time radar surveys will any nocturnal movements be identified.

4.8 Surveys during inclement weather

Aims To determine if distribution of common scoter wintering along the north Wales coast is influenced by inclement weather

Most ecological data concerning winter ecology of common scoter, including aerial surveys conducted to determine their numbers and distribution at sea, not surprisingly stems from observations undertaken during periods of good weather. Therefore, on an *ad hoc* basis during periods of inclement weather (and incidentally when collection of higher priority data was not feasible) some additional land-based common scoter observations were undertaken. These were conducted to give an insight into whether common scoter distribution appeared influenced by adverse conditions e.g. using sheltered bays not usually used as foraging areas to seek refuge from high seas during storms.

4.8.1 Methods

During periods of inclement weather i.e. c. force 6 or above (wind speeds > 40 km/hr) localities along the north Wales coast from Red Wharf Bay east to Abergele were assessed for presence/absence of common scoter by scanning with telescope and binoculars from land-based observation points. Basic behavioural activities i.e. feeding, loafing and displaying, were noted when possible.

4.8.2 Results

Observations, undertaken on two dates, are summarised below.

14 December 2003
Weather: NW, variable force 6-7 (occasionally gusting 8); sea state very rough in areas exposed to the prevailing wind with no protective land-mass.

a) Areas where no significant numbers of common scoter observed previously in autumn/winter 2003/04 but affording some shelter from prevailing wind/high seas:
i) Red Wharf Bay - no common scoter observed.
ii) west Colwyn Bay (sheltered by the Great Orme) from Llandudno - no common scoter observed.

b) Areas usually supporting significant numbers of common scoter but affording no shelter from the prevailing wind/high seas:
i) central Conwy Bay viewed from Llanfairfechan/Penmaenmawr - c.200 common scoter 1-2 km offshore on water, occasional more distant birds observed in flight. The majority of closer common scoter were loafing with some small groups displaying. No common scoter were observed feeding. Note: due to the rough seas severely limiting visibility, Conwy Bay was also viewed from Llandudno (east side of the Bay) to increase coverage but no common scoter were observed.

ii) Llanddulas – c.2,000-3,000 common scoter, distribution appeared more-or-less the same as observed in calmer weather. As at Llanfairfechan the majority were loafing although many were engaged in intermittent display and very occasionally diving.

24 February 2004
Weather: N 6; sea state rough; intermittent heavy rain.
All sites were visited with the exception of Llandudno. Red Wharf Bay in comparison with the December survey when the north end of Red Wharf Bay was partially protected from the prevailing north westerly wind, received the full force of the northerlies.

a) Areas where no significant numbers of common scoter observed previously in autumn/winter 2003/04 but affording some shelter from prevailing wind/high seas:
i) East Conwy Bay (sheltered by the Great Orme) viewed from north Conwy – no common scoter observed.

b) Areas usually supporting significant numbers of common scoter but affording no shelter from the prevailing wind/high seas:
i) central Conwy Bay viewed from Llanfairfechan/Penmaenmawr - c.150 common scoter c.3-4 km offshore visible only in flight due to rough seas and observation distance. This was the approximate location where this flock appeared to remain throughout most of the winter.

ii) Llanddulas – c.1,000 + common scoter but difficult to estimate because of poor visibility due to rough seas and rain. Their distribution appeared the same as in periods of calmer weather.

c) Areas where no significant numbers of common scoter observed previously in winter 2003/04 and affording no shelter from prevailing wind/high seas:
i) Red Wharf Bay – c. 80 common scoter 800 m and 900 common scoter over 1.5 km, offshore.

4.8.3 Discussion

From these limited land-based observations the distribution of common scoter appeared little or unaffected during periods of inclement weather. In the consistently occupied wintering localities i.e. off Llanfairfechan/Penmaenmawr and Llanddulas/Abergele, common scoter distribution remained more-or-less unchanged. Usually unoccupied areas but which afforded some protection from inclement weather in the vicinity of these localities remained unoccupied.

In December the numbers and distribution of common scoter appeared more-or-less the same as that in periods of calmer weather experienced in mid-October and other survey periods. About half of the Llanfairfechan flock (c. 200 individuals) were closer inshore (c.1-2 km) in comparison with the previous fairly calm day when 350 were counted 3.6 km offshore from the RV Prince Madog. These 200 common scoter were presumably part of this flock and additional birds could be seen in flight c. 3-4 km offshore in the vicinity of the previous day's observations. Llanfairfechan is a locality which most years harbours large numbers of common scoter (c.1000+) but numbers in the winter of 2003-2004 appeared down with the maximum count (350) made from the research vessel. Counts were not possible from shore owing to the great distance of the birds offshore, the results of aerial surveys may yield more precise information. The main flocks visible from land off the north Wales coast in winter 2003-2004 were to the east in Colwyn Bay spread from Penmaen Rhôs (just west of Llanddulas) to Abergele. Here the distribution appeared the same as in calmer conditions but with the majority of the closest birds perhaps 200 to 500 m further offshore.

In February the distribution of common scoter off Llanfairfechan (c.150 observed c.3-4 km offshore) and Llanddulas/Abergele was the same as usually encountered in calmer conditions. Very few common scoter were seen in Red Wharf Bay during the early winter (October/December survey periods). The only observations were of 28 during one visit in October 2003. The single December visit was made during very rough seas and it is possible that distant common scoter were overlooked. In February an estimated 900-1000 common scoter were present. There is apparently movement of common scoter between Red Wharf Bay and Conwy and Colwyn Bays and in the past Red Wharf Bay has harboured large numbers e.g. a flock of 1,800 present in December 1976 and 992 in December 1990 (Lovegrove *et al.* 1994). Common scoter often appear in this Bay from December onwards (D. Brown pers. comm.) and it appears that there may be some regular seasonal movement, presumably common scoter frequenting the area dependent upon food availability. Studies have shown that prey depletion influences Common eider *Somateria mollisima* distribution over the winter, patch use being correlated with food availability (Guillemette & Himmelman 1996), and that they locally track annual variation in food abundance, primarily related to the presence of mussels *Mytilus edulis* (Larsen & Guillemette 2000). It is reasonable to assume that common scoter exhibit similar behaviour and also adjust their feeding areas through the wintering period according to prey abundance and availability.

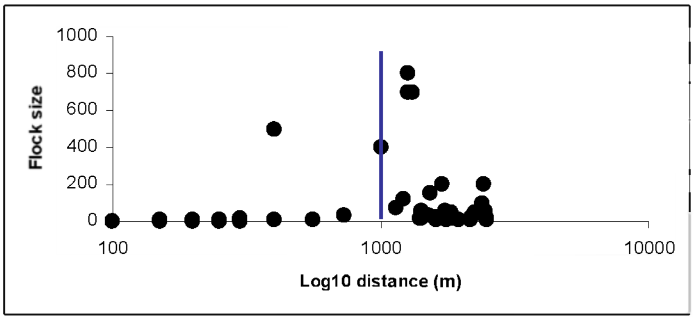


Fig. 4.1 Flush distances of common scoter from the RV Prince Madog showing the relationship between flock size and flush distance. Flush distance is plotted on a log scale.

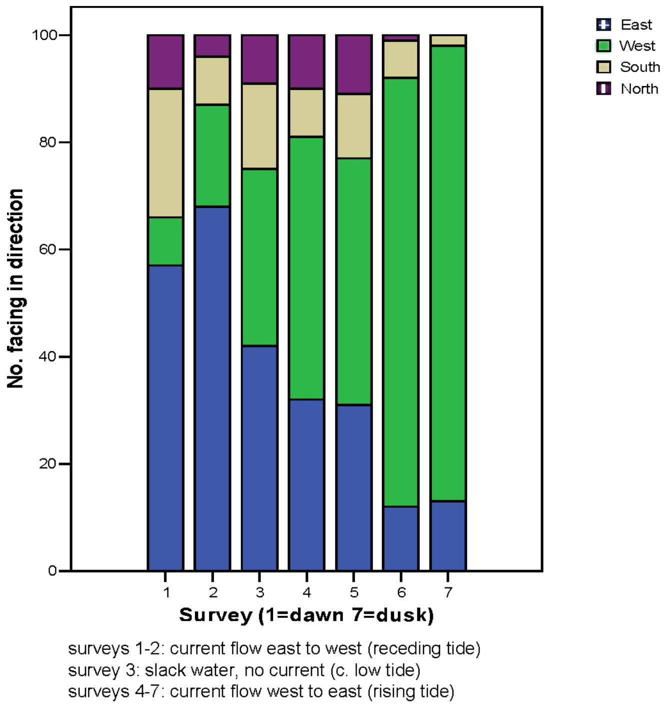


Fig. 4.2 Orientation of Common Scoter on a day (18/12/03) with wind speeds < 5 km/hr showing change in orientation with change in current direction.

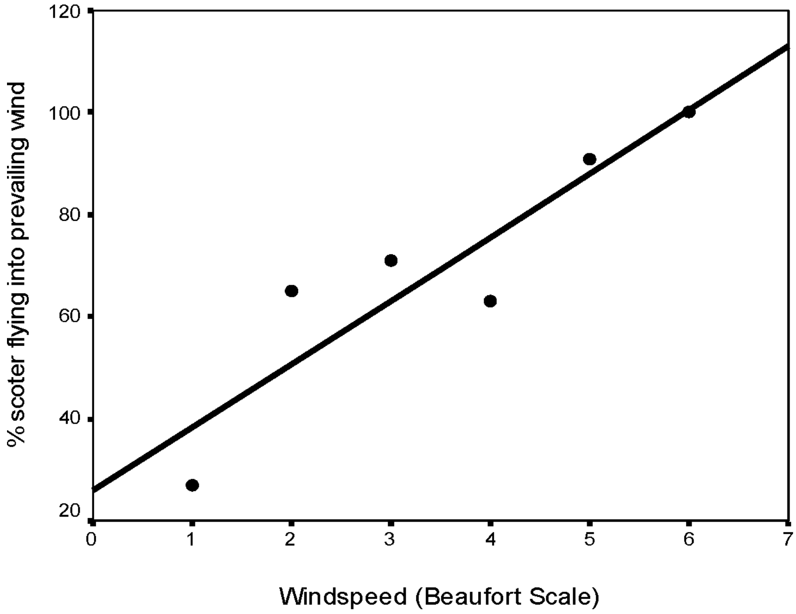


Fig. 4.3 Proportion of common scoter flying into/within 45°of prevailing wind with increasing windspeed.

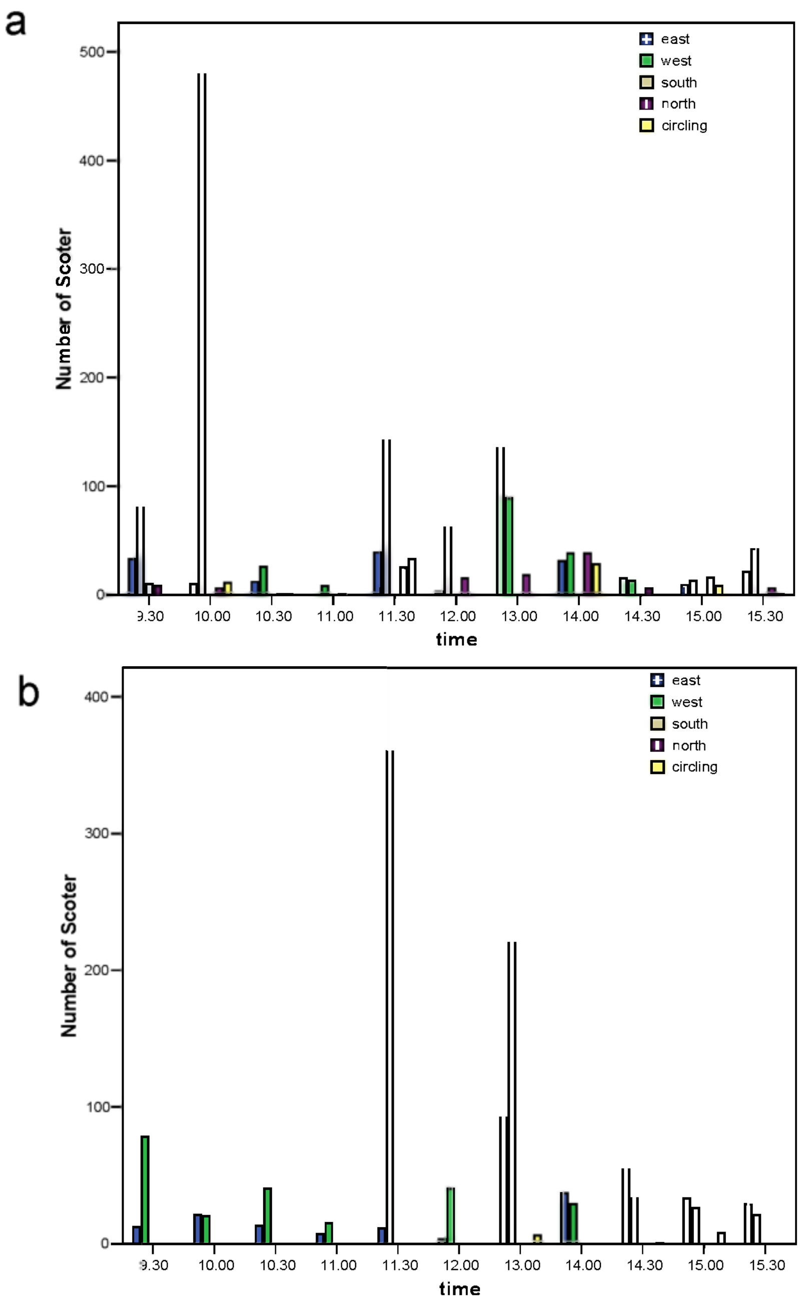


Fig. 4.4 (a) Flight direction of common scoter off west Llanddulas, 11/12/03.
(b) Flight direction of common scoter off east Llanddulas, 11/12/03.

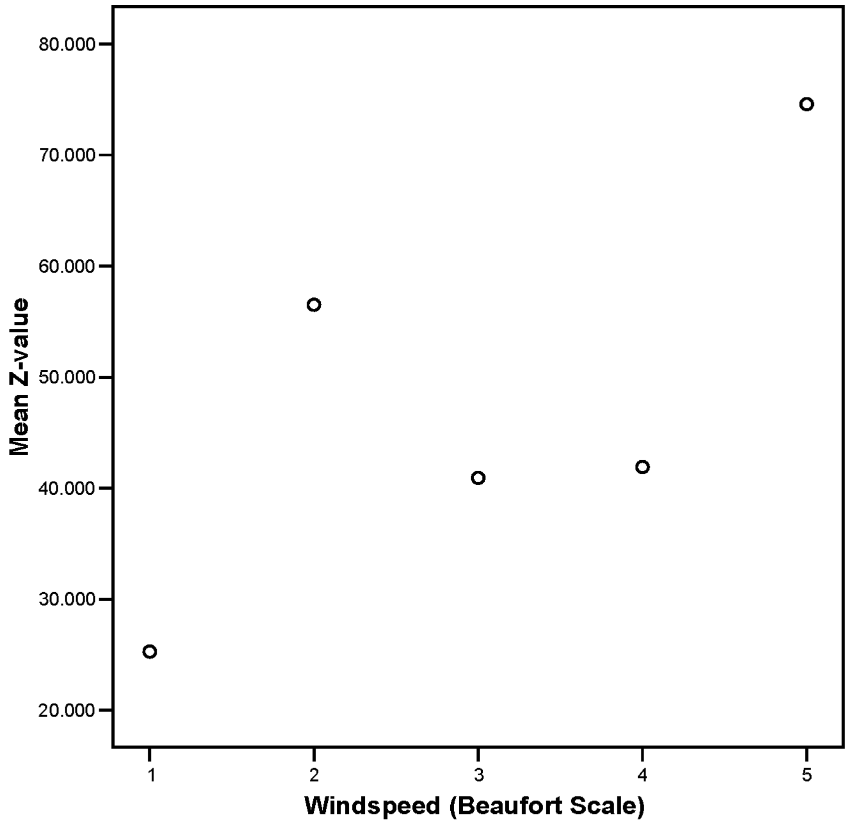


Fig. 4.5 Common Scoter orientation - mean Z-values plotted against windspeed (irrespective of current direction) indicating a trend (non-significant) towards a greater proportion of scoter facing into the prevailing wind with increasing wind speed.

5. Existing forms of disturbance

5.1 Introduction

One of the data requirements of the behavioural model was the estimation of the potential feeding area of the common scoter that would be unavailable to them due to existing anthropogenic activities such as shipping and aerial traffic. Garthe & Huppop (2004) classified common and velvet common scoter as the most sensitive of 26 species of seaducks and seabirds to disturbance by ship and helicopter traffic. In addition to studying the distribution of common scoter in relation to environmental parameters and the distribution of their prey, we were able to obtain information regarding the distribution of human disturbance from shipping and fishing disturbance. Repeated disturbance by ships, aircraft or other sources of disturbance could effectively lower the potential habitat value of areas that contain suitable and even abundant prey. Repeated and frequent disturbance will cause common scoter to fly and reposition to avoid the disturbance, thereby interfering with feeding, resting and incurring additional energetic costs. Thus it was necessary to quantify the location and occurrence of existing forms of anthropogenic disturbance that may impact upon common scoter in Liverpool Bay.

5.2 Methods

All spatial data were processed and analysed with ArcView GIS software using the model grid for reference (sections 2 and 3). The positions of the proposed windfarms were entered into ArcView as a map layer together with the tidal grid cells.

Commercial shipping intensity data was made available to us by Anatec UK Ltd through the COASTS database, and supplied as the number of ships (> 300 t) passing through each tidal grid cell per year. The COASTS database holds only data for vessels greater than 300 t (gross). The RV Prince Madog from which the flush distances were measured (section 4) is 390 t (gross). Hence the data represents vessels from 300 t up to super-tankers >> 90 000 t (gross). Vessels were assigned to each grid cell from the reported route taken by the vessel (port of embarkation, port of destination). Vessel routes are assumed to take the shortest possible linear distance other than to conform to the regulations imposed by navigational channels and separation zones (e.g. off the northern tip of Anglesey). Given the size of each of the model grid cells (3.7 x 3.35 km) and the known flush distance from a vessel of 390 t (1km – 2km), the grid cell size seems an appropriate scale at which to consider the extent of the disturbance created through each cell assuming vessels pass through the centre of that cell. The number of vessels that docked or embarked from each of the major ports around the North Wales and Lancashire coastline were extracted per month for the year 2003/2004 to determine any seasonality in the amount of potential disturbance from commercial shipping activity.

In addition to commercial shipping activities, fishing vessels from North Wales and Lancashire operate in Liverpool Bay and may generate additional disturbance for common scoter. These vessels will not appear in the COASTS database as most are < 24 m in length and << 300 t (gross). Larger fishing vessels such as beam trawlers of Dutch and Belgian origin fish in the Irish Sea but these are restricted to waters beyond 6 nautical miles from the shore. Detailed information of fishing activities in Liverpool Bay were ascertained for the period 1987 – 2002 from enforcement agency (Department of Environment, Food and Rural Affairs (DEFRA)) overflight data of direct observations of fishing vessels expressed as sightings per unit effort of observation (SPUE) (see Dinmore et al., 2003 for a full explanation of methods of data calculation and interpretation). These data were entered into the GIS ArcView software and interpolated to see to what extent fishing activities overlapped with the distribution of common scoter. The database includes fishing vessels of all types, but for the Northeastern Irish Sea this would primarily consist of otter trawlers, beam trawlers and scallop dredgers, although the latter are primarily confined to waters deeper than 20 m due to the location of scallop populations off the North of Anglesey and towards the Isle of Man. The data held within the database does not give information of routes taken by fishing vessels from their home port to fishing grounds, hence it is not possible to assess the possible disturbance caused by such activities, however it is likely to be highly variable as vessels from ports in the Northern Irish Sea target different fisheries according to market forces and movements of the target species.

The potential effects of disturbance by helicopter flights to and from oil and gas installations were also considered as these are likely to be regular and frequent for maintenance and personnel transfer.

Blackpool airport in Lancashire was the source of the flights to and from the oil and gas installations in the Irish Sea. Data were obtained from the SEA 6 report prepared for the DTI. The helicopter flight path is given as a corridor approximately 3 km wide.

5.3 Results

Although helicopter flights occurred directly across the main aggregations of common scoter off Blackpool and the River Ribble (Fig. 5.1), they were relatively infrequent occurring approximately once per day (one outbound and one inbound trip) for each installation. The low altitude of helicopter flights (300 – 600 m) is roughly similar to that used for the common scoter light aircraft surveys (500 m) which are known to flush birds at the water surface (P. Cranswick pers. Comm.). Nevertheless, the infrequent nature of these flights is likely to generate much less disturbance than the reported commercial shipping activities over the wider area of Liverpool Bay (see below).

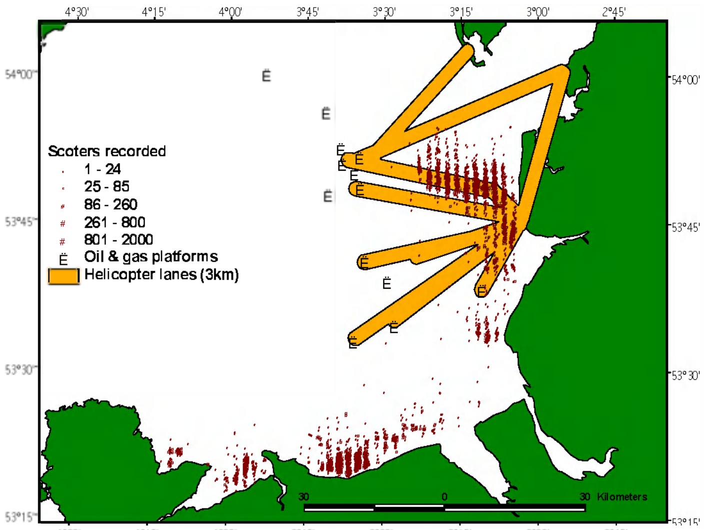


Fig. 5.1 Helicopter flight paths from Blackpool airport to oil and gas platforms (width 3 km) in relation to the distribution of common scoter observed during for the winter seasons 2002/2003 and 2003/2004. Helicopter flights occur approximately once per day at an altitude of 300 – 600 m.

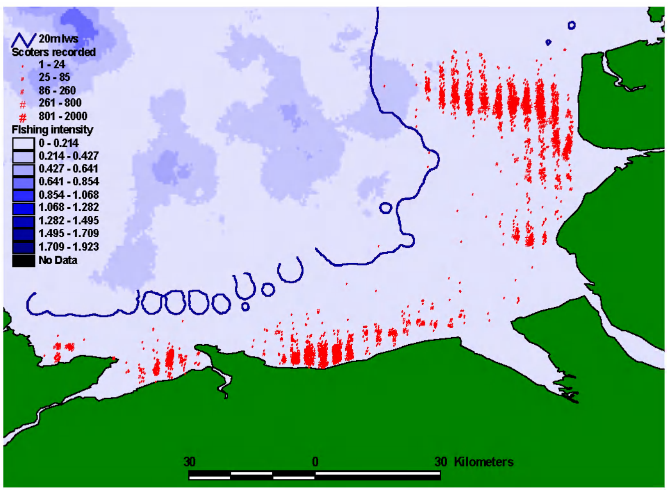


Fig. 5.2 The distribution of fishing effort in Liverpool Bay derived from DEFRA overflight data and the sightings of common scoter for the winter seasons 2002/2003 and 2003/2004.

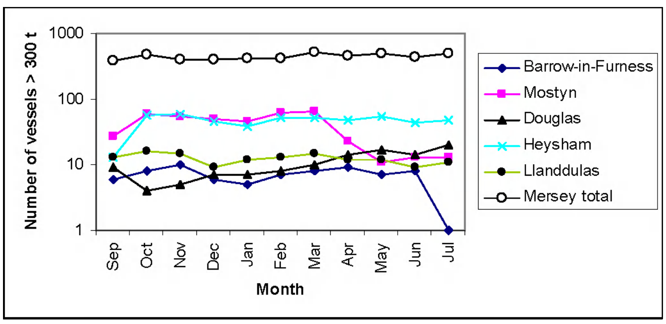


Fig. 5.3 Monthly figures for shipping activities at the main points in the northern Irish Sea. The y-axis is represented as a log scale. None of these trends deviated significantly from a slope of zero, hence the mean values give in Table 5.1 are an accurate representation of activity for each month.

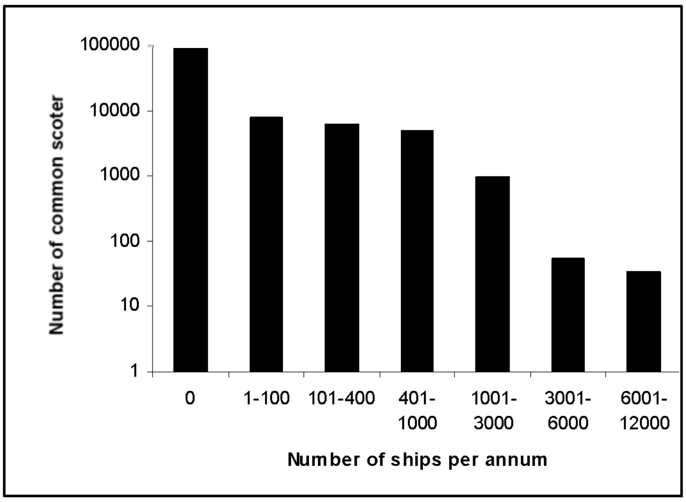


Fig. 5.4 Sum of common scoter observed during 8 overflights (2003/2004) for Liverpool Bay in relation to the number of ships > 300 t that passed through each 3.7 x 3.35 km cell defined for the behavioural ecology model

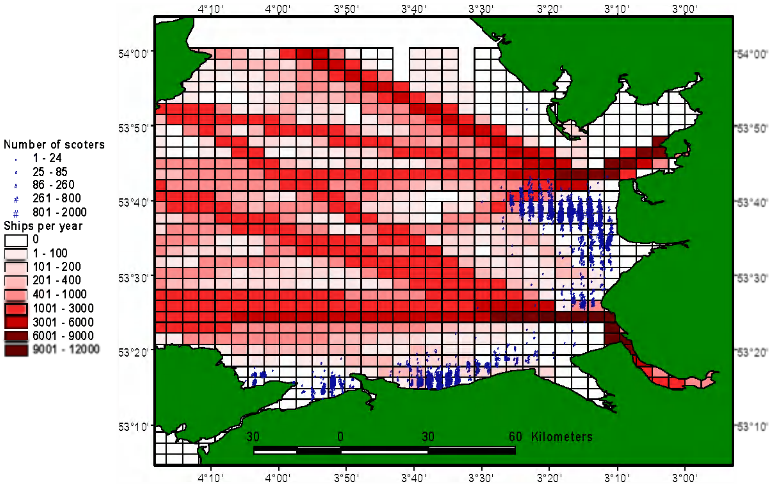


Fig. 5.5 The number of ships > 300 t that passed through each 3.7 x 3.35 km cell defined for the behavioural ecology model for the period September 2003 to July 2004. The number of common scoter sighted during 8 overflights for the period 2002/2004 is shown for reference.

The level of fishing activity in all areas in which common scoter occurred was extremely low, with only light fishing activity on the extreme western edge of Shell Flat. The majority of the fishing activities occurred much further offshore in the waters just to the south of the Isle of Man (Fig. 5.2).

Shipping activity in and out of the main eastern Irish Sea ports did not vary significantly through the period of September 2003 to July 2004 (all relationships non-significant with time $P > 0.05$). Thus there are no seasonal patterns in shipping activity that might be relevant with respect to fluctuations of disturbance to common scoter throughout the year. However, shipping activity was spatially aggregated at the 3.75 x 3.25 km grid scale such that c. 82% of common scoter observed through the period 2002/2004 occurred in cells that had zero shipping activities for ships > 300 t. The number of birds observed declined steeply with increasing levels of shipping activity (Fig. 5.4, Table 5.2). The distribution of common scoter differed significantly from an equal distribution of birds among all model cells (Table 5.2, x^2 = 51173, d.f. = 6, P <<< 0.0001).

Table 5.1 The mean number of vessels (> 300 gross tonnes) arriving and departing from the main ports in the northern Irish Sea for an area of coastline that extends from Point Lynas (Anglesey) to Barrow-in-Furness (Cumbria). Data were extracted from September 2003 to July 2004 (11 months).

Barrow-in-Furness	6.82	±	2.40
Mostyn	38.36	±	21.19
Douglas	10.45	±	5.13
Heysham	46.27	±	12.61
Llanddulas	12.45	±	2.30
River Mersey total	447.00	±	47.65

Table 5.2 Table of shipping activity for each 3.7 x 3.35 km represented as the number of vessels > 300 t passing through that a cell per annum. Only those cells selected for the behavioural ecology model have been analysed, any shipping areas with a depth greater than 25 m have been excluded. The sum of the number of common scoter observed over during the 8 overflights is also shown. These values are expressed as percentage in parentheses.

Ships per year per cell	Number of common scoter	Number of cells
0	90153 (82)	60 (48)
1-100	7777 (7)	23 (19)
101-400	6097 (5)	23 (19)
401-1000	4811 (4)	7 (5)
1001-3000	933 (1)	4 (3)
3001-6000	56 (<<1)	4 (3)
6001-12000	34 (<<1)	2 (1)

5.4 Discussion

The effect of human disturbance is often measured in terms of behavioural changes in response to human presence but from a conservation perspective such disturbance is important only if it affects survival or fecundity and hence a population decline (Cayford 1993; Gill et al. 2001; West et al. 2002). To demonstrate any such effect on common scoter populations through disturbance on their wintering grounds would be virtually impossible. However, common scoter as demonstrated, are extremely wary and it has been suggested that species showing the greatest avoidance require the greatest amount of protection (Klein et al. 1995). This though may not be true for species where the costs of moving to an alternative site are likely to be small (Gill et al. 2001). Wigeon *Anas penelope*, for example show a strong human avoidance (Tuite et al. 1984) but for this mainly herbivorous species often grazing on short swards with many nearby alternative feeding sites, costs are probably low. One could argue that this is the case for common scoter as upon disturbance there are plenty of areas of undisturbed sea to which they could fly and settle. On the other hand fitness costs may be high if there were few or no other nearby suitable feeding areas to which they can go. Furthermore, the additional expenditure of energy associated with each disturbance flight can in some instances lead to a substantial increase in daily energy expenditure and necessitates an increased foraging effort in order to compensate (White-Robinson 1982; Riddington et al. 1996).

Shipping activities

Most (82%) of the common scoter were observed in 48% of the model cells that had no shipping activity for vessels > 300 t, with 12% of the birds occurring in 38% of the cells that had light shipping activity. This perhaps suggests that common scoter avoid areas with activity associated with large vessels. Fishing activities did not occur in close proximity to areas in which common scoter were observed except for the extreme tip of Shell Flat off Lancashire. Most fishing activities were concentrated further offshore and consequently appear unlikely to have a significant influence on the distribution of common scoter.

Taking the direct observations of flush distance from section 4 quantified for the response of common scoter to a 390 t vessel, the 3.75 x 3.35 km model cells would be cleared of common scoter if this vessel steamed through its centre line. Presumably flush distances vary dependent upon factors such as the prevailing weather conditions, the speed of approach of a vessel, the angle of approach, the size (and even colour) of the vessel, human activity visible on the deck, and the fitness of the birds themselves. However, within the confines of the current study it is impossible to take such factors into account. It may be that along regularly used shipping lanes birds might become habituated to the presence of boats. However the lack of overlap between intensively utilised shipping lanes and common scoter suggests that this does not occur to a significant degree.

Helicopter disturbance

Helicopter disturbance seems to be relatively inconsequential as the main helicopter flight paths crossed some of the main aggregations of common scoter on Shell Flat. In the main, these flights occur at most once per day along each trajectory. Other forms of disturbance that are not accounted for within the study are the disturbance generated by pleasure craft such as sail boats and jet-skiis. The latter generate considerable noise and may affect areas much larger than their size would suggest. Nevertheless there is no available information to suggest the extent to which these activities might affect use of areas of the sea by common scoter. This perhaps requires further investigation as these activities are not currently measured.

Other potential sources of disturbance

Our ability to determine those sources of disturbance that influence the distribution of common scoter is limited by the availability of information on those sources of disturbance. The coastal zone is heavily utilised for recreational purposes and as such the effects of yachting and jet-skiing. The former is likely to be heavily concentrated around areas with marinas e.g. Menai Strait, Conwy, Rhos on Sea and Fleetwood, while jet skiing is likely to be focused on those areas with convenient launch facilities. Neither of these activities is currently recorded in a format suitable for incorporation in our considerations but might warrant further investigation in the future. Both activities have the potential to cause disturbance, yachts are highly visible due to their sails while jet-skiis have a noise disturbance envelope that can extend to multiple km.