Ecology of Maplin Sands

and the coastal zones of Suffolk, Essex and North Kent

Institute of Terrestrial Ecology
NATURAL ENVIRONMENT RESEARCH COUNCIL

Natural Environment Research Council

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L. A. Boorman and D. S. Ranwell
Institute of Terrestrial Ecology
Colney Norwich

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Institute of Terrestrial Ecology
Colney Research Station
Colney Lane
Colney
NORWICH NR4 7UD
0603 (Norwich) 54923 - 5

The Institute of Terrestrial Ecology (ITE) was established in 1973, from the former Nature Conservancy's research stations and staff, joined later by the Institute of Tree Biology and the Culture Centre of Algae and Protozoa. ITE contributes to and draws upon the collective knowledge of the fourteen sister institutes which make up the Natural Environment Research Council, spanning all the environmental sciences.

The Institute studies the factors determining the structure, composition and processes of land and freshwater systems, and of individual plant and animal species. It is developing a sounder scientific basis for predicting and modelling environmental trends arising from natural or man-made change. The results of this research are available to those responsible for the protection, management and wise use of our natural resources.

Nearly half of ITE's work is research commissioned by customers, such as the Nature Conservancy Council who require information for wildlife conservation, the Forestry Commission and the Department of the Environment. The remainder is fundamental research supported by NERC.

ITE's expertise is widely used by international organisations in overseas projects and programmes of research.

Cover photographs:
Top — Reclaimed marshland, Ham, Kent
Photograph Miss A. Macey
Centre — Left, The Bazooo, amphibious survey vehicle. Photograph Miss R. Waters
Right, Dark-bellied Brent goose
Photograph Dr. K. Charman
Bottom — Saltmarsh vegetation, Dengie, Essex
Photograph Dr. L. A. Boorman

Contents

Foreword

This study represents a major investment of public money in a survey of plants and animals on Essex and North Kent coastlines and the likely effects of an airport development.

Two years before the study was commissioned, the Nature Conservancy anticipated the need for improved knowledge of this coast, and a pilot survey was carried out in 1971 by its Coastal Ecology Research Station (now I.T.E. Colney Research Station, Norwich). This survey helped to establish the feasibility of the techniques and much background information vital to the effective planning of the major study.

There is no doubt that public concern for wildlife, expressed through the voluntary bodies and effectively focussed within official circles, led to adequate funds for the main study being made available from the Department of the Environment in 1972.

In planning the study, it seemed essential to produce not only the best possible predictions about the consequences of the airport for wildlife, but also to produce information relevant to other types of development on this coast in the event of the airport proposal being abandoned, as in fact happened.

The study was carried out by a team of scientists recruited under contract and led by a permanent member of staff, Dr. L. A. Boorman. Vital information was provided by many voluntary helpers, whose assistance was indispensable to the success of the study. Bearing in mind the time-scale of three and a half years from recruiting to reporting, perhaps one of the most notable features of the study was the effective co-operation of people from government departments, voluntary bodies and universities towards the achievement of the objectives.

Certainly one of the most exciting features was the dialogue that developed between biologists and hydraulic engineers over intertidal conditions controlling the growth of eelgrass (***Zostera***). Eelgrass is an important food plant of Brent geese and both were likely to be lost from their main stronghold in England by airport development at Maplin.

It was interesting to find that the pilot study predicted correctly four of the top five priority substitute sites identified in need of special protection should Maplin be lost, and it also estimated 80 per cent of the eelgrass resources recorded in the main study. These facts emphasise the value of consulting ecological specialists even when there is no time for detailed measurement or lengthy research in relation to land management problems. Only by detailed survey, however, was it possible to estimate hidden food resources such as the mud-dwelling organisms on which birds feed. Research on Brent geese and their food was essential to some understanding of the supreme importance of behavioural factors in these birds in relation to feeding ecology and reaction to disturbance from people.

The study was carried out in 1972 - 75 during exceptionally favourable weather conditions for Brent geese. The remarkable doubling of the world population of these geese that occurred in this period (for reasons still not fully understood) demonstrated how rapidly existing food resources at the coast could become inadequate and how promptly the birds turned to feeding on crops inland at an unprecedented level. Clearly, a very different story might have emerged had the study been conducted over a period of exceptionally cold winters. We must conclude, therefore, that we are still a long way from being able to model the system and to predict with accuracy the effect of a major development on this sector of our coast. We have, however, gained valuable quantitative data on the energetics of the Brent goose food sub-system relevant to such a model.

Apart from general benefits, in the form of the considerable experience gained in the planning and running of this type of study (likely to make future ones more effective), the results seem to justify the expenditure in two ways. They provide a base-line of quantitative information in the form of maps, species population estimates, and habitat area estimates at a particular cross-section in time. This information is relevant to planning issues of all kinds on this coast, and, from it, some measurable assessment of future changes can be made. Results have also revealed more of the complex nature of living systems, which should enable us to make better predictions of future changes, first by means of conceptual models and, eventually, by more sophisticated mathematical models. What is clear is that unless we continue to invest in comprehensive studies designed to reveal both qualitative and quantitative environmental relationships, we shall continue to run the risk of damaging unwittingly the fabric of the environment in which we exist.

D. S. RANWELL

Institute of Terrestrial Ecology
Colney Research Station
Norwich

24th February 1977

Summary

1. This report describes a three and a half year (1972-76) scientific study of the ecology of the coastal zone between the Orwell estuary in Suffolk and the Kentish shore of the Thames Estuary.

2. The work was done by the Natural Environment Research Council's Institute of Terrestrial Ecology, with ornithological help from independent bodies. It was carried out under contract to the Department of the Environment, and formed part of the evaluation of the environmental impact of the proposed Third London Airport at Maplin.

3. The coasts of the study area are 'soft', composed of easily mobilised sediments. Maps of the intertidal flats, salt marshes, reclaimed marsh and margins of built up areas have been made from air photographs, validated by ground survey. About a fifth of all the salt marshes, and a substantial proportion of the tidal flats, in Britain occur in the study area, and Maplin is the largest area of continuous intertidal flats on the British coast.

4. The mud flats support large populations of invertebrate animals, important as food to wading birds. The two most important plants on the flats are eelgrass (***Zostera***), the staple food of the dark-bellied Brent goose, and a green alga (***Enteromorpha***), also important as food for wildfowl. The distribution and abundance of these plants and invertebrates have been determined for the first time. The vegetation of the salt marshes and reclaimed marsh has been described, again for the first time, and the distribution of rare or local species recorded.

5. The study area is internationally famous for the wading birds and wildfowl that winter there, including at least 20 per cent of the world population of dark-bellied Brent geese and over 1 per cent of the European populations of 15 other species. The numbers and distribution of these birds have been determined, and related to habitat, including food. A detailed study of the Brent geese has confirmed increasing numbers, which could apparently exceed the capacity of the inter-tidal feeding grounds and has led to overspill on to agricultural land.

6. Had the airport been built at Maplin, 30 per cent (Stage 1) to 60 per cent (Stage 2) of the mudflat area would have been reclaimed, obliterating the winter habitat of 7,500 – 15,000 wading birds, and some 4,500 dark-bellied Brent geese. It would also have destroyed the only viable pioneer population of the small cord-grass (***Spartina maritima***) in Britain.

7. Airport construction would also have had indirect effects on the bird fauna, affecting up to 275,000 individuals. Some displaced birds would probably have found habitats elsewhere on the south-east coast; others (such as the geese) might have increased their pressure on farmland.

8. No 'alternative' area matching all the environmental features of Maplin was found, but a series of "substitute" sites which, if conserved collectively, would perpetuate the habitats of most of the species found there was identified. Management could enhance the value of such sites for wildlife, but would be unlikely to do so to such an extent that all the populations displaced from Maplin were accommodated.

9. The study has emphasised the inter-relationship between the processes of accretion and erosion on such coasts, water movement, sediment load and the flora and fauna, and indicated topics for both background research and field experiment.

10. Although the Maplin Airport project did not proceed, therefore, the study has been of value in providing a mass of detailed scientific information about the environmental patterns and processes in a major coastal region that will certainly come under continuing pressure from development in future. It has also indicated the sites of most value for wildlife conservation, and demonstrated factors to be taken into account in their management.

J. N. R. JEFFERS
18th March 1977

Introduction

BACKGROUND

The Natural Environment Research Council was commissioned in 1972 by the Department of the Environment to undertake ecological surveys of those parts of the coasts of Kent, Essex and Suffolk that might be affected by the proposed airport and seaport of Maplin (Foulness), to predict the possible impact of this development on wildlife, and to suggest ways in which this impact might be mitigated. The work was undertaken by Dr. L. A. Boorman, Mr. K. Charman, Miss Julia E. Head, Dr. D. G. Kay, Mr. R. D. Knights, Miss Anne Macey, Dr. N. W. Owens, Mrs Julia Say, Miss Rosalind J. Waters and Dr. D. W. Wyer, based at the Institute of Terrestrial Ecology, Colney Research Station, Norwich. Because there was particular concern for the effects on birds, some projects were subcontracted to a consortium of the Wildfowl Trust, British Trust for Ornithology, the Royal Society for the Protection of Birds and Durham University. This work was carried out by Mr. A. St. Joseph and Mr. T. J. Bennet, supervised by Professor G. V. T. Matthews (Wildfowl Trust); Mr. R. Blindell, supervised by Dr. J. Flegg and Mr. A. Prater (British Trust for Ornithology); and Mr. P. Smith, supervised by Dr. P. E. Evans (Durham University). The Nature Conservancy Council undertook a special study of the implications of the scheme for nature conservation.

This report summarises what has been done in the three and a half years, 1st September 1972 to 31st March 1976, in the study area from the Orwell estuary (Suffolk) to the Thames estuary (Kent) (Fig 1). The original contract between DOE and NERC was terminated on 30th November 1974 following the abandonment of the airport proposal. Arrangements were then made to continue some of the projects dealing with Brent geese under a new contract terminating in March 1976, in order to extract the best possible scientific return from the funds already expended. Data were originally collected to assess the impact of building an airport on wildlife and to improve sustitute areas by management, but these data can be used in a similar relationship to any proposed large-scale development on this coast.

The work was undertaken in liason with other interested groups, especially the Nature Conservancy Council; Hydraulics Research Station; Ministry of Agriculture, Fisheries and Food; Local Authorities; the Royal Society for the Protection of Birds; the Wildfowl Trust; the British Trust for Ornithology; the Wildfowlers Association of Great Britain and Ireland; County Naturalists Trusts; and Natural History Societies. The work could not have been completed without the assistance of these groups and the many helpers associated with the voluntary bodies.

SCIENTIFIC OBJECTIVES

The contract between DOE and NERC included the following objectives:—

a. To provide information on the species, amount, distribution and habitats of the most important elements of the natural fauna and flora of the area to enable an evaluation to be made of the effects on these of the construction and operation of a major international airport.

b. To establish whether or not there are unique features of scientific interest which will be irretrievably lost and which should therefore be studied before completion of the airport.

c. To provide information to enable the appropriate bodies to select the best substitute sites in their efforts to conserve as many as possible of the species and habitats that are associated with this part of the coast.

d. To undertake trials for the purpose of providing guidance for the future management and improvement of substitute sites to increase their wildlife potential.

THE STUDY AREA

The study area (Fig 1) consists of a predominantly 'soft' coastline of easily mobilised sediments as opposed to hard rock. The habitats of mud and sand flats, shell and shingle spits, backed by salt marshes, sand dunes or man-made sea embankments, are critically dependent on the balance between accretion and erosion. Volume and flow pattern of drainage from the land, and tidal movement from the sea result in an intermingling of fresh and salt water which produces special ecological conditions. In recent decades, conditions in many estuaries have been altered by polluting matter brought down the rivers or discharged directly into the estuarine zone.

The intertidal flats and banks are rich in invertebrate animals, many of which burrow into the substratum and feed upon detritus settling from above. Molluscs (such as mussels and cockles) and worms (such as the common lugworm, ***Arenicola***) are abundant, together with small crustaceans. The bottom-living (or benthic) animals form food sources for the bottom-feeding fish, and at low tide provide the staple food of wading birds and seabirds. The intertidal flats also support plants. Diatoms play a part in stabilizing accreting sediments, and larger algae and eelgrass (***Zostera***) form extensive growths on which wildfowl (geese and ducks) feed.

The soft coasts and estuaries of this country provide wintering grounds for a large number of birds that migrate north in summer to breed in the Arctic. These wintering grounds are particularly favoured because the big tidal ranges and gently shelving shores expose large areas of intertidal flats with abundant food in a mild oceanic situation at the western margin of Europe, rarely frozen or ice-covered in winter. Maplin lies centrally in this area and is favoured by

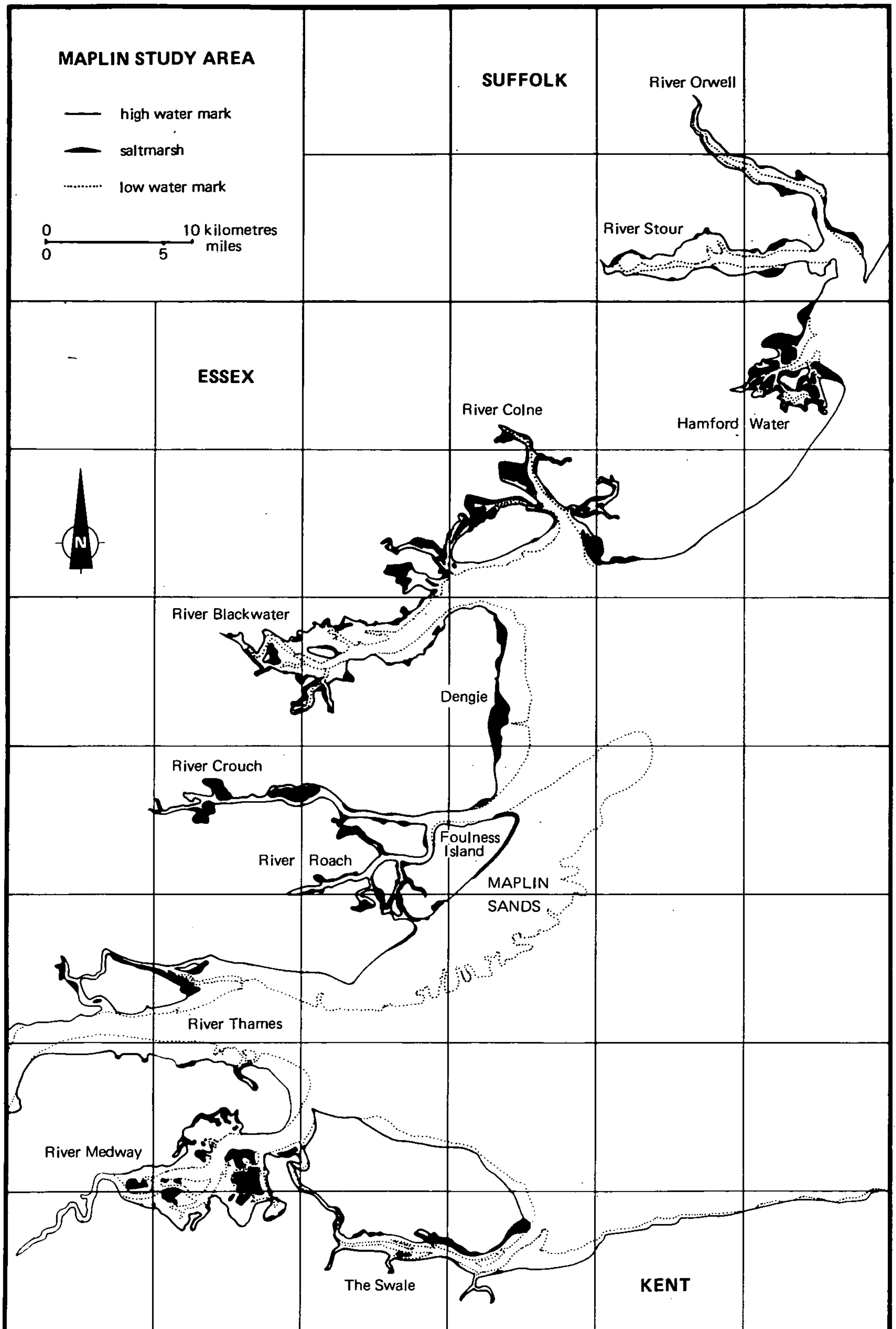

Figure 1. Maplin Study Area

a quarter of the world population of the dark-bellied Brent goose (***Branta bernicla bernicla***).

At higher levels, the stabilisation of the sediments is augmented by encroachment of salt marsh plants which form a more or less continuous sward whose composition varies with level. These salt marshes support substantial populations of terrestrial invertebrates and also provide grazing for wildfowl and feeding and breeding sites for other birds. Wave attack on the coast is reduced by the presence of salt marshes, so they are an aid in sea defence. Their capacity to accrete silt and raise the surface level has led to extensive reclamation for agriculture behind sea embankments on this coast.

The coastal ecosystems of the area under study thus involve a number of interacting species, among which the plants are important both in constructing the habitat and as food for grazing wildfowl and stock, and the invertebrates are important as food for fish and wading birds. Changes in the habitat, whether direct, by affecting the areas occupied by marsh or flats, or indirect, by altering the balance of accretion, erosion, or plant and animal populations, can have repercussions throughout the system.

HABITAT SURVEY

Some idea of the status of the survey area in the national context can be gained from the fact that about one seventh of the tidal flats, and about one fifth of the total area of salt marsh in Britain occur in the study area.

The objective of the investigation was a survey of the semi-natural habitats of the coastal zone, using specially commissioned aerial photographs to produce up-to-date, large scale maps showing the extent of tidal flats, the character of coastal vegetation, and built up areas.

The aerial survey was carried out with stereoscopic panchromatic photography, taken with a minus-blue filter, at a scale of 1:10,560 and from a height of 5000 ft with a six-inch focal length lens. The overall quality achieved by the photography, carried out by Meridian Airmaps Ltd., was good. The scale was accurate and there was little noticeable distortion due to tilt. The clarity of detail in some areas was excellent and the tonal contrast striking, especially in the Dengie marshes and Colne saltings photographs. The total cost of the 950 photographs received was £7,500 (in 1973).

The air photographs covered the zone from low water to three quarters of a mile inland over 150 square miles of coast from Felixstowe (Suffolk) to Whitstable (Kent). These were used to produce a set of 49 maps at a scale of six inches to the mile (Fig 2). Effective mapping would have been impossible without this specially commissioned air photography.

Techniques for much closer interpretation than usual were developed especially for a survey of this type of coastal terrain. Photographs were interpreted, with validation on the ground, to show the items of information in Table 1.

These maps provide much of the information needed to achieve the first objective of the study namely the recording of the abundance and distribution of the main habitat types. It is estimated there are 28,000 ha of intertidal flats, 7,043 ha of salt marsh and 4,340 ha of semi-natural reclaimed marsh in the study area, and the exact distribution of these habitat types on this coast has been defined.

Maplin consists of 10,500 ha of intertidal flats as a single unit occupying 38 per cent of this category in the study area. No other single unit of continuous intertidal flats of this size occurs on the British coast. This size gives plenty of room for birds to avoid temporarily disturbed areas and

Table 1. Categories of information on habitat maps

Salt marsh	**Reclaimed marsh**	**Other items**
Zostera species	Unimproved ungrazed marsh	Intertidal flats (limited by low water mark)
Large beds of green algae	Unimproved grazed marsh	Sand/shell/shingle accumulations
Pioneer salt marsh	Semi-improved pasture	Oyster pits
Aster tripolium		Degraded salt marsh
Salicornia species	Improved pasture	Sea embankments
Spartina species		
	Seasonally flooded wetland	Nature reserves
Mature salt marsh		Boating facilities
Youthful *Puccinellia*	Arable and other land usage	
Wet *Puccinellia*		Caravan sites
Grazed *Puccinellia*	Drainage channels	
Trampled *Puccinellia*		Chalet sites
Species rich (salt pan)		Railways
Eroded marsh		
Runnels		Roads and tracks
Agropyron pungens,		Rubbish dumps
Limonium spp. and		
Halimione portulacoides		Sewage works
In combination with above		Gravel pits
Reeds		25 ft contour
		Streams and rivers

AREAS OF DISTURBANCE

CS	Caravan site
ChS	Chalet site
BS	Boating facilities
⊕⊕⊕	Sewage works
ENT	Essex Naturalists Trust Reserve

SALT MARSH

Plant Species

i) Pioneers

S	*Spartina* spp.
S̸	*Salicornia* spp.
A	*Aster tripolium*

ii) Others

H	*Halimione portaculoides*
P	*Puccinellia* spp.
L	*Limonium* spp.
G	*Agropyron pungens*
R	Reeds
ȷ̸	Algae
	Zostera spp.

Note Capital or upper case letters in each box denote that species is *dominant*. Where species is an *associate*, letter is in lower case:

e.g. Pl — *Puccinellia* spp. dominant, *Limonium* spp. associate

Marsh Types

Py	Youthful *Puccinellia*
Pw	Wet *Puccinellia*
Pg	Grazed *Puccinellia*
Pt	Trampled *Puccinellia*
	Species-rich (Salt-pan)
	Vegetation poor
e	Eroded marsh
z	Runnels
	Sand/Shell/Shingle
	Vegetated sand, shell or shingle

Note Where letter in box is underlined, marsh is very dissected.

RECLAIMED MARSH

1a	Unimproved ungrazed
1b	Unimproved grazed
2	Semi-improved pasture
	Improved pasture
	Seasonally flooded wetland
	Arable and other landusage

Plate 1(a) Key to the Habitat Maps showing the various categories of information given on these maps.

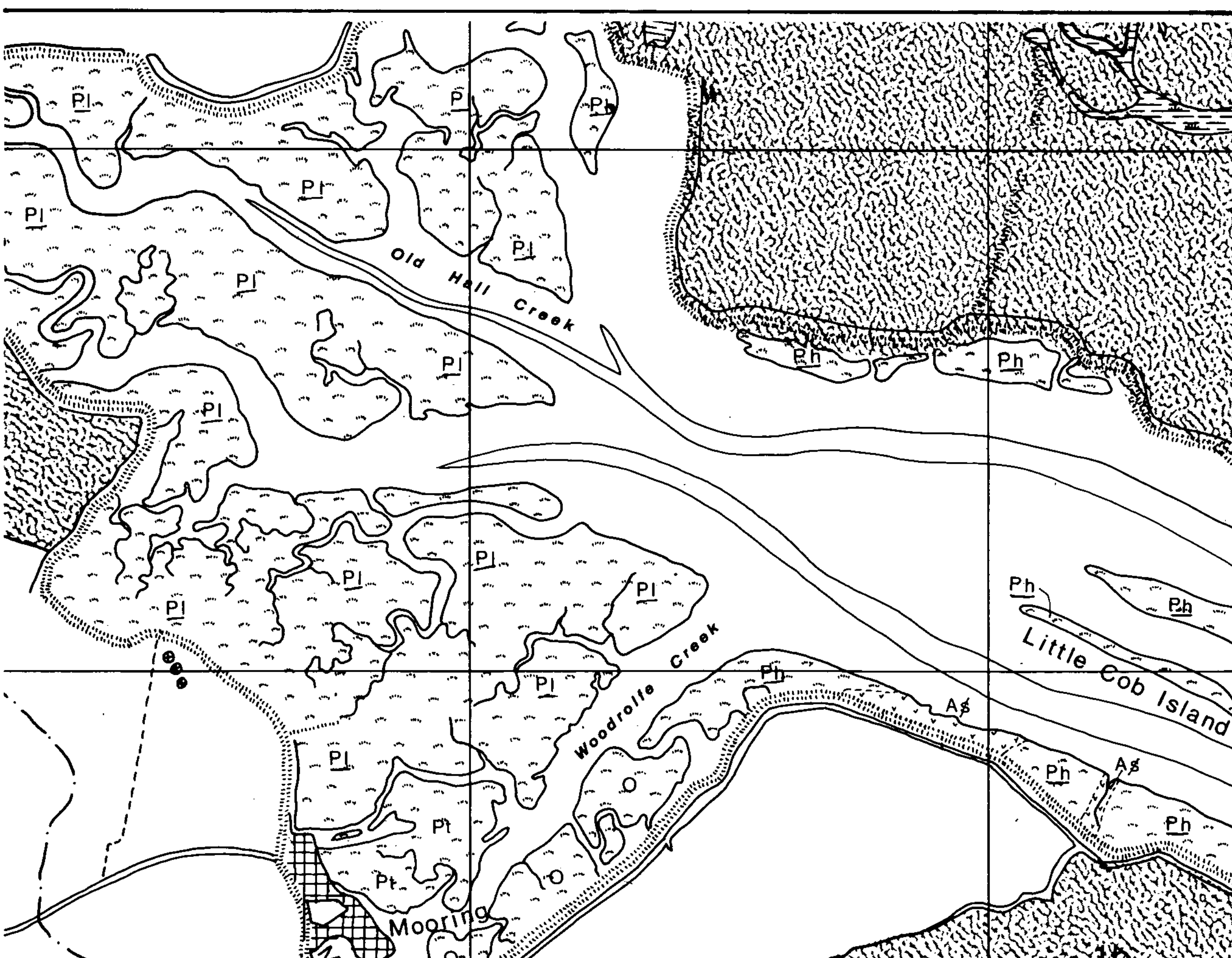

Plate 1(b) Sample of the Habitat Maps – Map 14 Tollesbury, Essex.

Plate 2 Aerial photograph of Foulness Point showing salt marsh fringed by the prominent shell spit.
Photo Meridian Airmaps Ltd

Plate 3 Aerial photograph of Colne Point, Essex, showing a sand spit. These structures appear to be building up at present. They enclose areas of mudflats and encourage salt marsh development. Photo Meridian Airmaps Ltd.

Plate 4. Aerial photograph of the Zostera bed at Leigh Marsh, Essex. This bed amounts to 25% of the total standing crop of Zostera noltii in the study area, and thus it is an important winter feeding ground for Brent geese.

is a significant feature for easily disturbed birds like geese and waders.

The maps provide a basis for the selection of substitute sites and, incidentally, a valuable planning aid for all subsequent development proposals likely to affect this coast.

TIDAL FLAT VEGETATION

The two principal types of plants found on the tidal flats are green macro-algae (seaweeds), mainly ***Enteromorpha*** species, and eelgrass (***Zostera*** species). These plants create distinctive communities, stabilize mudflats, act as precursors to salt marsh formation, and provide food for wildfowl.

The objectives of this part of the study were to locate and measure these food resources in such a way that their amount and energy content could be estimated relative to the food requirements of individual populations of Brent geese. It must be appreciated that seasonal variations in growth introduce errors which could not be fully assessed in the time available for the study, though every effort was made to reduce errors at each stage of measurement.

Two species of ***Zostera*** occur on the tidal flats, ***Zostera noltii*** and ***Zostera marina*** var. ***angustifolia***. They were estimated to occupy 844 ha (783 ha on the Suffolk/Essex coast and 61 ha on the Kent coast) and to produce a standing crop of 917 tonnes (825 and 92 respectively) fresh weight in 1973. ***Zostera noltii*** was partially winter-green and showed some growth in the mild winters at the time of the study and was thus available to the geese, especially in early winter. ***Zostera noltii*** occupied an estimated area of 440 ha and produced a standing crop of 249 tonnes fresh weight in 1973. Bomb calorimetric measurements indicated a total calorific value of 2.02×10^8 k cal.

Zostera marina var. ***angustifolia*** was estimated to occupy 343 ha and produced 576 tonnes fresh weight standing crop in 1973 with a total calorific value of 2.94×10^8 k cal. However this species had shed most of its leaves by October before most of the geese had arrived.

Enteromorpha was estimated to occupy 2,222 ha with a standing crop fresh weight of 4,450 tonnes (evenly balanced between Suffolk, Essex and Kent) and had a total calorific value of 4.86×10^8 k cal.

Table 2 shows that the fresh weight calorific value of ***Zostera noltii*** is nearly four times that of ***Enteromorpha*** so that geese presumably have to eat only a quarter the amount of ***Zostera noltii*** compared with ***Enteromorpha*** to obtain the same amount of energy. The special significance of the Maplin area derives from the fact that half the total ***Zostera noltii*** within the study area occurs there, with a further one quarter of the total on the neighbouring mud-flats at Leigh. Thus, Leigh is the only site which could approach Maplin as a substitute, but is so close that it might easily be affected by any major changes at Maplin.

Table 2. Calorific values of Zostera and green macroalgae

Species	**Calorific value k cal/g**	
	Dry weight	**Fresh weight**
Ulva	3.01	0.30
Z. marina	3.19	0.41
Enteromorpha	3.34	0.22
Z. noltii	3.84	0.81

SALT MARSHES

Nearly one fifth of the total salt marsh area in Great Britain occurs in the study area. In terms of area alone, therefore, the salt marsh habitats of the study area form a greater proportion of the national total than any of the other habitats within it.

The objectives of this part of the study were to determine the amount, distribution and composition of the salt marsh vegetation and to locate populations of rare species or those best represented in the study area in order to aid in the selection of substitute sites.

A total of 7,043 ha of salt marsh (5,142 ha in Suffolk/Essex and 1,901 ha in Kent) were estimated to occur in the study area. Samples were taken of the flora and soil at 307 sites in 71 salt marsh systems. Detailed descriptions of the species composition of the vegetation and the physical and chemical properties of the soil at each site were made. Prior to this survey, virtually nothing was known about the floristic composition and soil type of most of these marshes.

Maplin contains the only extensive population in Britain (possibly in Europe) of the rare salt marsh grass ***Spartina maritima***, which is a pioneer colonist on mudflats. Before the survey, this plant was only known as small populations at higher salt marsh levels. Many marshes of the study area are notably rich in lime and this favours the growth of the local species golden samphire (***Inula crithmoides***). The biggest populations are in the high-level marshes at Hamford Water and in the Medway.

Analysis of cover value vegetation data separates five floristic groups, accounting for 87 per cent of the sample variance. Four of the groups consist of components with a single dominant species: ***Aster tripolium, Halimione portulacoides, Limonium vulgare*** and ***Puccinellia maritima***. The fifth group is dominated by a pair of species: ***Armeria maritima*** and ***Plantago maritima***. The results emphasise the single species dominance which is characteristic of salt marsh vegetation. Species fall into the following categories:— 1. opportunist species such as short-lived perennials like ***Aster tripolium*** capable of rapidly colonising temporary gaps; 2. longer lived perennial woody species characteristic of more permanent ungrazed marsh areas like ***Halimione*** and

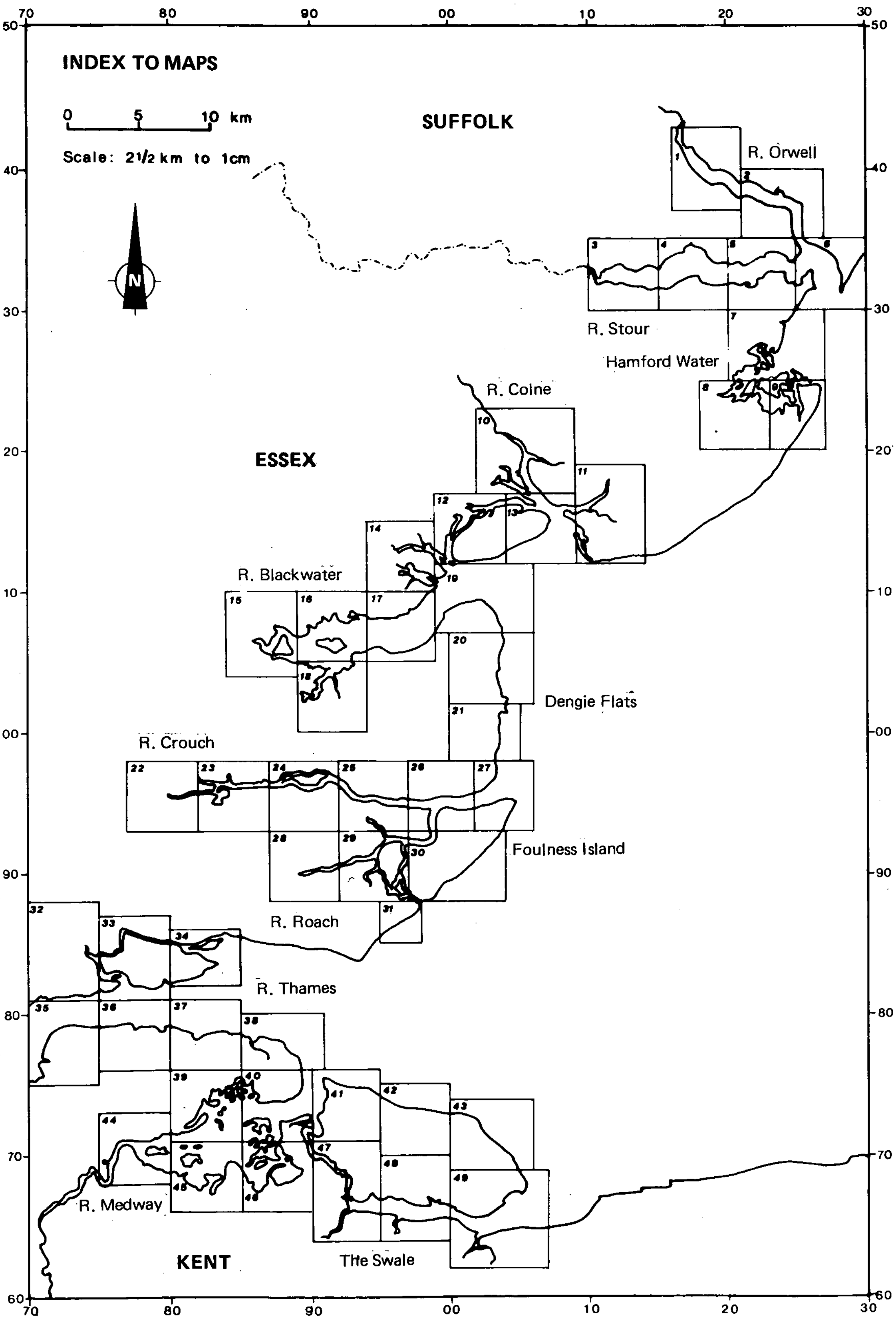

Figure 2. Index to maps

Plate 5 Different types of intertidal flats at Dengie, Essex. (i) Firm sand flats showing the casts of Arenicola

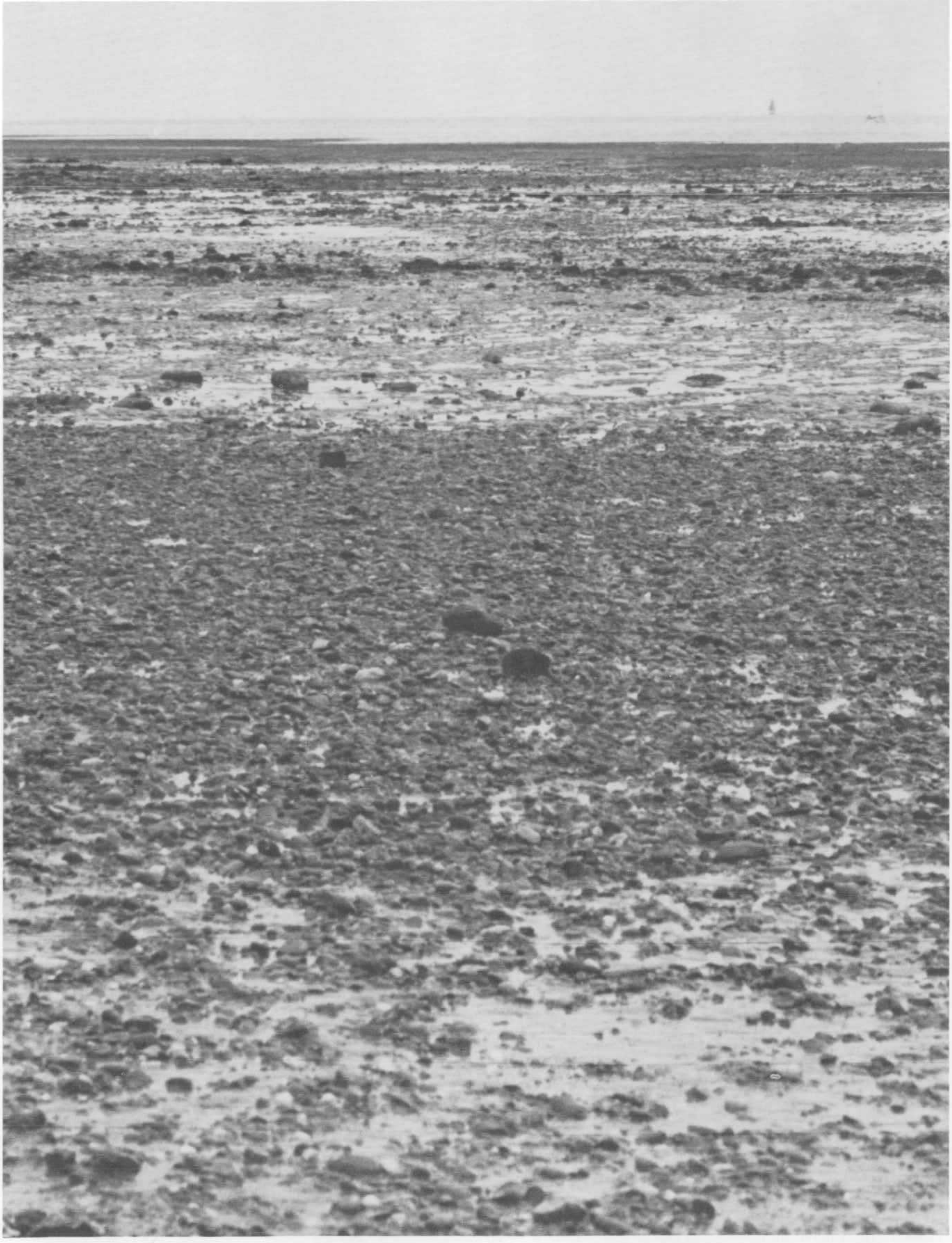

Plate 5 (ii) Shingle and sand occur where the tidal currents are strongest

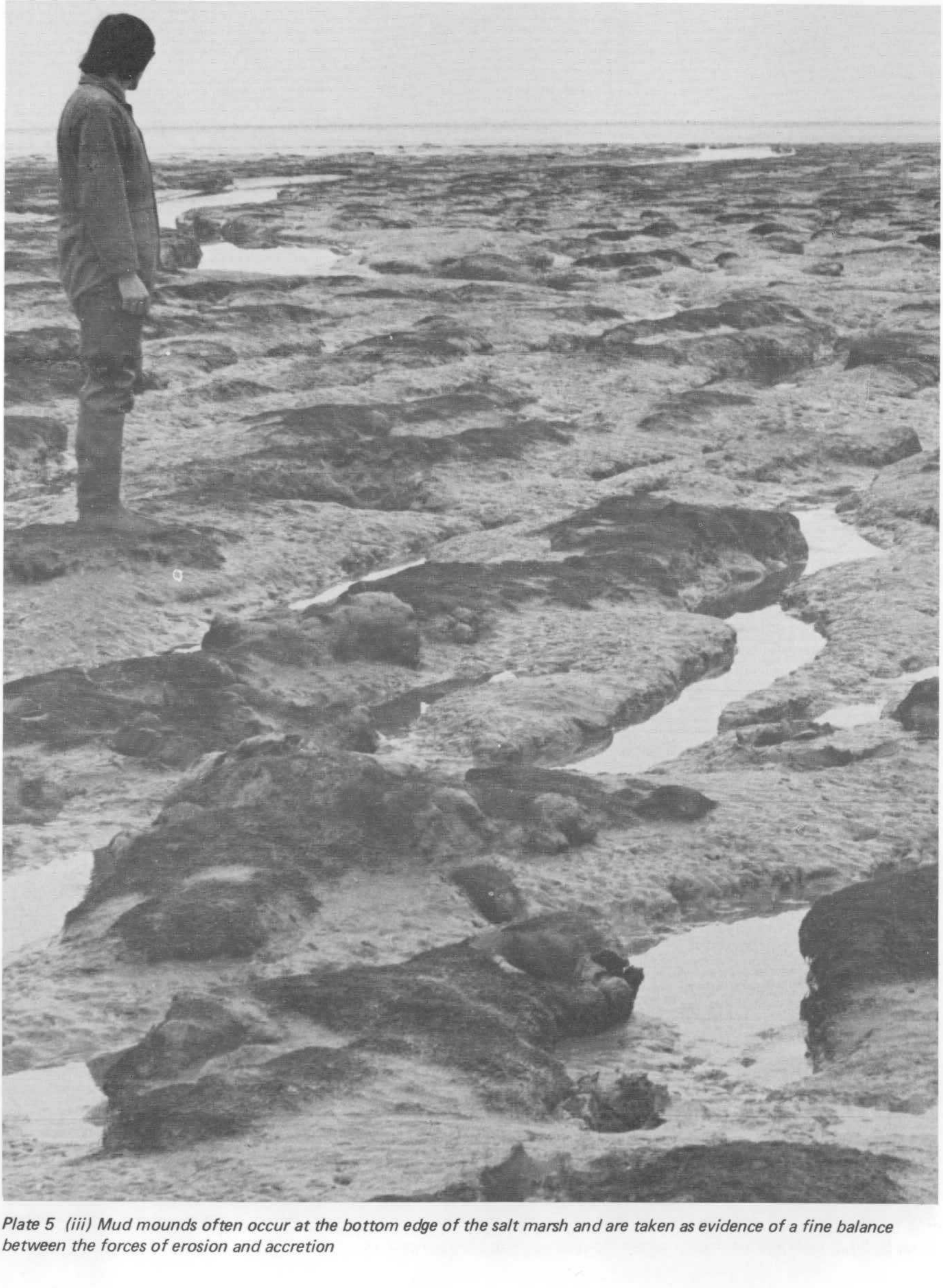

Plate 5 (iii) Mud mounds often occur at the bottom edge of the salt marsh and are taken as evidence of a fine balance between the forces of erosion and accretion

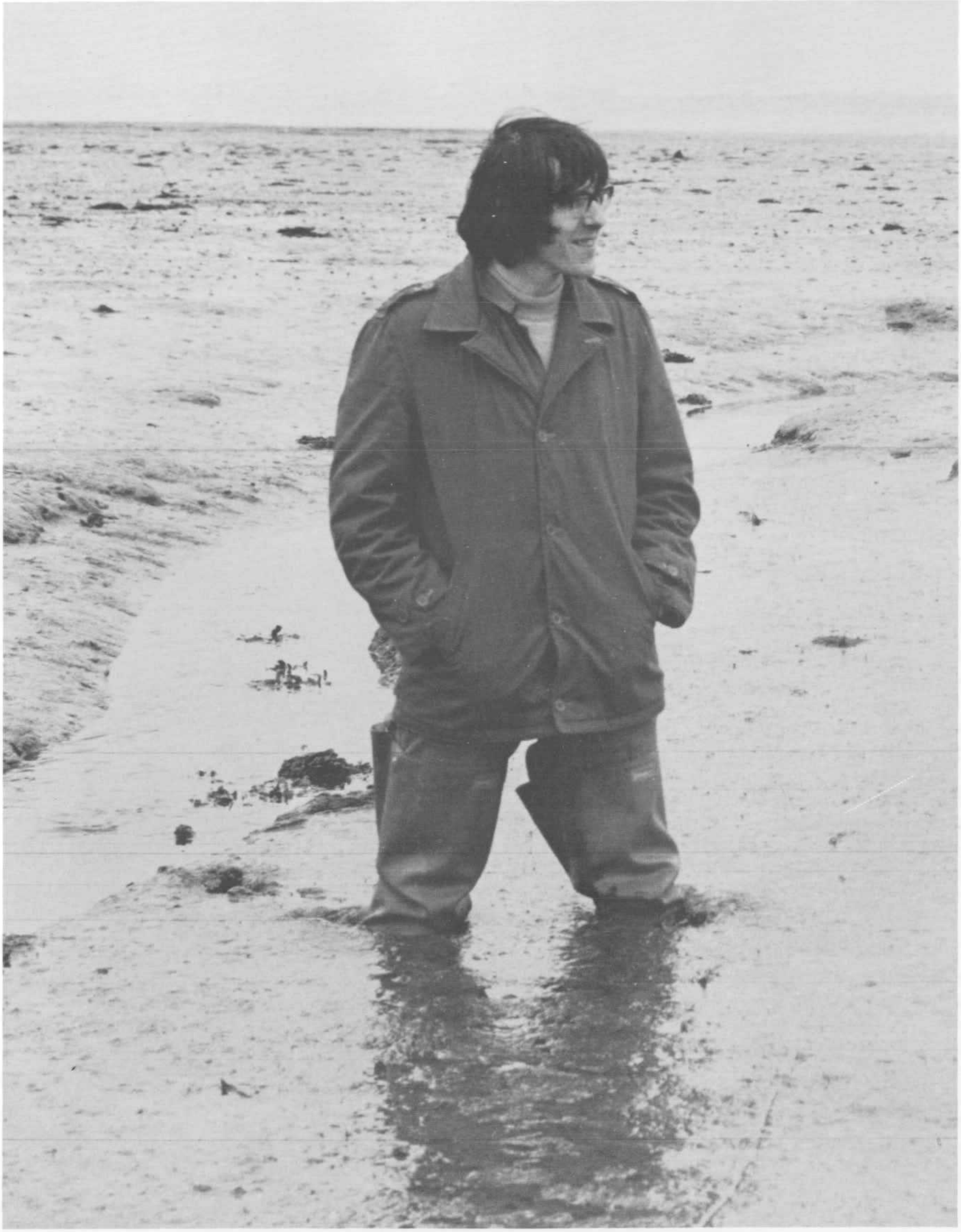

Plate 5 (iv) Soft mud – large areas of the intertidal zone in the study area are of this type. Relatively low energy water movements allow fine sediments to be deposited. These areas are particularly rich in invertebrate life. Photo Dr. D. Kay

Limonium; 3. perennial short grass and herb species characteristic of grazed marsh areas such as ***Puccinellia, Plantago maritima*** and ***Armeria.***

Further analysis indicated the presence of gradients from low level pioneer marsh to two types of high level marsh, one with low species diversity and the other with high species diversity, clearly related to the types of ungrazed and grazed marsh mentioned above. The fact that this second analysis only accounted for a third of the sample variance suggests that other factors which could not be measured in the time available for the present study (such as past grazing activity as a cause of present floristic patterns) may be of critical importance.

Soil analysis revealed a group of 24 lime-rich sites, predominantly in middle marsh levels at Dengie and Hamford Water, and possibly related to localised shell accumulations.

The nine most important salt marsh sites (Table 3) are selected from those combining high species diversity, presence of rare species, those at the edge of their geographical range, presence of the best examples of plant communities, and those with the lowest levels of human disturbance to the habitat.

RECLAIMED MARSHES

Since the Roman occupation, reclamation of salt marshes on the inherently fertile clay/silt soils of this coast has been undertaken whenever economic conditions allowed. There are now 4,340 ha of semi-natural reclaimed land in the study area. With improved protection from inundation from the sea, increased values of agricultural land, and better access, this type of land is being increasingly drained and ploughed. The objectives of this part of the study were similar to those of the salt marsh study. Techniques for identifying seven categories of reclaimed marsh from aerial photographs were developed (Table 1). Geographically representative blocks of semi-natural reclaimed marsh above 10 ha in size were examined, using an average of twenty 5 x 5 m quadrats per site in 27 sites (Table 4) and representing 3,095 ha, i.e. about three quarters of the total area of this habitat in the study area (Fig 3).

Table 3. The nine most important salt marsh sites

County	Site	Area (ha)
Suffolk	Orwell (N-side)	80
Essex	Blackwater	917
Essex	Colne	656
Essex	Dengie	542
Essex	Hamford Water	971
Essex	Maplin	609
Kent	Medway	1468
Kent	Swale	433
Kent	Yantlet	20

Over 200 species of vascular plants were recorded in semi-natural reclaimed marsh in the study area, and one site of 80 ha held 90 species. This type of land is the optimum habitat for a number of very locally distributed species which have their stronghold in this part of Britain (Fig 4 and 5).

This is the first analytical study of such a habitat in Britain. The structural uniformity imposed on the habitat by man provides a basis for classifying sub-habitats of reclaimed marsh wherever they occur on the north-west European coastline. The significant sub-habitats of semi-natural reclaimed marsh were distinguished as:—

1.	Sea wall, seaward side	5.	Low lying pasture
2.	Sea wall, landward side	6.	Inland banks
3.	Borrowdyke	7.	Fleets and ditches
4.	Pasture ungrazed	8.	Trackway

Three types of marshes were distinguished, using similarity coefficient analyses:—

1. Cattle and sheep grazed marshes of mean size 230 ha (e.g. Chetney and Ham marshes, Kent).
2. Cattle grazed marshes north of the Thames of mean size 60 ha (e.g. Brightlingsea, Suffolk and Shotley marshes, Essex).
3. Ungrazed marshes mainly in Essex of mean size 50 ha (e.g. Langenhoe and Bramble Island, Essex).

The study was concerned only with the flora of reclaimed marsh habitats. A full assessment should take into account their importance for birds, mammals, amphibia and invertebrates. The relative isolation of these sites from human disturbance increases the importance of the marshes as a wildlife refuge. Emergent vegetation of fleets and dykes provides nesting sites for a variety of birds, and seeds from the extensive stands of ***Scirpus maritimus*** form an important part of waterfowl diet. Pasture areas are used as feeding and roosting areas by large flocks of waders, ducks and geese, and provide breeding habitats for many bird species. Amphibia and small mammals occur and the invertebrate fauna is likely to be rich in local species compared with that of agricultural land. For example the rare frosted orange moth (***Gortina borelli***), found nowhere else in Britain and which feeds on ***Peucedanum officinale***, occurs in the study area.

INTERTIDAL MACRO-INVERTEBRATES

The aim of this part of the study was to provide information about the distribution of populations of macro-invertebrate species inhabiting the extensive intertidal sand and mudflats in the study area. These flats are used as a winter-feeding

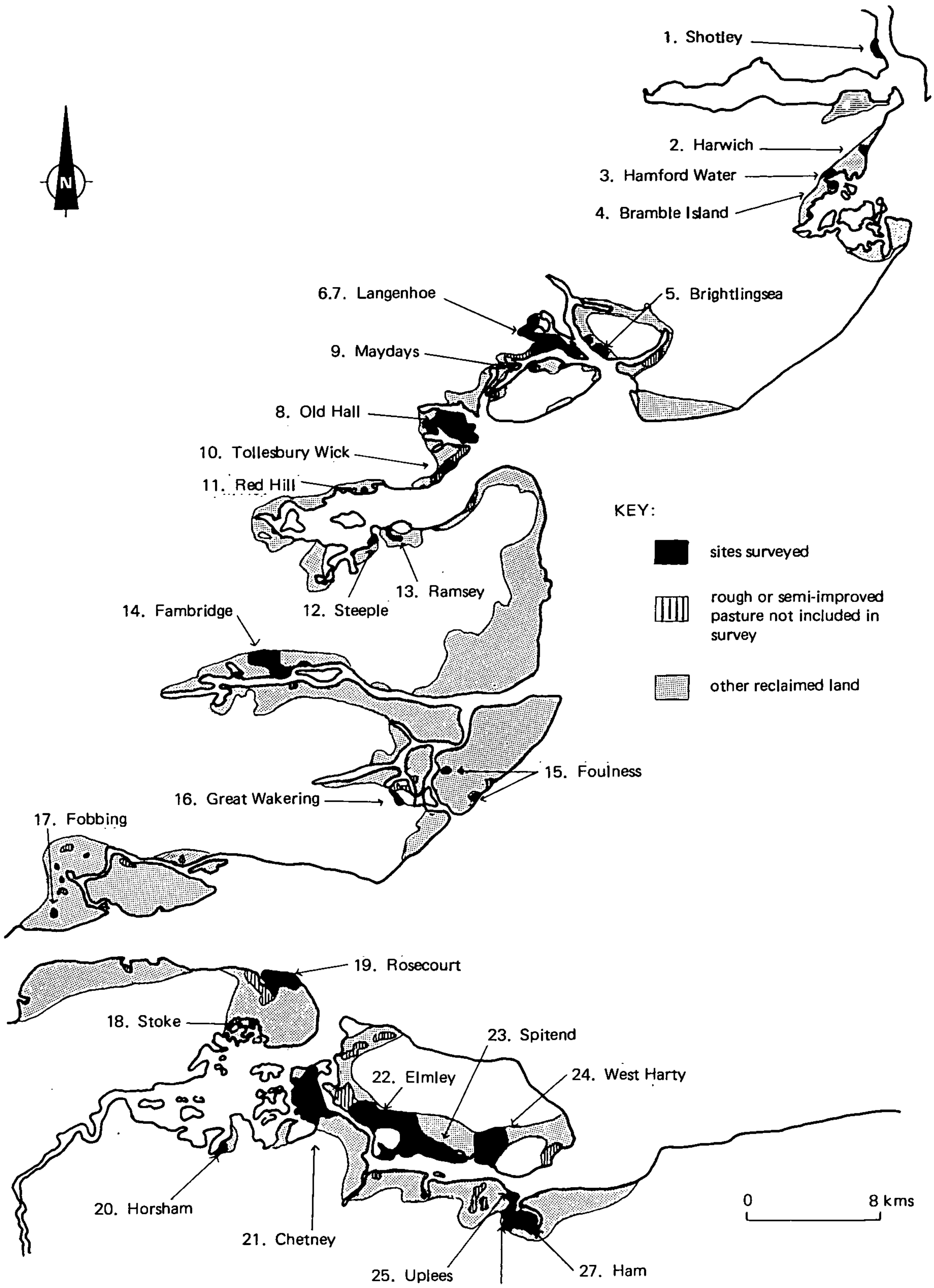

Figure 3. The extent of reclaimed land and location of survey sites in the Study Area

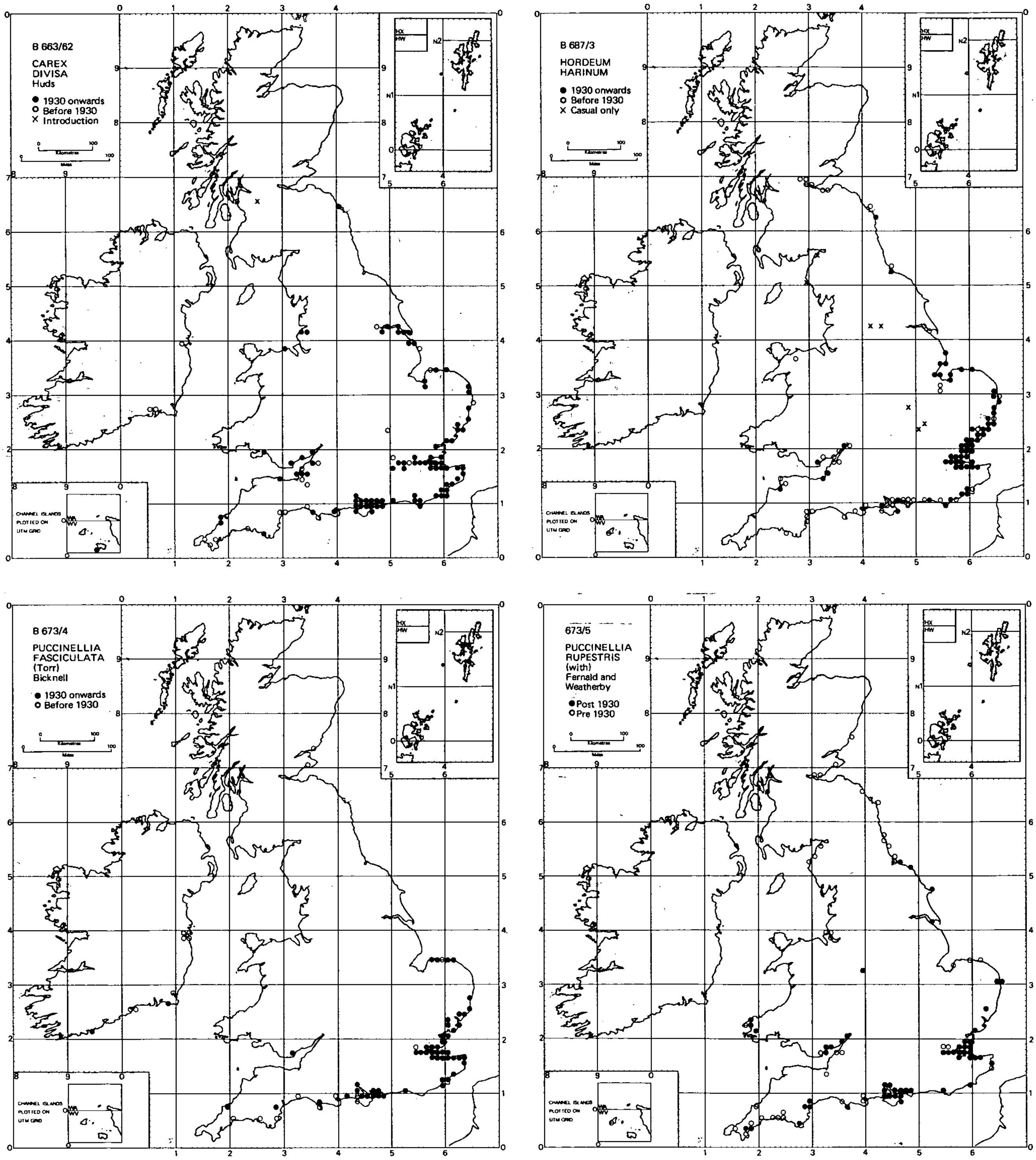

Figure 4. Plant Distribution of reclaimed marsh species

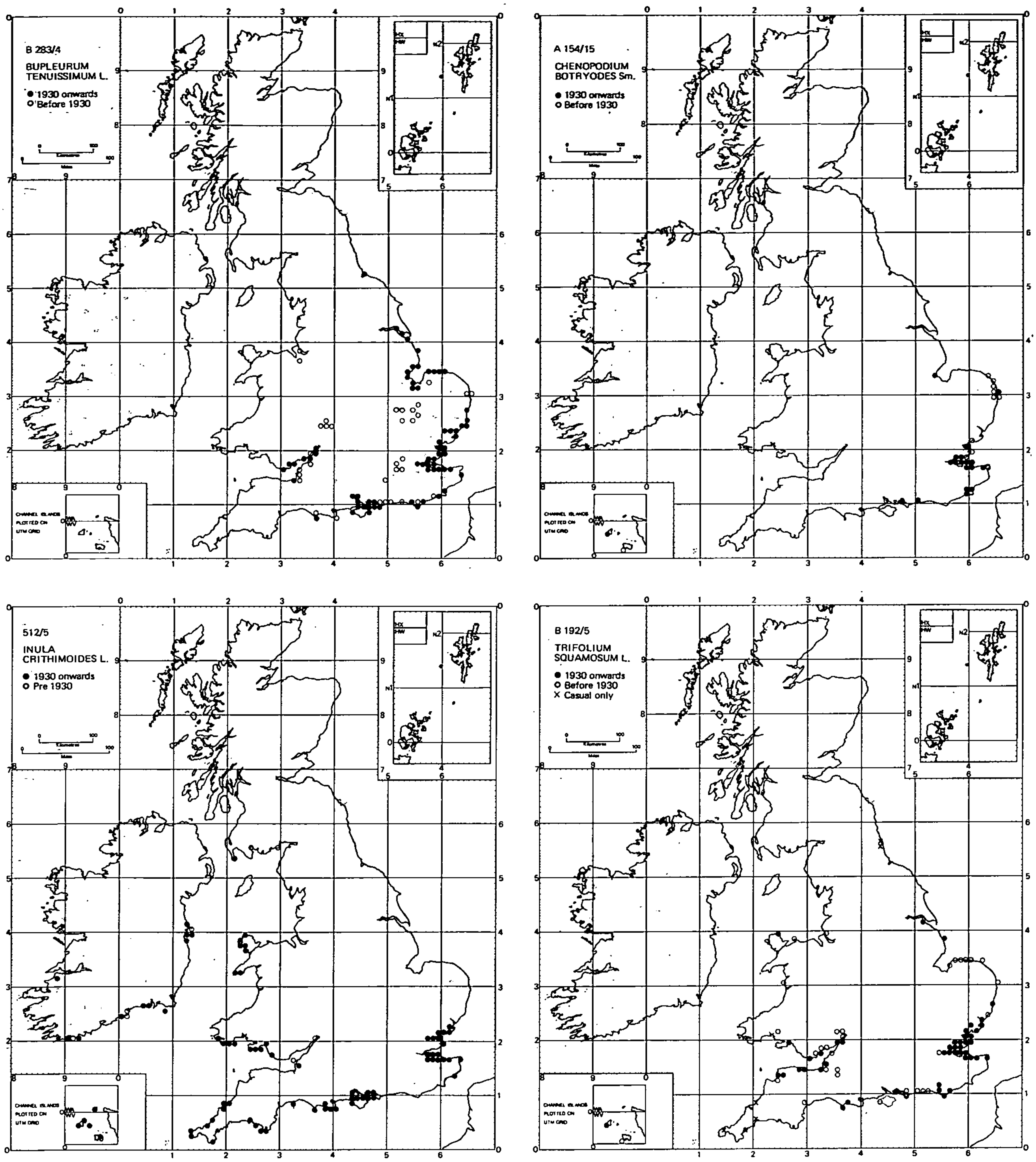

Figure 5. Plant distribution of reclaimed marsh species

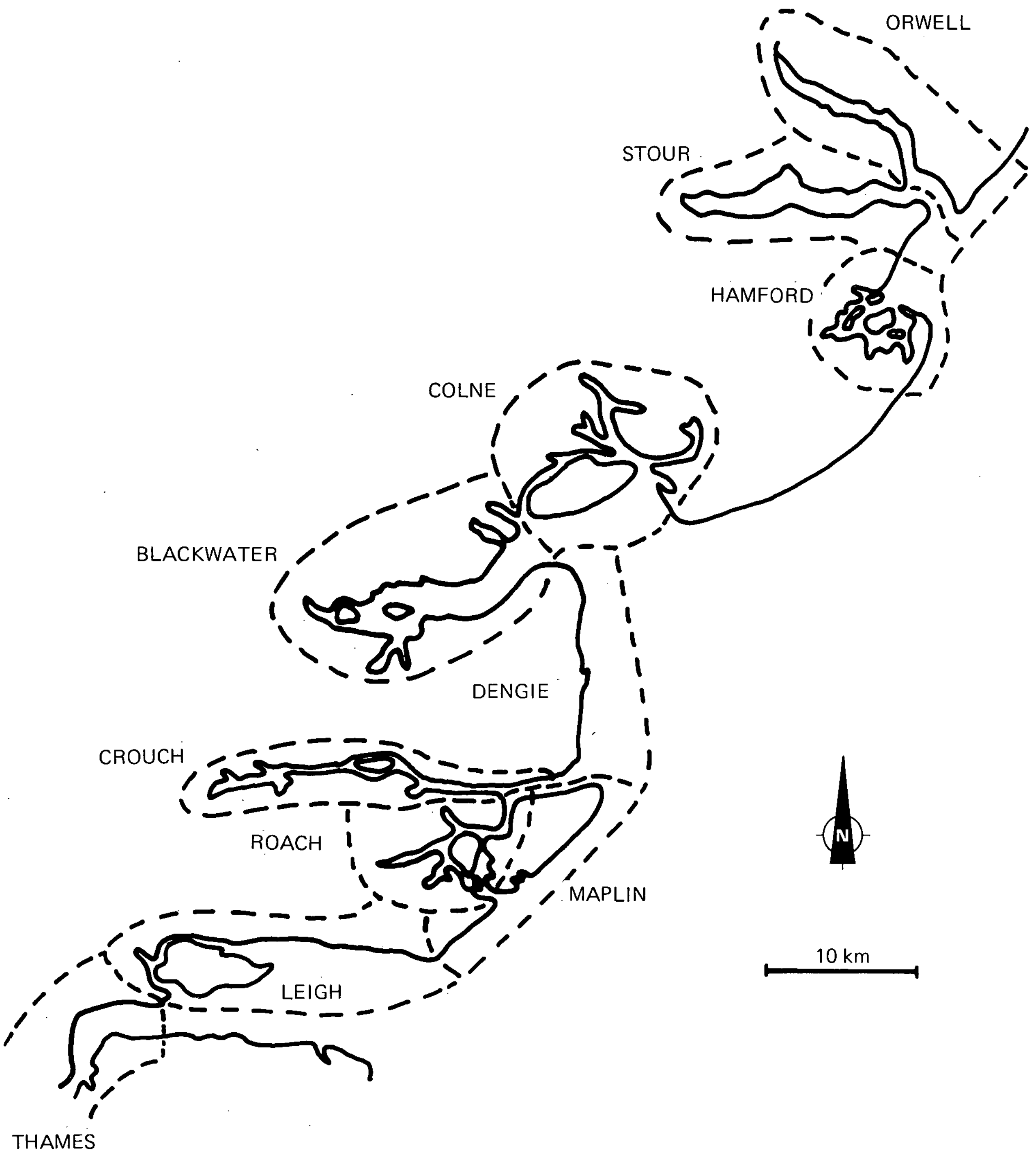

Figure 6. Bird Study Areas

Table 4. Number of species of vascular plants in the different habitats in semi-natural reclaimed marsh sites

Site	County	Size (ha)	Age (years)	Grazing	Management	Number of species recorded: Total	Seawall: Sea-ward	Seawall: Land-ward	Borrow-dyke	Pasture/ un-grazed	Low pasture	Inland Banks	Fleets & ditches	Track-way	Total no quadrats
Shotley	Suffolk	20	–	cattle	herbicide	67	8	3	5	19	20	22	19	6	9
Harwich	Essex	7.5	200+	ungrazed	walls mown	45	14	17	3	7	6	18	–	9	7
Hamford Water	Essex	5	–	ungrazed		37	6	17	5	12	–	10	12	4	7
Bramble Island	Essex	10.5	100	ungrazed		26	5	5	2	7	–	–	–	6	6
Brightlingsea	Essex	80	200-400	cattle	walls mown	90	26	39	3	16	32	28	7	22	25
Langenhoe	Essex	173	150	ungrazed		64	12	21	8	23	9	13	5	27	35
Langenhoe	Essex	57	150	sheep/cattle		47	13	18	2	22	7	–	6	6	13
Old Hall	Essex	294	–	cattle		70	21	30	5	23	14	27	8	12	48
Maydays	Essex	25	200+	cattle		50	16	18	1	13	6	15	11	13	8
Tollesbury Wick	Essex	69	200+	cattle	walls mown	54	15	14	6	22	13	23	2	11	19
Redhill	Essex	11	200-400	–		39	8	8	2	13	11	11	7	–	11
Steeple	Essex	15	150	cattle		43	5	10	2	15	11	20	3	8	8
Ramsay	Essex	15	150	cattle		57	7	12	8	18	13	15	1	20	12
Fambridge	Essex	140	200	cattle	walls mown	68	14	11	4	19	16	37	12	–	25
Foulness	Essex	35	150	ungrazed		55	11	16	2	7	24	22	3	8	16
Gt. Wakering	Essex	23	200	cattle		50	4	6	2	19	9	21	4	7	11
Fobbing	Essex	11	150	cattle		40	–	19	–	12	7	20	2	9	6
Stoke	Kent	24	–	cattle		68	18	16	10	19	7	13	3	7	9
Rosecourt	Kent	133	–	cattle		85	47	49	3	23	21	42	4	–	29
Horsham	Kent	38	–	cattle		48	7	17	2	19	15	16	1	7	8
Chetney	Kent	357	200+	cattle/sheep	herbicide	83	29	50	4	33	28	41	9	20	52
Elmley	Kent	818	–	cattle/sheep		91	37	37	4	34	24	50	13	18	61
Spitend	Kent	218	–	cattle/sheep		72	43	42	7	28	27	41	7	13	39
W. Harty	Kent	326	–	cattle/sheep	herbicide mole ploughing	89	22	42	6	31	15	39	12	14	39
Uplees	Kent	38	–	cattle		53	3	15	10	12	12	15	3	–	8
Oare	Kent	19	–	ungrazed		31	11	8	1	11	6	–	–	–	6
Ham	Kent	102	–	cattle/sheep		80	36	41	7	15	16	42	15	10	32

ground for up to 140,000 wading birds and consequently a study of their potential food is essential to a study of the likely ecological implications of any major development in the Maplin area.

Sampling was by 1 x 0.5 km grids and 692 sample units of mud cores were taken within the 28,000 ha of intertidal flat. Unlike the other species, the invertebrates recorded were in general hidden from the eye beneath the mud surface. Samples were sieved for the macro-invertebrates retained on a 1 mm mesh size sieve. The macro-invertebrates were counted, oven-dried, and weighed. Their biomass was expressed in terms of their ash-free dry weight.

Identification of these little-studied animals presented special problems and, in some cases, it was only possible to identify down to groups above the species level. However, over 80 of the more conspicuous macro-invertebrates were identified to species. These large areas of level, featureless flats harbour large populations of relatively few species (e.g. the mollusc ***Hydrobia ulvae*** in densities up to 128,000/m^2) and are less notable for their species diversity than for the quantity of the invertebrate food they form for birds. The number of species per site was usually less than 10. It is of interest, therefore, that the survey proved sufficiently sensitive to detect the marine worm, ***Clymenella torquata***, on Dengie flats at the mouth of the Blackwater estuary, a species hitherto only recorded in one other site in Europe (Whitstable, Kent).

A comparative assessment of the invertebrate resources of each estuary is presented. The numbers of animals present and the total standing crop biomass were highest in the large mudflat areas of the Medway-Swale group and in the varied substrata associated with the Orwell, Stour and Blackwater group. These groupings were derived by association analysis (Table 5). This analysis shows that species number increases markedly from the smaller estuaries (Group 1) to the larger ones (Group 3) which have a greater range of substrata. The average number of animals per site is very much larger in the big mudflat areas (Group 2), compared with big sandflat areas (Group 5). The big sandy/silt flats of Group 4 are intermediate between Groups 2 and 5 in this respect (Table 5).

In terms of potential food resources for waders overwintering in the area, the estuaries in Group 3 (Orwell, Stour and Blackwater) are shown to be the most productive in terms of standing crop biomass of potential macro-invertebrate food for waders. Of these three areas, the Orwell had the highest average biomass (52.9 g dry weight/m^2) the next highest was the Stour (32.1 g dry weight/m^2), and the lowest was the Blackwater (11.2 g dry weight/m^2).

WADING BIRDS AND WILDFOWL

By virtue of its position in south-east England, at the southern end of the North Sea and close to the Continent, the study area is most important for passage populations of waders in both autumn and spring. For most species, the passage in the autumn is heavier and more prolonged than in spring. A total of 24 species of waders is regularly recorded in autumn.

European representatives at the Mar Conference of the International Union for the Conservation of Nature (and other international bodies) in 1962 made a special plea that the United Kingdom should preserve as much of the intertidal flats of the south-east English coast as possible, to conserve migratory waders displaced by reclamation activities elsewhere on the European coast. At that time, detailed knowledge of wader populations was limited, though wildfowl populations were better known.

The aim of this part of the study was to record the populations of waders, wildfowl and seabirds in the study area. The Kent shore of the lower Thames estuary had to be excluded from the survey because of limited counting resources.

A team of about 110 volunteer amateur bird watchers was assembled and each allotted a particular stretch of shore about 3 to 4 miles long. They were asked to count all estuarine birds once per month. Counts were synchronised for Sundays with high spring tides as birds are easier to count when concentrated at the top of the shore. When bad weather reduced visibility, repeat counts were made when the weather improved. The numbers of birds in large flocks were estimated by a partition technique, where a section of the flock was counted as accurately as possible and the flock size estimated by multiplying the number in a section by the number of sections estimated in the flock.

Amateur bird watchers were found to underestimate population sizes, originally by up to 20 per cent, especially with small birds in large flocks. Special efforts were made by the organiser to check counters' errors and improve their

Table 5. Classification of intertidal sites in relation to their macro-invertebrate populations

Association analysis groups	**1**	**3**	**2**	**4**	**5**
Sites	Roach Crouch Colne Inner Hamford	Stour Orwell Blackwater	Medway Inner Swale	Dengie S. Thames N. Thames	Foulness Outer Swale Sheppey Outer Hamford
No. species identified	36	68	40	49	49
Average no. species/sample unit	7.0	9.9	7.4	6.8	7.2
Average no. animals/sample unit	131	194	257	74	52
Average total biomass (g)/ sample unit	0.35	1.11	1.12	0.77	0.76

Plate 6 Taking a core sample from a mud flat during the survey of intertidal invertebrates. Photo Dr. D. Kay

Plate 7 To separate out the macro-invertebrates from the mud the core samples are sieved. The mud washes through and the invertebrates are retained on the mesh of the sieve. They are all identified and counted. Photo Dr. D. Kay

Table 6. Percentage of European winter populations of bird species recorded at levels of "international significance" (by definition 1% or more. Figures of less than 1% are not included in this table), in individual estuaries and tidal flat units of the study area and the number of species in each site with populations in this category 1972-75.

Species	Orwell	Stour	Hamford Water	Colne	Blackwater	Dengie	Crouch	Foulness	Leigh	Thames
Pintail		1.5								
Shelduck		2	1	1.5	2					1.5
Brent goose	1	1	3.5	2	6.5	2.5	1	16	3	
Oystercatcher								1		
Ringed plover			1.5	1	1			1	1	
Grey plover		2	2.5	1	2	2.5		1.5	1	
Curlew			1.5	1	1	1		1.5		
Black-tailed godwit		1.5	1							
Bar-tailed godwit								2.5		
Redshank	1.5	3	2	2.5	1.5					
Knot								1.5		
Dunlin		1.5	1		1				1	
Sanderling			1.5	1.5		1				
Total species	2	7	9	7	7	4	1	7	4	1

accuracy. However, the nature of the task was such that it could only have been done by a large amateur ornithological force. Precise limits of error cannot be placed on the counts; current experience from the National 'Birds in Estuaries Enquiry' suggests that the figures obtained are fairly close to true values.

Bird numbers have been expressed in two ways:— 1. The wintering populations of each species are estimated for the estuaries or tidal flat units of the study area (Fig 6) as the average of the November to February counts; 2. Peak numbers give the only available estimate of holding capacity. However, it must be emphasised that detailed studies of behaviour over a much longer period than the three and a half years available for the study would be required to estimate throughput or maximum sustained holding capacity of the different species in sub-units of the study area.

A site is considered of 'international significance' to a species if it holds at least 1 per cent of the European wintering population and of 'national significance' if it holds at least 1 per cent of the British Isles wintering population, as defined in the Report on the International Conference on the Conservation of Wetlands and Waterfowl held at Heiligenhafen (West Germany) 1974, published by the International Waterfowl Research Bureau, Slimbridge, Gloucestershire. All the estuaries or tidal flat units of the study area were found to contain at least one species with wintering populations of 'international significance' with the exception of the smallest, the Roach estuary. The individual coastal units holding seven or more species in this category were Hamford Water, the Stour, Colne and Blackwater estuaries, and the Foulness flats (Table 6).

About 45,000 wildfowl winter in the study area and peak numbers of 56,000 have been recorded. The study area has been found to hold at least 20 per cent of the world population of dark-bellied Brent geese and populations of 1 per cent or more of the European populations of shelduck (7 per cent), pintail (2 per cent), wigeon (2 per cent), teal (1½ per cent), and mute swan (1 per cent).

The proportions of British populations of wildfowl greater than one per cent held by the whole study area, together with population percentages found in estuaries and tidal flat units, are given in Table 7. Seven species breed fairly regularly in the region: mallard, teal, gadwall, shoveler, tufted duck, pochard and shelduck.

Plate 8 (i) (a) Marine worms Some of the many different species found during the survey of intertidal invertebrates
1 Arenicola marina (Lugworm) 2 Scholoplos armiger 3 Lanice conchilega

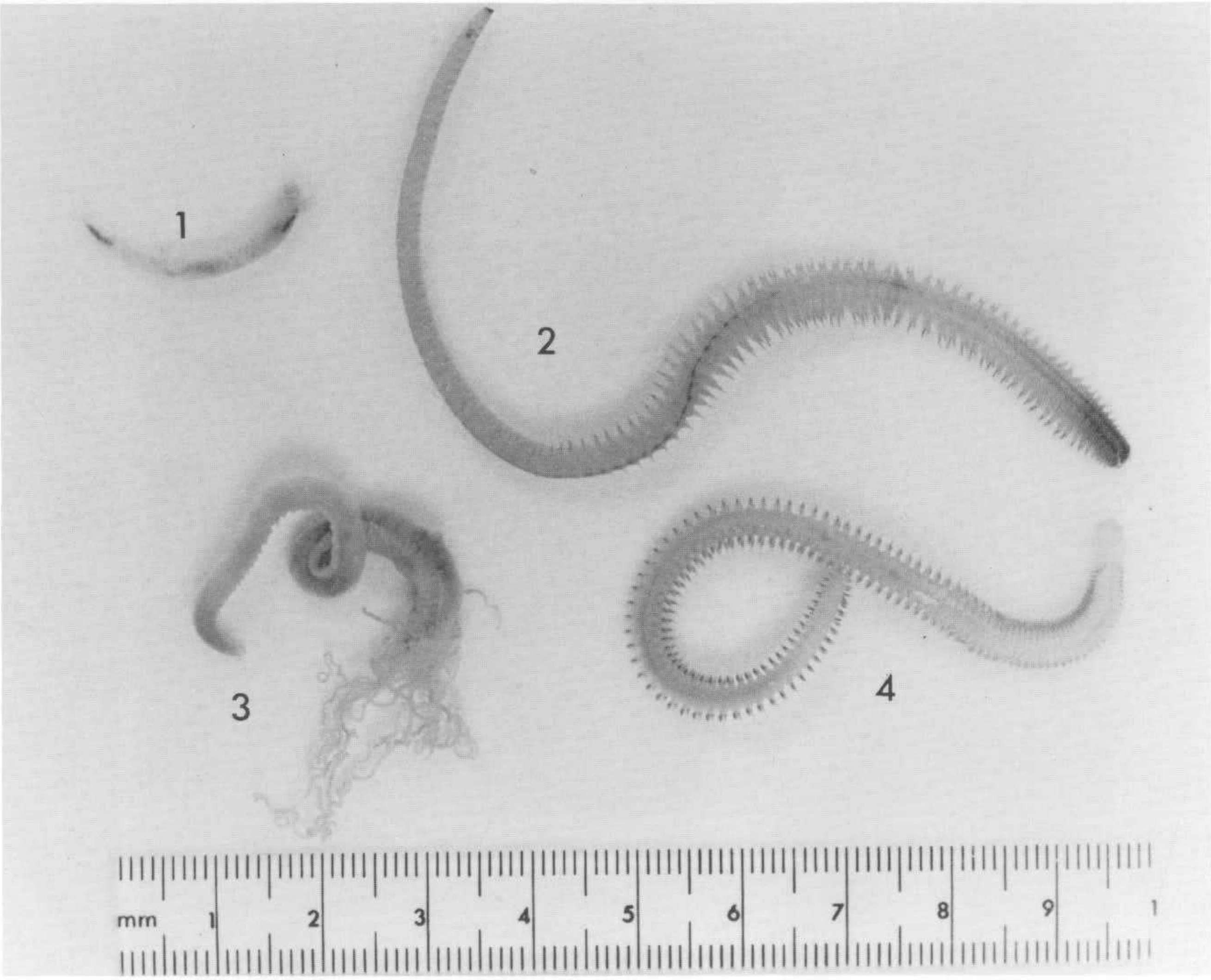

Plate 8 (i)(b) 1 Ampharete grubei 2 Nereis diversicolor (Ragworm) 3 Amphitrite johnstoni 4 Nephtys hombergii (Catworm)

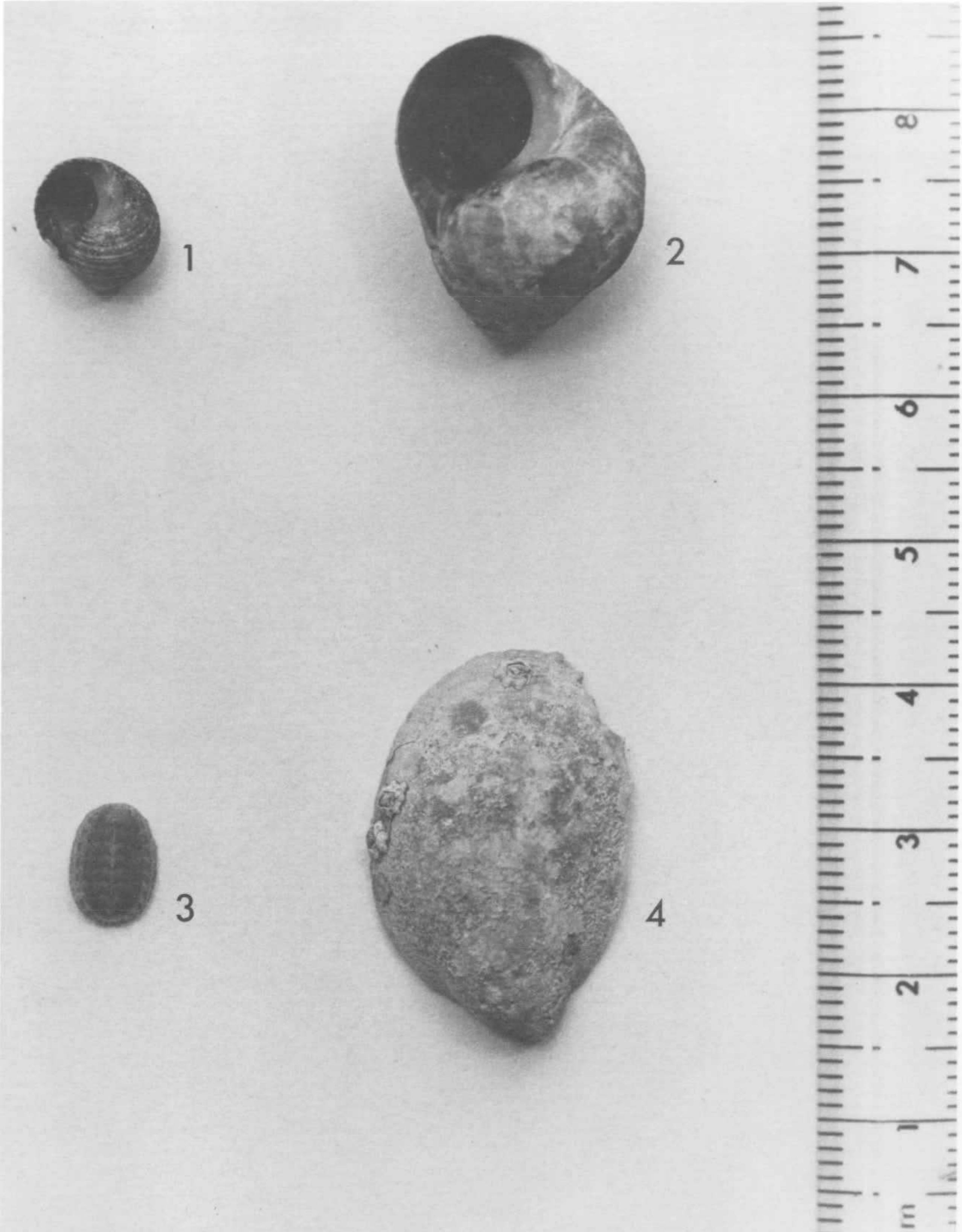

Plate 8 (ii)(a) Molluscs 1 Littorina saxatilis (Rough Periwinkle) 2 Littorina littorea (Common Periwinkle) 3 Lepidochitona cinereus 4 Crepidula fornicata (Slipper Limpet)

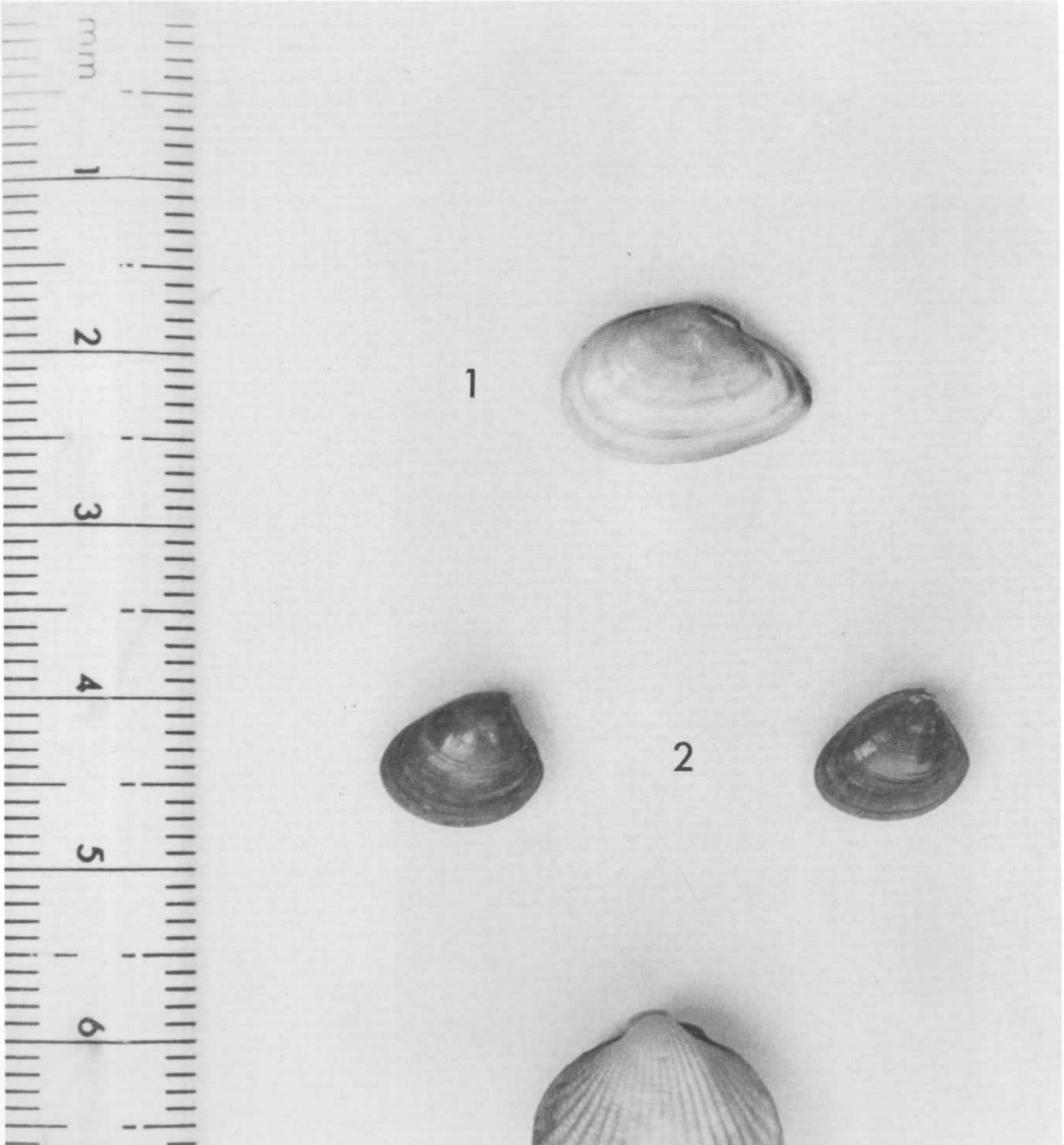

Plate 8 (ii)(b)   1 Tellina fabula   2 Nucula turgida   3 Cardium edule (Cockle)
Photos Dr. D. Kay

About 133,000 waders winter in the study area and they represent about 5 per cent of the estimated total for Europe and about 8½ per cent of the British total. Peak numbers of 143,000 have been recorded in the study area. It holds winter populations of 5 per cent or more of the European populations of the redshank (11 per cent), grey plover (8½ per cent), ringed plover (6 per cent), dunlin (6 per cent) and curlew (5 per cent) and one per cent or more of sanderling, bar-tailed godwit, black-tailed godwit, knot and oystercatcher. The proportions of British and European populations percentages found in estuaries and tidal flat units are given in Table 8. Four species of wader breed regularly in the study area: redshank (c. 1,200 pairs), lapwing (c. 320 pairs), ringed plover (c. 275 pairs) and oystercatcher (c. 180 pairs).

The counts show there are at least 30,000 sea birds wintering in the study area and at least half of these are black-headed gulls. In addition, some 4,000 twites (a species of finch) feed on the saltings during the winter, and the beaches support variable numbers of shorelarks and snow buntings.

Totals of the principal seabirds and certain other species are given in Table 9.

In summer, the study area supports breeding populations of black-headed gull (c. 8,000 pairs), common tern (c 220 pairs), little tern (c. 150 - 200 pairs), sandwich tern (c. 40 pairs) and heron (c. 100 pairs). The little terns represent up to 11 per cent of the total British breeding population.

One or two very rare marsh harriers feed in the area. Birds of prey in winter include hen harrier (10 - 20), merlin (10), short-eared owl (100) and rough-legged buzzard (11 in 1974 - 75).

BRENT GEESE

Introduction

Reliable records of dark-bellied Brent goose populations have only been kept since about 1960. In the 1930s a disease severely reduced food stocks of ***Zostera*** on European and North-east American coastlines. The species principally affected in Europe was ***Zostera marina***, and the extent to which ***Zostera noltii*** was affected is by no means clear. The meagre evidence available from occasional records, often years apart, suggested that populations of the two sub-species of Brent geese declined in both Europe and North America after the disease.

Table 7. Distribution of estuarine wildfowl in the study area 1972-75. Average winter populations of species per area as percentage of total average winter population of species for the study area. Proportions (1% or more) of the latter of British and European populations are also given.

Species	Orwell	Stour	Hamford Water	Colne	Blackwater	Dengie	Crouch	Roach	Foulness	Leigh	Thames	Average total pop.	% British	% European
Mallard	6.5	13	5.5	12	13	17.5	5	3.5	3	1	20	5015	1.5	
Teal	3	2.5	7.5	7.5	11.5	8.5	28.5	6	5.5	3	15.5	2475	3	1.5
Wigeon	11	28	5	1.5	16.5	7	10	1	9.5	10	0.5	6865	3.5	2
Pintail	13.5	44	8.5	1	8	5.5	5.5		0.5		13.5	1045	5	2
Shoveler	33	6.5	3.5	10.5	14.5	1.5	16.5	3.5	4	4	1.5	150	3	
Tufted duck	24.5	2		12.5	17.5			4	2		37	285		
Pochard	5.5		1.5	3	5			0.5	1.5		82.5	1260	3	
Goldeneye	13	6.5	5.5	37.5	33	3.5						455	4	
Long-tailed duck	6.5			25	31	19	6		12.5			16		
Common scoter	2		13	16	2.5	6			60.5			190		
Eider	15		3	24	27.5	9	3		15	3		33		
Red-breasted merganser	3.5		22	33.5	30.5	6.5	0.5	1.5	1.5			180	2	
Shelduck	11	20.5	10.5	13	20.5	2.5	3	3	4	0.5	11.5	8640	13	7
Brent goose	2	2	13.5	6.5	24.5	7	2		33.5	9.5		15830	40	20
Mute swan	29	26	1.5	14.5	12		1	1.5	4.5	1	20	865	5	
Coot	53.5	6.5			6.5		4.5	3	19.5		7	1085		

Table 8. Distribution of estuarine waders in the study area 1972-75. Average winter populations of species per area as percentage of total average winter population of species for the study area. Proportions (1% or more) of the latter of British and European populations are also given.

Species	Orwell	Stour	Hamford Water	Colne	Blackwater	Dengie	Crouch	Roach	Foulness	Leigh	Thames	Average total pop.	% British	% European
Oystercatcher	3.5	3.5	5	5.5	7	13.5			59	2.5		7245	3	1
Lapwing	8	7.5	9.5	9	16	6.5	16	9.5	8.5	6	3.5	7640		
Ringed plover	7	8	21	10	15	2.5	3	2	8	14	9.5	1200	12	6
Grey plover	1.5	10.5	22.5	6.5	16	19.5			11.5	9	2	2575	32	8.5
Golden plover		1	31	11.5	16.5	16	6.5		17			2945		
Turnstone	16	10.5	9.5	15	20	14.5			7	7		1385	14	
Common snipe	6.5	3	18	6.5	9	1	6.5	2.5	2	22	23	390		
Curlew	6.5	8	17	12	15	9	4	3	20	6		7480	10	5
Black-tailed godwit		76	23									595	4	1.5
Bar-tailed godwit			2.5		7	8.5			81.5			2110	3.5	2.5
Redshank	13	18.5	14.5	14.5	9.5	3	4.5	5	5	7	5	13765	14	11
Knot	1	4.5	1.5		3.5	27			54	8		11050	3	2
Dunlin	8.5	13	15	9	15	5.5	2	2	9	12	8.5	74165	1.5	6
Sanderling			29	35		8			1			375	4.5	4
Ruff			7.5		5						87.5	40	4	

Since the 1930s, there has been some recovery of ***Zostera***. It has also become apparent that a high frequency of breeding failure, as a result of adverse weather conditions on the Arctic breeding grounds, is an important factor affecting populations of dark-bellied Brent geese. In addition, the birds have been subjected to human predation on their breeding ground and to shooting on their winter grounds until recently.

The immediate prohibition of the shooting of the light-bellied Brent goose in North America for a number of years from 1933 resulted in a fairly rapid recovery in number. The prohibition of shooting of the dark-bellied race was more difficult to achieve, since its wintering range encompasses five countries. However, since 1950 all of these countries (except West Germany) have introduced legislation against the shooting of Brent geese. Since the 1950s, a gradual increase in dark-bellied Brent geese has taken place and the world population was estimated to have reached 25-30,000 in the late 1960s. At that time, numbers appeared to be stabilising, and it was thought that habitat destruction of the winter feeding grounds might be imposing a limit to further increase. Land reclamation since the war, especially in the Netherlands, has placed increasing pressure on wintering areas for Brent geese. Since 1968, however, the world population of dark-bellied Brent geese has more than doubled in size, to about 84,000 birds in 1973. The intertidal feeding grounds were apparently insufficient to support this population and substantial numbers of birds fed on agricultural land.

Feeding Ecology

The aims of this part of the study were to determine the detailed distribution of Brent geese on their winter feeding grounds within the study area, to determine their seasonal choice of food, and to relate their energy requirements to the food supply.

This information could then be applied to an assessment of the Maplin food supply, and the potentiality of substitute sites to support Brent geese displaced by a development at Maplin.

At the start of the study there was a justifiable assumption that Brent geese fed almost exclusively in the intertidal zone. That the study coincided with a doubling in population size and a change in feeding behaviour could not have been predicted. Originally, provision was not made to cover inland feeding. Even salt marsh feeding on the scale that it occurred in the unusually mild winters was something of a surprise. However, the very size of the differences in food use in the feeding study (see below) underlines the magnitude of these changes in feeding behaviour from traditional patterns (although disturbance was an additional factor that had to be taken into account).

From the time of their arrival in September until January, more than half the Brent geese in Essex feed on the ***Zostera*** beds at Foulness and Leigh. After this date, the majority of birds are to be found in the other estuaries of the study area feeding mainly on ***Enteromorpha.*** In January-February 1973-74, when peak counts of Brent geese in the study area were about double those in 1972-73, over 30 per cent fed on winter cereals and grass pasture landward of the sea wall (Table 10). Feeding on agricultural land had previously only been recorded during the severe winter of 1962-63.

Juvenile birds spend 95 per cent of their time feeding. Initially adults spend only 75 per cent of their time feeding, but this approaches 95 per cent as the amount of food declines through the winter.

Food intake was measured:– (1) by comparison of food biomass within and outside grazing enclosures (2) from formulae based on energy requirements in relation to body weight; and (3) from estimates of the total weight of faeces produced per bird per day and estimates of food intake from the relative ash content of food and faeces.

Estimates of food consumption derived from basal metabolic requirements (287 k cal per day for an active Brent goose of 1,300 gm live weight) give good agreement with the values derived by other methods.

The values of standing crop of the intertidal foods ***Zostera*** and ***Enteromorpha*** were divided by the estimates of food consumption and from this, figures for the potential goose days grazing obtained (Table 11). No estimates of the standing crops of salt marshes, pastures, or cereals were obtained. Suggested reasons for the differences between actual use by geese of all available food stocks and estimated potential use of surface intertidal food stocks are summarised in Table 12.

It is estimated that the consequences of removal of the large area of ***Zostera*** at Maplin, should reclamation take place, would be to place additional demands of about 1,000,000 goose days grazing on the rest of the area. It is predicted that this would result in an earlier and more rapid stepwise progression down the gradient of food preference from ***Zostera*** to ***Enteromorpha*** to cereals. In consequence, it seems likely that loss of Maplin food resources for dark-bellied Brent geese would result in increased goose grazing on agricultural land. In addition it is not known whether less favoured foods would provide an adequate diet.

Movements

Until the present study, only 16 individual dark-bellied Brent geese had ever been ringed in the British Isles. The initial aim of this study was to develop techniques for

Table 9. Distribution of seabirds in the study area 1972-75. Average winter populations of species per area as percentage of total average winter population of species for the study area.

Species	Orwell	Stour	Hamford Water	Colne	Blackwater	Dengie	Crouch	Roach	Foulness	Leigh	Thames	Average total pop.
Great crested grebe	29	15.5	2	9.5	29	9.5	2	1	0.5	1	1	105
Little grebe	42	2	15	5.5	7	0.5	11	5	11.5	0.5		165
Cormorant	18.5	12.5	4	8	20.5	21.5	3	1.5	5	1.5	3	485
Heron	5.5	6.5	5.5	6.5	15	3	8.5	18.5	13	13	5	93
Greater black-backed gull	3.5	8	13	4	9.5	5	1	3.5	4	43	5.5	2040
Lesser black-backed gull	1	0.5	19	1	1.5	2	2	2	1	10	60	750
Herring gull	2	2	30	3.5	4	19.5	1.5	4.5	11	10	12	1160
Common gull	3.5	6	10	2	4	44.5	3.5	5	12.5	2	7	2350
Black-headed gull	5.5	4.5	8	5.5	5.5	7	4	3.5	3.5	7	45	17720
Twite	1.5		36	5.5	6	36	6	6	1.5	1.5		4175

Table 10. The percentage of total population of Brent geese in the study area feeding on different food types for each month during the winters from 1972-75.

Food type	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
				1972 – 73				
Zostera	66.7	97.5	83.4	88.5	60.4	44.6	33.6	52.4
Enteromorpha	33.3	2.5	16.6	7.9	29.9	38.7	51.4	24.6
Saltmarsh	0.0	0.0	0.0	3.6	9.7	16.7	15.0	23.0
Cereals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rough grazing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
				1973 – 74				
Zostera	100.0	92.6	84.2	53.0	36.9	27.4	19.6	20.8
Enteromorpha	0.0	7.4	15.8	21.0	20.0	31.6	38.5	57.5
Saltmarsh	0.0	0.0	0.0	4.4	10.2	10.4	12.1	4.9
Cereals	0.0	0.0	0.0	11.9	16.8	12.3	8.4	0.0
Rough grazing	0.0	0.0	0.0	9.7	16.1	18.3	21.4	16.8
				1974 – 75				
Zostera	98.3	91.4	67.5	53.3	33.9	23.1	21.6	91.6
Enteromorpha	1.7	8.6	32.5	28.0	30.7	34.1	40.7	8.1
Saltmarsh	0.0	0.0	0.0	5.9	9.5	12.3	12.9	0.3
Cereals	0.0	0.0	0.0	6.0	12.1	9.5	6.1	0.0
Rough grazing	0.0	0.0	0.0	6.8	13.8	21.0	18.7	0.0

catching and marking substantial numbers of these birds. Subsequent aims were to define the role of Maplin as a holding and dispersal area, to record goose movements to other areas, to examine their fidelity to sites from year to year and to contribute information on flock behaviour. Catching these wary birds on open mudflats depended very much on the capacity to predict accurately where they would alight, and on split-second timing in trapping them.

Cannon nets were designed to overcome the difficult and novel problems of catching the birds on mudflats, but the size of the catch had to be limited to the number of birds that could be processed without risk to operators or birds. When feeding in saltings and agricultural pasture developed, traditional rocket net techniques designed previously by the Wildfowl Trust allowed larger catches to be made. A total of 817 geese (1 per cent of the maximum recorded world population) was caught (Table 13). These were marked with individually coded, coloured tarsal rings and 3,343 re-sightings were made of 578 (71 per cent) of them (Table 14).

The presence of family units was detected in 1973-74. One family party of four ringed on Foulness was followed north to the Blackwater and then south to Chichester harbour (where two were seen the following year). The same family party travelled at least 500 miles (from Chichester harbour to the Dutch Waddenzee) in 24 hours.

A background analysis of local wildfowl counts showed that Maplin was an early winter resort and on average 70 per cent of all British dark-bellied Brent geese were there in October during the period of study (Table 15). Colour marked birds dispersed to other English estuaries from Maplin and along the south coast into France. The spring migration of marked birds from these late winter resorts through the Netherlands and West Germany was also traced. Details of sightings of colour marked birds are given in Table 16.

In the year following capture, between 41 per cent and 53 per cent of birds were re-sighted in the sites where

Table 11. Best estimated potential goose days grazing available of surface intertidal foods (derived from values of standing crops and daily food intake) together with the actual number of goose day grazing used on all food sources in each of 11 sites.

Site	Best estimate of potential grazing on intertidal food in thousands of goose days			The actual usage of sites in thousands of goose days		
	Years			Years		
	1972-3	1973-4	1974-5	1972-3	1973-4	1974-5
Orwell	234	234	243	3.7	57.7	26.5
Stour	323	323	329	41.4	41.5	46.8
Hamford Water	90	90	91	107.6	413.1	322.0
Colne	74	74	74	140.8	214.6	184.6
Blackwater	428	428	432	281.2	796.3	633.4
Dengie	160	160	160	177.3	220.2	262.4
Crouch	186	186	186	–	35.4	49.6
Foulness	692	692	822	766.9	1164.8	817.0
Leigh	157	157	188	208.3	225.9	183.6
Swale	635	635	644	31.6	72.1	47.8
Medway	1671	1671	1677	30.8	165.2	80.9

Plate 9 Feeding ground of the Brent goose – Zostera Noltii and mud with goose foot-prints. Photo Dr. D.S. Ranwell.

they had been marked. Further evidence that a high proportion of birds were faithful to particular sites was shown by the fact that some birds even returned to the same particular parts of estuaries. In contrast, birds from many different English estuaries were seen gathered together in flocks on spring migration in the Netherlands and Germany.

Increases in the size of the Brent goose population depend on good breeding years. In only eight of the last fifteen seasons have significant additions been made to the population (Fig 7). No other goose species has such a variable breeding success leading to unbalanced age class structure in the population likely to affect social behaviour.

In good breeding years (1972 and 1973), adults and juveniles migrated together in autumn. In 1974, when few Brent geese bred, adults migrated in autumn ahead of two year-old birds. It is probable that adult experience is important to the survival and well-being of juveniles and Maplin may be of special importance, not only as a gathering point from which autumn migrants disperse, but also as a learning site for juveniles on their first winter grounds.

The approximate age composition of the British population of dark-bellied Brent geese was calculated for 1973-74. The total population was estimated at 41,000, with about 15,400 first-winter birds, 7,600 breeding adults and 18,000 full grown birds without young (from the estimated mean brood size of 4.0 and the estimated percentage of first-winter birds as 37.5). The full grown birds without young were probably mostly in their second winter, for Brent geese do not usually breed until their third or fourth summer.

Behaviour of Brent Geese

It was clear from the results of the marking studies that Brent geese, in common with other geese, have a well-marked social structure based on the family unit. Social behaviour of higher organisms like geese must be taken fully into account in interpreting distributional relationships. Interaction between flocks and individuals also modified their reactions to disturbance factors. The objectives here were to determine the main causes of disturbance to Brent geese in the study area, their frequency and effectiveness in disturbing geese, the plasticity of response to disturbance, and the amount of feeding time lost through disturbance.

Six sites (Colne, Goldhanger and St. Lawrence Bay – Blackwater, Dengie, Leigh and Maplin) were selected for the study to include a range from little disturbed sites (Maplin) to very disturbed sites (Leigh). Together these support about two thirds of the British population of dark-bellied Brent geese. Data on geese and disturbance factors were recorded in over 10,000 watching-time units of 1 minute each. Feeding time lost by disturbance was estimated by comparing the percentage of time spent feeding during

Table 12. Summary of differences between estimated actual use by Brent geese of all available food stocks and estimated potential use by geese of surface intertidal food stocks in estuaries and tidal flat units of the study area and probable reasons for discrepancies.

Site	Years 1972-3	1973-4	1974-5
Orwell	Actual less than potential: disturbance	Actual less than potential: disturbance	Actual less than potential: disturbance
Stour	Actual less than potential: disturbance	Actual less than potential: disturbance	Actual less than potential: disturbance
Hamford Water	Actual equal to potential	Actual greater than potential: feeding on rough grazing	Actual greater than potential: feeding on rough grazing
Colne	Actual greater than potential: saltmarsh feeding	Actual greater than potential: feeding on saltmarsh, cereals and rough grazing	Actual greater than potential: feeding on saltmarsh
Blackwater	Actual less than potential: disturbance	Actual greater than potential: feeding on cereals and rough grazing	Actual greater than potential: feeding on cereals and rough grazing
Dengie	Actual equal to potential	Actual greater than potential: feeding on cereals	Actual greater than potential: feeding on cereals
Crouch		Actual less than potential: disturbance	Actual less than potential: disturbance
Foulness	Actual greater than potential: ***Zostera*** root feeding	Actual greater than potential: feeding on ***Zostera*** roots, cereals and rough grazing	Actual equal to potential
Leigh	Actual greater than potential: ***Zostera*** root feeding	Actual greater than potential: ***Zostera*** root feeding	Actual equal to potential
Swale	Actual less than potential: disturbance	Actual less than potential: disturbance	Actual less than potential: disturbance
Medway	Actual less than potential: disturbance	Actual less than potential: disturbance	Actual less than potential: disturbance
Average Brent goose winter population	11,600	18,800	16,700

Table 13. Catches of dark-bellied Brent geese for each month at each site.

					Years							Total catch for each site
		1972-3				1973-4				1974-5		
Site	Jan	Feb	Mar	Nov	Dec	Jan	Feb	Mar	Nov	Dec	Feb	
Foulness	29	4	2	93	49				41	40		258
Crouch		24					12				89	125
Blackwater				6	10	10	80				57	163
Hamford								130				130
North Norfolk							57					57
Wash								84				84
Total		59				531				227		817

Table 14. The number of sightings of marked Brent geese by years for each site.

	Years			
Site	1972-3	1973-4	1974-5	Total for each site
Foulness	59	363	860	1282
Germany	0	57	782	839
Blackwater	0	116	251	367
Hamford Water	0	5	264	269
Netherlands	0	73	160	233
North Norfolk	0	10	100	110
Leigh	2	11	44	57
Chichester Harbour	0	51	20	71
Crouch	2	20	18	40
Langstone Harbour	8	20	10	38
Colne	0	13	1	14
Orwell	0	2	5	7
Swale	0	5	1	6
Medway	0	2	2	4
Dengie	0	3	1	4
Pagham	0	2	0	2
Total for each year	71	753	2519	3343

undisturbed and disturbed periods. The effect of flock size on susceptibility to disturbance was measured by standard approaches on foot.

The main causes of disturbance were people on the shore or sea wall and propeller-driven small aircraft. These together accounted for 75 per cent of all disturbance recorded (Table 17). People on the ground caused 48 per cent of the disturbance; aircraft (all types) 39 per cent; the remaining 13 per cent were caused by loud noises (boats, gunshots etc.). Brent geese were found to be particularly susceptible to disturbance from aircraft, and any aeroplane flying below about 500 m and up to 1½ km away could put them to flight. They were very slow to become habituated to aircraft, though at Leigh Marsh they did cease responding by January and February to transport aeroplanes taking off regularly from Southend airport. In the November to December period, birds were put to flight about 30 per cent of the times when they were approached within 100 m by people. In the January to March period, they were only put to flight 12 per cent of the time by a similar stimulus. Brent geese learned the dangers associated with particular places and became more wary in areas where they had previously been threatened. For example, in February, geese could not be approached within 500 m on the Colne saltings which were much used by wildfowlers, while in contrast the same birds could be approached to within 150 m on the Colne mudflats which were less disturbed. Experimental approaches to flocks of between 6 and 400 geese on Norfolk salt marshes in February and March showed there was a tendency for larger flocks to take flight at greater distances.

Taking all sites into account, disturbance prevented geese

Table 15. 1973-74 The monthly total of dark-bellied Brent geese at each of their regular wintering sites in Britain. Below the main table are the December figures for the whole of the wintering range. The sum of these and the British figures are the World Total. 0 = no geese nc = no count ( ) = incomplete coverage

	Months						
Area	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**
South Coast + Wales							
Burry Inlet	0	0	42	57	62	35	1
Exe	0	425	625	650	205	93	25
Poole Harbour	0	0	101	190	146	52	0
Isle of Wight	0	41	237	335	209	310	9
Solent	0	0	100	320	(321)	202	1
Portsmouth Harbour	0	0	200	320	(200)	180	nc
Langstone Harbour	54	(2000)	6075	5500	4513	2407	652
Chichester Harbour	105	425	6070	6850	7390	5215	420
Pagham Harbour	0	0	300	500	(500)	635	65
Total	159	(2891)	13750	14722	(13546)	9129	1173
Essex — Kent							
Swale	26	343	923	320	349	448	8
Medway	20	250	565	766	568	200	160
Leigh, Canvey	800	3300	1650	425	604	428	202
Foulness	9782	12868	6707	3576	2100	1451	695
Crouch, Roach	0	7	420	640	1226	3	1
Dengie	900	400	580	935	1040	1650	475
Blackwater	297	2900	6117	4518	4850	4838	2939
Colne	6	98	1150	2033	1754	1785	289
Hamford Water	278	405	2200	3000	3360	3130	1170
Stour	138	310	360	188	79	219	66
Orwell	0	290	540	650	400	132	0
Total	12247	21171	21212	17051	16330	14284	6005
North Norfolk — Wash							
North Norfolk	(14)	(296)	2000	2284	3855	(628)	(231)
The Wash	3252	4323	4224	3765	3998	3917	2918
Total	(3266)	(4619)	6224	6049	7853	(4545)	(3149)
British Total	(15672)	(28681)	41186	37822	(37729)	(27958)	(10327)

Britain 41186; Jersey 1150; France 31700; Netherlands (Friesland Isles) 1682; Netherlands (Mainland) 5426; Germany (3000); Denmark 257.

World total = (84,401)

from feeding for an average of 3.5 per cent of their time. The greatest losses of feeding time were recorded at weekends at Leigh and Goldhanger (Table 18). When in tidal areas, Brent geese spend most of their time feeding. Tide cover limits food availabitity. Using a nightscope it was established that Brent geese fed at night throughout the winter, sometimes in cloudy weather, and in some cases on quite sparse ***Enteromorpha.*** Brent geese appeared not to feed so intensely at night as during the day, and were almost exclusively confined to the tide edge.

Brent geese were shown to lose a mean of 9 per cent body weight from November-December to January-February in 1974, a mild winter when the world population was at a maximum. No such loss in weight was found when measurements were made in Denmark in 1963-65, when the world population was less than one third of the 1974 value. Evidence from white-fronted geese in the 1962-63 cold winter showed that birds that had died of starvation were 42 per cent lighter than the average for normal winters.

Table 16. Dark-bellied Brent goose populations in British and Continental sites and numbers of marked birds seen in relation to observation frequencies 1973-75.

Site	Peak pop. (to nearest 100) 1974-5	No. of observation days 1973-4	1974-5	No. of marked birds identified 1973-4	1974-5
Foulness	8600	65	63	108	208
Langstone	5600	5	6	7	6
Chichester	5200	11	7	18	14
Blackwater	4600	36	52	53	105
Hamford Water	3500	2	18	4	83
Leigh/Canvey	3100	5	7	7	25
North Norfolk	2600	3	11	9	46
Colne	1900	4	2	8	1
Dengie	1800	2	1	3	1
Crouch	800	6	2	9	12
Swale	700	2	2	2	1
Medway	700	2	2	1	1
Pagham	700	2	0	1	0
Orwell	400	1	2	2	5
	Total Gt. Britain	146	175	232	508
Föhr	3500	3	30	31	86
Langeness	4000	1	44	2	88
Rest of Germany		3	2	13	1
Texel	5000	12	10	15	15
Schiermonnikoog	3000	13	43	14	30
Rest of Netherlands		2	23	7	14
	Total Continental sites visited	34	152	82	234
	Total all sites visited	180	327	314	742

Even a 9 per cent loss in body weight could result in reduced breeding performance.

MANAGEMENT STUDIES

The final objective of the study was to undertake trials for the purpose of providing guidance for the future management of substitute sites to increase their wildlife potential.

Practical management consists of either improving conditions favourable to a desired aim or reducing conditions that are detrimental to it. It was apparent at the start of the study that certain basic ecological information was essential to plan any detailed management activities. It was equally clear that trials relating to the feasibility of management activities were desirable in three main areas of study. These were:— (1) provision of additional food resources for particular species; (2) reduction in competition from other species; and (3) reduction in disturbance and pollution in substitute sites.

Until the basic ecological information had been collected, and from this information, possible substitute sites identified, management trials could not be planned comprehensively. It was anticipated that they would have formed an important part of continuing studies in the event of a major development at Maplin going ahead. Since such studies take several seasons to complete, some input on management trials seemed desirable and contributions have therefore been made on the feasibility of transplanting ***Zostera***; the potential of existing mudflat areas for additional ***Zostera*** growth; and the significance of competition between Brent geese and wigeon which share common food plants.

Zostera noltii turfs were transplanted on a pilot scale trial on sheltered estuarine mudflats at Breydon Water, Norfolk, in March 1972. All of the 20 turfs planted survived to the end of the first year, 35 per cent after 2 years, and 5 per cent after 3½ years. Some transplants flowered and seeded in each year after planting.

A field scale trial, approaching 1 ha in size, was set up at a cost of £1,000 in 1973 using about 2,000 ***Zostera noltii*** turfs. There was 3 per cent survival after 1 year and 0.2 per cent survival after 2 years.

The feasibility of transplanting ***Zostera noltii*** is shown by the facts that some turfs in both trials showed an 8 to 10-fold increase in area during the first summer after transplanting and at least some turfs flowered and seeded and persisted for over 3 years. Three lines of evidence suggest the site used was unsuitable for longer term growth of ***Zostera noltii***. First, measurements of changes in the mud surface levels revealed that, while survival did occur in areas where the level changed ± 7 cm per year (or up to ± 3 cm per week), the overall trend on the mudflat over a 3 year period was one of erosion. Second, there was a very rapid natural colonization of the transplant area during the trials by ***Zostera marina*** var. ***angustifolia***, a species favouring marginally lower-lying and wetter areas than ***Zostera noltii***. Third, map evidence of the natural distribution of ***Zostera noltii*** (a newcomer to the site and which spread outside the planting areas in the course of the trials) shows that it favours slightly higher creek bank sites which drain more freely than the planting trial sites.

Research studies carried out at the Hydraulics Research Station suggest that few, if any, extensive mudflat areas suitable for creating new ***Zostera*** beds exist at present in the study area. The possibility remains of creating suitable areas by engineering activities.

Another strategy might be to encourage geese to feed on agricultural land and compensate farmers for any damage done to crops. However, it must be remembered that inland areas will not be available to Brent geese when these areas are frost-bound or snow-covered.
There is considerable potential for improving existing salt marsh and reclaimed marsh vegetation to improve food resources for Brent geese, but it must be borne in mind that even such saline feeding areas will only be fully available in relatively mild winters. The fully saline mudflat feeding grounds washed daily by the sea remain available and ice-free in all but the severest winter periods. Formerly, most of the salt marshes in the study area were grazed by sheep and this encourages a type of sward more suitable for goose grazing than the present ungrazed swards. The general principles of manipulating salt marsh swards are moderately well-known from farming practice and recent experimental management studies. Feasibility trials would be necessary to relate this knowledge to the marshes in the study area.

Wigeon also feed on ***Zostera*** and ***Enteromorpha*** and therefore could compete with Brent geese for these foods. Had an airport been built at Maplin, Brent geese might have been faced with such competition in other Essex sites, and from known numbers of wigeon present this could have been an important factor. The present distribution and density of Brent geese and wigeon in the study area does not appear to bring these birds into direct competition for food. The presence of light-bellied Brent geese and wigeon, both in substantial numbers at Lindisfarne, Northumberland, suggested this would be a suitable area for study although a different race of Brent goose was involved. The feeding ecology and behaviour of light-bellied Brent geese at Lindisfarne, Northumberland, was found to be basically similar to that of dark-bellied Brent geese in Essex. Study of the distribution of light-bellied Brent geese and wigeon (and also whooper swans) at Lindisfarne showed that they generally occupied separate (though sometimes adjoining) feeding areas in 1973-74 (Fig 8). Overlap tended to occur when the tide restricted the availability of feeding areas, and it seems likely that severe weather conditions might have a similar effect. The few interspecific encounters recorded among light-bellied Brent geese and wigeon occurred when the tide restricted access to feeding grounds.

Table 17. The nature and frequency of disturbance that put to flight some or all of the Brent geese being watched.

				Nature and number of disturbances											
				People on the ground											
Site	**Time of year**	**Total time between disturb's (min)**	**Mean time between disturb's (min)**	**On shore or sea wall**	**Wild-fowlers**	**Bait-diggers**	**Propeller driven small aircraft**	**Propeller driven large aircraft**	**jets**	**Heli-copters**	**Boats with out-board engines**	**Army explo-sions**	**Gun shots**	**Total**
Colne	Jan – Mar	1179	147	1	1		1					4	1	8
Goldhanger	Nov – Dec	1439	60	10	1	1	7			2			3	24
Goldhanger	Feb – Mar	1428	179	2	1	1	4							8
Goldhanger	Jan – Feb (weekends)	452	75	5									1	6
St. Lawrence Bay	Feb – Mar Nov	611	76	4			1	1	1		1			8
Dengie	Nov – Mar	1958	218	2		3	4							9
Foulness	Oct	581	290									2		2
Leigh	Nov – Dec	862	32	14			4	6			3			27
Leigh	Jan – Mar	947	118	1		2	4				1			8
Leigh	Oct – Nov (weekends)	600	25	7		3	10	4						24
Total		167h 37min.		46	3	10	35	11	1	2	5	6	5	124

Table 18. The feeding time lost by Brent geese as a result of disturbance.

Site	Months	Year	% Time feeding no disturbance (A)	% Time feeding overall (B)	% Time disturbance prevented feeding (A-B)	Time watched min.
Colne, mudflats	Feb – Mar	1973	41.8	41.1	0.7	235
Colne, Geedon saltings	Feb – Mar	1973	91.1	90.3	0.8	209
Goldhanger	Nov – Dec	1973	64.3	61.2	3.1	519
Goldhanger	Feb – Mar	1974	50.0	48.0	2.0	581
Goldhanger	Jan – Feb (weekends)	1974	51.9	44.8	7.1	295
St. Lawrence Bay	Feb – Mar – Nov	1973	67.8	63.3	4.5	501
Dengie	Mar Nov Dec Jan – Feb	1973 1974	59.3	57.3	2.0	435
Foulness	Oct	1973	82.4	80.5	1.9	581
Leigh	Nov – Dec	1973	79.3	74.4	4.9	862
Leigh	Jan – Mar	1974	62.7	62.9	0.2	697
Leigh	Oct – Nov (weekends)	1974	53.3	41.6	11.7	600

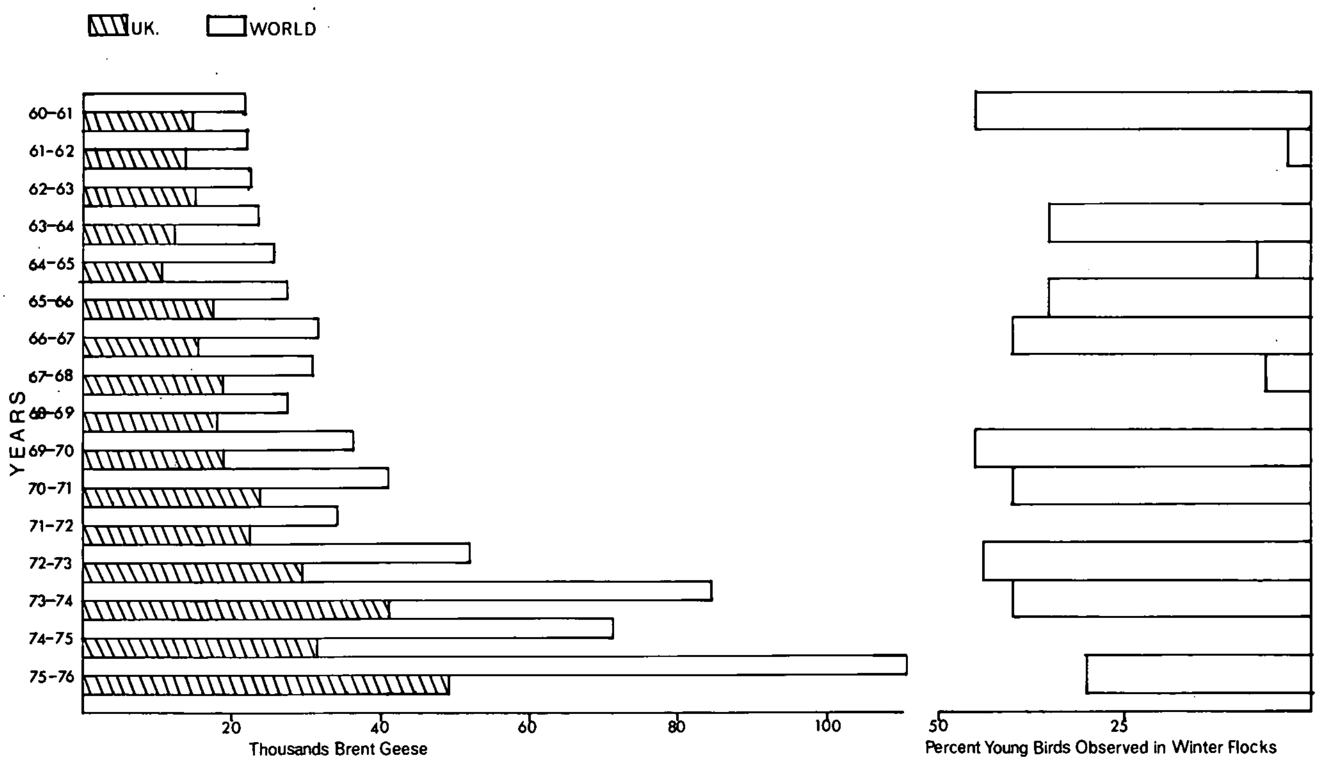

Figure 7. Population changes in dark-bellied Brent geese 1960-75

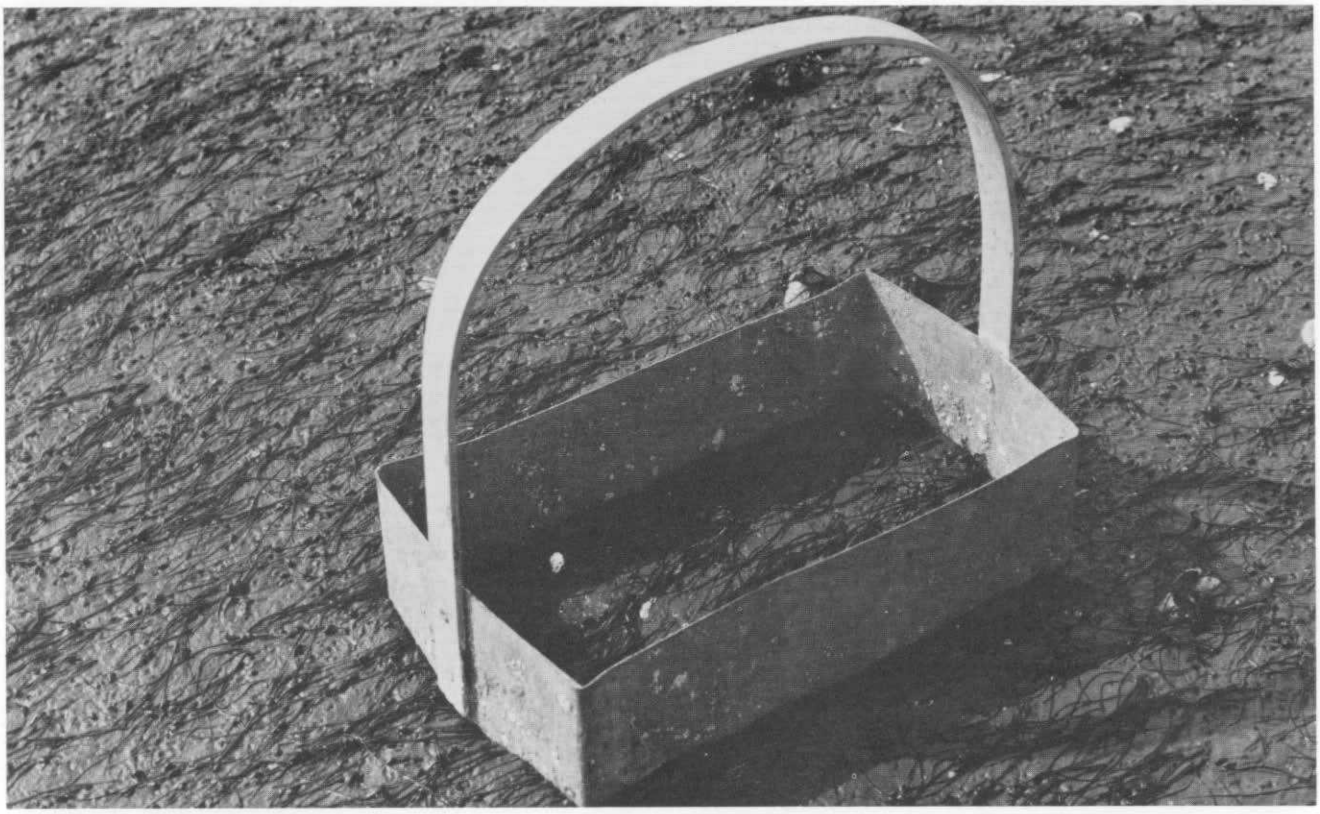

Plate 10 Zostera was transplanted to see if it was possible to establish beds in new areas to replace any losses elsewhere.
(i) Turfs were cut from the surface of the Zostera bed with a specially designed cutter

Plate 10 (ii) The cut turf carefully lifted out with the help of a spade to support the sample

Plate 10 (iii) The turf was transferred to a plastic tray for transport

Plate 10 (iv) Polythene sheeting was used to keep the turfs separate. Each tray held three turfs. Photographs reproduced by permission from Elsevier Scientific Publishing Company

Interpretation

INTRODUCTION

The state of knowledge at the start of the study and the specific practical requirements relating to the proposed airport development controlled the pattern of the work, and to some extent, influenced the results. It seems important here to start with an overview of certain general relationships affecting the area which in the light of this study now help us to understand the changing nature of this coastline.

The coastline of the study area is the product of centuries of human management imposed on a natural system left as a legacy from the end of the last glaciation, some 10,000 years ago. Many papers in local journals, historical documents, and imprints on the ground surface visible in air photographs testify to the impact of man on mud flats and marshes since the arrival of the first Neolithic settlers over 5,000 years ago.

Mud (for brick-making), salt, samphire, wildfowl, shellfish, stock grazing and reclaimed land have all been won from this coast and have modified its contours. Sea defence activities have been of paramount importance on this coast which has a long history of gradual land submergence. Most of the marshlands outside the sea wall were grazed by stock between the wars; most of the reclaimed land enclosed inside sea walls was pasture. Labour costs made shepherding of open range stock uneconomic and the development of building associated with recreation near the coast between the wars increased disturbance to birds and stock from people and dogs. The rising prices of agricultural land and new techniques of drainage have led to extensive ploughing of reclaimed pasture for arable in the last twenty years.

OVERVIEW OF TRENDS IN THE STUDY AREA

This short-term study of three and a half years provides a picture which is effectively a cross-section in time of the study area. A perspective view must take into account long-term temporal changes in land and sea levels (isostatic balance) and climatic fluctuations. In addition, the human historical influences which have modified and helped to create this coastal landscape have interacted with these long-term trends and sometimes obscured them.

Isostatic balance

Several lines of evidence draw attention to the delicate balance between accretion and erosion that is a special feature of this coast and there are important consequences following from this for the plants and animals that live on it.

It is evident from current proposals for a tidal barrage in the upper Thames estuary, and the evidence on the need for this, that there is a trend towards submergence on this coast of the order of 30 cm per century. Recent unpublished studies on the Medway confirm that submergence features characterise that site also. Physiographic studies on the Dengie and Foulness coast confirm a close balance between accretion and erosion at the salt marsh seaward edge, where it seems that salt marsh increase in level is approximately balanced by submergence due to isostatic adjustments.

Studies organised by the Hydraulics Research Station on potential ***Zostera***-planting areas suggest that ***Zostera*** flats at Maplin are in a state of dynamic equilibrium, with erosional losses of material just counterbalanced by accretion. Measurements associated with ***Zostera*** transplant studies further north at Breydon, Norfolk, confirm that ***Zostera*** survives on mudflats with a low amplitude of surface oscillation ($< \pm 7$ cm/annum). The mudflat level records in the transplant site at Breydon show net erosion over the period of study. This might be a very local effect, but it might be part of the general trend towards submergence mentioned above. In addition, the presence of species only capable of tolerating low levels of accretion, such as ***Spartina maritima*** and ***Salicornia perennis*** in the pioneer salt marsh zone at Maplin and certain marshes as far north as the Stour, confirms the close balance between erosion and accretion at the seaward margin of these marshes.

It would seem that the abundance of ***Zostera*** found in this part of the British coast could depend on this fine balance between accretion and erosion.

Climatic influences

The main study was conducted during a period of exceptionally mild winters, at a time when general climatic trends in the Northern Hemisphere are towards year-round cooler weather. In severe winter conditions, some of the winter food resources for Brent geese reported in this study (salt marsh, reclaimed marsh pasture and cereals) would be frozen hard or snow-covered and not available, and even in less severe conditions they would be less available, so birds would be likely to come under stress through lack of food. The remarkable upsurge in the population of Brent geese in 1973-74 in the middle of the period of study possibly also reflects the interaction of climate with breeding success on the breeding grounds, about which very little is known. Any prediction of effects of a major development at Maplin has to make allowances for very different climatic conditions than those operating in the period of study. There is also the possibility that bad breeding conditions in summer may chance to occur in conjunction with severe winters. The same general arguments apply to other wildfowl and waders.

Population fluctuations due to disease

Violent fluctuations in wildlife populations are a fact of life. We are at this time witnessing marked reduction in the population of elm trees due to disease, and in the 1950s myxomatosis severely reduced the rabbit population. In the 1930s, a fungal disease wiped out huge areas of ***Zostera*** on coasts either side of the Atlantic in circumstances which

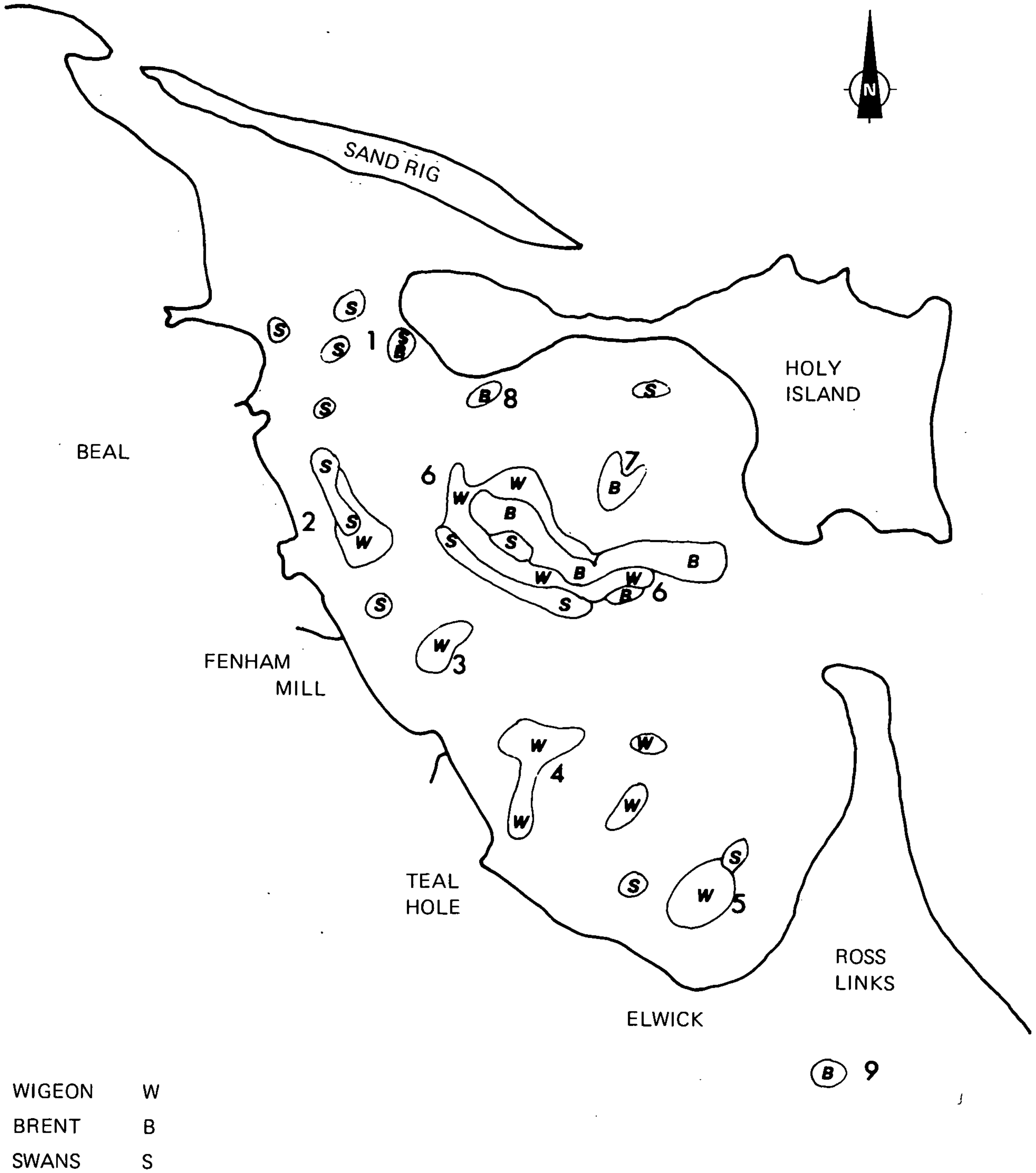

Figure 8. Main Feeding Locations of Herbivorous Wildfowl — Lindisfarne

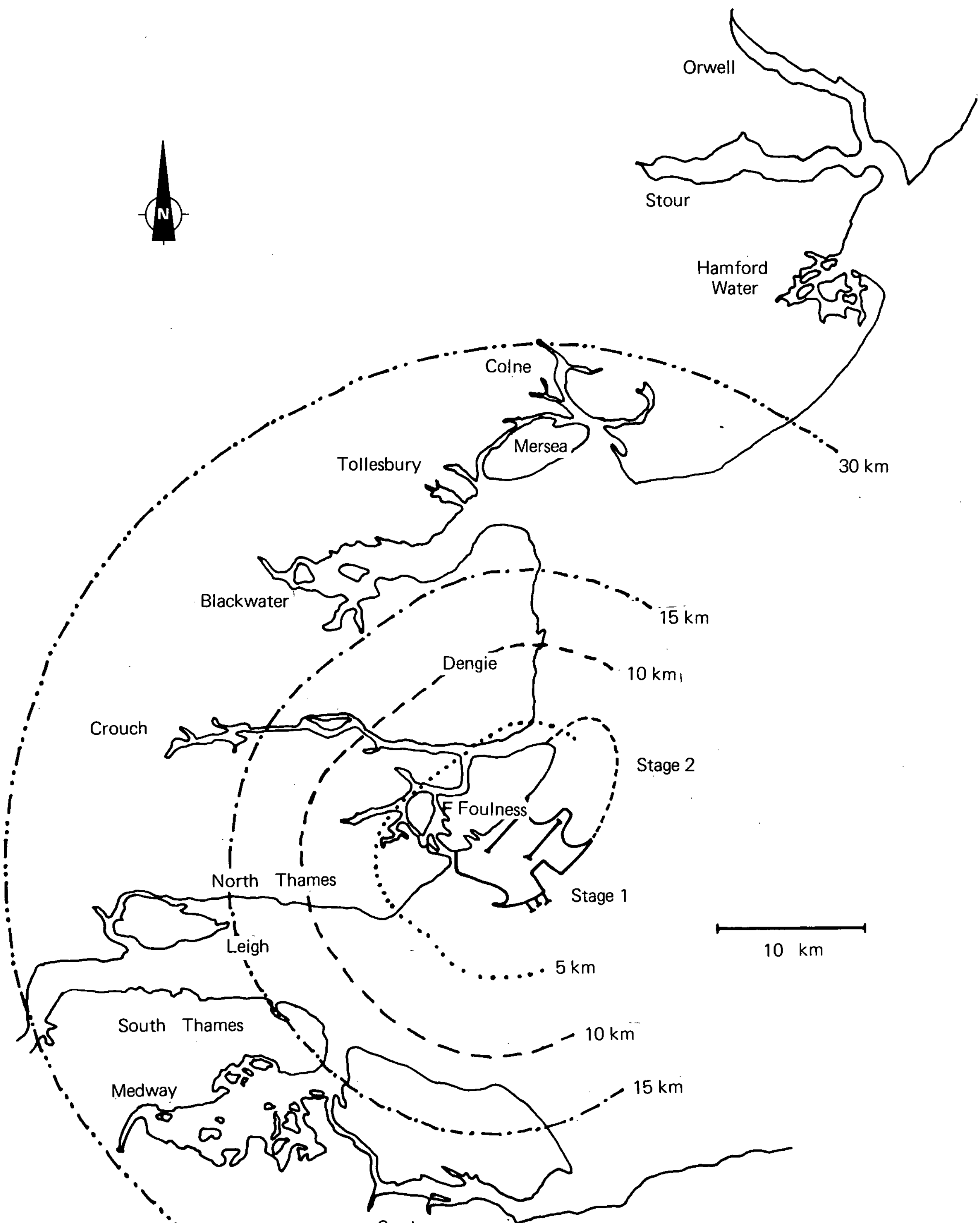

Figure 9. Impact Zones Maplin Development

are still obscure. After many years without any record of it, ***Zostera*** disease re-appeared (in ***Zostera marina*** var. ***angustifolia***) at Lindisfarne, Northumberland, during the study period.

The earlier literature refers persistently to ***Zostera marina*** as a main food of Brent geese. It is now apparent that this species or its var. ***angustifolia*** is either rarely available (as its leaves are shed in early autumn) or, for some other reason is now rarely eaten. This study confirms this fact, and it must be emphasised that ***Zostera noltii*** was effectively the only species of ***Zostera*** recorded as eaten by dark-bellied Brent geese during the present study. Nevertheless in view of the above any attempts to transplant this species on a large scale would need to be carefully supervised to minimise the risk of inducing an epidemic.

The human element

Human influences have affected this coastline historically in three main ways:— 1) by altering the proportions of semi-natural habitats, 2) by altering their nutritional status, and 3) by adding an element of disturbance which affects wildlife and particularly bird behaviour.

Sea defence embankments have been built since Roman times to protect existing agricultural land and to take in new land in the form of salt marshes ripe for reclamation. No less than three hundred of the four hundred miles of Essex coastline are modified in this way. As a result, scarcely any natural transitions between salt marsh and hinterland coast survive, except on very short lengths of coast, for example on part of Harty marshes, Sheppey. Reclamation has truncated the upper limits of salt marsh and obliterated the natural habitat of many species, though some of them (like ***Trifolium squarrosum*** on sea embankments and ***Scirpus maritimus*** in drainage ditches) have found a new home in man-made habitats. Apart from alterations in the nature of the coastal boundary, embankment changes the relative proportions of coastal habitats.

If we assume that the 16,900 ha of farmland flooded on the Essex coast in 1953 is a rough measure of the salt marsh areas reclaimed since Roman times, and compare this with the 7,000 ha of salt marsh currently remaining, we have some indication of the order of size of changes brought about by man. It may be argued that reclamation stimulates salt marsh development (from evidence in the Wash). This may have been so in the past, but from the evidence we have at present salt marsh advance is very limited on this coast at the present time.

Studies by the Hydraulics Research Station show that there appeared to be a foreshortening and steepening of the intertidal mudflat zone in estuaries within the study area, so that there was simply no room for further ***Zostera*** growth. It seems possible that while salt marsh accretion continues, erosional features will dominate the mudflats and contribute to over-steepening of shorelines and reduction of intertidal mudflat habitat. In other words, the pace of reclamation may not only have truncated the upper limits of marsh, but also narrowed the zone where ***Zostera*** could grow.

It has not proved possible to assemble data on long term nutrient and disturbance changes within the study area. However, it is evident from existing river nutrient analyses that enhanced levels of major nutrients (e.g. nitrogen in the Stour) exist in some of the estuaries, and domestic and industrial effluents and fertiliser run-off or leaching from agricultural land are likely to be responsible. Human disturbance in the past may have been much more widespread on the marshes and mudflats, with a larger agrarian population and a more intensive use of marshlands than there is today. Within the past one hundred years, the trend has been to denser aggregations of people in towns and recreational areas resulting in locally high, but not necessarily widespread disturbance activity. The proportion of coast actually built on (developed) to undeveloped in Essex is in the ratio of 1:4.5. However, even at Southend and Leigh although the landward side of the coastline is completely built on, the seaward intertidal zone still carries thriving communities of ***Zostera***, intertidal invertebrates, Brent geese and waders at present. How long they will last is another matter, especially in view of increasing risks from oil pollution.

It is concluded that the primary human influences on this coast have been those that directly resulted in major changes in habitat type and proportion, and that indirect influences such as altered nutrition and increased disturbance have been of secondary importance.

EFFECTS OF HUMAN DEVELOPMENTS AT MAPLIN

Although the original remit was concerned with the assessment of the effects of the proposed airport development at Maplin (Stage I) and projected post-airport development (Stage II), the study was planned not only to assess these effects, but to contribute to a knowledge of the effects of development generally on the Essex coast, and in the Maplin area in particular.

Having found out what plant and animal populations are at Maplin and its environs, and to some extent how they relate to each other, we are now in a position to assess direct and indirect effects of airport development at Maplin, and in the study area as a whole. This has been done in relation to zones of varying intensity and kind of impact from Maplin (Fig 9).

Direct effects of reclamation at Maplin

The direct effects of reclamation for airport development are likely to be similar to the effects of reclamation for any other purpose, as the area ripe for reclamation is likely to be the same in each case. The various configurations for the runways suggest that direct loss would be mainly in the intertidal zone. If they were on the mudflats seaward of the ***Zostera*** beds, the direct loss of mudflat habitat would be 3,200 ha (Stage I Airport development) or 6,200 ha (Stage I and II projected post-airport developments). These values represent 30 per cent and 60 per cent of the total Maplin mudflat area respectively, or 1.5 per cent and 3.0 per cent of the estimated total British acreage of intertidal flat area. On a crude area to bird population ratio, Stage I airport development would obliterate habitat for some 7,500 wading birds, i.e. one third of the average winter population using the Maplin flats. In the case of the additional Stage II developments, 15,000 wading birds or two thirds of the average wintering population at Maplin would lose their habitat. In addition to direct area to bird population ratio effect, there is the likelihood that substantial losses would occur in populations of certain species at present of international significance (as defined previously) at Maplin. Up to 3 per cent of the European population of bar-tailed godwit, 2 per cent of grey plover and knot, and around 1 per cent of curlew, oystercatcher and ringed plover could be put at risk by either Stage I alone or Stage I and II developments together.

The airport proposal or any extensive reclamation adjoining the south-east shore of Foulness Island would result in the loss of at least 80 per cent of the ***Zostera noltii*** bed at Maplin, which in turn represents 40 per cent of the entire ***Zostera noltii*** resources of the study area. The amount of ***Zostera noltii*** lost could support 4,500 dark-bellied Brent geese or about 13 per cent of the total wintering British population of this bird. The airport proposal or reclamation of the Foulness shore would also result in the loss of the only surviving viable population of ***Spartina maritima*** in its pioneer situation in Britain, and a loss of a substantial part of the British population of this species as a whole.

Indirect effects of airport development at Maplin

The principal indirect effects of airport development at Maplin concern birds and not their food resources. Perhaps the simplest approach to assessment is to consider the first three zones e.g. at 5, 10, and 15 km from the perimeter of the airport reclamation (Stage I), see Fig. 9.

The perimeter and 5 km zone includes the whole of Maplin intertidal flats, Foulness, Potton, Havengore and Wallasea islands and most of the Roach estuary and the lower Crouch. Within this zone, average winter populations of 27,000 waders and 4,000 duck, and peak values of 180,000 gulls, and 14,000 dark-bellied Brent geese (20 per cent of the world population) have been recorded in winter, and up to 100 pairs of little tern (6 per cent of the British population) breed in summer at Foulness point. Heavy birds like the Brent geese and ducks, waders forming large dense flocks like knot and dunlin, and those species at present positioned at the end of proposed runways like the little terns at Foulness point would all tend to be discouraged in the area for aircraft safety reasons, let alone by the noise and disturbance of building and operating a new major international airport. Approaching a quarter of a million birds would be at risk in the airport perimeter and 5 km zone.

The 5 to 10 km zone includes the Southend shore, most of the Crouch and the southern half of the Dengie perimeter. This area provides winter habitat for an additional average winter population of 7,500 waders and 2,000 duck and an additional peak value of 3,700 dark-bellied Brent geese (a further 5 per cent of the total world population). Such birds would be subject to increased disturbance but, without detailed knowledge of aircraft flight paths, it is not possible to predict the effects on their behaviour. However, at least 13,200 birds could be affected in this zone.

The 10 to 15 km zone brings in the north part of the North Kent marsh, Leigh marsh in the Thames estuary and the rest of the Dengie peninsula. This would add a further average winter population of 18,000 waders and 4,700 duck, plus an unknown but comparatively large population of duck (in particular) on the North Kent marshes, and peak values of up to 10,000 gulls and 4,700 dark-bellied Brent geese. At this distance from the airport development, disturbance would certainly be minimal, but with a population of 37,400 birds in this area there could be problems relating to safety of aircraft operation. In total, therefore, some 275,000 birds could be affected within a 15 km radius of the proposed airport perimeter.

Indirect effects of a major development at Maplin on the study area as a whole

The net effect of eliminating Maplin from the coastal habitat series in Britain would be to displace bird populations in the orders of size given above which might or might not be accommodated in suitable sites within the study area or further afield.

It is particularly important to bear in mind that during the period of the study, it chanced that population numbers of dark-bellied Brent geese doubled in size. Feeding observations and marking studies demonstrated that coastal sites had already reached capacity limits so that birds were dispersed to new untraditional inland feeding grounds. This seems a clear demonstration that birds of this type displaced from one feeding habitat can adapt rapidly by changing their behaviour. However in the case of Brent geese, the long term consequences of this adaption are unknown.

One consequence, therefore, of eliminating Maplin for wildlife by development would be to put additional pressure of wildlife use on adjoining coastal and possible inland agricultural and reservoir shore habitats. For example coastal waders have recently become adapted to feeding on Abberton reservoir..

The evidence from marking studies in dark-bellied Brent geese emphasised the significance of Maplin as a dispersal point for these birds in Britain and as a sanctuary for juveniles developing novel feeding habits. Just how novel these techniques of winter feeding must be for juveniles is underlined by the fact that Brent geese are observed to subsist initially on mosses and lichens among rocks on their Arctic tundra feeding grounds..

Coastal plants tend to migrate along the tidal litter line and a study of their distribution makes it clear that industrialized inlets or rocky promontories may act as barriers to dispersal. A near-sterile species like ***Spartina maritima***, which can only effectively reproduce vegetatively, may well be prevented from re-establishing pioneer populations north or south of Maplin if this shore were developed.

SUBSTITUTE SITES

The special features revealed by the study at Maplin include its exceptional size, unusually large high-protein ***Zostera*** food resources, and its carrying capacity for one fifth of the world population of dark-bellied Brent geese. It also has a special role as transit and dispersal point for about one third of the British population of these birds, and importance as a little-disturbed nursery ground for their juveniles. It has a large resource of wader food and wader population holding capacity and is on a main migration line for European migratory birds. It is the only site in the study area where an internationally significant population (2.5 per cent of the European population) of bar-tailed godwits overwinter. It has special physiographic features favouring the largest shell bank in Britain which supports 6 per cent of the British breeding populations of rare little terns. These features cannot be matched in the study area, and indeed, in this combination, anywhere else in Europe. We conclude therefore that **no alternative** site to Maplin exists. The best that can be considered is to provide evidence from which sites could be chosen that might partially substitute for losses incurred by development at Maplin.

The following assessment of site areas takes into account all the factors investigated and attempts to provide integrated information on which a choice of substitute sites, as they stand at present, could be made. The site areas are given in what would appear to be overall priority order, but subsequent consideration will be given to special cases and the possibilities of management for improving certain sites. Within each site, the features are dealt with in order of importance. Exact boundaries cannot be specified at this stage but the general physiographic limits of the Suffolk and Essex sites can be seen in Fig 6, and Kent sites in Fig 9.

Blackwater

The Blackwater has the largest mudflat area of all sites outside Maplin, but this is only just over a quarter of the size of Maplin. It has greater macro-invertebrate species diversity than Maplin, but only about half the standing crop biomass of macro-invertebrates per unit area. However, these food resources support nearly half the number of waders as at Maplin. These include internationally significant populations of grey plover, redshank, dunlin, ringed plover and curlew. The Blackwater has only one tenth of the standing crop of ***Zostera noltii*** compared to Maplin, but six times as much ***Enteromorpha***. Consequently the Blackwater is able to support 6.5 per cent of the world population of Brent geese. This site also has the highest number of species of regularly wintering wildfowl, waders and seabirds of any site (including Maplin). The Blackwater contains twice as much salt marsh as Maplin (including notable populations of rare species such as ***Inula crithmoides, Spartina maritima*** and ***Suaeda fruticosa***) and seven times as much undeveloped reclaimed marsh with a third more species of flowering plants than at Maplin.

Medway

The Medway has one third the area and biomass of ***Enteromorpha*** found in the whole study area and about fourteen times that at Maplin, but little ***Zostera noltii***. It has twice as much salt marsh as Maplin, and notable populations of the rare species ***Inula crithmoides***. This site contains one sixth of the total undeveloped reclaimed marsh in the study area and about ten times that at Maplin. It is also 50 per cent richer in reclaimed marsh plant species than Maplin. Besides the intrinsic interest of the Medway marshes, they provide a source of food for herbivorous wildfowl, so it is not surprising to find they carry about one third of the total wildfowl (excluding Brent geese) of the whole study area and above five times as many as at Maplin. The Medway supports internationally significant populations of wigeon, pintail, shelduck and teal.

Hamford Water

The salt marshes of Hamford Water are only surpassed in area by those of the Medway and form about one eighth the total in the study area. Notable populations of local species such as ***Inula crithmoides*** and ***Limonium humile*** on salt marsh, ***Peucedanum officinale*** in reclaimed marsh, and ***Eryngium maritimum*** on sand bars occur here, and ***Inula*** reaches its northern limit on the east coast in this area. Although mudflat area and invertebrate food resources are relatively low, this site carries regular winter wader populations as high as 80 per cent of those at Maplin, though actual peak numbers are less than half, which perhaps reflects the importance of Maplin as a transit area. No less than seven internationally significant populations of wader species overwinter: grey plover, redshank, ringed plover, curlew, black-tailed godwit, dunlin and sanderling. Although neither ***Zostera*** nor ***Enteromorpha*** occur in quantity in Hamford Water, salt marsh and reclaimed marsh are capable of supporting 3.5 per cent of the world population of Brent geese. This is one of the least disturbed sites in the study area and significantly carries two populations of breeding little terns (The Naze and Dovercourt) which together approach in size that at Maplin. However, poor breeding success indicates that local disturbance does affect the Hamford Water colonies.

Colne

Although one of the smaller sites in the study area, the Colne is one of the richest in variety of both plant and bird species and the least disturbed (as a result of Nature Reserve wardening and Military range restrictions on access). It has the fourth largest area of reclaimed marsh consisting of one ninth the total in the study area. The Colne is especially notable for plant species diversity which may well reflect the long history of human activity (dating back to Neolithic times) in this area. It has the greatest number of both salt marsh and of reclaimed marsh plant species of any site in the study area. It has notable populations of ***Spartina maritima*** and of most of the local species found in reclaimed marsh. Although only 4 per cent of the area of Maplin, its relatively undisturbed mudflats support an average winter population of waders nearly half that at Maplin. Moreover, no less than five wader species (redshank, sanderling, curlew, grey plover and ringed plover) with populations of international significance are found in this relatively small area. Nearly one fifth the number of Brent geese (2 per cent of the world population) and almost twice as many wildfowl occur on the Colne as at Maplin. The Colne also supports a breeding population of little terns half the size of that at Maplin.

Stour

The Stour mudflats are one sixth the size of those at Maplin but they are second only to the Blackwater in numbers of macro-invertebrate species and these are comparable with the numbers at Maplin. The biomass of macro-invertebrates per unit area is second only to that on the Orwell and more than one and a half times that at Maplin. Although the mudflats of the Stour are only one sixth the size of those at Maplin, they carry no less than 70 per cent of the wader populations found at Maplin, whether measured as peak populations or as average winter populations. Four populations of wader species of international significance occur on the Stour: redshank, grey plover, black-tailed godwit (75 per cent of the population in the whole study area) and dunlin. The Stour carried one twelfth of the standing crop fresh weight of ***Zostera noltii*** in the study area (one sixth of the amount at Maplin). These food resources support more than twice as many wildfowl as at Maplin and populations of international significance of wigeon and shelduck (the latter dependent especially on the herbivorous molluscs, ***Hydrobia*** sp. generally abundant on ***Enteromorpha*** in these estuaries. The numbers of Brent geese however are surprisingly low in view of the food resources, and this is attributed largely to disturbance from people on the banks and from boats in the channel on this comparatively narrow estuary.

Swale

The Swale site contains half the total unimproved reclaimed marsh in the study area and about thirty times that at Maplin. It has the greatest diversity of reclaimed marsh plant species of any site in the study area and substantial populations of most of the local species in this habitat. Moreover, it contains rare natural transitions to unimproved terrestrial habitats and a variety of brackish to freshwater transitions. Over 10 per cent of the total acreage and standing crop fresh weight of ***Enteromorpha*** in the entire study area occurs in the Swale mudflats, that is, five times as much as at Maplin. These plant food resources support wildfowl populations (other than Brent geese) second only to those of the Medway and more than four times the numbers found at Maplin. The site also supports an internationally significant population of wigeon.

Dengie

Dengie contains about one fifth the mudflat area at Maplin, but this supports a macro-invertebrate biomass per unit area comparable to Maplin, and one third the peak numbers of waders and one half the average winter population of waders compared with Maplin. There are internationally significant populations of grey plover, sanderling and curlew. Dengie is the least disturbed site in the whole study area and is of particular importance as a transit site for passage waders and wildfowl. Its position on an open coast exposed to waves generated by dominant north easterly winds is thought to prevent growth of ***Zostera*** and to limit that of ***Enteromorpha***. However, it acts as a refuge for Brent geese disturbed by military activities at Maplin and supports 2.5 per cent of the world population of these birds. Dengie contains the largest continuous block of salt marsh and represents 8 per cent of the whole in the study area. Its drainage pattern is a relatively simple one facilitating access for management. It contains notable populations of local species such as ***Limonium humile, Salicornia perennis*** and ***Spartina maritima***.

Leigh

Leigh has 25 per cent of the total ***Zostera noltii*** (fresh weight standing crop basis) in the study area on a site only 13 per cent of its size. Also the standing crop per unit area at Leigh is twice that found in the other parts of the study area. This unusually high productivity is probably attributable to shelter and elevated nutrient levels in the Thames estuary. Leigh supports about 3 per cent of the world population of Brent geese. Like Dengie, Leigh contains about one fifth the mudflat area at Maplin, a macro-invertebrate biomass per unit area comparable to Maplin and similar wader population levels to those at Dengie. The site also supports internationally significant populations of ringed plover, grey plover and dunlin.

Management of substitute sites

Since Maplin contains more than half the total ***Zostera noltii*** in the whole study area, there is no possiblility that Maplin Brent geese could be accommodated on this food source elsewhere even if the rest of the ***Zostera*** in the study area were preserved for them. It has been demonstrated that ***Zostera noltii*** can be transplanted on mudflats but that extensive suitable sites for its establishment do not exist at the present time within the study area. Some protection of existing stocks could be undertaken by controlling the growth of plants like ***Spartina anglica*** which can replace ***Zostera***, but this is only likely to be successful on a very limited scale in isolated estuaries (like Breydon Water, Norfolk), where an attempt is being made to exterminate ***Spartina***. To create potential ***Zostera*** beds or augment high level tidal flats suitable for macro-invertebrates on which birds feed, it would be necessary to use engineering works. These would be prohibitively expensive for this purpose alone, but suitable habitat might be created in association with reservoir schemes such as those being investigated in the Wash.

The creation of a new salt marsh area to offset loss by reclamation is much more practicable than creating ***Zostera*** beds. It should be possible to create salt marsh in association with dredge spoil islands and this has been done successfully in America (e.g. Cape Fear estuary, North Carolina). A possible site for such an acitvity would be the Outer Thames estuary, as an artificial extension of the natural deltaic formation of islands that is found there already. Again there are possibilities of creating salt marsh in association with proposed fresh water impoundments in the Wash.

To attract geese away from arable crops it would be necessary to change the structure and vegetation composition of existing ungrazed salt marshes within the study area. One of the most promising sites for this would be at Dengie which is relatively free of deep creeks, thus facilitating the use of grass-cutting machinery and grazing of stock. There is no experimental information on the conversion of ***Halimione*** dwarf shrub marsh (as at Dengie) to salting pasture. Such a conversion could probably be achieved by mowing and grazing over a 5 to 10 year period on suitable sites. Available evidence suggests that no alternative food matches ***Zostera noltii*** for availability in cold winters and protein richness; nevertheless salt marsh pasture grasses such as ***Puccinellia maritima*** are more nutrious than ***Enteromorpha*** and more freely available in cold winters (because of salt depression of the freezing point), than inland pasture or arable crops.

Although geese in other parts of Britain co-exist with agriculture, hitherto dark-bellied Brent geese have been notable for feeding exclusively on vegetation in the intertidal zone. The question of whether or not they should be encouraged to feed inland has political implications beyond the remit of this study. Quite apart from this, the fact that Brent geese have recently turned to crop feeding does not mean they will continue to thrive on this type of food.

The remarkable diversity and abundance of plant and bird life of the Colne estuary is believed to be the product of natural habitat diversity, gradual changes in land use over a long period of time, and current control of human disturbance. Disturbance is related to the shape of sites, and long narrow estuaries like the Stour with a high proportion of disturbed edge (embankment and river channel) to area, might hold greater wildlife populations if human disturbance could be reduced.

In reclaimed marsh areas the right combinations of damp pasture, ditches and fleets and even controlled flooding can produce an exceptionally rich habitat for feeding and breeding wildfowl, and breeding grounds for rare wading birds (as in the Ouse washes, for example). Opportunities for the application of such management exist on the Dengie peninsula. Management of reclaimed marshes for wildfowl is already in practice, or under consideration in the Medway, Swale and Colne areas. A great variety of management is applied to sea embankments including mowing, grazing and burning, with little understanding of the effects on their sea defence properties and the wildlife they support. In fact, apart from their primary role in sea defence, they carry not only great diversity of plant species, but also are one of the few locations where substantial populations of insects (e.g. butterflies) can breed in coastal marshes.

Further Research

INTRODUCTION

Expediency demands short-term intensive studies of the kind completed for the Maplin study, but it is evident that long-term studies are essential for an effective understanding of complex biological systems. Much has been learned in the present study, but the rapid fluctuations in the populations, and changes in feeding responses of Brent geese, even over a period of only three years, make it clear that we still have a great deal to learn. Before- and after-studies are difficult to interpret if changes within the period of study are greater than those recorded at the beginning and end of the study. It follows that the better basic understanding we have of behavioural responses and the closer we can track population changes, the better we shall be able to predict the consequences of large-scale disturbances.

BACKGROUND RESEARCH

Good liaison was developed with engineers from the Hydraulics Research Station on the special hydraulic conditions required for ***Zostera*** growth, and, by inference, the special conditions that the presence of ***Zostera*** indicates. This inter-disciplinary area of study would repay follow-up both for the biologist concerned with food resources and the engineer concerned with sediment stability. We are particularly ignorant about the long-term persistence of ***Zostera*** beds, thresholds of stability required for their establishment, and their response to small scale accretion/ erosion phenomena. The special conditions which favour ***Spartina maritima*** at Maplin deserve study in relation to this also. Engineers might find ***Zostera*** and other mudflat growths useful indicators of sediment surface stability. Results of transplant experiments can indicate in an integrated way patterns of erosion or accretion.

Zostera species are exacting in their growth requirements, but pioneer salt marsh plants like ***Salicornia*** species, ***Puccinellia maritima*** and ***Spartina anglica***, are almost universally present on hundreds of thousands of acres of high level mudflats wherever conditions are sufficiently stable for salt marsh growth on European coasts. Because such areas are flat, salt marsh colonisation is peculiarly susceptible to very small changes in land or sea level. The possibility needs to be examined whether the state of salt marsh seaward edges round our coast are an advance indicator of gradual, long-term isostatic changes. There are implications here for sea defence maintenance.

The study briefly reported here appears to indicate measurable relationships between such birds as Brent geese and their food resources, their flexibility in feeding behaviour and their vulnerability in relation to breeding in harsh climates. Brent geese hitherto have been one of the last remaining wild geese species in Europe to survive on natural vegetation and so have rarely come into direct conflict with agricultural interests. Now that it is definitely known that they can adapt to feeding on agricultural land, it becomes necessary to investigate more closely the means of population control. In particular, study will need to be made of their feeding behavioural responses under cold winter conditions which were not experienced in the present study.

SPECIFIC RECOMMENDATIONS

1. Improved instrumentation and measurements of hydraulic forces affecting ***Zostera*** beds, and studies on the biology of ***Zostera*** and ***Spartina maritima*** directed towards the prediction of their growth requirements need to be developed, as the presence of such species is indicative of specific sedimentary conditions.
2. A trial needs to be undertaken to see if it is possible to establish a viable ***Zostera noltii*** bed in association with engineering works on mudflats (e.g. in the Wash).
3. Relationships between salt marsh formation and erosion in relation to isostatic change on the British coast are worthy of study in connection with sea defence.
4. The use of dredge soil needs to be considered for the possible formation of additional salt marsh in the study area. Parts of the Medway estuary salt marshes might be restored in this way, or new marshes created in the outer Thames estuary to offset losses from reclamation.
5. Field experiments might be undertaken to discover the right combination of cutting and mowing to create salting pasture suitable for wildfowl and stock in ungrazed salt marshes such as Dengie.
6. Field experiments could be carried out on methods of managing reclaimed marshes, and their ditches and embankments, to improve these habitats for local plant species, and breeding, feeding and roosting birds (e.g. in the Swale area). Study is particularly needed of the type and management of the vegetation of sea embankments in relation to sea defence.
7. Feeding responses of dark-bellied Brent geese under cold winter conditions and factors affecting their population control require study, to improve predictions about the future of this species in relation to human activities at the coast.

Publications arising from this study

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