WASH FEASIBILITY STUDY

DRAFT REPORT TO THE CENTRAL WATER PLANNING UNIT OF THE ECOLOGICAL STUDIES IN THE WASH

PART I

NATURAL ENVIRONMENT RESEARCH COUNCIL

MARCH 1975

Part I ECOLOGICAL STUDIES

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INTRODUCTION

Organisation

1. In March 1971 the Secretary of State for the Environment authorised the Water Resources Board to undertake a Feasibility Study into the possibility of storing fresh water in three or four bunded reservoirs in the Wash. The Natural Environment Research Council (NERC) was invited to put forward proposals for a programme of work to enable the ecological effects of the engineering proposals to be assessed. A programme was submitted to the Wash Steering Committee and was approved at its meeting in February 1972. The work was to start in April 1972 and be completed in two years. The proposals were subsequently incorporated in a contract between the Water Resources Board and the Natural Environment Research Council. Five projects were specified:

1. Common Seal survey
2. Wader and wildfowl survey
3. Marine fish and shellfish studies
4. Intertidal invertebrate studies
5. Intertidal vegetation survey and process studies.

2. The responsibility for the work was divided between two NERC organisations: the Institute for Marine Environmental Research was to be responsible for Projects 1, 3 and 4 and the Nature Conservancy, through its Coastal Ecology Research Station, for Projects 2 and 5. During 1973 and 1974 various organisational changes took place. The Water Resources Board was dissolved and its contractual responsibilities for this Study were taken over by the Central Water Planning Unit and the Coastal Ecology Research Station became part of a new NERC institute, the Institute of Terrestrial Ecology. The contract was extended by eight months with a final reporting date of February 1975. On the engineering side, the need for all four reservoirs, proposed in the Desk Study, which would have occupied the whole of the southern shore of the Wash, diminished; and in 1974 the ecologists were asked to comment on four alternative sites for a Stage 1 reservoir and three alternative combinations of sites for Stage 2. These are illustrated in Figure 1. Figure 2 is a map of the Wash showing the places referred to in the text.

3. This report is in two parts. Part I is a summary of the ecological work carried out during the 2½ years of the study with a set of predictions based on that work. It has been written by members of the staff of NERC and is to be considered formally as the NERC report.

4. Part II is a collection of detailed reports on different aspects of the ecology of the Wash. They fall into four categories:

(1) Those prepared by the staff of NERC institutes:

A. B. C. D. E. H. J. P. Q. R.

(2) Those prepared by former Nature Conservancy staff, now employed by the Nature Conservancy Council (NCC):

S. T.

(3) Those prepared by the staff of CWPU:

U. V.

(4) Papers prepared by amateur and professional ornithologists who belong to various organisations and whose work has been co-ordinated by an Ornithological Working Group:

F. G. K. L. M. N. O.

5. Documents S and T have been drawn on by the NCC in its own Report which has been prepared independently, as Part III of the Ecological Report. Data in the third and fourth groups of papers have been used in compiling the present Report; the full texts of these papers are included in Part II for completeness but it should be made clear that these are reports to NERC by the individuals or groups concerned and have not been subject to the same editing and supervision as the work undertaken by NERC staff.

Objectives

6. The ecological research in the Wash has been of two interdependent types,

(i) Pattern studies involving the survey of species distribution and abundance spatially and in time, and

(ii) Process studies involving the correlation of species distribution and performance with environmental variation, and the analysis of functional and trophic relationships.

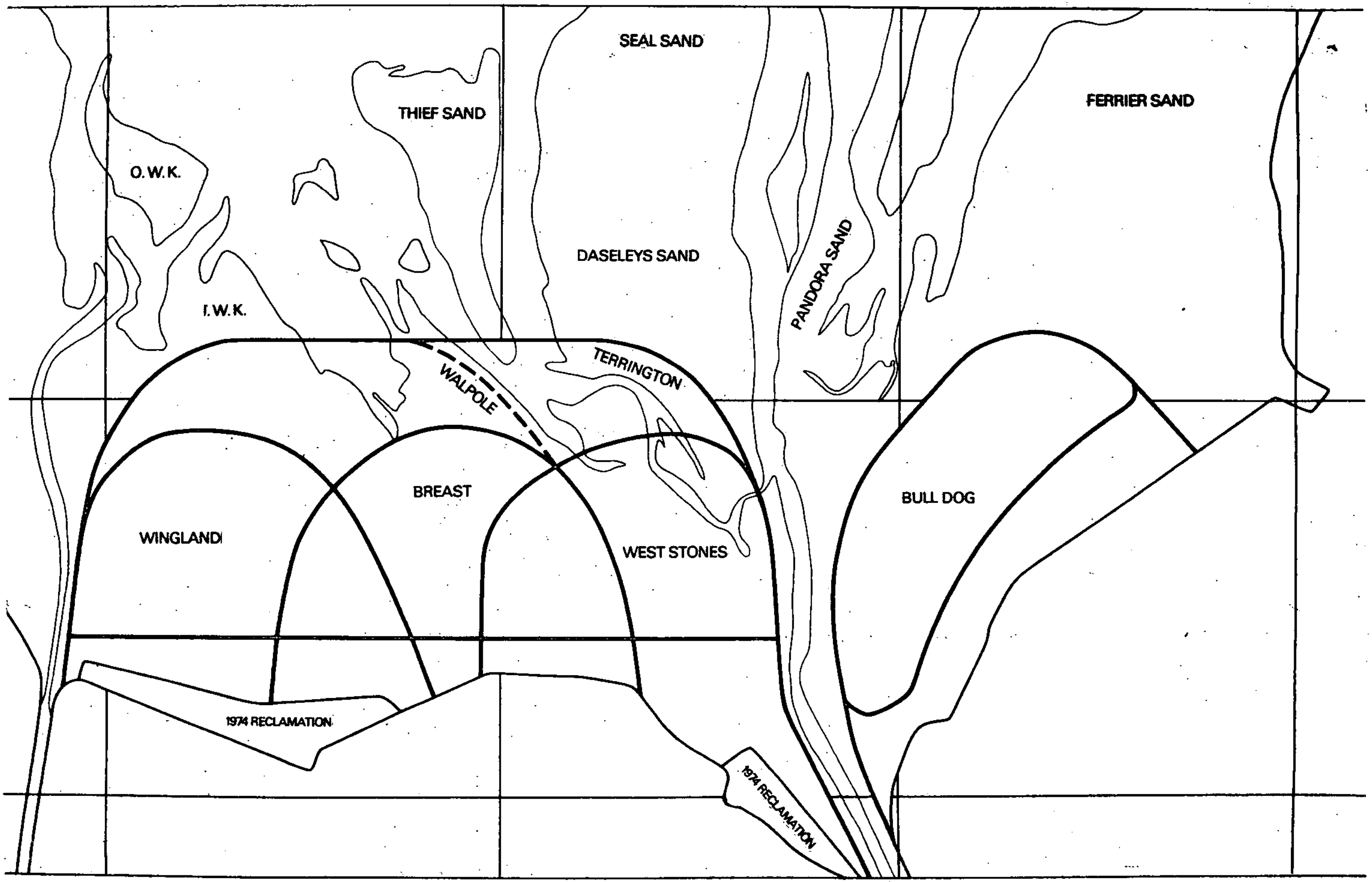
These two types, the first attempting to measure, the second to explain, the biological phenomena concerned, together form the basis for the ultimate objective of this work, namely predicting the likely impact of the reservoir schemes on the ecology of the Wash.

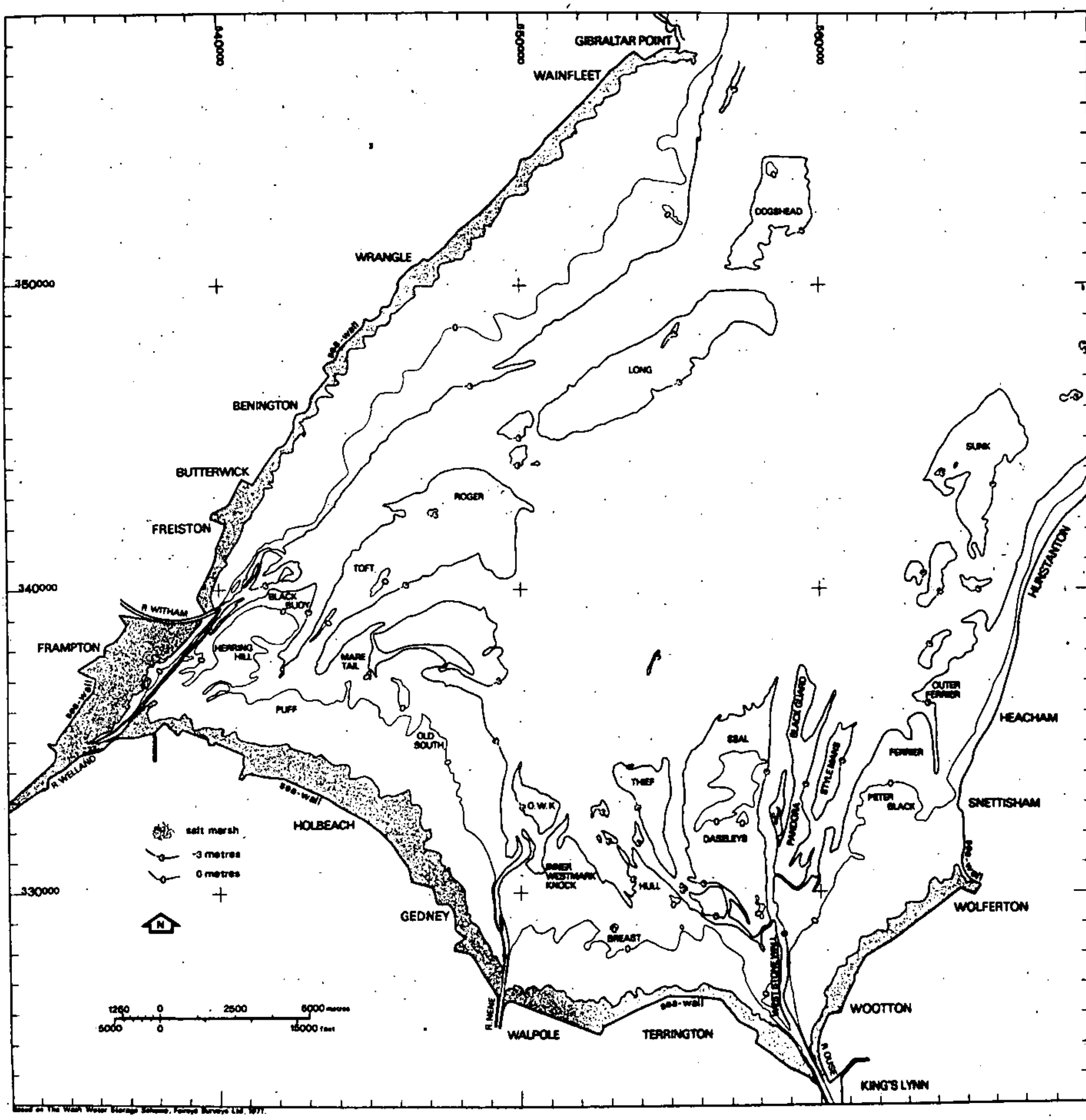
7. Botanical pattern studies have included surveys of the macro- and micro-algae of the mudflats and salt marshes, of Eel-grass (Zostera) species, of the plant communities of the salt marshes, and of the flowering plants of reclaimed farmland surrounding the Wash. The process research has investigated the role of algae in mudflat stabilisation (by field and laboratory experiments) and the development of salt marshes (by simulation modelling).

8. Pattern studies of the birds of the Wash have included surveys of the numbers and distribution of waders, wildfowl, breeding birds, seabirds (notably gulls) and twite. Process studies have principally focussed on the relationship between wading birds and shelduck and their invertebrate food supply (largely by field observation of bird feeding and behaviour).

9. Although concerned to predict the effects of Stage 1 and 2 impoundments (Fig. 1) the research has covered the whole Wash area (Fig. 2). This wider picture is essential because of the physiographic and ecological interrelationship of the different sections of the Wash.

Fig. 1 THE PROPOSED RESERVOIRS





Based on The Wash Water Storage Scheme, Fairey Surveys Ltd. 1977.

Fig. 2 THE WASH

THE WASH ENVIRONMENT

10. The Wash is a large bay rather than an estuary. The main rivers entering it are the Great Ouse, Nene, Welland and Witham and all are canalised up to their entry into the bay, and are tidal for several miles upstream. The rivers have navigational channels through the inner and outer sand banks which are kept clear by strong tidal currents and those of the Great Ouse and Witham are bounded by training walls. The salinity of the water was measured by staff of the Hydraulics Research Station over several tidal cycles at each of 39 stations in the Wash between April and October 1972. Their report on the observations (H.R.S. 1974) states:

> "At the more seaward stations water was well mixed with average salinities of 32.5°/oo to 34°/oo. Significant salinity variations in the course of a tide are not met with until the confined low-water channels leading to the tidal rivers are reached. At high water, values in excess of 31.5°/oo occur even at the most landward stations, but at low water surface tongues of low salinity extend out into the Wash. The most noticeable was found on spring tides in Daseleys Sled where some 12 km seaward of the land-locked reach of the Great Ouse, surface salinity dropped to 14°/oo at low water. On the same day salinities in the neighbouring Bulldog Channel and Cork Hole did not fall below 27°/oo....... No corresponding depression of salinity was found as far seaward off the Nene and Welland/Witham outfalls..... The basic pattern at neap tides was the same, apart from less seaward penetration of the freshwater tongues."

Salinities of 32.5°/oo to 34°/oo are typical of North Sea Coastal waters.

11. This salinity distribution explains why there is no ecological evidence for freshwater influences between the low water river channels in the intertidal area. For example the plant species characteristic of brackish transition zones are confined to the canalised river banks and the saline seepage areas within reclaimed land. Similarly, typically intertidal invertebrate species have been recorded some distance above the mouth of the Great Ouse (see Study U).

12. Although only the Great Ouse among the major rivers entering the Wash falls in Class 1, (rivers unpolluted and recovering from pollution) (DOE 1971) industry contributes little to the pollutant input most of which consists of nutrients derived from domestic sewage and agricultural drainage. There is no direct evidence of any effect of these nutrients on the ecology of the Wash, although they may play a part in promoting the general biological richness of the area.

13. An outstanding feature of the Wash is its large size. The area of 620 square kilometres south west of a line from Gibraltar Point to Hunstanton may be divided into the following major habitats:

Permanently covered by sea and rivers	290 km^2
Intertidal sand and mud flats	270 km^2
Salt marshes	44.5 km^2
Sand dunes	3 km^2
Shingle beaches	1.6 km^2

In addition over 320 km^2 of land has been reclaimed around the margins since the 17th century.

14. Of the intertidal sand and mud flats about 185 km^2 form the shore and 85 km^2 are detached sand banks, varying in size and in the width of the channel separating them from the shoreline. For instance the Outer Westmark Knock is about 3 km^2 in extent with a channel only about 200 metres wide at low water, while Long Sand covers about 14 km^2 and is separated from the north western shore by a channel 2 km wide.

15. A survey of the composition of the sediments in the intertidal and sublittoral areas was carried out by the Institute of Geological Sciences (a component institute of NERC) during 1972 and their report (The Wash Water Storage Scheme. Report on the geological investigations for the feasibility study, IGS 1974) was submitted to CWPU in March 1974. The cores from which the surface sediments were described were up to 1.6 metres in depth and the intertidal area was classified broadly into "sand", "sand with mud laminae" and "mud with sand laminae". Cores from the second group generally contained over 70% clean medium sand while sediments in the mud with sand laminae group contained over 50% silty mud. These broad divisions are useful for correlation with the distribution of intertidal invertebrates, (see Study A). A more detailed description of the southern part of the western shore off Freiston has been given by Evans (1965). He recognised five major intertidal subhabitats or "sub-environments of deposition" from land to sea below the salt marsh, "higher mud flats, inner sand flats, Arenicola sand flats, lower mud flats and lower sand flats", with creeks and their borders providing another sub-environment. He used cores of 0.6 m depth but he says that the terms "mud flat" and "sand flat" are based on general appearance and not on precise composition. His zones have proved useful descriptions for some of the studies (such as Study B) although over most of the shore only the three zones "upper mud flat", "Arenicola sand flat" and "lower sand flat" are common.

16. The position of the main sub-environments in relation to reference tide levels and Ordnance Datum (Newlyn) at three sections of the shore on the west, south and east coasts are shown in Figure 3, which also shows some of the characteristic plants and animals of the zones. The mean spring tidal range in the Wash is 6.7 metres, with the main reference levels:

Mean high water springs	+ 3.7 m O.D.
Mean high water neaps	+ 2.0 m O.D.
Mid tide	+ 0.3 m O.D.
Mean low water neaps	- 1.3 m O.D.
Mean low water springs	- 3.0 m O.D.

17. The fringe of salt marsh occurs above mean high water neaps and is fronted by the wide gently-sloping intertidal flats which absorb the energy of the incoming tide and thus provide shelter for salt marsh development to occur. The flats contain large populations of invertebrate animals, the food of wading birds for which the Wash is internationally famous among ornithologists.

18. The above general description of the Wash as it is today in terms of salt marsh, intertidal sand and mud flats, sand banks and open water would also have been applicable two centuries ago. But the shapes of the features and their relative areas would have been different because one of the main features of the borders of the Wash is the way in which they have been changed by man's continuing reclamation of salt marsh for agriculture. This changing pattern and its consequences are discussed in some of the later sections.

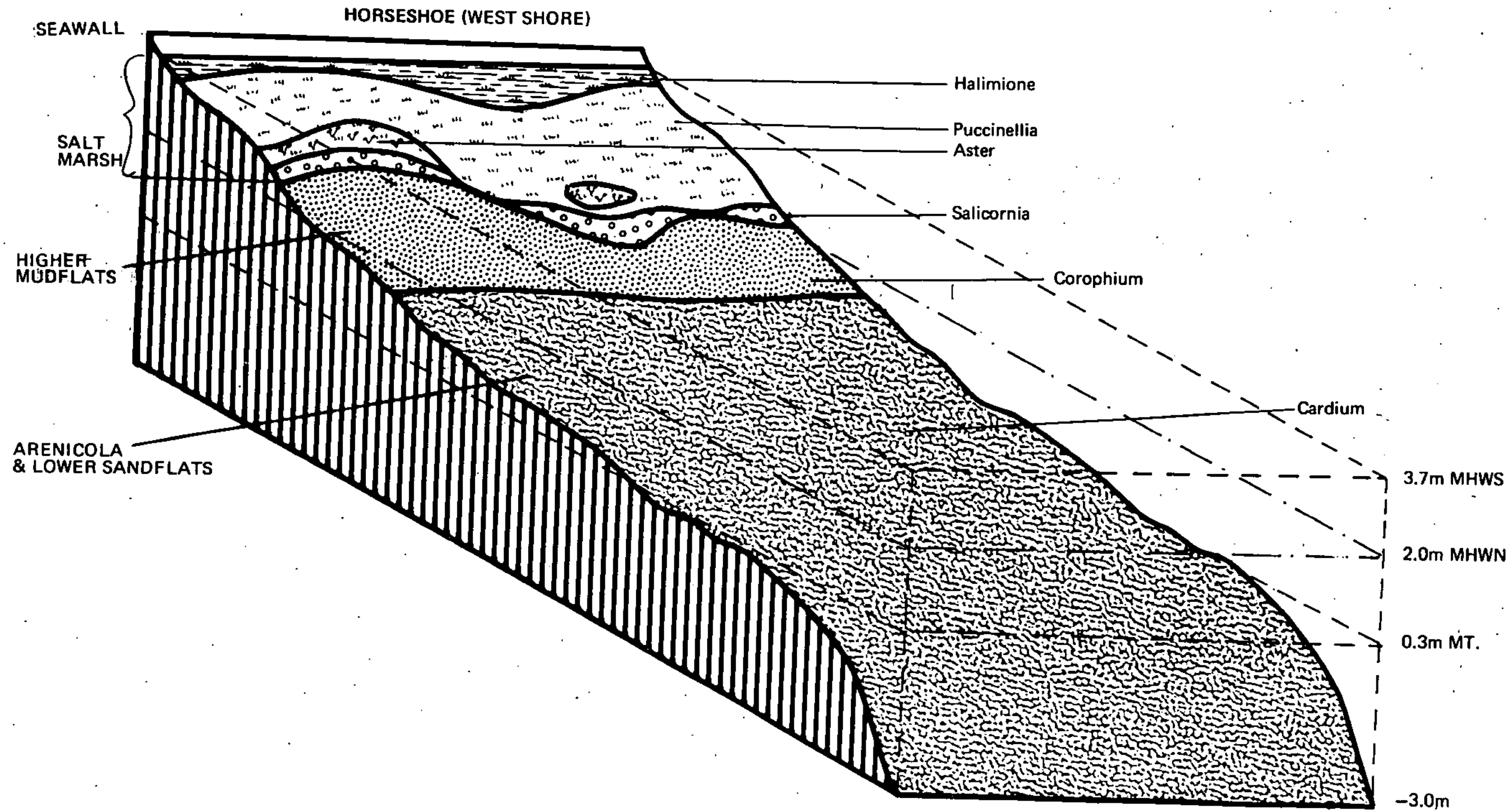
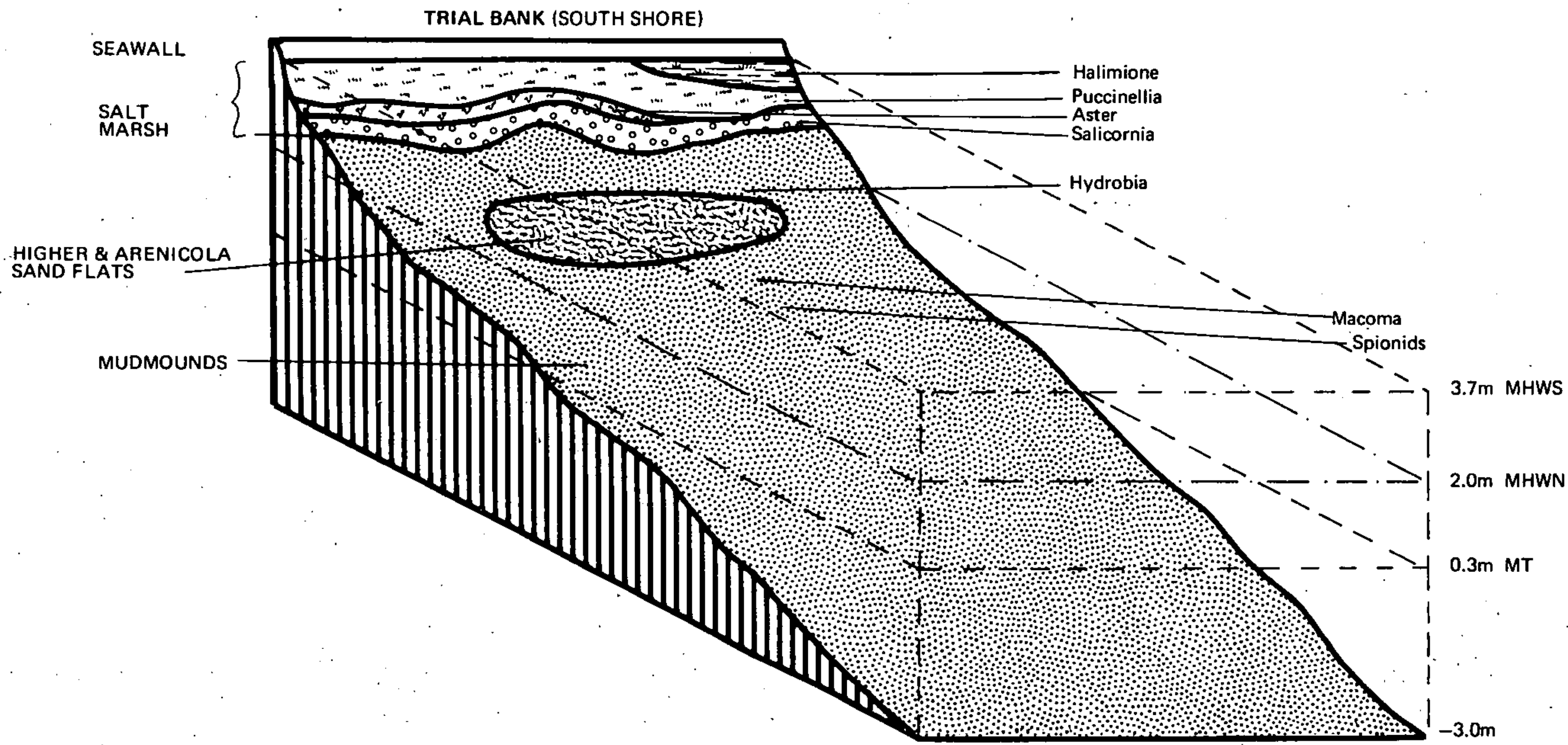
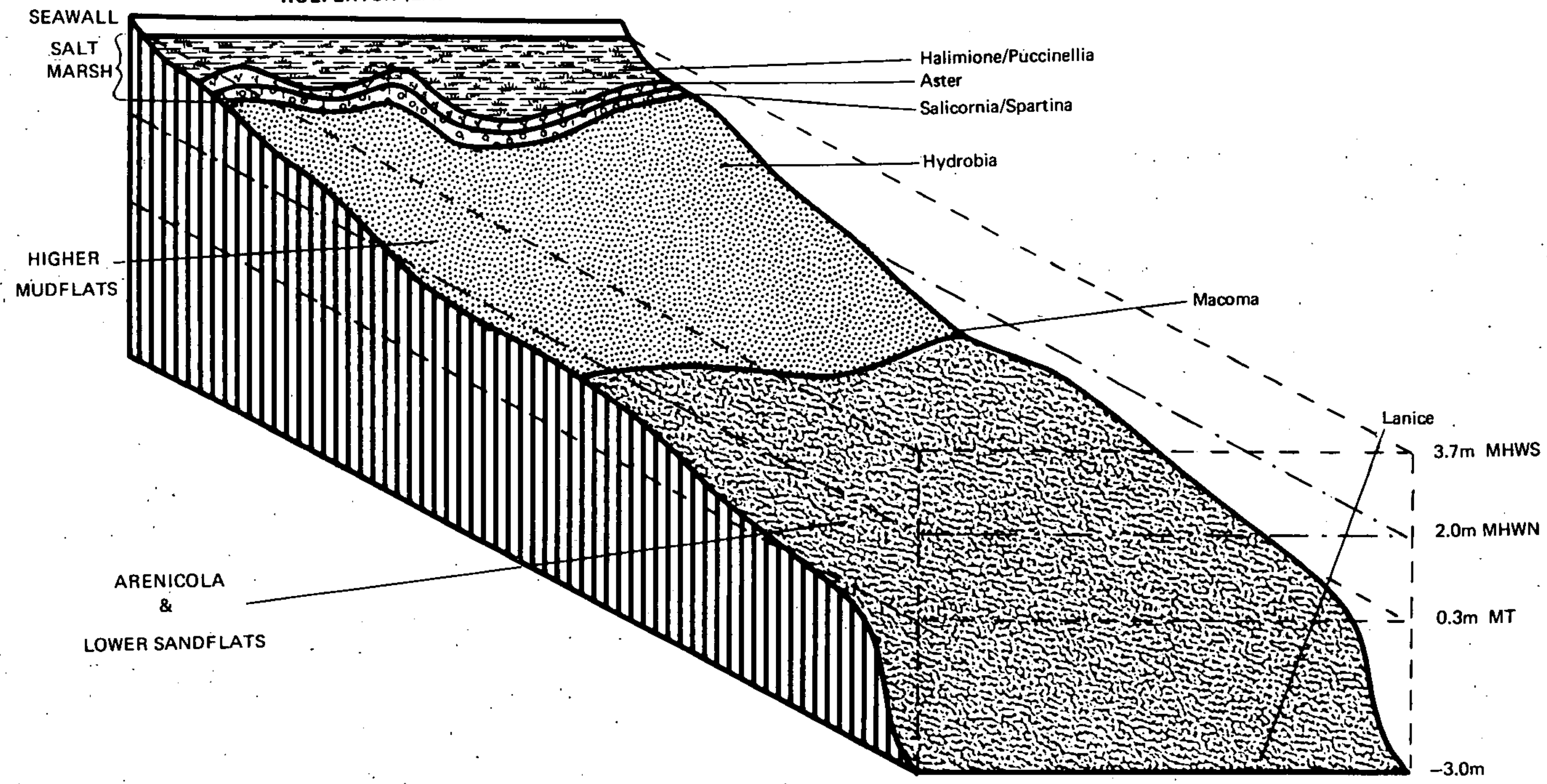


Fig 3 : DIAGRAMMATIC REPRESENTATION OF 3 SECTIONS OF SHORELINE AROUND THE WASH.

Major zones are given on the left and some common species listed on the right.


TRIAL BANK (SOUTH SHORE)
SEAWALL
SALT MARSH
HIGHER & ARENICOLA SAND FLATS
MUDMOUNDS
Halimione
Puccinellia
Aster
Salicornia
Hydrobia
Macoma
Spionids
3.7m MHWS
2.0m MHWN
0.3m MT
–3.0m

WOLFERTON (EAST SHORE)



ALGAE AND FLOWERING PLANTS

Surveys of algal and flowering plant distribution

19. Micro-algae: Permanent 2m x 2m quadrats were established around the Wash close to and extending beyond the transect lines set up for the salt marsh vegetation studies (Study C). Changes in topography and in macro- and micro-algal distribution and abundance were mapped monthly for a period of one year.

20. Data from the permanent quadrats indicate that benthic micro-algae (principally diatoms, blue-green algae and species of *Euglena*) are a highly significant component of the algal flora of the Wash.

21. The most numerous and widespread benthic algae are the epipelic diatoms, which are free living on the mud surface. Episammic diatoms, which live attached to sand grains, and non-motile colonial diatoms, are less abundant. The epipelic diatoms occur mainly in the top 2mm of fine sediment and are motile, migrating down into the mud to avoid adverse conditions and returning to the surface in response to favourable conditions for photosynthesis. They occur in extremely large numbers, densities ranging from $5 \times 10^4/cm^2$ to $1 \times 10^6/cm^2$, within the permanent quadrats and reaching more than $5.5 \times 10^6/cm^2$ on sheltered creek banks within the salt marshes (values which are comparable to those found by other workers elsewhere although densities over 3 times as high have been recorded). Distinctive seasonal trends in diatom numbers in both mudflats and salt marshes are difficult to detect. The larger diatoms, such as species of *Pleurosigma* are most frequent in the wetter microhabitats, particularly during times of large sediment influxes, whilst the dry habitats are characterised by very small diatoms.

22. Most of the blue-green algae recorded were filamentous forms belonging to the Oscillatoriaceae which, because of their mobility, seem well adapted to withstand the accretion of fine sediment.* Coccoid and heterocystous forms were largely restricted to the salt marshes and it is significant that sedentary forms like *Calothrix aeruginea* were found only in mature salt marsh at Gibraltar Point. The four main species recorded from the permanent quadrats were *Microcoleus lyngbyaceus*, *Spirulina subsala*, *Schizothrix arenaria* and *S.calcicola*.** Although present throughout the year the largest numbers occurred in late summer and early autumn, numbers decreasing appreciably at most sites in the winter. Blue-green algae are apparently able to tolerate a wide range of adverse conditions such as hypersalinity and drought although optimum development may be in the wetter microhabitats. There is evidence to suggest that their distribution may be limited by the grazing of mudflat invertebrate species.

23. Species of the mobile *Euglena* are widely distributed but are most abundant in the permanently wet, soft habitats such as the sides of creeks where blooms often give a distinctive colour to the mud. Numbers up to $2 \times 10^5/cm^2$ were recorded, *E.limosa* being the most abundant species.

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* The word 'accretion' is used by different authors to refer to (i) the actual short-term process of settling out from the water column of formerly suspended sediments, or (ii) the increase in mudflat or marsh height over a longer period of time due to both sediment settlement and stabilisation. It is used in this report in the second, broader, sense.

** Many algal species have no common English name, and to avoid confusion the few unequivocal ones which do exist have not been used.

24. Macro-algae: The macroalgal populations were surveyed by regular observations of the permanent quadrats and general exploration of other areas.

25. On the mudflats beyond the salt marshes macro-algal species are relatively scarce and their populations fluctuated rapidly and widely in abundance, a feature thought to be related to the lack of firm substrata and the generally high rates of sediment accretion. Enteromorpha prolifera and Vaucheria subsimplex are the two commonest species on the higher mudflats, Enteromorpha growing on firm mud mounds largely to the west of the Nene, and Vaucheria, apparently tolerant of fairly soft mounds, occurring along most of the south shore. Extensive beds of Enteromorpha also occur on the creek border areas of the outer sand flats of the west shore (a total of about 300 ha), at the southern end of the west shore (about 150 ha) and along the south shore (about 60 ha). On the mudflats populations of both common species vary seasonally, Vaucheria showing growth peaks in early spring and autumn and Enteromorpha in late summer. They are susceptible both to summer drought and to storms especially in the autumn. Enteromorpha populations on the outer sand flats of the west shore are particularly transient, often developing rapidly and being easily removed by storms even during summer.

26. Although the populations of macroalgae in the salt marshes are also transient, there are more species and, notably in the pioneer marsh zones, these are much more widespread. The main marsh areas where the vegetation is dense are poor in species but varied and extensive populations may occur in grazed areas. The majority of common British salt marsh species can be found on the Wash but distinct communities are difficult to delimit. Some species are associated with distinct zones or topographical features such as pioneer marsh, mature marsh, pools and grazed areas. Within these sub-habitats patterns of seasonal growth are observable; for example the rapid annual spring growth and decline of Ulothrix flacca on the pioneer marshes and of Petalonia fascia in pools at the edge of east shore marshes.

27. Although comprising almost 60 species the macro-algal communities of the Wash are less diverse than those on the nearby north Norfolk coast. (Study C, Appendix I gives a full list of species identified in the Wash).

28. Salt marsh plant communities: Apart from interruptions by the major river outfalls, the salt marshes of the Wash form a continuous fringe seaward of the sea banks from Snettisham on the east shore to Gibraltar Point on the west shore. Varying in width from 300 metres to over 1.6 km, they occupy a total area of approximately 4457 ha (11,013 acres). This area is at least three times greater than that in Morecambe Bay (Gray 1972) and represents c.10% of the total salt marsh area in Britain (estimated in an unpublished ITE report at about 44,800 ha or 110,900 acres).

29. The salt marshes north of Hunstanton and those of the dune ridge complex at Gibraltar Point are considered to be physiographically and floristically distinct from those fronting the artificial sea walls of most of the Wash and have not been described here. The main Wash salt marshes contrast with those at its edges, including the north Norfolk coast, in terms of their lower floristic diversity, very large areas being covered by very few species. From aerial photographs, with ground verification, it was estimated that more than half of the total salt marsh area is dominated by only two species, Sea purslane Halimione portulacoides and the salt marsh grass Puccinellia maritima, either singly (Halimione predominating in 30% of the total area, Puccinellia in 11%), or in combination (co-dominating a further 12%). These species also occur in other communities, particularly those of the mid-level salt marsh where Sea blight, Suaeda maritima, and Sea aster, Aster tripolium, are abundant.

30. Similar communities were found in all areas in zones generally parallel to the shoreline. These were

(i) a pioneer community which on the east and south shores is commonly dominated by Cord grass, Spartina anglica, whereas on the sandier west shore it contains predominately glasswort, Salicornia species, with Aster, Puccinellia and Spartina locally abundant;

(ii) A zone immediately landward of the pioneer zone, characterised by a continuous stand of Aster together with varying proportions of Salicornia fragilis, Suaeda and Puccinellia, and varying in width, height and density of Aster around the Wash. On the sandier marshes at the northern end of the west shore Puccinellia becomes more frequent at this level than Aster;

(iii) A community consisting of varying proportions of Puccinellia, Halimione, Suaeda and Aster;

(iv) A mosaic alternation of Puccinellia sward and Halimione bushes predominating over very large areas, and

(v) A Sea couch Agropyron pungens zone, mainly on the well-drained creek edges at higher levels and often forming dense stands to the exclusion of other mature marsh species.

31. Plant species characteristic of the higher-level, mature stages of salt marsh in Britain are restricted in distribution in the Wash. They are more or less confined to areas where no recent reclamation has taken place and include Sea fescue, Festuca rubra, Sea lavender, Limonium vulgare, Sea plantain, Plantago maritima and Sea arrow-grass, Triglochin maritima.

32. The salt marsh plant communities are described in Study D. They are particularly affected by grazing and reclamation. Grazing, by favouring the survival of Puccinellia and a number of prostrate herb species such as Scurvy grass, Cochlearia officinalis, and Sea spurry, Spergularia media, at the expense of Halimione, Aster and Spartina, increases the structural diversity of the Wash vegetation as a whole. Reclamation, in addition to reducing the area of mature salt marsh, plays an important part in the process of continual salt marsh development (below and Study D).

33. Reclaimed land: The continual process of salt marsh reclamation in the Wash has produced some 32,000 ha of agricultural land since the 16th century. Although the land is intensively farmed, small uncultivated areas remain, which, despite their artificial origins, support a characteristic assemblage of flowering plant species repeatedly found in paramaritime reclaimed land habitats in other parts of S.E. England (Gray, in press a).

34. 136 sites, selected in advance from maps and aerial photographs, were visited during 1974 and the flowering plant species recorded. The sites were grouped into

(i) the seaward faces of seawalls,

(ii) the landward faces of seawalls,

(iii) aquatic and wetland habitats (e.g. counter dykes, old creeks, fleets, decoy ponds, marshland), and

(iv) old sea banks and grassland.

(See Study R).

35. The 190 species recorded include typically paramaritime species, salt marsh species, common agricultural weeds and common marshland and aquatic species (a full species list is given in Study R, Table 1). In addition a number of local or rare species occurred including Spiral tassel pondweed *Ruppia spiralis*, Seaside crowfoot *Ranunculus baudotii* and Stiff salt-marsh grass *Puccinellia rupestris*. Among a number of new county records were the Marsh and Twayblade orchids, *Dactylorchis praetermissa* and *Listera ovata*. The absence of a number of common species may be related to the isolating effect of large areas of intensive arable farmland.

36. The vegetation of the reclaimed land habitats in five sections of the Wash are compared in Study R. Habitats such as old creeks, old sea walls and pasture, which support a wide range of animals, are disappearing as land and food values rise and arable farming is intensified - this is particularly so in the Nene-Ouse section. Despite this a number of floristically diverse areas remain as do several uncommon species.

The dynamics of marsh development

37. The algal rich zone: The most distinctive feature of the distribution of benthic micro-algae is the contrast between the persistently high but variable numbers on the higher mudflats and in the pioneer saltmarshes and the generally low numbers on the sand flats beyond them.

38. This algal rich zone extends beyond the marsh for 200 to 300 metres in many places, and is absent only in one or two very localised areas of the west and south shores. The lower limit of the zone corresponds approximately to the boundary between the higher mudflats and the inner sand flats except in areas with pronounced mud mounds where the zone extends on the tops of the ridges for almost as far as the ridges persist.

39. An extensive feature of the Wash, the algal rich zone covers almost 8% of the intertidal area beyond the salt marshes and is equivalent to about 45% of the area covered by salt marsh. The area tends to dry out at times in the summer and in places the surface layers may crack and flake. Blue-green algae persist throughout the summer and the numbers of diatoms remain relatively high except in very dry areas. Macro-invertebrates occur only in the wetter microhabitats and, with the exception of Brent geese (*Branta bernicla*) and shelduck (*Tadorna tadorna*) which use a part of it, the zone is relatively unimportant as a bird feeding area. The Grey mullet (*Mugil* sp.) utilises the micro-algae directly, scraping off the surface layers, but gut analyses have shown that it is not wholly dependent on the algal rich zone.

40. There is little information about algal rich zones in other areas of Britain but it is likely that that in the Wash is the largest and most significant. Its presence may be related to the very wide gently sloping intertidal flats, the continuous ample supply of sediment and the continual land reclamations. It appears to be an essential precursor to the forward extension of salt marsh, and it is notable that there is no continuous micro-algal rich zone in areas such as Holbeach range where there has been no recent reclamation and where marsh growth has slowed or erosion of the front edge has begun.

41. The role of algae in accretion and stabilisation: The amount and type of sediment supplied to the salt marshes and upper mudflats is primarily controlled by physical factors and the hydraulic aspects of this process have been relatively well studied in the Wash (e.g. Inglis & Kestner 1958, Kestner 1962, and in press). Until the present study the role of micro-biological factors in sediment accretion and stabilisation had not been investigated, either in the Wash nor it seems in detail elsewhere.

42. Sediment accretion was measured in association with the permanent quadrat studies of algae, using a coloured marker technique (See Study C). This work indicated that, although the rates of accretion vary greatly from month to month, there is a sharply contrasting pattern of accretion between sites on the outer flats and those on the algal rich zone and salt marsh. On the outer flats accretion occurs mainly in the summer months and erosion in the winter months whereas on the flats adjacent to the salt marshes and in the pioneer marshes accretion is a more or less continual process. In these latter areas local erosion may occur during excessively rough weather and a limited area just beyond the marsh edge is affected by the flaking off of the surface sediments during the summer. Seasonal variation in accretion rate occurs within the continually accreting zone, with peaks in spring and autumn which correspond with the probably greater sediment loads of the Equinoctial spring tides. Interestingly accretion rates were generally higher in the mudflat zone adjacent to the salt marshes than in the marshes themselves.

43. The coincidence of a major zone of more or less continual fine sediment accretion with the area of most dense micro-algae populations suggested a possible causal relationship. The importance of mucus secreted by benthic diatoms in trapping and stabilising fine sediments on mudflats has been noted by several authors (Brockman 1935, Linke 1939, Reinhold 1949, Straaten 1951, Straaten & Kuennen 1957, Kamps 1962) but no published experimental work to substantiate these observations is known. Experiments by Scoffin (1970) and Neumann et al (1970) using an underwater flume have demonstrated that sediments containing mats of blue-green algae, which produce a mucilagenous sheath, could withstand current velocities of at least twice that which produced surface erosion in unbound sediments. Euglena limosa also produces copious mucilage (Leedale 1967).

44. In the present study experimental evidence from three sources indicate that micro-algae have an essential function in mudflat accretion. In one series of experiments micro-algae were destroyed in the field by a range of suitable reagents, with a dramatic effect - there was no accretion and even erosion in the treated areas compared with a continuous layer of freshly accreted material in the control (seawater treated) sites. This effect could be demonstrated after only two tides. In a second series of experiments the addition of increasing amounts of live diatoms to sediment shaken in cylinders of water significantly increased the settling rate of particles from suspension, cultures of dead (boiled) diatoms being used as a control. Examination of the living diatoms after such tests showed that each diatom could trap several sediment particles and, on a solid surface, could move away from the resulting aggregate. Finally the preliminary results of laboratory tests recently begun indicate that surfaces with living micro-algae can withstand currents, generated by a submerged rotating paddle, of at least twice the force of those which break up an equivalent unbound sediment.

45. Although beds of Enteromorpha may both reduce the scouring effects on mudflats and increase accretion rates, the macro-algae of the Wash in general are thought to be of relatively little importance for sediment accretion. Their effects are generally local and may be short-lived.

46. In summary, therefore, it appears that, whilst the rate of supply of fine sediment to the salt marshes and upper flats is controlled largely by physical factors, the stabilisation or 'locking into position' of such sediments may depend on a biological component of those areas, the dense populations of mucus secreting micro-algae. By altering the properties of the particles involved the micro-algae enable fine sediments to be accumulated in what may be hydraulically marginally unsuitable areas.

47. Salt marsh development: The process by which salt marsh develops on the higher mudflats can be measured by changes in a number of factors such as surface height, the rate of accretion, the number of tidal submergences, the physical composition of the soil, the abundance of different plant species, and so on. All of these changes are closely interrelated. For example, in general terms, the rise in the height of the marsh brought about by accretion leads to a reduction in tidal submergence, changes in the physical and drainage characteristics of the soil, and an alteration in the species composition of the vegetation; factors which in turn affect the rate of accretion.

48. The way in which these factors are linked implies cause/effect relationships and invites a 'whole system' approach in which salt marsh development is conceived as a process made up of a whole series of interacting and interdependent events. The relationships between such events have been expressed in this study as a mathematical model, the structure of which is based on hypotheses derived from previous salt marsh work and an understanding of salt marsh systems in general. The model is made 'mathematical', rather than purely conceptual, by quantifying the relationships between its parts with numerical parameters derived from actual field data.

49. These data were collected in the Wash from 51 permanent quadrats (10m x 10m) each of which was adjacent to one of 12 transect lines distributed around the Wash more or less at right angles to the seawalls (See Study D). A number of measurements of floristic and environmental variation were taken from within each permanent quadrat. These included the actual level with respect to Ordnance Datum (Newlyn), the number and hours of tidal submergence at each site, the accretion rate (using mainly a silica flour core technique based on that of Kestner (1959)), physical and chemical soil properties (methods as described by Gray and Bunce 1972), and estimates of floristic abundance and biomass (See Study D).

50. The levelling survey indicated that the Wash salt marshes occur between approximately +2.3m O.D.N. and +3.7m O.D.N., at or before which level they are often reclaimed for agriculture (usually when the surface has risen to about +3.35m O.D.N.). Pioneer species such as Spartina anglica and Salicornia appear at about +2.3m O.D.N. in the muddier marshes of the southeast where they are covered by more than 500 tides per year, whereas, on the sandier marshes of the northwest they appear at about +3.0m O.D.N. (c.330 tidal inundations/year). It is estimated that even the highest study site (Frampton, Quadrat B) is inundated more than 90 times a year, indicating the immaturity of the Wash salt marshes under the system of continual reclamation. (Compare this for example with the highest marshes in Morecambe Bay with an average of about 6 tidal inundations per year - Gray & Bunce 1972).

51. Accretion decreases rapidly towards the landward end of each transect where mean annual accretion rates of less than 2mm were commonly recorded. Rates as high as 31mm/year were recorded from the lower salt marsh zones and rates of about 20mm/year were average for the less well vegetated pioneer marsh zone. High accretion rates in the pioneer zones of the northwest Wash were due to wind-blown sand accretion.

52. The salt marsh soils show the expected trends from the immature, relatively organic and nutrient poor soils of the pioneer zones to the more developed, relatively organic and nutrient rich upper marsh soils. The proportions of fine sand increase significantly towards the lower levels of the transects. The northwest shore sites are sandier than those of the south and east, which contain the highest proportion of clay.

53. The results of the floristic survey have been referred to already in the section on plant communities. Although floristic composition is closely related to site level grazing has a marked effect on both species composition and biomass (as illustrated in Study D). Biomass is reduced under grazing notably by the disappearance of Halimione in favour of Puccinellia. The sandiness of the soil too is correlated with reduced biomass.

54. The interrelationships between the various floristic and environmental factors have been examined using a number of statistical techniques, mainly regression analysis and Principal Component analysis, and from these are derived the values of the model relationships. These are described in Study D. The simulation model is referred to briefly below and the predicted effects of reservoir construction on salt marsh development are discussed later.

55. The general picture of the Wash salt marshes which emerges is of an extensive, fast-accreting, highly dynamic, floristically uniform but highly productive system maintained locally in an immature state by the frequent hydraulic changes which follow reclamation of the upper marshes. Only in areas where there has been no recent reclamation is there evidence of a balance between erosive and accreting forces. Elsewhere the changes in ebb velocity and in the relative duration of flood and ebb tides which result from reclamation continually recreate conditions for the accelerated upward and seaward extension of the pioneer marsh zone. Other important influences on the vegetation are the effects of grazing and the sandier nature of the soils of the northwest marshes. On this northwest shore, where the reclamation enclosures are generally longer, narrower, and less frequent in construction, the pioneer zone is also subject to wind-blown sand accretion.

56. Simulation modelling: After defining from field data the parameters which are believed to determine the rates and magnitudes of the processes involved, the mathematical model is translated into a suitable computer language, and may then be 'run' on the computer and used to simulate the salt marsh development. A flow chart of the model is given in Fig. 4.

57. The computer runs of the model, in which the variables are successively updated through a series of 'time steps' representing the passage of real time, gave encouraging results which clearly resembled the successional changes occurring in both the environmental factors and the plant species. A comparison with data from the Wash suggested, however, that the model was inaccurate in its simulation of the duration of each stage, the rate of seral development being too low. A small adjustment to the threshold level between upper and lower marshes (assumed to have different accretion rates) produced a more realistic time course. It is in the need to make adjustments of this type that the value of simulation modelling lies. The validity of basic assumptions about the system is constantly being questioned and insights into the process are gained by the continual review and refinement of the hypotheses on which the model is based.

58. Modifications of the model to simulate grazing produced floristic changes similar to those observed in the field, and modifications to simulate the situation in the northwest Wash by the inclusion of wind-blown accretion produced a pioneer zone at a higher level and floristic differences similar to those in the field. These results suggest that, although their testing requires a long programme of observation and experiment, the hypotheses underlying the model structure are based on a reasonable understanding of the process of salt marsh development in the Wash.

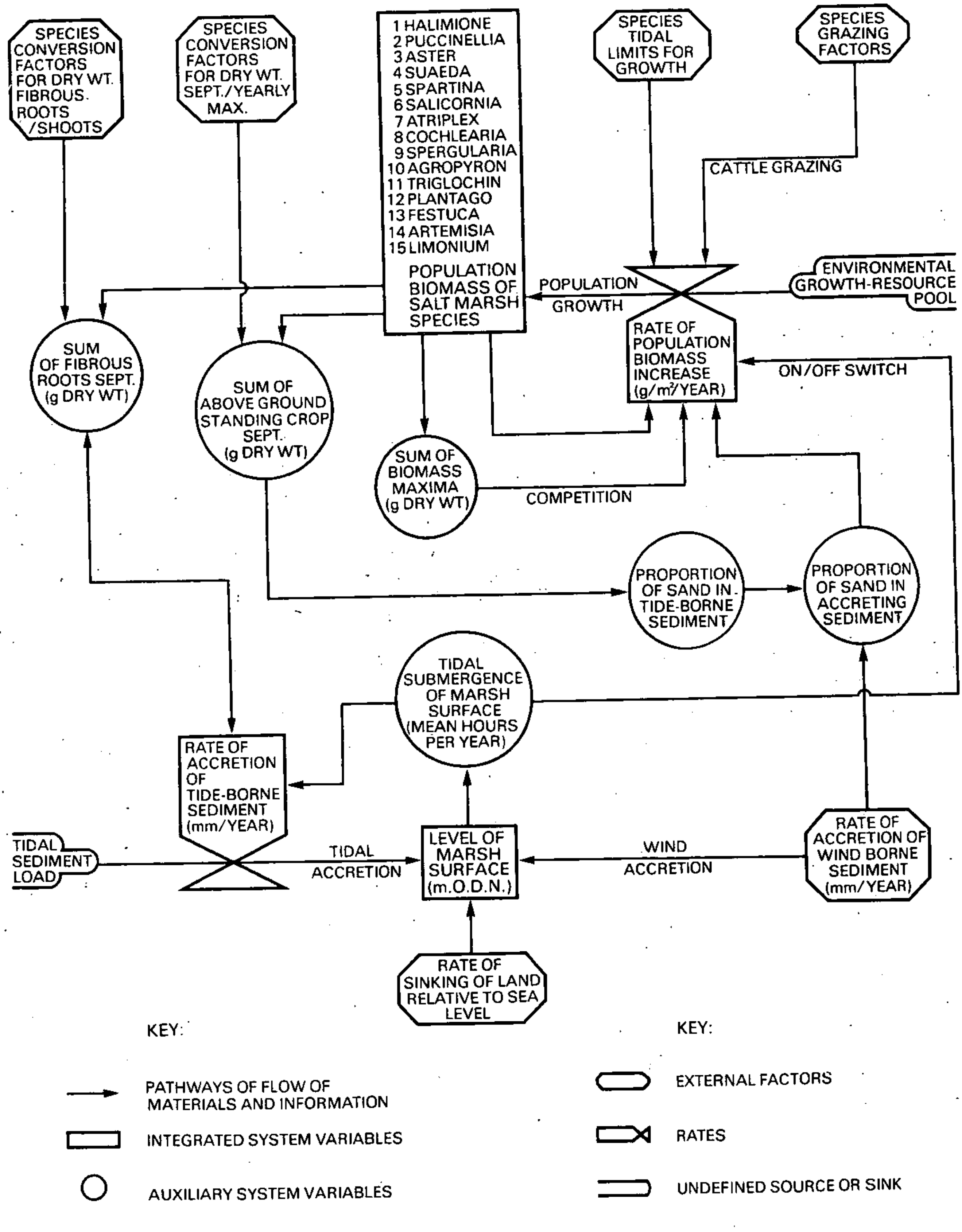

Fig. 4 FLOW CHART OF WASH SALT MARSH MODEL

INTERTIDAL INVERTEBRATES

59. The results of the surveys of intertidal invertebrates are set out in Study A. Study B is a report on part of a continuing intensive study of a small area off Wolferton.

60. The emphasis of the surveys was on the quantitative aspects of the distribution of the main species rather than the production of a complete fauna list: the "main" species are those which are most numerous including all those which are important as food for waders. Two full quantitative surveys were to be made each year, in early autumn when the invertebrate numbers should be at a maximum and before the birds arrive in large numbers, and in spring when the invertebrates might be expected to be near a minimum after predation and before the new season's broods were present. The most comprehensive survey was carried out in the autumn of 1973 when samples were taken at 335 stations round the shore and on the inner sand banks. Over 300 stations were sampled in spring 1974 and nearly 200 in spring 1973. At each station two samples were taken with a stainless steel corer of area $0.01m^2$ to a depth of 0.15m, and the cores were washed separately through a sieve with mesh 0.5mm. During the survey in autumn 1973 soil samples were also taken for sediment analysis.

61. The first obvious feature of the results is that a small number of species makes up the bulk of the biomass. These species are from three main groups, molluscs, crustacea and worms. Three species of bivalve mollusc, Cardium edule (cockle), Macoma balthica and Mytilus edulis (mussel), form the largest volume of animals, while the tiny snail Hydrobia ulvae sometimes occurs in very large numbers. The dominant crustacean is the small tube-building amphipod Corophium. The commonest of the widely distributed large worms are the lugworm Arenicola marina and the catworm Nephthys hombergi with Lanice conchilega forming dense colonies in some areas. The small tube-building spionid worms and the free-living nematodes are locally abundant.

62. The distribution of each species is related to tidal height and type of sediment. Over most of the Wash the intertidal sediments are mainly fine sand and so tidal height becomes the dominant influence on zonation. Hydrobia and Corophium live at the top of the shore about the level of high water neap tides. Of the two, Hydrobia prefers more muddy situations including the outer part of the salt marsh: it is abundant all the way round the south and south-east shores from the River Welland to Snettisham and maximum densities of over 10,000 per square metre occurred in areas of fine silty sand off Holbeach, west of the Nene mouth and off North Wootton and Wolferton. Corophium is abundant in areas of fine sand in the west and south east, and very few were found in the muddier areas of Breast Sand and the south west corner. (Fig. 5).

63. Macoma, which is an important food item for many waders is found between high water neaps and half tide and is uncommon on the lower shore (Fig. 6). The highest densities were in areas of fine sand with some mud in the south east area between the Nene and the Ouse and on Bulldog Sand east of the Ouse. It is less common on the sandy western shore, where there is a band of moderate density near the top of the shore. Further down on the western shore is a band of Cardium whose centre of distribution is about half tide (Fig. 7). This area has been fished commercially in the last few years, as has the prolific cockle bed on Daseleys Sand. There was also some fishing during 1973-74 near the Old Barrier Wall to the west of the Ouse channel. Other small dense patches of cockles were found off Gedney and off Snettisham but neither was in a suitable position for commercial exploitation. During the summer of 1973 there was a heavy spatfall of young cockles which were abundant in autumn all round the Wash. But during the winter, before the spring survey, they disappeared, except for a few small patches. For the other species

examined the patterns of distribution were very similar in the three main surveys, with some decrease in numbers in most species between autumn 1973 and spring 1974. The amount of the decrease varied from species to species and from place to place but was generally between 20% and 40% of the autumn numbers.

64. The larger worms Arenicola and Nephthys are widely distributed between high water neaps and low water neaps; at this level Arenicola was present everywhere except the muddiest areas of the south east and south west and in the coarsest sand of the more exposed beaches and sand banks (Fig. 8). Lanice, however, has a distribution restricted to the area below low water neaps and its tubes sometimes form dense carpets, particularly on the Ferrier and Outer Ferrier sands. The spionid worms live in muddy sand as well as cleaner sand and are widely distributed, while the nematodes are found mainly in mud.

65. Between September 1973 and July 1974 seven surveys were carried out in an area off Benington which was an important wader feeding ground in autumn 1973. From the changes in density and size distribution of the animals the availability of food for the birds could be assessed. The greatest change was the rapid decline in numbers of cockle spat which were apparently the main reason for the birds' presence in autumn and their subsequent movements away from the area. From measurements of Macoma and Cardium on all the surveys, their availability to birds, different species of which take different size groups, could be assessed for various parts of the shore.

66. The intertidal invertebrate distribution in the Wash has been compared with published information for other estuaries, and particularly Morecambe Bay, the Dee Estuary and the Solway Firth, which have all been considered recently for water storage schemes. All these areas have similar fauna in which the same few species make up the bulk of the biomass with the same pattern of zonation on the shore. The Wash fits into this pattern and is unique only in its particular distribution of banks and shores and the relative proportions of sandy and muddy areas, and perhaps also in the fact that cockle and mussel fisheries still flourish. Cockle fishing was once important in the Dee, and particularly in Morecambe Bay where the fishery collapsed after the cold winter of 1962-63 when stocks were severely reduced.

67. As a whole the Wash presents a picture of stability of its intertidal fauna. Cockles and mussels have been fished for centuries and there is not much change in the position of the main fishing areas from decade to decade. That the same species have been dominant for decades and centuries can be seen from excavations in the salt marsh and in the reclaimed land where assemblages of shells of cockles and mussels, Macoma and other less abundant species can be found in the old sand and mud, buried by later silt. This process is continuing with accretion and seaward advance of the salt marsh, rejuvenated from time to time by reclamation for agriculture (as described in the previous section). This long term process gradually reduces the area of intertidal flats available for those species such as Macoma, Cardium and Arenicola which live between high water neaps and low water neaps, because the seaward movement of the salt marsh is not matched by as great a seaward movement of the low water mark. In the long term the shore will get narrower and steeper. This is an aspect of change which could be predictable with a knowledge of the present rate of accretion and of the processes involved.

68. Other changes in the patterns of distribution have a shorter time scale and at present are largely unpredictable because they depend so much on the weather both as temperature effects and the effects of wind in current patterns and storm waves. Some indication of these changes is given in the two year survey at Wolferton with monthly observations (See Study B) and the observations over one year at Benington (See Study A). On a scale of months the most obvious changes are those caused by the seasonal pattern of recruitment of juveniles to the

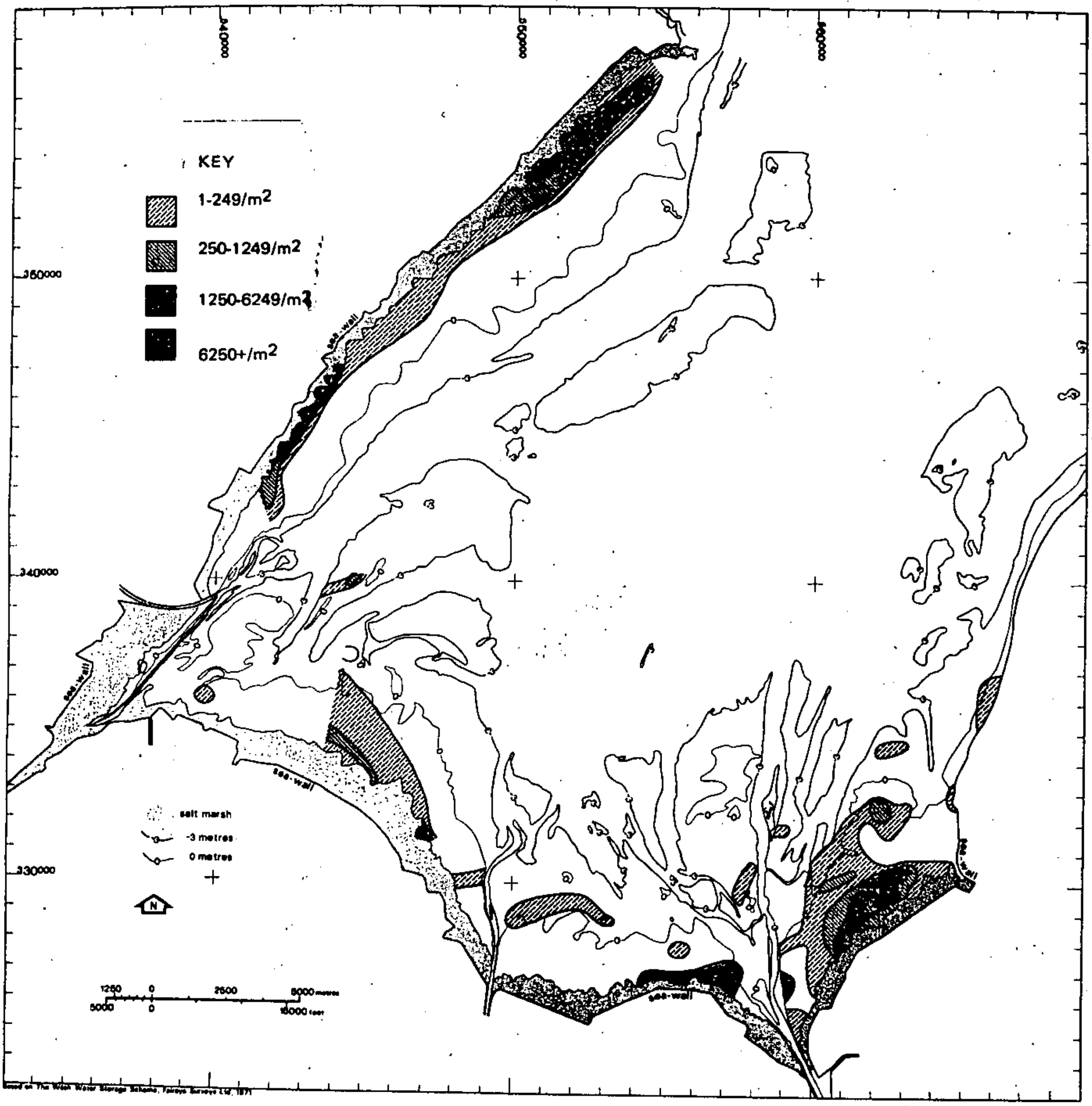

FIG 5. DISTRIBUTION OF **COROPHIUM**, AUTUMN 1973

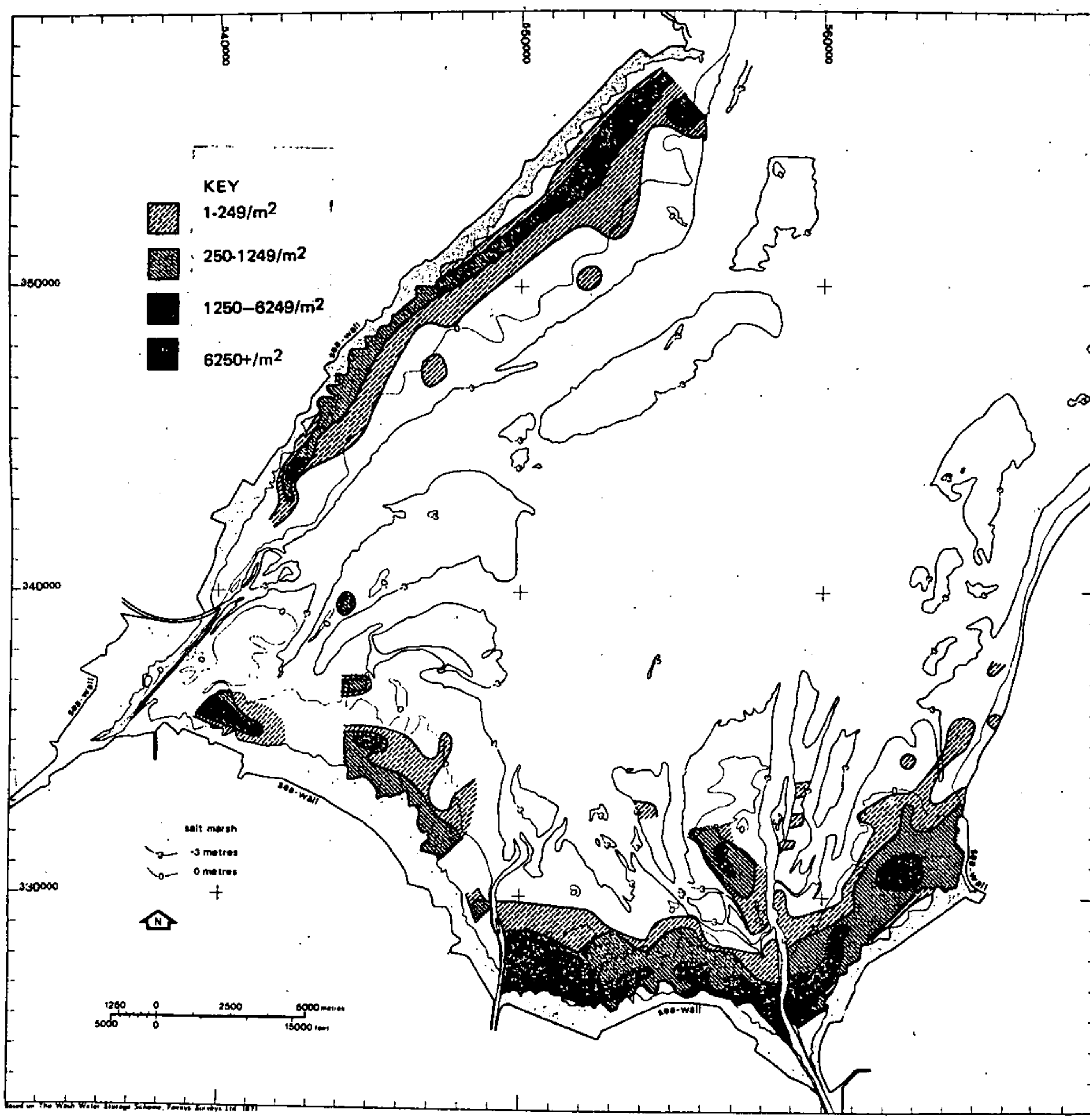

FIG 6. DISTRIBUTION OF __MACOMA__, AUTUMN 1973

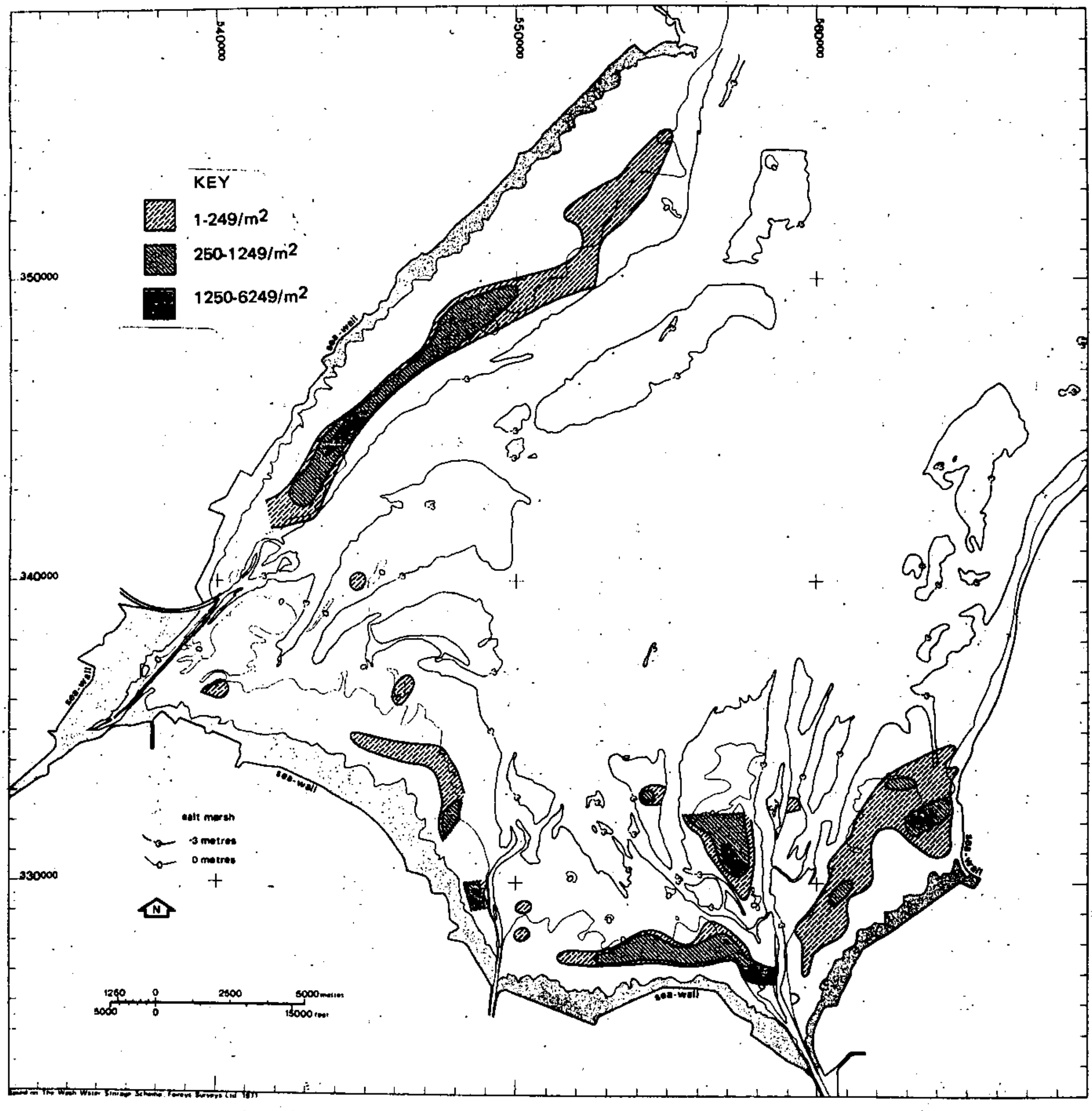

FIG 7. DISTRIBUTION OF ADULT **CARDIUM**, AUTUMN 1973

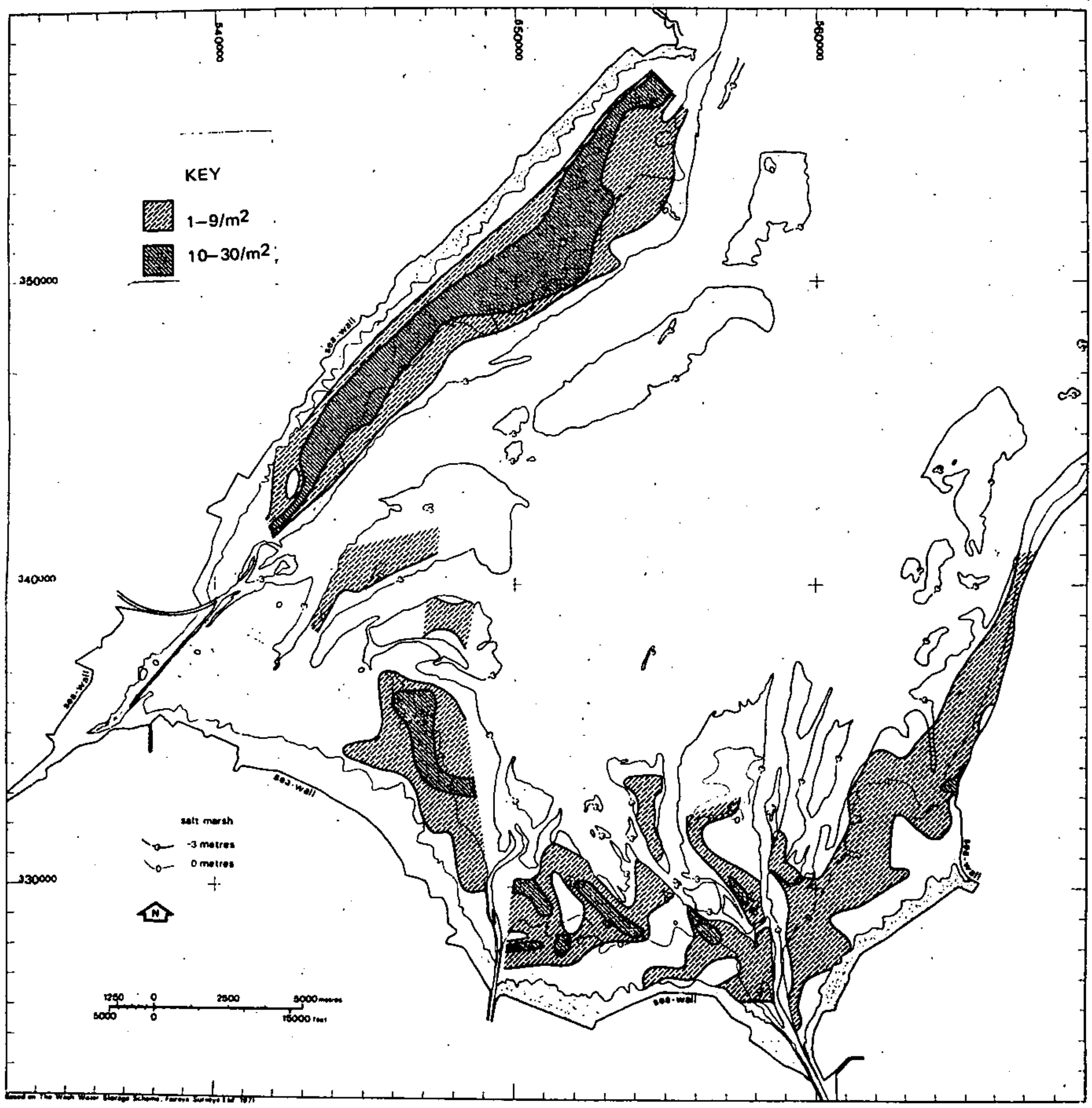

FIG 8. DISTRIBUTION OF ARENICOLA, 1973–1974

population in the summer and their decline in numbers during the winter whether from natural mortality or predation. Examples are given of the rapid decline of the number of juvenile cockles all round the Wash in the winter of 1973-74. The study at Wolferton shows, however, that the 1972 brood did not suffer such a severe mortality during its first winter (1972-73).

69. This leads to the second major change, with a time scale of a few years, since within each species the brood of one year may eventually produce a larger number of adults than that of another year. Two main factors are involved, the numbers of a brood which settle on the shore and the numbers which survive to maturity; and the two may not be related. At Wolferton Hydrobia was three times more abundant in 1974 than in 1972, largely because the 1973 brood was more abundant than the broods of 1971 and 1972 when it settled and also suffered less mortality during its first winter. There was a slow decline in numbers of Macoma in the study area during the two years, related to the 1972 brood being more successful than those of 1973 and 1974. These sorts of differences will change the balance of species in an area slightly from year to year. The present surveys have taken place during a series of mild winters. A severe cold spell might cause a much greater mortality for some species, and change the balance of species for some years ahead.

BIRDS

Surveys of bird numbers and distribution

70. Although the research has focussed mainly on wading birds, other aspects of the ornithology of the Wash have been covered (See Studies F-O), particularly concentrating on those species which are most likely to be affected by the reservoir proposals. The birds using the Wash may be conveniently divided into those which breed there and those which occur mainly outside the breeding season.

71. Breeding birds: The numbers of birds nesting on the salt marshes were estimated in 1972 and 1973, using a standard method, in five sample plots around the Wash (See Study L). Although few species were recorded from each plot (from 5 to 11) the densities of redshank Tringa totanus (46-53 pairs/km^2), skylark Alauda arvensis (79-105 pairs/km^2), Meadow pipit Anthus pratensis (26-76 pairs/km^2), and Reed bunting Emberiza schoeniclus (51-80 pairs/km^2) were high by comparison with those recorded from coastal and other habitats elsewhere in Britain. Total densities (of all species) were higher in plots on the upper marshes (200-306 pairs/km^2) than in those on lower marsh areas (100-137 pairs/km^2) and breeding success is affected by the liability of nest sites to tidal flooding.

72. A total estimated breeding population of about 1,400 pairs of redshank occurs in the Wash which is thought to be of National importance as a breeding area for this species. The numbers of shelduck Tadorna tadorna breeding in the Wash and its hinterland, particularly the east side where about 200 pairs bred in 1974, are also estimated to be a high proportion of the British breeding population.

73. Black-headed gulls Larus ridibundus largely breed in one very large colony, provisionally estimated at 22,000 pairs in 1974, on Frampton and Kirton marshes. This colony has increased in numbers in recent years, possibly partly with birds displaced by reclamation of high level salt marsh elsewhere in the Wash, and has associated with it smaller numbers of nesting Common terns Sterna hirundo (the total Wash population of which has reached 126 pairs in recent years). The gulls' eggs are harvested by local people at Frampton.

74. Other nesting habitats in the Wash include sea walls, the Hunstanton cliffs, reclaimed farmland and sandy beaches. The last two habitats are used particularly by oystercatchers Haematopus ostralegus (a total Wash population of over 100 pairs) and ringed plovers Charadrius hiaticula (116 pairs), whilst nesting short-eared owls Asio flammeus were recorded from the sea walls. Fulmar Fulmarus glacialis nest on the cliffs at Hunstanton (40 pairs in 1974) and other seabird species, notably terns, occur in large breeding colonies on the nearby north Norfolk coast.

75. The reclamation of salt marsh for agriculture is thought to be the largest single factor affecting the salt marsh breeding bird populations of the Wash (See Study L).

76. Waders: The British Trust for Ornithology/Royal Society for the Protection of Birds/Wildfowl Trust 'Birds of Estuaries Enquiry' counts have confirmed that the Wash is one of the two most important areas in Britain in terms of the total numbers of waders which feed there for all or part of the winter. Although smaller numbers of some species are present throughout the year (some of them, such as redshank and oystercatcher, breeding locally) from late July onwards large flocks begin to arrive from their breeding grounds in the far north. They come mostly from the arctic and sub-arctic, ranging from northeast Canada to central Russia, and can be divided into two groups, a western group breeding in Canada, Greenland and Iceland and an eastern group breeding in Scandanavia and the USSR. Some species have populations breeding in both regions, whilst others come to the Wash only from the eastern region.

77. The length of stay of individual birds in the Wash varies between species and even between groups within species. Some pause briefly on their way to wintering grounds, generally further south, others remain to undergo their annual moult and then move on, some remain throughout the winter, and yet others occur on their spring passage northwards. There are even distinct summering populations, notably of juvenile birds, in addition to the breeding residents. Thus individual birds, as in the case of some sanderling Calidris alba, may spend only a few days in the Wash whilst others, as in the case of some of the alpina race of the dunlin Calidris alpina, may stay for up to ten months. Individuals occurring in the Wash have been recorded from as far north as Peary Land (80°N) in northern Greenland and as far south as South Africa.

78. For these reasons the numbers of the ten major wader species given in Table 1 below (See Study F) whilst, as 'average peak counts' they may be compared with other British estuaries, are underestimates of the total numbers of individuals which actually visit the Wash.* (The only areas in Britain with comparable peak counts are Morecambe Bay (c.230,000), the Ribble (c.160,000), the Dee (c.150,000) and the Solway (c.140,000)).

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* 'Average peak counts' are computed by averaging the highest of the monthly counts of each species for each of the four winters of the survey (1970/71-1973/74) irrespective of the month in which this occurred. They are underestimates of the total numbers of each species visiting the Wash annually. Study G pioneers a method of relating these counts to the total numbers based on the ringing and biometric data. Provisional figures cautiously suggest some 228,000 individual waders may visit the Wash during the year.

Table 1 Average Peak counts of ten wader species in the Wash for 4 winters (1970/71 - 1973/74). See also Study F, Table 1. Also given are % of the British and European counts of those species for which this can be assessed with reasonable accuracy.

	Average peak count	% of total British count	% of total European count
Oystercatcher	18,730	8	3
Ringed plover	550	-	-
Grey plover	3,280	23	9
Turnstone	930	-	-
Curlew	6,610	9	4
Bar-tailed godwit	8,300	17	10
Redshank	6,320	7	5
Knot	74,000	18	12
Dunlin	52,350	10	5
Sanderling	1,450	-	-
Total average peak count of all wader species	175,700		

79. Details of the counts, including monthly and year to year variations, of all wader species are given in Study F, where variation in numbers in each month in different sections of the Wash can also be seen. The percentages which the Wash counts represent of the total British and European counts underline the importance of the Wash as a habitat for waders, and particularly for Grey plover, Bar-tailed godwit, knot and dunlin.

80. Table 2 summarises information on the breeding areas, movements, distribution within the Wash, and main food species of ten main wader species. The table is based on data presented in the reports on wader numbers (See Study F), on ringing and biometric studies* (See Study G) and on wader feeding (See Study H), where both methodology and further details are given.

81. In further summarising these data the following points should be made. First, the Wash is used in different ways both by different species and by different groups of the same species. Thus individual groups may either pass through, moult, moult and overwinter, overwinter having moulted elsewhere, and so on.

82. Second, it is apparent that all sections of the Wash are used at some stage by at least one species or sub-group of a species. However, in general the west shore carries large numbers of passage migrants (notably oystercatcher, Bar-tailed godwit, and knot) and the southeast corner supports both the largest overall numbers and the largest populations of overwintering birds.

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* This work was begun by the Wash Wader Ringing Group in 1959. Some 95,000 waders had been ringed up to June 1974, an additional 13,000 recaptures of ringed birds had been made, and biometric data have been recorded for approximately 40,000 birds. These data (weights, wing and bill lengths etc.) provide a means of classifying the sub-groups in certain species.

Table 2 — Notes on the Breeding areas, movements, distribution and food of the ten major wader species in the Wash

	Breeding areas	Numbers and Movements	Distribution in the Wash	Food
Oystercatcher Haematopus ostralegus	Majority from Norway Smaller numbers Holland, Faeroes, Scotland, Sweden, USSR and local breeding population.	Adults arrive late July. Peak numbers in September (15,000). Trough in December, numbers increasing again in January. Summering population about 2,000.	West shore most important (3 times east shore numbers). Relatively small numbers on south shore. East shore important in summer.	Cardium, Mytilus, Some Macoma
Ringed Plover Charadrius hiaticula	Many local breeders (hiaticula race). Birds on passage from Northern Scandanavia and USSR (arcitica race). Iceland and Greenland (hiaticula race).	Spring and autumn peaks of passage migrants breeding further north. Relatively large summer population which winter in W. Britain and is absent from November to January.	East (Snettisham/Heacham) and west (Gibraltar Point) shores most important. A few birds on south shore at passage periods.	No information
Grey Plover Pluvialis squatarola	Siberia	Peak numbers in August. Some migrate further, others stay to moult. Steady winter population (1,400). Return passage. Often substantial summering non-breeding population.	Large numbers can occur on any shore but Holbeach/ Dawesmere and Terrington areas of S. shore particularly important.	Lanice and other polychaetes partic. Nereis diversicolor Some Macoma, Hydrobia and Carcinus
Turnstone Arenaria interpres	Most from Greenland. Also Scandanavia (no evidence of USSR)	Scandanavian birds arrive July, leave August. Greenland adults arrive July/ August, most overwinter Greenland first year birds arrive Aug./Sept. pass south and some return to summer. Peak numbers September.	Most occur on the East shore and at Terrington. Small numbers elsewhere mainly during autumn migration.	Small Carcinus, Littorina, Mytilus and Chitons. Cardium
Curlew Numenius arquata	Majority from Scandanavia (excluding Norway). Smaller numbers from USSR and Low Countries. No evidence of British breeders.	Peak numbers August. Most moult in Wash. Unexplained decrease in numbers from October onwards. About 1,000 summering young birds.	Large flocks in all but the west shore and around the Welland. Holbeach/ Dawesmere and Terrington particularly important.	Carcinus, Lanice, Arenicola, Nereis and Nephtys, plus most bivalves in smaller numbers
Bar-tailed Godwit Limosa lapponica	Presumably USSR and Siberia.	Peak numbers from August to October. Stable winter level of 3,000. Large summer population in last 2 years.	Largest flocks in autumn (up to 10,000) on west shore. Wintering number on W. shore 1,000. Higher wintering numbers on east shore. Smaller numbers on south shore.	Lanice and Macoma plus other polychaete worms and some Cardium

Redshank _Tringa totanus_	Britain and Iceland. Small numbers from Scandanavia and other European areas.	August/September peak (5,500) of British breeders plus influx in July/Aug. of Icelandic birds. Latter population outnumber former from mid-August. Steady winter level of 2,000 after many British and some Icelandic birds move on. About 2,800 resident breeders.	South and east shores most important (Holbeach/Dawesmere and Terrington). Small numbers on west shore and around Welland. Similar distribution to Curlew.	_Macoma_, _Corophium_, small _Carcinus_, _Hydrobia_, _Crangon_, _Cardium_, _Nereis_ and _Nephtys_
Knot _Calidris canutus_	Greenland and northeast Canada (Ellesmere Island). Small number from Siberia.	Peaks in November and January with a 20,000 decrease in December in all 4 years of the study. Two types - one arriving July/August then moulting and moving on (to west coast of Britain or France), other type arriving November via Waddensea. Juveniles winter further south. Small summer population (2-300).	East shore very important (average of 32,000) throughout autumn, winter and early spring. West shore numbers largest in autumn. Terrington important in winter.	_Macoma_, _Cardium_ and some _Hydrobia_
Dunlin _Calidris alpina_	Majority from N. Scandanavia, USSR and western Siberia (_alpina_ race). Smaller numbers from Iceland and southern Scandanavia (_schinzii_ race). Very few from Greenland (_artica_ race).	Large numbers (more than 25,000) present in all months except June. October, January and March peaks. Some moult, move away in October and return on passage in spring. Others moult in Waddensea and overwinter in Wash. _Schinzii_ occur on passage to Africa in early autumn.	Terrington area most important (22,000). 13,000 on east shore and Holbeach/Dawesmere. West shore and Welland less important but still average nearly 10,000.	_Nereis_ and _Nephtys_, _Hydrobia_. Some _Macoma_, _Cardium_ and _Corophium_
Sanderling _Calidris alba_	Greenland and Siberia.	Large peak (up to 2,000) in July/August with Greenland birds passing through rapidly. Many Siberian birds moving off in October after moult leaving wintering population of 2-300. Smaller spring passage.	More or less confined to Gibraltar Point and north part of east shore.	No information

83. Third, there is evidence that the different groups in the different sections of the Wash behave as discrete populations. This was tested by a specifically designed programme of catches between September 1972 and March 1974 (See Study G) which suggest that only knot and to a lesser extent oystercatchers, move from one section of the Wash to another both within and between seasons.

84. Finally, the above findings make it difficult to characterise or group species on the basis of their ecology in the Wash. On the basis of their general distribution three groups may be recognised: those occurring mainly on the northern sections of the east and west shores and having spring and autumn peaks of passage migrants (Ringed plover, sanderling and, to a lesser extent turnstone), those with large numbers on the west shore during autumn and with large east shore populations and relatively smaller numbers on the south shore (oystercatcher, knot, and Bar-tailed godwit) and those with large populations on the south shore (Grey plover, curlew, redshank, and dunlin). However, a categorisation on the basis of food preferences cuts across many of these groups. Feeding studies (See Study H) have revealed variation with season and availability in the main prey taken, and variation in the width of the dietary spectrum of different species. Therefore an attempt to assess the effects of the proposed Wash reservoirs on waders must consider the requirements of each species in turn.

85. Wildfowl, seabirds and wintering passerines: The most numerous species of wildfowl occurring in the intertidal zone of the Wash are Dark-bellied Brent geese (Branta bernicla), Pink-footed geese (Anser brachyrhynchus), shelduck (Tadorna tadorna), mallard (Anas platyrynchos) and wigeon (Anas penelope) (See Study K).

86. The increase in numbers of Brent geese in the Wash from a peak count of 3,500 in 1972/73 (12% and 7% of the British and world populations respectively) to almost 6,000 in 1973/74 is part of a marked increase in the world population of this species (Ogilvie 1974). Those in the Wash occur mainly on the west shore and, particularly in the spring, on the Welland/Ouse section of the south shore, and feed principally on Enteromorpha (Zostera being an insignificant food resource for Brent geese in the Wash) (See Study C). In contrast Pink-footed geese, which feed inland and roost in the Wash, are more widely distributed, substantial flocks occurring for part of the winter on the east shore. The Wash is the most southerly wintering area in Britain for this species, and 5,600 were recorded in January 1974.

87. Shelduck both overwinter and breed in the Wash and are by far the most numerous wildfowl species. The peak figure of 13,900 in 1971/72 was more than twice that recorded for any other British estuary. The south and east shores carry the largest numbers of both wintering adults and young, over two thirds of the Wash population of young birds being counted on the east shore in July 1973 (See Study L).

88. Mallard is a difficult species for census, being widely dispersed within the Wash and feeding both within the intertidal area and on agricultural land, but counts made by wildfowlers at flight times suggest that more than 9,000 occurred in the Wash during the midwinter period 1973/74. The traditional winter flocks of wigeon in the Wash have decreased in size in recent years apparently in favour of the inland sanctuary of the Ouse Washes. However, large numbers occasionally occur, particularly in the southwest corner and a figure of 8,800 was recorded for the whole Wash in December 1973.

89. The numbers of other dabbling duck species are generally small although counts of around 500 teal (Anas crecca) and 200 pintail (Anas acuta) have been made in this survey. Diving ducks which occasionally appear in large numbers include goldeneye (Bucephala clangula), particularly in the southwest corner, and scaup (Aythya marila) whereas, Common scoter (Melanitta nigra) and eiders (Somateria

mollissima) are the most numerous of the more marine species. Further details of numbers and of other wildfowl species which occur are given in Study K and Study N.

90. With the exception of the observations on gulls (See Study M) no survey was made of seabirds because it was believed that the reservoirs would have a relatively small effect on them. A statement on the status of seabirds in the Wash, based on existing information, is given as Study N. Gulls use the Wash both as a roosting and feeding area (as well as breeding), and in this study the numbers roosting in winter were estimated by counting birds arriving at nocturnal roosts (in September/October and January of both 1972/73 and 1973/74). The highest number recorded was over 83,000 (regarded, because of counting difficulties, as a minimum estimate). The Black-headed gull was the most frequent species but others which occurred were Common gull Larus canus, Herring gull L.argentatus and both Lesser and Greater black-backed gull, L. marinus and L.fuscus. There was a considerable drop in numbers from the autumn to the winter counts in all species apart from Common gull, a decline which is matched by the counts undertaken as part of the 'Birds of Estuaries' counts of gulls feeding in the Wash.

91. Gull flight line observations indicate that most birds approach the Wash along the lines of the rivers of the south shore. In the west, birds fly from inland and form small roosts where they cross the shoreline. Very few come from inland in the east where there is a pattern of coasting to the Snettisham mudflats. Gull roosting behaviour is complex and not well understood but the Wash and the nearby Ouse Washes may be regarded together as having a single, mobile, wintering population. Most foreign birds come from Scandanavia and Western Europe.

92. A feature of the Wash in winter is the flocks of small passerine birds, feeding mainly on the seeds of salt marsh plants, including species such as Reed bunting, Meadow pipit, skylark, greenfinch Carduelis chloris, linnet Acanthis cannabina, and twite A.flavirostris. This latter species is the most numerous and was the subject of a special study (See Study O). Twite occur in the Wash from September to March feeding gregariously on the salt marshes. The numbers reach peaks in December and February and estimates were obtained of a Wash wintering population of between 20,000 and 60,000 - more than the whole of the rest of the British Isles. The twite breeds on moorland from the South Pennines northwards, in Iceland and in Scandinavia and, although there is insufficient evidence to determine the origins of Wash birds, these numbers suggest that Scandinavian breeders occur. Although they occur all around the Wash flocks are concentrated near the outfalls of the rivers Witham, Welland and Nene, a particularly large section of the population occurring in the Frampton/Kirton area.

93. Feeding studies indicate that, whilst they will exploit other foods, twite in the Wash feed mainly on the seeds of Aster tripolium, Suaeda maritima and Salicornia spp., and make regular drinking flights to freshwater on farmland from the low marsh Aster/Salicornia zone (involving round trips up to 6km).

Wader Feeding Ecology

94. Process research (See Study H) has focussed on the current balance between the waders and their food supply. Whatever its other effects, a Wash reservoir will remove at least part of the present feeding grounds of some species, and the extent to which a species finds it easy or difficult to meet its food requirements now is thought to be an indicator of its reaction to a reduced food supply. The extent to which food supply on their winter feeding grounds is a factor limiting the numbers of waders is a subject for long term studies, knowledge of which would enable more accurate predictions to be made. However, data on the feeding ecology of the main species in the Wash collected during the course of this two-year study have enabled a scale to be attached to the risk each species faces in the removal

of feeding ground by a particular reservoir scheme.

95. The first step has been to describe the diet and to locate the principal feeding grounds of each species. The techniques used, a combination of observation and analysis of pellets, droppings, and gizzard contents (Goss-Custard 1973), together with the main results are given in Study H. Figs. 9-12 taken from that report give examples of the feeding distribution of four species. Although two distinct patterns of feeding, at the tide edge and upshore, were noted, each species collected its food from a limited proportion of the whole area of intertidal flats. Many of the most important of these restricted feeding areas occur within the section of the southeast corner of the Wash for which Stage 1 and 2 reservoirs are proposed.

96. As might be expected the restricted feeding areas occurred where the main prey species were abundant, as revealed by the surveys of invertebrate distribution (See Studies A and B). These latter surveys (especially Study A) have also indicated that there are areas where prey are present, in some cases in apparently suitably high densities, but which were not normally exploited by the birds (See Study H). Such areas were only used by individual birds when the tides or high wind forced them from the preferred sites and it thus becomes important to understand not only why these areas are hardly used at the moment but also whether they could provide alternative feeding on a long term basis when some of the preferred areas are lost.

97. Possible reasons for the concentration of feeding into certain areas are advanced in Study H and are related to the relative efficiency with which birds can meet their energy requirements (these being met less efficiently outside the preferred areas for such reasons as less dense, or less available, prey, or feeding on prey of lower calorific value). Measures of feeding efficiency, such as feeding rate (i.e. the number of food items successfully captured by an individual bird in a standard time of searching), were also used to investigate the possibility that food shortages, or at least difficulties in obtaining food, occur at the moment and may be limiting bird numbers (in which case the removal of feeding ground would have a significantly greater effect). For example, a relationship was demonstrated between feeding rate and prey density in the oystercatcher (See Study H).

98. Other potential indicators of food shortage examined for a number of species were

(i) variation in the amount of time spent feeding,

(ii) variation in the numbers of corpses discovered in systematic searches of the tidal driftline,

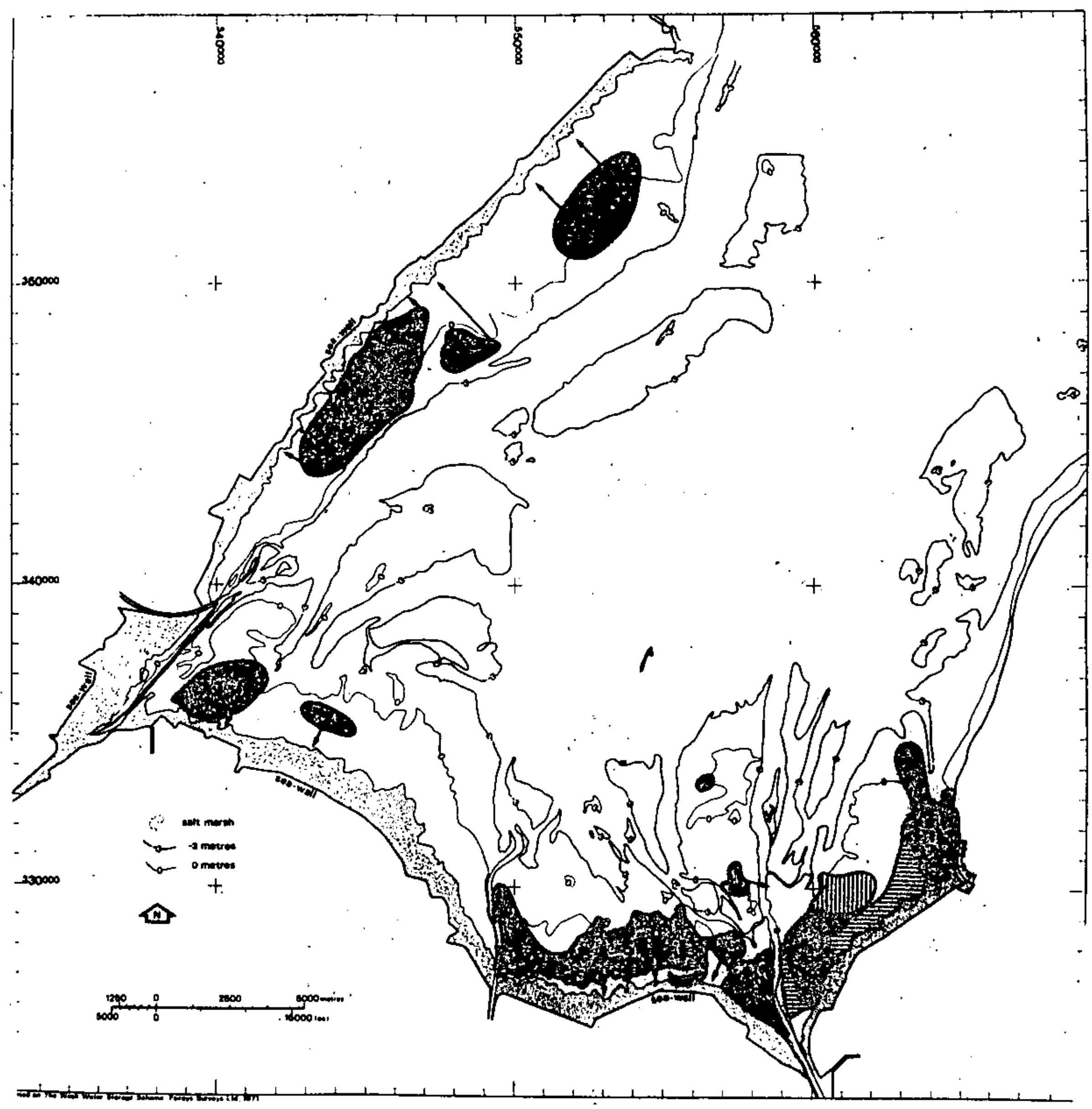
(iii) variation in body weights (obtained from ringing and biometric studies, See Study G),

(iv) variation in the rates of aggression (e.g. birds fighting over food items),

(v) variation in the food supply itself as the season progresses (particularly as a function of the impact of predation), and

(vi) variation in the availability of food, especially in relation to temperature (and measured by the success with which birds collected food at different mud surface temperatures).

Fig. 9 **Main feeding areas of knot**



FEEDING AREAS OF KNOT <u>Calidris canutus</u> IN THE WASH

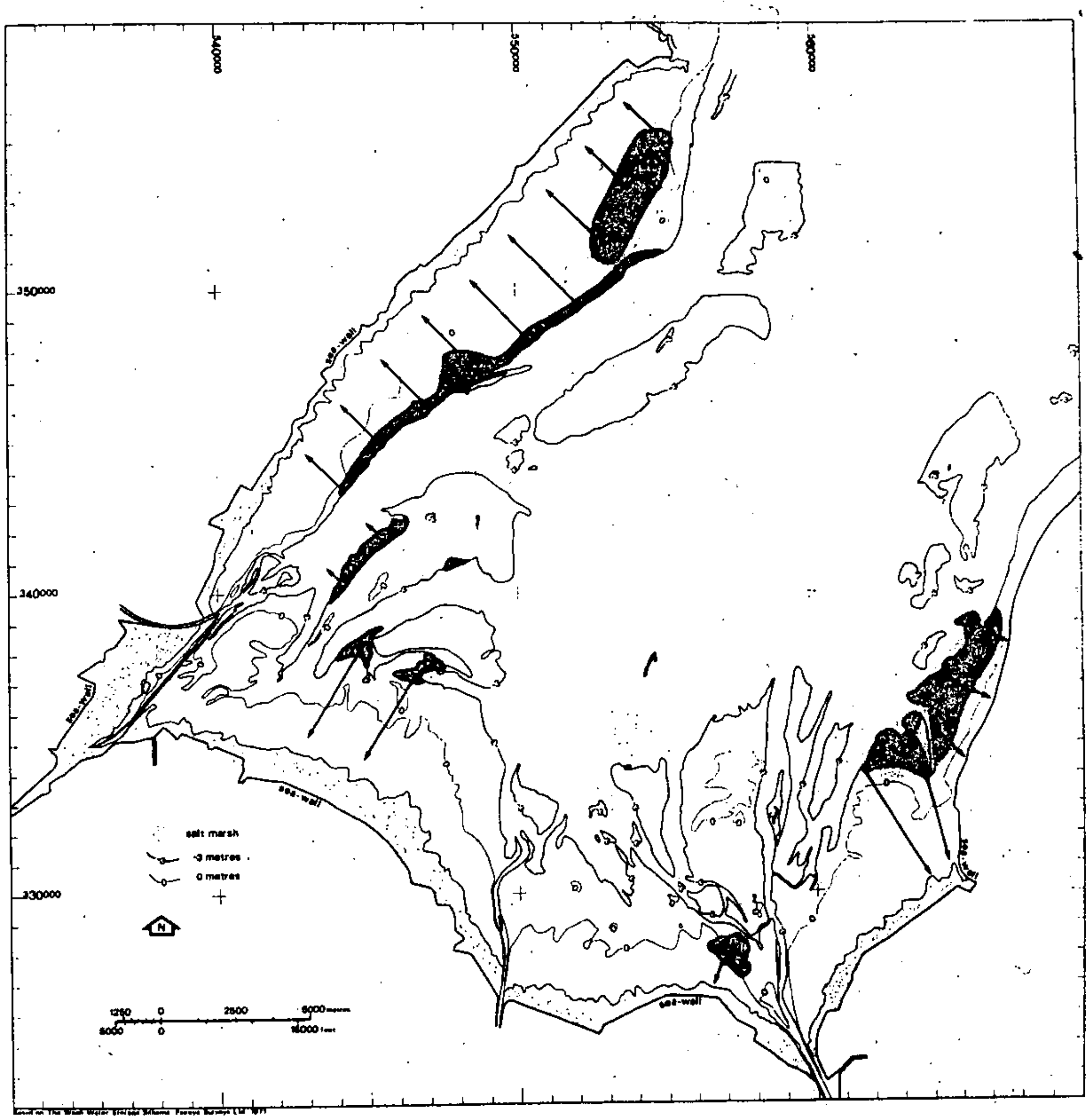
Black = main areas used by the birds when exposed by the tide. (Matching indicates different use on east shore in the two years). Arrows indicate the areas used as the tide ebbed and flowed.

Fig. 10 Main feeding areas of oystercatcher

FEEDING AREAS OF OYSTERCATCHER <u>Haematopus ostralegus</u>
IN THE WASH

Black = main areas used by the birds as exposed by the tide.
Stippled areas = feeding on mussel beds. Arrows indicate the areas used as the tide ebbed and flowed.

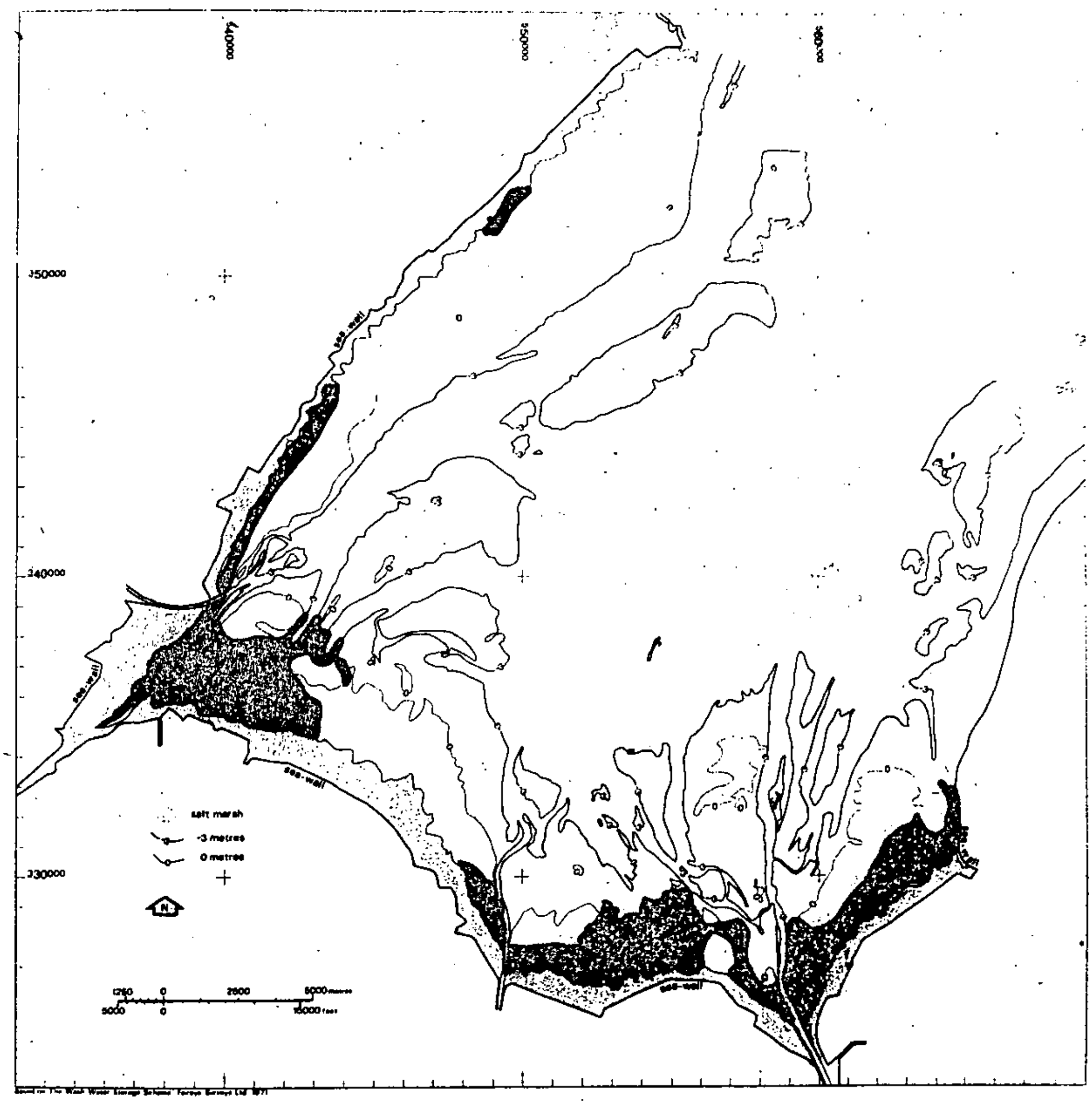
Fig 11 Main feeding areas of Bar-tailed godwit



FEEDING AREAS OF BAR-TAILED GODWIT **Limosa lapponica**
IN THE WASH

Black = main areas used as exposed by the tide (generally feeding at waters edge). Arrows indicate the areas used as the tide ebbed and flowed.

Fig 12 Main feeding areas of shelduck



MAIN FEEDING AREAS OF SHELDUCK <u>Tadorna tadorna</u>
IN THE WASH

99. The problems of methodology and interpretation of each of these measures are discussed in Study H (and Goss-Custard in press) - some are thought to be good, others poor, indicators of food shortage. Taken together they suggest that, although there was no conclusive evidence of mortality (or emigration) induced by food shortage during the period of this study, for most species food was more difficult to collect during the midwinter period (December, January and February) than at other times. This difficulty was more marked in some species (e.g. knot) than others (e.g. oystercatcher). The two years of the study had notably mild winters and it is expected that a severely cold spell would reduce the rate of feeding of those species not experiencing particular difficulty during the past two years.

100. Whether or not a species has difficulty in feeding now, with reservoirs covering part of its feeding grounds, it faces the possibility of increased densities on the remaining feeding areas. Two effects of increased density may be distinguished - the birds are likely to reduce their food supply more rapidly (little growth in or recruitment to these supplies occurs during winter*) and they are likely to interfere more one with another in collecting their food. Studies of the impact of the birds on their food, by invertebrate sampling at appropriate stages of predation and by exclosure experiments (See Study H), suggest that in oystercatcher and knot feeding on cockles and Macoma and of other species (mainly Bar-tailed godwit, curlew and Grey plover) feeding on Lanice, the birds already remove a large proportion of the initial winter stocks on some parts of the store and could be responsible for much of any winter decline that occurred (See Study H). The effects of density on feeding rate have been studied in some species. High bird densities can reduce feeding rate in redshank feeding by sight on Corophium but not directly in knot, which detects its prey by touch. However, knot may fight more at higher densities, thus losing feeding time, and their pattern of dispersion over the feeding grounds suggests that density-dependent regulating mechanisms may be operating in this species.

101. In general, therefore, the work on wader feeding goes some way towards the very difficult, and potentially inaccurate, exercise of predicting the effects of removing a part of the feeding grounds.

SEALS

102. The Wash supports more Common seals (Phoca vitulina) than any other bay in the British Isles, with an estimated population of between 5,000 and 7,000 (See Study P). The seals are found on most of the sand banks and also on some of the salt marshes. Most are seen on the tidal banks where they haul out during low water, but some haul out during high water on the edges of creeks that penetrate the salt marshes. From aerial surveys made since 1968, 33 hauling out areas on the edges of banks or of the shore have been recognised; they are always in places where the sand shelves steeply into deep water, and usually the sites are quite small and the seals occur in groups. The sites are distributed on all the banks, but the greatest number of seals is usually found in the south west. One reason may be that the Holbeach bombing range affords a certain amount of protection from human interference.

103. There is some seasonal variation in distribution associated with breeding, and the most important pupping areas lie in the south western part of the Wash between the Nene and the Welland where there is a wide area of salt marsh on which

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* In addition the availability of the prey is reduced. Study B shows, for example, that in midwinter as few as 18% of the potentially available Macoma are at a depth where they can be taken by the shorter billed species such as knot, dunlin and Grey plover.

the females haul out to give birth. Between 1960 and 1973, pups were hunted for their pelts and on one occasion the number killed was almost 900. A programme of pup tagging and subsequent recovery of tags from the catch of licensed hunters has been used to estimate production of pups. This varies from year to year with an average of 1,450 (± 239) from which it is calculated that the total seal population is not less than 6,525 (± 1,076). This number is much larger than the number actually counted on any one occasion from the air. The discrepancy would be explained if many of the seals travel outside the Wash to feed: indeed seals tagged in the Wash have been recovered from as far away as North Berwick and Essex as well as from France, Belgium and Holland.

104. Support for the hypothesis that seals feed outside the Wash comes also from the feeding studies made in 1972 and 1973. These studies proved difficult for a variety of reasons, one of which was that the majority of seals which were shot and recovered had empty stomachs. The food remains that were present included Thornback ray, whiting and other small gadoids, flounders and other small flatfish, garfish, sandeels and shrimps. It is likely that seals feed on whatever species is most readily available to them, and this will depend on the time of year; sprats and herring are more abundant in winter and plaice, mullet and rays in summer.

105. The number of seals seen at any one time may be greatly influenced by human activities. For instance, the presence of cockle fishermen on a nearby sandbank may cause the seals to vacate a site for some weeks. But they usually return when the disturbance stops.

MARINE FISHERIES

106. The Wash is one of the most important shellfish areas in England and Wales, producing about 50% of the shrimps landed, 40% of the mussels and 30% of the cockles, although these proportions vary from year to year (See Study Q). At the two main ports of King's Lynn and Boston, shrimps account for between 45% and 60% of the value of the annual landings, cockles 25-45% and mussels 7-12%. The annual value at first sale has varied in recent years from £208,000 in 1971 to £319,000 in 1973, and King's Lynn had increased its share from 37% in 1970 to 57% in 1973.

107. The shrimp fishery is concerned with two species, the Pink shrimp Pandalus montagui and the Brown shrimp Crangon crangon. Pink shrimps occur over a wide area of the Wash but are most abundant in the deeper water in the centre and the fishery is concentrated in water deeper than 10 metres in an area about 15 miles long and 2-3 miles wide extending north westwards from the Roaring Middle. Brown shrimps are found in shallower water and are fished by smaller boats in the more sheltered channels between the inner banks such as Teetotal Channel and Daseleys Sled. Altogether about 40 boats are involved in the shrimp fishery.

108. Cockles are found in the intertidal sandy areas over most of the Wash and from time to time different banks or parts of the shore may provide the best fishing depending on the success of the spatfall in a particular year. The chief commercial beds in recent years have been along the west shore between Butterwick and Wrangle and on Roger, Gat, Thief, Daseleys, Pandora and Stubborn sands. In 1973-74 the King's Lynn boats fished particularly successfully on Daseleys Sand and in an area of the shore just east of the West Stones wall which had not been fished before. Since there is great variation in the success of the broods from year to year and a successful "year class" may occur only once in several years, the cockle fishery is subject to great fluctuations in landings over the years.

109. Mussel beds are found in the lower parts of the intertidal area along the southern shore and on most of the main inner banks and the fishery is generally more important from Boston than from King's Lynn.

110. Demersal and pelagic fish are much less important in the Wash than are shellfish: the only species of significant value being sprats, which are fished in the central deep water channel. The sprat fishery fluctuates greatly and for the last few seasons values have ranged from £25,000 in 1967-68 to nil in 1971-72. Some Thornbank rays and soles are caught, but the quantities landed are small. The Wash is a nursery ground for young flatfish, plaice, dabs and soles, which are found in shallow water along the shores and banks and in the channels.

PREDICTED EFFECTS OF RESERVOIRS

Introduction

111. Two levels of prediction may be distinguished. The first is a prediction of the 'direct effects' of reservoir construction and is made by superimposing onto a map of the Wash the various reservoir schemes (Figure 1) and, from a knowledge of the distribution of the flora and fauna, quantifying the areas of habitat and numbers of species directly displaced. The second level, that of predicting the 'indirect effects', is considerably more complex, involving a prediction of the changes likely to occur both to seaward and landward of the reservoirs and relying on our understanding of biological processes. A major constraint on the prediction of indirect effects is the relative inadequacy of our picture of new environments and particularly of the nature of environmental changes in tidal and sedimentation patterns seaward of the reservoir. The predictions of future sedimentation and current patterns have been based on discussions with the staff of the Hydraulics Research Station who are working on the physical and mathematical models. Such predictions as occur in the Scientific Studies are based on discussions in late August 1974, while those given here are based on a meeting held in early February 1975. These predictions may need revision after study of the final report on the model studies.

Predicted effects on the vegetation

112. Direct effects: The line of landward bunds of all Stage 1 and Stage 2 reservoirs lies beyond the lower limits of pioneer salt marsh vegetation, and banks constructed from their extreme edges back to the present sea wall (Fig. 1) would enclose both salt marsh and some intertidal flats.

113. The macro-algae within the areas which would be enclosed by the banks are mainly very abundant species which can be found on most British salt marshes. Macro-algae associated with the pioneer marsh pools on the east shore would be directly affected by a Bulldog reservoir, but these occur elsewhere, albeit less extensively. The most species-rich salt marsh areas for macro- and blue-green algae occur on the west shore and would be unaffected by any of the proposed schemes.

114. The micro-algal rich zone of the higher mudflats is particularly well developed in the southeast corner of the Wash, notably in the section between the Ouse and Nene. Here occur the most extensive and actively growing mud mounds in the Wash (and, with the possible exception of the Dengie peninsular in Essex, probably in Britain). Of the Stage 1 reservoirs those at Breast and Wingland would destroy the greatest area of this type of habitat, the physiographical and ecological significance of which is relatively poorly understood. However, even the largest Stage 2 scheme would leave unaffected large areas of algal-rich upper mudflats and mud mounds.

115. The estimated areas of salt marsh directly affected by each of the reservoir schemes are given in Table 3, the figures taking account of the agricultural reclamations carried out in 1974 at Wingland and Ongar. Of course, by the time of the actual start of reservoir construction (possibly 15 or more years hence) there will have been both considerable further development of salt marsh and, no doubt, further reclamation. Thus it will be necessary to recalculate at that time the figures in Table 3. However, in general, since it fronts the longest section of sea wall, a reservoir at Bulldog is most likely to be the Stage 1 scheme displacing the largest area of salt marsh. On the same basis, Terrington + Bulldog of the Stage 2 schemes, will directly enclose the largest area of salt marsh.

Table 3. Areas of salt marsh (ha) directly displaced by Stage 1 and 2 schemes* (see text). (1 ha = 2.471 acres)

Stage 1 Scheme	Area displaced	Stage 2 Scheme	Area displaced
Bulldog	297.8	Walpole + Bulldog	584.4
West Stones	190.5	Terrington	414.8
Breast	173.7	Terrington + Bulldog	712.6
Wingland	204.1		

*if built in 1974

116. Although extensive in area, none of the present salt marsh which might be lost as a result of Stage 1 and 2 construction is unique floristically in relation to the Wash as a whole.

117. 'Indirect' effects: The prediction of indirect effects of reservoir construction on the vegetation is restricted by an inadequate understanding of the future patterns of sedimentation seaward of the reservoirs. The hydraulic model studies have so far indicated general areas where reduced ebb velocities, and potentially accretion, are likely to occur. They have not indicated the rates or amounts of accretion or the types of sediments involved.

118. However, it is possible on the basis of present knowledge to make some predictions. For example, conditions of increased sedimentation are likely to reduce the populations of macro-algae occurring seaward of a reservoir. This applies in particular to the macro-algal flora associated with some mussel beds at Snettisham which are likely to be affected by any accelerated accretion resulting from the construction of the Bulldog reservoir. We may also assume that, probably following a period of extreme instability, fine sediments accreted beyond the reservoirs will, at the appropriate tidal levels, be colonised rapidly by the mucilage-secreting benthic micro-algae characteristic of the present algal-rich zone. The stone face of the outer bunds will provide a firm substrate to which a number of algae currently rare in the Wash could become attached.

119. Using the simulation model, fairly precise predictions could be made about the rate of development and type of salt marsh which would occur given more detailed data on the rates of accretion, the probable levels of new intertidal flats, and the type of sediment likely to be accreted. However, it is understood that the essential initial conditions for salt marsh development, i.e. sufficiently fine stable sediments at a sufficiently high tidal level (c.2.5m O.D.N.) for flowering plant colonisation, will eventually occur to seaward of all the schemes.

On this basis, taking into account the different reservoir shapes, areas of potential salt marsh development have been delimited (See Study D).

120. A reservoir at Bulldog would probably result eventually in extensive salt marsh formation to the northeast, between the reservoir and the Snettisham shore. Other Stage 1 constructions are likely to result in less extensive strips of marsh, but some replacement of the areas covered by the reservoir can be expected after a sufficient length of time. It is expected that an adequate supply of colonising species propagules would be available from nearby salt marshes.

121. Of the Stage 2 sites, Walpole would provide greater opportunity for salt marsh development (on its eastern edge) than would Terrington which is closely flanked by the Nene and Ouse channels.

122. The more exposed offshore position of many of the new salt marshes are likely to result in physiographic and floristic conditions more closely resembling those of the present west shore marshes. For example, the pioneer zones would probably be less dominated by Spartina than they are currently in this part of the Wash. They may also be more subject to cliffing at the pioneer zone than in more inshore positions and have an accelerated succession.

123. The development of salt marshes seaward of the reservoirs might be encouraged by the construction of appropriately sited training walls to suitable levels. The construction of the reservoirs would present a unique opportunity for hydraulic engineers, agricultural scientists and ecologists to design, create and manage completely new environments. Management options which combine water storage with maximum reclamation for agriculture, or with the creation of habitats designed to attract wild life, or with some combination of these, could be explored and evaluated. Land reclaimed principally for agriculture in coastal areas has a potentially high wild life interest (Gray, in press a and b).

Predicted effects on the intertidal invertebrates

124. If it is assumed that none of the invertebrates can emigrate from the areas to be impounded, then mortality will be total within these areas. The size and location of the selected scheme in relation to the present pattern of distribution and abundance of each species will determine the proportion of the total Wash populations that are lost. Because of differences in distribution, this proportion will vary between species.

125. Table 4 is an attempt to predict the direct loss of areas accessible to each species and the proportion of the populations of the Wash that would be lost. Two calculations were made for each species in each scheme, based on the results of the survey in Autumn 1973:

A - Area lost. This is the area inside the proposed reservoir which is now occupied by each species, expressed as a percentage of the total area occupied by that species in the Wash.

B - Population numbers lost. This is the total number of animals which would be killed by each scheme, expressed as a percentage of the total number of that species in the Wash.

126. In order to compare the area estimates (A) with the areas to be impounded, the intertidal area to be enclosed by each scheme was expressed as a percentage of the total area of the shore and inner banks of the Wash (between the salt marsh edge and -3.0 m O.D.). This is about 5% for each of the Stage 1 schemes, 16-17% for Stage 2 Terrington alone or Walpole/Bulldog and 22% for Terrington/Bulldog.

127. From Table 4 it can be seen, for example that if they had been built in Autumn 1973 each of the Stage 1 reservoirs would take away 8% to 10% of the area now occupied by Macoma in the Wash but the proportion of the total Wash population of this species that would be killed varies from 10% for Breast to 18% for Bulldog. All the predicted losses, in respect of Macoma, are higher than the proportion of the "total" area occupied by each of the proposed schemes (which lie in areas where Macoma is abundant, especially in the Bulldog area). On the other hand, Lanice would be only slightly affected because nearly all the worms of this species in the Wash are outside the areas proposed for the reservoir schemes. There are several other differences between species. For example, the effect on Corophium of three of the Stage 1 schemes would be very slight but the Bulldog scheme would remove 30% of the area now occupied by this species in the Wash and would kill 40% of the total population; however, even the largest of the Stage 2 schemes would cause only a relatively slight increase in this percentage. Spionid worms are fairly evenly distributed in the Wash; consequently the areas affected and the mortality resulting from each scheme would be in direct proportion to the size of each scheme.

128. A study of Table 4 shows that, judged by the direct loss of invertebrate fauna of the main species, a Stage 1 reservoir on the Bulldog site would have the greatest effect. There is little to choose between the three sites (Wingland, Brease and West Stones) in the Terrington area, but on balance the Breast site would affect the fewest of the animals which are important as food for waders. Of the three Stage 2 proposals it is clear that Terrington alone would have the least effect and Terrington plus Bulldog the greatest (it would remove about 50% of the Macoma population in the Wash, 45% of Corophium and 16% of Cardium, for example).

129. The main indirect effect will be from accretion outside the bunds. If a Bulldog reservoir is built accretion is most likely to occur to the north east, in the area between the bund and Wolferton and Snettisham. This is an area already rich in several species such as Hydrobia and Macoma. If accretion takes place slowly the populations would flourish for a time, but eventually the level of the shore would rise sufficiently for salt marsh to develop, with a consequent further reduction of the area available for the intertidal animals. It is unlikely that accretion will take place outside the wall to the north west to compensate for this secondary loss of intertidal sand. Similarly there would be accretion associated with each of the three other Stage 1 schemes, in each case with the eventual formation of salt marsh. With the West Stones reservoir it would be to the west and south west, with Breast mainly to the west but with some to the east and with Wingland it would be on the east side. There would be little accretion to the north of these reservoirs on the Terrington shore since the deflected currents would probably keep the channels open. So the secondary effect in each case would be likely to be a further reduction of the intertidal area available for invertebrates. The timing of these changes cannot be assessed on the information available.

130. Accretion outside a Terrington reservoir is likely to be patchy and mainly to the north and north west of the outer bund. It will probably not be a very productive area judging by the present Inner Westmans Knock, with the northern edge becoming a wave exposed beach like the present north ends of Thief and Seal sands. The Old Lynn Roads and Teetotal Channel will silt up slowly and new channels may possibly develop to the north east and north west of the reservoir with the Nene and Ouse channels respectively. So new areas for colonisation by intertidal animals will not be large. A similar situation would exist to the north of a Walpole reservoir, where accretion would be slow and most likely in the Inner Westman Knock area. Some accretion leading to salt marsh development and so a smaller area for the fauna would take place to the south east of a Walpole reservoir.

TABLE 4. ESTIMATED DIRECT EFFECT OF RESERVOIR SCHEMES ON SOME INTERTIDAL INVERTEBRATES EXPRESSED AS:

A - PERCENTAGE OF DISTRIBUTION AREA IN THE WASH THAT WOULD BE LOST

B - PERCENTAGE OF TOTAL WASH POPULATION NUMBERS THAT WOULD BE KILLED (Based on data from the survey of Autumn 1973 - see text)

		STAGE 1				STAGE 2		
		WINGLAND	BREAST	WEST STONES	BULLDOG	TERRINGTON	TERRINGTON + BULLDOG	WALPOLE + BULLDOG
MACOMA	A	10	10	8	9	25	36	27
	B	15	10	12	18	32	50	41
CARDIUM ADULT	A	3	6	8	8	16	24	17
	B	1	3	10	3	13	16	7
CARDIUM SPAT	A	9	9	8	7	20	27	24
	B	10	8	8	7	20	27	24
MYTILUS	A	1	2	1	0	5	5	3
	B	1	2	1	0	5	5	3
HYDROBIA	A	8	7	7	9	17	26	20
	B	9	7	7	10	17	27	21
COROPHIUM	A	2	2	3	30	5	35	32
	B	1	2	3	40	5	45	42
NEPHTHYS	A	5	4	5	4	10	14	12
	B	5	4	5	4	10	14	12
ARENICOLA	A	4	4	4	7	15	22	17
	B	2	2	2	4	7	11	9
SPIONIDS	A	5	5	5	5	15	20	15
	B	5	5	5	5	15	20	15
LANICE	A	0	1	1	0	5	5	5
	B	0	1	1	0	2	2	2

AREA COVERED BY RESERVOIR SCHEMES AS % OF TOTAL WASH SHORE AND INNER BANKS	5	5	5	5	17	22	16

131. The eventual situation to the north of each reservoir will depend to some extent on the place and method of the closure of the bunds during construction.

Predicted effects on the birds

132. Direct effects: The most obvious direct effects on birds of the construction of the reservoirs are

(i) the removal of intertidal sand and mud flats which currently provide feeding grounds, principally for waders and wildfowl,

(ii) the replacement of salt marsh, a habitat used by birds for nesting, roosting and to a lesser extent feeding, by a new habitat (not necessarily unsuitable for such activities), and

(iii) the provision of a new deep water habitat - the reservoir itself.

133. Both the proportion of the wader feeding grounds removed by each of the proposed schemes and the actual numbers of each of the major species affected have been calculated. (Good estimates of the latter may be obtained from measurements of the former combined with counts at the appropriate high-tide roosts). The data are given in full in Study H. Summarised below in Table 5 are the approximate numbers of 8 abundant wader species, the feeding grounds of which will be directly covered by each of the four Stage 1 and three Stage 2 options*. The figures are an oversimplification, ignoring the effects of throughput during the year and fluctuations in site use, but they give an order of magnitude for 8 species based on the observed current use of the proposed reservoir areas.

134. Of the Stage 1 reservoirs Breast, if built before 1973 would have removed the feeding grounds of marginally more birds in total, affecting particularly redshank, dunlin, turnstone and knot. In addition the feeding grounds currently used by a fifth of the Grey plover in the Wash would have been removed by Breast reservoir. On the other hand, the Bulldog scheme, whilst affecting fewer curlew, redshank and dunlin, would have removed the feeding grounds of many more oystercatchers and knot (in the latter case those used by nearly a third of the Wash population). Wingland and West Stones each affect marginally fewer birds than the two other schemes.

135. Whereas the Stage 1 schemes may each affect up to a fifth of the waders the Stage 2 schemes may directly affect between a third and a half. Terrington + Bulldog removes the most feeding ground, used in 1972/73 by over 80,000 birds, a half of the Wash count of all wader species that year.

136. It is possible to make similar calculations of the direct effect on nesting birds of the removal of salt marsh. However, it would give a misleading impression of accuracy to calculate the numbers of pairs displaced by each scheme from estimates of salt marsh displaced together with estimates of nesting density. This is because the areas of upper salt marsh suitable for successful breeding vary from the Nene to Snettisham, the nesting densities on the two sample plots vary (by an overall factor of three), and the recent reclamations at Wingland and Ongar Hill have already removed the major salt marsh nesting habitat in those areas. Nevertheless, such calculations can be made (See Study K) for accurately

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* Values are based on the proportion of flats used for feeding as the tide ebbs and flows and thus give a maximum figure (See Study H).

TABLE 5: The numbers of 8 wader species whose feeding grounds would have been removed by the respective reservoir schemes in 1973

Stage	Scheme		Curlew	Redshank	Oystercatcher	Dunlin	Grey Plover	Turnstone	Knot	Bar-tailed Godwit	Totals
STAGE 1	WINGLAND	Nos.	1,300	970	430	8,260	450	190	10,560	0	22,160
		%	16	12	3	14	15	19	18	0	14
	BREAST	Nos.	1,060	1,650	370	14,370	590	330	12,680	790	31,840
		%	13	21	2	24	20	33	22	9	20
	WEST STONES	Nos.	660	1,260	450	11,190	520	250	10,970	790	26,090
		%	8	16	3	19	17	25	19	9	16
	BULLDOG	Nos.	500	690	2,250*	6,960	0	0	17,790	0	28,190
		%	6	9	15	12	0	0	31	0	17
STAGE 2	WALPOLE + BULLDOG	Nos.	2,240	2,070	2,780	24,080	970	390	35,800	700	69,030
		%	28	27	19	40	32	39	63	8	43
	TERRINGTON	Nos.	2,300	2,480	1,090	21,360	1,040	530	23,630	790	53,220
		%	29	32	7	36	35	54	41	9	33
	TERRINGTON + BULLDOG	Nos.	2,810	3,170	3,340	28,310	1,040	530	41,430	790	81,420
		%	35	41	22	47	35	54	73	9	51

Note 1. The numbers are based on feeding as the tide ebbs and flows rather than at low water (see Study H)

2. The %'s are of the peak counts for the entire Wash for each species during the year the feeding observations were made (1972/73) (Study F)

* count made in 1973/74

counted areas and could be made shortly before reservoir construction begins. If approximately equal areas of suitably high level salt marsh develop around the Wash in the time interval between the latest agricultural reclamation and the start of reservoir construction then, of the Stage 1 schemes, Bulldog might be expected to affect the greatest number of nesting birds because it fronts the longest stretch of marshland (assuming the present low densities at Wolferton to be related to low habitat availability). Similarly, the Terrington + Bulldog Stage 2 scheme could remove all the suitable salt marsh nesting habitat between the Nene and Snettisham - at current densities this would directly affect in the order of 400 pairs of redshank alone.

137. Calculations of the numbers of salt marsh feeding birds such as the twite directly displaced would also have to be made nearer the date of construction. The preference of twite for the Salicornia/Aster/Suaeda zones suggest that its feeding patterns may have changed considerably by that time. The current importance of the Frampton/Kirton marshes (as for breeding birds) suggests that a large proportion of the population would be unaffected by the present proposals.

138. Of the wildfowl shelduck and Brent goose, both of which feed in the intertidal zone, are likely to be directly affected by reservoir construction. Estimates of the proportion of the current feeding grounds of shelduck removed by each Stage 1 scheme (given in detail in Study H Table 3) vary from around 40% for Wingland and West Stones to around 70% for Breast and Bulldog - the Stage 2 schemes vary from about 55% for Terrington to more than 85% for Terrington + Bulldog. In terms of the removal of their current feeding grounds shelduck are therefore among the bird species most likely to be directly affected by the reservoirs. In contrast, only a relatively small proportion of the Wash Brent goose population, which occurs mainly on the west and southwest shores, is likely to be directly affected. An area used by up to 500 Brent geese in the spring might be lost by any of the Stage 1 proposals. Pink-footed geese currently roost for part of the winter on mudflats which would be covered by the Bulldog reservoir but, the reservoir itself could prove an attractive alternative roost for this inland-feeding species. The potential of the reservoir for wildfowl is discussed in Study T.

139. The direct effects on gulls are difficult to assess since the use of roost sites is variable, and choice of site not well understood. However, estimates (See Study M) suggest that between 300 and 18,000 gulls of various species depending on the site and the time of year could be directly displaced from their present roosts. It appears likely that the reservoirs would be attractive roosting areas for gulls (Studies M and T) and would be used by seabirds in general both for loafing and roosting and eventually, by some species, for feeding (See Study T).

140. 'Indirect' effects: Predicting indirect effects of reservoir construction on birds is considerably more difficult than predicting direct effects. Some of the major problems and pitfalls are discussed in Study H and by Goss-Custard (in press). For most species there is insufficient evidence available on which to base predictions of indirect effects.

141. For waders (and shelduck) it seems likely that a proportion of birds directly displaced by the reservoirs may die or be forced to leave the Wash and that this proportion will vary from species to species. The probability that all the birds directly displaced will leave can be assessed for each species from a knowledge of their feeding ecology. Table 6 lists the characteristics of wader species which indicate high or low risk in this respect. This table embodies the general maxim that specialisation, (in this case in feeding or behaviour), whilst it enables the more successful exploitation of a specific ecological niche, carries with it attendant risks - particularly in the face of the removal of habitat. For example, a specialised way of feeding on a prey species restricted in size or distribution,

TABLE 6: Characteristics of wader species which affect the probability that the numbers permanently lost to the Wash will equal the numbers directly displaced by the reservoirs

A. High risk characteristics	B. Low risk characteristics
1. Current immobility within the Wash or between estuaries and no indication of an ability to locate alternative feeding areas	1. High mobility within the Wash and between estuaries and demonstration of a current ability to locate new feeding grounds
2. A major part of the winter spent on the Wash	2. Passage migration or high population turnover
3. Specialist feeding on invertebrates restricted in distribution or size	3. Specialist feeding on widely distributed invertebrates and feeding on, or capable of adapting to, a wide range of prey species and sizes
4. Feeding on relatively sedentary prey items (cockles, *Macoma* etc.)	4. Feeding on prey brought in by each tide (shrimps, crabs etc.)
5. A restricted range of feeding methods	5. A wide repertoire of feeding methods
6. Feeding by visual searching (would be more affected by increase in bird density)	6. Touch feeding
7. Evidence of current depletion of a relatively high percentage of food resources by spring	7. Evidence of current depletion of relatively low percentage of food resources
8. Signs of current difficulty in finding food (e.g. long time spent feeding, night feeding, fighting on feeding grounds)	8. No current signs of difficulty in finding food
9. Overt density-dependent fighting	9. No fighting
10. Apparent ceiling to numbers in preferred sites (as indicated by distribution as the birds arrive in autumn and spread out over the feeding grounds)	10. No evidence of an apparent ceiling to numbers in preferred sites

may be regarded as a feature reducing the chances of a species being accommodated elsewhere on the Wash compared with a large repertoire of feeding methods and a wide dietary spectrum.*

142. Not surprisingly, no one species exhibits either all the high risk or all the low risk characteristics listed in Table 6. Even knot, which shows most of the high risk features, is highly mobile. Most species show a mixture of attributes and it is on the balance between these that the overall risk for each species has been assessed (below). As far as possible predicted changes in the invertebrate fauna associated with sediment changes have been taken into account in assessing the risk for birds, but the long term implications of, for example, the loss of the juvenile Macoma zone (See Study B), are difficult to assess.

143. Table 7 is a summary of the predicted effects of a reservoir in the Wash on the major wader species (and shelduck). It combines the direct effects given in Table 5 with the risk attributes given in Table 6. (For example, the feeding grounds of some species exhibiting high risk characteristics are well outside the part of the Wash for which reservoirs are proposed.)

144. The data in Table 7 suggest that, of the Stage 1 schemes, Wingland and West Stones will have the least overall effect, significantly affecting only knot and shelduck, the two species at greatest risk generally. Bulldog may affect a greater percentage of both knot and shelduck whilst Breast, in addition to these two species, could affect significant percentages of the Wash populations of Grey plover, turnstone, redshank and dunlin. Of the Stage 2 schemes Terrington + Bulldog clearly has the greatest effect, significantly affecting all species but Ringed plover, Bar-tailed godwit and sanderling. It is predicted that all Stage 2 schemes are likely to have a significant effect on at least 7 out of the 10 species considered.

145. Since it is based on percentages, the data in Table 7 disguises the variation in actual numbers of birds affected. Thus, for example, a score of 2 for turnstone at the Breast site being 33% of the Wash numbers represents 330 birds, whilst a score of 2 for knot at West Stones although only 19% of the Wash population represents 11,000 birds. The table takes no account of factors, such as the number of individuals of species affected in relation to their national and European status.

Predicted effects on the seals

146. Each of the reservoir proposals can have two possible effects on the seal populations. Firstly, during the construction there will be considerable disturbance and secondly, when the reservoir is completed, there will be some rearrangement of banks and channels which will deprive seals of some of their traditional hauling out sites. None of these haul-out sites would be lost directly by any of the Stage 1 proposals, but a small area known as Pie Corner near Hull Sand would be lost in a Stage 2 Terrington or Walpole reservoir. The Stage 1 site which would be least likely to cause disturbance during the construction

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* The fact that certain species are apparently currently restricted in their choice of prey item is not conclusive evidence of feeding inflexibility (since for example knot are known to take a wider range of food, both in captivity, and in other estuaries). However, coupled with evidence that food shortage is currently occurring it indicates a measure of reluctance to turn to less preferred foods which suggest that these are less profitable, for this species, in terms of energy balance.

TABLE 7: Predicted effects of reservoir construction on the major wader species and shelduck

Species	Risk categories	Stage 1 Schemes				Stage 2 Schemes		
		Wingland	Breast	West Stones	Bulldog	Walpole + Bulldog	Terrington	Terrington + Bulldog
Oystercatcher	M	-1	-1	-1	1	1	-1	2
Ringed plover	L	-1	-1	-1	-1	-1	-1	-1
Grey plover	M	1	2	1	-1	3	3	3
Turnstone	L	1	2	1	-1	2	3+	3+
Curlew	M	1	1	-1	-1	2	2	3
Bar-tailed godwit	H	-1	1	1	-1	1	1	1
Redshank	M	1	2	1	1	2	3	3
Knot	H	2	3	2	3	3+	3+	3+
Dunlin	M	1	2	1	1	3	3	3+
Sanderling	H	-1	-1	-1	-1	-1	-1	-1
Shelduck	M	3	3+	3	3+	3+	3+	3+

Categories of effect: Each species has been subjectively classed as having a 'high', 'low' or 'medium' risk that the numbers displaced directly by the reservoir will not be accommodated on the remaining feeding grounds in the Wash (based on the considerations in Table 6). Combined with the estimates of the numbers of birds displaced (Table 5) this gives the following categories:-

- -1 Small effect. Less than 5% of the Wash population currently feeding in the proposed reservoir site.
- 1 Less than 10% of the Wash population of a high risk species currently feeding in the site; less than 20% of a medium risk species; less than 30% of a low risk species.
- 2 10-20% of a high risk species; 20-30% of a medium risk species; 30-40% of a low risk species.
- 3 20-40% of a high risk species; 30-50% of a medium risk species; 40-50% of a low risk species.
- 3+ Very large effect. More than 40% of a high risk species and more than 50% of all other species.

phase would be Bulldog as no seals are found in that area and any later accretion would be unlikely to affect any haul-out sites. The West Stones reservoir area would not encroach directly on any of the existing haul-out sites or breeding areas, but construction traffic would cause disturbance to seals inhabiting creeks further west during the breeding season. The construction of Breast and Wingland reservoirs could affect seals hauled out on Outer Westmark Knock and further inshore.

147. Seals coming in to the marsh to breed would be affected, but the 1974 marsh reclamation in the Wingland area will probably have driven them away already.

148. The Stage 2 proposals would have similar effects to those described for Stage 1, a Terrington reservoir having the greatest effect. The number of seals displaced would be relatively small and it seems probable that existing banks would be capable of absorbing them.

149. If there was a lot of boat traffic offshore in Teetotal Channel or Old Lynn Roads during construction of any of the reservoirs, seals on Thief and Seal Sands might be disturbed. The seals disturbed by construction traffic or later displaced by loss of suitable haul-out sites are likely to move to the nearest suitable undisturbed site, such as those on Gat and Roger Sands. Eventually accretion outside the bunds might produce new sites suitable for hauling out and they would be most likely to be occupied by seals displaced from traditional sites.

Predicted effects on the Fisheries

150. Because of the long distances involved, boats from Boston do not usually fish in areas that may be affected by the Stage 1 and Stage 2 reservoirs. The direct effects of the schemes, by enclosing intertidal areas that are fished at present, are likely to be small and confined to cockle and mussel fisheries, but the indirect effects of accretion and siltation may be greater and will also affect the brown shrimp fisheries.

151. Of the Stage 1 proposals the Bulldog reservoir would have no direct effect on commercial stocks. A West Stones reservoir would have a direct effect on cockle stocks since part of the area around the Old Barrier Wall has been fished heavily in 1973-74. Of greater importance, however, are the navigational problems which would be likely to arise from the obstruction of access to Teetotal Channel from the Great Ouse: fisherman would no longer be able to use this passage from King's Lynn to cockle and shrimp fisheries to the west, and this could limit their catches during periods of poor weather when they cannot go round to the north of Seal Sand. However, it is not certain that this passage would be lost altogether, because it is possible that the deflected currents will keep open a channel between the reservoir and Daseleys Sand. A Breast reservoir would have little direct effect on cockle stocks, but several mussel beds near Hull Sand, which are little used at present, would be lost. The potential mussel relaying grounds in Scotsman's Sled might be lost by subsequent siltation. A Wingland reservoir would have no direct effect on cockle or mussel stocks.

152. The effects of a Stage 2 reservoir can be gauged by adding the Stage 1 effects just described. But the effects of a Terrington reservoir would be greater than the sum of West Stones, Breast and Wingland because it extends further north and takes in more of the mussel beds around Hull Sand and Scotsman's Sled and on the south of Daseleys Sand and parts of the channels where brown shrimps are fished. However, it is the secondary effect which could be more important because the Teetotal and Old Lynn channels will be affected by accretion and siltation which would be slow but could adversely affect shrimping in these areas. The present channel between the Teetotal Channel and the Great Ouse would be blocked by a Terrington reservoir

and it is less likely that it would be kept open than with a West Stones reservoir.

153. A Walpole reservoir would have less effect than a Terrington reservoir because the Teetotal Channel would probably remain open and also the channel from there to the Great Ouse Channel.

Predicted effects during construction

154. Some of the special problems which will arise during the construction of the reservoir have been mentioned in the preceeding sections: for instance the noise and extra boat traffic will affect the seals on the nearby sand banks. But the effects on other aspects of the ecology such as the invertebrates and the birds which prey on them cannot be assessed until more information is available on the proposed methods of construction and closure of the bunds. This information has been requested from the consulting engineers but has not yet been received.

THE ECOLOGY OF A RESERVOIR

155. This section is based on Study V, on reports on water quality prepared for the Engineering and Water Quality Working Party by P.J. Long of the Department of the Environment and by A.E. Warn of Central Water Planning Unit, on a note about a trout fishery prepared by J. Corlett for the Economic and Amenity Working Party of the Wash Feasibility Study and a note on fish farming by R.G. Shelton of the Ministry of Agriculture Fisheries and Food. The comments apply primarily to a Stage 1 reservoir on any of the four proposed sites.

156. The area of a Stage 1 reservoir is likely to be about 9 km^2; the bottom will be mainly fine sand with some muddy areas, and the depth, when full, will be from 9.5 metres near the shore to about 12.5 metres in the deepest parts. The water for the reservoir will be pumped from some point on the River Great Ouse, possibly near Denver.

157. The water in the Ouse at Denver is rich in nutrients, and calculations made from water quality forecasts and yield data give a rough estimate of the nutrient "loading" as 6 grams of phosphorus per square metre per year and 148 $gr/m^2/year$ of nitrogen as nitrate and ammonium. This would be a eutrophic reservoir by any standards. So it must be assumed that there will be a continuing potential for algal blooms. Whether a bloom will develop in any season or year will depend on several factors such as the stirring effect of the wind, which would cause increased turbidity (and so reduced light) and would take the algae for a time below the optimum level of light for growth. This stirring could also be affected by artificial circulation. The amount of drawdown is also important as algal blooms would be more likely in shallower conditions. The potential for blooms should be recognised by the provision of appropriate water treatment and the siting of the take-off point some distance away from the shore in the south-west corner from which the prevailing wind comes. There will be a plentiful supply of green and blue-green algae and diatoms for colonisation of the reservoir in the raw water from the river. The water entering the reservoir will be chlorinated to prevent the growth of the Zebra mussel Dreissena polymorpha in the pipes, and some of the algae will be killed. But chlorination will probably not be continuous and sufficient algae will enter the reservoir to form an inoculum.

158. Similarly, chlorination is unlikely to prevent some of the zooplankton from the river entering the reservoir, and ostracods such as Daphnia and copepods such as Cyclops are likely to thrive.

159. The bottom of the reservoir is likely to be colonised by animals derived from the river and also by flying insects which lay their eggs direct into the water. Among the latter group are midges of the family Chironomidae: these are likely to colonise the reservoir quite rapidly. Simultaneous mass emergence of adults in early summer can result in dense clouds of midges appearing. But the larvae form the food of several species of fish, and once a balanced community is established in a reservoir the numbers of larvae will be controlled by predators. The bottom mud will probably be colonised quite early by oligochaet worms such as *Limnodrilus*, and amphipods such as *Gammarus* and *Crangonyx* are likely to become common. Later other insects will appear, and the eventual fauna may be something like that of the Flood Relief Channel which runs parallel to the river between Denver and King's Lynn.

160. It is unlikely that emergent vegetation will be able to survive round the margin of a reservoir once it is fully in operation because of the amount of drawdown each year. However if there is only a little drawdown in the early years when the reservoir is not being used to full capacity a narrow reed bed could develop; this would harbour other species of insects than those which inhabit the bottom mud.

161. The lower reaches of the Ouse have a good coarse fish population including perch, pike, roach, rudd, bream, carp, tench and zander as well as eels. The fry of these species are likely to enter the reservoir at some time or other, especially if chlorination is intermittent and is stopped for a time in early summer when the fry are abundant. The earliest colonisers are likely to be perch and minnows which are both able to spawn on the sand and gravel of an open shore. Other species such as roach, rudd, bream and pike will not breed so successfully in a reservoir because they attach their eggs to vegetation. But there is likely to be a regular supply of larvae each year from the river, and a mixed population will develop which could be the basis of a coarse fishery. This might take 5-10 years to develop and there will probably be a demand from anglers for stocking so that a fishery can develop more quickly. Stocking with coarse fish would be practicable provided there is enough food in the reservoir for them. The effect of the drawdown in not allowing sufficient vegetation to develop can be mitigated by building a weir round a corner of the reservoir so that it could be held at a regular high water level with little fluctuation. This would provide a breeding area for fish and some insects.

162. The only salmonid fish in the lower reaches of the Ouse are occasional sea trout: so trout would not colonise a reservoir naturally. If there should be a demand for a trout fishery in a Wash reservoir it would have to be developed by artificial stocking and managed intensively to keep competitors and predators to a minimum. Artificial feeding might also be necessary in the early stages. The management of such a "put-and-take" fishery would be expensive, and the economics are being considered by the Working Party on Economic and Social Aspects.

163. The use of a reservoir for fish farming of either salmonids or coarse fish in floating cages has been considered but is not recommended because of problems caused by poor water quality and heavy drawdown in some years. (See Study Q).

164. The proposed reservoir scheme might involve taking all the flow of the Great Ouse at times of low flow from above a new sluice at Denver, or elsewhere, and replacing it with sea water pumped from the Wash to just below the sluice. The flora and fauna of the tidal reach of the river were studied during the summer of 1973 and an assessment made of likely changes caused by such a sea-water compensation scheme. (See Study U).

165. Although the river is tidal beyond Denver, which is 15 km from the entry into the Wash, there is a slight brackish water influence there only at high water of spring tides with low freshwater flows. The bankside vegetation is well developed but many of the species are ruderals, and there are few submerged or emergent macrophytes. The fauna is sparse with a limited number of species and few individuals, probably because of the strong currents and the highly mobile nature of the bed. If a sluice were built, the section of the river above it would become fresh and would develop the flora and fauna characteristic of a fenland river such as the Ely Ouse. Below the sluice conditions would be more variable than at present with the water regime fluctuating between one similar to the present in times of flood to one entirely sea water in times of drought. This would probably further reduce the fauna from its present low level.

SUMMARY

166. This report deals with research done over a period of 2½ years to consider and predict the effects of the proposed reservoir schemes in the Wash. It concerns 5 main projects on

(i) intertidal algae and salt marshes,

(ii) intertidal invertebrate animals,

(iii) waders, wildfowl and other birds,

(iv) seals and

(v) marine fisheries.

167. Approximately half of the 62,000 ha (620 sq.km.) area of the Wash bay is intertidal, comprising a fringe of salt marsh (4,450 ha) fronted by wide, gently sloping sand and mudflats with offshore sand banks (28,000 ha). A zone containing dense populations of micro-algae was identified within and to seaward of the salt marshes. The micro-algal flora of this zone which covers almost 8% of the area beyond the salt marshes (and is equivalent to 45% of the area covered by salt marsh), consists chiefly of mobile forms of benthic diatoms, blue-green algae, and of species of Euglena. The importance of these mucilage-secreting species in the process of stabilising fine sediments as a precursor to salt marsh growth has been emphasised by field and laboratory experiments.

168. The macro-algal flora of the Wash is poor in species by comparison with the nearby north Norfolk coast. The two most abundant mudflat species, Enteromorpha prolifera and Vaucheria subsimplex occur, often in dense mats, mainly on the west and south shores. Enteromorpha is the main food species of the Brent goose (Branta bernicla) in the Wash. Other species of macro-algae are associated with topographical features such as salt marsh pools.

169. In addition to their size (comprising approximately 10% of the total area of salt marsh in Britain) the Wash salt marshes are characterised by their lack of floristic variation. More than half of the area of salt marsh is made up of plant communities classified as being dominated by two species, Sea meadow grass Puccinellia maritima and Sea purslane Halimione portulacoides. Other frequent species occurring in communities zoned parallel to the sea walls are, from seaward to landward, Cord grass Spartina anglica, glasswort Salicornia sp., Sea aster Aster tripolium, Sea blight Suaeda maritima, and, on the upper marshes, Sea couch grass Agropyron pungens.

170. Salt marsh development has been studied by measuring (at 51 sites around the Wash) what are believed to be critical interrelated factors such as surface height, tidal submergence, accretion rate, physical and chemical soil properties, and plant species frequency, cover and biomass. These data have been used to construct a mathematical model simulating the process of salt marsh development. Preliminary computer runs of this model, simulating the effects of grazing and of wind-blown sand accretion, produced results similar to those observed in the field on the composition of the plant communities, vegetation biomass, and the height (O.D.) of the pioneer zone. Although the model requires further validation and development, the results are encouraging and suggest that it may provide a way of predicting the effects of changes associated with reservoir construction.

171. The single factor having the greatest overall effect on the Wash vegetation is the practice of continual reclamation for agriculture of the upper salt marshes. In addition to removing high marsh communities, reclamation is frequently followed by changes in tidal ebb velocity and in ebb and flood duration, continually recreating conditions of increased sediment input to the lower marsh zones. Most of the Wash marshes are highly dynamic, rapidly accreting, floristically uniform systems, other conditions occurring only in areas of foreshore where reclamation has temporarily ceased.

172. Large numbers of invertebrate animals live in the intertidal sand and mud and the Wash is notable for the great density of animals of relatively few species. Their distribution is mainly governed by the nature of the sediment and tidal height. The sediments range from coarse and medium sand on the outer sand banks and exposed beaches to fine sands with a large proportion of mud in the south west and south east corners. In general the biomass is least at the two extremes of coarse sand and soft mud and greatest in the large areas of fine sand with some silt which make up much of the shore and banks. In areas with similar sediments tidal height is the dominant influence on zonation. At the top of the shore about the level of high water neap tides the burrowing amphipod Corophium is common in the more sandy areas on the east and west shores, and the small gastropod mollusc Hydrobia is abundant in more muddy situations, particularly round the south and south east from the Welland to Snettisham. The bivalve mollusc Macoma is commonest between high water neaps and mid-tide and has its greatest densities in areas of fine sand and some silt between the Nene and Wolferton. Cockles are found in a band about mid-tide on the west shore and are also abundant in patches on most of the inner sand banks: they are less dense on the other shores. Dense patches of mussels occur in the more sheltered areas particularly on the south west shore and the sheltered parts of the inner sand banks. The larger worms Arenicola and Nephthys are widely distributed between high and low water of neap tides, while the large tubeworm Lanice is restricted to the area below low water neaps where it forms dense carpets in some areas.

173. The south east of the Wash from the Nene to Snettisham generally has a greater biomass of animals than the west shore or the Welland-Nene area.

174. The intertidal sand and mudflats of the Wash are the winter feeding grounds of very large numbers of wading birds. The average peak count over four winters (1970/71 - 1973/74) of 175,700 birds is certain to be an underestimate of the actual numbers using the Wash because different populations of the same species may either pass through briefly on their way to and from wintering grounds elsewhere or may stay for longer periods (up to 10 months). However, when compared with figures obtained by comparable counting methods in other areas this number indicates that the Wash is one of the two most frequented bays in Britain (the other being Morecambe Bay with average peak counts of c.230,000). It is particularly important in a national and international context as a winter habitat for Grey plover Pluvialis squatarola (3,280), Bar-tailed godwit (Limosa lapponica (8,300), knot Calidris canutus (74,000) and dunlin Calidris alpina (52,350) (being 23%, 17%, 18% and 10% respectively of the British counts and 9%, 10%, 12% and 5% respectively of the European counts).

175. Evidence from counts and from feeding, ringing and biometric studies suggests that particular sections of the Wash are favoured by both individual species and individual populations within species, and that, with the exception of knot and oystercatcher Haematopus ostralegus, there is little movement of individual birds from one section of the Wash to another, both within and between seasons. The west shore carries large numbers of passage migrants whereas the southeast corner supports both the largest overall numbers, and the largest populations of overwintering birds.

176. Studies of their feeding ecology suggest that the distribution of waders over their feeding grounds reflects the relative efficiency with which they can meet their energy requirements, there being distinct preferred areas for each species and other areas (where food is less dense, or less available, or of lower calorific value) exploited only when the preferred areas were unavailable. There was no conclusive evidence of mortality (or emigration) induced by food shortage during the two notably mild winters of this study, but a number of indicators of food shortage (e.g. increased time spent feeding as opposed to roosting) suggest that for most species food was more difficult to collect during the midwinter period (December, January and February) than at other times. This difficulty was greater in some species (e.g. knot) than others (e.g. oystercatcher).

177. The shelduck Tadorna tadorna is the most numerous wildfowl species, a peak figure of 13,900, more than twice that in any other British estuary, wintering on the Wash in 1971/72. In addition about 200 pairs of shelduck nested on the east Wash in 1974. Brent geese and Pink-footed geese Anser brachyrhynchus wintered in numbers often exceeding 5,000, the former being largely restricted to the west and south shores.

178. Other wintering bird species include gulls (Larus species) which both feed and roost in the Wash in large numbers (a minimum estimate of 83,000 arriving at the nocturnal roosts on one occasion), and a small linnet-like bird, the twite Acanthis flavirostris which feeds in flocks on seeds of salt marsh plants and occurs in numbers (20,000+) which exceed those in the whole of the rest of the British Isles.

179. Although only a few species nest on the salt marshes the densities of redshank Tringa totanus, skylark Alauda arvensis, Meadow pipit Anthus pratensis and Reed bunting Emberiza schoeniclus are high by comparison with those previously recorded from any habitats. Total densities for all species on census plots on upper marshes reached 200-300 pairs/km^2. Black-headed gulls Larus ridibundus largely breed in one very large colony (c.22,000 pairs in 1974) at Frampton in the southwest Wash.

180. Common seals are widely distributed in the Wash and form the largest single concentration of the species in the British Isles. The population has been estimated from tagging of pups and from aerial survey as being between 5,000 and 7,000. They haul out at low water on most of the sand banks and have their regular sites where the banks shelve steeply to deep water channels. Some seals haul out at high water on the edges of creeks in the salt marshes. The salt marshes are also important areas for pupping, especially in the area between the Nene and the Witham. The largest numbers of seals are in the south west sector where there is least human interference. Much of the feeding probably takes place outside the Wash, and the seals tagged in the Wash have been found along most of the east coast of England.

181. The three main fisheries in the Wash, for shrimps, cockles and mussels are based mainly on the ports of King's Lynn and Boston. Between 1970 and 1973 the value of the catch fluctuated between £200,000 and £320,000 at first sale. Of this the shrimp fishery accounted for between 47% and 60%, cockles between 28% and 45% and mussels between 7% and 11%. There are cockle and mussel beds on most of the inner sand banks and the position of the best fishery varies from time to time, depending on the survival of the spatfall from year to year and place to place. In the last few years the best cockle fisheries have been along the west shore for boats from Boston and on Daseleys Sand and a small area near the Old Barrier Wall for boats from King's Lynn. Mussels are fished chiefly in the south west part of the Wash. Brown shrimps are fished in the channels between the inner sand banks such as the Teetotal Channel and Daseleys Sled. Pink shrimps are found, however, in deeper water and are fished in the outer part of the Wash.

182. Predictions of the 'direct' effects of the construction of each of the proposed Stage 1 and Stage 2 reservoirs in the Wash have been made by estimating the areas of salt marsh, the numbers of each of the main species of invertebrates and numbers of each bird species feeding, roosting or breeding within the areas actually covered by each scheme. For the invertebrates and ten major wader species and shelduck some 'indirect' effects have also been considered, assuming for the birds that the ability to utilise the remaining feeding grounds will vary from species to species depending on aspects of its feeding and behavioural flexibility. As a general principle, enclosure of upper levels of marsh and flats for reservoirs is likely to lead to accelerated accretion of silt and new marsh development off-shore - thus permitting continuing reclamation for agriculture. But the amount of mud flat providing a habitat for invertebrates and hence a food resource for birds is likely to be progressively reduced. The extent to which these tendencies apply varies in each case.

183. Because it fronts the longest section of sea wall the Stage 1 reservoir at Bulldog is likely to displace the largest area of salt marsh (as it would have if built in 1974) whatever the pattern of salt marsh growth and reclamation between now and the start of construction. The south shore Stage 1 sites displace similar areas of marsh although they vary in the extent to which new salt marsh might be formed to seaward. None of the sites would eliminate salt marsh with unique floristic features. The Stage 2 sites would have a considerably larger effect, Terrington + Bulldog displacing an existing area of over 700 hectares of salt marsh and a part of the algal-rich zone in the Wash characterised by mud mounds, as well as displacing many salt marsh breeding birds, (e.g. approximately 400 pairs of redshank, a species for which the Wash is a nationally important breeding site). The area supporting the largest number of salt marsh nesting birds, in the southwest corner of the Wash, is likely to remain unaffected.

184. The southeast corner of the Wash is the main feeding area for waders and shelduck, with the densest populations of most of the intertidal animals. It supports up to a half of the total Wash population of all wader species (over 80,000 birds in 1972/73). The effects of a water storage reservoir in this area are thus greater than the proportion of the Wash area it covers would suggest. The species most affected would be knot and shelduck, both of which would have large proportions of their feeding ground displaced and might find difficulty in being accommodated elsewhere. In contrast, oystercatchers, for example, could remain largely unaffected, even by a Stage 2 scheme. Taking into account the potential of each species for meeting its feeding requirements elsewhere on the Wash the Stage 1 reservoir sites may be ranked in increasing order of effect on wader species as follows: Wingland or West Stones, Bulldog, Breast, although the greatest biomass of invertebrate food species was in the Bulldog area. The Stage 2 schemes may be similarly ranked: Walpole + Bulldog, Terrington, Terrington + Bulldog.

185. The seals would not be directly affected by any of the Stage 1 schemes when built, as there are no haul-out sites in the areas covered, and only a small site would be covered by the Terrington or Walpole Stage 2 schemes. The greatest effect on the seals would be caused by boat traffic and noise associated with the building of any reservoir. This would disturb the seals and possibly cause them to desert the haul-out sites near the affected channels.

186. The direct effect of any of the Stage 1 reservoirs on commercial fisheries is likely to be small. The West Stones area encloses cockle beds that have been recently fished, the Breast area encloses some little used mussel beds, and there are no fisheries in the Bulldog and Wingland areas. Of greater importance however would be the obstruction of access to the Teetotal Channel from the Great Ouse by a West Stones reservoir if no new channel is opened to the north of the bund. A Stage 2 Terrington reservoir would enclose the cockle and mussel beds mentioned above and other mussel beds to the south of Daseleys Sand, and would also block the channel between the Teetotal Channel and the Ouse. The main secondary effect of a Terrington reservoir would be siltation in the Teetotal and Old Lynn channels which would adversely affect the brown shrimp fishery.

187. From the foregoing it should be clear that there is no one of the four Stage 1 schemes that is "best" or "worst" from all ecological points of view. Table 8 is an attempt to evaluate the various proposals using arbitrary scoring. On balance the Wingland scheme would have the least effect and a Bulldog or Breast reservoir the most effect. Of the Stage 2 proposals a Terrington plus Bulldog scheme would undoubtedly cause most damage and Terrington alone the least.

188. The construction of a freshwater reservoir in the Wash could provide a unique opportunity both to study the effects on the vegetation and birds and by incorporating imaginative design features, to create totally new environments. A policy decision would be needed at an early stage on whether maximal accretion and reclamation of land for agriculture should be sought (and included in cost-benefit analyses), or whether creation of new wildlife habitats should have priority, or both. This decision would be more soundly based if the models developed in this study were further validated and better prediction of likely sediment accretion and tidal patterns obtained.

TABLE 8: EFFECT OF RESERVOIR PROPOSALS

1 = Little or no effect.

2 = Moderate effect.

3 = Major effect.

+ = Worst effect of the schemes considered.

A. STAGE 1

	WINGLAND	BREAST	WEST STONES	BULLDOG
INVERTEBRATES	3	3	3	3+
SEALS	1	2+	1	1
FISHERIES	1	2	2+	1
BIRDS (WADERS)	3	3+	3	3
BIRDS (SHELDUCK)	3	3	3	3+
SALT MARSH	2	2	2	3+

B. STAGE 2

	TERRINGTON	TERRINGTON + BULLDOG	WALPOLE + BULLDOG
INVERTEBRATES	3	3+	3
SEALS	2	2+	2
FISHERIES	2	2+	2
BIRDS (WADERS)	3	3+	3
BIRDS (SHELDUCK)	3	3+	3
SALT MARSH	2	3+	3

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