# An introduction to Holocene land–ocean interaction and environmental change around the western North Sea

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The majority of the research presented in this Special Publication arises from the Land–Ocean Evolution Perspective Study (LOEPS), one component of the Land–Ocean Interaction Study (LOIS), Phase 1 of which ended in 1998. It is therefore appropriate to introduce this research in the context of LOIS as a whole before summarizing the main conclusions relating to LOEPS.

## An overview of the Land–Ocean Interaction Study

The Land–Ocean Interaction Study (LOIS), was a seven-year Natural Environment Research Council (NERC) funded Community Research Project (CRP). The detailed planning for LOIS began in 1990 and continued into 1991 as a series of workshops, which laid the foundations for the LOIS Science Plan (1992). The LOIS CRP was conceived as a collaborative multidisciplinary study to be undertaken by UK scientists from NERC institutions and the higher education institutes (HEI). The coastal zone was to be studied in an integrated way, to provide a holistic view of the way coastal systems work and to demonstrate how they might respond to future changes resulting from human activities. It was also anticipated that LOIS research would interface with other contemporary NERC CRPs, including the North Sea Project (see e.g. Charnock *et al.* 1994), the Biogeochemical Ocean Flux Study (see, e.g. introduction in Savidge *et al.* 1992), and the Terrestrial Initiative in Global Environmental Research (see e.g. Oliver *et al.* 1999).

The objectives of LOIS were set out in the science plan (LOIS Science Plan 1992) and then in revised form in the implementation plan (LOIS Implementation Plan 1994).

(1) To estimate the contemporary fluxes of momentum and materials (sediments, nutrients, contaminants) into and out of the coastal zone, including transfers via rivers coasts, ground-water, the atmosphere and the shelf–ocean boundary.
(2) To characterize the key physical and biogeochemical processes that govern coastal morphodynamics and the functioning of coastal ecosystems, with particular reference to the effects of variations in sediment supply and inputs of pollutants.
(3) To describe the evolution of coastal systems from Holocene to recent (*sic*, we assume this was meant to mean present) in response to changes in relative sea-level and the impact of human activities.
(4) To develop coupled land–ocean models to simulate the transport, transformation and fate of materials in the coastal zone, and provide the basis for predicting hydrological, geomorphological and ecological conditions under different environmental scenarios for the next 50–100 years.

It was hoped that these objectives would be achieved by the implementation of four interlinked, and in some cases overlapping component studies as described in Fig. 1. Much of the LOIS research was centred on the River–Atmosphere–Coast Study (RACS) site (Fig. 2), which included the east coast of England between Berwick-upon-Tweed and Great Yarmouth, to include the various river catchments and the adjoining area of the North Sea.

## The Land–Ocean Evolution Perspective Study

The Land–Ocean Evolution Perspective Study (LOEPS) was charged with meeting objective 3 of LOIS (see above). It was clear that understanding the history of material fluxes over long time scales was a prerequisite for making

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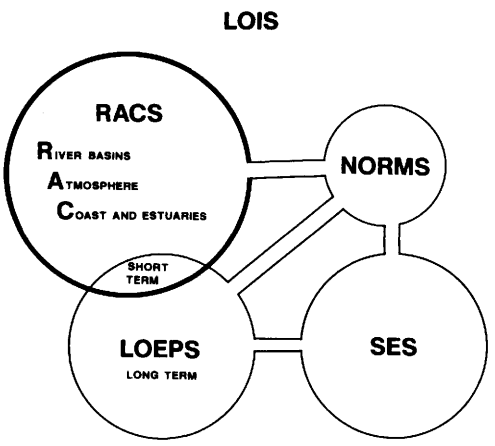


**Fig. 1.** Schematic representation of the interrelation between the four component studies of LOIS. RACS, River–Atmosphere–Coast Study; NORMS, North Sea Modelling Study; SES, Shelf Edge Study; LOEPS, Land–Ocean Evolution Perspective Study. The overlap between RACS and LOEPS reflected overlap on decadal to centennial time-scales.

sensible predictions about the way the coastal zone might respond to future environmental changes. It was envisaged that five LOEPS objectives would be addressed (LOIS Implementation Plan 1994).

(1) To determine, through study of the Holocene sedimentary record and changing coastal disposition, how sediment fluxes between the land and ocean have been influenced by changes in sea level, climate, geomorphology and land-use.
(2) To determine the regional history of sediment fluxes, sources and sinks at the RACS site, with particular reference to the relative importance of fluvial, coastal and sea-bed sediment sources.
(3) To determine the historical components of relative sea-level change along the coast, enabling refined predictions for the next 50–100 years.
(4) To improve absolute dating of Holocene sedimentary sequences.
(5) To model Holocene tidal and storm circulation affecting sedimentation in collaboration with the North Sea Modelling Study (NORMS) (see Fig. 1).

The overall aim of LOEPS was thus to describe the evolution of coastal systems over the last 10 000 years in response to changes in natural climatic conditions, changes in relative sea-level and the changes wrought by human activities. This was to be achieved through special topic thematic studies, typically at HEIs, and through a Core Programme of central and co-ordinating functions performed by the British Geological Survey (BGS). The Core Programme was to: (a) compile and maintain the LOIS geoscience database; (b) administer and manage sediment sampling and curation, including a drilling campaign of new cored boreholes both offshore and onshore; (c) co-ordinate a radiocarbon dating programme through the NERC East Kilbride Laboratory; (d) compile and refine the regional Holocene stratigraphy of the RACS area in both a national and European context; (e) to assemble data on the regional history of sediment flux in the RACS area, its sources and sinks through the Holocene to the present day.

## Implementation of LOEPS research

Following on from the LOIS Science Plan (1992), LOIS research began in 1993 and the LOIS Implementation Plan (1994) was published. By this time the details of the LOEPS had crystallized into 15 special topics (Table 1), co-ordinated by the Core Programme as envisaged in the science plan. Specific objectives were focused to reflect the research teams assembled and centred on five key areas.

Objectives 1 and 2 were essentially unchanged from the planning stage (see above) and have involved the Core Programme at BGS, special topics concentrating largely on new core material from the Tees Estuary (**Plater *et al.***), the Humber estuary (**Andrews *et al.***; **Metcalfe *et al.***; **Rees *et al.***; **Ridgway *et al.***), the Lincolnshire Marshes, the Fenland (**Brew *et al.***), North Norfolk (**Andrews *et al.***), the river catchments draining into the Humber and Tees (**Macklin *et al.***), lake systems within the Humber catchment, and the integration of the data from all these areas. Sediment source, sink and flux information was aided by a geochemical study as part of the Core Programme (see e.g. Plater *et al.*; Rees *et al.*, Ridgway *et al.*).

The other objectives were defined later, at the stage of finalizing the LOIS Implementation Plan in 1994. Objective 3 to determine the historical components of relative sea-level change along the coast, enabling refined predictions for the next 50–100 years, required the synthesis of data collected by many of the research teams (**Shennan *et al.***). There have been four major elements to address objective 4: a large, co-ordinated accelerator mass spectrometry (AMS) radiocarbon dating project (**Shenan *et al.***); development of

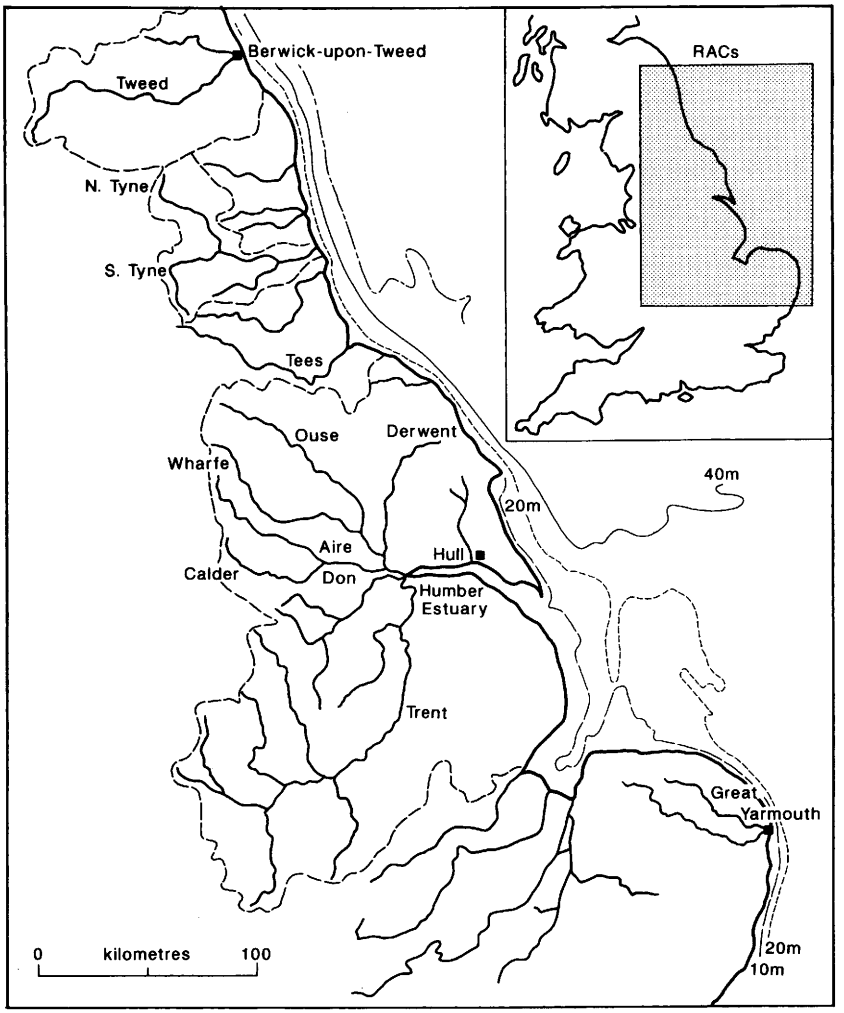


**Fig. 2.** Map of the RACS study site (shaded area on inset) showing principal catchments studied (pecked line).

new techniques in luminescence dating (**Bailiff & Tooley**; **Clarke & Rendell**) application of palaeomagnetic techniques to coastal clastic sediments (**Ridgway *et al.***); geochemical and isotope techniques for the last 150 years (**Andrews *et al.***; **Plater *et al.***). Objective 5 involved three main elements. **Horton *et al.*** report new approaches to identify and date different tide levels from Holocene sequences and **Shennan *et al.*** model Holocene tidal circulation affecting in the western North Sea. The final element, to model both Holocene tidal and storm circulation and how in combination they affect sedimentation, forms part of Phase 2 of LOIS, which continues to AD 2000.

A key element to the success of LOEPS has been the integration and interaction between all elements of the special topics and the Core Programme. The papers presented at the symposium and the contributions to this volume aim to reflect this integration rather than summarize the results of individual research projects or the achievement of a single LOEPS objective. The contributions are arranged into four thematic sections:

- techniques;
- Humber catchment;
- other areas within the RACS study site;
- regional scale analyses.

**Table 1.** *The 15 thematic special topics*

| LOIS project No. | Principal investigators | Special topic title |
|---|---|---|
| 12 | M. G. Macklin & J. Ridgway | Holocene and historic environmental change in the Yorkshire Ouse, Tees and Tweed basins and its influence on sediment and chemical fluxes to east coast estuaries and the coastal zone |
| 31a | J. E. Andrews, T. D. Jickells, B. A. Maher, A. Grant, P. F. Dennis & R. M. Middleton | Organic carbon, nutrient and metal contents and storage in saltmarsh and estuarine sediments of the Humber |
| 32 | G. M. Harwood†, J. E. Andrews, P. N Chroston, B. M. Funnell, A. C. Kendall, B. A. Maher, P. Balson, I. K. Bailiff, C. Bristow M. J. Tooley & G. B. Shimmield | Sedimentary evolution of the North Norfolk barrier island coastline in the context of Holocene sea-level change |
| 33 | A. J. Plater | Relating post-glacial sediment fluxes in the Tees Estuary to changes in sea-level, coastal morphology and catchment land-use |
| 41 | H. Rendell, P. Townsend & R. Parish | Development of a methodology for luminescence dating of Holocene sediments |
| 65 | J. R. L. Allen, A. Parker & K. Pye | The Wash–Fenland embayment: sediment sources and supply in the Holocene |
| 75 | J. Orford, P. Wilson & A. Wintle | Recent environmental history of coastal dune fields in north Norfolk and northeast Northumberland in relation to land–sea interactions |
| 78 | F. Oldfield, R. W. Battarbee, R. Thompson & G.A. Wolff | A lake-sediment-based study of the Holocene history, flux and characterization of fine, particulate, terrestrially derived sediments in the Humber region |
| 240 | I. K. Bailiff & M. J. Tooley | Development of a methodology for luminescence dating of Holocene sediments. |
| 272 | J. Sheail | Documentary evidence of changes in the fluxes of the riverine and coastal ecosystems |
| 283 | A. Wintle | Development of a methodology for luminescence dating of Holocene sediments |
| 313 | I. Shennan | Differential crustal movements within the RACS study site (Berwick-Upon-Tweed to north Norfolk) |
| 316 | I. Shennan & R. T. R. Wingfield† | Modelling Holocene depositional regimes in the western North Sea at 1 ka time intervals |
| 346 | P. S. Balson & D. S. Brew | Sediment provenance and palaeogeographical evolution of the Wash embayment |
| 348 | S. Metcalfe, S. Ellis, J. Pethick, I. Shennan & M. J. Tooley | Holocene evolution of the Humber Estuary |

† Deceased.

## Techniques

Because some of the methodologies and techniques were common to a number of the special topics, the paper by **Ridgway *et al.*** was conceived in part to communicate the details of various methods, such that the information is not repeated in all of the individual papers. However, **Ridgway *et al.*** are also able to demonstrate how the ensemble of techniques are applied at a regional level. A number of cores from the Holocene of the Humber were chosen to illustrate how the multi-technique approach yields data sets that are reinforcing, leading to confident and powerful environmental reconstructions.

**Horton *et al.*** present quantitative methods, transfer functions for fossil foraminifera assemblages calibrated from contemporary analogues, that together with AMS radiocarbon dating of calcareous foraminifera enable a greater range of Holocene sediments than previously available to be used as indicators of past tide levels. Wider application of these techniques offers new

directions for research in sea-level reconstruction at scales ranging from individual estuaries to regional phenomena such as changes in tidal parameters during the Holocene and differential effects of glacio- and hydro-isostasy. These data are used in other contributions to this volume.

A major area of concern was to try and improve the methodologies for dating minerogenic sediments within the Holocene coastal sediments, especially those that were water-laid. To this end, considerable effort was directed towards improving the methodologies for luminescence dating. The achievements in this area are reflected in two papers that specifically address methodology (**Bailiff & Tooley**; **Clarke & Rendell**), while other aspects of method development and application are implicit in the contributions from **Orford *et al.***, **Andrews *et al.***, (Norfolk) and **Plater *et al.*** **Clarke & Rendell** focused on the use of alkali feldspars as ideal 'dosimeters', utilizing a better understanding of the characteristics of the feldspars to optimize the luminescence signal for dating marine coastal zone sediments. **Bailiff & Tooley's** contribution centres on a Fenland core where radiocarbon-dated organic intercalations occur at various levels within an otherwise minerogenic core. Infra-red-stimulated luminescence (IRSL) of the silt fraction of these water-laid sediments gives ages that are largely consistent with the radiocarbon dates. Chronological resolution of 1 ka or better is probably achievable by the (IRSL) method employed.

## Humber Estuary

The Holocene sediments of the Humber catchment and estuary and their evolution were very poorly understood before LOEPS. This led to a number of allied studies focused on the Humber system. Using the Ouse system as an example from the Humber catchment, **Macklin *et al.*** investigated the geomorphological, geochemical and chronological elements of fluvial sedimentary sequences from the upland to the estuarine lowland. They reveal a complicated relationship between river response and environmental forcing parameters such as land-use and climate change. They suggest that for much of the Holocene, sediment delivery from the Ouse catchment to the Humber Estuary was relatively low. **Rees *et al.*** used the new sediment cores from the LOEPS Core Programme to establish a lithostratigraphic and chemostratigraphic framework for the Holocene sequences of the infilled estuary. Eight characteristic sediment suites were identified, which show the progressive influence of marine sediments as sea level rose. In addition, widespread erosive episodes have left distinct geomorphic surfaces, while partially removing or redistributing older sediments. The preserved volumes of the sediment suites were calculated, while **Metcalfe *et al.*** studied the environmental facies evolution of the Holocene sediment prism as a whole. Sixteen environmental facies were identified mainly by diatom and pollen data, and using the radiocarbon chronologies to constrain sea-level history, maps of the changing environments and geography were constructed. In closely related work, **Andrews *et al.*** used various geochemical data from the Humber cores to reconstruct the storage history of organic carbon, nutrient elements and sulphur. This data, while contributing to the environmental facies identification, was used principally to construct one of the first well-constrained Holocene organic carbon budgets for a temperate estuary. A major result of this allied Humber research work has been to identify the clear effect of human activity on material and chemical flux in the late Holocene. The modern managed estuary has almost no space to store sediments or attendant chemicals, whereas the pre-reclamation system was a large sediment and material sink.

## Other areas within the RACS study site

The coastal morphology and Holocene evolution of the Tees Estuary, studied by **Plater *et al.***, like other coastal regions studied under LOEPS, has been influenced by sea-level change and human activity. The Tees area has been rebounding since the removal of glacial ice, such that the sea-level rise was decelerating between 8 and 3 ka BP. The sedimentary sequence is thus more strongly influenced by riverine-derived sediments, in contrast to sequences further south. Human activity and climatic changes have probably also influenced sediment flux, and the record of human activity is archived as metal pollution. The Holocene evolution of the north Norfolk barrier coast in the south of the study area contrasts strongly with the more estuarine sites. **Andrews *et al.*** demonstrate that the structure of the pre-Holocene surface is not a simple shelf, but contains a buried trough feature, probably an old river valley or glacial outwash feature. Details of the sandy barrier facies in this area were recorded for the first time, and the overall control on sedimentation is proposed to be autocyclic, superimposed on a facies evolution

governed broadly by sea-level rise. **Orford *et al.*** show that the initiation and survival of coastal dune sequences in Northumberland and north Norfolk relate to macroscale relative sea-level changes over the last 4 ka. Because of differential isostatic effects (see **Shennan *et al.***) the Northumberland dunes formed earlier and have responded to relative sea-level fall, while those in north Norfolk are much younger, forming and surviving under dominant relative sea-level rise. Both dune systems appear to respond to shorter-term disturbances, such as the Little Ice Age, and may also indicate small-scale variations in relative sea-level. The largest inland Holocene sediment sink on the east coast, the Fenland embayment, is analysed by **Brew *et al.***; their geochemical analyses suggest a general consistency of sediment provenance. They identify three macroscale episodes related to varying responses between sedimentation and relative sea-level change: initial and rapid transgression; sediment infilling of the embayment; deposition of intertidal clastic sediments alternating with peat accumulation.

## Regional scale analyses

The final two contributions analyse sea-level data from the whole study area. In the first, **Shennan *et al.*** quantify the isostatic effect of the glacial rebound process, including both the ice (glacio-isostatic) and water (hydro-isostatic) load contributions, showing a *c.* 20 m range at 8 cal. ka BP from north to south in the RACS area. By 4 cal. ka BP relative sea-level in Northumberland was above present, whereas in areas to the south relative sea-level was below present throughout the Holocene. Estimates for pre-industrial relative sea-level change range from $1.04 \pm 0.12\,\mathrm{mm\,a^{-1}}$ in the Fenland to $-1.30 \pm 0.68\,\mathrm{mm\,a^{-1}}$ (i.e. sea-level fall) in north Northumberland although this may overestimate the current rate of sea-level fall. Local-scale processes identified include possible differential isostatic effects within the Humber Estuary and the Fenland, tide-range changes during the Holocene, and the effects of sediment consolidation. These processes help explain the variation in altitude between sea-level reconstructions derived from index points taken from basal peats and those from peats intercalated within thick sequences of Holocene sediments. In the second paper, **Shennan *et al.*** use data from the RACS site and cores from the floor of the North Sea taken as part of the LOEPS Core Programme. The full data set enables the development and testing of models of the palaeogeographies of coastlines in the western North Sea and models of tidal range changes through the Holocene epoch. Key stages include a western embayment off northeast England as early as 10 ka BP; the evolution of a large tidal embayment between eastern England and the Dogger Bank before 9 ka BP with connection to the English Channel prior to 8 ka BP; and Dogger Bank as an island at high tide by 7.5 ka BP and totally submerged by 6 ka BP. After 6 ka BP the major changes in palaeogeography occurred inland of the present coast of eastern England. The models predict tidal ranges smaller than present in the early Holocene, with only minor changes since 6 ka BP.

This volume is just one output from LOEPS. As with any large science programme, much of the detailed research will be published in forthcoming scientific journal articles, many of which are referenced in the individual contributions here. Data arising from LOEPS are compiled and maintained at the LOEPS Data Centre at BGS, Keyworth, UK and will be published on a CD-ROM in 1999. This extensive LOEPS knowledge base can now be taken forward and factored into modelling studies and management strategies intended to promote improved environmental conditions in our rivers, estuaries and low lying coasts.

The research presented in this Special Publication stems largely from a symposium held at the Geological Society on 7 September 1998, jointly supported by the Geological Society and the Quaternary Research Association.

In addition to the commitment of the research teams, in particular the various post-doctoral and post-graduate research assistants, the success of LOEPS also stems from the effort and vision of the LOEPS Steering Committee and N. McCave, LOEPS Scientific Chairman up to 1996. We hope that our colleagues on the Steering Committee, R. Arthurton, I. Bailiff (from 1996), P. Balson, C. Evans, M. Macklin (from 1996), F. Oldfield (to 1996), J. Pethick and M. Tooley, will consider the book a fitting reflection of the imagination and hard work they put in to LOEPS. We are grateful to Lisa Tempest for her contribution to the organization of the symposium and the production of this Special Publication.

Finally, it is fitting to mention that two members of the LOEPS research community, Gill Harwood and Robin Wingfield, died before they were able to see the final results of their work. Gill was seriously ill throughout the planning and early years of LOIS research, and died in 1996. Robin completed his commitment to both special topic and Core Programme research and was present at the Geological Society Symposium in September 1998, but sadly died in Spring 1999 before seeing his results in print. We salute their efforts and hope that this volume is a fitting memorial to their memory.

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