Long-term estuary processes and morphological change

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with contributions from

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Available 'top-down' methods relying on data analysis.

Method	Comment
Holocene Analysis	Description of geological development of basin. Usually includes estimates of sea level change and identification of periods of marine regression and transgression.
Accommodation Space	Changes in sediment storage capacity of the estuary over Holocene timescale (10,000 years).
Regression Techniques	Use simple regression models to relate sediment types and vegetation to environmental variables.
Historical Trend Analysis	Interrogation of time series data to identify directional trends and rates of processes and morphological change over varying time periods.
Sediment Budget Analysis	Establishment of scenario(s) of sediment inputs, outputs and sources and sinks within the estuary system. Can use results from 'bottom-up' modelling.
Saltmarsh Analysis	Relates properties of exposure and tidal range to the presence and distribution of species. Can use results from 'bottom-up' modelling.
Expert Geomorphological Analysis	Using results from many of the different methods, together with an understanding of how different types of estuary form evolve, to assess the expected development of the estuary system.

Available ‘top-down’ methods relying on equilibrium assumptions or theoretical concepts.

Method	**Comment**
Regime Relationships	Relates estuary form properties such as cross-sectional area, plan area of inter-tidal or sub-tidal to tidal prism, volumes to given elevations, sediment type, and erosion threshold.
Form Analysis	Uses shape descriptions to characterise the estuary form (e.g., exponential width decay, or power law width and depth).
Tidal Asymmetry Analysis	Examines changes in tidal wave propagation as a function of estuary form.
Inter-tidal Form Analysis	Considers the equilibrium shape of the cross-shore profile.
Estuary Translation (rollover)	Defines the vertical and horizontal movements of the whole system as a consequence of changes in sea level.

Available 'hybrid' techniques.

Method	Comment
Coupled hydraulic and regime relationships	Given a perturbation to the estuary modelled this method uses a target equilibrium, defined by some form of regime relationship, to iterate to a new equilibrium.
Coupled hydraulic and entropy relationships	As above but defines a target steady state based on the concept of minimum work in the system as a whole.
Zero divergence of sediment flux	In this type of method, sediment is moved within the estuary and equilibrium is achieved when equal amounts are moved on the flood and ebb tide.
Coupled hydraulic and energy relationships	Examines the distribution of bed shear stresses and compares these values with an erosion threshold.
Other combinations of 'top-down' and 'bottom-up' techniques	Catch all category – but important to recognise that nearly all predictions of long-term morphological change associated with process based models utilise some form of 'top-down' input as the basis of inferring change.

Table of morphological predictive methods

Model Type	Model Name
Top Down	Accommodation Space
	Expert Analysis/Sediment Budget Analysis
	Regime Theory
	Mudflat Analysis
	Rollover
	Sed Balance
	Estplan
	Estform
	POLANT / ANST / ANSE
	Historical Trends Expert Analysis
	SHAPE-SED
	NICHE
	Conceptual Estuarine Model
Hybrid	Estmorf
	Mudpack
	Hymorph
	Estent
	Estreg
	Statistical-Dynamical Method
Bottom Up	Sedtrans
	POLEST
	Estbed
	ISIS
	Telemac 2D & 3D
	DIVAST 2D / TRIVAST 3-D
	1-D Cohesive Sediment Transport Model
	CUMBSED
	Bird Population
	Mike 11/12/21 suite/3
	PISCES

Historical Trend Analysis (HTA):

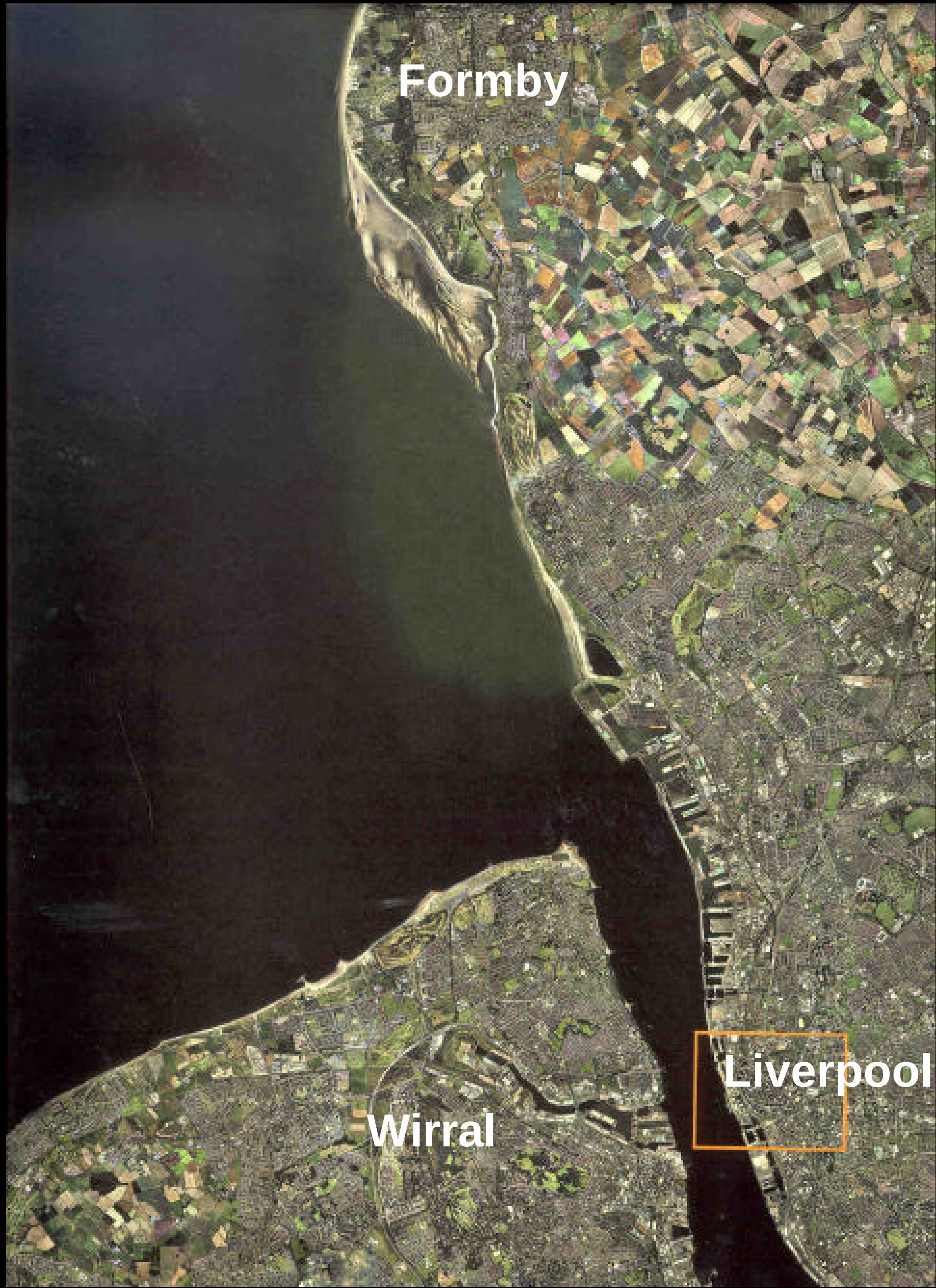
"Interrogation of time-series data to identify directional trends and rates of processes and morphological change, over varying time periods".

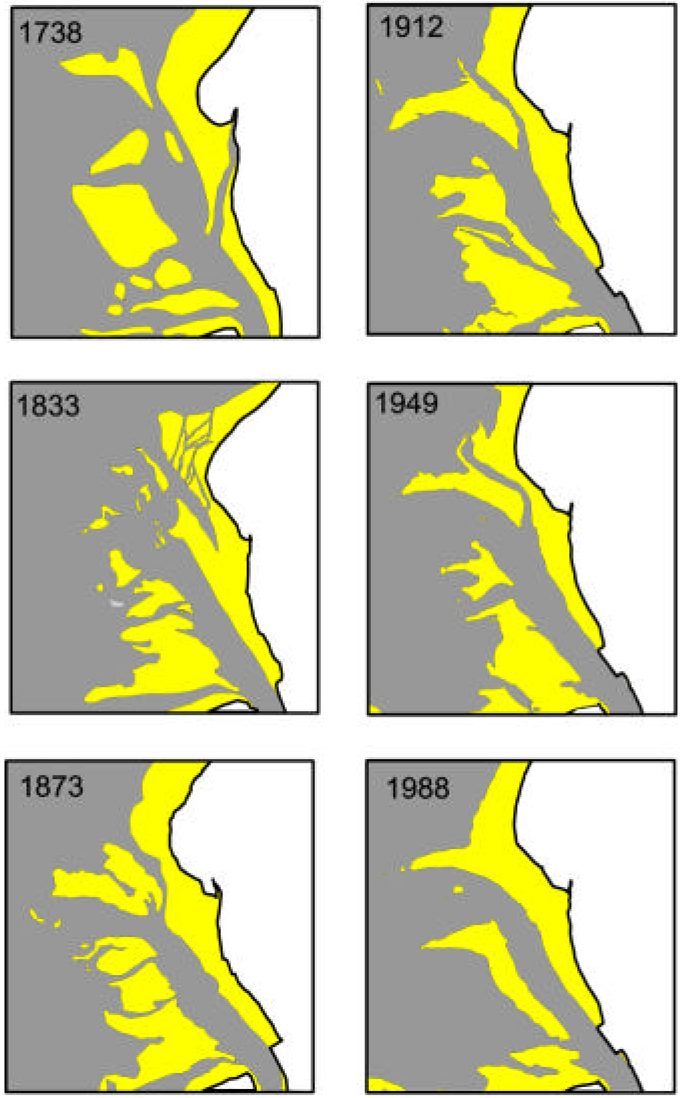
Expert Geomorphological Assessment (EGA):

"Integration of HTA with information about physical, chemical and biological processes, geological constraints, sediment properties and information about process-form interactions determined through field and laboratory experiments".

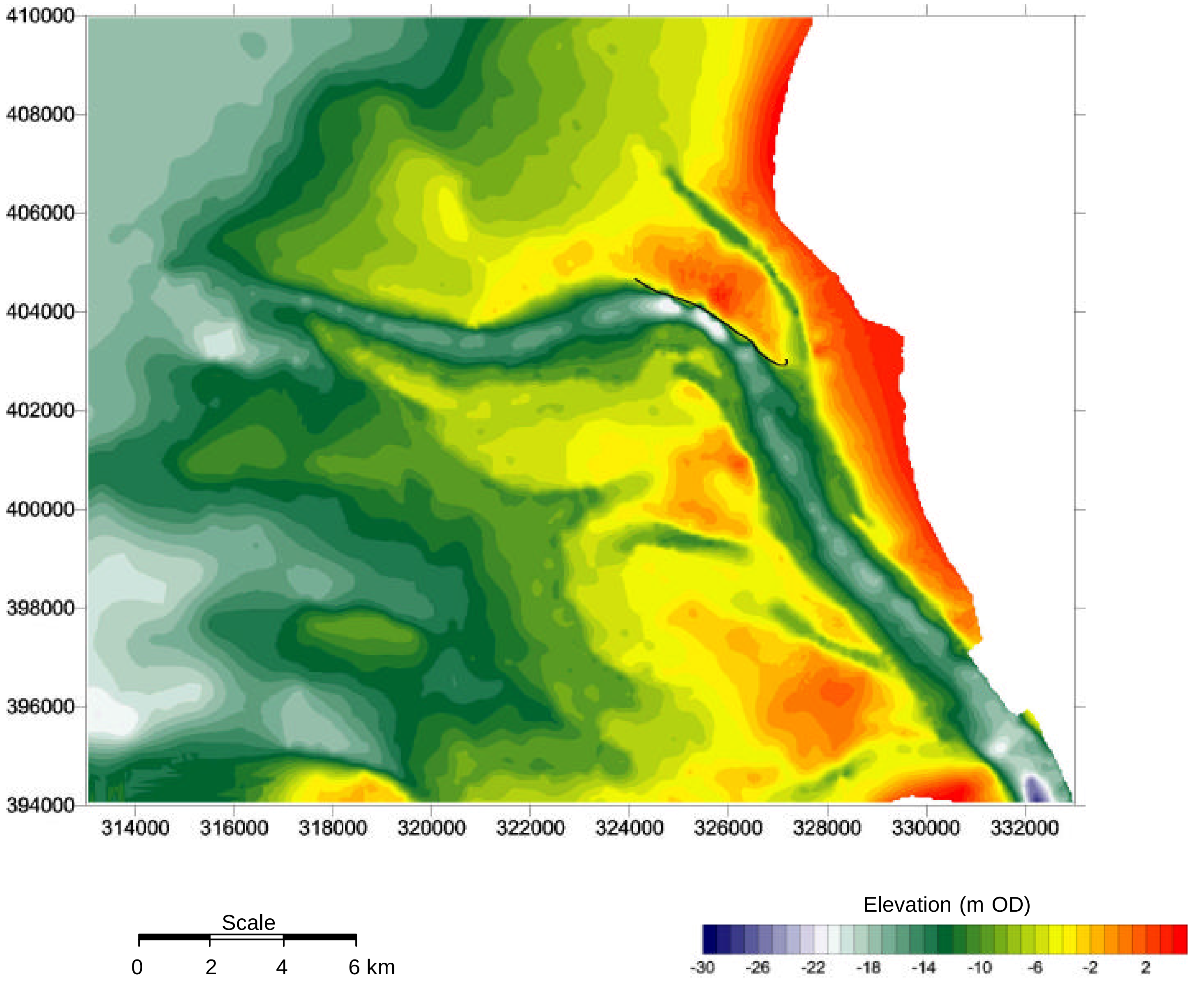
After Pye *et al*. (2002).

Aerial photograph of the Outer Mersey Estuary and Liverpool Bay.

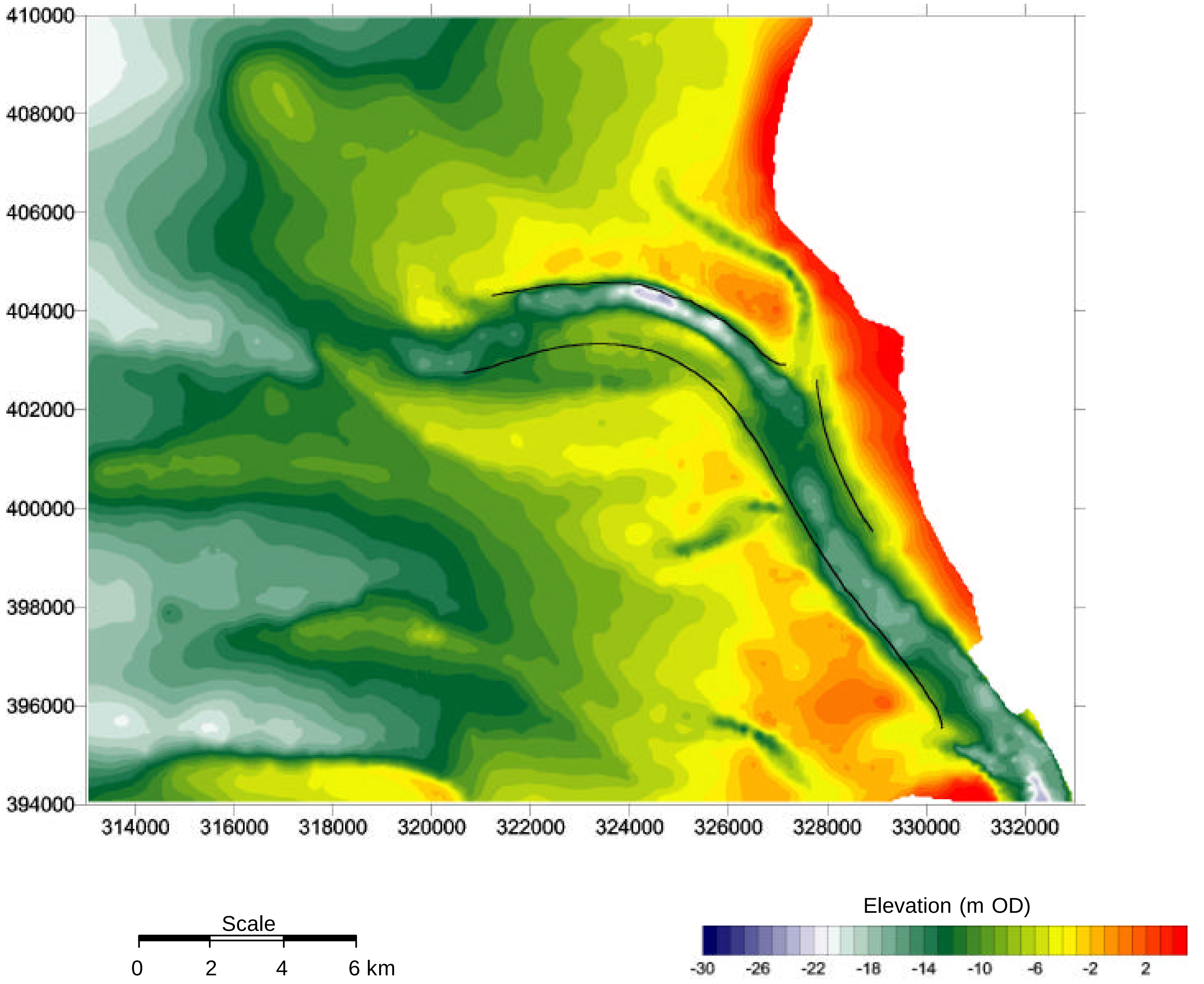




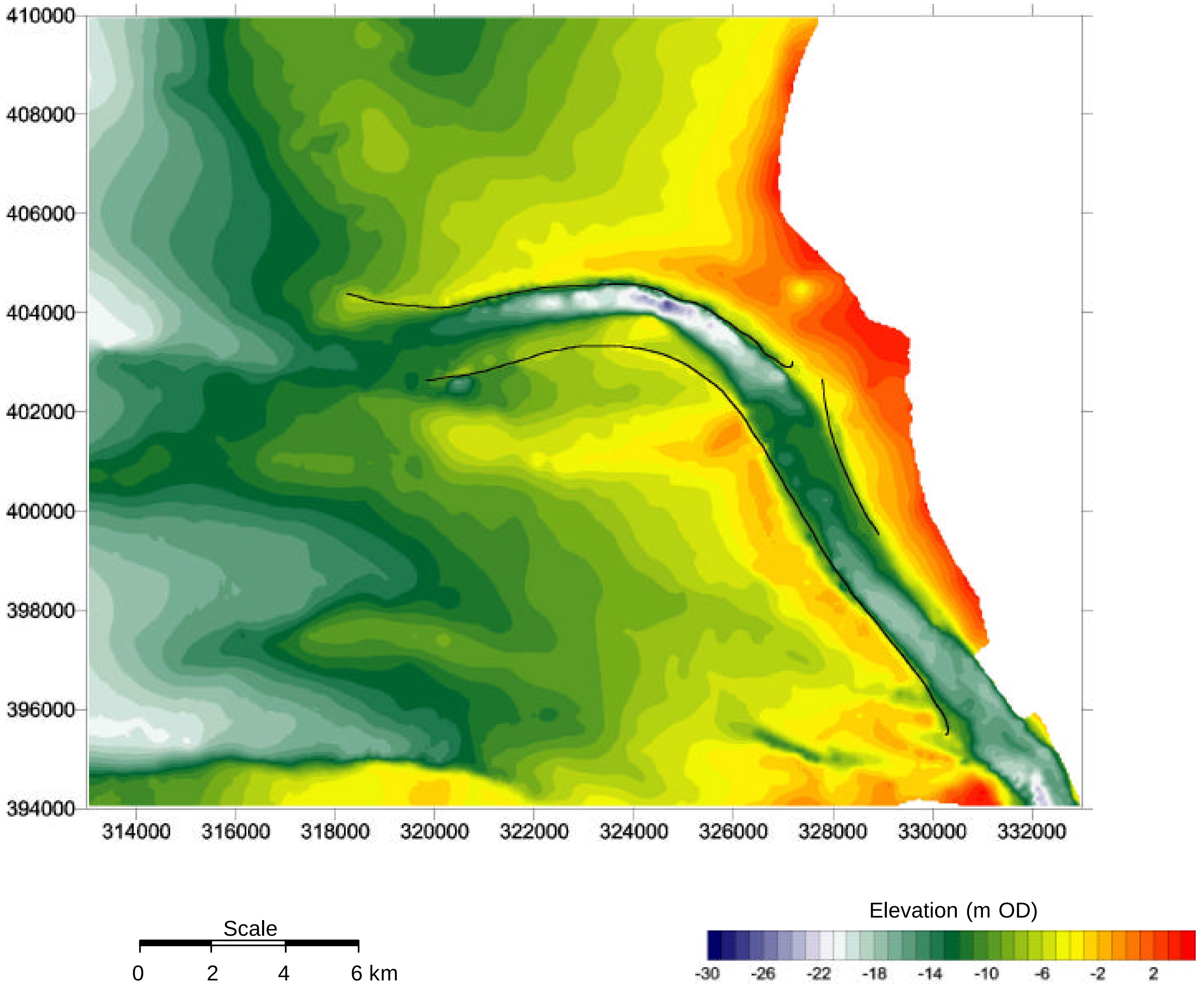
Position of sand banks and channels (areas above chart datum) in the Outer Mersey Estuary and Liverpool Bay digitised from historical charts (after van der Wal and Pye, 2000).



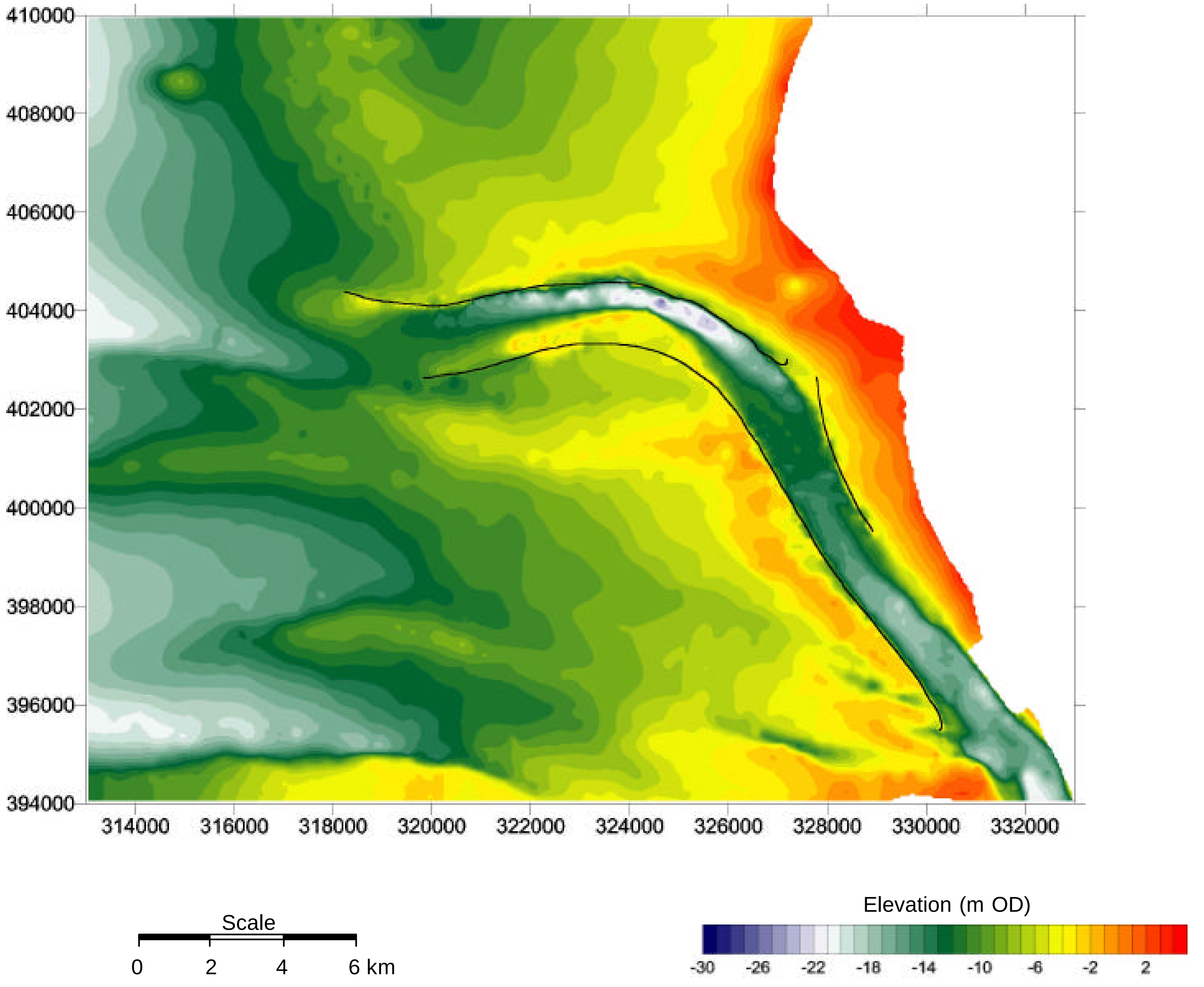
Bathymetric chart of the Outer Mersey Estuary and Liverpool Bay in 1912.



Bathymetric chart of the Outer Mersey Estuary and Liverpool Bay in 1949.



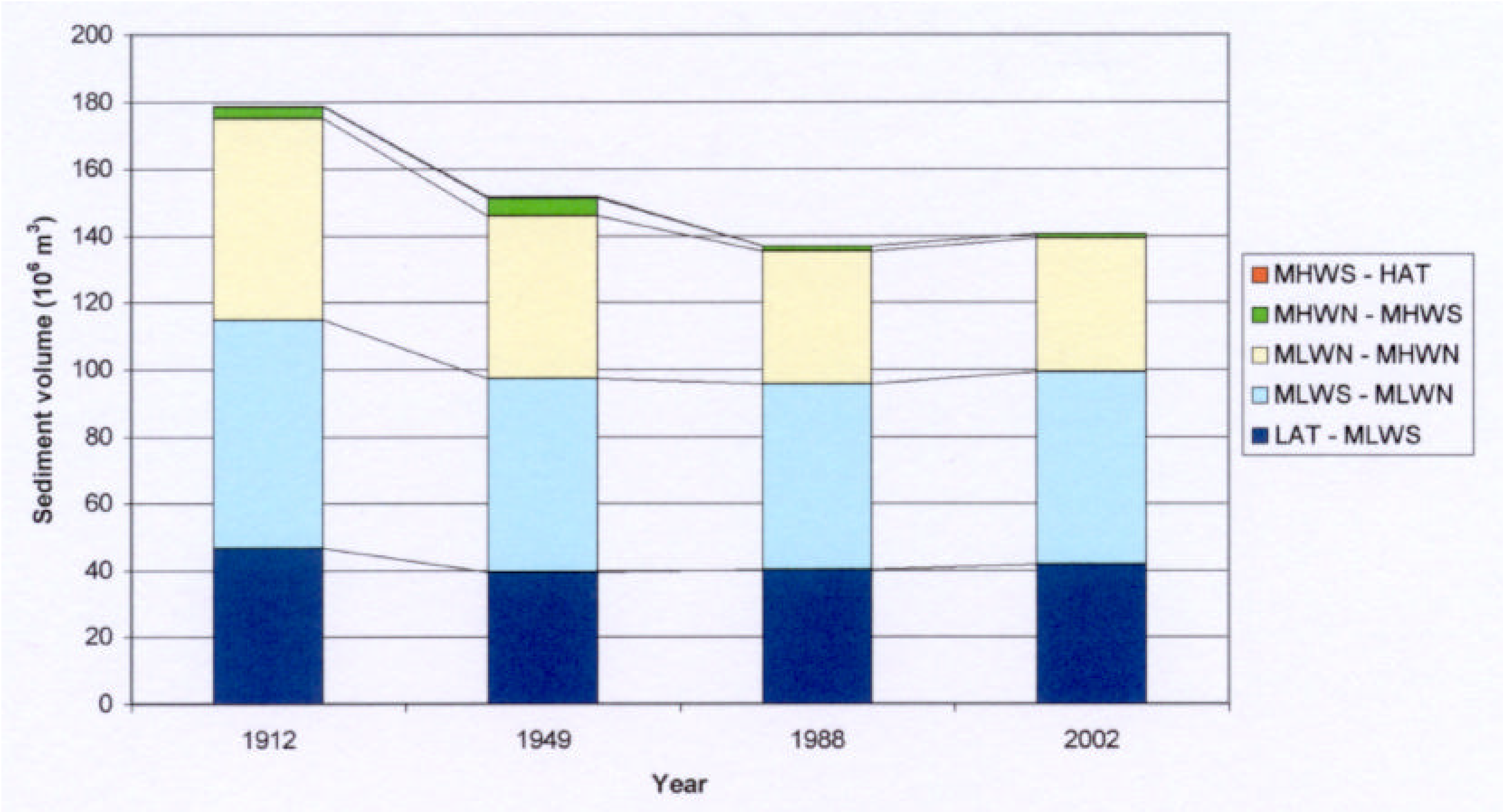
Bathymetric chart of the Outer Mersey Estuary and Liverpool Bay in 1988.



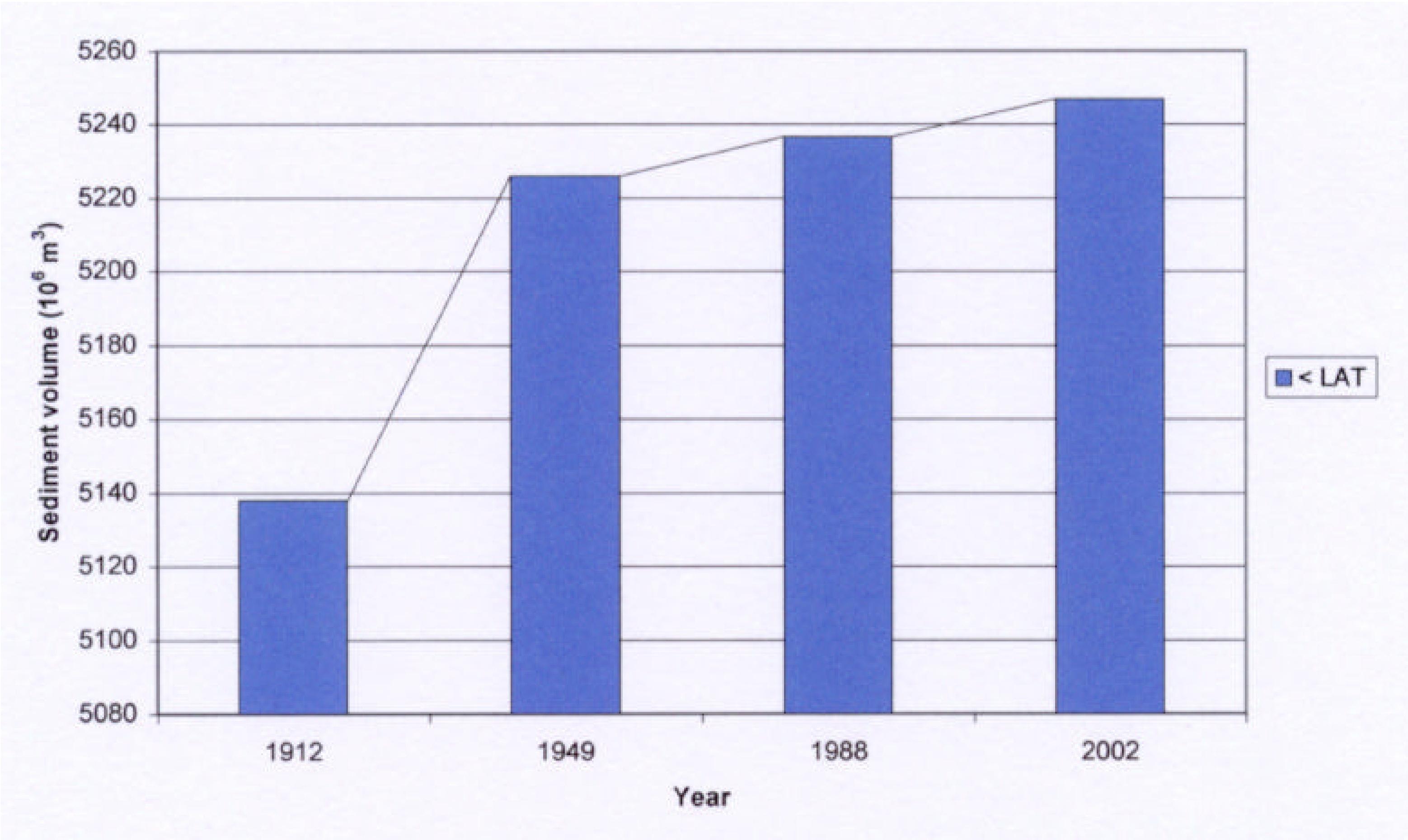
Bathymetric chart of the Outer Mersey Estuary and Liverpool Bay in 2002.

Table showing volumes (10^6 m^3) and areas (10^6 m^2) of sediment above various height datums in the Outer Mersey Estuary and Liverpool Bay (after Pye *et al.*, 2002).

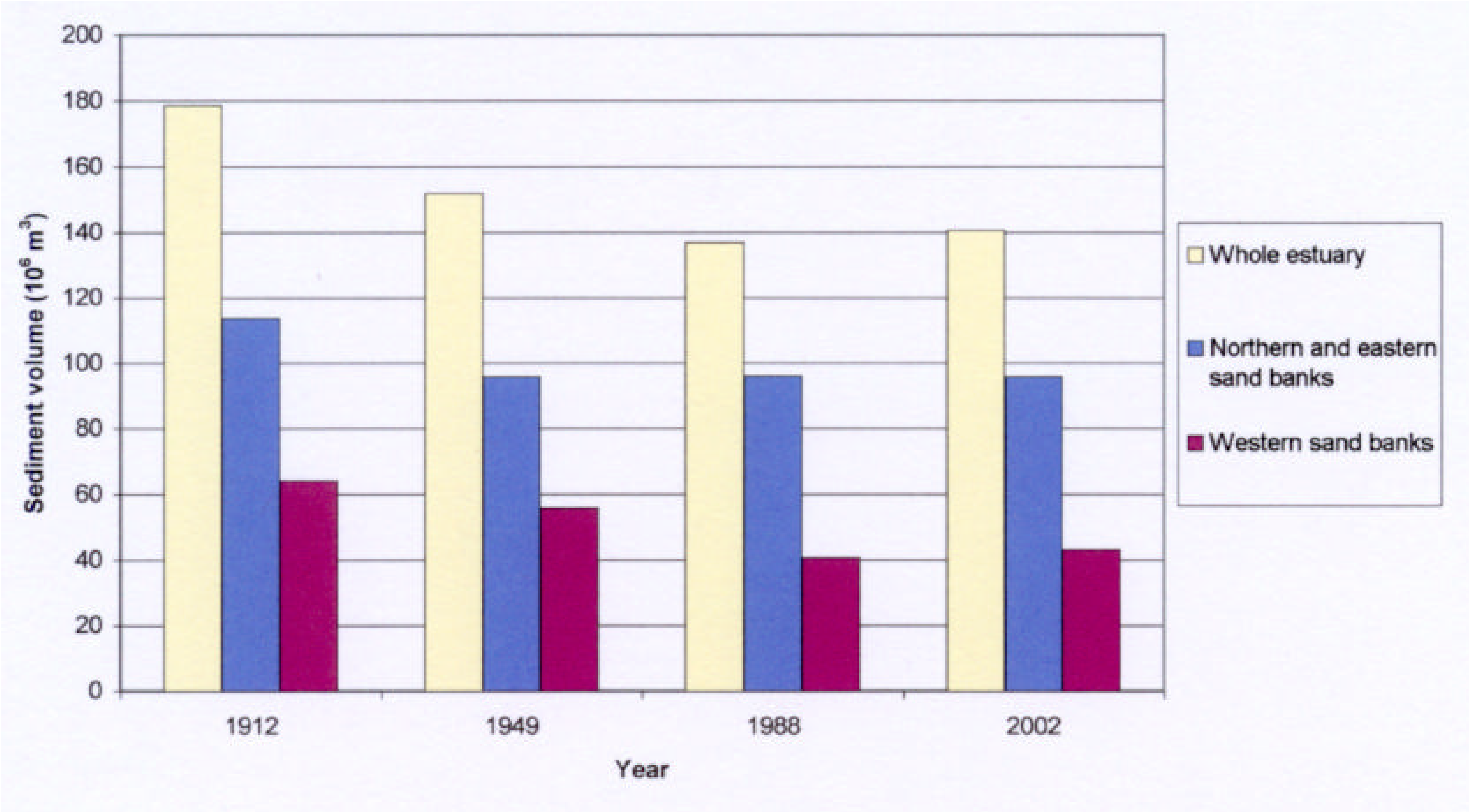
	1912	1949	1988	2002
Volume of sediment (above plane)				
HAT (5.27 m)	0.00	0.02	0.00	0.00
MHWS (4.37 m)	0.01	0.43	0.00	0.00
MHWN (2.47 m)	3.61	5.80	1.69	1.39
MLWN (-2.03 m)	63.78	54.53	41.27	41.33
MLWS (-4.03 m)	132.00	112.32	96.81	96.89
LAT (-4.93 m)	178.64	151.80	136.94	140.67
Plane (-10 m)	648.48	628.66	615.56	628.36
Plane (-15 m)	1495.22	1535.48	1532.78	1547.05
Plane (-20 m)	2699.04	2759.78	2582.33	2769.73
Plane (-30 m)	5316.74	5377.92	5373.75	5387.75
Volume of sediment relative to LAT				
HAT (5.27 m)	178.64	151.78	136.94	140.67
MHWS (4.37 m)	178.63	151.37	136.94	140.67
MHWN (2.47 m)	175.03	146.00	135.25	139.28
MLWN (-2.03 m)	114.86	97.27	95.67	99.34
MLWS (-4.03 m)	46.64	39.48	40.13	41.78
LAT (-4.93 m)	0.00	0.00	0.00	0.00
Planar area (above plane)				
HAT (5.27 m)	0.00	0.08	0.00	0.00
MHWS (4.37 m)	0.08	0.79	0.00	0.00
MHWN (2.47 m)	4.05	4.44	2.16	1.83
MLWN (-2.03 m)	25.01	20.78	17.33	18.37
MLWS (-4.03 m)	44.09	36.61	38.65	40.05
LAT (-4.93)	57.60	50.79	49.87	52.46
Plane (-30 m)	260.21	260.21	260.21	260.21
Intertidal area				
HAT-LAT	57.60	50.71	49.87	52.46
Springs	44.01	35.82	38.65	40.05



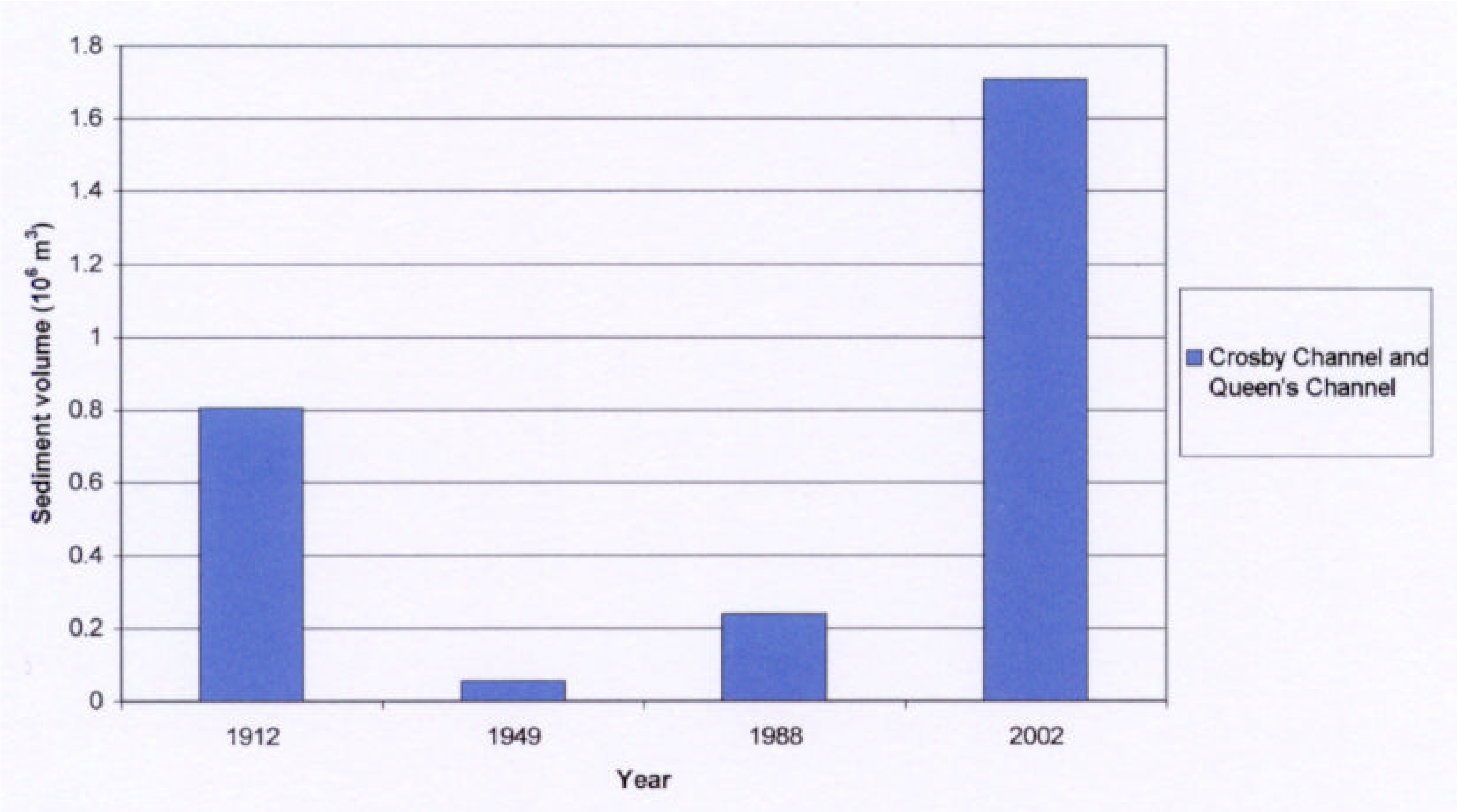
Changes in intertidal sediment volume in the Outer Mersey Estuary and Liverpool Bay (after Pye *et al*., 2002).



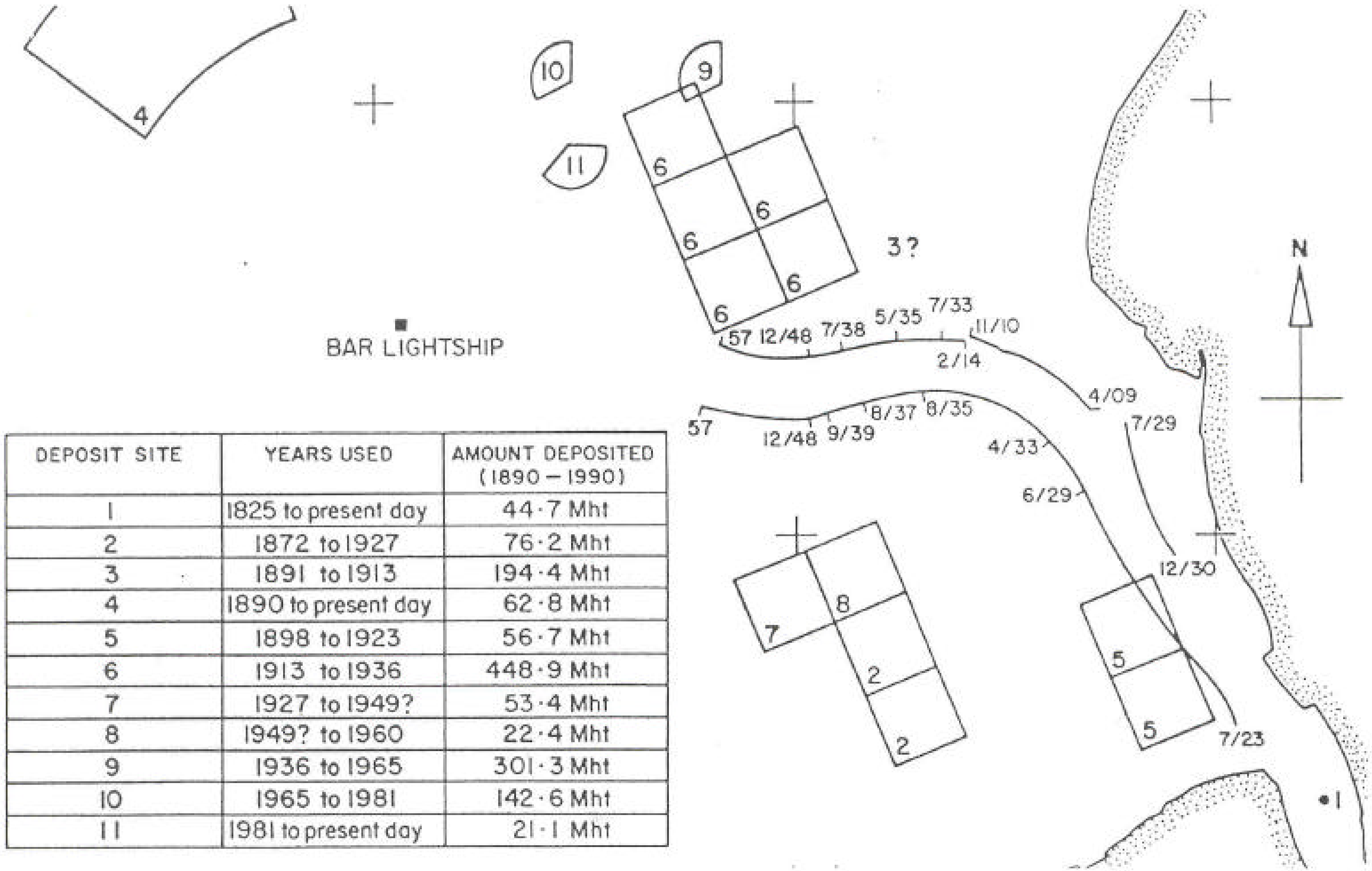
Changes in subtidal sediment volume in the Outer Mersey Estuary and Liverpool Bay (after Pye *et al*., 2002).



Changes in sediment volume above lowest astronomical tide in different areas of the Outer Mersey Estuary and Liverpool Bay (after Pye *et al*., 2002).

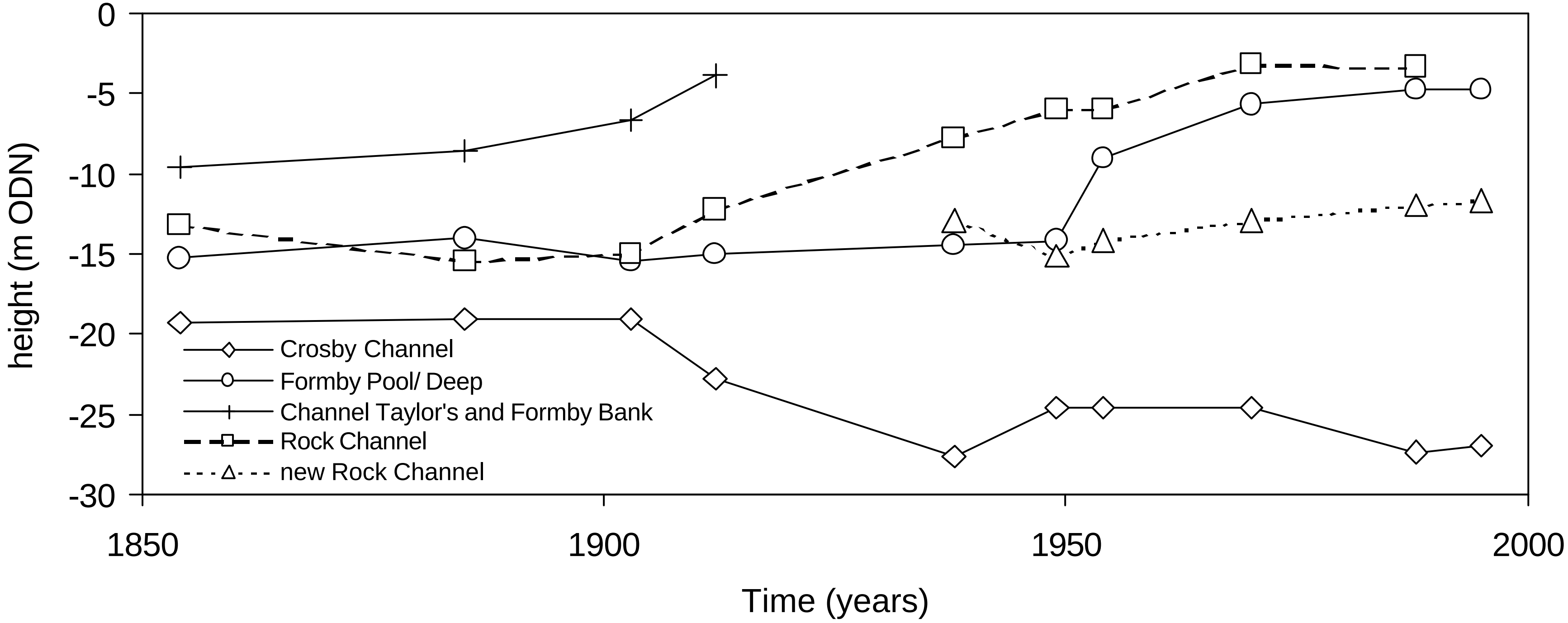


Changes in sediment volume above lowest astronomical tide in Crosby Channel and Queens Channel (after Pye *et al.*, 2002).



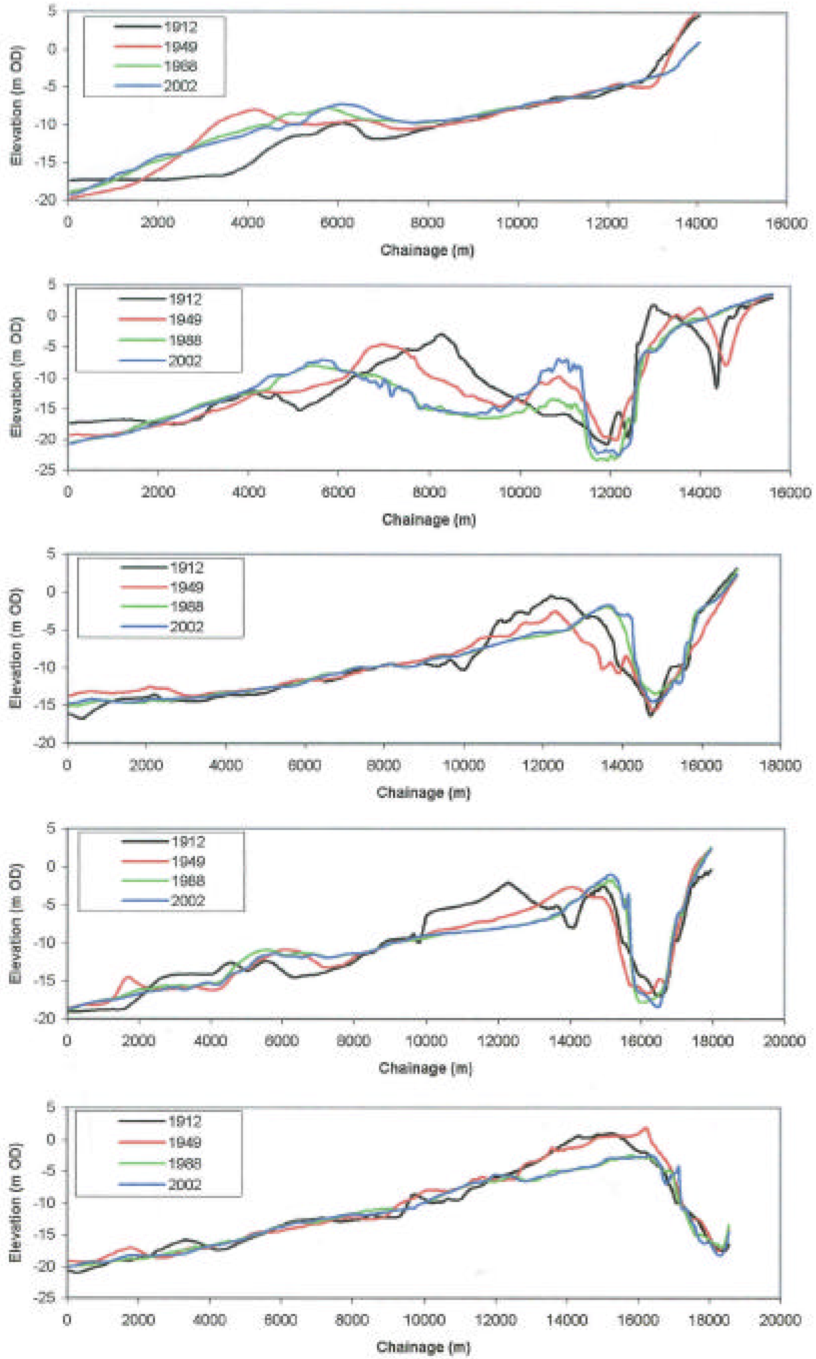
DEPOSIT SITE	YEARS USED	AMOUNT DEPOSITED (1890 – 1990)
1	1825 to present day	44·7 Mht
2	1872 to 1927	76·2 Mht
3	1891 to 1913	194·4 Mht
4	1890 to present day	62·8 Mht
5	1898 to 1923	56·7 Mht
6	1913 to 1936	448·9 Mht
7	1927 to 1949?	53·4 Mht
8	1949? to 1960	22·4 Mht
9	1936 to 1965	301·3 Mht
10	1965 to 1981	142·6 Mht
11	1981 to present day	21·1 Mht

Training walls and dredge spoil grounds in the Outer Mersey Estuary (after van der Wal and Pye, 2000).



Development of subtidal channels in the Outer Mersey Estuary and Liverpool Bay.

West-east cross-sections of the Outer Mersey Estuary for 1912, 1949, 1988 and 2002 (after Pye *et al*., 2002).



Y = 408000 m OS

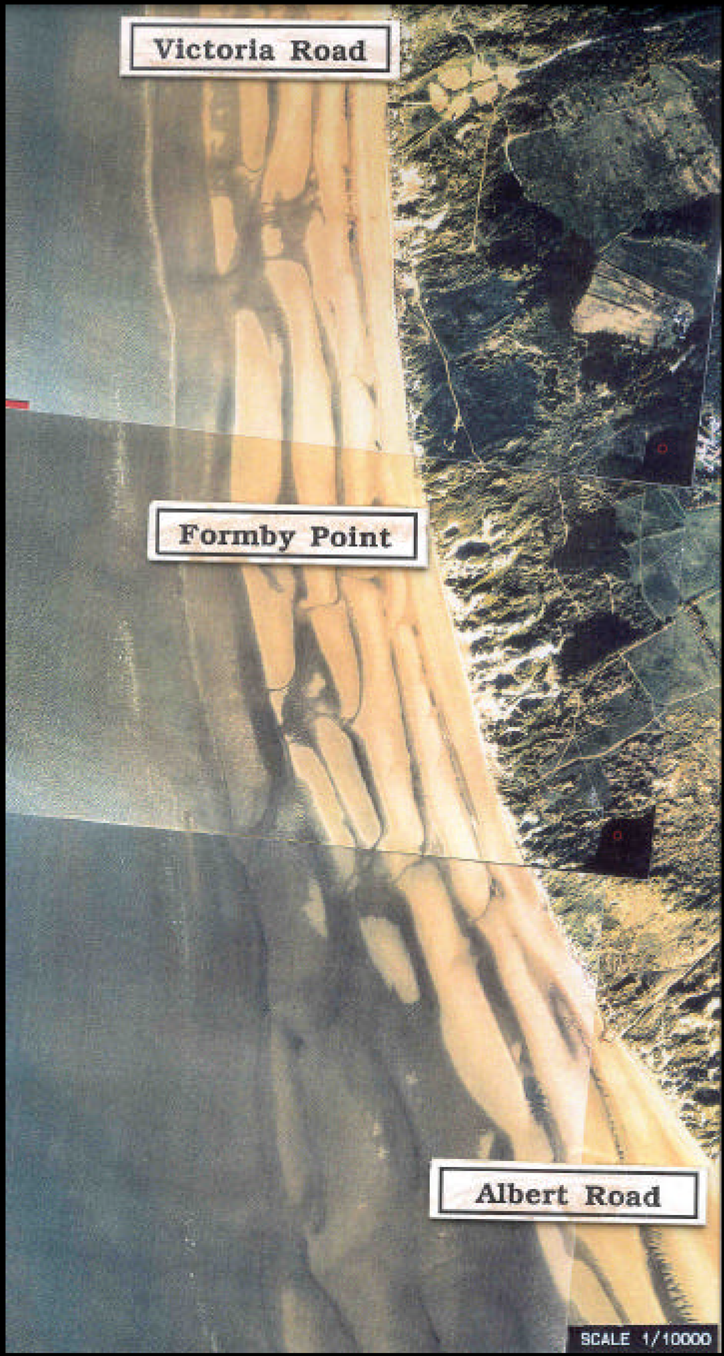
Y = 404000 m OS

Y = 400000 m OS

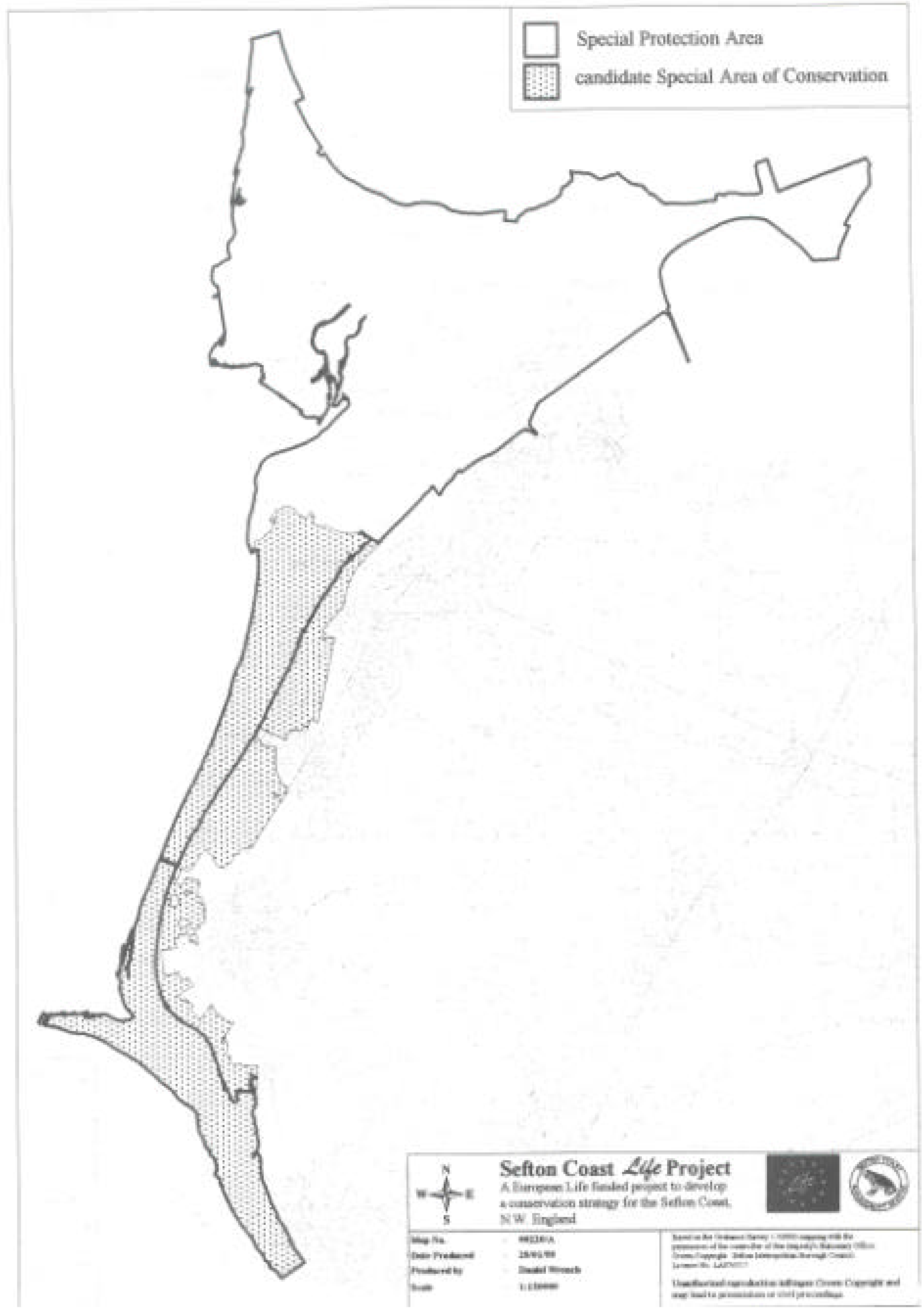
Y = 398000 m OS

Y = 396000 m OS

Vertical air photograph showing the area to the south of Formby Point in 1997.



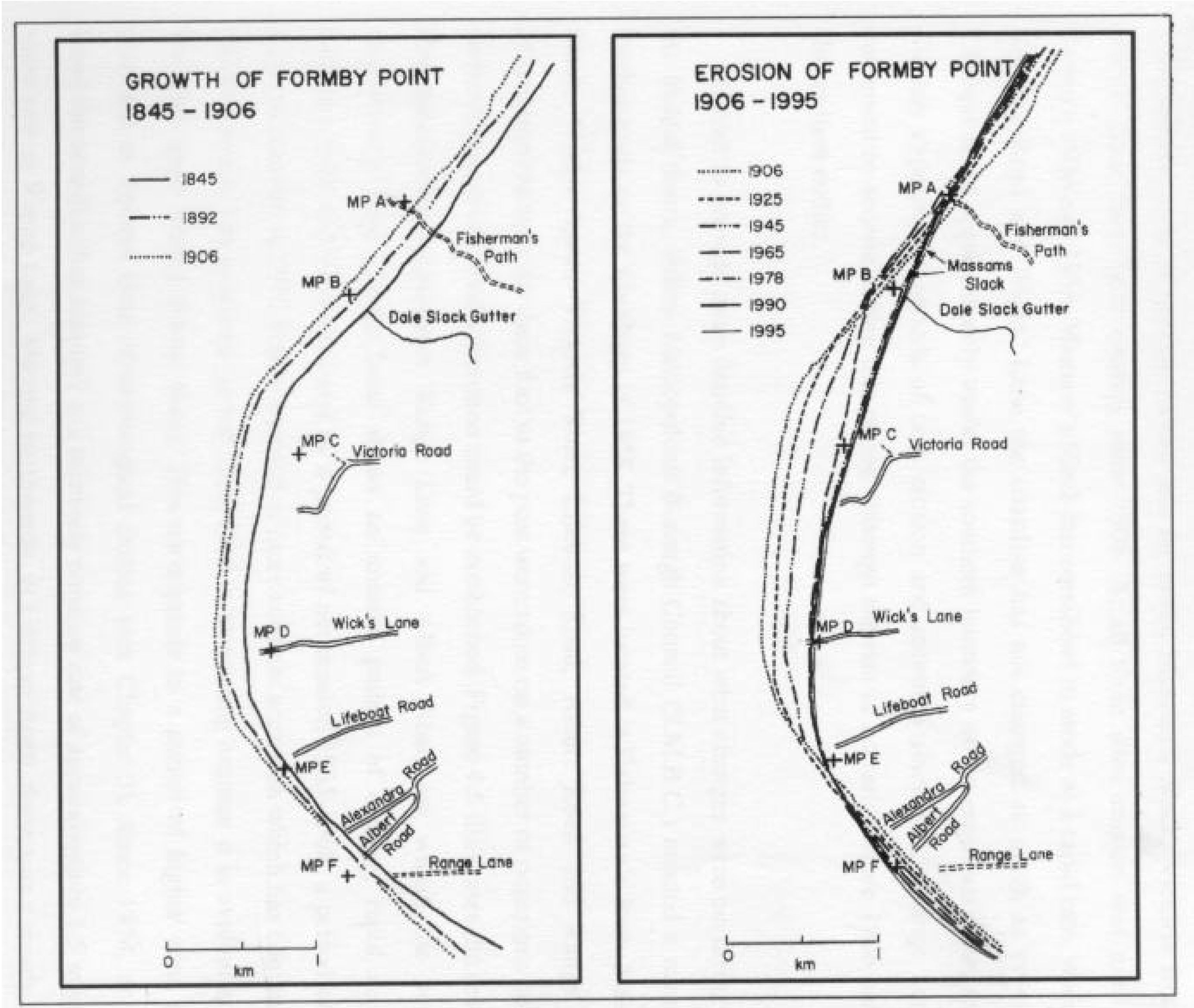
Extent of SPA and cSAC on the Sefton coast in 2000.



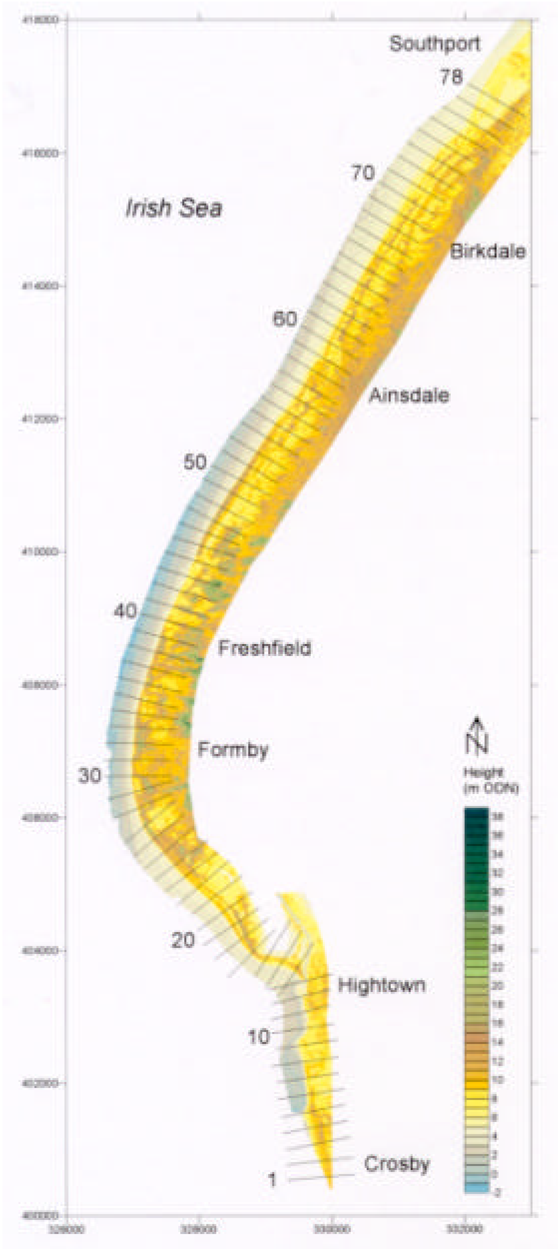
Cliffed dune frontage on eroding coast at Formby Point north (July 2001).

Boundary between eroding and accreting dune frontage, Ainsdale (July 2001).

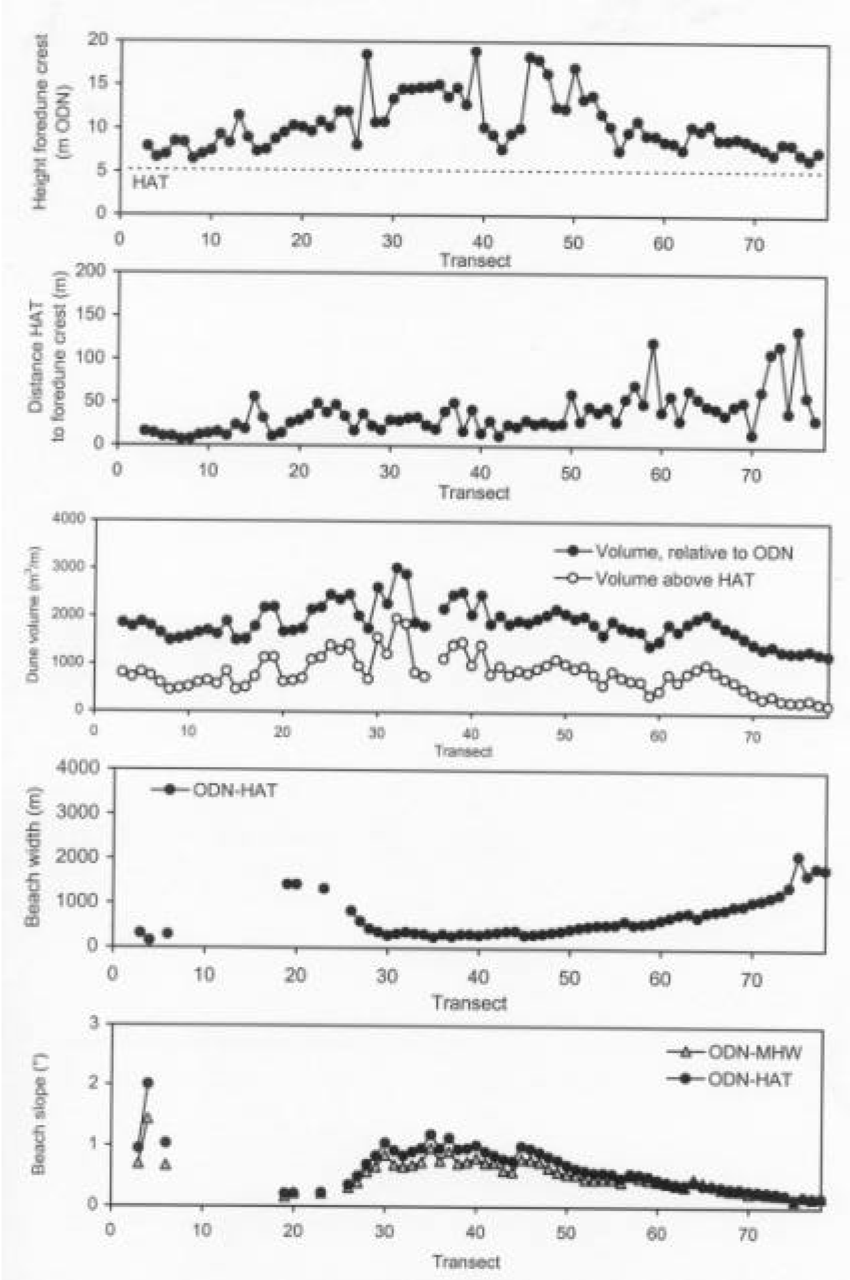
Accreting dune frontage at Formby Point south (July 2001).



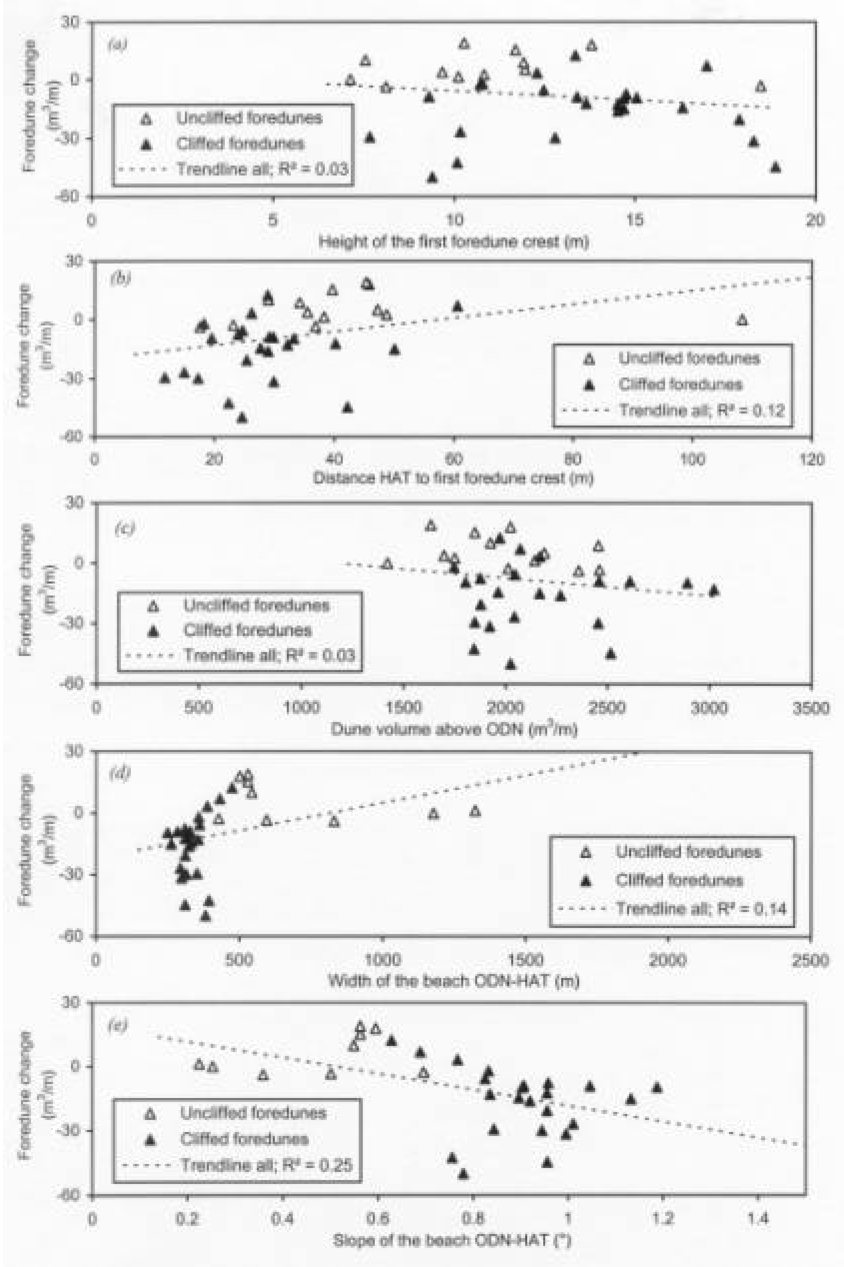
Growth and subsequent erosion of Formby Point, 1845-1995. After Jay (1998) updated from Pye and Neal (1994).



Digital terrain map of the Sefton coast from lidar data, March 1999 (after van der Wal *et al*., 2001).

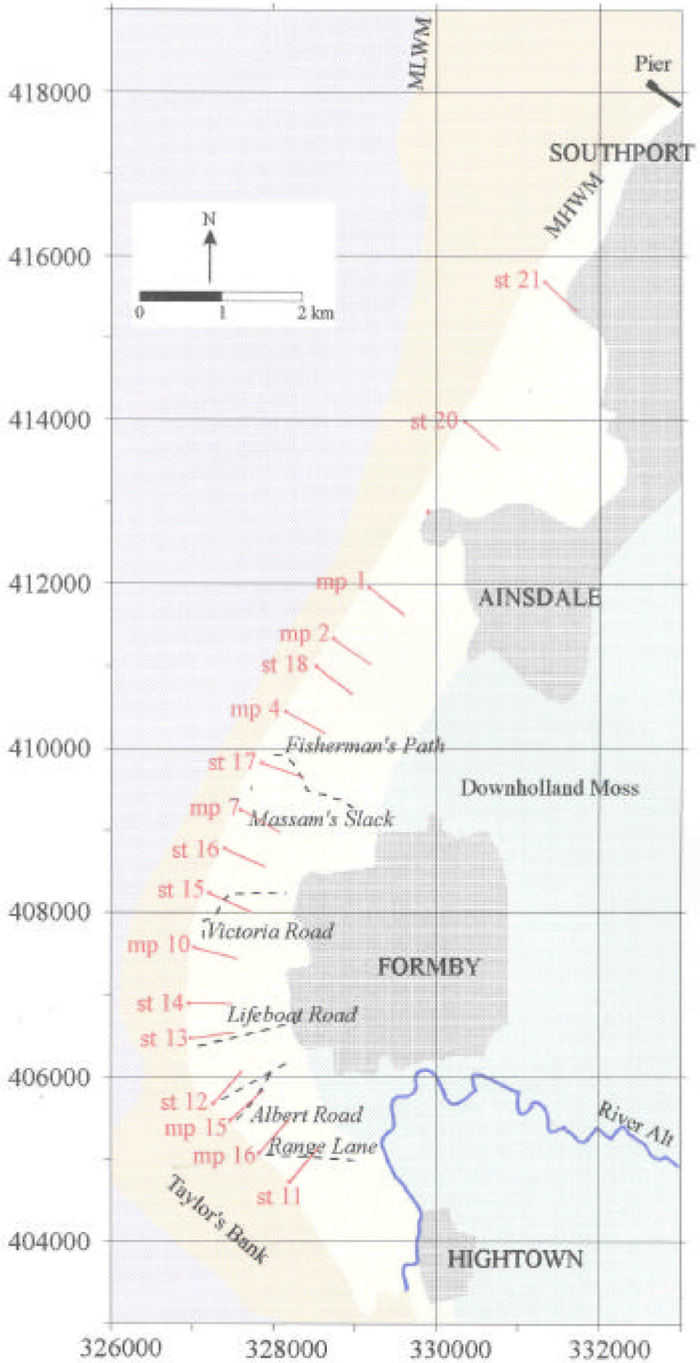


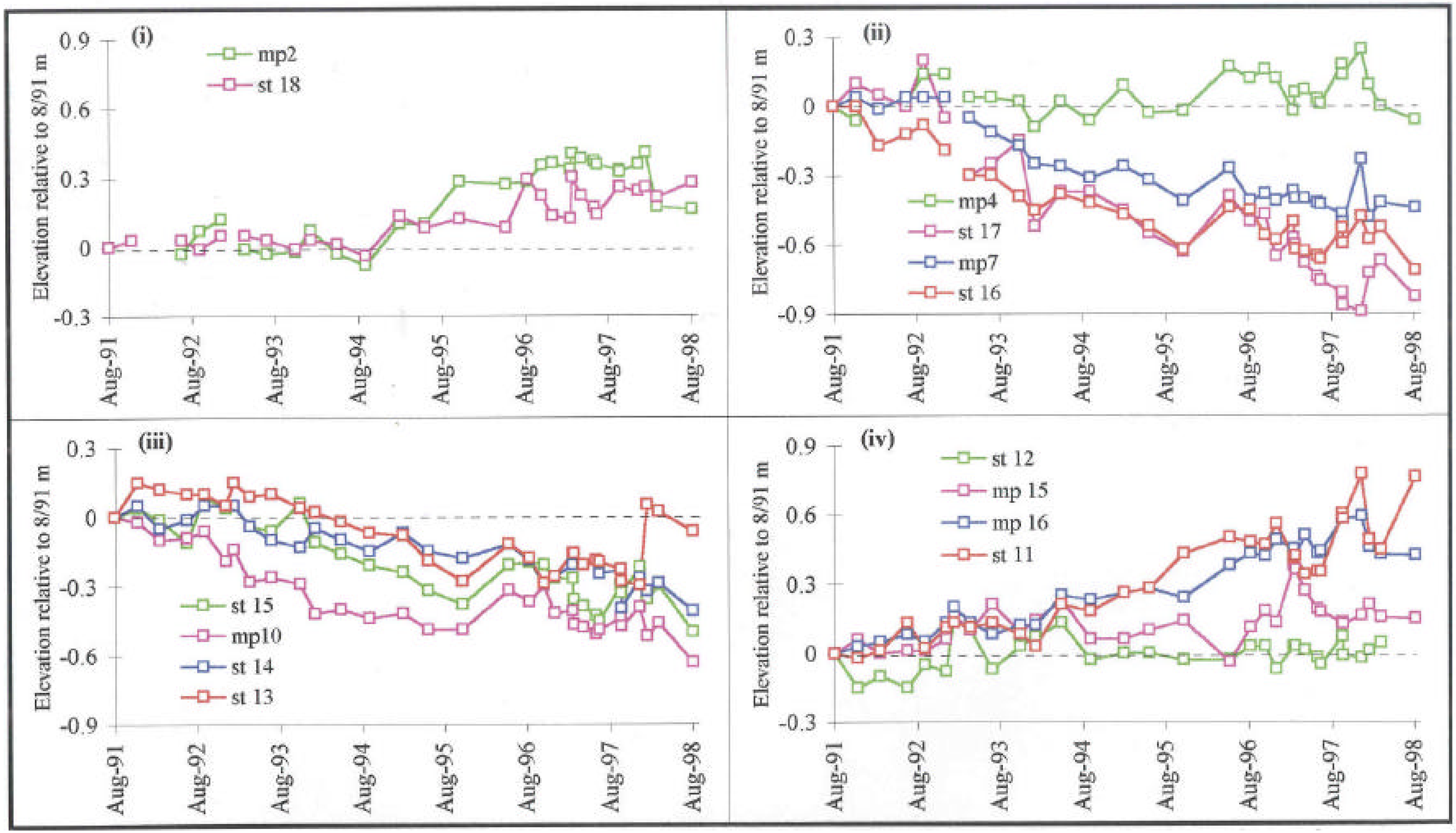
Morphometric parameters for the beach and frontal dunes along the Sefton coast (after van der Wal *et al.*, 2001).



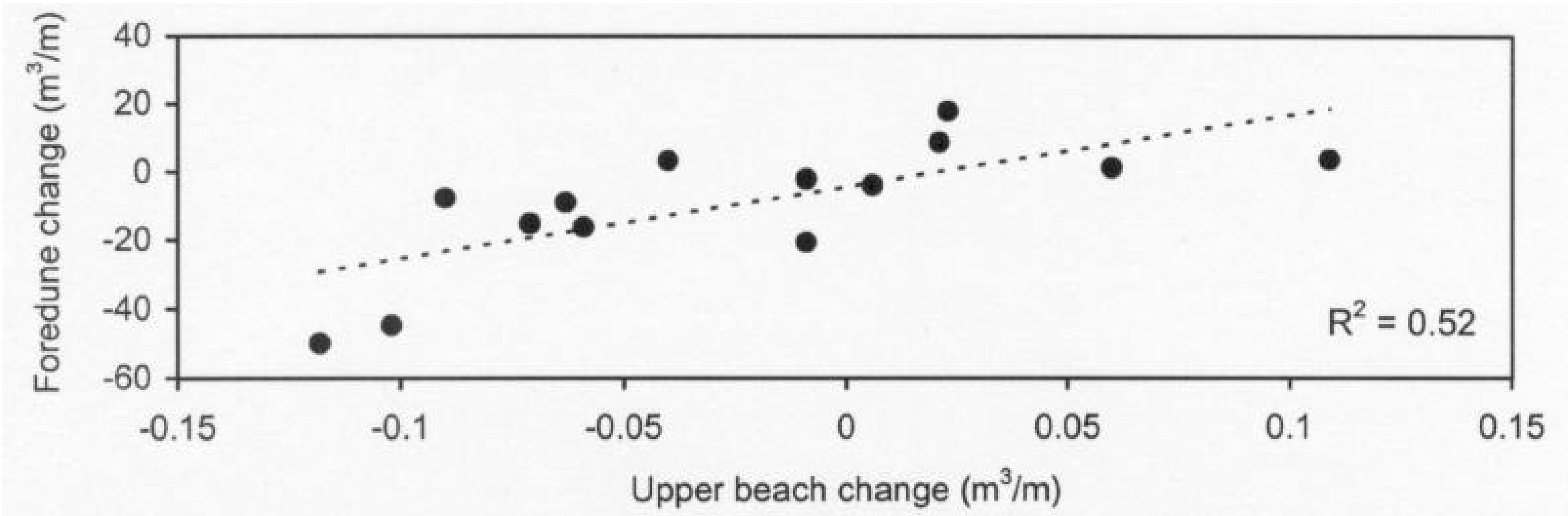
Foredune change (1996 to 1998) related to beach and dune morphometry from lidar data.

Positions of dune transects surveyed along the Sefton coast (Jay, 1998).



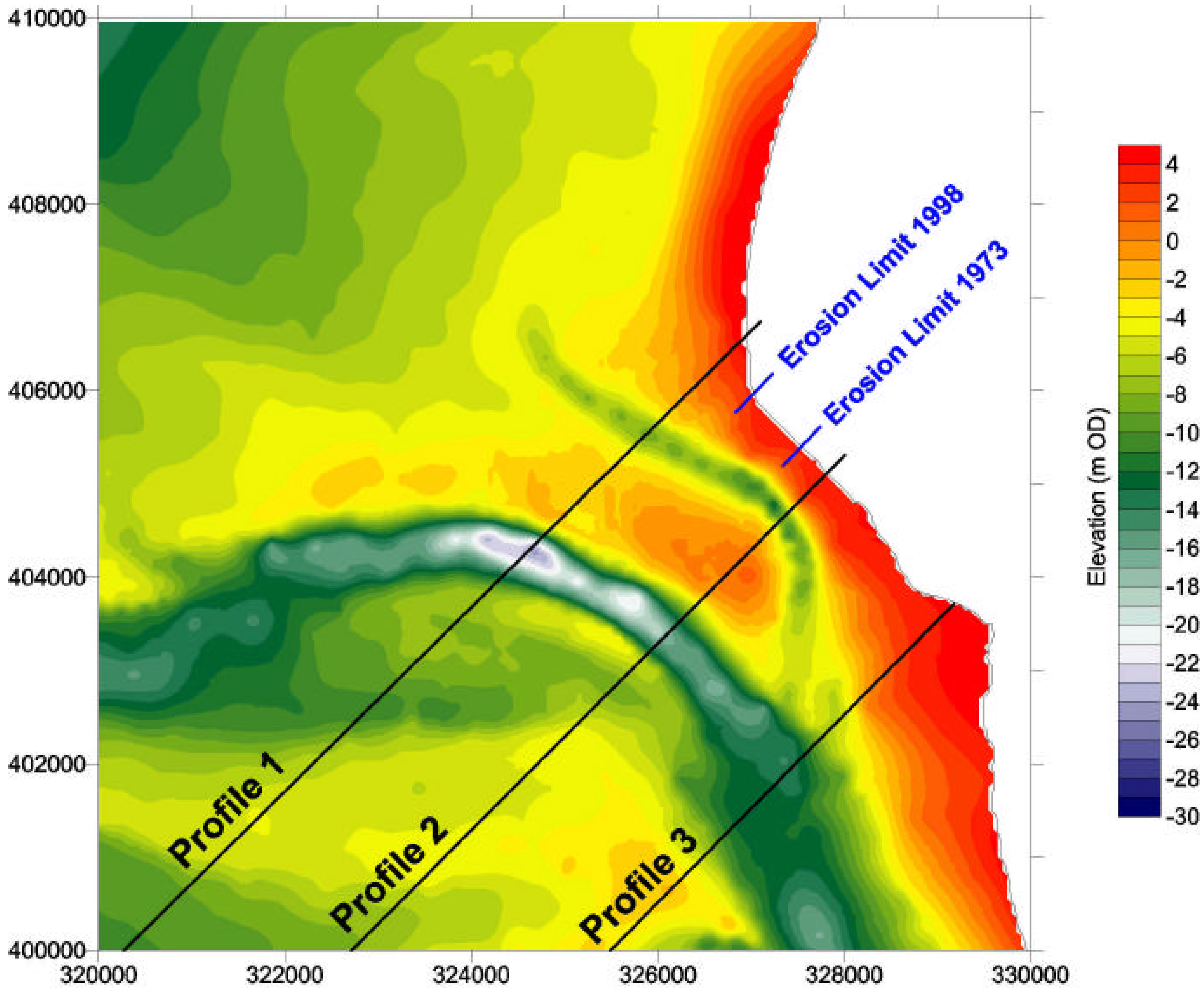


Changes in beach profile at selected stations on the Sefton coast, based on ground surveys 1991 to 1998 (after Jay, 1998).

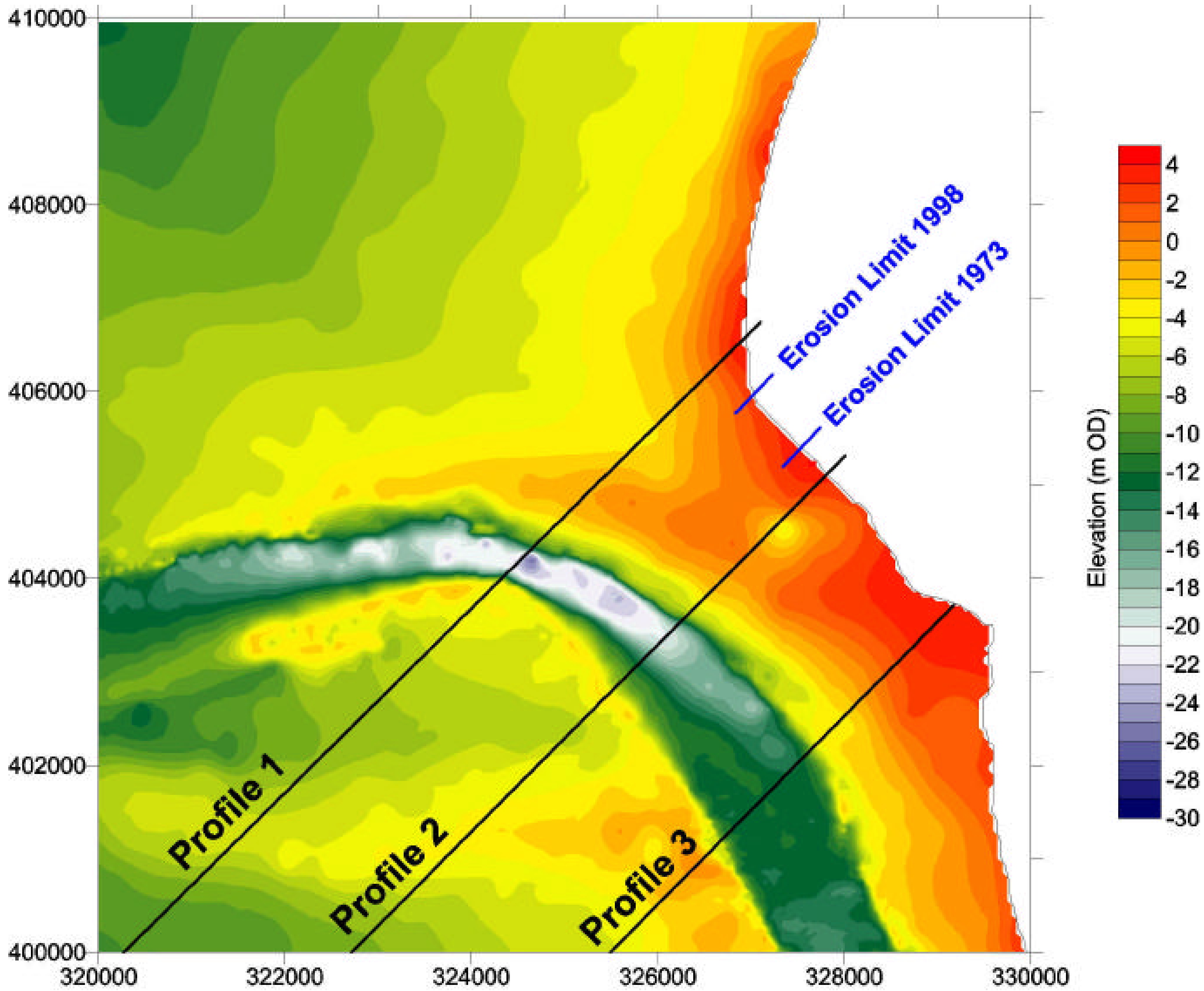


Relation between changes in upper beach volume (1995 to 1996) and changes in foredune volume (1996 to 1998) (after Jay, 1998).

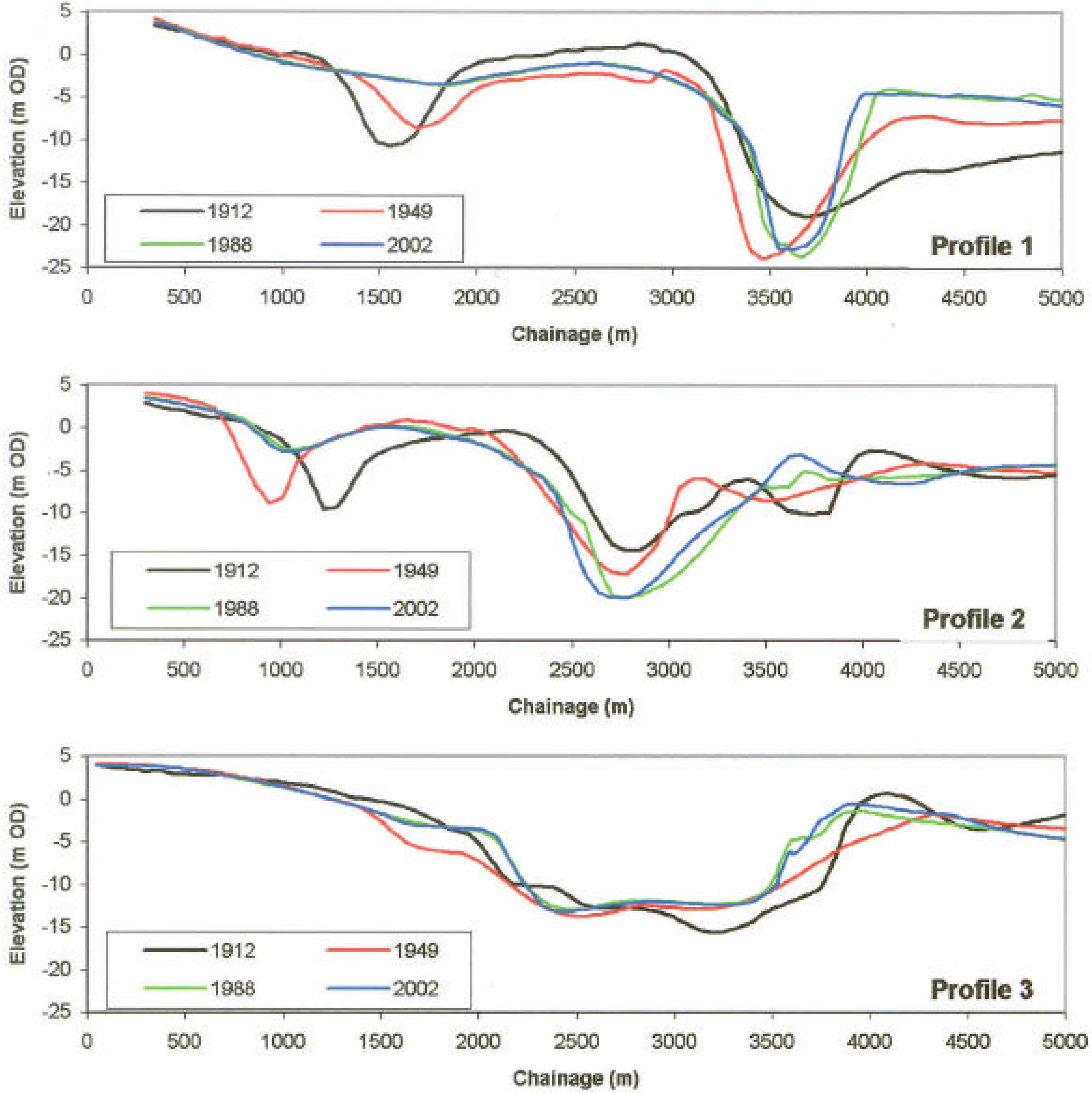
Bathymetric chart of Queen's Channel and the Sefton Coast (1949).



Bathymetric chart of Queen's Channel and the Sefton Coast (2002).



NE-SW cross-sections of the Outer Mersey Estuary (after Pye and Blott, 2002).

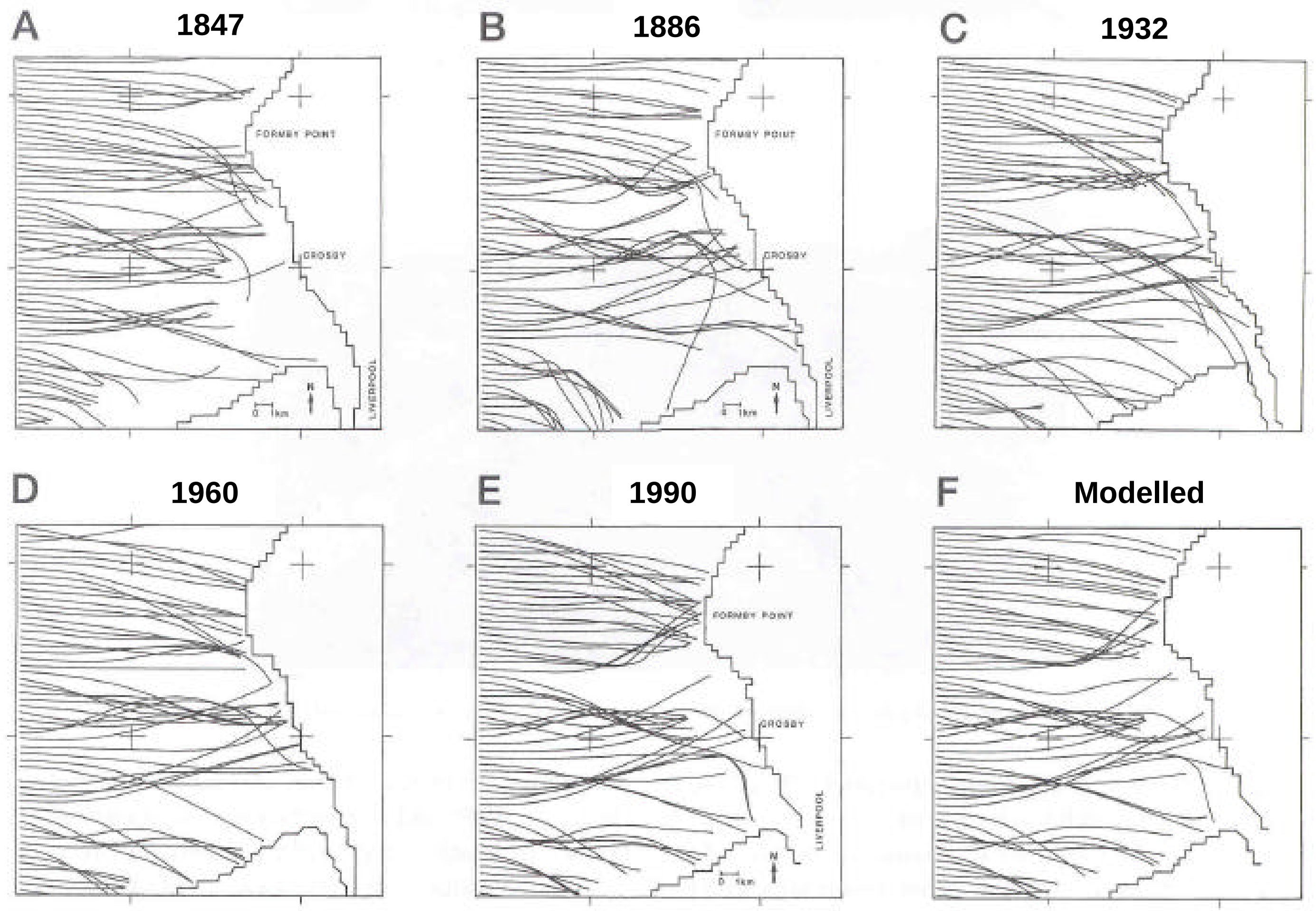


Beach widths and slopes (OD to MHW) from lidar data (1998).

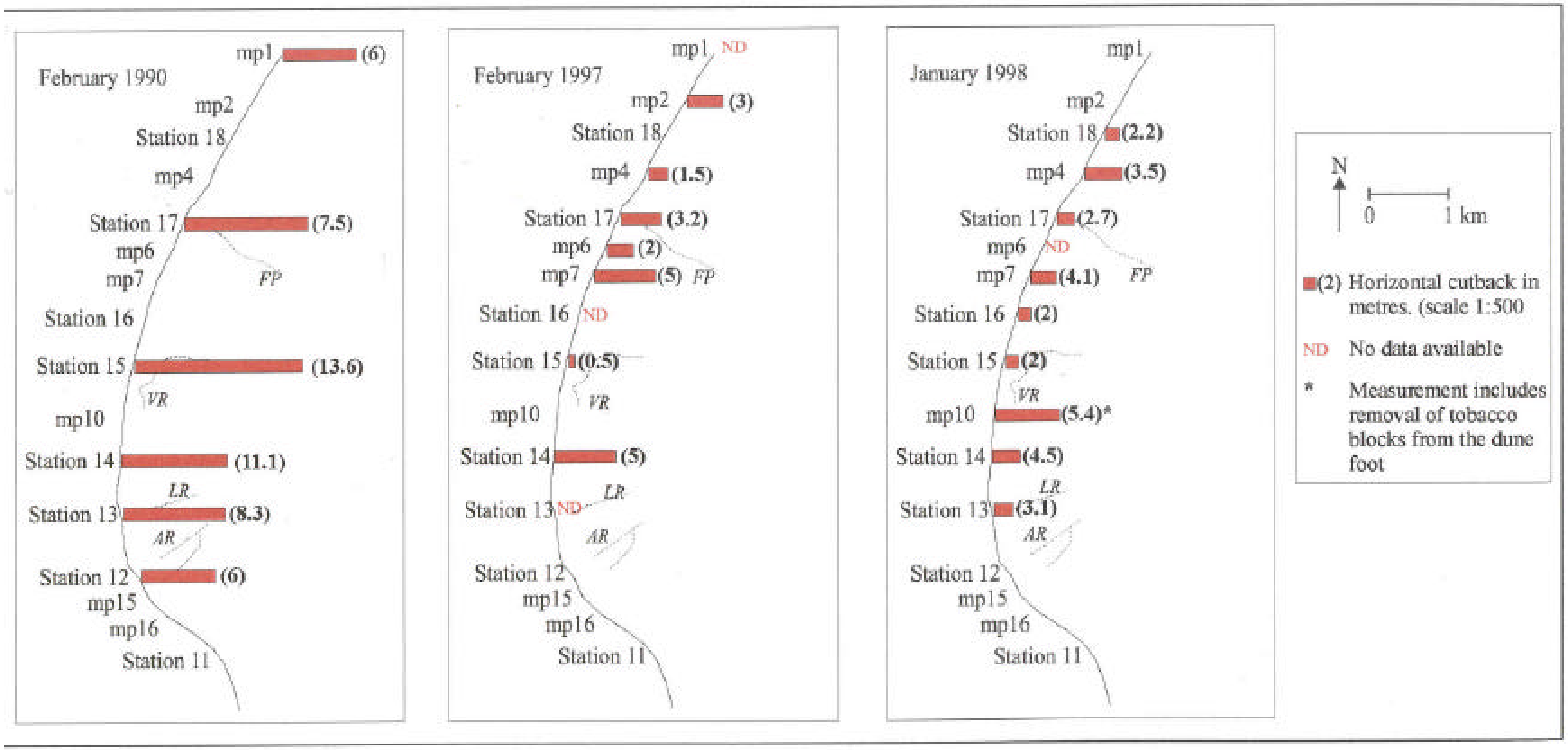
Profile	Erosion/ Accretion	Beach Width (m)	Beach Slope (degrees)
60	Accreting	460	0.40
48	Transition	310	0.60
30	Eroding	230	0.80
26	Transition	610	0.30
20	Accreting	920	0.20

Beach widths and slopes (OD to MHW) from bathymetric charts (1949 and 2002).

Profile	1949			2002		
	Erosion/ Accretion	Beach Width (m)	Beach Slope (degrees)	Erosion/ Accretion	Beach Width (m)	Beach Slope (degrees)
1	Eroding	540	0.35	Eroding	410	0.45
2	Eroding	200	0.90	Accreting	460	0.40
3	Accreting	640	0.30	Accreting	690	0.25



Wave ray diagrams for moderate storm waves approaching the Sefton coast from the west (after Pye and Neal, 1994).

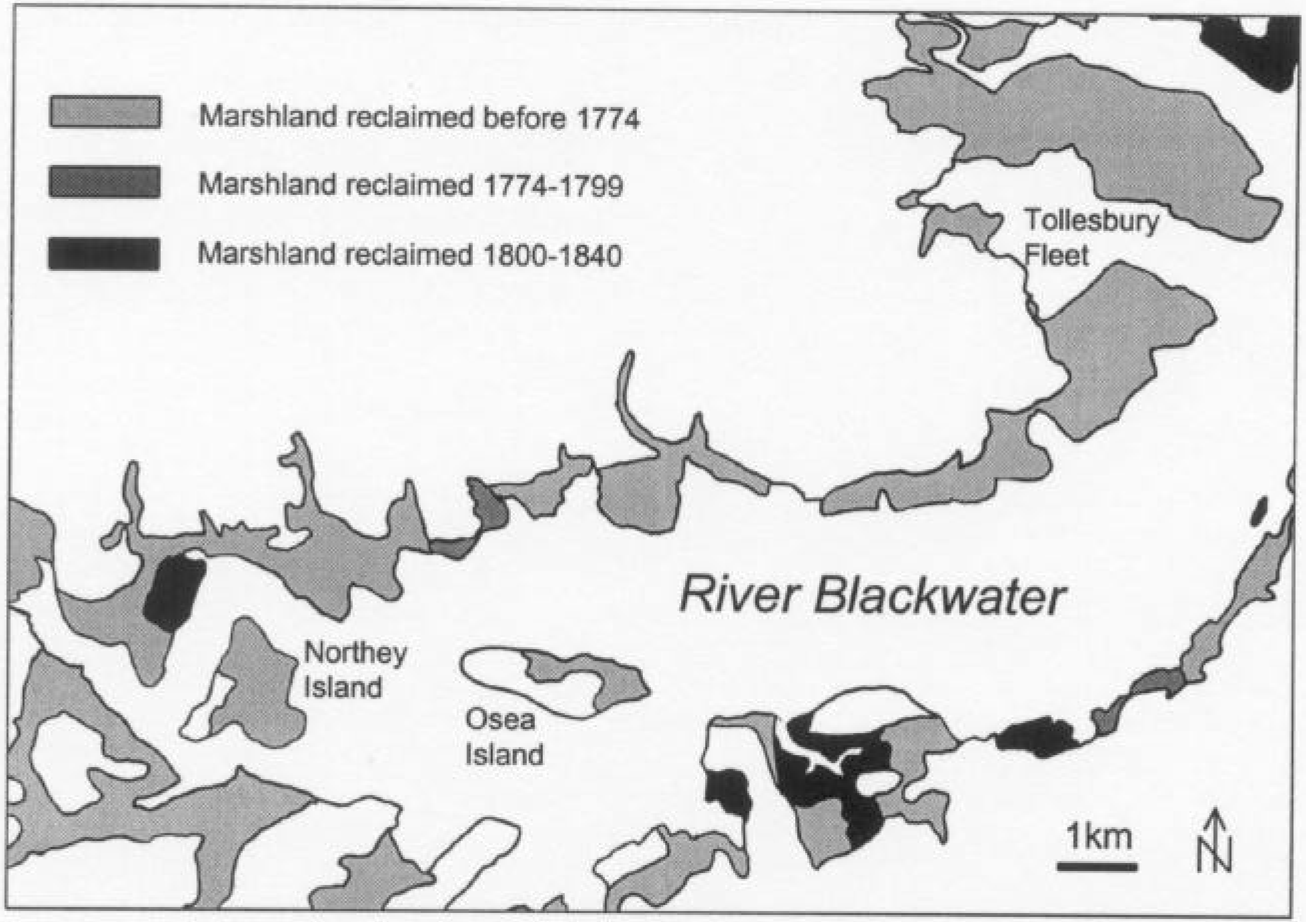


Frontal dune erosion resulting from three storm surges in 1990, 1997 and 1998 (after Jay, 1998).

Aerial photograph of the Blackwater Estuary

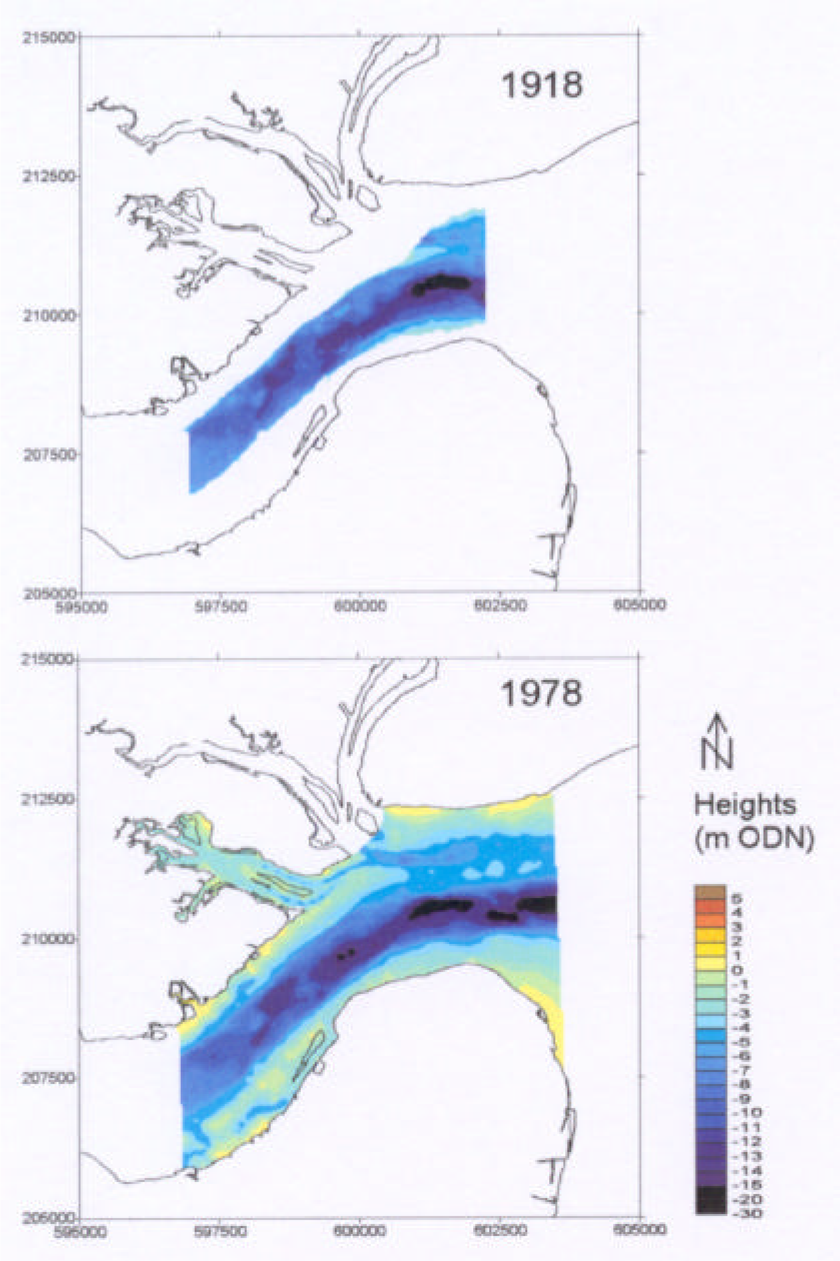
Abbotts Hall

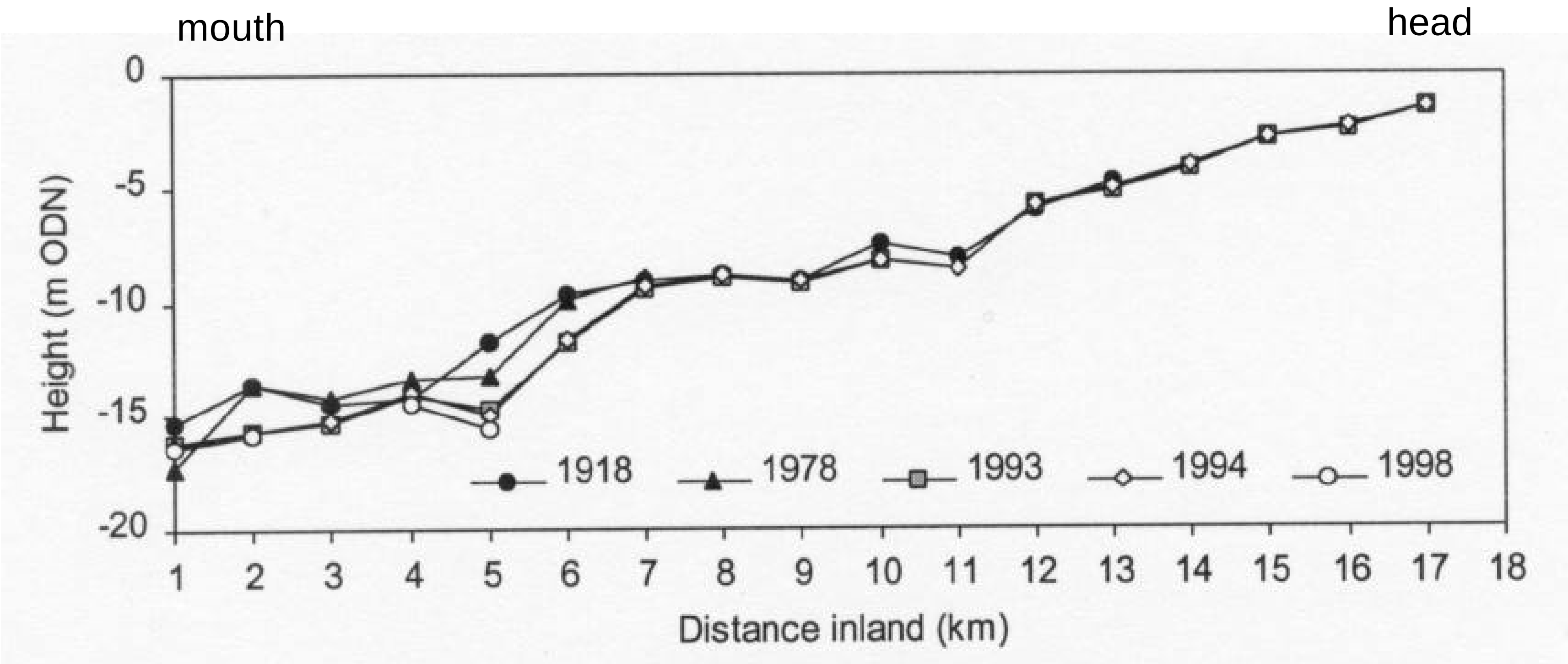
Naturally eroding marsh, Abbotts Hall Saltings, October 2002.



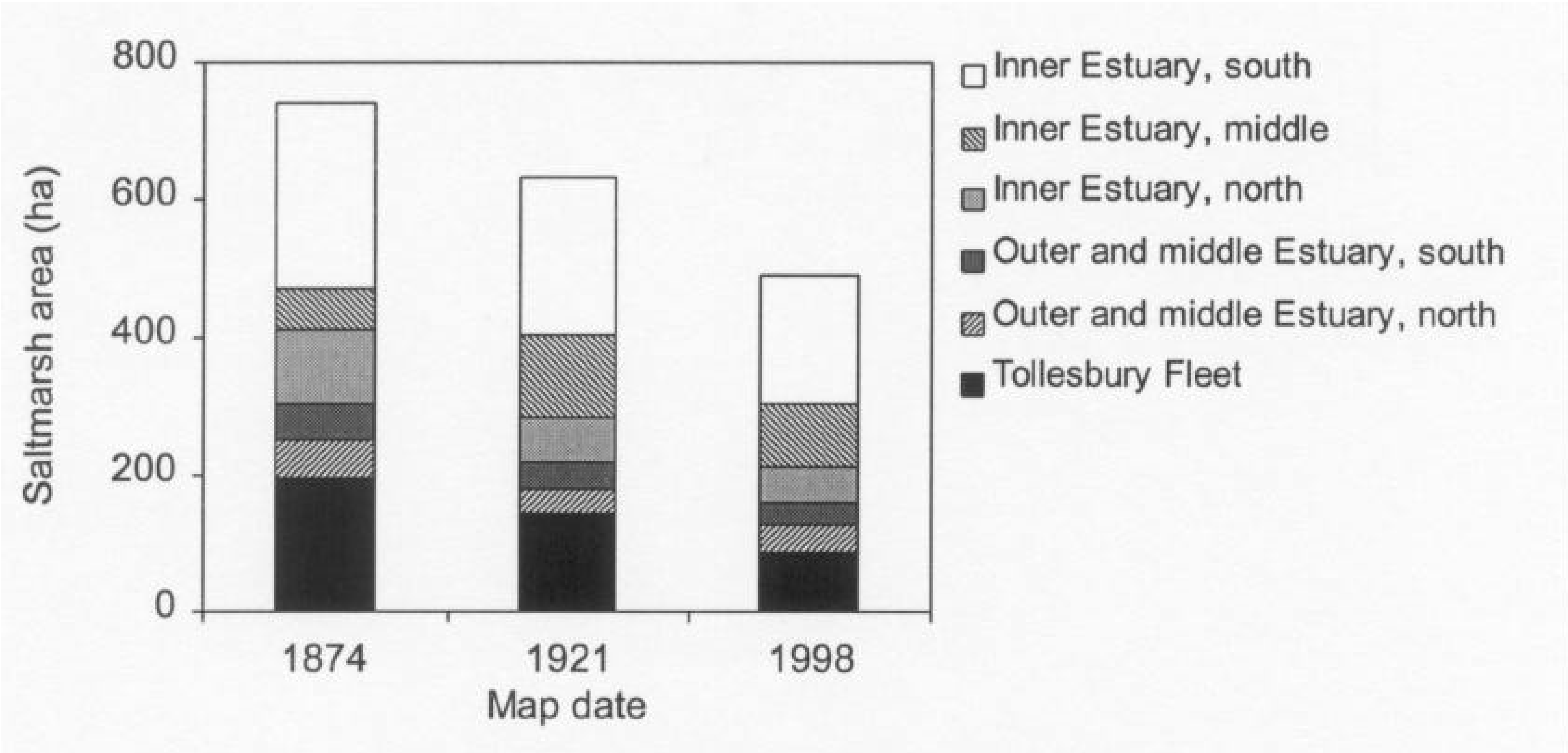
Land reclamation in the Blackwater Estuary until 1840
(after Gramolt, 1960).

Bathymetry of the Blackwater from Admiralty Charts (after Van der Wal and Pye, 2000).

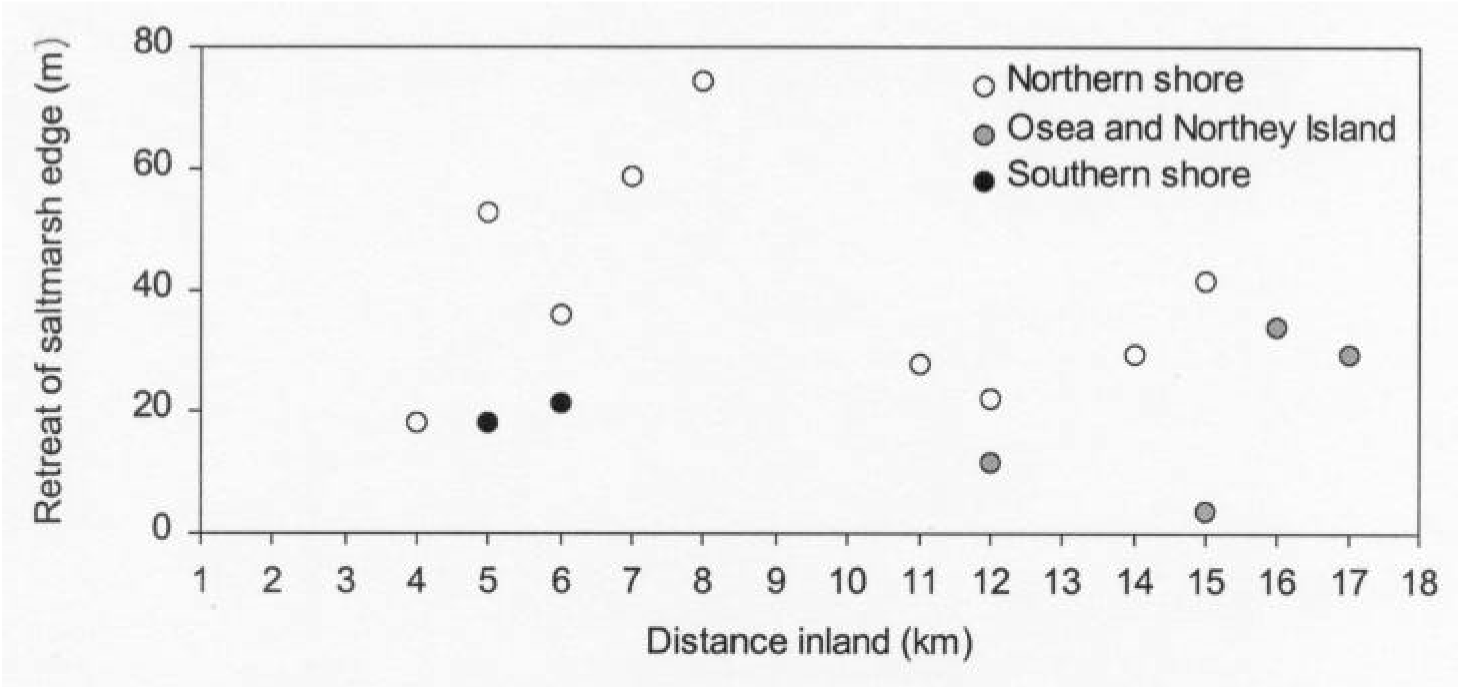




Thalweg of the Blackwater Estuary, giving the deepest points of the transects shown on the location map (after Van der Wal and Pye, 2000).



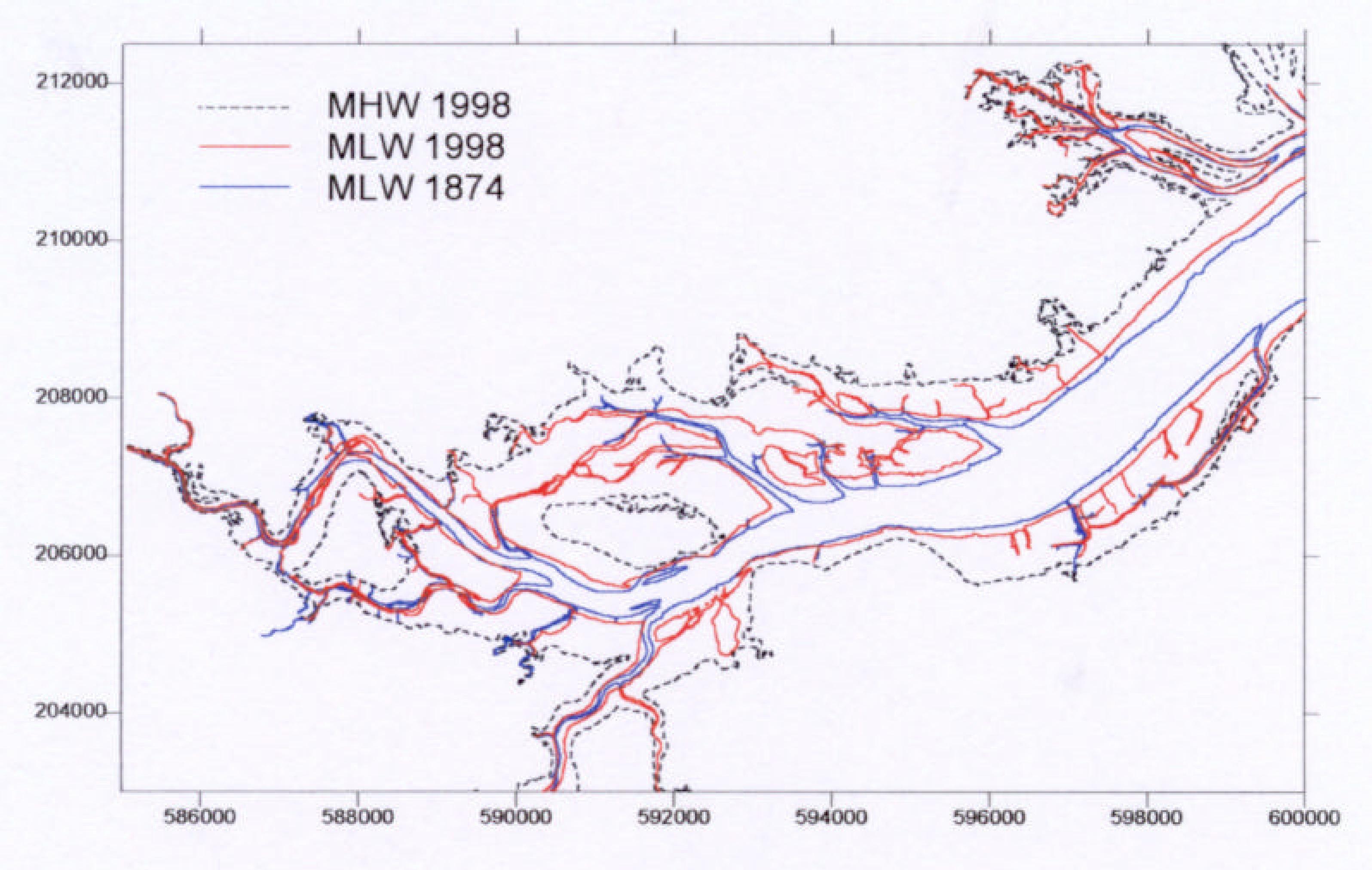
Changes in saltmarsh area in the Blackwater Estuary (van der Wal and Pye, 2000).



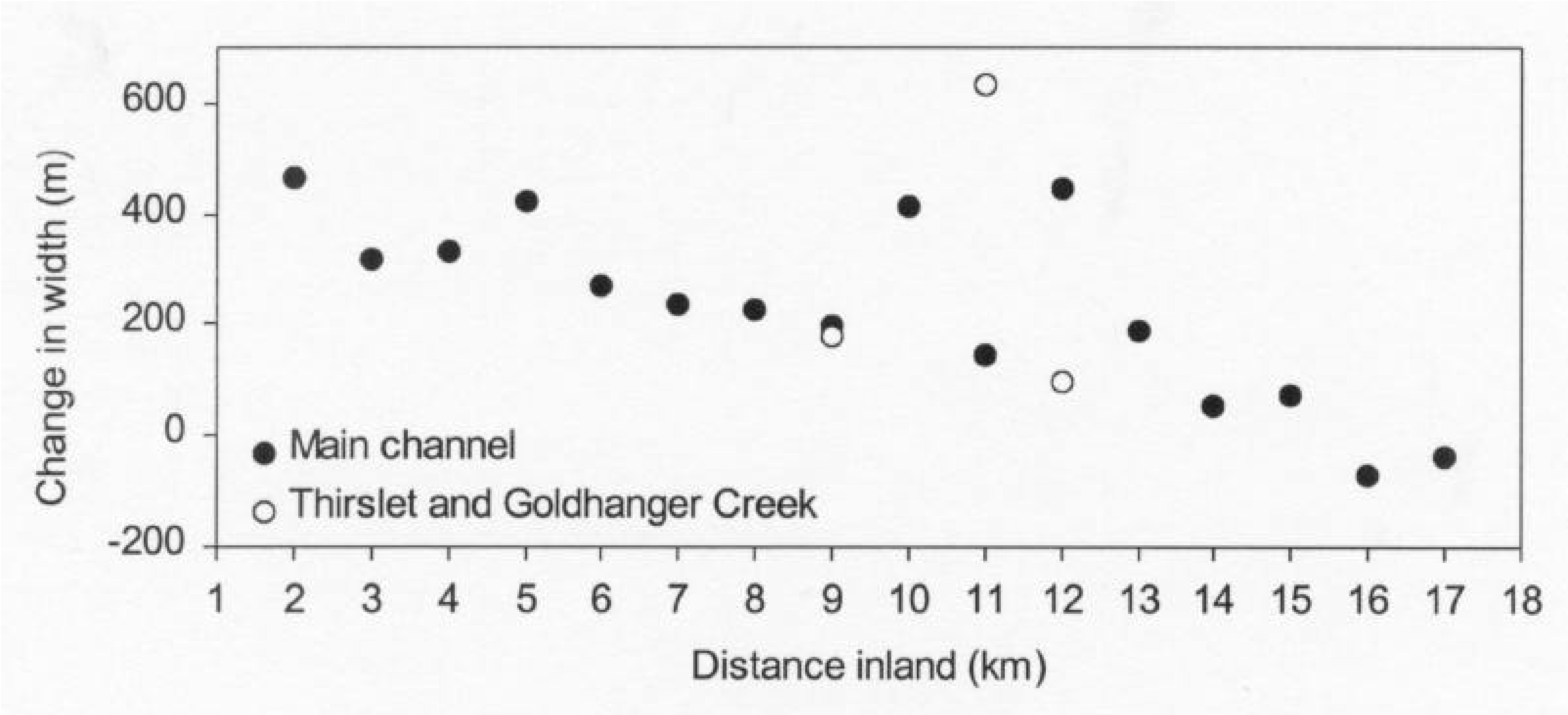
Retreat of the saltmarsh edge between 1874 and 1998 in the Blackwater Estuary (after van der Wal and Pye, 2000).

Changes in saltmarsh area for different regions in the Blackwater Estuary (after Van der Wal and Pye, 2000).

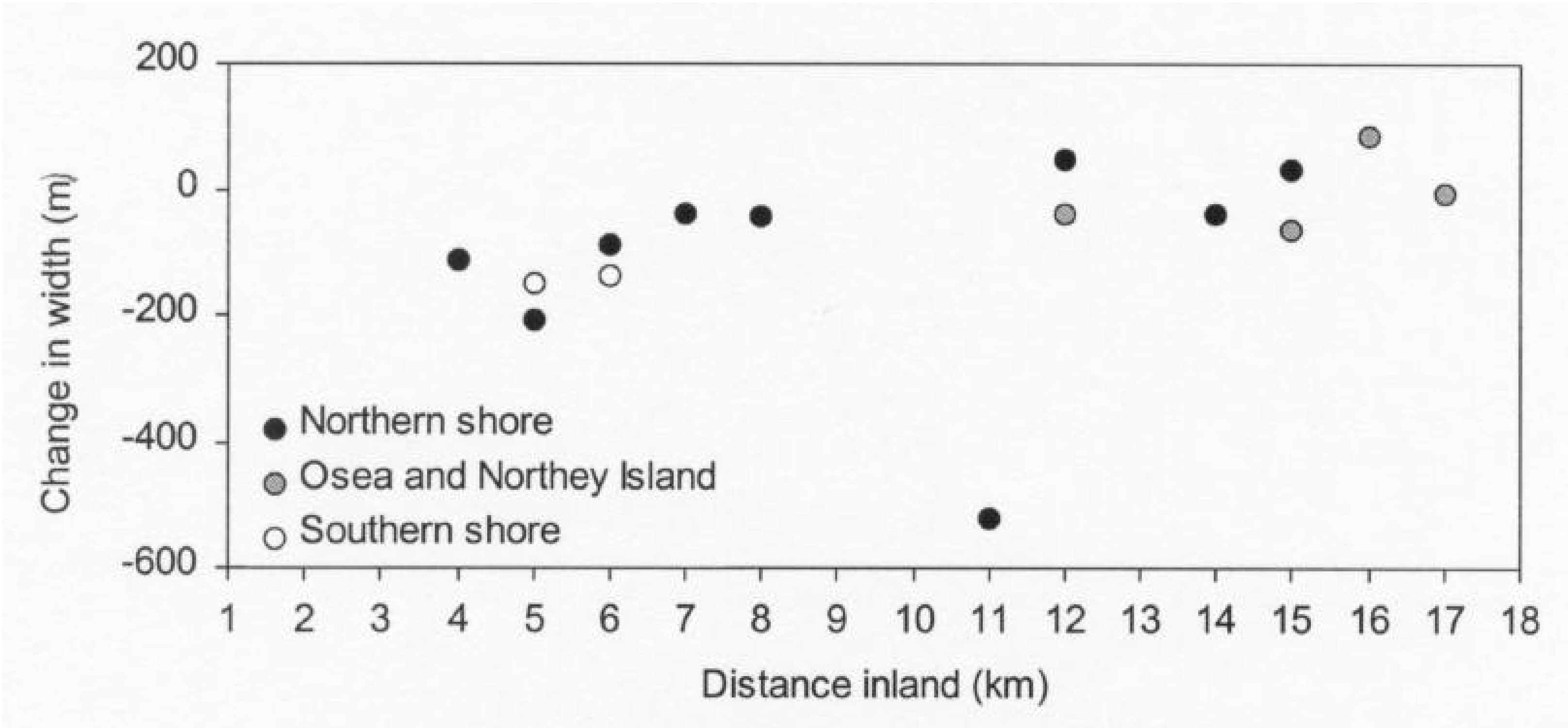
Site	Area			Change in area			
	1874 (ha)	1921 (ha)	1998 (ha)	1874-1921 (ha)	1921-1998 (ha)	1874-1921 (%)	1921-1998 (%)
Tollesbury	195.46	142.69	87.50	-52.77	-55.19	-27	-39
Outer and Middle Estuary, south	50.33	40.47	32.90	-9.86	-7.57	-20	-19
Outer and Middle Estuary, north	56.17	36.31	40.47	-19.86	4.16	-35	11
Inner Estuary, south	271.24	230.97	185.91	-40.27	-45.06	-15	-20
Inner Estuary, north	106.90	63.45	50.67	-43.45	-12.78	-41	-20
Inner Estuary, middle	61.66	117.66	91.74	56.00	-25.91	91	-22



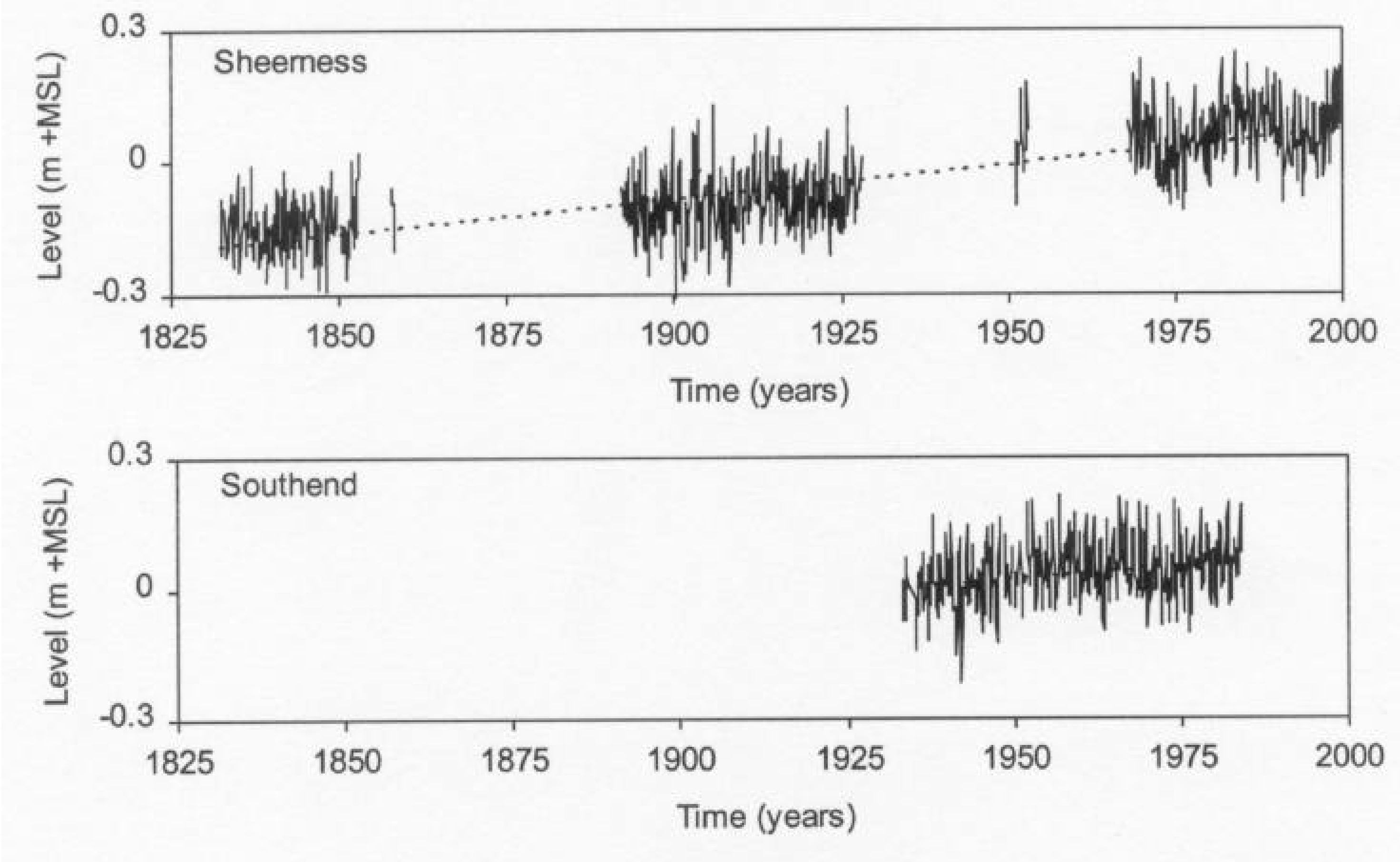
Changes in the mean low water contour in the Blackwater Estuary, from Ordnance Survey maps (after Van der Wal and Pye, 2000).



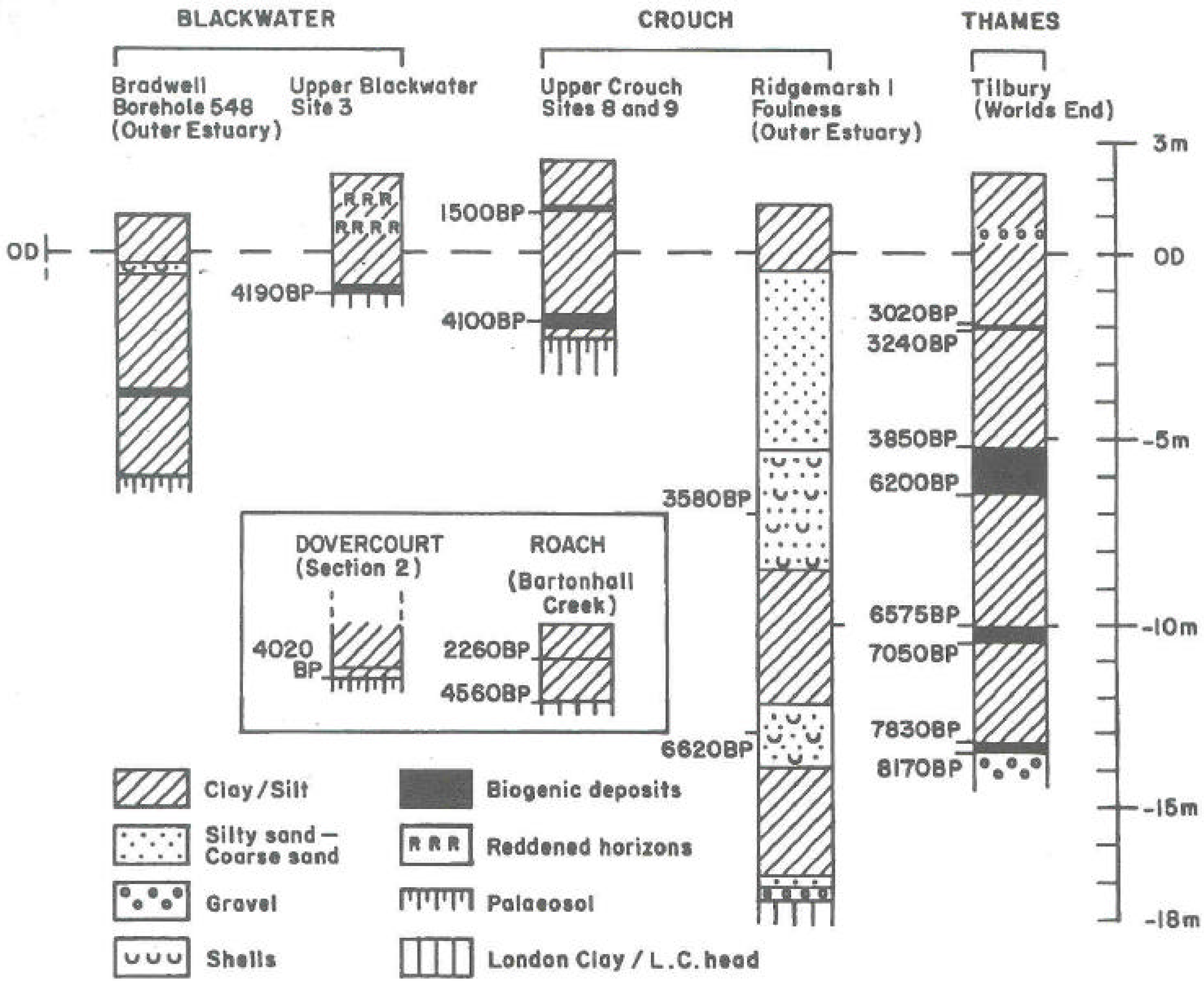
Changes in the width of the mean low water channel in the Blackwater Estuary between 1874 and 1998 (after van der Wal and Pye, 2002).



Changes in the width of the intertidal zone in the Blackwater Estuary between 1874 and 1998 (after van der Wal and Pye, 2000).

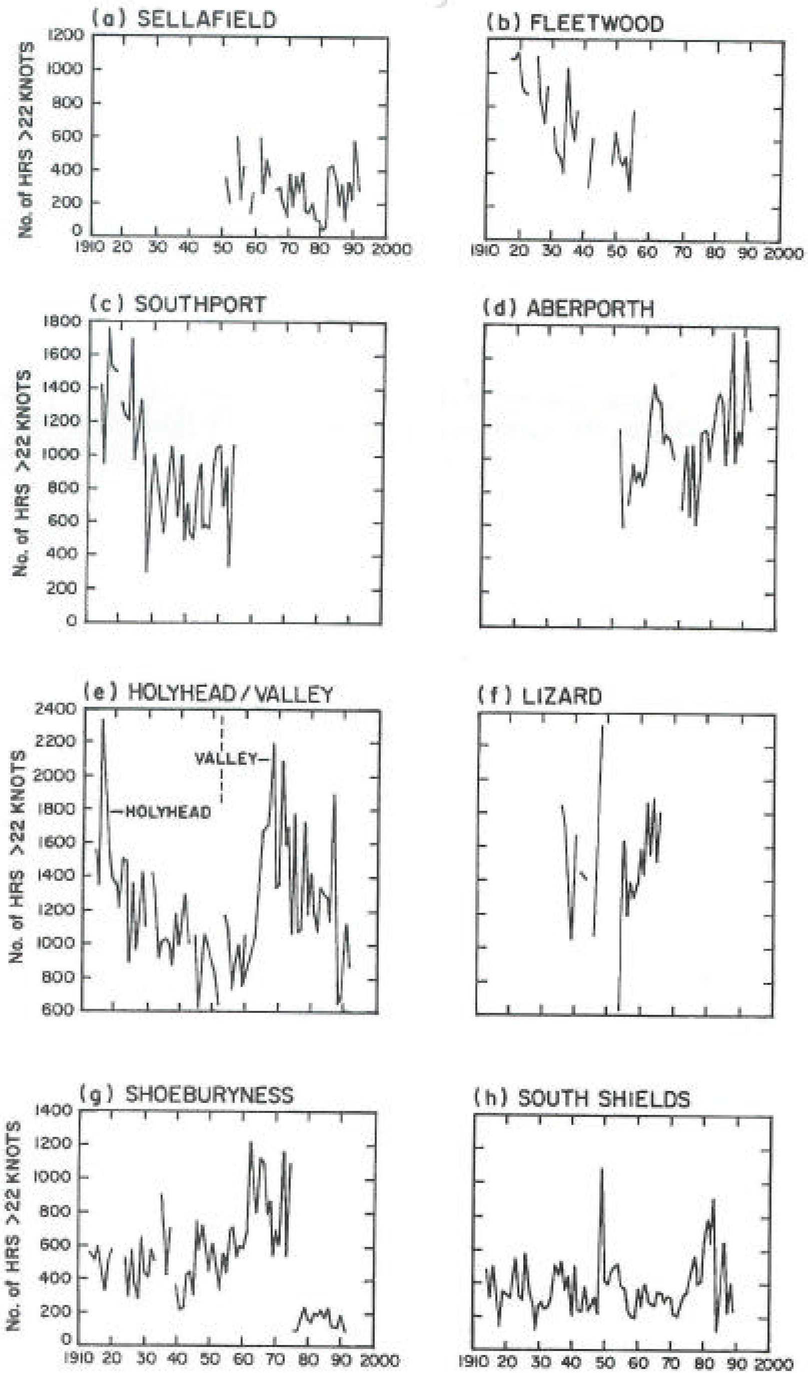


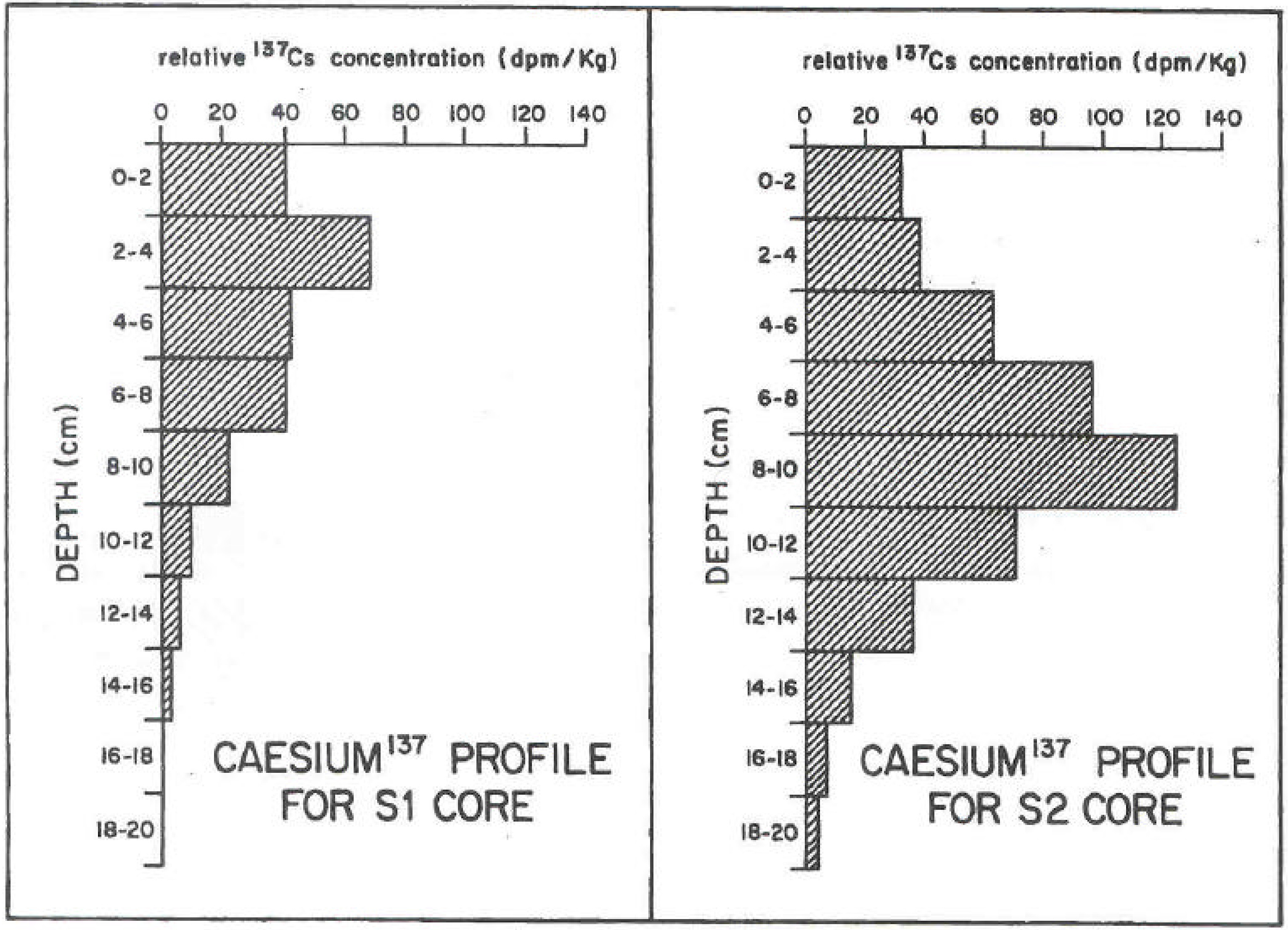
Changes in relative mean sea level at Sheerness and Southend (data from PSMSL, 2000).



Stratigraphical evidence for sea level rise in south Essex (after Pye, 2000).

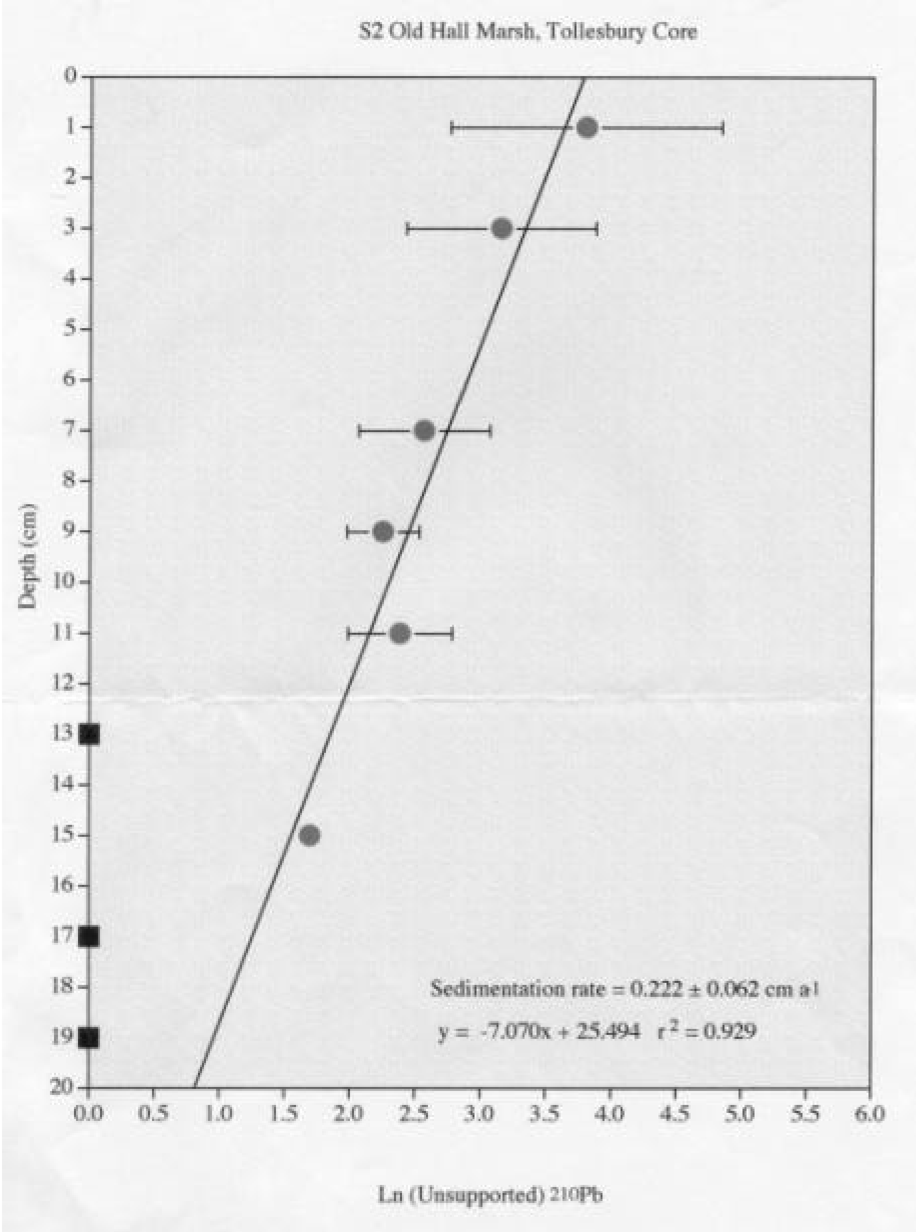
Variation in wind speed at selected stations in England and Wales, 1914 to 1992 (after Pye, 2000).

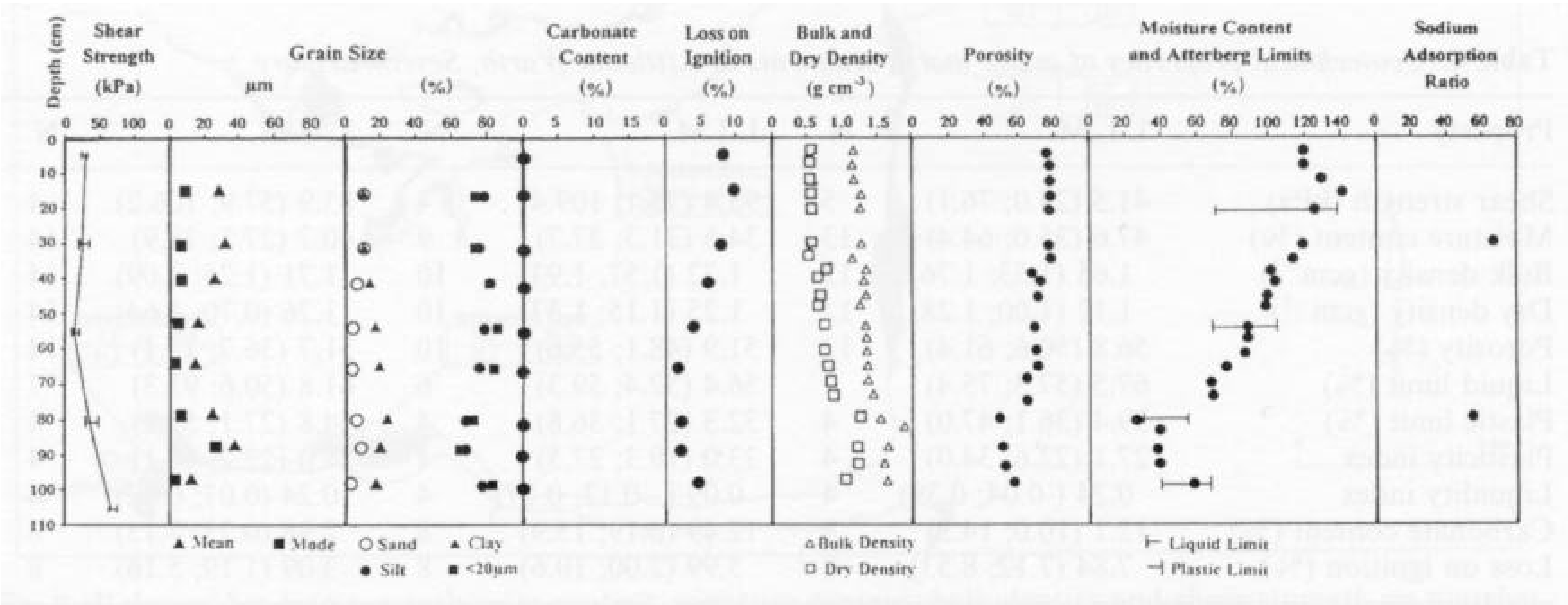




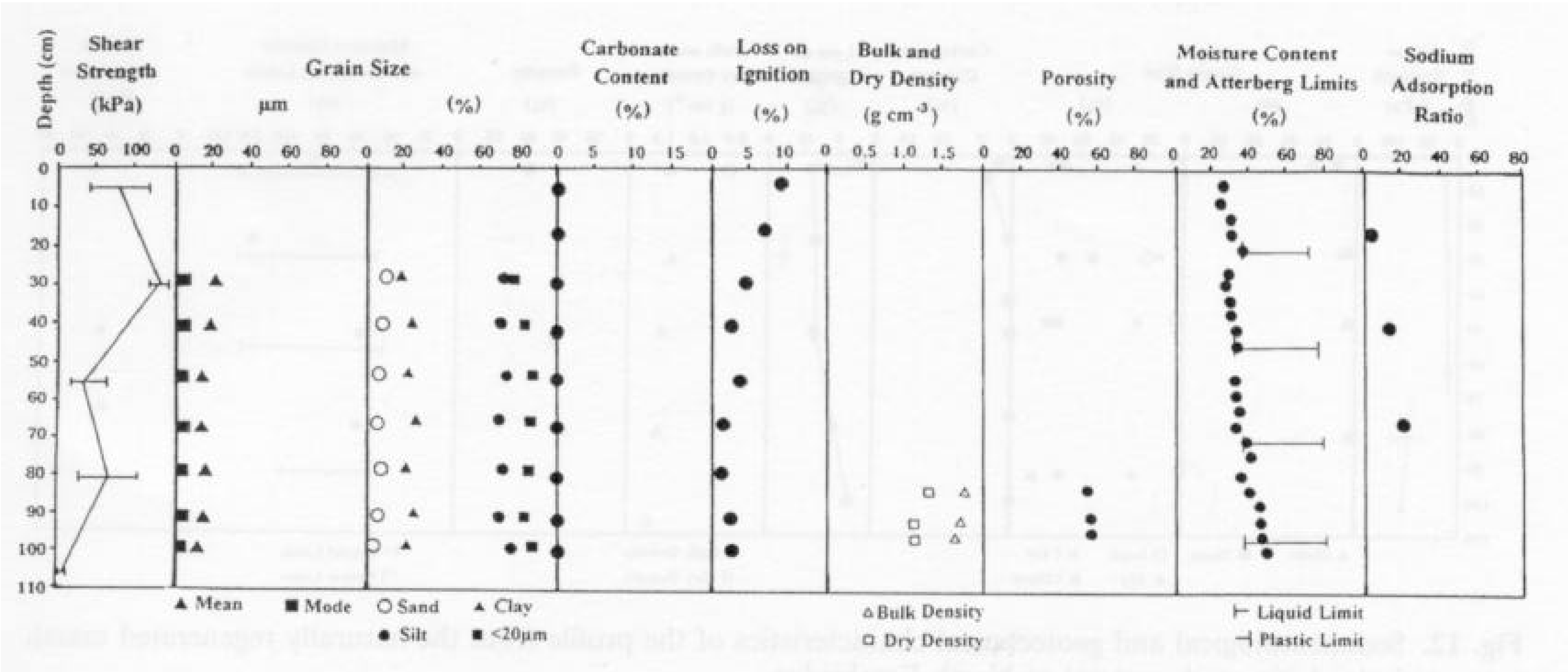
Cs^{137} distribution in two sediment cores from Old Hall Marshes, Tollesbury (after Saye, 1996).

Pb^{210} profile in active marsh at Old Hall, Tollesbury – sedimentation rate 2.2 mm yr^{-1} (after Black and Pye, unpublished).





Sedimentological and geotechnical characteristics of the profile from Old Hall active marsh, Tollesbury (after Crooks and Pye, 2000).



Sedimentological and geotechnical characteristics of the profile from the reclaimed marsh, Tollesbury (after Crooks and Pye, 2000).

Archive photograph showing dissected nature of the marsh at Tollesbury, *c*. 1910.

Location of previous sea wall breaches used as historical analogues for saltmarsh creation (after Burd *et al*., 1994).

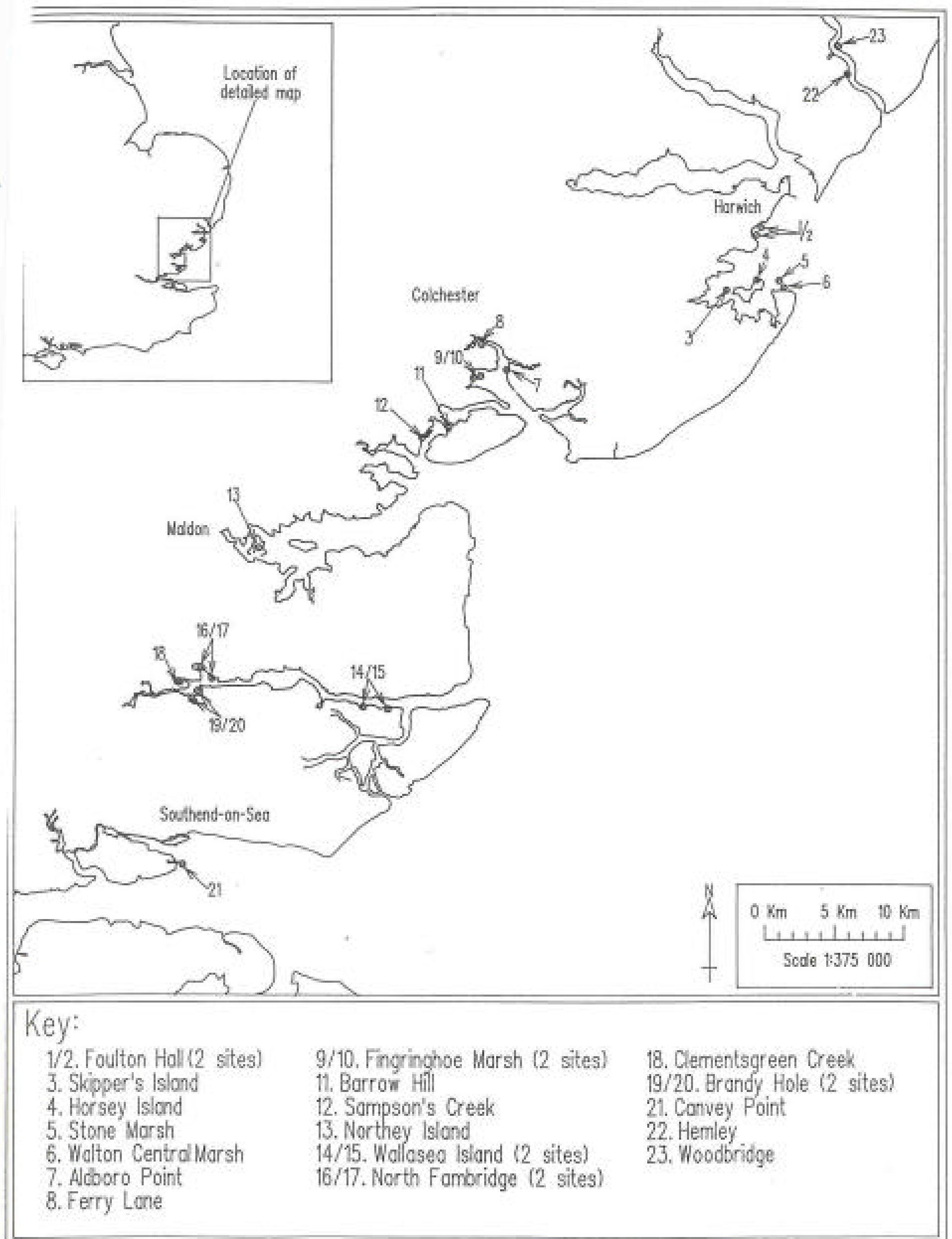
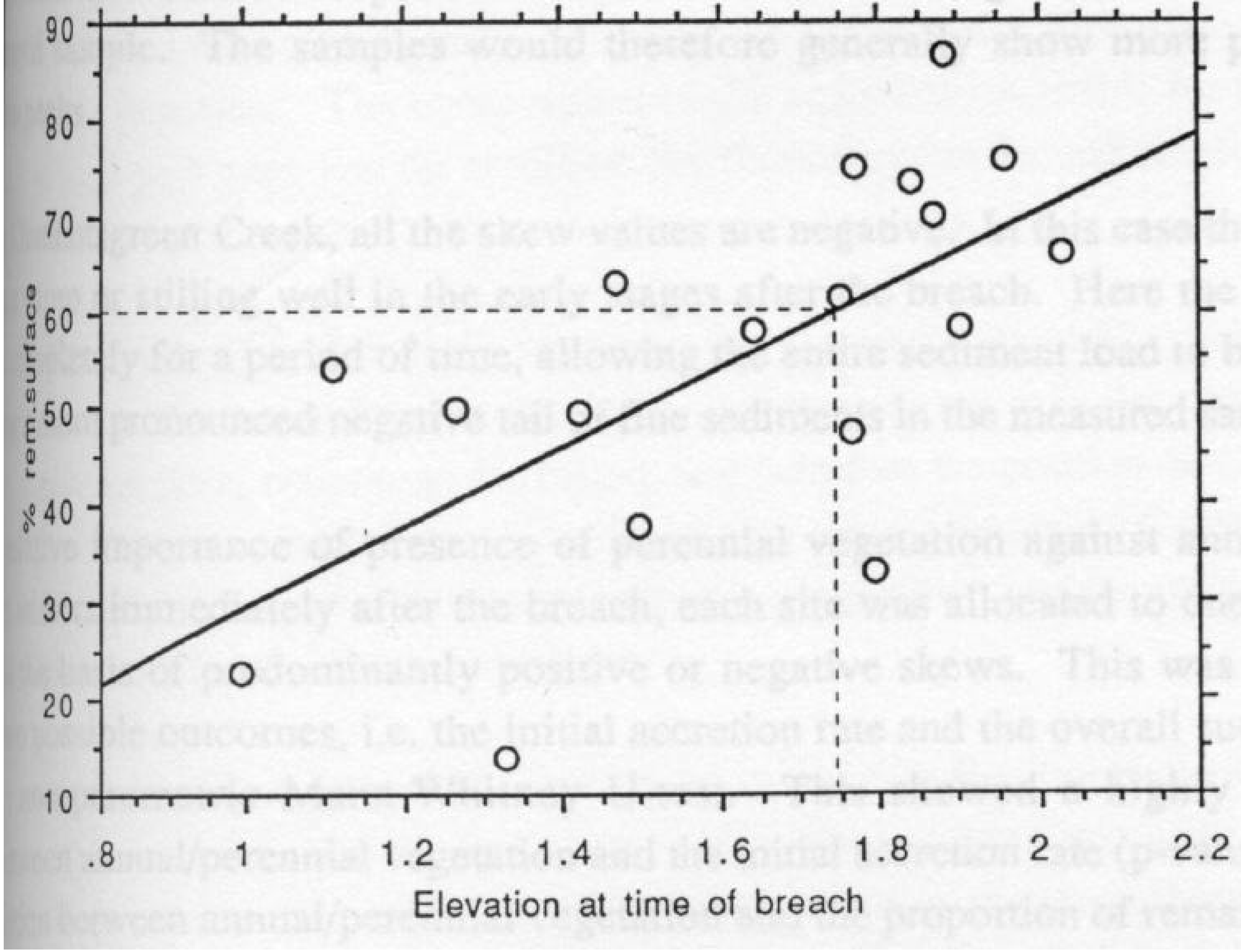
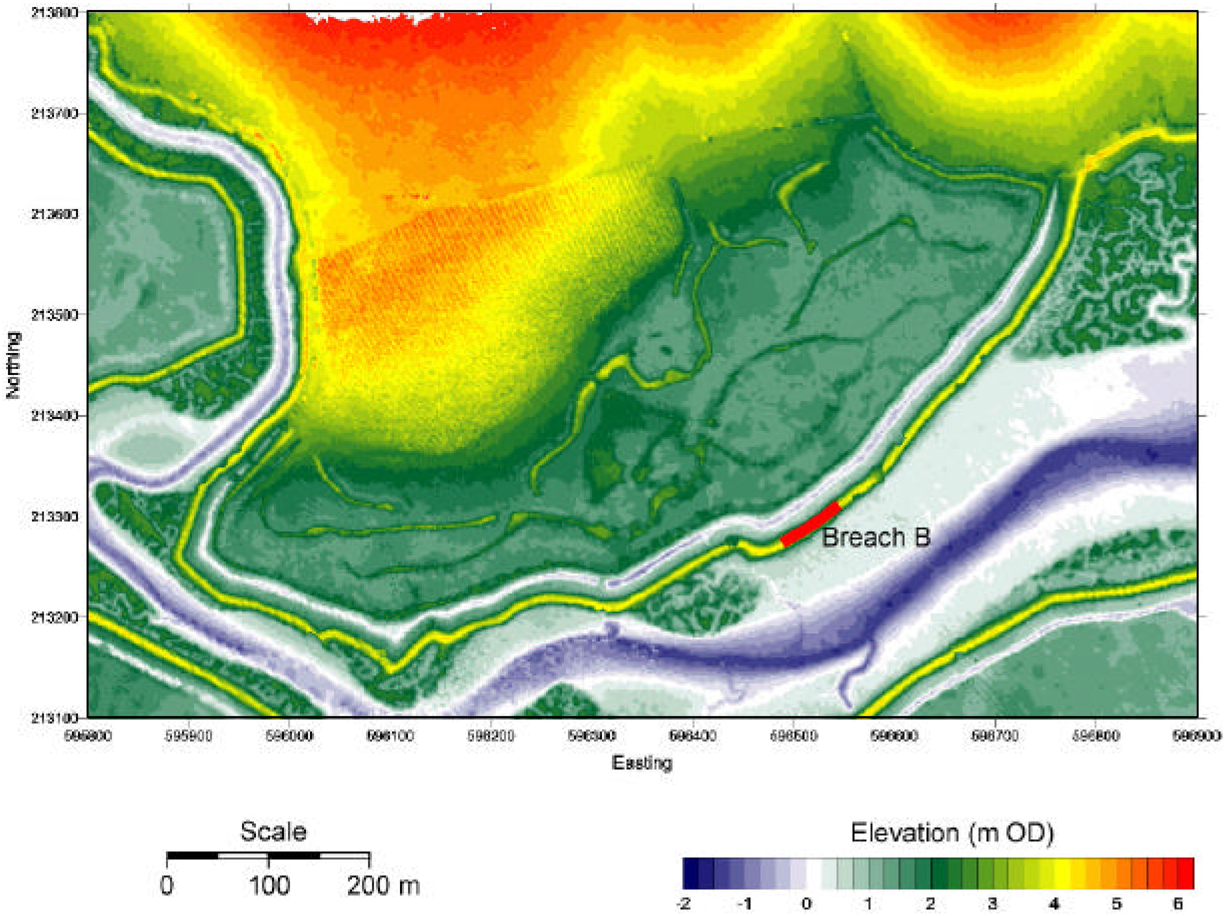


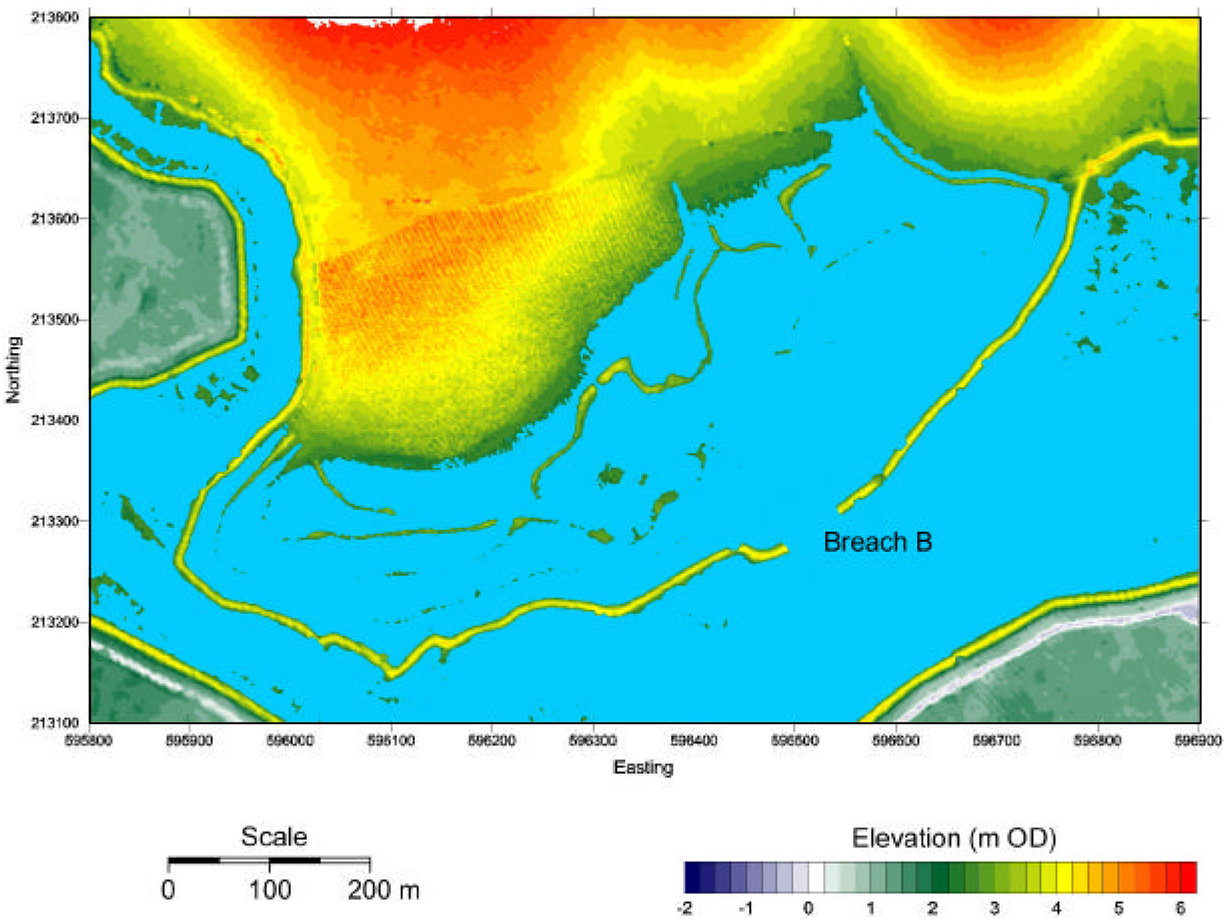
Figure 2.3 Location of study sites

b) **Elevation at time of breach related to present % remaining surface (after Burd *et al*., 1994).**

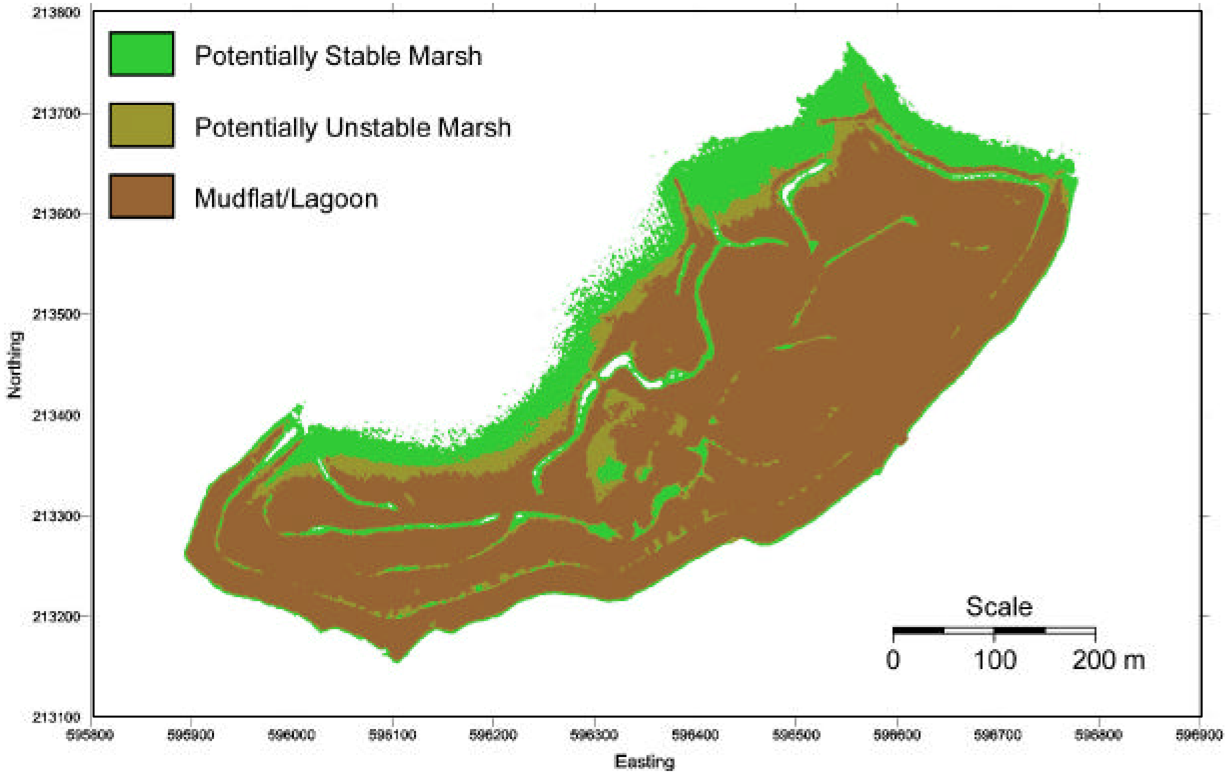




Digital terrain model of part of Abbotts Hall managed retreat site from lidar data (after Pye and Blott, 2002).



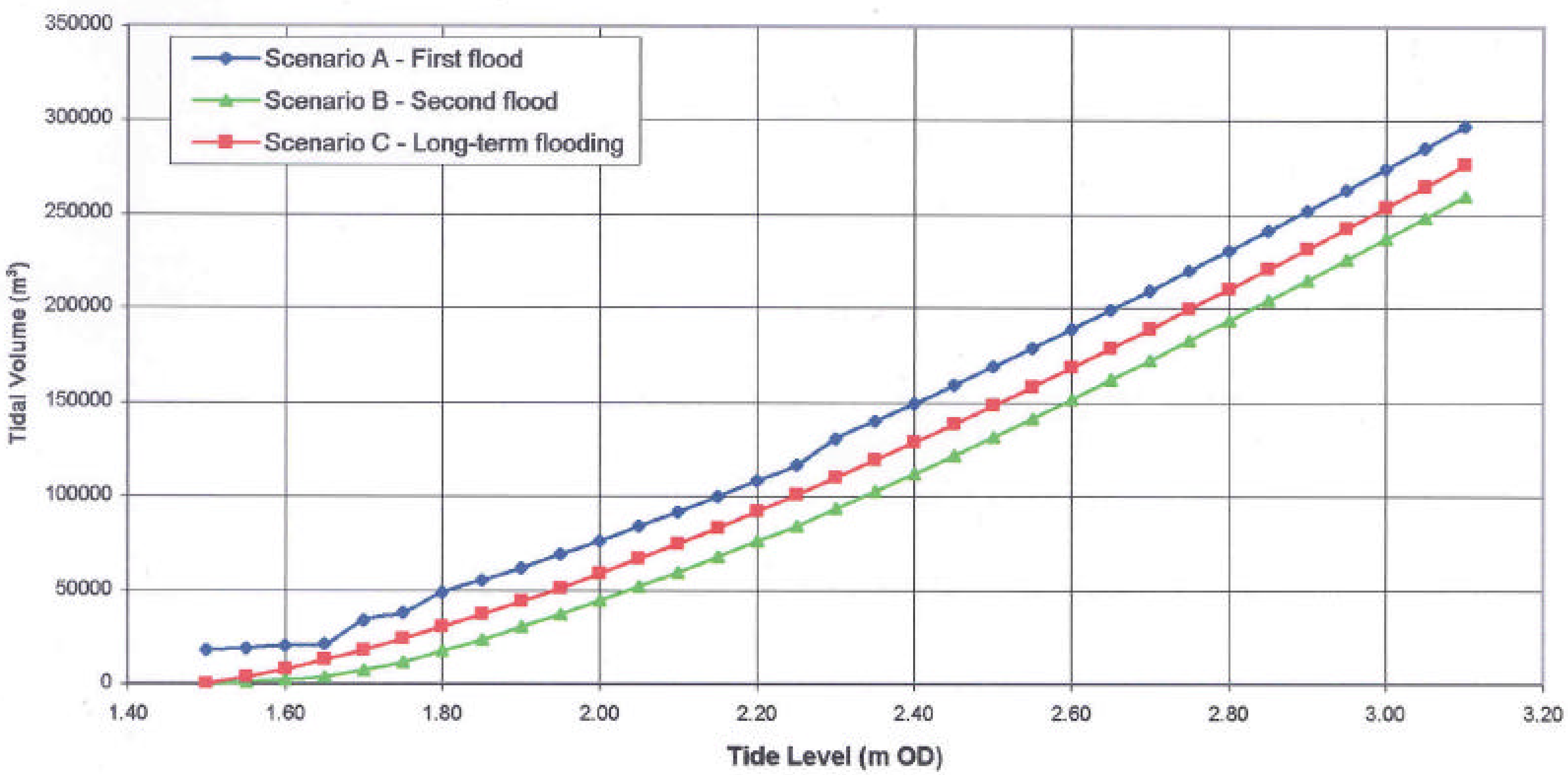
Land flooded behind Breach B at mean high water springs, 2.40 m OD (after Pye and Blott, 2002).



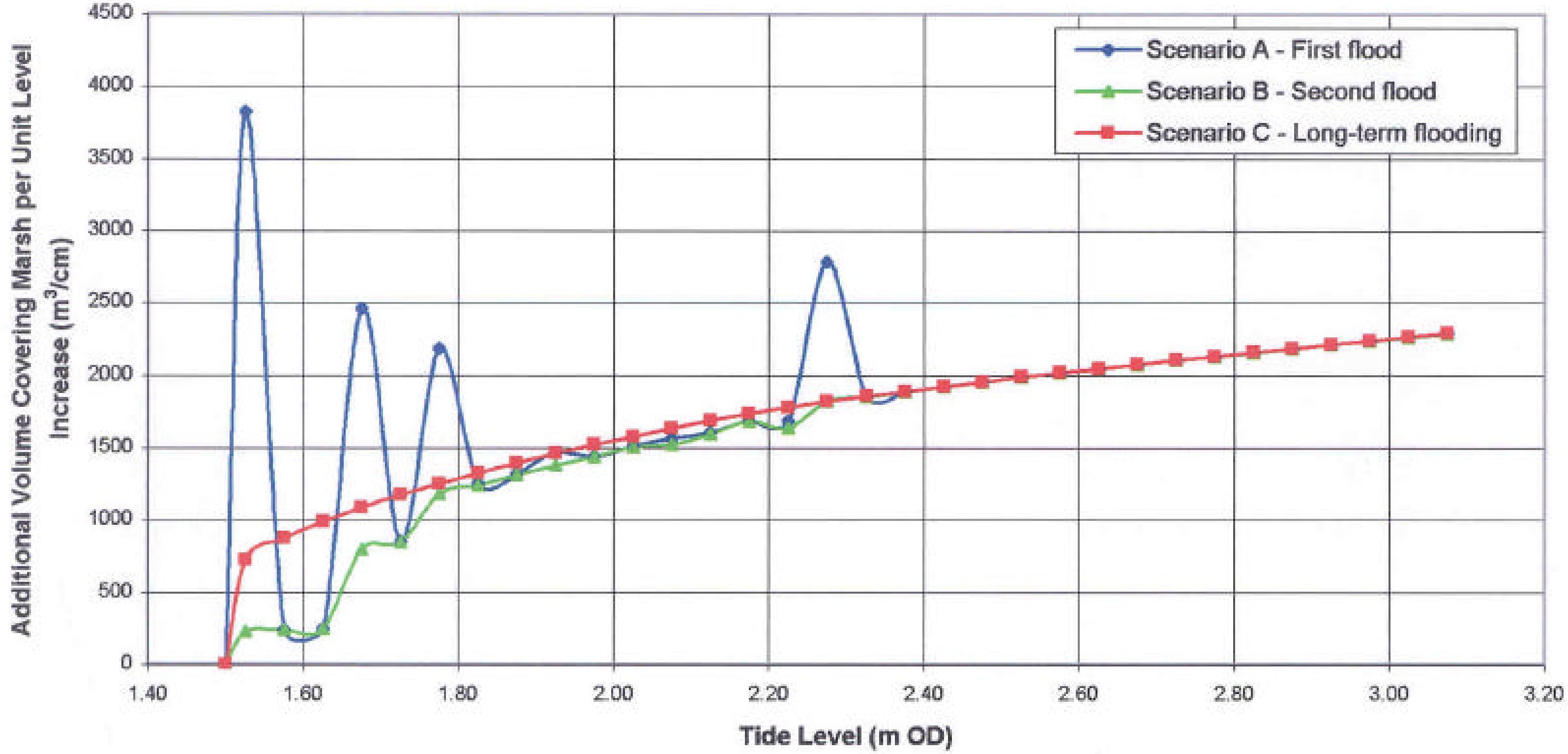
Areas of potentially stable saltmarsh (> 2.35 m OD), potentially unstable saltmarsh (2.10 m to 2.35 m OD) and mudflat/lagoon (< 2.10 m OD) created at Breach B, predicted using data from historical sea wall failures in Essex (after Pye and Blott, 2002).

Predicted areas of potentially stable saltmarsh, unstable saltmarsh and mudflat/lagoon at Abbotts Hall managed retreat site (after Pye and Blott, 2002).

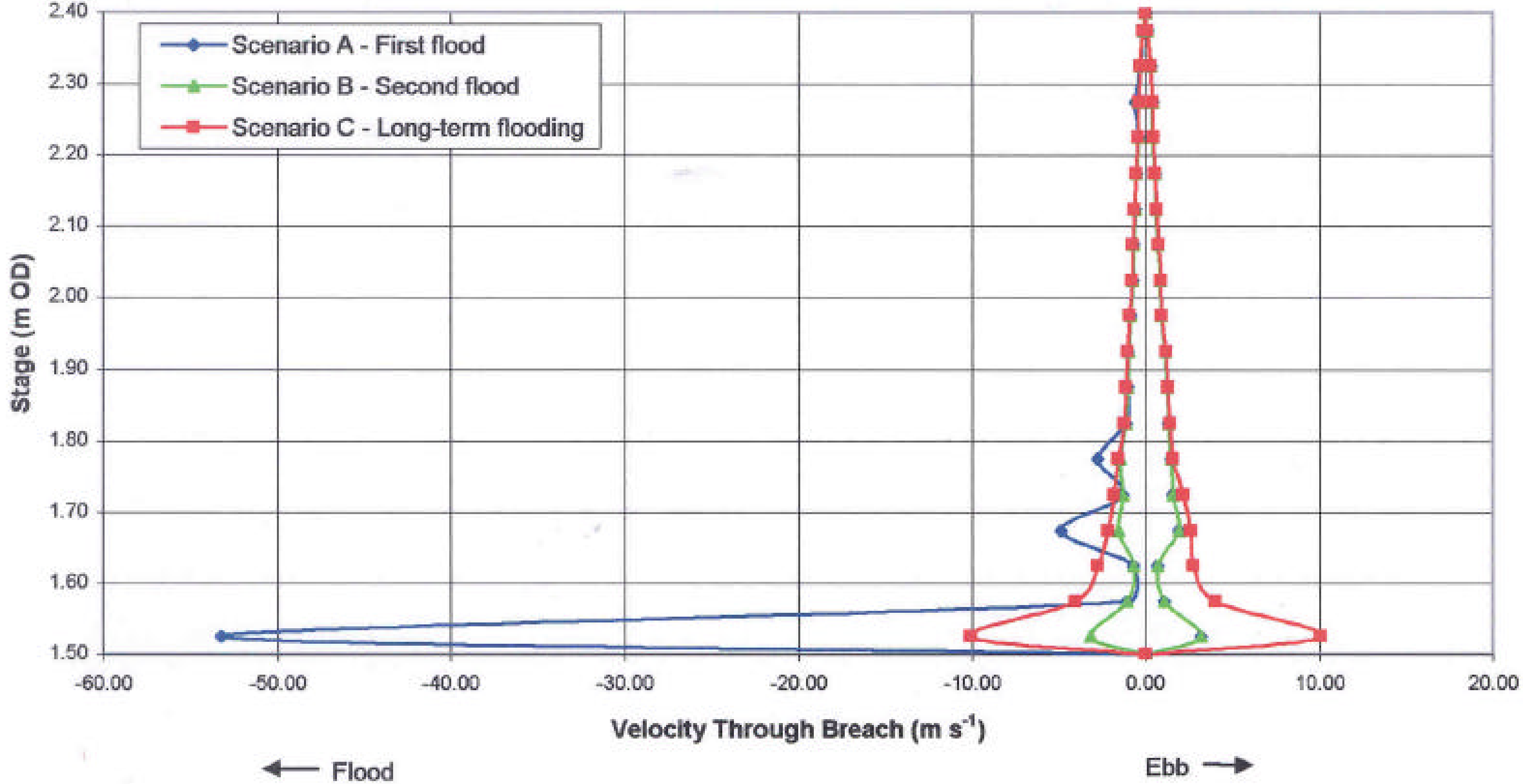
Breach	Stable Marsh (> 2.35 m OD)		Potentially Unstable Marsh (2.10 – 2.35 m OD)		Mudflat (< 2.10 m OD)	
	m^2	%	m^2	%	m^2	%
Breach A	6100	85.3	1054	14.7	0	0.0
Breach B	43239	18.8	30372	13.1	156929	68.1
Breaches C and D	48275	74.5	11942	18.4	4567	7.1
Breach E	25995	95.0	885	3.2	479	1.8
Totals	123609	37.5	44253	13.4	161975	49.1



Tidal prism behind Breach B for differing tide levels at varying intervals after initial breach (after Pye and Blott, 2002).



Tidal volume flowing through Breach B as a function of tidal stage at varying intervals after initial breach (after Pye and Blott, 2002).

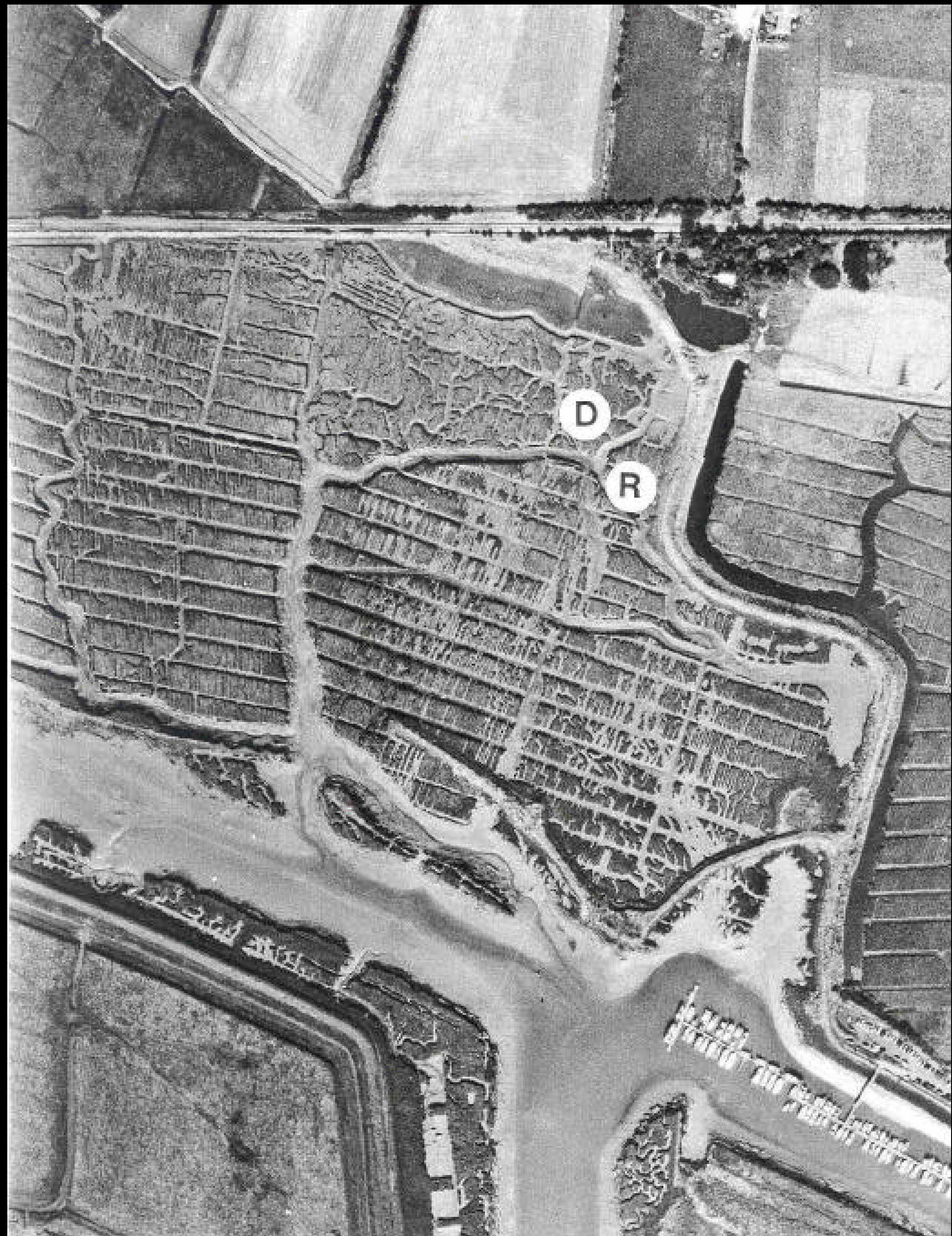


Velocity-stage curves for Breach B during a mean spring tide at varying intervals after initial breach (after Pye and Blott, 2002).

Flooded low-lying ground behind breach B, on falling spring tide October 2002.

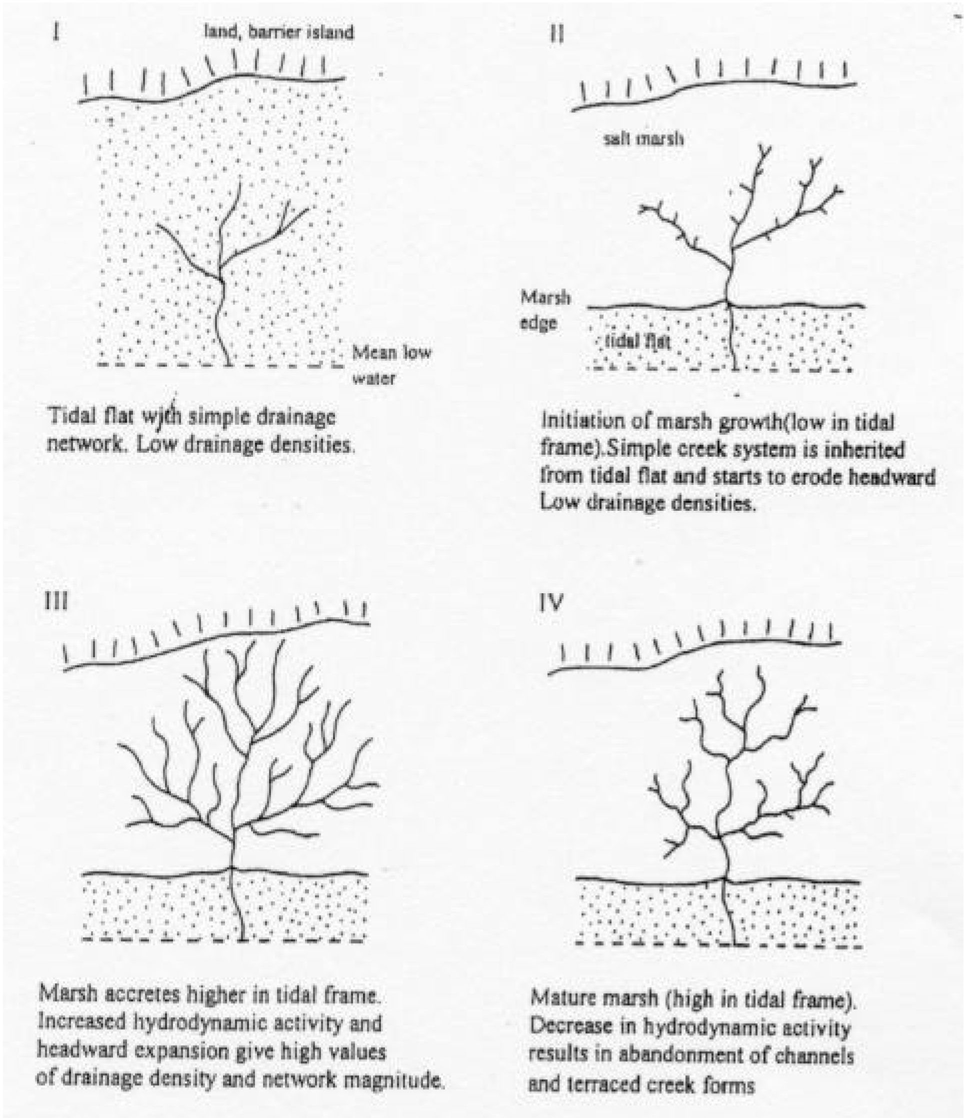
Breach B at Abbotts Hall, falling spring tide, October 2002.

Reactivated marsh created after natural breach in sea wall, November 1897 at North Fambridge, Crouch Estuary.

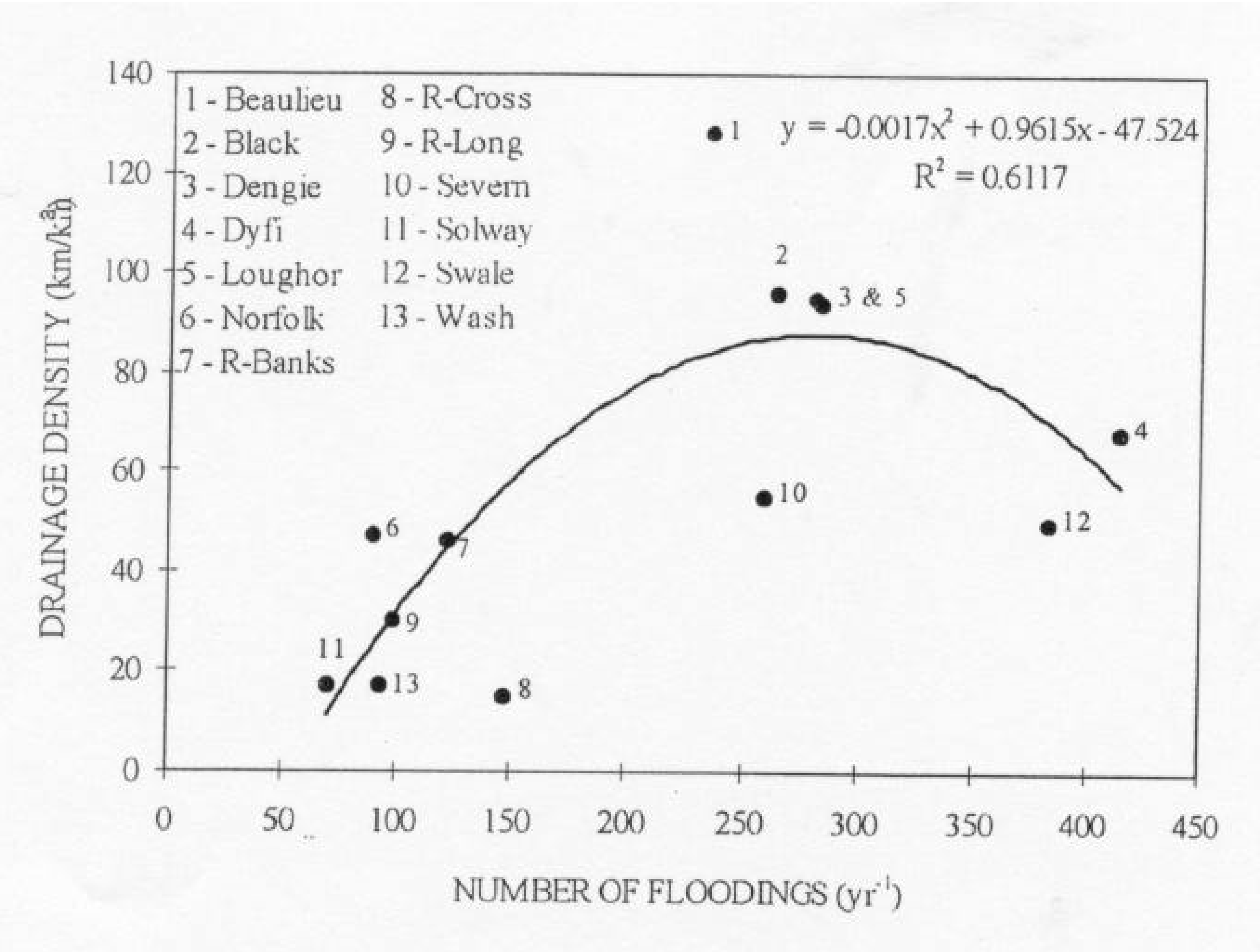


Severely eroded marsh at Canvey Point, formed by sea wall failure in 1881.

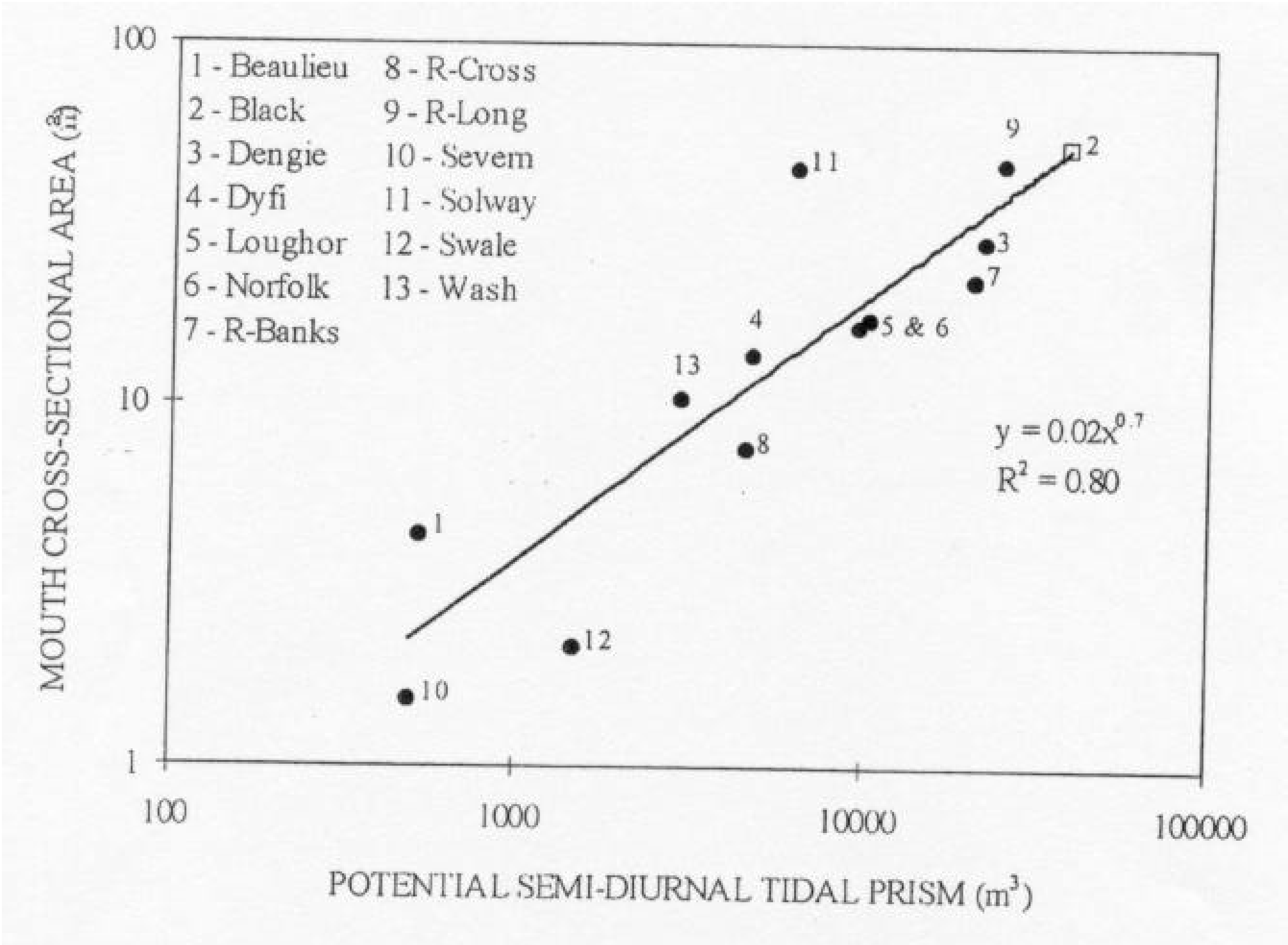
Artificially engineered creeks behind Breach A, Abbotts Hall, October 2002.



Schematic model showing the hypothesized stages of saltmarsh network evolution (after Steel and Pye, 1997).



Drainage density versus mean annual number of tidal floodings for some British saltmarshes (after Steel and Pye, 1997).



Mouth cross-sectional area versus potential semi-diurnal tidal prism for some British saltmarshes (after Steel and Pye, 1997).

Tidal prisms and breach widths at Abbotts Hall managed retreat site (after Pye and Blott, 2002).

	Breach height (m OD)	Breach width (m)	Tidal prism (m^3)		Equilibrium mouth cross-sectional area (m^2)		Actual mouth cross-sectional area (m^2)	
			MHWS	HAT	MHWS	HAT	MHWS	HAT
Breach A	2.25	2 ? 10	170	2524	1.0	7.5	3	17
Breach B	1.50	80	128978	276979	115	210	72	128
Breaches C and D	1.70 and 2.60	20 and 10	8443	34445	17	50	14	33
Breach E	2.10	20	374	7817	1.8	15	6	20

Conclusions

1. Selection of long-term (i.e., top-down) modelling methods must be strongly dependent on data availability and quality.

2. Key aspects are consideration of past historical changes at site of interest and at analogue locations.

3. Final conclusions must be based on expert assessment of output of all available models, experimental results and existing data.