South West of England Regional Development Agency

Wave Hub
Appendix G to the Environmental Statement

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Halcrow

South West of England
Regional Development Agency

HALCROW GROUP LTD
WAVE HUB PROJECT
ENVIRONMENTAL BASELINE SURVEY

Report No.: 68-8695

VOLUME I
(ENVIRONMENTAL BASELINE SURVEY REPORT)

Final Report

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Document Arrangement

Volume	Name
I	**Environmental Baseline Survey Report**
II	Biotope Classification Report
III	Appendices
IV	Charts

SUMMARY OF SURVEY RESULTS

Proposed Location:

Original Wave Hub Proposed Location			
Latitude:	50°21'50.400"N	Northing:	58 015.3m
Longitude:	5°40'19.200"W	Easting:	138 956.5m

Geographical (WGS84) and Grid (UTM, CM 2°W)

Environmental Survey Strategy:

For the purposes of survey design the area was split into four sections:

- Offshore Regional Area – around original Wave Hub area (9.5km x 8.5km).
- Original Wave Hub Deployment Area (2km x 4km).
- Offshore Cable Route – 500m wide, *circa* 28km corridor between St. Ives Bay and original Wave Hub location.
- Nearshore Cable Route – St. Ives Bay section of cable route.

Grab Sampling

Thirty grab sampling stations were positioned using geophysical data from a previous survey. Samples were initially located in areas expected to comprise surficial sediments, then positioned to give sufficient geographical and bathymetric coverage. Proposed locations were distributed as follows:

- Offshore Regional Area = 11 stations (stn 9 and 12 to 22, excluding 16)
- Original Wave Hub Deployment Area = 9 stations (stn 1 to 8 and 16)
- Offshore Cable Route = 3 stations (stn 10, 11 and 23)
- Nearshore Cable Route = 7 stations (stn 24 to 30)

The proposed sampling plan was completed as planned, with the following exceptions: only 2x replicate macrofaunal samples were obtained at station 24 due to coarse substrate; station 30 was relocated due to the shallow water depth; and stations 20 to 23 were not sampled due to coarse substrate.

Beam Trawl Sampling

Twenty beam trawl transects (T) were positioned using geophysical data, with midline coordinates corresponding to particular grab stations to sample both infauna and epifauna. Proposed locations were distributed as follows:

- Offshore Regional Area = 9x transects (T5 to 14, excludingT8)
- Original Wave Hub Deployment Area = 4x transects (T1 to 3 and T8)
- Offshore Cable Route = 1x transects (T4)
- Nearshore Cable Route = 6x transects (T15 to 20)

All proposed beam trawl sampling was completed as planned.

Seabed Photography

Eighteen camera transects (C) were positioned, after preliminary review of grab and beam trawl data. Proposed locations were distributed as follows:

- Offshore Regional Area = 6 transects (C8 to 13)
- Original Wave Hub Deployment Area = 4 transects (C14 to 17)
- Offshore Cable Route = 4 transects (C5 to 7 and C18)
- Nearshore Cable Route = 4 transects (T1 to 4)

Camera transects were subsequently reoriented according to tidal conditions, to facilitate sampling.

Bathymetry:

Across the offshore regional area the seabed elevations varied between a minimum of 31m Chart Datum (CD) in the south-east of the area to 60m along the north-west boundary.

Within the original Wave Hub deployment area the general seafloor elevation varied between 60m to the north-west of the area shoaling to 50m to the south. In the centre and to the south of the area there were regions of exposed bedrock that rose to a maximum elevation of 36m.

The offshore cable route shoaled from an approximate depth of 54m to 20m towards the nearshore region. The nearshore cable route (designated as starting where the exposed bedrock was covered by surficial sediments) shoaled from approximately 30m to the shoreline.

Seabed Features: The offshore Wave Hub area, including the regional offshore area and the original Wave Hub deployment area comprised exposed bedrock or bedrock covered by varying depths of different sediments. To the north and north-west of the entire area, the sediment type covering the bedrock was described as predominantly silty SAND over ROCK, as corroborated by grab sampling (stn 1, 2 4 and 13 to 18.

To the west of the original Wave Hub deployment area, the sediment type was described as comprising sandy GRAVEL over ROCK, while the corresponding grab (stn 12) comprised coarse SAND and SHELL.

Sediments to the south and east of the survey area were described as a thin veneer of clayey SAND/ GRAVEL over ROCK, as corroborated by grab sampling (stn 19 and 20). Sedeiments within the original Wave Hub deployment area were seen from grab sampling (stn 3 and 5 to 8) to comprise very poorly sorted SAND and PEBBLE over ROCK.

Grab sampling along the nearshore cable route indicated that sediments within the confines of St. Ives Bay comprised fine SAND (stn 27 to 30a), changing to very poorly sorted PEBBLE outside the bay (stn 25 and 26).

Note seabed features information was provided from a previous survey by EGS.

Granulometry: The sediment distribution across the site varied considerably, ranging from poorly sorted pebble (-4.65 phi) at stn 25 to moderately well sorted fine sand (2.75 phi) at stn 28. Percent fines varied between 0.05% (stn 16 and 18) to 8.97% (stn 20), while percent sand ranged from 14.5% to 99.6% (stn 5 and 30a, respectively) and coarse material (i.e. >2mm) from 0.0% to 84.0% (stn 28 and 25, respectively).

Multivariate analysis of granulometry data identified four statistically different clusters, which generally corresponded to geographically distinct areas:

- Cluster a comprised stations located on the inshore cable route in St Ives Bay (stn 27 to 30), dominated (i.e. the mode sediment fraction) by fine sand (3.0 phi), which accounted for a mean of 63.8% of the sediments.
- Cluster b included stations located both on the inshore cable route outside of St Ives Bay (stn 25 and 26) and within the regional survey area (stations 7, 8 and 19), dominated by large PEBBLE (<-4.0 phi) accounting for a mean of 63.4% of the sediments.
- Cluster c comprised stations from the southern halves of the original Wave Hub deployment area (stn 4, 5 and 6) and regional area (stn 9 to 12 and 20), bimodally distributed with main peak (mean = 19.9%) for medium PEBBLE (-5.0 phi) and less prominent peak (mean = 13.29%) for medium SAND (2.0 phi).
- Cluster d included all stations from the northern halves of the Wave Hub deployment area (stn 1, 2 and 16) and regional area (stn 13 to 15, 17 and 18), and was dominated by very coarse SAND, accounting for a mean of 36.35%.

Total Organic Carbon: The proportion of organic carbon within the sediments was relatively homogeneous across the site, ranging from 1.4% to 3.8% (stn 30a and 20, respectively.

Proportions of organic carbon and fines (<63µm) typically correlate well together. A weak correlation was evident for the data from this survey, with stations 20 and 5, recording the two highest levels of both fines (6.4% and 8.9%, respectively) and organic carbon (3.8 and 3.5%, respectively).

Hydrocarbons:

Levels of total hydrocarbon and total n-alkane concentrations across the site were low, with both measures showing a similar pattern of distribution. Total hydrocarbon concentrations ranged from 0.89µg.g^{-1} to 4.83µg.g^{-1} (stn 18 and 20, respectively), while total n-alkane concentrations ranged from 0.06µg.g^{-1} (stn 17, 18 and 27) to 0.32µg.g^{-1} (stn 20). Hydrocarbon concentrations correlated reasonably well with the proportion of fines (<63µm) within the sediment. This explains the observed hydrocarbon concentrations at stn 20 and 18, which recorded the highest and lowest percent fines, respectively (8.97% and 0.05%).

Individual n-alkanes exhibited a characteristic signature for coastal sediments, with higher concentrations evident for longer chain n-alkanes and odd carbon number alkanes. This distribution is consistent with the presence of terrestrial derived n-alkanes from the wax cuticles of higher plants, which typically comprise the long-chain, odd carbon number n-alkanes (nC_{25-33}).

The carbon preference index (CPI) was used to assess the relative contribution from petrogenic and biogenic sources of hydrocarbons, determined by calculating the ratio of the sum of odd- to even-carbon alkanes. CPIs (nC_{12-36}) ranged from 0.97 to 1.82 (stn 3 and 9, respectively). While generally toward the lower end expected, these values were considered to represent background levels of hydrocarbons. Lower levels of CPI observed at, *inter alia*, stn 3 and 29, appeared to be caused by reduced levels of terrestrial n-alkanes from riverine sediment inputs.

Heavy and Trace Metals:

Heavy metal analysis revealed that arsenic, copper lead, tin and zinc concentrations were generally higher for inshore stations. This is borne out by the literature; a previous study in the Hayle Estuary recorded elevated levels of these metals, which were attributed to tin mining. Higher concentrations of these metals at inshore stations are consistent with a riverine source of these metals.

The remaining metals showed no discernible pattern of distribution within the survey area.

Macrofauna:

<u>Grab Infauna</u>

Primary and univariate parameters showed substantial variation across the survey area with little overall trends evident for stations from different regions. The only discernible pattern within these data was shown by the inshore stations (stn 27 to 30) which exhibited considerably depressed numbers of both species and individuals, recording a minimum of 5 species and 8 individuals (stn 30) compared to a mean of 49 species and 320 individuals for the entire survey.

Multivariate analysis (0.2m^2) highlighted the presence of 4 statistically significant clusters. Subsequent SIMPER analysis highlighted the key characterising species for each cluster, as follows:

- Cluster a comprised stations from the inshore cable route (stn 27 to 29) characterised by taxa typically observed in shallow sublittoral sandy sediment environments, including three amphipod crustaceans, *Urothoe poseidonis*, *Bathyporeia guilliamsoniana* and *Bathyporeia tenuipes* and two polychaetes *Chaetozone setosa* and *Nephtys cirrosa*. This is consistent with the depth of <18m and fine SAND sediment recorded at these stations.
- Cluster b included stations located further along the nearshore cable route (stn 24 and 26) exhibiting coarse sediment comprising very poorly sorted pebble. Accordingly, this cluster was characterised by the presence of species requiring coarse substratum, including the cryptic crab *Pisidia longicornis*, encrusting polychaetes of the Serpulidae family, and the

polychaete *Typosyllis* sp. which inhabits unnocupied Serpulid tubes.

- Cluster c comprised stations from the southern parts of the original Wave Hub deployment and regional offshore areas (stn 3, 4, 6, 8, 9, 12 and 20) with poorly sorted PEBBLE sediments. This cluster was characterised by similar species to cluster b, sharing the same three most characteristic taxa (*Pisidia longicornis*, Serpulidae and *Typosyllis* sp.) albeit at higher densities.
- Cluster d included the majority of stations from the northern parts of the Wave Hub deployment and regional offshore areas with sediments of coarse to very coarse SAND. Fauna were dominated by carnivorous the polychaetes *Glycera lapidum*, *Typosyllus* sp., *Eunice* sp., *Kefersteinia cirrata*, *Ehlersia cornuta* and *Protodorvillea kefersteini*, which were thought to predate on the polychaete *Polygordius* sp.

Trawl Epifauna

No particular pattern was evident for primary and univariate parameter within the offshore survey area. However, as observed for grab macrofauna, lower numbers of both species and individuals were recorded for the inshore cable route trawls (T18, 19 and 20) with a minimum of 8 species (T19) and 14 individuals (T20) compared to a mean of 25 species and 141 individuals for the whole survey area.

Multivariate analysis identified the presence of 3 statistically significant clusters across the survey area. Subsequent SIMPER analysis highlighted the key characterising species for each cluster, as follows:

- Cluster a delineated the fine SAND substrate areas located on the inshore cable route within St Ives Bay (T18, 19 and 20) and was characterised by a sparse epifauna with low numbers of fish including sand gobies, *Pomatoschistus* spp. and sole, *Solea solea.*
- Cluster b comprised trawls from the southern regional offshore area (11 to 14) and original Wave Hub deployment area (T3) as well as the nearshore and offshore cable route (T4, 16 and 17) and was characterised by the porcelain 'crab' *Pisidia longicornis* and brittlestar *Ophiothrix fragilis*.
- Cluster c included trawls from the northern parts of the regional offshore (T5, 6, 7, 9 and 10) and original Wave Hub deployment areas (T1, 2, 8) and was dominated by queen scallops (*Aequipecten opercularis*) and hermit crabs (*Pagurus prideaux*).

Seabed Photography:

Underwater video/stills acquired from sediment substrates confirmed the presence of the three main communities (clusters) identified from the multivariate analysis of the grab and trawl data.

A number of other communities associated with bedrock habitats (not sampled by grabs or trawls) were identified throughout the survey area. These assemblages included dense beds of the brittlestars *Ophiothrix fragilis* and *Ophiocomina nigra* on bedrock plateaus, assemblages dominated by the feather star, *Antedon bifida* on rock outcrops and diverse sponge and bryozoan communities.

1 INTRODUCTION

1.1 Scope of Work

Alluvial Mining Limited (AML) were commissioned by Halcrow Group Limited to provide Geotechnical/ Environmental Survey Services in association with the "Wave Hub – offshore survey stage 2" in NW Cornwall. The Environmental Department of Fugro Survey Limited (FSLTD) was subcontracted by AML to perform the offshore environmental field operations and subsequent analysis and interpretation.

The environmental baseline survey was required to provide baseline data relating to the physico-chemical and macrofaunal benthic environment. The survey comprised grab sampling using a 0.1m^2 Hamon grab for physico-chemical and biological analysis of the sediment, 2m beam trawls for epibenthic fauna and high resolution stills photography with video framing capability along transects.

Due to adverse weather conditions experienced, the environmental survey was completed in two Phases. Phase I was performed using the survey vessel Vos Baltic with the cruise dates between 18/10/2005 and 31/10/2005 and involved acquisition of all grab samples, beam trawls and camera transects 1 and 2. Phase II was performed using the survey vessel Portree II with the cruise dates between 18/11/2005 and 24/11/2005 and involved the acquisition of the remaining camera transects (see Appendix A for details of personnel).

This volume, Volume I, details the results of the environmental baseline survey for the Wave Hub survey area. Biotope mapping classification is presented in Volume II, while Appendices are presented in Volume III. Charts 1 to 19 (including overview chart) are presented in Volume IV.

It should be noted that during the reporting process, the original Wave Hub deployment area was revised and relocated to the east of the regional offshore area.

The Service Warranty in Appendix G outlines the limitations of this report.

1.2 Survey Regions

The field survey was split into four sections:

- Offshore Regional Area – survey of area surrounding original Wave Hub deployment area location (9.5km x 8.5km).
- Original Wave Hub Deployment Area – survey at original Wave Hub deployment area footprint (2km x 4km).
- Offshore Cable Route – survey of the 500m wide cable corridor running approximately 28km between St. Ives bay (from area of exposed bedrock) and original Wave Hub proposed location.
- Nearshore Cable Route – survey of the St. Ives Bay section of the cable route (from exposed bed rock area to the most nearshore station).

1.3 Proposed and Actual Sediment Sampling Strategy

A total of 30 grab sampling stations were positioned by the FSL Environmental Department using geophysical data from a previous survey obtained in July 2005 by EGS Ltd. Grab samples were initially located in areas which were expected, from geophysical survey data, to comprise surficial sediments, thereby avoiding areas of bedrock (Table 1.2). Stations were then positioned to give sufficient geographical and bathymetric coverage of the area to represent the diverse range of sediment types present within the survey area.

Stations 1 to 8 and 16 were located within the original Wave Hub Deployment Area. Stations 9 and stations 12 to 20 (excluding station 16) were located around the regional offshore area (outside the original Wave Hub deployment area). Stations 10 and 11 were located along the offshore cable route, whilst stations 24 to 30 were located along the nearshore cable route. Station 24 was only sampled for two samples, FA and FB. Samples FC and PC (physico-chemical) were not sampled due to the coarse

nature of the sediment. Station 30 was repositioned for safety reasons due to shallow water depth at this station. Stations 20 to 23 were not sampled due to the coarse nature of the substrate.

1.4 Proposed and Actual Beam Trawl Strategy

A total of 20 beam trawl transects were also positioned by FSL using the geophysical data. Trawls 1 to 3 and 8 were positioned within the Wave Hub deployment area. Trawls 5 to 14 (excluding trawl 8) were located around the regional offshore area, trawl 4 was located along the offshore cable route and trawls 15 to 20 were located along the nearshore cable route.

Midline coordinates for beam trawls corresponded to particular grab stations, so that both infauna and epifauna communities could be investigated at these locations.

1.5 Proposed and Actual Camera Transect Strategy

A total of 18 camera transects were positioned after preliminary review of grab and beam trawl data. Transects 14 to 17 were located within the original Wave Hub deployment area. Transects 8 to 13 were located around the regional offshore area, transects 5 to 7 and transect 18 were located along the offshore cable route and transects 1 to 4 were located along the nearshore cable route.

Camera transects were reoriented according to tidal conditions, to facilitate the effective survey of transects. At the request of the client, a drop-down camera deployment was undertaken to investigate a magnetic anomaly located along the cable route, which was subsequently identified as a wreck.

1.6 Survey Sample Locations

Table 1.1 shows the original Wave Hub Proposed Location. Table 1.2 shows the proposed grab sample locations. Table 1.3 shows proposed camera transects whilst Table 1.4 shows proposed beam trawl transects.

The overview chart, included in Volume IV, shows the locations of all the grab sample locations, beam trawl transects and camera transects overlying shaded relief bathymetry. Figures 4.1a and 4.1b in section 4 of this report also show these locations in relation to bathymetry.

Table 1.1 Original Wave Hub Proposed Location

Original Wave Hub Proposed Location			
Latitude:	50°21'50.400"N	Northing:	58 015.3m
Longitude:	5°40'19.200"W		138 956.5m

Table 1.2 Proposed Grab Sample Locations

Survey Area	Station	Proposed Coordinates		Samples
		Easting (m)	Northing (m)	
Wave Hub	1	138 962.20	57 962.24	PSA, CHEM, BIO
	2	139 831.00	57 622.98	PSA, CHEM, BIO
	3	139 483.50	57 126.51	PSA, CHEM, BIO
	4	138 192.70	57 043.76	PSA, CHEM, BIO
	5	139 169.10	56 381.79	PSA, CHEM, BIO
	6	140 327.50	55 786.02	PSA, CHEM, BIO
	7	139 516.60	55 239.90	PSA, CHEM, BIO
	8	138 771.90	55 181.98	PSA, CHEM, BIO
Offshore	9	137 307.30	55 148.88	PSA, CHEM, BIO
	10	138 830.20	54 423.68	PSA, CHEM, BIO
	11	139 361.60	53 373.67	PSA, CHEM, BIO
	12	135 317.50	54 474.22	PSA, CHEM, BIO
	13	134 963.70	58 454.49	PSA, CHEM, BIO
	14	137 061.20	58 429.22	PSA, CHEM, BIO
	15	136 265.20	59 768.61	PSA, CHEM, BIO
	16	138 539.60	59 098.92	PSA, CHEM, BIO
	17	138 666.00	60 931.11	PSA, CHEM, BIO
	18	142 772.60	59 718.07	PSA, CHEM, BIO
	19	142 001.80	57 658.44	PSA, CHEM, BIO
	20	143 050.60	55 649.35	PSA, CHEM, BIO
	21	143 669.70	53 741.34	No data acquired
	22	144 513.60	53 814.30	No data acquired
Cable	23	141 422.90	52 267.48	No data acquired
Inshore	24	150 535.80	43 187.35	BIO (x 2)
	25	152 387.90	42 777.59	PSA, CHEM, BIO
	26	153 977.70	42 089.21	PSA, CHEM, BIO
	27	154 649.70	41 581.12	PSA, CHEM, BIO
	28	155 207.00	40 761.61	PSA, CHEM, BIO
	29	155 370.90	39 876.54	PSA, CHEM, BIO
	30	155 233.60	39 094.58	PSA, CHEM, BIO

PSA = Particle Size Analysis; CHEM = Sub-sampled for heavy/ trace metal and hydrocarbon analyses; BI0 = 3 x Macrofaunal Samples (1.0mm sieve); CAM = Drop down camera video/ stills.

Table 1.3 Proposed Camera Transects

Survey Area	Station	Start of Line		End of Line	
		Easting (m)	Northing (m)	Easting (m)	Northing (m)
Inshore	1	155 071.37	40 994.99	154 744.44	41 442.74
	2	154 545.44	41 655.96	154 111.90	41 997.11
	3	151 709.66	42 878.40	151 190.83	43 020.55
	4	150 430.35	43 233.76	150 110.53	43 674.41
Cable Route	5	148 056.54	47 618.92	147 608.79	47 924.53
	6	143 168.36	50 987.92	142 664.09	51 393.98
	7	141 617.40	52 110.69	141 198.07	52 444.73
Offshore	8	143 669.94	53 741.53	144 512.98	53 813.87
	9	141 911.64	55 742.04	141 863.83	56 240.38
	10	142 113.86	60 325.26	141 753.54	60 685.58
	11	140 839.21	61 529.35	140 346.77	61 451.28
	12	135 146.06	56 502.80	135 242.15	55 037.48
	13	135 316.37	54 475.31	135 359.04	53 960.62
Wave Hub	14	138 745.78	57 805.31	139 212.82	58 143.26
	15	139 135.94	57 767.60	138 784.94	58 151.96
	16	139 619.08	57 014.67	139 332.31	57 436.19
	17	139 619.49	55 711.31	139 517.59	55 239.26

Table 1.4 Proposed Beam Trawl Transects

Survey Area	Station	Proposed Midline Coordinates	
		Easting (m)	Northing (m)
Inshore	1	138 962.20	57 962.24
	2	138 192.70	57 043.76
	3	138 771.90	55 181.98
Offshore	4	138 830.20	54 423.68
	5	134 963.70	58 454.49
	6	137 061.20	58 429.22
	7	136 265.20	59 768.61
	8	138 539.60	59 098.92
	9	138 666.00	60 931.11
	10	142 772.60	59 718.07
	11	142 001.80	57 658.44
	12	143 050.60	55 649.35
	13	143 669.70	53 741.34
	14	144 513.60	53 814.30
Wave Hub	15	150 535.80	43 187.35
	16	152 387.90	42 777.59
	17	153 977.70	42 089.21
	18	154 649.70	41 581.12
	19	155 207.00	40 761.61
	20	155 370.90	39 876.54

1.7 Survey Reference System

All co-ordinates in this report are based on the Spheroid WGS84. Grid co-ordinates are on the Universal Transverse Mercator Projection, Central Meridian 2°W.

Table 1.5 Geodetic Parameters

Project Spheroid Parameters

Spheroid	WGS84
Semi-major axis:	6377563.396
1st Eccentricity squared (e^2)	0.006 670 539 997 76

Project Projection Parameters

Unit	International Metre
Projection	Transverse Mercator
Latitude of Origin	49° North
Central Meridian	2° West
Scale factor on CM:	0.9996012717
False Easting	400 000 metres
False Northing	-100 000 metres
Datum	OSGB36 ODN

1.8 Document Arrangement

Volume	Name
I	**Environmental Baseline Survey Report**
II	Biotope Classification Report
III	Appendices
IV	Charts

1.9 Abbreviations

5. AML Alluvial Mining Limited
6. CCCs Continuous Calibration Checks
7. CD Chart Datum
8. CM Central Meridian
9. CPI Carbon Preference Index
10. DVD Digital Video Disk
11. SVHS Super Video Home System
12. DCM Dichloromethane
13. FSLTD Fugro Survey Limited
14. GC Gas Chromatography
15. GCFID Gas Chromatography Flame Ionisation Detection
16. GCMS Gas Chromatography Mass Spectrometry
17. H_2S Hydrogen Sulphide
18. HSE Health, Safety and Environment
19. ICPMS Inductively Coupled Plasma Mass Spectrometry
20. ICPOES Inductively Coupled Plasma Optical Emission Spectrometry
21. IMS Industrial Methylated Spirit
22. JNCC Joint Nature Conservation Committee

23.	KP	Kilometre Point
24.	LAT	Lowest Astronomical Tide
25.	LOI	Loss on Ignition
26.	MCS	Marine Conservation Society
27.	MSDS	Materials Safety Data Sheets
28.	MSL	Mean Sea Level
29.	MV	Motor Vessel
30.	NIST	National Institute of Standards and Technology
31.	nMDS	Non-Metric Multidimensional Scaling
32.	OSGB36	Ordnance Survey of Great Britain 1936 Datum
33.	PAH	Polycyclic Aromatic Hydrocarbons
34.	PPE	Personal Protective Equipment
35.	PRIMER	Plymouth Routines in Multivariate Ecological Research
36.	PTFE	Polytetrafluoroethylene
37.	SACFOR	Superabundant, Abundant, Common, Frequent, Occasional, Rare
38.	UTM	Universal Transverse Mercator
39.	VHF	Very High Frequency
40.	WAS	Wilson Auto-Siever
41.	WGS84	World Geodetic System 1984

2 FIELD OPERATIONS

2.1 HSE Considerations

Prior to the deployment and during the deployment and recovery of each separate operation, the following was carried out or taken into account:

1. After considering any priorities set out by Client/ Client Representative and in agreement with Party Chief, the Surveyor directed the Captain/Mate towards each location. When the Captain/Mate was satisifed with the position of the vessel, having taking into account prevailing weather and current directions, permission to deploy was given. The Captain/ Mate was informed when the grab was deployed, when it reached the seabed, when it left the seabed and when it was safely back aboard the vessel. The Captain/ Mate, Surveyor and Deck-Supervisor were in constant communication by radio at all times.

2. All personnel involved in deployment and recovery of the grab wore the appropriate personal protective equipment (PPE). This comprised a hard-hat, steel toe-capped boots, overalls, a life-jacket and gloves.

3. The senior Environmental Scientist was responsible for the correct storage and handling of the chemicals used during the sampling process. In addition to the standard PPE, butyl gloves and safety goggles were worn while handling formaldehyde solution. The appropriate Materials Safety Data Sheets (MSDS) for chemicals used were issued to the Captain and Senior Environmental Scientist, additional copies were stored with the chemicals themselves.

4. All weight bearing equipment (wires, shackles, swivels and lifting points) had valid lift certification, copies of which were kept by the Captain, Party Chief and Senior Environmental Scientist.

5. Task-specific work instructions and risk assessments were set out prior to the commencement of the survey; copies of these were issued to the onboard Client Representative, Captain, Party Chief and Senior Environmental Scientist. Toolbox talks were held before a new task began to ensure that all personnel understood their specific role within the operation.

2.2 Hamon Grab Operations

All Hamon grab operations were performed from the M.V. Vos Baltic during Phase I.

2.2.1 Grab Sampling – Deployment and Recovery

Seabed sampling was undertaken using an industry standard 0.1m^2 Hamon grab. The Hamon grab is the preferred sampling device when biological and physico-chemical samples are required from coarse substrata, although a disturbed sample is obtained. This method of sampling prevents gravel becoming trapped between the leading edge of the sample bucket and the retaining plate, thereby reducing sample washout.

A winch secured to the mid foredeck of the vessel was used to deploy the grab; from this the cable ran through a metal eye in the boat's gunwale to a block suspended from the vessel's crane. The crane arm was used to deploy the grab to the water's surface and to recover it to deck.

Operational procedures for grab sampling were as follows;

The 0.1m^2 Hamon grab was cleaned prior to use using a solvent; dichloromethane (DCM). The Hamon grab was cleaned using water and DCM at every station prior to obtaining the physico-chemical sample. A length of new, degreased wire was used to attach the Hamon grab to the main cable to avoid contamination.

The Hamon grab was primed accordingly, with the lifting arm held in place by the release hook prior to deployment. The captain communicated to the deck via a VHF radio when the vessel was steady on location and the Hamon grab was deployed.

When the winch operator observed that the Hamon grab had reached the seabed (evidenced through a distinct slackening of the wire rope and snatch block) the on-line surveyor was informed (via VHF radio) and a fix was taken.

On recovery to the deck, the inspection hatches on the grab were opened and the sample was judged for acceptability through applying a number of criteria. The sample was considered unacceptable in the following instances (and was classified as a no-sample);

1. The sample represented less than half of the grab's capacity.

2. The sample was more than the accepted range from the target location.

3. Hag Fish, *Myxine glutinosa* and/ or mucous coagulants were present.

4. The sample was unacceptable to the Client Representative for any other reason.

If the sample was accepted, it was retained for either macrofaunal analysis or physico-chemical analysis. In general, to increase survey efficiency, the first three samples were retained for macrofaunal analysis (FA, FB and FC), with the final sample processed for physico-chemical analysis.

Samples retained for macrofaunal analysis were thoroughly washed into the sediment collection tray and the grab was immediately redeployed (after obtaining permission from the Bridge). The retained sediment was then transferred to the semi-automated *Wilson Auto-Siever* (WAS) for sieving.

If the sample was to be used for physico-chemical subsampling, the bridge was informed and the vessel transited immediately to the next station. The sample was processed during transit.

2.2.2 Grab Sampling - Processing

Macrofaunal Processing

After the sediment was transferred to the Wilson Auto-Siever the sediment was broken down using a low powered seawater jet spray. The finer sediment was removed through a 1mm mesh sieve. The remaining residue was then transferred to a 5 litre bucket. The residue in the bucket was preserved with a 20% formalin solution [added at a proportion of 1:1 (water: formalin), ensuring a final formalin concentration of approximately 10%].

Physico-chemical Sub-sampling

The physico-chemical grab sample was photographed showing a scale bar. The sediment was then subsampled for heavy metal, hydrocarbon and particle size analyses. Two subsamples were collected for heavy metal analysis using a plastic scoop and stored in two 200ml plastic jars. Two subsamples were then collected for hydrocarbon analysis using a metal scoop (pre degreased using DCM and methanol baths) and transferred into two 250ml tins. A single subsample was obtained for particle size analysis and 'double bagged' in freezer bags.

All samples were transferred to an onboard freezer (-20°C) for storage until demobilisation. The samples were then shipped back in cool boxes to Fugro Survey Limited's Great Yarmouth office for redelivery to the relevant laboratories.

2.2.3 Grab Sampling - Logging

The first macrofauna sample (FA) was photographed with a label which clearly showed the job and station numbers and a scale bar (ruler). A close-up of the sample, including the labels and scale bar was also taken. A further photograph was taken of the fauna retained after sieving when this was appropriate.

The following characteristics were described for each grab sample (see Appendix B):

1. Sample volume (eg ½ full)
2. Colour (using a Munsell chart, recording Hue and Value/ Chroma)
3. Sediment classification (eg Fine to medium SAND)
4. Layering (depth, colour of surface/ subsurface layers and presence of anoxic layer)
5. Smell (presence of H_2S)
6. Obvious fauna
7. Bioturbation (presence/ absence)
8. Anthropogenic debris (eg drill cuttings, seeds)

2.3 Beam Trawl Operations

All beam trawl operations were performed from the M.V. Vos Baltic during Phase I.

2.3.1 Beam Trawling – Deployment and Recovery

Beam trawls were undertaken using a 2m metal beam trawl with a 20mm mesh net and 4mm mesh codend liner (for design specification see Jennings *et al*, 1999). The trawl was deployed and recovered in the same way as the Hamon grab and camera system. A weak-link with a breaking strain of 2 tonnes was used to attach the trawl to the main cable; this was included to prevent damage to the crane or dangerous cable recoil in the event of the trawl becoming snagged. A backup trawl and replacement chafers were carried onboard.

Prior to acquiring survey data, two experimental trawls were undertaken to determine adequate towing distance. A distance of 500m was found to obtain a sample of manageable size that was considered representative of the epifaunal community. This distance was maintained throughout the survey to ensure inter-sample comparability.

Operational procedures for trawl sampling were as follows:

Before every deployment, the trawl and fixtures were checked for damage. The net was checked for residual fauna from previous trawls and washed if necessary.

The trawl was deployed when the vessel was approaching the designated start of line. To deploy, the crane was used to slowly swing the trawl over the water and lower it to the surface. Before the warp was paid out, the trawl was towed along the surface water to ensure that it was towing correctly.

After reaching the seabed the trawl was towed against the prevailing current at a maximum speed of 1.5 knots over the ground. Warp payout was 3 to 5 times the water depth (60-200m), depending on conditions.

A line fix (i.e. continuous series of fixes taken at 30 second intervals) was taken to determine the position of the trawl throughout each transect; to ensure positioning accuracy each fix was derived using an offset incorporating crane arm and warp length.

At the end of the trawl the beam trawl was winched up to deck level with the crane arm still over the water. The trawl was then swung slowly onto the deck before being secured so that the catch could be safely emptied. Further evidence of good bottom contact was sought by examination of the trawl shoes, the net was also checked for damage that may have resulted in loss of material.

2.3.2 Beam Trawling - Sample Processing

The majority of the catch was identified in the field and returned; specimens that couldn't be identified *in situ* (generally due to their small size) were fixed in ~10% buffered formaldehyde solution for laboratory analysis. All solitary taxa were identified to the lowest practicable taxonomic level (typically species) and enumerated. Where a high abundance of a specific taxon (e.g. *Aequipecten opercularis*) was

encountered, a quarter subsample was enumerated and the resultant figure multiplied to approximate total abundance; care was taken to ensure that taxa morphologically similar to the abundant taxon were not overlooked.

Colonial taxa and macrophytes were again identified to the lowest possible taxonomic level and then semiquantified by use of a scale in which taxa are classed as either superabundant, abundant, common, frequent, occasional or rare (SACFOR scale). Brief descriptions of colonial taxa that could not be identified *in situ* were made prior to their fixation and their abundance was noted.

The SACFOR scale utilised was adapted from that used in the JNCC's Marine Nature Conservation Review (Hiscock (ed.), 1999), its use will allow cautious comparison to be made between the trawl data and the biotope characterising data used in 'The Marine Habitat Classification for Britain and Ireland' (Conner *et al*, 2004). The scale splits taxa into two broad groups, those that form extensive (and often aggregated) colonies that cover the substrate and those in which smaller discrete colonies are evident. The taxa which form large colonies are further split into two growth forms, encrusting and massive and the taxa which form smaller colonies are subdivided by colony size. Examples of SACFOR scale use include: *Pentapora foliacea*, a bryozoan with a massive growth form, was found to comprise over 80% of sample T14; using the scale this species was semi-quantified as superabundant in the sample. *Nemertesia antennina*, a hydroid that forms ~10cm high colonies, made up less than 1% of T7; it was therefore semi-quantified as occasional. Table 2.1 summarises the SACFOR scale used while Table 2.2 gives examples of taxa that fit the six growth classifications.

Table 2.1 SACFOR Scale

Percentage Fauna (by Volume)	Growth Form		Colony Size			
	Encrusting	Massive	<1cm	1-3cm	3-15cm	>15cm
>80%	S		S			
40-79%	A	S	A	S		
20-39%	C	A	C	A	S	
10-19%	F	C	F	C	A	S
5-9%	O	F	O	F	C	A
1-5%	R	O	R	O	F	C
<1%		R		R	O	F

S = superabundant, A = abundant, C = common, F = frequent, O =occasional, R = rare.

Table 2.2 Growth Form of Taxa Encountered

Phylum	Growth form		Colony size			
	Encrusting	Massive	<1cm	1-3cm	3-15cm	>15cm
PORIFERA	*Halichondria*			*Tethya*	*Stelligera*	
ANTHOZOA		*Alcyonium*			*Nemertesia* *Sertularia* *Hydrallmania*	
BRYOZOA	*Schizomavella* *Aetea*	*Pentapora* *Flustra*			*Cellaria* *Amathia*	
CHORDATA	*Botryllus*					
RHODOPHYCOTA		*Gelidium*				
CHLOROPHYCOTA	*Ulva*					

2.3.3 Beam Trawling - Sample Logging

After landing each catch was photographed and the following details logged (see Appendix B):

1. Time, position and depth at start and end of line
2. Sediment type

3. Catch volume
4. Fauna : sediment ratio
5. Warp length

2.4 Seabed Photography Operations

Camera transects 1 and 2 were performed from the M.V. Vos Baltic during Phase I whilst the remaining transects were performed from the H.V. Portree II during Phase II.

Underwater high resolution digital stills and accompanying low resolution video photography was acquired using a Simrad Kongsberg oe14-208 (a backup camera of the same model was carried as a precaution against equipment loss or malfunction). The camera system was configured within a specially designed stainless steel camera frame, complete with a separate strobe and lamp. The full camera specification is provided below.

Standard Features	
Image Resolution	Range between 2,048 x 1,536 pixels and 2,048 x 1,360 pixels
Light Sensitivity	ISO 100, 200, 400 Automatically Selected. 0.02 Lux (faceplate)
Scene Illumination	1 Lux
Sensor Type	1/ 1.8” format high density CCD sensor
Signal to Noise	>41dB
Framing Video	625 Line/ 50Hz PAL. 525 Line/ 60Hz NTSC
Image Storage	Images digitally stored in internal memory. Estimated capacities of fine quality JPEG images on a 512Mb card are: At 2,048 x 1,536 resolution – 320 images At 640 x 480 resolution – 3200 images
Up-Load Times	
Environmental	
Water Depth	3000 metres
Temperature	Operating: -5°C to + 40°C in water Storage: -20 °C to + 60 °C Vibration 10g, 20-150Hz. 3-axes (non-operating) Shock; 30g peak, 25ms half-sine pulse
Optical	
Standard Lens	F=8–24mm [35mm (135) format equivalent to 38-115mm] f/ 2.5-4 with macro
Iris Control	Automatic (Factory Set) Manual override available
Focus Control	300mm to infinity Manual mode to allow focus to 20mm
Angle of View	(7.5°) x 24° - 60° Diagonal in water (with digital zoom)
Mechanical	
Size	Diameter: 154mm exc. Guard
	Length: 180mm exc. Connector
Weight	Air: 6.4kg
	Water: 3.0kg
Standard Housing	Titanium alloy: 6AL/ 4V ASTM B3 48
Connector	8 Pin Burton 5506-1508 (or equivalent)

The seabed video footage was displayed on a monitor and recorded directly onto DVD and SVHS. A video overlay unit was used to overlay a navigation string from the ship's reference point, supplying the following information; time, date, easting, northing and depth. The client name, contractor name, job number and job description were also displayed in addition to station number (manually updated).

2.4.1 Seabed Photography – Deployment and Recovery

The system was deployed and recovered from the M.V. Vos Baltic in the same manner as the grab. On the H.V. Portree II the system was deployed by a winch at the rear of the foredeck; from this the wire ran through a block secured at the mid-foredeck to a second block hung from the vessels crane. As on the MV Vos Baltic, the crane was used to lower the equipment to the surface of the water and to recover it to deck after retrieval.

Operational procedures for seabed photography transects were as follows:

The camera system was setup and tested on deck prior to deployment. A photograph of a bucket lid showing the transect number was taken immediately prior to deployment so as to simultaneously test the camera system and record the transect number.

The camera system was deployed into the water until it was just under the sea surface. The camera lamps were then switched on and the video overlay unit was checked for correct operation (i.e. to ensure that the overlay was updating regularly). The DVD and SVHS were set to record and the station number was rechecked.

The umbilical cable was maintained under tension throughout the camera system's deployment and recovery and during stills/ video acquisition. Carbine hooks, lashed to the umbilical at 10m intervals, were fastened to the lifting wire during deployment to prevent the umbilical streaming out with the current. Tape was used to secure the umbilical to the wire at 20m intervals to prevent the cable from becoming twisted with the lifting wire.

After the camera system reached the seabed the sediment was allowed to settle before photography started. Whenever a photograph was taken this information was relayed to the on-line surveyor and a simultaneous fix was taken. These photographs were also time stamped to allow the photographs to be matched to a fix number in the event of a discrepancy between the numbers of fixes and the numbers of photographs taken.

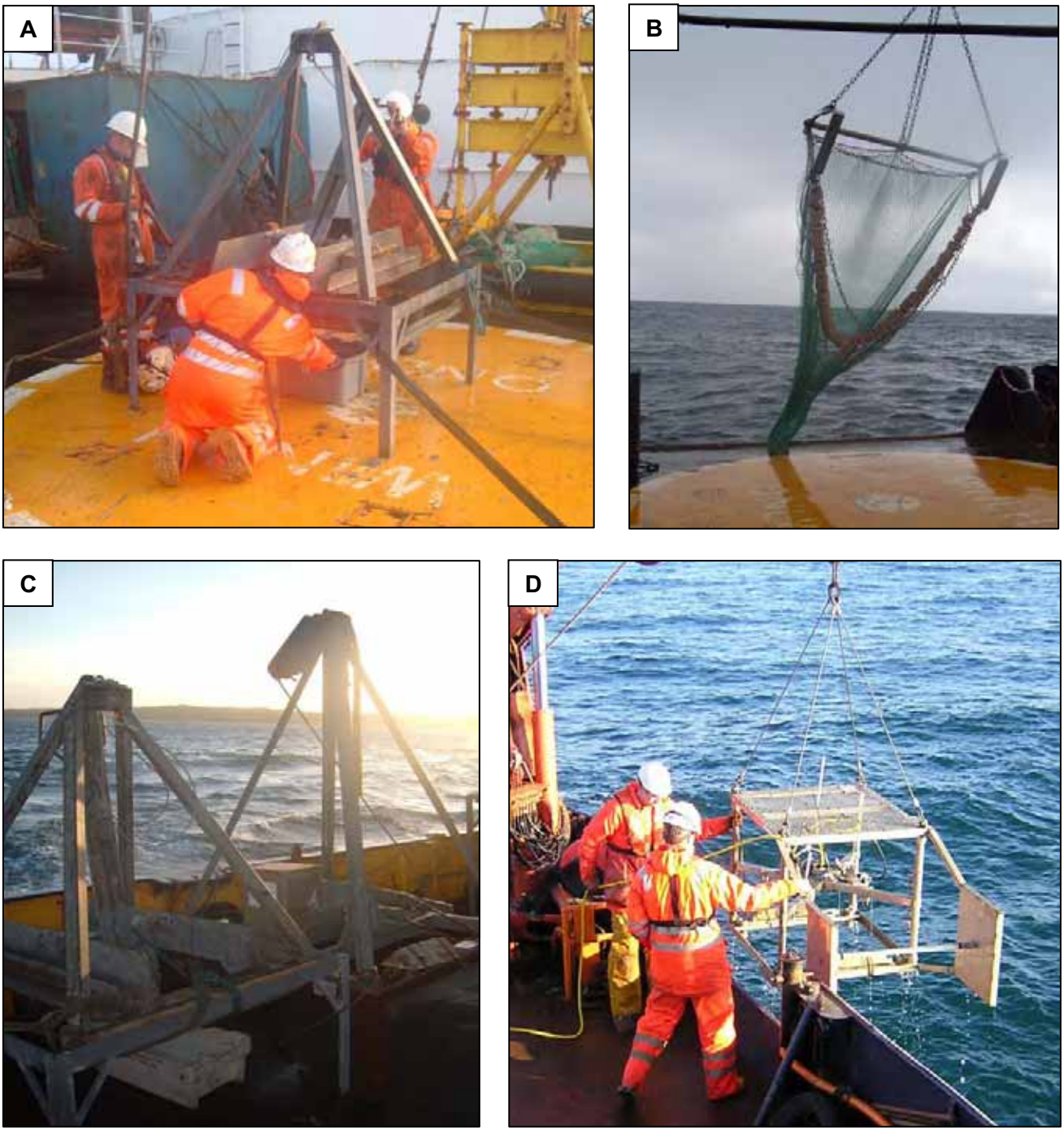
After the initial stills acquisition however, the camera was then raised by 3-5m and the vessel transited 20-30m along the predetermined transect, the system was then lowered again and more stills were taken; this process was repeated for the duration of the transect.

The camera system was recovered to the deck and the vessel was cleared to move onto the next station for further camera operations (see General Sampling and Seabed Photography Operations).

2.4.2 Seabed Photography – Photography and Video Logging

The seabed photographs and seabed video footage was viewed by environmental scientists in the office after demobilisation. Each photograph was described in terms of sediment type and fauna and flora composition (Appendix D, Volume III) whilst the seabed video footage was also summarised in similar terms (Appendix D, Volume III).

Figure 2.1 Sampling Operations



A = Collection of sample from Hamon Grab (Vos Baltic)

B = Beam trawl recovery (Vos Baltic)

C = Hamon grab (Vos Baltic)

D = Camera deployment (Portree II)

3 LABORATORY ANALYSIS AND STATISTICAL METHODOLOGIES

3.1 Particle Size Analysis (PSA)

Particle size analysis was sub-contracted to Emu Ltd. Methods for the analysis of samples submitted for particle size distribution were based on Emu Ltd's in-house procedures based on BS1377; part two; 1990.

Representative sub-samples of each sediment sample were oven dried to constant weight and sieved through a series of mesh apertures corresponding to whole phi units described by the Wentworth scale. The weight of the sediment fraction retained on each mesh was measured and recorded. Where the proportion of fines was >5% the sediment samples were then subjected to further analysis using laser diffraction to determine the proportion of the silt/ clay components at 0.5 phi intervals. The two components were combined using an algorithm.

Raw data was then processed in-house to describe particle size distributions in terms of phi mean, fraction percentages (i.e. coarse sediments, sand and fines) (Table 3.1), sorting (mixture of sediment sizes) (Table 3.2) and skewness (weighting of sediment fractions above and below the mean sediment size) (Folk and Ward, 1957).

Table 3.1 Phi and Sieve Apertures with Wentworth Classifications

Phi Units	Microns (μm)	Sediment Description
>-6 → -2	<640000→ 4000	Pebble
>-2 → -1	<4000 →2000	Granule
>-1 → 0	<2000 → 1000	Very Coarse Sand
>0 → 1	<1000 → 500	Coarse Sand
>1 → 2	<500 → 250	Medium Sand
>2 → 3	<250 → 125	Fine Sand
>3 → 4	<125 → 63	Very Fine Sand
>4 → 5	<63 → 31.5	Coarse Silt
>5 → 6	<31.5 → 15.6	Medium Silt
>6 → 7	<15.6 → 7.8	Fine Silt
>7 → 8	<7.8 → 3.9	Very Fine Silt
>8 → 9	<3.9 → 2.0	Coarse Clay
>9 → 10	<2.0 → 1.0	Medium Clay
>10	<1.0	Fine Clay

Table 3.2 Sorting Classifications

Sorting Coefficient	Sorting Classifications
>0 → 0.35	Very well sorted
>0.35 → 0.50	Well sorted
>0.50 → 0.71	Moderately well sorted
>0.71 → 1.00	Moderately sorted
>1.00 → 2.00	Poorly sorted
>2.00 → 4.00	Very poorly sorted
>4.00	Extremely poorly sorted

3.2 Organic Carbon Analyses

Total organic analysis was performed by TES Bretby Ltd, Burton on Trent, Staffordshire. Method statement is provided by TES Bretby Ltd.

3.2.1 Total Organic Carbon (TOC)

One gram of air-dried and ground sample (<200µm) was placed in a crucible and dried in an oven at 50±2.5°C until constant weight was achieved. The final sample weight was recorded to the nearest 0.1% and the sample was allowed to cool in a dessicator. The sample was then placed in an unheated muffle furnace and then heated to 450±2.5°C for 4 hours. The crucible was removed from the furnace and allowed to cool to room temperature in a dessicator. The crucible was then reweighed and the percentage loss on ignition (LOI) calculated. CO_3 was not removed before determination.

Loss on ignition is calculated as:

LOI (dry soil basis) = (c-f)/c x 100% w/w

Where: LOI = loss on ignition; c = weight of dried analysis sample (g); f = weight of residue after ignition (g)

3.3 Hydrocarbon Analysis

Hydrocarbon analysis was performed by ERT (Scotland) Ltd (ERT). The following method statement was provided by ERT (Scotland) Ltd.

3.3.1 General Precautions

To effectively eliminate all possible sources of hydrocarbon contamination from the analysis the following precautionary measures were taken prior to sample work-up.

All solvents were purchased as high purity grade. Each batch was checked for purity by concentrating approximately 400ml down to a small volume (<1ml) and analysing by gas chromatography (GC). All water used was distilled through an all glass still and dichloromethane/ pentane extracted to minimise contamination from plasticisers. All glassware was cleaned using an acid/ base machine wash. The glassware was rinsed with acetone then finally with dichloromethane prior to use. Procedural blanks, replicate analyses and laboratory reference material were run with each batch of samples.

3.3.2 Ultrasonication Extraction for Hydrocarbons in Sediment

Sediment samples were thawed, homogenised and accurately weighed into a 250ml conical flask. A solution containing an appropriate amount of the following internal standards was added to each sample using a 100µl microsyringe.

Aliphatic standards	Aromatic standards
heptamethylnonane	d_8 naphthalene
d_{34} hexadecane	d_8 acenaphthylene
1-chloro-octadecane	d_{10} phenanthrene
squalane	d_{10} pyrene
	d_{12} chrysene
	d_{12} perylene

Methanol (50ml) was added and the solvent mixed with the sediment. Dichloromethane (DCM) (60ml) was then added and the sample mixed again. The flasks were then capped with solvent cleaned aluminium foil and ultrasonicated for 30 minutes.

After being allowed to settle the solvent was decanted through a GF-C filter paper into a 1 litre separating funnel. The extract was then partitioned with 100ml of DCM/ pentane extracted distilled water and the DCM layer run-off into a clean 500ml round-bottomed flask. The ultrasonic extraction was repeated a further two times using 50ml DCM and 15 minutes of ultrasonication, each time the filtered extract was partitioned with the remaining methanol/ water in the separating funnel. The DCM extracts were bulked and reduced in volume to approximately 2ml using a rotary evaporator then further reduced to approximately 1ml under a gentle stream of nitrogen prior to cleanup.

Correction factors for wet/ dry sediments were obtained by drying a sub-sample of the homogenised sediment to constant weight at 110°C.

3.3.3 Clean-Up of Extracts by Column Chromatography

The removal of polar material, including lipids was carried out using a silica gel column. The silica gel used was 70 to 230 mesh which was heated at 400°C for at least four hours to remove impurities and residual moisture then stored at 200°C prior to use. The sample extract was added to the silica gel column, containing 5g of adsorbent and approximately 1g of activated copper powder (for removal of free sulphur), and eluted with 35ml of DCM/ pentane (1:2). The eluant was reduced in volume using the evaporator to approximately 2ml before being further reduced under a gentle stream of nitrogen to an appropriate volume and analysed by gas chromatography (GC) and gas chromatography-mass spectrometry (GCMS) (see Table 3.3).

Table 3.3 GC and GCMS Techniques

	Gas Chromatography (GC)	Gas Chromatography-Mass Spectrometry (GCMS)
Instrument	HP 6890 Series GC with 7673 autoinjector	ThermoFinnigan Trace GC - DSQ mass selective detector with AS3000 autoinjector
Column	100%-dimethylpolysiloxane bonded fused silica, 60m, 0.25µm film thickness, 0.32mm internal diameter	(5%phenyl)-methylpolysiloxane bonded fused silica, 60m, 0.25µm film thickness 0.32mm internal diameter
Carrier Gas	Hydrogen (constant flow 5ml/ min)	Helium (constant flow 1.4ml/ min)
Injector	On–column (1µl injection)	Splitless, 250°C, split flow 40ml/ min, vent time 1 min (1µl injection)
Oven Temperature Programme	80°C - 1 min 80 to 320°C at 15°C/ min 320°C – 10 min 320 to 350°C at 10°C/ min	60°C - 1 min 60 to 120°C at 15°C/ min 120 to 325 °C at 5°C/ min 325°C – 9 min
Source/ Detector Temperature	300 °C (FID)	280°C
Electron Energy		70eV
Selected Ion Monitoring (SIM)		8 groups - 6 ions per group
Dwell Time (per Ion)		0.05 second

3.3.4 Method Specifications

Total Hydrocarbons by Gas Chromatography – Flame Ionisation Detection (GCFID)

Total hydrocarbons were calculated using an internal standard method. Total hydrocarbon calibration was undertaken using average response factors obtained from the n-alkane standard solutions. The total area of the chromatogram between C_{12} and C_{36} was quantified.

Limit of Quantification (matrix and oil type dependent) = approximately 0.5µg.g^{-1} dry weight.

N-Alkanes, Pristane and Phytane

The n-alkanes between nC_{12} and nC_{36} were reported, as were the ranges between nC_{12} and nC_{20} and nC_{21} to nC_{36}. Carbon preference index (CPI) values (the ratio of odd to even carbon numbered

compounds) for the same ranges were also calculated. Pristane and phytane (and associated ratio) were also quoted.

Calibration was undertaken using a range of n-alkane standard solutions containing the even carbon number compounds between nC_{12} and nC_{36} and a range of suitable internal standards. Individual response factors were calculated for each of the n-alkanes present in the calibration solution. Response factors for the non-calibrated n-alkanes (and pristane and phytane) were taken to be equivalent to closely eluting compounds.

Limit of Quantification (matrix dependent) = approximately $1ng.g^{-1}$ dry weight per compound.

Quality Assurance

An independent standard solution was analysed with each batch of samples to verify instrument calibration. Sample blanks were run with each batch. At least one Laboratory reference sediment sample and one sample duplicate analysis was carried out for each study. ERT participates in the Quasimeme international laboratory performance scheme.

3.4 Heavy Metal Analysis

Heavy metal analysis was performed by TES Bretby Ltd, Burton on Trent, Staffordshire. The following method statement was provided by TES Bretby Ltd.

3.4.1 Sample Preparation

Sediment samples were homogenised and a 50g portion was air dried at room temperature. Each sample was ground down to a fine powder (<100µm) by hand using a mortar and pestle. A clean blank sand sample was hand ground prior to the sediment sampled to identify the presence of any trace metals.

3.4.2 Sample Digestion Procedure

Hydrofluoric/ Boric acid Extractable Metals (Total Metals)

Approximately 200mg of the sediment was accurately weighed out and placed in a PTFE bottle. Hydrofluoric acid (2.5mls) was added and the bottle was placed in an oven at 105±5°C for approximately 30 minutes. The bottle was then allowed to air cool and then 60ml of 4% boric acid was the added. The contents were mixed thoroughly and placed in a polypropylene flask and made up to 100ml. The sample was then analysed by either inductively coupled plasma optical emission spectrometry (ICPOES – for BA, Cr, Cu, Ni, V and Zn) or inductively coupled plasma mass spectrometry (ICPMS – for As, Cd, Hg, Pb and Sn).

3.4.3 Method Quality Control

A certified reference material (NIST 1646a Estuarine Sediment, Batch 692603) and a procedural blank were prepared as a sample according to the digestion method described above.

3.4.4 Analytical Methodology

Inductively Coupled Plasma Optical Emission Spectrometry (ICPOES)

Operating Conditions

RF Power		650W
Plasma Gas	Ar	34psi
Carrier	Ar	30psi
Coolant Gas	Ar	25psi

Calibration

The instrument is calibrated using dilutions of the 1ml = 10mg spectroscopic solutions. The final calibration solutions are matrix matched with the appropriate acid(s). An initial 5 point calibration was performed at the following emission wavelengths.

	Heavy Metals								
	As	**Ba**	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**V**	**Zn**
Wavelength (nm)	189.04	233.53	226.50	267.72	324.75	231.60	220.35	290.88	213.86

Instrument Quality Control

Quality control consists of running a procedural blank together with continuing calibration checks (CCCs) at a frequency of 1 every 20 samples. A certified reference material was also run at a frequency of one per batch or every 20 samples.

Inductively Coupled Plasma Mass Spectrometry (ICPMS)

Operating Conditions

RF Power	1300W
RF Matching	2V
Sample Depth	6.5mm
Carrier Gas	1.28 l/ min

Calibration

The instrument was calibrated using dilutions of the 1ml = 10mg spectroscopic solutions. The calibration line consists of 7 standards measured at the following atomic masses:

Ni 60 , Cd 111 , Zn 66, Pb 208, Cu 65, As 75, V 51, Cr 52,

Target analytes were measured in the samples by direct comparison to the internal standard which has the nearest mass and ionisation properties. The internal standards used were scandium (45), yttrium (89) and terbium (159).

Instrument Quality Control

Quality control consists of running full method blanks together with continuing calibration checks (CCCs) at a frequency of 1 every 10 samples). A certified reference material was also run at a frequency of one per batch or every 20 samples.

3.4.5 Analytical Detection Limits

Limits of detection ($\mu g.g^{-1}$) for the quoted methods are as follows:

Instrument	ICPMS					ICPOES					
Type	As	Cd	Hg	Pb	Sn	Ba	Cr	Cu	Ni	V	Zn
Detection limit	1	0.1	0.01	1	1	5	1	1	1	1	5

3.5 Macrofaunal Analysis

On arrival at the laboratory the grab samples were checked in and their details logged onto the job worksheet, this workbook then automatically generated the labels and data recording sheets applicable to the samples.

3.5.1 HSE Considerations

All macrofaunal analysis was conducted in Fugro Survey's taxonomic laboratories in Great Yarmouth. Conformance with the following health and safety procedures was maintained throughout the analytical process.

All chemicals were handled and stored in accordance with the Control of Substances Hazardous to Health (COSHH) regulations (1990). All chemical stock and samples containing formaldehyde were stored in locked COSHH cabinets with the appropriate MSDS safety sheets. All containers were labelled with their contents and the appropriate hazard stickers. Samples containing formaldehyde solution were only opened in the laboratory fume cupboard by staff wearing lab coats, gloves and safety goggles.

All waste chemicals and contaminated sediment were appropriately labelled and stored (in a locked storeroom) to await collection by a specialist waste disposal company.

Work instructions and risk assessments specific to the different stages of the macrofaunal analysis were displayed in the appropriate workspaces.

3.5.2 Grab Sample Sorting and Identification

After being logged in the grab samples were then transferred from their 10% formaldehyde fixative to 70% Industrial Methylated Spirit (IMS) for safe handling and storage.

In order to extract the fauna from the grab samples they were washed, using a spray head, through a stack of sieves of graduated mesh. The bottom sieve in the stack was of the mesh size specified by the client (1.0mm). The coarser (>2.0mm) fractions separated by this process were transferred to trays of water and placed under a freestanding light source; the fauna was then extracted using forceps. To ensure efficient removal of smaller invertebrates from the less coarse (<2.0mm) fractions, these were poured in small quantities into a Petri dish and examined under a stereo microscope. Where large volumes of fine sediment were present in samples repeated elutriations of the fine fraction were carried out to extract the fauna. The animals were stored in labelled jars or vials filled with 70% IMS. At each stage of the extraction process care was taken to ensure that no animals remain on the sieves or in the containers used for sample fraction storage.

The specimens were identified to the lowest practicable taxonomic level (generally species) and enumerated using stereo and compound microscopy, and dissection where appropriate. Non-enumerable colonial taxa were identified and their presence in the sample recorded by placing a "P" on the datasheet.

To ensure data quality and consistency various control systems were adhered to. Residues from the finer sample fractions were double-checked to ensure that all of the fauna had been removed. The senior taxonomist also checked all of the identifications. A reference collection of all fauna encountered during the survey was created and used to ensure consistency in identification; after completion of the project

these were retained as part of the laboratory's permanent reference collection. Non-reference specimens were recombined by station and again stored in 70% IMS.

Species data were entered into the environmental database (DES) and an Excel spreadsheet with the appropriate Marine Conservation Society (MCS) codes (Howson & Picton, 1997) was produced.

3.5.3 Trawl Sample Specimen Identification

Specimens collected from the trawl samples were retained in formaldehyde in the laboratory's COSHH locker. Their storage in this medium (as opposed to IMS) prevented the bleaching of taxa in which pigmentation provides useful taxonomic information (e.g. sponges). As the number of samples was relatively small and their processing was completed within two weeks of demobilisation, their storage in formaldehyde was not considered a significant health and safety risk.

Before identification the specimens were drained and then washed, using a spray head, over a 4mm mesh sieve (the same size as in the trawl's codend). The specimens were then transferred to water filled trays and identified, enumerated and stored in the same way as the specimens from the grab samples. Colonial taxa were semi-quantified by reference to the data sheets completed in the field.

3.6 Statistical Analysis

The final species abundance dataset for the macrofauna samples was analysed using routines in the PRIMER (Plymouth Routines in Multivariate Ecological Research) (version 5) software package to aid the identification of any underlying patterns in the benthic community through a combination of univariate and multivariate methods, as per OSPAR Commission guidelines (OSPAR Commission, 2004).

3.6.1 Primary and Univariate Variables

A range of primary (number of individuals and species) and univariate (Shannon-Weiner Diversity, Margalef's Richness, Simpson's Diversity and Pielou's Evenness) variables were calculated both for the samples and the pooled replicates for each station using the PRIMER v5.0 DIVERSE procedure (Clarke & Warwick, 2001). The objective of this analysis was to calculate a single value to quantify a particular characteristic, generally the diversity, of each sample or station to enable ease of comparison. Diversity is typically thought to comprise two different factors: the number of species (species richness) and the equitability of species abundances (evenness or equitability) (Magurran, 1988). Thus a range of primary and derived univariate indices were calculated which attempt to quantify the species richness, the evenness and a combination of both (Clarke & Warwick, 1994).

Species Richness (S) - the simplest measure of species richness, i.e. the total number of species in a given area.

Number of Individuals or Abundance (N) - the simplest measure of abundance, i.e. the total number of individuals.

Shannon-Wiener Diversity Index (H) – the most widely used index of diversity, incorporating aspects of both the species richness and equitability (Shannon & Weaver, 1949). This index may be calculated using logs e, 2 or 10 - in this case log 2 was used.

$$H' = -\sum_i p_i (\log p_i)$$

Where: H' = Shannon-Wiener Diversity Index; p_i is the proportion of the total count arising from the ith species.

Margalef's Richness Index (d) – a simple index derived using a combination of the number of species (S) and the total number of individuals (Clifford & Stevenson, 1975).

$$D_{Mg} = \frac{(S-1)}{\log N}$$

Where: S = total number of species; N = total number of individuals

Equitability Index (*J'*) – a measure of equitability, i.e. how evenly the individuals are distributed among different species (also known as Pielou's Evenness (Pielou, 1969)). Low evenness indicates that a sample is dominated by one or a few highly abundant species whereas high evenness means that total abundance is spread more evenly among the constituent species.

$$J' = \frac{H'}{\log S}$$

Where: *J'* = Equitability Index; *H'* = Shannon-Wiener Diversity Index; S = total number of species

Simpsons *D* Index: a measure of dominance heavily weighted to the abundance of the commonest species (Simpson, 1949). In its traditional form as *D* increases, diversity decreases. As such the reciprocal of *D* (1-*D*) is more usually expressed.

$$D = \sum \left(\frac{n_i (n_i - 1)}{N (N - 1)} \right)$$

Where: *D* = Simpson's Index; n_i = the number of individuals in the *i*th species; *N* = the total number of individuals.

3.6.2 Multivariate Analysis

Multivariate analysis of community data allows a more thorough examination of differences between samples by preserving the identity of species when calculating similarities. For the purposes of this report, this analysis was undertaken using the widely used statistical package, Plymouth Routines in Multivariate Ecological Research (PRIMER) v6.0 (Clarke & Gorley, 2006).

Pre-treatment of Community Data

Prior to analysis, species abundance data typically undergo transformation to down-weight the effect of abundant species in determining inter-sample similarities. These transformations vary in their effect through:

1. No transform
2. Square root (√)
3. Fourth root (√√)
4. Logarithmic
5. Reduction to presence/ absence

At the top end of the spectrum (no transform) all attention will be focused on the dominant counts, at the bottom end (reduction to presence/ absence) more emphasis is paid to the rarer species (Clarke & Warwick, 1994). In this case the dataset underwent a fourth root transformation so that the analysis took account of all components of the community but retained some quantitative information. This transformation effectively reduces data to a 6 point scale (0 = absent, 1 = one individual, 2 = handful, 3 = sizeable number, 4 = abundant, ≥5 = very abundant).

Creating Similarity Matrices

A triangular similarity matrix was then produced from the transformed data, by calculating the similarity between every pair of replicate samples. In this case the Bray-Curtis similarity coefficient was used (Bray & Curtis, 1957), which is widely considered to be the most suitable similarity measure for community data (Clarke & Warwick, 2001).

A zero-adjusted Bray-Curtis coefficient was used for denuded assemblages (Clarke *et al*, in press), in this case for the colonial dataset, with sparse samples of few shared species. This involves the addition of a dummy species present at the same abundance in each sample, resulting in increased similarities between sparse or blank samples, which may be reasonably to be denuded for the same reason.

Hierarchical Agglomerative Clustering (CLUSTER) and Similarity Profile Testing (SIMPROF)

The CLUSTER programme uses the similarity matrix to successively fuse samples into groups and the groups into clusters according to their level of similarity. The end point of this process is a single cluster containing all the samples, which is displayed by means of a dendrogram with similarity displayed on one axis and samples on the other.

A series of similarity profile permutation tests (SIMPROF) may also be performed, which look for statistically significant evidence of genuine clusters in samples which are *a priori* unstructured (i.e. with no prior statistical design, such as collecting samples from both polluted and non-polluted sites to establish any differences), as typically seen for a baseline survey such as this. By combining this significance testing with the CLUSTER function, dendrograms may be produced indicating those clusters which are statistically significant.

Non-Metric Multidimensional Scaling (nMDS)

N-MDS also uses the similarity matrix, but unlike hierarchical agglomerative clustering nMDS simultaneously displays the similarity between all pairs of samples on 2 or 3 dimension ordinations. In producing this low-dimensional ordination there is some distortion of the between sample similarities. The degree of distortion involved in producing an ordination gives an indication of the adequacy of the nMDS representation and is recorded as a stress value:

nMDS Stress	Adequacy of Representation for 2-Dimensional Plot
0.0 → ≤0.05	Excellent representation with no prospect of misinterpretation.
>0.05 → ≤0.1	Good ordination with no real prospect of a misleading interpretation.
>0.1 → ≤0.2	Potentially useful 2-dimensional picture, though for values at the upper end of this range too much reliance should not be placed on the detail of the plot; superimposition of cluster groups should be undertaken to verify conclusions.
>0.2 → ≤0.3	Ordination should be treated with scepticism. Cluster groups may be superimposed to verify conclusions although ordinations achieving stress values >2.5 should be discarded. A 3-dimensional ordination may give a more adequate representation.
>0.3	Ordination is unreliable with points close to being arbitrarily placed in the 2-dimensional plot. A 3-dimensional ordination should be examined.

Similarity Percentages Analysis (SIMPER)

This programme calculates the individual contribution of different species to both the similarity of samples within a cluster group and the dissimilarity between different cluster groups. It is therefore possible to identify those species which are characteristic of a particular habitat and those species which act as discriminating species between habitats.

3.6.3 Data Presentation Using Contouring Software

The contouring and 3D surface mapping software package, Surfer, Version 8, was utilised to aid interpretation and visual representation of environmental data. By interpolating irregularly spaced geographical information (XYZ data) regularly spaced grid data may be produced. These grids may then be displayed in a number of forms, including contour, shaded relief and wireframe maps.

Interpolation of bathymetry and environmental variables (discrete values for sampling stations) was undertaken according to the following criteria:

Bathymetry Interpolation	
Gridding Method	Kriging
Search Radius	3m
Contour Scaling	Coded on each figure
Grid Line Spacing	10m

Environmental Variables Interpolation	
Gridding Method	Kriging
Search Radius	100m
Contour Scaling	Coded on each figure
Grid Line Spacing	10m

Image Scales	
A3 plots – Wave Hub Region	1:45,000
A3 plots – Cable Route	1:60,000
A4 plots – Wave Hub Region	1:75,000
A4 plots – Cable Route	1:100,000

4 RESULTS

4.1 Grab Sampling Operations

In all, a total of 26 from 30 stations were sampled with 3 macrofaunal replicates, 1 station was sampled with only 2 macrofaunal replicates and 1 physico-chemical replicate was retained for analysis at 26 of these stations during Phase 1 (Table 1.2). The outstanding grab stations were cancelled from the programme and not completed during Phase 2.

A total of 158 grab sample attempts were made with 106 samples retained (Table 4.1). The 52 'no samples' were recorded due to little or no sample being retained. 'No samples' were most likely caused by bedrock outcropping at the seabed surface and only a thin veneer of overlying sediment.

Table 4.1 Summary of Equipment Sample/ Deployment Success for Grab Sampling

Activity	Number of Attempts/ Samples
Attempts	158
Samples	106
% Success	67

% success = Number of attempts/ Number of good samples

Positioning accuracy was good for the sediment sampling part of this survey, with 95% of samples obtained within 15m of the target location (Table 4.2).

Table 4.2 Summary of Grab Sample Proximity to Target Location

Distance from Target Location (m)	Retained Samples	Cumulative Frequency	Number of Stations
0 < 5	50%	50%	52
5 < 10	40%	90%	42
10 <15	5%	95%	6
15 < 20	0%	95%	0
20 < 30	0.9%	95.9%	1
30 < 35	0.9%	96.8%	1
> 35	3.2%	100%	4
Total	100%	100%	106

4.2 Bathymetry

Geophysical data were divided into 4 main areas for ease of description; the original Wave Hub deployment area, the offshore regional area surrounding the original Wave Hub deployment area, the offshore cable route (designated as ending where the exposed bedrock was overlaid consistently by surficial sediment) and the nearshore cable route (designated as starting where the bedrock gave way to sediments and ending at the shoreline). Bathymetry is shown in Figures 4.1a and 4.1b.

Across the offshore regional area the seabed elevations varied between a minimum of 31m Chart Datum (CD) in the south-east of the area to 60m along the north-west boundary.

Within the original Wave Hub deployment area the general seafloor elevation varied between 60m to the north-west of the area shoaling to 50m to the south. In the centre and to the south of the area there were regions of exposed bedrock that rose to a maximum elevation of 36m.

The offshore cable route shoaled from an approximate depth of 54m to 20m towards the nearshore region. The nearshore cable route (designated as starting where the exposed bedrock was covered by surficial sediments) shoaled from approximately 30m to the shoreline.

Figure 4.1a Offshore Wave Hub Region showing Bathymetry with Proposed Grab Locations, Actual Camera and Trawl Transect

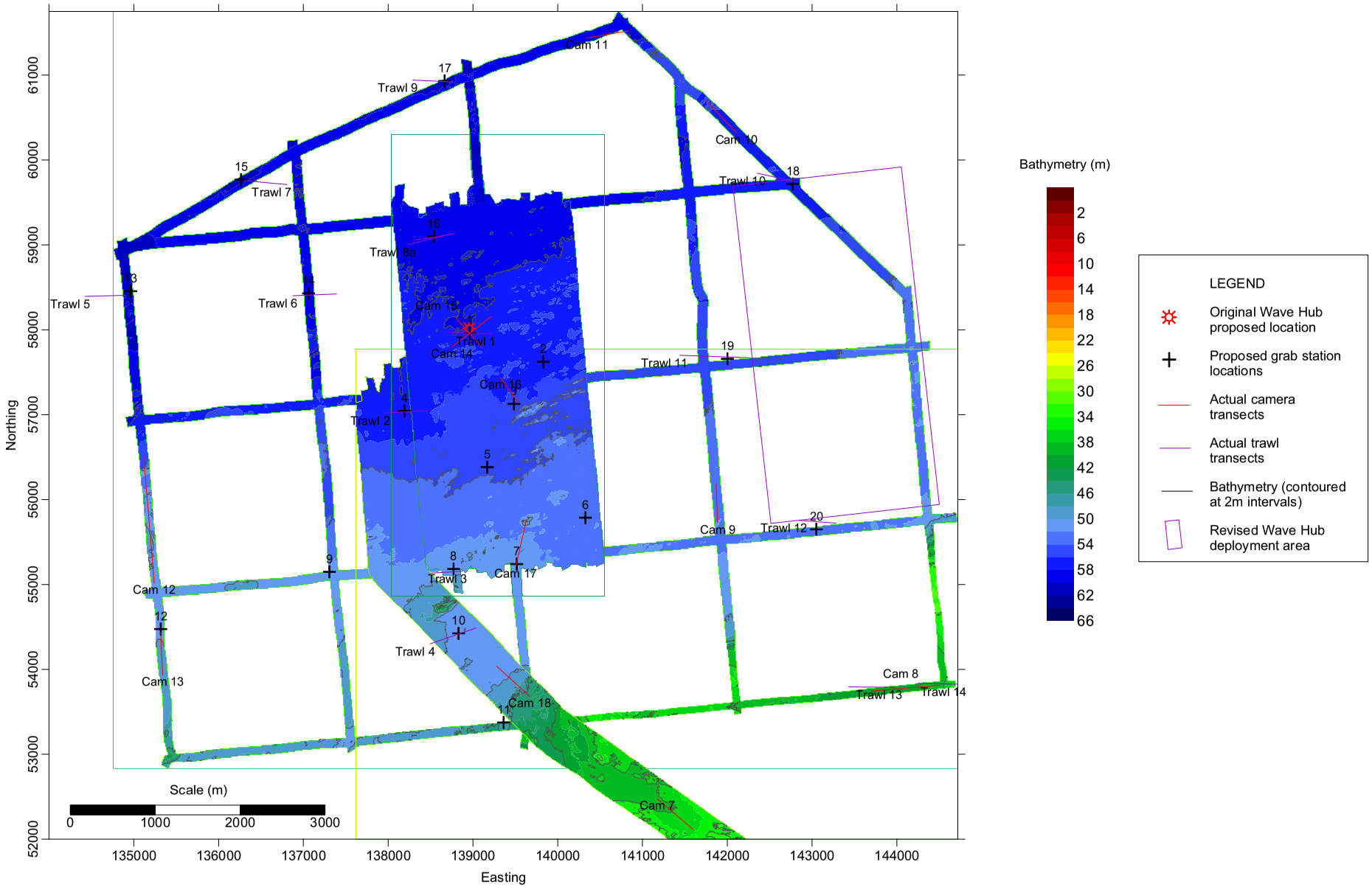
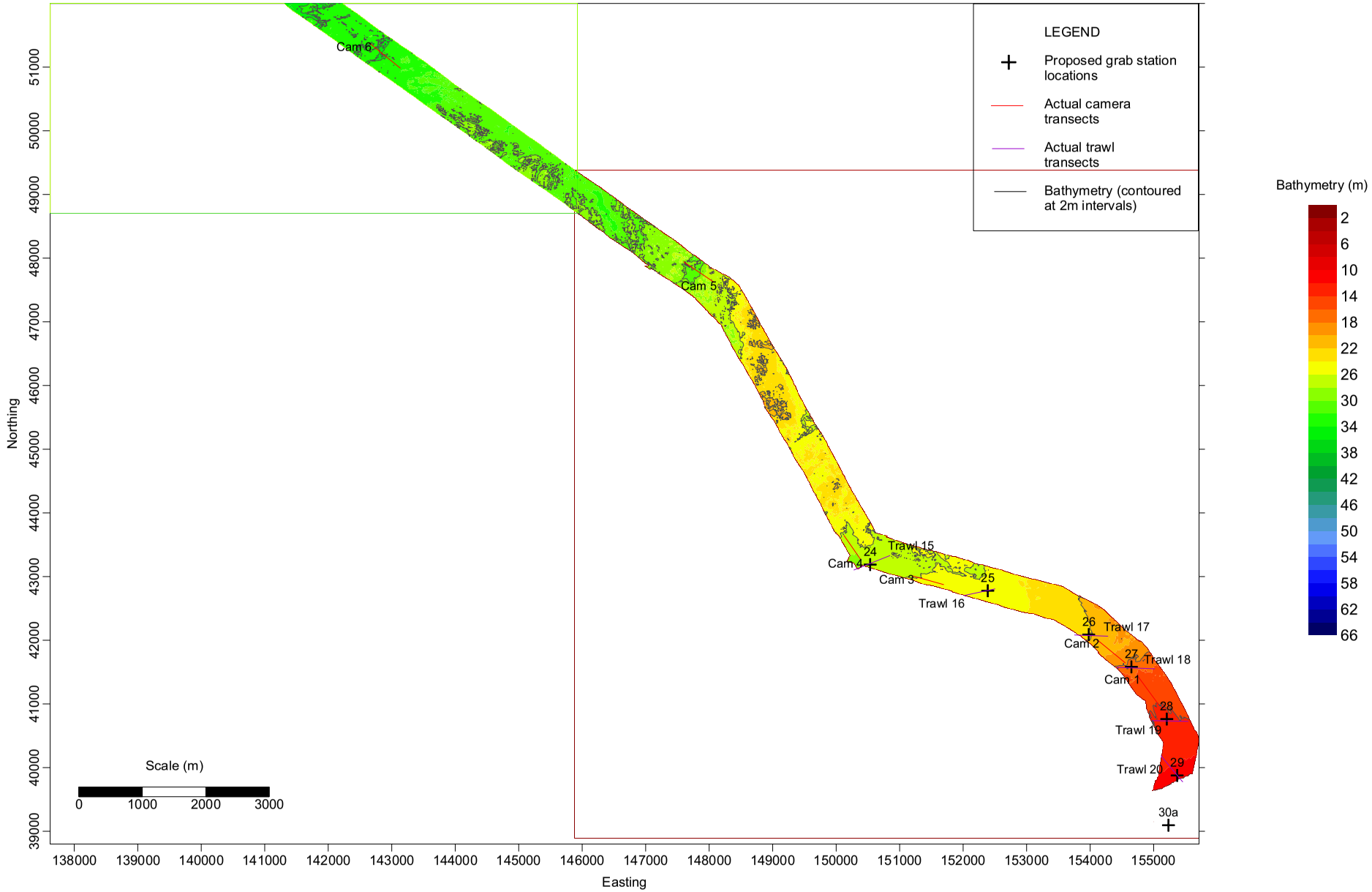


Figure 4.1b Cable Route showing Bathymetry with Proposed Grab Locations, Actual Camera and Trawl Transect



4.3 Seabed Features and Particle Size Distribution

The seabed features maps have been reproduced using the geophysical data obtained from the survey performed by EGS in July 2005 (Figures 4.2a and 4.2b).

The offshore Wave Hub area, including the regional offshore area and the original Wave Hub deployment area comprises exposed bedrock and areas where the bedrock is covered by varying depths of different sediment types. To the north and north-west of the entire area, the sediment type covering the bedrock was described by EGS as predominantly silty SAND over ROCK. Grab sampling (see Table 4.3 and Photoplates - Appendix C) at stations 1, 2 4 and 13 to 18 supported this interpretation.

To the west of the original Wave Hub deployment area, the sediment type was described as comprising sandy GRAVEL over ROCK. Station 12 (see Photoplates - Appendix C) was comprised of coarse sand and shells.

The sediment type to the south and east of the survey area, was described as comprising a thin veneer of clayey SAND/ GRAVEL over ROCK. Grab sampling, at stations 19 and 20, supported this interpretation (see Photoplates - Appendix C). Within the original Wave Hub deployment area, as revealed by station 3 and 5 to 8 (see Table 4.3) the sediment overlying the bedrock comprised very poorly sorted SAND and PEBBLE.

Along the nearshore cable route, stations 27 to 30a, within the confines of St. Ives Bay, comprised fine SAND. Stations 25 and 26 comprised very poorly sorted PEBBLE. The high percentage of coarse material with some sand content is typical of the area due to its geology and the close proximity of bedrock to the seabed surface (English Nature, 2004).

Figure 4.2a Offshore Wave Hub Region showing Seabed Features with Proposed Grab Locations, Actual Camera Transects and Trawl Transects

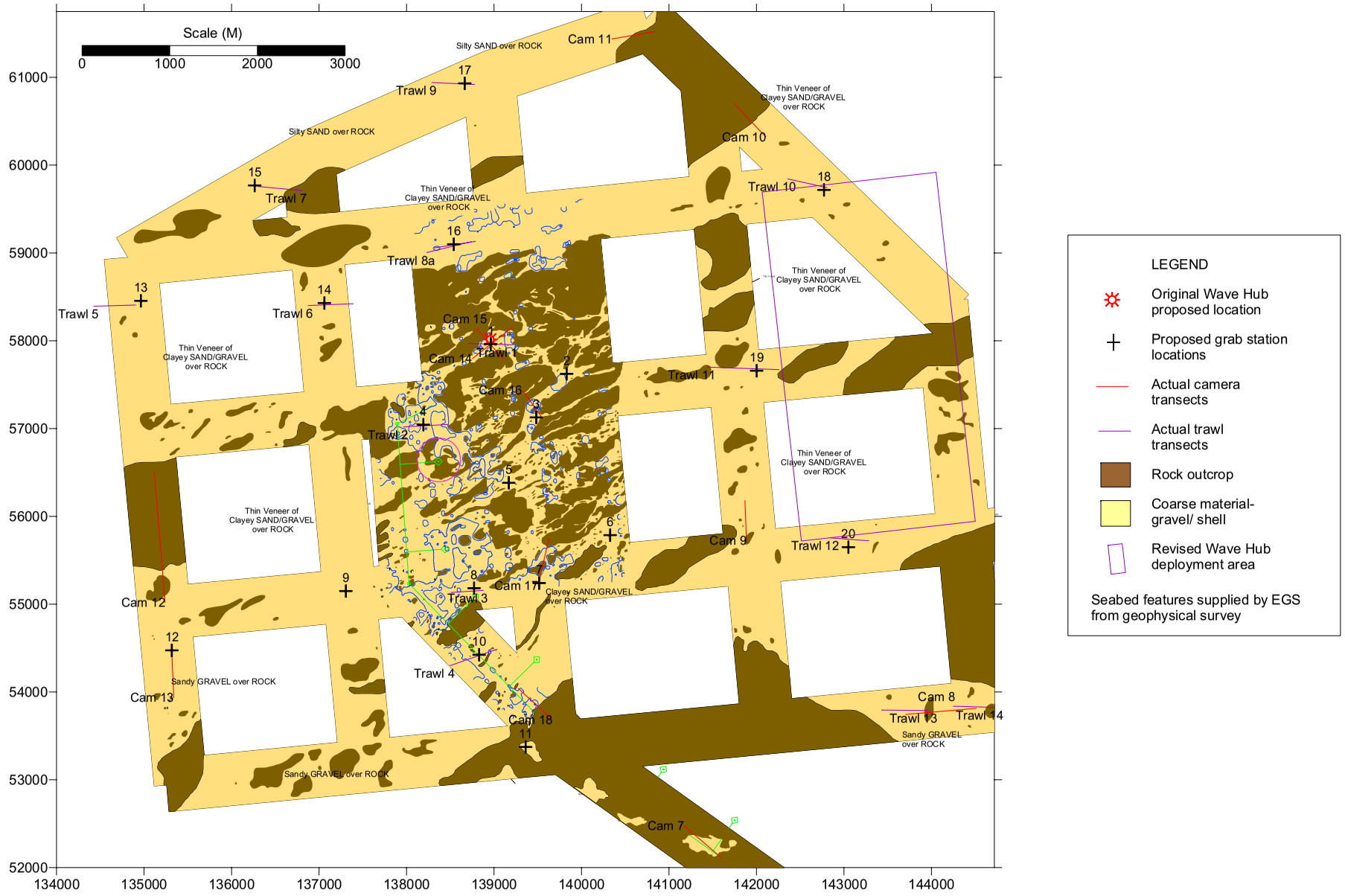
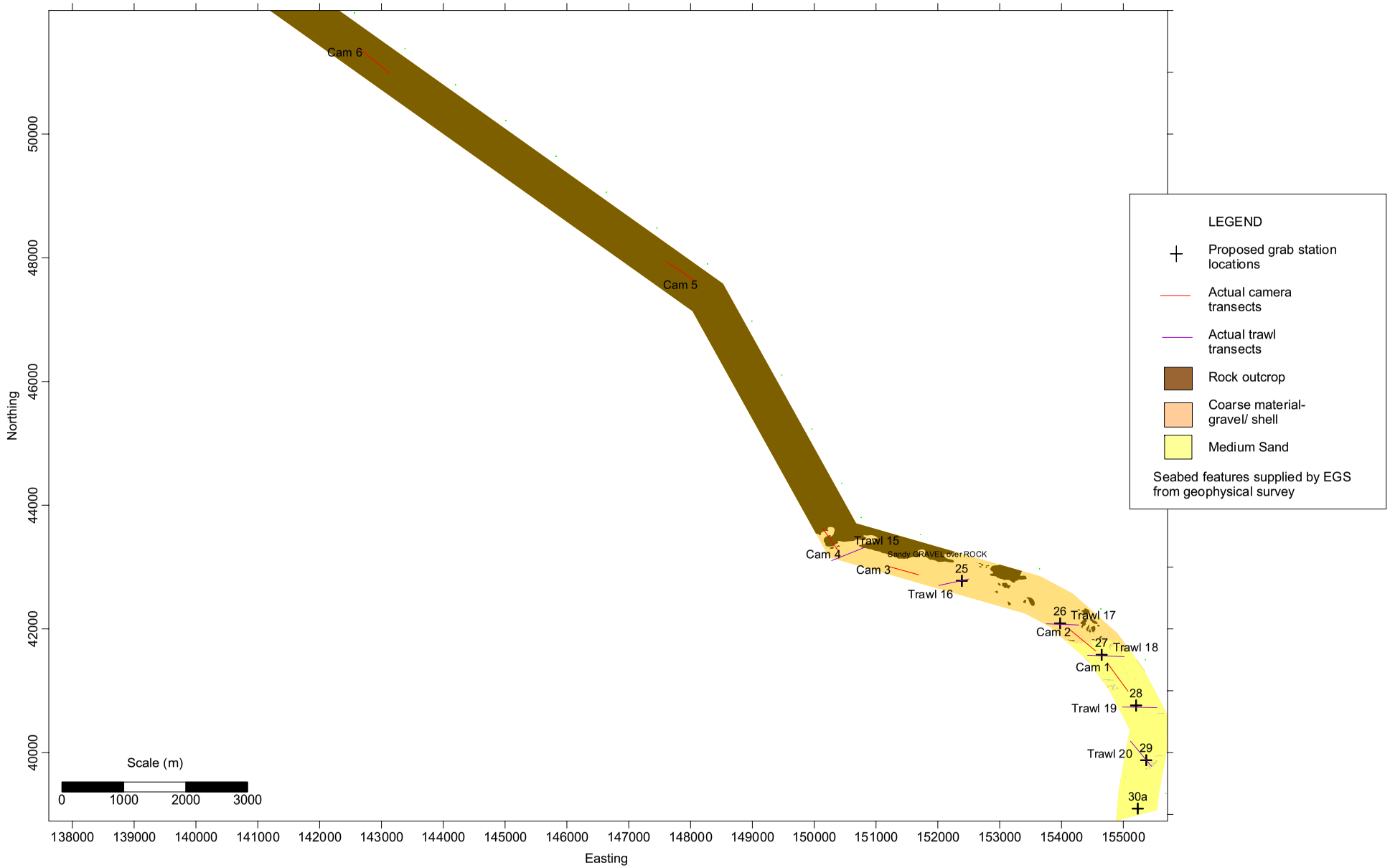


Figure 4.2b Cable Route showing Seabed Features with Proposed Grab Locations, Actual Camera Transects and Trawl Transects



4.4 Particle Size Distribution

Particle size analysis was performed using dry sieving techniques and laser diffraction. Results are summarised in Table 4.3 and Figures 4.3 to 4.7. A description of the sediment type of each sample is also given based on the Wentworth Classification (Buchanan, 1984), and B.S.5930 for descriptive terms. The full dataset is presented in Appendix C.

The sediment distribution across the site varied considerably, comprising very poorly sorted pebble to moderately well sorted fine sand. Mean phi ranged from 2.75 to -4.65 (stations 28 and 25, respectively) and the sorting coefficient ranged from 0.42 to 3.37 (stations 27 and 5, respectively).

The proportion of fines found at the grab sample locations ranged from 0.05% (stations 16 and 18) to 8.97% (station 20) and the proportion of sand ranged from 14.5% to 99.6% (stations 5 and 30a, respectively). Coarse material (i.e. >2mm) ranged from 0.0 to 84.0% (stations 28 and 25, respectively).

Table 4.3 Summary of Particle Size Analysis and Organic Carbon

Survey Area	Station	Depth (m)	TOC (% LOI)	Mean mm	Mean Phi	Sorting	Fines (%)	Sand (%)	Coarse (%)	Wentworth/ B.S.5930 Classification
ORIGINAL WAVE HUB DEPLOYMENT AREA	1	63.9	2.8	1.60	-0.68	1.56	0.1	67.8	32.1	Poorly sorted v coarse SAND
	2	62.8	2.5	1.45	-0.54	1.68	0.2	68.0	31.8	Poorly sorted v coarse SAND
	3	61.9	2.1	4.10	-2.04	2.28	0.2	33.6	66.2	V poorly sorted PEBBLE
	4	63.3	3.4	1.32	-0.40	2.27	1.6	68.1	30.3	V poorly sorted v coarse SAND
	5	59.8	3.5	7.87	-2.98	3.37	6.4	14.5	79.1	V poorly sorted PEBBLE
	6	56.2	3.2	6.19	-2.63	2.95	0.9	36.0	63.1	V poorly sorted PEBBLE
	7	54.7	2.5	11.08	-3.47	2.72	0.2	29.9	69.9	V poorly sorted PEBBLE
	8	54.4	2.9	10.34	-3.37	2.59	0.4	32.2	67.4	V poorly sorted PEBBLE
OFFSHORE	9	55.6	3.3	3.58	-1.84	2.84	1.2	44.5	54.3	V poorly sorted GRANULE
	10	55.3	3.5	8.90	-3.15	2.70	0.4	23.4	76.2	V poorly sorted PEBBLE
	11	53.1	3.2	4.88	-2.29	2.74	0.6	31.3	68.1	V poorly sorted PEBBLE
	12	56.5	3.2	1.86	-0.89	2.27	0.7	52.0	47.3	V poorly sorted v coarse SAND
	13	66.4	3.1	1.01	-0.01	1.04	0.1	83.5	16.4	Poorly sorted v coarse SAND
	14	63.9	2.7	1.80	-0.85	1.28	0.2	60.4	39.4	Poorly sorted v coarse SAND
	15	64.8	3.2	1.47	-0.55	1.46	0.2	66.3	33.5	Poorly sorted v coarse SAND
	16	62.3	3.1	1.22	-0.29	0.92	0.1	80.0	19.9	Moderately sorted v coarse SAND
	17	62.6	3.5	0.81	0.30	1.10	0.1	87.8	12.1	Poorly sorted coarse SAND
	18	61.3	3.1	1.11	-0.15	1.25	0.1	79.0	20.9	Poorly sorted v coarse SAND
	19	60.9	2.5	19.65	-4.30	2.63	0.3	17.8	82.0	V poorly sorted PEBBLE
	20	59.9	3.8	1.30	-0.37	3.27	9.0	50.9	40.1	V poorly sorted v coarse SAND
NEARSHORE	25	29.3	2.4	25.11	-4.65	2.69	0.3	15.7	84.0	V poorly sorted PEBBLE
	26	25.2	2.9	10.48	-3.39	3.35	0.2	24.3	75.5	V poorly sorted PEBBLE
	27	19.7	2.1	0.18	2.50	0.42	0.5	99.3	0.2	Well sorted fine SAND
	28	18.4	1.8	0.15	2.75	0.61	0.8	99.2	0.0	Moderately well sorted fine SAND
	29	17.9	2	0.17	2.59	0.64	0.7	98.0	1.4	Moderately well sorted fine SAND
	30a	8.4	1.4	0.26	1.97	0.62	0.3	99.6	0.1	Moderately well sorted medium SAND
Mean		*50.40*	*2.83*	*4.92*	*-1.11*	*1.97*	*0.99*	*56.27*	*42.74*	-
SD		*18.17*	*0.60*	*6.27*	*2.09*	*0.95*	*2.04*	*28.74*	*28.40*	-

Granulometry definitions: Fines = <63µm, Sand = 63µm to 2mm; Coarse Material = >2mm; LOI = Loss on Ignition.

Figure 4.3a Particle Size Analysis (Offshore Wave Hub Region) - Mean Phi

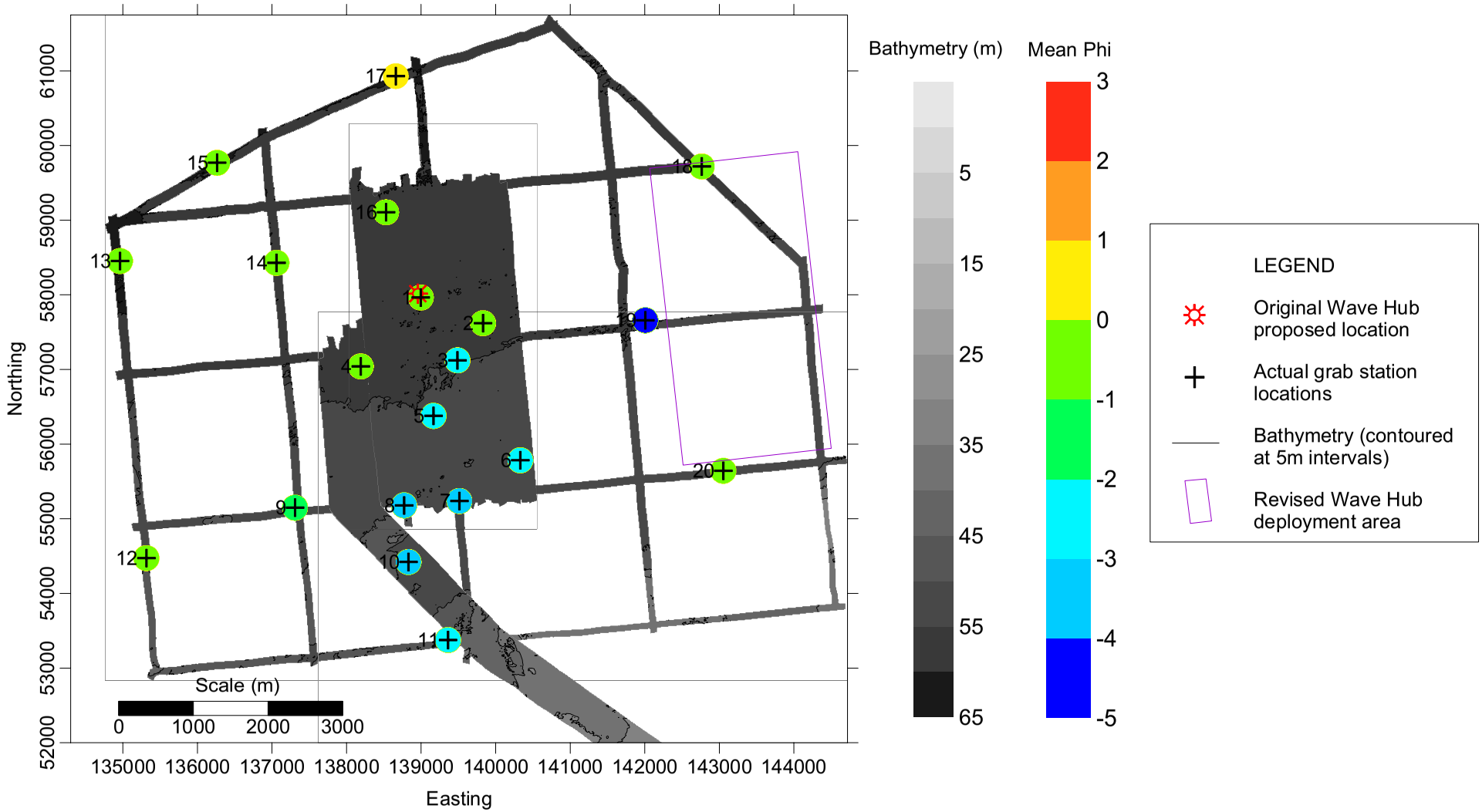


Figure 4.3b Particle Size Analysis (Cable Route) - Mean Phi

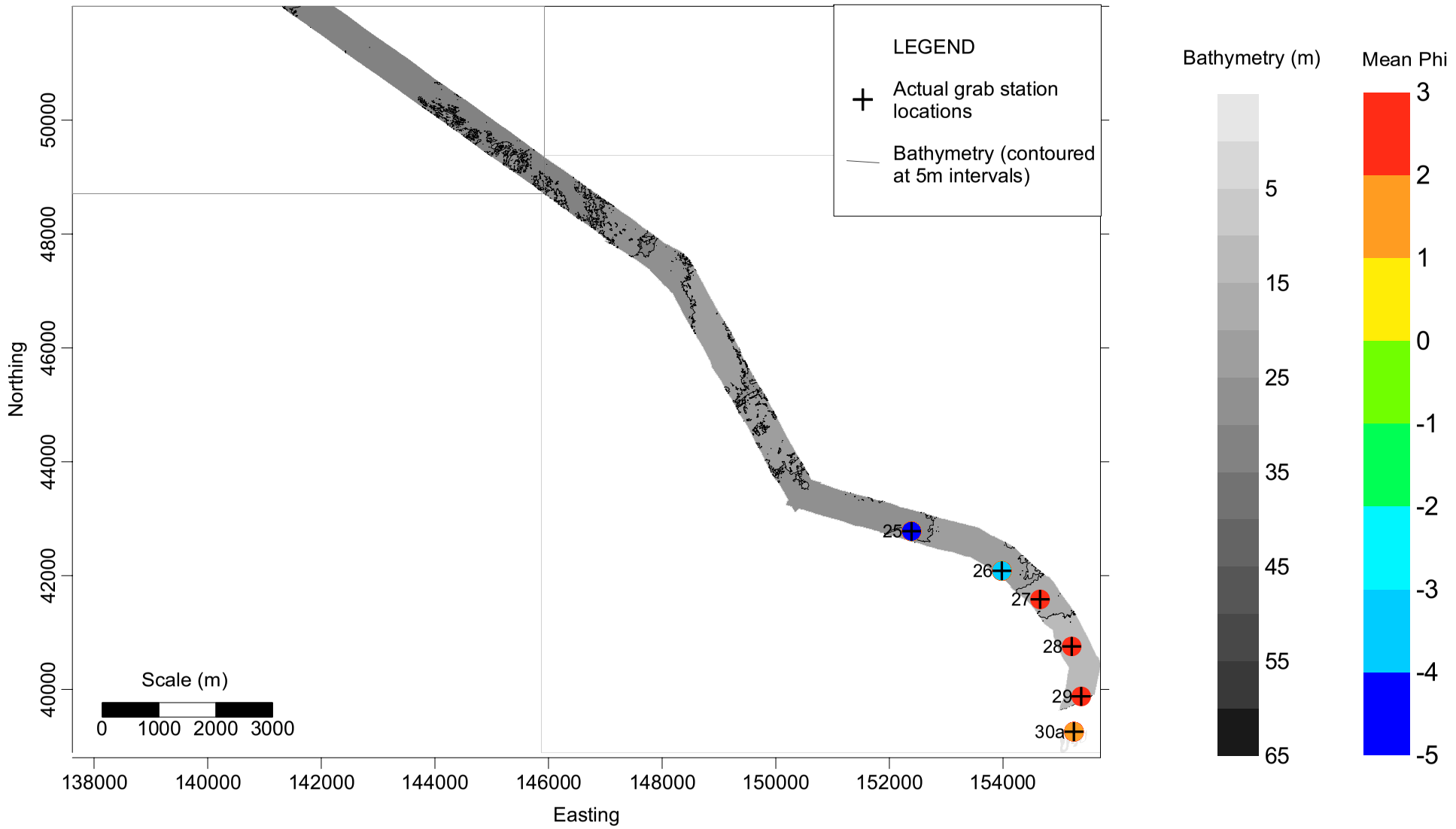


Figure 4.4a Particle Size Analysis (Offshore Wave Hub Region) - Sorting

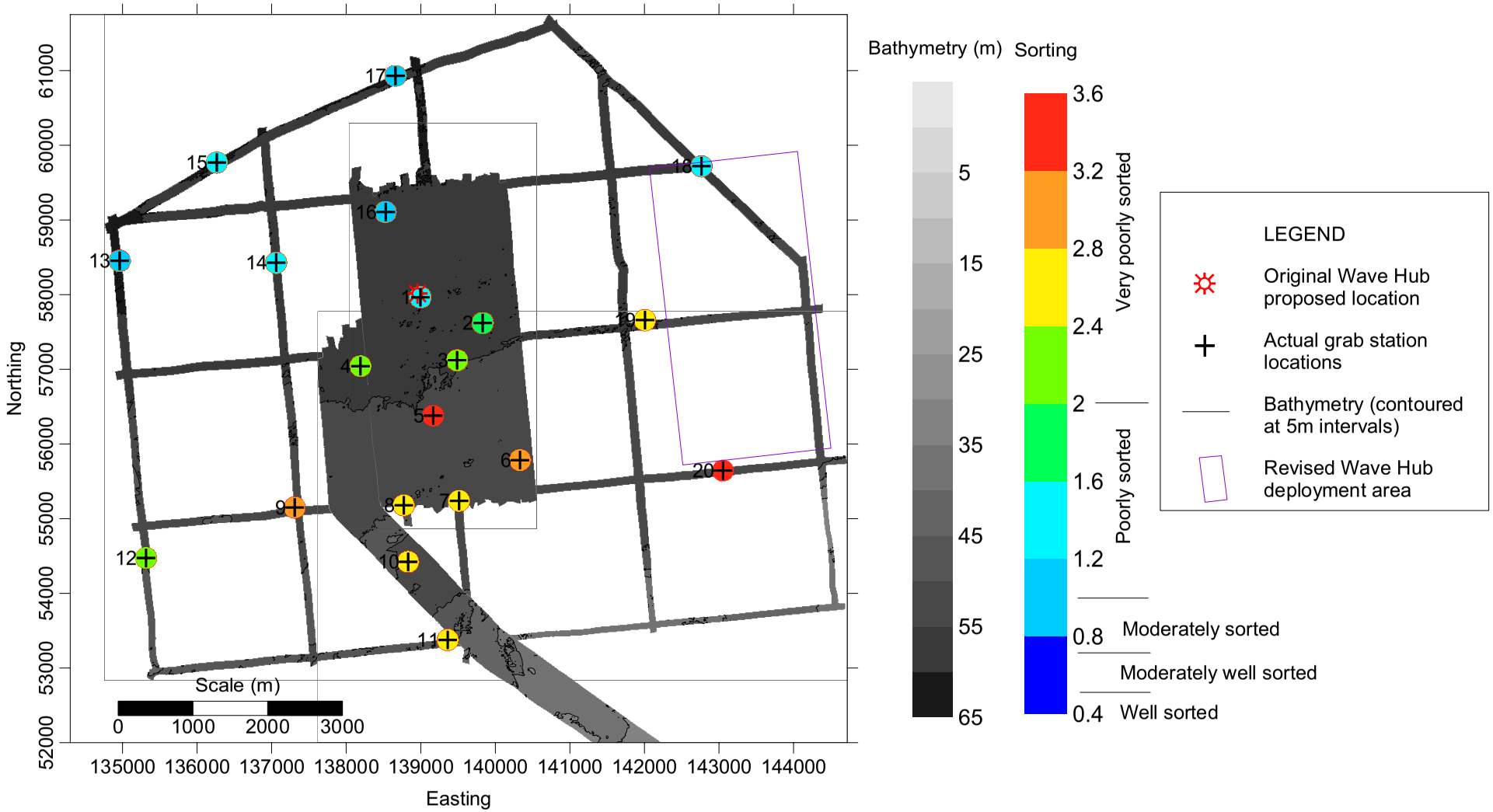


Figure 4.4b Particle Size Analysis (Cable Route) - Sorting

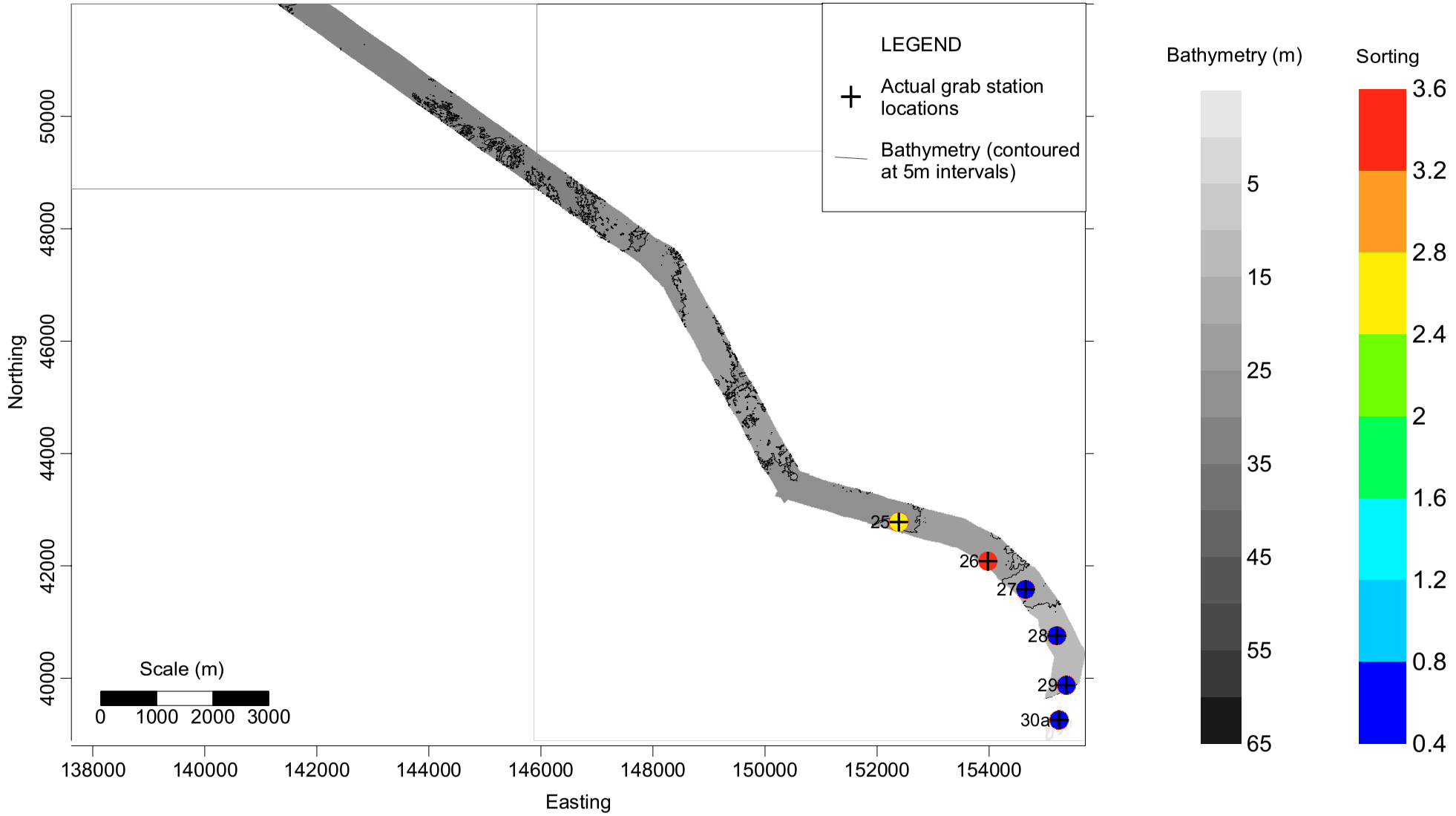


Figure 4.5a Particle Size Analysis (Offshore Wave Hub Region) - Percent Fines (<63µm)

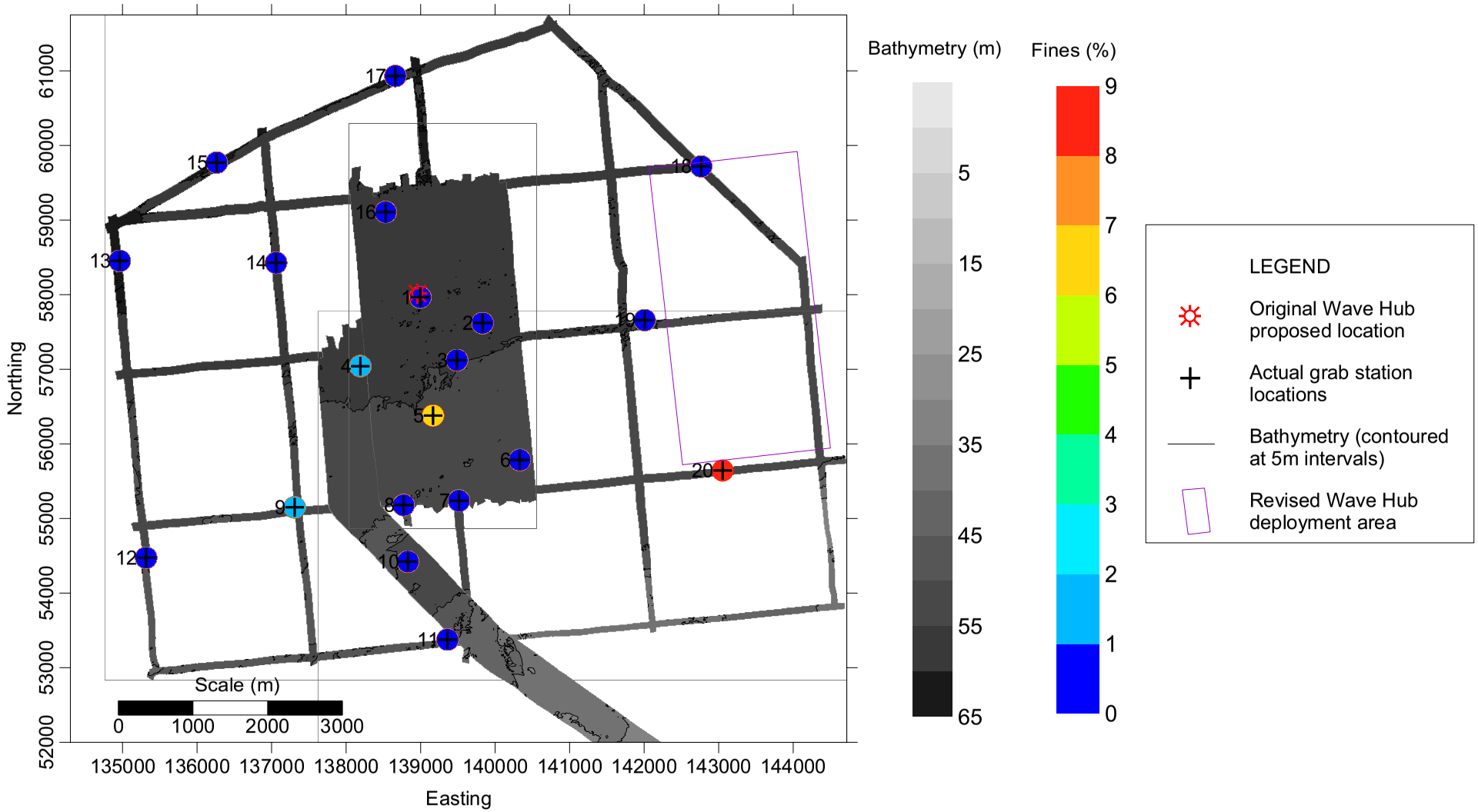


Figure 4.5b Particle Size Analysis (Cable Route) - Percent Fines (<63µm)

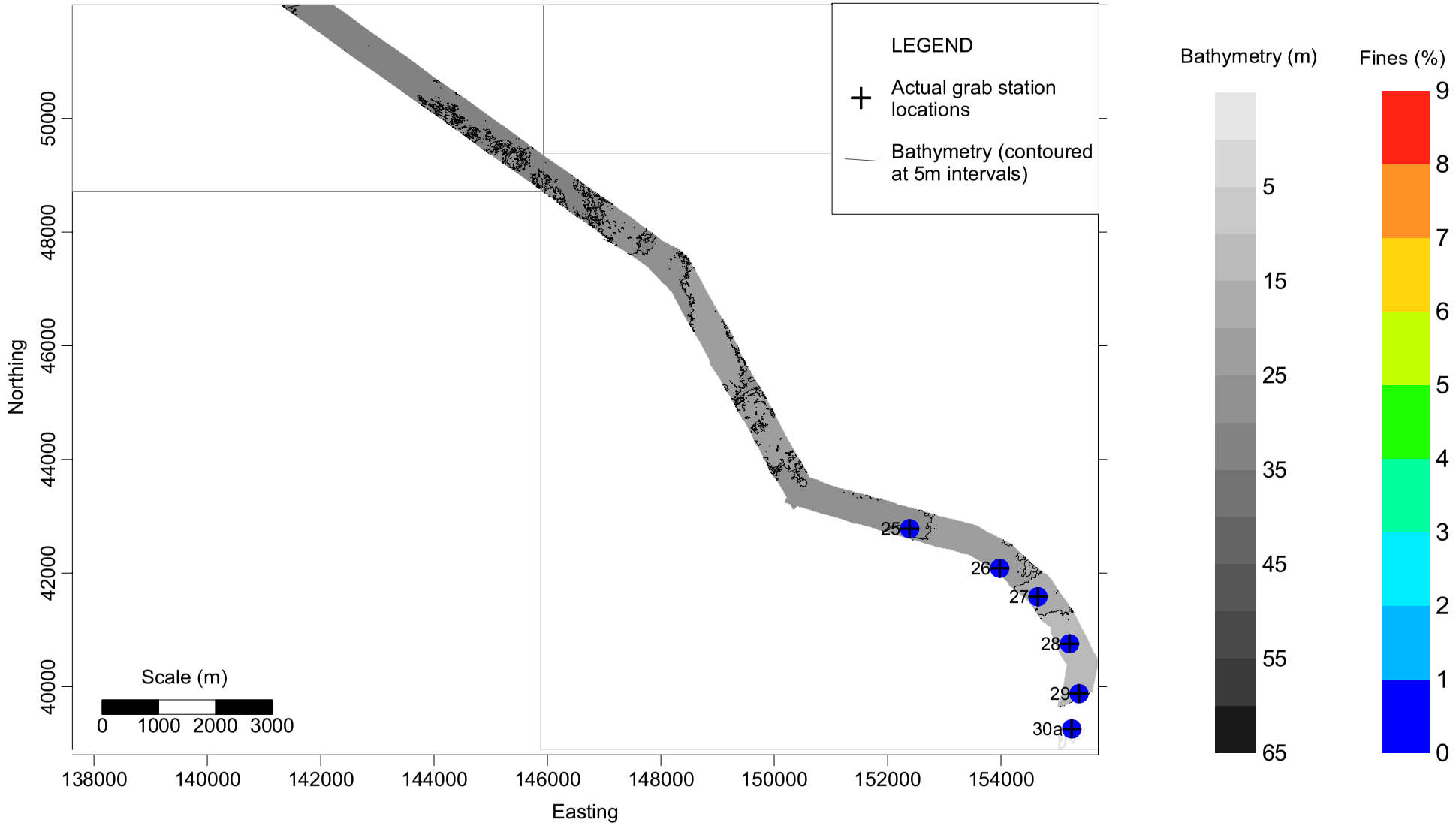


Figure 4.6a Particle Size Analysis (Offshore Wave Hub Region) - Percent Sand (<63µm to 2mm)

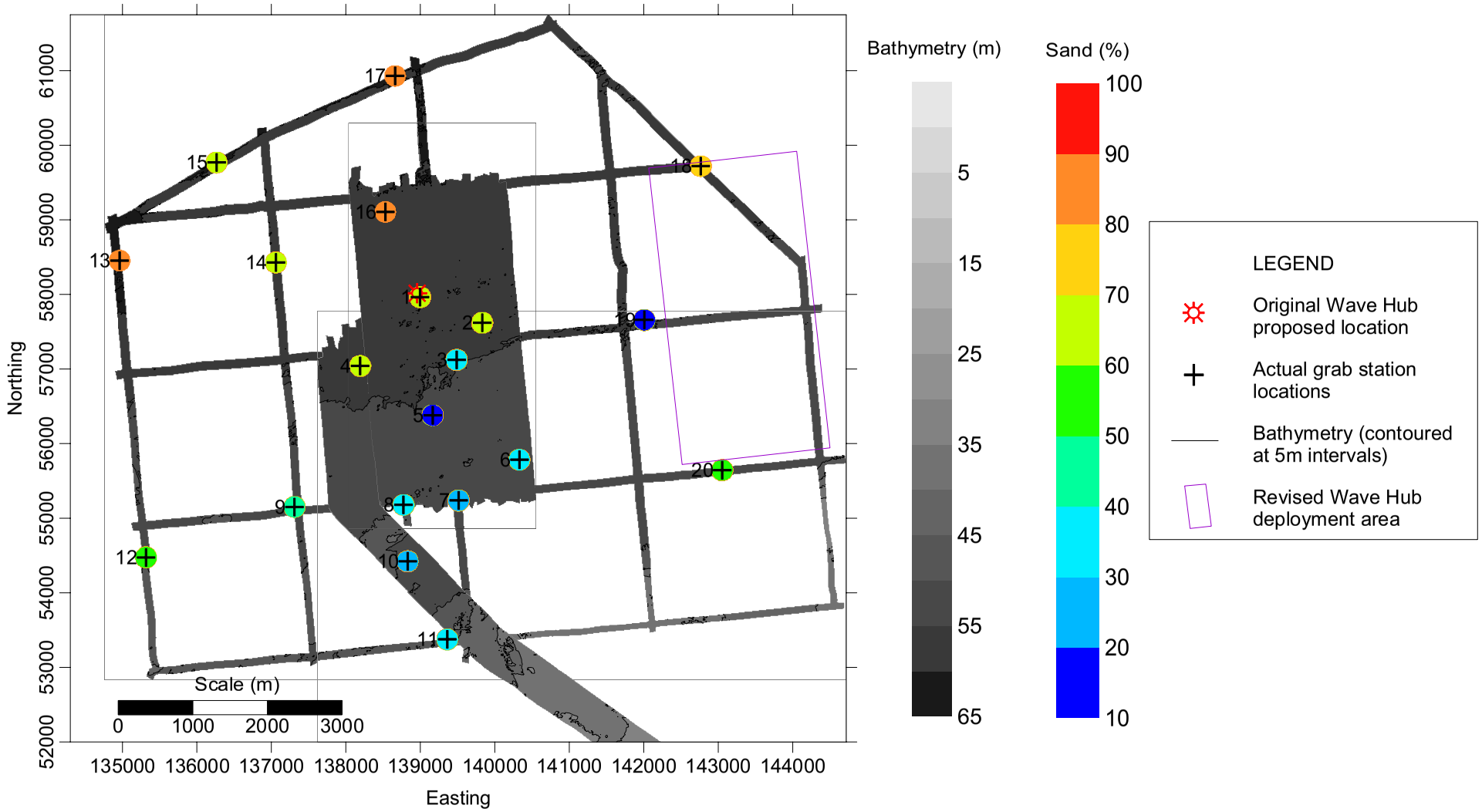


Figure 4.6b Particle Size Analysis (Cable Route) - Percent Sand (63µm to 2mm)

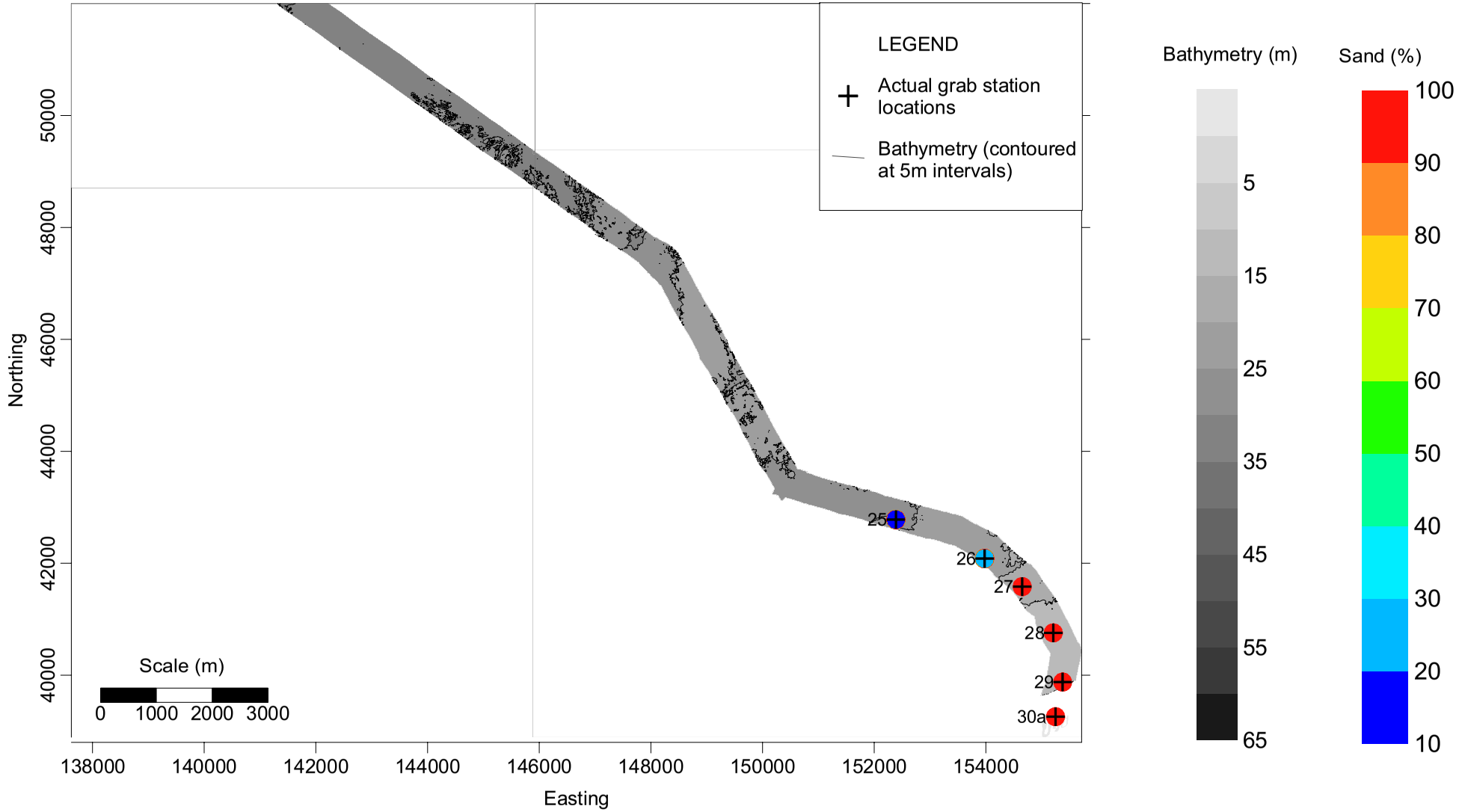


Figure 4.7a Particle Size Analysis (Offshore Wave Hub Region) - Percent Coarse (>2mm)

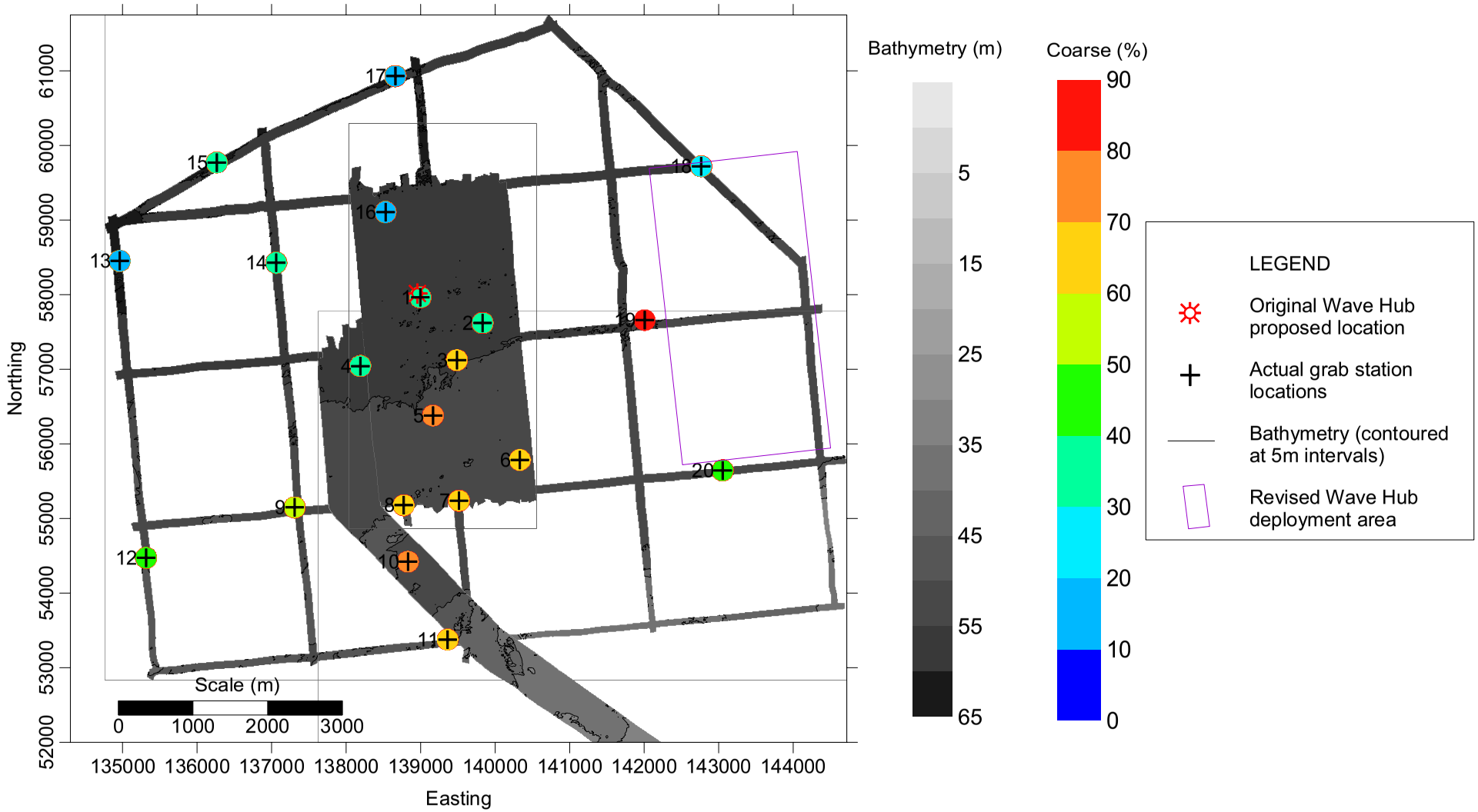
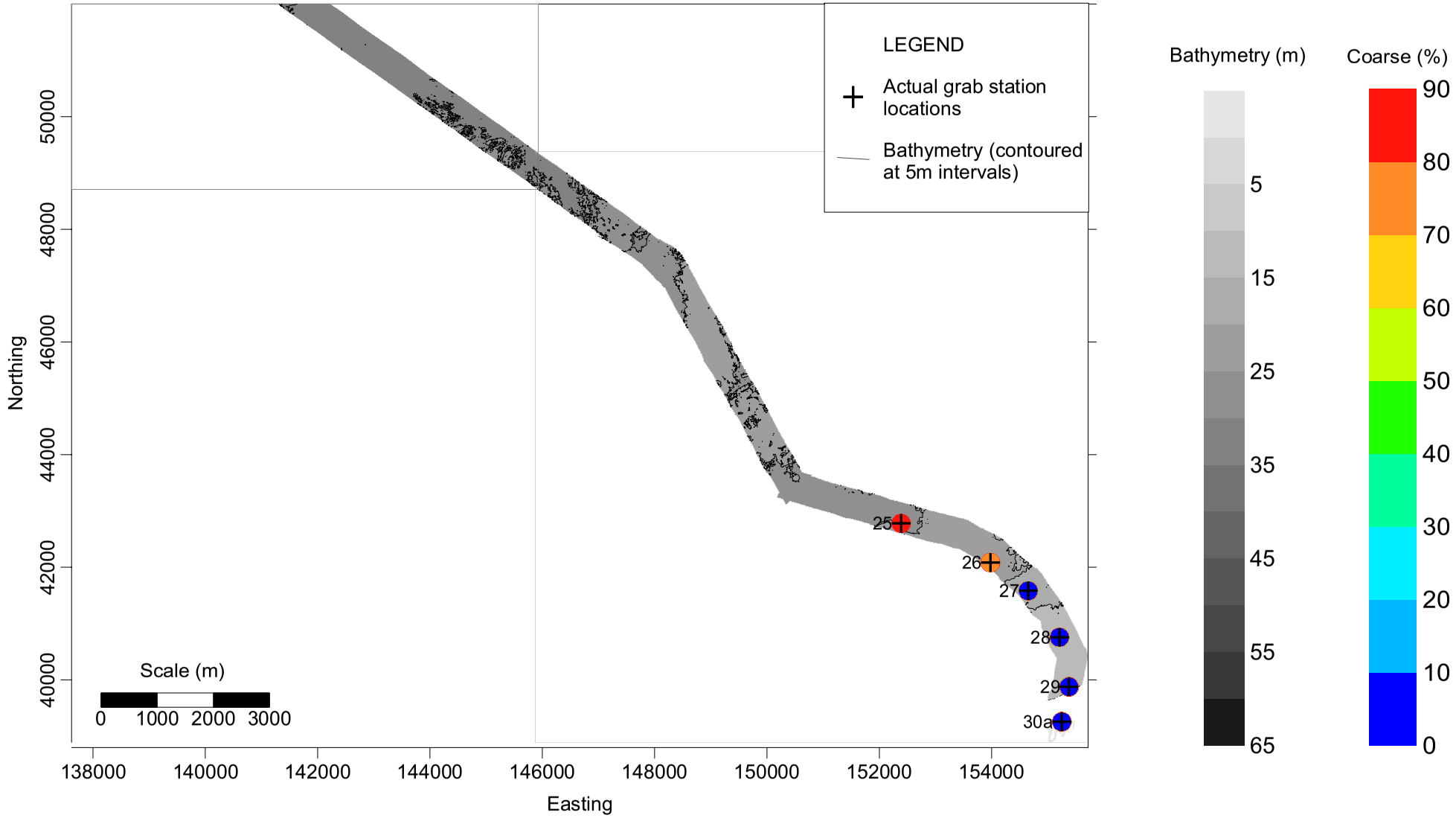


Figure 4.7b Particle Size Analysis (Cable Route) - Percent Coarse (>2mm)



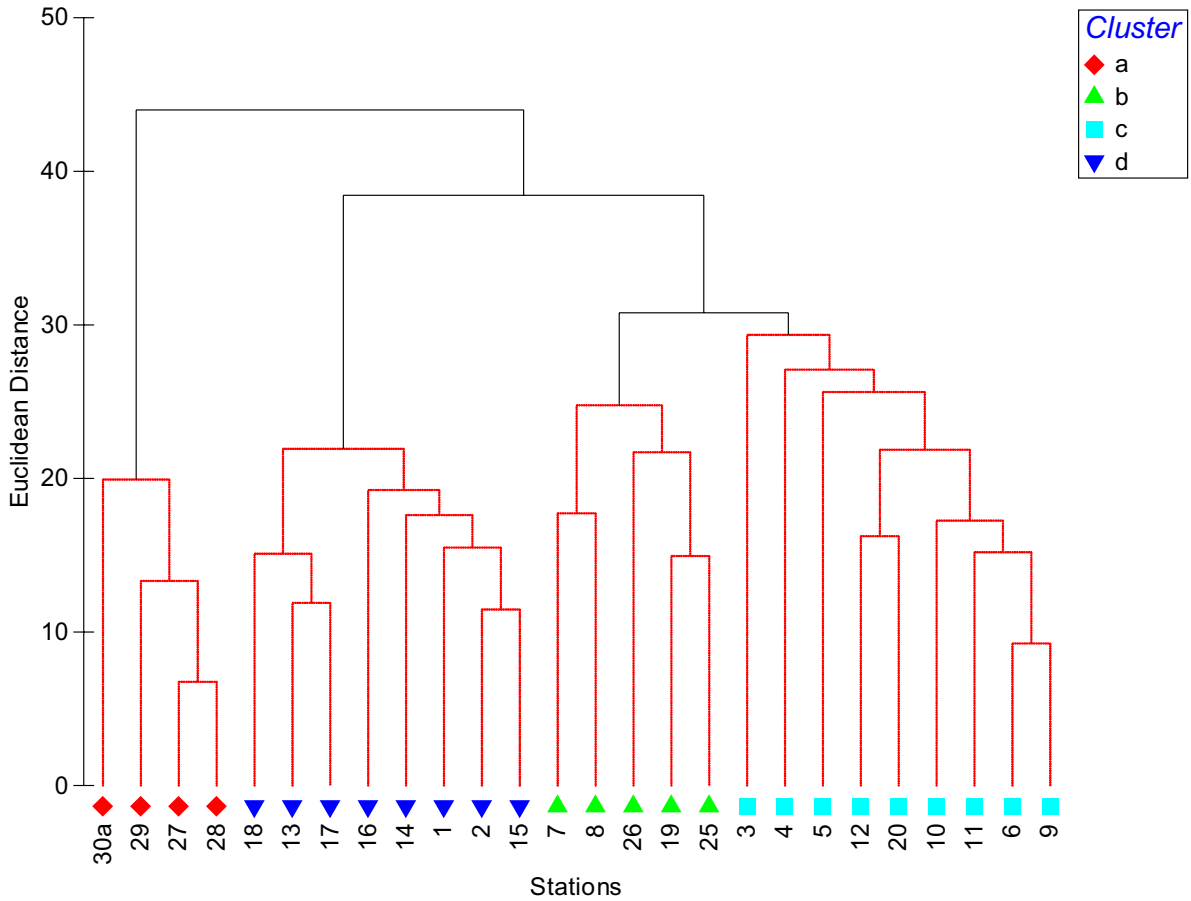
4.4.1 Multivariate Analyses

Patterns in the distribution of seabed sediments were examined further by means of multivariate analyses, in order to identify clusters of sites of similar granulometry. The influence of sediment granulometry on other environmental variables, means that clusters of sites with similar granulometry may also exhibit similar physico-chemical and biological characteristics.

Multivariate analyses were undertaken using the Plymouth Routines in Multivariate Ecological Research (PRIMER) v6.0 statistical package (Clarke & Gorley, 2006). Data for the percentage composition within 0.5 phi size classes were ranked to normalise the data, following which a similarity matrix was produced using the Euclidean distance similarity measure.

Two techniques have been used here to illustrate and identify differences in the data – cluster analysis which outputs a dendrogram displaying the relationships between samples based on the similarity measure and non-metric multi-dimensional scaling (nMDS) in which the samples are ordinated as a 2-dimensional ”map”. The resultant dendrograms and 2-dimensional nMDS plots are displayed in Figures 4.8 and 4.9.

Figure 4.8 Dendrogram of Ranked Granulometry Data for Stations by Euclidean Distance

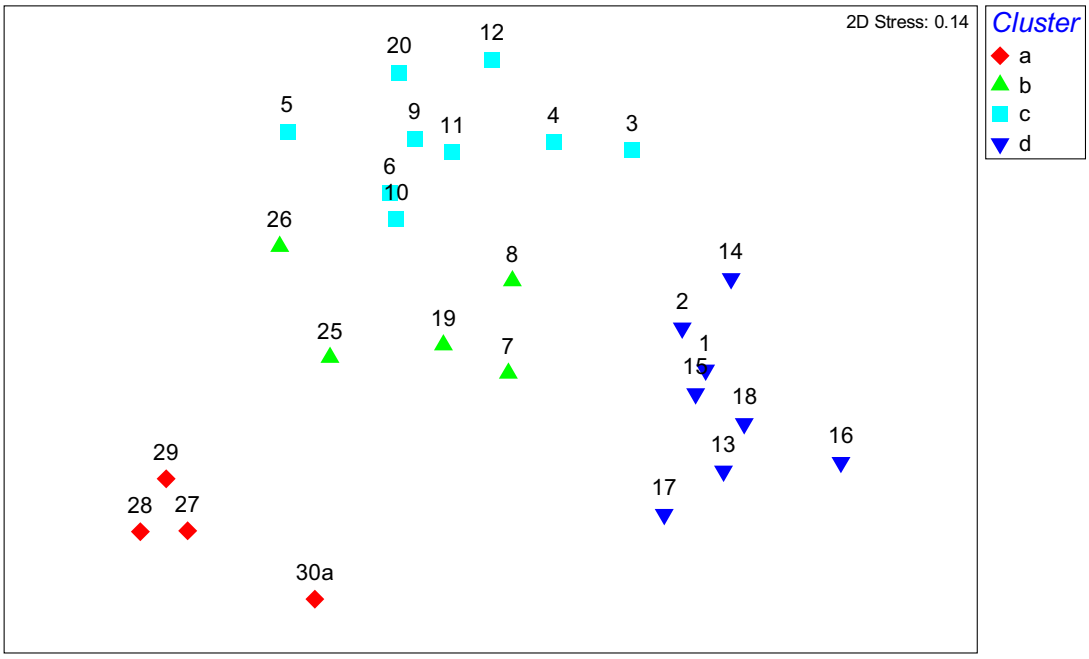


The dendrogram displayed in Figure 4.8 shows four statistically different clusters, with intra-group Euclidean distances of between 19.95 and 29.36. Clusters tended to be geographically distinct, with neighbouring stations forming statistically similar clusters.

The four clusters denoted in Figure 4.8 were also clearly defined in the nMDS ordination plot (Figure 4.9), with the stress factor of 0.14 indicating that the plot represents a potentially useful ordination. Summary

particle size distribution data for each distinct cluster group are given in Table 4.5 and displayed in Figure 4.10. Location of each station in relation to the cluster analysis is provided in Table 4.4 and Figure 4.11.

Figure 4.9 Non-Metric Multidimensional Scaling (nMDS) of Ranked Granulometry Data for Stations by Euclidean Distance



The nearshore cluster, cluster a, comprised stations 27 to 30a, located at depths of <18m. These stations were characterised by sediments ranging from coarse silts (4.5 phi or 44µm) to small pebbles -3.0 (3mm). The mode (i.e. most dominant) size class within cluster a sediments was fine sand (3.0 phi or 125µm), which accounted for a mean of 63.8% of the sediments.

Cluster b comprised stations located in depths of between 24m and 61m, both along the cable route (stations 25 and 26) and within the regional survey area (stations 7, 8 and 19). Sediments grouped within this cluster ranged in size from coarse silts (4.5 phi or 44µm) to large pebbles (-6.0 phi or 64mm), but were dominated by large pebbles (-4.0 to -6.0 phi or 16 to 64mm) accounting for a mean of 63.4% of the sediments.

Cluster c, included the majority of stations from the southern half of the original Wave Hub deployment area (stations 4, 5 and 6) and to the south of the regional area (stations 9 to 12 and 20) encompassing a depth range of 53 to 60m. Sediments ranged from coarse silts (4.5 phi or 44µm) to medium pebbles (-5.0 phi or 32mm). A bimodal distribution was evident, with the main peak (mean = 19.9%) evident for medium pebbles (-5.0 phi or 32mm) and a less prominent peak (mean = 13.29%) for medium sand (2.0 phi or 250µm).

The outermost cluster, cluster d, included all the stations from the northern half of the Wave Hub deployment area (stations 1, 2 and 16) and regional area (stations 13, 14, 15, 17 and 18), at depths of between 61 and 67m. As for cluster c sediments ranged from coarse silts (4.5 phi or 44µm) to medium pebbles (-5.0 phi or 32mm), but were dominated by very coarse sand, accounting for a mean of 36.35%.

Table 4.4 Summary of Particle Size Analysis for Clusters A-D – Station Location

Station	Description of Location	Cluster	Sediment Classification
27	Nearshore Cable Route	a	Well sorted fine SAND
28	Nearshore Cable Route	a	Moderately well sorted fine SAND
29	Nearshore Cable Route	a	Moderately well sorted fine SAND
30a	Nearshore Cable Route	a	Moderately well sorted medium SAND
7	To the south and within the original Wave Hub deployment area (OWHDA)	b	V poorly sorted PEBBLE
8	To the south and within the OWHDA	b	V poorly sorted PEBBLE
19	To the east of the OWHDA	b	V poorly sorted PEBBLE
25	Offshore Cable Route	b	V poorly sorted PEBBLE
26	Offshore Cable Route	b	V poorly sorted PEBBLE
3	To the south of the OWHDA	c	V poorly sorted PEBBLE
4	To the south of the OWHDA	c	V poorly sorted v coarse SAND
5	To the south of the OWHDA	c	V poorly sorted PEBBLE
6	To the south of the OWHDA	c	V poorly sorted PEBBLE
9	To the south and west of the OWHDA	c	V poorly sorted GRANULE
10	To the south of the OWHDA along the offshore cable route	c	V poorly sorted PEBBLE
11	To the south of the OWHDA along the offshore cable route	c	V poorly sorted PEBBLE
12	To the south and west of the OWHDA	c	V poorly sorted v coarse SAND
20	To the south and east of the OWHDA	c	V poorly sorted v coarse SAND
1	To the north of the OWHDA (at the original Wave Hub proposed location)	d	Poorly sorted v coarse SAND
2	To the north of the OWHDA	d	Poorly sorted v coarse SAND
13	To the north-west of the offshore regional area.	d	Poorly sorted v coarse SAND
14	To the north-west of the offshore regional area.	d	Poorly sorted v coarse SAND
15	To the north-west of the offshore regional area.	d	Poorly sorted v coarse SAND
16	To the north-west of the offshore regional area.	d	Moderately sorted v coarse SAND
17	To the north of the offshore regional area.	d	Poorly sorted coarse SAND
18	To the north and east of the offshore regional area.	d	Poorly sorted v coarse SAND

OWHDA – Original Wave Hub Development Area

Table 4.5 Summary of Particle Size Analysis for Clusters A-D – Phi Classification

Cluster		Sieve Size (Phi)											
		-6.0	-5.0	-4.0	-3.0	-2.0	-1.0	0.0	1.0	2.0	3.0	4.0	4.5
a	Mean	0.00	0.00	0.00	0.19	0.08	0.14	0.34	2.15	17.73	63.80	15.00	0.56
	SD	0.00	0.00	0.00	0.38	0.17	0.11	0.11	2.33	16.81	12.97	13.37	0.21
b	Mean	26.6	28.3	8.42	4.52	3.03	4.77	7.95	7.09	5.23	3.03	0.68	0.28
	SD	25.9	21.9	6.47	1.19	0.92	2.31	4.75	2.46	2.42	3.21	0.57	0.12
c	Mean	0.00	19.9	11.6	11.0	8.69	7.00	9.48	11.51	13.29	3.87	1.22	2.34
	SD	0.00	16.7	7.35	5.74	5.13	2.61	4.82	6.85	6.15	2.26	0.77	3.12
d	Mean	0.00	2.38	1.93	1.71	3.19	16.5	36.35	25.37	10.72	1.51	0.15	0.14
	SD	0.00	2.44	2.81	1.47	1.50	5.68	5.30	7.99	6.10	0.97	0.07	0.07

Figure 4.10 Mean Particle Size Distribution for Clusters A-D

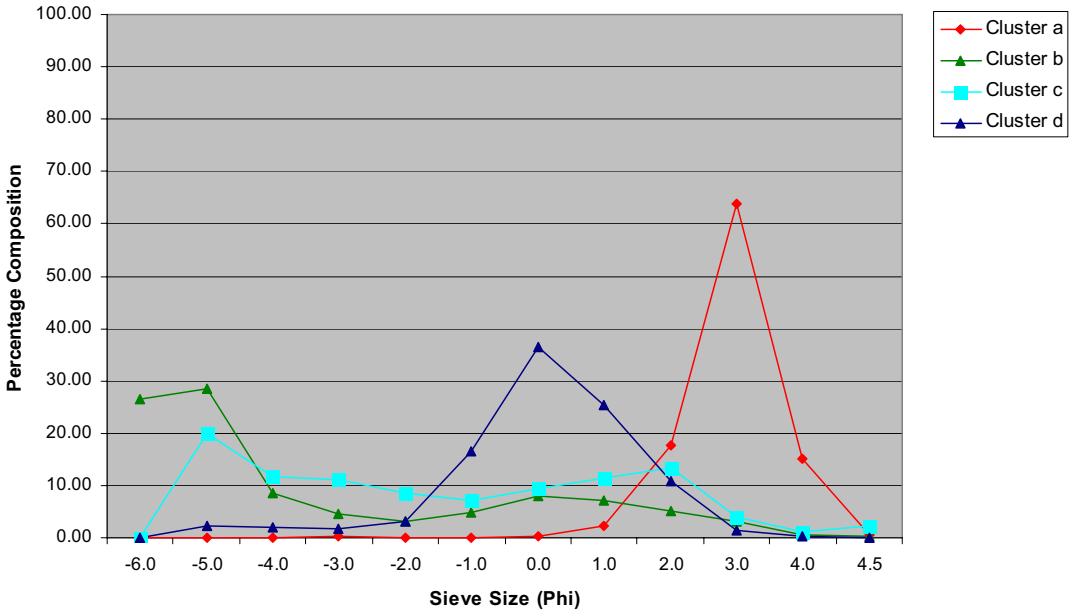
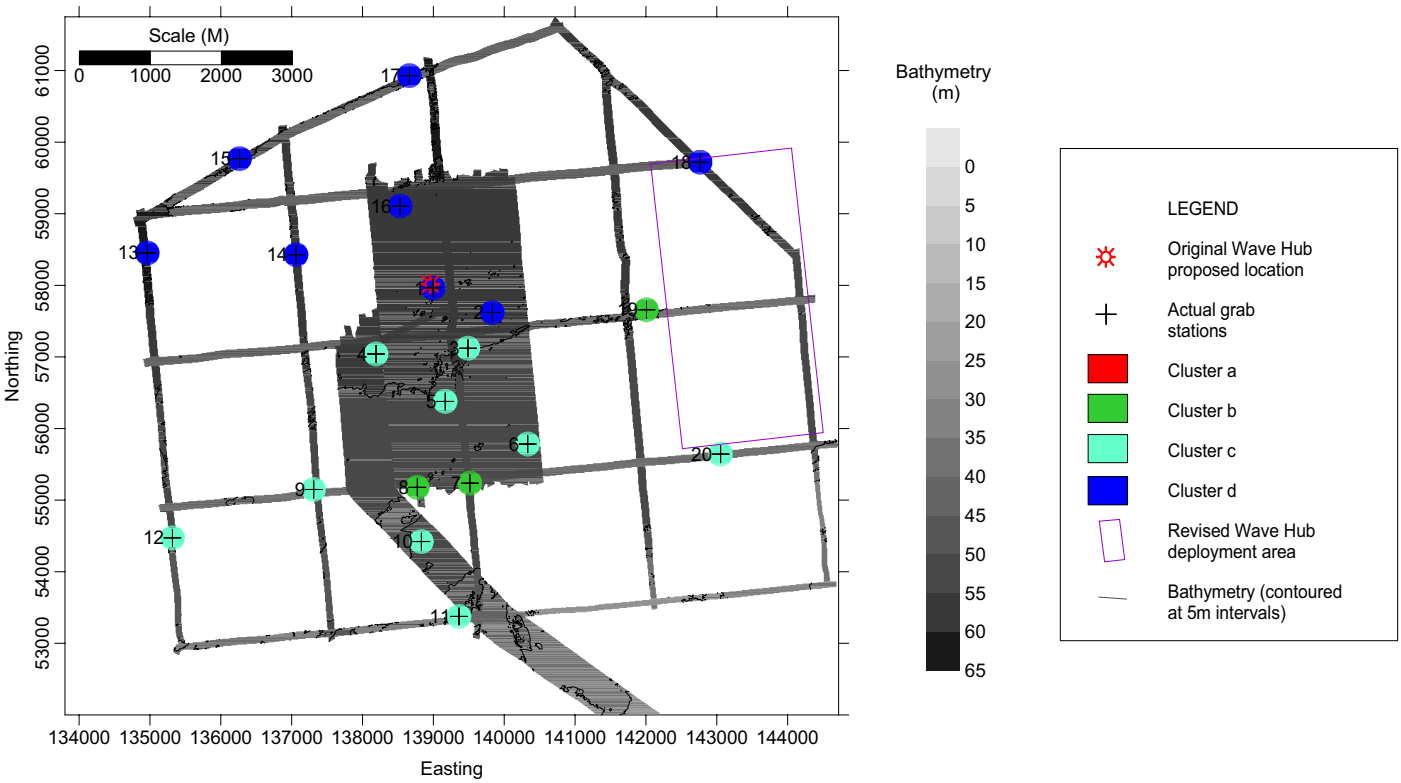


Figure 4.11 Cluster Analysis - Grabs Particle Size Analysis



4.5 Organic Carbon Analysis

Organic matter, primarily comprising detrital matter and naphthenic materials i.e. carboxylic acids and humic substances, performs an important role in marine ecosystems providing a source of food for suspension and deposit feeders, who may then be predated by carnivores. This has led to the suggestion that variation in benthic communities is, in part, caused by the availability of organic carbon (Snelgrove & Butman, 1994). Organic carbon is also an important adsorber (scavenger) of heavy metals and may be of use in interpreting the distribution of metals (McDougall, 2000).

The proportion of organic carbon within the sediments was relatively homogeneous across the site (see Table 4.3). Total organic carbon ranged from 1.4% to 3.8% (stations 30a and 20, respectively). The proportion of organic carbon within sediments typically correlates well with the proportion of fines (<63µm). However, this correlation was not evident for the data from this survey, with the exception of stations 20 and 5 which recorded the two highest levels of fines (6.4% and 8.9%, respectively) and also the highest levels of total organic carbon (3.8 and 3.5%, respectively).

Figure 4.12a Organic Carbon Analysis (Offshore Wave Hub Region) - Total Organic Carbon (by Percent Loss on Ignition)

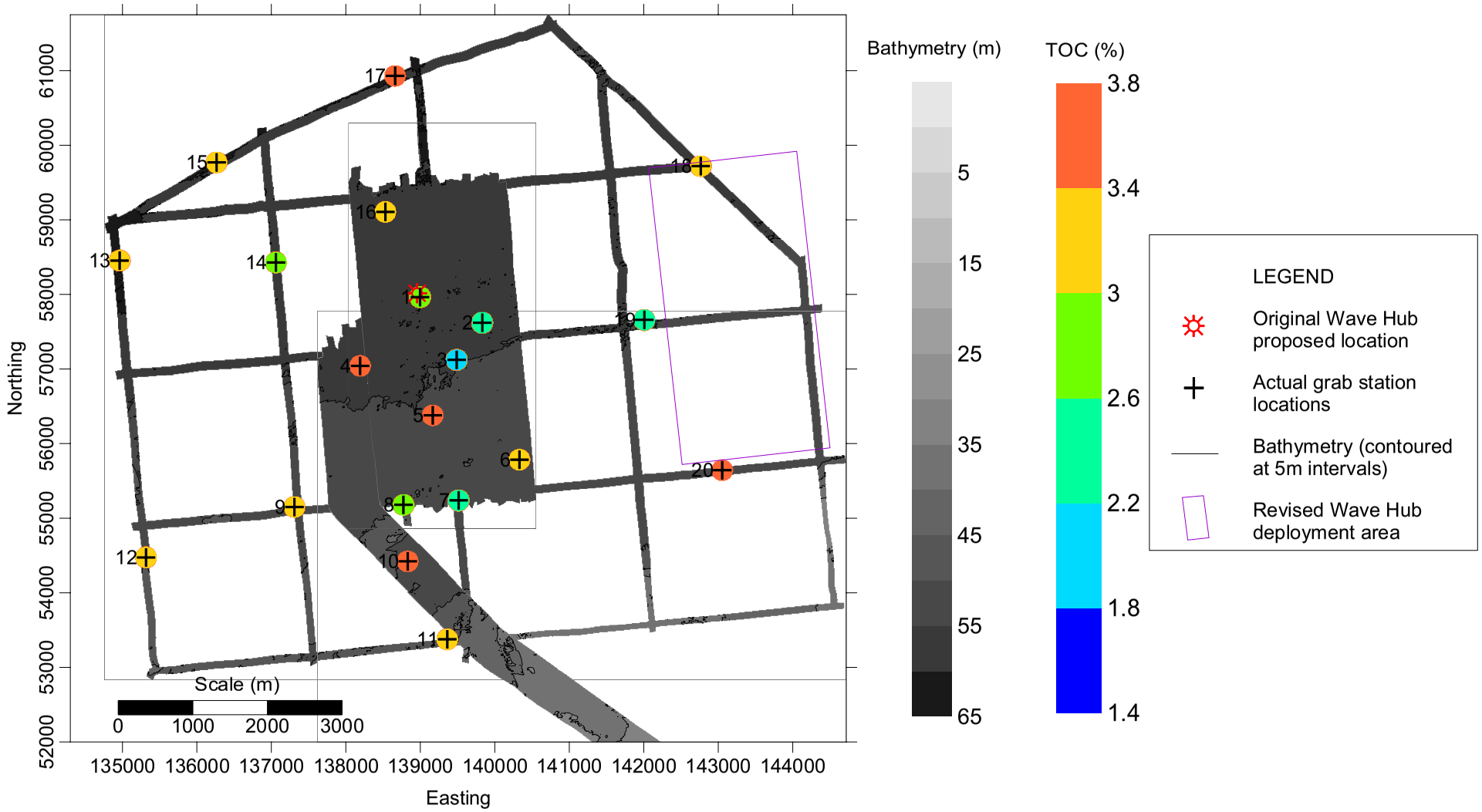
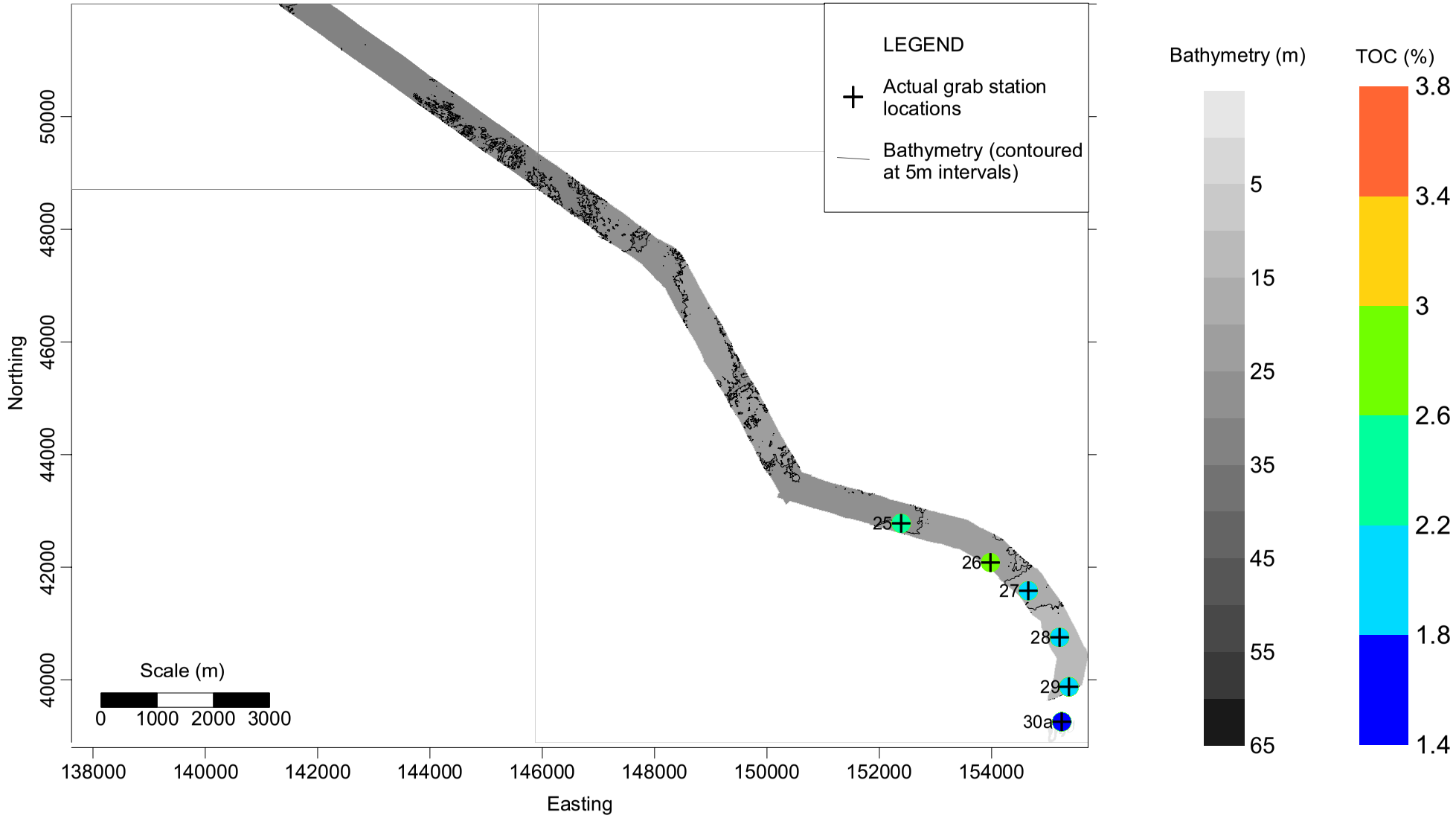


Figure 4.12b Organic Carbon Analysis (Cable Route) - Total Organic Carbon (by Percent Loss on Ignition)



4.6 Sediment Chemistry

4.6.1 Hydrocarbon Analysis

Hydrocarbon concentrations (total hydrocarbon concentrations, total n-alkanes and carbon preference index (CPI)) are summarised for each station in Table 4.4, while values for individual n-alkanes are given in Table 4.5. Gas chromatography (GC) traces showing the aliphatic hydrocarbon traces for each station and labelled with individual n-alkanes (nC12-36) are contained in Appendix F. The isoprenoid hydrocarbons, pristane (Pr, IP18) and phytane (Ph, IP19) are marked together with the internal standards heptamethylnonane (A), D34 hexadecane (B), chlorooctadecane (C) and squalane (D).

Extraction of hydrocarbons was undertaken on wet sediment samples. This technique is considered to extract a greater proportion of the target analytes than dry extraction methods: Wong & Williams (1980) estimated that around 16% of hydrocarbons determined by wet extraction procedures were lost as a consequence of the drying process. As such, comparison of recorded hydrocarbon levels with baseline concentrations from other surveys or published literature should be undertaken with caution. A sub-sample of the homogenised sample was dried to constant weight at 110°C, so as to provide a correction factor for wet/ dry sediments (see Methods 3.3).

Table 4.5 Summary of Hydrocarbon Concentrations (µg.g^{-1} dry weight)

Station	Fines (<63µm)	THC	n-Alkanes			UCM	CPI			Pr (ng.g^{-1})	Ph (ng.g^{-1})
			nC12-20	nC20-36	nC12-36		nC12-20	nC21-36	nC12-36		
16	0.05	0.95	0.02	0.04	0.07	0.64	0.92	1.40	1.21	1.6	0.66
18	0.05	0.89	0.02	0.04	0.06	0.60	0.88	1.46	1.23	1.35	0.86
17	0.10	1.00	0.02	0.04	0.06	0.72	0.95	1.65	1.34	1.33	0.78
1	0.13	1.04	0.03	0.04	0.07	0.69	0.77	1.45	1.14	1.35	0.72
7	0.14	2.13	0.03	0.11	0.14	1.64	0.89	1.28	1.19	0.91	0.69
13	0.14	1.90	0.04	0.06	0.11	1.42	0.93	1.36	1.17	1.47	1.86
14	0.19	3.34	0.03	0.07	0.10	2.93	0.98	1.35	1.22	1.99	1.29
15	0.20	1.42	0.03	0.05	0.07	1.05	0.79	1.72	1.29	0.58	1.51
3	0.22	1.33	0.03	0.11	0.15	0.89	0.87	1.00	0.97	2.15	3.11
2	0.23	1.22	0.03	0.07	0.10	0.84	0.86	1.24	1.10	1.43	1.18
26	0.24	2.14	0.04	0.08	0.12	1.48	1.69	1.72	1.71	1.61	1.51
19	0.25	1.61	0.05	0.10	0.15	1.10	0.93	1.37	1.22	2.06	0.39
30a	0.29	1.19	0.03	0.07	0.10	0.81	0.93	1.29	1.16	1.57	2.61
25	0.31	2.68	0.04	0.15	0.19	1.86	1.10	1.82	1.64	1.32	1.18
10	0.41	3.01	0.03	0.13	0.16	2.14	1.03	1.81	1.62	1.03	1.03
8	0.46	1.89	0.07	0.08	0.15	1.30	0.57	2.15	1.23	1.39	1.06
27	0.53	1.38	0.02	0.04	0.06	1.10	0.91	1.37	1.20	1.14	1.37
11	0.60	3.68	0.06	0.18	0.24	2.44	0.96	1.61	1.41	3.68	1.52
29	0.65	3.36	0.06	0.14	0.20	2.19	1.10	1.05	1.06	3.73	3.16
12	0.70	2.47	0.03	0.09	0.12	1.89	0.83	1.46	1.26	1.06	0.73
28	0.78	3.55	0.05	0.13	0.18	2.41	1.42	1.53	1.50	8.17	2.64
6	0.90	3.04	0.04	0.12	0.16	2.20	0.93	2.08	1.72	8.28	1.02
9	1.23	3.60	0.03	0.15	0.19	2.34	1.09	2.03	1.82	1.16	1.14
4	1.66	2.49	0.04	0.09	0.14	1.82	1.06	2.25	1.77	7.32	1.48
5	6.38	2.39	0.04	0.11	0.15	1.57	1.05	1.63	1.44	5.94	1.19
20	8.97	4.83	0.07	0.25	0.32	3.10	0.84	1.52	1.34	23.71	2.12
Mean	*0.99*	*2.25*	*0.04*	*0.10*	*0.14*	*1.58*	*0.97*	*1.56*	*1.34*	3.36	1.42
SD	*2.04*	*1.06*	*0.01*	*0.05*	*0.06*	*0.73*	*0.21*	*0.32*	*0.24*	4.73	0.75

Data are sorted in ascending order by % fines (<63µm). THC = Total Hydrocarbon Concentrations; UCM = Unresolved Complex Mixture; CPI = Carbon Preference Index (ratio of sum of Odd- to sum of Even-Carbon Alkanes).

Total Hydrocarbon Concentrations

Total hydrocarbon concentrations (THC) across the site were low, ranging from 0.89µg.g^{-1} to 4.83µg.g^{-1} (stations 18 and 20, respectively), with a mean concentration of 2.25µg.g^{-1} (Standard Deviation = 1.06µg.g^{-1}) (Tables 4.5 and 4.6, and Figure 4.13). Levels of total hydrocarbons appeared to correlate reasonably well with the proportion of fines (<63µm) within the sediment, for example station 20 registered a substantially higher proportion of fines (8.97%) compared to the other stations and accordingly the highest THC (4.83µg.g^{-1}), whereas station 18 recorded the lowest fines (0.05%) and accordingly the lowest total hydrocarbon concentrations (0.89µg.g^{-1}).

Total N-Alkanes

Concentrations of n-alkanes were low, ranging from 0.06µg.g^{-1} (stations 17, 18 and 27) to 0.32µg.g^{-1} (stations 20), with a mean concentration of 0.14µg.g^{-1} (SD = 0.06µg.g^{-1}) (Table 4.5 and 4.6, and Figure 4.14). As with THC levels of total n-alkanes show a good correlation with percentage fines (<63µm), with the stations recording the highest and lowest proportions of fines (stations 20 and 18, respectively) also recording the highest and joint lowest levels of n-alkanes (0.32µg.g^{-1} and 0.06µg.g^{-1}, respectively).

Individual n-alkanes found across the site were recorded at between 0.55ng.g^{-1} and 44.54ng.g^{-1} (Table 4.6). Concentrations of n-alkanes were generally higher for the longer chained carbons than for the shorter chained carbons, with the exception of station 8, which recorded 41.29ng.g^{-1} for nC_{12}. This was particularly evident for the odd numbered alkanes. This distribution is consistent with the presence of terrestrial derived n-alkanes from the wax cuticles of higher plants, which typically comprise the long-chain, odd carbon number n-alkanes (nC_{25-33}) (Eglinton *et al*, 1962), whereas marine organisms (phyto- and zooplankton) preferentially synthesize short-chain, odd carbon number (nC_{15-21}) (Blumer *et al*, 1971). Terrestrial matter is often evident in marine sediments, particularly inshore sediments, although it has also been observed for samples from the North Sea (Fugro, unpublished) and Atlantic Margin (McDougall, 2000), having entered the marine environment through run-off from adjacent land masses.

Carbon Preference Index

The carbon preference index (CPI) is used to assess the relative contribution from petrogenic and biogenic sources in hydrocarbon samples and is determined by calculating the ratio of the sum of odd- to the sum of even-carbon alkanes. The range of alkanes from nC_{21}-nC_{36} is of particular interest as odd carbon n-alkanes from terrestrial plants elute in this region. Pristine sediments exhibiting a predominance of odd number biogenic alkanes might be expected to have a CPI value of greater than 2.0, while crude oil or refined products show no preference for odd or even n-alkanes and achieve a CPI close to unity (1.0) (McDougall, 2000).

CPI values for n-alkanes (nC_{12-36}) (Table 4.5 and Figure 4.15) across the stations ranged from 0.97 to 1.82 (stations 3 and 9, respectively). A similar pattern was observed for the sub-set of n-alkanes from nC_{21}-nC_{36} with the CPI for the majority of stations ranging from 1.00 (station 3) to 2.25 (station 4) and the sub-set of n-alkanes from nC_{12-20} which ranged from 0.57 to 1.69 (station 8 and 26, respectively).

Calculated CPI levels for the survey area, while generally toward the lower end expected, are considered to represent background levels of hydrocarbons. The lower levels of CPI for nC_{12}-nC_{36} observed at certain stations, e.g. stations 3 and 29, appear to be caused not by higher levels of petrogenic n-alkanes but rather by considerably reduced levels of terrestrial n-alkanes. Stations 3 and 29 recorded comparable CPI in contrast with the remaining dataset for nC_{12}-nC_{20} (0.87 and 1.10, compared with a mean of 0.97), but depressed CPI for nC_{21}-nC_{36} (1.00 and 1.05, *vs.* a mean of 1.56) elevated levels of long-chain, odd number n-alkanes derived from terrestrial plants would be typically expected. The stations recording lower CPI are therefore likely to be subject to less influence from riverine sediment inputs.

Furthermore, as individual n-alkanes were close to the analytical threshold, it is possible that insignificant changes in n-alkanes may considerably skew the results. For this reason, associated ratios (e.g. CPI) often used to assist in the interpretation of possible sources of contamination should be interpreted with caution.

Table 4.6 Individual Aliphatic Concentrations (ng.g^{-1} dry weight)

Alkane (ng.g^{-1})	Stations												
	1	2	3	4	5	6	7	8	9	10	11	12	13
nC12	2.37	2.34	3.48	3.05	2.68	2.35	1.75	41.29	2.17	1.82	3.08	2.21	3.28
nC13	5.09	5.40	4.45	6.71	6.09	4.90	3.54	4.33	3.80	4.48	7.09	4.86	6.96
nC14	8.27	8.59	7.96	10.74	9.48	7.95	5.64	7.07	5.65	7.03	9.87	7.66	10.48
nC15	2.62	3.24	3.96	4.27	4.31	3.55	3.06	2.96	3.27	3.11	6.04	2.78	4.78
nC16	2.31	2.25	2.40	2.87	2.70	2.69	1.81	2.05	2.66	2.15	3.93	2.00	2.94
nC17	2.03	2.63	3.22	3.48	4.56	3.05	2.73	3.26	3.08	2.95	6.32	2.23	3.20
nC18	2.47	2.86	3.49	3.26	4.16	4.18	3.97	3.81	3.33	2.99	6.79	3.41	4.14
nC19	1.98	2.48	2.98	6.11	5.15	4.67	3.26	3.76	5.02	3.93	7.44	3.43	3.83
nC20	1.78	2.16	2.35	1.90	2.92	2.93	3.74	3.22	2.48	1.94	13.27	3.78	1.88
nC21	0.90	0.80	2.11	3.44	6.58	6.70	2.42	4.67	7.47	9.12	8.02	4.08	1.53
nC22	1.09	1.21	2.86	5.09	1.48	2.34	1.33	1.15	1.74	1.41	2.49	1.53	1.68
nC23	0.76	1.22	3.99	2.10	1.70	2.06	1.78	1.41	2.14	1.78	2.83	1.35	1.44
nC24	0.93	1.19	6.36	2.07	1.43	1.58	2.57	1.49	2.17	1.79	2.14	1.36	2.14
nC25	1.35	1.64	7.90	3.05	2.37	3.05	3.90	1.98	3.93	2.68	4.02	2.05	2.15
nC26	1.67	2.43	10.93	2.70	2.49	2.99	5.77	2.97	3.58	3.22	2.63	2.63	2.62
nC27	2.64	3.43	15.20	6.30	3.89	6.75	9.91	5.61	8.77	7.09	10.25	4.25	4.01
nC28	1.73	3.26	11.24	4.12	3.03	4.78	6.20	0.50	4.63	3.88	7.51	1.27	1.02
nC29	6.30	7.79	13.35	18.48	19.41	22.87	14.28	13.21	32.05	23.76	31.05	12.45	8.39
nC30	2.32	4.01	10.39	2.35	8.57	7.67	7.37	1.35	11.53	8.58	15.09	2.55	1.68
nC31	5.29	7.09	6.81	12.28	13.58	15.81	11.35	11.53	22.02	14.98	22.38	10.37	6.75
nC32	4.56	6.90	5.57	3.05	10.25	3.79	10.65	5.30	10.67	9.92	13.00	8.61	6.17
nC33	4.81	7.05	4.23	9.64	9.75	13.47	10.23	7.05	13.53	11.80	16.21	7.38	5.70
nC34	3.75	6.53	5.48	5.44	8.74	10.39	9.71	7.20	11.13	12.18	13.16	11.31	8.01
nC35	4.09	6.43	1.65	8.92	9.34	9.65	8.70	6.14	11.50	10.66	14.47	8.21	6.16
nC36	2.24	4.25	2.70	5.72	7.25	7.71	6.98	4.92	6.89	7.03	10.75	6.44	4.74
Pristane	1.35	1.43	2.15	7.32	5.94	8.28	0.91	1.39	1.16	1.03	3.68	1.06	1.47
Phytane	0.72	1.18	3.11	1.48	1.19	1.02	0.69	1.06	1.14	1.03	1.52	0.73	1.86
Total n-Alkanes	**0.07**	**0.10**	**0.15**	**0.14**	**0.15**	**0.16**	**0.14**	**0.15**	**0.19**	**0.16**	**0.24**	**0.12**	**0.11**
THC	1,043	1,215	1,325	2,491	2,393	3,044	2,131	1,894	3,597	3,007	3,685	2,470	1,905
UCM	694	845	892	1,817	1,567	2,199	1,640	1,302	2,345	2,142	2,438	1,886	1,417
CPI (nC12-20)	775	863	873	1,065	1,051	927	893	575	1,086	1,030	965	830	933
CPI (nC20-36)	1,448	1,236	998	2,254	1,627	2,076	1,279	2,150	2,027	1,806	1,606	1,461	1,360
CPI (nC12-36)	1,141	1,102	969	1,769	1,443	1,718	1,192	1,229	1,821	1,622	1,408	1,260	1,174

UCM = Unresolved Complex Mixture; THC = Total Hydrocarbon Concentrations; CPI = Carbon Preference Index (ratio of the sum of Odd- to the sum of Even-Carbon Alkanes); Mean = Mean of the dataset SD = Standard Deviation of the mean dataset.

Table 4.6 (cont'd). Individual Aliphatic Concentrations (ng.g^{-1} dry weight)

	Stations												
Alkane (ng.g^{-1})	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**25**	**26**	**27**	**28**	**29**	**30a**
nC12	2.95	3.04	2.30	1.79	1.60	2.63	4.26	2.79	2.05	1.72	3.18	2.99	2.34
nC13	5.04	5.11	4.13	4.12	3.54	5.58	7.54	4.98	4.09	3.19	5.37	5.71	4.53
nC14	8.05	7.90	6.15	6.58	5.96	9.94	8.30	7.69	6.19	5.49	6.95	9.06	7.13
nC15	4.19	2.48	2.34	2.52	1.97	4.56	7.20	4.54	3.69	2.20	5.06	5.04	2.93
nC16	2.29	1.83	1.56	1.60	1.40	3.45	8.33	2.32	3.35	1.43	5.68	5.07	2.38
nC17	3.10	1.65	2.16	2.24	1.84	5.14	7.83	4.79	11.65	2.08	7.93	5.68	3.36
nC18	2.76	2.10	2.16	1.93	1.79	4.79	12.45	5.33	3.32	1.76	4.09	5.08	3.38
nC19	2.75	1.94	1.89	2.14	1.88	4.82	6.89	5.67	5.28	1.67	9.70	10.67	3.39
nC20	1.58	1.63	0.99	1.21	1.03	4.32	8.20	2.78	1.45	1.12	2.95	8.50	2.59
nC21	2.13	1.67	0.55	1.82	1.00	3.16	15.28	8.58	4.41	1.16	11.05	8.41	6.00
nC22	1.70	1.24	0.81	0.87	1.09	2.52	5.42	2.11	3.99	1.15	7.73	9.22	2.46
nC23	1.98	1.17	0.86	0.84	0.93	1.82	8.10	2.82	2.18	1.03	4.22	3.19	2.55
nC24	2.24	1.31	1.03	1.02	1.00	2.23	33.47	2.73	2.10	1.73	4.46	3.91	2.66
nC25	3.10	1.45	1.22	1.22	1.20	8.40	7.39	3.74	2.91	1.69	4.18	3.80	2.64
nC26	4.15	1.34	1.86	1.40	1.29	5.75	8.16	5.14	3.77	1.68	5.09	3.94	2.66
nC27	5.40	4.68	3.76	2.62	3.71	8.60	16.16	12.09	6.09	4.15	8.40	9.59	5.34
nC28	3.54	0.76	1.75	1.42	1.34	5.12	3.09	5.22	4.68	2.36	10.55	14.91	2.08
nC29	8.30	6.02	5.06	4.99	4.83	13.46	44.54	25.03	13.35	5.86	24.46	25.14	4.85
nC30	3.89	1.38	2.18	1.01	1.85	5.71	13.16	7.25	2.73	1.66	4.10	4.30	1.61
nC31	6.63	5.33	4.81	4.29	4.21	10.47	30.52	18.68	8.65	5.14	11.46	8.45	4.00
nC32	5.74	4.75	4.39	3.55	3.95	7.42	14.58	9.56	4.54	3.20	12.67	13.24	4.09
nC33	6.74	4.69	4.44	4.71	3.61	8.31	20.27	15.42	5.88	3.00	10.12	5.83	4.78
nC34	5.44	4.12	3.80	3.66	3.72	7.68	12.05	16.66	3.67	3.55	4.68	13.69	8.23
nC35	5.18	4.08	4.14	3.66	3.71	3.65	8.51	10.70	3.70	0.99	6.22	7.59	5.53
nC36	3.67	2.43	2.90	2.26	2.49	7.11	10.83	6.65	2.39	1.84	2.97	2.37	5.52
Pristane	1.99	0.58	1.60	1.33	1.35	2.06	23.71	1.32	1.61	1.14	8.17	3.73	1.57
Phytane	1.29	1.51	0.66	0.78	0.86	0.39	2.12	1.18	1.51	1.37	2.64	3.16	2.61
Total n-Alkanes	**100**	**70**	**70**	**60**	**60**	**150**	**320**	**190**	**120**	**60**	**180**	**200**	**100**
UCM	3,338	1,416	948	1,002	886	1,607	4,832	2,682	2,142	1,382	3,545	3,360	1,193
THC	2,926	1,045	644	721	596	1,098	3,103	1,860	1,477	1,098	2,415	2,194	808
CPI (nC12-20)	984	790	916	950	882	929	837	1,103	1,691	907	1,418	1,099	926
CPI (nC20-36)	1,347	1,719	1,402	1,649	1,455	1,375	1,516	1,820	1,722	1,371	1,534	1,051	1,286
CPI (nC12-36)	1,221	1,295	1,208	1,339	1,227	1,224	1,338	1,638	1,711	1,196	1,502	1,059	1,157

UCM = Unresolved Complex Mixture; THC = Total Hydrocarbon Concentrations; CPI = Carbon Preference Index (ratio of the sum of Odd- to the sum of Even-Carbon Alkanes); Mean = Mean of the dataset SD = Standard Deviation of the mean dataset.

Figure 4.13a Hydrocarbon Analysis (Offshore Wave Hub Region) - Total Hydrocarbon Concentrations (µg.g^{-1})

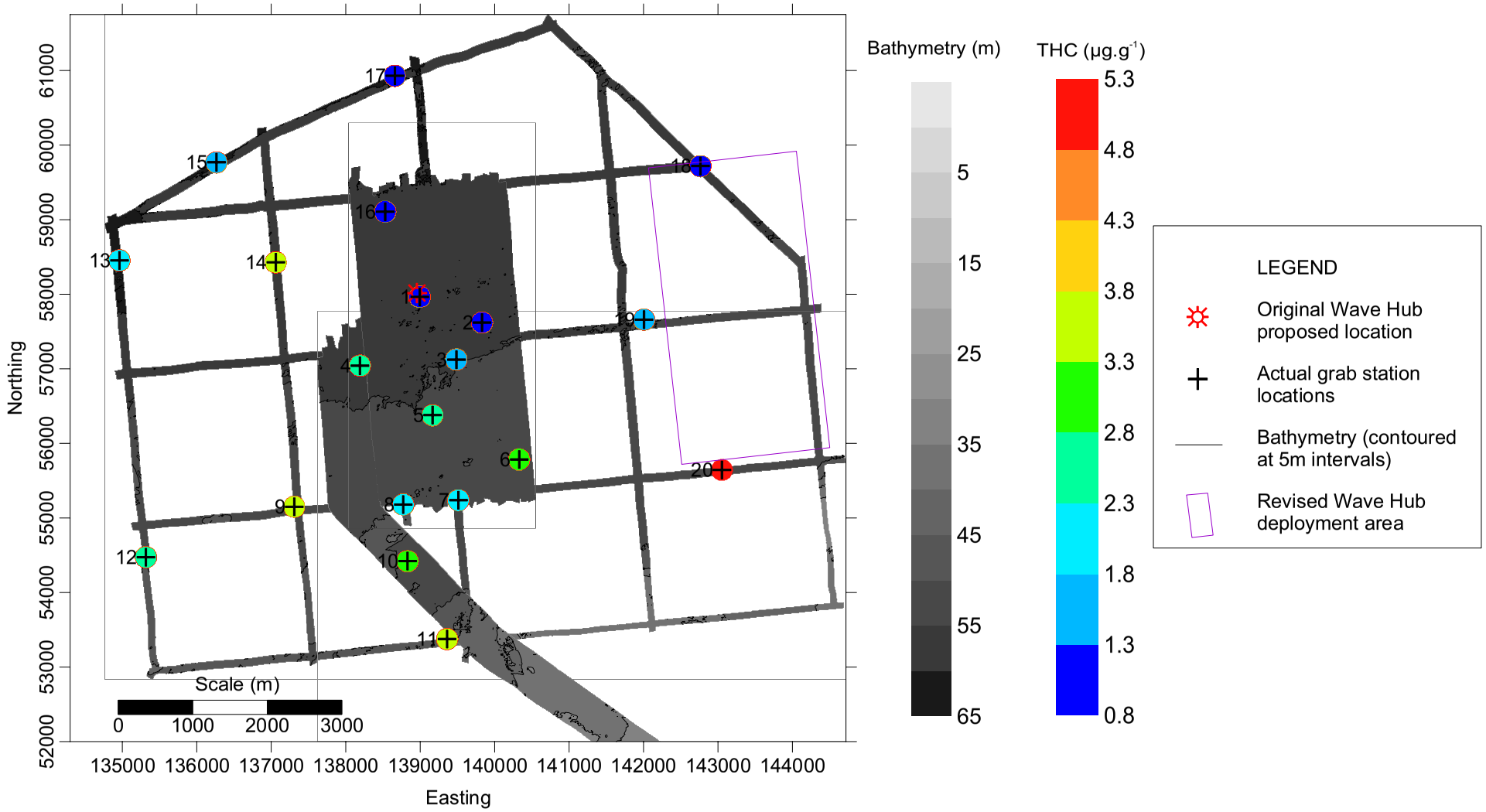


Figure 4.13b Hydrocarbon Analysis (Cable Route) - Total Hydrocarbon Concentrations (µg.g^{-1})

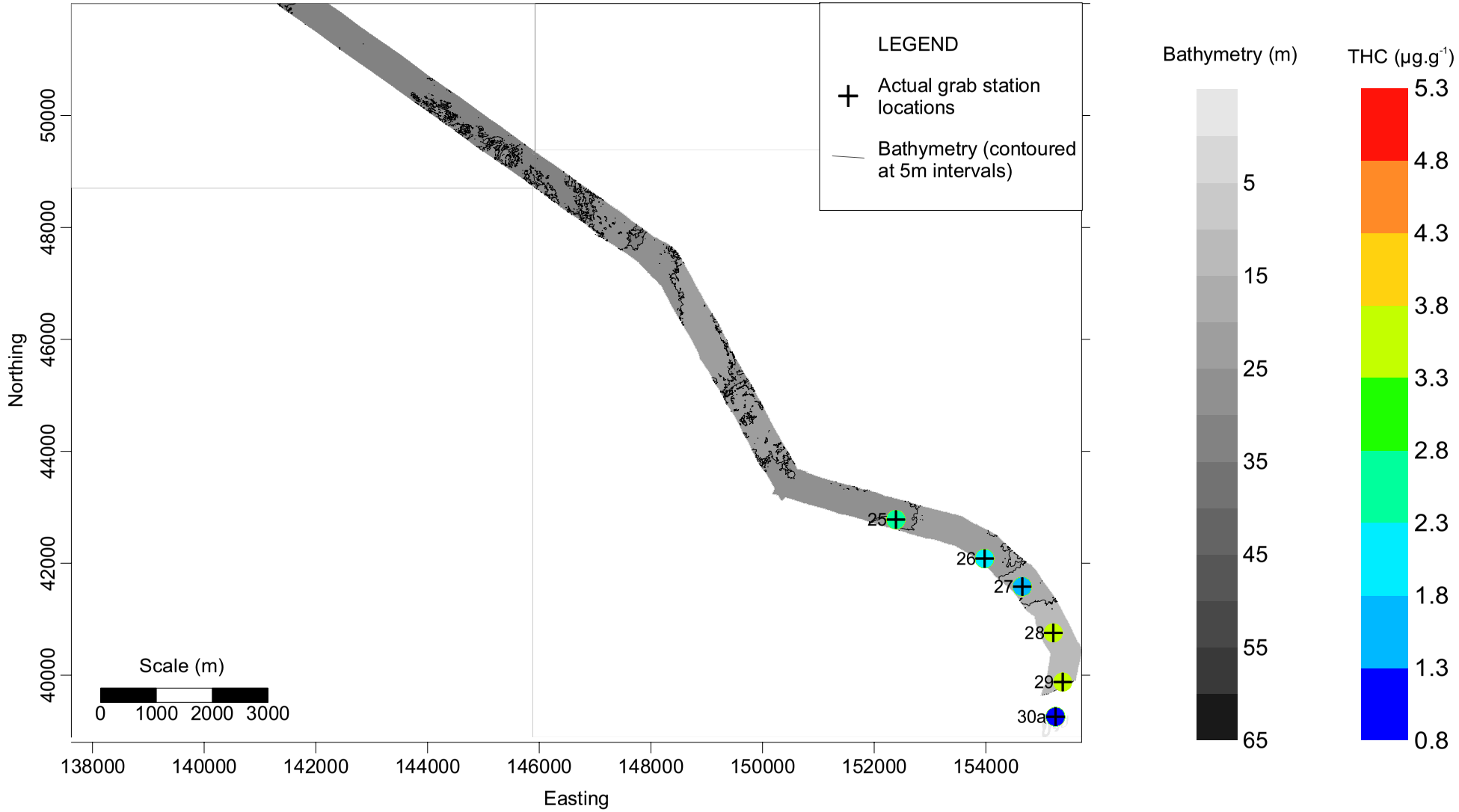


Figure 4.14a Hydrocarbon Analysis (Offshore Wave Hub Region)- Total n-Alkanes Concentration (µg.g^{-1})

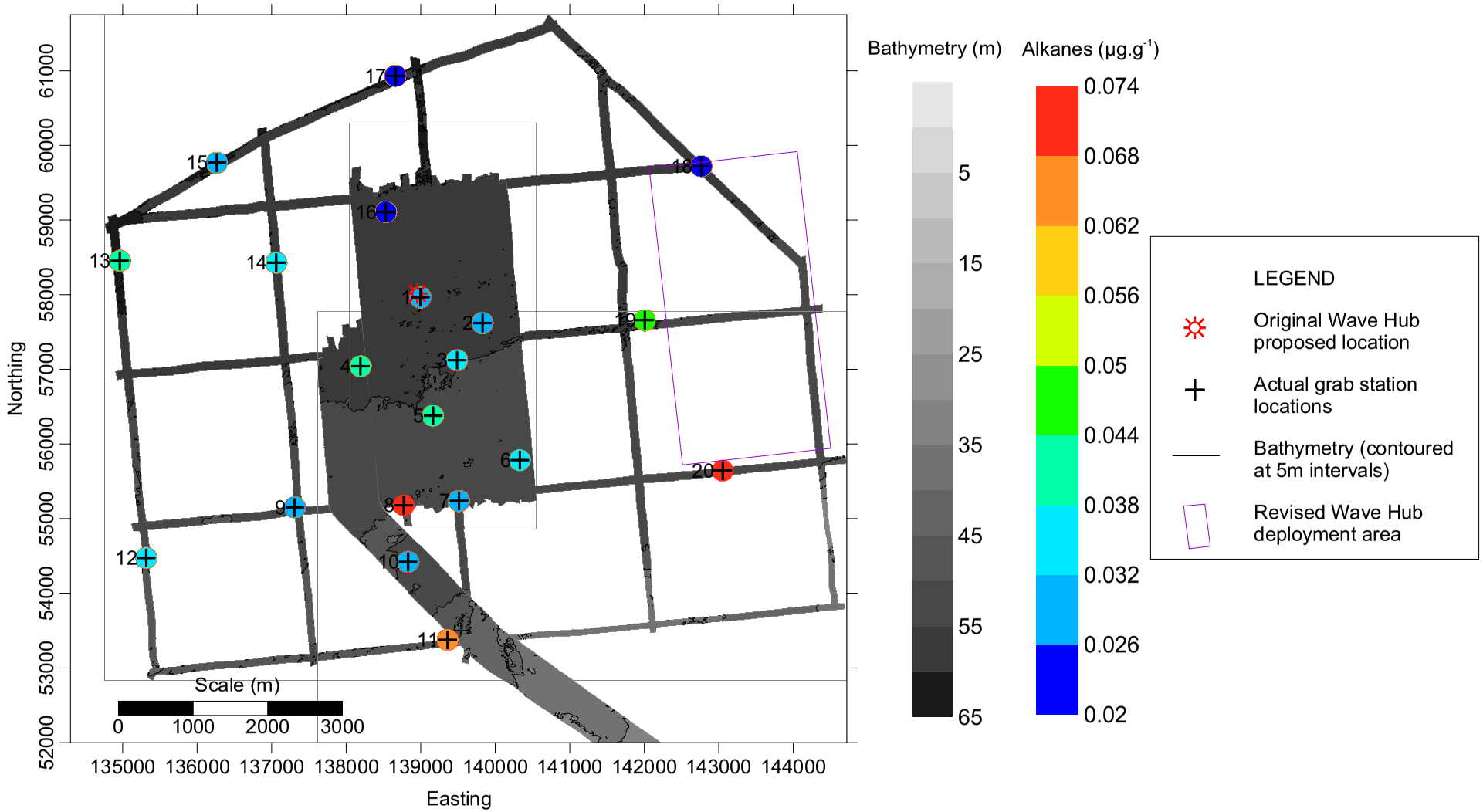


Figure 4.14b Hydrocarbon Analysis (Cable Route) - Total n-Alkanes Concentration (µg.g^{-1})

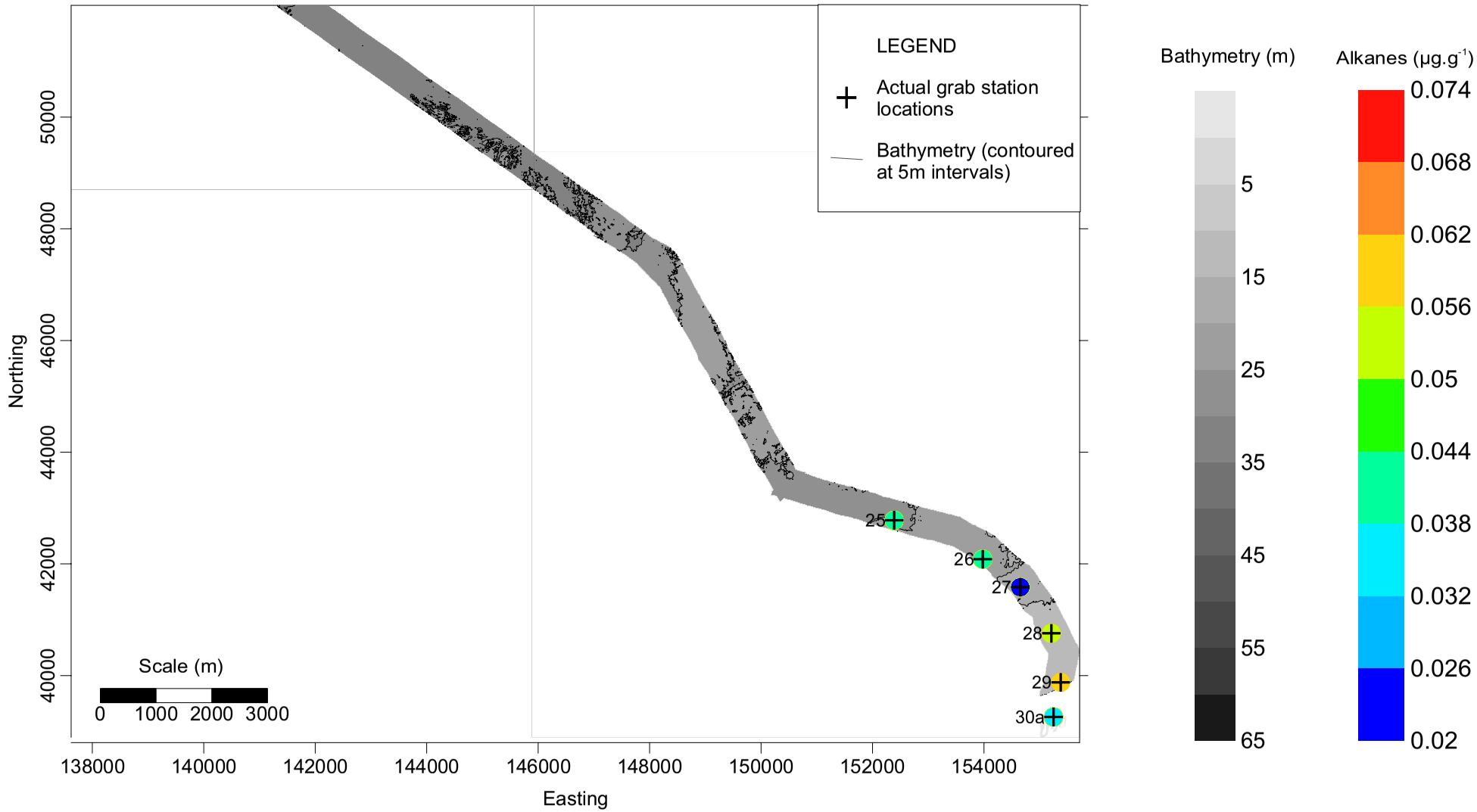


Figure 4.15a Hydrocarbon Analysis (Offshore Wave Hub Region) - Carbon Preference Index (CPI) (nC12-nC36)

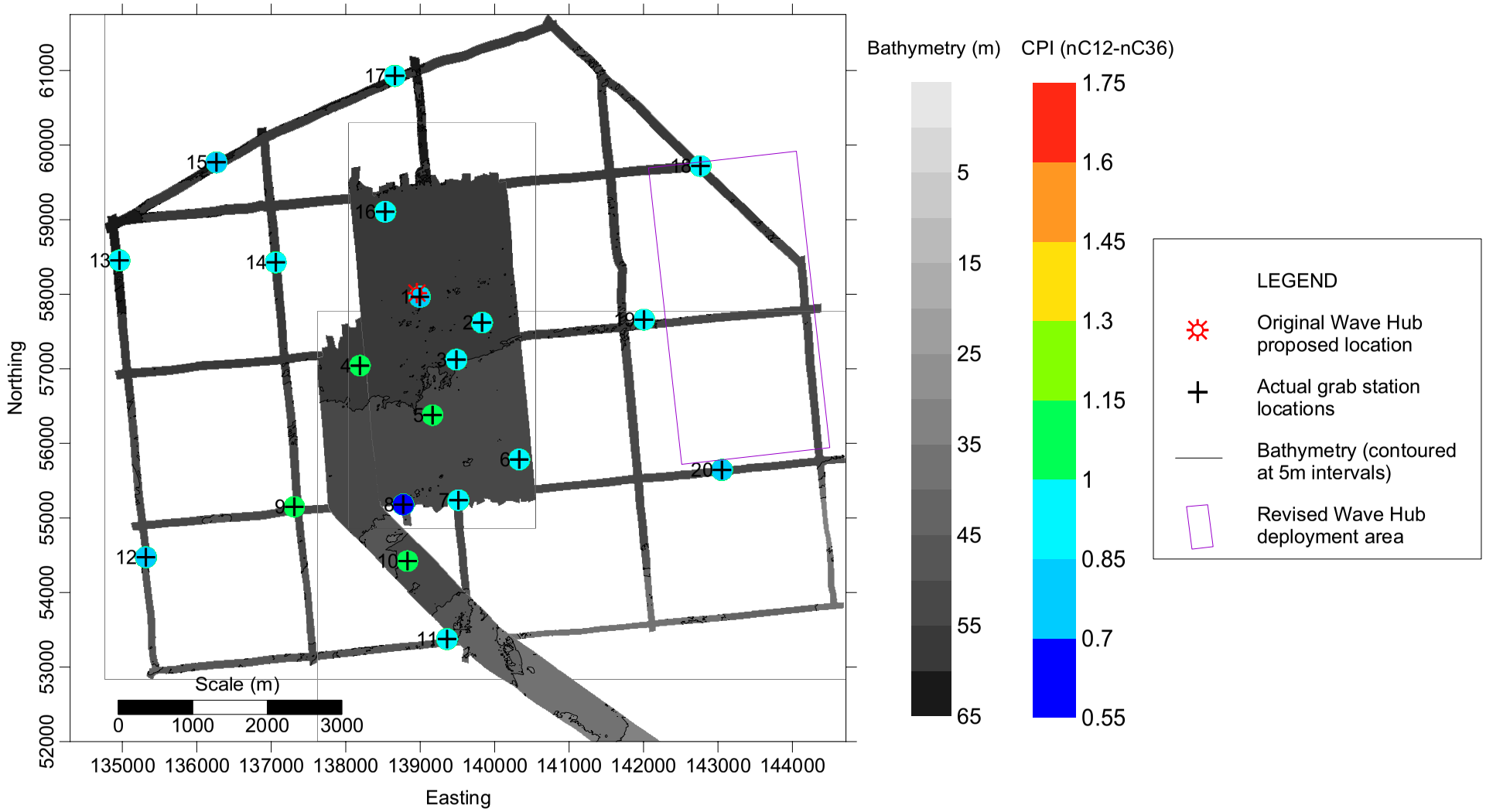
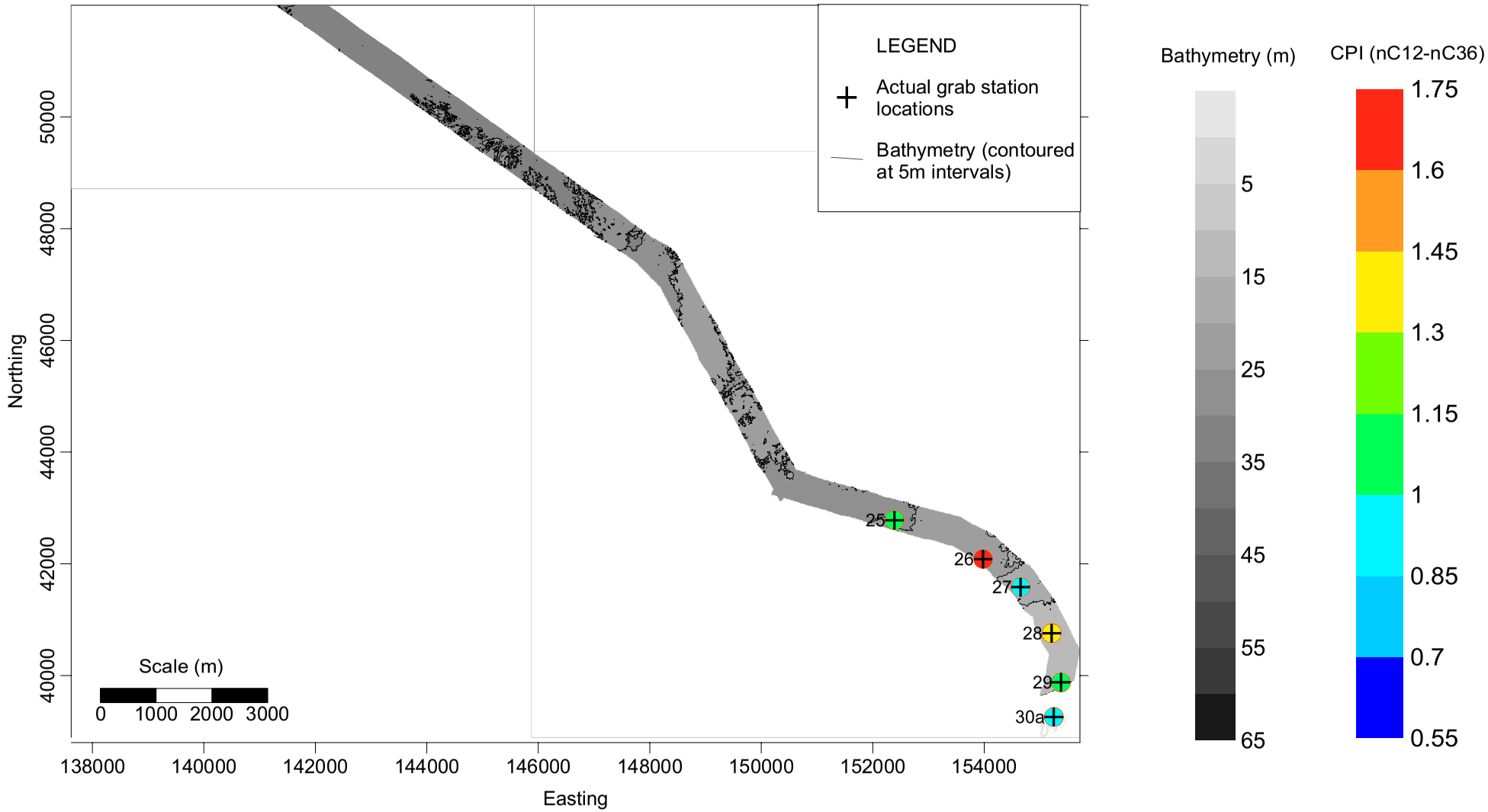


Figure 4.15b Hydrocarbon Analysis (Cable Route) - Carbon Preference Index (CPI) (nC12-nC36)



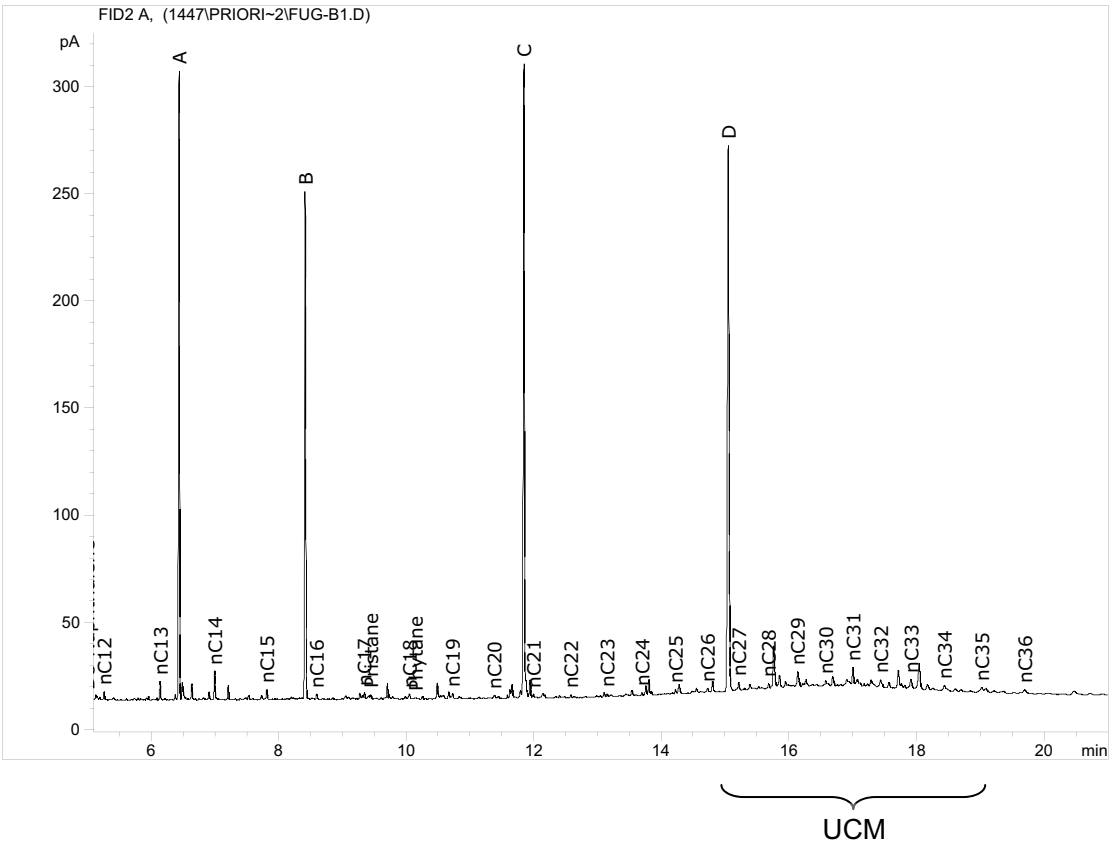
Gas Chromatogram (GC) Traces

GC traces for all stations (Appendix F, Volume IV) showed a relatively flat baseline consistent with the low levels of total hydrocarbons recorded and the low level petroleum hydrocarbons evidenced by the lower CPI ratios for the sub-set of n-alkanes nC_{12-20} (Table 4.4). A distinct but low-level homologous series of alkanes dominated by odd carbon numbers was also evident from around nC_{21-36}, associated with the low-level UCM (unresolved complex mixture) hump. This UCM probably relates to the degradation products of terrestrial n-alkanes from plant cuticular waxes (evident as a low series of n-alkanes dominated by odd carbon numbers from around nC_{21-36}).

A further low-level homologous series of n-alkanes in the range nC12-15 was evident on the majority of GC traces (including the blank), which is considered to be due to minor laboratory contamination. However, this hydrocarbon signature is low-level and not thought to be of significance.

A typical GC trace showing the UCM is illustrated in Figure 4.16.

Figure 4.16 Typical GC Trace (Station 1)



4.6.2 Heavy and Trace Metal Analysis

A summary of results for the heavy and trace metal analyses is given in Table 4.7 and presented in Figures 4.18 to 4.21 (NB: only those metals recorded at greater than the limit of detection at the majority of stations and showing substantial variation between stations were plotted i.e., As, Cu, Pb and Zn). All of the heavy and trace metals analysed (As, Ba, Cd, Cu, Hg, Ni, Pb, Sn, V, and Zn) underwent a single hydrofluoric acid (HF) extraction, a total digestion of metals mineralised within the sediment.

Table 4.7 Total Heavy and Trace Metal Concentrations (µg.g^{-1} dry weight)

Survey Area	Station	Fines (<63µm)	As	Cd	Cu	Pb	Hg	Ni	Sn	V	Zn	Ba
Wave Hub	1	0.1	3.7	0.3	1.6	19.2	<0.10	3.4	<0.50	5.7	112.9	15.0
	2	0.2	3.6	0.1	1.0	6.0	<0.10	3.6	<0.50	5.1	19.7	11.0
	3	0.2	13.2	<0.10	3.8	9.5	<0.10	12.8	<0.50	21.1	29.3	13.0
	4	1.7	3.8	0.1	5.1	7.0	<0.10	5.1	<0.50	7.2	124.7	15.0
	5	6.4	7.7	0.2	4.3	11.0	<0.10	11.5	<0.50	15.1	48.6	13.0
	6	0.9	4.9	<0.10	3.6	7.4	<0.10	8.6	<0.50	10.4	23.3	14.0
	7	0.1	6.6	<0.10	4.8	10.7	<0.10	12.3	<0.50	13.4	28.7	17.0
	8	0.5	6.1	<0.10	2.6	7.4	<0.10	7.1	<0.50	10.9	16.6	12.0
Regional Area	9	1.2	4.1	<0.10	2.9	6.0	<0.10	6.8	<0.50	9.6	17.3	11.0
	10	0.4	4.2	<0.10	2.0	8.7	<0.10	6.0	<0.50	9.0	18.6	13.0
	11	0.6	4.2	<0.10	3.1	7.1	<0.10	7.5	<0.50	9.7	16.5	14.0
	12	0.7	3.7	<0.10	3.4	5.9	<0.10	9.2	<0.50	9.8	24.5	13.0
	13	0.1	3.6	<0.10	1.1	5.7	<0.10	3.7	<0.50	6.0	8.2	13.0
	14	0.2	5.2	<0.10	1.0	6.1	<0.10	4.8	<0.50	8.6	13.6	10.0
	15	0.2	4.0	0.1	<0.50	5.7	<0.10	3.5	<0.50	6.2	7.9	10.0
	16	0.1	3.7	0.3	0.7	5.6	<0.10	4.7	<0.50	5.8	25.0	10.0
	17	0.1	4.3	<0.10	<0.50	4.7	<0.10	2.5	<0.50	6.3	6.3	23.0
	18	0.1	4.0	<0.10	0.5	4.9	<0.10	2.7	<0.50	5.6	22.8	14.0
	19	0.3	6.0	<0.10	4.9	8.0	<0.10	9.9	<0.50	10.9	23.3	15.0
	20	9.0	8.2	0.1	3.0	10.0	<0.10	7.4	<0.50	12.6	19.5	11.0
Inshore	25	0.3	17.4	<0.10	16.3	16.0	<0.10	12.5	3.3	17.4	65.1	11.0
	26	0.2	24.9	<0.10	20.3	9.9	<0.10	5.4	6.1	14.2	42.6	12.0
	27	0.5	41.4	<0.10	19.1	12.7	<0.10	11.0	2.7	17.3	49.7	15.0
	28	0.8	38.2	<0.10	35.5	10.4	<0.10	7.0	9.3	13.1	46.1	16.0
	29	0.7	66.3	0.1	64.3	13.0	<0.10	7.6	12.6	13.0	70.4	17.0
	30a	0.3	34.0	0.1	15.8	6.8	<0.10	3.6	4.1	7.0	36.7	12.0
Mean		-	-	*12.6*	-	-	*8.7*	-	*6.9*	-	*10.4*	*35.3*
SD		-	*15.73*	-	-	*3.54*	-	*3.22*	-	*4.26*	*29.69*	*2.83*

Mean and standard deviation cannot be calculated for data where less than (<) values occur.

Heavy metal analysis by hydrofluoric/ boric acid digestion (i.e. total metals) revealed that arsenic, copper lead, tin and zinc concentrations were generally higher for the inshore stations than the offshore stations. This is demonstrated by Figure 4.17 which shows As, Cu, Pb, Sn and Zn concentrations against sample location using the Northing as a proxy for distance offshore. However, while the majority of stations fit this trend zinc was recorded at its highest and second highest concentrations at stations 4 and 1, respectively, located within the original Wave Hub deployment area.

Industrial exploitation (ie. mining) and the geology of the area are considered to be the main cause of heavy and trace metal distributions in the area. A study conducted in the Hayle estuary found elevated levels of arsenic, copper, lead, tin and zinc in sediment cores and attributed this to the tin mining in the area (Yim, 1976). The higher concentrations of these metals observed at inshore stations during this study are consistent with a riverine source of these metals.

The remaining metals, with the exception of mercury which was below the limit of detection at all stations, all showed variations in their concentrations throughout the survey area. However, these metals did not appear to correlate with distance from the shore, percentage fines (<63µm) or percentage LOI. It should be noted that the presence of substantial variable quantities of shell and shingle within the sediments of the survey area makes LOI an unreliable measure of sediment organics.

Figure 4.17 Concentrations of Arsenic, Tin and Copper against Northing as a Proxy for Distance Offshore

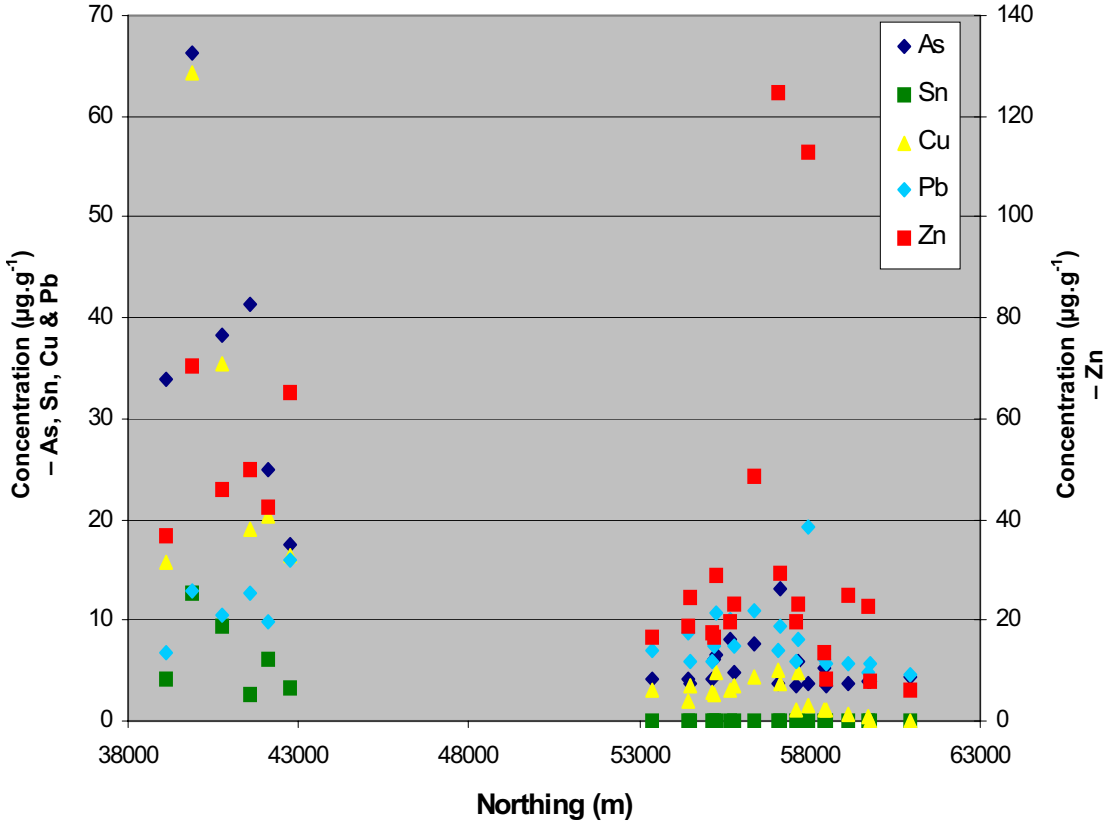


Figure 4.18a Heavy and Trace Metal Analysis (Offshore Wave Hub Region) - Arsenic (µg.g^{-1})

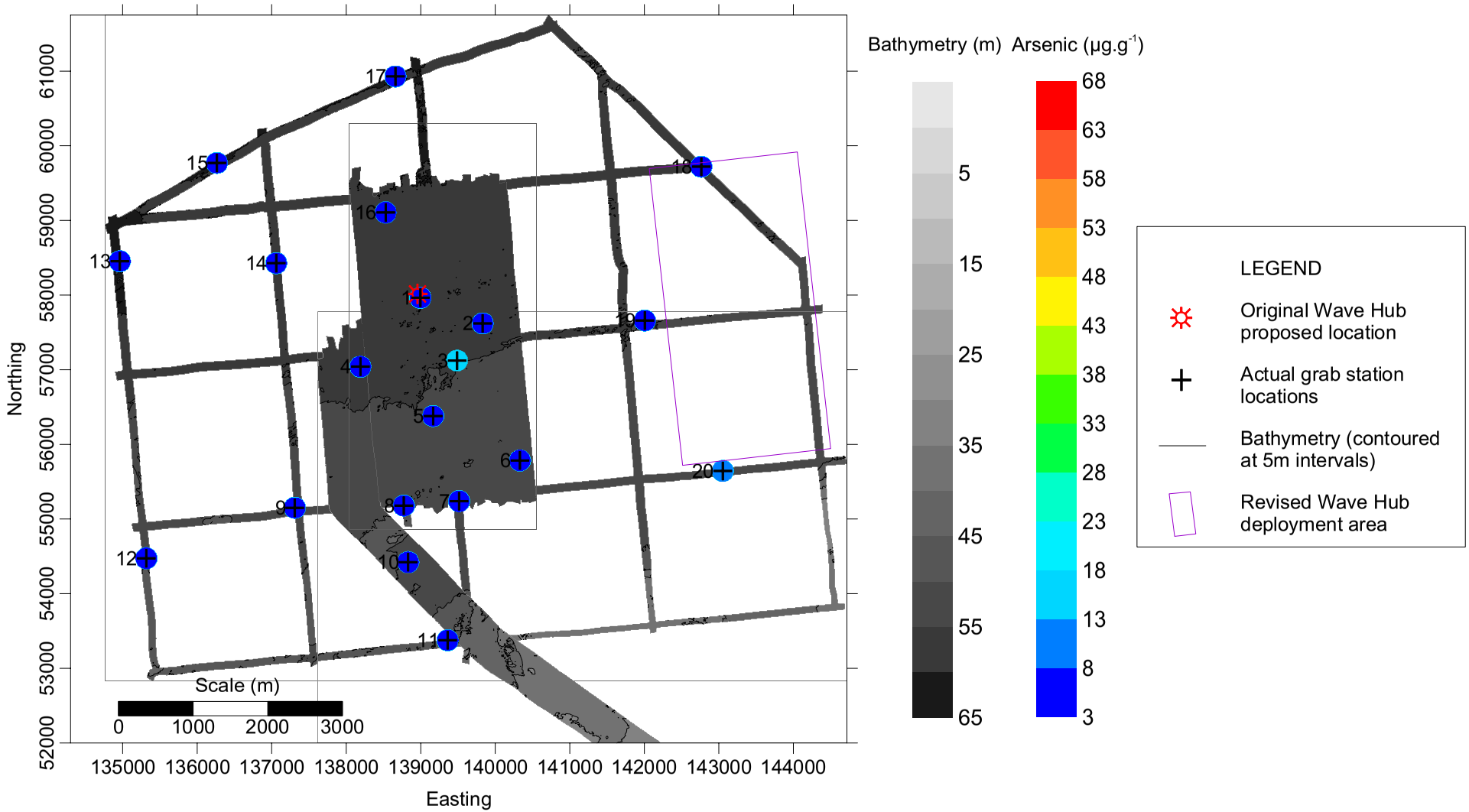


Figure 4.18b Heavy and Trace Metal Analysis (Cable Route) - Arsenic (µg.g^{-1})

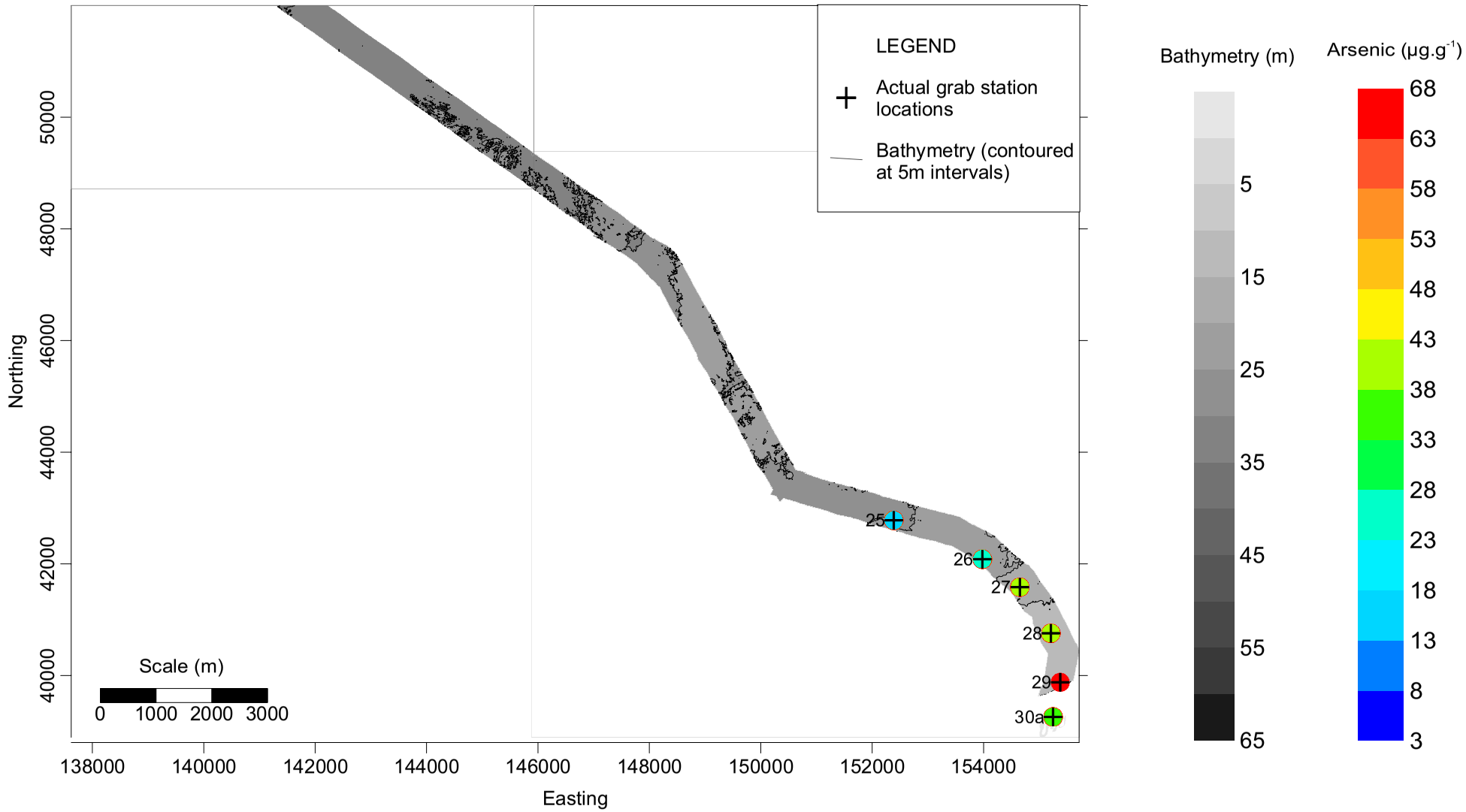


Figure 4.19a Heavy and Trace Metal Analysis (Offshore Wave Hub Region) - Copper (µg.g^{-1})

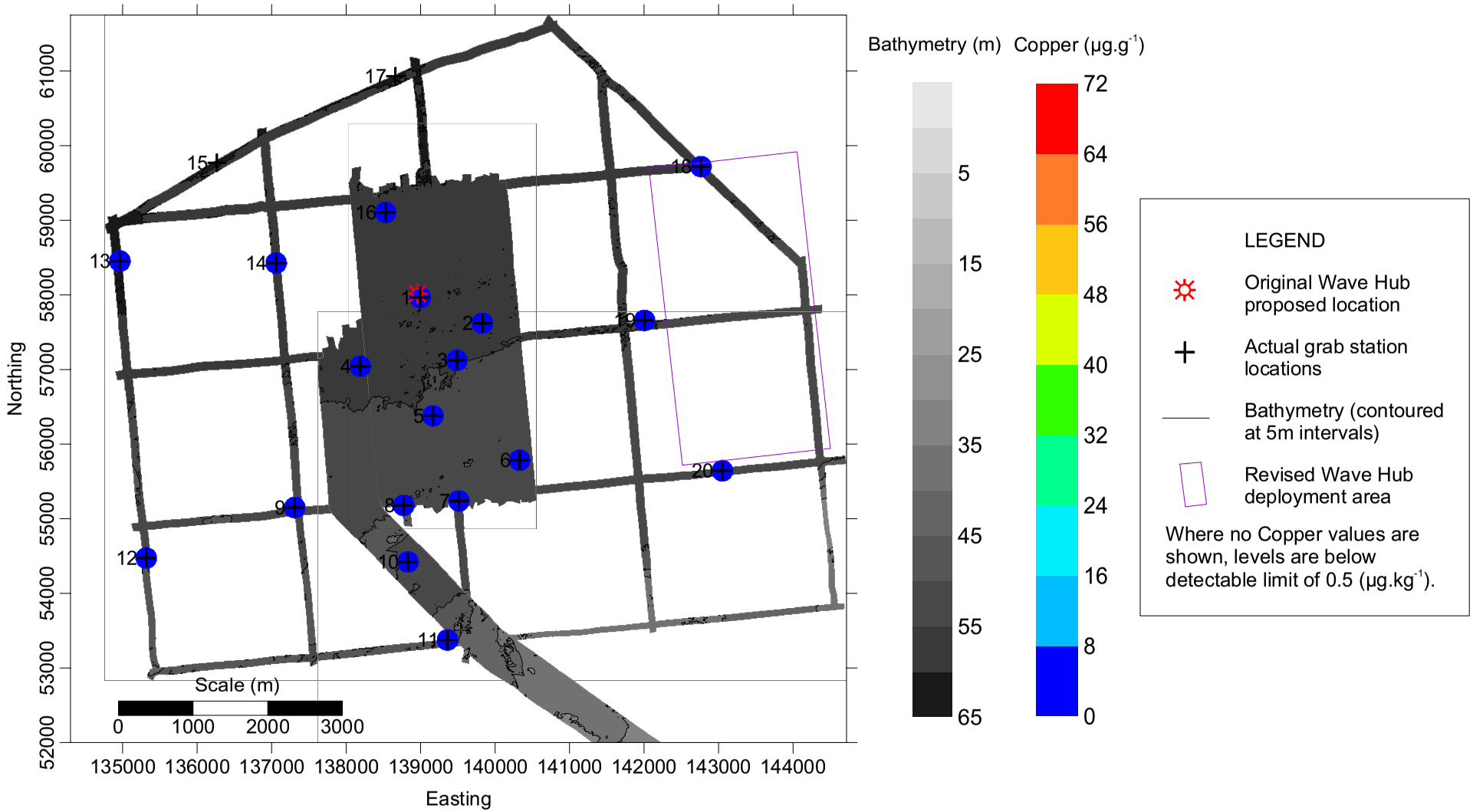


Figure 4.19b Heavy and Trace Metal Analysis (Cable Route) - Copper (µg.g^{-1})

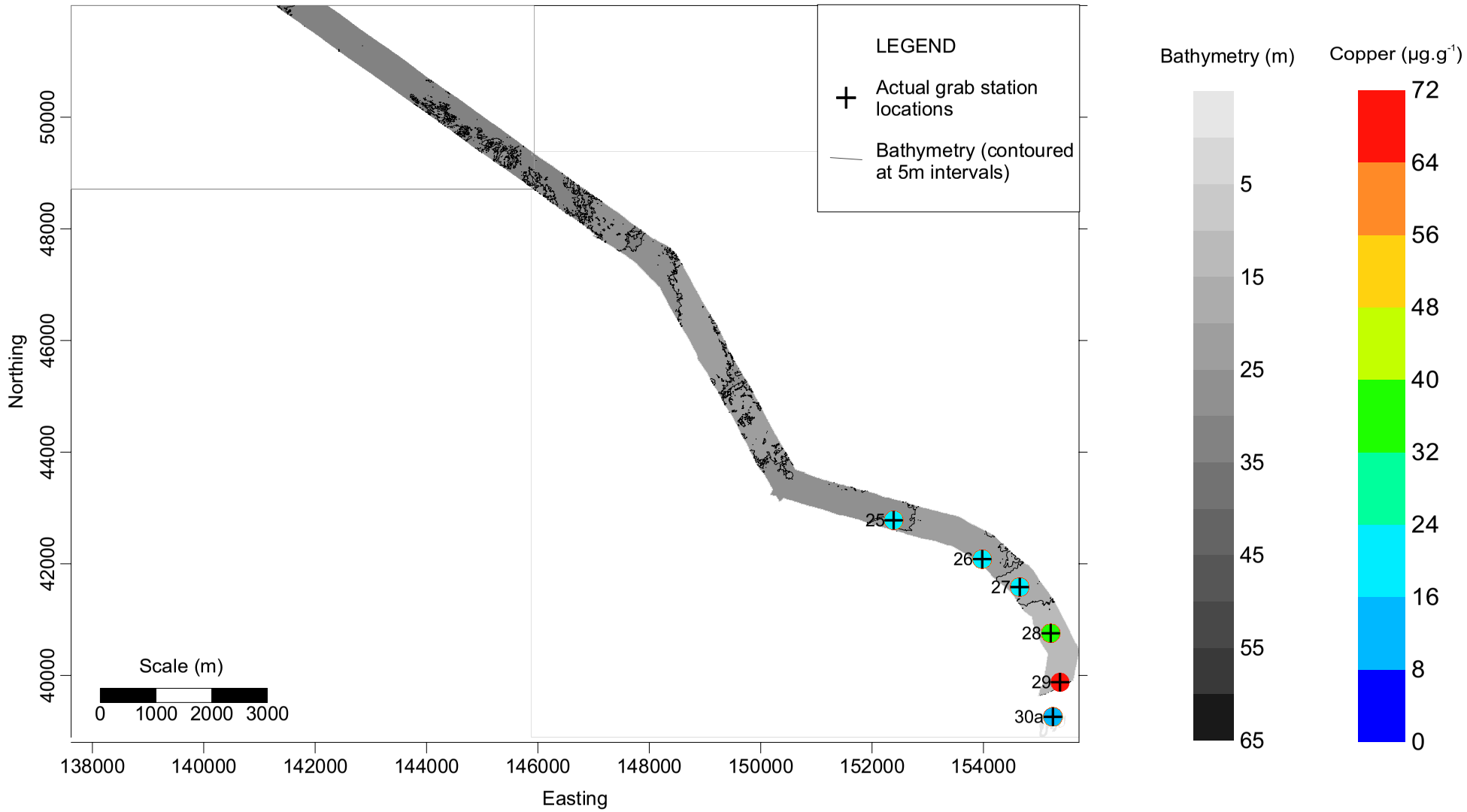


Figure 4.20a Heavy and Trace Metal Analysis (Offshore Wave Hub Region) - Lead (µg.g^{-1})

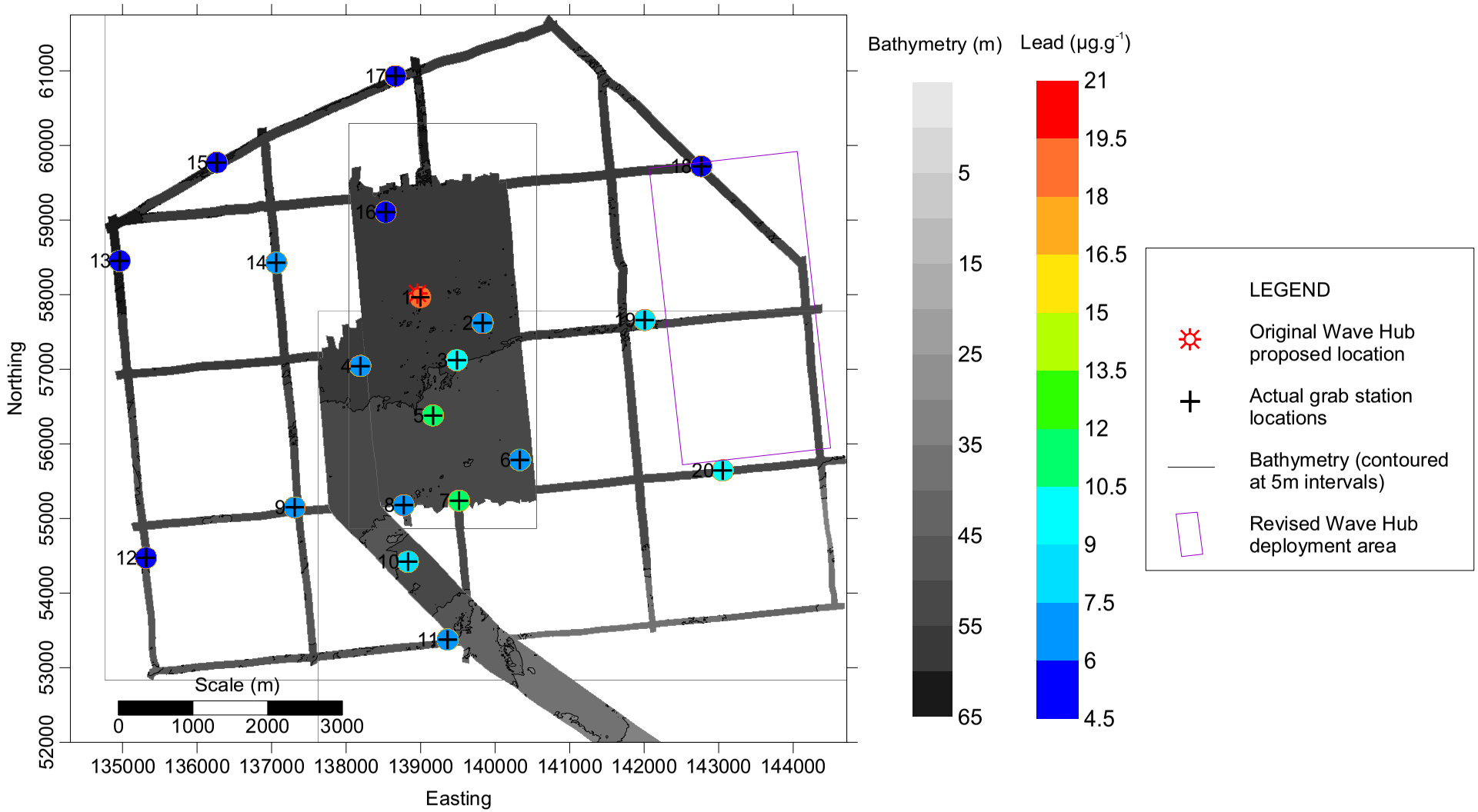


Figure 4.20b Heavy and Trace Metal Analysis (Cable Route) - Lead (µg.g^{-1})

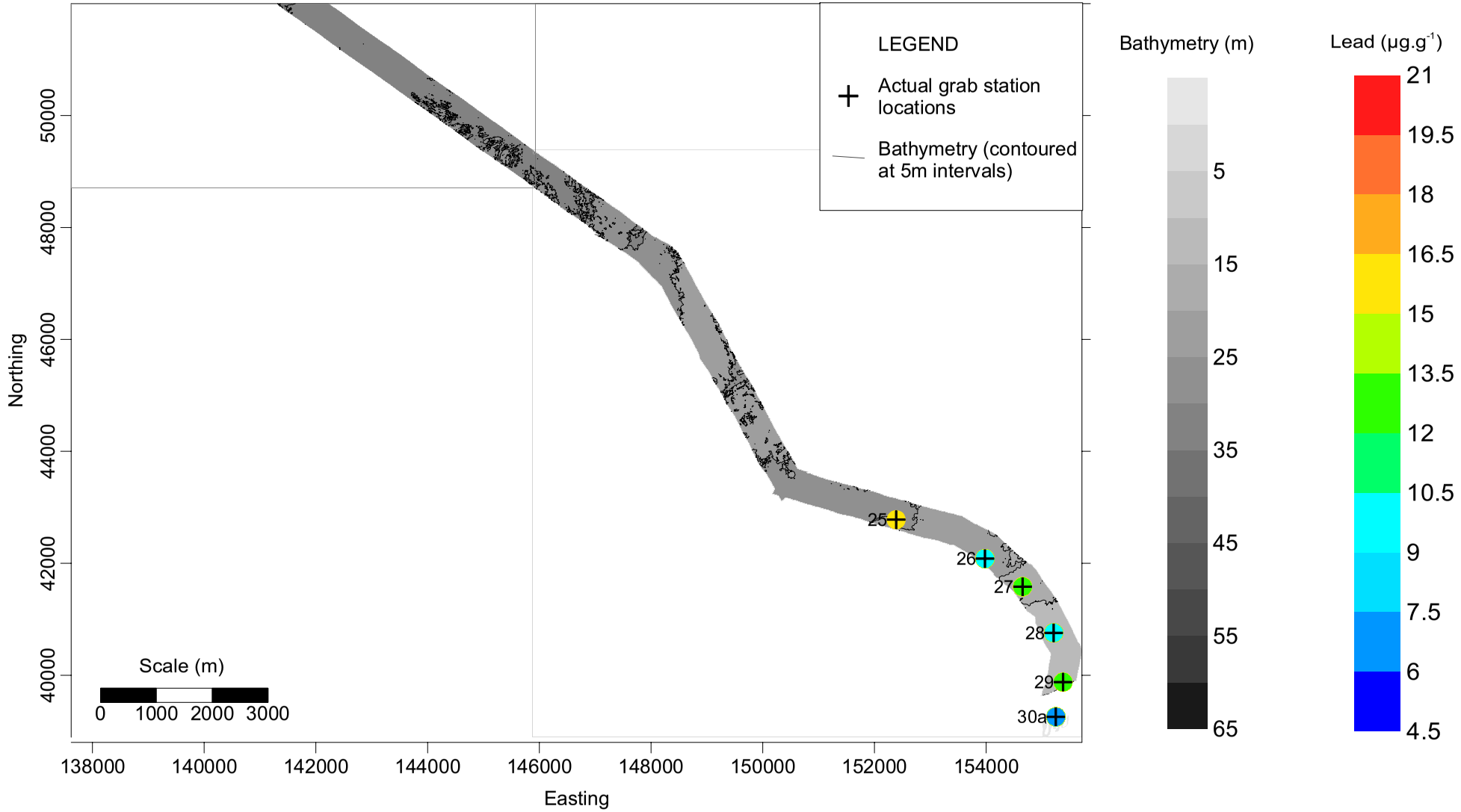


Figure 4.21a Heavy and Trace Metal Analysis (Offshore Wave Hub Region) - Zinc (µg.g^{-1})

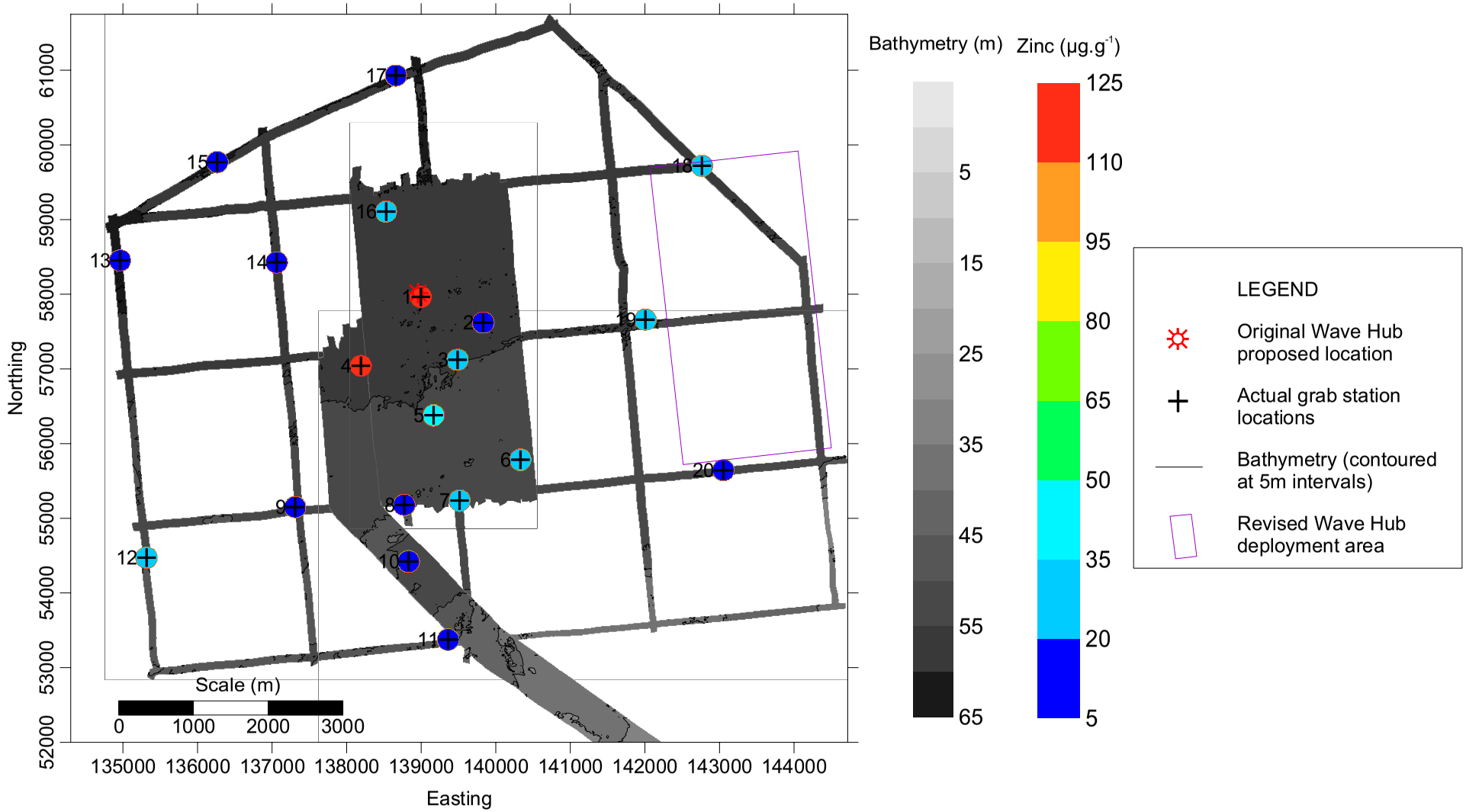
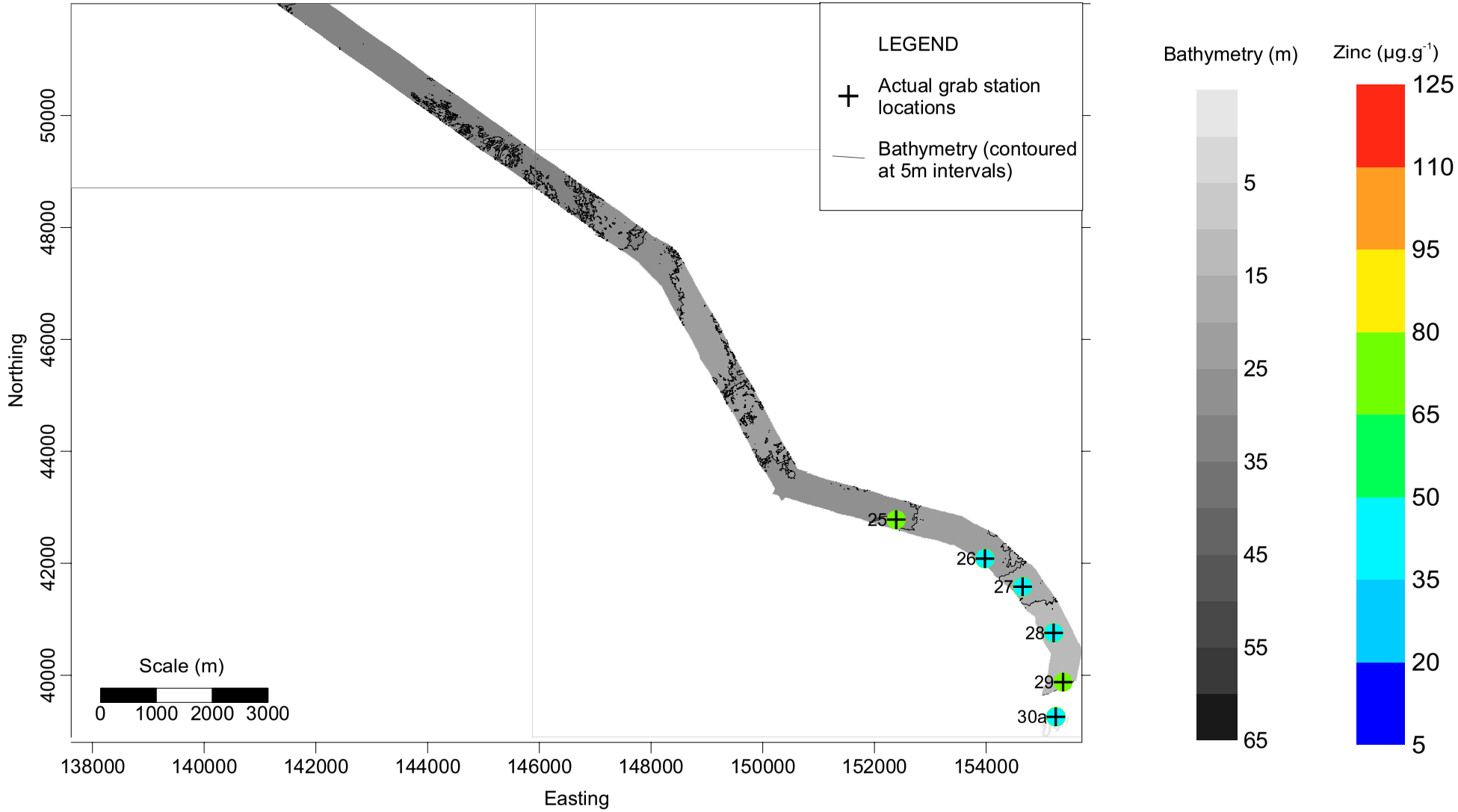


Figure 4.21b Heavy and Trace Metal Analysis (Cable Route) - Zinc (µg.g^{-1})



4.7 Macrofauna Analysis

4.7.1 Grab Sampling

General Description

At each of the 27 sample stations, two macrofaunal replicate grab samples of 0.1m^2 were analysed giving a total of 54 samples. The full species list for macrobenthic fauna is presented in Appendix E. Individuals of infaunal species were enumerated and expressed as abundance per sample (0.1m^2) and per station (0.2m^2).

In accordance with OSPAR Commission guidelines (OSPAR Commission, 2004), colonial organisms or those belonging to meiofaunal groups were recorded, but removed from the macrofauna dataset prior to calculation of community indices or multivariate analyses of community structure. Macrofauna are taken to be those animals retained by a 0.5mm sieve (Lincoln & Boxshall, 1987). As only a small proportion of the total abundance of nematodes will have been sampled by the 1mm mesh, nematodes were also excluded from the analysis.

Newly settled juveniles of benthic species may at times dominate the macrofauna, but due to heavy natural post-settlement mortality, they should be considered an ephemeral component and not representative of prevailing bottom conditions. Statistical analysis has been undertaken on data excluding juveniles.

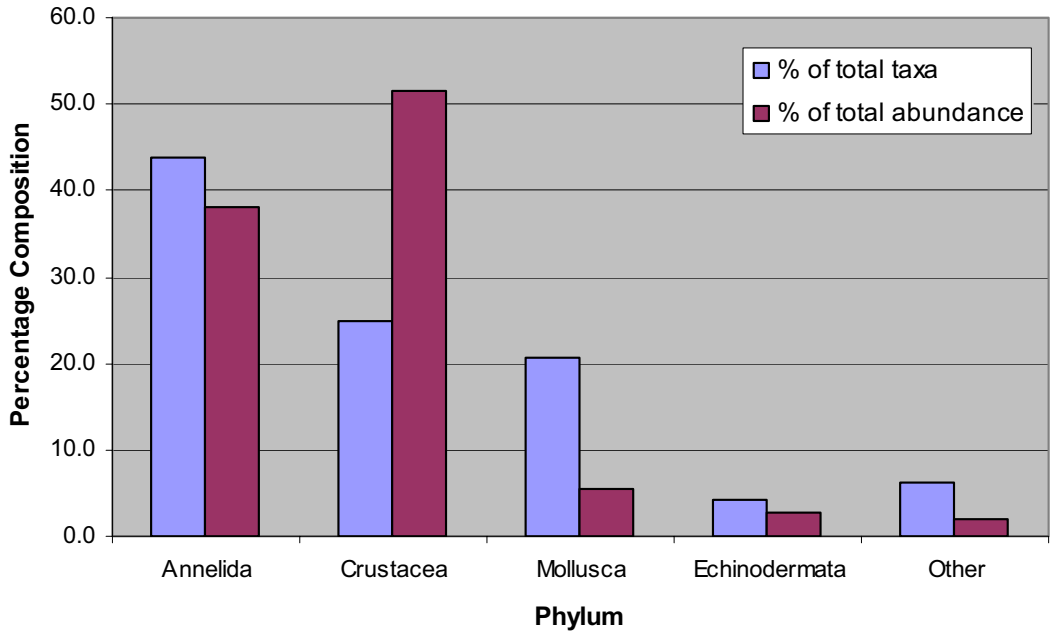
A total of 276 infaunal species (excluding 56 colonial, 3 pelagic, 1 meiofaunal and 28 juvenile taxa) were found during the course of this survey. These comprised 121 Annelida (43.8% of total taxa), 69 Crustacea (25.0%), 57 Mollusca (20.7%), 12 Echinodermata (4.3%) and 17 taxa from other phyla (6.2%) (see Table 4.8 and Figure 4.22).

In terms of abundance Crustacea were dominant making up 51.4% of the fauna, the Annelida constituted 38.1%, Mollusca accounted for 5.6% and Echinodermata 2.8%, whilst other minor phyla represented just 2.1% of fauna (see Table 4.8 and Figure 4.22).

Table 4.8 Abundance of Taxonomic Groups

Taxonomic Group	Number of Taxa (S)	% of Total Taxa	Number of Individuals (N)	% of Total Abundance
Annelida	121	43.8	3289	38.1
Crustacea	69	25.0	4442	51.4
Mollusca	57	20.7	480	5.6
Echinodermata	12	4.3	246	2.8
Other	17	6.2	178	2.1
TOTAL	276	100.0	8635	100.0

Figure 4.22 Abundance of Taxonomic Groups



The crustacean *Pisidia longicornis* was the most abundant species overall, with an average abundance of 54.8 individuals per sample (0.1m^2), approximately five times the abundance of the next most abundant taxa, the annelid Serpulidae, at 11.6 individuals per 0.1m^2 (Table 4.9). The remaining ten most abundant species were found at average abundances of <7.2 per sample, including four annelids (the polychaetes: *Typosillis* sp., *Harmothoe* sp. *Polydora caeca* agg. and *Polygordius* sp.) three crustaceans (the amphipods: *Corophium sextonae* and *Leptocheirus tricristatus*, and the isopod: *Janira maculosa*) and an echinoderm (the echinoid: *Echinocyamus pusillus*).

While *P. longicornis* was the most abundant taxa, it was not the most frequently encountered taxa within samples, appearing in 31 of the 54 samples (57%) (see Table 4.9). The most frequently occurring taxa was *Typosyllis* sp., which was seen in 41 of the 54 samples (76%), followed by Serpulidae (72%), *Harmothoe* sp. and *Glycera lapidum* (61%), and Janira maculosa and Echinocyamus pusillus (56%). The remaining dominant taxa were found in 26 or less of the 54 samples (≤50%). The discrepancy between the most abundant taxa and their frequency of occurrence within samples is caused by taxa occurring in high abundances within relatively few samples.

Table 4.9 Ten Most Dominant Taxa by Numerical Abundance and Rank Dominance

Taxa	Rank Abundance	Mean Abundance	Rank Dominance	Frequency (%)
Pisidia longicornis	1	54.83	3	57.41
Serpulidae	2	11.63	2	72.22
Corophium sextonae	3	7.19	10	33.33
Typosyllis sp.	4	6.85	1	75.93
Harmothoe sp.	5	4.57	4	61.11
Leptocheirus tricristatus	6	3.30	19	40.74
Janira maculosa	7	2.78	5	55.56
Polydora caeca agg.	8	2.70	24	40.74
Polygordius sp.	9	2.65	14	46.30
Echinocyamus pusillus	10	2.43	9	55.56
Notomastus sp.	11	2.41	7	50.00
Galathea intermedia	12	2.33	8	50.00
Glycera lapidum agg.	13	2.31	6	61.11

By ranking the taxa recorded for each sample in terms of abundance and summing the rank scores for all samples to give the overall rank dominance for each taxon, it is possible to examine which taxa were consistently dominant throughout the survey area (Table 4.9). This method is less susceptible to bias toward species which may occur in extremely high densities within a small proportion of the samples. This is emphasised by the fact that, *P. longicornis*, which ranked as the most abundant taxon, was only the third most dominant in terms of rank dominance, indicating that it was not consistently represented in samples, but when present was found in high numbers. Another taxon with a similarly clumped distribution was *Corophium sextonae*, which ranked third most dominant in terms of abundance but only tenth in terms of rank dominance; explained by the fact that it was identified in only 33% of samples. Conversely, *Typosyllis* sp. was the fourth most abundant taxa but the most dominant by rank dominance, explained by its presence within 76% of samples.

The general disagreement between the overall abundances and dominances of taxa was not unexpected. Given the wide variation in environmental conditions across the survey area, with bathymetry ranging from +2m to 60m and the substratum varying between fine SAND and very coarse GRANULE, it is reasonable to expect a variety of distinct biological communities to be evident. Few taxa, if any, were therefore likely to be represented within all these biological communities.

Primary Variables and Univariate Analysis

Primary variables (numbers of species and abundance) together with the ecological measures evenness (J′), richness (D), dominance (1-λ) and Shannon-Weiner diversity (H′) were calculated for pooled replicates from each station (Table 4.10), using the PRIMER v 6.0 DIVERSE procedure (Clarke & Gorley, 2006). The same parameters have been calculated for the replicate sample data and are displayed in Appendix E. For ease of analysis and clarity of interpretation only the pooled data will be discussed.

Evenness Index (J′) is a measure of equitability, i.e. how evenly the individuals are distributed among different species. Low evenness indicates that a sample was dominated by one or a few highly abundant species whereas high evenness means that total abundance is spread more evenly among the constituent species. The Shannon-Weiner Index (H′) (Shannon & Weaver, 1949) combines both the components of species richness and evenness to calculate a measure of diversity. See Magurran (1988) for further discussion on these indices.

Both primary and univariate parameters showed substantial variation across the survey area, as evidenced by the high standard deviations associated with the mean values for these parameters, with little overall trends evident for stations from different regions (Table 4.10 and Figures 4.23a To 4.2b). The only discernable pattern within these data was shown by the inshore stations 27 to 30a which exhibited depressed numbers of both species and individuals.

The primary variable (S and N) displayed the greatest variation across the survey area, ranging from lows of 5 species spread across 8 individuals at station 30a, the most inshore sampling location, to highs of 98 species at station 3 in the Wave Hub deployment area and 1308 individuals at station 12 in the offshore regional area. Univariate parameters were similarly variable, with station 30a recording the lowest species richness (1.92) and Shannon Weiner diversity (2.25) as a results of the depressed numbers of species at this station, while the highest species richness was found at station 3 (14.10). Equitability was highest at station 3, indicating that the few fauna present at this station were not present at similar abundances, and lowest at station 6 located within the Wave Hub deployment area. The highest value for Shannon Weiner diversity (5.33) was recorded at station 19, located in the offshore regional area, due to the higher than average number of species (68) and lower than average number of individuals (206) recorded at this station. Station 19 also recorded the highest Simpson's dominance (0.966), suggesting an inequitable spread of species at this station, while the lowest value was recorded at station 10 (0.542), also within the offshore regional area.

Table 4.10 Primary and Univariate Parameters by Station (0.2m^2)

Survey Area	Station	No of Taxa (S)	Abundance (N)	Richness (D_{Mg})	Equitability (J')	Shannon-Weiner (H')	Simpson's D (1-λ)
Wave Hub	1	36	103	7.55	0.892	4.61	0.952
	2	42	148	8.20	0.853	4.60	0.945
	3	98	974	14.10	0.640	4.24	0.834
	4	76	705	11.44	0.696	4.35	0.887
	5	20	66	4.53	0.750	3.24	0.841
	6	55	663	8.31	0.439	2.54	0.554
	7	43	89	9.36	0.853	4.63	0.927
	8	60	289	10.41	0.689	4.07	0.829
Offshore	9	73	747	10.88	0.572	3.54	0.765
	10	46	431	7.42	0.443	2.45	0.542
	11	51	383	8.41	0.532	3.02	0.651
	12	83	1308	11.43	0.543	3.46	0.807
	13	66	218	12.07	0.865	5.23	0.963
	14	43	115	8.85	0.871	4.73	0.948
	15	58	195	10.81	0.875	5.12	0.963
	16	32	107	6.63	0.813	4.07	0.907
	17	50	153	9.74	0.875	4.94	0.957
	18	51	205	9.39	0.871	4.94	0.958
	19	68	206	12.58	0.876	5.33	0.966
	20	75	472	12.02	0.735	4.58	0.888
Inshore	24	36	238	6.40	0.681	3.52	0.830
	25	65	428	10.56	0.597	3.60	0.788
	26	43	137	8.54	0.829	4.50	0.929
	27	15	52	3.54	0.729	2.85	0.798
	28	17	145	3.21	0.671	2.74	0.778
	29	15	50	3.58	0.926	3.62	0.921
	30a	5	8	1.92	0.969	2.25	0.893
Mean		49.0	319.8	8.59	0.744	3.95	0.853
SD		22.9	315.0	3.15	0.150	0.92	0.118

Figure 4.23a Macrofaunal Analysis, Excluding Juveniles (Offshore Wave Hub Region) - Number of Species (S) per 0.2m²

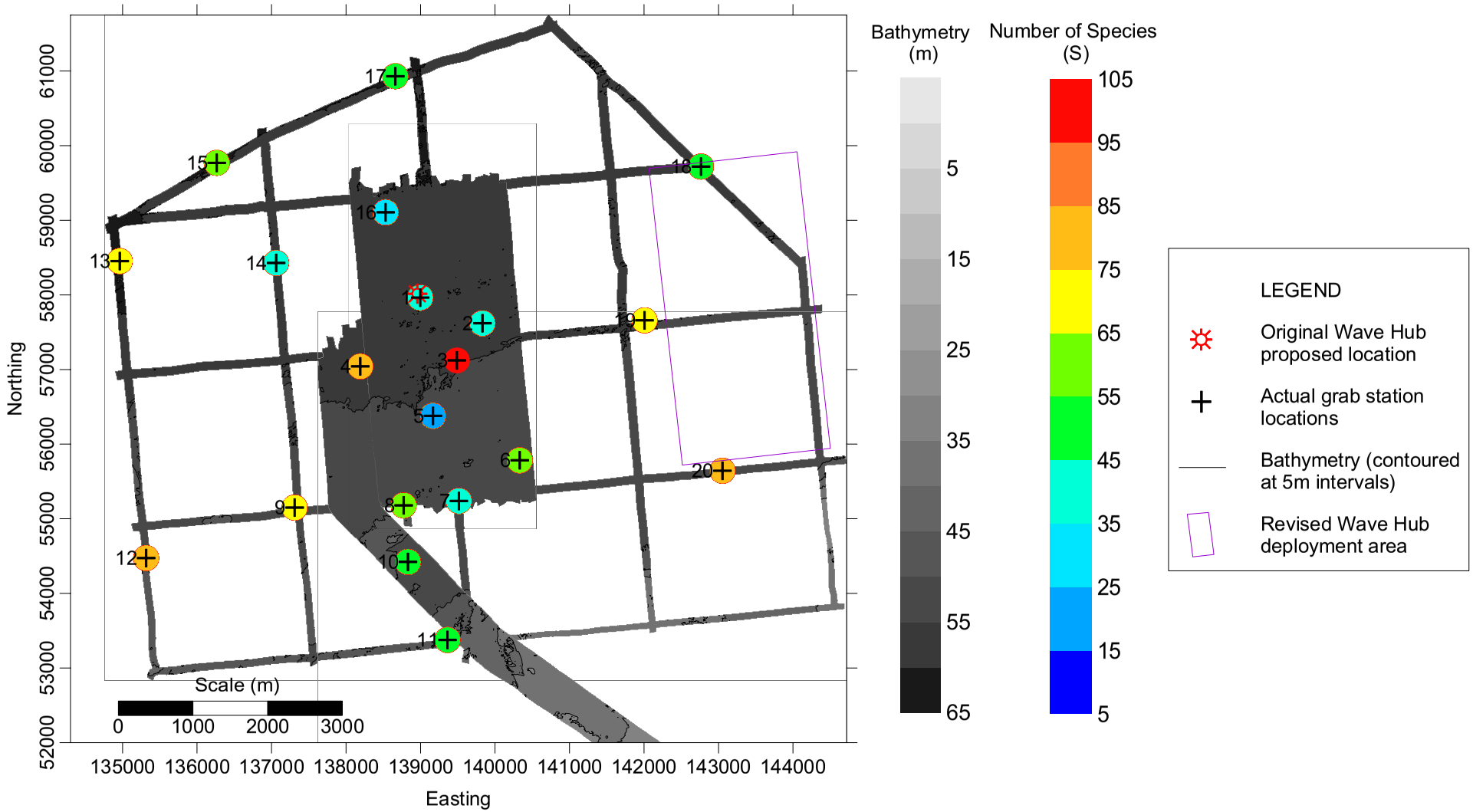


Figure 4.23b Macrofaunal Analysis, Excluding Juveniles (Cable Route) - Number of Species (S) per 0.2m²

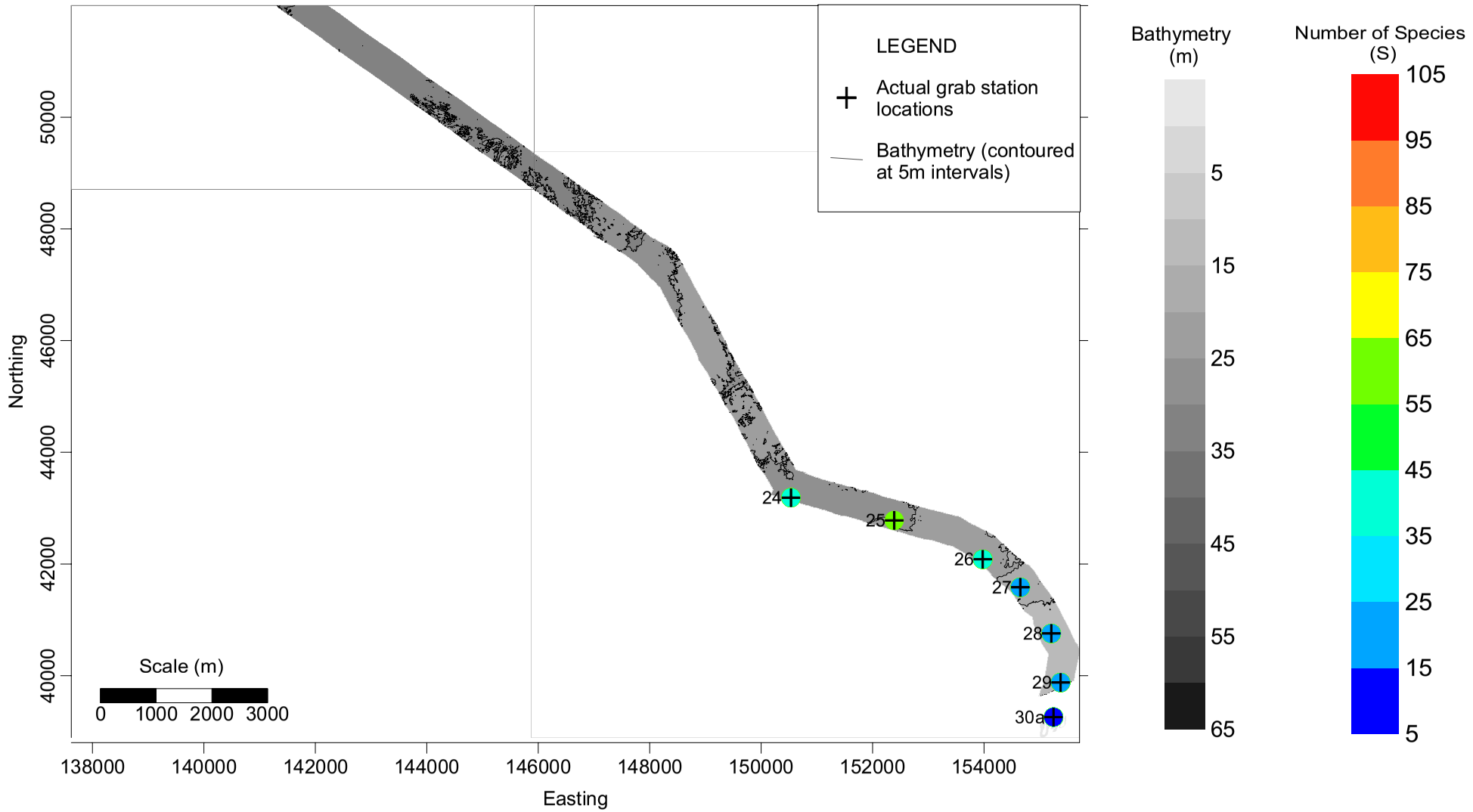


Figure 4.24a Macrofaunal Analysis, Excluding Juveniles (Offshore Wave Hub Region) - Number of Individuals (N) per 0.2m²

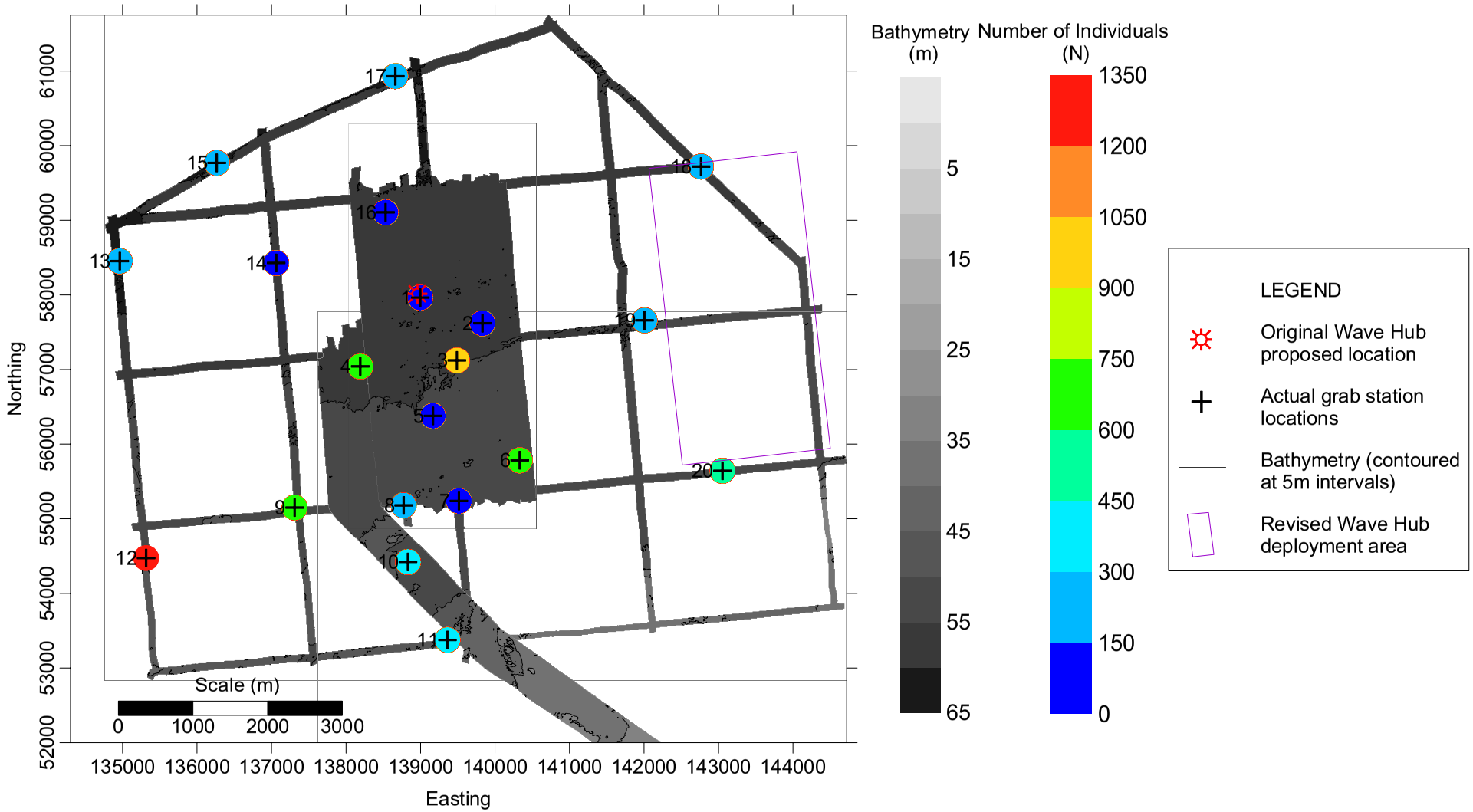


Figure 4.24b Macrofaunal Analysis, Excluding Juveniles (Cable Route) - Number of Individuals (N) per 0.2m²

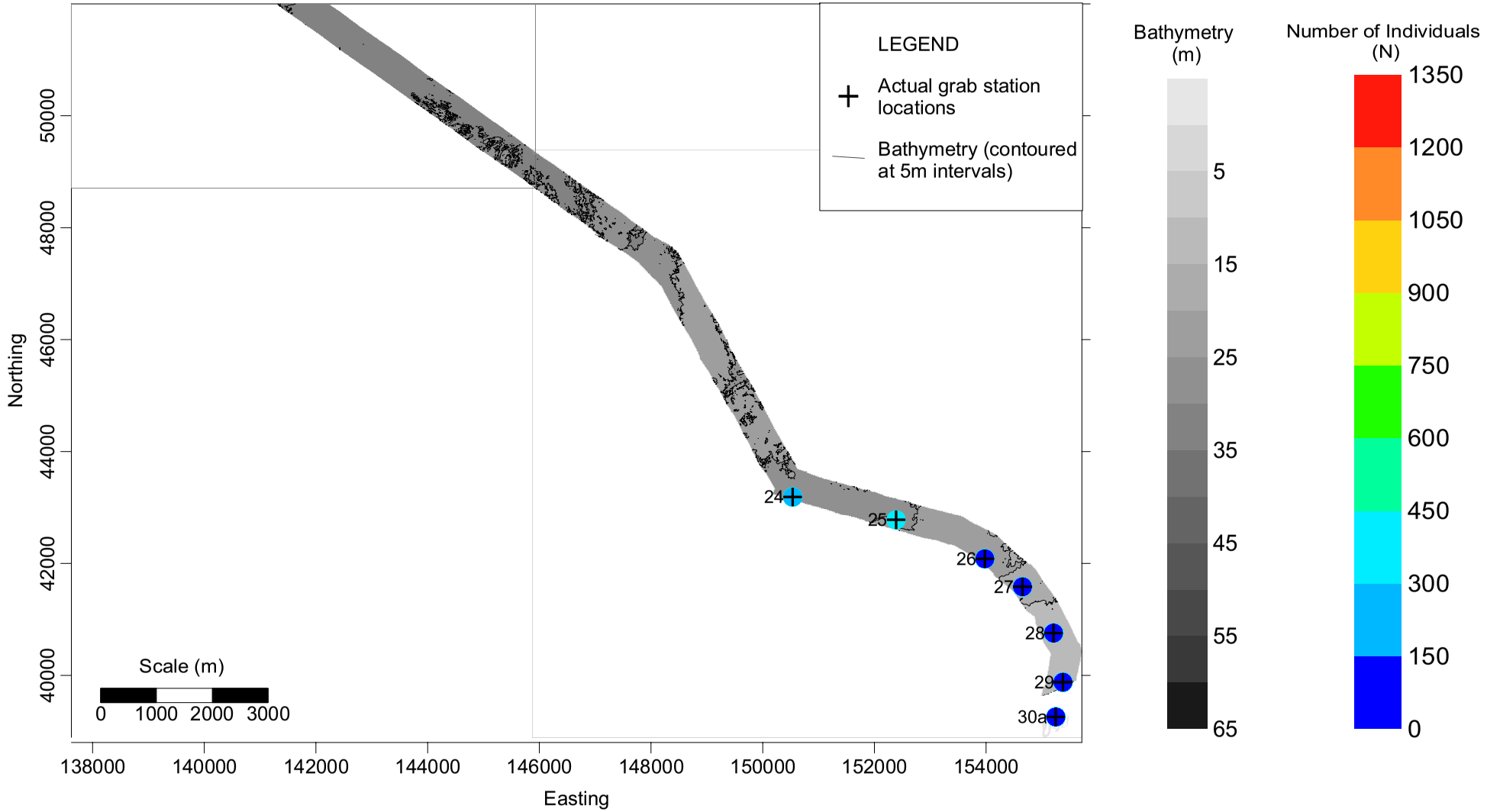


Figure 4.25a Macrofaunal Analysis, Excluding Juveniles (Offshore Wave Hub Region) - Species Richness (D) per 0.2m²

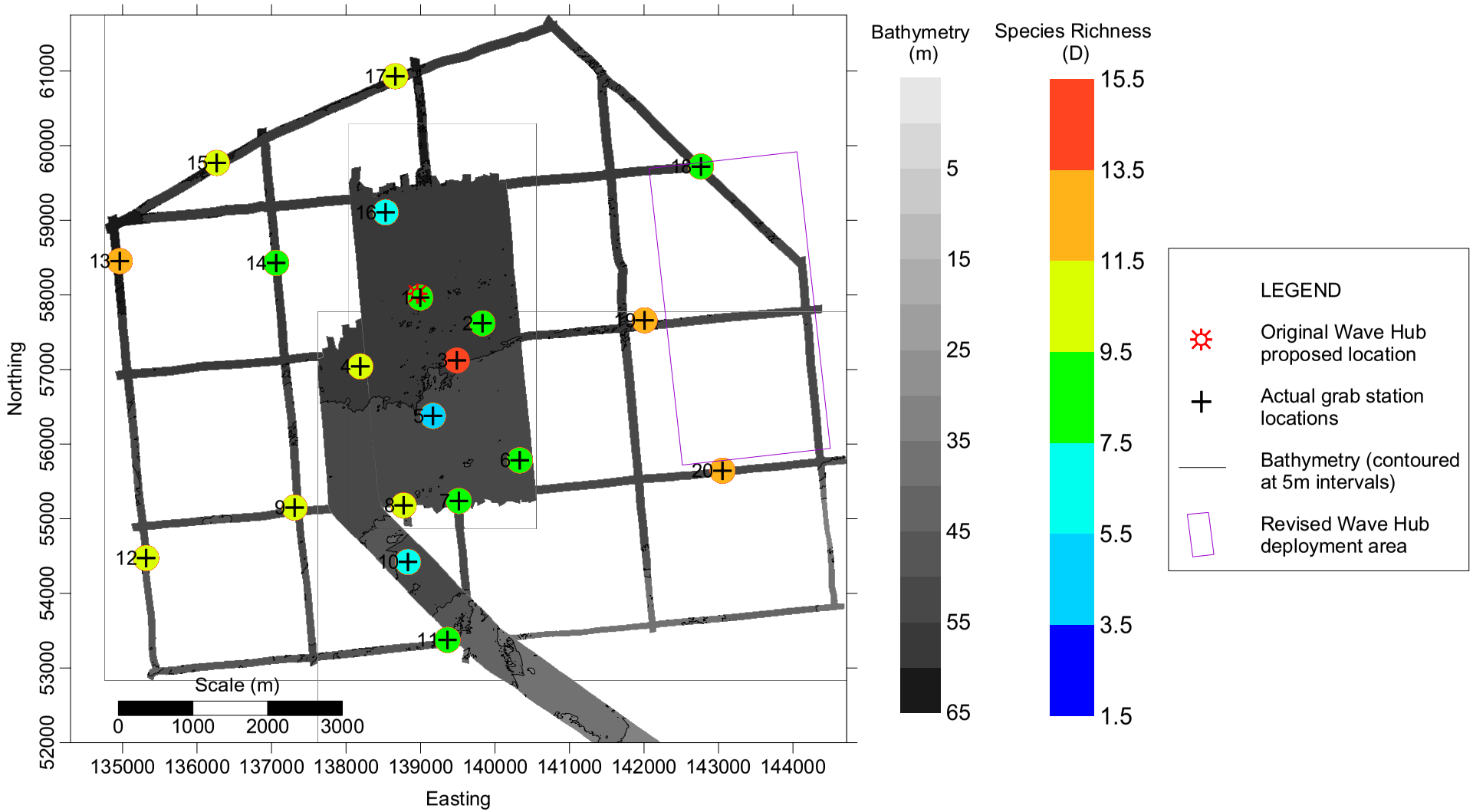


Figure 4.25b Macrofaunal Analysis, Excluding Juveniles (Cable Route) - Species Richness (D) per 0.2m^2

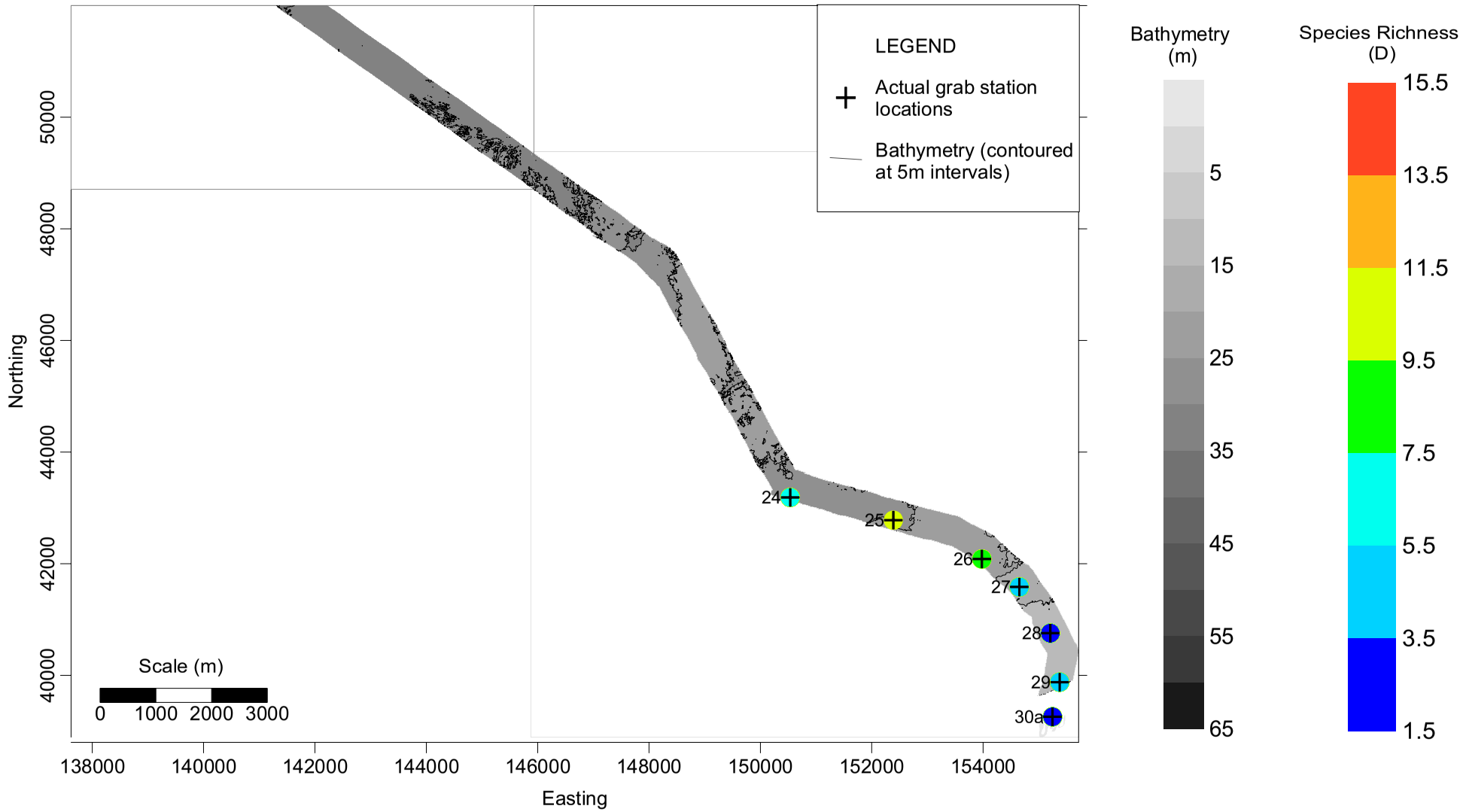


Figure 4.26a Macrofaunal Analysis, Excluding Juveniles (Offshore Wave Hub Region) - Evenness (J') per 0.2m²

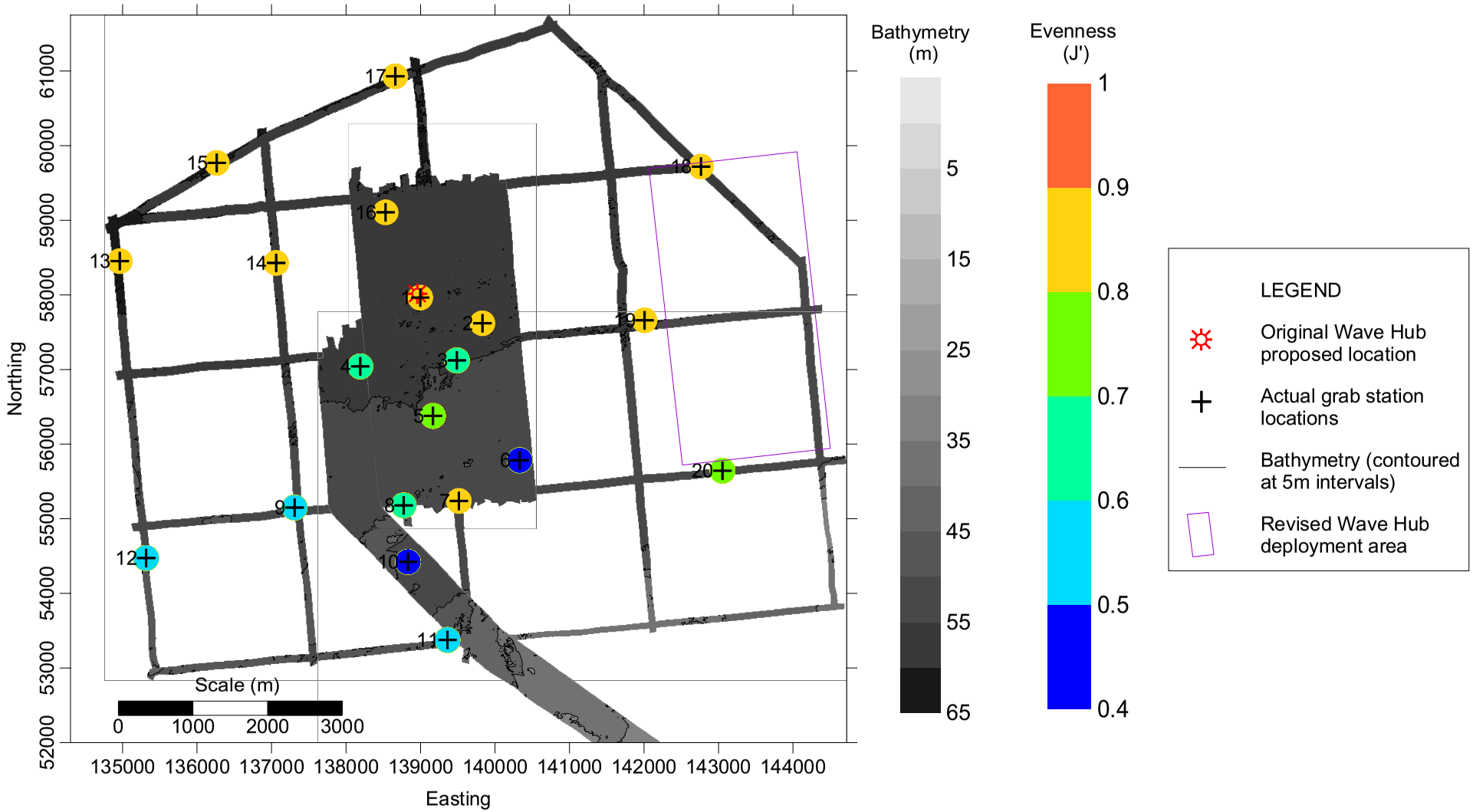


Figure 4.26b Macrofaunal Analysis, Excluding Juveniles (Cable Route) - Evenness (J') per 0.2m²

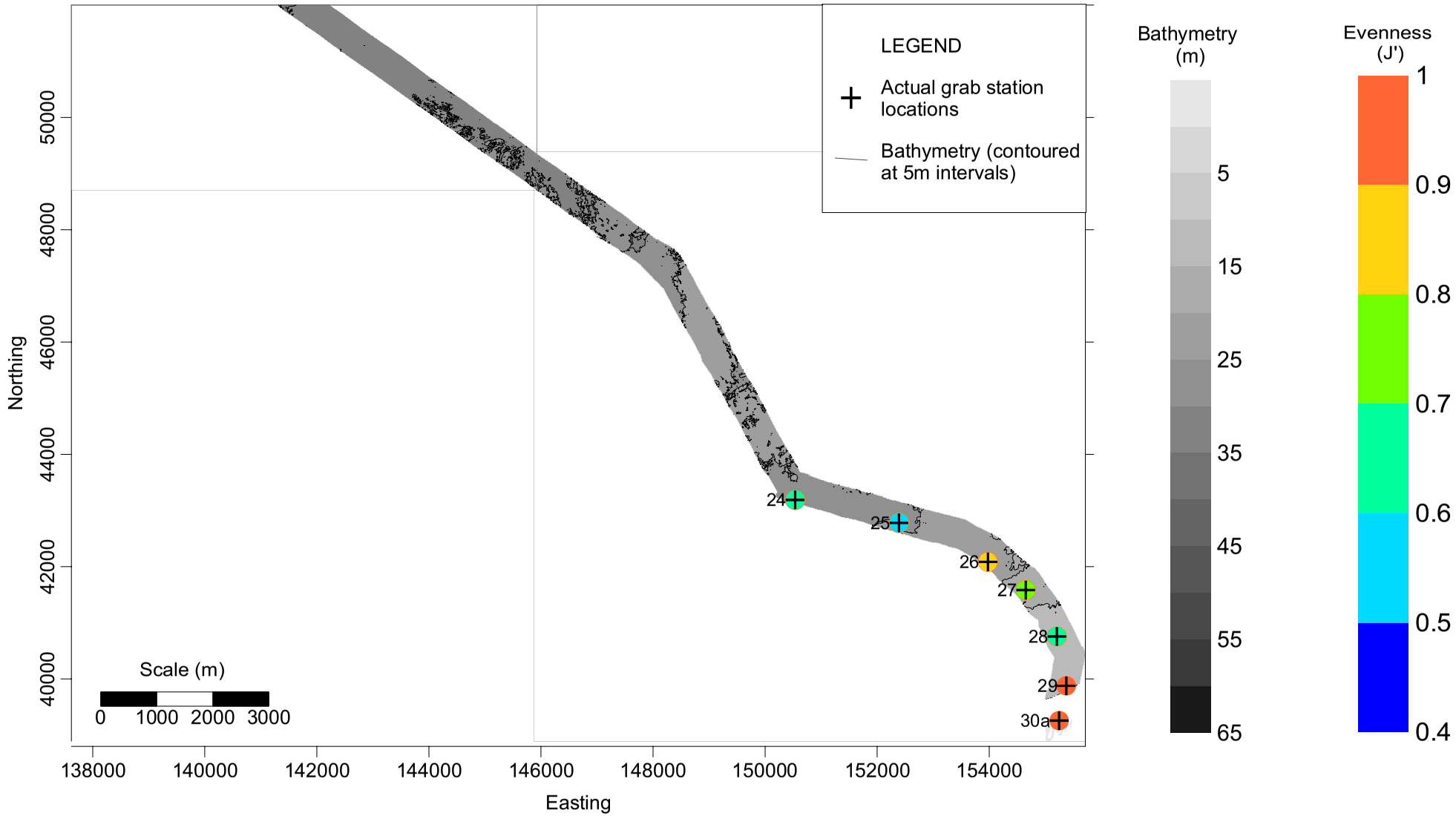


Figure 4.27a Macrofaunal Analysis, Excluding Juveniles (Offshore Wave Hub Region) - Shannon-Wiener Diversity (H') per 0.2m²

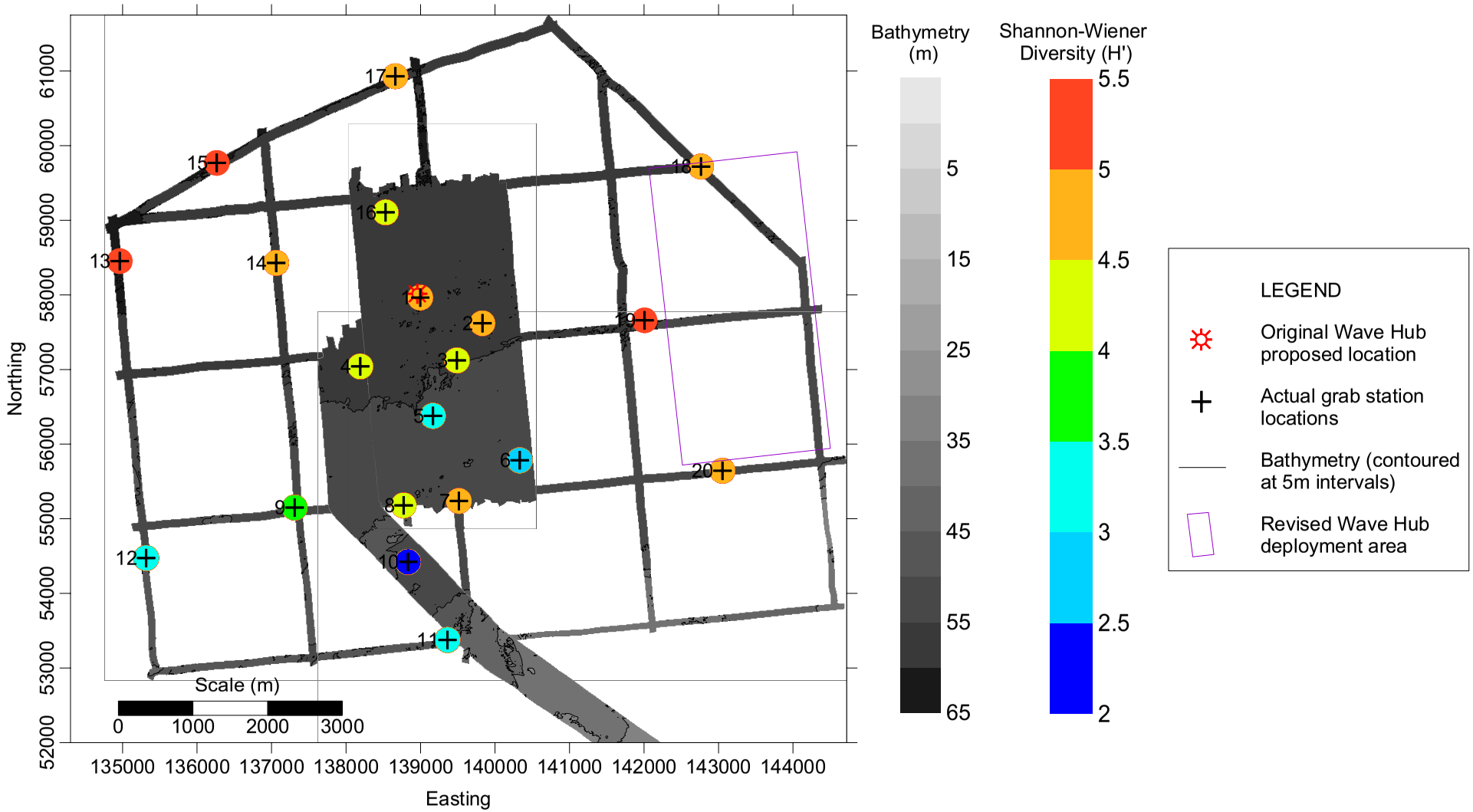


Figure 4.27b Macrofaunal Analysis, Excluding Juveniles (Cable Route) - Shannon-Wiener Diversity (H') per 0.2m^2

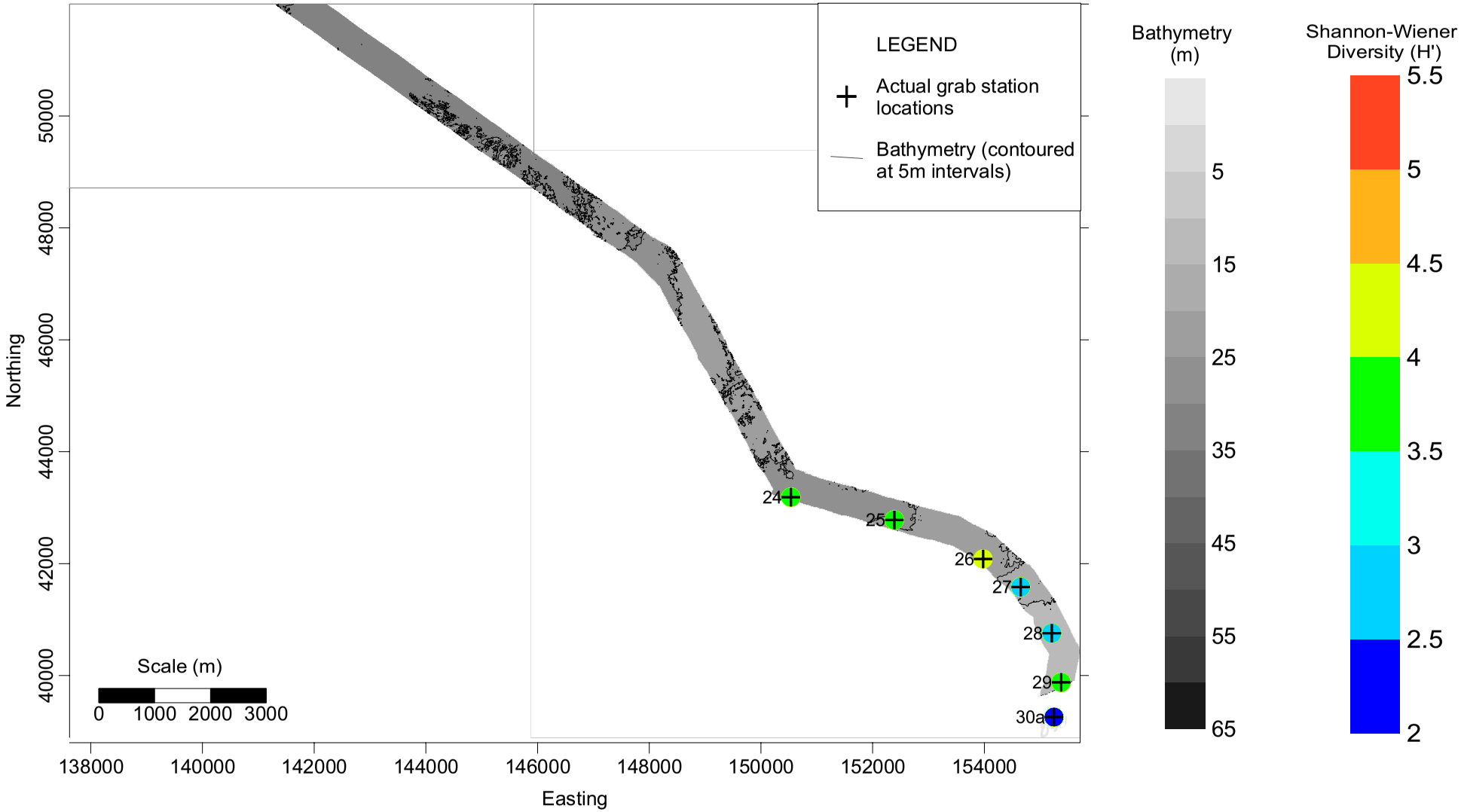


Figure 4.28a Macrofaunal Analysis, Excluding Juveniles (Offshore Wave Hub Region) - Simpson's D per 0.2m²

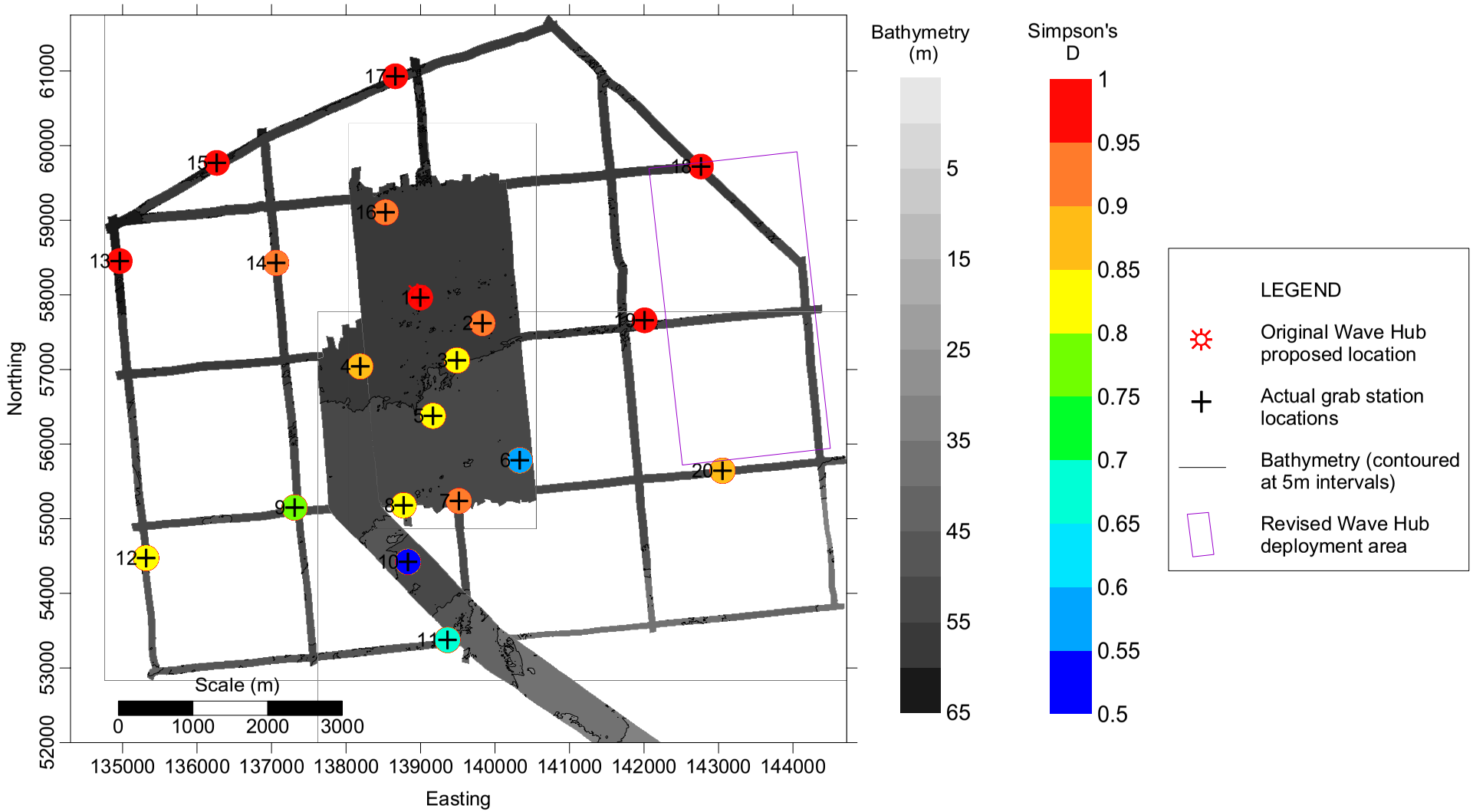
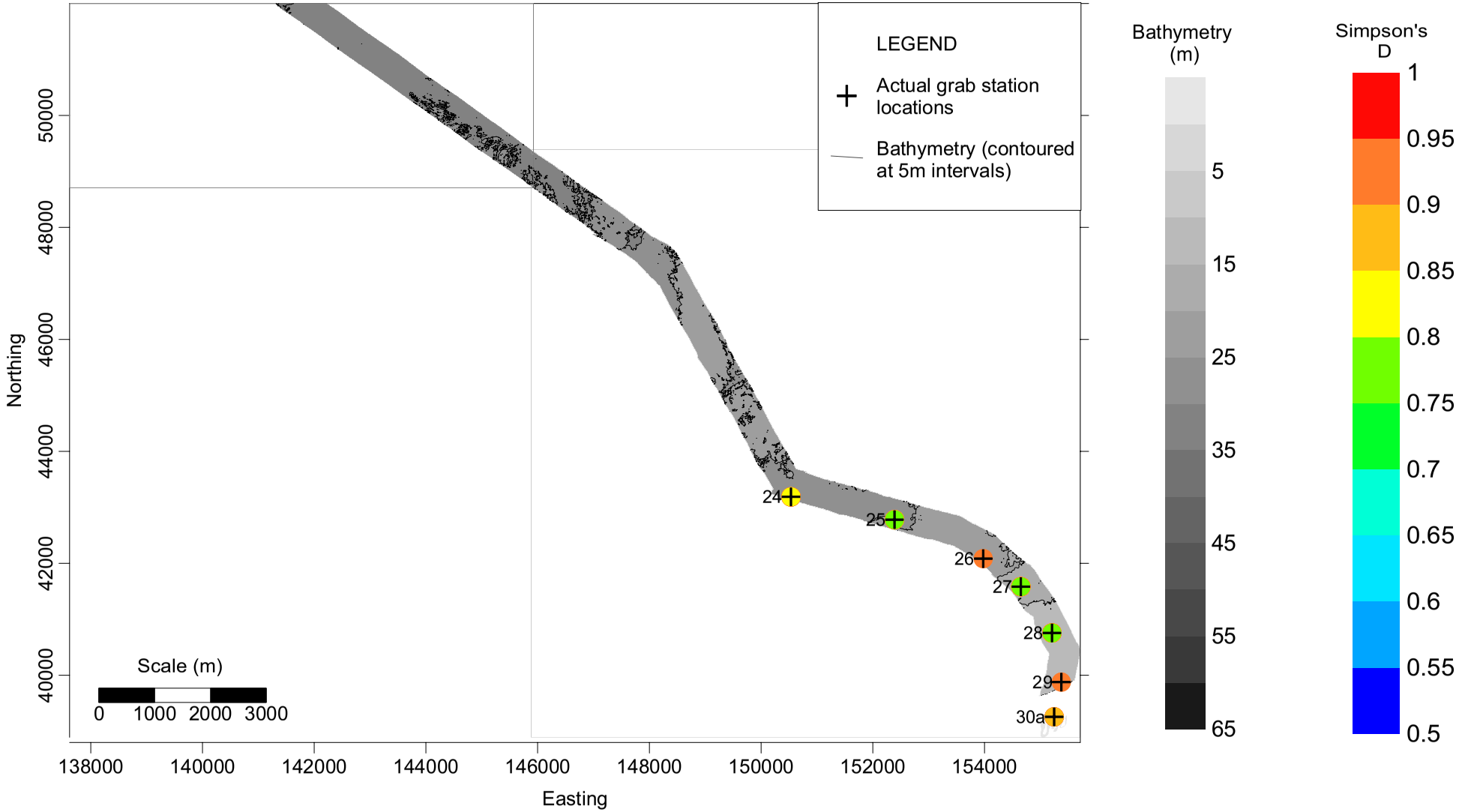


Figure 4.28b Macrofaunal Analysis, Excluding Juveniles (Cable Route) - Simpson's D per 0.2m²



Multivariate Analysis

Multivariate analysis of data allows a more thorough examination of differences between sites that cannot be achieved by examination of univariate measures alone. Multivariate analysis preserves the identity of species when calculating similarities between samples/ pooled station data, whereas this information is lost when computing univariate measures.

Analysis was undertaken using the Plymouth Routines in Multivariate Ecological Research (PRIMER) v6.0 statistical package (Clarke & Gorley, 2006). Two techniques have been used here to illustrate and identify differences in the data – cluster analysis which outputs a dendrogram displaying the relationships between samples/ pooled station data based on the similarity measure and non-metric multi-dimensional scaling (nMDS) in which the samples/ pooled station data are ordinated as a 2-dimensional ”map”. The resultant dendrograms and 2-dimensional nMDS plots are displayed in Figures 4.29 – 4.33.

Preliminary analysis indicated that sample 30FA contained only two individuals from two species, which were not represented in any other samples, and accordingly this sample was rated as being 0% similar to any other sample. Sample 30FA was subsequently removed from the analysis so that the wide disparity between this sample and the remaining samples did not prevent investigation of the interrelationships between other samples. The dendrogram shown in Figure 4.32 shows patterns in sample similarities, with statistically significant splits shown as solid black lines and non-significant splits shown as dotted red lines. Eleven clusters of statistically similar samples were identified within the dataset (Clusters a to k), in addition to five outlier samples, which were significantly different from all other samples. As the majority of these clusters grouped together samples located in close proximity to each other, they were named in a manner which aids visualisation of their spatial position, with cluster a comprising the most inshore cluster and cluster k the outermost cluster. Individual cluster descriptions are given in Table 4.11.

Table 4.11 Macrofauna Cluster Descriptions for Sample Data (0.1m^2)

	Cluster	No. of samples	Samples	Average intra-cluster similarity (%)
↓ Offshore ↓	a	4	28FA,28FB,29FA & 29FB	54.08
	b	2	27FA & 27FB	36.82
	c	3	25FA,25FB,26FB	39.87
	d	6	5FA, 5FB, 7FB, 24FA, 24FB & 26FA	28.16
	e	2	25FA, 25FB & 26FB	52.86
	f	3	8FB, 10FA & 10FB	44.16
	g	9	11FA & 11FB	50.91
	h	2	6FA & 12FA	48.49
	i	2	4FB & 19FA	48.55
	j	12	1FA, 1FB, 2FA, 2FB, 13FA, 14FA, 15FA, 15FB, 17FA, 17FB, 18FA, & 18FB	46.32
	k	4	13FB, 14FB, 16FA & 16FB	47.64
	Outliers	5	7FA, 8FA, 19FB, 30FA & 30FB	NA

Inter-cluster similarity was generally greater between clusters located in close proximity. For example the inshore clusters a and b were approximately 32% similar to each other but only approximately 3% similar to any other cluster. Clusters tended to include both replicates from particular stations indicating a degree of small-scale homogeneity in the macrofaunal communities. Several of the identified appeared to form part of larger groups of similar clusters, although not statistically significant, for example clusters e, f, g, h and I, which showed inter-cluster similarities of between 40 and 43%.

The clusters denoted in Figure 4.29 were also evident in the corresponding nMDS ordination plot (Figure 4.30). The associated stress factor of 0.12 means that the plot represents a useful 2-dimensional picture, but too much reliance should not be placed on the detail of the plot. However, the large number of samples and close similarity of clusters c and e to k prevented closer examination of the interrelationships between these clusters and, as such, the analysis was repeated including only these clusters (Figure 4.31). The resultant nMDS plot (stress level = 0.17) showed analogous interrelationships between clusters as denoted by the cluster dendrogram.

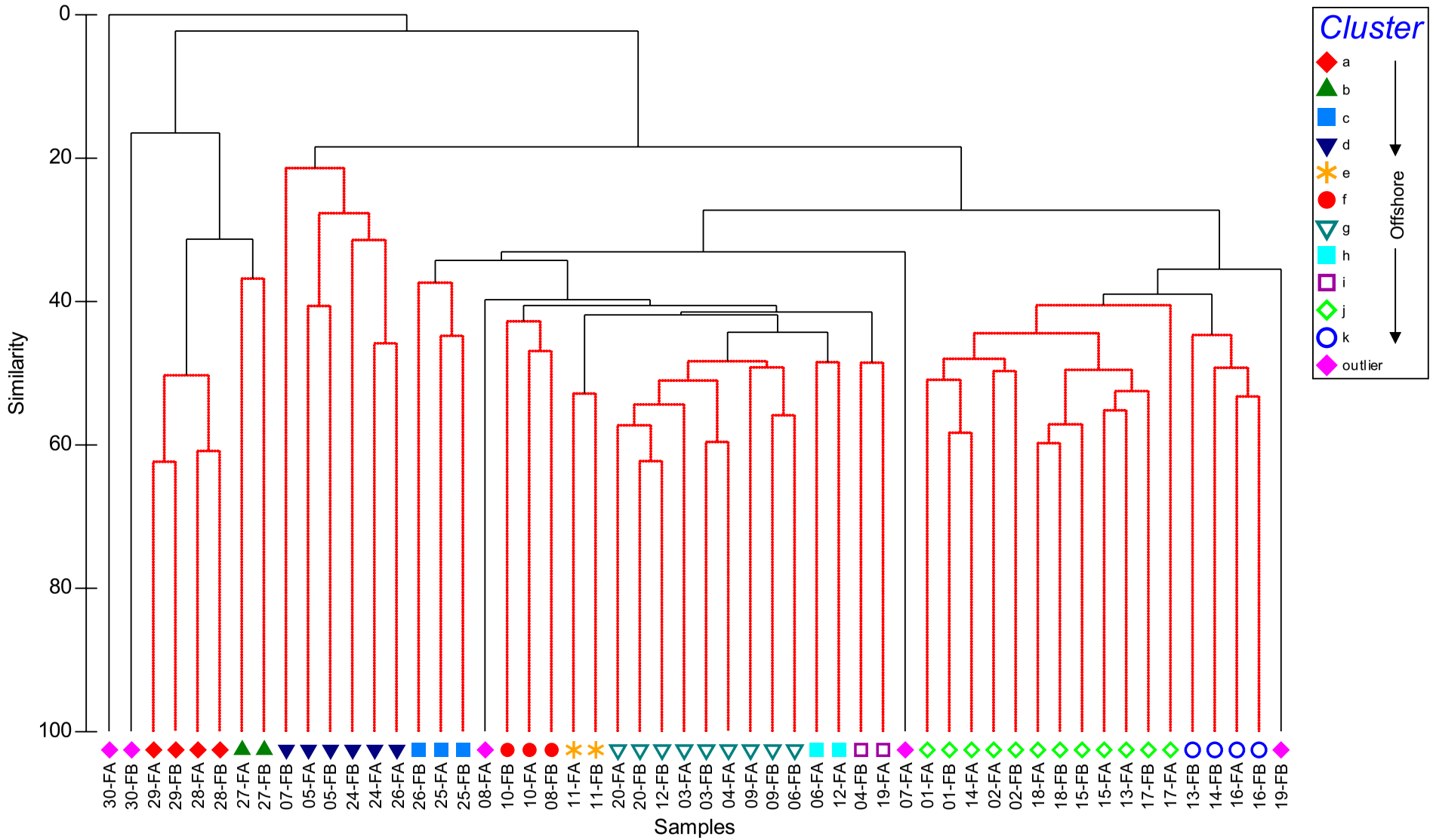


Figure 4.29 Dendrogram of all Samples by Bray–Curtis Similarity on Fourth Root Transformed Data

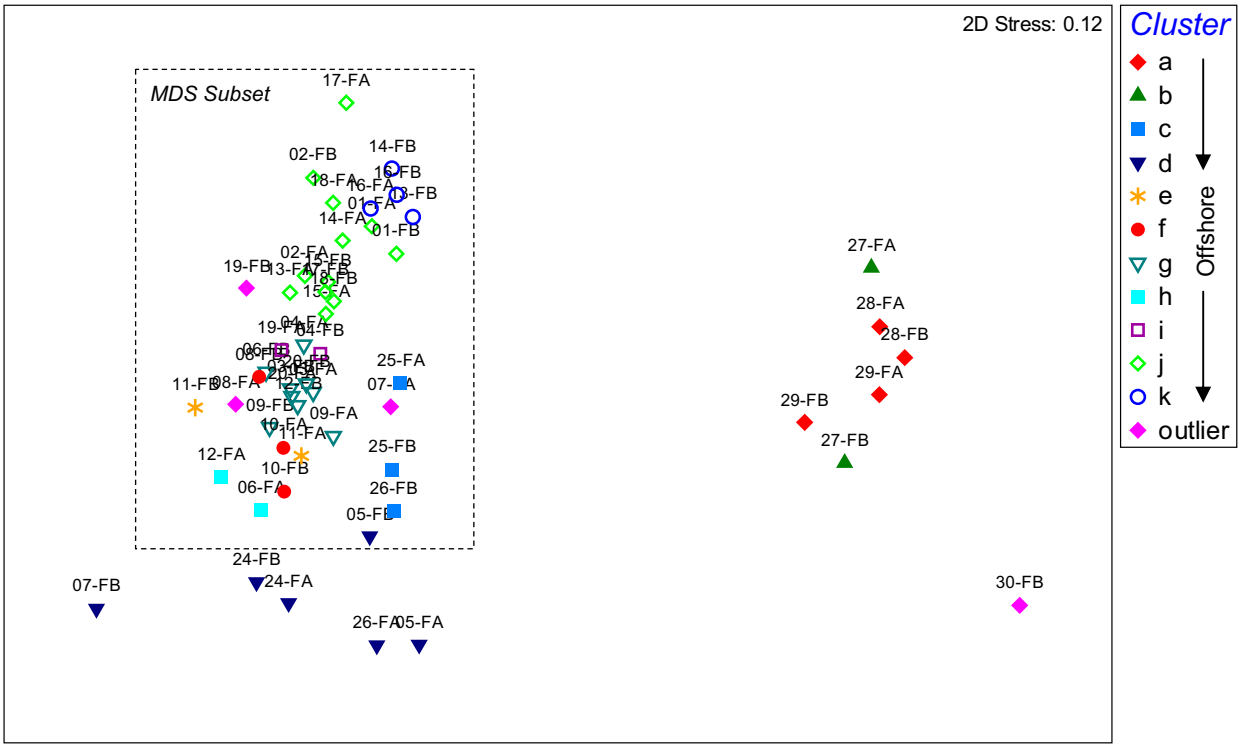


Figure 4.30 **Non-Metric Multidimensional Scaling (nMDS) of Samples by Bray Curtis Similarity on Fourth Root Transformed Data**

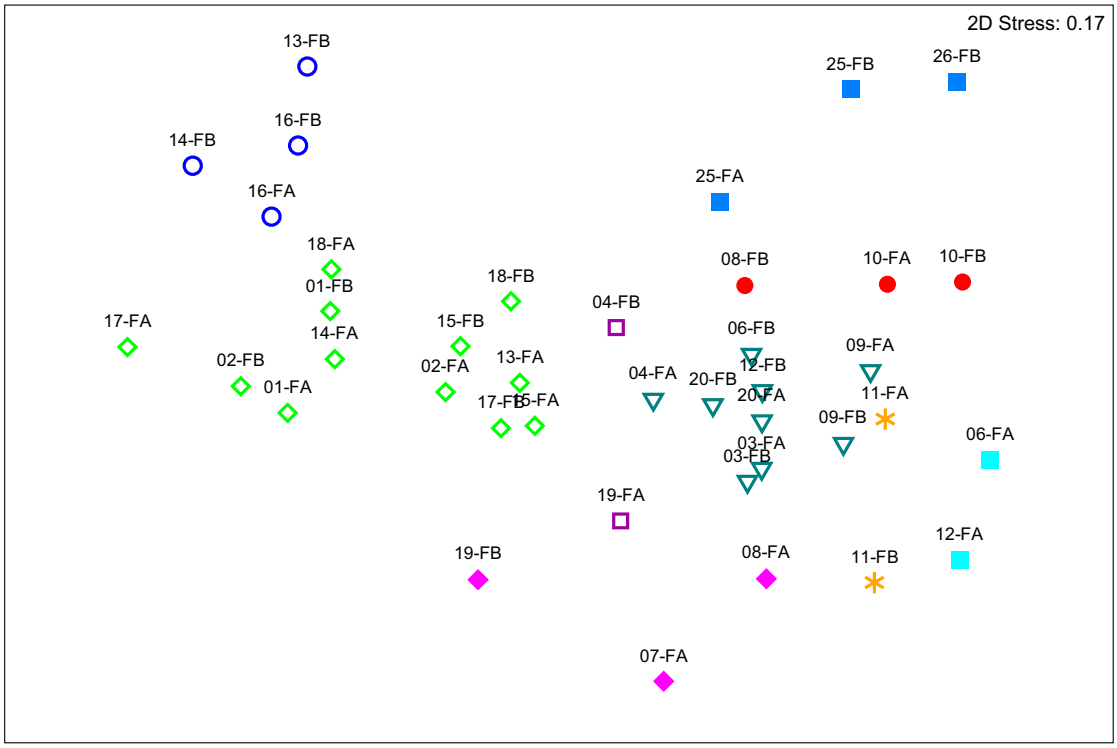


Figure 4.31 **Non-Metric Multidimensional Scaling (nMDS) Analysis for a Subset of Samples by Bray Curtis Similarity on Fourth Root Transformed Data**

Multivariate analyses were re-run for pooled station data (0.2m^2) to examine more broad scale trends in the data (Figures 4.32 and 4.33). This resultant dendrogram identified four significant cluster groupings through the aggregation of clusters evident in sample data, for example cluster a comprises clusters a and b for sample data, and cluster d comprises clusters j and k for sample data. Clusters were again named according to their general proximity to the shore. Individual cluster descriptions are given in Table 4.12.

Table 4.12 Macrofauna Cluster Descriptions for Station Data (0.2m^2)

	Cluster	No. of Samples	Stations	Average Within Cluster Similarity (%)
← Offshore	a	3	27, 28 & 29	46.89
	b	2	24 & 26	36.17
	c	7	3, 4, 6, 8, 9, 12 & 20	55.80
	d	8	1, 2, 13, 14, 15, 16, 17, 18	53.30
	Outliers	7	5, 7, 10, 11, 19, 25 30	NA

The results therefore suggest that the macrobenthos within the survey area comprised four different communities, corresponding to clusters a to d:

- Cluster a - three adjacent stations located on the inshore cable route;
- Cluster b - two neighbouring, but not adjacent, stations located on the nearshore cable route;
- Cluster c - seven neighbouring stations, although not occupying a contiguous area, located within the southern part of the original Wave Hub deployment and regional offshore areas, and;
- Cluster d – eight adjacent stations covering the northern part of the original Wave Hub deployment and regional offshore areas.

The remaining outliers are thought to represent transitional communities between those defined in clusters a to d. The nMDS plot for station data (Figure 4.32) shows the majority of outliers (stations 7, 10, 11, 12, 19 and 25) positioned around cluster c, and it is therefore likely that these stations represent either the same community or a closely related form. Similarly station 5 appears similar to cluster b and may well represent a variant of this community type.

The predominant influence of sediment granulometry on macrofaunal community composition within the survey area is evident from the high degree of similarity between clusters identified from both particle size distribution and macrofauna data (Table 4.13). Clusters a and d were dominated by sediments of fine and very coarse sand, respectively. In contrast, clusters b and c comprised more poorly sorted sediments, dominated by large and medium pebbles and shell fragments.

Table 4.13 Comparison of Granulometry and Macrofauna Cluster for Station Data

Station	1	2	3	4	6	8	9	12	13	14	15	16	17	18	20	26	27	28	29
Granulometry Clusters	d	d	c	c	c	b	c	c	d	d	d	d	d	d	c	b	a	a	a
Macrofauna Clusters	d	d	c	c	c	c	c	c	d	d	d	d	d	d	c	b	a	a	a
Cluster Agreement	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Outlier stations and those for which data were not available are not displayed. Cluster agreement is denoted by Y (= Yes) and disagreement by N (= No).

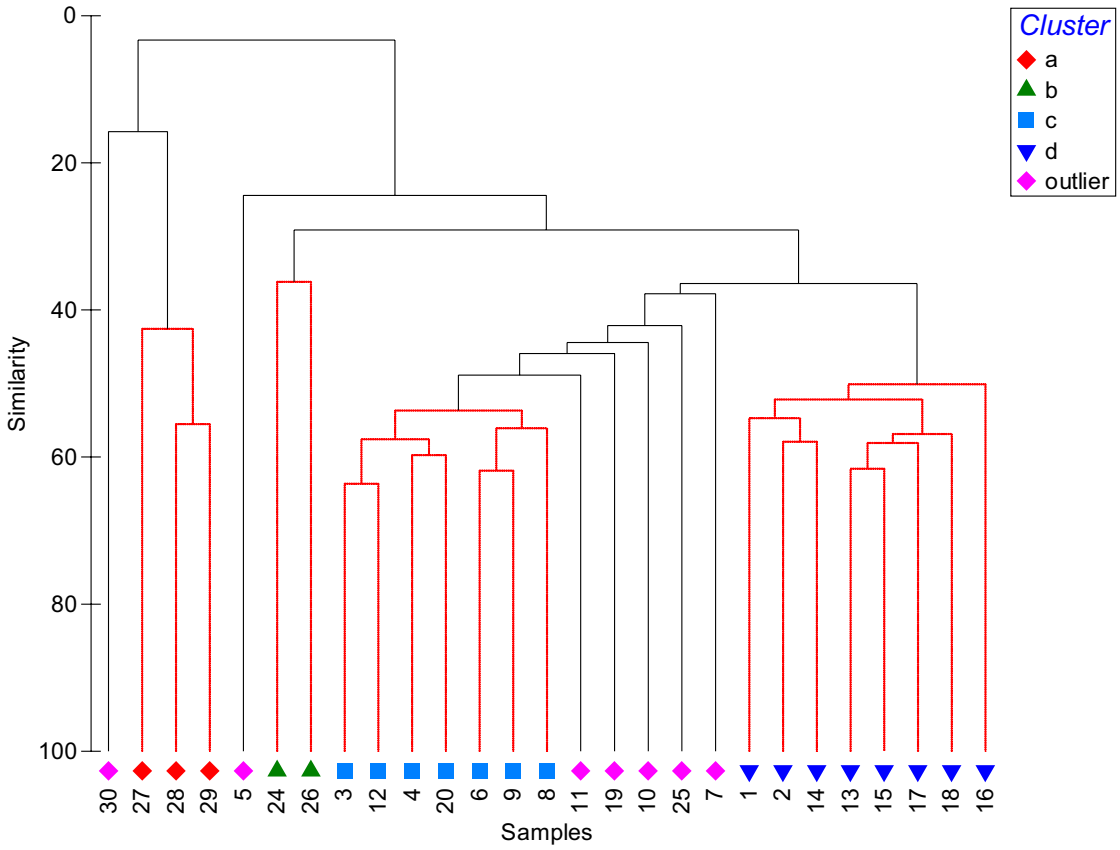


Figure 4.32 Dendrogram of Stations by Bray–Curtis Similarity on Fourth Root Transformed Data

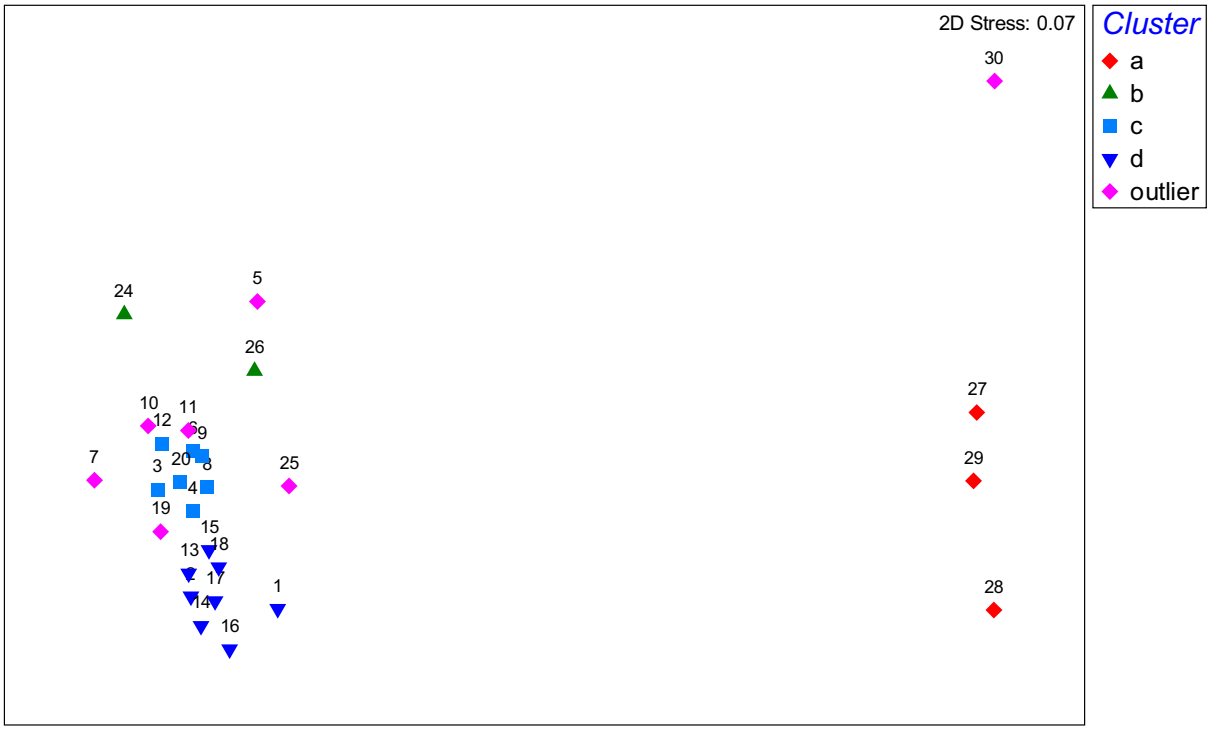


Figure 4.33 Non-Metric Multidimensional Scaling (nMDS) of Stations by Bray Curtis Similarity on Fourth Root Transformed Data

The PRIMER similarity percentage analysis (SIMPER) routine was run on the sample dataset. This routine identifies those species which contributed highest to both the similarity within clusters and the dissimilarity between clusters. The resultant similarities for are displayed in Tables 4.14 to 4.17, for clusters a to d, respectively.

Table 4.14 SIMPER Results for Cluster A Stations (0.2cm^2)

Taxon	√√ Transformed Mean Abundance	Non-Transformed Mean Abundance	Average Similarity	Similarity /SD	Similarity Contribution (%)	Similarity Cumulative Contribution (%)
Urothoe poseidonis	1.70	9.33	7.45	8.42	15.89	15.89
Magelona filiformis	1.89	22.00	7.07	16.63	15.08	30.97
Bathyporeia guilliamsoniana	1.58	8.33	6.33	7.59	13.49	44.46
Magelona johnstoni	1.57	9.33	5.78	4.53	12.32	56.78
Tellimya ferruginosa	1.25	3.00	5.2	14.02	11.09	67.88
Owenia fusiformis	1.11	1.67	4.91	12.82	10.47	78.35
Chaetozone setosa	1.37	13.33	2.73	0.58	5.83	84.18
Bathyporeia tenuipes	0.97	3.00	2.17	0.58	4.63	88.81
Nephtys cirrosa	0.84	1.67	2.12	0.58	4.52	93.32
Myrtea spinifera	0.67	0.67	1.59	0.58	3.40	96.72

Cluster a = Stations 27, 28 and 29.

Table 4.15 SIMPER Results for Cluster B Stations (0.2m^2)

Taxon	√√ Transformed Mean Abundance	Non-Transformed Mean Abundance	Average Similarity	Similarity /SD	Similarity Contribution (%)	Similarity Cumulative Contribution (%)
Pisidia longicornis	2.63	55.50	4.48	NA	12.39	12.39
Serpulidae	2.16	23.50	3.84	NA	10.63	23.01
Typosyllis sp.	1.25	2.50	2.41	NA	6.66	29.67
Websterinereis glauca	1.58	8.50	2.41	NA	6.66	36.32
Verruca stroemia	1.66	11.50	2.41	NA	6.66	42.98
Janira maculosa	1.34	3.50	2.41	NA	6.66	49.63
Mediomastus fragilis	1.31	4.00	2.02	NA	5.6	55.23
Polycirrus sp.	1.37	5.00	2.02	NA	5.6	60.83
Maera othonis	1.00	1.00	2.02	NA	5.6	66.42
Anthura gracilis	1.25	3.00	2.02	NA	5.6	72.02

Cluster b = Stations 24 and 26.

Table 4.16 SIMPER Results for Cluster C Stations (0.2m^2)

Taxon	√√ Transformed Mean Abundance	Non-Transformed Mean Abundance	Average Similarity	Similarity /SD	Similarity Contribution (%)	Similarity Cumulative Contribution (%)
Pisidia longicornis	4.07	301.71	3.76	6.72	6.74	6.74
Serpulidae	2.55	56.43	2.2	6.03	3.94	10.68
Typosyllis sp.	2.38	36.14	2.15	10.75	3.85	14.53
Corophium sextonae	2.42	53.00	1.97	4.31	3.53	18.06
Janira maculosa	1.89	13.29	1.81	7.3	3.25	21.31
Harmothoe sp.	2.11	26.00	1.81	8.38	3.25	24.55
Notomastus sp.	1.8	12.14	1.63	5.53	2.93	27.48
Polydora caeca agg.	1.81	19.00	1.51	5.15	2.71	30.19
Galathea intermedia	1.7	11.00	1.49	5.02	2.67	32.86
Ceradocus semiserratus	1.64	8.43	1.47	5.55	2.64	35.5

Cluster c = Stations 3, 4, 6, 8, 9, 12 and 20.

Table 4.17 SIMPER Results for Cluster D Stations (0.2m^2)

Taxon	√√ Transformed Mean Abundance	Non-Transformed Mean Abundance	Average Similarity	Similarity /SD	Similarity Contribution (%)	Similarity Cumulative Contribution (%)
Polygordius sp.	1.98	16.13	3.31	5.73	6.21	6.21
Glycera lapidum agg.	1.77	10.88	2.86	6.28	5.36	11.57
Echinocyamus pusillus	1.74	10.50	2.78	5.56	5.21	16.78
Typosyllis sp.	1.65	8.00	2.67	8.6	5	21.78
Glycymeris glycymeris	1.73	11.13	2.61	4.51	4.89	26.67
Eunice sp.	1.62	8.63	2.46	5.44	4.61	31.28
Kefersteinia cirrata	1.23	2.38	2.05	4.86	3.84	35.12
Ehlersia cornuta	1.34	4.38	1.99	4.82	3.74	38.86
Protodorvillea kefersteini	1.32	5.13	1.82	1.62	3.41	42.27
Branchiostoma sp.	1.28	4.63	1.81	1.56	3.4	45.68

Cluster d = Stations 1, 2, 13, 14, 15, 16, 17 and 18.

The results of SIMPER analyses highlighted key characterising species within the different cluster groups. By understanding the ecology of these species it is possible to suggest the likely mechanisms behind the shift in species composition within the survey area.

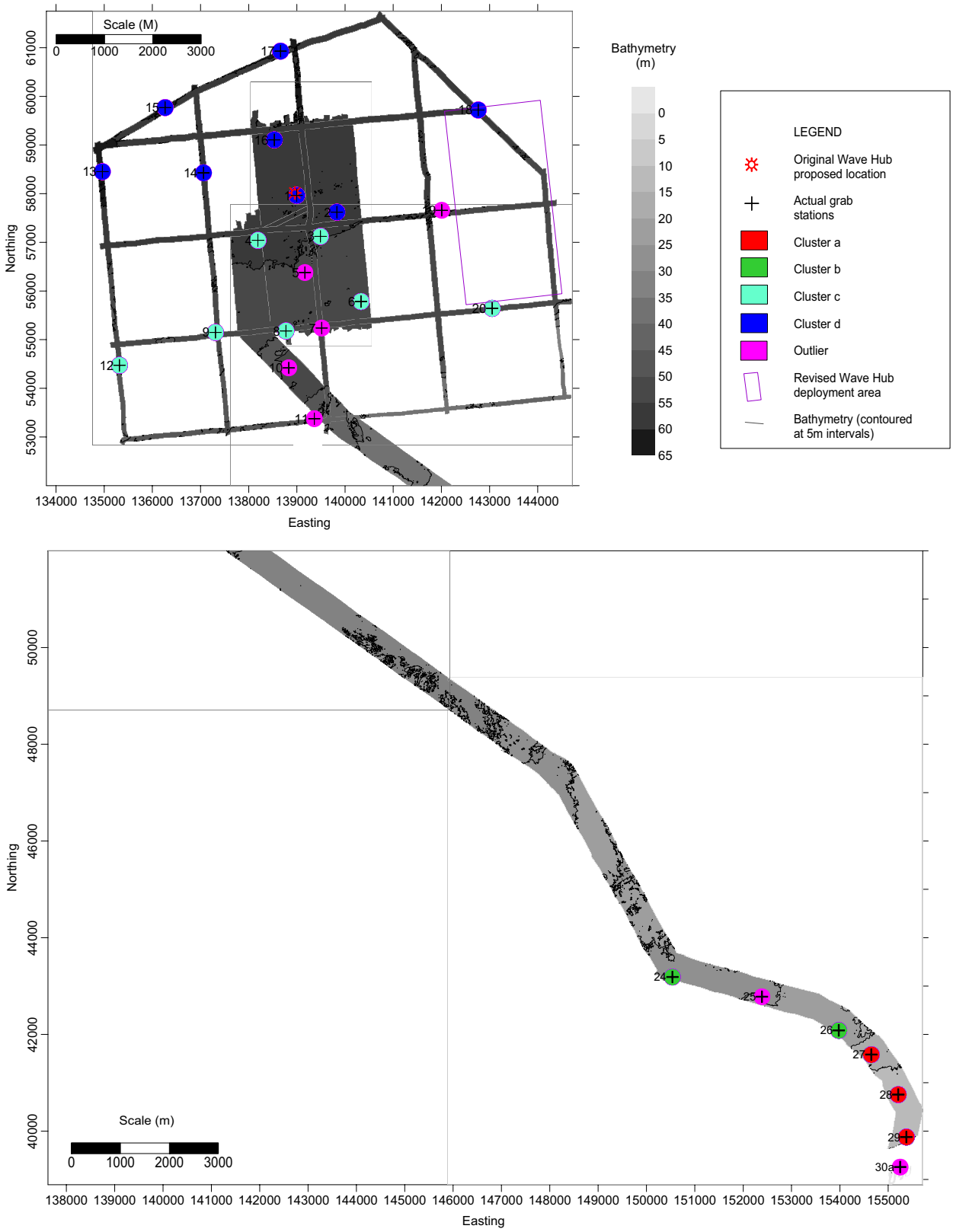
Cluster a was characterised by three amphipod crustaceans, *Urothoe poseidonis*, *Bathyporeia guilliamsoniana* and *Bathyporeia tenuipes*, typically recorded in shallow sublittoral sandy sediments. This is consistent with the depth range of <18m and the moderately well to well sorted fine SAND sediment at these stations. Similarly, the polychaetes *Chaetozone setosa* and *Nephtys cirrosa*, which were also among the ten most characteristic taxa for this cluster, are more commonly observed in shallow sandy sediment environments.

Further along the nearshore cable route stations grouped within Cluster b (stations 24 and 26) exhibited coarse sediment comprising very poorly sorted pebble. Accordingly, this cluster was characterised by the presence of species requiring coarse substratum. Such species include the crab, *Pisidia longicornis*, which is a cryptic species commonly found in crevices and under boulders, and polychaetes of the Serpulidae family, which inhabit calcareous tubes cemented to the surfaces of pebbles and shells. Another taxon, *Typosyllis* sp. is typically found within unoccupied Serpulidae tubes and so is similarly dependant on the presence of hard substratum.

Within the southern parts of the original Wave Hub deployment and regional offshore areas the sediments also comprise very poorly sorted PEBBLE. As may be expected cluster c is characterised by similar species to cluster b, sharing the same three most characteristic taxa (*Pisidia longicornis*, Serpulidae and *Typosyllis* sp.). That these taxa were present at substantially higher densities within cluster c may indicate that cluster b was transitional between clusters a and c.

The northern parts of the Wave Hub deployment and regional offshore areas were distinct in terms of both granulometry and macrofauna community composition. The sediments of this cluster were classified as poorly to very poorly sorted coarse to very coarse SAND. Unlike clusters b and c none of the characteristic fauna for this cluster were dependant on the presence of coarse substratum, with the fauna instead dominated by polychaetes. The majority of the key taxa are considered to be carnivorous, for example the polychaetes *Glycera lapidum*, *Typosyllus* sp., *Eunice* sp., *Kefersteinia cirrata*, *Ehlersia cornuta* and *Protodorvillea kefersteini*. It is further postulated that these carnivorous polychaetes predate on, *inter alia*, the polychaete *Polygordius* sp. as well as interstitial nematodes, which would not be effectively sampled by the 1mm mesh used during this survey.

Figure 4.34 Cluster Analysis - Grab Infauna



4.7.2 Beam Trawling Sample Analysis - Epifauna

General Description

Twenty trawl samples were sampled and analysed, the full macrofaunal dataset is presented in Appendix E. The trawls ranged in length from 370m (T3) to 820m (T11). Monitoring of the warp during trawling and examination of the trawl shoes after gear recovery suggested that the trawl maintained good seabed contact at all sampling stations. The trawls sustained damage during sampling of stations 1, 2 and 8, and a re-run was performed at station 8 as the trawl net had been damaged during the first deployment.

Trawl sample volume varied between approximately 1L (samples T13, T19 and T20) and 120L (sample T5). It should be noted that around 95% of the volume of the latter was made up of sediment and shell. The volume of biota returned ranged from approximately 1L (samples T13, T19 and T20) to 50L (sample T1) (see Appendix B for the trawl deck log).

Although trawl sampling is the most efficient means to sample motile or sparse epifauna, its efficiency varies with topography, sediment type, prevalent weather conditions and tidal state. The motility of solitary fauna (especially fish) and the attachment of some colonial fauna can also introduce a positive or negative taxon bias within trawl datasets. The following analyses should therefore be considered a comparison of catches from which information regarding epibiota can be inferred, rather than a fully quantitative comparison of different benthic communities. As in other studies of benthic epifauna in which trawl sampling was used (e.g. Basford *et al*, 1989; Brown *et al*, 2001), species that were considered infaunal were not excluded from data analysis.

Table 4.18 (0 – 52m) and Table 19 (52 – 60m) provide summary information for each trawl sample, with samples ordered by increasing distance offshore which generally corresponds to increasing bathymetry. The sediment type displayed was derived from a combination of PSD data and the seabed features data. The dominant fauna are presented in order of decreasing abundance.

Trawl sample composition was found to vary greatly across the survey area. It appears likely that sediment type was the main determinant of epifauna distribution, with different dominant taxa being found in association with different substrate types.

The innermost section of the nearshore cable route was found to have a well sorted SAND sediment. Of the samples taken here two (T19 and T20) contained a relatively poor fauna dominated by the crab *Polybius henslowii* and sand gobies of the genus *Pomatoschistus*. Although these species were also found in T18, the presence of colonial fauna (which require hard substrate for attachment) and crab species characteristic of coarser sediment, suggest that the trawl sampled both SAND and PEBBLE substrates. Trawls T16 and T17 were taken from the predominantly PEBBLE substrate further along the cable route and were dominated by coarse substrate associated fauna such as the anomuran *Pisidia longicornis* and brittlestar *Ophiothrix fragilis*. T15 was taken from the margin of the exposed bedrock section of the cable route, its fauna contained some of the taxa characteristic of PEBBLE substrata (e.g *O. fragilis*) but was dominated by the bryozoans *Pentapora foliacea* and *Flustra foliacea*, large colonies of which are generally restricted to rock or boulders.

With the exception of T11 and T14 the original Wave Hub deployment area and regional offshore area samples can be divided, in terms of faunistic composition, into two groups. The samples taken from the predominantly PEBBLE substrate area (T3, T4, T12 and T13), encompassing the southern parts of the Wave Hub deployment and regional offshore areas, were similar to T16 and T17 (along the offshore and nearshore cable route), with a fauna dominated by *P. longicornis*.

The samples taken from the more northerly offshore silty SAND region (T1, T2 and T5 to T10) were dominated by either queen scallops, *Aequipecten opercularis,* or the hermit crab *Pagurus prideaux*; *Adamsia carcinopados*, an anemone that lives commensally with *P. prideaux*, was also abundant.

T14, to the extreme south-east of the region, was dominated by *P. foliacea* and the featherstar *Antedon bifida*, taxa usually associated with bedrock areas. T11, to the east of the original Wave Hub deployment area, was dominated by *A. bifida* and *O. fragilis*, a species that is also found in high density on rock outcrops.

Table 4.18 Beam Trawl Sample Summary (0 - 52m)

Trawl	Location	Length (m)	Orientation SOL-EOL	Bathymetry (m Below LAT) and Topography	Sediment Types	Dominant Fauna
T20	Neashore Cable Route	510	NW-SE	9-13m flat	Fine SAND	Swimming crabs (*Polybius henslowii*), brittlestars (*Ophiothrix fragilis*) and gobies (*Pomatoschistus* sp.)
T19	Neashore Cable Route	560	E-W	13m flat	Fine SAND	*P. henslowii, Pomatoschistus sp.*and cuttlefish *(Sepiola atlantica)*
T18	Neashore Cable Route	590	E-W	16-18m flat	Fine SAND	*O. fragilis, Pomatoschistus sp.,* dragonets (*Callionymus lyra*) and several crustacean species.
T17	Neashore Cable Route	520	E-W	20-22m flat	PEBBLE	*O. fragilis,* porcelain 'crabs' *(Pisidia longicornis)* and true crab species
T16	Neashore Cable Route	500	W-E	24-25m flat	PEBBLE	*P. longicornis, O. fragilis* and three spider crab species.
T15	Neashore Cable Route	610	SW-NE	25-28m generally flat but with occasional outcrops	PEBBLE and bedrock outcrops	Bryozoans (*Pentapora foliacea*, *Flustra foliacea*) and squat lobsters (*Galathea nexa*).
T14	Regional Offshore Area	480	E-W	32-36m generally flat but with occasional outcrops	PEBBLE and bedrock outcrops	*P. foliacea,* featherstars (*Antedon bifida*), *G. nexa* and *P. longicornis.*
T13	Regional Offshore Area	540	E-W	40-42m flat	PEBBLE	*P. longicornis,* crabs (*Xantho pilipes*) and queen scallops (*Aequipecten opercularis*)
T04	Offshore Cable Route	570	W-E	48-52m generally flat but with occasional outcrops	PEBBLE and bedrock outcrops	*P. longicornis*, *A. bifida* and *O. fragilis*
T03	Original Wave Hub Deployment Area	370	E-W	50-51m generally flat but with occasional outcrops	PEBBLE and bedrock outcrops	*P. longicornis*, *A. opercularis* and starfish (*Marthasterias glacialis*).

Table 4.19 Beam Trawl Sample Summary (52-60m)

Trawl	Location	Length (m)	Orientation SOL-EOL	Bathymetry (m Below LAT) and Topography	Sediment Types	Dominant Fauna
T12	Regional Offshore Area	440	W-E	52-54m flat	PEBBLE	*P. longicornis*, *A. opercularis* and spidercrabs (*Macropodia tenuirostris*)
T02	Original Wave Hub Deployment Area	510	W-E	54-58m topographically compex with filled gulleys	Shell and coarse SAND and bedrock outcrops	*A. opercularis* and the sea urchins (*Psammechinus miliaris* and *Echinus esculentus*)
T11	Regional Offshore Area	820	W-E	54-56m raised outcrops with flat areas in between	PEBBLE and bedrock outcrops	*A. bifida* and *O. fragilis*.
T01	Original Wave Hub Deployment Area	510	E-W	56-58m topographically compex with filled gulleys	Shell, coarse SAND and bedrock outcrops	Hermit crabs (*Pagurus prideaux*) and their commensal anemones (*Adamsia carcinopados*) and *A. opercularis.*
T10	Regional Offshore Area	460	W-E	56-58m flat	Shell and coarse SAND	*A. opercularis* extremely dominant.
T06	Regional Offshore Area	520	W-E	58-60m flat	Shell and coarse SAND	*P. prideaux* (with *A. carcinopados*) and *A. opercularis.*
T05	Regional Offshore Area	480	W-E	58-60m flat	Shell and coarse SAND	Shrimps (*Pandalina brevirostris*), *P. prideaux* (with *A. carcinopados*) and *E. esculentus.*
T07	Regional Offshore Area	500	E-W	58-60m flat	Shell and coarse SAND	*E. esculentus* and *P. prideaux* (with *A. carcinopados*).
T09	Regional Offshore Area	490	W-E	58-60m flat	Shell and coarse SAND	*P. prideaux* (with *A. carcinopados*) and starfish (*Asterias rubens*).
T08	Original Wave Hub Deployment Area	520	W-E	60m flat	Shell and coarse SAND	*A. opercularis* extremely dominant.

Colonial Epifauna and Macrophytes

In accordance with OSPAR Commission guidelines (OSPAR Commission, 2004) the colonial fauna and plants found were recorded, but not included in univariate or multivariate community analyses. Of the 27 colonial taxa recorded, two were labels for incomplete colonies that may be represented elsewhere in the data (PORIFERA and Sertulariidae), and were therefore excluded from this analysis. Of these taxa found 14 (56%) were bryozoa, 6 (24%) were cnidaria, 4 (16%) were porifera, and 1 (4%) was a chordate. The five plant taxa were not considered as they represented fragments that had probably been washed into sampling locations. The frequency and abundance of the ten most frequently occurring colonial taxa are listed in Table 4.20 with the mode and maximum abundance shown. The SACFOR scale is used for classifying abundance.

Table 4.20 Frequency and Abundance of the Ten Most Frequently Occurring Colonial Taxa

Taxon	Frequency	% Frequency	Mode abundance	Maximum abundance
Cellaria sp.	13	65	Occasional	Abundant
Amathia lendigera	13	65	Occasional	Occasional
Nemertesia antennina	11	55	Occasional	Frequent
Hydrallmania falcata	11	55	Occasional	Occasional
Alcyonidium diaphanum	9	45	Occasional	Occasional
Pentapora foliacea	8	40	Rare	Superabundant
Schizomavella cristata	8	40	Rare	Rare
Alcyonium digitatum	7	35	Rare	Rare
Stelligera stuposa	6	30	Occasional	Occasional
Halichondria panicea	3	15	Rare	Occasional

The most frequently encountered colonial taxa in the trawl samples were bryozoans *Amathia lendigera* and *Cellaria* sp., both found in 65% of the samples (Table 4.20). The hydroid species *Hydrallmania falcata* and *Nemertesia antennina* were the next most frequently encountered taxa, being found in 55% of the samples.

The bryozoan *Pentapora foliacea* was the only species found in superabundance (sample T14). It was also found to be abundant in sample T15. *P. foliacea* forms large honeycomb-like structures up to 2m in diameter composed of bilaminar sheets of zooids. It is restricted, at least in its massive form, to bedrock and boulder substrates (Hayward and Ryland, 1999). The bryozoan *Flustra foliacea* was found in abundance along with *P. foliacea* at T15 and the bryozoan *Cellaria sp.* was found to be abundant at T6.

The most obvious trend in colonial epifauna distribution was the restriction of all but seven of the taxa to samples T1-T15. This can be attributed to the reduced amount of hard substratum available for attachment at the predominantly sandy nearshore stations.

Free-living fauna

Newly settled juveniles of benthic species may at times dominate the macrofauna, but due to heavy natural post-settlement mortality, they should be considered an ephemeral component and not representative of prevailing bottom conditions. In this survey eight (5%) of the solitary taxa found were juvenile. The subsequent analysis was undertaken on data that excluded juveniles, in keeping with the procedures recommended by OSPAR (OSPAR Commission, 2004).

To prevent potential replication, the dataset was further refined by the removal of 4 taxa that represented damaged specimens, 6 epilithic taxa could not practically be enumerated [recorded as present (P) in the dataset] were also removed. At the nearshore trawls the crab *Polybius henslowi* was recorded in high abundance. *P. henslowi* is an epipelagic deep-sea species, 'enormous numbers' of which can be washed ashore after storms (Lincoln, 1996); as an ephemeral community component this species has also been excluded from the analysis.

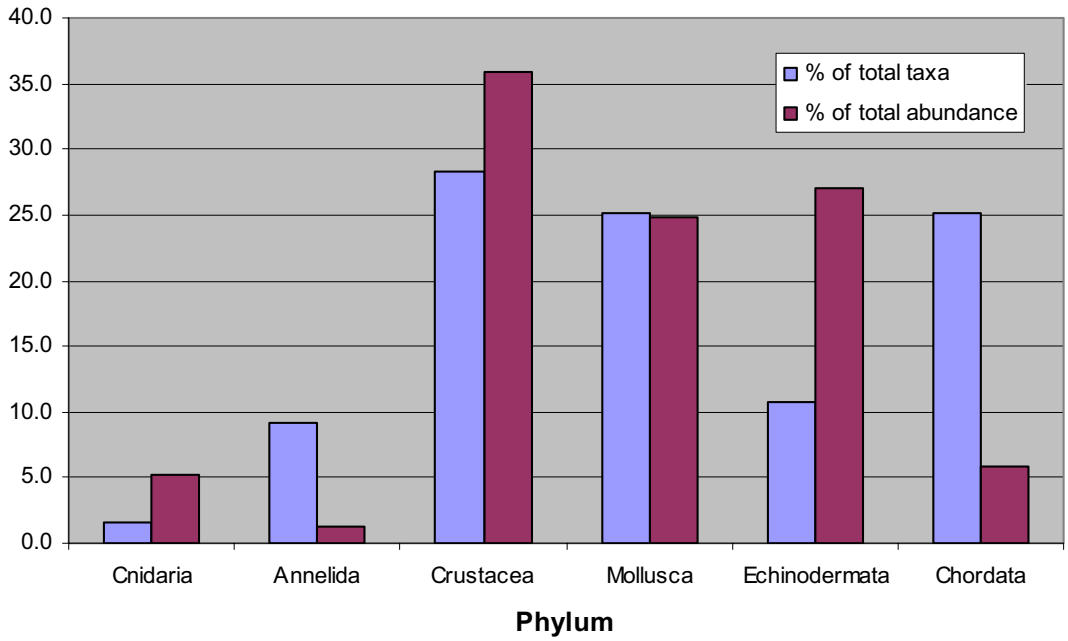
Of the phyla represented, the crustacea contributed both the greatest proportion of species (28.2%) and greatest total abundance (35.9%) (Table 4.21 and Figure 4.35). The echinodermata were the next most abundant phylum (contributing 27% of the total), but were only the fourth highest contributor to the total

number of taxa (10.7%). This disparity can largely be attributed to the high abundances of 3 species (*Antedon bifida*, *Ophiothrix fragils* and *Echinus esculentus*) which made up 66% of the echinoderm total.

Table 4.21 Abundance of Taxonomic Groups

Phylum	Number of taxa	% of total taxa	Abundance	% of total abundance
Cnidaria	2	1.50	145	5.10
Annelida	12	9.20	34	1.20
Crustacea	37	28.2	1011	35.9
Mollusca	33	25.2	700	24.8
Echinodermata	14	10.7	760	27.0
Chordata	33	25.2	167	5.90
Total	**131**	**100**	**2817**	**100**

Figure 4.35 Abundance of Taxonomic Groups



Summary information for the ten most dominant taxa found are presented in Table 4.22. The mollusc *Aequipecten opercularis* (queen scallop) was the most abundant taxon overall, 496 individuals of this species were recorded, over twice as many as the next most abundant species. *Pisidia longicornis* (225 individuals), *Pagurus prideaux* (218), *Antedon bifida* (179) and *Ophiothrix fragilis* (166) were the next most abundant. The remainder of the ten most dominant taxa comprised 2 echinoderm species, a cnidarian and a crustacean. It should be noted that the cnidarian, *Adamsia carcinopados*, is a commensal species on the shell of *P. prideaux*, a prevalent hermit crab.

The rank dominance for each taxon was calculated by ranking the species present at each station according to abundance and then giving a rank score to each species; 1 to the most abundant taxon, increasing for each subsequent taxon. The total rank score for each taxon across all stations gave the ten most dominant taxa i.e. those taxa achieving the ten lowest rank scores (modified from Eleftheriou & Basford, 1989).

The ten most abundant taxa occupied a frequency range of 40-75%, with rank dominance not corresponding to rank abundance; for example *Pisidia longicornis* was the second most abundant species, but had a rank dominance of 8, indicating that the high abundance was produced from few samples. An even more pronounced disparity was evident for the shrimp *Pandalina brevirostris*, the ninth most abundant taxon overall with a rank dominance of nineteen. This was caused by its absence from 12

of the 20 samples (60%), but the high abundance where found (63 individuals were collected from trawl 4).

Table 4.22 Ten Most Dominant Taxa by Abundance, Frequency and Rank Dominance

Taxon	Rank abundance	Total abundance	Frequency %	Rank dominance
Aequipecten opercularis	1	496	75	1
Pisidia longicornis	2	225	60	8
Pagurus prideaux	3	218	60	3
Antedon bifida	4	179	50	15
Ophiothrix fragilis	5	166	75	6
Echinus esculentus	6	157	65	2
Adamsia carciniopados	7	144	50	7
Psammechinus miliaris	8	95	70	5
Pandalina brevirostris	9	81	40	19
Macropodia tenuirostris	10	71	70	4

Only 23 of the 159 taxa encountered in the survey occurred at an average abundance of >1 individual per trawl and 39 taxa occurred only once throughout the entire survey. The apparent patchiness in the distribution is likely to result from the heterogeneity of the survey area as a whole; bathymetry varied considerably between the nearshore and offshore sections of the site and a wide range of sediment types were sampled.

Univariate Community Analysis

Abundance and species number together with community measures of evenness (J'), richness (D_{Mg}), dominance (1-λ) and Shannon-Weiner diversity (H') were calculated for each sample using the PRIMER v 6.0 DIVERSE procedure (Table 4.23) (Clarke & Warwick, 2001).

Evenness (J′) (Pielou, 1969) is a measure of equitability (how evenly individuals are distributed among species). Low evenness indicates that a sample is dominated by few abundant species whereas high evenness means that abundance is spread more equally among constituent taxa. The Shannon-Weiner Index (H′) (Shannon & Weaver, 1949) combines components of species richness and evenness to calculate a measure of diversity (summary in Magurran, 1988).]

The univariate parameters calculated for the trawl samples are presented in Table 4.23. The number of taxa per sample ranged from 8 to 45 (samples T19 and T5, respectively), faunal abundance from 14 to 341 individuals (T20 and T5), richness from 2.23 to 7.54 (T19 to T5), equitability from 0.392 to 0.979 (T10 to T18), Shannon-Weiner diversity from 1.82 to 4.31 (T10 to T5) and the reciprocal of dominance from 0.416 to 0.926 (T10 to T18) (Table 4.23). Of the top five samples in terms of abundance, three samples (T5, T2 and T6) were also in the top five with regard to the number of taxa present. The relatively high richness, diversity and equitability and the low dominance calculated for these show that abundance was evenly distributed among the taxa. In the other two samples in the top five in abundance terms (T11 and T10), a few dominant taxa were shown to contribute most of the abundance. This was particularly pronounced in station T10, where the massive contribution of *A. opercularis* depressed equitability, diversity and the reciprocal of dominance to the lowest level levels seen. The high standard deviations seen for all of the univariate measures calculated show that there was a great deal of variation between samples.

Table 4.23 Primary and Univariate Parameters by Trawl Sample

Station	Number of taxa S	Abundance N	Richness d	Equitability J'	Shannon-Weiner H' (log_2)	Simpson's D 1-λ
T1	32	148	6.20	0.795	3.98	0.901
T2	37	282	6.38	0.760	3.96	0.894
T3	28	168	5.27	0.751	3.61	0.858
T4	21	100	4.34	0.765	3.36	0.855
T5	45	341	7.54	0.784	4.31	0.916
T6	40	237	7.13	0.772	4.11	0.896
T7	33	166	6.26	0.822	4.14	0.912
T8	24	169	4.48	0.461	2.11	0.498
T9	27	148	5.20	0.832	3.96	0.909
T10	25	210	4.49	0.392	1.82	0.416
T11	26	254	4.51	0.607	2.85	0.755
T12	26	120	5.22	0.742	3.49	0.825
T13	17	33	4.58	0.830	3.39	0.836
T14	24	167	4.49	0.726	3.33	0.849
T15	22	38	5.77	0.911	4.06	0.921
T16	16	66	3.58	0.736	2.94	0.787
T17	25	111	5.10	0.774	3.59	0.857
T18	15	22	4.53	0.979	3.82	0.926
T19	8	23	2.23	0.782	2.35	0.718
T20	10	14	3.41	0.942	3.13	0.867
Mean	***25***	***141***	***5.04***	***0.758***	***3.42***	***0.820***
SD	***9***	***93***	***1.27***	***0.140***	***0.70***	***0.137***

SD. = standard deviation of the dataset

Multivariate Analysis

Multivariate analysis of data allows a more thorough examination of differences between sites that cannot be achieved by examination of univariate measures alone. Multivariate analysis preserves the identity of species when calculating similarities between samples, whereas this information is lost when computing univariate measures. In order to compensate for the variation in trawl length, the abundance data were standardised to density of individuals per $1000m^2$ (the area that would be covered by a 500m trawl).

Analysis was undertaken using the Plymouth Routines in Multivariate Ecological Research (PRIMER) v6.0 statistical package (Clarke & Warwick, 2001). Two techniques have been used here to identify relationships within the community data: cluster analysis produces a dendrogram displaying relationships between samples based on Bray-Curtis similarity measures; non-metric multi-dimensional scaling (nMDS) represents similarities between samples as a 2-dimensional ordination.

Transformation was necessary to weight common and rare species contribution for non-parametric multivariate representation. A $\sqrt[4]{}$ transformation was applied prior to analysis to take account of rarer species, as abundance varied by two orders of magnitude between species and samples. The resultant plots are displayed in Figures 4.36 and 4.37.

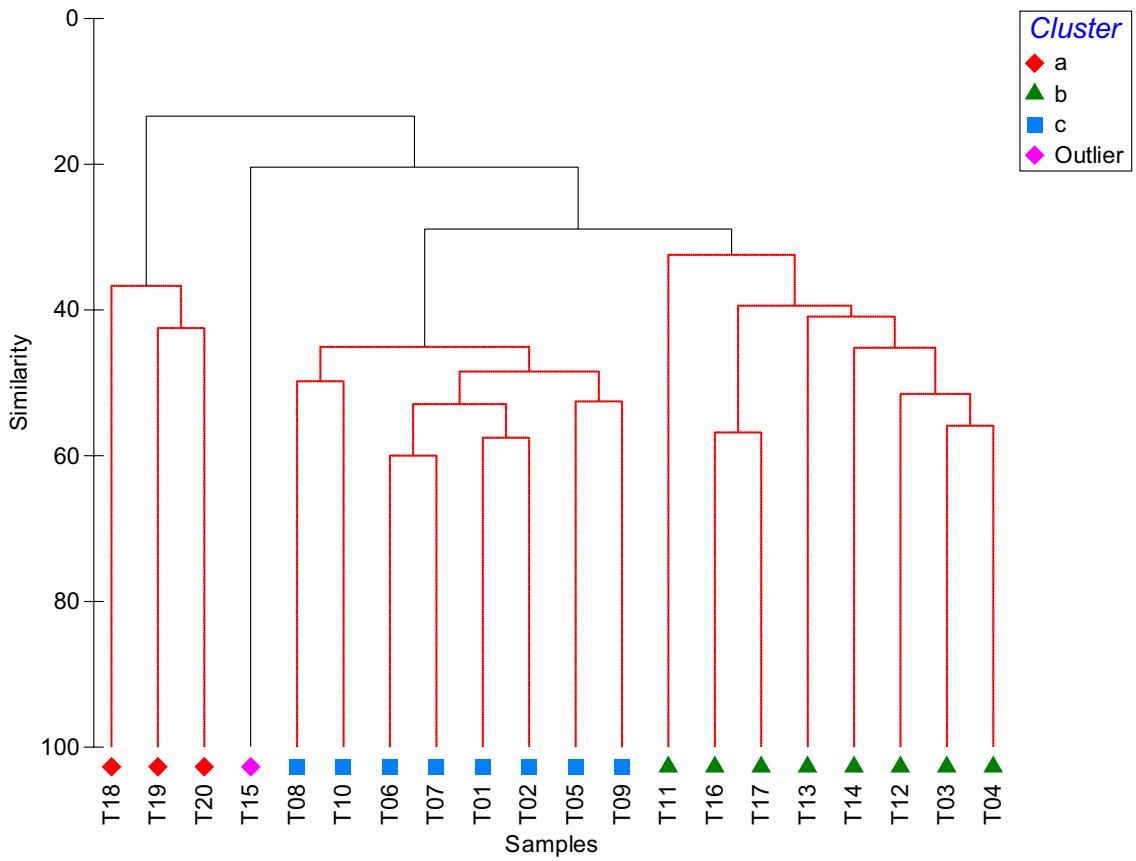


Figure 4.36 **Dendrogram of all Samples by Bray-Curtis Similarity on Fourth Root Transformed Data**

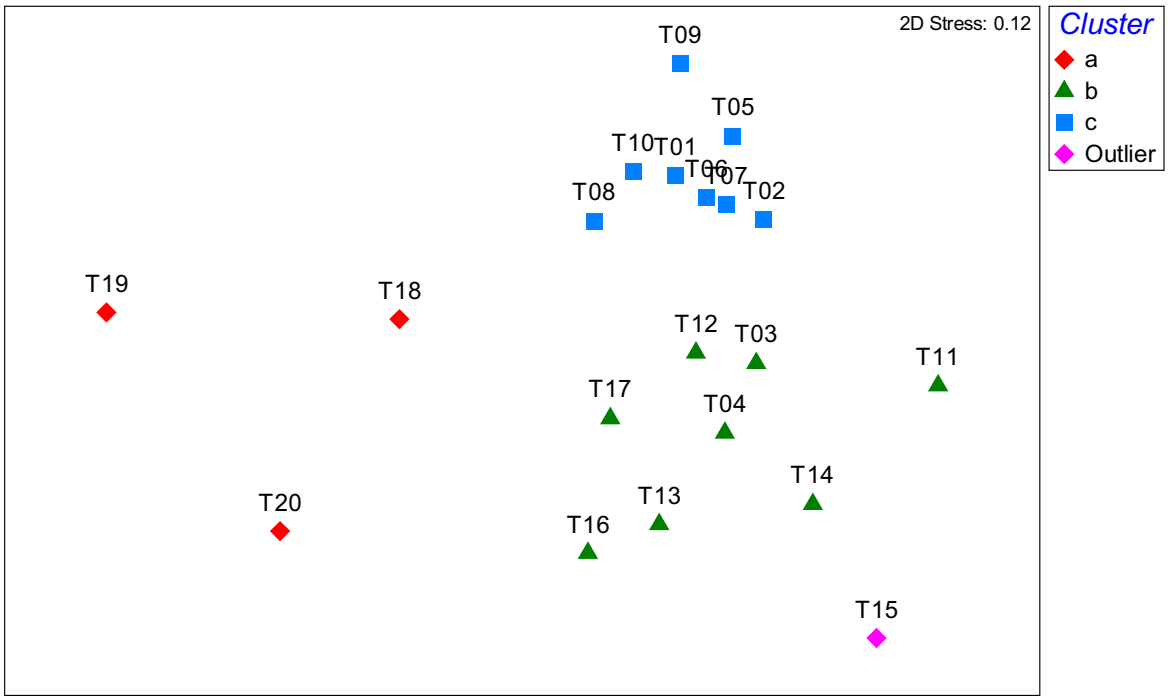


Figure 4.37 **Non-Metric Multidimensional Scaling Analysis of all Samples by Bray Curtis Similarity on Fourth Root Transformed Data**

The dendrogram presented in Figure 4.36 shows patterns in sample similarities. The red colouration is a product of the SIMPROF procedure and indicates three statistically significant groupings (clusters) of samples at the 5% significance level. Cluster A is composed of samples T1, T2 and T5 to T10. The dendrogram shows that these samples are at least 45.1% similar, as determined by the Bray-Curtis similarity index. Cluster B is made up of samples T3, T4, T11 to T14, T16 and T17 (minimum similarity 32.5%) and cluster C is composed of samples T18 to T20 (minimum similarity 36.7%). Sample T15 was shown to be an outlier as it did not group with any of the other stations in a statistically significant manner.

The clusters denoted in Figure 3.36 were defined to a varying degree in the nMDS ordination plot (Figure 4.37). Cluster C is the best defined in the plot as it has the greatest shared similarity. Clusters A and B are much less tightly grouped. A stress factor of 0.12 indicates a good representation of the data with a low probability of misinterpretation.

Similarity percentage analysis (SIMPER) was run on the groupings identified in dendrogram and MDS ordinations; this routine identifies those species that contribute most highly to similarity within clusters.

Table 4.24 SIMPER Results for Cluster A Trawls

Taxon	√√ Transformed Mean Abundance	Non-Transformed Mean Abundance	Average Similarity	Similarity /SD	Similarity Contribution (%)	Similarity Cumulative Contribution (%)
Pomatoschistus sp.	1.44	5.33	10.3	4.46	26.7	26.7
Solea solea	1.00	1.00	8.34	6.20	21.5	48.2
Eutrigla gurnardus	0.67	0.67	3.29	0.58	8.49	56.7
Pleuronectes platessa	0.67	0.67	3.29	0.58	8.49	65.1
Callionymus lyra	0.79	1.33	3.06	0.58	7.88	73.0
Ophiothrix fragilis	0.84	1.67	2.94	0.58	7.59	80.6
Sepiola atlantica	0.80	1.67	2.57	0.58	6.63	87.2
Pisidia longicornis	0.73	1.00	2.47	0.58	6.38	93.6
Inachus phalangium	0.73	1.00	2.47	0.58	6.38	100

Table 4.25 SIMPER Results for Cluster B Trawls

Taxon	√√ Transformed Mean Abundance	Non-Transformed Mean Abundance	Average Similarity	Similarity /SD	Similarity Contribution (%)	Similarity Cumulative Contribution (%)
Pisidia longicornis	2.02	26.6	5.71	1.66	13.9	13.9
Ophiothrix fragilis	1.89	18.8	5.3	4.48	12.9	26.9
Psammechinus miliaris	1.15	2.00	3.59	7.18	8.77	35.7
Aequipecten opercularis	1.48	9.25	3.58	1.67	8.75	44.4
Inachus phalangium	1.08	2.50	2.91	1.57	7.10	51.5
Antedon bifida	1.46	21.25	2.39	0.97	5.84	57.3
Macropodia tenuirostris	0.99	3.25	1.96	1.01	4.79	62.1
Xantho pilipes	0.82	1.88	1.67	0.72	4.08	66.2
Ebalia tuberosa	0.79	2.00	1.31	0.71	3.21	69.4
Anapagurus hyndmanni	0.65	0.75	1.21	0.72	2.96	72.4

Table 4.26 SIMPER Results for Cluster C Trawls

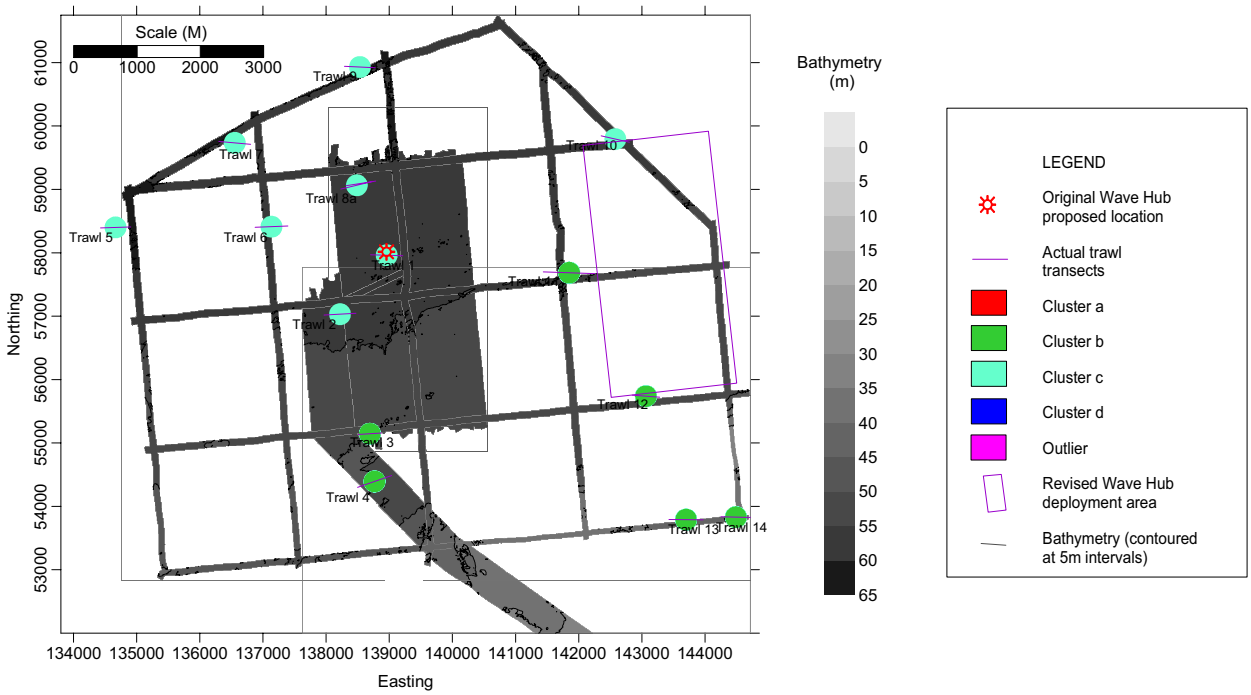
Taxon	√√ Transformed Mean Abundance	Non-Transformed Mean Abundance	Average Similarity	Similarity /SD	Similarity Contribution (%)	Similarity Cumulative Contribution (%)
Aequipecten opercularis	2.36	52.7	4.34	2.32	8.92	8.92
Pagurus prideaux	2.11	26.1	4.07	4.94	8.37	17.29
Echinus esculentus	1.9	17.1	3.72	7.72	7.64	24.93
Asterias rubens	1.65	8.38	3.51	4.88	7.21	32.14
Macropodia tenuirostris	1.49	5.63	3.12	7.35	6.42	38.56
Adamsia carciniopados	1.78	17.0	3.01	1.62	6.18	44.74
Glycymeris glycymeris	1.35	4.75	2.66	3.78	5.47	50.21
Pandalus montagui	1.30	3.75	2.63	5.44	5.41	55.61
Ebalia tuberosa	1.17	3.38	1.95	1.65	4.01	59.62
Macropodia linaresi	1.11	3.00	1.87	1.57	3.84	63.47

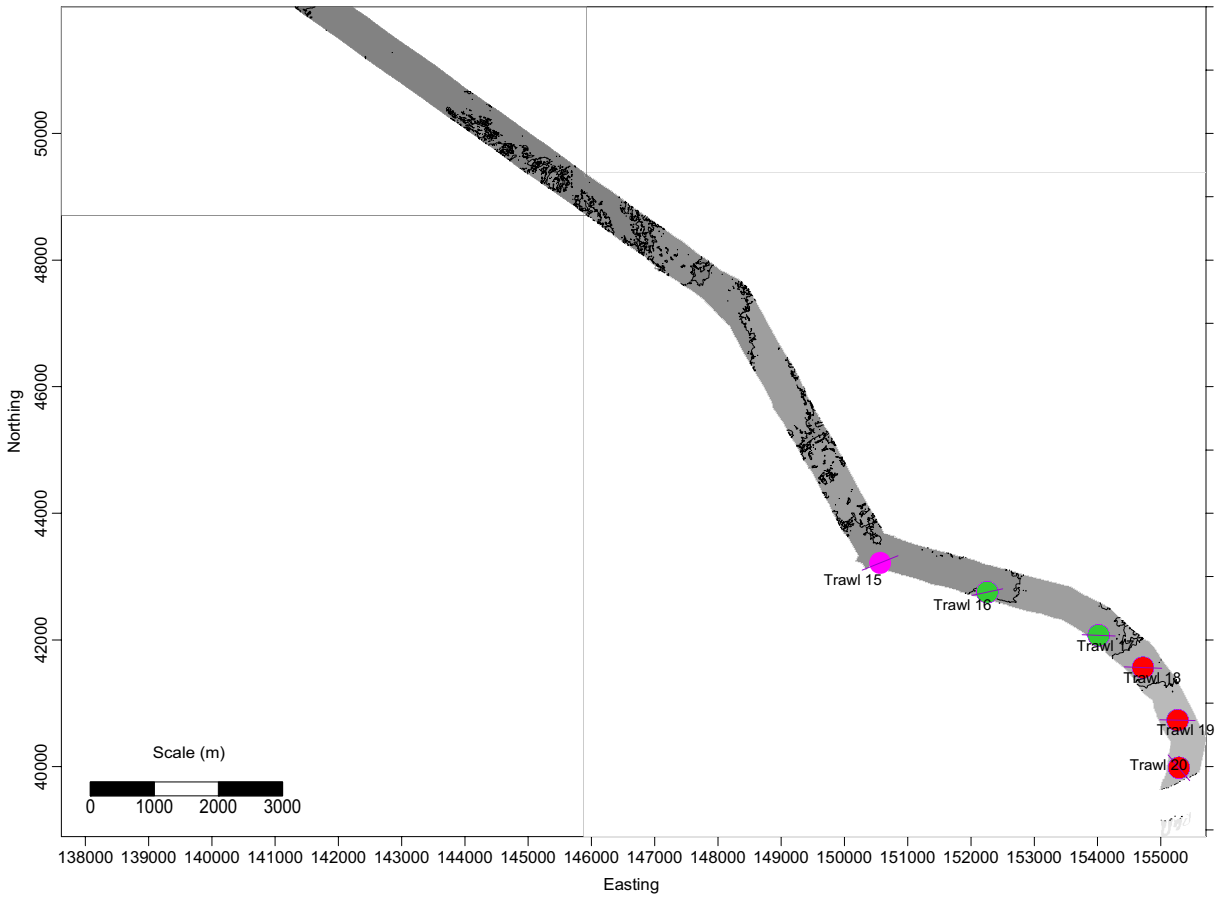
The cluster a samples were shown to have an average similarity of 38.8%.This cluster was characterised by two fish taxa; sand gobies of the genus *Pomatoschistus* and sole, *Solea solea*. The low diversity of these samples was evident as only nine taxa contributed all of the cluster's similarity. The remaining 14 species were only present in one of the three samples. Cluster B (average similarity 41.0%) was shown to be characterised by the anomuran crustacean, *Pisidia longicornis* and the brittlestar, *Ophithrix fragilis*. Cumulatively, these species contributed just fewer than 27% of the cluster's total similarity.

SIMPER analysis showed that cluster c had a shared similarity of 48.6%. The species that contributed most significantly to this was the queen scallop, *A. opercularis*. High abundance of this species within the samples (52.75 individuals on average) can therefore be considered characteristic of the cluster. The hermit crab, *P. prideaux* was found to make the second highest contribution to cluster c similarity followed by the echinoderms, *Echinus esculentus* and *Asterias rubens*. The characterising taxa for cluster c showed a more evenly distributed contribution to similarity than those of clusters a and b, where two taxa contributed a large proportion of the total.

There was an average dissimilarity of 82.3% between cluster c and station T15. The greatest contributions to the dissimilarity were made by *A. opercularis* and *P. prideaux*, both absent from T15 samples. The characterising taxon of cluster b, *P. longicornis,* was also not present at T15 and correspondingly contributed most to the 76.1% dissimilarity found. It was the presence of the crustaceans *Pilumnus hirtellus* and *Galathea nexa* in T15, which contributed most of the 91.6% dissimilarity between the station and cluster a. SIMPER showed that five species found in T15 were exclusive to this sample, the gastropod *Ocenebra erinacea*, starfish *Henricia oculata* and fish *Myxocephalus scorpius*, *Agonus cataphractu*s and *Pholis gunnellus*; only one specimen of each species was present.

Figure 4.38 Cluster Analysis - Trawls Epifauna





4.8 Seabed Photography

4.8.1 General Description

Underwater video/ stills were acquired for 18 continuous camera transects. The changes in substrate and benthic community identified are summarised in Table 4.27. The positions of the camera transects are presented in Charts 1 to 19 (transect 12 is divided into 2 charts, 12 A and 12B), alongside selected stills photographs. The completed logs for the camera transects are presented in Appendix D.

A preliminary biotope assessment was made in the field after completion of the grab sampling and beam trawl sampling. Seabed photography transects were positioned and prioritised by examination of this in conjunction with bathymetric and seabed features. All except three of the camera transects were between 450 and 650m in length; the exceptions were transect 16, where a shorter ~370m transect was deemed adequate to investigate a GRAVEL filled gully near the proposed Wave Hub location and transects 8 and 12 (~800m and ~1500m, respectively), which were positioned to investigate more wide scale seabed change. Transect 8 was specifically placed to determine the extent of a *Pentapora foliacea* dominated area that had been identified by trawl sampling. Transect 13 was positioned to investigate the effect of deepening bathymetry on community structure on a bedrock outcrop.

The orientation of the camera transects was largely determined by the tidal and weather conditions at the time of their investigation. As a result of this photograph numbering does not increase in a manner consistent with increasing bathymetry or, in the case of the cable route, with increasing KP.

Digital copies of all photographs, including close-up photographs, are included on a CD-ROM attached within volume III, Appendices. DVDs of video footage from all transects have also been supplied.

Table 4.27 Summary Table showing the Location, Sediment Type and Dominant Flora/ Fauna along the Camera Transects

Transect	Location	Orientation	Bathymetry (m below LAT)	Distance (m)	Sediment Type	Dominant Fauna
1	NSCR	NW-SE	12m	0-580	Fine SAND	None
2	NSCR	NW-SE	16-18m	0-350	Small COBBLES	*Nemertesia spp.* (thecate hydroid)
				350-580	Fine SAND	None
3	NSCR	W-E	24m	0-530	Medium COBBLES	None
4	NSCR	SE-NW	26m	0-15	Medium COBBLES	None
				15-530	Exposed BEDROCK	*Pentapora fascialis* (bryzoan) and *Alcyonium digitatum* ('Dead man's fingers' – anthozoan)
				530-550	ROCK outcrop	P. fascialis
5	OSCR	SE-NW	26-28m	0-10	ROCK outcrop	*Echinus esculentus* (sea urchin) and *Cliona celata* (sponge)
				10-565	Medium COBBLES	None
				565-575	Coarse SAND and small COBBLES	None
6	OSCR	NW-SE	30-32m	0-190	BEDROCK with thin layer of GRAVEL	None
				190-535	ROCK outcrop	Super-abundant *Ophiothrix fragilis* (brittle star)
				535-650	BEDROCK	*C. celata, O. fragilis* and *Ophiocoma nigra* (brittle star)
7	OSCR	NW-SE	38-40m	0-550	BEDROCK with GRAVEL	None
8	ORA	W-E	42m	0-800	Medium COBBLES	*O.fragilis* and *Pisidia longicornis* (crab)
9	ORA	S-N	52m	0-45	ROCK outcrop	Crisiidae (bryozoan), *Nemertesia antennina* ('Sea beard' – thecate hydroid) and *Polymastia boletiformis* (sponge)
				45-70	Coarse shelly SAND	None
				70-450	COBBLES	Abundant *P. longicornis*
10	ORA	SE-NW	54m	0-130	Coarse SAND	*Aeqipecten opercularis* ('Queen scallop' – bivalve)
				130-175	Medium COBBLES (many bivalve shells)	
				175-260	BEDROCK	
				260-300	Coarse SAND	None
				300-535	ROCK outcrop	Patches of super-abundant *O. fragilis*
11	ORA	W-E	58m	0-275	Coarse shelly SAND	None
				275-445	BEDROCK covered by sand	Crisiidae and *Cellaria sp.* (bryzoan)
				445-500	Coarse shelly SAND	None

Table 4.27 (cont'd) Summary Table showing the Location, Sediment Type and Dominant Flora/ Fauna along the Camera Transects

Transect	Location	Orientation	Bathymetry (m below LAT)	Distance (m)	Sediment Type	Dominant Fauna
12	ORA	S-N	50-52m	0-10	Exposed BEDROCK	*P. fascialis*
				10-880	GRAVEL over BEDROCK	*O. nigra* and *E. esculentus*
				880-945	Prominent ROCK outcrop	Abundant *Antedon bifida* (feather star), *Cellaria sp.*, *E. esculentus and crisiidae*
				945-1120	ROCK outcrop with coarse SAND	*A. bifida, N. antennina, E. esculentus, A. opercularis, P. fascialis, Ciocalypta penicilus* (sponge) and crisiidae
				1120-1270	Coarse shelly SAND	None
				1270-1395	BEDROCK	*A. bifida, E. esculentus, A. digitatum* and *C. celata*
				1395-1485	Coarse SAND	Abundant crisiidae and *Cellaria sp.*
13	ORA	S-N	50m	0-405	Medium COBBLES	Super-abundant *A. bifida*, abundant *O. fragilis, A. opercularis* and *P. longicornis*
				405-435	BEDROCK with COBBLES	Super-abundant *A. bifida*
				435-530	Medium COBBLES	Abundant *A. bifida* and *O. fragilis*
14	OWHDA	SW-NE	50-52m	0-560	GRAVEL over small (<5m) exposed BEDROCK patches	*N. antennina*
				560-580	BEDROCK	None
				580-595	Course SAND and small PEBBLES	
				595-600	BEDROCK	
15	OWHDA	SE-NW	52-54m	0-160	Coarse SAND	None
				160-340	COBBLES (bivalve shells) overlying coarse shelly SAND	*A. opercularis* and *Nemertesia spp.*
				340-475	Coarse shelly SAND	None
				475-490	ROCK outcrop	*A. bifida, O. nigra* and *E. esculentus*
16	OWHDA	NW-SE	54-52m	0-185	Course shelly SAND	*A. opercularis*
				185-370	COBBLES (all bivalve shells)	None
				370-375	ROCK outcrop (into distance)	
17	OWHDA	S-N	50-52m	0-160	Medium COBBLES	Abundant *P. longicornis, Stelligera stuposa* (sponge) and *Marthasterias gracialis* (starfish)
				160-210	ROCK outcrop	Abundant *A. bifida, E. esculentus* and *C. celata*
				210-485	Small COBBLES	*E. esculentus*
				485-550	ROCK outcrop	Abundant *O. nigra, A. bifida* and *E. esculentus* (and patch of abundant *Corynactis viridis* ('Jewel anemone'))

Table 4.27 (cont'd) Summary Table showing the Location, Sediment Type and Dominant Flora/ Fauna along the Camera Transects

Transect	Location	Orientation	Bathymetry (m below LAT)	Distance (m)	Sediment Type	Dominant Fauna
18	OSCR	SE-NW	46-50m	0-195	ROCK outcrop with coarse SAND	Super-abundant *O. nigra* and *E. esculentus*
						Abundant crisiidae, *Cellaria sp.*, *A. bifida* and *A. digitatum*
				195-460	BEDROCK	Super abundant *A. bifida*
				460-490	Medium COBBLES	Abundant *O. fragilis*
				490-525		*A. bifida*
						Abundant *P. longicornis*

NSCR = Nearshore Cable Route; OSCR = Offshore Cable Route; OWHDA = Original Wave Hub Development Area; ORA = Offshore Regional Area

4.8.2 Camera transect descriptions

Cam1
Well sorted sand ripples for entire transect. Only visible fauna was 1 *Pagarus* sp.

Cam 2
Substratum was diverse across transect, but fauna only ever appeared in low numbers. First ~250m was composed of poorly sorted large and small cobbles. 1 *Pagarus* sp., 1 blenny and some macroalgae were only fauna observed. Remainder of transect was composed of sand waves with several unidentified fish.

One camera drop landed on a bedrock outcrop with high diversity – ascidiacea, *Ciocalypta penicilus* and other turf-like organisms were present.

Cam 3
Substratum composed of cobbles and few large boulders for the entire transect. Fauna was mainly turf-like encrusting organisms (bryozoa, cf *Ciocalypta penicilus* and serpulidae tubes – likely *Pomatoschistus* spp.), and a few *Nemertesia antennina* and *Alcyonium digitatum*.

Cam 4
Substratum diverse across transect with many transitions. First ~440m was poorly sorted large and small cobbles with occasional shingle matrix. No species were obviously dominant. Species present in low numbers included encrusting porifera, brozoa and coralline algae, ascidiacea, *Marthasterias gracialis* and seastar.

Rocky patches with larger boulders were present at 180 and 240m camera drops. Mostly turf-like algae were present.

From 460-540m the substratum went through an obvious transition to sandy sediment with no obvious fauna. A patch of exposed bedrock at 520m was heavily encrusted with fauna, including tunicates and turf-like organisms.

Cam 5
Predominately bedrock, with sporadic covering of large cobbles and boulders. No obviously dominant species. Most gravel was covered with some encrusting bryozoa, porifera, ascidiacea, serpulidae and/or coralline algae. Species present included *Pentapora fascialis*, *Marthasterias gracialis*, cf. *Ciona celata*, Porifera D, *Microcionadae*, *Henricia sanguinalenta*, *Alcyonium digitatum*, *Echinus esculentus*, *Flustra foliacea*, *Nemertesia spp*., *Trisopterus minutus*, *Caryophyllia smithii*, and *Lanice conchilega*.

Cam 6
Bedrock overlain by cobbles and coarse sand along the transect. High diversity, with some encrusting bryozoa, porifera, ascidiacea, serpulidae and/or coralline algae on most surfaces. Species present included cf. *Ciona celata*, *Marthasterias gracialis*, *Ophiothrix fragilis*, *Ophiocoma nigra*, *Eunicella verrucosa*, *Nemertesia antennina*, *Nemertesia ramose*, *Polymastia spp*., *Asterias rubens*, and *Echinus esculentus*.

Massive dominance of *Ophiothrix fragilis* (with some *Ophiocoma nigra* present) at a few drop-down locations; abundant at 380-460m and 140-260m.

Cam 7
Coarse sediment comprising with cobbles and few boulders. Bedrock exposed at 520m, but it is suspected to be present underlying the surficial sediment for much of transect due to presence of certain hydroid species. Species present in low abundance included *Marthasterias glacialis, Flustra foliacea, Anguinella palmata, Eunicella verrucosa, Alcyonium digitatum, Stelligera stuposa, Macropodia sp., Henricia sanguinalenta, Ciocalyptus penicilus* and *Pecten maximus*.

Exposed bedrock (520m) with some encrusting bryozoa, porifera, ascidiacea, serpulidae and/or coralline algae on most surfaces. Some *Pentapora fascialis* present.

Cam 8
Cobbles with few boulders for ~800m, then coarse shelly sand with few cobbles for remaining 40m. Community composition changes dramatically with habitat change. Massive dominance of *Pisidia longicornis* observed at drops at 360, 400 and 600m. The species is very small and may be dominant at other drops, but not apparent from the stills. Other species present in relatively low numbers (<10 per sample) include *Kirchenpaueria sp*., *Nemertesia antennina*, *Galathea sp*., *Flustra foliacea*, Aequipecten opercularis, *Marthasterias gracialis*, *Pilumnus hirtellus*, *Diphasia sp*., *Liocarcinus*/*Polybius sp*., *Atelecyclus rotundatus*, *Pagarus sp*., *Pagarus prideaux*, *Adamsia carcinopagos*, *Lanice conchilega*, *Ophiothrix fragilis*, *Inachus sp*., *Ebalia tuberosa* and some encrusting bryozoa, porifera, ascidiacea, serpulidae and/or coralline algae on most surfaces.

The community on the coarse sand was dominated heavily by *Ophiothrix fragilis* (abundant), with many *Pisidia longicornis* still present and also few *Macropodia sp*., *Pagarus prideaux* and *Adamsia carcinopagos*.

Cam 9
Substratum was bedrock at 0m, changing to coarse sand overlying bedrock at 40m, and consisting of cobbles and boulders from 80-440m. Fauna for the first 40m consists mainly of *Eunicella verrucosa*, with some *Nemertesia antennina*, *Pentapora fascialis*, *Polymastia sp*., cf *Raspailia ramosa*, *Stelligera stuposa* and encrusting bryozoa, porifera, ascidiacea, serpulidae and/or coralline algae.

The cobble community observed for most of the transect was composed of *Pisidia longicornis*, *Alcyonium digitatum*, *Ophiothrix fragilis*, *Caryophylia smithii*, *Inachus sp*., *Pentapora fascialis*, Cf. *Ciona celata*, Porifera D, Cf. Microcionadae, *Nemertesia antennina*, *Nemertesia ramosa*, *Marthasterias gracialis*, *Echinus esculentus*, *Stelligera stuposa*, *Cellaria sp*., *Macropodia sp*. and *Trisopterus minutes*.

Massive dominance of *Pisidia longicornis* observed at 160m; due to the small size of the species, it is expected that dominance at other cobble drops on transect may not be apparent from the stills.

Cam 10
Substratum was highly diverse across the transect: sand for the first 80m; then coarse sediment, pebbles and bivalve shells over bedrock up to 320m; cobbles at 360m; bedrock with sand until 460m; coarse sand waves at 460m; bedrock again at 480m; and coarse shelly sand at 520m.

The biological community up to 360m was composed of serpulidae, hydroids, ophiuroidea, bryzoa and ascidiacea. Identified species were *Echinus esculentus*, *Pilumnus hirtellus* and *Nemertesia antennina*.

The community on cobbles at 360m was composed predominately of *Ophiothrix fragilis* and *Ophiocoma nigra*. Other species present in low numbers (<5) were *Pagarus prodeaux*, *Adamsia carcinpados*, *Ebalia tuberosa* and Aequipecten opercularis.

At 390m, the community was completely dominated by *Ophiothrix fragilis*, with a few actiniaria spp., *Inachus sp*., *Alcyonium digitata* and *Caryophyllia smithii*.

From 460-520m the habitat was typically coarse shelly sand with few organisms. A rock outcrop at 480m was covered with many serpulidae tubes, *Pyura tesselata* and *Stelligera stuposa*, and few *Caryophyllia smithii*, *Alcyonium digitatum, Nemertesia antennina* and *Aequipecten opercularis*.

Cam 11
Sediment composed of coarse shelly sand with a few rock outcrops along transect (60 and 180m). Sand community comprised *Nemertesia sp*., *Nemertesia ramosa*, *Pagarus sp*., *Pagarus prideaux*, *Adamsia carcinopados*, *Eunicella verrucosa*, *Cellaria sp*, ascidiacea spp., *Lanice conchilega*, *Munida rugosa* and *Marthasterias gracialis* in low numbers.

Bedrock community composed of many *Eunicella verrucosa*, some *Cellaria sp*., *Nemertesia antennina*, encrusting bryozoa, *Ciocalypta penicilus*, coralline algae, few *Pentapora fascialis*, *Stelligera stuposa* and *Raspailia ramosa*, 1 *Echinus esculentus* and 1 *Munida rugosa*.

Cam 12
The substrate was comprised of sand for the first 120m, then bedrock up to 600m, followed by patches of coarse sediment overlying bedrock up to 1080m, cobbles and pebbles at 1140m, bedrock from 1220-1380m with overlying coarse sediment at 1260m and 1380m, cobbles and boulders at 1480m, and then bedrock again at 1480m.

Coarse sediment over bedrock (over bedrock) communities comprised *Eunicella verrucosa*, *Nemertesia ramosa*, *Nemertesia antennina*, cf *Ciocalypta penicilus, cf Raspailia ramose,, Galathea sp*., *Pisidia longicornis*, *Marthasterias gracialis*, *Filigrana implexa*, *Ciocalyptus penicilus*, *Lanice conchilega*, *Pagarus sp*., and *Echinus esculentus*.

Bedrock communities were composed of *Eunicella verucosa*, *Nemertesia antennina*, *Nemertesia ramosa*, *Cellaria sp*., *Pentapora fascialis*, cf *Ciocalypta penicilus, cf Raspailia ramosa, cf. Ciona celata, Trisopterus minutus*, serpulidae tubes, *Marthasterias gracialis*, *Ophiothrix fragilis*, *Ctenolabrus rupestris*, *Caryophyllia smithii*, *Pisidia longicornis*, *Alcyonium digitatum*, *Galathea sp*., *Stelligera stuposa*, *Polymastia robusta*, *Antedon bifida*, *Echinus esculentus*, and *Aequipecten opercularis*. Other unidentified encrusting bryozoa, porifera, ascidiacea, serpulidae and/or coralline algae were also present.

Of the bedrock communities, *Cellaria sp*. dominated the assemblage at 600m, *Eunicella verucosa* dominated at 420m, and super-abundant *Antedon bifida* dominated from 160-200m, at 410m, and at 540m.

Cam 13
The sediment was composed of cobbles along the entire transect, except for exposed bedrock at 120m. Species present included *Pisidia longicornis*, *Antedon bifida*, *Ophiothrix fragilis*, *Ophiocoma nigra*, *Cellaria sp*., *Nemertesia sp*., *Pagarus sp*., *Stelligera stuposa*, *Echinus esculentus*, *Inachus sp*., *Marthasterias gracialis*, Aequipecten opercularis and encrusting serpulidae, bryozoa, porifera, ascidiacea, and/or coralline algae. High numbers of *Ophiothrix fragilis*, *Antedon bifida* and *Pisidia longicornis* were present at most points along the transect.

Pisidia longicornis was noticeably dominant in the cobble community from 440-520m. Due to the small size of the species, it is expected that dominance at other cobble drops on transect may not be apparent from the stills.

Antedon bifida was super-abundant and dominant where bedrock was present (260m) and at the drop preceding the bedrock (80m).

Cam 14
The first 540m of the transect comprised coarse shelly sand, before underlying bedrock was exposed at 570-580m, and the substratum became wholly bedrock at 600m.

Only observable components of the sand communities were *Pagarus prideaux* and *Adamsia carcinopados*.

Bedrock communities were composed of macroalgae, porifera, echinodermata and ophiuroidea. Identified components include *Polymastia robusta*, *Eunicella verrucosa*, *Flustra foliacea*, *Alcyonium digitatum*, and encrusting serpulidae tubes, bryozoa, porifera, ascidiacea, and/or coralline algae.

Cam 15
The whole transect was composed of coarse sand and bivalve shell aggregations overlying hard substrate, with exposed bedrock at 100 and 510m.

Sand communities comprised low numbers of *Nemertesia antennina*, Aequipecten opercularis, *Marthasterias gracialis*, *Pagarus sp*., *Trisopterus minutus*, and poorly developed *Pentapora fascialis*.

Bedrock at 180m was colonised by *Adreus fascicularis*, *Nemertesia antennina*, encrusting serpulidae tubes, bryozoa, porifera, ascidiacea, and/or coralline algae. Bedrock at 510m also had high numbers of *Antedon bifida*, and some *Echinus esculentus*, *Lanice conchilega*, *Ophiothrix fragilis* and *Ophiocoma nigra*.

Cam 16
The first 280m of the transect was composed of cobbles and many cobble-sized bivalve shells, before becoming coarse shelly sand and smaller aggregations of dead bivalve shells. Both communities were similar, comprising serpulidae tubes, *Galathea sp*., *Pisidia longicornis*, *Marthasterias gracialis*, *Echinus esculentus* and *Pomatoschistus sp*.

Cam 17
Substratum was bedrock for the initial 60m, then cobbles and bivalve shells for the remaining 480m with a rock outcrop at 320m.

The bedrock community was varied with a few highly abundant taxa. *Corynactis viridis* was not observed during any other part of the survey was super-abundant at 0m. 20m later *Ophiocoma nigra* was highly dominant. Other taxa present on the bedrock included *Echinus esculentus*, Aequipecten opercularis, *Alcyonium digitatum*, *Caryophyllia smithii*, holothuridae, *Filigrana implexa*, encrusting serpulidae tubes, bryozoa, porifera, ascidiacea, and coralline algae. The rock outcrop at 320m also had *Marthasterias gracialis, Antedon bifida,* and many *Echinus esculentus*.

Taxa present in the cobble community were *Pomatoschistus sp*., *Marthasterias gracialis*, *Alcyonium digitatum*, Aequipecten opercularis, *Henricia sanguinolenta*, *Pisidia longicornis*, *Pagarus sp*., *Stelligera stuposa*, *Ophiothrix fragilis*, *Ophiocoma nigra*, and encrusting serpulidae tubes, bryozoa, porifera, and ascidiacea.

Cam 18
The subtrate was composed of cobbles for the first 280m, then bedrock from 320-480m, and coarse shelly sand at 520m.

The cobble community was varied with a few highly abundant taxa. *Antedon bifida* was abundant at 80m and *Pisidia longicornis* was super-abundant at 120 and 200m. Due to the small size of the species, it is expected that dominance at other cobble drops on transect may not be apparent from the stills. Other components of the cobble community were serpulidae, *Ophiothrix fragilis, Ophiocoma nigra, Nemertesia antennina, Nemertesia ramosa, Macropodia sp., Galathea sp., Aequipecten opercularis, Cellaria sp*., *Marthasterias gracialis*, *Henricia sanguinalenta*, *Aspitrigla cuculus*, *Halecium sp*., and encrusting serpulidae tubes, bryozoa, porifera, and ascidiacea.

The bedrock community tended to be dominated by two species: Ophiuroidea (mostly *Ophiocoma nigra*) were abundant at 360-400m and at 480m; and *Eunicella verrucosa* were abundant at 425-440m. Other components of the bedrock community included *Diphasia pinaster*, *Cellaria sp*., *Antedon bifida*, *Alcyonium digitatum*, *Henricia sanguinolenta*, *Pilumnus hirtellus*, *Caryophyllia smithii*, Cf. Ciona celata, and encrusting serpulidae tubes, bryozoa, porifera, and ascidiacea.

Only *Stelligera stuposa*, *Eunicella verrucosa* and *Cellaria sp*. were apparent in the course sand community.

Porifera spp.

Porifera A – *Ciocalypta penicilus*

Porifera B – suspected to be *Raspailia ramosa*

Porifera C – cf. *Ciona celata*

Porifera D – could be a number of taxa including *Cliona* sp. and *Haliclona* sp.

Porifera E – cf. *Microcionadae*

5 REFERENCES

1. Blumer, M., Guillard, R.R.L. & Chase, T. 1971. Hydrocarbons in marine phytoplankton. *Mar. Biol.* 8:183-189.
2. Clarke, K.R. & Warwick, R.M. 2001. *PRIMER v 5.0 suite of programs*. Plymouth Marine Laboratory, Natural Environment Research Council, UK.
3. Bray, J.R. & Curtis, J.T. 1957. An ordination of the upland forest communities of Southern Wisconsin. *Ecol. Monogr.* 27: 325-349.
4. Buchanan J.B. 1984. Sediment Analysis. In *Methods for the study of marine benthos*, Ed. by Holme N.A. and McIntyre A.D. Blackwell Scientific Publications, London.
5. Clarke, K.R. & Warwick, R.M.1994. *Changes in marine communities: an approach to statistical analysis and interpretation*. Plymouth. Plymouth Marine Laboratory, Natural Environment Research Council, UK. 144 pp.
6. Clarke, K.R. & Gorley, R.N. 2006. *PRIMER v6: User Manual/ Tutorial*. PRIMER-E: Plymouth.
7. Clifford, H.T. & Stephenson, W. 1975. *An Introduction to numerical classification*. Academic Press, London.
8. Eglinton, G., Gonzalez,. A.G., Hamilton, R.J. & Raphael, R.A. 1962. Hydrocarbon constituents of the wax coatings of plant leaves: a taxonomic survey. *Phytochemistry*. 1: 89-102.
9. Eleftheriou, A. & Basford, D.J. 1989. The macrobenthic infauna of the offshore northern North Sea. *J. Mar. Biol. Ass. UK.* 69: 123-143.
10. English Nature, 2004. The south Western peninsula marine natural area.106pp
11. Folk R.L. & Ward F.C. 1957. Brazos river bar: A study of the significance of grain size parameters. *J. Sediment. Petrol*. 27: 3-26.
12. Hiscock, K. (ed.) 1996. *Marine Nature Conservation Review: rationale and methods*. Joint Nature Conserservation Committee, Peterborough. 167pp.
13. Howson, C.M. & Picton, B.E. 1997. *Directory of the British Marine Fauna and Flora*. Marine Conservation Society. 472pp.
14. Jennings, S., Lancaster, J., Woolmer, A. and Cotter, J. 1999. Distribution, diversity and abundance of epibenthic fauna in the North Sea. *J. Mar. Biol.Ass. UK.* 79:385-399.
15. Lincoln, R.J. & Boxshall, G.A. 1987. *The Cambridge illustrated dictionary of natural history*. Cambridge University Press. Cambridge.
16. Magurran, A. E. 1988. *Ecological diversity and its measurement.* Princeton University Press, Princeton, New Jersey. 179 pp.
17. McDougall, J. 2000. *The significance of hydrocarbons in the surficial sediments from Atlantic Margin regions*. in Atlantic Margin Environmental Surveys of the Seafloor, 1996 & 1998. Atlantic Frontier Environmental Network. CD-Rom.
18. OSPAR Commission, 2004. *OSPAR guidelines for monitoring the environmental impact of offshore oil and gas activities*. Meeting of the OSPAR Offshore Industries Committee (OIC), 15 – 19 March, 2004.
19. Pielou, E.C. 1969. *An introduction to mathematical ecology*. Wiley, New York
20. Shannon, C. E. & Weaver, W. 1949. *The mathematical theory of communication*. University of Illinois Press, Urbana. 117 pp.
21. Simpson, E. H. 1949. Measurement of Diversity. *Nature*. 163: 688.
22. Snelgrove, P.V.R. & Butman, C.A. 1994. Animal-sediment relationships revisited: cause vs. effect. *Oceanography and Marine Biology: an Annual Review.* 32: 111-177.

23. Wong, M.K. & Williams, P.J. le B. 1980. A study of three extraction methods for hydrocarbons in marine sediment. *Mar. Chem.* 9: 183-190.

24. Yim, W.W.S., 1976. Heavy metal accumulation in estuarine sediments in a historical mining Cornwall. *Marine Pollution Bulletin*, 7: 147-150.