2. Data and Methods

This chapter outlines the available physical data sets for the NWMR and NNMR and the process of acquiring additional sediment samples to fill gaps in data coverage. Chapters 2.1 – 2.3 provide details of existing quantitative physical data sets for the NWMR and NNMR that have been used in this study. Chapters 2.4 – 2.7 discuss the procedure for identifying (from both internal and external data repositories), selecting and procuring samples, and generating the grainsize and carbonate data. All of the metadata and assays from the procurement and analysis of the samples are contained in Geoscience Australia's marine samples database, MARS.

2.1. EXISTING PHYSICAL DATA FOR THE NWMR

2.1.1. Bathymetry

Bathymetric data for the EEZ and all smaller divisions within it were derived from classifications of the Australian Bathymetry and Topography Grid (June 2005). The grid is a synthesis of 1.7 billion observed data points, and resolution at any point is equal to or better than 250 m. It provides full coverage of Australia's EEZ including areas under Australian jurisdiction surrounding Macquarie Island and the Australian Territories of Norfolk Island, Christmas Island, and Cocos (Keeling) Islands. The area selected does not include Australia's marine jurisdiction off the Territory of Heard and McDonald Islands and the Australian Antarctic Territory.

Water depths for individual data points and ranges for data points were sourced from original survey documentation. Metadata did not include water depths for around 30% of the total data points used in this study. Depths for these points were generated by intersecting point data with the Australian Bathymetry and Topography Grid.

2.1.2. Geomorphology

Geomorphic province and feature boundaries for the EEZ and all smaller divisions within it were derived from a recent study of the geomorphology of Australia's margin and deep seafloor (Heap and Harris, in press). These boundaries were delineated using the 250 m bathymetry grid and previous local seabed studies. Feature names are based on those endorsed by the International Hydrographic Office (IHO 2001). Features are nested within larger geomorphic provinces of shelf, slope, rise and abyssal plain/deep ocean floor (Table 2.1).

Table 2.1. List of geomorphic provinces and features represented in the NWMR and NNMR (Heap and Harris, in press-a). Original definitions are adapted from IHO (2001), except for sand waves and sand banks, which are from Ashley et al. (1990).

No.	Name	Definition
Geomorphic Provinces		
-	Shelf	Zone adjacent to a continent (or around an island) and extending from the low water line to a depth at which there is usually a marked increase of slope

		towards oceanic depths.
-	Slope	Slope seaward from the shelf edge to the upper edge of a continental rise or the point where there is a general reduction in slope.
-	Rise	Gentle slope rising from the oceanic depths towards the foot of a continental slope.
-	Abyssal Plain/ Deep Ocean Floor (AP/DOF)	Extensive, flat, gently sloping or nearly level region at abyssal depths.

Geomorphic Features

1	Shelf (unassigned)	Area of Shelf Geomorphic Province in which no other geomorphic features have been identified
2	Slope (unassigned)	Area of Slope Geomorphic Province in which no other geomorphic features have been identified
3	Rise (unassigned)	Area of Rise Geomorphic Province in which no other geomorphic features have been identified
4	AP/DOF* (unassigned)	Area of Abyssal Plain/ Deep Ocean Floor Geomorphic Province in which no other geomorphic features have been identified
5	Bank/shoal	Elevation over which the depth of water is relatively shallow but normally sufficient for safe surface navigation. Offshore hazard to surface navigation that is composed of unconsolidated material.
6	Deep/hole/valley	Deep: In oceanography, an obsolete term which was generally restricted to depths greater than 6,000 m. Hole: Local depression, often steep sided, of the sea floor. Valley: Relatively shallow, wide depression, the bottom of which usually has a continuous gradient. This term is generally not used for features that have canyon-like characteristics for a significant portion of their extent.
7	Trench/trough	Trench: Long narrow, characteristically very deep and asymmetrical depression of the sea floor, with relatively steep sides. Trough: Long depression of the sea floor characteristically flat bottomed and steep sided and normally shallower than a trench.
8	Basin	Depression, characteristically in the deep sea floor, more or less equidimensional in plan and of variable extent.
9	Reef	Rock lying at or near the sea surface that may constitute a hazard to surface navigation.
10	Canyon	A relatively narrow, deep depression with steep sides, the bottom of which generally has a continuous slope, developed characteristically on some continental slopes.
11	Knoll/abyssal hills /hill/mountains/peak	Knoll: Relatively small isolated elevation of a rounded shape. Abyssal Hills: Tract, on occasion extensive, of low (100-500 m) elevations on the deep sea floor. Hill: Small isolated elevation. Mountain: Large and complex grouping of ridges and seamounts. Peak: Prominent elevation either pointed or of a very

		limited extent across the summit.
12	Ridge	(a) Long, narrow elevation with steep sides. (b) Long, narrow elevation often separating ocean basins. (c) Linked major mid-oceanic mountain systems of global extent.
13	Seamount	Large isolated elevation, greater than 1000 m in relief above the sea floor, characteristically of conical form
	Guyot	Seamount having a comparatively smooth flat top
14	Pinnacle	High tower or spire-shaped pillar of rock or coral, alone or cresting a summit. It may extend above the surface of the water. It may or may not be a hazard to surface navigation.
15	Plateau	Flat or nearly flat area of considerable extent, dropping off abruptly on one or more sides.
16	Saddle	Broad pass, resembling in shape a riding saddle, in a ridge or between contiguous seamounts.
17	Apron/fan	Apron: Gently dipping featureless surface, underlain primarily by sediment, at the base of any steeper slope. Fan: Relatively smooth, fan-like, depositional feature normally sloping away from the outer termination of a canyon or canyon system.
19	Sill	Sea floor barrier of relatively shallow depth restricting water movement between basins.
20	Terrace	Relatively flat horizontal or gently inclined surface, sometimes long and narrow, which is bounded by a steeper ascending slope on one side and by a steeper descending slope on the opposite side.
21	Tidal sandwave/sand bank	Sandwave: Wave-like bed form made of sand on the sea floor. Sand bank: Submerged bank of sand in a sea or river that may be exposed at low tide.

2.1.3. Sediment Data

A total of 575 samples in the NWMR and 318 in the NNMR with quantitative sediment data were available in the MARS Database prior to this study. These sample locations contained bulk carbonate, grainsize (Wt%; μm) and/or laser grainsize (Vol%; μm) data. Quantitative carbonate data were available for 550 samples in the NWMR and 264 samples in the NNMR. Quantitative grainsize data were available for 557 samples in the NWMR and 313 samples in the NNMR (Fig. 2.1). The samples were sourced from 20 marine surveys conducted between 1959 and 2006 (Table 2.2), and included dredge, grab and core samples. Samples that occur outside of the NWMR were included to supplement scarce data for the abyssal plain /deep ocean floor to capture the full spectrum of environments.

Where quoted, sediment coverage statistics are calculated from textural data only (mud, sand, and gravel fractions). These also reflect the distribution of carbonate data except in the Central Western Shelf Transition around Shark Bay where there exist 11 additional carbonate assays.

All sample and assay data was quality controlled, and those samples that failed to meet the minimum metadata standards outlined in Geoscience Australia's Data Standards, Validation and Release Handbook, 4th Edition (2004) were excluded from the analysis. Only analyses conducted on dredges, grabs or the top 0.1 m of a core and where the gravel, sand and mud fractions totaled 100% +/- 1% were included. Core samples that did not include depth measurements were also excluded, and duplicates were removed. Ongoing quality control of data may have resulted in slight variations between total samples reported in this document and milestone progress reports.

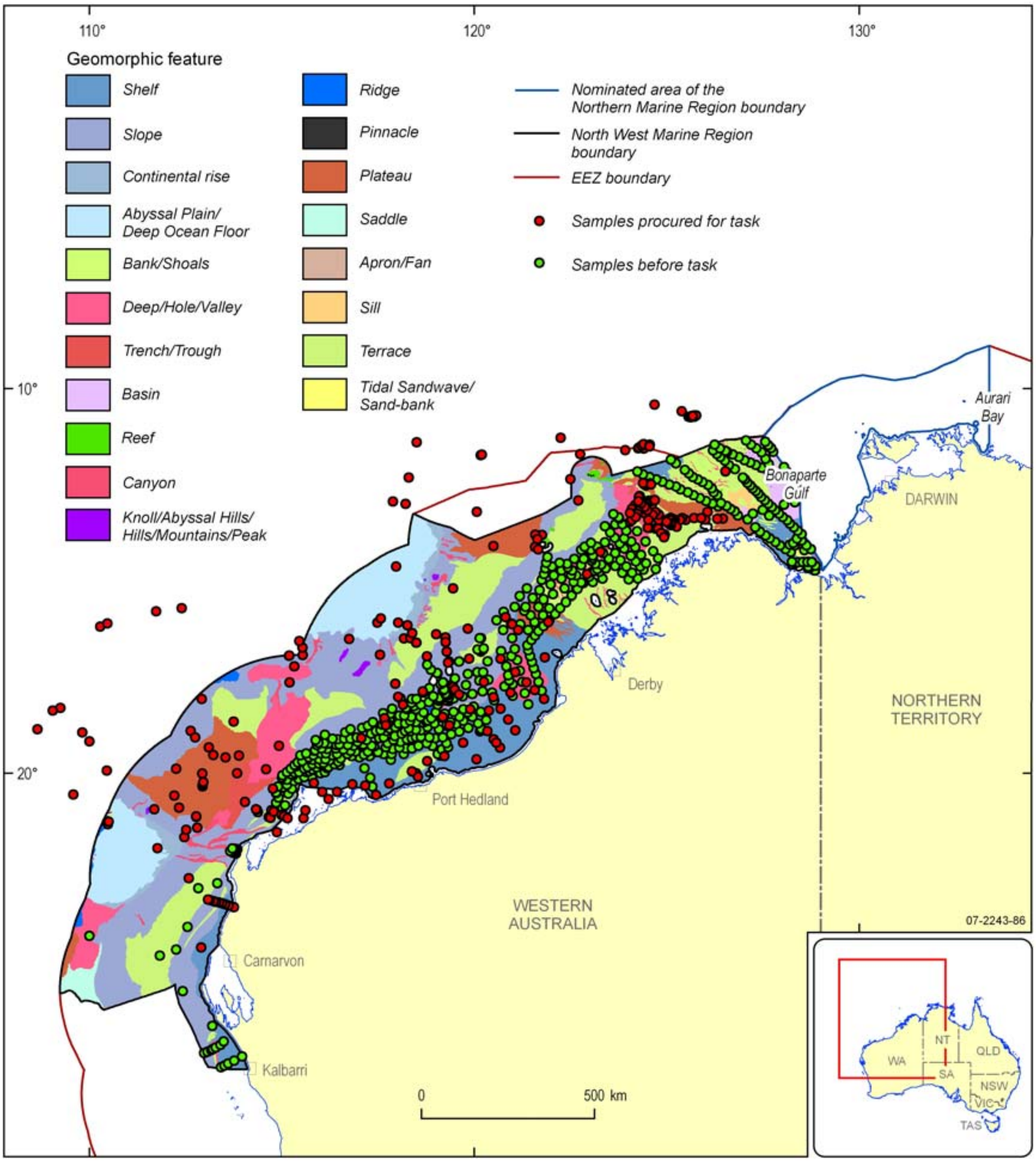

Figure 2.1. Samples with either carbonate and/or grainsize data available in the MARS database prior to and following the task in relation to bioregions of the NWMR and NNMR. See Figure 3.5 for unobstructed view of geomorphic features

Table 2.2. Metadata for sediment samples with either carbonate or grainsize data in MARS for the NWMR prior to the Memorandum Of Understanding (MOU).

Survey Name	Vessel	Year	Sample Types	No. of Samples
ANU/CSIRO				
FR 10/1995	Franklin	1995	Gravity cores	3
CSIRO				
Southern Surveyor 07/2005	Southern Surveyor	2005	Grabs	19
Curtin University				
Holocene Biogenic Sedimentation, Nth Rottnest Shelf.	Franklin	1996	Benthic and pipe dredges	11
DEWHA				
Mermaid Reef	Bhagwan K	2006	Grabs	1
GEOMAR (Germany)				
Sonne 8	Sonne	1979	Box and gravity cores	13
Geoscience Australia				
North West Shelf Sampling 1	Kos II	1967	Grabs	142
North West Shelf Sampling 2	Espirito Santo	1968	Grabs	196
Central North West Shelf Seepage	Southern Surveyor	2006	Grabs, gravity cores and vibro cores	72
Scripps Institute of Oceanography				
Timor Sea 1	Matila	1960	Grabs and gravity cores	49
Timor Sea 2	Stranger	1961	Dredges, grabs and gravity cores	44
University of Sydney				
Holocene Terrigenous Sedimentation, NT	Un-named 15 m+ small boat	1979	Pipe dredges	23
University of WA				
Shark Bay, WA	Un-named 15 m+ small boat	1956	Grabs	2

Table 2.3. Metadata for sediment samples with either carbonate or grainsize data in MARS for the NNMR.

Survey Name	Vessel	Year	Sample Types	No. of Samples
CSIRO				
AUROREX: Part B, Leg 1	Sprightly	1982	Grabs	5
CSIRO Surveys in NT and WA	Un-named 15 m+ small boat	1989	Grabs	12
Geoscience Australia				
Arafura Sea 1	Yamato	1969	Dredges	57
Arafura Sea 2	San Pedro Sound	1969	Dredges	90
Arafura Sea Marine Survey	Southern Surveyor	2005	Grabs and gravity cores	9
Parks and Wildlife, NT				
Beagle Gulf Benthic Survey	Kunnunyah	1993	Dredges	7
Scripps Institute of Oceanography				
Timor Sea 1	Matila	1960	Gravity cores	63
Timor Sea 2	Stranger	1961	Dredges, grabs and gravity cores	66
University of Sydney				
Holocene Terrigenous Sedimentation, NT	Un-named 15 m+ small boat	1979	Pipe dredges	9

2.2. PREVIOUS DATA COVERAGE OF THE NWMR

Prior to this study the majority of samples within the NWMR were recorded from within the Northwest Shelf Province, the Northwest Transition and the Northwest Shelf Transition (Fig. 2.1). A total of 871 of the 894 pre-existing sediment samples occurred in water depths of 10-500 m within the shelf and slope geomorphic provinces. The shelf (unassigned), slope (unassigned) and terrace geomorphic features contained the most samples, while significantly fewer samples occurred on abyssal plain/deep ocean floor (unassigned), apron/fan, canyon, knoll/abyssal hills/hills/mountains/peak, reef, sill, tidal sand waves/sandbanks, and trench/trough geomorphic features.

Highest sample density occurred on the shelf and slope of the Northwest Shelf Province, the Northwest Transition and the Northwest Shelf Transition. In each of these bioregions, most samples occur within 0-0.025 km of the nearest sample.

2.3. ASSESSMENT OF SIGNIFICANT GAPS IN EXISTING SAMPLE COVERAGE FOR THE NWMR

The relationship between data coverage and the other physical variables determines the accuracy of the final interpretations of sediment distribution. The NWMR contains areas where samples, for various reasons, provided insufficient coverage to estimate sediment distribution. Recognition of these gaps was used to guide sample selection for this study. A targeted approach for the addition of sediment data allows for more efficient improvement in sediment information for the NWMR in the short to medium term. Similar assessment of gaps in data coverage resulting from this task (Chapters 4 & 5) will be used to guide sample collection and procurement in the future.

Three types of data gaps were identified and used to guide sample procurement for this study, namely:

- Gaps in spatial coverage. This was determined by mapping data density across the NWMR and identifying areas in the Provincial Bioregions, primary bathymetric units and geomorphic features, where the least samples existed for large areas of seabed.

- Gaps in spatial coverage of specific features. An assessment of distribution of samples within the area of a provincial bioregion, primary bathymetric unit or geomorphic feature, was conducted by assessing the coverage of the number of separate occurrences of the feature and degree to which samples are clustered within these. This determines whether assays are likely to be representative of the range and relative proportion of sediment types.

- Knowledge gaps are not always directly related to sample density. Conceptual understanding of seabed morphology in different geomorphic features and high resolution information derived from local studies and seabed images means that we can estimate the sample spacing required to map actual variations in seabed character to a given resolution. Comparison between this required sample density and the density of existing data can be used to identify areas where data is inadequate to estimate sediment properties.

2.4. SAMPLE IDENTIFICATION IN THE NWMR AND SELECTION FOR ANALYSIS

2.4.1. Sample Identification

MARS database

Prior to this study, a total of 930 samples without grainsize data and 1,800 samples without calcium carbonate data were contained in MARS. More than 1,000 of these were located in Geoscience Australia's archives. The remainder were located in external institutions, including: Federal Institute for Geosciences and Natural Resources (BGR) Germany, Lamont Doherty Earth Observatory and the University of Adelaide, or they were found to no longer exist.

External Databases
A total of 150 samples were also identified in external databases including the National Oceanic and Atmospheric Administration (NOAA) database and the Integrated Ocean Drilling Program core database. 70 were confirmed to contain adequate volumes of surficial sediment to be sub-sampled. These samples were located at six international institutions: Oregon State University, Integrated Ocean Drilling Program Texas A&M University, Research Centre for Marine Geosciences (GEOMAR) Germany, BGR Germany, Scripps Institute of Oceanography and Lamont-Doherty Earth Observatory.

2.4.2. Sample Selection

A total of 297 samples were selected for analysis for this study based on the gap analysis. These consisted of core, dredge and grab samples collected on 25 surveys conducted between 1964 and 2004 (Table 2.4). 163 samples were located in the Geoscience Australia data repository, and 134 were located in external repositories, including: BGR and GEOMAR, Germany; Lamont Doherty Earth Observatory; Oregon State University; Integrated Ocean Drilling Program Texas A&M University; and the University of Adelaide.

Significant data gaps were identified in the Central Western Shelf Transition, Central Western Province, Central Western Transition, Timor Province and Northwest Province. Sediment samples increase coverage of all bioregions except for the Central Western Province. Data coverage of the Central Western Shelf Transition, the Central Western Province and the Central Western Transition remains limited; however, sample density in the Timor and Northwest Provinces is increased.

Significant spatial data gaps were identified especially for deep-water (>4000 m) areas of the NWMR. The addition of 297 samples has significantly increased sample density on the lower slope and abyssal plain/deep ocean floor; however, relative to shallower areas coverage in these areas remains sparse (abyssal plain/deep ocean floor average sample density <1:10,000 km^2, shelf coverage 1: 700 km^2). Few samples have been collected in deepwater areas of the NWMR (>4000 m) that are not now included in our sample coverage. To improve our understanding of sediment distribution in deep-water areas, 42 samples from extensions of these features adjacent to the NWMR were selected for analysis. These points have been used to characterise the sedimentology of the abyssal plain/deep ocean floor and lower slope within the NWMR.

Table 2.4. Metadata for sediment samples analysed for this study.

Survey Name	Vessel	Year	Sample Types	No. of Samples
ANU				
FR 03/1996	Franklin	1996	Gravity cores	15
Curtin University				
Holocene Biogenic Sedimentation, Nth Rottnest	Franklin	1996	Benthic and pipe dredges	10

Shelf.

Deep Sea Drilling Program				
DSDP 27	Glomar Challenger	1972	Core catcher	1
GEOMAR (Germany)				
Sonne 7	Sonne	1978	Grabs and gravity cores	32
Geoscience Australia				
North East Australia Heat Flow	Rig Seismic	1986	Gravity cores	8
Exmouth Plateau 2	Rig Seismic	1986	Gravity cores	1
Canning Exmouth	Rig Seismic	1990	Gravity cores	1
Vulcan Graben 2	Rig Seismic	1990	Grabs and vibro cores	28
Bonaparte 1	Rig Seismic	1991	Vibro cores	2
Sahul Shoals	Rig Seismic	1993	Vibro cores	8
Timor Sea Geology	Rig Seismic	1997	Gravity cores	21
Franklin Cruise 5	Franklin	2000	Grabs and gravity cores	42
Seeps and Signatures 1	Parmelia K	2004	Grabs and gravity cores	27
BGR (Germany)				
Scott Plateau and Java Trench	Valdivia	1977	Piston cores	2
Lamont Doherty Earth Observatory				
Vema Cruise 20, Leg 8	Vema	1964	Piston cores	3
Vema Cruise 24, Leg 9	Vema	1967	Piston cores	1
Conrad Cruise 11, Leg 7	Robert D Conrad	1967	Piston cores	3
Conrad Cruise 14, Leg 3	Robert D Conrad	1971	Piston cores	7
Vema Cruise 28, Leg 11	Vema	1971	Piston cores	8
Vema Cruise 33, Leg 14	Vema	1977	Piston cores	5
Vema Cruise 34, Leg 4	Vema	1977	Piston cores	1
Ocean Drilling Program				
Ocean Drilling Program, Leg 122 & 123	Joides Resolution	1988	Piston cores	7
Oregon State University				
MD 111	Marion Dufresne	1998	Piston cores	2

University of Adelaide				
Franklin Cruise 4	Franklin	1999	Benthic dredges	62

2.5. SAMPLE ACQUISITION AND ANALYSIS

Samples from repositories outside Australia were sent to Geoscience Australia. Material held at Adelaide University by Dr Yvonne Bone was sub-sampled by project officers. Between 12 and 50 g of sediment were used for grainsize and carbonate analyses. Each sample was analysed as follows:

- **Grainsize (Vol%; µm):** The grainsize distribution of the 0.01–2,000 µm fraction of the bulk sediment was determined with a Malvern Mastersizer 2000 laser particle analyser. All samples were wet sieved through a 2,000 µm mesh to remove the coarse fraction. A minimum of 1 g was used for samples comprising relatively fine material and between 2–3 g for samples comprising relatively coarse material. Samples were ultrasonically treated to help disperse the particles. Distributions represent the average of three runs of 30,000 measurement snaps that are divided into 100 particle size bins of equal size.
- **Grainsize (Wt%):** Gravel, sand, and mud concentrations were determined by passing 10–20 g of bulk sediment through standard mesh sizes (Gravel >2,000 µm; Sand 63 µm-2,000 µm; Mud <63 µm). The resulting gravel, sand, and mud concentrations represent dry weight proportions.
- **Carbonate content (Wt%):** Bulk, sand and mud carbonate concentrations were determined on 2–5 g of material using the 'Carbonate bomb' method of Muller and Gastner (1971). Carbonate gravel concentrations were determined by visual inspection.

All analyses were conducted by the Palaeontology and Sedimentology Laboratory at Geoscience Australia. Where sample volumes were insufficient to complete all analyses, laser grainsize and bulk carbonate were completed as a priority. Further information on the data analysis is available in Appendix C.

2.6. ASSESSMENT OF SIGNIFICANT GEOMORPHIC FEATURES

Prior to this study, analysis of sediment type and distribution was completed at Bioregional Planning Region and Bioregion scales. Within these regions, analysis was also completed for features identified as ‘significant’. Significant features are defined as single or groups of geomorphic features that characterise the seabed and therefore represent potentially significant areas for conservation that are based on a set of criteria (Table 2.5). Significant features have been identified for the NWMR and individual bioregions within it. Significance of features could not be assessed at international scales as equivalent datasets are not available for areas outside of the AEEZ. Where a feature (significant or otherwise) contained <3 samples, quantitative analysis of sedimentology within this feature was not undertaken due to the low number of samples. Sedimentology for significant features without adequate quantitative data is described from previous studies where possible.

Table 2.5. Criteria for assessing significance of geomorphic features in the NWMR or Provincial Bioregion.

Criteria	Explanation
Feature is best represented in NWMR or Bioregion	Feature covers significant area of the NWMR or bioregion **OR** Feature is not abundant elsewhere in Australia's EEZ (significant portion of total area of this feature occurs in NWMR or bioregion)
Feature is unique to NWMR or Bioregion	This occurrence has a physical attribute i.e: -extent -sedimentology -bathymetry -latitude that differs from that of other occurrences of this feature in the NWMR or EEZ

2.7. MAP PRODUCTION

2.7.1. Percent Gravel/Sand/Mud and Folk Classification and Percent Carbonate

Maps for %Gravel, %Sand, %Mud, Folk Classification, and %Carbonate were clipped from rasters created for the entire EEZ. These were created by:

- Querying the MARS database to obtain all numeric grainsize and carbonate content data for Australia's EEZ and any samples located outside the EEZ but within 100 km of the boundary;
- Compiling the results into gravel, sand and mud fractions (%), mean grainsize (μm) and carbonate (%);
- Checking that gravel, sand and mud for each sample had all three fractions reported, and that these fractions were in the appropriate range when summed (100 +/- 1%); and then
- Resolving cases of duplication.

The sediment classification proposed by Folk (1954) has been used to present information on sediment type. Sediment fraction interpolations were combined into a single raster file and values for each cell at 0.05 decimal degree resolution were exported as points. Folk classes were defined from Folk (1954) diagram and a script automating classification based on these definitions was written in Perl. This script was applied and results exported to point data. Classified cell values were imported back into ArcGIS for map production. Areas for classes on all interpolated maps are calculated only for the interpolated area that lies within the NWMR.