

Irish Sea Marine Aggregate Initiative (IMAGIN) Technical Synthesis Report

Including:

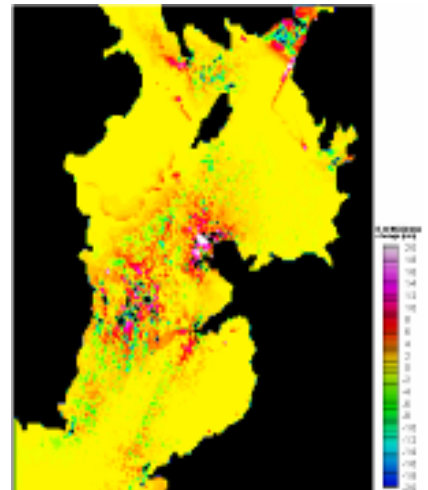
**Geological Assessment, Environmental Assessment, Morphodynamic Modelling
Web-based GIS System, Cost Benefit Analysis**



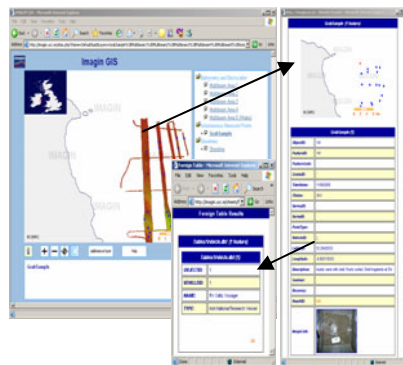
Geological Assessment



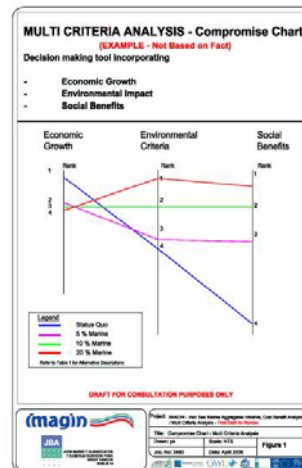
Environmental Assessment



Morphodynamic Modelling



Web-based GIS System



Cost Benefit Analysis

December 2008

Compiled and Edited by Gerry Sutton

ISSN NO: 1649-0053

Marine Environment and Health Series, No. 36, 2008

This document is based on material from the following reports:

Irish Sea Marine Aggregates Initiative (IMAGIN) Work Package 1. Kozachenko, M., Fletcher, R., Sutton, G., Monteys, X., Van Landeghem, K., Wheeler, A., Lassoued, Y., Cooper, A. and Nicoll, C. (2008) A geological appraisal of marine aggregate resources in the southern Irish Sea. Technical report produced for the Irish Sea Marine Aggregates Initiative (IMAGIN) project funded under the INTERREG IIIA Community Initiative Programme 2000-2006. University College Cork, Ireland, 390pp. ISBN 978-0-9556109-2-9.

Irish Sea Marine Aggregates Initiative (IMAGIN) Work Package 1. IMAGIN: Regional Environmental Assessment of Aggregate Extraction in the Irish Sea. September 2007. Gerard Morgan, Derek Casey, Paula Harrison, David Gillespie and Stuart Warner.

Irish Sea Marine Aggregates Initiative (IMAGIN) Work Package 1 Morphodynamic Modelling in the Irish Sea. November 2007. Alan Berry, Tomasz Dabrowski and Michael Hartnett.

Irish Sea Marine Aggregates Initiative (IMAGIN) Work Package 2. GIS and Prototype Decision Support System. Yassine Lassoued.

Irish Sea Marine Aggregates Initiative (IMAGIN) Work Package 3. Cost Benefit Analysis Final Report 16th March 2007. T. Paul, P. Kinghan and P. Glanville.

Irish Sea Marine Aggregates Initiative (IMAGIN). Aggregate Resources and Markets – Wales Forming a part of the Final Report of INTERREG IIIA project ref. no. 5634. prepared and written for Geoscience Wales Limited, Wales lead partner on the IMAGIN project, by C. Nicoll of Scott Wilson.

Suggested Citation

Sutton, G. Irish Sea Marine Aggregate Initiative (IMAGIN) Project Synthesis Report Including: Geological Assessment, Environmental Assessment, Morphodynamic Modelling Web-based GIS System, Cost Benefit Analysis, Aggregate Resources and Markets-Wales. Marine Environment and Health Series, No. 36. 2008.

Contact Information

Gerry Sutton, Coastal and Marine Resources Centre, University College Cork, Haulbowline Naval Base, Cobh, Co. Cork. Ireland (gerry.sutton@ucc.ie).

Acknowledgements

The editors would like in particular to acknowledge the contribution of the members of the IMAGIN steering committee, original report authors as well as the following individuals in providing input and comment during the final preparation of this technical synthesis report: Mark Russell (British Marine Aggregate Producers Association); Linda Scott (Welsh Assembly Government); Cathal O'Mahony, Michelle Cronin, and Mike Fitzpatrick (Coastal and Marine Resources Centre).

Project Partners

The following partners formed the core group from inception with overall responsibility for implementation and management in Ireland and Wales:

Marine Institute (Lead)

80 Harcourt Street
Dublin 2
Ireland
Tel: +353 1 4766500
Fax: +353 1 4784988
Web: <http://www.marine.ie>

Coastal and Marine Resources Centre (Project Management)

Environmental Research Institute,
University College Cork,
Naval Base, Haulbowline,
Cobh, Co. Cork,
Ireland.
Tel: +353 21 4703100
Fax: +353 21 4703132
Web: <http://cmrc.ucc.ie>

Geological Survey of Ireland

Beggars Bush
Haddington Road,
Dublin 4.
Ireland
Tel: +353 1 6782000
Fax: +353 1 6681782

Geoscience Wales (Project Management, Wales)

Geoscience Wales Limited,
Conwy Business Centre,
Junction Way,
Llandudno Junction,
Conwy LL31 9XX, UK
Tel: +44 (0) 1492 574563
Fax: +44 (0) 1492 574516

Project Participants:

The following Government Departments, organisations and companies participated in and contributed actively to the project.

Department of Communications, Marine, and Natural Resources. (DCMNR).
National Assembly of Wales (now Welsh Assembly Government) SRD Planning Division.

Readymix Plc. (Now CEMEX Ireland Ltd.)
Roadstone Dublin, Ltd.
Kilsaran Concrete Ltd.
RMC Marine, (Now CEMEX UK Ltd.)
Lagan Group.
Aggregate Industries.

Subcontractors:

Lead Partnership, (Now Bluefox Technology)
Marcon Computations
John Barnett and Associates (JBA).

FOREWORD

Scope of Document

This report provides an overview and synthesis of the work undertaken by INTERREG IIIA Irish Sea Marine Aggregates Initiative (IMAGIN) project. It is intended as a succinct guide and introduction, particularly for a non-specialist audience, to the wider body of IMAGIN outputs.

Structure of Document

This report is divided into five main sections each of which presents a summary distilled from the contents of the IMAGIN main project reports listed above which deal with

- Geological appraisal of marine aggregate resources in the southern Irish Sea
- Regional Environmental Assessment of Aggregate Extraction in the Irish Sea.
- GIS and a Prototype Decision Support System
- Morphodynamic Modelling
- Cost Benefit Analysis
- Resources and Markets – Wales

In most instances these are based closely on the individual executive summaries presented in the full reports. Annex 1 presents an overview outlining the structure and contents per chapter for the two largest of the main reports (Geological Appraisal and REA).

A separate report dealing with the development of a regulatory framework for marine aggregate extraction in the Irish Sea has also been published as Report No. 32 of the Marine Institute's Marine Environment and Health Series and is available on the Marine Institute's web site at <http://www.marine.ie/home/publicationsdata/publications/MEHS.htm>

TABLE OF CONTENTS

1	INTRODUCTION	1
1.1	<i>Project Outline.....</i>	1
1.1	<i>Driving Factors for Extraction of Marine Aggregates in Ireland.....</i>	1
1.2	<i>Study Area</i>	3
2	GEOLOGICAL APPRAISAL OF MARINE AGGREGATE RESOURCES IN THE SOUTHERN IRISH SEA.....	4
2.1	<i>Introduction and Background to the Geological Study.....</i>	4
2.2	<i>Overview of Study and Methods:.....</i>	4
2.3	<i>Summary of Findings:.....</i>	7
3	REGIONAL ENVIRONMENTAL ASSESSMENT OF MARINE AGGREGATE EXTRACTION IN THE SOUTHERN IRISH SEA	11
3.1	<i>Introduction</i>	11
3.2	<i>Background.....</i>	11
3.3	<i>Study Approach.....</i>	11
3.4	<i>Benthos and Benthic Impacts of Aggregate Extraction</i>	12
3.5	<i>Irish Sea Demersal Fish and Shellfish.....</i>	15
3.6	<i>Impacts on Fish and Shellfish Resources in the IMAGIN Study Domain</i>	19
3.7	<i>Selected References.....</i>	22
4	MORPHODYNAMIC MODELLING	23
4.1	<i>Introduction</i>	23
4.2	<i>Fundamental Numerical Modelling Framework</i>	23
4.3	<i>High Resolution Models.....</i>	23
4.4	<i>Morphodynamic Modelling Scenarios.....</i>	26
4.5	<i>Summary of Findings</i>	27
4.6	<i>Bed Characterisation Sensitivity Analysis.....</i>	32
4.7	<i>Bed Load Transport Analysis.....</i>	33
4.8	<i>Summary Discussion of Results</i>	34
4.9	<i>Validity of Model Predictions</i>	35
4.10	<i>Selected References.....</i>	35
5	PROTOTYPE DECISION SUPPORT SYSTEM.....	36
5.1	<i>Introduction</i>	36
5.2	<i>Survey Data Model Design</i>	36
5.3	<i>Metadata Design.....</i>	37
5.4	<i>IMAGIN Web-GIS Prototype Decision Support System (DSS).....</i>	38
6	COST BENEFIT ANALYSIS (CBA).....	41
6.1	<i>Introduction</i>	41
6.2	<i>Scope of Work.....</i>	41
6.3	<i>Summary of Methods and Results.....</i>	42
6.4	<i>Selected References.....</i>	50
7	AGGREGATE RESOURCES AND MARKETS-WALES.....	51
7.1	<i>Introduction</i>	51
7.2	<i>Markets.....</i>	51
7.3	<i>Overview of UK Aggregates.....</i>	52
7.4	<i>Marine Aggregate Dredging UK Practice.....</i>	54
7.5	<i>Policy Perspectives.....</i>	55
7.6	<i>Prospecting</i>	57
7.7	<i>Environmental Impact Assessment (EIA)</i>	58
7.8	<i>Licensing</i>	59
7.9	<i>Monitoring.....</i>	59
7.10	<i>Aggregates Supplies and Markets.....</i>	59
7.11	<i>Information Sources and Further Reading.....</i>	61
8	OVERALL FINDINGS AND RECOMMENDATIONS.....	62
9	Appendix 1.....	66
9.1	<i>Structure and Layout of the Full Geological Report.....</i>	66
9.2	<i>Structure and Layout of the Full REA Report.....</i>	66

1 INTRODUCTION

1.1 Project Outline

The Irish Sea Marine Aggregates Initiative (IMAGIN) is a collaborative project between Ireland and Wales focused on the sustainable management of marine aggregate resources. IMAGIN was a 2-year project with a total budget of €1.1 million. IMAGIN was part funded (66%) under the Ireland/Wales Inter Regional (INTERREG) IIIA Community Initiative Programme 2000-2006. The remaining project budget was met by contributions from partner organisations (19%) and aggregate companies – CEMEX, Lagan Ltd., Kilsaran Concrete and Roadstone Ltd. (15%).

The IMAGIN grouping was a collaborative partnership comprising experts in Ireland and Wales from 3rd level Institutes, State agencies and industry. The grouping included the Coastal and Marine Resources Centre – University College Cork, Marine Institute, Geological Survey of Ireland, Geoscience Wales and representatives from the aggregate companies.

The overall aim of the IMAGIN project is to facilitate the evolution of a strategic framework within which the exploitation of marine aggregate resources from the Irish Sea may be sustainably managed with minimum risk of impact on marine and coastal environments, ecosystems and other marine users. IMAGIN was structured around a series of work packages, each focusing on the different aspects of the marine aggregate question (see Figure 1.1)

Marine aggregates can be defined as sedimentary material - sand or gravel of various grain and class sizes (grades). Extraction of marine aggregates typically involves dredging of the deposit to remove it from the seabed. Aggregates may be screened at sea before being transported to a port or wharf facility for unloading and then further processing, if required, and subsequent transportation. In common with terrestrial aggregates, sands and gravels sourced from the seabed are an important economic resource, which can contribute to the development and maintenance of infrastructure, e.g. buildings, roads and bridges. Marine aggregates are also used for beach nourishment and coastal defence purposes, the demands for which have become more pressing when set against the predicted implications of climate change, sea level rise and associated effects on low lying coastal areas. A number of countries have sought to meet the demand for aggregates by utilising sources from the seabed to replace or complement terrestrial sources. Belgium, the Netherlands and the United Kingdom are primary examples of countries within Europe that have a long established practice of marine aggregate extraction, providing an alternative to sole reliance on terrestrial sources.

1.2 Driving Factors for Extraction of Marine Aggregates in Ireland

It is clear that, in Ireland, land aggregates and particularly sand grades, are now at a premium, although in the absence of official statistics we must rely on informed judgment to predict how long economically viable supplies can be maintained. The aggregate demand in 2005 was estimated by the Irish Concrete Federation (ICF) to be approximately 130 million tonnes, which translates to circa 30 tonnes per person per annum (approximately four times the EU average per capita demand). Currently, in Ireland, all primary aggregates required to meet existing and planned (e.g. NDP infrastructure requirements) are sourced from land-based quarries. The use of secondary /recycled aggregates is at a relatively low level, and whilst recycling capacity has expanded rapidly, the nature of our building stock will restrict this contribution to around 5% of requirement at best. The industry is increasingly turning to manufactured sand (from crushed rock) as a stopgap, but the medium to long-term viability and sustainability of this practice is questionable, due to high energy consumption and associated environmental (e.g. CO₂ emissions) and economic costs. Nevertheless, land-based sources are likely to be the main supply option for primary aggregates in the short to medium-term. In Ireland, marine aggregates have been utilised in the past for specific non-market purposes including beach nourishment, reclamation, backfill, and coastal defence. Whilst no commercial extraction is currently permitted

in Ireland, the IMAGIN project has identified and highlighted marine aggregate resources in the Irish Sea that represent a future additional aggregate supply option. This applies in particular for the Greater Dublin area and other high demand coastal regions in which economies of scale can be achieved. The situation is different in Wales where dredging of marine aggregates has occurred on an industrial scale for many decades. In the absence of significant land based alternatives the contribution of marine aggregates to South Wales in particular is as much as 90% and thus critical to maintaining supplies.

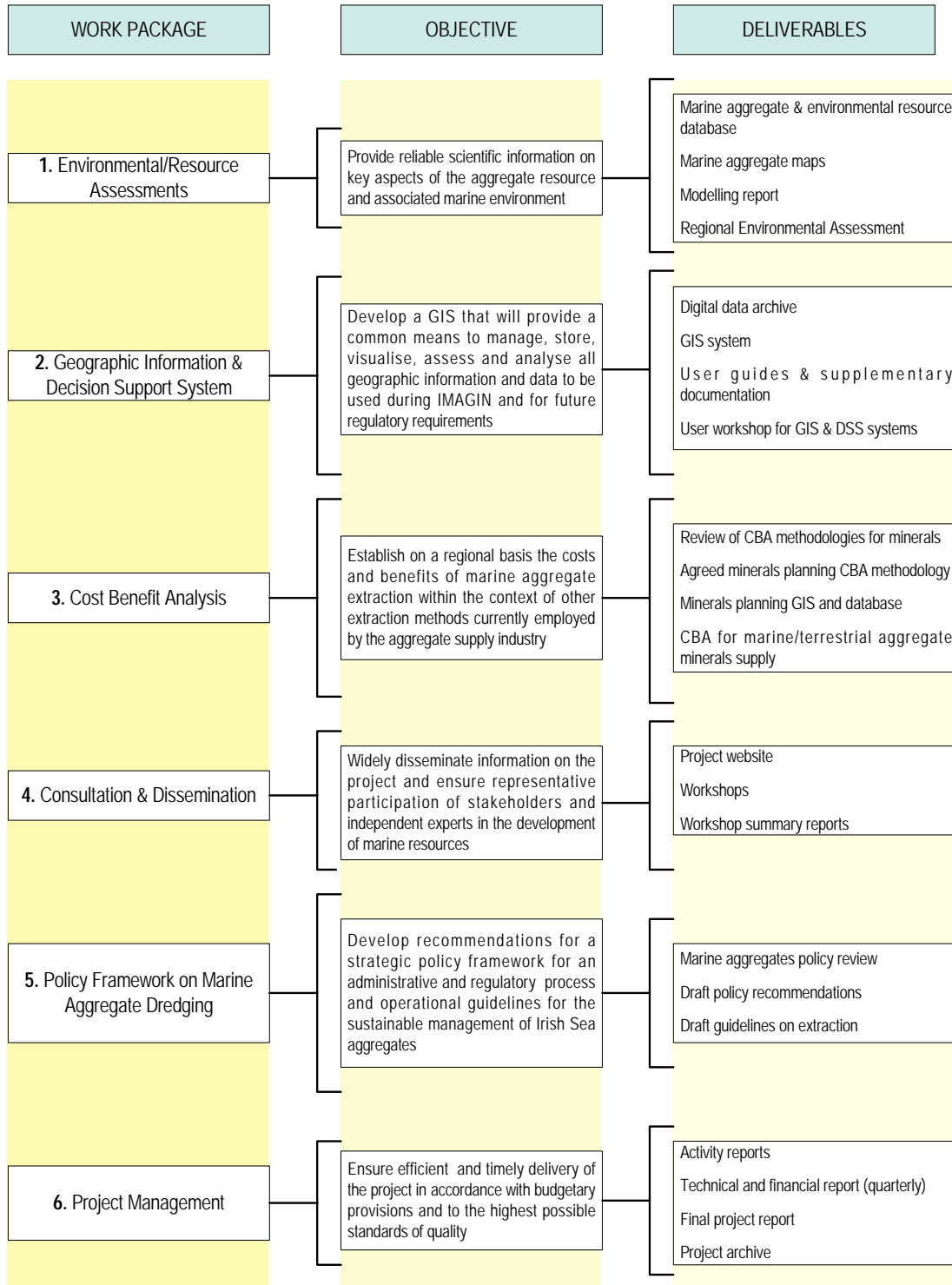


Figure 1.1. Schematic showing structure of IMAGIN work packages and deliverables.

1.3 Study Area

The overall IMAGIN study area was defined at the start of the project. The area is shown in Figure 1.2 and is bounded by the east coast of Ireland and the west coast of Wales. It extends from 53.74°N to 51.36°S, being bounded from the south and north by continuation of the onshore INTERREG IIIA county boundaries. The 20m depth contour (precautionary limit avoiding high sensitivity inshore-zone) and 60m depth contour (practical limit for economic dredging) were adopted as landward and seaward limits within which the research activities were targeted. Five sub-areas were subsequently selected as candidates for more focused study based on existing information that suggested these areas were characterised by relatively high marine aggregate potential and relatively low potential for interactions. (See Section 2.2)

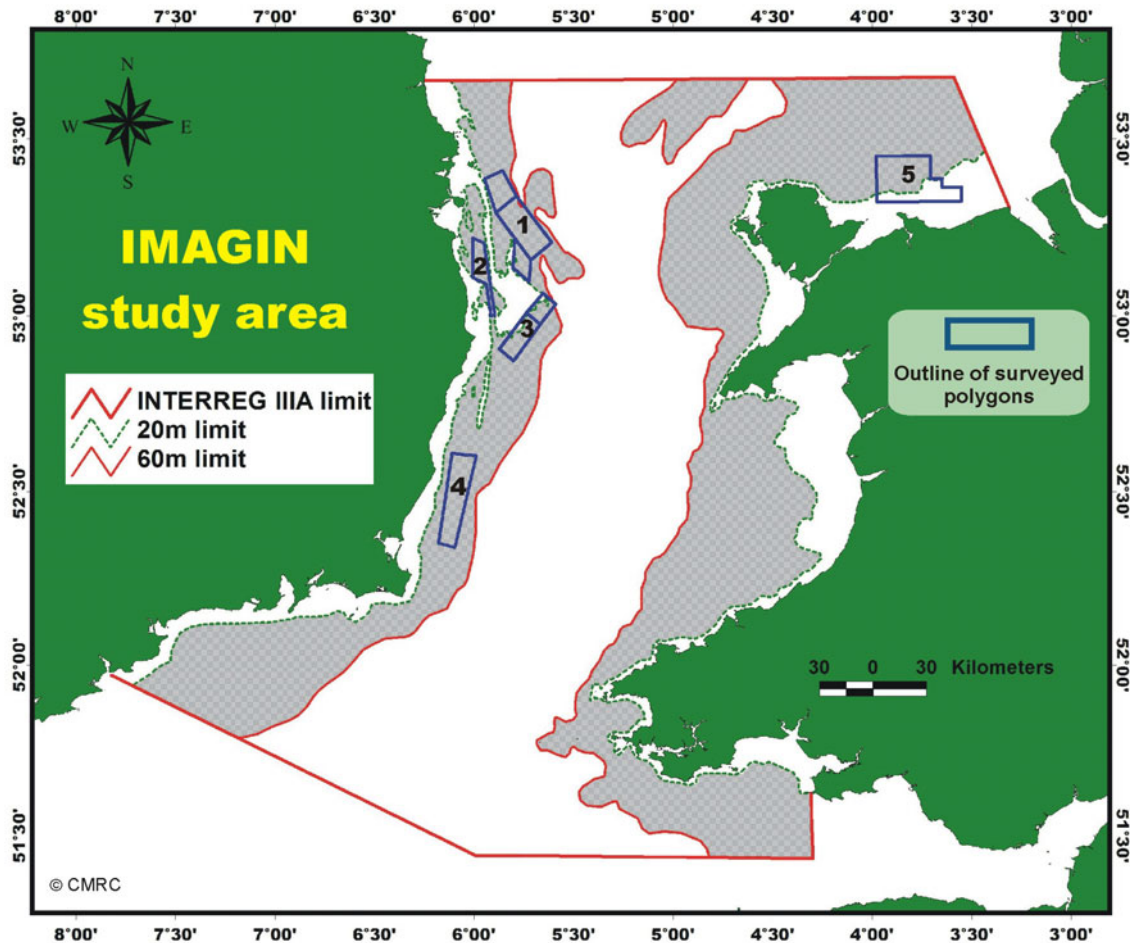


Figure 1.2. Overall study domain showing the northern and southern INTERREG III A limits that enclose the south Irish Sea area. Research effort was focussed towards the grey areas between 20m and 60m, and particularly within the detailed study areas (1-5) outlined in blue.

2 GEOLOGICAL APPRAISAL OF MARINE AGGREGATE RESOURCES IN THE SOUTHERN IRISH SEA

2.1 Introduction and Background to the Geological Study

The work summarised in this section comes under Work Package 1 [Environmental/Resource Assessments] and Work Package 2 [Geographic Information and Decision Support System] of the IMAGIN project. The main aims of these Work Packages were:

- to evaluate available aggregate resources and ascertain where they may best be exploited with the minimum of disturbance to the environment and human activities.
- the development of a marine database and advanced Geographic Information System (GIS) to: (i) manage and present pertinent spatial information; (ii) inform stakeholders and scientists; and, (iii) act as an operational tool to facilitate the management of future regulatory processes.

In the offshore context, aggregates were defined as sand and gravel sized material present on the seabed as part of the superficial sediment cover that should be at least 2m thick, preferably with no overburden material and suitable for particular industrial end-use “as dredged” or after some processing

2.2 Overview of Study and Methods

2.2.0 Desk studies and field work

In order to build a general understanding of the geology, environment and infrastructure of the Irish Sea study area the project undertook a detailed desktop study. The main purpose of this work was to collate and assess archival geological and geophysical datasets that were made available to the project by the Geological Survey of Ireland (GSI), the Petroleum Affairs Division (PAD) of the Department of Communications, Marine and Natural Resources, Ireland, and the British Geological Survey (BGS). These datasets were supplemented with additional data from existing printed and online sources. This exercise helped to pinpoint potential resources and identify gaps in the existing data coverage. GIS analysis also assisted in the identification of the areas where there might be potential interaction between future aggregate dredging and other marine uses such as Natura 2000 designated areas (SACs/SPAs), fish spawning and nursery grounds, pipelines and cables, ship wrecks etc. (Figure 2.1).

This process led to the identification of five locations (outlined in Figure 1.2 above) that were adopted as study sites to be mapped in detail during new offshore surveys using the Marine Institute’s research vessel RV Celtic Voyager. These surveys took the form of multi-disciplinary seabed mapping and regional environmental assessment and were carried out in order to develop enhanced understanding of the resource potential and marine geomorphological processes in the region. Over 30 days of ship time were devoted to offshore data collection. Subsequent post-cruise data processing, analysis and interpretation were carried out over a period of approximately one year.

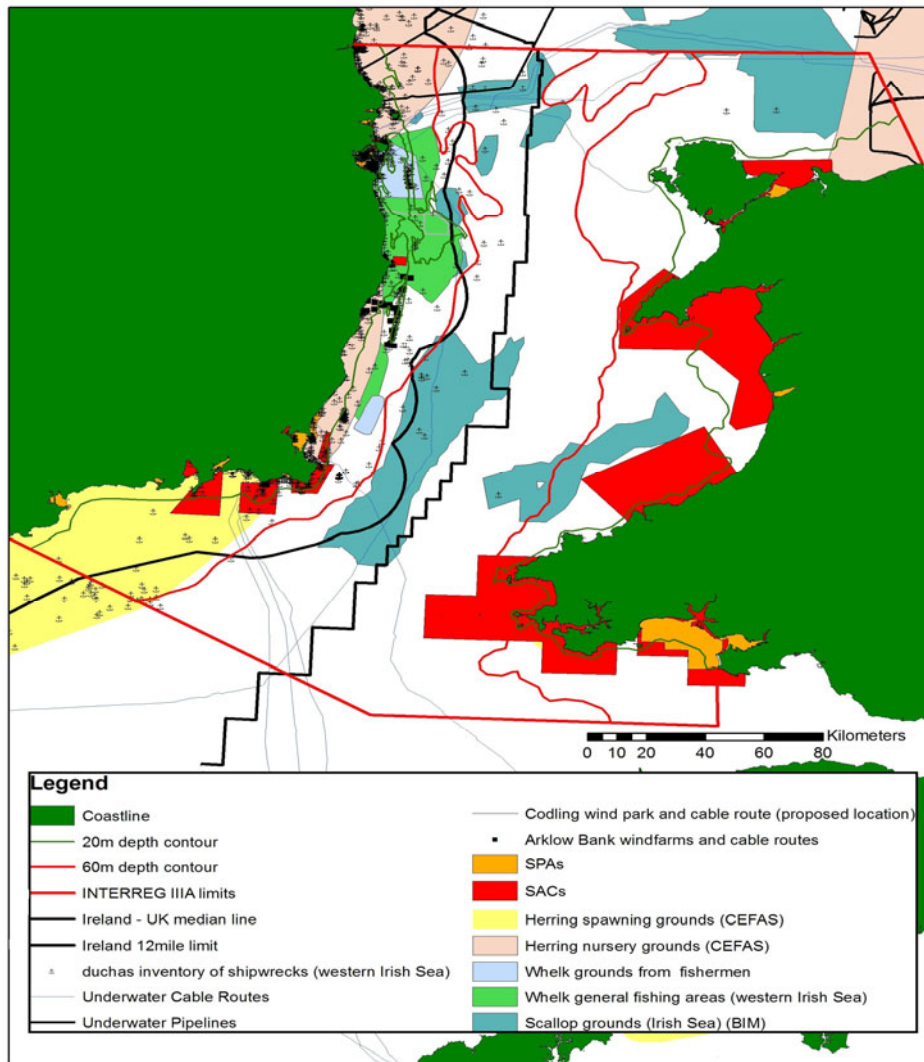


Figure 2.1. Summary map indicating where interactions might occur between potential marine aggregate extraction, infrastructure, other marine uses and environmental resources.

2.2.1 Approach to Mapping

The mapping process was designed to facilitate a progression from low to high resolution. Acoustic remote sensing techniques such as multi-beam and side-scan sonar were used for primary mapping. In a departure from the conventional (full area coherent coverage) method, IMAGIN acoustic coverage was created as a series of intersecting corridors between which areas were left unsurveyed. This approach allowed a much wider overall area to be cost-effectively mapped than would otherwise have been possible. These acoustic mapping techniques provided the basis for establishing the principal morphological characteristics of the seabed. This included mapping the distribution of sedimentary bedforms and inferring the distribution and configuration of seabed sediment types based on variations in their acoustic response. Seismic profiles were also collected during the same mapping runs using a Boomer system. Subsequent higher resolution ground-truthing surveys were undertaken using an underwater video system and sediment grab sampling. These were planned and targeted on the basis of an initial review of the acoustic results (Figure. 2.2 A-B). The Boomer seismic profiling facilitated the determination of sediment structure beneath the seabed and was used to locate the positions for vibro core samples (Figure. 2.2 D). Detailed particle size analysis (PSA) of sediment samples was undertaken in order to assess the quality of raw materials in relation to Industrial standards (Figure. 2.2 C).

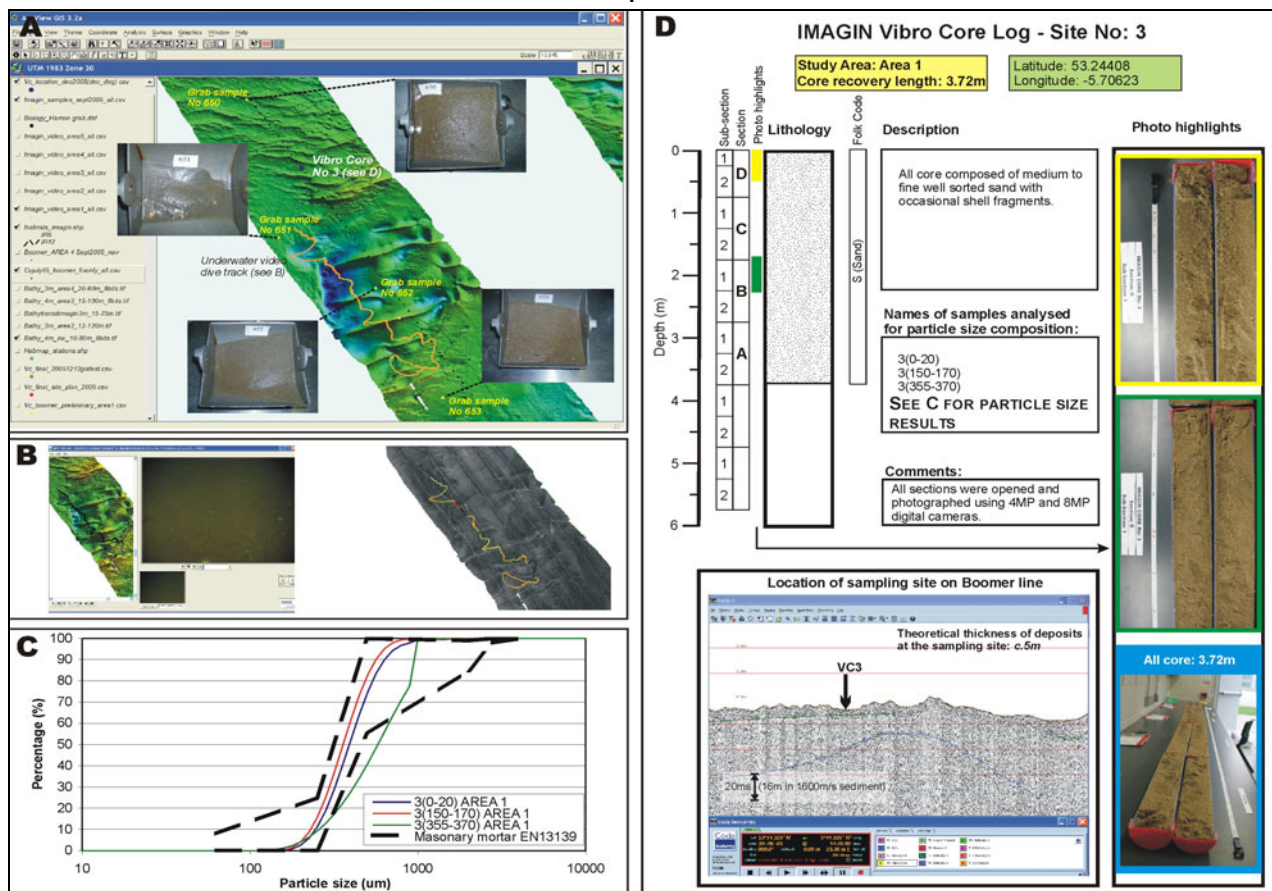


Figure 2.2. Examples of data collected and interpreted by the IMAGIN project. (A) Fragment of the GIS from study area 1 demonstrating how assorted data types were integrated. (B) Screen grab from video data acquisition software (on the left) and colour-coded video dive interpretation superimposed on multi-beam backscatter (on the right). (C) Cumulative plots for samples from Vibro Core 3 showing compliance of material with EN13139 standard. (D) Log for vibro core site No 3.

Sediment sample PSA also allowed systematic characterisation of sediment types that had been inferred acoustically as well as providing insights into sediment mobility. Desktop GIS was used to provide an operational framework within which all datasets could be managed, visualised and assessed both individually and in combination with one another. After the completion of the data processing and interpretation, all spatial data were restructured to conform to the ARCGIS Marine Data Model standard (see Section 5, and Appendix 4 of the full report by Kozachenko *et al.*, 2008). This form of data structure was adopted in order to facilitate data storage, management, sharing and exchange by providing a robust, coherent and easily reproducible schema that is widely adopted nationally and internationally. The structure was also adopted in order to facilitate data integration and dissemination via the IMAGIN web-enabled GIS system (see Section 5). As well as being a primary mechanism for disseminating the project findings, the system has been designed as a prototype decision support system that can assist in the management and regulatory functions associated with future marine aggregate licensing processes. It can be accessed at <http://imagine.ucc.ie>. (see also Chapter 5 below). The following summarises the offshore field datasets that were collected between July 2005 and December 2005:

Acoustic remotely sensed:

- Multi-beam (July – September 2005, RV Celtic Voyager) [c.3000km lines];
- Side-scan sonar (July – September 2005, RV Celtic Voyager) [few 100s km lines];
- Boomer seismic (July – September 2005, RV Celtic Voyager) [c. 800km lines];

Ground-truthing:

- Underwater video imaging (September 2005, RV Celtic Voyager) [c. 45km lines];
- Grab sediment sampling (September 2005, RV Celtic Voyager) [200 samples];
- Vibro core sediment sampling (December 2005, ILV Granuaile) [36 cores recovering 130m of sediment].

The following list describes the various derived/interpreted datasets that were produced between January 2006 and February 2007 covering all five study areas:

- Digital photographs of grab sediment samples;
- Digital photographs of opened vibro core samples;
- Vibro core lithological logs with photo highlights, description, location of sub-samples with PSA, and location of each sampling station on Boomer seismic record;
- Particle size data for grab sediment samples;
- Particle size data for vibro core sediment samples;
- Facies interpretation for video data;
- Interpretation of the Boomer seismic data;
- Seabed facies interpretation based on Folk (Particle Size) (Folk, 1954) classification;
- Integrated seabed facies interpretation taking into account sediment particle size, bedforms and morphodynamics;
- Acoustic seabed classification (QTC^R);
- GIS layers outlining marine aggregate resource potential areas within the study domain as well as at the broader scale within the overall IMAGIN study area.

2.3 Summary of Findings

The key findings are presented firstly for the individual study areas (1 -5), and then for the IMAGIN domain as a whole.

2.3.0 Summary of Findings for Each Study Area

Area 1:

- Acoustic mapping showed that most of the area is characterised by high relief sand waves. Crest alignment indicates sediment transport in a predominantly northward direction. The intensity of morphodynamic forcing decreases in the northern part of the area with a gradual transition towards lower relief sand waves, rippled sand sheets and eventually smooth seabed.
- High resource potential can be implied from boomer seismic evidence supported by vibro core sampling which suggested the thickness of the superficial sands to be (c.5-30m) within an area of approx. 230 sq km.
- PSA of grab and vibro core samples confirmed that raw material from Area 1 closely correlates with the following international standards: Masonry mortar EN13139; Concreting sand 0/4(CP) EN12620; Concreting sand 0/4(MP) EN12620; and, Building sand BS1200. Material from this area may thus be suitable for direct use with a minimum of additional processing.
- Area 1 is estimated to contain a potential resource in the region of 1-3 billion cubic metres of sandy aggregate.

Area 2:

- Acoustic mapping revealed a rather complex surface geology of this area. The southern part is characterised by a diverse range of geomorphological features including sand waves, gravel waves and ridges, hollows, and, rippled sand sheets. The northern part possesses a relatively smooth seabed with some topographical variation. Alignment of sediment wave crests as observed in seismic records suggests a predominantly northern sediment transport direction.

- Video and grab samples confirmed the seabed types interpreted from acoustic mapping, namely that darker backscatter corresponds to coarse material (gravel, stones, boulders) and lighter backscatter corresponds to sandy sediments.
- PSA of grab samples confirmed that in the northern part of the area the seabed is composed mainly of gravely sand, whereas gravels, gravely sands, sandy gravels and sands predominate in the southern part.
- Seismic profiles revealed a complex sub-seabed structure wherein the true thickness of superficial sediments is not always clearly discernable. Combined interpretation of this data with vibro core samples confirmed that superficial sands are in places 1.5-3.5m thick and underlain by stiff till deposits. In other places the interpretation suggested that theoretical thickness of the upper sand layer varies between 3-14m.
- PSA of grab and vibro core samples confirmed that material from the northern part of the area complies with the following construction industry standards: Masonry mortar EN13139; Concreting sand 0/4(CP) EN12620; and, Building sand BS1200. The more mixed sediments in the southern part of Area 2 are less amenable to direct comparison against standards in their raw form, however potential exists for their utilisation in processed or blended form.
- Area 2 is estimated to contain a potential resource in the region of 0.1-0.2 billion cubic metres of gravely sand spread over approx. 70 sq km of seabed and 0.2-0.4 billion cubic metres of mixed sand and gravel deposits spread over approx. 70 sq km of seabed.

Area 3:

- Acoustic mapping in Area 3 revealed a predominantly smooth seabed with some minor topographical variations. In places, small belts of low relief sand waves were documented, tentatively suggesting that this area experiences sediment starvation conditions.
- Combined video imagery and grab sampling confirmed the gravely nature of the seabed surface. Most of the area can be classified as gravel/sandy gravel which is interspersed with occasional patches of gravely sand in the form of sand waves.
- Vibro core sampling results confirmed that, in general, the superficial sediment cover is very thin (20-60cm) and underlain by stiff till deposits. Therefore, most of Area 3 may be considered as having low potential as a resource. By contrast the northern part of the area contains thicker gravel layers with theoretical thickness up to 11m in places. Samples were compliant with the following standards: BS882 (1992) Coarse; 0/4(CP) EN12620; 0/20 all-in EN12620.
- Area 3 is estimated to contain a potential resource in the region of 0.07-0.2 billion cubic metres of mainly coarse aggregates within a seabed area of approx. 20 sq km. As this estimate is currently based on extrapolating the seismic results with a single vibro core sampling station, additional confirmatory site investigation work will be required for confirmation.

Area 4:

- Acoustic mapping revealed Area 4 to be geomorphologically complex. The western edge of the area mainly comprised regular sand waves. The south-eastern extent of the area is characterised by “abnormal” sand waves which are migrating over a gravely substrate. These represent comparatively very large stand alone seabed features which are elongated in an east-west direction, with a wave length c. 130-140m and width of up to 420m.
- Video and grab samples confirmed the variability in seabed types interpreted from acoustic mapping, namely that darker backscatter corresponds to coarse material (gravel, stones) and lighter backscatter corresponds to sandy sediments.

- Evidence from the combined results of boomer seismic and vibro core analyses indicates the thickness of superficial sands to be in the range 5-14m, suggesting reasonable resource potential.
- PSA of grab and vibro core samples confirmed that raw material from Area 4 conforms to the following international standards: Masonry mortar EN13139; Concreting sand 0/4(CP) EN12620; Concreting sand 0/4(MP) EN12620; and, Building sand BS1200 Type G.
- Area 4 is estimated to contain a potential resource in the region of 0.2-0.5 billion cubic metres of sandy and mixed deposits.

Area 5:

- Acoustic mapping in this area revealed a fairly uniform sand plain with some small to medium NNW-SSE trending sand waves in the central area. Gravels and lag deposits predominate in the south-eastern and northern parts of the area.
- Video imagery confirmed the sandy seabed in the areas represented by light toned backscatter and gravely seabed in the areas represented by dark toned backscatter in the eastern part of Area 5. A region of sand waves occurs in the central part of Area 5, where the main wave bodies are dominated by a covering of smaller ripples.
- Surficial sands up to 5-10m in thickness have been inferred from the boomer seismic sections, which suggests good resource potential. However, in the absence of contemporary vibro core sampling, firmer estimates of the volume of the potential resource have not been made.
- PSA of grab and BGS archival vibro core samples confirmed that raw material from Area 5 is closely compliant with the following international standards: Masonry mortar EN13139; Concreting sand 0/4(CP) EN12620; and, Building sand BS1200.

2.3.1 Resource context at the sub-regional scale (i.e. whole study domain)

By combining data from all available sources (contemporary - IMAGIN, and archival - BGS and GSI) it has been possible to outline 25 polygons which delineate areas that may contain exploitable aggregates (Figure 2.6)

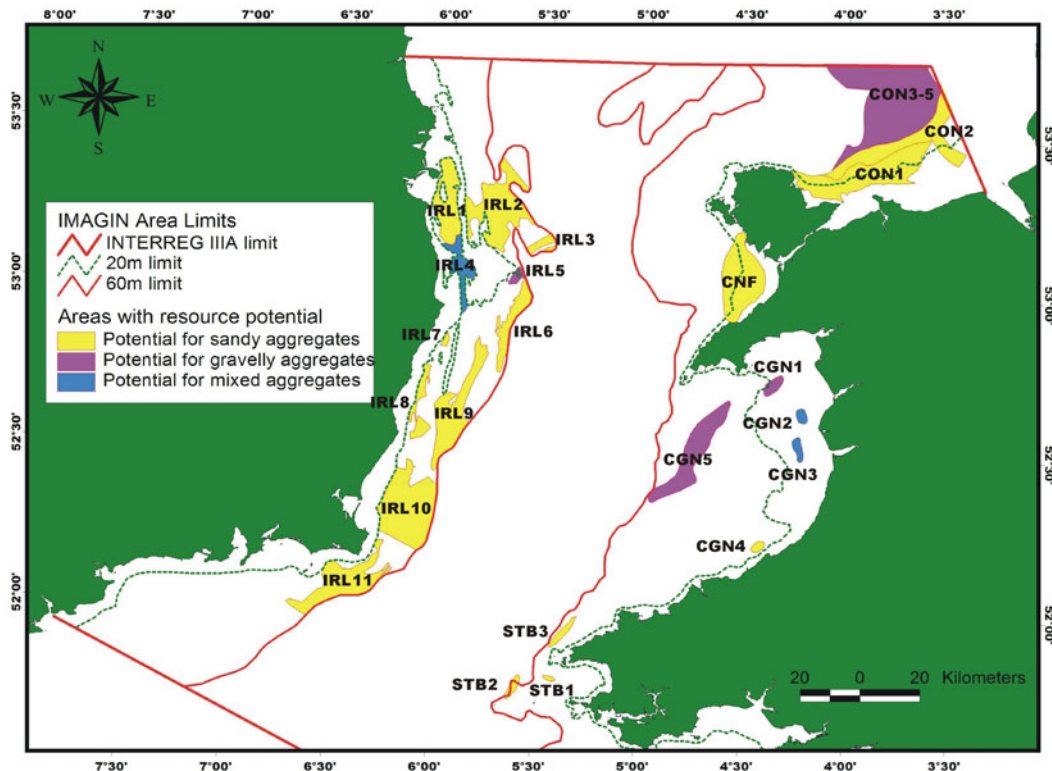


Figure 2.6. Map outlining areas with potential for exploitation of marine aggregates.

Further detailed field investigations will be required to prove the quality and quantities that may be available in these areas. However, some tentative estimates are given here for indicative purposes. In total, 11 resource blocks (with a total surface area of 2.3 billion sq m) have been identified within Ireland's territorial waters. This gives an indicative potential volume of between 4.7 and 12.4 billion cubic metres based on assumed exploitable sediment thickness of between 2 and 5m. Within UK/Wales territorial waters 12 resource blocks (with a total surface area of 2.6 billion sq m) have been identified (Figure 2.6). This gives an indicative potential volume of between 4.2 and 8.3 billion cubic metres based on assumed exploitable sediment thickness of between 2 and 5m. Table 2.1 below gives a breakdown of the areas and theoretical volumes per area. Please refer to Chapter 7 of the main report by Kozachenko *et al.* 2008 for further details. Copies of the project DVD are available from the CMRC upon request. This DVD contains all IMAGIN datasets in a simple GIS viewer together with copies of all the project reports and other relevant documentation.

Table 2.1: Summary of aggregate resource potential for all blocks identified by the IMAGIN project.

Aggregate potential blocks	Thickness (min) [m]	Thickness (max) [m]	Area size [km ²]	Volume (min) [million m ³]	Volume (max) [million m ³]
IRL 1	2	4	240	480	960
IRL 2	2	10	440	880	4400
IRL 3	2	2	40	80	80
IRL 4	3	5	120	360	600
IRL 5	3.5	10	20	70	200
IRL 6	2	5	150	300	750
IRL 7	2	5	10	20	50
IRL 8	2	5	90	180	450
IRL 9	2	5	330	660	1650
IRL 10	2	5	520	1040	2600
IRL 11	2	2	330	660	660
CON 1	2	4	490	980	1960
CON 2	2	4	360	720	1440
CON 3-5	1	2	920	920	1840
CNF	2	4	390	780	1560
CGN 1	0.5	0.5	40	20	20
CGN 2	0.5	0.5	20	10	10
CGN 3	0.5	0.5	30	15	15
CGN 4	2	2	20	40	40
CGN 5	2	4	310	620	1240
STB 1	2	4	10	20	40
STB 2	2	4	20	40	80
STB 3	2	4	30	60	120
Total Ireland: (Areas within which vibro core truthing was carried out during IMAGIN, Irl-1,2,4,5,8)			910	1970	6610
Overall Total Ireland:			2290	4730	12400
Total Wales:			2640	4225	8365
Grand Total			4930	8955	20765

3 REGIONAL ENVIRONMENTAL ASSESSMENT OF MARINE AGGREGATE EXTRACTION IN THE SOUTHERN IRISH SEA

3.1 Introduction

The Regional Environmental Assessment (REA) was carried out in order to provide reliable scientific information on the marine environment in the INTERREG IIIA domain of the southern Irish Sea. The approach and level of detail can be regarded as partially fulfilling standard requirements as set out under Strategic Environmental Assessment (SEA) legislation.

This REA is designed to provide technical information on key aspects of the environment that current scientific knowledge would suggest could potentially be most at risk from marine aggregate extraction.

The marine ecosystem can be divided into two main components, the seabed and the water column. The seabed is referred to as the benthic component and the water column as the pelagic component. In this Chapter a summary of the methods used and main findings of the studies related to the benthos and fisheries are presented. For further detailed information the reader is referred to the main report of Morgan *et al.* 2007.

Editorial Note: The findings and recommendations in this report are those of the authors, and do not necessarily represent the views or proposed policies of the Irish or Welsh Assembly Governments.

3.2 Background

Industrial scale marine aggregate extraction has been undertaken on a regular basis in European waters since the late 1970s. Since that time a sizeable body of literature and expertise has accumulated on the effects of this extractive industry on the marine environment. In keeping with the main impact associated with removal of the seabed sediments, much of the literature addresses the impacts of extraction on the benthic environment and to a lesser extent the water column and marine fisheries. The two main extraction techniques are (i) anchor dredger and (ii) trailer-suction dredger (most common). Anchor dredgers excavate from a fixed mooring point and can create deep crater-like depressions in usually thick gravel deposits, whereas trailer suction dredgers are mobile and traverse a licensed area in linear fashion much like a tractor ploughing a field. The drag-head removes a 30-50cm layer of surface sediment, which is pumped as a slurry with seawater along a hollow arm to the hold of the ship where it is stored in bulk or screened to remove the finer sand and silt fractions which are then rejected overboard. These rejected screenings deposit on the seabed within 50m-100m of the dredger and can have a profound impact on the ecology of the benthic communities depending on several factors, such as the nature of the substrate, local hydrodynamics etc. Dredging is also associated with a plume of suspended solids in the water column, which will have greater or lesser amounts of material present depending on whether or not on-board screening is undertaken, and the nature of the deposit. Plumes are known to be detectable for over 2km from a dredger depending on local conditions, although solids levels usually return to near background levels within 200-500m of a dredger. From this it can be observed that the most significant impacts associated with aggregates extraction concern the benthic or demersal environment, whilst lesser and more transitory impacts are experienced within the water column or pelagic environment. For this reason the bulk of the effort in the IMAGIN REA has been concentrated on benthic impacts.

3.3 Study Approach

The bulk of effort underpinning the Regional Environmental Assessment (REA) for IMAGIN was concentrated on the benthos, fisheries and fishing. The work was based on the compilation of existing mainly published and some unpublished information about the marine environment of

the Irish Sea and its biological resources, with particular emphasis on the area covered by the IMAGIN study domain. A general overview of the study domain was generated and summarised the key attributes of the regional sea: geographic extent; water movement and stratification; nutrient dynamics and suspended sediment; phytoplankton and primary production; sediment types and benthic communities. New field data concerning benthic and epibenthic invertebrate fauna were collected within five detailed study areas (hereafter referred to as “study areas”), four off the east coast of Ireland and one off the north Wales coast (Figure 3.1). Areas of high risk or sensitivity were delineated in the light of information from archival sources and with reference to newly collected datasets.

3.3.0 Overview

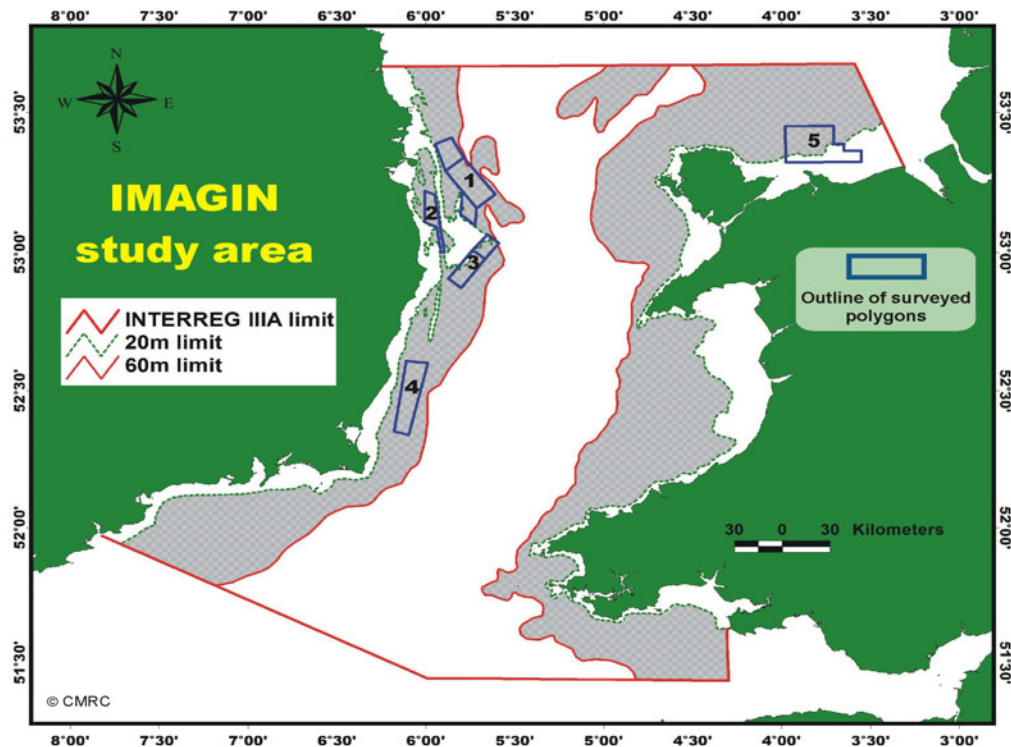


Figure 3.1. Map of the study area showing the overall study domain and each of the five IMAGIN Study Areas.

3.4 Benthos and Benthic Impacts of Aggregate Extraction

3.4.0 Broad Benthic Study Procedure

Sample locations were selected on the basis of geological and geophysical information previously gathered by the geological team working on IMAGIN. (See Section 2 and Kozachenko *et al.*, 2008). Biological samples were collected and processed following recognised standard methods (Holme and McIntyre, 1984; Kenny and Rees, 1994; Thomas, 2001) and the resultant specimens appropriately recorded and preserved. Specialist taxonomists were employed to identify the main faunal groups identified within the study areas. Benthic faunal assemblages were classified using both JNCC and EUNIS classification schemes. Multi-variate analysis applied to the data collected from benthic sampling across each study area identified several clusters of sampling sites which had similar benthic faunal assemblages. These site clusters in turn had characteristic ranges of sediment grain sizes, which generally typified the aggregate present across each study area or a small number of sub-areas within each. To simplify the findings we can say that sub-areas within study areas 1 and 5 were characterised by samples that contained (>75%) sandier sediments. By contrast samples containing a high gravel fraction (66%-75%) predominated throughout all areas within study area 3. Study areas 2 and 4 occupied intermediate positions, between these two groupings, in terms of their gravel to sand ratios. In general, muddy fractions were either absent or else formed a very minor portion the grain-size fractions of the sites where they were recorded.

3.4.1 Broad Benthic Study Findings

The benthic communities associated with the five study areas were assigned to JNCC and EUNIS classifications (Connor *et al.*, 2004; <http://eunis.finsiel.ro/eunis/index.jsp>). These classifications formed a fairly limited range of widely distributed biotopes. Although in several cases the IMAGIN benthic assemblages didn't fit neatly into these standard classifications, the communities showed strong associations with particular habitat types, or in other cases could be described as intermediate between two category types. The diversity of the communities sampled varied from low in unstable, more hydrodynamically active areas to relatively high in certain parts of study area 3. There was evidence in study area 3 in particular of more structured bottom type communities with reef forming species such as the bivalves *Modiolus modiolus* and *Mytilus edulis* and the tubiferous polychaetes, *Sabellaria* spp. Biotope maps outlining identified assemblages for each study area are presented in Figures 3.2 to 3.6.

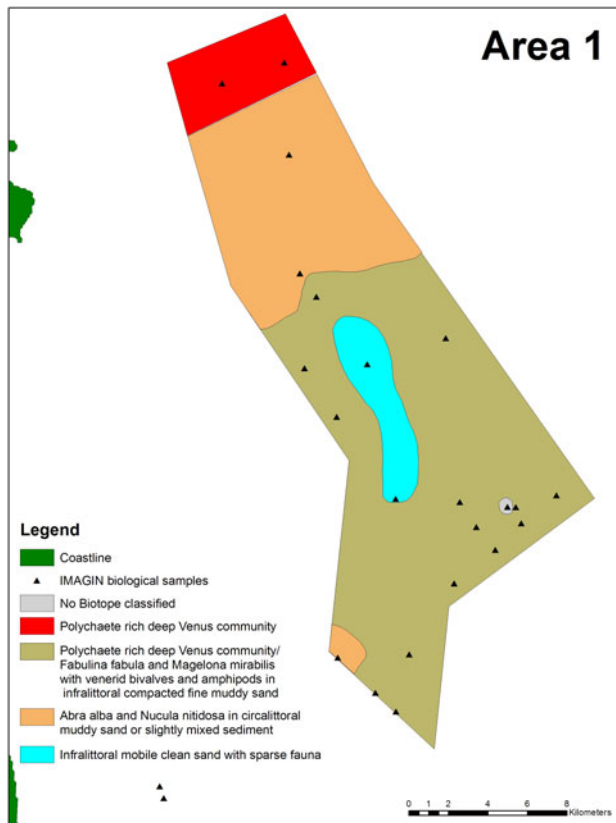


Figure 3.2. Biotope map for study area 1.

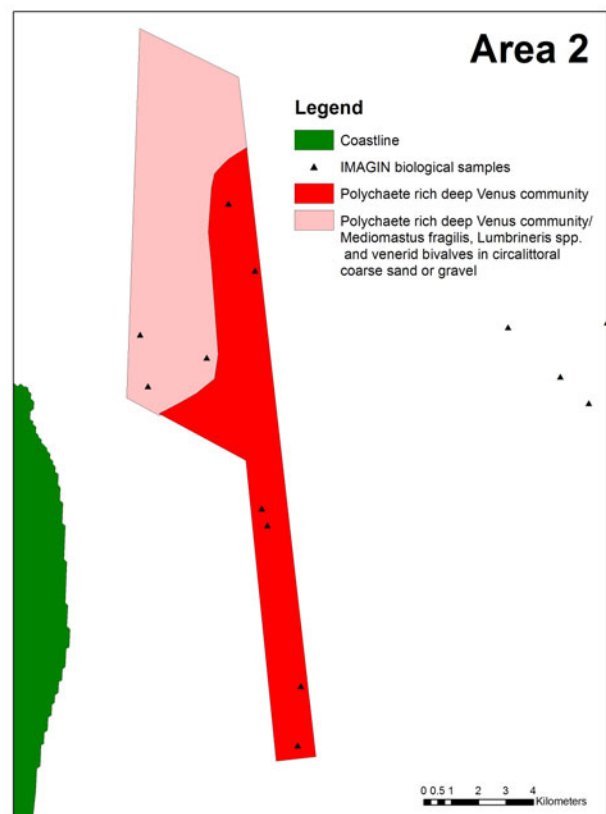


Figure 3.3. Biotope map for study area 2.

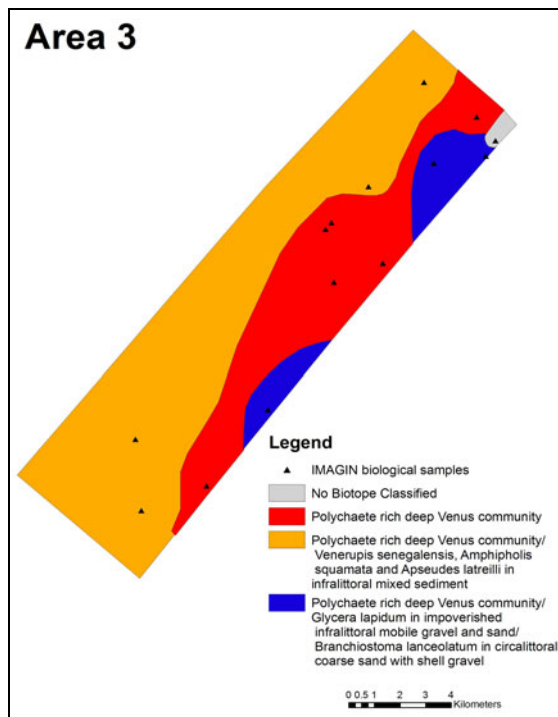


Figure 3.4. Biotope map for study area 3

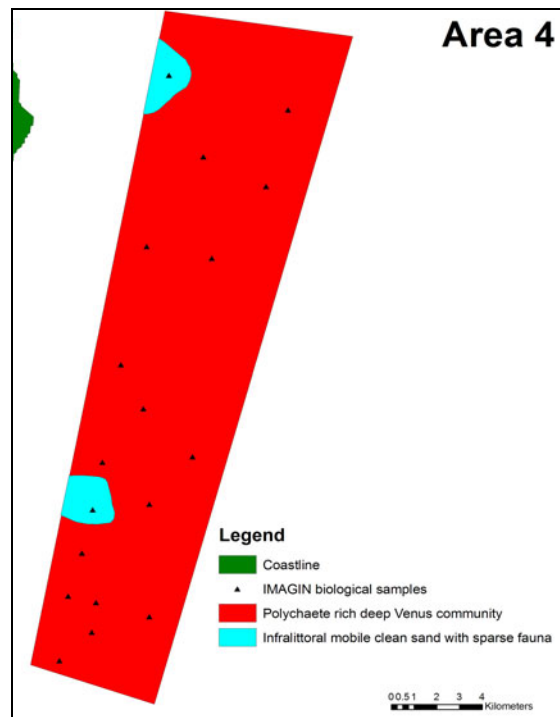


Figure 3.5. Biotope map for study area 4.

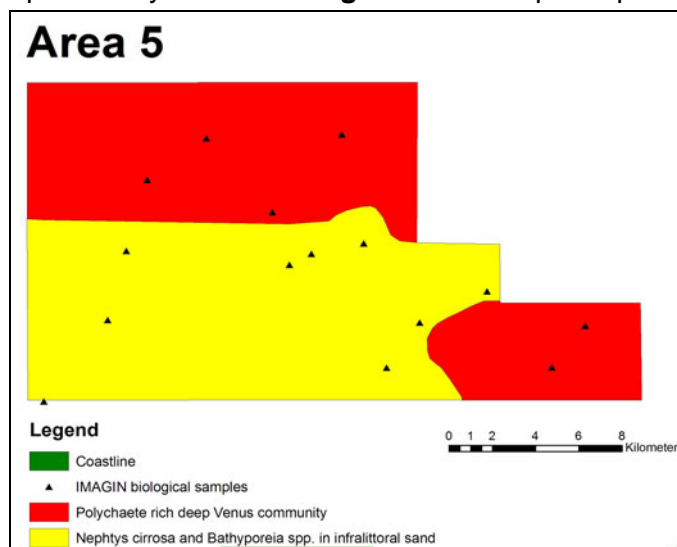


Figure 3.6. Biotope map for study area 5.

3.4.2 Benthos Recovery

Previously published data indicates that ambient hydrodynamic conditions are one of the main determinants that influence rate of recovery for benthos following cessation of dredging. In relation to the IMAGIN study areas, mobile rippled sands will recover more quickly than stable gravel dominated areas where bed stresses may be lower. In general areas dominated by species with short life-cycles and rapid reproduction abilities will tend to be much less impacted than areas where larger, slower growing species such as certain bivalve molluscs and echinoderms predominate. The best case scenarios would suggest that much of study area 1 (off Dublin Bay-north Wicklow) and study area 5 off north Wales would have the potential to recover substantially from the main effects of aggregate extraction within 1-2 years after cessation of extraction. For most of study areas 2 and 4 recovery times may be longer (3-5 years post extraction), whilst parts of study area 3 may take more than 6 years to recover. The duration in this case is due to the complex nature of the systems concerned and particularly the presence of reef-building communities (e.g. *Sabellaria*).

Experience from past studies has shown that other important factors which strongly influenced recovery were related to the particular characteristics of the dredging operations. The occurrence of on-board screening and the intensity and orientation of extraction are important factors. Longer recovery times are associated with high levels of on-board screening which can lead to e.g. over-sanding, and can also be expected in areas that are more intensively dredged.

3.4.3 Mitigation Measures for the Benthos

The primary mitigation tool is the selection of areas for aggregate extraction which are the least sensitive, have minimal interactions with other users and have conditions conducive to optimum recovery. Nevertheless, it is recognised that within any given extraction site, a range of operational measures can be adopted to reduce the impacts on the benthos and other marine species. These include, inter alia:

- The type of equipment employed;
- Whether on-board screening takes place;
- Dredging intensity;
- Whether gaps or fallow areas are left un-dredged to act as faunal refuges;
- Seasonal and tidal timing of dredging; and,
- Orientation of dredging with respect to prevailing currents.

3.5 Irish Sea Demersal Fish and Shellfish

3.5.0 Overview

A major part of the study entailed the analysis of available groundfish survey data from Irish and UK fisheries agencies, namely the Marine Institute and the Centre for Environment, Fisheries and Aquaculture Science, (CEFAS). Distribution maps were generated for key commercial and non-commercial species averaged over the period of the record (up to 13 years of data in some cases) using geostatistical methods similar to those that were employed in the Eastern Channel Habitat Atlas for Marine Resource Management (CHARM) project (Carpentier *et al.*, 2005). Other data sources included those held by the Sea Fisheries Protection Authority (SFPA) and Bord Iascaigh Mhara (BIM) the Irish Sea Fisheries Board, for data on seed mussels and whelk in particular as well as other minor exploited species. Catch statistics for International Council for Exploration of the Seas (ICES) statistical rectangles and data on port landings (both from the SFPA) as well as information from fishermen and fisheries scientists were processed to provide a simplified first-estimate of the current fisheries value for the Irish fleet (>10m in length) from each of the ICES sub-rectangles within the IMAGIN domain. Data for the study area 5 off north Wales was more complete as it included catches by all vessels regardless of size. Finally, the potential impacts of aggregate extraction on fish and shellfish, and on commercial fishing, were reviewed from the literature.

3.5.1 Fish Distribution

Maps showing the general distribution in the Irish Sea of several commercial and some non-commercial fish species were generated from the analysis of groundfish survey data of Irish and UK fisheries agencies. An example for cod is shown in Figure 3.7 which illustrates the type of relative biomass (fish density in kg per square km) distribution maps that were produced. Please refer to the main report of Morgan *et al.* 2007 for additional information on other fish species.

In addition, the same datasets were examined for catch trends at particular survey sites, i.e. those which coincided exactly or very nearly with the IMAGIN detailed study areas (Figure 3.8). These analyses showed the frequent occurrence of species such as plaice, dab and sole, in IMAGIN study area 5 and study area 1, but to a lesser extent in study area 2, although sole was less abundant on the Irish side.

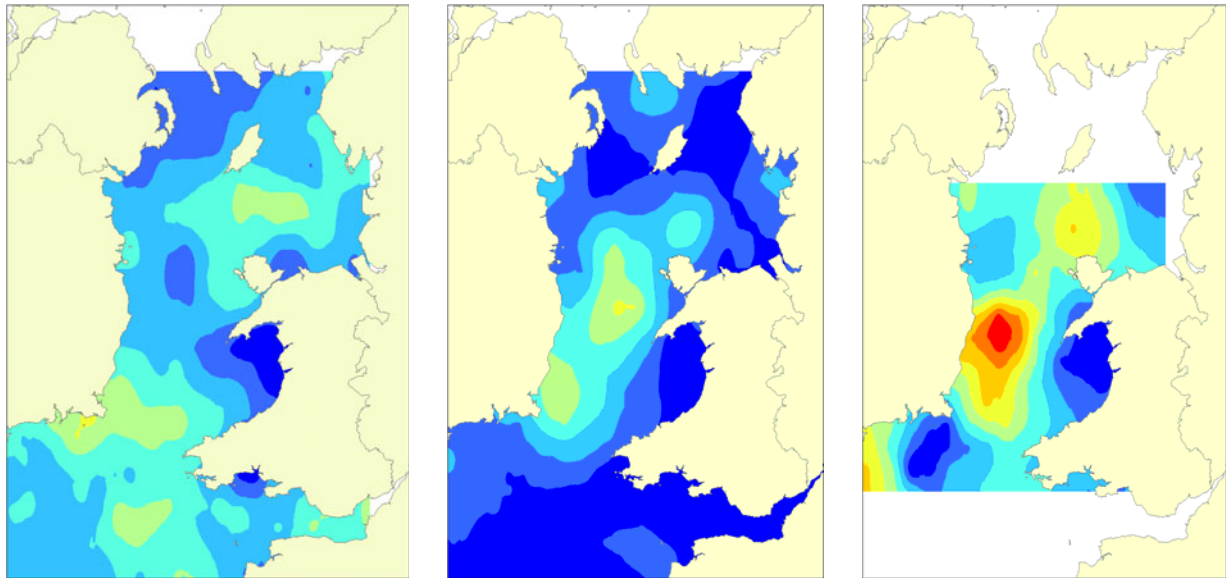


Figure 3.7. Relative biomass distribution maps for cod produced from multi-annual data. (left) CEFAS spring, (middle) CEFAS autumn, (right) MI autumn. Warm shades indicate areas with higher relative biomass, cool shades indicate where biomass was lower.

Various ray species were also documented (thornback in study area 5) cuckoo, spotted and blonde in the southern end of study area 1 and the northern end of study area 2. Whiting was the most abundant gadoid in study area 5, and study areas 1 and 2, while haddock were often taken in appreciable numbers and cod occasionally in study area 1. Monkfish (Angler Fish) and turbot in study area 2 and flounder and brill in study area 5 were taken as lesser species. Occasional surveys took high numbers of queen scallop and moderate numbers of brown crab in study area 2. Non-commercial species such as lesser-spotted dogfish, dragonet and grey gurnard also frequently occurred at both sides of the Irish Sea (Figures 3.9 and 3.10)

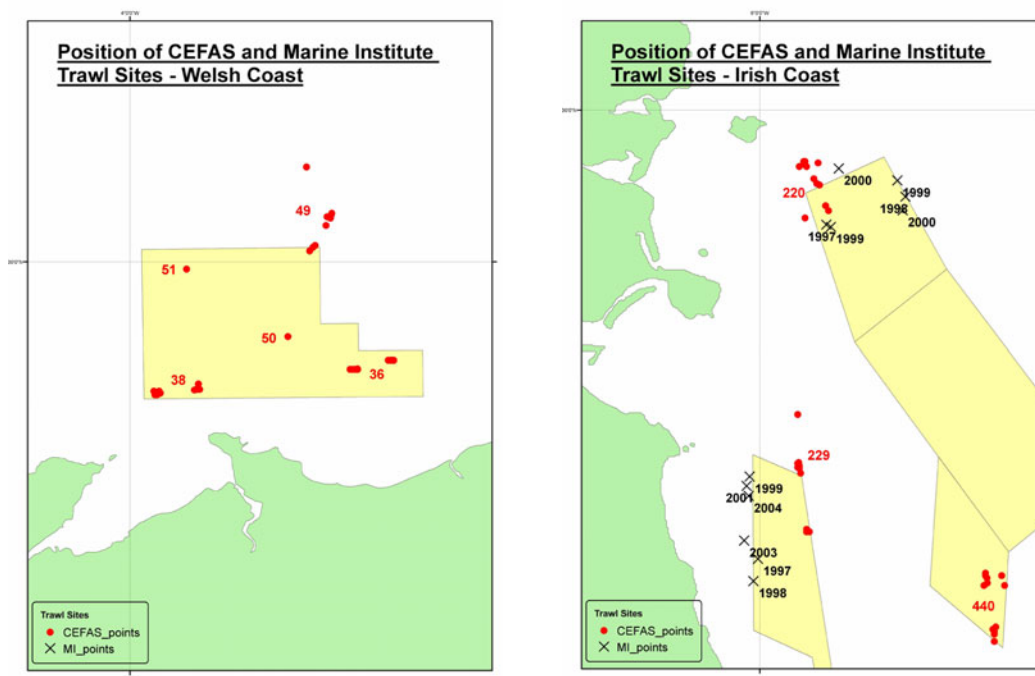


Figure 3.8. A schematic of study area 5 off the north Wales coast and study areas 1 and 2 on the Irish east coast showing where groundfish trawl surveys stations coincide with IMAGIN study areas.

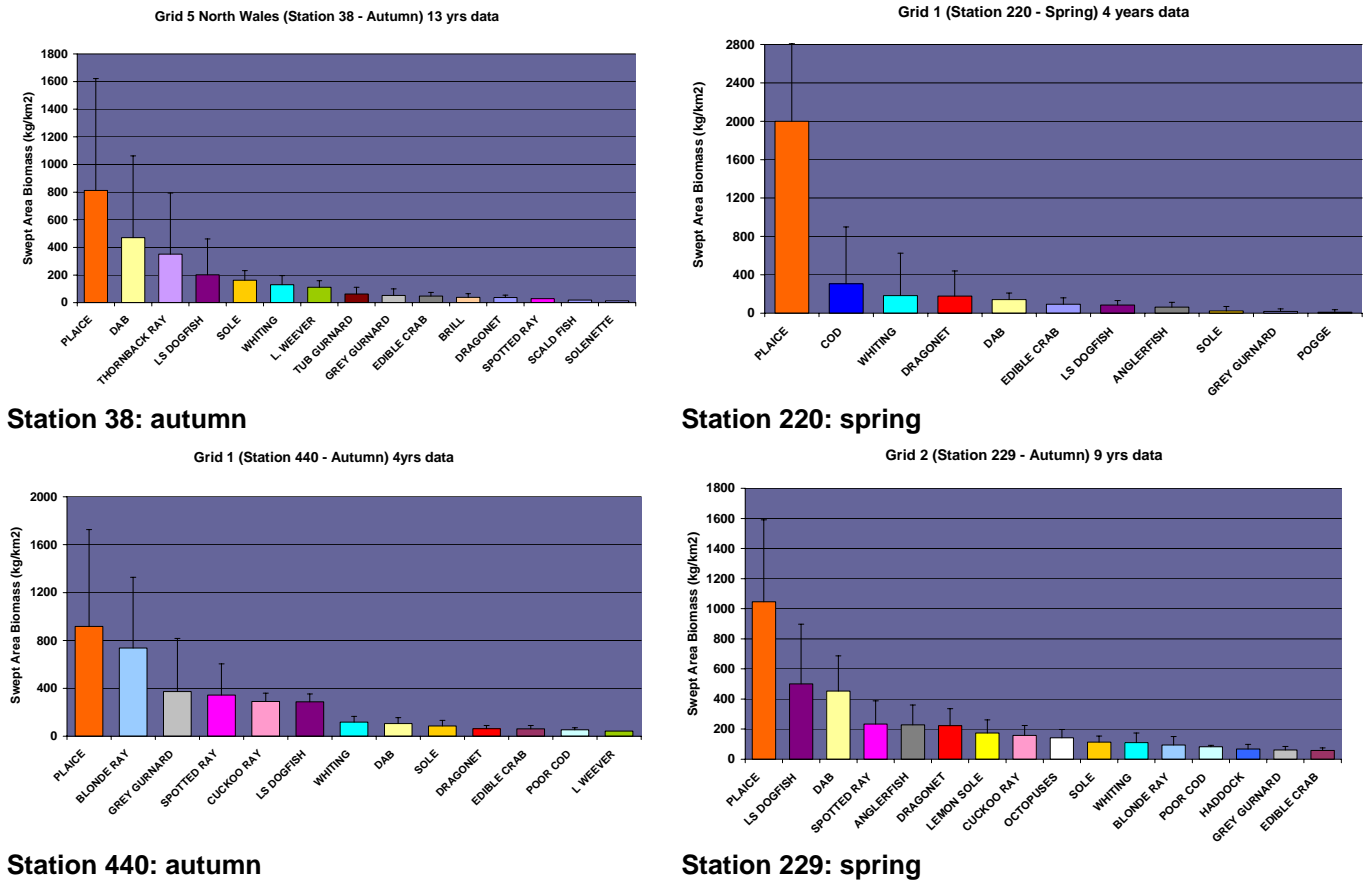


Figure 3.9. Top species (biomass) annually in CEFAS beam trawl surveys averaged over the period of the survey. Some lower ranked species are excluded (see methods in main report by Morgan *et al.* 2007). Bars denote standard deviation. (NB term “grid” equates to study area)

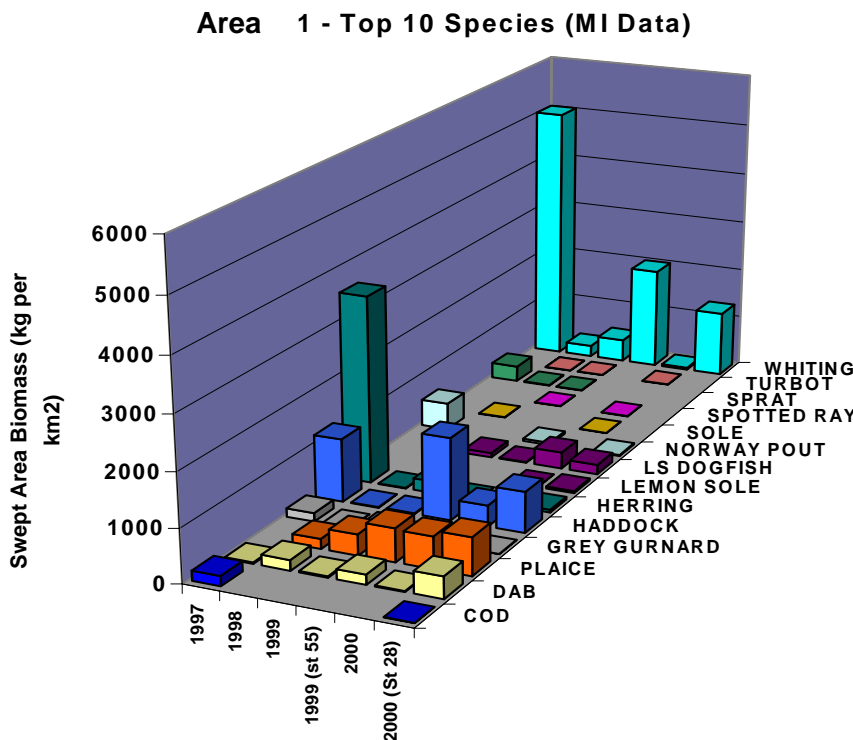


Figure 3.10. Marine Institute (MI) survey trawl data for six stations in study area 1. Note that two stations were chosen in 1999 and 2000 in the area

3.5.2 Shellfish

Seed mussel beds are concentrated off Wicklow Head, Arklow and off Wexford Harbour in fairly well defined areas, albeit with considerable inter-annual variation. These beds are generally in waters less than 20m and exploited for on-laying in Wexford Harbour, Carlingford Lough, the Foyle Estuary, Cromane Harbour and Waterford Harbour. The recognised primary beds do not coincide with any of the IMAGIN study areas although there are some smaller occurrences of mussels that are immediately adjacent to study areas 2 and 4.

Whelk are fished extensively along the east coast, in particular by inshore vessels, from Dublin Bay to Wexford with the main concentration of effort being around Arklow-Wicklow and Courtown. Whelk is potentially the most vulnerable stock in the area. However information describing the localised distribution of the resource is lacking. A very generalised map of where whelk are distributed off the east coast of Ireland is shown in Figure 3.11. This also shows that IMAGIN study area 1 and most of the northern part of study area 2 are not regarded as important whelk grounds, whereas whelk are known to be present in the southern and mid portions of study area 3 and the northern half of area 4. However, within these areas it is unlikely that whelks are evenly distributed and more detailed studies at appropriate scales would be required to accurately map their distribution.

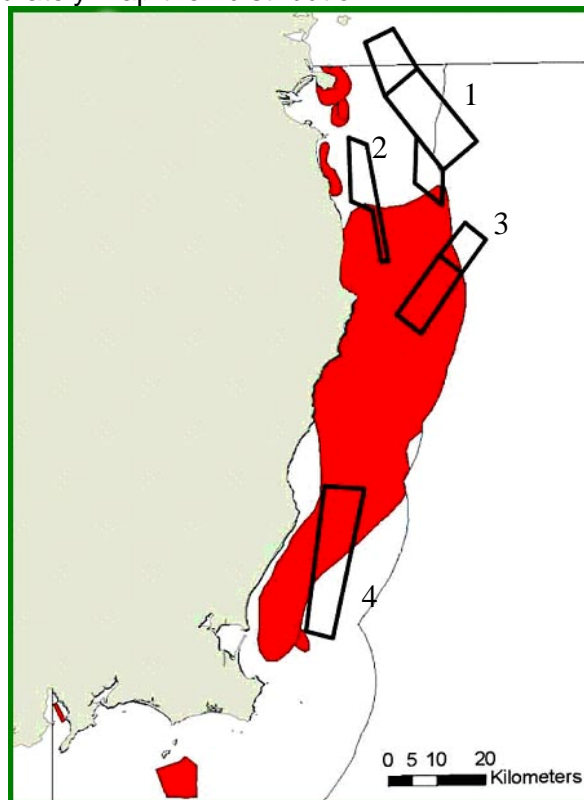


Figure 3.11. The general distribution of whelk along the southeast coast of Ireland. (courtesy of Fahy *et al.*, 2002, in the Irish Marine Atlas) The black rectangles represent IMAGIN study areas 1 – 4.

Other shellfish such as razor pods and scallop occur just outside the IMAGIN study domain to the north west of study area 1 and the south east of study area 4 respectively.

3.5.3 Commercial Fishing

First estimates of the value of fish and shellfish taken from ICES statistical rectangles would indicate that the highest value of landings is concentrated around study areas 1 – 3 off Dublin-north Wicklow and that the lowest are around study area 4 off Wexford, see Figure 3.12. However, more localised area-specific information would be required in order to fully assess the potential impacts of aggregate extraction operations in any specific site

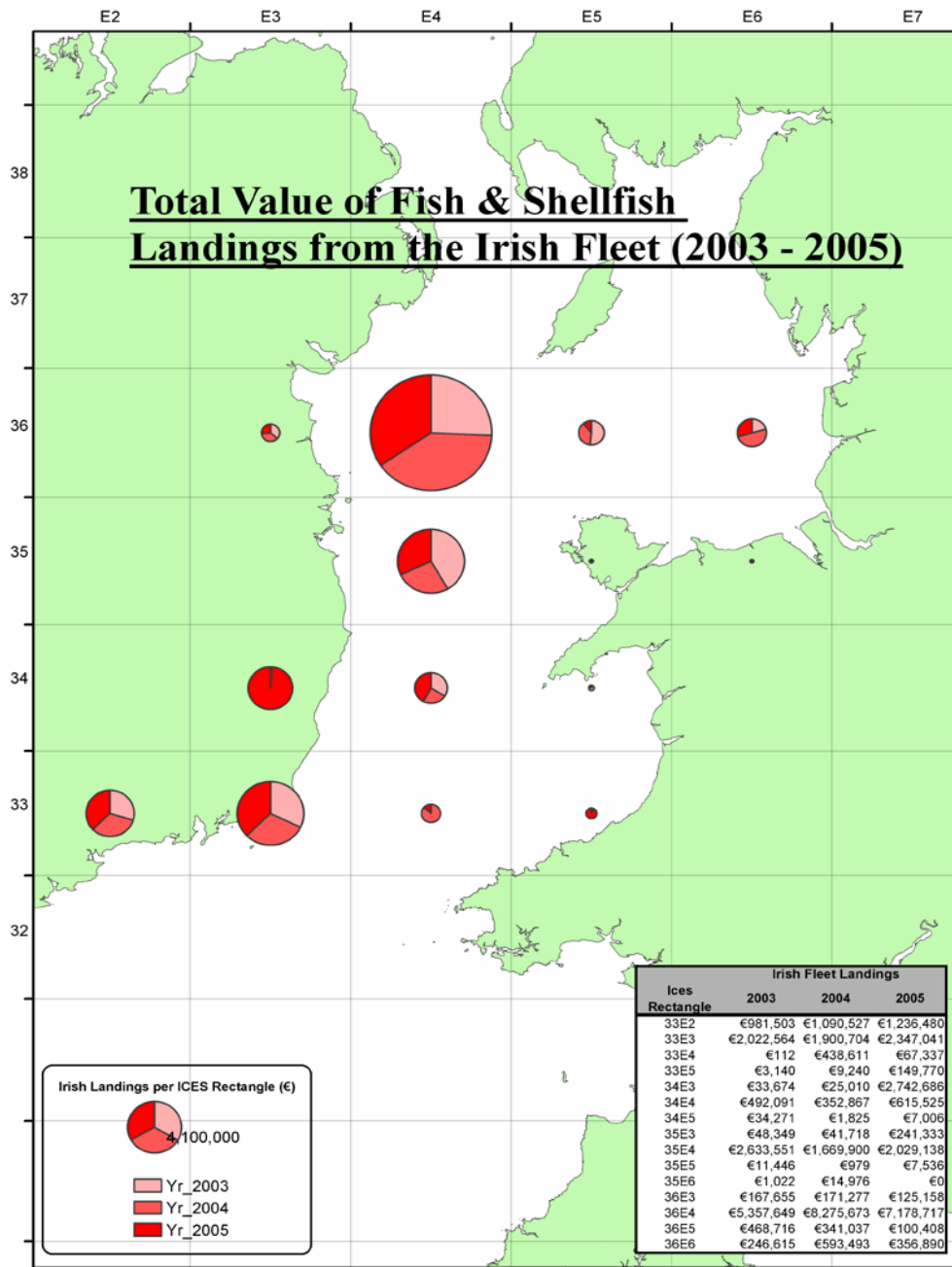


Figure 3.12. Value (€) of total fish and shellfish landings by the Irish >10m fishing fleet from selected Irish Sea statistical rectangles (data source SFP, 2003-2005)

3.6 Impacts on Fish and Shellfish Resources in the IMAGIN Study Domain

It is generally accepted that aggregate extraction in, and adjacent to, important fish spawning e.g. herring beds, or within commercially important shellfish fisheries (i.e. scallop beds) would constitute a major risk of adverse impact on fish and shellfish fisheries. Beyond these very obvious examples, the impact of aggregate extraction on fisheries and commercial fishing is less clear. For example, we know that the area around Dublin and north Wicklow and off north Wales which coincide with IMAGIN study areas 1-3 and 5 are variously recognised as areas for gadoid and flatfish pelagic spawning (Figure 3.13). What isn't known is whether extraction activity e.g. production of sediment plumes would have a significant adverse impact on pelagic eggs or larvae.

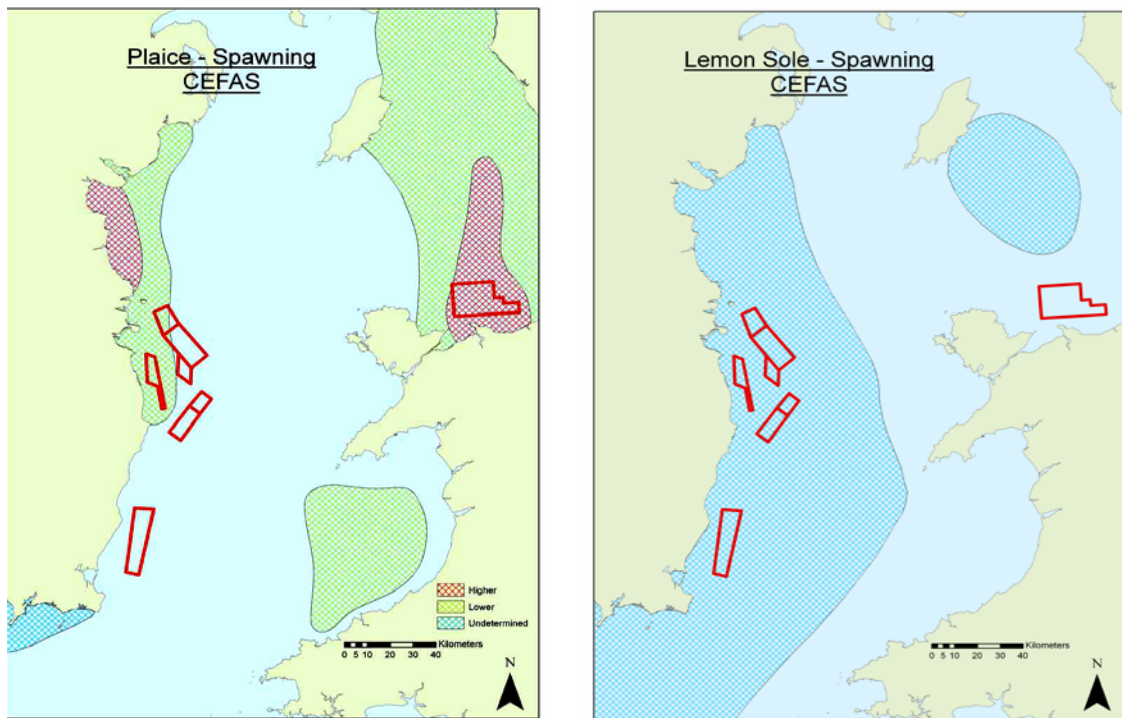


Figure 3.13. Diagrams showing spawning areas for key species in the Irish Sea and the overlap with IMAGIN study areas. Darker areas denote higher concentrations of spawning (data from CEFAS)

Aggregate extraction removes the surface layers of seabed sediment together with the benthic communities that are contained within it. Extraction may also alter the native grain size distribution by increasing the amount of finer-grained material in and adjacent to the dredging activity (over-sanding). Removal of the surface layer in particular results in a dramatic reduction in benthic biomass and diversity in all cases, which takes from 1-2 years to recover in areas of mobile sands to greater than 6 years to recover in low bed-stress (or sediment starved) stable gravel dominated areas. Flatfish and other demersal species (rays and skates, cod, whiting haddock) as well as many non-commercial fish species (dragonets, gobies, sandeel) are heavily dependent on benthic communities for food, shelter or both. Considering the area-related potential impacts and possible recovery times the IMAGIN study areas (see section 3.4.3 above), could become less productive of fish biomass in general, at least for the duration of the benthic community recovery, which might be from 1-6+ years.

Alterations in the grain size composition of gravelly or sandy gravel sites has been shown in a study off Dieppe in France (Desprez, 2000; 2007) to result in significant alterations in fish communities and behaviour associated with these sites; some of these changes appear to be evident for many years post dredging. Further evidence from this study off Dieppe, indicates that some of the observed changes in community structure and associated fish feeding behaviour are not necessarily negative. It is thought that such changes may be associated with dredging processes having increased the topographic and sedimentological heterogeneity of the seabed. Such changes may or may not be significant commercially depending on the species involved.

More specific information for whelk was available from a follow-up study that was conducted in order to assess the impact of extraction of aggregates for beach nourishment on the whelk fishery off the coast of County Wicklow (Fahy *et al.*, 2002). The study concluded that outside the immediate area from which most of the aggregate was removed (~1.5km²), it was difficult, four months after dredging operations ceased, to conclusively demonstrate any reduction in the performance of the fishery. This study might suggest that aggregate dredging only impacts whelks in the immediate dredged area. However, this was not addressed in the study. Studies of epifauna in a dredge site on the English east coast suggest that whelk may be adversely impacted at intensively dredged sites (Smith *et al.*, 2006).

It is important to note that the Arklow and Courtown sectors of the east coast whelk fishery, which overlap in part with the IMAGIN study areas (Figure 3.14) are considered to be nursery and spawning grounds for whelk, so any extraction activity within these areas has the potential to doubly impact whelks (i.e. both growers and spawners). Whelks are thought to favour hard substrates on which to anchor their egg masses so that an increase of sand in an otherwise gravel dominated site might reduce the suitability of an area for whelk spawning, a feature of a site that might be persistent for many years, depending on the strength of the local currents.

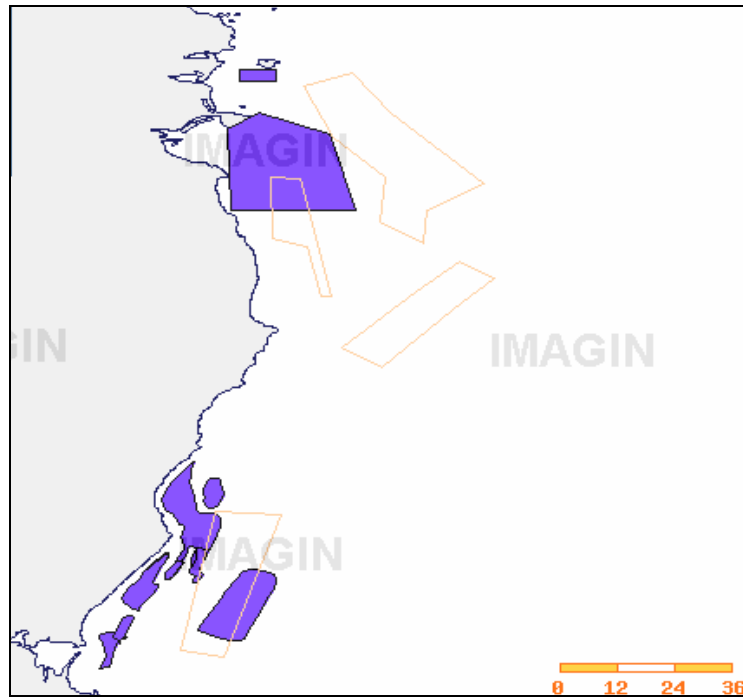


Figure 3.14. Screen capture from IMAGIN online GIS showing areas (purple) that are actively fished (potted) for Whelk. Source: BIM-(based on 2006 data provided directly by local fishermen).

Studies of the interaction between commercial fishing and aggregate extraction activities off the Isle of Wight showed that fishermen using static gear (pots or nets) were vulnerable to loss of gear owing to entanglement by dredge plant. Furthermore, insufficient consultation and communication between fishing and dredging operators regarding the day-to-day location of dredging effort led to a situation where fishermen tended to avoid larger areas around the licensed extraction boxes than would otherwise have been necessary. A number of other impacts were cited by trawler fishermen:

- Reduction in trawling efficiency in the aftermath of dredging where the seabed is left criss-crossed with furrows;
- Damage to fishing gear from large boulders and debris exposed and left uncovered on the seabed by dredging;
- Physical presence of dredgers, especially within inshore waters, has the effect of:
 - Displacing inshore fishermen to deeper and more exposed offshore waters with clear implications for safety at sea;
 - Displacing fishing activity into adjacent areas due to dredger activity in traditional fishing grounds can also give rise to greater conflict between neighbouring fishermen and greater fishing pressure on the affected areas stocks.

Clearly all these impacts are site-specific and may occur to a greater or lesser extent depending on local conditions. Nevertheless they highlight some of the sensitivities at issue.

3.7 Selected References

- Carpentier A., Coppin, F., Dauvin, J.-C., Desroy, N., Dewarumez, J.-M., Eastwood, P.D., Ernande, B., Harrop, S., Kemp, Z., Koubbi, P., Leader-Williams, N., Lefebvre, A., Lemoine, M., Loots, C, Martin, C.S., Meaden G. J., Ryan, N., Tan, L., Vaz, S., Walkey, M. (2005) CHARM Project – Final Report (Atlas and Technical Report) , Project CHARM – Rapport Final (Atlas et Rapport Technique), INTERREG IIIA, 225 & 54 pp.
- Connor, D.W, Allen, J.H., Golding, N, Howell, KL, Lieberknecht LM, Northen, K.O.and J.B. Reker (2004) *The Marine Habitat Classification for Britain and Ireland version 04.05* JNCC Peterborough ISBN 1 861 07561 8 (internet version).
- Desprez, M., (2000) Physical and biological impact of marine aggregate extraction along the French coast of the eastern English Channel: short- and long-term post-dredging restoration. *ICES Journal of Marine Science*, **57**: 1428-1438.
- Desprez, M., (2007) Presentation at annual ICES WGEXT meeting, Helsinki, Finland.
- Fahy, E, O’Toole, M, Stokes, D. and Gallagher M. (2002) Appraisal of the whelk (*Buccinum undatum*) fishery on a part of the Codling Bank following aggregate extraction for a beach restoration at Bray, Co. Wicklow. Fisheries Leaflet 182. Marine Institute, Dublin.
- Holme, N.A. & McIntyre, A.D. (eds.) (1984) Methods for the study of marine benthos. International biological programme handbook (2nd Edition). Oxford: Blackwell
- Kenny, A.J. & Rees, H.L. (1994) The effects of marine gravel extraction on the macrobenthos. Early post-dredging recolonisation. *Marine Pollution Bulletin*, 28, 442-447.
- Kozachenko, M., Fletcher, R., Sutton, G., Monteys, x., Van Landeghem, K., Wheeler, A., Lassoued, Y., Cooper, A. and Nicoll, C. (2008) A geological appraisal of marine aggregate resources in the southern Irish Sea. Technical report produced for the Irish Sea Marine Aggregates Initiative (IMAGIN) project funded under the INTERREG IIIA Community Initiative Programme 2000-2006. University College Cork, Ireland. 390pp. ISBN 978-0-9556109-2-9.
- Morgan, G., Casey, D., Harrison, P., Gillespie, D., and Warner, S. (2007) Irish Sea Marine Aggregates Initiative (IMAGIN) Work Package 1. IMAGIN: Regional Environmental Assessment of Aggregate Extraction in the Irish Sea.
- Smith, R., Boyd, S.E., Rees, H.L., Dearnaley, M.P and Stevenson, J.R (2006) Effects of dredging activity on epifaunal communities - surveys following cessation of dredging Estuarine and Coastal and Shelf Science 70 207-223.
- Thomas, N.S. (2001) Procedural Guideline No. 3-9. Quantitative sampling of sublittoral sediment biotopes and species using remote-operated grabs. In the Marine Monitoring Handbook (Jon Davies, John Baxter, Martin Bradley, David Connor, Janet Khan, Eleanor Murray, William Sanderson, Caroline Turnbull and Malcolm Vincent eds.) JNCC UK Marine SACs Project.

4 MORPHODYNAMIC MODELLING

4.1 Introduction

The Marine Institute, as IMAGIN lead partner, commissioned MarCon Computations International Limited to undertake the mathematical modelling component of the project under a contract entitled “Morphodynamic Modelling of the Irish Sea” for the purpose of aiding in the derivation of seabed sediment zonation patterns, and in the prediction and assessment of the morphological and environmental impacts of potential marine dredging scenarios.

4.2 Fundamental Numerical Modelling Framework

The ECOMSED numerical model, previously developed by MarCon for the Irish Sea domain, encompassed the region from 51°N to 56°N and from 2.5°W to 7°W. The model operated on a horizontal orthogonal grid at a resolution of 1/60° latitude and 1/40° longitude, approximately 2km x 1.6km, with a vertical sigma grid consisting of 21 layers (this represents the structure of the water column from seabed to surface). The model incorporated hydrodynamic, surface heat flux, wind waves and sediment transport modules and a custom encoded bed sediment load transport module. The model was validated for the 1995 period against data provided by the Proudman Oceanographic Laboratory Coastal Observatory Project, the British Oceanographic Data Centre and data collated from published literature. The extents of the model are shown in Figure 4.1.

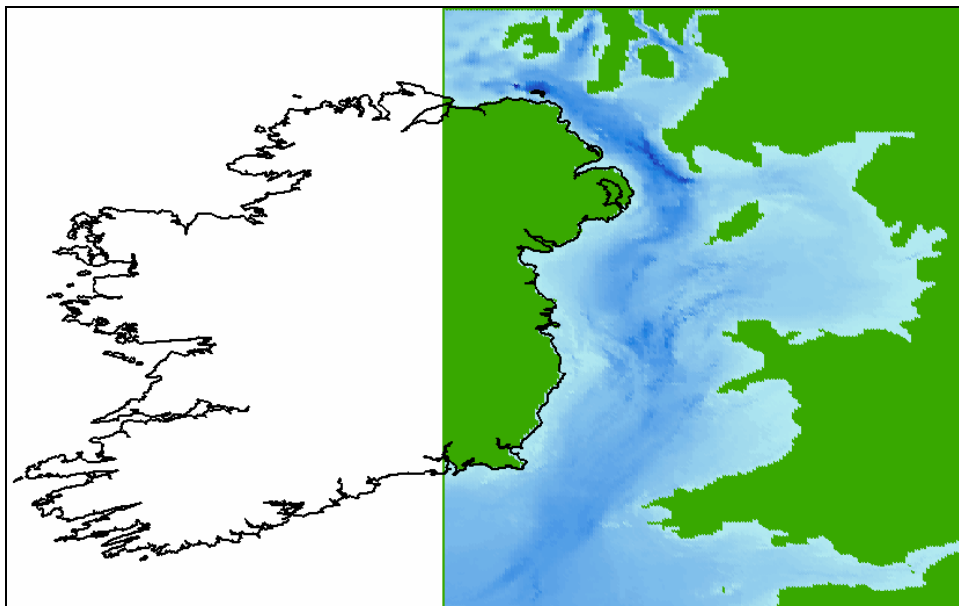
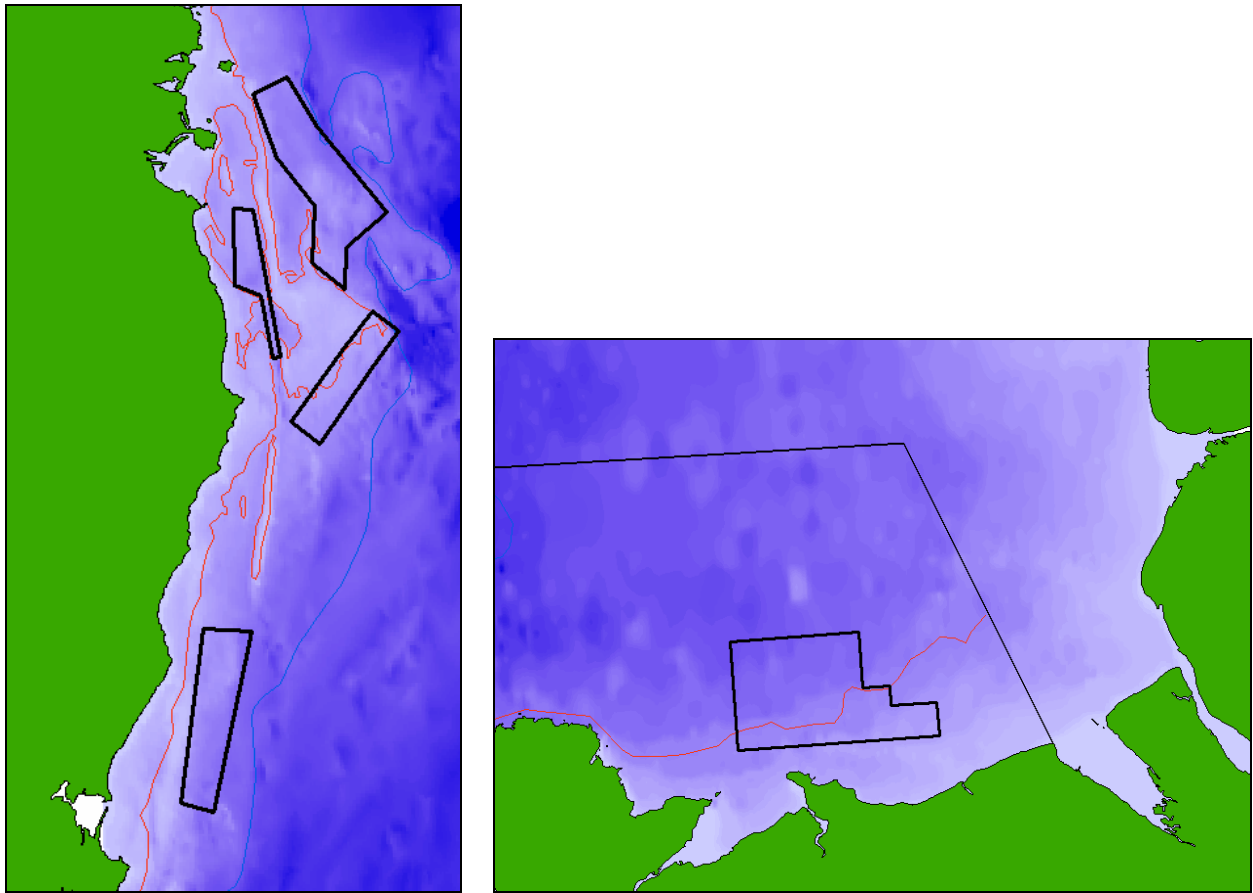


Figure 4.1. Extent of ECOMSED numerical model

4.3 High Resolution Models

Two small scale models at approximately 500m resolution were developed within the larger Irish Sea model to investigate specific environmental aspects of marine aggregate extraction. One model was developed for the eastern Irish seaboard and the other for the northern Welsh seaboard. Hydrodynamic and sediment transport boundary conditions for both small scale models were provided from the large scale Irish Sea model domain on an hourly basis. The bathymetry and extents of both high resolution models are shown in Figures 4.2a and 4.2b, respectively.



Figures 4.2a (left) and 4.2b (right) show the bathymetry (20m (red) and 60m (light blue) isobaths) and extents of the Irish and Welsh high resolution models with location and extent of the detailed study sites superimposed.

The models were used to: identify the areas of potential natural net erosion; evaluate the rates of bed sediment erosion; calculate suspended sediment concentrations; identify the pathways along which the sediment is transported; and, identify the subsequent areas of natural net deposition for a number of different scenarios.

Actual sediment characteristics of the Irish Sea, including bed sediment type and particle size distributions were defined to the models at the same resolution as the respective model grids in order to provide highly detailed sediment boundary conditions.

Whilst every effort was made to ensure that all available sediment characteristics were defined as accurately as possible to the sediment module, no direct calibration exercise could be undertaken within the scope of this project. Thus it was not possible to ensure that the predicted results from the modelling exercise resulted in precise, accurate, values of the sediment erosion/deposition and transport processes. Model predictions do compare favourably with available field data and findings from other independent sources giving confidence that the results are valid on a relative basis. Figures 4.3 (spring tide situation) and 4.4 (neap tide situation) show the broad agreement between spatial distributions of suspended sediment concentrations around the Island of Anglesey as predicted by the ECOMSED model and as sampled by Smith *et al.* (2003). Figure 4.5 illustrates a similar pattern of agreement between model predictions and SeaWifs satellite imagery reflectance (Weeks and Simpson, 1991), which is a close proxy for suspended sediment concentration.

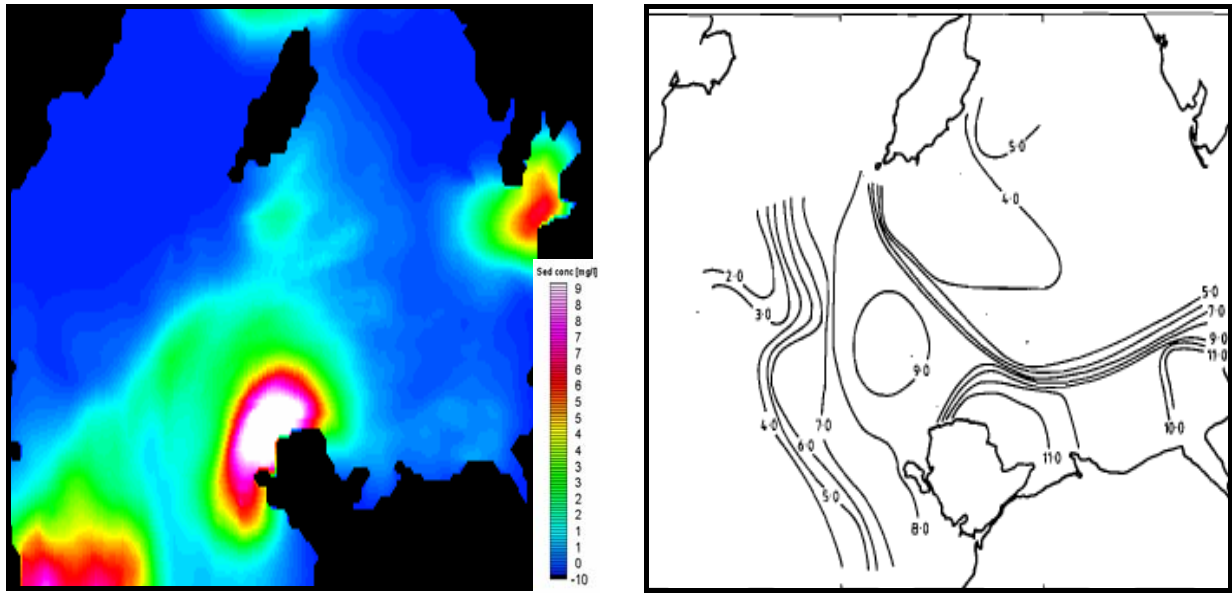


Figure 4.3. Comparison of model predictions v sampled data on a spring tide.

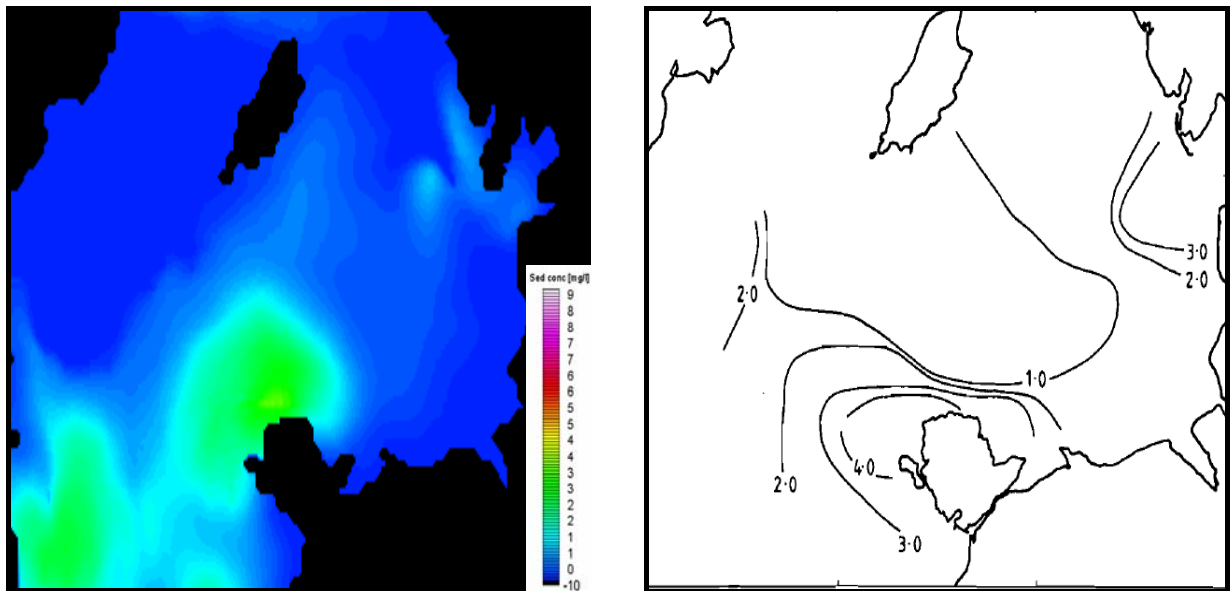


Figure 4.4. Comparison of model predictions v sampled data on a neap tide.
(30 March 1987 to 4 April 1987)

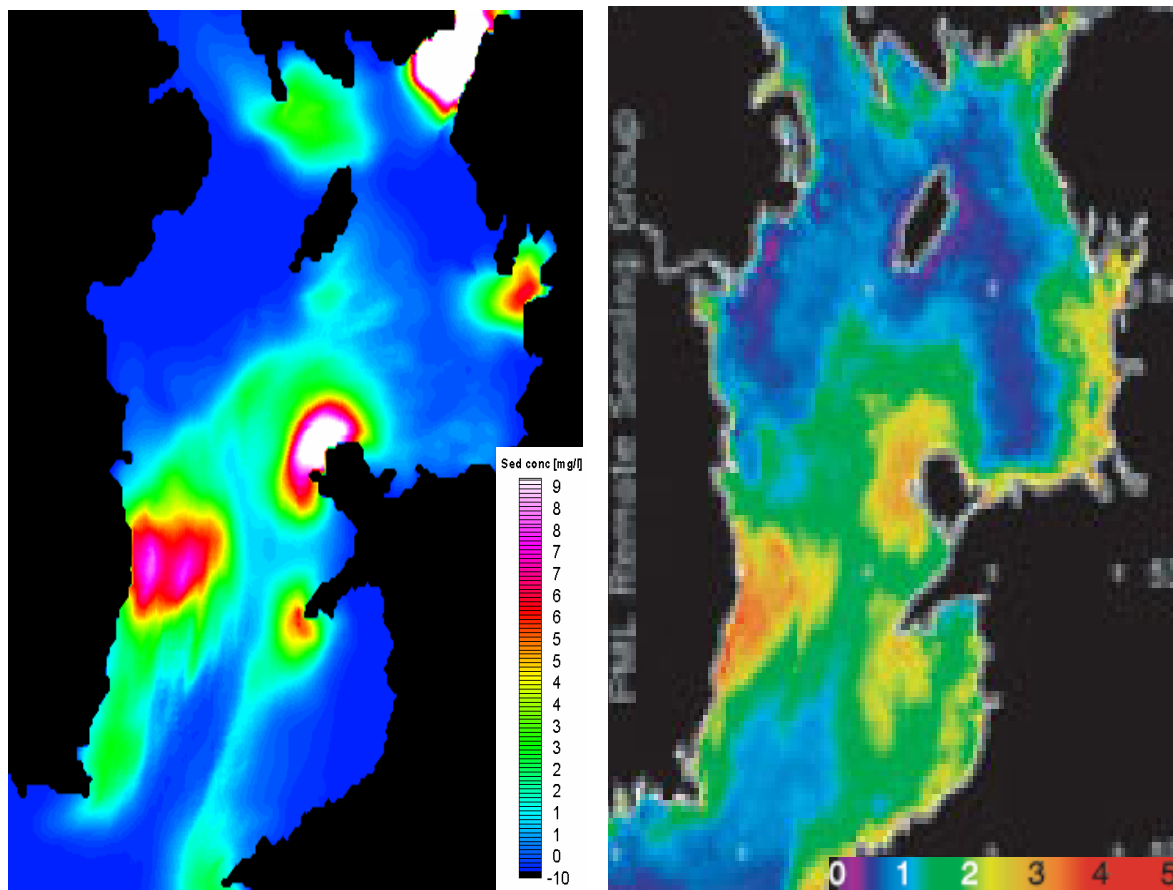


Figure 4.5. Comparison of model predictions versus satellite imagery (1998).

Sensitivity analysis was undertaken in order to assess the response of the model to changes in the formulation of the seabed sediment composition as this is one of the main forcing parameters of the sediment transport module. It was found that changes in the bed sediment composition had a significant effect on the quantity of material that was eroded, transported and deposited. An analysis of the bed load transport formulation encoded to the numerical model was also undertaken in order to examine the extent of transport of sediments at the seabed. It was determined that both formulations used gave broadly similar rates and directions of bed load transport and were commensurate with transport rates in similar studies.

4.4 Morphodynamic Modelling Scenarios

Six different modelling scenarios were defined in consultation with the project partners in order to address the main objectives of the work package namely: to provide spatially and temporally detailed information regarding water circulation and sediment transport pathways throughout the Irish Sea; to aid in the derivation of seabed sediment zonation patterns; and, to predict and assess the morphological and environmental impacts of potential marine dredging scenarios. A summary of morphodynamic modelling scenarios which were all run over a period of one year is given in table 4.1 below. Stored outputs for every tidal cycle over one year consisted of predicted change in bed sediment thickness (arising from localised mobilisation of sediment, suspended sediment concentration, (cohesive and non cohesive), and sediment transport vectors.

Table 4.1. Summary of modelling scenarios.

Model Used	Scenario Number	Details
Irish Sea Model	1	Simulate morphological conditions in the Irish Sea, identify areas of natural sediment mobility, calculate suspended sediment concentrations, and identify transport pathways.
Small Scale Irish Model	2	Simulate morphological conditions off the eastern seaboard at higher resolution.
	3	Simulate morphological processes off the eastern seaboard, in particular beaches, to determine probable natural mobility of beach material in the absence of contribution from offshore areas.
	4	Simulate morphological processes in the offshore region of the Irish east coast with particular reference to investigating the stability of the Arklow Bank region in relation to the sediment flux within the region in the absence of external sediment supply.
Small scale Welsh Model	5	Simulate morphological processes along the northern seaboard of Wales in order to determine the sedimentary conditions within the region with particular reference to the Constable Bank.
	6	Examine the effects of a theoretical dredging operation on the Constable Bank, including water movements, bank stability and probable recovery rates.

4.5 Summary of Findings

A summary of main findings of the study is presented together with sample graphics that illustrate important points and provide an overview of the types of output generated. Readers are encouraged to refer to the main project report where these scenarios are presented in detail.

One of the main outcomes was the determination of the sediment transport pathways throughout the Irish Sea. Presented in Figure 4.6 are the annual average suspended sediment transport vectors throughout the whole Irish Sea model domain as predicted by the Irish Sea model. The vectors in the figure represent the mass transport of suspended sediment with respect to time in the units of grammes/second per unit metre. In terms of scale 10 grammes/second equates to 315 tonnes/year. Figure 4.7 presents the sediment transport vectors in more detail as predicted by the high resolution eastern Irish seaboard model.

Investigation of the evolution of the sediment bed at the higher resolution provided by the small scale models presented a greater level of detail in relation to the sedimentary processes. Presented in Figure 4.8 are the natural changes in the thickness of the bed sediment layer as a result of wave and tidal action at the end of one year's simulation off the eastern seaboard of Ireland. The change in thickness of the bed sediment layer is expressed in centimetres (positive = deposition, negative = erosion) and is indicative of the volume of sediment material mobilised locally at each computational cell in the model; Figure 4.9 provides the same information for one year's simulation off the north coast of Wales

A change of 10cm in the thickness of the sediment bed translates to the natural localised mobilisation of approximately 62,000 tonnes of marine sediment over the course of a year through wave and tidal forces, given the area of one numerical model cell equals $247.5 \times 10^3 \text{ m}^2$ and the average density of bed sediment equals 2500 kg/m^3 .

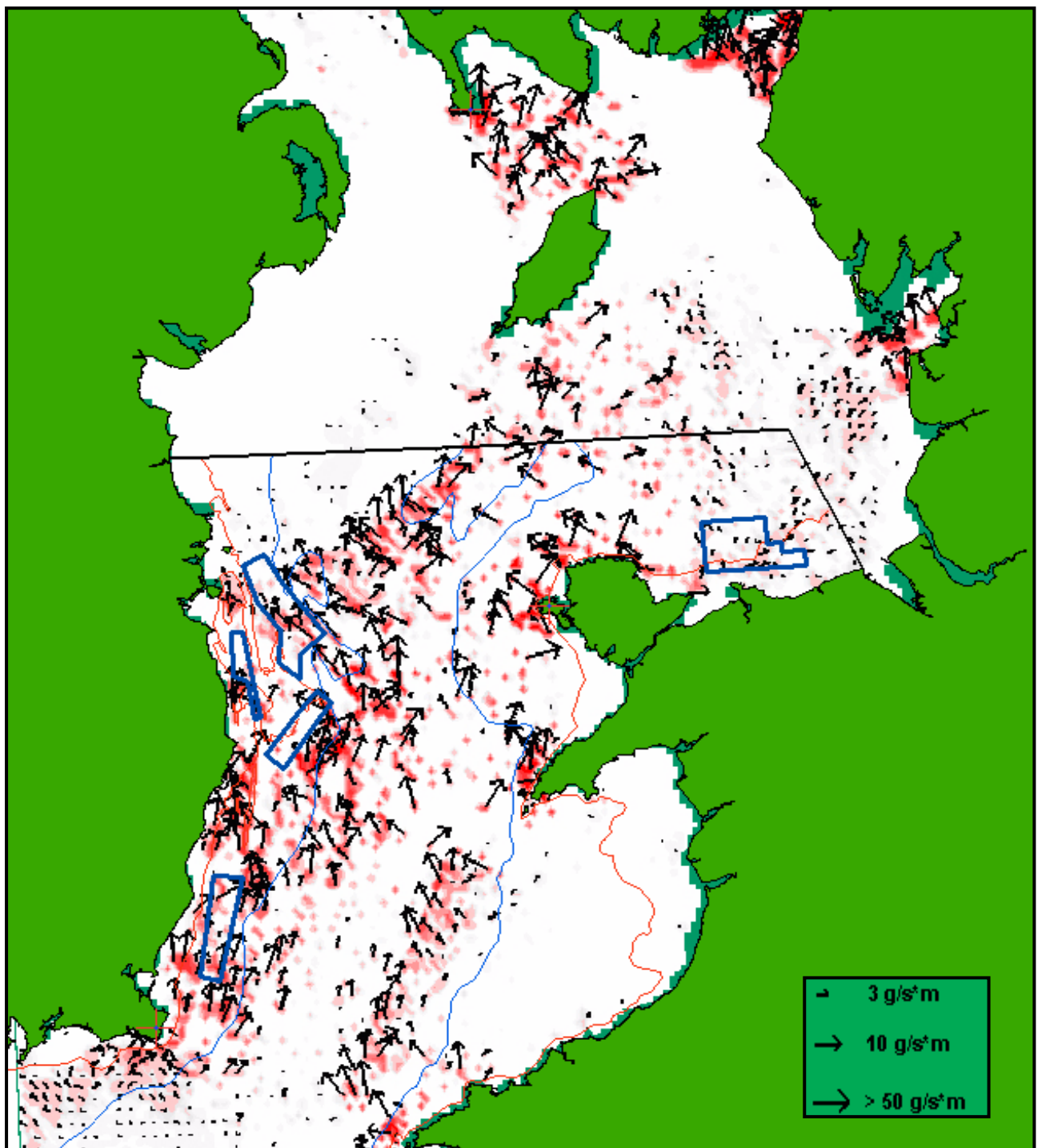


Figure 4.6. Suspended sediment transport vectors

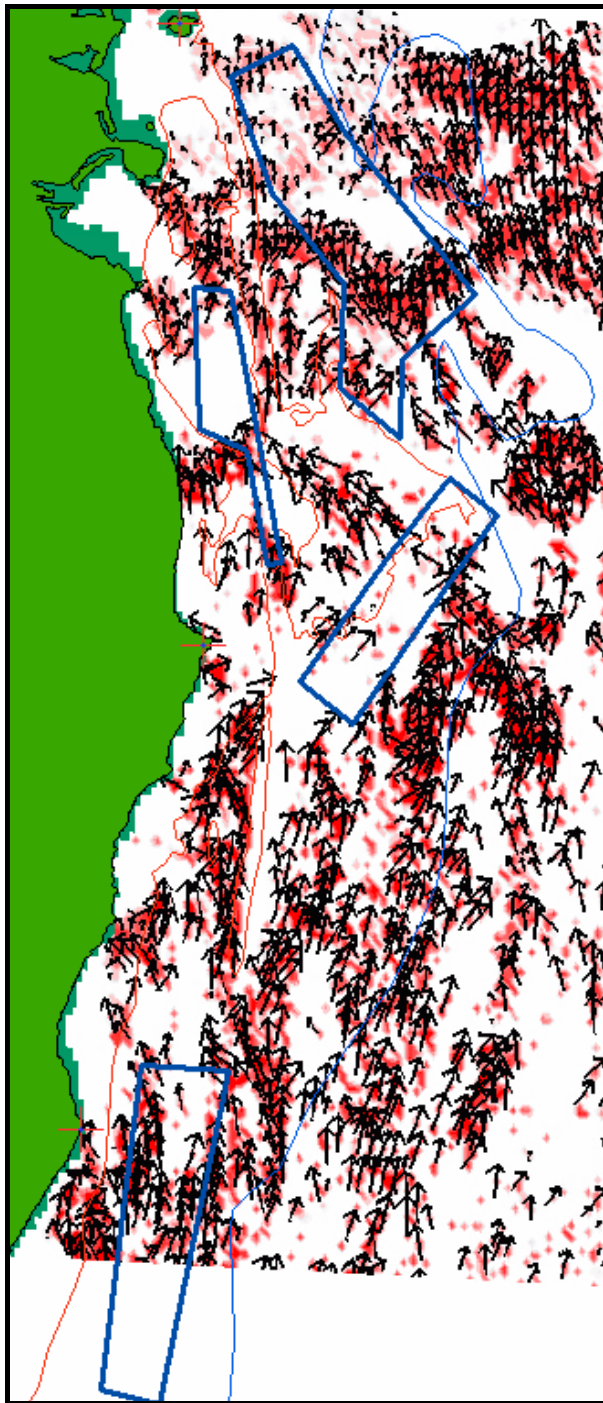


Figure 4.7. Small scale eastern Irish seaboard model suspended sediment transport vectors

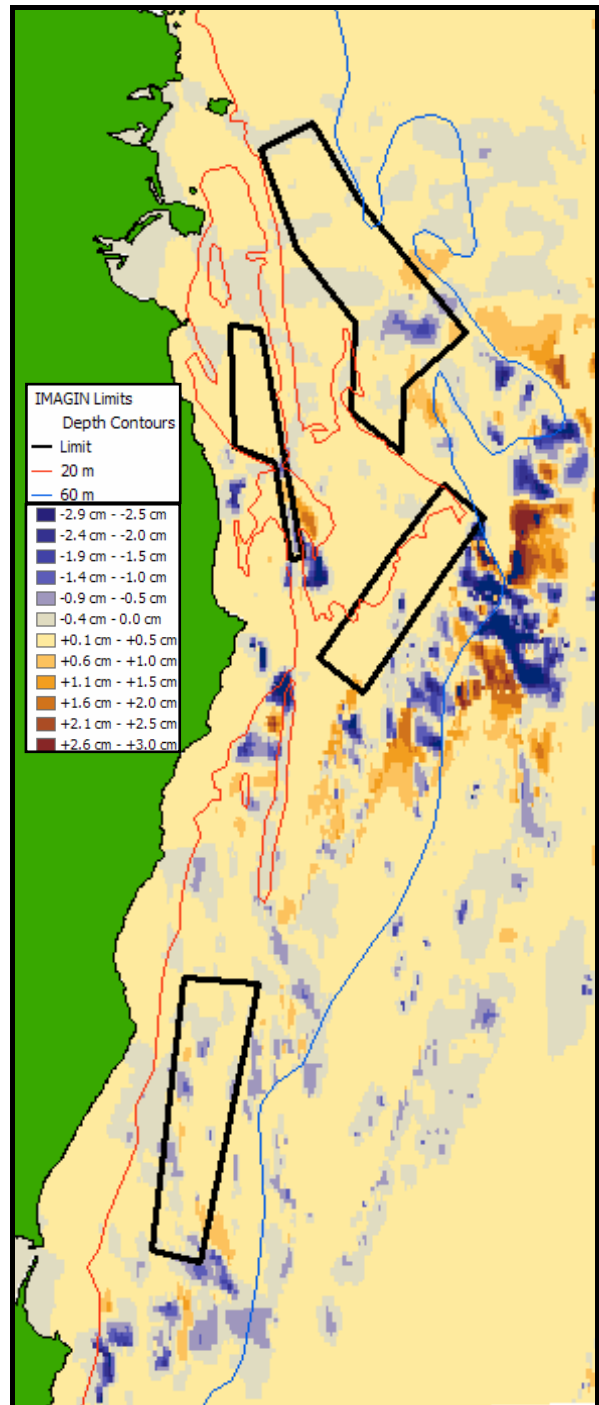


Figure 4.8. Predicted changes in bed sediment thickness after one year (small scale eastern Irish seaboard model)

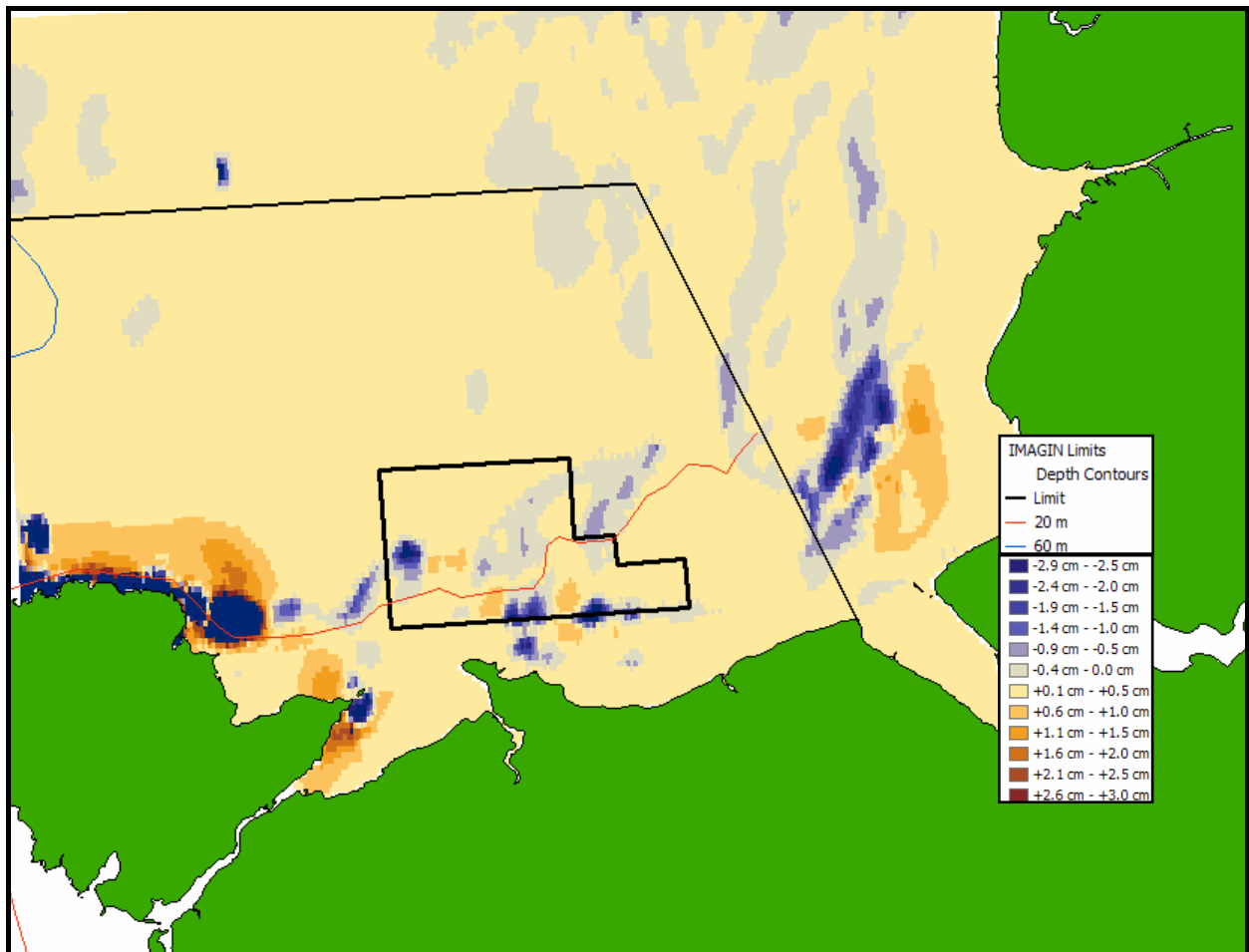


Figure 4.9. Predicted changes in bed sediment thickness after one year. (Small scale Welsh seaboard model)

The predicted transport of sediment off the eastern seaboard of Ireland can be summarised as follows:

- The net suspended sediment transport along the entire east coast of Ireland was predicted to be in a net northerly direction with complex regions of highly mobile bed sediments, especially in the vicinity of the 60m contour off the Wicklow coast.
- The suspended sediment transport between the 20m and the 60m contour, (the limit of the IMAGIN study area), off the coast of Wicklow and Dublin is in a net northerly direction towards the north-western part of the Irish Sea. The patterns of localised mobility of the bed sediments, expressed as changes in bed sediment thickness, in this area are very complex with large volumes ($\sim 125 \times 10^3$ tonnes) of sediment mobilised locally over the course of a year.
- The reason for such complexity in the patterns of sediment mobility off the east coast of Ireland can be attributed to the bed sediment classifications as defined by the British Geological Survey. The sediment classification in this region is very complex with areas of sand, interspersed with regions of sandy gravel, gravelly sand, and gravel.

The predicted transport of sediment off the northern seaboard of Wales can be summarised as follows:

- The net suspended sediment transport off the north Wales coast was predicted to be offshore and in a net northerly direction. The transport of suspended sediments in the regions was much lower than that predicted along the Irish east coast owing to the relatively lower current speeds in the area.

- The predicted patterns of natural changes in the thickness of the bed sediments in this area, and associated potential bed sediment mobility were much simpler than those occurring off the Irish east coast. The near bed current velocities are such that there was relatively little sediment eroded from the bed resulting in low values of sediment mobility and low rates of change in bed elevation, with the exception of the area around Anglesea.
- This region exhibited much less complexity than the east coast of Ireland due to the relatively uniform sorting of the sediments with predicted erosion occurring in the regions of slightly gravelly muddy sand, (sgms), sand, (snd), and slightly gravelly sand, (sgsd).
- The predicted changes in the thickness of the bed sediment layer over the course of a year were of the order of +/- 2.5cm, ($\sim 15 \times 10^3$ tonnes/yr mobilised locally), and occurred in outer Liverpool Bay and offshore of Llandudno.

The fact that such relatively small quantities of bed sediment are mobilised off the north Wales coast, when compared to the eastern seaboard of Ireland, would suggest that this region might be more susceptible to physical impacts on the structure of the seabed as a result of dredging activity than the highly dynamic sediment environment evidenced along the eastern seaboard of Ireland. Presented in Figure 4.10 are the predicted changes in the thickness of the bed sediments at the end of one year's simulation along the Arklow Bank. These results indicate that, in the absence of external sources of sediment, the bank might be subject to progressive erosion along its entire length. This erosion is rather strong and is greater in the northern parts of the bank. It was also found that the material eroded from the bank tends to be accreted around the slopes of the bank. Also, the model predicts a gradient in the suspended sediment concentrations along the bank, and the concentrations increase when moving northwards. Considering the above, and the fact that the model was executed without external sources of sediments, the obtained results indicate that these external sources may play an important role in ensuring the stability of the Arklow Bank, and therefore their careful management should be considered.

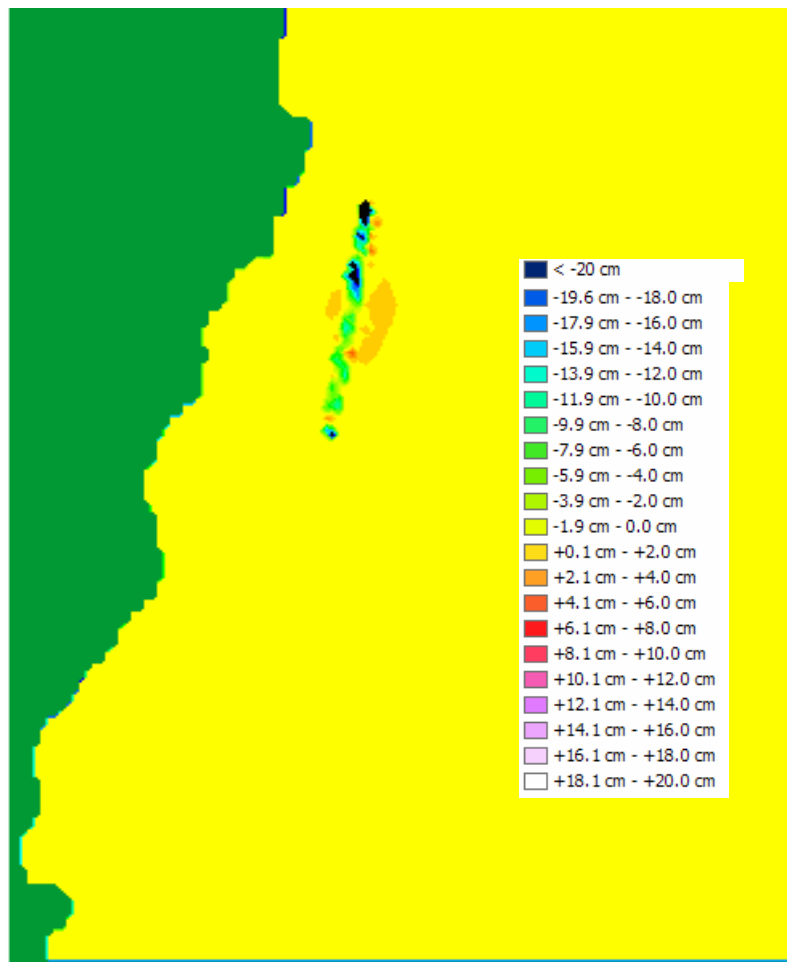


Figure 4.10. Changes in bed thickness of Arklow Bank after one year

4.6 Bed Characterisation Sensitivity Analysis

This element of the work was undertaken in order to investigate the sensitivity of the model predictions to the manner in which the bed sediment composition was classified. The bed sediment composition was one of the boundary conditions that drove the ECOMSED sediment model and therefore changes in the bed sediment composition would have a relatively greater effect on the quantity of material eroded, transport and deposited than any of the other empirical calibration parameters. The sensitivity analysis was undertaken on the small scale eastern Irish seaboard model. A ‘median’ and ‘random’ method were tested, a detailed treatment of which is presented in the main report.

The authors are of the opinion that the random method for specifying the bed composition was more representative of the heterogeneity of the seabed sediments, showing a greater level of detail with respect to the formation of successive erosion and depositional areas off the east coast. These regions of successive erosion and deposition reflect the nature of the seabed in this region, with large sand wave fields in a north-south direction offshore, albeit at a higher frequency than that predicted by the numerical model owing to the model resolution of approximately 500m. Comparative results are illustrated in Figure 4.11.

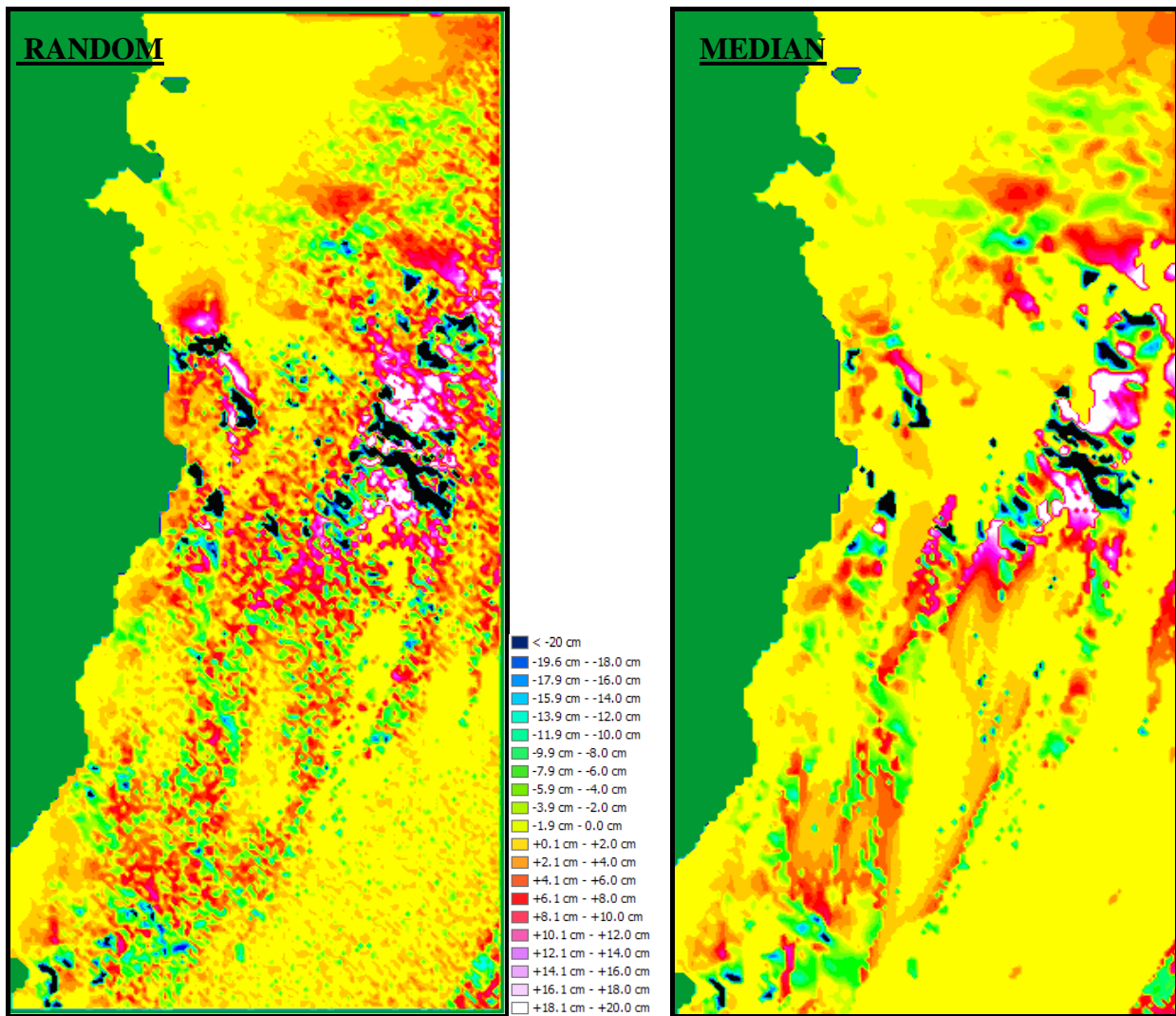


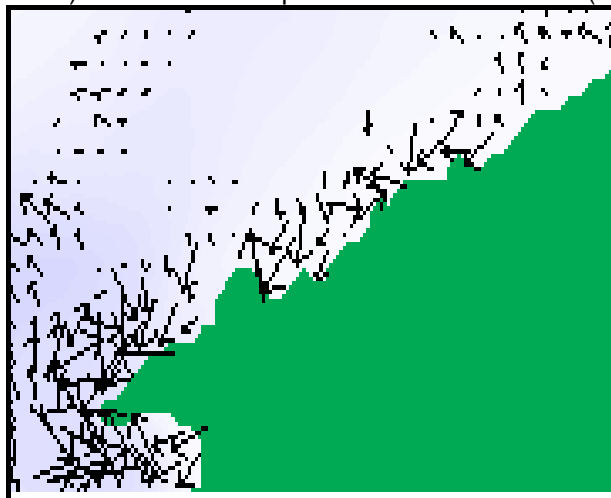
Figure 4.11. Predicted changes in bed sediment thickness after one year.

4.7 Bed Load Transport Analysis

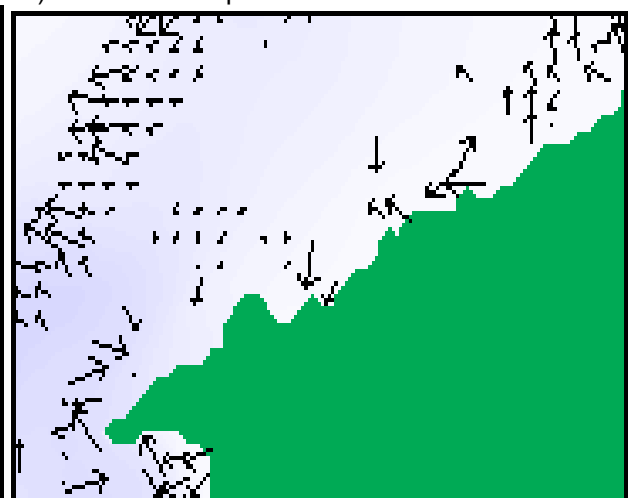
In order to examine the extent of transport of sediments at the seabed, a bed load transport analysis was undertaken. Two commonly used formulations Bagnold (1963) as modified by Gadd *et al.* (1978), and Meyer-Peter and Mueller (1948) were tested. The results of these analyses were expressed and visualised in the form of bed load transport vectors. Comparisons were subsequently made against results from the Futurecoast study (DEFRA, 2002). These show that the results from both formulations compare favourably with published information (Figure 4.12).



a) Sediment transport vectors from DEFRA (2002) Futurecoast report



b) Monthly average bed-load transport (after Bagnold)



c) Monthly average bed-load transport (after Meyer-Peters & Mueller)

Figure 4.12. Comparison of bed load transport vectors against DEFRA (2002) study output.

4.8 Summary Discussion of Results

Regulatory decisions may be informed by advice and information from a variety of sources, including vested interests or on the best available scientific information (be that an un-calibrated morphological model). Un-calibrated morphological models and predictions can be used as a tool by policy makers and decision makers to anticipate possible effects of offshore sand extraction processes. Although the sediment transport component of the numerical modelling framework is not precisely calibrated, it does indicate the probable morphological evolution of the seabed in the Irish Sea and can indicate the possible effects of dredging operations.

Model predictions have shown that there is significant natural mobility in the seabed sediments off the eastern seaboard of Ireland. Both the Irish Sea model and the small scale eastern Irish seaboard model predicted natural localised movement of bed sediment of approximately 250,000 tonnes/km² over the course of a year at numerous locations, This would be equivalent to 100 dredging events in the same area over the course of a year using a standard 2,500 tonne capacity dredger.

Given that the benthic environment is currently subjected to the natural localised mobilisation of large volumes of bed sediment in certain areas, it would be expected that the removal of bed sediment through dredging operations from similar highly dynamic areas would have a minimal biological impact in the long-term.

The most recent published figures from the British Marine Aggregate Producers Association, (BMAPA), state that approximately 25 million tonnes of marine aggregates were produced from a total dredged area of approximately 140km² in 2006, which translates to an average annual value of approximately 179,000 tonnes / km², a figure close to that predicted by the morphological models as being mobilised naturally through wave and tidal action off the eastern seaboard of Ireland.

4.9 Validity of Model Predictions

Although the sediment transport component of the ECOMSED numerical model was not calibrated or validated in the strict scientific sense, the model has predicted suspended sediment concentration within the same range as sampled data for both spring and neap tides, the model has predicted suspended sediment concentrations throughout the Irish Sea domain within the same range and spatial extent as data inferred from satellite imagery, the model has predicted similar rates of bed-load sediment transport rates as measured and predicted in the English Channel, and finally the model has predicted similar transport vectors for the bed-load sediments at a number of locations around the coast of England and Wales.

4.10 Selected References.

- Bagnold, R. A., (1963) Sedimentation: beach and near-shore processes. In: HILL, M.N. (ed.) The Sea. Vol 3. Wiley-Interscience, New York, 507-553.
- BMAPA, (2006) http://www.bmapa.org/who_key01.php
- Defra (2002) Futurecoast Study. CD available from Defra, Ergon House, 17 Smith Square, London SW1P 3JR.
- Gadd, P.E., Lavelle, J.W., & Swift, D.J.P., (1978) Estimates of sand transport on the New York shelf using near-bottom current-meter observations. *Journal of Sedimentary Petrology*, 41t, 239-252.
- Meyer-Peter, E., Mueller, R., (1948) Formulas for bed-load transport. Proc. IAHR, Stockholm, 1948.
- Smith, C.N., Stewart, T.H., & McDonald, P., (2003) Results from an intensive measurement programme for suspended particulate matter in a region of the Irish Sea between Anglesey and the Isle of Man. *Continental Shelf Research* (23) pp 1005-1018
- Weeks, A. and Simpson, J. H. (1991) 'The measurement of suspended particulate concentrations from remotely-sensed data', *International Journal of Remote Sensing*, 12:4, 725 – 737

5 PROTOTYPE DECISION SUPPORT SYSTEM

5.1 Introduction

Large volumes of data have been collected and processed within the IMAGIN project and will have to be accessed and analysed by various stakeholders and scientists. IMAGIN data are intended for marine aggregates extraction use purposes, but also for broader fields of application. It is expected that these data will be accessed by other systems and users, and combined with other data and resources. Given their high cost and value, it is very important that these data can be easily presented, interpreted and reused by the different stakeholders. In order to maximise the quality of data presentation, interoperability and reusability, considerable effort has been spent on data model optimisation. This comprises both survey datasets themselves and their documentation, i.e. metadata (data about data – a comprehensive set of information pages that describe all relevant aspects of each dataset e.g. origin, type, processing, usage, scale, spatial extent etc.).

5.2 Survey Data Model Design

For many practical reasons including ease and consistency of management, storage, retrieval and interoperability all datasets must be structured in a logical and understandable way. The ESRI ArcGIS Marine Data Model (Arc Marine) provides a general framework for envisioning the core feature classes required to represent coastal and marine data. Arc Marine aims to provide more accurate representations of the location and spatial extent of marine features and to help users conduct more complex spatial analysis of these data. The model also guides users to take new approaches that effectively integrate marine data in space and time."

Although Arc Marine has been initially designed for one of the worlds leading GIS products Environmental Systems Research Institute (ESRI), more specifically ArcGIS, and although IMAGIN data are not embedded in ArcGIS, it was still considered relevant to use Arc Marine as a model for IMAGIN data. The objectives were to:

- guarantee schematic and semantic (shared understanding of meanings for terms) interoperability by conforming to the data structure defined by Arc Marine;
- facilitate the data loading into a geodatabase; and
- ensure a high quality, intuitive, accessible and practical presentation of the data. In addition, Arc Marine provides ready-to-use feature classes for representing complex data such as location series, time series, profiles, etc.

Not only does Arc Marine allow a well-structured and easily reusable model of marine data, it is also achieving formal recognition as a standard that is increasingly being adopted by marine organisations. For these reasons, the ArcMarine Data Model has been adopted as a standard for this work. Figure 5.1 shows an extract of the IMAGIN data model that has been developed as an extension to Arc Marine.

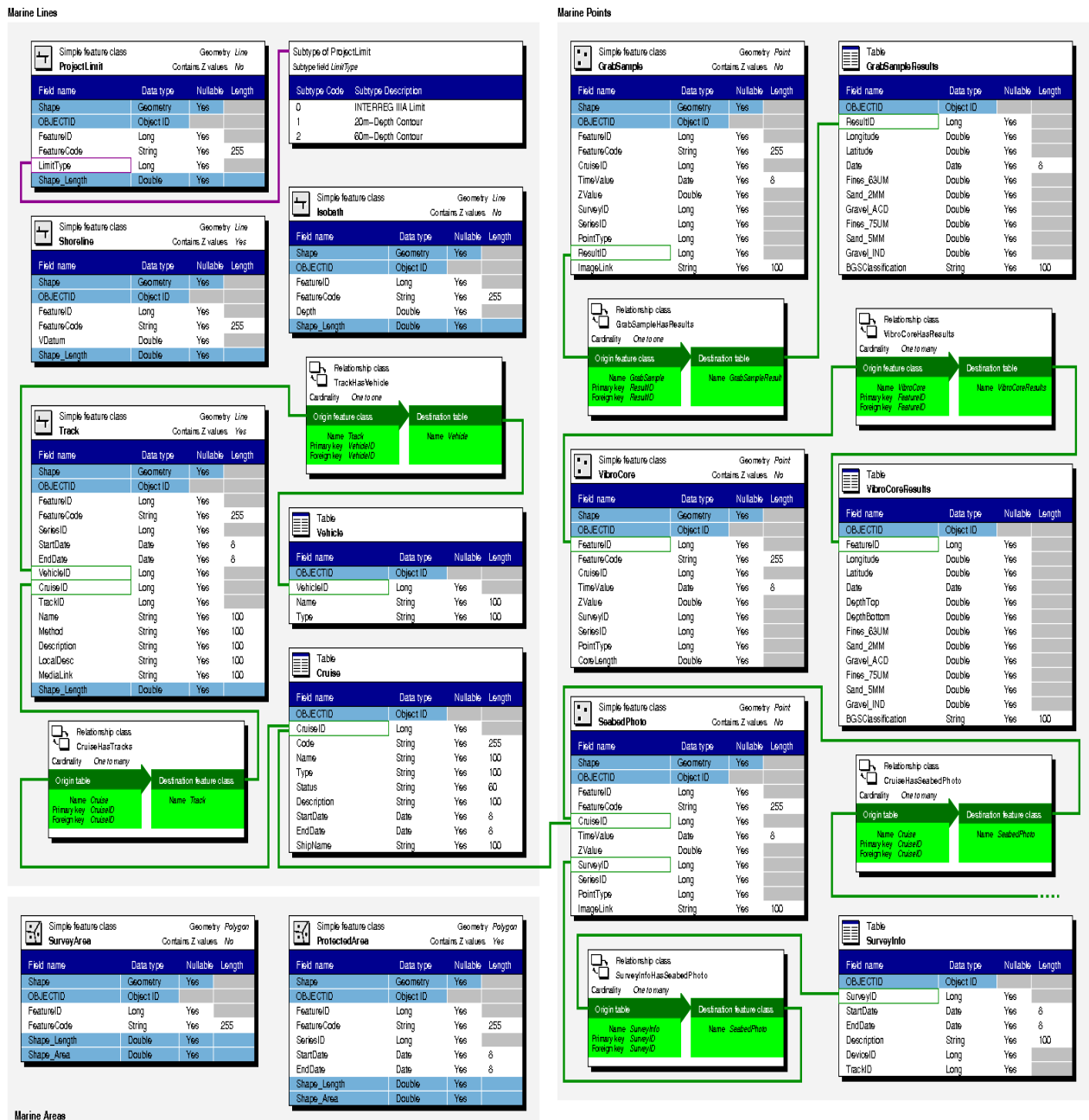


Figure 5.1. IMAGIN Data Model based on Arc Marine

5.3 Metadata Design

A second part of the database consists of information about data, or metadata. Metadata are crucial for the development of any GIS; they provide geographic data producers and users with a more comprehensive knowledge of their holdings and allow them to better manage data production, storage, updating, and reuse. As a result metadata records facilitate data discovery and access by providing content and location information for resources. They also facilitate syntactic and semantic interoperability by providing syntactic and semantic information about resources. In addition, metadata provide provenance and quality information, which facilitate preservation and ensure correct and valid use of data, by defining their fitness for use. Potential users of data must understand beforehand the quality and limitations of the data they intend to procure. The critical element here is the determination whether the data under consideration is 'fit for the intended use'.

Several metadata models are available. However, given the growing trend among leading organisations, we believe that the ISO-19115 standard and its XML implementation ISO-19139

are leading the field in terms of interoperability. An ISO-19115 metadata profile has been defined as part of the IMAGIN project. The IMAGIN metadata profile, illustrated in Figure 5.2, includes the ISO-19115 core metadata set. A metadata editor, MetaGIS, with a graphical user interface, has been developed (in Java) to allow users to create and edit metadata files. Generated metadata are encoded in XML code conforming to the ISO-19139 standard.

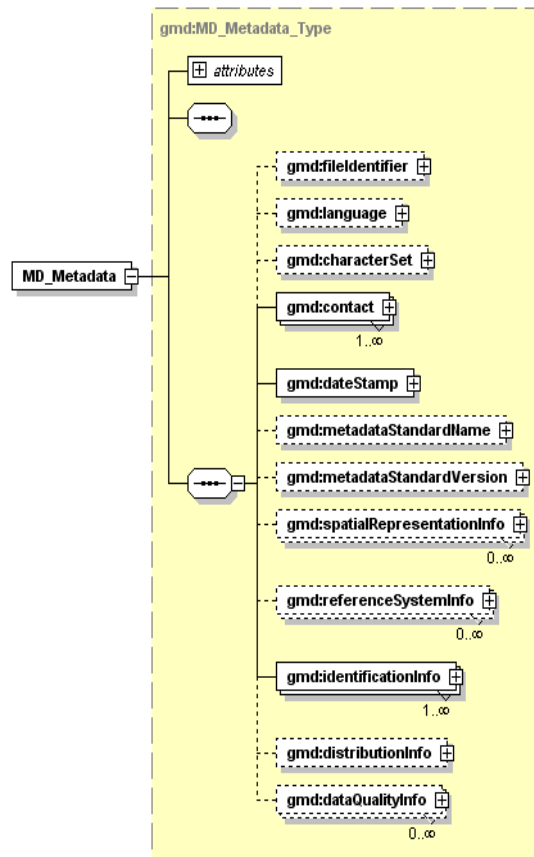


Figure 5.2. IMAGIN ISO-19115 Metadata Profile

5.4 IMAGIN Web-GIS Prototype Decision Support System (DSS)

The IMAGIN Prototype-DSS has been designed to help scientists use the datasets provided by the IMAGIN participants in order to answer complex questions like: “Where, within a given area, a potential marine aggregates resource might be exploited without (or with minimum) impact on the seabed and environment? And which period of the year, with relation to the fishing activity and fish abundance, might the extraction be performed or suspended?”, etc.

In order to achieve this, IMAGIN prototype DSS integrates different resources (data, metadata and maps) provided by the IMAGIN participants. A user-friendly graphical interface offers easy access to IMAGIN resources and allows users to visualise and interact with the data. The system can be accessed at <http://imagin.ucc.ie/>. More advanced users are enabled to query and to download the available resources in order to perform further analysis using their own systems and applications. For this purpose the IMAGIN prototype DSS also provides a set of standard Web services that allow users to search and query IMAGIN resources.

The IMAGIN prototype DSS has been designed with a service-oriented architecture that implements the Open Geospatial Consortium (OGC) Web services standards which establish a common and consistent way for systems to function and interoperate (see Figure 5.3). IMAGIN system architecture implements the OGC Web Feature Service (WFS), Catalogue Service for the Web (CS-W), and Web Map Service (WMS).

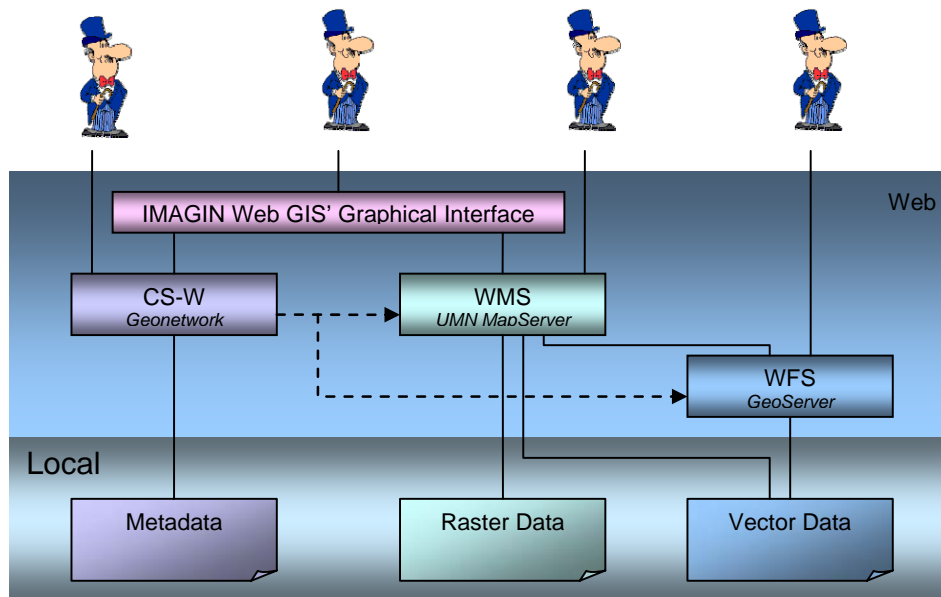


Figure 5.3. IMAGIN Web DSS Architecture: An OGC service-oriented Architecture that uses the OGC Web Feature Service (WFS) for delivering vector data, the OGC Catalogue Service for the Web (CS-W) for delivering metadata, and the OGC Web Map Service (WMS) for delivering image maps.

5.4.0 Web Feature Service (WFS)

The OGC Web Feature Service (WFS) defines interfaces for data access and manipulation operations on geographic features using Hypertext Transfer Protocol (HTTP-another internet standard for transfer of information). Via these interfaces, a web user or service can combine, use and manage geospatial datasets using HTTP requests. Data delivered by WFS are encoded in GML, the Geography Markup Language. GML is the Extensible Markup Language (XML) grammar defined by OGC to express geographical features. GML serves as an exchange data format for the delivery of geographic data on the Web, by WFS. The use of a WFS as part of IMAGIN prototype DSS enables users to query, manipulate and download IMAGIN vector (lines and points) data and perform advanced analysis on them. In terms of implementation, IMAGIN prototype DSS uses GeoServer software as WFS implementation.

5.4.1 Catalogue Service for the Web (CS-W)

Catalogue services allow users to publish and search collections of descriptive information (metadata) for data and services using HTTP. Implementing this service enables IMAGIN prototype DSS users to search and query metadata records. This facilitates data discovery and access. IMAGIN CS-W also delivers metadata records to the graphical user interface. The software system that implements this service is GeoNetwork.

5.4.2 Web Map Service

A Web Map Service produces maps of geospatial data dynamically from geographic information. In the IMAGIN prototype DSS, a web map service (WMS) generates maps from the web feature service (WFS) data and from raster data. The WMS delivers maps both to the graphical user interface (i.e. that of the current user) and to Web users (other users) and applications. These WMS functions are delivered by means of UMN Mapserver which is a popular and well tested open-source (free non proprietary) software system developed by the University of Minnesota.

The aim of this Web service based architecture is to allow (i) more modularity within the prototype DSS and (ii) more interoperability by enabling scientists and stakeholders to interact (possibly via applications) with a catalogue of the available resources and download data, metadata and maps, through OGC services. These can then be used locally as required for more advanced analysis and computations.

The IMAGIN prototype DSS offers an easy-to-use graphical interface that allows dynamic construction of the layer list. In other words users can choose from a list of available datasets which ones they want to display. Data layers are structured into categories and can be browsed and visualised easily. The graphical interface also handles the relational aspect of the ArcMarine data model by allowing navigation between different related tables based on a foreign key mechanism. Taking the example of a sediment sample location, the sample description, photo and the vehicle (survey platform) information are all retrieved and shown. This is illustrated in Figure 5.4. The IMAGIN prototype DSS also has the capacity to handle multimedia data such as photos and videos.

The IMAGIN graphical user interface allows users not only to view and query datasets but also to view associated metadata and download data (if made available) through a hyperlink from its metadata file once the data become available online (through the Web Feature Service).

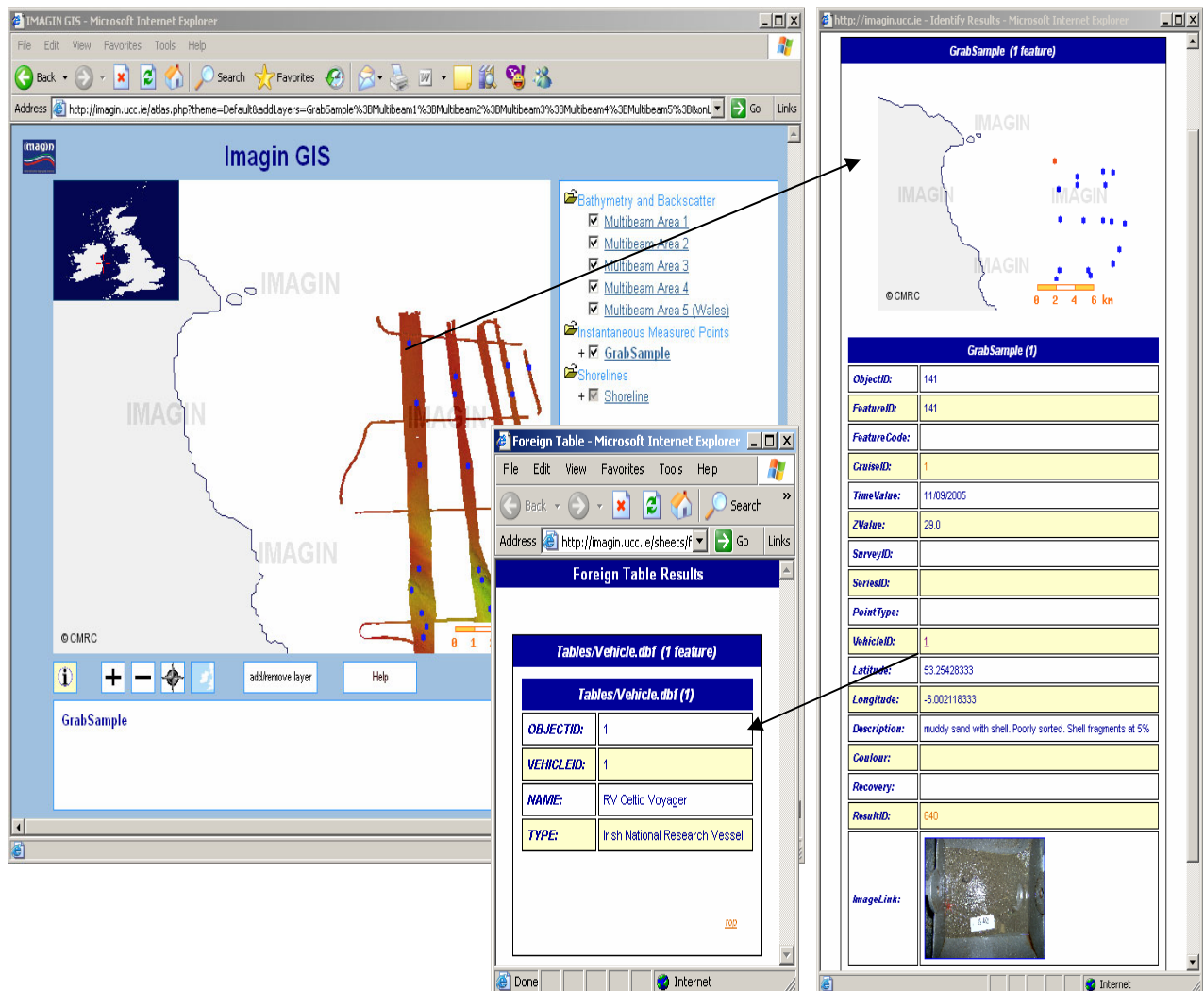


Figure 5.4. IMAGIN Decision Support System's Graphical User Interface

6 COST BENEFIT ANALYSIS (CBA)

6.1 Introduction

The overall objective of this component of the IMAGIN study was to develop:

An Analysis on a regional basis of costs and benefits in relation to potential future extraction of marine aggregates from the Irish Sea.

The work was undertaken by a consulting team from John Barnett and Associates led by Mr. Tim Paul.

6.2 Scope of Work

The overall geographic scope of the IMAGIN CBA included consideration of the wider IMAGIN area as outlined in Section 1. However, the detailed study was effectively focused on the designated counties in Ireland.

The analysis comprised two main parts Phase 1: Data Collection and Phase 2: Cost Benefit Analysis. The scope of work for each of these phases is summarised below:

6.2.0 Phase 1 – Data Collection

Data was collected for the Irish INTERREG IIIA counties comprising Carlow, Dublin, Kildare, Kilkenny, Meath, South Tipperary; Waterford, Wexford and Wicklow.

The main tasks were:

- Assessment of the aggregate supply and demand;
- Regional identification of the land-based sand and gravel resources and significant planning / environmental constraints to future development;
- Assessment of alternative aggregate supply options;
- Identification of port facilities along the Irish INTERREG IIIA coastline; and,
- Review of relevant policies

The deliverable from this phase was a database and GIS layers.

6.2.1 Phase 2 – Cost Benefit Analysis

- Review of existing cost benefit methodologies for the assessment of the sustainability of aggregate supply options.
- Recommend a methodology for the IMAGIN project
- Assess the sustainability of alternative aggregate supply options.

The deliverables from this phase comprised a report on the review of existing methodologies and a final report describing the 'cost-benefit' analysis and the conclusions / recommendations arising from this work package.

6.3 Summary of Methods and Results

6.3.0 Phase 1. Supply and demand

Two main types of aggregates were defined as follows:

- Primary aggregates - naturally occurring rock and sand and gravel extracted directly from land or from marine sources; and,
- Secondary / recycled aggregates - previously used materials that are capable of substituting for primary aggregates. These include waste materials arising from demolition of buildings and road surface planings etc.

Demand

The total primary aggregate demand for Ireland in 2005 was estimated by the Irish Concrete Federation to be approximately 130 million tonnes (ICF, 2006), all of which was sourced from land based quarries. Based on estimates that extrapolate demand from the county population census figures, the existing aggregate demand within the INTERREG IIIA Irish region is approximately 64 million tonnes per year. The Greater Dublin Area (Dublin, Kildare, Meath and Wicklow) accounts for approximately 50 million tonnes (or 79%) of this total annual demand within the region.

Supply

Primary Aggregates: Land Based Sources

The main producers of sand and gravel products within this region are:

- | | |
|---------------------------------------|--------|
| • Kilsaran Concrete: | 8 pits |
| • Roadstone (CRH Plc.): | 7 pits |
| • Cemex Plc. (formerly Readymix Plc.) | 4 pits |
| • Dan Morrissey (Irl.) Ltd. | 4 pits |

Combined, these companies operate 23 out of 84 sand and gravel pits within the region. The geographical location of these pits is generally concentrated around urban areas such as the Greater Dublin region, where demand for construction materials is greatest. Five regional land-based sand and gravel resource areas were identified within the INTERREG IIIA study area, using publicly available geological information. These five areas are shown in Figure 6.1.

- Area A: Fluvio-glacial deposits in south Meath / north Kildare
- Area B: Glacial outwash deposits in east Kildare / west Wicklow
- Area C: Fluvial deposits associated with the River Barrow
- Area D: Fluvial deposits associated with the River Nore
- Area E: Aeolian sand deposits in east Wexford.

Available information indicates the presence of sand and gravel resources in these areas. However, they do not represent areas where the resources have been proven (in extent and quality) to be of commercial interest to the construction materials sector. It should also be noted that these resource areas have been identified on the basis of available information only. This information is incomplete and the nature, extent and quality of this geological information are variable across the region. Hence, there are likely to be further resource areas within the INTERREG IIIA Irish region that have yet to be identified.

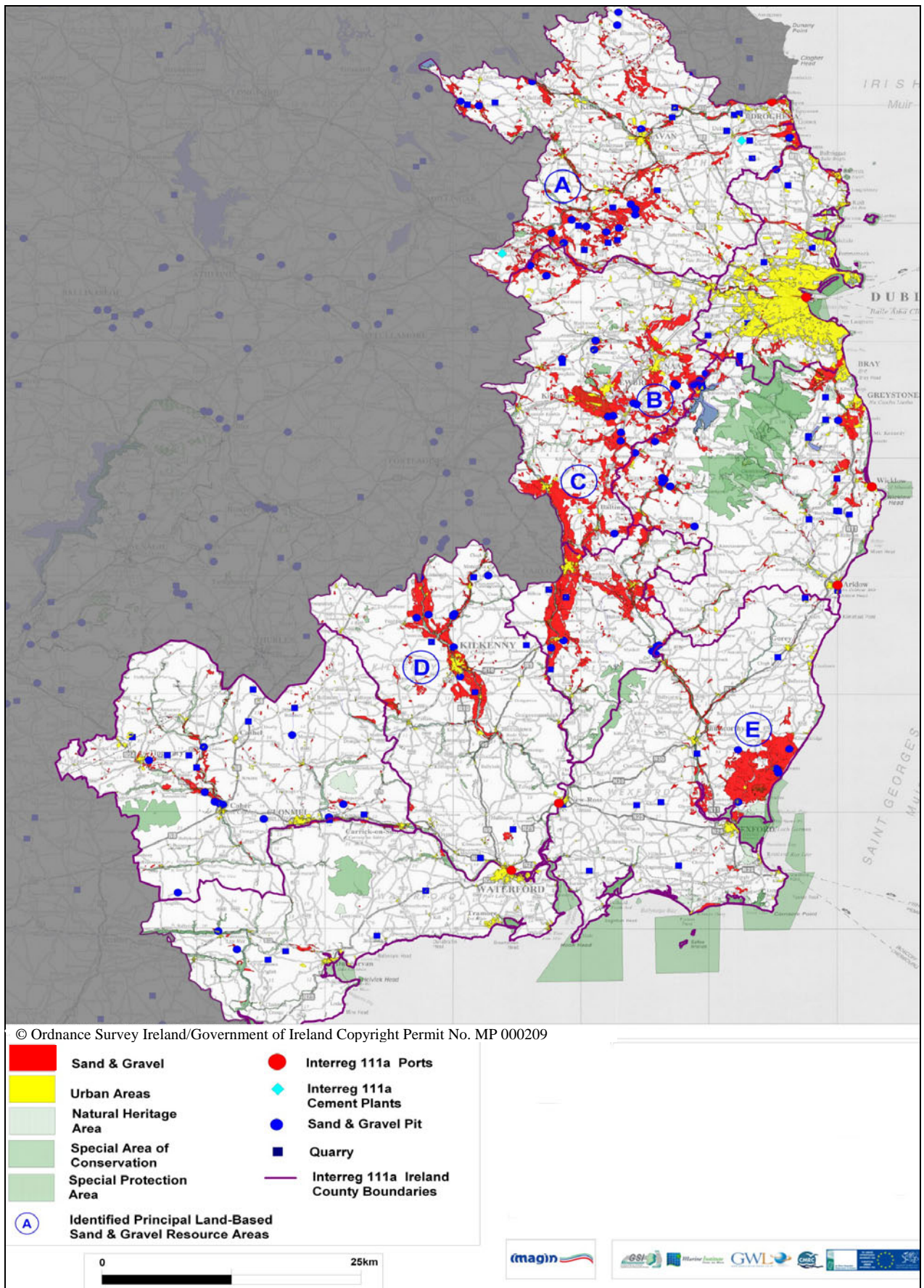


Figure 6.1. Composite image produced by JBA from GIS layers illustrating the distribution of the five main land-based aggregate resource areas and accompanying pits.

Primary Aggregates - Marine Sources

A number of studies have confirmed that there are significant areas around the Irish coastline where marine sediments are suitable for extraction and use as marine aggregates (Marine Institute, 2000). More recently, the work undertaken by the IMAGIN project has identified a number of potential resource areas off the east coast of Ireland, (refer to Section 2). These areas are shown on Figure 2.6. It should be noted that these areas have been identified as part of a limited investigation programme and that there are further resource areas within the Irish Sea that have yet to be identified

Currently, there is no commercial extraction of marine aggregates in Ireland. Harbour dredging operations result in marine sediments being extracted, but it is general practice that this material is 'dumped' at sea. One exception to this within the INTERREG IIIA region is at Drogheda Port where marine sediments arising from port dredging operations have been stored on a temporary basis on land adjacent to the harbour. This material has been processed and used as construction aggregates by a local quarry operator on a lease basis.

The marine aggregates sector is currently regulated under the Foreshore Act (1940). The existing framework in the Act is not suitable or appropriate for the regulation of a future marine aggregate sector. EPA (2007) recommended that a regulatory framework for marine aggregates in Ireland be developed and implemented to increase the potential use of marine sediments as construction aggregates. Such a framework is currently being developed under the IMAGIN project in consultation with the relevant stakeholders, refer to companion volume (*O' Mahony et al., 2008*)

Secondary (or Recycled Aggregates)

The use of secondary / recycled aggregates is at a relatively low level but is set to increase under the influence of factors including: landfill levy; the establishment of the National Construction and Demolition Waste Council (www.ncdwc.ie); construction and demolition waste recycling facilities at major urban centres; and, the greater acceptance of the use of secondary / recycled aggregates. Recovery of 50% of available secondary waste would represent less than 5% of the projected demand for construction aggregates.

The key limiting factor is the relatively small volume of construction and demolition waste stream (concrete / rubble etc.) that is actually available for recycling into secondary aggregates compared to the overall demand for construction aggregates. Thus land based (or marine based if they become available in the future) resources will remain as the principal future source of aggregates in Ireland for the next 20 years and beyond.

Spatial Data

A database and associated GIS data layers have been developed which complements the resource and environmental data being obtained / managed under Work Packages 1 and 3 of the IMAGIN project and described in the previous sections. These have been integrated into the web-based GIS DSS, and are also available on CD in ArcInfo GIS format. The main data sources utilised as part of the data collection exercise were as follows:

- Ordnance Survey of Ireland (Base mapping)
- Teagasc Subsoil Mapping, 2004 (sand and gravel resource areas)
- Geological Survey of Ireland – Quarry Directory, 2001 (Quarries and Pits)
- National Parks and Wildlife Service (NHA, SAC and SPA areas)
- John Barnett and Associates Ltd. (Sand and gravel resource areas)
- Department of Communications, Marine and Natural Resources (Ports)

The following GIS data layers have been developed from these data sources.

- Layer No. 1 Base mapping
- Layer No.2 Sand and gravel resource areas (Teagasc)
- Layer No. 3 Solid (bedrock) geology
- Layer No. 4 Urban areas
- Layer No. 5 Designated areas
- Layer No. 6 Ports
- Layer No. 7 Cement plants
- Layer No. 8 Sand and gravel pits
- Layer No. 9 Quarries
- Layer No. 10 IRL INTERREG IIIA boundaries
- Layer No. 11 Sand and gravel resource areas (JBA In house)

6.3.1 Phase II Cost Benefit Analysis (CBA)

The first requirement for the CBA was to identify a suitable methodology. A review of existing methods for assessing the sustainability of aggregate supply options was carried out. Aggregate supply option assessments prepared for projects in the UK, Australia, US and Ireland were reviewed. Most of these reports contained some relevant information that was of use in the general context of the IMAGIN Project. The review is provided in Appendix B of the full report. Ultimately, a Multi Criteria Analysis (MCA) methodology was adopted in consultation with the project steering group. This allowed aggregate supply options to be evaluated under key criteria covering economic, environmental and social issues. The sustainability of each supply option was assessed on a relative basis, without the requirement to assign financial values on a subjective basis to environmental and social issues.

The key criteria adopted for the IMAGIN project were:

- Aggregate supply prices
- CO₂ emissions
- Equivalent road transport
- Aggregate resource area
- Employment
- Health and Safety

Assessment of Sustainability Criteria for Alternative Supply Options

The basic alternative supply options considered comprise:

1. Maintain the status quo - predominantly land based primary aggregate supply, with limited use of secondary / recycled aggregates (less than 5% of the current aggregate demand).
2. Continue with the land based primary aggregate supply, with the introduction of some replacement of this supply by primary aggregates from marine sources. In future, marine aggregate supply could provide 10 to 20% of the overall annual aggregate demand for the INTERREG IIIA region, including the Greater Dublin Area (6.4 to 12.7 million tonnes per year).

Aggregate Supply Prices

The price per tonne of aggregates delivered to the market was considered the most appropriate economic indicator as it includes all of the costs associated with a particular supply option. Figure 6.2 shows the aggregate supply prices for sand products at a number of locations – Dublin (100% land-based supply), Liverpool (both land and marine based supply), Cardiff (predominantly marine based supply) and London. The equivalent prices (€ per tonne) for the delivered supply of sand at each market location are shown in Table 6.1 below:

Table 7.1 Comparison of Sand Aggregates Prices

Market Location	Sand Prices (€ per tonne)
Dublin (100% land supply only)	8 to 15 (Excluding delivery costs)
South Wales (100% marine supply only)	12 to 18 (Delivered to market)
Liverpool (Land and marine based supply)	18 to 21 (Delivered within 25 km radius)
London (Land and marine based supply)	23 to 34 (Delivered to market)

Results of this study show that taking into account transport costs, the price for sand aggregate products in Dublin appear to be broadly similar to South Wales, slightly cheaper than Liverpool, and considerably cheaper than the London area.



Figure 7.2. Aggregate supply prices at various locations in Ireland and UK. Values are averaged market prices obtained from various suppliers on the 8th November 2006.

Whilst definitive data on the actual cost of extraction of sand and gravel from land and marine is not readily available and subject to wide variation (depends on many factors including type of material), available data suggest that the cost of sand and gravel extraction from land sources in Ireland is of the order of €5 to €6 per tonne, and the cost of marine aggregate extraction in the Bristol Channel is of the order of €9 per tonne (delivered to the wharf). It is likely that marine aggregates sourced from the Irish Sea and supplied to the Dublin market would be priced at, or below, the current Dublin market prices for sand and gravel.

Carbon Dioxide (CO₂) Emissions

This indicator assesses the emissions produced during the extraction, production, and transport of the aggregate supply options. The carbon dioxide - CO₂ emissions (in terms of grams per tonne (g/t)) for each of these activities as assessed and determined by WRAP (2005) have been adopted.

Extraction Operations

Typical CO₂ emissions for extraction operations are summarised in Table 6.2 below.

Table 7.2. Typical CO₂ Emissions – Extraction Operations (WRAP, 2005)

Quarrying – Hard Rock	Excavating from pits Sand & Gravel	Dredging from Sea
CO ₂ (g/t)	CO ₂ (g/t)	CO ₂ (g/t)
736.78	276	100.47

The CO₂ emissions associated with extraction using marine dredging techniques are less than half those associated with those from sand and gravel pits, and less than 15% of those associated with extraction from hard rock quarries, refer to Table 6.2 above. Considering extraction operations only (excluding transport considerations) use of marine aggregates could result in a reduction of approximately 176 tonnes of CO₂ emissions per million tonnes extracted, compared to use of land based sand and gravel resources.

Processing of Aggregates

The CO₂ emissions associated with processing (crushing and screening) range from 1338g/t for sand and gravel to 1666g/t and 1822g/t for limestone and sandstone, respectively (WRAP, 2005).

Transport of Aggregates

Land based aggregates are currently delivered to the Dublin market using heavy goods vehicles via the national, regional and local road network. A comparison of CO₂ emissions arising from transport of land aggregates and marine aggregates from their sources to the Dublin market has been undertaken using the typical CO₂ emission values outlined in Table 6.3 below.

Table 6.3. Typical CO₂ Emissions – Aggregate Transport (WRAP, 2005)

Transport of Aggregates	32t Truck CO ₂ g/t/km	14t truck (motorways) CO ₂ g/t/km	14t truck (urban) CO ₂ g/t/km	14t Truck (rural) CO ₂ g/t/km	Ship CO ₂ g/t/km
	1,040	933	650	583	9.92

The calculation of the CO₂ emissions (see Appendix C of full report for details of calculation) associated with transport of each of the aggregate supply assumed that marine aggregates are transported by sea into Dublin port and from the port by road to the Dublin market. (The basis of the road transport distances for each of the land-based aggregate supply options is provided in the full report in Appendix D.)

The CO₂ emissions associated with the transport of aggregates from the land based supply options range from 25,500 to 79,900 tonnes CO₂ per million tonnes of aggregates supplied. This compared to approximately 3,500 tonnes CO₂ per million tonnes of aggregates supplied from the identified marine supply options. CO₂ emissions associated with the transport of marine aggregates were at least 35% less than those associated with the transport of land sourced aggregates.

On the basis of the above, it is clear that the CO₂ emissions associated with the extraction and transport of marine aggregates to the Dublin market are potentially considerably less than those emissions associated with land sourced aggregate supply options.

Equivalent Road Transport

This indicator assesses the distance (km) that aggregates travel by road from their source to the market. It indirectly considers environmental issues associated with road transport of aggregates – (traffic congestion, physical impact on road infrastructure, traffic noise etc.). Distance travelled is calculated in terms of km – equivalent road transport calculated assuming 1 road tonne km has the equivalent impact to 6 water tonne km (a similar approach to that adopted in the UK ESRSA aggregate supply Sustainability Tool (WRAP, 2005)). The calculation of equivalent road transport figures for each of the aggregate supply options is provided in the Tables 6.4 and 6.5 below. The basis of the land-based route distances from the resource areas to Dublin City Centre is provided in the full report in Appendix D.

Dublin is the centre of highest demand for aggregates, and to optimise the sustainability benefits of marine aggregates it is essential that these materials are landed as close as possible to the Dublin area. On this basis, Dublin Port is the most suitable location for a future marine aggregate wharf. Any future development plan and strategy for Dublin Port should make provision for such a facility in the medium term. The nearest alternative port would be Drogheda but the requirement to transport the marine aggregates by road (from Drogheda to Dublin: 45km) would eliminate any sustainability benefits arising in terms of reduced CO₂ emissions or equivalent road tonne km.

Table 6.4. Land Based Aggregate Supply – Equivalent Road Tonne Km (per million tonnes of aggregate supply to Dublin): Note Sources D & E are not current sources of supply to Dublin

Land Based Resource Area (refer to Figure 5)	Centre Point of Resource Area	Distance from Resource Area to Dublin City Centre (km)	Equivalent Road Tonne km (per million tonnes supply)
A	Rathmolyon	53	53,000,000
B	Ballymore Eustace	43	43,000,000
C	Carlow Town	85	85,000,000
D	Kilkenny City	122	122,000,000
E	Blackwater, Co. Wexford	120	120,000,000

Table 6.5. Marine Based Aggregate Supply – Equivalent Road Tonne Km (per million tonnes of aggregate supply to Dublin)

Marine Based Resource Area (refer to Figure 5)	Shipping Distance to Dublin Port (km)	Urban Road Distance From Port to Dublin City Centre (km)	Equivalent Road Tonne km (per million tonne supply)
1	36	25	31,000,000
2	29	25	29,833,333
3	50	25	33,333,333

Based on the land / marine aggregate resource areas identified within the project and considering aggregate supply to the Dublin market, the equivalent road transport associated with marine aggregates would be at least 30% less than that arising from land based aggregate supply options.

Aggregate Resource Areas (Footprints)

The long-term aggregate supply (and potential impact) will be affected by the rate at which the resource base is developed. Land-based resources are considered non-replenishable, whereas marine resource areas may be replenished in the medium to long-term (depending on the hydrodynamic regime). Based on existing data for the spatial areas involved the land resource area is approximately 7.2% of the land area whereas, the marine aggregate resource area is 1.4% of the area included in the IMAGIN Interreg domain (as shown in Figure 1.1) .

Employment

A review of employment at sand and gravel pits indicates that approximately 5 to 7 people would be employed at a pit that extracted 300,000 tonnes of sand and gravel per year. This level of employment excludes haulage of products to the market, and equates to approximately 2 to 3 staff per 100,000 tonnes extracted. Based on UK experience a marine dredging operation would employ 10 to 12 people per dredger (2,500 – 3,000 tonnes per day), plus 4 to 6 admin / port staff. Based on an annual extraction rate of 800,000 tonnes per year, this equates to 2 to 3 staff per 100,000 tonnes extracted. Employment levels associated with land based sand and gravel extraction are broadly similar to those associated with marine dredging. However, there would be higher levels of employment associated with the haulage of land-based aggregates to the market.

Health and Safety

A review of the available health and safety statistics for the quarrying sector in Ireland and the marine aggregates sector in the UK was carried out based on information sourced from the Health and Safety Authority (HSA), and the UK Marine Accident Investigation Branch (MIAB), refer to Appendix E of the main report and Tables 6.6 and 6.7 below.

Table 6.6. Quarry Reported Accidents in Ireland 1998 – 2005 (HSA)

	1998	1999	2000	2001	2002	2003	2004	2005
Non – Fatal	96	103	78	86	50	38	50	99
Fatal	1	3	3	5	2	1	0	6

Table 6.7. Sea Dredging Reported Accidents 1998 – 2005 (MAIB, UK)

	1998	1999	2000	2001	2002	2003	2004	2005
Non – Fatal	16	12	14	6	5	7	8	8
Fatal	0	0	0	0	1	1	0	0

During 2005 in Ireland there were 99 reported non-fatal injuries and 6 fatalities within the sector. During the corresponding period 2005 in the UK there were 8 non-fatal injuries and zero fatalities within the marine dredging sector.

Table 6.8 compares the health and safety figures for land and marine based extraction operations. This comparison is based on the available health and safety statistics for the period 1998 to 2005, and average annual extraction rates over this period of 110 million tonnes and 20 million tonnes, for land based extraction in Ireland and marine aggregate extraction in the UK, respectively (ICF, 2000 and BMAPA, 2006).

On this basis, marine dredging operations are at least as safe if not safer than land-based aggregate extraction

Table 6.8. Comparison of Health & Safety Incidents (based on period 1998 – 2005 and normalised to extraction rate)

	Land Based Extraction in Ireland (No. of incidents per Year per 10 Mt)	Marine Extraction in the UK (No. of incidents per Year per 10 Mt)
Non-Fatal	6.8	4.8
Fatal	0.24	0.13

6.4 Selected References

- O'Mahony, C., Sutton, G., McMahon, T., O'Cinneide, M., Nixon, E., (2008). Policy Report – Issues and Recommendations for the development and Regulation of Marine Aggregate Extraction in the Irish Sea. Marine Environment and Health Series, No. 32. ISSN No. 1649-0053.
- BGS, 2003. *Collation of Results of the 2001 Aggregate Mineral Survey for England and Wales*. Commissioned Report CR/03/53N prepared by the British Geological Survey. Publ. HMSO, London.
- BMAPA, 2006. *Strength from the Depths: A Sustainable Development Strategy for the British Marine Aggregate Industry*. Prepared and published by the British Marine Aggregate Producers Association. www.bmapa.org
- EPA (2007). *Environmental Management in the Extractive Industry*. RTDI Project No. 2000-MS-11. Synthesis Report prepared by John Barnett & Associates Ltd. in association with The Centre for Environmental Research, University of Limerick; The Geological Survey of Ireland; and Centre Terre et de la Pierre, Belgium. Publ. Environmental Protection Agency. www.epa.ie/downloads/pubs/research/waste.
- ICF, 2000. *A Strategy for the Concrete Industry in Ireland*. Prepared by KPMG in association with Chapman Flood Mazars and Fitzpatrick Associates for the Irish Concrete Federation, Dublin (ICF).
- ICF, 2006. *Irish Concrete Federation - Annual Report 2005*.
- Marine Institute, 2000. *Geological Appraisal of the Kish, Burford, Bray and Fraser Banks, Outer Dublin Bay Area*. (Authors: Wheeler, A.J.; Walshe, J. & Sutton, G.D.). Publ. Marine Institute, Dublin.
- ODPM, 2003. *National and Regional Guidelines for Aggregate Provision in England 2001 – 2016*. Published by the Office of the Deputy Prime Minister, London, UK.
- WRAP, 2002. *The Case for Using Recycled & Secondary Aggregates*. www.aggregain.org.uk
- WRAP, 2005. *Environmental Sustainability of Recycled and Secondary Aggregates*. Published by WRAP, May 2005 – The Waste & Resources Action Programme. www.wrap.org.uk

7 AGGREGATE RESOURCES AND MARKETS - WALES

7.1 Introduction

This is a summary of a component of Work Programmes 3 and 5, the industrial and economic part of the marine dredging equation, focusing on the UK position, and in particular Wales (north of Pembroke). The full report examines:

- the role of aggregates in the economy;
- the position of marine aggregates within total aggregate production in Wales;
- practical aspects of marine dredging;
- economic considerations;
- ownership, licensing, planning and policy;
- long-term supply requirements;
- potential future development scenarios in Wales; and,
- suggestions on how Ireland may draft new marine dredging policy.

7.2 Markets

Potential resources of aggregates have been identified within the Welsh project area; and the objective was to examine potential markets for these resource locations. Potential markets in Ireland were considered, given the potential for exporting marine dredged aggregates directly from Wales to the east coast of Ireland, and England, since Wales has to include supply and demand in northwest England

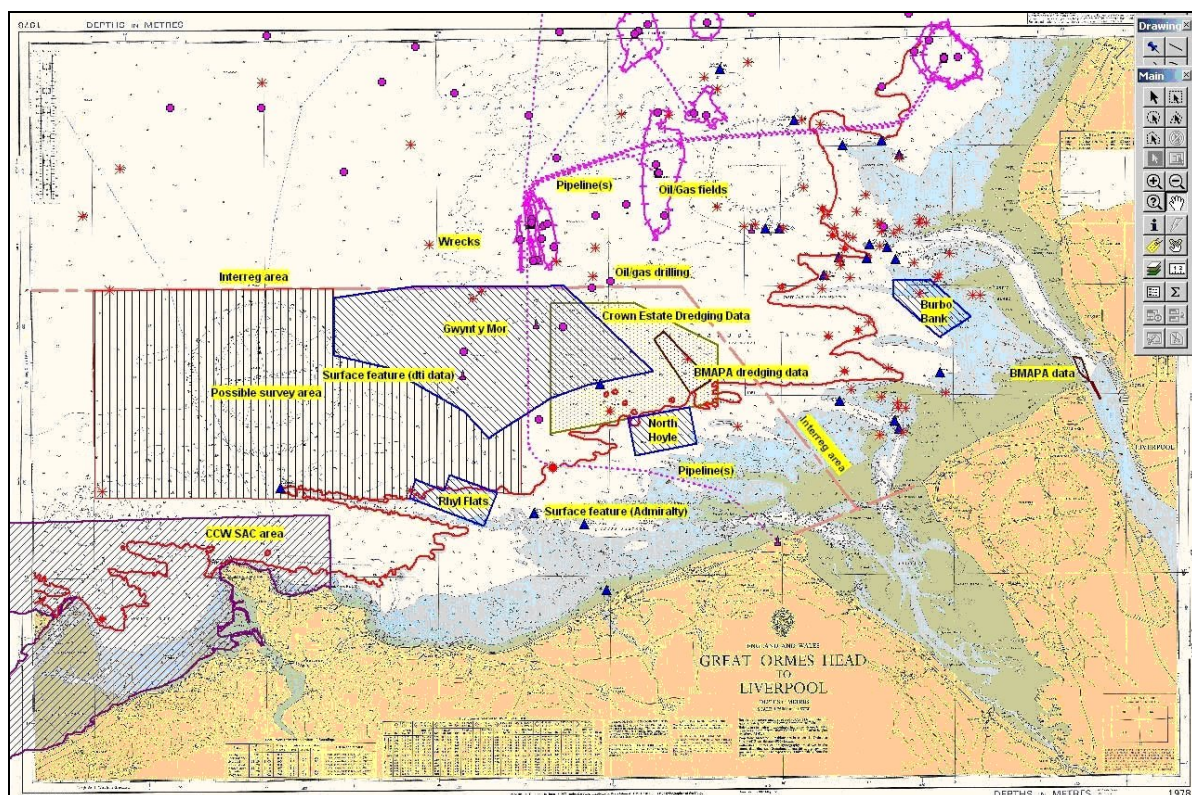


Figure 7.1. Map of north Wales with potential resources and interactions overlain

7.3 Overview of UK Aggregates

The market for aggregates in the UK is free and open without regional barriers and there is substantial cross boundary (inter-regional) transfer, in addition to international exports (around one third of production) and imports (small). However incorporation into UK law of wider EU policy initiatives relating to protection of marine habitats, sustainability, SEA and EIA is likely to change the basis for future resource assessment and marine dredging.

7.3.0 Overview of UK Aggregates Production

The largest single demand is for coarse sand and stone in concrete (collectively, concrete aggregate) at around 40%. The remainder is used in roadstone (bitumen coated and uncoated), as bulk fill material and mortar sand. Decorative sand and aggregate, e.g. for use on golf courses and driveways, is a minor component of total demand. The term aggregate excludes cement and brick making clays, slate and dimension stone, and china clay. Aggregate is produced as crushed rock aggregate, or as sand and gravel, and exists in every region of the country. Total production is in excess of 200 million tonnes, but with a gradual declining trend for about the last 10 years. Production is not even or uniform across the country. Marine dredged sources make a significant contribution to total production at around 20 million tonnes, 6.5 Mt are exported - the UK's principal mineral export after petroleum and natural gas. There are currently no marine exports from the UK to Ireland. Geologically there remain very substantial volumes of suitable hard rock on land for producing crushed rock aggregate, amounting to over 50 years supply at current rates of production. However, land based sand and gravel reserves are more limited - just over 10 years of production.

7.3.1 Resources

Long-term, in the UK as a whole, there are substantial aggregate resources, but on a regional basis there is a complicated picture of different supply options meeting overall demand. The distance travelled into urban areas is increasing as local sources are reduced, with consequential pressure on the remaining rural quarries to produce more or for longer. The extensive marine sand and gravel resources known to exist could have an important long-term supply role, where they can be brought into the main centres of demand economically and sustainably.

7.3.2 Marine Aggregate Contribution

Dredging of marine aggregates has occurred on an industrial scale in the UK from the 1960's, and accounts for one fifth of England and Wales total production (there is currently no commercial marine aggregate dredging off Scotland or Northern Ireland). Dredging takes place most substantially:

- on the south coast of England;
- southern North Sea and Humber;
- the Bristol Channel and,
- Liverpool Bay.

In the absence of significant land based alternatives the contribution to south east of England as a region and South Wales (as much as 90%) is critical to maintaining supplies. Due to land-based constraints this level of supply as a proportion is likely to grow.

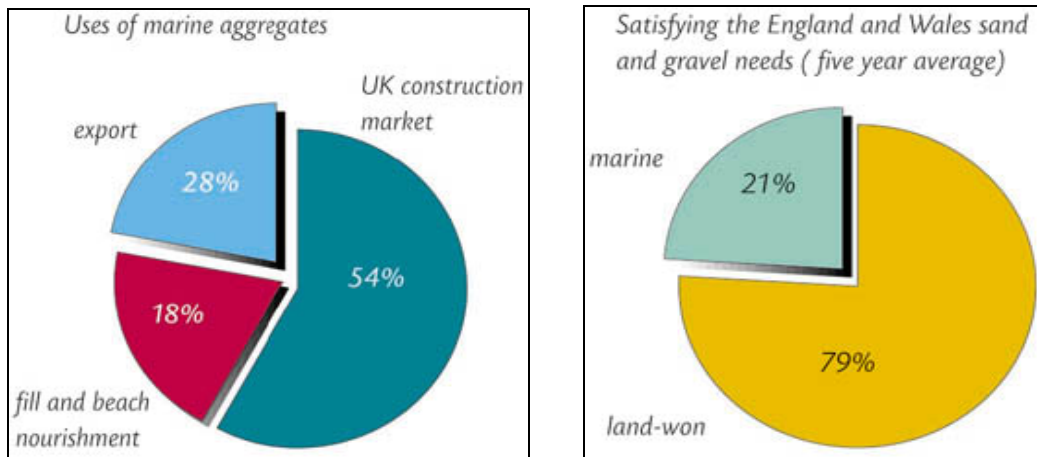


Figure 7.2. Contribution of Marine Aggregates to UK Aggregates Production

7.3.3 Aggregate Quality and Standards

Industry standards specify the quality of aggregate regardless of origin (coarse aggregate, gravel, or marine). Until 1979, the majority of coarse aggregate produced in the UK was sand and gravel, but since then there has been a steady replacement by crushed rock. There is only limited difference in the performance of concrete produced from gravel aggregate or that of crushed rock aggregate. The choice between gravel and crushed rock is determined by availability of the raw material and economics of production rather than any other factor. The chemical composition of seawater varies around the coast of the British Isles. In some licence locations or wharfs it is necessary to wash the material to reduce the chloride content or blend it with land won material.

7.3.4 Existing Welsh Dredging Licences

The amount of marine dredged aggregate landed in Welsh ports is 5% of the total for the UK. Dredging licences granted by the Crown Estate Commissioners operate in South and North Wales, but none exist on the western and northern coastline, between St David’s in Pembrokeshire and the Hilbre Swash licence in the far northeast, approximately 5 miles off the mouth of the River Dee. The Welsh marine dredging industry is notable for a number of reasons:

- nearly all aggregate landed is sand, not coarse aggregate (gravel);
- 90% of the sand demand in South Wales is satisfied from marine sources; and,
- there are potentially significantly larger resources in areas which have not been investigated in detail.

Table 7.1 shows aggregate landings into UK east coast and Welsh ports.

Table 7.1. Marine Aggregate Landings Wales and NW England 2002-2004

Location	Port Landings – Tonnes			
	2002	2003	2004	2005
Bangor	66,334	48,455	52,307	47,250
(Liverpool)	260,260	237,200	385,900	428,850
(Heysham)	106,000	105,800	95,550	95,285
Total NW	573,900	512,220	653,871	716,090
Pembroke	30,229	34,206	44,509	66,600
Burry Port	140,969	67,029	113,163	107,350
Port Talbot	169,634	181,755	221,131	198,795
Swansea	110,267	137,326	103,591	74,450
Newport	254,714	264,217	253,508	275,140
Barry	22,624	20,581	14,689	16,350
Cardiff	243,463	275,947	292,910	263,100
Total Wales	1,019,290	1,029,516	1,095,808	1,049,035

7.4 Marine Aggregate Dredging UK Practice

Dredging takes place between 10m and 40m water depth with 20-30m common, and accounting for tidal variation, 10m minimum depth. Sieving of the pumped material during loading is used to change the ratio of seabed sediments from 'all in' as raised to one that is tailored for market needs. For example a deposit that is 75% sand, 25% gravel can be loaded as a 50/50 mix with oversize and unwanted sand discharged. A licence area which comprises chiefly gravel may still be dredged solely for sand, if that is what is required. Commonly encountered constraints include:

- geomorphology and composition of the seabed is not uniform;
- wrecks, pipelines, cable routes and other features apply restrictions; and,
- sediment mix may change significantly from sand areas to gravel rich areas.

7.4.0 Dredging Impacts

Dredging impacts are considered at the licence application stage - thereafter licenses are monitored annually and may include *inter alia*: biological and physical monitoring of the seabed; monitoring of the shoreline to appraise coastal impacts. Habitat – which varies with: geology (simplistically, a gravelly sediment supports different communities to those supported by a sandy one); depth; temperature; current; etc. Repeated and intense dredging alone may only reduce the seabed by 1-3m depending on factors such as topography, sediment type, dredging intensity and hydrodynamics.

7.4.1 Land vs Marine

A 200,000 tonnes p.a. dredging operation would, over a 10 year period, be the equivalent of a land based sand pit excavating from around 3ha of land. The quarry may also require additional space for washing plant, silt settlement ponds and site restoration.

7.4.2 Ownership

In the UK the aggregate resources of the seabed below the mean tidal level is vested in the Crown, and managed on the Crown's behalf by the Crown Estate Commissioners. In Ireland the seabed is the property of the State.

7.4.3 Licensing - responsibility

All activity impacting upon the UK continental shelf requires Crown Estate approval with marine aggregates managed as a distinct function of the Commissioners. Licensing is separate to the issue of development approval (by central government) - the 'Government View'. The grant of an extraction licence is by the Commissioners, and done by tender based on a fee payable (royalty per tonne).

7.4.4 Licensing - procedure

Each year the Crown invites the dredging companies to lodge expressions of interest for potential future licence areas. Interested parties are permitted to undertake initial non-exclusive sampling of prospective areas under licence. If interest is registered a tender round begins, further prospecting is allowed, and a conditional option granted to allow time to secure the necessary working permit from central government. Historically this process has taken at least 5 years to complete. A small fraction of the total licence area and tonnage limit is dredged in any one year. In 2005, of the 1179km² licensed, 137.6km² (11.7%) was active, 90% of which was within 45km² (yield = 1532.7t/hectare).

7.4.5 Economics - Dredgers

Marine aggregate dredging requires a number of unique factors to be considered when assessing economic costs and profitability. The capital cost for a typical new marine dredger of around 2500t capacity is some £9-10M and would be depreciated over 25 years. Older and refitted vessels cost less, but with a significantly reduced working life. The new 8000t capacity deep-water vessels are reported to cost in the region of £20M.

Such vessels are required to be at sea as much as possible and may only be docked for storm conditions and essential maintenance, working a two weeks on, two weeks off two-shift pattern. Most UK operating vessels are registered in the UK and manned by experienced UK crews. The act of dredging aggregate is very abrasive (especially gravel) upon equipment such that the wear on pumps, conveyors and equipment results in high annual maintenance bills. In some licensed areas gravel is present in quantity, but not landed for this reason in favour of land based supplies. Significant operational costs include:

- Marine fuel oil - distance dependant;
- Employee wages; and,
- Equipment maintenance.

7.4.6 *Dredgers: Examples*

Dredgers operating in Liverpool Bay and the Bristol Channel are around 2500 tonne capacity and work in relatively shallow waters, generally within 10km of the shore or port. The ships can therefore operate on each tide and unload twice every 24 hours, and hence small vessels are economic. The larger vessels operating off the east coast and outer English Channel operate in deeper waters, further from port, so can only discharge every other tide, and have to carry a larger load to be economic.

7.4.7 *Economics - Royalties*

The Crown, as owner of the seabed, is paid a royalty for each tonne of aggregate landed, under the terms of the dredging licence. A royalty range of 40p-90p per tonne of coarse aggregate is currently paid depending on the quality, location and age of licence agreement. Most licence agreements are for a 15-year term.

7.4.8 *Economics - Ports*

Ports and wharfs are commercial businesses and wharf or dock duties are paid on a royalty basis (per tonne). Waterfront: additional plant site land may be leased from the port operating company or commercial landlord. The competing interests, e.g. property developers and others is an important consideration in the economics that govern port activities.

7.4.9 *Economics - Resource*

The potential reserves base for the UK marine aggregate sector is very large. However the volume of actual reserves are relatively small - due to the requirements for obtaining permits to operate and lack of detailed geological information.

7.5 **Policy Perspectives**

In Wales and England there are substantial aggregates planning and development policy for both land based and marine resources. Supply is demand led and there has on a national basis never been a shortage of aggregates. Planning for land based aggregate provision is a function of local government managed by the Mineral Planning Authority (MPA) of the local authority. Policy is determined in accordance with a statutory plan system The MPA are required to maintain sufficient planned supply for a 7-10 years period. Policy may identify preferred areas of search but, beyond that, development is progressed speculatively by the minerals industry on a commercial basis.

The system for consenting marine aggregate dredging is an historical and informal one called the 'Government View (GV) Procedure' and decisions are taken at the national level. The administrative system for considering land based and marine aggregate extraction are separate procedures with weak strategic policy linkages; there is no published policy or guidance document to assess which supply route or source is the most appropriate or sustainable method of extraction. In Wales there are also some geographical gaps in the application of marine aggregate policy. Marine Aggregate Dredging Policy 1 (MADP), introduced as an interim policy in 2003, is concentrated towards the licensed dredging areas of the Bristol Channel that serve south Wales and SW England with little reference to the areas outside the Bristol Channel which are within the INTERREG IIIA/IMAGIN area.

7.5.0 Competing interests for use of UK seas:

The main human activities with which marine aggregate extraction interacts in the marine domain are:

- Fishing;
- Protection of rare and important marine environments and habitats;
- Public amenity; and,
- Energy policy, renewable sources - offshore wind farms (wind farms effectively sterilise the seabed for marine dredging)

7.5.1 Jurisdiction

UK land based (above mean low tide) aggregates policy is vested by the planning acts in the Mineral Planning Authority (MPA), i.e. at local level (County or Unitary Council). Marine planning is the responsibility of national government, a Secretary of State or minister, managed by a civil service department. In England, aggregate licences are administered from Westminster. In Wales, aggregate licences are administered from Cardiff (by the Welsh Assembly Government Department of Environment, Planning and Countryside) with the following consultees:

- local and mineral planning authorities; and,
- statutory and non-statutory groups (including Countryside Council for Wales (CCW) and the Marine Information Network (Marinet) supported by Friends of the Earth).

7.5.2 Planning Policy

Minerals planning policy in the UK is clearly separated into land based aggregates policy and marine policy:

- Land based policy administered by the Mineral Planning Authority (MPA); and,
- Marine policy administered by the central government.

The activity is wholly commercial and policy emphasises sustainable development and community involvement in the plan process. Policy requires MPAs to make clear and adequate provision for minerals development. MTAN1 requires the LDF to make available a land bank of 10 years worth of crushed rock and 7 years sand and gravel.

7.5.3 Planning Policy - England vs Wales

England has an 'ancillary policy objective' to 'encourage' the supply of marine-dredged sand and gravel above that of supply being met from land based sources. Wales has less guidance on the strategic role of marine dredging, other than it should be 'taken into account' by the RAWPs and MPAs. MADP makes no reference to the strategic allocation of the role of marine vs. land based resources, in contrast to MPS1 in England. Regional Aggregate Working Parties (RAWPs) predict demand and supply requirements, but marine policy is determined at the national level - Westminster or Cardiff. MPAs are required by policy to maintain a land bank, but there is little policy linkage between the two sectors.

7.5.4 RAWPs and Regional Apportionment

MPAs are required to develop their policy on a local authority basis, but the distribution of mineral resources and development constraints requires a wider perspective. Consequently, since the 1970s, RAWPs have been established across a number of local authorities to jointly examine supply needs on a wider basis. RAWPs comprise both planning officers and industry and interested representatives and meet on a formal basis, reporting to central government and the local authorities. The RAWPs do not consider planning applications, but do collate mineral production and sales data, thus informing policy makers of production trends. There are two RAWPs, serving north and south Wales

7.5.5 Interim Marine Aggregates Dredging Policy (Wales) (MADP)

MADP (adopted by the WAG in November 2004) is unique in UK marine aggregate dredging as it defines policy in a spatial resource context, grading areas of the Bristol Channel considered to be sensitive or at environmental risk from aggregate dredging. The configuration of policy zone areas is shown in Figure 7.3.

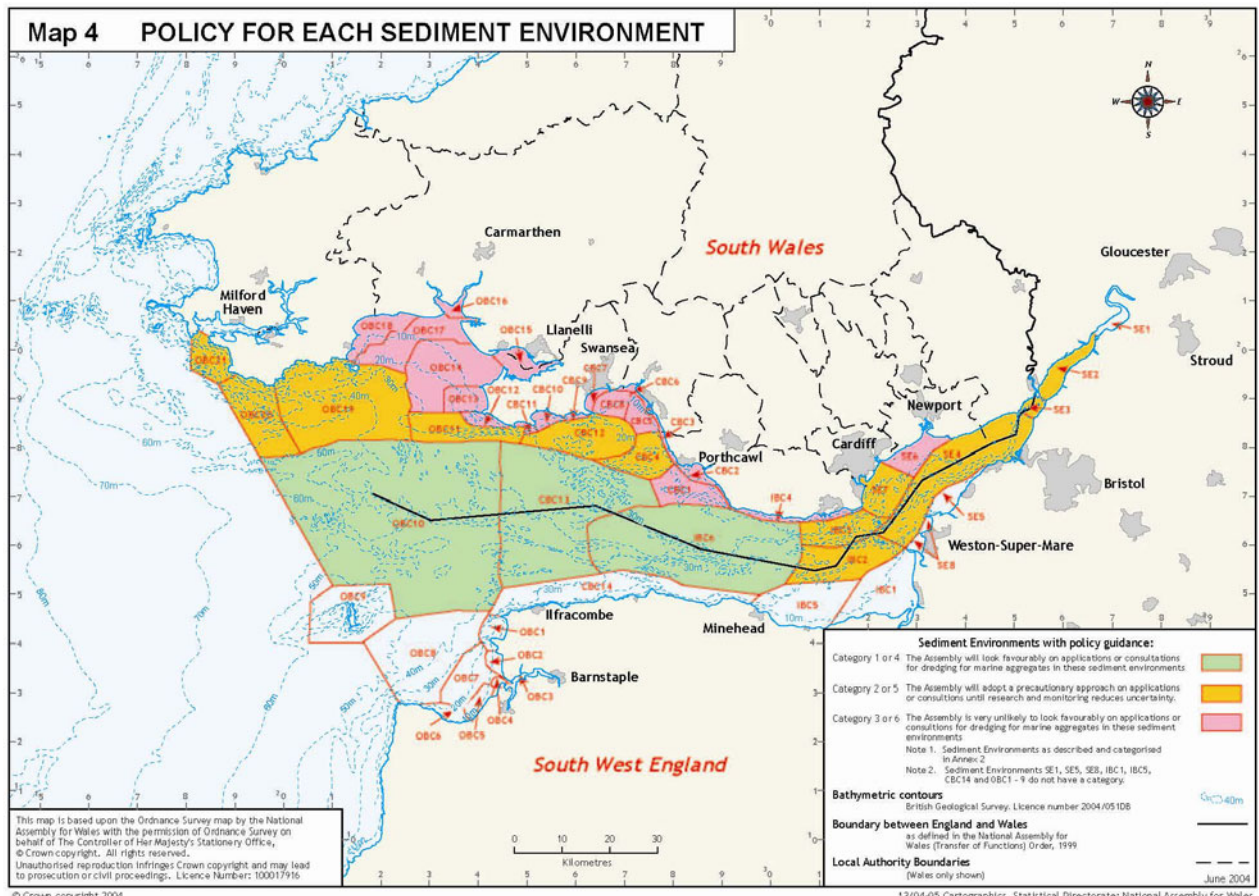


Figure 7.3. Map showing Bristol Channel with zonation scheme for defined sedimentary environments and associated policy guidance. Source: Summary consultation document – Marine Aggregated Dredging Policy South Wales.

7.5.6 Marine Spatial Planning (MSP)

MSP has been adopted as a key feature of the Marine Bill, published for consultation by DEFRA in March 2006 and applying to the whole UK. The aim of the Bill, if enacted, will be to enable a more comprehensive, integrated, but streamlined, system of marine habitat protection and resource use policy across a broad range of interests.

7.5.7 Data Collation

The data in the geological report can form the basis for future investigation and resource assessment. It is outside the scope and budget of the IMAGIN project to identify where marine dredging should or should not take place, but the data does indicate where dredging operators may wish to undertake prospecting or more detailed assessment.

7.6 Prospecting

Prospecting for marine aggregates takes place under licence within the scope of the tendering procedure managed by the Crown Estate Commissioners (CE). It includes both physical and electronic data collation to determine the broad issues upon which to develop a tender application and scope any subsequent EIA. The nature of the seabed sediment can often indicate the type of benthos communities that exist in the area, but example community and habitat surveys are often undertaken simultaneously. The CE is now operating a “general consent” system for prospecting that includes broad areas of seabed intended to provide an information base for more detailed extraction licence application.

7.7 Environmental Impact Assessment (EIA)

EU Directive 85/337/EEC (as amended by Directives 97/11/EC and 2001/42/EC) on the Assessment of the Effects of Certain Plans and Programmes on the Environment, requires certain developments likely to have significant environmental effects to be subject to EIA. The aim of EIA is to pre-determine the likely environmental impact of a development, plan or process and can be very far ranging. The EIA should then inform developers and decision makers. EIA has become along with Coastal Impact Study an integral part of marine aggregate licence applications. The EIA process has been an integral statutory element of land-based minerals planning since the introduction of the first statutory regulations in 1988. The main legal instruments that contribute to an EIA are:

- Coastal Protection Act 1949 (empowers Coastal Protection Authorities to control dredging within 3 miles of the coast);
- Sea Fisheries (Wildlife Conservation Act) 1992;
- Protection of Wrecks Act 1973;
- Transport and Works Act 1991;
- The Telecommunications Act 1984;
- Water Resources Act 1991; and,
- Water Environment (Water Framework Directive) Regulations 2003.

The informal EIA process has followed the formal land based three-stage process of screening, scoping, assessment and mitigation:

Screening – the initial procedure to determine whether a full EIA is required, is that the activity falls within the criteria of scheduled list of activities with the potential to have harm to the environment, including areas protected by the Wildlife and Countryside Act 1991 i.e. Special Area of Conservation (SAC). All the smallest levels of marine dredging invoke the requirement for an EIA.

Scoping - where the extent and limitations of the EIA are proposed by the applicant and submitted to the regulator, who consults statutory bodies for compliance and replies. Scoping is undertaken at an early stage and aids the developer to plan a project path, lead times and allocation of resources. The scoping exercise to a modest extent is a negotiation because of the significant costs involved; it is not however final and additional information may be requested later.

Impact Assessment - the detailed risk assessment based upon a working model, which may be refined as a result of the EIA that may also propose mitigation. The EIA is meant to reflect an independent consideration of the impact of the proposal, and may be undertaken by a considerable number of expert groups specialists in individual fields. Other baseline data required includes:

- tidal regime;
- wave conditions (requiring extended survey);
- sediment transport;
- coastal morphology;
- suspended transport concentration;
- benthic and epibenthic communities in and around the survey area;
- mammals and elasmobranchs (sharks and rays);
- sea birds;
- fish and shellfish;
- spawning and nursery areas;
- migration routes;
- commercial fish landings;
- archaeological data (wrecks); and,
- physical obstructions.

7.8 Licensing

Once an application for a GV is registered, there is a significant amount of consultation within government, involving many external parties. The consultation period may last for several years and involve additional reporting and data assessment before the application is considered to be complete. The grant of a positive GV licence is made on the 'precautionary principle', so that potential impact has to be shown to meet an acceptable minimum before approval is issued. Most, if not all, new licence applications go to public inquiry due to opposition being voiced on the licence proposal.

7.9 Monitoring

Monitoring requirements are specified as an integral part of a licence. The monitoring reports are available for public inspection as well as being considered by experts on behalf of NAW. More substantial formal reviews are also undertaken at intervals, typically every five years, but more frequently in sensitive areas. The NAW decides upon the future of the dredging operation and can require changes or revoke a permission if it is considered appropriate in order to protect the environment from significant damage. If it is necessary to revoke a dredging permission then the Notice served by the NAW will state the reasons for revoking the licence and allow parties 28 days to make representations to the NAW. NAW may decide that a case will be considered by an inspector. Finally, the NAW will notify all parties involved of the decisions and the reasons for them. If the NAW deem a licence should be revoked then the dredging operators have the right of appeal.

7.10 Aggregates Supplies and Markets

7.10.0 Aggregate Landbanks

Figures 7.4 and 7.5 provide a general overview of the aggregate supply/demand situation for Welsh and NW English counties.

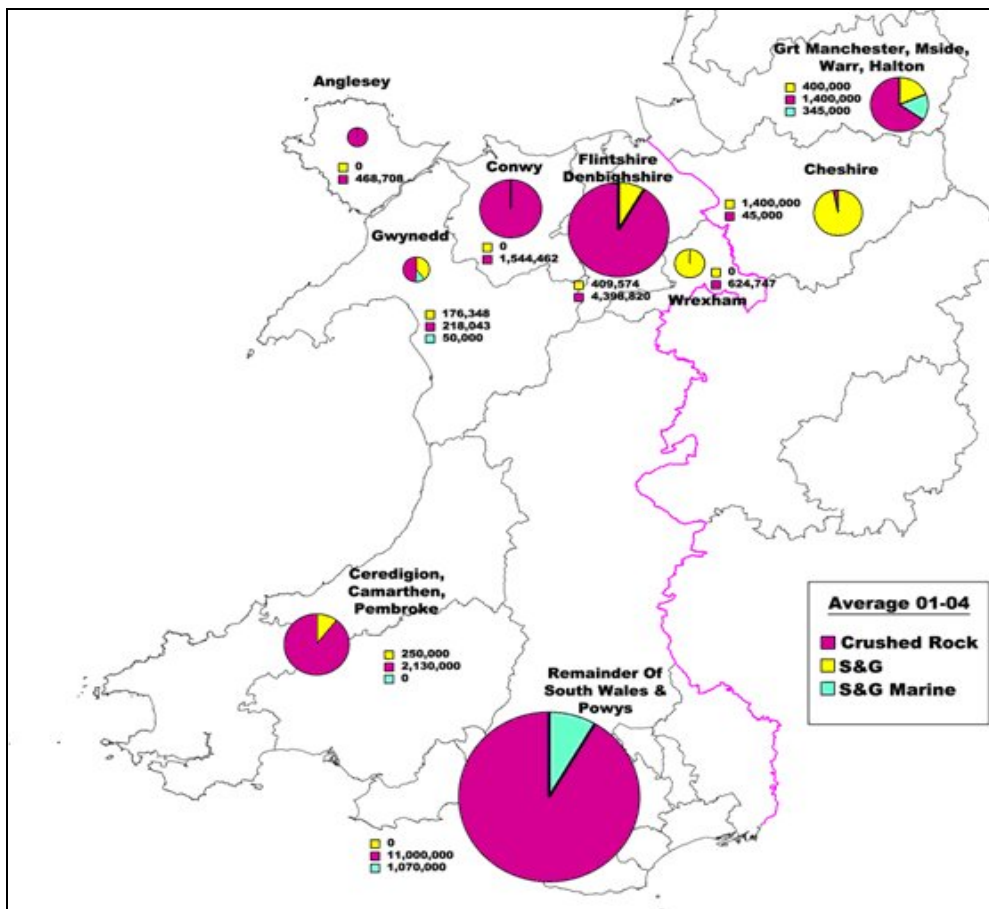


Figure 7.4. Average Aggregate Sales in Wales and Northwest England 2001-2004

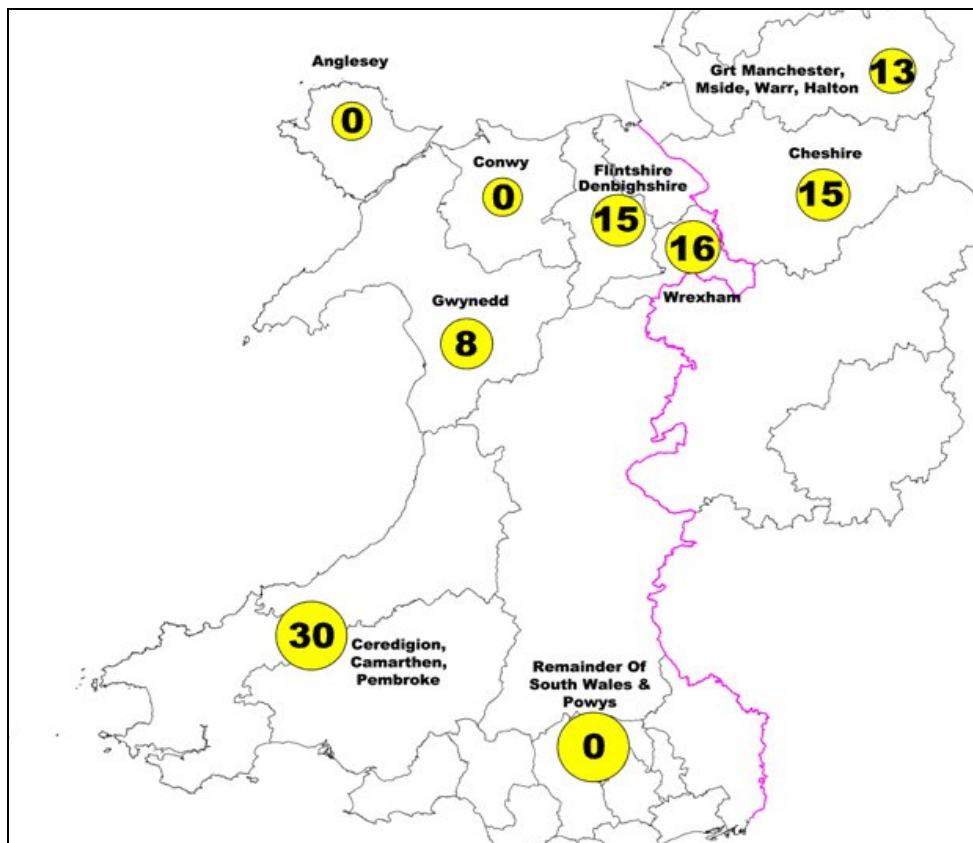


Figure 7.5. Years of Land Based Sand and Gravel reserves by County/Mineral Planning Authority

7.10.1 Long-term Aggregate Demand

North Wales: there is adequate coarse grade primary aggregate provision of crushed rock for the foreseeable future. The land bank of permitted reserves is calculated to be c. 24 years for limestone and over 50 for high quality igneous rock (NWRAP 2004). There is unlikely to be a requirement for new sites to be developed soon, with relatively small extensions likely in a few cases.

Central areas, Powys and Ceredigion: the existing pattern of meeting demand by a combination of supply from a small number of large sites and numerous smaller local sites, substituted at the edges by imports from the surrounding counties is likely to continue. The lack of a suitable (new) port for marine sand along the west coast, adequate road links, and intrinsically low demand rules out marine sand making a substantial contribution above existing levels in these areas. Any short-term demand peak is likely to be met by flexibility in the market.

In North Wales, there is currently approximately 8 years land bank of land based sand reserves in Gwynedd (based on the Regional Apportionment requirements that include Conwy, Anglesey and Snowdonia). Although in excess of the MTAN 1 land bank need for 7 years, the existing operational sites are unlikely to be able to extend operational life notably beyond that time.

7.10.2 Landing sites:

- Holyhead Port, Anglesey
- Expanded Port Penrhyn, Bangor
- Llanddulas quarry jetty, Conwy
- Mostyn Port, Flintshire
- Manchester Ship Canal (Ellesmere Port, Runcorn etc)
- Other North West Wharfs: limited opportunities elsewhere in NW England.

7.10.3 Export to Ireland

There is no published UK political or planning policy restriction preventing the export of marine aggregate resources to Ireland from UK waters.

7.11 Information Sources and Further Reading

1. Annual Minerals Raised Inquiry (AMRI), Office of National Statistics.
2. Crown Estate Landing Statistics, 2005
3. Crown Estate Port landings, 2005
4. Mineral Planning Statement 1 (England), accompanying Practice Guide
5. BGS UK Minerals Yearbook, 2005
6. BGS Mineral Planning Factsheet 'Construction Aggregates', 2005.
7. BGS 'Primary Aggregate Reserves in England 1990-2004'
8. BGS: The Role of Imports to UK Aggregates Supply, 2005
9. Environmental Impact Assessment and Natural Habitats (Extraction of Minerals by Marine Dredging) (Wales) Regulations 2007.
10. Marine Spatial Planning Pilot MSPP Consortium February 2006.
11. A Bellamy – "The UK marine sand and gravel dredging industry: an application of Quaternary Geology"
12. "Comparison of length changes, flexural strengths and compressive strengths between concrete made by rounded gravel and concrete made with crushed limestone" Ohio Dept. of Transportation, January 2005.
13. "Comparative Impact Assessment of Land and Marine Sand and Gravel in South East Wales" Symonds for WAG 2002.
14. "Assessment of the Rehabilitation of the Seabed Following Marine Aggregate Dredging", CEFAS, 2005.
15. "Seabed Characteristics and the Effects of Marine Aggregate Dredging" Andrews Survey, see <http://www.dclgaggregatefund.co.uk/themea.htm>
16. "Impacts of Overboard Screening on Seabed and Associated Benthic Biological Community Structure in Relation to Marine Aggregate Extraction" Marine Ecological Surveys, see: <http://www.dclgaggregatefund.co.uk/themea.htm>.
17. "Measurement of the seabed mobility in licensed dredging areas and the impact of near bed plumes generated by aggregate dredging" Compass Hydrographic Services Ltd. 2004, as reported by Andrews Surveys.
18. "The Area Involved", The Crown Estate 8th Annual Report, 2005.
19. "A Development Plan for Marine Aggregate Extraction in England' ODPM 2004 section 5.2 etc.
20. "Marine Aggregate Environmental Impact Assessment Approaching Best Practice". Posford Haskoning (EIA Guidance), see: www.dclgaggregatefund.co.uk/themea.htm
21. "Sand and Gravel Resources of North West Wales", University of Liverpool and Enviros Consulting.
22. "Comparative Impact Assessment of Land and Marine Sand and Gravel in South East Wales" Symonds, 2002, for Welsh Assembly Government.

Websites:

23. <http://www.statistics.gov.uk/StatBase/Product.asp?vlnk=606> (Office of National Statistics)
24. <http://www.communities.gov.uk/index.asp?id=1144305> MMG1 (England 2002)
25. www.dclgaggregatefund.co.uk/themea.htm <http://new.wales.gov.uk/?lang=en> (Welsh Assembly Government)
26. <http://www.qsrmc.co.uk> (Certification for Construction Materials)
27. http://www.thecrownestate.co.uk/40_aggregates
28. www.uma.co.uk (Dredging operations through a consortium)
29. <http://www.defra.gov.uk/marine/legislation/index.htm> (Marine and Fisheries, Marine Bill)
30. <http://www.abpmer.net/mspp/> (Marine Spatial Planning Pilot Consortium, defra)
31. <http://www.jncc.gov.uk/page-2767> (The Irish Sea Pilot Final Report, 2004)
http://new.wales.gov.uk/docrepos/40382/epc/planning/403821/403827/40382/614359/Draft_EIA_guide_to_good_pra1.pdf?lang=en (Environmental Impact Assessment: A guide to good practice and procedures)

8 OVERALL FINDINGS AND RECOMMENDATIONS

Section eight presents a summary of the main conclusions and recommendations arising from the work of the IMAGIN project. Recommendations have been grouped under relevant headings for clarity.

Geological Assessment:

1. The programme of reconnaissance geological mapping carried out under the IMAGIN project has:
 - identified, mapped and quantified significant commercially exploitable marine aggregate resources;
 - improved understanding of seabed sedimentary characteristics and processes in the context of the possible effects of extraction thereon;
 - produced a detailed technical report (380pp); an archive of physical and digital data and value added data products which are accessible via desktop and online GIS interfaces.
2. The methodology adopted by the IMAGIN team for assessing the quality of marine resources i.e. in relation to particle size distribution or industrial grading was found to be effective. This approach could be more widely adopted in future studies whereby the value of sediment samples can be realised for both scientific and industrial purposes.
3. In order to raise confidence in the interpretation of the aggregate resource capacity within the detailed IMAGIN study areas it is recommended that further ground-truthing of the sub-seabed sediments should be carried out (e.g. vibro core sampling in key areas which may be determined with reference to IMAGIN database).
4. Similarly for areas where interpretations were based on existing legacy archival data or general literature sources it is recommended that additional ground-truthing of the sub-seabed sediments should be carried out (e.g. vibro core sampling) as an absolute minimum. Many such areas would also benefit from comprehensive mapping in accordance with the methodologies employed during the IMAGIN project.
5. The overall approach adopted in undertaking geological mapping for IMAGIN, particularly in relation to data structuring, standards, processing steps, products and in the use of GIS offers a promising model for future adoption by other groups and projects with a view to improving compatibility and interoperability thereby optimising opportunities for future reuse and integration.
6. Whilst general aspects of the seabed sediment transport patterns pertaining in the study area have been elucidated with particular reference to the form and orientation of sedimentary features, more detailed considerations will require deployment of instrumentation capable of recording simultaneous (near bed and water column) current velocity and sediment concentration from a selection of representative sites throughout the Irish Sea. Information on the in-situ erodability of sediments (such as can be obtained from a benthic flume) would add to this and serve as input to improve the potential resolution, reliability and validity of predictions from existing morphodynamic models (including the modelling framework developed under the IMAGIN project).

Modelling

7. Morphodynamic modelling carried out in the IMAGIN project has enabled predictions of the main sediment transport pathways to be produced that include both material suspended in the water column and that transported near the bed. Predictions compare favourably with published material. Potential changes in seabed thickness under natural and simulated extraction scenarios have been examined.
8. The predicted transport of sediment off the eastern seaboard of Ireland can be summarised as follows:
 - The net suspended sediment transport along the entire east coast of Ireland was predicted to be in a net northerly direction with complex regions of highly mobile

- bed sediments, especially in the vicinity of the 60m contour off the Wicklow coast.
- The patterns of localised mobility of the bed sediments, expressed as changes in bed sediment thickness, in this area are very complex with large volumes (~125 x 10³ tonnes) of sediment mobilised locally over the course of a year. The complexity is a reflection of the highly variable and complex nature of sediment types present in the area.
9. The predicted transport of sediment off the northern seaboard of Wales can be summarised as follows:
- The net suspended sediment transport off the north Wales coast was predicted to be offshore and in a net northerly direction. The transport of suspended sediments in these regions was much lower than that predicted along the Irish east coast owing to the relatively lower current speeds in the area.
 - The predicted patterns of natural changes in the thickness of the bed sediments in this area, and associated potential bed sediment mobility were much simpler than those occurring off the Irish east coast. The near bed current velocities are such that there was relatively little sediment eroded from the bed resulting in low values of sediment mobility and low rates of change in bed elevation, with the exception of the area around Anglesea. The predicted changes in the thickness of the bed sediment layer over the course of a year were of the order of +/- 2.5cm, (~15 x 10³ tonnes/yr mobilised locally), and occurred in outer Liverpool Bay and offshore of Llandudno
10. The fact that such relatively small quantities of bed sediment are mobilised off the north Wales coast, when compared to the eastern seaboard of Ireland, would suggest that this region might be more susceptible to physical impacts on the structure of the seabed as a result of dredging activity than the highly dynamic sediment environment evidenced along the eastern seaboard of Ireland.
11. Model predictions have shown that there is significant natural mobility in the seabed sediments off the eastern seaboard of Ireland. Both the Irish Sea model and the Small scale eastern Irish seaboard model predicted natural localised movement of bed sediment of approximately 250,000 tonnes/km² over the course of a year at numerous locations. This would be equivalent to 100 dredging events in the same area over the course of a year using a standard 2,500 tonne capacity dredger.
12. Predictions showing changes in the thickness of the bed sediments at the end of one year's simulation along the Arklow Bank, indicate that, in the absence of external sources of sediment, the bank might be subject to progressive erosion along its entire length.
13. Given that the benthic environment is currently subjected to the natural localised mobilisation of large volumes of bed sediment in certain areas, it would be expected that the removal of bed sediment through dredging operations from similar highly dynamic areas would have a minimal biological impact in the long-term.
14. Sensitivity analysis on different methods used for specifying the composition of seabed sediments used by the model showed that the random method was more representative of the heterogeneity of the seabed sediments, showing a greater level of detail with respect to the formation of successive erosion and depositional areas off the east coast.

Biological Assessments (REA)

15. The REA conducted under the IMAGIN project has:
- generated a body of reliable scientific information on the marine environment in the INTERREG IIIA domain of the southern Irish Sea, with specific reference to 5 detailed study areas. Outputs are available in the form of a comprehensive written report and GIS layers that are accessible for desktop use or via the internet;
 - identified key aspects of the Irish Sea environment that could potentially be most at risk from marine aggregate extraction

The main recommendations that arise from the IMAGIN regional environmental assessments in relation to the sustainable management of future marine aggregate extractive operations are as follows:

16. That operations be steered away from areas with stable, diverse and more biogenically structured biotope types such as those recorded in study area 3 in particular, where further studies are needed to confirm the extents of such structures.
17. That operations avoid on-board screening as far as possible, or where this is impractical, avoid periods that might coincide with vulnerable life-cycle windows for sensitive species.
18. Encourage consideration of larger areas of low intensity more extensive forms of dredging in preference to intensive dredging within confined areas. It is recognised that this would need to be considered on a site-by-site basis.
19. Local hydrodynamic conditions should be taken into account when considering aggregate extraction in the proximity of important seed mussel beds in order to ensure that sediment plumes do not adversely impact on their viability.
20. Extraction should avoid areas of known commercially / ecologically significant shellfish resources (e.g. whelk, scallop, seed mussels, razor clams etc.) as these species have no means of avoiding removal by the dredger
21. Extraction activity should be steered towards areas where the hydrodynamic conditions are relatively conducive to sediment mobility which in turn gives rise to a benthic community dominated by organisms which are small and have a short generation time. Areas with these characteristics are typified by mobile sands and gravels, which have faster recovery times than other biotopes. Study areas 1 and 5 in particular are known to contain such areas, while they are also present in parts of study areas 2 and 4, but least in study area 3.
22. Initial site selection for aggregate extraction locations should avoid where possible areas on the landward side of the 20m contour given the general importance of this zone as a fish nursery area.
23. Establish a comprehensive set of protocols to guide the establishment of monitoring programmes at dredge sites and suitable control sites in order to assess impact and recovery.
24. IMAGIN has made a start in the task of consulting fishermen as perhaps the main third-party stakeholders in most of the areas that may be targeted for aggregate extraction. This process should become more systematic and structured at the stage that a National Plan is drawn up for aggregate extraction and at the SEA and EIA stages.
25. Any areas selected for inclusion in a potential aggregate extraction zone, which are within the IMAGIN study domain, but outside the five study areas, should firstly be subject to equally rigorous multi-beam sidescan sonar survey combined with granulometric and biological ground-truthing surveys to accurately identify the nature of the seabed and its associated biological communities and habitats.
26. At a research level, more effort should be made to link bottom type to benthic production and fisheries suitability and biomass. This would allow planners to more assuredly identify areas with higher value and greater sensitivity

Decision Support

27. The IMAGIN prototype Decision Support System (DSS) provides an accessible and intuitive web-based interface, together with a comprehensive archive of relevant datasets that together serve as means to support decision making in relation to the sustainable management and potential future regulation of marine aggregate extraction.
28. The system is fully compliant with international quality standards, includes metadata, and is founded on robust open sourced elements that are assembled in accordance with modular architecture.

29. These features should ensure that the system will endure, providing a long lasting, robust, extensible tool principally for use by resource administrators in government and industry. This inherent flexibility also allows considerable scope for extension and modification to suit a range of other marine or terrestrial applications such as Marine Spatial Planning and SEA.

Cost Benefit Analysis

30. The current aggregate demand in Ireland is approximately 130 million tonnes per year, of which it is estimated approximately 64 million tonnes per year arises within the INTERREG IIIA region.
31. The Greater Dublin Area (comprising Dublin, Kildare, Meath and Wicklow) accounts for approximately 50 million tonnes (or 79%) of the annual aggregate demand within the INTERREG IIIA region.
32. Land-based sources are likely to be the main supply option for primary aggregates to the region in the medium to long-term.
33. Secondary (or recycled) aggregates offer a limited alternative supply option for some types of aggregates, but this option is constrained by the relatively small volume of construction and demolition (C & D) waste arising within the region suitable for recycling into aggregates, compared to the overall annual aggregate demand.
34. Marine aggregate resources in the Irish Sea, identified under the IMAGIN Project, represent a future alternative contribution to aggregate supply for the region, and in particular the Greater Dublin Area. These resources would supplement the existing land-based aggregate supply, particularly sand products.
35. A comparison of the costs of aggregate extraction from land based sources in the Greater Dublin Area and marine sources in the UK indicates that the relative cost of extraction is broadly similar.
36. A comparison of aggregate prices in Dublin and the UK indicates that marine aggregates sourced from the Irish Sea and supplied into Dublin are likely to be priced at or below current Dublin market prices for such materials.
37. An initial comparison of land-based and marine-based aggregate supply options for the region indicates that introduction of a marine aggregate supply option could provide significant benefits in terms of sustainability, compared to current land-based sources. These benefits relate to:
 - Reduced CO₂ emissions arising from both extraction and transport activities
 - Reduced road transport requirements – reduced heavy goods vehicle (HGV) traffic volumes on the national, regional and local road networks.
38. In order to optimise these sustainability benefits it is critical that the marine aggregates are landed as close as possible to the main centre of demand – in Ireland's case; Dublin. This is consistent with the 'Proximity Principle' and sustainable development. On this basis, provision should be made for a future marine aggregate wharf facility within the Dublin Port area.
39. Employment levels associated with land-based sand and gravel extraction are broadly similar to those associated with marine dredging. There would be higher levels of employment associated with haulage of land-based aggregates to the market.
40. Based on a review of available health and safety records for the period 1998 to 2005, marine dredging operations are at least as safe, if not safer than land-based extraction operations.

9 APPENDIX 1

9.1 Structure and Layout of the Full Geological Report

Chapt. No	Summary Contents
1	Executive summary.
2	Background information about the IMAGIN project and introduce the concept of marine aggregates in an industrial context.
3	Broad scale review of the geography and geology of the Irish Sea basin, providing a background contextual setting in terms of solid and Quaternary geology to aid comprehension of the main features and evolution of the study area.
4	Summary review of archival data reappraisal, identification of broad aggregate potential areas, gap analysis and general targeting for new surveys.
5	GIS spatial analysis including human and infrastructural interactions; final boundary definition for new survey areas
6	Methods and results for new offshore multidisciplinary surveys presented by area, and detailed results of archival data re-evaluation.
7	Overall assessment of aggregate resource potential combining new and archival source data (Aggregate Potential Blocks; Data Sources; Level of Confidence (in terms of aggregate potential); Interactions; Logistical Considerations; Type and Quality of Material; Thickness of Aggregates; and Size of Area) for 23 sub areas.
8	Conclusions and recommendations.
Appendices 1-3	Compliment and extension to Chapter 3 providing additional contextual information on Pre-Pleistocene (bedrock) geology, Quaternary glacial geology and BGS seabed sediment data.
Appendix 4	Presents a technical description of the architecture and key elements that support the operation of the web based GIS/prototype decision support system.

9.2 Structure and Layout of the Full REA Report

Chapter	Contents	Chapter	Contents
	Executive Summary	7	Principal Fish and Shellfish
1	REA Introduction	8	Distribution and Value of Irish Commercial Landings
2	The Marine Ecosystem and Study Components	9	Impacts on Fish and Shellfish Resources
3	The Irish Sea – A Brief Overview	10	Impacts on Commercial Fishing
4	Benthic Community and Habitat Assessment	11	Conclusions and Recommendations
5	Irish Sea Demersal Fish and Shellfish	Appendices 1-8	Data, technical details of methods, photographs etc.
6	Distribution of Irish Sea Demersal Fish		