MESH Guide to Habitat Mapping: a synopsis

February 2008

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Contents

Preface 5

Acknowledgements 6

About the MESH Project 7

MESH Project Partners 8

Background to the MESH Guide 9

1 What is habitat mapping? 11

1.1 Habitat mapping in the MESH Project 12
1.2 Why do we need habitat maps? 13
1.3 What are habitats? 14
1.4 What do you want to map? 17
1.5 How do you map habitats? 18
1.6 What are the limitations of habitat mapping? 19
1.7 Data management 21
1.8 How do you plan for habitat mapping? 22
1.9 Summary 23

2 What do I want to map? 25

2.1 Scope the mapping programme 25
2.2 The Scoping Tool 26
2.3 Determine the Information Gaps 28
2.4 Specify new survey work 29
2.5 Optimise the Remote Sensing 30
2.6 Optimise the ground-truthing 32
2.7 Summary 34

3 How do I collect my data? 35

3.1 Why do I collect mapping data in a standard way? 35
3.2 Technical expertise required for undertaking surveys 36
3.3 MESH Recommended Operating Guidelines (ROGs) 36
3.4 Using techniques in combination 40
3.5 Survey data: organisation and metadata requirements 41
3.6 Data cleaning and basic processing 42
3.7 Summary 42

4 How do I make a map? 43

4.1 Determine the strategy 44
4.2 Optimise the ground-truth analysis 48
4.3 Optimise the physical coverages 49
4.4 Optimise the map making 50
4.5 Design of the habitat map 53
4.6 Summary 53

5 How good is my map? 55

5.1 What is accuracy? 56
5.2 How can I assess the accuracy of my map? 56
5.3 How do I interpret my accuracy assessment? 57
5.4 How much confidence should I put in a map? 58
5.5 The MESH Confidence Assessment Scheme 60
5.6 How do I interpret a confidence assessment? 61
5.7 Summary 63

6 What can I do with my map? 65

6.1 Using maps 66

6.2 Describing maps *67*
6.3 Contributing maps *68*
6.4 Converting maps *69*
6.5 Combining maps *70*
6.6 Sharing maps on the internet *71*
6.7 Summary *71*

7 Bibliography **73**

8 Glossary **75**

Appendix 1 Contents of the full version of the *MESH Guide* **86**

Preface

The *MESH Guide to Marine Habitat Mapping* provides a methodological framework for marine habitat mapping giving the information required to ensure **consistency and compatibility** between seabed habitat maps. It offers users a complete understanding of all the processes and decisions required to deliver a comprehensive, fit for purpose, quality assured seabed habitat map. It is only available online at: www.searchMESH.net/mapping-guide

The present printed document - *MESH Guide to Marine Habitat Mapping*: *a synopsis*, only provides an overview of the seabed mapping process proposed by the MESH Project, aimed at readers who only wish to acquire a basic knowledge of the stages involved in creating a seabed habitat map. Introduced the primary concepts, processes and terminology used. It aims to help bridge the gap in knowledge between those commissioning seabed mapping studies, users (policy makers, marine environmental managers) and the mapping scientists and technitions undertaking the actual mapping work to ensure the final products meet the user's requirements. It is an aid to effective communication. This condensed version is arranged into the same 6 chapters as the full version which cover the entire mapping process from planning, survey, analysis, quality checking and use. The full *MESH Guide* is provided on the DVD attached to the inside backcover for offline use.

The full *MESH Guide* offers simple explanations together with detailed, practical step-by-step assistance through the mapping process. Each section of the *MESH Guide* has a hierarchical structure with the top level explaining the key principles in simple terms and then increasing levels of detail as the user navigates down the levels. It is a gateway to the information required regardless of a user's level of involvement in a mapping project. There are links throughout the *MESH Guide* and it is hoped that users can easily navigate to the information they want.

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Acknowledgements

The *MESH Guide to habitat mapping* is the result of a collaboration of the entire MESH Partnership and all Partners should be acknowledged for all their work to make the initial ideas into a real product. The MESH Partners acknowledge the financial and management support of their organisations, their sponsors and the INTERREG IIIB programme for North West Europe (www.nweurope.org).

In addition, when drafting the individual sections of the *MESH Guide* the authors included the following acknowledgements:

What do I want to map?

We acknowledge the contribution of David Long (BGS) to parts of this chapter and thank the following for valuable comments on previous drafts: Jon Davies & David Connor (JNCC), Bob Foster-Smith (Envision Ltd), David Long (BGS), Vera van Lanker (Ugent).

How do I collect my data?

The authors would like to thank the review group: David Connor, Jon Davies, Roger Coggan, Dave Long, Jacques Populus and Bob Foster-Smith for their comments on drafts and acknowledge the support of the Irish National Seabed Survey, INFOMAR, the Geological Survey of Ireland and the Marine Institute during the MESH Project.

How good is my map?

The MESH Partnership wishes to acknowledge the efforts of the Accuracy and Confidence Working Group in the compilation of the tables and the considerable work carried out by Dan Foster-Smith (Envision Ltd) in the creation of the *MESH Confidence Tool* flash application.

About the MESH Project

MESH is short for **M**apping **E**uropean **S**eabed **H**abitats that was an international marine habitat mapping programme that started in spring 2004 and finished in January 2008.The MESH Partnership comprised a consortium of 12 partners across north-west Europe including the UK, Ireland, the Netherlands, Belgium and France, who brought together a balanced mix of skills including scientific and technical habitat mapping skills, national data collation and management expertise and experience in the use of habitat mapping in management. The MESH Project received financial support from the EU INTERREG IIIB fund for North West Europe.

Two of the key aims of the MESH Project were to produce seabed habitat maps for north-west Europe delivered via the internet (see the MESH webGIS - www.searchmesh.net/webGIS) and to develop international standards and protocols for seabed mapping studies - the *MESH Guide for Habitat Mapping*. In addition, many additional products were delivered throughout the project and are available through the *Product Library* section of the MESH website (www.searchMESH.net/Products). The key MESH outputs were:

- The first collated and harmonised map of seabed habitats for the north-west Europe (using the European EUNIS habitat classification system).
- A comprehensive catalogue of describing over 1000 seabed mapping studies available online in the online *MESH metadata catalogue*.
- A methodology for assessing the quality habitat maps – *MESH Confidence Assessment Tool*.
- A series of new mapping studies that helped test, evaluate and improve the mapping protocols and standards.
- Models for the prediction of habitat type, based on physical and hydrographic information within different habitat areas and water depths.
- Case studies that will demonstrate the political, economic and environmental use of marine habitat maps for spatial planning and management at local through to international scales.
- An international Conference, Dublin Castle, 14-15 March 2007 with published Proceedings.
- A variety of educational and display materials including posters and presentations on aspects of habitat mapping.

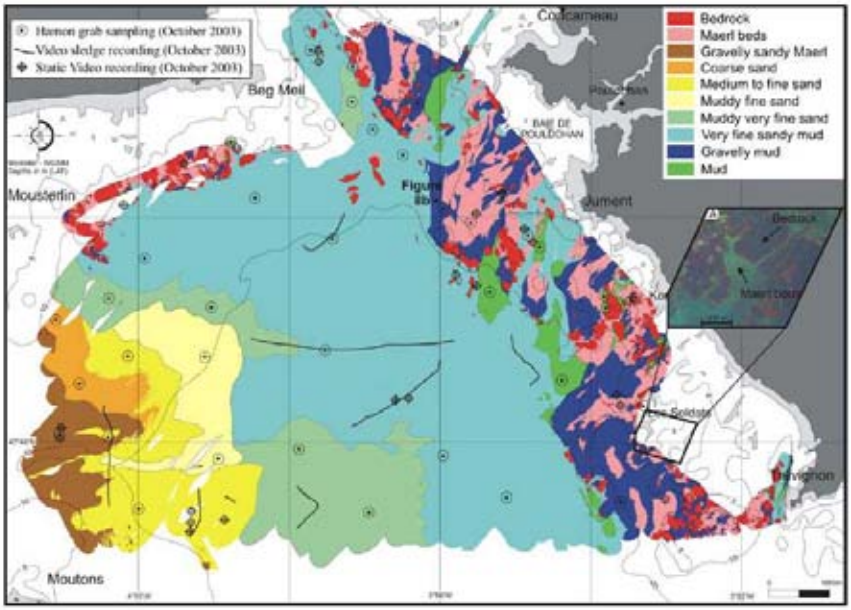
For further information on the MESH Project, the MESH Partners and to access the full range of outputs including all those listed above, please visit the main website at www.searchmesh.net.

MESH Project Partners

The **Joint Nature Conservation Committee** (JNCC) is the statutory adviser to Government on UK and international nature conservation. Its work contributes to maintaining and enriching biological diversity, conserving geological features and sustaining natural systems. JNCC were the Lead Partner for the MESH Project. website: www.jncc.gov.uk	JOINT NATURE CONSERVATION COMMITTEE
Ghent University is one of the most important institutions of higher education and research in the Dutch-speaking part of Europe. It distinguishes itself as a socially committed and pluralistic university in a broad international perspective, open to all students, regardless of their ideological, political, cultural or social background. website: www.rcmg.ugent.be/	UNIVERSITEIT GENT
Ifremer is the National French institute for marine research. Ifremer contributes, through studies and expert assessments, to knowledge about the ocean and its resources, monitoring of marine and coastal zones and the sustainable development of maritime activities. website: www.ifremer.fr	Ifremer
The **Marine Institute** is the Irish national agency responsible for Marine Research, Technology Development and Innovation. website: www.marine.ie	Marine Institute
Wageningen IMARES specialises in strategic and applied marine ecological research. website: www.wageningenimares.wur.nl/UK/	WAGENINGEN UR
TNO is a Dutch institution which aims to apply scientific knowledge to strengthening the innovative power of industry and government. website: www.tno.nl	TNO
Cefas is an internationally renowned scientific research and advisory centre working in fisheries management, environmental protection and aquaculture. website: www.cefas.co.uk	Cefas
Agri-Food and Biosciences Institute (AFBI) (formerly DARD) is a public body based in Northern Ireland and one of the world's leading providers of scientific research and services to government, non-governmental and commercial organisations. website: www.afbini.gov.uk	afbi Agri-Food and Biosciences Institute
Natural England (formerly English Nature) is a UK Countryside Agency working for people, places and nature to conserve and enhance biodiversity, landscapes and wildlife in rural, urban, coastal and marine areas. website: www.naturalengland.org.uk	NATURAL ENGLAND
Envision Mapping Ltd is a private consultancy and research company with specialist expertise in environmental mapping, management and data services. website: www.envision.uk.com	ENVISION
The **National Museum Wales** (NMW) is an independent chartered body and a registered charity. It aims to develop, care for, study and encourage access to its collections for the benefit of society in perpetuity. website: www.museumwales.ac.uk/	national museum wales / amgueddfa cymru
The **British Geological Survey** (BGS) is a public sector organisation responsible for advising the UK government on all aspects of geoscience as well as providing impartial geological advice to industry, academia and the public. website: www.bgs.ac.uk	BGS 1835 British Geological Survey NATURAL ENVIRONMENT RESEARCH CO

Background to the MESH Guide

The *MESH Guide to Marine Habitat Mapping* was borne out of a need to standardise approaches and techniques in habitat mapping to improve the compatibility between maps and data, and give easy-to-understand advice to anyone involved with, or using seabed habitat maps.



It *MESH Guide* aims to provide a methodological framework for marine habitat mapping so that future mapping studies will produce high quality data and maps which are inter-compatible and their outputs can be assimilated into common, harmonised maps. It will help to make habitat maps more compatible by illustrating tried and tested standards and procedures in a step-by-step manner. Each step in the decision making process is explained with links to a resource folder, where the user can access a range of tools, templates and more detailed descriptions of practical worked examples and relevant case studies.

This MESH Project framework is presented as general guidance backed up by in-depth discussion, case studies and signposting to other sources of information. The guidance is intended for both those commissioning surveys and those undertaking surveys. The primary medium for delivering the guidance is through the website (www.searchMESH.net/mapping-guide) that allows the user to start from general principles of habitat mapping and follow the process from establishing aims and objectives, through survey strategy design, the selection of techniques, data acquisition, processing and interpretation to evaluation of outputs. The user is guided through decision-making at all stages of survey focussing on making key points. These are linked to guidance notes with discussion provided at each stage in the process and the user can access more detailed information, such as protocols for specific techniques and relevant case studies, by following links.

Habitat mapping has its own framework for planning and survey that is distinct from other forms of environmental survey, such as condition/quality monitoring. The purpose of the *MESH Guide* is to give assistance to all those involved with habitat mapping and this is summarised as a flow chart that guides people in a systematic, step-wise progression through the decisions that need to be made. This guide is emphatically not going to make decisions for you: there is no single right way of planning and executing a habitat mapping programme (although there may be many wrong ways!). However, it is hoped that the guidance will assist you to make sound choices and encourage you to justify your decisions.

In summary, the *MESH Guide* provides an introduction and discussion on seabed habitat mapping together with more practical step-by-step assistance through the planning process. Although some sections are designed to be only read as background reading, its main purpose is to act as a gateway to the information you require. There are links throughout the text and it is hoped that you can easily navigate to the information you want. However, users should note that that they reach a point where it is necessary need to backtrack to more general discussion or jump directly to examples and case studies or some other product from the MESH Project. Such jumps are only possible in an electronic version and readers of this *MESH Guide Synopsis* will need to consult the contents page or the DVD to jump to other sections.

1 What is habitat mapping?

Lead Authors: Bob Foster-Smith (Envision), David Connor (JNCC) & Jon Davies (JNCC)

Habitat mapping is defined by the MESH Project to be:

Plotting the distribution and extent of habitats to create a map with complete coverage of the seabed showing distinct boundaries separating adjacent habitats.

Throughout the *MESH Guide,* the term 'seabed' refers to both intertidal and subtidal areas; the habitat mapping process applies equally to both areas.

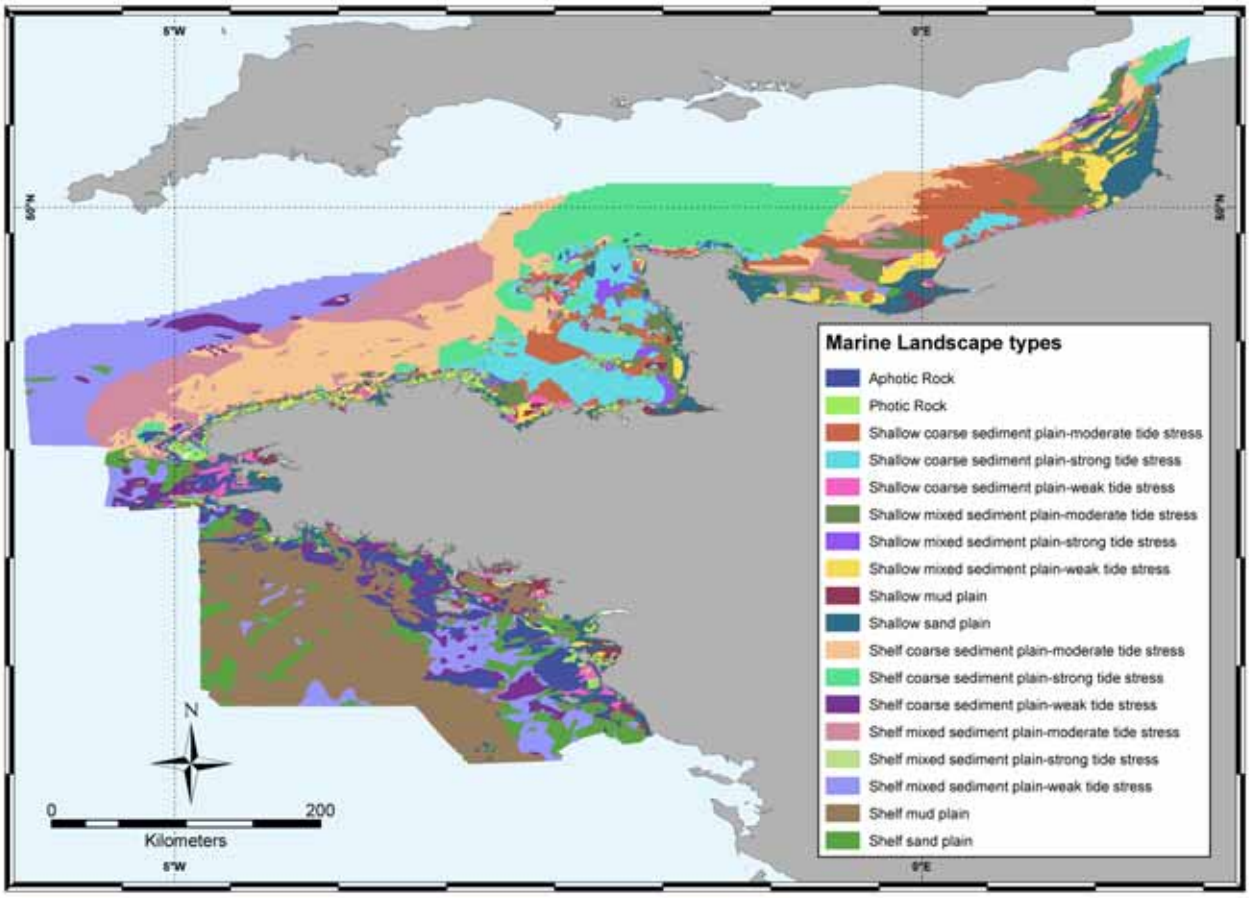


Figure 1-1 Seabed habitat map showing modelled landscapes at a regional level in France.

Habitat mapping within this *MESH Guide* adopts a specific methodology: seabed habitat maps show the distribution of habitats by interpreting physical data layers, often derived from remote sensing, using biological information about habitats obtained from direct sampling and observation of the seabed. Only a small proportion of the seabed can be observed or sampled and the complete coverage of habitats is inferred from the association between the physical habitat data and the seabed samples so the final maps ***predict***[1] the distribution of seabed habitats. The physical habitat factors act as a ***proxy*** for the biological habitat data.

Full coverage maps of physical habitat factors (the proxy data) are obtained either directly from some form of remote sensing (e.g. bathymetry from acoustic surveys) or derived from mathematical models of the marine environment (e.g. wave energy from weather prediction models). The inferential process to link the sample data with the physical maps is loosely termed ***modelling***. In some cases this may be a simple process of using expert

[1] ***Bold italicised text*** refers to technical terms described in the glossary

judgement whilst in other cases, the modelling might take the form of a multi-step process of transforming and combining many datasets to derive the final maps.

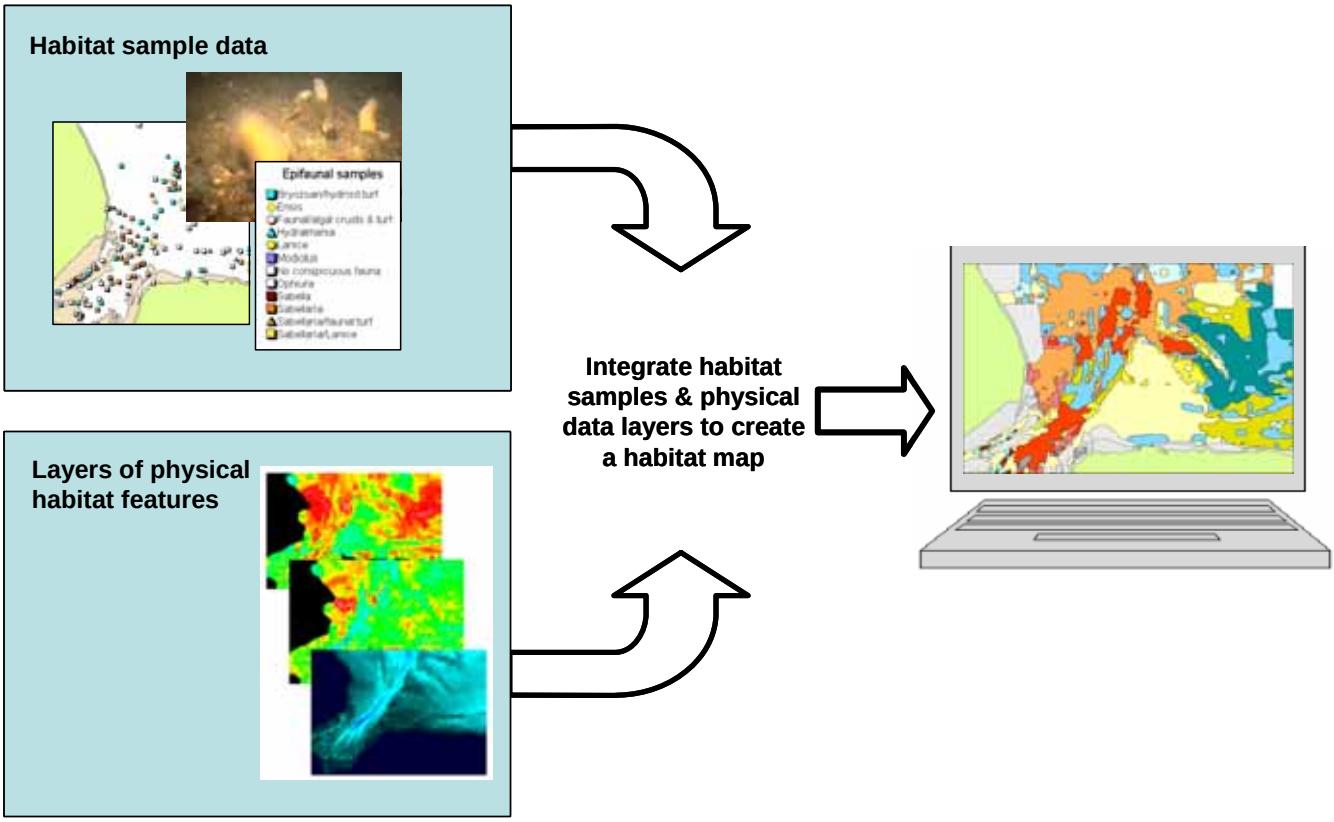


Figure 1-2 A summary of the habitat mapping process promoted by the MESH Project. It is important to remember that the final map predicts the distribution of habitats.

In summary the habitat mapping process involves surveying, collating information, analysing and modelling data to derive the habitat distribution and then designing the layout of habitat maps that are clear and fit for their intended purpose.

The present Chapter introduces the topic of marine habitat mapping by laying the foundations needed for the user to fully understand the basic concepts, uses and limitations of marine habitat mapping and sets the scene for the subsequent Chapters that describe the process in more detail.

1.1 Habitat mapping in the MESH Project

A basic knowledge of, and familiarity with all the stages of habitat mapping is required by those commissioning habitat mapping projects so that their expectations are realistic and to ensure that the work undertaken is fit for the intended purpose. From a surveyor's viewpoint, a thorough appreciation of the tasks is required so that they can be confident that they are collecting and processing data to a standard that is suitable for habitat mapping. This Introduction sets out the foundations of mapping so that all those involved with habitat mapping can jointly make decisions about the best way to achieve the desired goals.

Seabed habitat maps show the predicted geographical distribution of habitat classes. Habitat mapping, as distinct from the map itself, is the process of producing the habitat map. However, habitat mapping is really an ongoing process of developing our knowledge of the marine environment. In a sense, there is no end point to the habitat mapping process since the maps are predictive, they need testing through use and then further refinement as our knowledge improves to increase the ***accuracy*** of our predictions to boost our ***confidence*** in using maps. It is important to remember that:

A habitat map is a statement of our best estimate of habitat distribution at a point in time making best use of the knowledge we have available at that time

In a more restricted sense, habitat mapping is the plotting of the distribution and extent of habitats as a complete ***coverage*** (sometimes termed a ***continuous surface***) with indicative boundaries between adjacent habitats. The following figure summarises the habitat mapping process; this figure will appear throughout the *MESH Guide* although the contents of each box will reflect the particular aspect of habitat mapping being described.

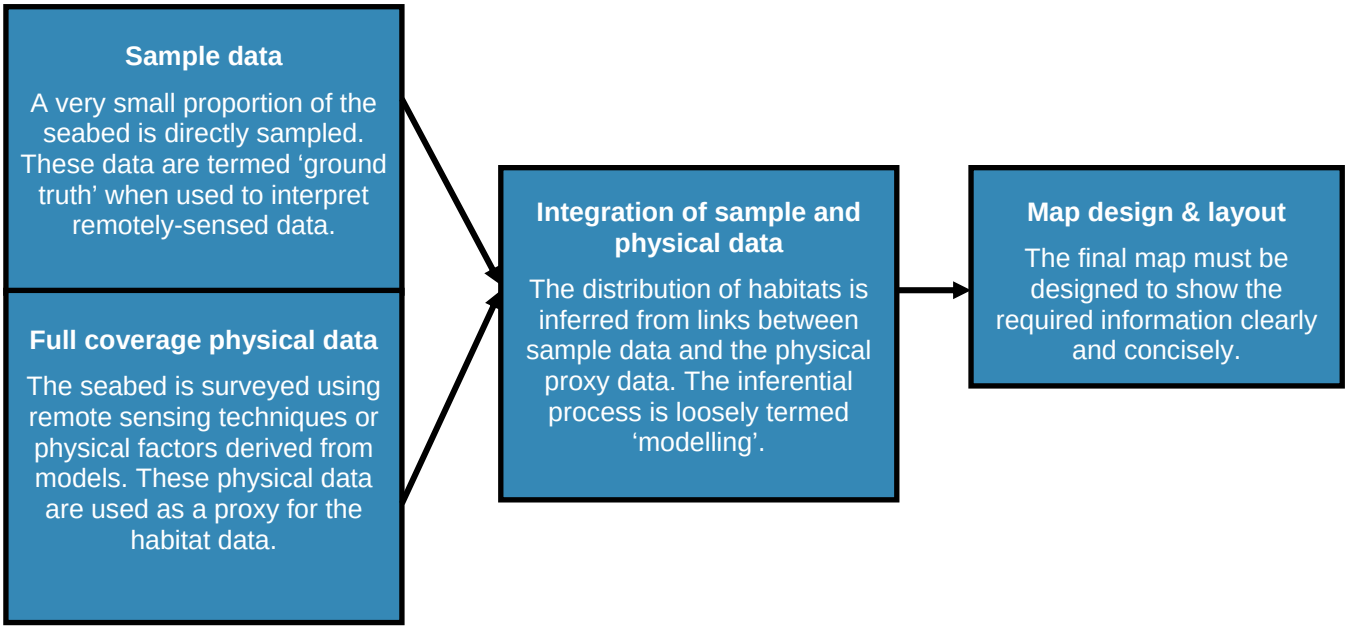


Figure 1-3 A flow chart of the main stages in making a habitat map by integrating sample data and full coverage physical data.

Habitat mapping is a complex process that requires considerable expertise and resources to produce seabed habitat maps that meet the requirements of end users. Before embarking on a habitat mapping project, it is important to understand the scientific and policy drivers that establish our need for seabed habitat maps.

1.2 Why do we need habitat maps?

Knowledge of the spatial distribution, quality and quantity of seabed resources is fundamental to our understanding of marine ecosystems and our ability to manage human activities to deliver effective sustainable development and maintain marine ecosystem function. Maps have a wide range of applications in management, planning, policy and research and form an important and integral part of management information systems. The following are some of the areas where habitat maps are needed.

- Provide a fundamental information layer for spatial and strategic planning;
- Support sustainable use of seabed resources;
- Help implement an ecosystem-based approach to the management of human activities to protect the marine environment;
- Improve *State of the Environment* assessments, particularly by setting the results from monitoring stations into a wider geographic context;
- Help focus monitoring effort;
- Support the identification of marine protected areas (MPAs);
- Assess the importance, rarity and extent of habitats over local, regional, national and international scales.
- Increase our understanding of marine ecosystem functioning – particularly its' relationship to hydrography, water column, fish communities and climate; and,
- Scientific research.

In addition there is a growing demand from international policy instruments for habitat mapping information to support their aims and implementation, including:

- 1992 EC Habitats Directive
- 1996 North Sea Ministerial Declaration
- 2000 EC Water Framework Directive
- 2001 EC Strategic Environmental Assessment Directive
- 2003 OSPAR Biodiversity Strategy
- 2007 EC Maritime Strategy
- 2008 EC Marine Strategy Framework Directive (to be adopted in May 2008)

The term 'habitat' is frequently used in these policy instruments and more widely in the scientific, policy and environmental management communities. Consequently, it has many definitions that can lead to confusion when 'habitat maps' prepared for one purpose are passed to another user from a different user group. For the purpose of clarity in this *MESH Guide*, our interpretation of a habitat is described in the following section.,

1.3 What are habitats?

The term ***habitat*** was originally defined to mean the place where an animal or plant lives (i.e. a single species). However, this can be extended to include many species together (known as a ***community*** or ***assemblage***) instead of a single species. The use of the term 'habitat' in MESH means both the physical and environmental conditions that support a particular biological community together with the community itself. In this way a seagrass bed in shallow sand is considered to be a different habitat from rocky reefs which support kelp and other seaweeds. Similarly habitats can be further subdivided so that a rocky reef can be split into habitats that support kelp forests and habitats that support filamentous and foliose seaweeds. Examples of habitats are shown in the following figure.

Seapens on mud | Mussel bed | Maerl bed

Figure 1-4 Habitats are defined by the biological community and the physical structure that supports it.

Unfortunately the term 'habitat' is commonly used generically in many scientific circles, as well as in management, policy and legal arenas where it often has a much broader definition. For example, the OSPAR Convention defined a list of 'rare and threatened and/or declining habitats' that includes features such as 'seamounts' that are much more akin to a physical feature rather than the narrower definition used in the MESH Guide. Such uses of the term habitat are further explained in the sections 'Related scientific terms' and 'Legal and policy use of the term habitat'.

The scientific community has over the years established a number of different terms, such as ecotope, physiotope, association, biocenosis and assemblage, to describe various aspects of habitat and community. Some have specific meanings, whilst others appear to have similar meanings, having arisen in different countries. For further information on these scientific terms see Olenin & Ducrotoy (2006); see also the 2006

report of the ICES Working Group on Marine Habitat Mapping for further discussion on the definition of habitat and biotope (www.ices.dk/reports/MHC/2006/WGMHM06.pdf).

Whilst the term habitat strictly speaking refers to the abiotic element of a biotope, the term is more widely used in legal and policy mechanisms to include the biological component, and thus often encompasses the biotope concept. International environmental instruments, including the EC Habitats Directive Annex I, the OSPAR and HELCOM Conventions and national mechanisms such as the UK Biodiversity Action Plan have developed lists of habitat types which require specific conservation and management measures. Use of the term habitat in this context typically encompasses both the communities of species and their physical environment, and therefore follows the more widely used use of the term.

The MESH Project and hence this MESH Guide have adopted the more widely used term 'habitat' but we define it in its 'biotope' form to mean both the physical and biological characteristics of an area of the seabed.

In the natural world, physical, environmental and biological parameters (temperature, salinity, depth, a species' geographic distribution) change gradually from one place to the next and sharp boundaries or discontinuities are rarely encountered. It is extremely difficult to visualise and describe a habitat without introducing clear divisions of these main parameters. In very simple terms, if take an example where habitats are defined by only two physical factors where we sub-divide each factor into thirds, when we combine the two physical factors we have nine possible combinations (see Figure 1-5). These combinations are classes. In the marine environment, there are many physical factors and many marine organisms so the process of 'classification' is more complex leading to many more habitats.

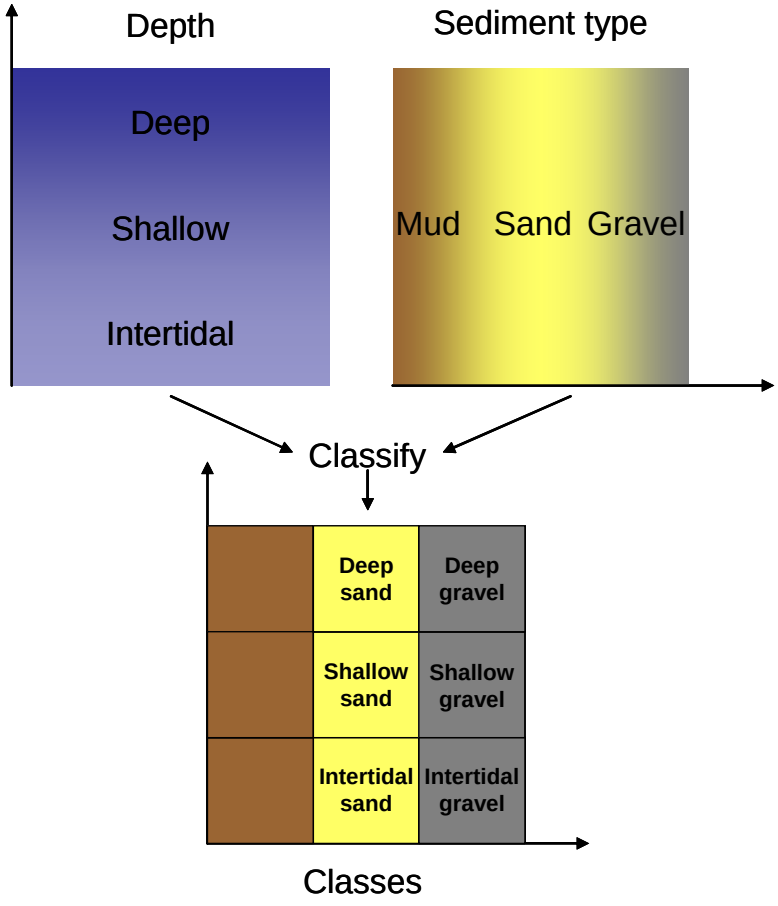


Figure 1-5 Habitat classes are defined by placing hard boundaries on continuous variables.

Habitat classification schemes are devised to define habitats in a consistent way, such that similar data can be consistently assigned to particular habitat types so these data may be compared between geographic areas and/or over time. Classification schemes are designed so that habitat types can be consistently applied by different workers and across different geographical regions. Different habitat classification schemes exist because the way the environment is sub-divided is linked to the end-user's requirement. Classification schemes

are often hierarchical such that broadly-defined habitats are subdivided into finer and finer units to suit end-user needs for differing levels of detail. For instance a kelp habitat can first be divided into kelp forest (plants are densely packed) and kelp park (sparsely distributed plants) and then further sub-divided based on different kinds of kelp species and their associated plants and animals (see following figure for an example).

Within Europe, there is a single pan-European habitat classification scheme together with a number of 'national' and 'local' schemes which encompass marine habitats. Such classification schemes are intended to aid the consistent interpretation of habitat data for use in nature conservation to help prioritise conservation action and to support the management of protected areas.

The European Environment Agency (EEA) developed a classification scheme for habitats as part of its EUNIS system (**Eu**ropean **N**ature **I**nformation **S**ystem) for managing species, site and habitat information. The EUNIS habitat classification scheme is a pan-European classification of terrestrial, freshwater and marine habitats that was developed for the EEA by the European Topic Centre on Biological Diversity (ETC/BD). The latest version can be accessed from the EUNIS website (eunis.eea.europa.eu/habitats.jsp).

EUNIS is the only classification system covering all European waters and consequently was adopted by MESH as the standard scheme to which all its habitat mapping data are being presented. This ensures data arising from MESH are in a common European classification system and that EUNIS is thoroughly tested as to its suitability to marine habitat mapping. However, EUNIS is still under development (JNCC are responsible for promoting its further development for the north-east Atlantic and Baltic Sea) and its use within MESH provides an opportunity to test, and if necessary recommend modifications to, the classification to ensure it is of practical use in north-west Europe. The EUNIS habitat classification is a hierarchical scheme. There are six hierarchical levels and discrimination between marine habitats is largely based on the concepts of biological zone (littoral, infralittoral, circalittoral etc), substrate type, hydrodynamic energy (i.e. wave exposure, tidal strength), environmental variables (e.g. salinity) and characterising species. A more detailed outline of the hierarchical structure is presented in the section EUNIS marine habitat classification of the full MESH Guide.

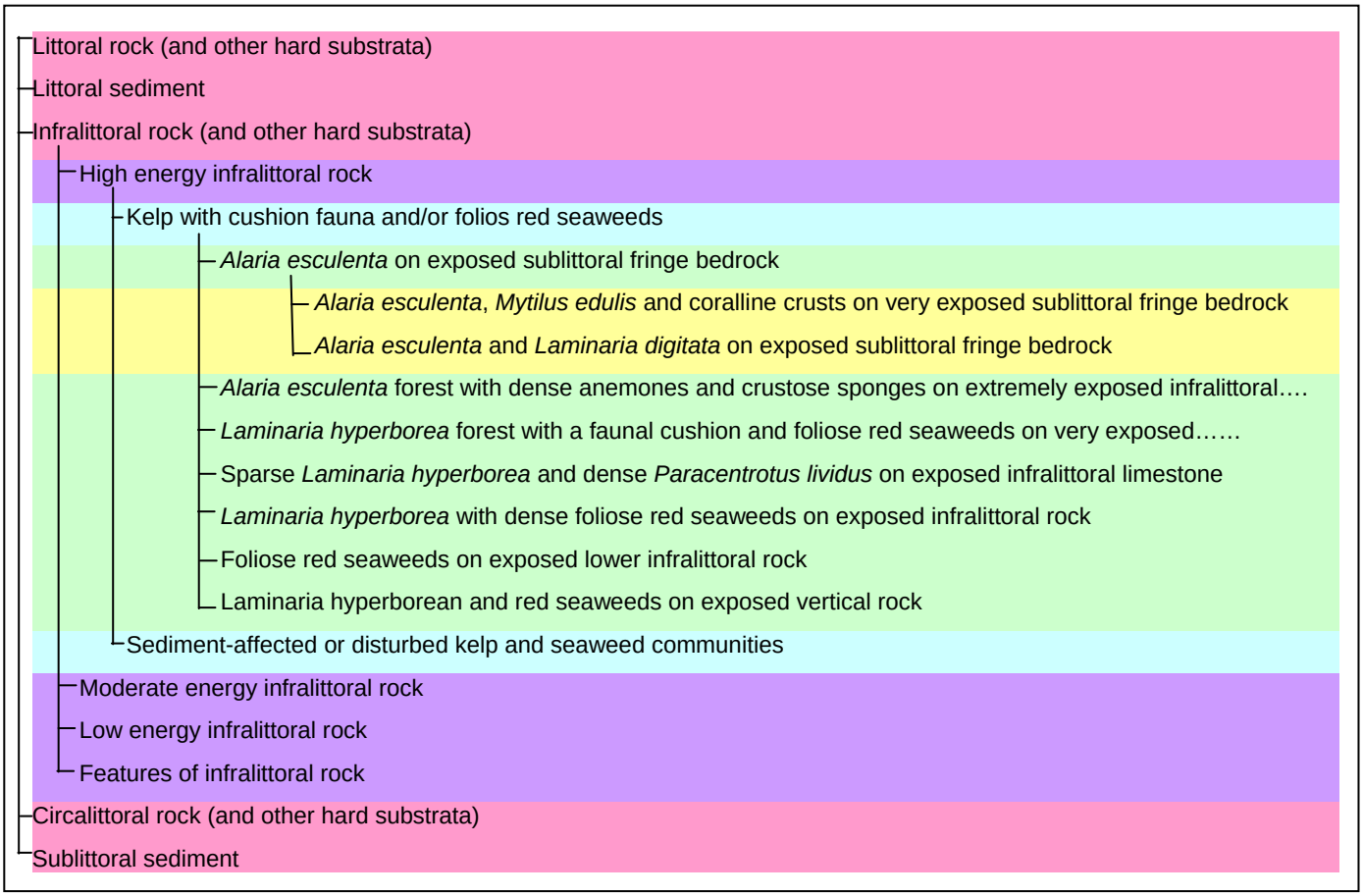


Figure 1-6 An example of a hierarchical classification of seabed habitats, expanded to show the increasing level of detail for kelp habitats.

Habitat maps have a particular meaning within the context of the MESH Project: seabed habitat maps show the predicted geographical extent and boundaries of habitat classes. Habitat maps show the sizes and shapes of the habitats and the way they relate to each other and fit together. Homogeneity, patchiness and connections between habitats are important ecological considerations that can be assessed from habitat maps.

In the survey and mapping context of this *MESH Guide*, the use of the term 'habitat' refers to both the physical environment and its associated biological community, and is thus synonymous with the term ***biotope***. As such, habitat mapping is about mapping ecologically relevant features and is more than mapping purely physical characteristics (e.g. seabed sediment maps), although the latter can often be used to infer much about the habitats. It is important to emphasise that:

A habitat map is a statement of our best estimate of habitat distribution at a point in time making best use of the knowledge we have available at that time.

The most important first step in the habitat mapping process is the clear definition of the type of habitats we intend to map; the next critical decisions in the mapping process are deciding what area we wish to map, and the level of detail we hope to show on the final habitat map.

1.4 What do you want to map?

Understanding the core concepts of ***scale*** and ***habitat detail*** is fundamental to the success of a habitat mapping project. Such knowledge is required by those commissioning mapping projects because it helps establish realistic expectations, by those planning field surveys so that the appropriate equipment is selected, and for those analysing data and drawing the maps so that the products meet the requirements of the end-user.

A habitat map shows the geographic distribution of habitat classes on the seabed. A map can be printed onto paper or displayed electronically on a screen. Regardless of the display medium, a map shows a defined and thus restricted geographic area of the seabed. Clearly establishing the geographic area of interest is fundamental to the success of a mapping project.

Representing a geographic area onto a display medium introduces the concept of map scale that is normally shown as the ratio of the size of the map to the size of the geographic area it depicts. An A4 page is approximately 20 cm wide by 30 cm tall (in portrait view). If this showed a map covering an area 2km wide by 3km tall (20,000 cm by 30,000 cm) – such as a small bay the scale would be 20:20,000 (30:30,000) or 1:10,000. Taking the opposite view, a feature shown on such a map that was 1 cm long would be 10,000cm long, or 100m, in the real world. If the same A4 map depicted and area 200km by 300km – for example a regional sea such as the Irish Sea, its scale would be 1:1,000,000 with a map feature 1 cm long representing 10km in the real world.

A similar element of 'size' appears in the definition of a habitat: the minimum size of a marine habitat unit is generally taken to be about 25m^2 (5m by 5m). 'Size' is also reflected in habitat classification schemes where is it is more commonly linked to 'biological detail'. At one end of the spectrum, habitat classes may represent a very high level of biological detail: for instance *a Zostera marina* seagrass bed on coarse sediment. At the opposite end of the spectrum, a habitat class may be very broadly defined – for instance, rock with seaweeds and could cover intertidal and subtidal areas of the seabed. Most often, detailed habitats cover relatively small areas of the seabed (10-100m dimensions); broadly defined habitats cover larger areas of the seabed (> 1km). When planning a habitat mapping project, setting out the level of biological detail that needs to be depicted on the final maps is fundamental to the whole mapping process because it has a very significant bearing on the choice of mapping strategy, the equipment required, the type of analysis needed and hence the overall cost of the project (see Chapter 2).

Not surprisingly, there is a clear link between the geographic area to be mapped and the level of biological detail to be displayed when determining the effort (cost) required in producing the map. Setting out to map all the detailed habitats in the Irish Sea and print the results legibly on A4 paper would require a large number of pages! The following table shows the effort required to produce maps at either end of the area and habitat detail spectra, and introduces the common habitat mapping terms of 'broad-scale' and 'fine-scale' maps.

Effort related to area & detail		Habitat detail	
		Low	High
Area	Large >100km by 100 km	Effort matches area to be surveyed: a typical broad-scale survey	Very high effort demanding high level of resources: e.g. a national survey program
	Small < 20km by 20 km	Returns do not justify the survey effort	Effort matches area to be surveyed: a typical fine-scale survey

Figure 1-7 Effort (and funds) required for habitat mapping are related to a combination of map area and required level of habitat detail.

The two ends of the area/habitat detail range of mapping activities can be loosely termed '***fine-scale***' and '***broad-scale***' respectively.

Once you have clearly established the level of habitat detail required on the final map, the extent of the geographic area of interest, and secured the necessary resources to undertake the mapping work, you need to be aware of the different routes available to produce the final maps. The following section describes the main consideration when deciding how to map the habitats in your chosen area.

1.5 How do you map habitats?

The MESH Project promotes a habitat mapping process whereby habitat maps are derived from integrating a continuous coverage of the physical properties of seabed (intertidal or subtidal) with observations of the habitats present at discrete locations. This process is summarised in Figure 1-8.

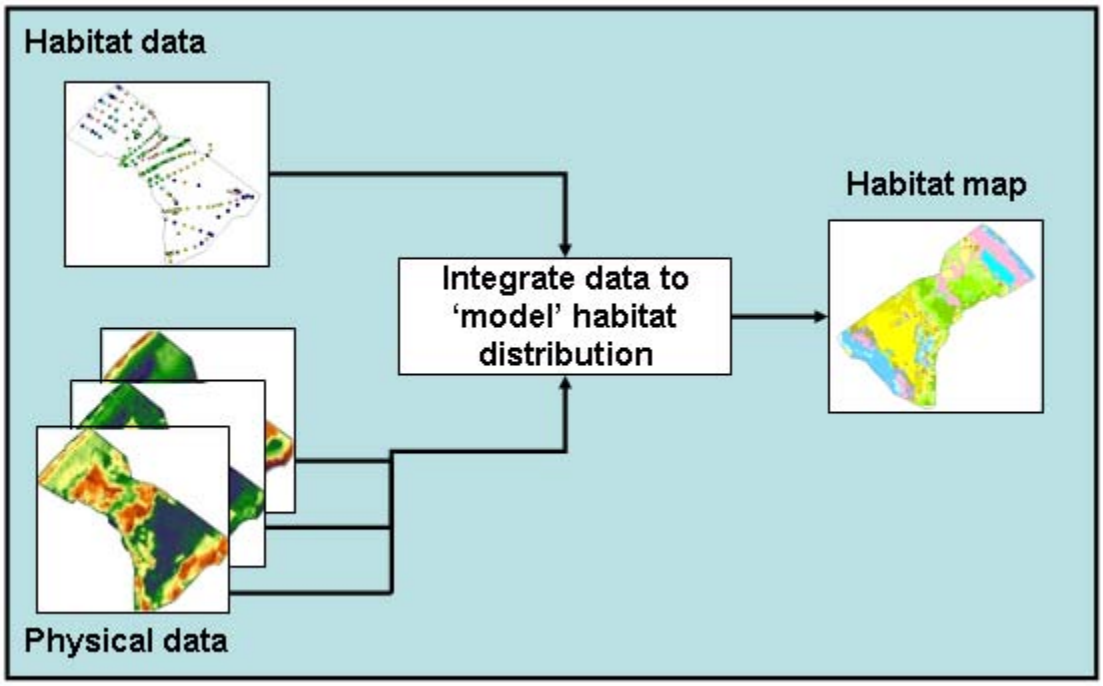


Figure 1-8 A summary of the habitat mapping process promoted by the MESH Project. It is important to remember that the final map is a prediction of the distribution of habitats.

Earlier sections have described some of the key questions that need answering when commissioning a habitat mapping project:

- Is the size of area to be mapped large or small?
- What level of detail do I need (very coarse habitat types or much fine detail)?
- What level of resources are available (time/funds/data/equipment)?

Answers to these questions will shape the overall habitat mapping strategy to be adopted. When it comes to actually undertaking the work, the main differences in the approach taken relates to the source of the physical and habitat data. Habitat maps can be derived from either existing data using desk-based studies, or new data from bespoke field investigations, or a combination of both approaches.

In this section of the full guide, the following issues are described:

- **Survey or modelling**: depending on the answers to the strategy questions above, you may need to undertake a desk study to model habitat distribution or to undertake new field survey to collect your own data to map the area of interest.
- **Remote sensing and ground-truthing**: most mapping studies are best undertaken by integrating remote-sensing data, which provides full coverage information of the seabed, with ground-truthing data that validates the features identifiable in the remote-sensing data.
- **Types of data are needed**: whether surveying or modelling, you need to understand which types of data will be needed to map your study area. These data relate to the biological, physical and environmental parameters which together determine the types of habitat present in the area.

A habitat map is the culmination of a complex process that is far from error-free! All elements have their strengths and weaknesses and those commissioning habitat mapping projects must be aware of some of the limitations and sources of error present in the final maps.

1.6 What are the limitations of habitat mapping?

Habitat maps show the predicted distribution of habitat classes. Habitat maps only represent a snapshot in time and the reliability of their representation of the distribution of habitats at any subsequent time will depend on the degree of natural variability present in the area shown on the map. Other than potential temporal changes, there are other limitations to the nature of this habitat information imposed by the way data are collected, interpreted, displayed and stored. These limitations must be understood since they have profound implications on the design of a mapping programme so that the end user's expectations of habitat mapping are realistic. Figure 1-9 shows the main limitations.

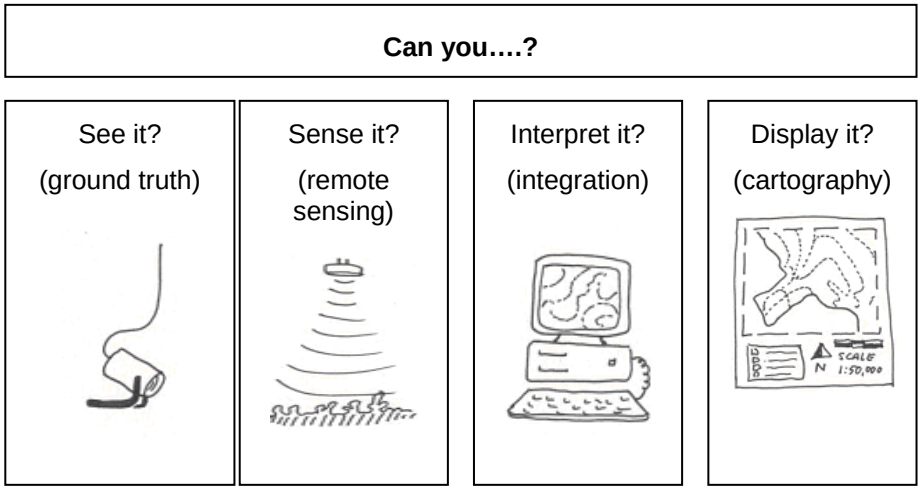


Figure 1-9 Key questions that indicate the main potential limitations in a mapping study.

To show a habitat on a map, you must answer 'yes' to each of these four questions. For a variety of reasons:

- You may not be able to detect the habitat of interest either because the ground- truthing techniques available are unable to 'see' it, or because the remote-sensing and interpretation techniques cannot separate out the target habitat from other similar habitats.
- You might not be able to display the habitat on your map at the chosen scale because its dimensions are too small.

In reality, it is unlikely that you will be able to make such a categorical statement for each habitat likely to occur in the area of interest, the answer is more likely to be more equivocal along the lines of 'maybe', 'probably' or 'possibly'. The degree of certainty with which you can answer the questions will depend upon our knowledge of the habitat itself: some habitats, for instance mussel beds, have a long history of scientific investigation so their physical and biological structure and the physical factors important to their functioning are relatively well understood. In contrast, we know very little about many deep sea habitats and hence whether it is possible to detect and then map such habitats.

Earlier sections have described the potential problems associated with scale, interpreting images and cartography. The size of patches of different habitats on the seabed varies enormously depending on prevailing environmental conditions and the underlying geology of the seabed. It may be possible to map such ***heterogeneity*** where the habitat patches are large compared to the resolution of the sensor and the required map scale. Unfortunately, there are many areas where such heterogeneity occurs over very small areas either beyond the detection limits of sensors or if detectable, at such a scale that the patches cannot be drawn on a map.

Habitats are defined by their predominant, conspicuous biological and physical characteristics. However, Figure 1-10 shows how such definition is complicated by three issues:

1. multiple habitats occur in a small area – they are mixed at a fine-scale;
2. the characterising biota of a sediment habitat mostly live within the sediment (infauna) and are not readily 'visible'; and,
3. the biodiversity of rocky habitats may lie in small niche habitats that are hard to sample remotely (under rocky ledges, under boulders, bored into the rock).

These issues are going to have an enormous impact on a mapping programme and the application of maps to provide answers to questions on biodiversity and the occurrence of rare species that might be crucial to policy implementation and subsequent management of human activities.

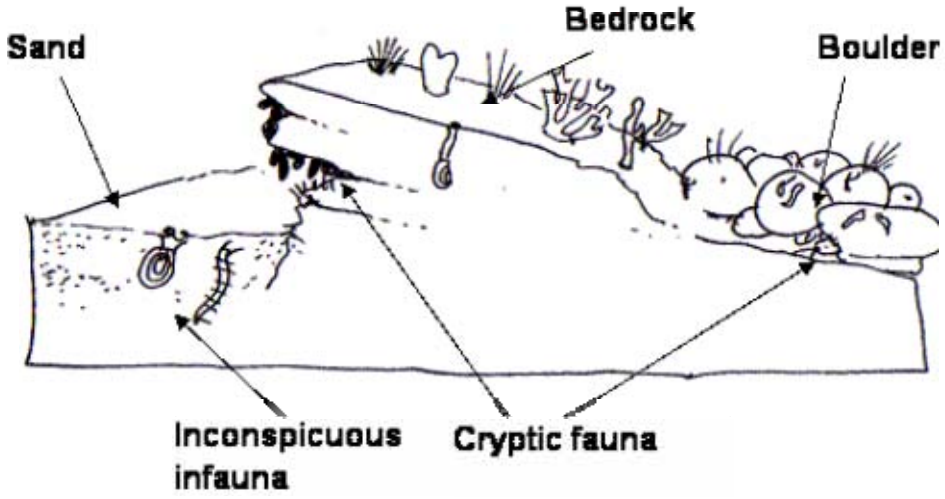


Figure 1-10 A diagram showing how the physical nature of the seabed can 'hide' the associated animals under ledges or boulders, or burrowed within sediment.

All these limitations will affect the quality of the final habitat map. Quality is directly linked to how well a map fits its intended use, and how much ***confidence*** it offers to the end user. Quality is often measured in terms of the accuracy and ***precision*** of a product against a specification. Assessing the quality of a map is a complex process but is clearly important to the end user, particularly when they have to make important decisions based

on that map. Chapter 5 How good is my map? of the *MESH Guide* describes the process for evaluating the quality of a map. The MESH Project developed a scheme supported by a web-based tool to assess the confidence of a habitat map (www.searchMESH.net/confidence) so that it could be displayed on the *MESH webGIS* (www.searchMESH.net/webGIS): the first time such a scheme has been developed.

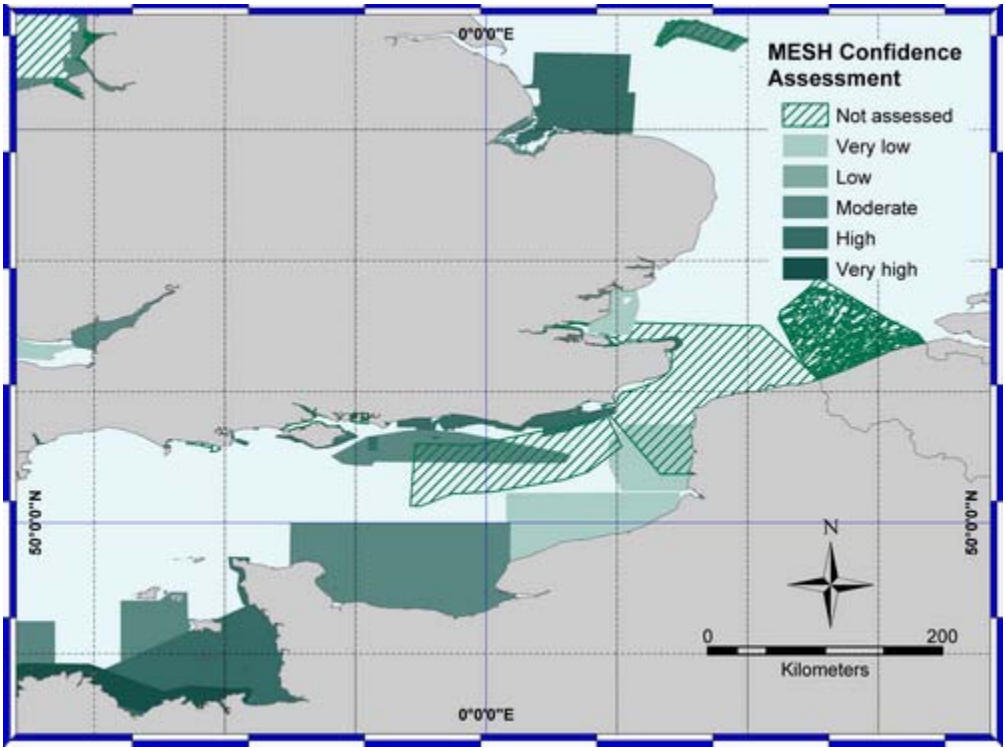


Figure 1-11 A section of the MESH Confidence Assessment layer from the *MESH webGIS.*

Habitat mapping studies collect a huge quantity of data that are eventually compressed into a habitat map. Some of these data are intermediate products on the journey towards the map. However, some information that has been recorded cannot be shown as habitat polygons on the final map: for example, the names of all the individual animal and plant species recorded from samples or observations of the seabed do not form part of the habitat description. Nevertheless such information is not 'lost' and important aspects (presence of a rare species) can still be plotted on a map in some other way if needed. It is vital that all information recorded at each stage in the habitat mapping process should be stored in database so that it is never lost and is available for further analysis and display, particularly at some future date. To maximise the value of data, it should be carefully described in a standard manner and properly archived so it always remains available for future work. Data management is covered in the following section and in more detail in Chapter 3 What is habitat mapping? and Chapter 6 What can I do with my map?

1.7 Data management

Habitat mapping studies generate considerable volumes of data; it is most important that sound data management practices are put in place to describe how the data were collected and processed and to describe how the resultant maps were developed. ***Metadata*** is the term used for the information that describes data. Poor data management can result in valuable data being lost (because it is not properly archived) or the data being passed to others without sufficient documentation to know the quality and possible limitations of the data.

Each study typically includes data of many different types (remote sensing and ground-truthing), some of which can be very large in volume (e.g. multibeam sonar data). Sound data management practices are therefore extremely important to track the data from the time they are collected, through the processing stages, and ultimately to when they are archived. The MESH Project developed a data management model supported by a database that will capture all the relevant metadata. This data model complies with international metadata standards and allows the user to send their data to data archiving centres and/or contribute metadata to international metadata catalogues. The MESH Project also offers data exchange formats (see Chapter 6 What

can I do with my map?) to enable users to store their data in a simple format that can be readily assimilated into other data collation activities.

Data management must be one of the elements considered during the planning stage of a habitat mapping project. The following section sets out the main considerations for planning such mapping studies.

1.8 How do you plan for habitat mapping?

Maps must be fit for purpose and planners should have a clear idea of the scale, resolution and level of habitat detail required in the final map(s), together with the knowledge of how the maps will be evaluated against the original aims and objectives to ensure the meet the necessary quality assurance standards. Planning a habitat mapping study involves a consideration of each of the stages of the habitat mapping process to ensure all necessary information is collected for the evaluation of the final map.

Once the need for a habitat map is clearly identified, planning the mapping process starts with setting realistic aims and objectives to deliver a map that is fit for purpose. An evaluation of the available information (possibly requiring a short desktop study) is required at the outset to clearly establish how to acquire the necessary data. Where the planning cycle identifies suitable data are available, it may suggest a desk-top mapping project to derive the required habitat maps from the interpretation and synthesis of existing data. However, if critical habitat data are lacking at the required scale and level of confidence, new surveys will need to be commissioned. A survey strategy will need to be planned, choosing techniques and strategies for deployment to collect appropriate data for the resulting maps to meet their stated purpose. The next stage in the planning should focus on the data analysis, interpretation and cartography. Ideally, the plan would include an flow chart through these stages showing the type of data required at each stage of the process. Finally, planners must consider the type of evaluation required at the end of the mapping process to ensure that appropriate data are available; for instance, if a statistical assessment of accuracy is required the survey strategy will have to collect an independent set of ground samples for validation. The planning cycle is summarised in the following figure.

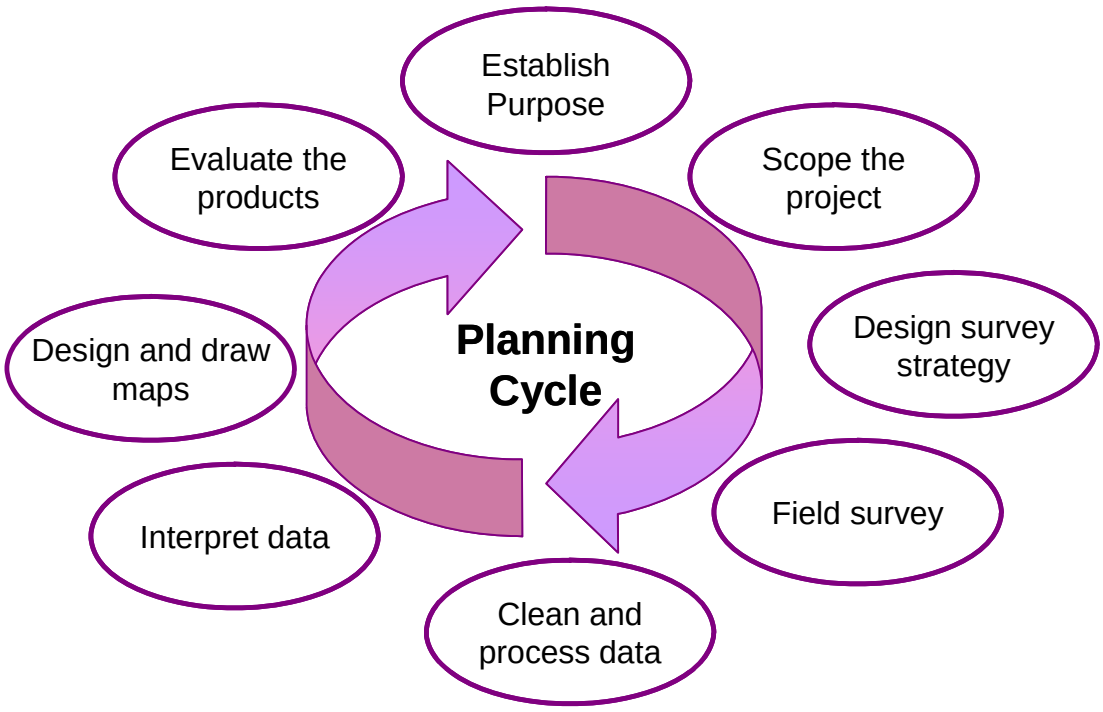


Figure 1-12 The planning cycle proposed by the *MESH Guide* for a habitat mapping project.

It is important that there is a good overview of the whole mapping project at the planning stage to ensure that all the necessary data and information are collected. It is likely that planning will involve visiting each of the major mapping stages in an iterative manner until the final plan becomes clear and fixed and can proceed to either the

field survey phase (Chapters 2 and 3) or the map production phase (Chapter 4) if sufficient existing data are available.

1.9 Summary

Habitat mapping is a process that ultimately generates a habitat map to meet a specific and clearly defined need.

A habitat map:

- Supplies information to meet a purpose;
- Predicts the distribution of habitats;
- Applies a habitat classification scheme to observed data; and,
- Requires thorough planning and scoping to ensure it meets its stated purpose.

A habitat map is not:

- Definitive; or,
- Simple or simplistic

The subsequent chapters of the *MESH Guide* describe each of the stages in the habitat mapping process, with the final chapter providing examples of how habitat maps were used to solve real problems.

2 What do I want to map?

Lead Authors: Roger Coggan (Cefas) & Jacques Populus (Ifremer)

The aim of this Chapter is to guide users through the planning stages of a mapping programme to ensure that the final products are fit-for-purpose and deliver the information required. As the mapping process can be very involved, it is important to have adequate consultation throughout the planning phase between the end users, the funders and the producers of the map so that each understands the scope of the project and the options available for undertaking the work. To help guide this planning and consultation, we divide the process into a series of stages, each of which is described in the subsequent sections.

2.1 Scope the mapping programme

The aim of the scoping exercise is to establish the purpose and objectives of the mapping programme to make it clear exactly what it is trying to achieve, and why it is needed. This knowledge will inform all the subsequent planning stages and determine precisely what is (or is not) required in the final mapped product. It is the responsibility of those who commission mapping programmes to make their requirements perfectly clear and they should be intimately involved in the scoping and planning process. The scoping exercise produces a scoping report that should be a shared document between the sponsors, managers, surveyors and mappers, and could form part of a contract specification.

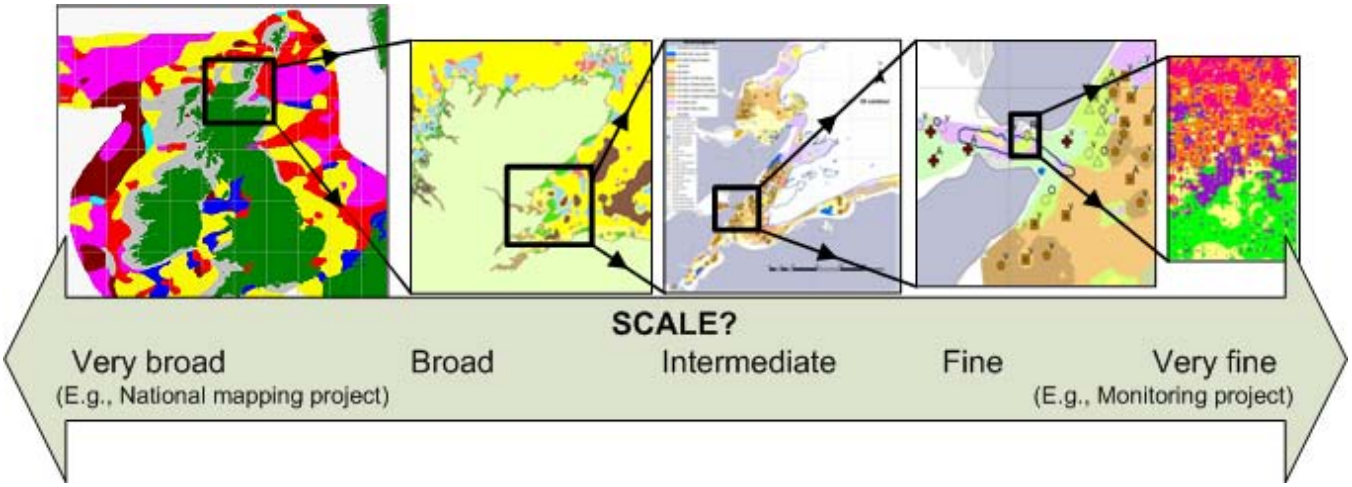


Figure 2-1 Mapping scale and purpose.

There is generally an inverse relationship between the information content (detail and resolution) of a map and the spatial area that it covers. Maps depicting large areas usually show generalised information, while those depicting small areas usually have a lot of fine detail. These different resolutions are commonly referred to as broad-scale and fine-scale maps, with intermediate-scale maps lying somewhere between.

Very broad scales are likely to be national mapping projects, while very fine-scale surveys will probably target particular biota or habitat parameters for quality-monitoring purposes. Most marine management and spatial planning requires an assortment of habitat maps between these two extremes. Such broad-, intermediate- and fine-scale mapping exercises need somewhat different approaches and form different elements of a mapping or survey programme, so each will need scoping separately.

The scoping process will determine the area to be mapped (extent), the scale of a printed map (e.g. 1:250,000) and resolution (the smallest unit to be mapped), the spatial precision required (e.g. ± 50 m), how accurate the map should be and the level of detail needed in the habitat classification. Here there can often be a trade-off, improving the nominal accuracy of the map (measured by its success in predicting what habitat exists at a given point) by settling for a more generalised (less precise) description of the habitat (e.g. EUNIS level 3 instead of EUNIS level 4).

Throughout the scoping process, the terms ‘Site’, ‘Area’ and ‘Region’ are frequently used to convey the concepts of different spatial extents, but the lack of any definition of these terms can lead to misunderstanding during the consultation and planning stages. The *MESH Guide* therefore offers the following definitions, and uses the terms to refer to a spatial hierarchy, as illustrated in Figure 2-2 below. A *Site* would normally be a specific location of

interest, say a particular beach or offshore feature (e.g. disposal ground) with an extent up to ~10 x 10km (generally, between 1 and 100 sq km). An *Area* would normally be larger than this, having some local geographical context such as an estuary or archipelago, or an extensive offshore feature such as the Dogger Bank or Anton Dohrn seamount, with an extent up to ~100 x 100km (generally between 100 and 10,000 sq km). A *Region* would be considered as a larger ecological unit such as the Eastern Channel or Irish Sea, with an area normally greater than 10,000 sq km. These definitions are not intended to be precise demarcations but rather an aid to conceptualising different spatial extents associated with mapping studies. Hence, one would normally think of broad-scale maps summarising information over a Region or Area, intermediate scale maps showing a moderate amount of detail about the distribution of habitats in an Area or a large Site, and fine-scale maps providing detailed information on the variety and location of biotopes encountered at a Site.

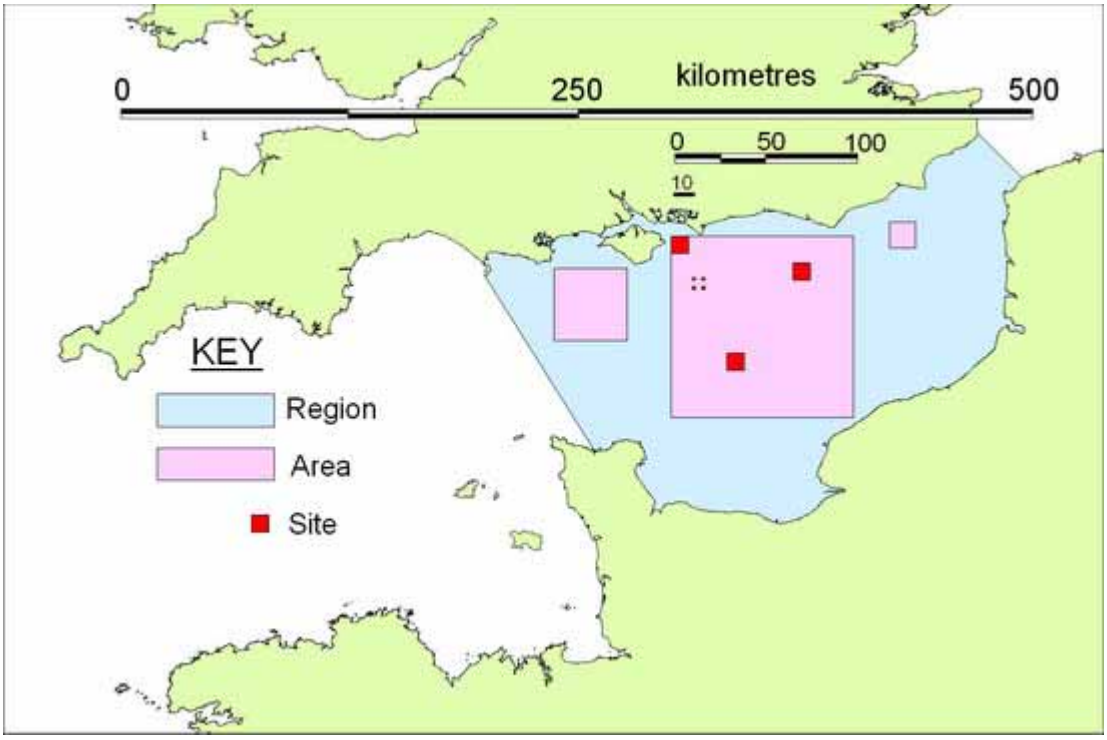


Figure 2-2 An illustration of the terms 'Site', 'Area' and 'Region' used in the *MESH Guide* to refer to different spatial extents (see text), here showing the Eastern Channel Regional Sea (as defined by the MESH Project), and a number of Areas and Sites of different size. The four smallest Sites each have an extent of 2 x 2km and their centres are 5km apart.

This part of the *MESH Guide* leads you through this scoping process. You should complete a Scoping Report (a scoping report pro-forma and examples of scoping reports are available online from the *MESH Guide to Habitat Mapping* website or on the attached DVD) to capture the purpose and objectives of the overall programme and each element within it. The report sets the framework for the programme and provides relevant information for all those who will be involved in planning and executing the work. To help in the decision making process, an interactive *MESH Scoping Tool* is provided, in the form of a Flash® animation, that allows you to test and assess various scenarios before finalising the scoping report.

2.2 The Scoping Tool

The *MESH Scoping Tool* guides you through a series of prompts asking you to consider the purpose of the survey, factors that will affect the amount of survey effort required and how different survey and environmental conditions will affect the suitability of various survey tools that may be available (http://www.searchmesh.net/Default.aspx?page=1931). A summary table highlights one or more potential survey strategies and provides a guidance comment based on an analysis of the choices you have made. The aim is to ensure that each element of the mapping programme is properly balanced and you are not anticipating too much or too little from the map or the data the survey might provide. If a mismatch is apparent, you can go back and try out various different scenarios.

The first section examines the overall scope of the survey and how the purpose, objectives and type of information required. The second section considers criteria about the mapping exercise that affect the likely survey effort required. The third section in the tool asks you to consider the environmental and other conditions likely to be met during the survey. Adjusting the slide bars will show how these conditions are likely to affect the suitability of a range of survey tools and techniques. The last section summarises your choices, giving the purpose and scope of the survey and list the tools that are most suitable. It offers one or more strategy options to choose and indicates a relative level of survey effort associated with the selected strategy. Summary comments provide helpful hints about how you might proceed. There is an option to print out the summary page.

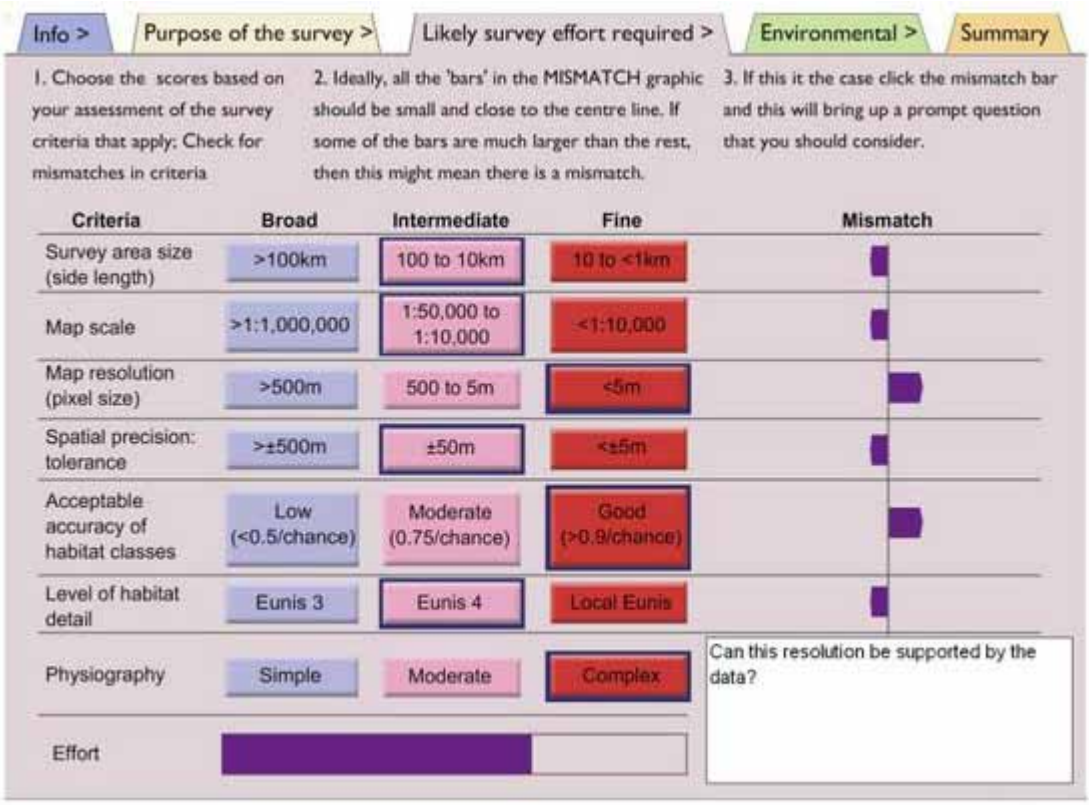


Figure 2-3 A screenshot of the *MESH Scoping Tool.*

The MESH Scoping Tool does not provide a definitive answer, but it helps guide the users thought processes when considering the scope of the mapping programme and what can be realistically achieved within each of the broad, intermediate and fine-scale elements. It can be used to promote focused discussion during consultation and to try out a number of potential scenarios.

Once the scoping phase of the planning process has been completed, all the consulted parties should have a clear understanding of:

- the purpose and objectives of the overall programme;
- the type of information needed by the end-users of the maps;
- any need to split the programme into separate related elements to provide different information content;
- the precise information content required in each element of the programme; and,
- the specific mapping criteria for each element of the programme.

After completing the Scoping Report, the next section in the planning process is to determine where there are any gaps in the available information.

2.3 Determine the Information Gaps

The scoping exercise will have given an indication of the types of information that the maps need to convey. The next step in the planning process is to assess what data are needed to provide that information and whether such data already exist to an adequate standard. Data that are missing or fail to meet the required standard will need to be collected through new surveys and/or generated by models. The thoroughness of this ***gap analysis*** can therefore be crucial in determining the overall cost of the mapping programme and the confidence that can be placed in the final mapped outputs.

Habitat maps are a composite interpretation of many different kinds of data, some of which may be actual measurements or observations, while others may be derived from a model (e.g. tidal predictions).

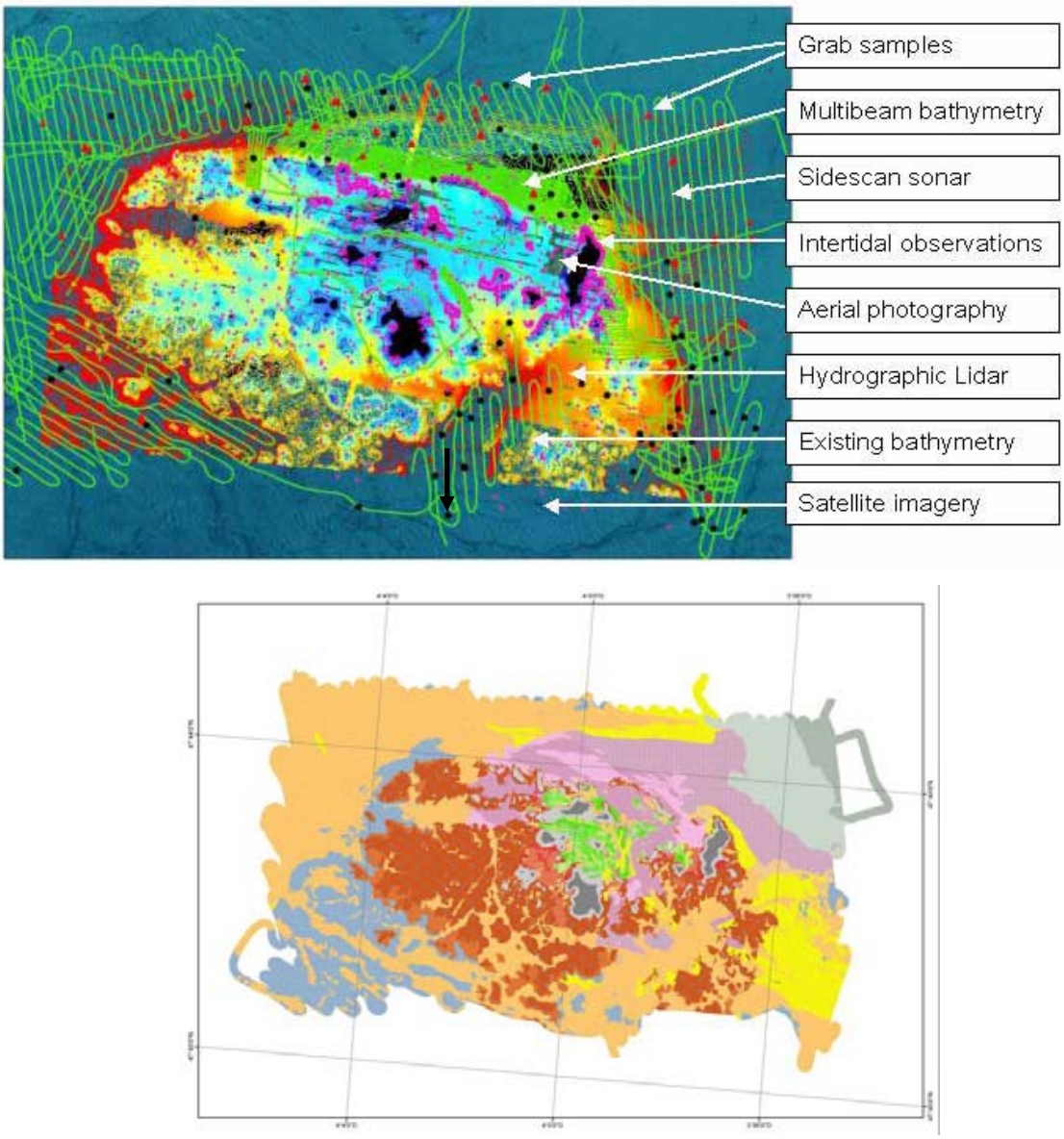


Figure 2-4 An example of the multiple data layers used in preparing a habitat map of the Glénan archipelago, Brittany.

The data-needs of the project will be driven primarily by the criteria used to discriminate between habitats, such as salinity, type of sediment and the species present. Not all classification schemes use the same criteria, so the data-needs of the relevant scheme should be understood at the outset. Hierarchical classification schemes, like EUNIS, use different criteria at different levels of the hierarchy, so some data sets will be fundamental to all levels of the hierarchy (e.g. bathymetry), while others will only be needed at the higher levels to distinguish between detailed habitat classes (e.g. the species present).

The Gap Analysis is a desk-study and should critically assess the availability, quality, coverage and compatibility of existing data sets, as there is great risk to the integrity of the map if any of these factors is mistakenly assumed to be adequate. This assessment is assisted by modern metadata catalogues, such as that provided by the MESH Project, which detail what, when, where, how and why the data were collected, and importantly, who owns it.

Some existing maps may be suitable as proxies for certain types of information, but checks should be made to understand the limitations of applying these interpretations of historic data to construct new habitat maps. Historical data sets should themselves be closely scrutinised to ensure they meet the needs of the current mapping project; if not, the data may need some form of manipulation, translation or truncation before it can be used.

The full *MESH Guide* gives further in-depth consideration to these points and provides a checklist summary table to record the outcome of your analysis. This will highlight the data gaps, indicating what data need to be collected through new surveys or derived through modelling.

2.4 Specify new survey work

If the gap analysis has identified a need for data to be collected through new surveys, the next stage in the planning process is to draw up a survey specification that will meet those needs. This specification requires some knowledge of different survey strategies and the capabilities of the various sampling tools that are available.

The general approach to seabed mapping involves the use of both remote sensing and direct sampling techniques. Remote sensing techniques provide coverage of an area of shore or seabed, but they do not (usually) detect habitats *per se*. Rather, they allow the area surveyed to be divided into a number of regions that represent different ground types. Direct sampling techniques typically supply physical and/or biological data from point samples, and it is these data that are needed to identify and classify the habitats. Habitat maps can be produced from direct sampling alone, but would require an intensive sampling programme to provide the spatial coverage necessary. Instead, it is more efficient and effective to use the two techniques in combination, targeting the direct sampling at different ground types. This provides both coverage and stratified ground-truth data that can subsequently be integrated and interpreted to produce a map. MESH recommends this basic strategy of remote sensing followed by directed ground-truth sampling to ensure representative sampling of the area to be mapped.

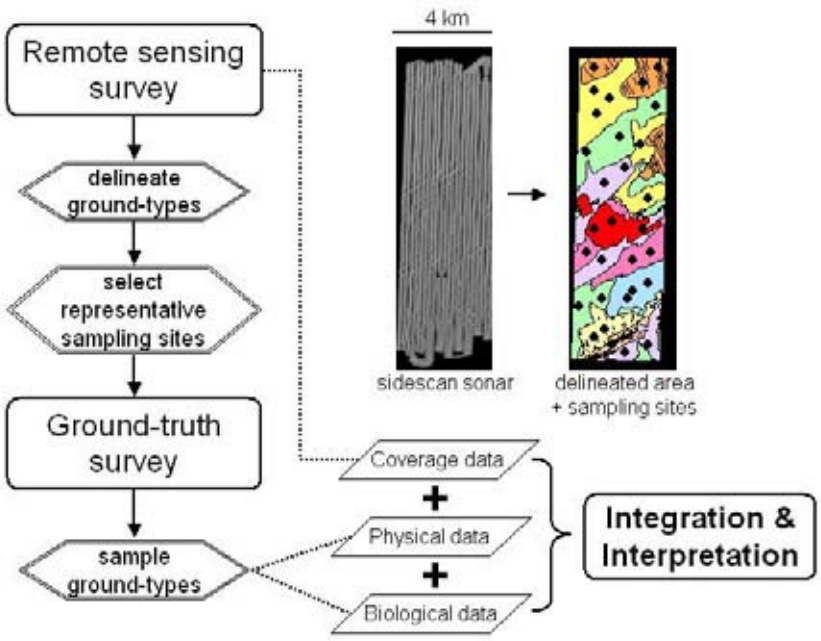


Figure 2-5 A simplified survey strategy where the data are acquired from remote surveys and directed ground-truth sampling, ready for input into the integration and interpretation phase of the mapping process.

Remote sensing and ground-truth surveys employ a range of different technologies, instruments and devices, some of which provide several different types of data (or sample), while others provide only one. Optical remote sensing techniques (e.g. satellite imagery, aerial photography and *LiDAR*) are effective on the shore and in clear shallow waters. Ship-based surveys use an array of acoustic techniques to image the seabed, with higher frequency systems like multibeam or sidescan sonar producing plan-images of the seabed surface while lower frequency systems (e.g. 'sub-bottom profilers') penetrate the seabed giving profile images of the underlying sediment layers and rock strata. Shore-based ground-truth surveys tend to favour direct observation but ship-based surveys tend to rely heavily on sampling devices like grabs, trawls and remote observation (video & 'stills' cameras). How the surveys are approached will depend on the particular combination of tools and techniques that are selected (or available). We summarise the capabilities and limitations of a variety of generic sensing and sampling techniques and, through the interactive scoping tool, allow the user to see how their suitability changes under different survey conditions. Guidelines for operating the specific sampling tools are given in Chapter 3.

This stage of the planning process should outline the survey strategy: a general plan of action required to meet the survey needs. This strategy should decide what type and how much remote sensing is needed. The rapidity of aerial survey techniques usually allows for full coverage of the shore and shallow intertidal areas, but the slower ship-based surveys are frequently constrained by time and cost such that a choice has to be made between a full coverage survey of a small area or a partial coverage survey of a larger area. As soon as the coverage falls below 100%, the ability to map at fine resolution is lost, but lower resolutions can be achieved to varying levels of confidence using interpolation techniques on partial coverage surveys. A 'nested' survey strategy combines partial coverage over a broad area with more detailed coverage targeting specific areas of interest.

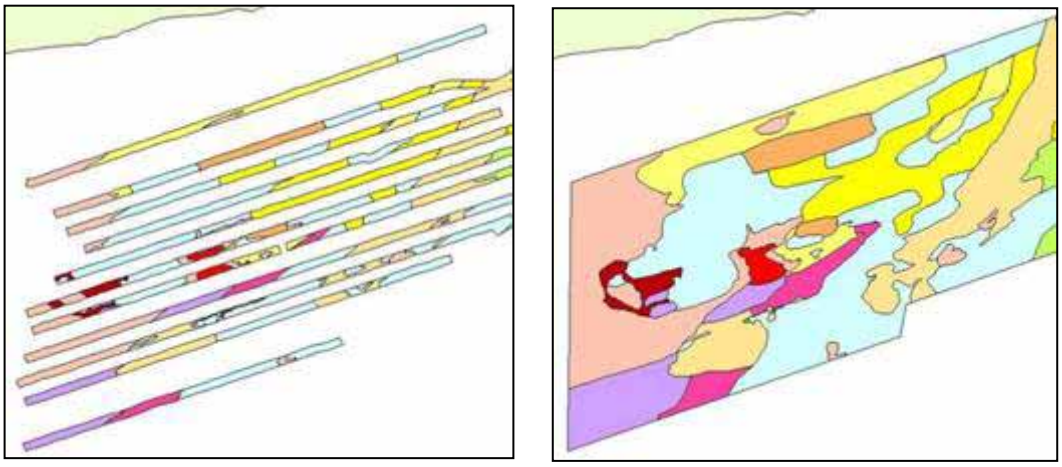


Figure 2-6 An example of a partial coverage survey (left) with resulting interpolated map (right). The area surveyed is ~20km wide.

The strategy for ground-truth sampling will be influenced by the purpose of the map and the level of confidence required. There are options to take one or more ground-truth samples from every distinct area shown by the remote survey, or just every distinct ground type. A greater number of samples will generally provide greater confidence in the final interpreted map. There may also be a need to further stratify the sampling to account for recognised ecological zonations, such as the immersion/emersion cycle of intertidal areas, or depth/turbidity gradients in deeper waters.

The output of this planning process should be a survey specification, which should detail the survey objectives and outline the strategies and sequence of work. There should be sufficient detail to allow those who are proposing the survey to estimate the likely cost, such that they can bid for funds or put the work out for tender. The detailed survey design would usually be agreed at a later stage, and may contain elements that are conditional on the outcome of the initial stages of the work. Once funding is secure and the scope of work agreed, it is common to consider both the remote sensing and ground-truthing in more detail to ensure the actual survey design is optimal in relation to the objectives of the study.

2.5 Optimise the Remote Sensing

Several tentative survey designs may have been considered when developing the survey specification, but optimising the survey design can only begin in earnest when the survey objectives and strategy have been

agreed. The aim is to make best use of the resources available to maximise the overall effectiveness and cost-efficiency of the survey. There is clearly a need to be aware of the previous stages in the planning of the programme, including the Scoping Report and Gap Analysis.

In remote sensing (RS) surveys, the simultaneous use of several different instruments makes efficient use of the survey platform (aircraft or ship) by removing the need to repeat the same survey lines for each instrument. However, as not all instruments work optimally under the same conditions (e.g. speed, altitude, depth), careful consideration should be given to the survey design to favour the 'most important' (principal) instrument while still allowing the others to collect data of an acceptable quality. The survey specification will likely determine which is the principal instrument.

Full coverage RS surveys are usually run in a series of parallel lines, building up a mosaic image of the ground or seabed. The separation between survey lines (***track spacing***) depends on the width of ground covered by the instrument (***swath width***), which in turn depends on the type of instrument used and its altitude above the ground or seabed. In some instruments the swath can be adjusted, a narrower swath usually giving a higher resolution. Optimal track spacing for full coverage surveys therefore depends on the characteristics of the principal instrument and of the area being surveyed. For hull-mounted instruments, swath width typically increases with depth to seabed, so surveys of shallow waters will need closer track spacing than those in deeper waters. This is not the case for instruments towed (or flown) at a fixed altitude above the seabed. There may also be an optimal orientation for the survey lines, for example running parallel to a major slope to maintain a constant swath width along individual survey lines.

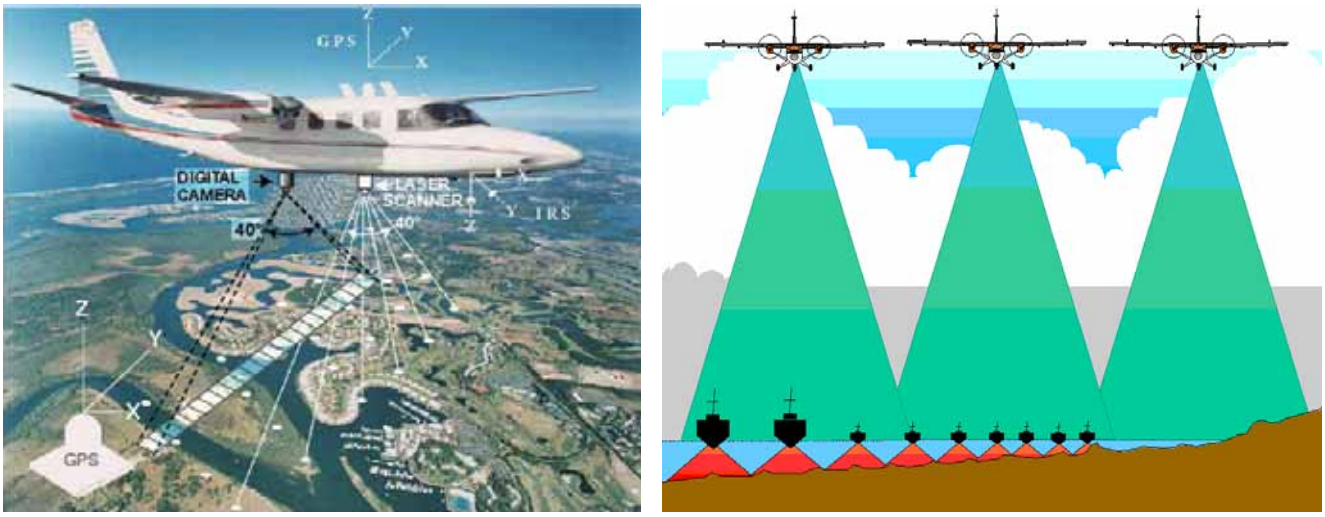


Figure 2-7 Left figure: combined LiDAR and aerial photographic survey (©Terra Imaging); right figure: illustration of track spacing and swath width for airborne LiDAR and shipborne multibeam sonar surveys (Image courtesy of Optech Incorporated).

Surveys of shallow water can use both optical (airborne) and acoustic (ship-borne) techniques and balance coverage between the ability of the optical techniques to penetrate the water and the ability of the vessels to access the shallow areas. Shallow turbid waters may not be amenable to either technique.

While the survey strategy will have indicated which generic RS techniques should be used, the optimal survey design determines the specific combination of instruments and how they are best deployed. Particular attention should be paid to the methods by which the data will be georeferenced, as this influences the spatial accuracy and precision of the mapped output. Selecting the optimal track spacing for partial cover surveys can be helped by running a few 'pilot' survey lines, usually in a perpendicular or grid pattern, to assess the heterogeneity/homogeneity of the survey area

All remote sensing surveys benefit from some ground sampling to provide reference material that gives meaning to the remotely sensed data. Many remote sensing techniques return streams of data that are, in themselves, meaningless numbers. Ground validation samples allow the range of data values to be segmented to reflect different ground types (supervised classification). If such samples are not available, the data-range may be segmented into artificial blocks, or by seeking 'natural' cluster groups (unsupervised classification). The survey design may consider running instruments over known ground types ('training' or 'calibration' sites) to identify their characteristic 'signatures'. The segmentation of data is important, as it is the basis on which the survey area is divided into different ground types that will be targeted for ground-truthing. Where a remote survey technique

produces an interpretable 'image' of the shore or seabed (e.g. aerial photography, sidescan sonar) ground types may be delineated directly, by eye.

This section of the planning should end with a draft plan of the remote sensing survey that can be handed to those who will conduct the survey to check operational feasibility (considerations of flight paths, shipping lanes, navigation hazards etc).

2.6 Optimise the ground-truthing

The function of ground-truthing is to sample the physical and biological components of a particular ground type to enable it to be characterised as a habitat. Where an existing classification scheme will be used, it is important to record the parameters relevant to that scheme, so the samples or observations can be matched with the appropriate habitat definition (top-down classification). Where an existing scheme is not available or not required, a variety of physical and biological parameters should be recorded consistently across the survey area to allow habitat classes to be determined, usually by statistical analysis (bottom-up classification).

Optimising the ground-truth survey is a matter of selecting the right sampling methods and directing their appropriate deployment to collect representative samples from the variety of ground types encountered in the survey area. The selection of sampling sites is guided by the knowledge gained from the remote sensing survey, and this 'directed' ground-truthing makes more efficient use of resources than a purely random placement of sampling sites.

Trained human observers are powerful ground-truthing 'tools' due to their ability to recognise and classify habitats on sight. Where they have access to a survey area, such as on the shore or during diver surveys, they can intelligently explore the area, constantly taking visual 'samples' and directing other sampling effort where most needed. Their skills can still be used to good effect in deeper waters, though observing video or camera images and piloting Remote Operated Vehicles.

In deeper water, knowledge of what is actually on the seabed relies on the use of a variety of sampling devices. These are usually limited to grabs and corers, which sample sediments and their ***infauna*** (animals living within the seabed), and trawls and dredges, which sample ***epifauna*** (animals living on the seabed). Human observers can still play a part, through the use of video and stills cameras mounted on towed sledges, drop-frames or Remote Operated Vehicles (ROVs) but these only view the epifauna and surficial substrata. A combination of these sampling and observational methods is required to provide all the information needed to classify the habitats present.

Figure 2-8 Some ground truth sampling methods: (from left to right) direct visual observation, a Hamon grab, a beam trawl and a towed video sledge.

Both ship-based and shore-based surveys should use the information available from remote sensing to help select ***sampling sites*** (a general location in which sampling will be undertaken), but the precise method of placing the ***sampling stations*** (a specific point at which a sample will be taken) may differ. On ship-based surveys, it is good practice to pre-plan a series of stations and specify which sampling gear(s) will be used at each one, so the vessel can plot an optimal route and arrive at each station fully prepared to deploy the gear. Stations may be selected to target specific features revealed by the remote sensing or to sample anywhere

within a particular ground-type. The same can apply to shore-based or diver surveys, directing a person to go to a particular point to take a sample, but these surveys can be made more powerful by allowing the observer some flexibility to fine-tune the sampling design according to their visual assessment of the sampling site. They can decide what type of samples should be taken, how many are needed and precisely where they should be placed. In the special case of top-down classification, they may decide there is no need to collect samples if a habitat can clearly be identified by direct observation.

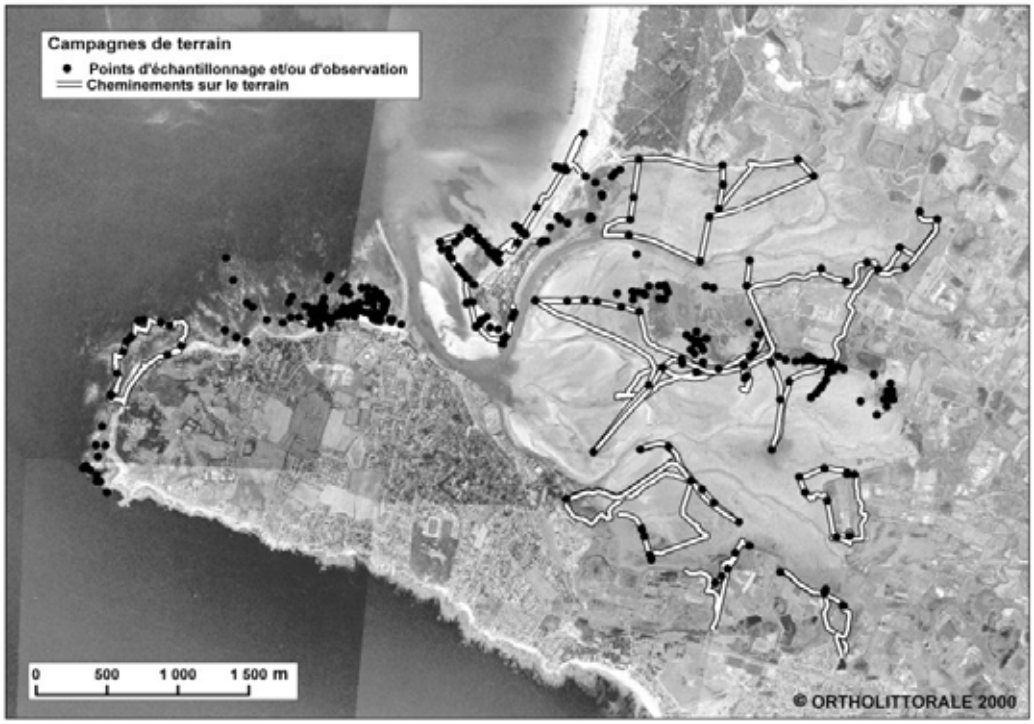


Figure 2-9 The location of sampling sites on a shore-based ground-truth survey in Brittany.

It is important that sampling should be representative rather than exhaustive as it is easy to become overburdened with samples, which are both costly and time-consuming to process, analyse and interpret. To be representative, appropriate sampling techniques should be used on each ground type, but further stratification may also be needed to sample across relevant ecological zones (e.g. depth, salinity, turbidity) that are know to influence the distribution of species.

A minimum sampling requirement should be set, considering the level of classification accuracy and confidence required in the final map. Single sampling of each ground type forces the assumption that it is homogeneous. Replicate sampling allows some assessment of variability within and between different sampling strata (ground type + ecological zone). The number of replicates taken may be determined by a rule of thumb, expert judgement or some formal assessment linked to the heterogeneity/homogeneity of the ground as it appears to the remote sensing instrument (so called ‘Optimal Allocation Analysis’).

In many cases it will be necessary to set aside a proportion of the ground truth samples to test the accuracy of the map once it has been produced. The need for these ‘validation’ samples should be factored into the survey design.

Optimising the ground-truth survey design is often an iterative process, and it should remain flexible to a certain degree. A draft plan of the ground-truthing survey can be handed to those who will conduct the survey to check operational feasibility (access to sites, navigation hazards, Health & Safety matters, etc). However, the fine detail of the design frequently depends on the outcome of the remote sensing survey and the prevailing conditions at the time of sampling.

2.7 Summary

Users must carefully plan the different stages of a mapping programme to ensure that the final products are fit-for-purpose and deliver the information required. When completed, the outcomes of the planning process will clearly identify:

- What to map (scoping report: aims);
- Why to map it (scoping report: objectives);
- Where new data are required (gap analysis); and,
- What new field surveys are required to collect that data (survey programme, survey strategy/design, selection of tools).

With this information you are ready to prepare for the field work. This includes drawing up detailed lists of the necessary equipment, which should include sufficient spares to cover the risks of equipment failure.

To assure the quality of the data that will be collected it is important to follow recognised procedures when using equipment in the field. There are many existing standards and protocols for the conduct of survey work, but these differ according to the specific purpose of the survey task, and may exceed or fail to meet the requirements for habitat mapping. Therefore, in Chapter 3 How do I collect my data? we set out a series of *Recommended Operational Guidelines* for using each of the survey techniques in the context of a habitat mapping project.

3 How do I collect my data?

Lead Authors: Jonathan White (Marine Institute) & Fiona Fitzpatrick (Marine Institute)

This chapter aims to describe how and why different techniques are used for habitat mapping, and explains how data should be collected in accordance with a set of standard methodologies so that they can be compared with data collected at different times and by different survey operators. The chapter provides practical advice on acquiring and recording data (*via* Recommended Operating Guidelines (ROGs), how to use techniques together and how to process data to suitable standards for analysis and interpretation. Having selected the required surveying methods and sampling needs it is then necessary to see how they can be best applied to survey areas, within the constraints of costs, time and available expertise. Furthermore, the chapter explains the basic data processing and data cleaning techniques to deliver raw data sets ready for analysis and interpretation into habitat maps.

Once the mapping target has been defined (using the MESH Scoping Tool described in Chapter 2), the next step is to select the required survey tools. The tools available for seabed habitat mapping are numerous including acoustic techniques (echo sounders), benthic sampling techniques (grabs, corers, dredges and trawls), seafloor imaging (video and stills cameras) and remote sensing (satellite and aerial photographic images). Many of these techniques are typically used in combination: for example using an echo sounding technique coupled with a grab sampling technique to ground-truth; remote sensing technique coupled with a foot survey of a beach or intertidal area or; towing a video camera along the seafloor with an accompanying photographic 'stills' camera, collecting higher resolution images to aid identification of animals/plants and seabed type.

The technique descriptions are supported by case studies which detail actual surveys that have been undertaken, to give examples of the survey techniques in use, showing the type of survey they can be used for and the results that can be expected.

3.1 Why do I collect mapping data in a standard way?

The method by which data are collected is integral to ensuring that the information they contain can be extracted and interpreted, and how these data are displayed on maps. The term 'data' covers many forms of information, most usually we think of data as numbers, but it can include written descriptions, photographs, video footage, pictures and even physical samples. To ensure that data are of sufficient quality to be displayed or printed, in ways that can be understood, interpreted and compared with other types of information; sampling and surveying should be conducted in accordance with standard operating procedures (or Recommended Operating Guidelines).

For habitat mapping this usually means presenting the information on a map – putting it in a space and a time framework where it can be compared to other information of a different age. To do this we can use an array of surveying and sampling technologies and techniques; some are simple to operate and some are very complex. However, they can be used in different ways and what makes the resulting data useful is the way they are used. If this use is standardised, then the resulting data can be compared with confidence.

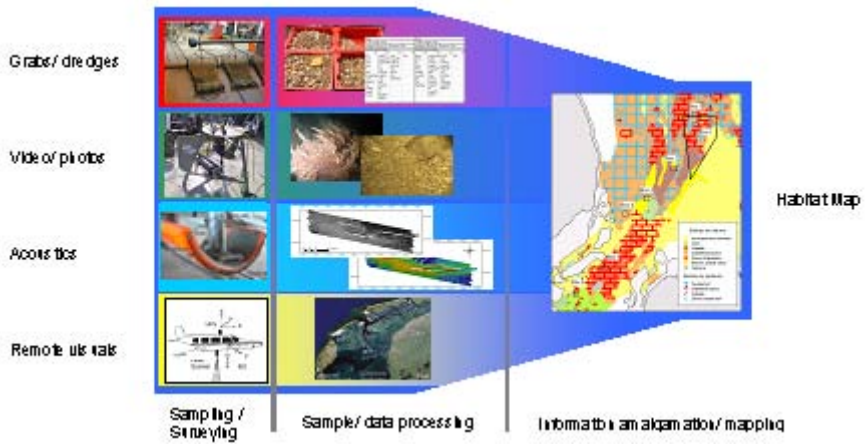


Figure 3-1 Data from surveys and samples through processing to plotting on charts.

If techniques are not used in an appropriate way, the information they collect may not be suitable for their intended purpose. To prevent this, techniques need to be used in pre-determined, appropriate ways; even simple tools like a small dredge used over the side of a boat in shallow water to check seafloor material, if used in an organised way – in accordance with a pre-determined set of rules – can be a powerful benthic habitat surveying instrument.

3.2 Technical expertise required for undertaking surveys

Such a large array of techniques requires mappers to have an understanding of many facets of marine technology, survey techniques and basic science. It is essential to have a basic understanding of marine biology and geology, including taxonomy, the composition of different types of biological communities, seafloor materials and a grasp of the relative spatial extents that are to be expected of the target habitats. In addition, a good understanding of seagoing activities is helpful, for example how the mechanics of a large grab sampler actually work in collecting a sample of the seafloor, or how it will be deployed over the side of a vessel. This can be contrasted to the knowledge needed of the remote technologies often used for habitat mapping – for example the physics involved in echosounders should be understood, to a rudimentary degree at least, in order to appreciate the details of the resulting maps.

This chapter details the knowledge that is necessary for data collection, which must be accompanied by detailed records of where and how data were acquired – metadata – and then the analysis of data requires a thorough understanding of data cleaning/quality control, integration and application of statistical analysis.

Many of the elements of data collection and processing are specific to individual techniques, while others are more generic, applicable to certain sets of techniques. Such a broad spectrum of techniques makes it sensible to document as much as possible, in as detailed a way as possible (while aiming not to overwhelm the reader), the information that is necessary for the successful application of each technique for the purpose of habitat mapping.

3.3 MESH Recommended Operating Guidelines (ROGs)

Marine habitat mapping requires a full coverage map of the physical structure of the seabed and information on the biological communities present throughout the study area. Remote sensing or acoustic survey technology is normally employed to map the physical structure of the seabed, with the biological information derived from remote sampling or direct observation of the seabed.

Most of the techniques used by habitat mappers were designed for other survey disciplines, most of which have well established standard operating procedures (SOPs) to provide quality data for their intended purpose. At its outset, the MESH Project undertook a Review of Standards and Protocols for Habitat Mapping with the aim of reviewing the suitability of existing material as guidance for a habitat mapping application (available from the Product Library of *MESH* website – www.searchMESH.net/Products). It became apparent, that various organisations and institutions were utilising the same equipment in slightly different ways. One of the main reasons for this divergence has been user's translation of application of a technique from its originally intended purpose to habitat mapping. As a result, the MESH *Recommended Operating Guidelines* (ROG) were identified as necessary to describe how best to use each technique in a marine habitat mapping context. Where applicable, existing standard operating procedures, ISO standards or equivalent are recognised and links are made to appropriate references and websites.

The MESH ROGs are not intended to be prescriptive as the range of conditions, situations and environments in which techniques are used will necessitate adaptation to suit local needs. They reflect operational experience of using particular techniques for marine habitat mapping and ensure that the data required and obtained for habitat mapping are of a suitable quality and compatible with similar data from other surveys. As many of the techniques can be used for purposes other than habitat mapping, it is important to indicate the particular way in which they should (or should not) be used for habitat mapping studies.

The following ROGs are available for download from the MESH Guide website.

Intertidal and shallow subtidal mapping	Subtidal mapping	Ground truth data collection
Aerial photography ROG	Single beam echo sounder ROG	Box Coring ROG
Airborne Digital Imagery ROG	ADGS ROG	Sediment Profile Imagery (SPI) ROG
LIDAR ROG	Sidescan Sonar ROG	Trawls and Dredges ROG
Satellite Imagery ROG	Swath Bathymetry ROG	Video ROG
	Sub bottom Profiling (Chirp) ROG	
	3D Seismic imagery ROG	

The following sections provide some additional information on the main groups of techniques.

3.3.1 Remote sensing techniques

Remote sensing techniques constitute an extremely sophisticated set of surveying approaches which include aerial photography, airborne or satellite digital imaging and ***LiDAR***. These images are recorded by sensors responding to both visible and non-visible radiation (light) are gathered from airborne and satellite platforms. Images are referenced to a geographic coordinate system – becoming georeferenced images before they are used for the purpose of seabed habitat mapping. These sensors are generally only applicable to intertidal and shallow subtidal areas with good water clarity. Electromagnetic radiation is readily absorbed by water, the degree of penetration depending on clarity, with penetration being typically no more than 15 to 20m even in clear water.

These techniques are reliant on specialist operations, be they satellite or airborne. Surveys are commissioned of specific areas (in the case of airborne and LiDAR surveys), or in the case of satellite techniques, data are acquired from technically competent organisations operating the systems who will deal with operational technicalities.

As an example, the simplest form of remote sensing is aerial photography, involving georeferenced photographs typically collected from aeroplane or helicopter. Such platforms enable high rates of acquisition and 100% coverage. The approach is useful for mapping tidal areas and shallow, clear waters where seafloor features are visible.

Figure 3-2 An orthophoto of Les Abers, north Brittany, showing the river mouth with mottled looking underwater seagrass (*Zostera*) beds and a number of rocky shoals and islands surrounded by thick fucoid algal cover.

3.3.2 Acoustic techniques

Acoustic techniques are devices which emit sound energy, in a series of continuous pulses, into the water column and then detect the returning echoes (sonar). Different strengths of the echoes are then used to determine the morphology of features and physical characteristics/properties of the seafloor. By knowing the speed at which sound travels through water, depth can be calculated from the echo return time. This can be an extremely accurate measurement which, when coupled with accurate positioning systems and motion sensors, can be used to produce very accurate seafloor maps. Similarly by knowing the speed of sound through different rock and sediment layers under the seabed, acoustic systems can measure the thickness of these layers to map the sub-surface structure of the seabed. Acoustic systems can be sub-categorised into single beam and 'swath' depth sounders, and sub bottom profilers

Single beam echosounders use one emitting and receiving transducer, which releases a series of energy pulses in the form of sound waves, 'ensonifying' (filling with sound) a small area underneath the boat. The signal reception of a single beam echosounder can be analysed to infer and classify seafloor habitats using acoustic ground discrimination systems (AGDS).

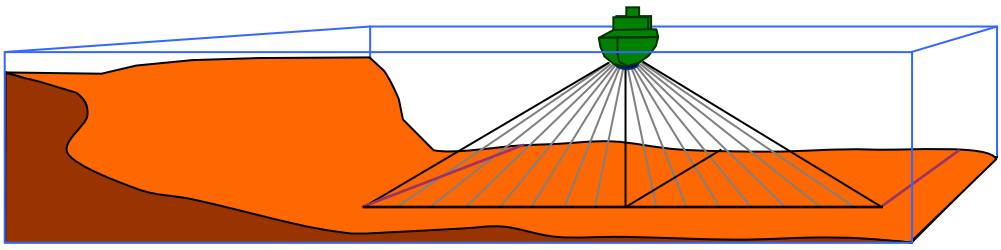


Figure 3-3 A schematic representation of the mode of operation of swath acoustic techniques.

Swath systems use slightly different applications of sound wave technology to emit a 'fan' of sound pulses on either side of the boat, so creating a swath of coverage. The width of this swath can be in the order of fifteen times the depth of water in which they are operated. There are three types of swath system that use slightly different technology to achieve broadly similar results. **Multibeam echosounders** and interferometric systems

are mounted on the vessel and are principally used to map the bathymetry of the seabed but the returning signals can be further processed to map to show the texture of the seabed structure using *backscatter data*[2]. Sidescan sonar systems mostly take the form of towed devices, being lowered in to the water behind the vessel by cable. This 'tow fish' emits a beam of energy which sweeps the seafloor perpendicular to the vessels course. Using a towed device effectively gets the sensor closer to the seafloor to increase the resolution of the data and reduce acoustic interference from the vessel. Sidescan sonar systems only record backscatter data to map the texture of the seabed and do not provide data on bathymetry; their backscatter maps are much higher resolution than multibeam or interferometric systems.

3.3.3 Benthic sampling techniques

Benthic sampling techniques are essential to habitat mapping studies since they provide the 'truth' data on the actual composition of the seafloor. When they are used in conjunction with either a remote sensing or an acoustic technique, they are said to 'ground truth' seafloor classifications. If samples are collected in high enough densities over survey areas they can be used to establish distributions and define habitats.

Samples commonly provide two categories of information:

- a sample of the seafloor material that can be analysed in terms of its structure, is often taken for geological analysis and known as a *physical sample*; and,
- a sample providing a collection of the species living on or in the seafloor that can be identified and counted to give detail of the biological assemblage present at a point, is known as a *biological sample*.

There is a range of sampling devices commonly in use for benthic sampling, each designed to provide a certain type of sample over a specific ground type. Grabs and corers are commonly used for both physical and biological sampling in softer, unconsolidated sediments while trawls and dredges provide only biological samples.

Commonly-used grabs include Shippek, Hamon, Van Veen and Day. There are also a range of corers available for sampling. Each has advantages and disadvantages depending upon the seafloor material, the type of sample required and its volume. The size of the sampling device will define the size of vessel needed to deploy it (or vice versa) and the number of people necessary to do so. For representative particle size analysis, greater volumes are required from gravel rich sediments than for muds.

Key to the choice of sampling device will be the targeted type of sample: geological or biological for infauna (animals living within the seabed) or epifauna (animals living on top of the seabed) and a prior knowledge or suspicion of the seafloor material. Trawls and dredges should not be used on fragile habitats owing to their destructive nature.

Figure 3-4 An example photograph of a benthic grab sample from a cobble/ pebble substratum (note the rule giving indication of scale). Grabs can also provide quantitative samples of benthic fauna including crabs.

[2] Technically, only multibeam systems generate 'backscatter' data; interferometric systems operate slightly differently but still provide an image of the seafloor texture.

Grabs disturb the sediment when collecting a sample of the seabed. To collect an undisturbed sample, a coring device is needed. Cores give information on the variation of material below the seabed and the depth of biological activity. Such devices include box corers, megacorers, gravity corers and vibrocorers. Their depth of penetration depends on the equipment type and the nature of the seabed material.

3.3.4 Underwater video and imaging techniques

Underwater video and imaging techniques record both still photographic images (also known as stills) and moving video pictures. Cameras may be mounted on drop frames, sledges and remotely operated vehicles (ROV). These imaging techniques have become an integral part of seabed surveying and habitat mapping studies, particularly for ground truthing mapping surveys. Operationally, sledges are towed behind a support vessel, drop frames lowered over the side while the vessel drifts or steams very slowly (<1knot) and ROVs are lowered over the side while the vessel either sits at anchor or on a fixed position using a dynamic positioning navigation system. There is a large array of literature describing use of video and cameras for habitat mapping; see the full version of the *MESH Guide* for further details.

Figure 3-5 Digital photograph taken from a Sea Tiger ROV.

3.4 Using techniques in combination

Most habitat surveys make use of several surveying techniques in combination to provide complimentary information of the same area. These techniques might be operated concurrently, for instance sub bottom profiling and seafloor acoustic discrimination techniques, or may be used at separate intervals, grab sampling and video camera tows for example. Other complimentary techniques may be used in surveys undertaken at greater time intervals from one another, for instance a shoreline aerial photometric survey and a ground truthing foot survey.

The requirements for using techniques in combination fall into a number of categories – to provide data sets that measure different variables for the same area to aid habitat discrimination and mapping; to provide ground truthing information for other, remotely used techniques and; to provide focused, detailed information of a smaller sub-zone of the survey area in order to investigate specific facets or activities and/ or to enable extrapolation to other areas. Additionally combinations may arise through collaborative interest surveys – a magnetometer may be used for geophysical purposes in a combined geological/ habitat mapping survey with echosounders.

Possible interference between surveying techniques must be considered. Interference may take the form of direct interference, for instance the sound waves emitted by certain acoustic systems interfere with one another causing noise blankets in the data sets. Additionally, incorrect deployment of sound-emitting systems can cause interference as the sound bounces off either the bottom of the vessel or the other towed body. Indirect sources of interference and incompatibilities among techniques also need consideration in the planning stages of a

survey. Some techniques cannot be used concurrently – grab sampling will not be possible while making a video tow, or a sidescan sonar tow fish cannot be used at the same time as towed video cameras.

3.5 Survey data: organisation and metadata requirements

Habitat mapping surveys generate very large volumes of data which need careful organisation and management. Additionally, surveys typically employ multiple techniques and surveyors, adding to the complexity of tracking what data has been collected, how, when, by whom and how it all interrelates. Once a survey programme has been completed, the data may be passed to other people or organisations for processing, analysis and storage. It is important that key information is recorded at the time of the survey, in a structured manner so its subsequent processing and interpretation are not hampered by gaps in survey detail. It is not good enough to rely on the memory of individuals as to how each piece of data were collected!

Information describing data are known as *metadata.* There are three main aspects to consider when recording survey metadata:

1. How should the survey data be organised?

   Management of multiple techniques, people, places, dates and samples so that their relationship to each other is properly documented. It is not much use taking a photograph of a grab sample if, at a later date, you cannot remember which photograph relates to which sample.

2. What information should be recorded?

   Recorded data need to ensure that future users of the data know how it was collected, when, by whom, to what standards and how it has been processed or manipulated. This is vital information about the provenance of the data that allows its users to know what it is suitable for (or more importantly what it is not suitable for). Consideration needs to be given to use of the data beyond the scope of the study, in national and international data archives. Was a multibeam dataset collected to international hydrographic standards to enable its use for navigational charts? Can I integrate grab sample datasets without knowing what sieve size was used?

3. How should the data be stored?

   Using an appropriate medium to store the data and ensuring it is correctly labelled will ensure they are readily usable in the future, will not deteriorate over time and may be easily integrated with similar data from other sources. Data without proper labelling (showing when and where they were collected) are expensive data that have little or no value in the future.

The *MESH Guide* provides advice on general issues relating to survey data management, offering a structure for organising data during a survey and provides recommended metadata fields for each type of technique employed.

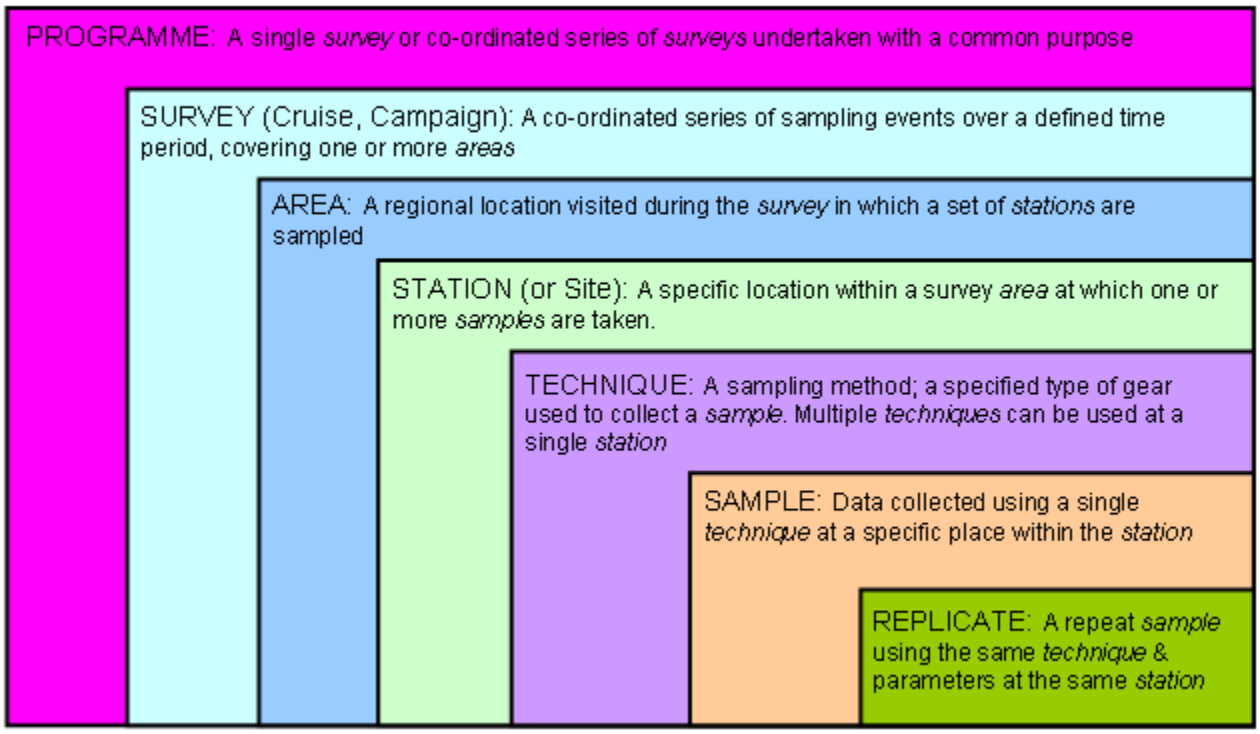


Figure 3-6 Hierarchical structure of sample site data organisation.

3.6 Data cleaning and basic processing

All sampling and surveying techniques require monitoring during operation to ensure they are performing correctly and the resulting samples or data are reliable. This may be achieved by correctly recording metadata, which can act in many cases as a check list to ensure data are properly recorded. Once collected, certain levels of processing, cleaning and storing will need to be undertaken before the data are in a suitable state for the analysis phase. This initial processing will check that data are correct – and provide a true record of the variable they were intended to record, positioned in the right place at the right time. At the end of this stage, a clean 'raw' data set should exist, which is suitable for archiving and to be passed to the next phase of analysis, whether this be for deriving a habitat map or another purpose for which the data are also appropriate.

3.7 Summary

There is a broad and ever developing range of techniques available for surveying seabed habitats. The selection of technique and its application for data collection should be governed by the information required to generate the desired habitat map. Using a standardised approach to data collection will assist analysts prepare the map outputs, will underpin quality assurance and, perhaps more importantly, ensure the data and maps are comparable with other similar products collected at different times, possibly by different organisations.

Seabed mapping is a resource intensive exercise and therefore it is essential that maximum value is gained from the data both for its original purpose and then for any future use, possibly for a slightly different application. Accurately describing datasets with survey metadata will ensure maximum value is extracted from the data.

Methods for converting survey data into information that can be mapped are the subject of Chapter 4 How do I make a map? It guides the interpretation of full coverage swath data, plotting of point and line data and where appropriate their extrapolation to cover full areas, and the integration of different data sets acquired by different techniques and analysed in different ways to create seabed habitat maps.

4 How do I make a map?

Lead Authors: Vera van Lancker (University of Gent) & Bob Foster-Smith (Envision)

Creating an effective habitat map requires both a full coverage map of the physical structure of the seabed and information on the biological communities present throughout the study area. The present chapter describes how the outputs from surveys or other sources of data (biological samples and coverages of physical habitat features) can be transformed and integrated to derive a biological habitat map that is fit for purpose. Note that the input data may themselves have gone through a process of analysis and interpretation from their original source material, especially in the case of desktop broad-scale habitat mapping.

The order of analysis and modelling is important: it is recommended that analysis of ground-truth data is considered *before* remotely-sensed/physical coverage data because a good understanding of the biological data is required to select and derive physical coverages that are more biologically relevant. This will enable a more meaningful integration with the ground-truth or sample data. This is not to be confused with the recommended order of survey, which is to undertake the remote sensing before the ground-truthing.

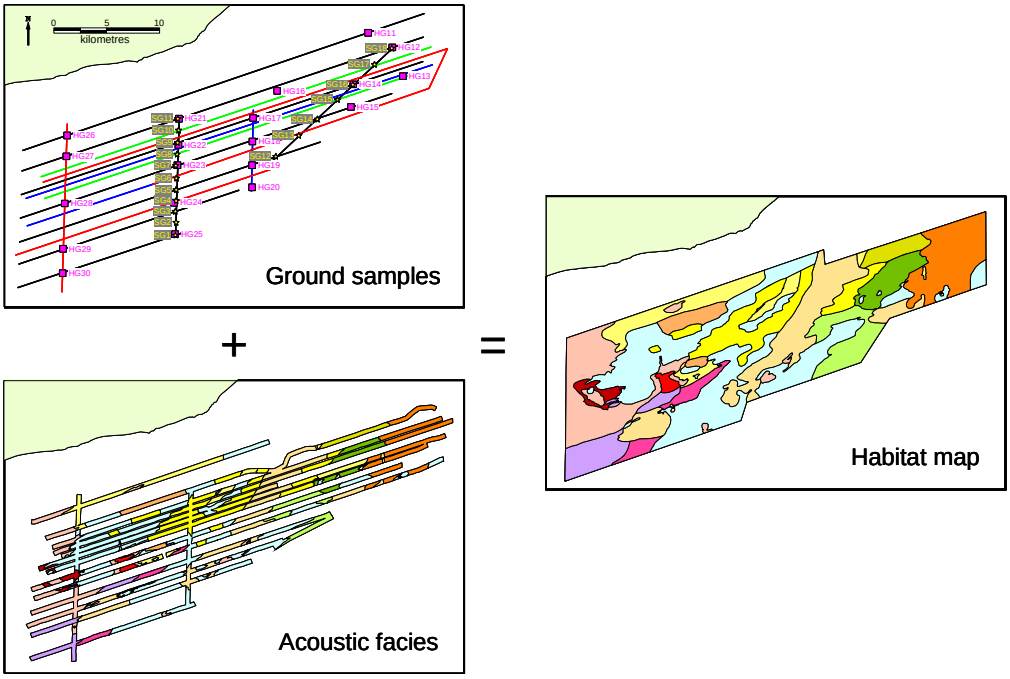


Figure 4-1 A summary of the process for making a habitat map; ground samples are used to interpret an acoustic map to derive a habitat map. © Cefas

The key steps in making a habitat map (as stressed throughout the Guide) are the combined use of habitat samples (often assumed to be observations or sampling points but may also be transect lines [trawl or video tows]) and **full *coverage*** data layers of physical habitat variables, (*hereafter* called physical coverages) derived from remote sensing images, by interpolating individual data points, or ***raster*** image layers. Data integration and modelling techniques are needed to derive the relationships between the biological and physical data. These relationships are then applied to the physical coverages to predict full coverage habitat distributions.

Habitat map production has five key steps:

1. Determine the strategy for map production;
2. Optimise the ground-truth data analysis;
3. Selecting and deriving the best available input and most appropriate physical coverages (includes analysis of remotely-sensed data);
4. The map making using the most appropriate techniques for interpreting the data through integration and modelling; and,
5. Designing the map to create a map fit for purpose.

The success of the final habitat map can be undermined if any one of these steps is not done well! The various techniques that can be applied to these five stages are explained in the following sections.

4.1 Determine the strategy

There are many approaches to habitat mapping, but it is convenient to illustrate the range of applications as lying along a scale spectrum: broad to fine-scale. This spectrum has been adopted throughout the *MESH Guide* and should now be familiar. Broad versus fine-scale best contrasts the different approaches, but become more difficult to explain for intermediate scales.

Benthic habitat mapping will inherently involve some form of modelling. In this context, a model can be seen as any representation of the sea floor based on a systematic investigation and analysis of the evidence for habitat distribution. This is an intentionally broad definition, which can range from expert knowledge interpretation 'by eye' and rule-based models through to statistical models based on an extensive analysis of data.

Bear in mind, however, that techniques described under one heading may be applied to other situations. For example, it is possible to use the 'broad-scale' modelling approaches for small geographic areas and to use the 'fine-scale' detailed approach for very large areas; for example the national seabed surveys in Ireland (INFOMAR - www.marine.ie/home/services/surveys/seabed) and Norway (Mareano - www.mareano.no).

4.1.1 Broad-scale habitat mapping for very large areas

A broad-scale habitat mapping approach, normally applied to whole seas or national waters, most commonly uses coverages for the major physical parameters that are combined to obtain the predicted distribution of a wide range of broadly defined habitat types (e.g. EUNIS levels 3 and 4). The data used are derived from multiple sources and the modelling carried out within a geographic information system (GIS). The combined errors and uncertainties of the input data layers will mean that the resulting maps are necessarily rather coarse and generalised in nature.

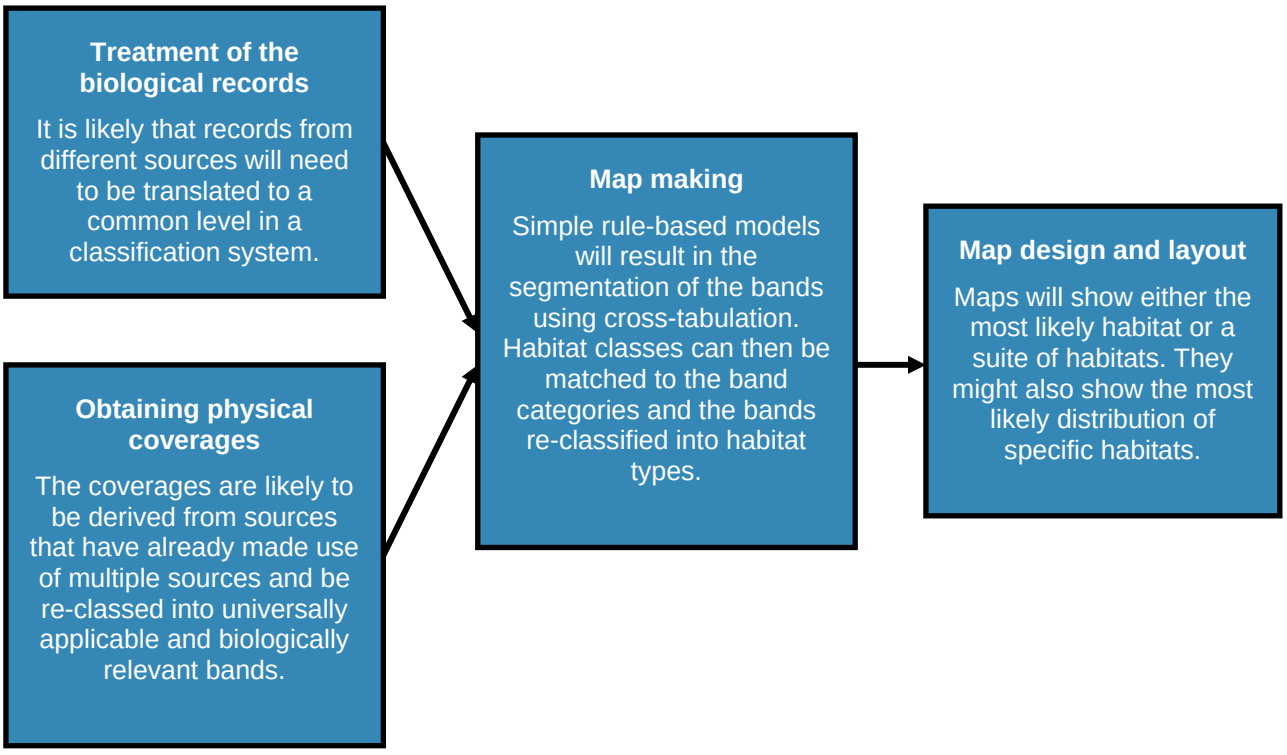


Figure 4-2 A summary of the broad-scale mapping approach.

The modelling will be based on applying general rules relying on knowledge of causal relationships, valid across a large geographic area. The area is divided up into habitat categories based on combinations of a limited number of zones for each of the key environmental structuring variables (e.g. depth, substratum and water

energy). This may involve expert opinion to reclassify the physical parameters into a small number of biologically relevant categories without recourse to sophisticated statistical methods to justify the upper and lower boundaries of the structuring variables.

The MESH EUNIS modelling approach is an example where the physical variables used to define EUNIS level 3 classes (substratum, depth and incident energy) have been combined to derive the predicted distribution of broad-scale habitats. The approached used by the MESH Partners to derive marine landscape maps adopts a similar approach, but also includes a layer for seabed slope making the product easier to understand from a physiographic/topographic viewpoint.

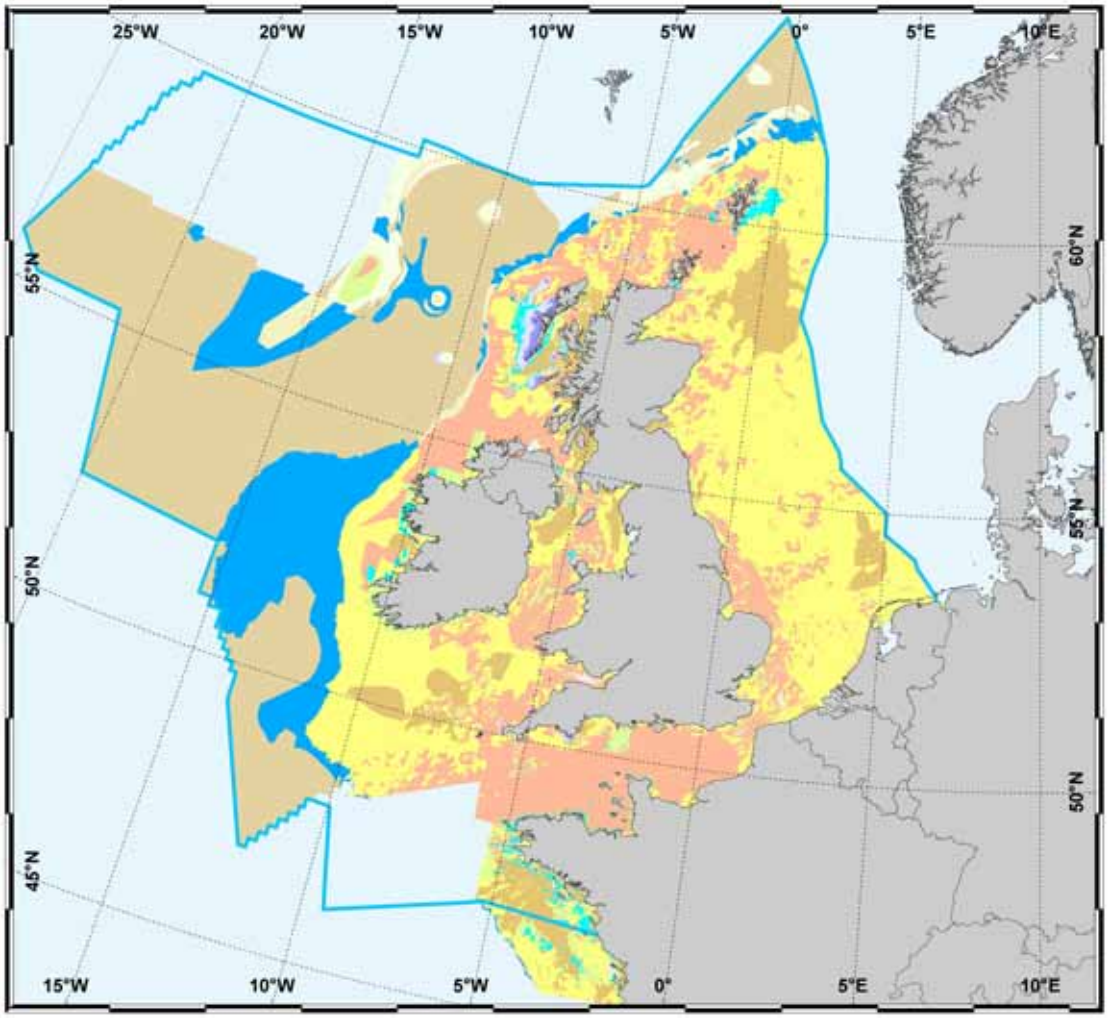


Figure 4-3 A simple model was used to predict the distribution of EUNIS habitats for the seabed of north-west Europe.

4.1.2 Fine-scale habitat mapping for small areas

At the other end of the modelling continuum, field surveys of small geographic areas usually adopt a *data-driven* approach. More narrowly defined habitats (e.g. EUNIS levels 4 and 5) can now be predicted and ground-truthing is usually more detailed. Mostly, 'signatures' are created from the physical coverages (usually acoustic or electromagnetic spectrum (EMS) reflectance values) using the ground-truth records as training sites. Interpretation of the data from each study is relatively self-contained in terms of its data requirements and no attempt needs to be made to derive rules that can be exported to other studies. This strategy is exemplified by *supervised classification* of remotely-sensed images and there are many examples of surveys where this approach has been used. It is likely that specific image-processing GIS software will be required. Side-scan sonar images may discriminate a much smaller set of habitats and be more straightforward to interpret than for

large areas: intermediate interpretation of side-scan sonar imagery to produce physical habitat maps may be by-passed by interpreting biological habitats directly.

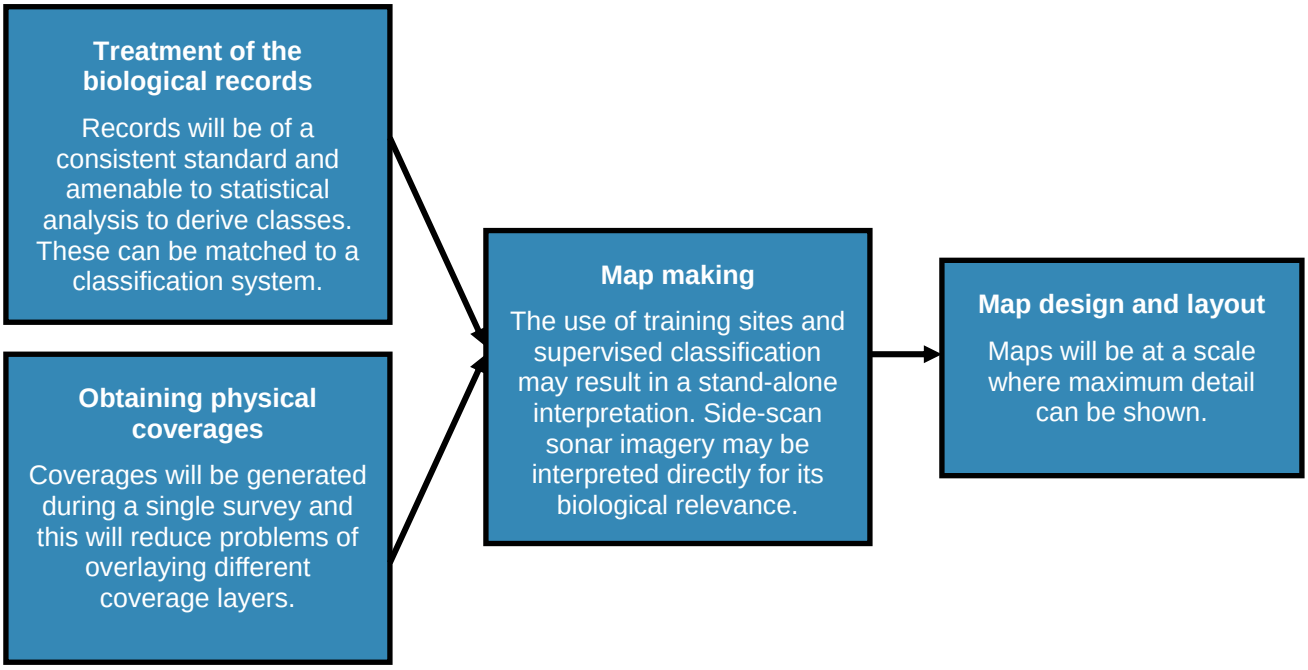


Figure 4-4 A summary of the fine-scale mapping approach.

4.1.3 Intermediate scale mapping

Intermediate scale modelling lies between the very broad and the fine-scales and it proves to be the most difficult type of modelling on which to offer guidance. It is likely that the input data will come from many surveys over an extended campaign or different campaigns. Some of the inputs may come directly from surveys whilst others will be modelled mathematically (such as bed stress). Modelling strategies might range from:

1. the use of statistical techniques to investigate relationships between different physical factors and the biology, using spatial statistics to optimise interpolation;
2. mostly data-driven and rule-based or knowledge-driven models; or,
3. mixtures of the two approaches can also be used together.

The first statistical approach is easier to apply to a single habitat (e.g. mussel beds) than to the complete range of habitats found in an area. The second is similar to the approach adopted for very broad-scale mapping and suitable for modelling the range of habitats present. The incorporation of more data-driven statistics into such a model bridges the distinction made between the two approaches. Greater emphasis on statistical models will require the use of specialist statistics and mathematical software, possibly requiring specially written routines.

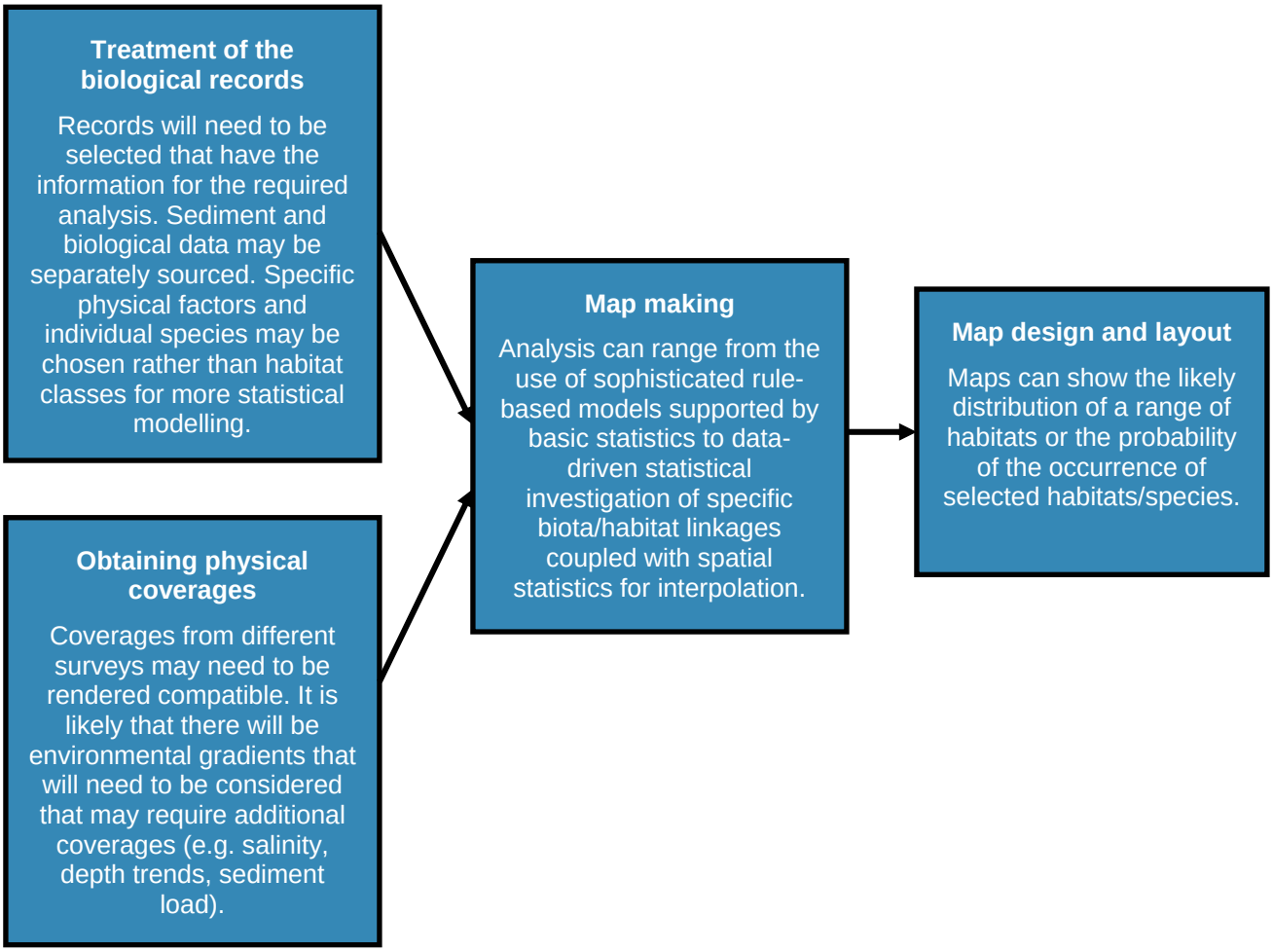


Figure 4-5 A summary of the intermediate-scale mapping approach.

An example of an intermediate scale mapping product is presented in Figure 4-6. A probability map (250m grid resolution) of the macrobenthic communities (EUNIS level 5) of the Belgian part of the North Sea is shown, based on data-driven statistical modelling. Related to the same area, an extract is shown of the EUNIS level 3 MESH EUNIS map (1 nm grid resolution). The differences are mostly observed in the coastal zone where the occurrence of one macrobenthic community is completely missed with the broad-scale approach.

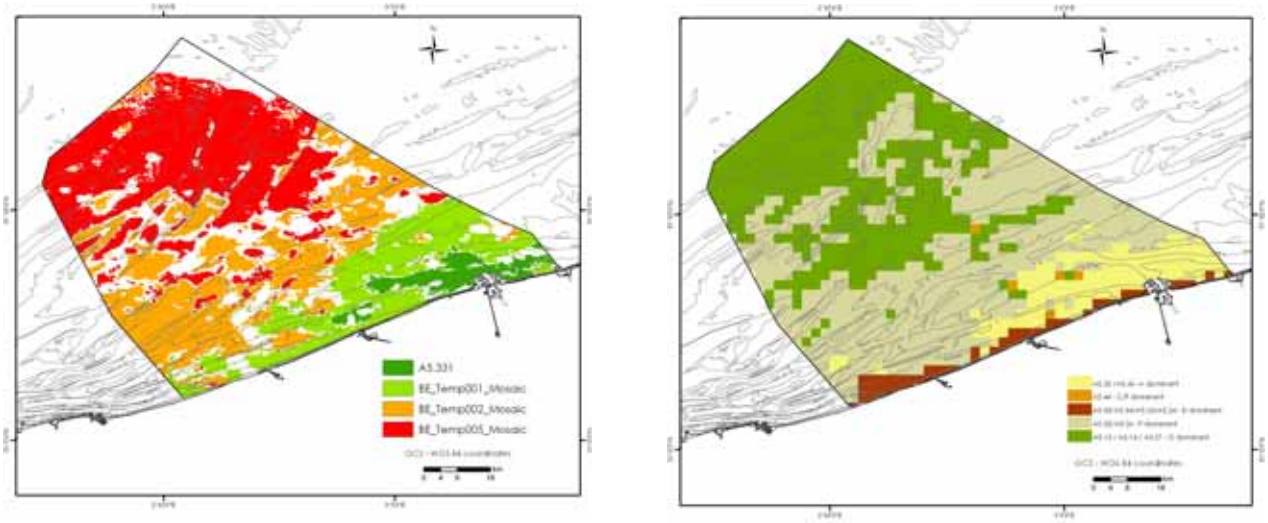


Figure 4-6 An example of an intermediate (on left) versus a broad-scale mapping product (on the right).

4.1.4 Types of modelling types for habitat mapping

Models are often divided into two forms: ***empirical*** and ***deterministic***. Empirical models are based on a statistical analysis of the data and the results are expressed as probabilities. It is not necessary to understand the causal relationships between a dependent and independent variable in the analysis of the data, just as long as the relationship works well enough to predict distributions. This type of modelling is also termed data-driven.

Deterministic models use knowledge of causal relationships to predict distributions. These models can be expressed as mathematical formulae (e.g. the calculation of sea floor currents) or by linguistic rules (e.g. stating the cut-off for light supporting algal growth). Deterministic models are often termed rule-based models. Expert knowledge is a version of rule-based modelling in that the 'rules' are in the form of expert knowledge and might not be expressed in a systematic way. If expert knowledge and direct observation are applied to coverages in order to draw habitat boundaries (e.g. shore mapping from aerial photos), this is referred to as ***direct mapping***.

Mixed models combine elements of both empirical and deterministic elements of modelling.

Additionally, if the modelling involves the manipulation of maps as well as other data within a GIS, the modelling is termed ***cartographic modelling***. Much habitat mapping is based on mixed models within a GIS where various data layers are input to predict the distribution of physical habitats likely to support a particular biological community or species. The resulting maps show the probability of finding the habitat or species at each location. These models are termed ***habitat suitability models*** (HSM) and their outputs for individual habitats may then be combined to create a single habitat map where the habitat with highest probability of occurrence at each location is shown..

4.2 Optimise the ground-truth analysis

The first step is the treatment of the biological records, their analysis and classification to produce data relevant for further integration with physical coverages to finally obtain a biologically relevant habitat map.

For the provision of physical and biological attributes, ground-truth data are a vital element in the mapping process. They are needed to validate the remote sensing data and to assign ground types to the mapped regions (e.g. rock outcrops, sandy beaches). However, it is important to determine the habitat classes that will be mapped. Associations need to be established between communities and their associated physical variables as the basis for inferring the distribution of habitats where physical coverages will be available (through sampling or modelling).

There are two fundamental approaches to populate a map with habitat classes:

1. Direct application of an existing classification system ('top-down' classification) by in-situ observation; using expert judgement to match what you see in the field to the classes listed by the scheme; and
2. Determining habitat classes from ground-truth sample data; that is analysing the data to find significant associations between biological and physical parameters ('bottom-up' classification).

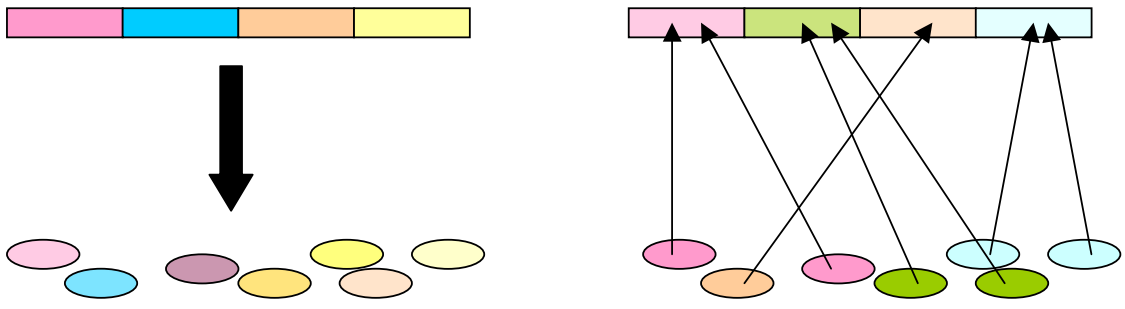


Figure 4-7 A diagram illustrating top-down versus bottom-up determination of habitat classes. In top-down (left), the existing classification system (blocks) is imposed on the sample data (circles). In bottom-up (right), similarity between samples is used to determine the classes.

Both approaches require the user to have a significant knowledge of the classification scheme they are using, and how it is structured, so they can apply the scheme correctly and have confidence in the accuracy of the assigned classes.

The MESH Video working group drafted guidance on the identification of habitat types from video imagery (White *et al.,* 2007).

4.3 Optimise the physical coverages

In a second step, the most appropriate physical coverages will need to be selected and this may require some preparation from the original data (e.g. if new remote survey data have been produced).

At this stage, it is assumed that data layers from single surveys (or series of coordinated surveys), such as acoustic maps, have been prepared to an acceptable standard (see Chapter 3) and the emphasis here is on preparing these and other sources of input data for integration with the ground-truth data to create biologically relevant habitat maps. 'Rough and ready' to more sophisticated approaches can be used; the latter extensively investigating the role of many variables. The experience gained from the ground-truth data analysis will drive the selection of the main variables.

Whether or not a particular location on the sea floor is *suitable* for a particular species (and by extension, assemblages of species characteristic of habitat types) is largely determined by the physical and environmental factors.

However, the presence of favourable habitat factors does not mean that a particular species will be present since many other factors may result in the species being absent (such as competition, recruitment history, predation, anthropogenic activities and so on).

A few physical and environmental factors are universally important for determining the distribution of all marine species and habitat types. Three are considered to be fundamental in the EUNIS scheme and form the basic input data for the predictive modelling of the EUNIS Level 3/4 map of the whole MESH area. A general discussion on the kind of data needed is provided in Chapter 2 and the importance of the necessary physical coverages is stressed below:

- Substratum: the nature of the seabed (e.g. rock, sand, mud, boulders) to be mapped as classes along a scale based on the grain size (e.g. the Wentworth scale) or on the relative proportions of silt, sand and gravel (the Folk triangle). However, the critical substratum characteristic will vary considerably between species and habitats and specific continuous variables, such as percentage silt or median grain size may be more biologically meaningful and are thus more suitable for modelling purposes. Some of these variables may be derived from remote sensing data through expert interpretation or through automated classifications;
- Bathymetry: many important environmental constraints on species distribution are derived from depth data. Light penetration is often quoted in terms of depth, but this depends on local and regional turbidity; and
- Water energy: energy impacting on the seabed from waves and tidal streams can be measured; however, it is often modelled from other factors and there are many ways of expressing and calculating water energy.

One should realise that there are other variables that may prove important for constraining the distribution of particular species and habitats such as water temperature, salinity, sediment transport and ***bedform*** features. In addition, surveys may result in the measurement of properties that are not immediately interpretable in terms of any biologically relevant factors, such as acoustic reflectance and backscatter.

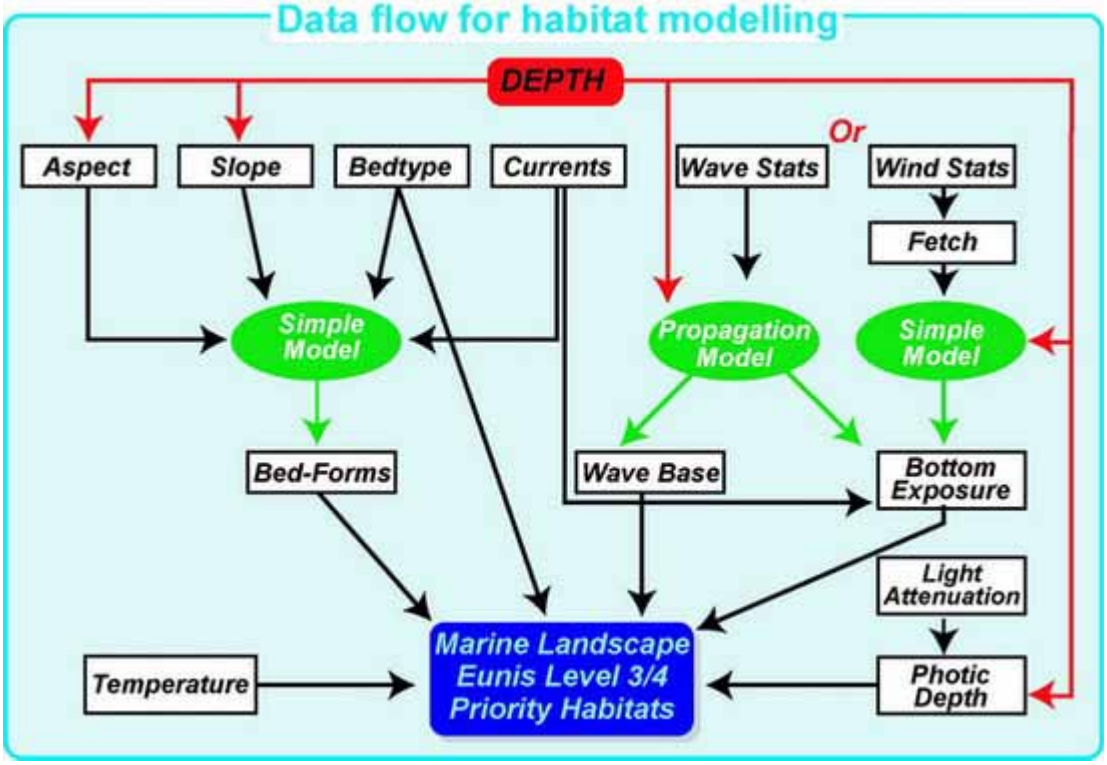
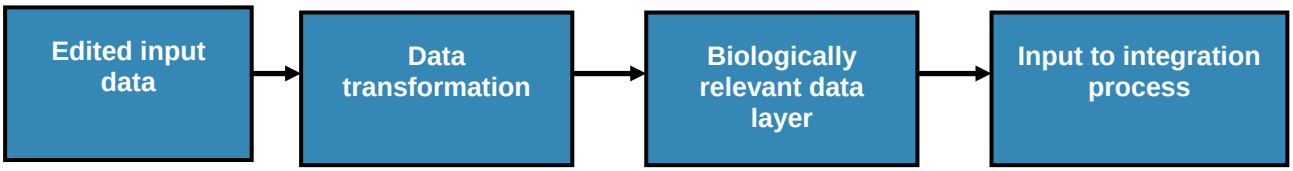


Figure 4-8 Different ways of combining environmental data for habitat modelling: the example shown is relevant for the modelling of rocky substrata.

As already indicated, the selected variables and coverages might need a transformation before integration with the ground-truth data. A range of transformation techniques can be applied to the input data in order to derive the required coverages for integration with the habitat records.



The transformation process can be quite simple, such as changing data formats (e.g. vector data may need to be transformed into a raster format or vice versa), or require more complicated processes such as raster calculations and classification (e.g. deriving seabed slope from its bathymetry), reclassification or even sophisticated modelling (e.g. advanced geostatistical techniques to optimally interpolate sediment distributions).

Finally, the coverages need to be combined following a strategy that is most meaningful towards its biological relevance.

4.4 Optimise the map making

The third step focuses on data integration and modelling and may require a range of strategies to integrate the ground-truth records with the physical coverages. The aim is to prepare a coverage of the distribution of habitat classes. As with the other stages, the methods for integrating the biological ground-truth data with the physical coverages range from the simple to the sophisticated ones:

1. Biological habitat classes can be overlain on physical coverages and their *match* verified. Similar matches can then be grouped together. Cross-tabulation is the most common technique to be used. A number of problems can arise, mostly related to the distribution of sampling points which is most often largely biased to particular habitats.

2. Images of the seabed (from side-scan sonar, swath backscatter, swath sun-illuminated bathymetric models, aerial photography or satellite) can be interpreted in terms of the habitat types directly using expert knowledge and judgement. The analyst draws a polygon shape around clearly visible features on the images and then assigns a habitat type to the polygon. The habitat type is verified from the ground-truth samples. On the shore, this might be a *direct interpretation* of aerial photos in the field; e.g. walking along the shoreline or using underwater cameras. The MESH Habitat Signature Catalogue gives an overview of known signatures of some habitats to help in direct interpretation.

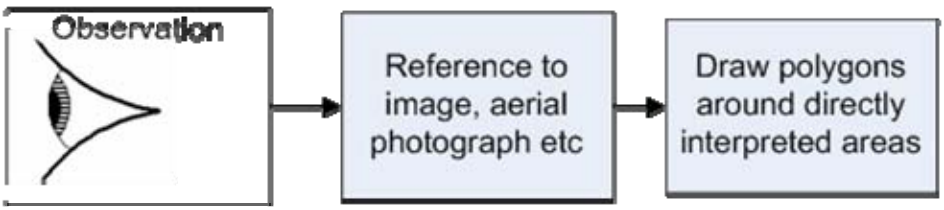


Figure 4-9 A summary of a direct mapping approach.

Using signatures may be relatively successful for small, simple areas, but as the survey area increases, confusion over the distribution of biota over similar patterns is more likely to occur. After integration with the ground-truthing, some images might need a reclassification.

3. A suite of *statistical techniques* can be used to model habitats. Most of the techniques can be grouped into seven categories (Guisan and Zimmermann, 2000):

   - multiple regression and its generalized forms;
   - classification techniques;
   - environmental envelopes;
   - ordination techniques
   - Bayesian approaches
   - neural networks; and,
   - other approaches including mixed approaches.

   The extent and quality of the data will mainly drive the choice of the approach. Specialist software and advanced technical skills might be required.

4.4.1 Direct mapping of seabed habitats

When dealing with intertidal habitats, the interpreter can go to the field and obtain direct observation of ground facies against how they appear on the imagery. The observer can quite easily forge their own idea of a signature. Generally such signature data are rather abundant as ground-truthing the intertidal zone is not so heavily constrained, and signatures can be refined to a high level of quality. In the case of subtidal habitats, direct observation is more difficult to achieve. Therefore getting reliable signatures may be more difficult in subtidal mapping.

Sidescan sonar images may be directly interpreted in terms of physical habitat features (sediment, bedform, topography) with a minimum of direct observation and then re-interpreted knowing which biological communities they support. When interpreting remote sensing imagery of seabed habitats, the interpreter needs to relate the expression of ground units given by the imagery to their reality in the field, in other words he looks at signatures of his facies or habitats.

Signatures can vary for a given facies or ground unit. They depend on natural factors, which will make them different to the observer even though they may be clearly assigned to a given class. Slight colour nuances in the composition of the facies itself can be of considerable influence on the way they are remotely-sensed. For example muddy sand can be covered with some microflora, which modifies its aspect on aerial photographs. The mapping scientists use their knowledge and expertise to allow for this variability.

An example is given in the Bay of Concarneau (France) with a pockmarked texture (figures), a spectacular facies never highlighted in previous studies in this bay. These bedforms are usually seen in deeper water. The pockmarks form a highly unusual chain pattern here. The numerous samples taken from these features were made up of a compact mud with highly concentrated *Haploops* communities on their surface.

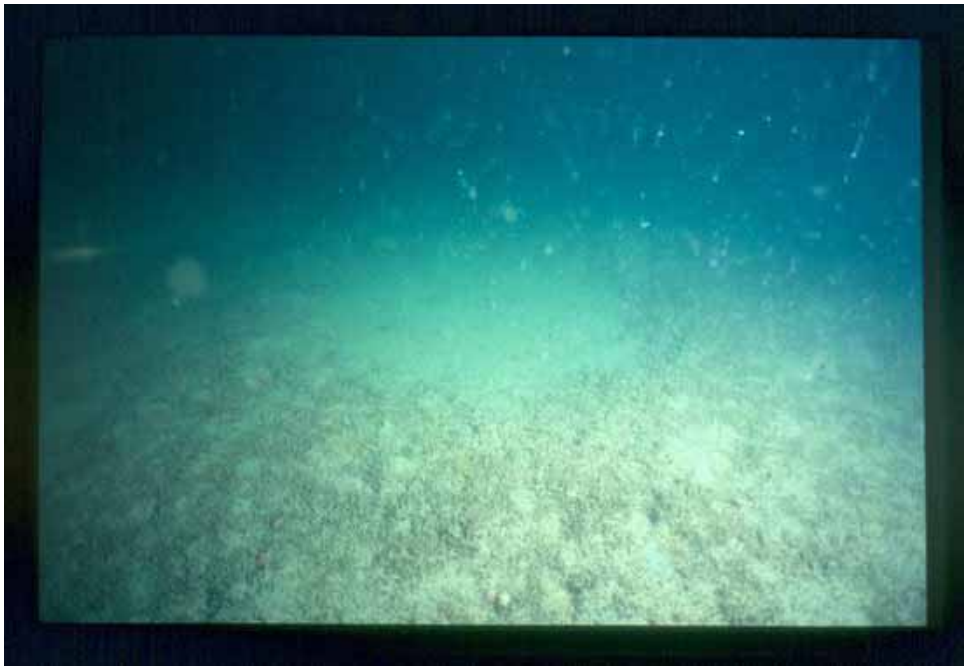


Figure 4-10 A still camera image showing a small-sized pockmark.

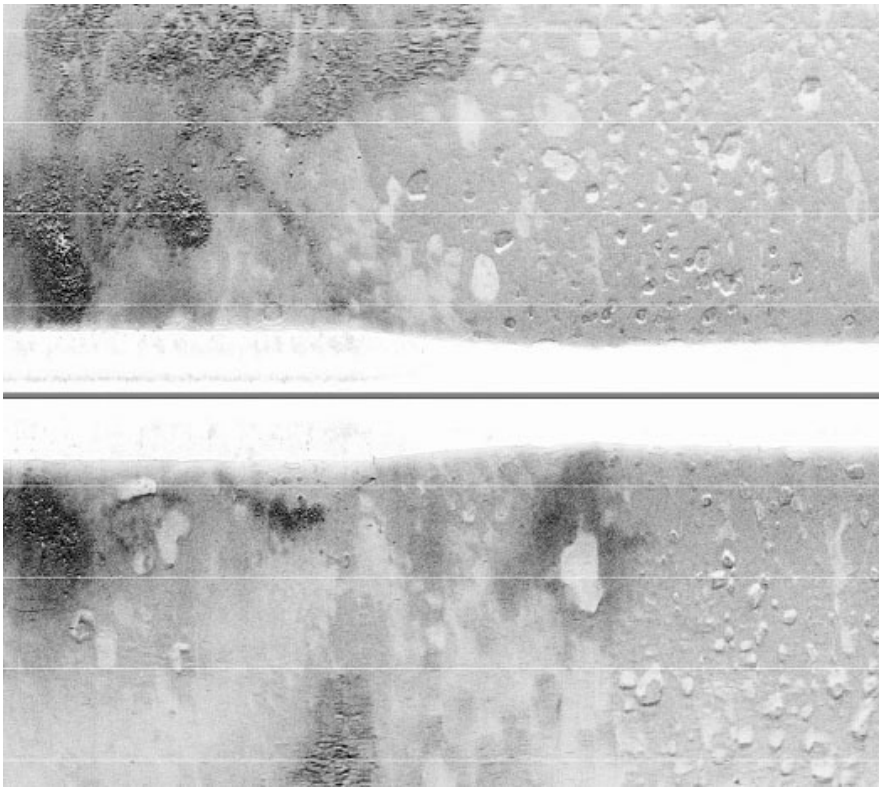


Figure 4-11 A side-scan sonar imagery of pockmarks in the Bay of Concarneau. The EUNIS class is 'Sandy mud'. The facies is described as 'clear grey facies with craters'.

These signatures can then either be used in automated classification or in direct manual interpretation, depending on the methodological choice of the interpreter. The quality of the interpretation will depend directly on the quality of these signatures.

4.5 Design of the habitat map

When designing a map, it is important to consider whether the final product needs to be a printed map or an electronic map. With electronic maps, users can zoom in and out freely to the desired resolution, whereas with printed maps, users are obliged to interpret the map at a specified scale. Still, with electronic mapping, users should be made aware to which scale the data still supports an adequate or meaningful level of zooming.

The full version of the *MESH Guide* offers advice on some of the common problems associated with *electronic cartography,* specifically with the creation of suitable habitat maps of the seabed and their visualisation them in Geographic Information Systems (GIS). Some practical solutions are suggested to improve map delivery in the full version of the *MESH Guide*.

Some important items to consider when designing maps are the correct use of coordinate systems for data, appropriate recording of metadata (e.g. data owner), and the location of suitable attribute information to create a key (e.g. is it stored in a table using unique codes that need to be translated into recognisable names of features). Knowing whether information on these issues is available with the data layers will influence the ease with which the final maps are prepared.

4.6 Summary

Creating habitat maps that are fit for purpose requires careful planning, expert analysis and interpretation, and clear design of the final map. From the outset, the analyst must have a clear understanding of the objective of the mapping study so that the most appropriate analytical route is selected.

A seabed habitat map is based on both a full coverage map of the physical structure of the seabed and information on the biological communities present throughout the study area. The order of analysis and modelling is important: it is recommended that analysis of ground-truth data is considered *before* the physical coverage data because a good understanding of the biological data is required to select and derive physical coverages that are most biologically relevant.

Once the final map is prepared, users need to understand how well it represents the real situation on the ground (its accuracy) and how well the maps meets the user's requirement (its confidence). These important concepts are the topic of Chapter 5 How good is my map?

5 How good is my map?

Lead Authors: Bob Foster-Smith (Envision), Natalie Coltman (JNCC) & Fiona Fitzpatrick (Marine Institute)

If a user needs to make an important decision based on the information contained in a habitat map, how can they gain a level of confidence that the map is reliable? If you have commissioned a survey, how can you be certain that the resulting habitat map will match your expectations? When a cartographers prepare maps, how can they convey its accuracy and limitations to the users?

Chapter 5 of the *MESH Guide* aims to give an awareness of the issues relating to accuracy and confidence in maps. The chapter contrasts the mathematical approach to map accuracy measurement to the user-based assessment of confidence and introduces the *MESH Confidence Tool*. A large number of terms can be used that could be applied to a map: accuracy, confidence, precision, value, usefulness, reliability amongst others. Some of these terms are very subjective; others imply some independent measure we could use in any assessment. What do these terms mean and how should we use them? Perhaps a good starting point is to discuss accuracy and confidence.

- *Accuracy* is a measure of the predictive power of a map to represent the world as measured against reality. If a map predicts a habitat at point X and it is found to be there, the map is correct. If it is not, then the map is wrong.
- *Confidence* is an assessment of the reliability of a map given its purpose. It is much more subjective and may involve a judgement of the relative importance of many contributing factors, such as level of information, how near the map is to reality ('near misses?'), how relevant to the purpose and so on.

An assessment of the usefulness of a map will depend upon the intended purpose and application of the map. A map may confidently present a broad overview of an area, but may have little use for an application where accuracy at a detailed level is required. What sort of information should accompany maps to alert people as to their legitimate use? These are very difficult questions to answer and in this present chapter of the *MESH Guide*, we discuss issues that should be considered so that users have a realistic expectation of maps without undermining the valuable contribution habitat maps undoubtedly make to marine spatial planning. The MESH Project covered an extremely wide range of mapping scales and Chapter 5 gives examples that illustrates this diversity and gives guidance on how accuracy and confidence can be assessed.

Habitat maps range in scale and detail from the small scale, broad-brush to the large scale, highly detailed. Whatever the scale, maps will vary considerably in their reliability. Chapter 1 What is habitat mapping? gives more discussion on scale and map purpose. However, the way in which we assess the value of a map may be very different depending upon scale-related issues. Broad-scale maps covering very large areas are created from multiple sources and the resulting habitat map must be judged by the credibility of these sources of data together with a proper evaluation of the process that has combined these data. At the other extreme, a large scale, single survey of a small area might be judged by the precision of the survey data and the accuracy of the habitat map. Often an accuracy assessment has not been made by the original surveyors and it is left to the judgement of the user to determine the appropriate level of confidence they will place in the map. In this chapter we suggest ways both for map makers to measure the accuracy of their maps, and for map users to objectively judge the confidence they will place in the map so that map usage can be justified. This last point is particularly important since maps are often created for one purpose but used by others for a different application.

The current chapter starts with a general discussion on accuracy and confidence. This is followed by a discussion of the problems of accuracy measurement and the interpretation of accuracy assessments: what does it mean if a map is inaccurate? This leads on to discuss how much confidence a user should have in a map, with a description of the MESH approach to confidence assessment as an example. The MESH Partners have developed an easy to use multi-criteria system for assessing confidence of seabed habitat maps. The approach was developed to facilitate the determination of confidence in habitat maps displayed on the *MESH webGIS*. Lastly, maps may best be judged against the success of their use. Were they found to be useful? Were the predictions of habitat distribution they contained accurate enough for the purposes to which they were put? The final section of this chapter briefly addresses these questions.

5.1 What is accuracy?

Accuracy as applied to habitat mapping is a measure of the predictive power of a map to represent the world as measured against reality; ***error*** is a measure of the departure of a map from reality. It is a mathematical measure based on 'hits and misses' (successful predictions and erroneous predictions). Error is a measure of inaccuracy. Note that this definition of accuracy is focused on the correct prediction of a habitat class at a particular location (in a vector map) or a pixel (in a raster map). In other words, there are two elements to accuracy - the correct habitat class at the correct location. This definition is often termed ***classification accuracy****;* in other words, have the data at point X been correctly classified?. Clearly, there is a positional element to this accuracy. For example, are boundaries between adjacent habitats accurately located? This could be restated as 'do the change in predicted habitats accurately mark the boundary between them in reality?'

Accuracy could be used as one of the criteria for assessing confidence. However, a strict mathematical measure of accuracy could be misleading, especially if two or more maps are being compared. For example, one map might class habitats in an area as either rocky or sandy and map these two classes with a high level of accuracy. Another might show each of these habitats as a patchwork of different types of rocky or sandy habitats. The second is likely to be far less accurate, but contain more useful information *allowing for a certain level of error*. The italicised phrase stresses the important point that some user-judgement has entered the assessment to make allowances for the lower accuracy. Thus, a user may have more confidence in the information contained in the second map despite its lower accuracy. The problem is that although many of the accuracy measures are mathematically sound, they still do not address the main issue of the overall confidence with which maps should be regarded. The same measure applied to different maps may give an erroneous impression of their relative 'success'.

Indeed, there is often a trade off between information content and accuracy of a map: a map showing a large number of classes on a particular theme contains more information than one with a small number of classes. However, the error associated with the predicted distribution of the former might be quite high.

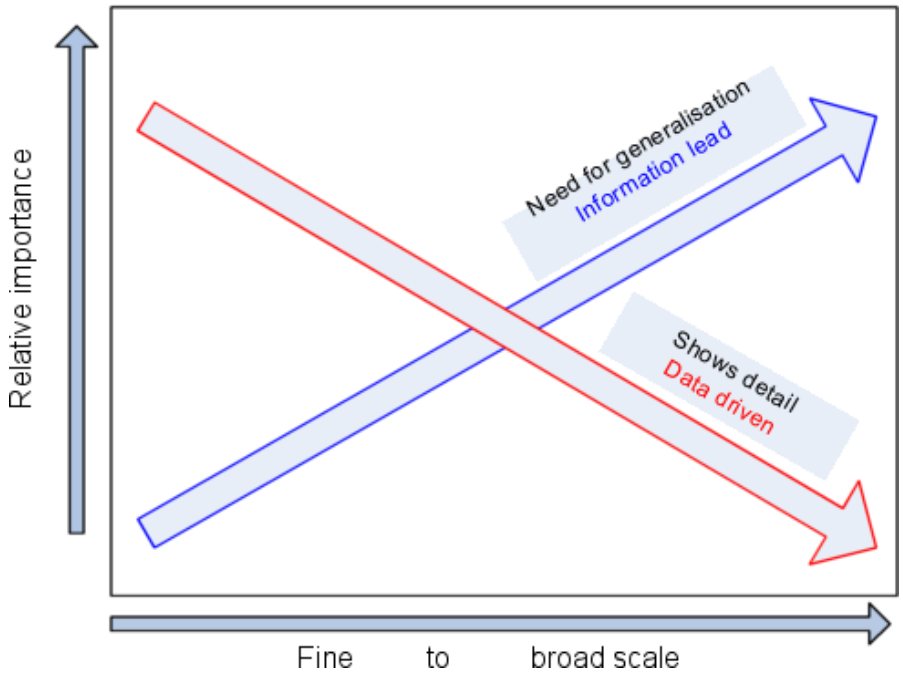


Figure 5-1 A schematic showing the changing relative importance of generalisation versus detail as the scale of a map changes.

5.2 How can I assess the accuracy of my map?

Accuracy has been introduced as a mathematical measure based on the predictive power of a map to correctly predict the habitat for a particular point (or pixel). If class 'A' is predicted to be present at location 'X' and this is found to be the case by observation, then the map is correct at that point; if it is not, then the map is wrong. This is the basis of all accuracy measures. If there are a larger proportion of wrong predictions, then the map is

inaccurate and might not be regarded with much confidence by a user. Accuracy is calculated by overlaying the ground-truthing data (or better still, the ***ground validation*** sample data) over the predictive map and presenting the success of the matches as an error matrix.

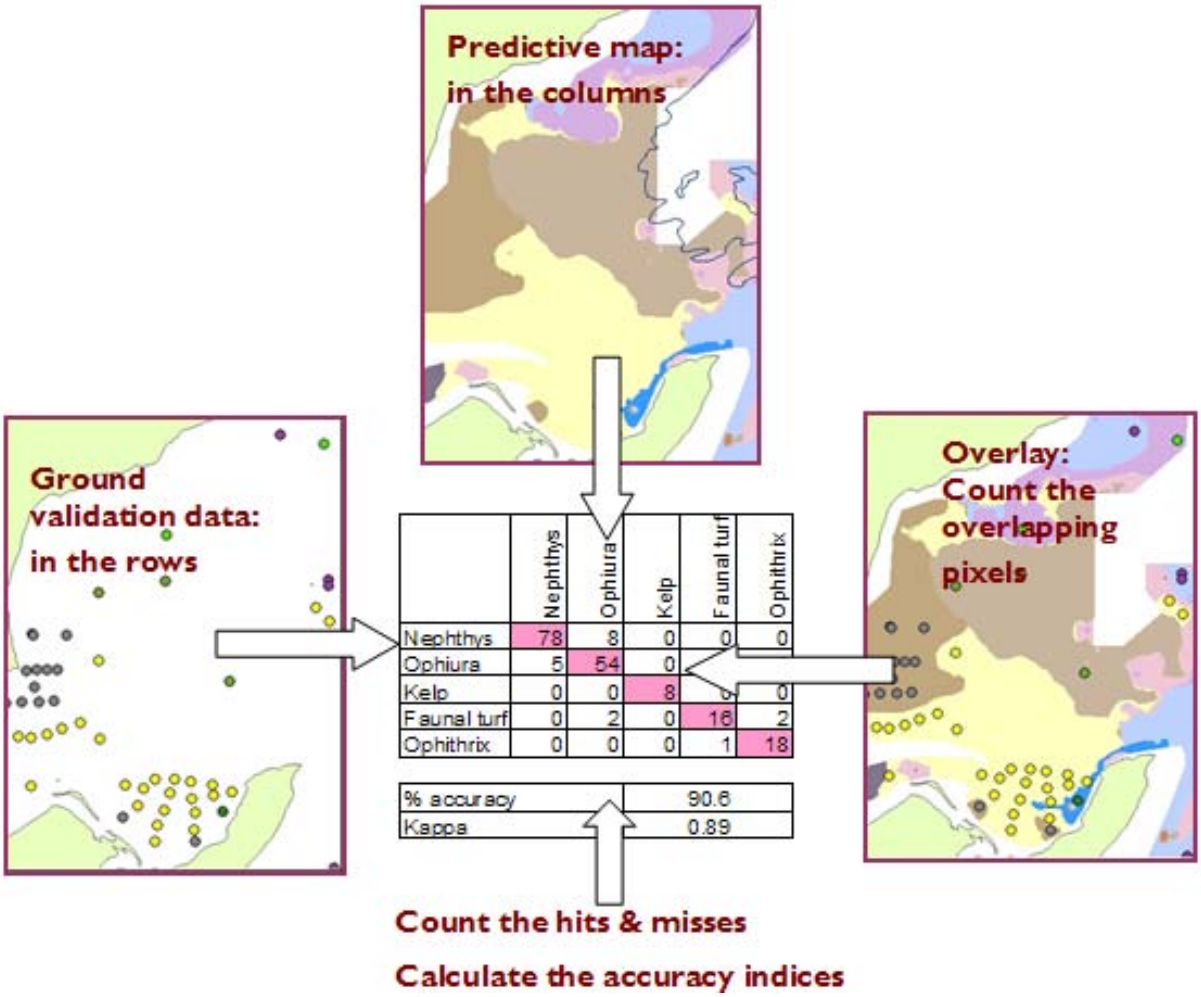


Figure 5-2 Overlaying ground validation data on to the predictive habitat map generates an error matrix showing the number correct 'hits' (coloured diagonal cells) and incorrect 'misses' (all other cells).

The diagonal cells in the error matrix contain the percentage of each class that were correctly predicted. The other cells which fall away from the diagonal show the incorrect predictions. The basic accuracy measure is the overall percentage of correct 'hits'. More sophisticated measures take into account the proportion of hits that might be expected to be 'correct' purely by chance.

5.3 How do I interpret my accuracy assessment?

Clearly, given the complex issues surrounding accuracy, it is not a simple matter of equating accuracy with usefulness. The example shown in Figure 5-3 shows two versions of the same map: the data were originally interpreted to 12 habitat classes. A number of these classes can be considered to be part of a more general 'reef habitat' (with outcrops of bedrock and boulders) with varied life forms, with the remainder being sediment habitats. If the classes are amalgamated into these two broad groups, map accuracy increases considerably. This might seem obvious. The detailed habitat map has lower accuracy because there is greater similarity between the habitats when modelling their distribution based on physical and biological characteristics; for example, kelp forest and kelp park differ mainly in their depth distribution. In contrast, there is a considerable difference in the physical and biological characteristics of the rocky habitats and the sediment habitats. It might well be the case that managers simply wish to know where reefs occur. However, the map to the left shows far more information about the distribution pattern of the component reef habitats and a degree of overlap might be acceptable, especially if this is between similar habitats.

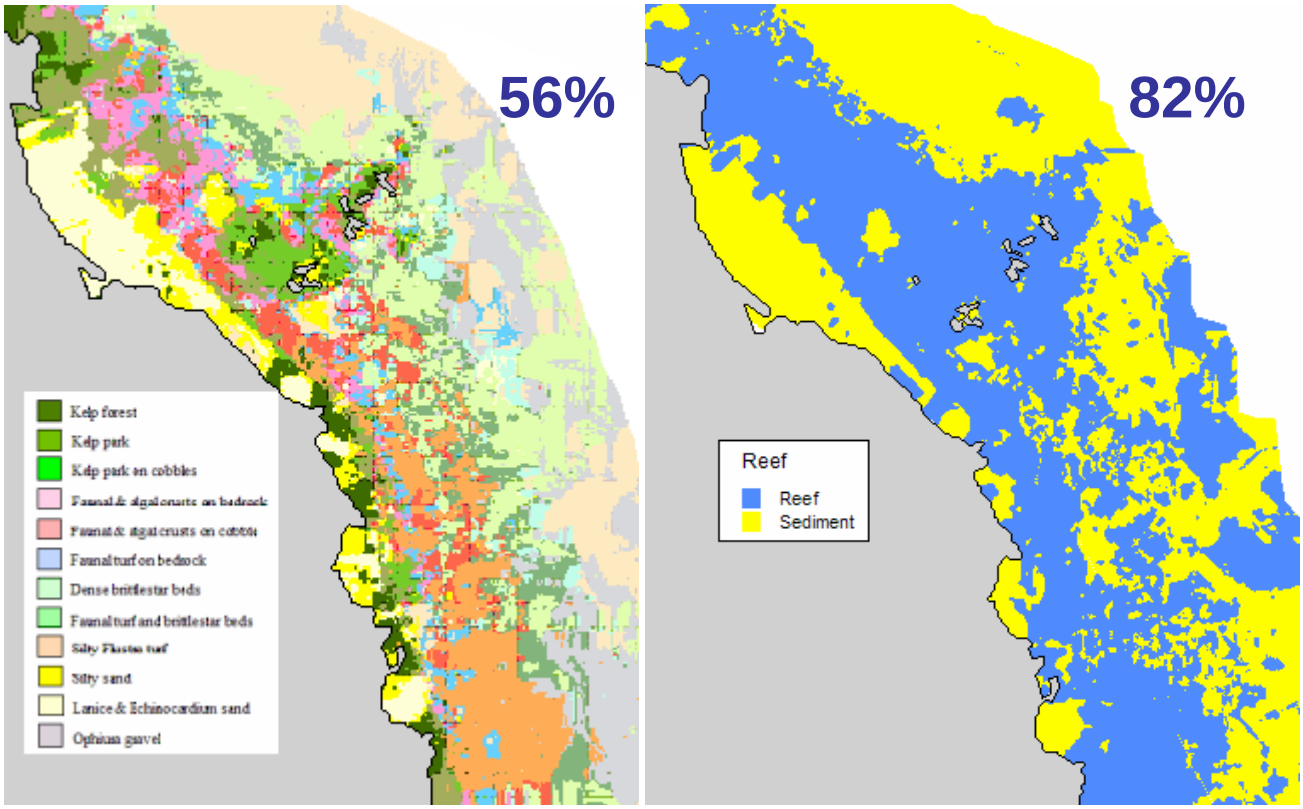


Figure 5-3 An example of how a map with fewer classes has higher accuracy, but potentially less useful to the end user.

In Figure 5-3, the map on the right is more accurate, but is it more useful? Accuracy is usually traded off against information content in the interpretation and analysis of a dataset. At one extreme, the interpretation may attempt to show subtle variation in habitat content that are simply not supported by the data. At the other extreme, the habitats are so general that the information is not useful for most purposes. An alternative to a measuring the accuracy of a map is to determine the confidence someone using the map for a particular purpose should have in the map. The next section discusses how confidence can be assessed and is followed by a section which describes the MESH Project's confidence assessment scheme.

5.4 How much confidence should I put in a map?

Accuracy measures, when applied to maps from a single survey, are a valuable way for surveyors to indicate how well their map performs as a predictive tool. However it should be clear from the discussion on accuracy that there are difficulties interpreting accuracy measures. These difficulties are compounded when habitat maps have been derived from data from many different sources. It might be possible to assess the accuracy of the contributory maps, but accuracy measurement rarely accompanies published maps and may not even have been undertaken as part of the mapping process. It may be possible to test the accuracy of final broad-scale map by testing its predictive power against a test data set. However, the results may not particularly meaningful or easy to interpret.

Confidence assessment might provide an alternative way of judging the usefulness of a map. Confidence is a more subjective form of assessment and is derived from a number of different criteria. This assessment can be completed by a map-user simply by checking the habitat map and any accompanying report and supporting maps for criteria that indicate the standard of mapping. This might be in the form of a check-list of questions. Does the published map show basic information about the origins of the map and its datum? Does the report show clearly how the map was derived?

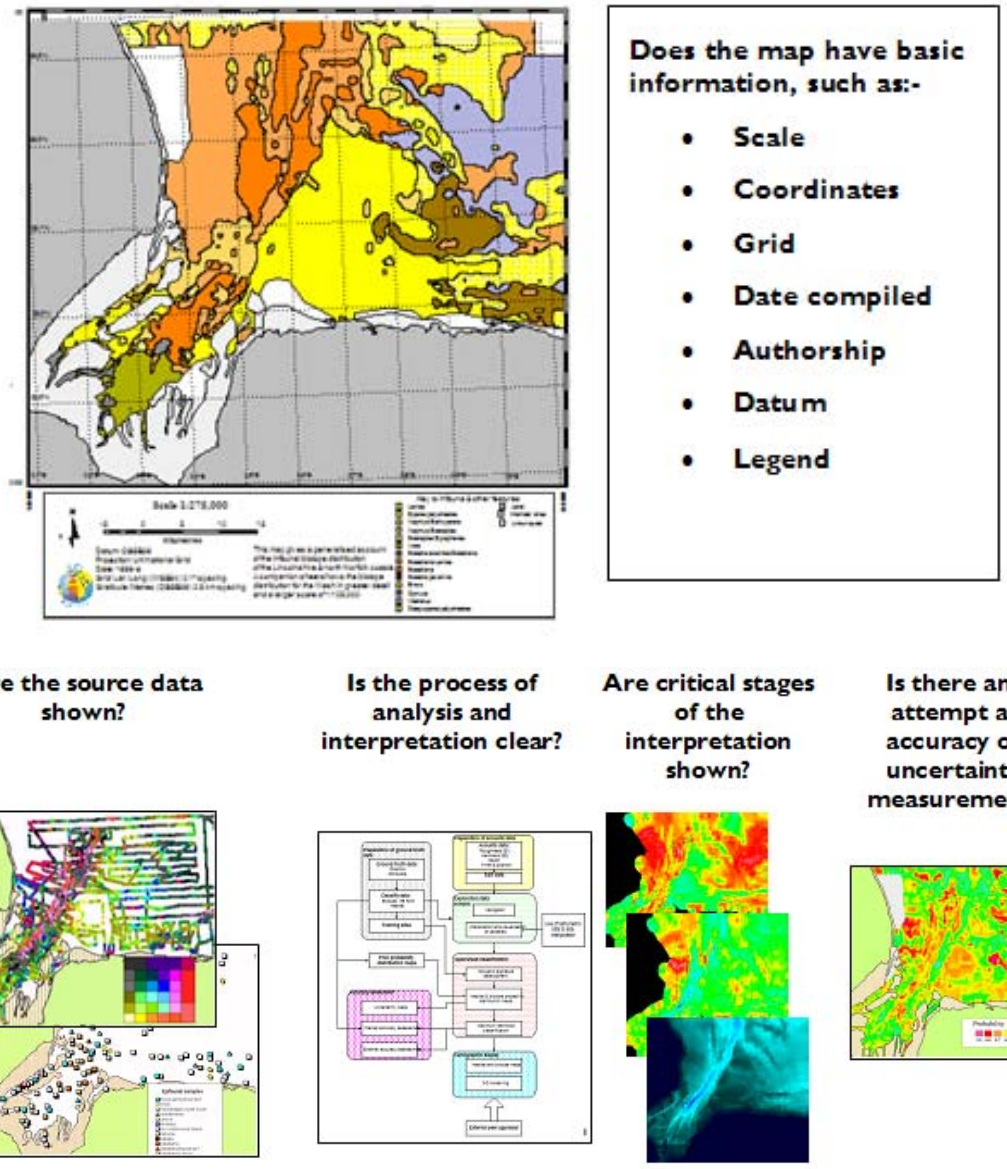


Figure 5-4 Map confidence is assessed using the answers to a series of basic questions about a map and its method of preparation.

Interpreted maps often show some of the supporting data: For example, the British Geological Survey's seabed sediment maps have inset maps displaying the location of grabs, cores and survey lines. The density and distribution of ground truth data gives a very good indication of the likely uncertainty associated with the interpretation. The full coverage maps of the remote sensing data should also be displayed. Often the preparation of these maps has involved some form of data manipulation. For example, data points from AGDS[3] are usually interpolated to produce a pseudo full coverage map and it is good practice to supply a map of the original track data showing the values of the data points. Interpolation can introduce spurious artefacts into the data that are quite often obvious when comparing the original point data to the interpolated data.

It is also valuable to see the process of making the habitat map as a flow chart showing the crucial stages in data manipulation and modelling. This alerts viewers to look carefully at these stages to see where errors might have been introduced into the process. Often these supporting maps and charts are provided in the original survey reports and these may not be available to the user. If the map is being used to make decisions that are

[3] Acoustic Ground Discrimination Systems that are traditionally based on single beam echosounders – see Chapter 3.3 MESH Recommended Operating Guidelines (ROGs)

critically dependent upon the detail of a habitat map, users should try to view the full report, not just the final interpreted map.

5.5 The MESH Confidence Assessment Scheme

To help users assess the confidence of a map, the MESH Project developed a systematic approach using a multi-criteria questionnaire. The MESH Project collated many maps produced for different purposes, ranging over many years, employing many different techniques and from a variety of sources. In many areas the maps overlap and users need to know the relative confidence they should have in these maps. The problem of map confidence is multifaceted and any assessment runs the risk of being very subjective and dependant on the person undertaking the exercise. Clearly, if some comparison is to be made between maps, then the assessment should be as objective as possible.

The MESH Partners decided that a confidence assessment system should be devised and the confidence factors stored as new ***metadata elements*** so that they are accessible together with the ***discovery metadata*** describing the map. The metadata already compiled by the project lacked sufficient detail to make objective decisions about the confidence of various factors. The purpose of the *MESH Confidence Assessment* was to visualise an overall confidence score on the *MESH webGIS* using study outlines, and to link these outlines to the full set of scores so that the assessment process remains transparent. The overall scores allow rough comparisons to be made between maps whereas the full set of scores enables users to identify why one map may have scored more highly than another. A scoring system based on a multi-criteria approach also allows survey planners to anticipate the effect of changing various survey parameters on the overall performance of a survey. In other words, it may help as a planning tool. Similarly, some criteria will also be useful to cartographers to determine which factors will increase or decrease the confidence a user may place in a map.

The *MESH Confidence Assessment* scheme is a compromise between being comprehensive and being easy to understand and usable. Many criteria have undoubtedly been left out and the exact scores suggested for each map may be challenged. The system is *not* designed to identify subtle differences between maps, but rather to give a simple and robust assessment. The exact score for any one field could be debated, but the overall score is little affected by tweaking the individual scores for the fields. Although the way a multi-criteria scoring approach is designed and operates is open to criticism, at least it is also open to inspection because the decision points are established and guidance is given to standardise scoring carried out by different individuals.

The *MESH Confidence Assessment* scheme has been built into two applications, each of which is best suited to a particular type of confidence assessment. For assessing multiple maps, we suggest using the *MESH Confidence Scoresheet* (a MS Excel™ spreadsheet) for ease of data entry and comparison between maps; it is available for download from the MESH website (www.searchmesh.net/Default.aspx?page=1635). For a more interactive tool which is best suited to the assessment of a single map, use the *MESH Confidence Tool*, built as a Flash™ application, available at www.searchmesh.net/confidence. This interactive tool allows the user to see the effect of changing individual scores and weightings on the overall confidence score. For those interested in the methodology but who will not be carrying out confidence assessments, the factors and scoring system are set out in the MESH Confidence Assessment Guidelines available from the MESH website (http://www.searchmesh.net/docs/MESH Confidence Assessment Guidelines.doc) and the attached DVD. The scoring guidelines are built into each application for quick reference.

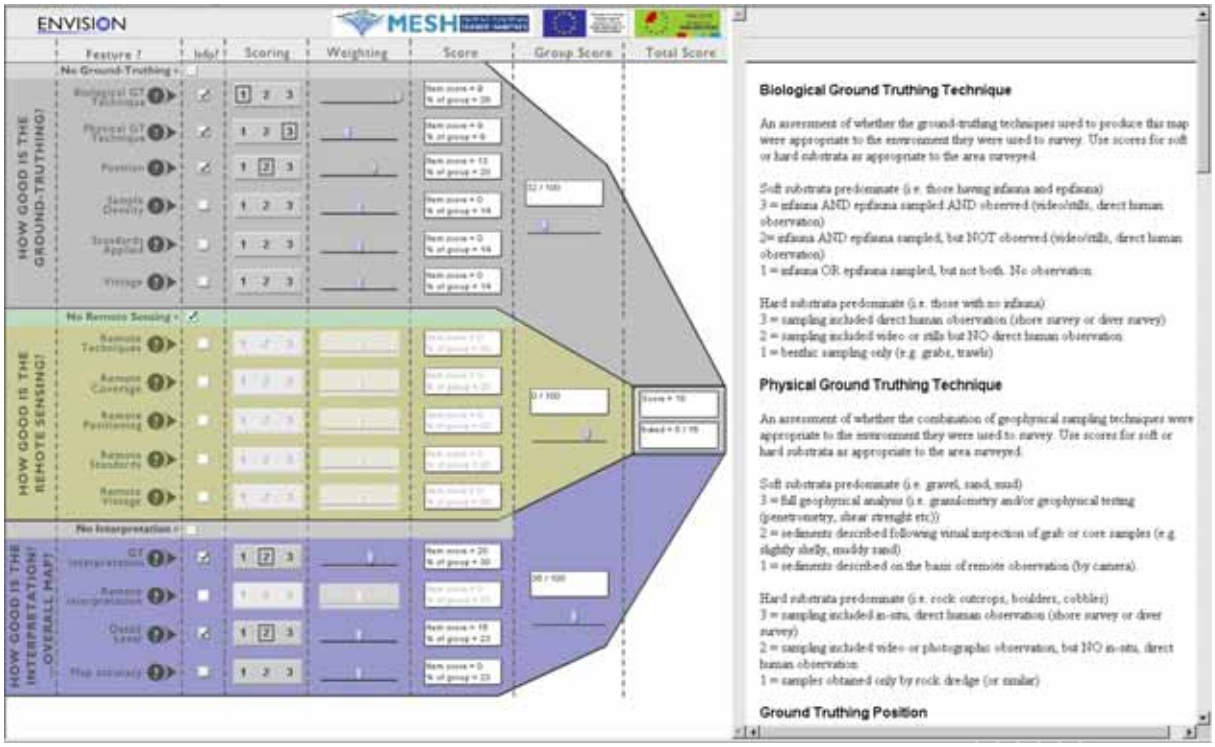


Figure 5-5 The MESH Confidence Tool, built as a Flash application. The scores and weightings of the factors are selected in the left-hand pane and the scoring guidelines are in the right-hand pane.

5.6 How do I interpret a confidence assessment?

All habitat maps are predictive to some degree and can only really be tested through practical use. Maps attract more confidence if they have been inspected and approved by external experts, particularly those with local knowledge of the area depicted on the map. Maps may have been used and found to predict accurately based on an independent validation. They might, more generally, have been used by stakeholders and found to be acceptable, particularly where the maps have stood the test of time.

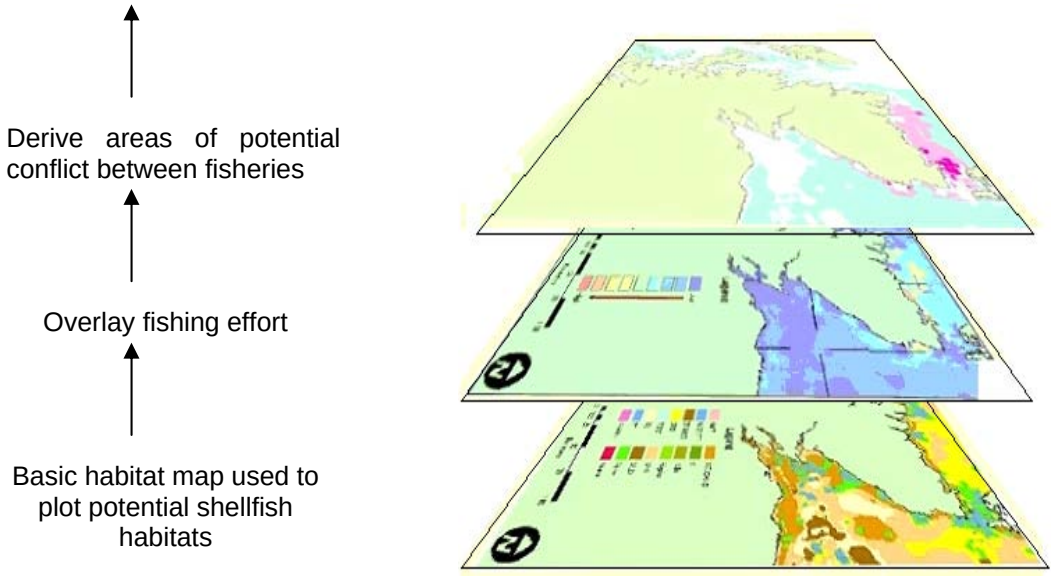


Figure 5-6 An example of how map confidence can increase when compared with additional data.

Maps may not score highly on any measure of confidence. But this does not necessarily mean that the have little use in certain applications. Indeed, such a map may turn out to match well to a completely independent data source and this can lead us to revise our opinion of a map. For example, the habitat map below was derived from data that were collected between 1994 and 1996, on different vessels, using only AGDS, with varied track spacing (often more than 500m apart), with an uneven spread of ground truth data collected using only towed video. Using the scoring system, the map attains an overall score of 51%, which is quite a low confidence score.

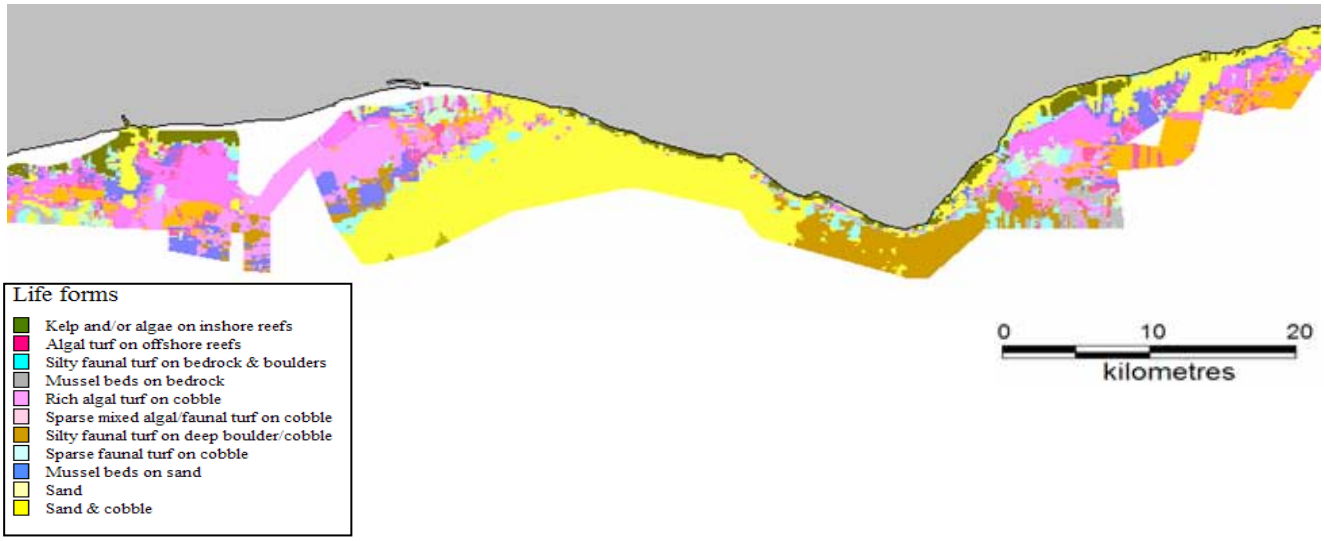


Figure 5-7 A basic habitat map of the Sussex coast, UK with a relatively low accuracy (51%).

The second map has overlain fisheries sightings data (coded according to fishing method). These data, collected between 2004 and 2006 also have their limitations as to accuracy. However, the correspondence between fishing activity and habitat distribution is readily apparent.

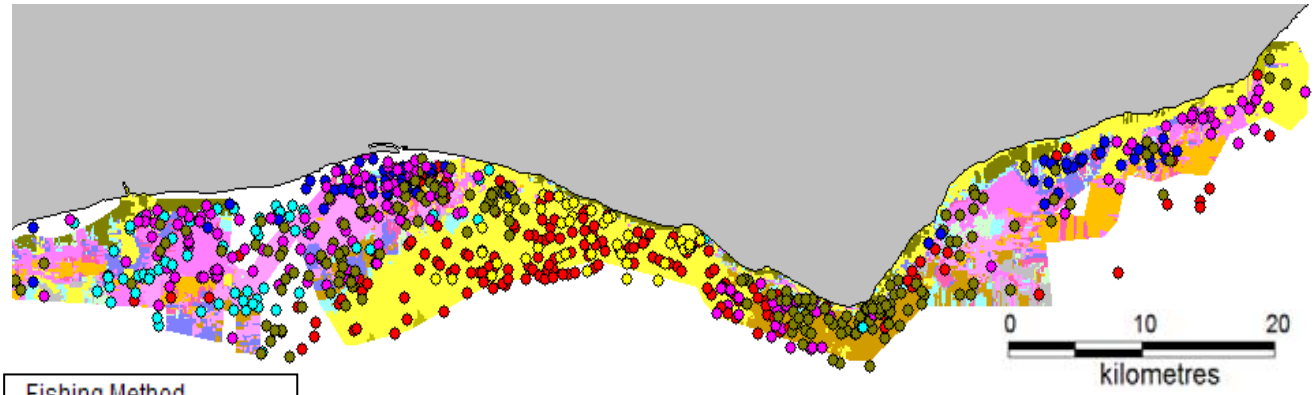


Figure 5-8 A habitat map overlain with known locations of fishing activity; despite the maps relatively low accuracy, the fishing methods broadly match the predicted habitat thus affording greater confidence to the map.

Thus, maps may prove to be useful even if they do not attract high confidence initially. It also follows that the survey strategy might also not be ideal, but all that is possible given the constraints, but still produce maps of some value.

5.7 Summary

Seabed habitat maps can play an important part in the decision making process when managing human activities and/or protecting the marine environment. Such decisions will often have significant socio-economic consequences and therefore a map user needs reassurance that the information presented on the map is correct. Assessing the quality of seabed habitat maps is a complex process, mostly due to the number of different datasets involved, each with their own sources of error, and the degree of data interpretation required by individual analysts.

There are two commonly used approaches to assessing quality:

- *Accuracy* is a measure of the predictive power of a map to represent the world as measured against reality. If a map predicts a habitat at point X and it is found to be there, the map is correct. If it is not, then the map is wrong.
- *Confidence* is an assessment of the reliability of a map given its purpose. It is much more subjective and may involve a judgement of the relative importance of many contributing factors, such as level of information, how near the map is to reality ('near misses?'), how relevant to the purpose and so on.

The MESH Project developed a multi-criteria questionnaire for users to assess map confidence – the *MESH Confidence Assessment Tool*. Users can assess their maps online via the MESH website, or download the tool for their local use.

When users have an understanding of the quality of their map, it can be used to solve practical environmental management issues; using maps is the topic of Chapter 6 What can I do with my map?

6 What can I do with my map?

Lead Authors: Natalie Coltman (JNCC), Paul Gilliland (Natural England) & Sytze van Heteren (TNO-NITG)

A habitat map is visual product that is the culmination of a complex process that involves the expert interpretation of data, designed to pass on specific messages to the map user. This chapter addresses how messages from maps are used in environmental management – the purpose for which the maps were intended – as well as how maps can be used beyond their original purpose. To many people, maps are pieces of art to be admired, but to others, they form an essential part of a toolset to solve complex problems in the natural environment. To further assist users in understanding the contribution that maps can make to environmental management, the first section in this chapter describes some actual examples of how maps were used to solve practical problems, followed by a discussion of how users' perceptions of maps can affect how successfully the maps are exploited. In addition to the map product itself, details should be provided to describe the map and to help map users interpret the information shown on the map. The second section considers how maps can be described to others through the use of this kind of information, known as metadata, and to raise awareness in the marine habitat mapping community of the importance of metadata. Habitat maps are an extremely valuable resource and it is important that maximum value is extracted from each map since these maps are quite likely to be the *only* habitat maps for that area of seabed. Wherever possible, habitat maps should be made available to the wider scientific and marine management community to avoid an unnecessary duplication of effort to collect data in the same area. The section describing contributing data to other organisations provides guidance on the use of *MESH Data Exchange Formats*, data processing and *MESH Data Agreements*.

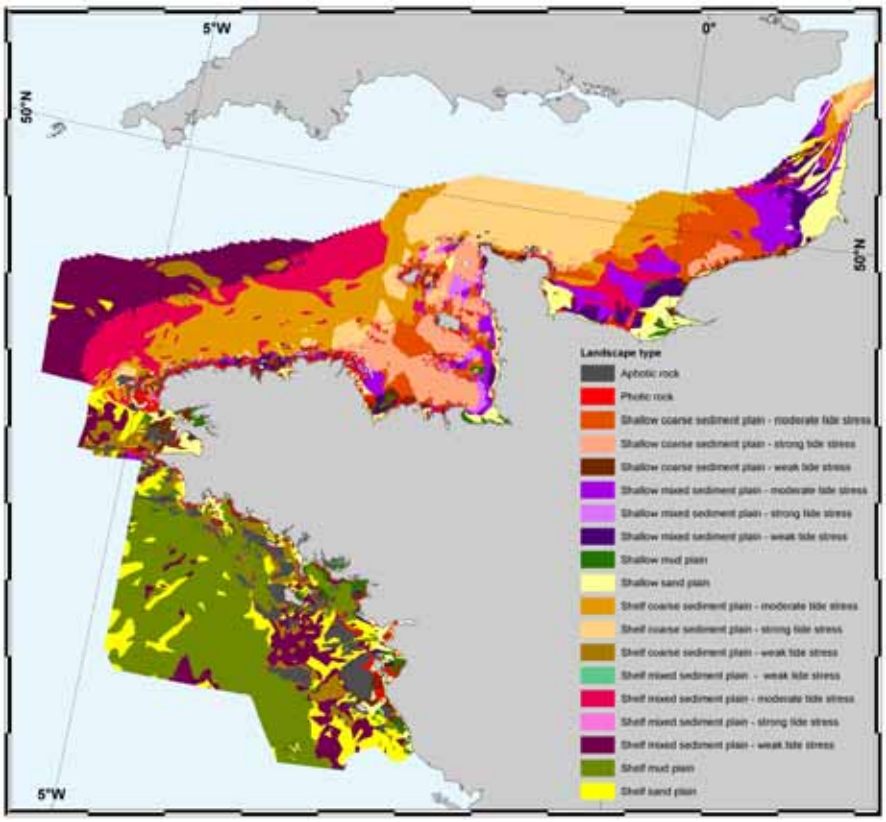


Figure 6-1 The predicted distribution of marine landscapes around northern France.

When marine habitat maps are made, mapping scientists chose mapping units which are best suited to the purpose of the map, perhaps to describe broad-scale physical features or detailed biological information. The variety of reasons for mapping the seabed has resulted in an almost equal variety of mapping units used to make maps. In the context of marine habitat mapping we call these mapping units habitat classes. A defined set of habitat classes is known as a habitat classification scheme. The process of converting habitat classes from one classification to habitat classes in a second classification scheme has been called translation by the MESH Project. The fourth section in this chapter will explain the benefits and feasibility of translation, and the processes by which it can be undertaken. When maps produced by individual habitat mapping studies are brought together,

there are likely to be areas where maps overlap. Overlapping maps are not a problem as such; however, the maps have probably been produced at different scales for different purposes and using different methods. Even after translation to a common classification scheme, it is anticipated that maps will not always concur in areas of overlap. The fifth section gives advice about combining maps, specifically overlapping maps and maps produced for viewing at differing scales.

With the rapid development of computer technology over the past decade, the capability to rapidly access and process data and information has significantly changed our approach to marine environmental research and management. It is now possible to quickly search for information across multiple sources via the internet, often with the additional capability to download data (physically for local storage, or dynamically) for display and analysis on local machines. This final section describes how it is possible to make maps available on the internet, whether by contributing to an existing mapping website or by building a mapping website, and includes an outline of how to combine your maps with other online maps.

6.1 Using maps

A habitat map is a visual product that is the culmination of a complex process that involves the expert interpretation of data. Maps are designed to pass on specific messages to the map user. To many people, maps are pieces of art to be admired, but to others, they form an essential part of a toolset to solve complex problems in the natural environment. Unfortunately, these two extremes become somewhat blurred when users trying to solve problems do not have an understanding of maps beyond the concept of 'art'. Hopefully this *MESH Guide to habitat mapping* will help improve users' understanding of habitat maps, in particular the limitations of maps, to escape the blurring of art and science. Remember that maps are *a* truth and not *the* truth: compare the maps of the Dutch continental shelf made for engineers and for biologists (Figure 6-2). Different map makers will produce differing maps of the same feature, unless they agree to use the same datasets and to follow the same protocols.

To further assist users in understanding the contribution that maps can make to environmental management, the full version of the *MESH Guide* describes some actual examples of how maps were used to solve practical problems, followed by a discussion of how users' perceptions of maps can affect how successfully the maps are exploited (see attached DVD for copies of the case studies). Seabed maps are a valuable resource because the data they are based upon are expensive to collect and time-consuming to interpret. This makes them relatively rare commodities; therefore it is vital that maximum value can be extracted from a data resource, both at the time of collection and into the future. This is addressed in the subsequent sections which deal with stages in the life of a map beyond using it for the purpose for which it was originally intended.

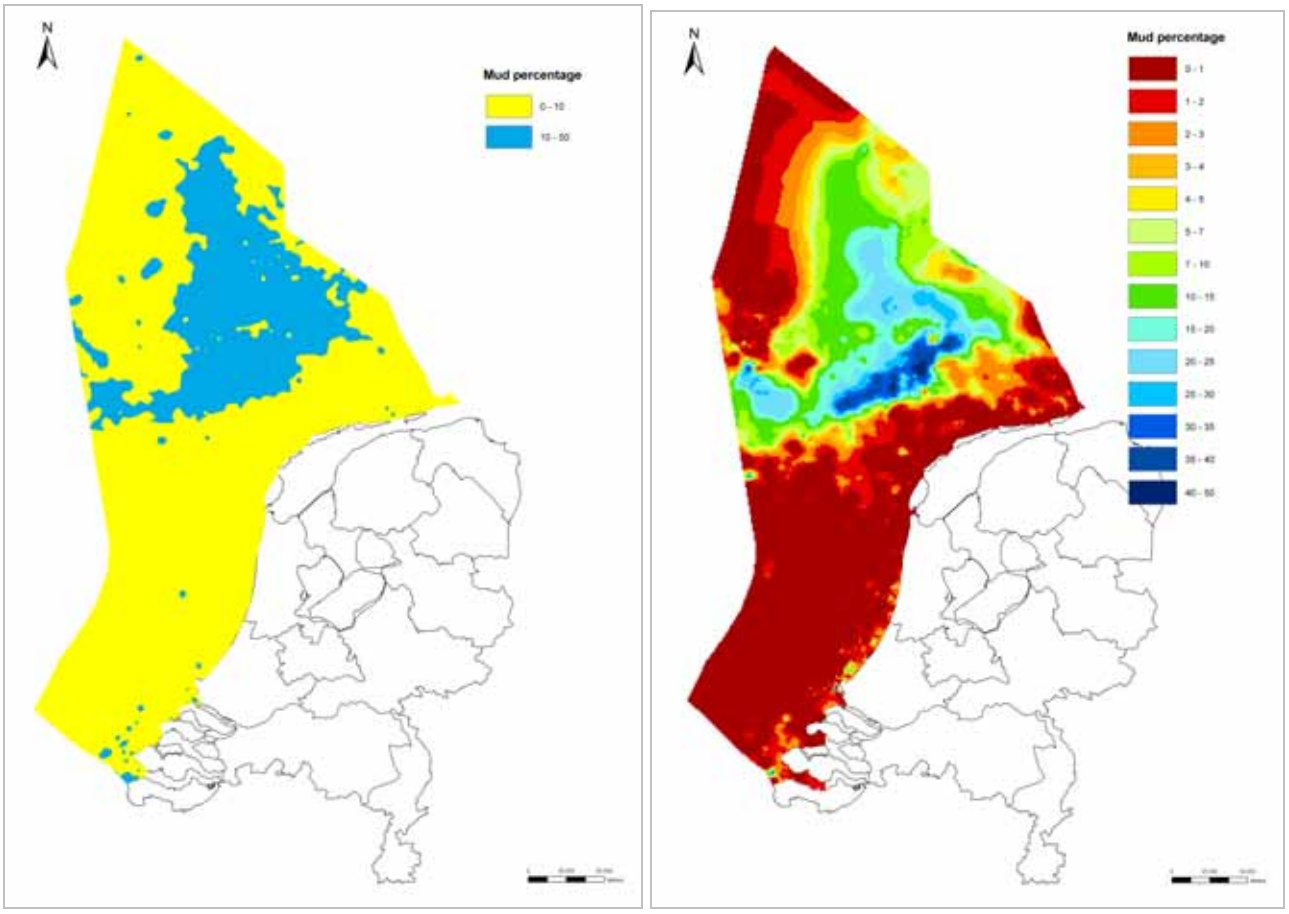


Figure 6-2 Sediment maps for the Dutch continental shelf:
Left map: a traditional mud-percentage map made for stakeholders from the engineering community, using primarily visually estimated mud content.
Right map: A digitally produced mud-percentage map made for stakeholders from the biological community, using measured mud-content values.

6.2 Describing maps

Maps are produced to convey information to other people. In addition to the map product itself, details should be provided to describe the map and to help map users interpret the information shown on the map. Maps can be described to others through the use of standardised information, known as ***metadata***. The MESH Project has tried to raise awareness in the marine habitat mapping community of the importance of metadata.

Metadata are data about data, for example giving information about the characteristics and provenance of the data. Metadata answer questions you may have about a particular dataset: What type of data were collected? When? By whom? For what purpose? What methods were used? Perhaps most importantly, *where* were the data collected? This last component adds a spatial aspect to metadata, and is an essential part of the metadata needed to describe seabed mapping data.

International sharing of metadata is becoming increasingly important. Seabed features do not follow national boundaries, and contemporary measures at 'ecosystem management' consider regional seas rather than national waters. A project working in the North Sea may be interested in finding data collected by organisations based in several countries bordering the area. Metadata provide crucial information to better understand a data resource, and to help users locate appropriate data that meets their needs. Combining metadata records for individual data resources into a database can offer the user the opportunity to search and query the resulting metadata 'catalogue' in order to track down records which meet their needs. Such a catalogue can be distributed via the internet to create an online search tool.

The MESH Project developed a metadata standard for habitat mapping studies (see section 6.3 Contributing maps) and build an online system to deliver the descriptions of all the existing habitat mapping studies sourced

by the project. The MESH Metadata Catalogue (www.searchMESH.net/metadata) offers a very flexible search tool for users to find studies of interest, and the search results are linked to the *MESH webGIS* so their location can be shown.

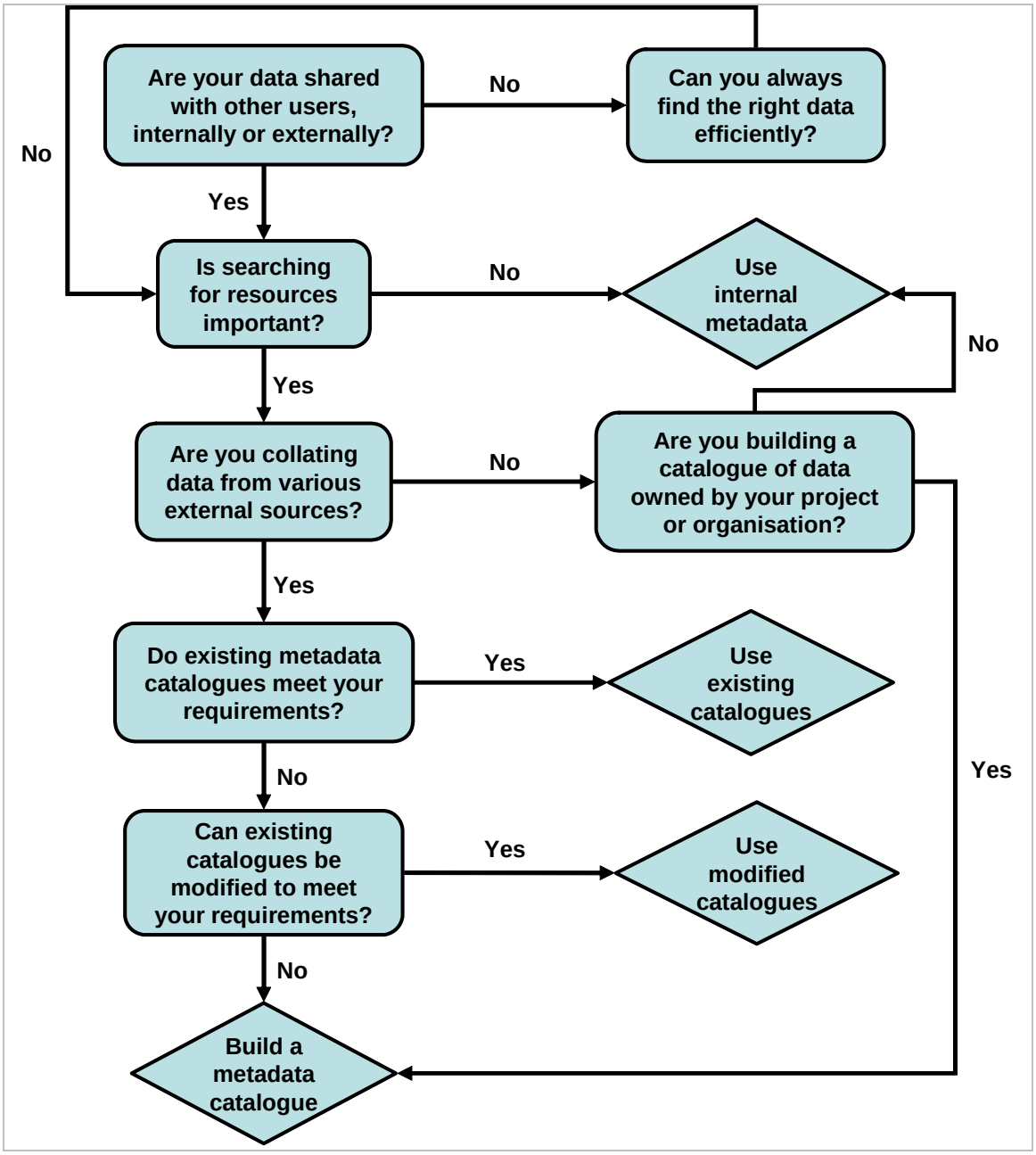


Figure 6-3 A decision process to help users decide whether they need to build a metadata catalogue.

Habitat mapping is an expensive and time consuming process and therefore the final products – the habitat maps themselves – are an extremely valuable resource. A useful and accurate description of the resource is almost as valuable as the resource itself, and hence metadata are an essential component of marine habitat mapping.

6.3 Contributing maps

It is important that maximum value is extracted from each map since they are likely to be the *only* habitat maps for that area of seabed. Wherever possible, habitat maps should be made available to the wider scientific and marine management community to avoid an unnecessary duplication of effort to collect data in the same area.

There are a number of issues to consider when transferring data between organisations. ***Data exchange formats*** facilitate the process of transferring maps. The MESH Project defined data exchange formats to define the characteristics of data to be exchanged in terms of the attributes and data structure, and has developed tools for cleaning and formatting GIS files into the required format. These MESH Data Exchange Formats can be downloaded from the MESH website and are available on the attached DVD.

A data agreement is a formal agreement that sets out both the terms and conditions for use and dissemination of a data resource (as required by a data owner when their data are supplied to another organisation), *and* the expectations of the recipient in terms of the quality and validity of the collated data resources. The agreement is required to ensure both parties (i.e. the Data Provider and the Data Recipient) have a clear understanding of the basis upon which the data have been provided and upon which they can hold, use and disseminate those data. This is particularly important if data may be used to compile new habitat maps which could be disseminated to other parties. The MESH Project has written a *Data Provider Agreement* which is a formal agreement between a MESH Partner and anyone providing material (i.e. data such as habitat maps) for use by the Partnership; a copy of this data agreement is available on the MESH website.

Gathering together existing data in this way plays a vital role in the habitat mapping process: the data collated may contribute to each of the main steps from the initial planning (e.g. to determine whether new data are required), to map production (e.g. by providing additional data layers for analysis) and interpretation of the results (e.g. by setting local results in a wider geographic context). Often, existing habitat maps will use a seabed classification system that is specific to the study and it will be necessary to convert the map to a more generic scheme for wider comparison.

6.4 Converting maps

When marine habitat maps are made, mapping scientists chose mapping units which are best suited to the purpose of the map, perhaps to describe broad-scale physical features or detailed biological information. The variety of reasons for mapping the seabed has resulted in an almost equal variety of mapping units used to make maps. In the context of marine habitat mapping these mapping units are called habitat classes. A defined set of habitat classes is known as a habitat classification scheme. The process of converting habitat classes from one classification to another has been called *translation* by the MESH Project. The full MESH Guide includes a detailed section on the benefits, the feasibility and the technical aspects of translation, including a description of the processes by which it can be undertaken.

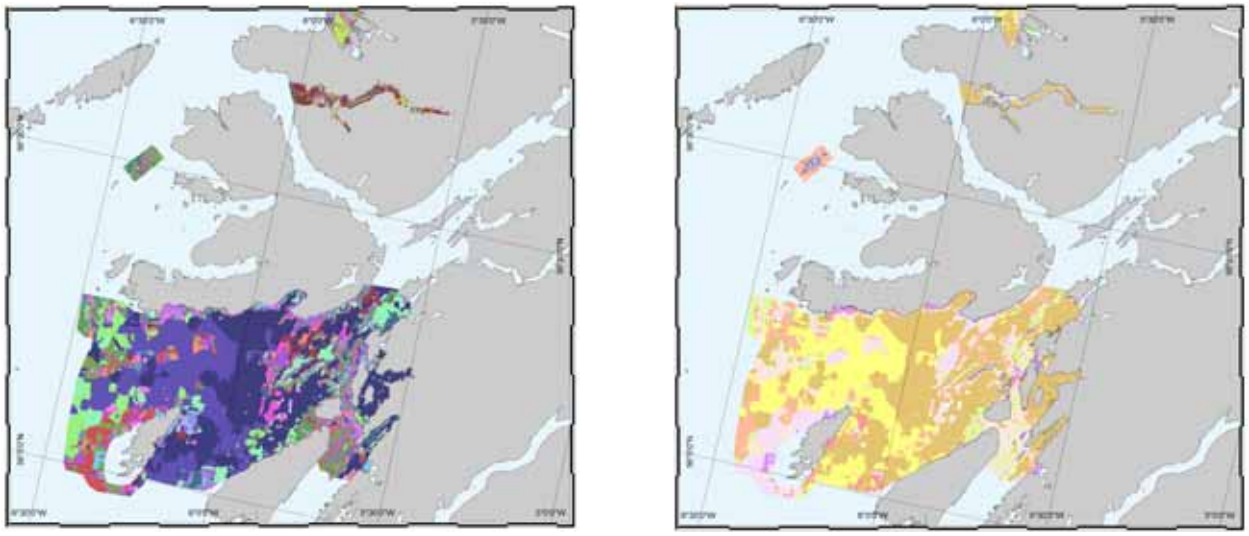


Figure 6-4 An example of how translation standardises maps from their original habitat classes (left) to the EUNIS habitat scheme (right).

The MESH Project focussed on translating maps to the EUNIS classification scheme (European Union Nature Information System: eunis.eea.europa.eu), because this is the only common classification scheme in Europe. When faced with an array of maps – often created for diverse purposes, and perhaps brought together by a data collation project – it is natural to want to use the maps to ask questions about the occurrence and extent of habitats that are of interest to you. Answering these questions is impossible without first converting maps to a

common set of mapping units, or habitat classes. Translation is vital in marine habitat mapping to allow maps to be used to answer the widest range of possible questions. Once maps have been translated, it then becomes possible to combine maps to create a single map with broader geographic coverage.

6.5 Combining maps

When maps produced by individual habitat mapping studies are brought together, there are likely to be areas where they overlap. Overlapping maps are not a problem as such; however, the maps have probably been produced at different scales for different purposes and using different methods. Even after translation to a common classification scheme, it is anticipated that maps will not always concur in areas of overlap. Furthermore, maps are produced to be viewed at a specific scale, and combining them into a single electronic map view (for example in a GIS or an interactive mapping website) can allow the user to zoom freely and view the maps at any scale. This gives the illusion of scale-free maps, unlike the case of printed maps where the size a feature that can be distinguished on a map depends on the paper size used. Combining electronic maps is not without its problems, particularly problems resulting from overlapping maps and flexible viewing scales. Maps are designed to visually convey a message to the map user, and the saying ‘a picture tells a thousand words’ is one often cited by map makers. How clearly those ‘thousand words’ are spoken after the map has been combined with others is dependant on successfully addressing challenges caused by this amalgamation.

Where features from different mapping studies overlap geographically but their attributes do not match, a structured approach must be adopted to determine which map takes precedence. The decision on which overlapping map should be taken in preference to another can be based on information provided in the metadata describing the study, particularly any assessment of confidence. For example, consider a situation in which two overlapping surveys contained conflicting information, where one map was produced using high quality multibeam echo sounder, side scan sonar and dense ground-truth sampling (a ‘high confidence’ map), while the other map was produced using interpolated ground-truth samples (a ‘low confidence’ map). The former map would take precedence over the latter on the basis of the confidence assessment. The part of the map with the lower confidence that overlaps the map with higher confidence could be removed, leaving a single layer from the two separate mapping studies.

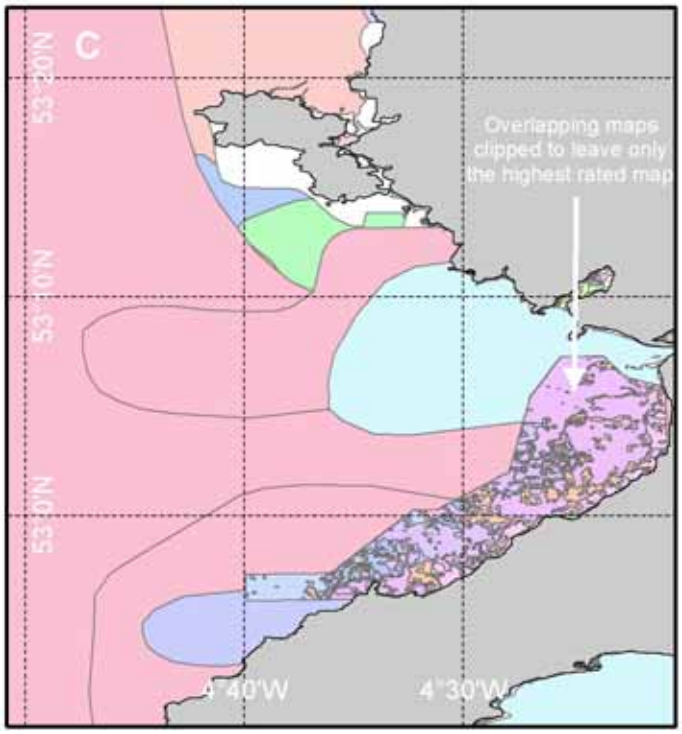


Figure 6-5 Habitat maps were combined to create a single EUNIS layer on the MESH webGIS; their MESH Confidence Assessment scores were used to select the best map in areas of overlap.

A key output of the MESH Project was a habitat map for north-west Europe based on the EUNIS classification scheme, derived from existing maps. Once the existing (source) maps were translated to the EUNIS scheme,

they were combined to create a single layer. Where the original source maps overlapped, the habitats in the area of overlap that had the highest score in the MESH Confidence Assessment were selected. This combined EUNIS map is available on the MESH webGIS, together will all the underlying source maps.

6.6 Sharing maps on the internet

With the rapid development of computer technology over the past decade, the capability to rapidly access and process data and information has significantly changed our approach to marine environmental research and management. It is now possible to quickly search for information across multiple sources via the internet, often with the additional capability to download data (physically for local storage, or dynamically) for display and analysis on local machines. Sharing maps on the internet has several significant advantages, both for the organisation that owns the maps, and users of the maps: sharing information can save resources by raising awareness about where data are already available so that additional survey effort is not required; data owners can get publicity for the data they hold; maps can be accessed by staff while they are away from the office intranet or network. With these advantages come some problems: with the escalating number of mapping websites there is often confusion in the user community about where to look for marine data. Making maps available online invites non-expert end-users to use and interpret maps for any purpose, without having to consult habitat specialists or consider the survey methodologies used. The once obvious necessity to communicate with map makers is no longer felt. Before deciding to build a mapping website for your organisation's mapping data, it is essential to verify whether resources could be saved by contributing your data to an existing mapping website.

Internet mapping can be delivered via a two main routes: by building a software package specifically for your purpose; or by customising a software development package to meet your needs. Examples of both options can be found throughout the internet. It is more common, and potentially more economical, to use proprietary development packages such as ESRI ArcIMS™ or MapInfo's MapExtreme™. More recently, 'open source' software such as MapServer (mapserver.gis.umn.edu) has appeared that has the advantage of not requiring a commercial licence to run the application on a web server. Unless the required mapping functions are extremely complex in terms of the range of functions currently offered by various packages, the development of bespoke software is unlikely to be justified. Alternative development environments will have advantages and disadvantages, but the basic choice is between:

- Using a proprietary package which has a large pool of experienced developers but accepting that there will be a licence fee.
- Using an open source package that may have a smaller pool of experienced developers but which does not require a licence fee to be paid.

The MESH Project chose the second of these options using the MapServer software; more information about the *MESH webGIS* can be found in the worked example *MESH webGIS user guide.doc* in the *Resources* section of the *MESH Guide* on the attached DVD.

Desktop geographic information system (GIS) technology allied to emerging international data standards for *geospatial interoperability* now enables complex visualisations of spatial data, using data located on both local machines and remote internet servers. It is possible to make maps using data available on the internet to compare with local maps to improve our ability to visualise the marine environment. Making the additional effort to share maps on the internet will significantly expand the seabed habitat map resource available to end-users to the mutual benefit of all, and help better manage human activities and deliver international commitments on sustainable development.

6.7 Summary

A habitat map is designed to pass on a specific message to the map user. Maps are important tools to support the wise management of the marine environment. Seabed habitat maps are valuable products since their creation is a very resource intensive process. Consequently, these maps should be carefully described using a standardised approach (metadata) and these descriptions made more widely available via a metadata catalogue (e.g. *MESH Metadata Catalogue*) to avoid unnecessary re-mapping of areas. Organisations should endeavour to make the actual data and the interpreted maps available to the wider community. Data sharing is facilitated if a standardised format is adopted (e.g. *MESH Data Exchange Format*) and terms and conditions for their use clearly specified in a data agreement.

If maps are clearly described and then made more widely available, it becomes possible to convert maps to a standard habitat classification scheme such as the EUNIS scheme. Once maps are standardised, it becomes possible to combine many maps to create a single map of a much larger geographic area. For example, the MESH Project standardised and then combined the maps sourced by the project into a single map for north-west Europe.

Internet technology enables these maps to be made easily available to a much wider audience using standard internet browsing software. Users can now search for information in their chosen area using interactive mapping websites such as the *MESH webGIS*. Furthermore, there is a big push to establish standards for sharing these data in a way that it becomes possible to readily download a live version to a local computer to enable users integrate web-data their own data. Such interactive data sharing will significantly enhance our ability to visualise the marine environment to better understand the complexities of marine ecosystems, and then improve our ability to manage human activities to effectively deliver sustainable development.

7 Bibliography

The following bibliography is only a selection of more general texts from the full bibliography of the *MESH Guide*.

Blondel, P. & Murton, B. 1997. *Handbook of seafloor sonar imagery*. John Wiley and Sons, London, 336 pp.

Bouma, H., de Jong, D.J., Twisk, F., & Wolfstein, K. 2006 (English version). *The Dutch ecotope system for coastal waters.* (ZES.1). Rijkswaterstaat, Middelburg (Report RIKZ/2005.024).

Brown, C.J., Hewer, A. J., Meadows, W. J., Limpenny, D.S., Cooper, K.M., Rees, H.L. & Vivian, C.M.G. 2001. *Mapping of gravel biotopes and an examination of the factors controlling the distribution, type and diversity of their biological communities.* CEFAS Scientific Series Technical Report No 114: 43pp. Lowestoft, UK

Bunker, F. S. D., & Foster-Smith, R. L., 1996. *Field Guide for Phase 1 Seashore Mapping*. Peterborough, UK., English Nature.

Connor, D.W., Allen, J.H., Golding, N., Howell, K.L., Lieberknecht, L.M., Northen, K.O., & Reker, J.B. 2004. *The national marine habitat classification for Britain and Ireland. Version 04.05.* Joint Nature Conservation Committee, Peterborough, UK (Internet version: www.jncc.gov.uk/MarineHabitatClassification).

Connor, D.W., Gilliland, P.M., Golding, N, Robinson, P., Todd, D., and Verling, E. 2006. *UKSeaMap: the mapping of seabed and water column features of UK seas.* Joint Nature Conservation Committee, Peterborough, UK. (Internet version: www.jncc.gov.uk/default.aspx?page=3918)

Coggan, R.A. 2006. Developing a strategy for seabed mapping at different spatial scales. In Cefas 2006, Monitoring the Quality of the Marine Environment, 2003 – 2004. *Scientific Series Aquatic Environment Monitoring report* **58**:13-34. ISSN 0142-2499.

Coggan, R., Populus, J., White, J., Sheehan, K., Fitzpatrick, F. & Piel, S. (eds.) 2007. *Review of Standards and Protocols for Seabed Habitat Mapping.* JNCC, Peterborough. (Download from http://www.searchmesh.net/default.aspx?page=1442)

Dauvin, J.C., Bellan, G., Bellan-Santini, D., Castric, A., Françour, P., Gentil, F., Girard, A., Gofas, S., Mahe, C., Noël, P., & Reviers, B. de. 1994. *Typologie des ZNIEFF-MER. Liste des paramétres et des biocoenoses des côtes françaises métropolitaines. 2nd ed.* Paris, Muséum National d'Histoire Naturelle, Secrétariat Faune-Flore. (Collection Patrimoines Naturels, Série Patrimoine Ecologique, No. 12.)

De Oliveira E., Populus J. & Guillaumont B. 2006. Using Lidar survey and satellite imagery for predictive modelling of coastal habitats - A case for seaweed in Brittany (France). *Earsel eProceedings*: **5(2)**:208-223

European Environment Agency. 2004. *EUNIS habitat classification, version 200410* (internet application: eunis.eea.europa.eu/habitats.jsp). European Environment Agency, Copenhagen.

Greene, H.G., Yoklavich, M.M., Starr, R. M., O'Connell, V. M., Wakefield, W. W., Sullivan, D. E., McRea, J. E. Jr. & Caillet, G.M. 1999. A classification scheme for deep seafloor habitats. *Oceanologia Acta*. **22(6)**:663-678. See also an addendum and further explanatory notes at geooce.mlml.calstate.edu/images.htm (Dec 2006).

Guisan, A. & Zimmermann, N.E. 2000. Predictive habitat distribution models in ecology. *Ecological Modelling*, **135(2-3)**:147-186

ICES Working Group on Marine Habitat Mapping. 2006. *Report of the Working Group on marine Habitat Mapping (2006). 4-7 April, 2006, Galway, Ireland.* International Council for the Exploration of the Sea, Copenhagen.

James, J.W.C., Coggan, R.A., Blyth-Skyrme, V.J., Morando, A., Birchenough, S.N.R, Bee, E., Limpenny, D.L., Verling, E., Vanstaen, K., Pearce, B., Johnston, C.M., Rocks, K.F., Philpott, S.L. & Rees, H.L. 2007. *Eastern English Channel Marine Habitat Map (EECMHM).* Scientific Series Technical Report, Cefas, Lowestoft, 139.

Mills, G.B. 1998. International Hydrographic Survey Standards. *International Hydrographic Review*. **75(2)**: 79-85.

Olenin, S., & Ducrotoy, J.P. 2006. The concept of biotope in marine ecology and coastal management. *Marine Pollution Bulletin* **53(2006)**: 20-29.

Roff, J.C. & Taylor, M.E. 2000. VIEWPOINT: National frameworks for marine conservation – a hierarchical geophysical approach. *Aquatic conservation and freshwater ecosystems*: **10**:209-223.

Valentine, P.C., Todd, B.J. & Kostylev, V.E. 2004. Classification of marine sublittoral habitats with application to the northeastern North America region. In P.W. Barnes and J.P. Thomas, editors. *Benthic habitats and the effects of fishing.* American Fisheries Society Symposium, Bethesda, Maryland.

Wyn, G., Brazier, P., Birch, K., Bunker, A., Cooke, A., Jones, M., Lough, N., McMath, A. & Roberts, S. 2006. *Handbook for marine intertidal Phase 1 biotope mapping survey*. Countryside Council for Wales, Bangor.

White, J., Mitchell, A., Coggan, R., Southern, I. & Golding, N. 2007. *Seafloor Video Mapping: Collection, Analysis and Interpretation of Seafloor Video Footage for the Purpose of Habitat Classification and Mapping.* MESH Video Working Group Report. Available from MESH website: www.searchMESH.net/Products.

8 Glossary

This is the full glossary from the online version of the MESH Guide to Habitat Mapping. It includes additional terms not used in the *MESH Guide Synopsis* but they are included because they refer to more technical aspects of habitat mapping and may help explain some of the broader issues.

Accuracy

The degree to which a measured value (either spatial resolution/precision or attribute) conforms to a true or accepted values. Accuracy is a measure of correctness. It is distinguished from precision, which measures exactness.

In a habitat mapping context, accuracy describes how closely a map predicts the actual habitat observed on the seabed at a given location.

Ambiguity

The confusion between classes often due to overlapping and shared attributes used to define the classes.

ArcCatalog™

ArcCatalog™ is an application used by ESRI's ArcGIS, for managing spatial data holdings and for recording, viewing, and managing metadata. ArcCatalog™ provides an integrated and unified view of all the data files, databases, and ArcGIS documents available to ArcGIS users.

ArcToolbox™

ArcToolbox™ is one of the applications comprising the ESRI™ desktop GIS package (together with ArcMap™ and ArcCatalog™). The ArcToolbox™ window is the central place where you find, manage, and execute geoprocessing tools.

Assemblage

A group of different species that occur together at a given location.

Attribute

Non-spatial information describing the characteristics of a map object (vector geographic feature in a GIS), usually stored in a database table and linked to the map object by a unique identifier. For example, a polygon feature drawn on a habitat map will have the type of habitat present as one of its attributes, where values are any text entry taken from the EUNIS classification scheme (e.g. A1.23).In raster datasets, an attribute is the information associated with each a raster cell that describes it value.

Attribute table

A database or tabular file containing information about a set of geographic features, usually arranged so that each row represents a feature and each column represents one feature attribute. In raster datasets, each row of an attribute table corresponds to a certain zone of cells having the same value. In a GIS, attribute tables are often joined or related to spatial data layers, and the attribute values they contain can be used to find, query, and symbolize features or raster cells.

Bedform (features)

Any deviation from a flat bed, generated by the flow of a transporting agent (water, ice or air). Bedforms range in size from ripples in the sand, a few centimetres apart and a few millimetres high, to 'dunes' with wavelengths of hundreds of meters, kilometres in length and a few to tens of meters high.

Biotope

A biotope is defined as the combination of an abiotic habitat and its associated community of species. It can be defined at a variety of scales (with related corresponding degrees of similarity) and should be a regularly occurring association to justify its inclusion within a classification system.

Broad-scale

Generally used to describe a map that shows the distribution of broadly-defined habitat types over a relatively large geographic area. It is often used instead of the more technically correct mapping expression small-scale

(e.g. 1:250,000). Broad-scale also implies that the primary purpose of a map is to present an overview of a large area. As opposed to *fine-scale*.

Cartographic modelling

Cartographic modelling is a general, but well-defined methodology that is used to address diverse applications of GIS in a clear manner. It is a technique used for both vector and raster based GIS, and as the term suggests, cartographic modelling involves models (i.e. of geospatial information) represented in cartographic form (i.e. as maps). Cartographic modelling is used to simultaneously analyse both the spatial and thematic characteristics of geospatial information.

Cartography

The process of making an informative, clear and concise map from data layers at a certain scale that is fit for purpose. Cartography places limitations on what can be shown of the underlying data layers and this should be considered in the planning stages of the mapping process.

Class

A class is a set of entities grouped together on the basis of shared attribute values.

Continuous data can be sub-divided into ‘chunks’ or classes. For example, a measure of tidal stream strength might range from 0-15 but could be divided into three classes for easier comparison - Low (0-5.0), Medium (5.1-10) and High (10.1 – 16).Classes can be created from complex multivariate data (such as the list of difference species, their abundance, type of seabed and wave exposure data at a specific location) by grouping together locations with similar values for each variable. These classes are the data format is required for habitat maps.

Classification (as a process)

The process of sorting or arranging entities into groups or categories. A term commonly used to describe the process of interpreting remotely sensed data as habitat classes or, sorting biological samples with lists of species into habitat types.

Classification (habitat)

Systematic arrangement of habitats into more broadly defined classes on the basis of an analysis of their attributes; the arrangement is often repeated to create a hierarchy with broadly defined habitats at the top, sub-dividing into more and more detailed, narrowly defined classes further down the hierarchy.

Classification accuracy

A measure of how correctly a classified remotely sensed image matches the classes recorded on the ground by an independent standard or ‘ground truth’ sample set.

Community

An assemblage of species, dependent on each other, and constituting an organized system through which energy, nutrients, and water are cycled.

Confidence

A statement about how reliable a map user thinks the map is given its purpose. This is not a mathematical definition like accuracy or uncertainty, but is a judgement made by the map-user and may therefore vary for any map. However, this judgment can be supported by evidence from: accuracy measures; supporting maps show underlying evidence used to interpret map; an evaluation of all contributing data; and, independent validation using other data.

Expert opinion

User support: Generally found to be acceptable by stakeholders and the map has stood the test of time

Continuous surface

A feature that is not spatially discrete. The transition between possible values on a continuous surface is without abrupt or well-defined breaks. A continuous surface can be generated through interpolation of discrete data points.

Coverage (map)

A single thematic map, usually in the context of one of many layers in a GIS. A coverage can be a data layer or overlay, storing geographic features. In a coverage, features are stored as both primary features (points, arcs, polygons) and secondary features (tics, links, annotation). In the MESH context coverage is also taken to mean that the coverage is full (100% cover) over the survey area.

Coverage (surveying)

In a data collection context, coverage is also taken to mean that the actual area of a survey area for which remotely sensed data are available. For example, an aerial photograph may cover all the area (100% coverage) but a sonar survey may record along a series of non-overlapping corridors with gaps between resulting in only 50% coverage.

Deterministic (modelling)

A model in which the parameters and variables are not subject to random fluctuations, so that the system is at any time entirely defined by the initial conditions chosen. In a habitat mapping context, the data layers a selected and fixed so that the user can vary the model parameters to explore the relationship between the habitat type and the physical data layers in the knowledge that the physical data itself will not be changed by the modelling process.

DEM - Digital Elevation Model

A digital elevation model (DEM) is a digital representation of the ground surface topography or terrain. It is also widely known as a digital terrain model (DTM). A DEM can be represented as a raster (a grid of squares) or as a triangular irregular network. A DEM - sometimes also called a digital surface model (DSM) - generally refers to a representation of the earth's surface (or subset of this), including features such as vegetation, buildings, bridges, etc. The DEM often comprises much of the raw dataset, which may have been acquired through techniques such as photogrammetry, LiDAR, IfSAR, land surveying, and remote sensing techniques. DEMs are used often in geographic information systems, and are the most common basis for digitally-produced relief maps. (From Wikipedia)

DEF - Data Exchange Format

A Data Exchange Format (DEF) defines the characteristics of data to be exchanged between parties. These characteristics will typically cover the data format (e.g. ESRI shapefile), the geographic co-ordinate system used (e.g. Ordnance Survey of Great Britain), the attributes required (e.g. depth, seabed type, habitat class) and their format (e.g. habitat type – text data no longer than 20 characters; depth – numerical data with no more than 2 decimal places).

Direct mapping

When a user views at a remotely-sensed image of the seabed, they will be able to see patterns that reflect changes in the surface structure. For example, when a user views an aerial photograph, the surface structures are clearly visible. A user can draw polygon shapes around these surface features to encapsulate an area that ‘looks’ the same and can be truthed/interpreted as a habitat type. This process of drawing boundaries around habitat types is called direct mapping; it is also known as segmentation.

Discovery metadata

Basic information that should provide a sufficient description of a data set to enable the user to establish whether the data meet their requirement. Typically, discovery metadata will answer the ‘who? what? where? and when? questions’ for a dataset).Technically, the term discovery metadata refers to a high level set of metadata elements.

Discrimination (for habitat mapping)

The ability to distinguish two or more habitat classes. There are two main stages in the habitat mapping process where discrimination must take place to map habitats as separate entities. Firstly, the field sampling system must detect features which can be used to separate classes. Secondly, the classes must be capable of being separated by their response to remote sensors or by differentiated on the basis of physical variables.

DTM - Digital Terrain Models

A digital terrain model (DTM) is (generally) a filtered version of a Digitial Elevation Model (DEM) to remove all the features on/above the surface (buildings, forests etc). The DTM provides a so-called bare-earth model, devoid of landscape features. See *DEM - Digital Elevation Models*.

Empirical (modelling)

Based on experiment and observation but not necessarily on proven scientific data, or based entirely on practical experience.

Empirical models are developed using field observations and practical experience to produce maps that can be tested (by field samples or observations) to 'prove' their reliability.

Epifauna

Animals (fauna) that live on or attached to the surface of the seabed.

Error (in mapping)

A measure of how far a predicted value or class varies from observation of the real world.

ESRI Shapefile

A ESRI™ vector data storage format for storing the location, shape, and attributes of geographic features. A shapefile is stored in a set of related files and contains one feature class. Shapefiles spatially describe points, polygons and polylines. The term shapefile is generally used to mean to a collection of files with '.shp', '.shx', '.dbf', and other extensions on a common prefix name (i.e. 'habitat.*'). The actual shapefile relates specifically to files with the '.shp' extension; this file alone is incomplete for dissemination, as it depends on the other supporting files.

Exclusive

Belonging to a particular group and no other.

Faithful (Faithfulness)

Usually used in the context of how consistently a species occurs in a single habitat class, and therefore is typical or characteristic of that habitat.

Fine-scale

Generally used to describe a map that shows the distribution of detailed habitat types over a relatively small geographic area. It is often used instead of the more technically correct mapping expression large scale (e.g. 1:10,000). Fine-scale also implies that the primary purpose of a map is to explore the distribution of small features with a measurable degree of accuracy. As opposed to broad-scale.

Fuzzy classes

The continuous nature of descriptors is acknowledged by assigning observations a membership value (e.g. probability) to all classes.

Gap analysis

A review of the availability of suitable coverages of the various parameters needed to create a habitat map. Availability should be assessed in terms of spatial extent and type of data. All gaps in coverage should be clearly identified and a strategy developed to secure the necessary data.

Geographic Information Systems (GIS)

An integrated collection of computer software and data used to view and manage information about geographic places, analyze spatial relationships, and model spatial processes. A GIS provides a framework for gathering and organising spatial data and related information so that it can be displayed and analysed. GIS are generally much more powerful than computer assisted drafting (CAD), although the distinction between them is not well defined.

Georeferencing

Aligning geographic data (map features) to a known coordinate system so they can be viewed, queried, and analysed with other geographic data. Georeferencing may involve shifting, rotating, scaling, skewing, and in some cases warping, rubber sheeting, or orthorectifying the features so that they fit the co-ordinate system.

Ground truthing

Direct observations and samples of the seabed provide information that can be used to interpret remotely sensed images; the observations are the 'truth' with regard to the habitats actually present on the seabed. Observations used in this way provide ground truth data. The process of using ground truth data for interpretation is often termed ground truthing. During this process the relationship between properties of the remote images at the observation/sample sites (in the form of points, irregular digitised areas or buffer areas around points) is determined. These relationships are then applied to the whole image to predict the distribution of habitat types. Ground truthing is distinct from *ground validation*.

Ground validation

Observations can be used to test the predictive power of a habitat map. The validation dataset is displayed on top of the habitat map and the predicted habitat class is compared with the actual class from the validation observation. This is the basis for many measures of accuracy and uncertainty. The ground validation dataset should not be the one also used for ground truthing, although this rule is often broken when sample data are sparse.

Habitat

The use of the term 'habitat' in MESH means both the physical and environmental conditions that support a particular biological community together with community itself. Used synonymously with biotope

Habitat classification (including habitat detail)

The organisation of different habitats into specific class types. These classes can vary in their level of detail from broad descriptions (e.g. Shallow subtidal sand) to highly detailed descriptions that include specific organisms (*Zostera marina* seagrass beds on clean coarse sand in sheltered water less than 5 m). In general, detailed habitat types will be more geographically limited to small areas of the seabed.

Habitat classifications scheme

A habitat classification scheme can be defined as a structured system of habitat types (classes), often arranged in a hierarchy, where the types are clearly defined and recur in different geographical places.

Habitat map

A habitat map is a visualisation of our best estimate of habitat distribution at a point in time making best use of the knowledge we have available at that time.

Habitat suitability analysis

A habitat requires specific physical (and chemical) environmental conditions to support its biological community. Searching a maps of physical variables to find the specific environmental conditions to suit a habitat is called suitability analysis. In other words, the appropriateness of an area to support a particular habitat is determined.

A similar approach can be applied to find the suitable conditions to support an individual species.

Habitat suitability modelling

Habitat distribution is normally defined by multiple environmental variables (depth, light penetration, incident energy etc). Habitat suitability models bring together these multiple data layers to simultaneous select the most appropriate area and therefore predict habitat (or species) occurrence.

Hard or crisp classes

Classes are usually 'hard' or 'crisp' in that the continuous nature of the variable have been artificially divided up into a number of categories with 'boundaries' separating the categories. Hard classes are especially appropriate for multivariate data.

Heterogeneity

The amount of diversity (or variability) of a variable (e.g. sediment type) or class (e.g. habitat type) within a geographic area. In offshore areas, extensive sediment plains tend to dominate the seabed with little variability in sediment type – low heterogeneity. Shallow inshore areas are often a mixture of rocky outcrops, gravel beds and many sediment types depending upon the tidal streams and/or wave action – there is much variability over small areas leading to high heterogeneity. Heterogeneity has practical implications for mapping at two levels. Firstly, there is heterogeneity within the minimum mapping unit of a map in which case what is displayed on the map must either try to represent this diversity using a mixed class or display some measure of diversity or the map class must simplify the situation on the ground by showing the predominant class. Secondly, the map may show many small polygons of different classes clustered together in which case there is likely to be reduced confidence in the exact position of each class. The map shows what might be found in the general region.

Homogeneity

The extent to which attributes are similar within a region. It is the opposite to heterogeneity.

Hypothesis

A hypothesis consists either of a suggested explanation for certain facts or observations or of a reasoned proposal suggesting a possible correlation between multiple phenomena. Experiments, tests or observations are used to establish whether the (reasoned) explanation is correct.

Inferences

The process of drawing a conclusion from given evidence. To reach a decision by reasoning.

Infauna

Animals (fauna) that live in into the substrate. ‘Infaunal communities’ normally consist of animals burrowing into sediment). As opposed to epifauna.

Information

Information is loosely defined as data that have been given meaning through some form of interpretation

Interoperability

The ability of two or more systems, or components to exchange information, and to use the information that has been exchanged. It is commonly used to describe the sharing of data on the internet where a mapping website will draw data from another website to give context to its data; for example, a website may draw a coastal outline from a central repository rather than try to maintain its own copy.

Interpolation

The estimation of surface values at unsampled points based on known surface values of surrounding points. Interpolation can be used to estimate elevation, rainfall, temperature, chemical dispersion, or other spatially-based phenomena. Interpolation generates a continuous surface from a series of discrete individual points.

Interpretation

The process of giving data meaning through directed analysis an reasoned explanation. More specifically (for habitat mapping) it is the systematic application of signatures, classification systems, models and rules to spatial data sets to map the predicted distribution of features.

LiDAR - Light Detecting and Ranging

In the particular case of mapping, LiDAR is an airborne surveying technique which utilises the travel time of laser light to measure the altitude of the aircraft above the ground. When the aircraft has a level flight path, variations in the measured altitude are actually changes in the height of the ground. LiDAR is the airborne equivalent of sonar. Infrared light is adapted for ground detection whilst green light, due to its penetration ability through water offers a way to carry out clear water bathymetry surveys.

Large scale

Scale that covers relatively small area on the ground and has a higher level of detail in the map features. As opposed to small scale.

Layers

The visual representation of a geographic dataset in any digital map environment. Conceptually, a layer is a slice or stratum of the geographic reality in a particular area, and is more or less equivalent to a legend item on a paper map. On a road map, for example, roads, national parks, political boundaries, and rivers might be considered different layers. In ESRI™ ArcGIS, a layer is a reference to a data source, such as a shapefile, coverage, geodatabase feature class, or raster that defines how the data should be symbolised on a map.

Maps

A simplified depiction of a space, a navigational aid which highlights relations between objects within that space. A graphic representation of a parameter that can be used to derive information for a specific area.

Marine landscape

The concept is a broad-scale classification of the marine environment based on geophysical parameters such as sediment characteristics, morphology and hydrodynamics, recognising that these are important in determining the nature of biological communities.

Metadata

Data about data. For example, giving information about the characteristics and provenance of the data.

Metadata element

One of the pieces of information recorded in a metadata record. For example, the title of a data set is a metadata element.

Metadata standard

A set of metadata elements that are needed to describe a particular type of data. Metadata standards are usually defined by official standards organisations, but they can also be defined by an organisation or project for a specific purpose: the MESH metadata standard (www.searchMESH.net/metadata) are the set of metadata elements necessary to fully describe seabed habitat map data.

Minimum habitat unit (MHU)

This is the smallest size of a habitat, which although not precisely defined in the EUNIS classification system, is taken to be about 5 x 5m for marine habitats. Any feature smaller than this is regarded as an attribute of the habitat. Note that, whilst the MHU is well within the resolution of many remote sensing systems, it is unlikely that the MHU will correspond with the minimum mapping unit unless the map scale is very small.

Minimum mapping unit (MMU)

The smallest object size that is represented on a map (smaller objects being either ‘lost’ or subsumed into a larger unit). In a single thematic map, such as a habitat map, this will be the minimum size of any habitat class that can be represented on a map at any given scale. Note that this means the size of the MMU will change with scale. This is distinct from the minimum habitat unit (MHU).

Models and modelling

The dictionary definition of the term ‘model’ that is most closely related to habitat mapping is: a simplified representation used to explain a real world system. Therefore any map representation of the seabed based on a systematic investigation of remotely sensed data correlated to ground truth information can be regarded as a model. Modelling is the process by which data are simplified to produce the map. All maps should be regarded as predictive and require testing against the real world. Cartographic modelling and mathematical modelling provide a more rigorous basis for maps than conceptual models that are based on expert opinion. Cartographic & mathematical modelling are more reproducible since there is no element of subjectivity in the analysis. Models can be re-run with changed parameters based on new evidence.

Monitoring

Continuous or repeated observation, measurement, and evaluation of environmental or technical data according to prearranged schedules in space and time, using comparable methods for sensing and data collection. Monitoring is used to detect trends over time.

Near-bed stress

A shearing force per unit area exerted on the seabed by water movements above the seabed. It is a useful parameter to determine seabed disturbance arising from waves and from tidal or residual currents.

Pixel

The smallest unit of information in an image or raster map, usually square or rectangular, the four sides of a pixel encloses a small, homogeneous area. Pixel is often used synonymously with cell. In remote sensing, a pixel is the fundamental unit of data collection. A pixel is represented in a remotely sensed image as a cell in an array of data values. The term mixel is used where a pixel is known to consist of more than one habitat classes on the ground.

Polygon

On a map, a closed shape defined by a connected sequence of x,y coordinate pairs, where the first and last coordinate pair are the same and all other pairs are unique. In the context of a habitat map a polygon is taken to be homogeneous within that enclosed area (i.e. every point within the shape shares the same attributes).

A simple polygon (hexagon)

Precision

In habitat mapping, there is confusion between this term and accuracy. Precision can be defined as the variability between repeated measurements but this has limited application to habitat mapping. However, in habitat mapping its more general usage is to define the likely error of a boundary (e.g. ±100 m, ±10 m). It could also be applied to the level in a hierarchy that a record has been assigned to (i.e. a EUNIS level 4 class is less precise than a level 5 class).

Prediction (of habitats)

All habitat maps derived from classification and modelling are predictive because the actual habitat present on the seabed has not been observed/sampled at all points of the map. The mapped habitat distributions are based on statistical links, assumptions and hypotheses between the source data (from remote sensing) and the classes to be mapped (determined from ground truth samples). This underlying predictive nature of maps is often conveniently ignored, but all maps must be judged by their predictive power.

Predictive power

The ability of a map to correctly predict what will be found on the seabed in each minimum mapping unit of the map. Note predictive power need not only apply to the mapped class – the predictive power of a map could be widened to include (for example) rarer biotopes associated with the dominant mapped biotope.

Probability

A measure of the likelihood that a particular outcome, such as a spatial pattern or event, will occur given a set of possible outcomes. Probability values range from 0 for impossible outcomes to 1 for completely certain outcomes. The probability that a tossed coin will land heads-up, for example, is 0.5, since landing heads-up is one of two possible outcomes.

In a seabed habitat mapping context, it is possible to determine the probability of a single habitat occurring at every location in a map: those areas where the prevailing physical conditions are suitable for the habitat will lead to a higher probability of occurrence than areas that are clearly unsuitable. When individual habitat probability maps are overlaid, for each location it is possible to see the ‘most likely’ habitat (highest probably) to be found, followed by the next most likely and so on to the least likely habitat.

Proxy

In ecological research, a proxy (variable) is something that can be easily measured and is known to be a substitute for a variable that cannot be easily measure. Clearly, the relationship between the proxy (variable) and the real variable must be understood, and be consistent. For example, ocean surface colour recorded by satellite sensors is used as a proxy for water clarity from which the depth of light penetration may be calculated. Often, the proxy is probably not in itself of any great interest. .

Raster

A spatial data model that defines space as an array of equally sized cells (pixels)arranged in rows and columns, and comprised of single or multiple bands. Each cell contains an attribute value and location coordinates. Unlike a vector structure, which stores coordinates explicitly, raster coordinates are contained in the ordering of the matrix. Groups of cells that share the same value represent the same type of geographic feature. Many single map and multi-map operations in a GIS involve raster maths that are not possible with vector format layers.

Raster images

Raster format is a graphics image or data file representing a generally rectangular grid of pixels, or points of colour, on a computer monitor, paper, or other display medium. The colour of each pixel is individually defined; for example colour images often consist of coloured pixels defined by three values — one each for red, green and blue. Raster graphics are distinguished from vector graphics in that vector graphics represent an image through the use of geometric objects such as curves and polygons.

The quality of a raster image is determined by the total number of pixels (resolution), and the amount of information in each pixel (often called colour depth). Raster graphics cannot be scaled to a higher resolution without loss of apparent quality. This is in contrast to vector graphics being dimensionless, which easily scale to the quality of the device on which they are rendered.

Resolution

The smallest spacing between two display elements, expressed as dots per inch, pixels per line, or lines per millimetre.

Sampling sites

Areas (large or small) sampled or designated for sampling.

Sampling stations

Georeferenced locations at which samples are recorded/acquired from.

Scale

Is the ratio or relationship between the distance between two points on a map and the corresponding distance between the same two points on the earth's surface. A map scale of 1/100,000 or 1:100,000 means that one unit of measure on the map equals 100,000 of the same unit on the earth. For example, if two points are 10,000cm (100m) apart on land and 1cm apart on a map, the map's scale is 1:10,000. A small ratio (1:250,000) is a small scale and shows objects to be small. A large ratio (1:10,000) is a large scale and shows objects to be large. There is often confusion over these terms and, where possible, MESH uses the terms broad scale to indicate that the map scale is small and fine scale to indicate that it is large.

Sediment type

Sediment is solid fragmental material eroded, transported and deposited by wind, water or ice, chemically precipitated, or secreted by organisms. It forms in loose, unconsolidated layers. Sediment type varies according to various parameters, including lithology, particle size distribution, compaction / bulk density, cohesiveness, shell content, and moisture content. It reflects a history of erosion, transportation and accumulation in different sedimentary environments.

Site condition monitoring

'Condition' is the defined quality or status of the biological features at a site. Assessing the current status of the features against the defined standard is termed site condition monitoring. Repeating these assessments over time will establish whether any changes in status may be linked to any trends in the physical environment or human activities.

Small scale

A map scale that covers a relatively large geographic area and shows the map objects to be small. See map scale.

Smallest cartographic unit (SCU)

It the smallest polygonal element that can be drawn on a map; it determines the resolution of the map layer. It is linked to the scale of the map.

Spatial error

The distance of a map coordinate from its correct location on the earth's surface. Spatial error is a measurement of inaccuracy and may be derived from an error in the measurement of a coordinate in the field, an error during the map making process, or both.

Spatial precision

A measure of the variation in position that might be expected in a mapped object as judged against real position (this could be expressed as the number of significant decimal places of a measurement) or the size of the error envelope from a series of measurements of the same object.

Supervised classification

A method for classifying images whereby thematic classes are defined by the characteristics of pixels within an image that correspond to training areas in the field chosen to represent known features (e.g. habitats). Each pixel within the image is then assigned to a thematic class using one of several decision rules.

It is a major tool for integrating ground-truth samples and remotely-sensed images. The user supervises feature classification by setting up prototypes (collections of field sample points) for each feature, class, or habitat type to be mapped. During this process the relationship between properties of the remote images spatially associated with the sample sites (in the form of points, irregular digitised areas or buffer areas around points) are then applied to the whole image.

Swath width

It is the actual area of the seabed imaged by a remote sensor during one 'pass'. Side scan and multibeam sonars project a beam of sound out to either side of the vessel's towpath to ensonify a wide region of the seafloor. Both right and left sonar channels added together make up the swath. Swath width is dependent on the water depth and can also be changed by altering the range setting of the sonar device. Swath width is an important factor in determining the lane spacing of vessel tracks in achieving the desired coverage of the survey area.

A similar principle applies to airborne remote sensing devices (cameras, LiDAR etc) where the sensor images an area of the seabed. The area imaged will depend on the altitude of the aircraft and the range settings of the sensor. Coverage will depend on these settings and the flight path of the aircraft.

Thematic accuracy

The success of assigning an observation to a particular biotope or habitat class (confidence of the operator in their analysis). This is not the same as classification accuracy, though it is sometimes assumed to be so.

Thematic resolution

The level of detail (hierarchical level) of habitat classes depicted on a map, ranging from high level (broadly defined classes) to low level (finely defined classes).

Topology

Topology is the spatial relationships between connecting or adjacent features in a geographic data layer (for example, arcs, nodes, polygons, and points). In geodatabases, topology can define and enforce data integrity rules (for example, there should be no gaps between polygons).

Training sites

A defined area of an image where the habitat class is known (normally from ground truth sampling) that is used for gathering image data to derive the relationship (correlation) between the habitat class and image. This

relationship can then be used to seek other areas of the image that match and may be assumed to be the same habitat type. These original areas are 'training' the classification process.

Track spacing

The distance between two adjacent parallel survey lines is known as track spacing. See *Swath width*.

Truncation

The term used for reducing the number of digits right of the decimal point, by discarding the least significant ones.

Uncertainty

The degree to which the measured value of some quantity is estimated to vary from the true value. Uncertainty can arise from a variety of sources, including limitations on the precision or accuracy of a measuring instrument or system; measurement error; the integration of data that uses different scales or that describe phenomena differently; conflicting representations of the same phenomena; the variable, unquantifiable, or indefinite nature of the phenomena being measured; or the limits of human knowledge. Uncertainty is the opposite of confidence.

USBL - Ultra-short baseline

A position fixing method for establishing the real position of an instrument (towed camera, towed sonar fish, a diver) below a survey vessel. It uses a sonar transponder-responder fitted to the deployed instrument and a transceiver mounted on a vessel at a known and surveyed position below the water line. The direction of origin of received signal from the instrument mounted transponder-responder indicates the towed instrument position relative to the support vessel, while the time delay between transceiver emitted signal and transponder/ responder return signal provides its distance. Positioning of the vessel mounted transceiver is related by survey to the position of GPS antenna, enabling accurate positioning relative the GPS defined position of the vessel.

Vector

A GIS data format where objects are represented by a coordinate-based data model that represents geographic features as points, lines, and polygons. Each point feature is represented as a single coordinate pair, while line and polygon features are represented as ordered lists of vertices. Many attributes are associated with each vector feature, as opposed to a raster data model, which associates only one attribute with a grid cell feature.

Vector graphics

Vector graphics is the use of non-dimensional geometrical primitives such as points, lines, curves, and polygons, which are all based upon mathematical equations to represent images in computer graphics. It is used by contrast to the term raster graphics, which is the representation of images as a collection of pixels (dots) which represent a given surface on the ground.

XML

Extensible Markup Language (XML) files are often used for exchanging information, both on and off the Web. Like HTML (Hypertext Markup Language) files, XML files use start and end tags to format their content. However, XML tags define the structure of elements in a document, whereas HTML tags define how elements should look. XML is extensible because you can extend it by adding your own.

Appendix 1 Contents of the full version of the *MESH Guide*

What is habitat mapping?

- Habitat mapping in MESH
  - Stages in habitat mapping
  - Other types of habitat map
- Why do we need habitat maps?
  - Generic need for habitat maps
  - Key policy drivers
  - Further uses for habitat maps
- What are habitats?
  - Defining a habitat
    - The biotope concept – a relationship between species and their environment
    - Related scientific terms
    - Legal and policy use of the term habitat
  - Why do we need to classify habitats?
  - What is a habitat classification scheme?
    - What classification schemes are available?
    - EUNIS marine habitat classification
    - National classification schemes
    - How are the 'legal and policy habitats' related to EUNIS?
  - What is the size of a habitat?
    - Boundaries and continua in the marine environment
    - Defining habitats at differing levels of detail – a hierarchy
    - Landscapes and habitats – different approaches to classification
- What do you want to map?
  - What is broad-scale and fine-scale habitat mapping?
    - Nested maps of different scales
  - What are the smallest habitat areas you can map?
    - Technical reasons why some habitats may not be mapped
    - Resolution in remote sensing terms
    - Limits to interpretation
    - Cartographic limitations [for vector maps]
    - Limitations of raster thematic mapping?
    - Scale, resolution and the SCU
- How do you map habitats?
  - What are the approaches to habitat mapping?
  - What data do you need for habitat mapping?
    - Rocky substrata
    - Soft substrata
- What are the limitations of habitat mapping?
  - Heterogeneity and aggregating data
  - Using data collected but not mapped
  - How much confidence can we place in habitat maps?
  - Temporal change and mapping as a long-term process
- Data management
  - Recording metadata– a journey from inception to maps and beyond
- How do you plan for habitat mapping?
  - What are the stages in habitat mapping?
- Summary

What do I want to map?

- Scope the mapping programme

- The Scoping Process
  - About MESH Scoping Tool
  - MESH Scoping Tool
- The Scoping Report

Determine the Information Gaps
- The Gap Analysis
  - What data does EUNIS use?
  - Data availability
  - Data quality
  - Data compatibility
  - Data coverage
  - Data limitations

Specify new survey work
- Basic survey strategy
- Sampling tools and techniques
  - 3-D seismic imagery
  - Suitability of survey tools
- Remote Sensing survey strategy
  - Remote sensing in shallow water
  - Partial coverage acoustic surveys
- Ground-truth survey strategy
- Survey specification

Optimise the Remote Sensing
- Suites of remote sensing instruments
  - Suites of acoustic techniques
  - Suites of airborne techniques
- Ground Validation

Optimise the ground-truthing
- Ground-truthing requirements (Physical & biological samples)
  - Physical information from ground-truthing
  - Biological information from ground-truthing
- Selecting a suite of survey tools
  - Complementary ground-sampling techniques
- GT Survey Design
  - Intertidal ground-truth surveys
  - Subtidal ground-truth surveys

Conducting surveys

How do I collect my data?

Why do I collect mapping data in a standard way?

Technical expertise required for undertaking surveys

Recommended Operating Guidelines (ROGs) for habitat mapping
- Structure of a ROG and considerations
- Remote sensing techniques
  - Aerial photography
  - Airborne digital imagery
  - Satellite imagery
  - LiDAR
- Acoustic techniques
  - Single beam echo sounder
  - Echo sounder and ADGS
  - Swath systems
  - Sidescan sonar

Sub bottom profilers
3-D seismic imagery
Benthic sampling techniques
Grab sampling
Box coring
Trawls and dredges
Intertidal surveying
Subtidal surveying using divers
Techniques for physical samples and geotechnical measurements
Geotechnical measurements
Underwater video and imaging techniques
ROG List
Using techniques in combination
Airborne sensors
Acoustic techniques
Other common combinations of techniques
Survey data: organisation and metadata requirements
Organisation of survey data
A MESH model for structuring survey data
Metadata – vital information about the data
Survey metadata – recommended standards
Data cleaning and basic processing
Data cleaning
Positional corrections
Tidal height corrections
Acoustic techniques
Multibeam echo sounder and single beam echo sounder
Benthic sampling techniques
Quality assurance of field identification, using the reference collections
Sediment analysis
Underwater video and photographic imaging techniques
Sediment Profile Imagery
Conclusions

How do I make a map?

Determine the strategy
Modelling in habitat mapping
Optimise the ground-truth analysis
Route to classifying your records
Habitat Matching Program
Applying an existing classification scheme
Defining survey-specific habitat classes
Patterns in biological data
Patterns in physical data
Correlate biological and physical patterns
Determine major characteristics
Match classes with classification system
Amalgamating data
Optimise the physical coverages
Where do coverages come from?
Transforming data
Expert-eye analysis of remote-sensing data
Transformation of acoustic backscatter images

- Deriving optimal data coverages
- Combining data
  - Marine landscape mapping approach
- Optimise the map making
  - Matching biological habitat classes
  - Direct mapping
    - Habitat signature catalogue
  - Statistical modelling
    - Supervised classification using image-processing tools
  - Examples of map making
    - Examples of broad-scale maps for large areas
    - Examples of fine-scale maps for small areas
    - Examples of intermediate scale maps
- Design of the habitat map
  - Making electronic maps using GIS
    - Tools to check and edit map data
  - Map layout

How good is my map?

- What is accuracy?
  - What do we mean by accuracy and inaccuracy?
  - Why are maps inaccurate?
    - Sources of uncertainty
  - Errors can multiply!
- How can I assess the accuracy of my map?
  - Summary statistics for accuracy and error
  - Ground truth, ground validation and the map-makers' dilemma
  - Mapping the confusion between classes – 'fuzzy' maps
  - Can I map uncertainty?
  - Statistical correlation techniques
  - Partitioning techniques
- How do I interpret my accuracy assessment?
- How much confidence should I put in a map?
  - Is there a structured way to assess confidence?
- The MESH Confidence Assessment Scheme
  - Design of the MESH Confidence Assessment
  - Selection and scoring of confidence factors
    - Data collection: Remote sensing factors
    - Data collection: Ground truthing factors
    - Interpretation factors
  - MESH Confidence Assessment Tools
    - Displaying confidence on the MESH webGIS
- How do I interpret a confidence assessment?

What can I do with my map?

- Using maps
  - Case studies on the use of habitat maps
    - Case Study 1: Sound of Arisaig candidate Special Area of Conservation - UK Marine SACs Project
    - Case Study 2: Eastern Channel Regional Environmental Assessment and monitoring for aggregates
    - Case Study 3: Assessment of human pressure on seabed features
    - Case Study 4: A Marine Spatial Planning Scenario - Tidal Stream Energy
    - Case Study 5: Using habitat maps for fisheries management

- Case Study 6: Sea Fisheries and the Flamborough Head European Marine Site
- Case Study 7: Mapping seabed and water column features of UK seas - UKSeaMap
- Understanding stakeholder perception of maps
- Making use of habitat maps beyond their original purpose
  - Data archiving

Describing maps
- What are metadata?
- Why collect metadata?
- Do I need to build a metadata catalogue?
  - Decision process
  - Metadata levels
- Do I need to develop a new metadata standard?
- How do I build and populate my metadata catalogue?
- How can I share my metadata with others?

Contributing maps
- Why contribute data?
- How do I contribute my data?
- Data exchange formats
- Further data processing
  - Spatial reference systems
  - Choosing file names
  - Topology
- Data agreements

Converting maps
- Why should I translate maps?
- Can I translate my map?
- The translation process
  - Using supporting data
  - Translation relationships

Combining maps
- Overlapping maps
- Maps for different scales
  - Summarising habitat classes
  - Automated raster filtering

Sharing maps on the internet
- Contributing to an existing mapping website
- Building a mapping website
- How do I combine my maps with others on the internet?
  - Geospatial interoperability