



# INFOMAR data supports offshore energy development and marine spatial planning in the Irish offshore via the EMODnet Geology portal

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**Abstract:** The characterization of the seafloor is a fundamental first step in informing resource management, marine spatial planning, conservation, fisheries, industry and research. Integrated Mapping for the Sustainable Development of Ireland’s Marine Resource (INFOMAR), Ireland’s national seabed mapping programme, delivers freely available, high-resolution seabed imagery derived from multibeam echosounder data in the Irish Exclusive Economic Zone. The European Union established the European Marine Observation and Data Network (EMODnet) Geology data portal, which provides harmonized broad-scale seabed substrate information for all European seas and confidence assessments of the information that underpins the geological interpretations. A multi-scale product has been produced using INFOMAR’s high-resolution seabed substrate information at the 1:50 000 scale. As part of the Supporting Implementation of Maritime Spatial Planning in the Celtic Seas project, the EMODnet Geology seabed substrate data portal assisted in addressing the challenges associated with the implementation of the European Union’s Marine Spatial Planning Directive. The seabed substrate data in the EMODnet Geology data portal were identified as a valuable tool for guiding the selection of sites for offshore wind farms in the Irish Sea and their subsequent characterization. This paper outlines the approach to delivering a multi-scale seabed substrate dataset for the Irish offshore and its applicability to marine spatial planning and the development of offshore energy resources.

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In an era where a commitment to map the bathymetry of the entire seafloor by 2030 is considered feasible (Mayer *et al.* 2018; Wöfl *et al.* 2019), it is no surprise that mapping the geological characteristics of the seafloor has witnessed its own advances in data acquisition, processing, analysis and dissemination. Autonomous and unmanned aerial, surface and underwater survey platforms and remote survey techniques (e.g. satellite-derived bathymetry, crowd-sourced bathymetry and artificial intelligence) are revolutionizing data collection, processing, analysis and presentation. Technological capabilities in acoustic survey techniques, in particular the multibeam echosounder (MBES), have enhanced survey productivity and it is now cost-effective to image large areas of the seafloor to provide baseline data for understanding the marine environment, including the surficial geology (Todd *et al.* 1999; Brown *et al.* 2011a). High-resolution backscatter data from modern MBES systems are equal, if not better, than side-scan sonar backscatter data (Le Bas and Huvene 2009), with the added benefit of the ability to acquire bathymetric data.

Policies such as the Marine Strategy Framework Directive (MSFD) (2008/56/EC) and the Marine Spatial Planning Directive (MSPD) (2014/89/EU) highlight the importance governments place on protecting and sustainably managing the marine environment. In 2017, amendments to the MSFD placed an emphasis on better linking the MSFD’s 11 descriptors to components of the ecosystem,

anthropogenic pressures and their impacts on the marine environment. One such descriptor is seafloor integrity, which references the physical loss and disturbance of the seabed and highlights the importance of understanding the extent of broad types of benthic, or similar, habitats. In terms of regulating activities involving the seafloor, the science that underpins better management relies on understanding the distribution of sediments, which informs the benthic resources. A recent assessment of the MSFD recommended cooperation between European Union (EU) Member States across regions and a more coherent and comparable set of environmental status criteria and standards. As a result, pan-European marine data initiatives, such as the European Marine Observation and Data Network (EMODnet) ([www.emodnet.eu](http://www.emodnet.eu)) and the European Global Ocean Observing System (EuroGOOS) (<http://eurogoos.eu>), which foster better integration of the available information and ocean observations, have been developed to ensure long-term, sustainable access to data to address societal challenges.

The Integrated Marine Plan (Government of Ireland 2012) is the Irish Government’s strategy to sustainably manage Ireland’s vast and diverse marine resources. The plan sets out the goals to achieve this through developing a thriving marine economy, focusing on healthy ecosystems (e.g. food, climate and well-being) and engaging with the sea in terms of maritime heritage and increasing the value of the marine environment. In direct terms, Ireland’s ocean

wealth is based on developing sea fisheries, shipping, aquaculture, tourism and leisure, renewable energy (wind, wave and tidal power), marine information and communications technology, and biotechnology, together with ensuring that ecosystems, habitats and species are protected. In an economic context, recent figures indicate that Ireland's ocean economy was valued at €6.23 billion in 2018, with an estimated 34 000 people employed in the sector (SEMUR 2019). Reliable data providing knowledge about the marine environment and how we make use of it is therefore essential.

The process towards the detailed mapping of Ireland's seafloor is currently implemented through Ireland's national marine mapping programme, Integrated Mapping for the Sustainable Development of Ireland's Marine Resource (INFOMAR), funded by the Department of Communications, Climate Action and Environment (DCCA) and jointly managed by the Geological Survey Ireland and the Marine Institute. Prior to INFOMAR, the Irish National Seabed Survey (INSS), funded by the Government of Ireland (through the then Department of Marine and Natural Resources), acquired and processed MBES, sub-bottom seismic reflection, gravity, magnetic and ancillary geological and water column data. The primary aim of the INSS was to enable data acquisition in the entire Irish offshore area on a phased basis. To achieve this, the area was divided into three zones: Zone 3 (water depth 200–4000 m); Zone 2 (50–200 m); and Zone 1 (0–50 m). The deep water mapping in Zone 3 had been completed by 2003 and mapping in Zone 2 was underway, with a proposal to continue mapping Zone 2 until 2006. At the same time, a feasibility study was commissioned to identify and prioritize the mapping requirements of a comprehensive inshore mapping programme (Zone 1) and to address the range of competing socioeconomic activities occurring close to the coast. The feasibility study recommended that several key products could arise from mapping the commercially valuable inshore areas, one such product being data and maps illustrating 100% coverage of acoustic backscatter data to identify the type of seabed bottom (Parsons *et al.* 2004). Following an extensive stakeholder consultation process to identify priority areas for mapping, 26 priority bays and three coastal areas were selected. INFOMAR was launched as Ireland's new programme for seabed mapping in 2006. A strategy for mapping had been prepared after a lengthy and detailed preparatory phase, which included commissioned research, independent assessment and extensive consultation with stakeholders (INFOMAR 2007).

The focus of the INFOMAR programme since 2006 has been in Ireland's nearshore territory, with the overall aim of providing comprehensive marine datasets to underpin Ireland's Blue Growth economy across multiple sectors, along with compliance with Safety of Lives at Sea obligations and government policy. This is being delivered through baseline mapping of the seabed in the nearshore (0–50 m) and remaining 50–200 m depth area, thus completing the mapping of the entire Irish offshore. Since its initiation, the programme has supported the attainment of national and European policy objectives and regulatory obligations and is considered to be a key enabler of marine decision support tools as critical inputs to the MSPD and to infrastructural development, as cited in Ireland's Integrated Marine Plan, *Harnessing Our Ocean Wealth* (Government of Ireland 2012). Data from the programme are presented in the INFOMAR web portal and all the data are freely and publicly available ([www.infomar.ie](http://www.infomar.ie)).

The programme is being delivered over 20 years in two phases. Phase 1 took place between 2006 and 2016, followed by Phase 2 with the aim of delivering seabed mapping data for the entire Irish offshore area by 2026. Hydrographic and seabed sediment classification maps – which are required to underpin economic growth in several sectors e.g. fisheries and aquaculture, coastal protection and engineering works, environmental impact assessments, marine spatial planning (MSP) and foreshore licensing

activities – were considered to be key targets for evaluation in a previous programme review (Price Waterhouse Coopers 2013).

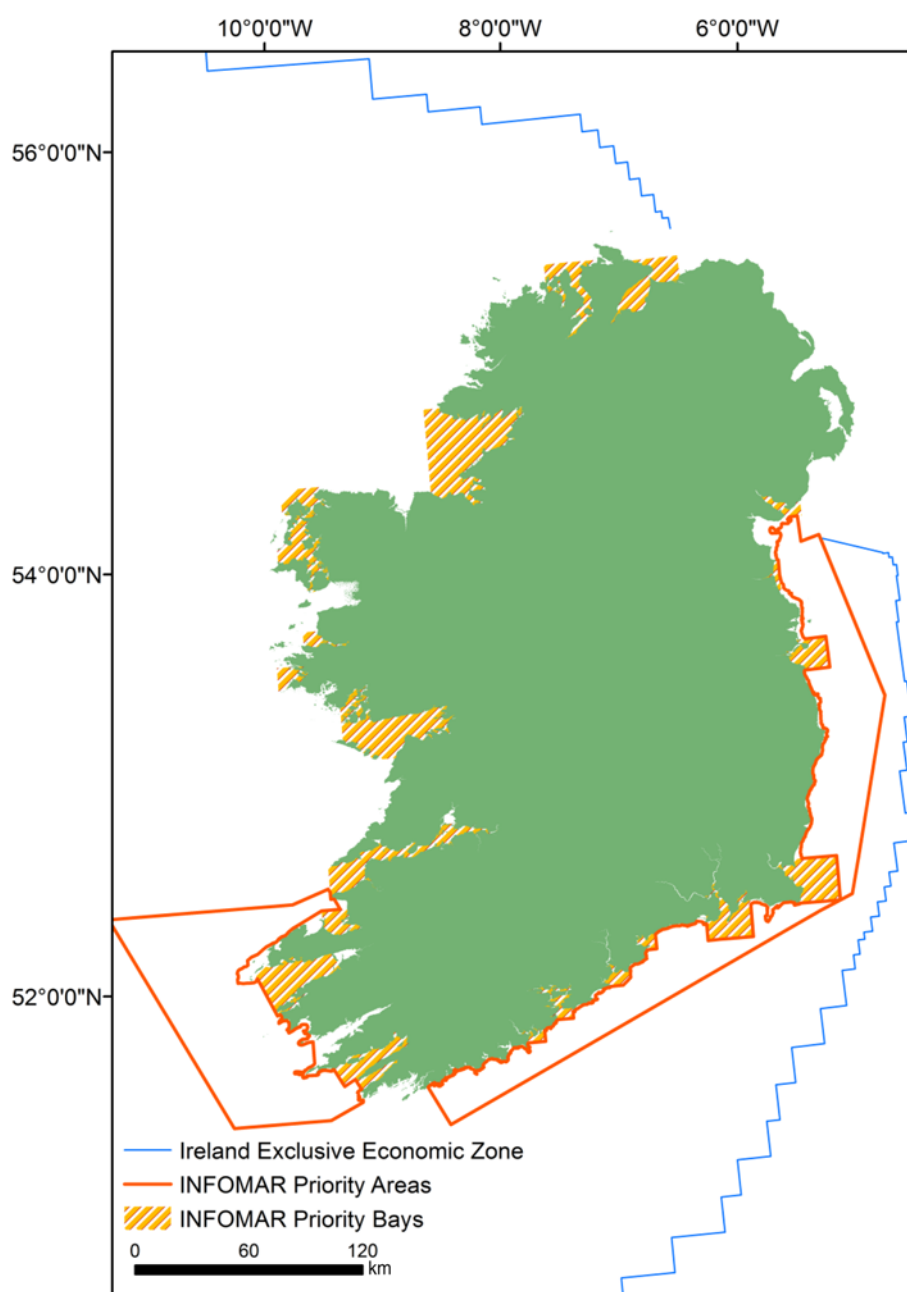
Sediment classification maps were identified as a key deliverable for each of the 26 priority bays and three priority areas around the Irish coast (Fig. 1). Sediment classifications have also been prepared for a number of areas at the request of stakeholders. Examples include physical habitat maps for fisheries management, such as the monitoring and assessment of scallops off the SE coast of Ireland (Tully *et al.* 2006; O'Keeffe *et al.* 2007) and an inventory of herring spawning grounds (O'Sullivan *et al.* 2013).

MBES technology has gained popularity over the past two decades as a widely used technique for the characterization of the seafloor (Kostylev *et al.* 2001; Galparsoro *et al.* 2010; Lamarche *et al.* 2011; Micallef *et al.* 2012; Diesing *et al.* 2014; Brown *et al.* 2019). Sound energy from a transducer travels to the seafloor, ensonifying the area below and acquiring information on bathymetry (water depth) and backscatter (the hardness of the seafloor). The analysis of backscatter data has a broad range of applications and these data can be used as an effective proxy for seafloor characterization, including the hardness of the seafloor and the properties of surficial sediments. Backscatter data are routinely used to classify the physical environment of the seafloor and to give an indication of the distribution of sediments.

MBES imagery has proved crucial in providing detailed geological maps of areas from the deep ocean (Huvette *et al.* 2011) to the continental shelf (Todd *et al.* 1999; Brown *et al.* 2011a; Todd and Kostylev 2011) and nearshore areas (Galparsoro *et al.* 2010). Backscatter data also provide information on seafloor hardness, which has applications in substrate classification and habitat mapping, where the spatial patterns of benthic habitats and biodiversity can be observed at continuous scales (Kloser *et al.* 2010; Brown *et al.* 2011b; Micallef *et al.* 2012). The usefulness of MBES bathymetry data to calculate terrain analysis descriptors (e.g. the benthic position index and slope and terrain ruggedness) as an approach to characterize the seafloor and identify small and large seabed features is widely recognized (Dartnell and Gardner 2004) and such calculations can be used to infer benthic habitat and biological diversity (Wilson *et al.* 2007; Guinan *et al.* 2009; Tong *et al.* 2012).

The combination of MBES bathymetry and backscatter data in conjunction with ground truth or *in situ* samples provides a robust means of producing maps of the surficial geology (Diaz *et al.* 2004; Galparsoro *et al.* 2010; Todd and Kostylev 2011). The key to the creation of such maps is the ability to segment or classify the MBES data into acoustic classes. Shaded relief bathymetry data can be used to delineate bedform features, such as rock outcrops and rocky reefs. Segmentation of the backscatter data (Brown *et al.* 2011a) can be applied in instances where seabed features are distinct and there are sharp demarcations between neighbouring substrate types (i.e. those representative of rocks and muddy substrates). Edwards *et al.* (2003) show how backscatter intensities are used as a qualitative descriptor to identify different types of substrate.

For the last ten years, INFOMAR has contributed seafloor substrate data to the EMODnet Geology project, initiated by the European Commission in response to the EU's Green Paper on Future Maritime Policy (European Commission 2006), which identified the fragmented and inaccessible nature of marine data resources across Europe as limiting economic growth and development in the marine sector. At the core of the EU's Integrated Maritime Policy lies the Blue Growth initiative to identify the potential for the exploitation of technological developments to create smart and innovative applications. EMODnet aims to make marine data, metadata and data products available to public and private organizations and to facilitate integrated approaches and investment in sustainable maritime activities. The EMODnet consortium connects over 170 organizations, which work together to provide improved access to quality-assured, standardized and



**Fig. 1.** Priority bays and areas designated under the INFOMAR programme.

harmonized marine data and make the information freely available as interoperable data layers and data products.

The EMODnet infrastructure includes seven thematic portals (Bathymetry, Geology, Seabed Habitats, Chemistry, Physics, Biology and Human Activities) that have made their data freely available online and accessible through the Central Portal ([www.emodnet.eu/portals](http://www.emodnet.eu/portals)). The Central Portal is the hub for all EMODnet services, data and information and delivers the latest data and products. More recently, the release of the EMODnet Geoviewer ([www.emodnet.eu/geoviewer/#/](http://www.emodnet.eu/geoviewer/#/)), which contains layers from every thematic portal, allows the visualization of multiple datasets in combination. EMODnet Geology consists of the marine departments of the geological surveys of Europe (through the Association of European Geological Surveys or EuroGeoSurveys), along with national organizations with responsibility for marine geological mapping. EMODnet Geology is delivering a pan-European seabed substrate map based on information from remote sensing (e.g. side-scan sonar, single- and MBES and seismic surveys) and sampling methods (e.g. grab sampling and coring) and the initiative is being developed through a stepwise approach in

three phases (Kaskela *et al.* 2019). The first phase (2009–12; ur-EMODnet) was developed as a prototype delivering data for a limited selection of European sea areas at low resolution (1:1 000 000 scale). The second phase (2013–16) saw an extension to the sea areas covered and improved data resolution, whereas the third phase (2017–19) prepared a multi-resolution map of the entire European sea area. The project is currently in its fourth phase.

### INFOMAR approach to sediment classification

As a result of the broad range of depths in the Irish Atlantic offshore, from shelf depths (<200 m) to the deepest depths (*c.* 4500 m), the differences in spatial resolution and data density used to determine the seabed type are constrained primarily by water depth and the survey characteristics. In shallow water, MBES has the ability to acquire a higher density of soundings and narrower beam prints, improving data resolution and achieving a resolution of up to 20 m × 20 m. In deeper waters (>4000 m), with a lower density of data and larger beam prints, the resolution is close to 200 m × 200 m.

Methods have been developed and tested to segment and classify MBES data. Data acquired in selected areas during the INSS were classified using a semi-automated image-based approach with Quester Tangent Corporation (QTC) Multiview software to produce high-resolution seabed classifications for selected areas. QTC Multiview provides an automated statistical approach to seabed classification of the acquired MBES data. The software uses statistical algorithms to generate >130 statistical features for each image patch and principal components analysis identifies the linear combinations of features that best describe the variance in the data (Preston 2009). The QTC system provides new insights, but the usefulness of the acoustic classification depends on the amount and quality (and extent) of the ground truth data, which is a key aspect when relating acoustic class to seabed type. The Porcupine Bank, lying west of Ireland in water depths between 150 and 500 m, was mapped in detail, resulting in high-resolution MBES data, and classification was carried out with QTC Multiview software (O'Toole and Monteyts 2010).

Expert interpretation classification has been applied to morphologically complex areas with distinct acoustic classes (e.g. the offshore west of Ireland). Different seafloor types require different approaches. Homogenous seafloors dominated by soft sediment with little variation in morphological features can benefit from semi-automated classification approaches – for example, object-based analysis software such as eCognition (Diesing *et al.* 2014). Manual interpretations can provide optimum solutions in complex areas where expert geological knowledge is required, but tend to be subjective, time-consuming and not repeatable. By contrast, new developments in semi-automated backscatter classification software tested in recent years (Brown and Blondel 2009; Preston 2009; Brown *et al.* 2011a) offer an objective method for the segmentation of acoustic backscatter data into acoustically similar characteristics.

As Phase 2 of INFOMAR commenced, a sediment classification working group was assigned to review the existing sediment classification maps to assess which priority areas required further work and their status. In the years leading up to this review, seabed classification maps had been prepared for selected coastal and offshore areas at broad scales as a result of INFOMAR's partner role in European projects, such as EMODnet Seabed Habitats, which includes all the data collated as part of the Mapping European Seabed Habitats (MESH) and MESH Atlantic projects, and EMODnet Geology (Kaskela *et al.* 2019). The review included an assessment of the available sediment classification maps, at both broad and fine scales, to determine where improvements could be made. These included the integration of new ground truth data made available since the first iteration of the map to improve the overall confidence. In parallel, the MBES backscatter products for each survey leg were reviewed and improved where necessary, making use of more modern algorithms such as Geocoder (Fonseca and Calder 2005). New backscatter mosaics were created as part of this review and were integral to the delivery of fine-scale sediment classification maps. As a result of the review, a priority was placed on producing fine-scale seabed classification maps for the bays where sediment classification maps were absent.

The production of fine-scale seabed classification maps requires not only acoustic measurements (multibeam or side-scan sonar coverage), but also direct observations (e.g. sediment samples or underwater videos). Seabed samples are crucial in verifying substrate interpretations in the preparation of seabed classification maps and provide greater confidence in the substrate map. Sediment sampling on survey legs requires additional time and resources and the spatial extent of INFOMAR ground truthing data for a number of the priority bays varies greatly. In line with the requirements to deliver data to the EMODnet Geology initiative, the working group adopted a modified Folk sediment classification (Fig. 2), establishing that the classes (e.g. mud, sand and gravel) can only be named as

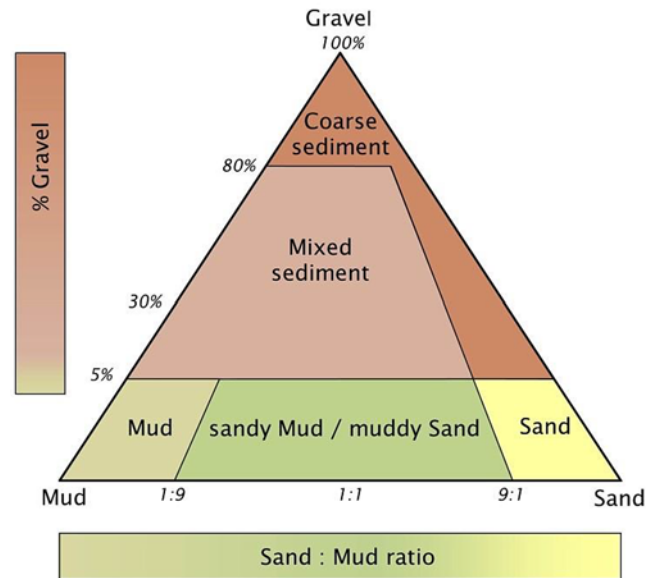


Fig. 2. INFOMAR Folk 7 classifications.

such if their content meets or exceeds 90%, as per the Folk 7 classification.

Although there is no single widely accepted approach to classify sediment distribution, it is generally agreed that the strategy taken is influenced by the quality of the available acoustic data and the physical characteristics of the site. One approach clusters the backscatter data into similar acoustic classes (Brown and Collier 2008; Ierodiaconou *et al.* 2011; Calvert, *et al.* 2015) and the technique involves two steps: auto-classification (image analysis) and expert interpretation. These classes are ground truthed using sediment samples to identify the sediment type. Areas of seafloor with heterogeneous sediment types are much easier to characterize using this technique than homogenous regions. As a result of the high quality of the bathymetric data, rocky areas are manually delineated from the shaded relief imagery. The result is a high-resolution, topologically clean substrate map for seamless integration to spatial datasets in cross-border applications.

Object-based image analysis has been used by INFOMAR to carry out seabed classification. The object-based image analysis approach applies a two-step process consisting of segmentation and classification. During the segmentation step, the image is divided into meaningful objects of variable sizes based on their spectral and spatial characteristics. The classification is determined by user-specified combinations of features in the image (Diesing *et al.* 2014). MBES data from the Malin Shelf has been classified using the object-based image analysis software eCognition.

An alternative approach was applied to classify the sediments in Dingle Bay. A backscatter mosaic with associated backscatter statistics was produced using Quality Positioning Services - Fledermaus Geocoder Toolbox (QPS-FMGT). The mosaic was segmented using eCognition software. Grouping analysis of the backscatter statistics was then performed (*k*-means-clustering). The backscatter statistical classes were applied to ground truthing data for quality control of unsupervised backscatter image classification. Backscatter statistical classes were then assigned to the segmented backscatter mosaic image and the statistical ground truthing data were used to assign sediment types to the backscatter statistical classes.

### Translation of Irish data for a European substrate map

Irish substrate data have been submitted to EMODnet Geology by delivering a variety of marine geological data and metadata. Data sourcing in the Irish context identified all seabed substrate datasets



detailing their origin – that is, from manual interpretation or the (semi-) automatic interpolation of acoustic data – as well as sediment sample descriptions and analyses. In addition, attribute information detailing the survey methods (e.g. MBES/side-scan sonar/LiDAR/aerial), the scale of the original data/map and the grain size (with reference to a grain size classification system (e.g. Folk or Wentworth) was submitted. In the case of the seabed substrate data, where information on seabed type is collated for all European sea areas, the extensive associated metadata includes information on the remote sensing methods used, along with the sampling methods and interpretation and modelling methodologies. EMODnet Geology provides, for the first time, a detailed geographical information system layer of seabed substrates for the European maritime areas. Delivering Irish substrate data involved the following steps: (1) the provision of an index map of the available data; (2) data harmonization; (3) data generalization; (4) data compilation; and (5) confidence assessment.

Harmonization of the INFOMAR data included the classification of the original data by translating national seabed substrate data into the EMODnet Geology classification scheme using the modified Folk sediment classification (Fig. 3). The classification, with three granularities of 15, six and four classes, each with an additional ‘rock and boulders’ class, allowed the INFOMAR data to be readily translated to the EMODnet Geology Folk scheme, with reclassification of the original national datasets that had not previously been classified using the Folk sediment classification (Kaskela *et al.* 2019). Where the national data were more detailed, the data were then generalized to the target scale using the Generalization toolset in ArcGIS’s Spatial Analyst toolbox following the procedure of Hyvönen *et al.* (2007). During the first phase of EMODnet Geology, seabed substrate data from the northern sea areas were

compiled at a 1:1 000 000 scale. Phase two produced a 1:250 000 map for all European seas and the low-resolution map was updated with data from the southern European sea areas.

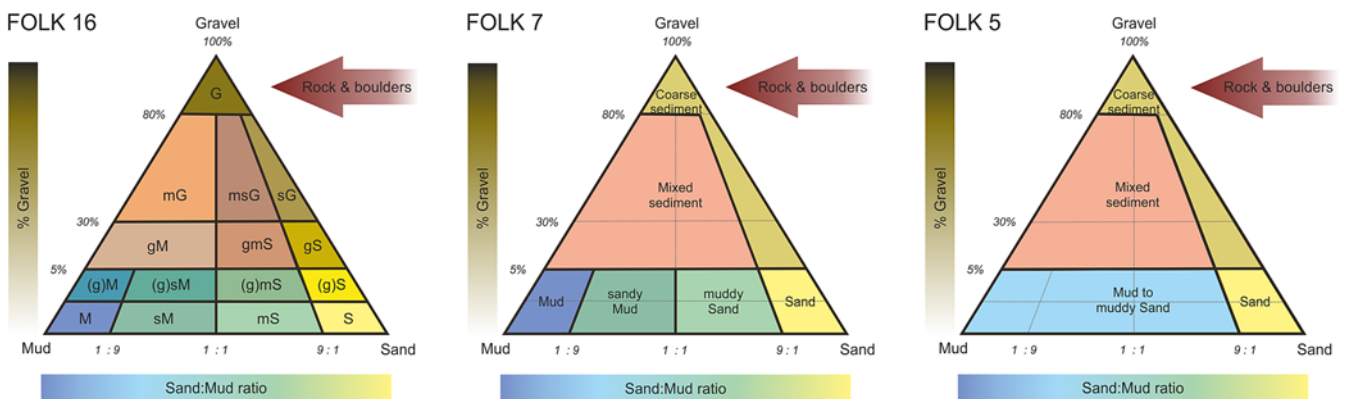
**Confidence assessment**

A confidence assessment was applied to provide the map user with a greater understanding of the origin of the data used to prepare the map. The assessment examines the certainty/uncertainty in the input data and the robustness of the analytical process. The mapped confidence then reflects the amount of information from seabed samples and the available acoustic data and contributes to the classification. A confidence assessment was applied to the submitted INFOMAR data and reflects the amount and type of data contributing to the development of sediment classifications (e.g. seabed samples and acoustic data) for the surveyed area. Specifically, the confidence decision tree used to assign a confidence score is based on the remote sensing coverage, the distinction of class boundaries and the amount of sampling (Kaskela *et al.* 2019).

**Results**

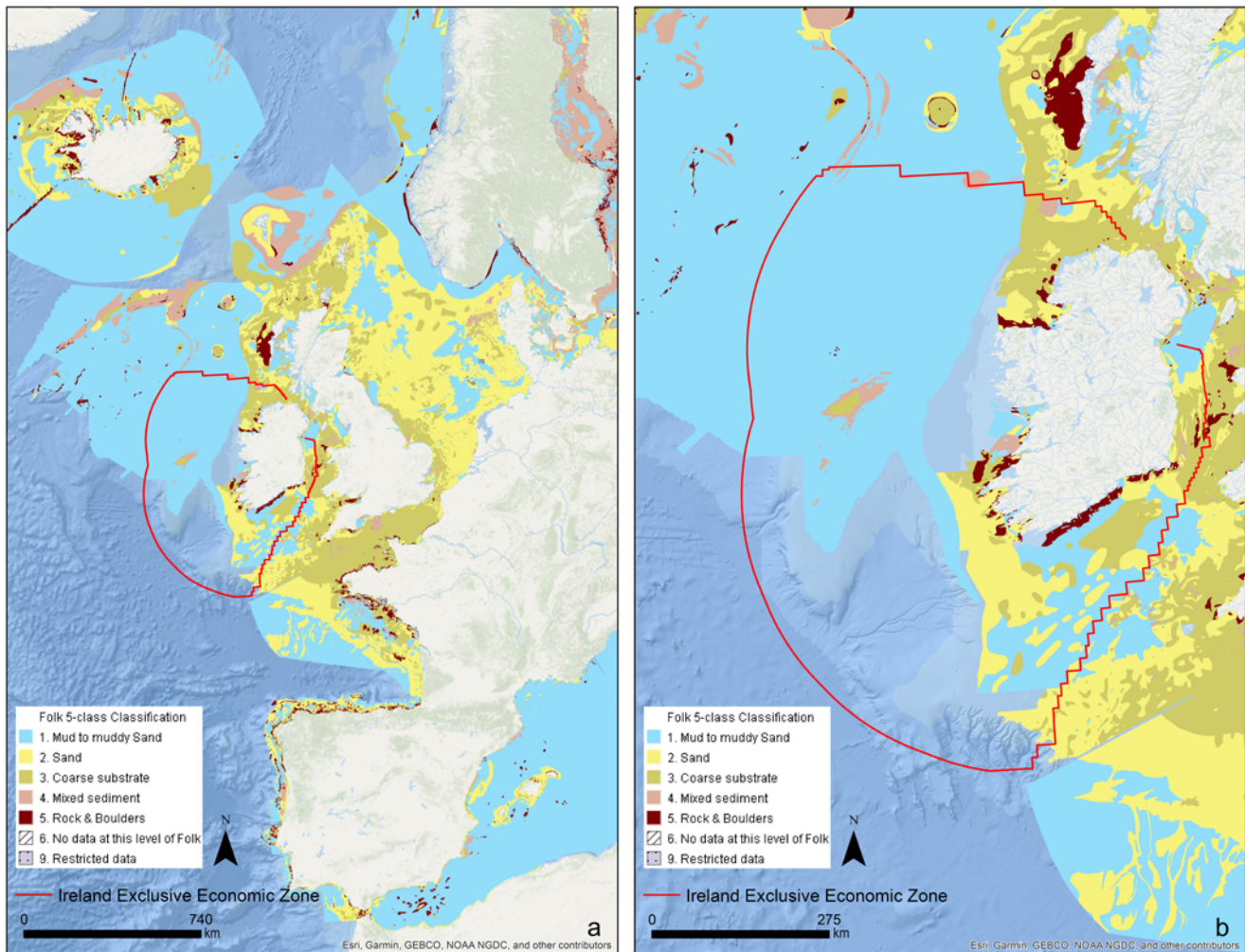
**Irish sediment classification data in a European context**

Irish seabed substrate data and associated metadata are for the first time presented in the context of a multi-resolution pan-European map. All the data are freely available via the EMODnet Geology data portal ([www.emodnet-geology.eu/](http://www.emodnet-geology.eu/)). Figures 4 and 5 show the seabed substrate data products with a hierarchy of five classes (Folk 5) at scales of 1:1 000 000 and 1:250 000. Although the maps are



| FOLK, 16 classes  | FOLK, 7 classes                                  | FOLK, 5 classes   |
|---|--|---|
| Rock & Boulders   | Rock & Boulders                                  | Rock & Boulders   |
| Gravel - G<br>sandy Gravel - sG<br>gravelly Sand - gS   | Coarse sediment                                  | Coarse sediment<br>(Gravel >= 80% or (Gravel >= 5% and Sand >=90%)) |
| muddy Gravel - mG<br>muddy sandy Gravel - msG<br>gravelly Mud - gM<br>gravelly muddy Sand - gmS | Mixed sediment                                   | Mixed sediment<br>(Mud 95-10%; Sand < 90%; Gravel >= 5%)            |
| (gravelly) Mud - (g)M<br>Mud - M  | Mud (Mud >= 90%; Sand < 10%; Gravel < 5%)        | Mud to muddy Sand<br>(Mud 100-10%; Sand < 90%; Gravel < 5%)         |
| (gravelly) sandy Mud - (g)sM<br>sandy Mud - sM  | sandy Mud (Mud 50-90%; Sand 10-50%; Gravel < 5%) |   |
| (gravelly) muddy Sand - (g)mS<br>muddy Sand - mS  | muddy Sand (Mud 10-50%; Sand 50-90%; Gravel <5%) |   |
| (gravelly) Sand - (g)S<br>Sand  | Sand (Mud < 10%; Sand >= 90%; Gravel < 5%)       |   |

Fig. 3. The Folk sediment triangle and the hierarchy of Folk classification (15, 6 and 4 classes, plus an additional class ‘rock and boulders’, indicated by the arrow) used in the EMODnet Geology project (Kaskela *et al.* 2019).



**Fig. 4.** EMODnet Geology seabed substrate data at scale of 1:1 000 000 for (a) the European seas and (b) the Irish offshore area; hierarchy of five Folk classes. EMODnet Geology 2016 seabed substrate 1:1 000 000–Europe © EMODnet Geology, European Commission, 2016. Available at [www.emodnet-geology.eu/geonetwork/srv/fin/catalog.search#/home](http://www.emodnet-geology.eu/geonetwork/srv/fin/catalog.search#/home) (last accessed May 2020).

broad scale, the Irish data viewed at these scales with data from adjoining sea regions highlight similarities in the type of seabed substrate. Mud to muddy sand is the dominant seabed substrate for the NE Atlantic, where the Irish designated area extends to Iceland's Exclusive Economic Zone (EEZ). The Western Mediterranean Sea is dominated by mud to muddy sand, with the Adriatic Sea characterized by mud to muddy sand and the sand class. Sand is the predominant class in the North Sea and White Sea. The Baltic Sea is characterized by mixed sediments. Coarse sediments are common in the Celtic Sea and the English Channel. At this scale, the bedrock and boulders class is mostly limited to small areas, but is extensive in the west of Scotland and northern Norway as well as the Baltic. All the INFOMAR seabed substrate data are available via the EMODnet Geology data portal and are accessible through common Open Geospatial Consortium web service standards. Data layers can be added to the user's desktop geographical information system application by accessing data directly from our servers.

### Confidence assessment

With full acoustic coverage for the majority of its EEZ, the Irish data score high for overall confidence. The assessment approach, which uses a combination of methods to assign the highest confidence, results in INFOMAR's full acoustic mapping data scoring highly. Despite absences in the MBES coverage in the Celtic Sea and shelf area west of Ireland, the extensive coverage in deep water areas and

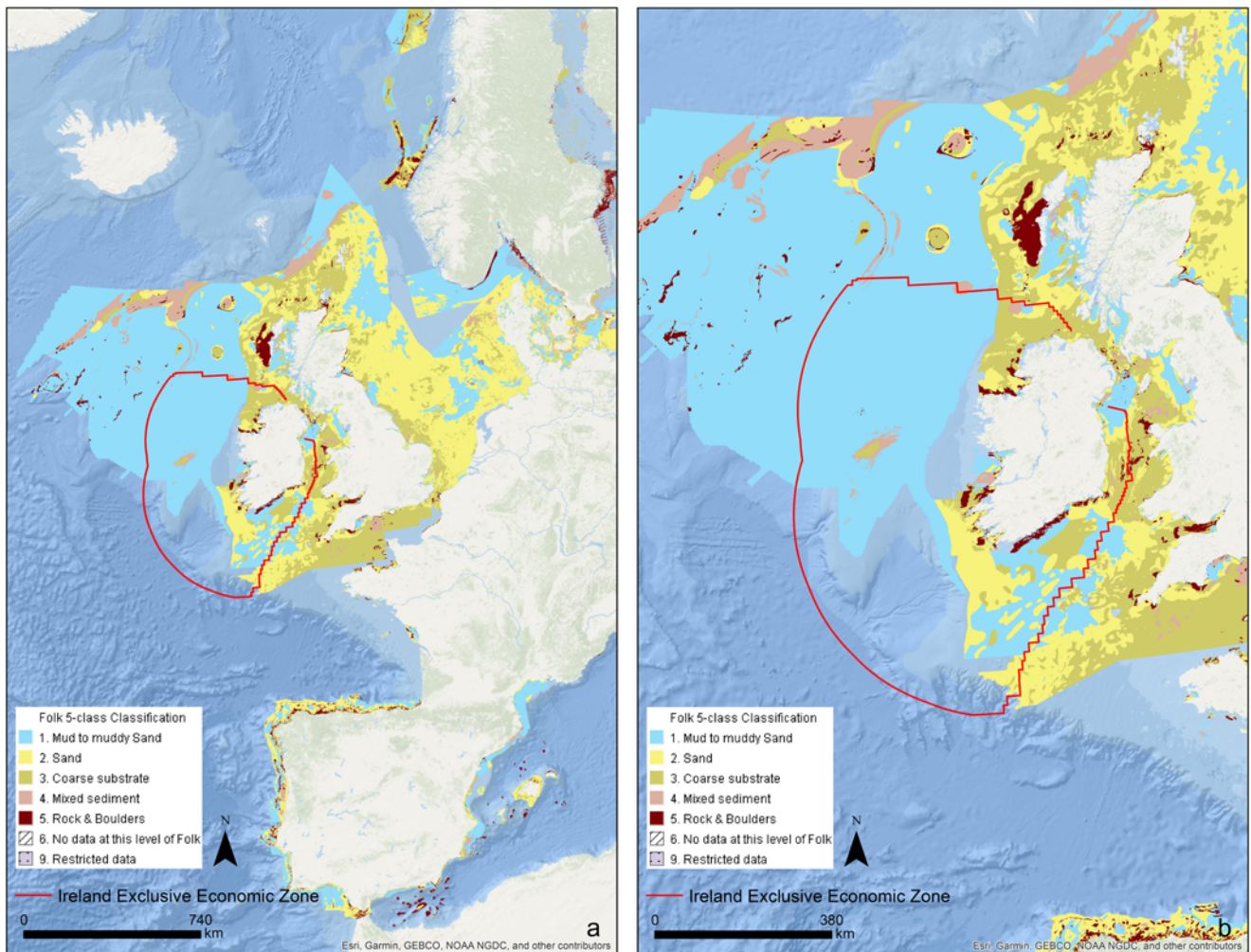
shelf seas results in a high confidence score. Sample density in the nearshore and shelf seas enhances the confidence score in these areas.

### Substrate data for European seafloor habitats

The most recent iteration of EUSeaMap was published in 2019. The map is a multi-resolution map of European Nature Information System (EUNIS) habitats in European waters generated by combining data from EMODnet bathymetry, EMODnet Geology substrate and modelled environmental variables (optical properties, waves, currents, salinity and oxygen). The EMODnet substrate layer is the most important layer in predicting EUNIS habitats and forms the base layer onto which additional data are added to transform the data into EUNIS classes. EUSeaMap has been used to qualitatively assess the impact of fishing activity (ICES 2019). These assessments are undertaken to fulfil the MSFD reporting on D6C1 (Spatial Extent and Distribution of Physical Loss to the Natural Seabed) and D6C4 (Extent of Loss of Habitat Type Resulting from Human Pressures Does Not Exceed a Specific Proportion of the Natural Extent of the Habitat Type in the Assessment Area).

We describe here how the use of INFOMAR substrate data in the EMODnet Geology data portal has added value to studies assessing the siting of offshore wind farms (case study 1) and in support of MSP in a transboundary context (case study 2).





**Fig. 5.** EMODnet Geology seabed substrate data at scale of 1:250 000 for (a) the European seas and (b) the Irish offshore area; hierarchy of five Folk classes. EMODnet Geology, 2016 seabed substrate 1: 250 000–Europe © EMODnet Geology, European Commission, 2016. Available at [www.emodnet-geology.eu/geonetwork/srv/fin/catalog.search#/home](http://www.emodnet-geology.eu/geonetwork/srv/fin/catalog.search#/home) (last accessed May 2020).

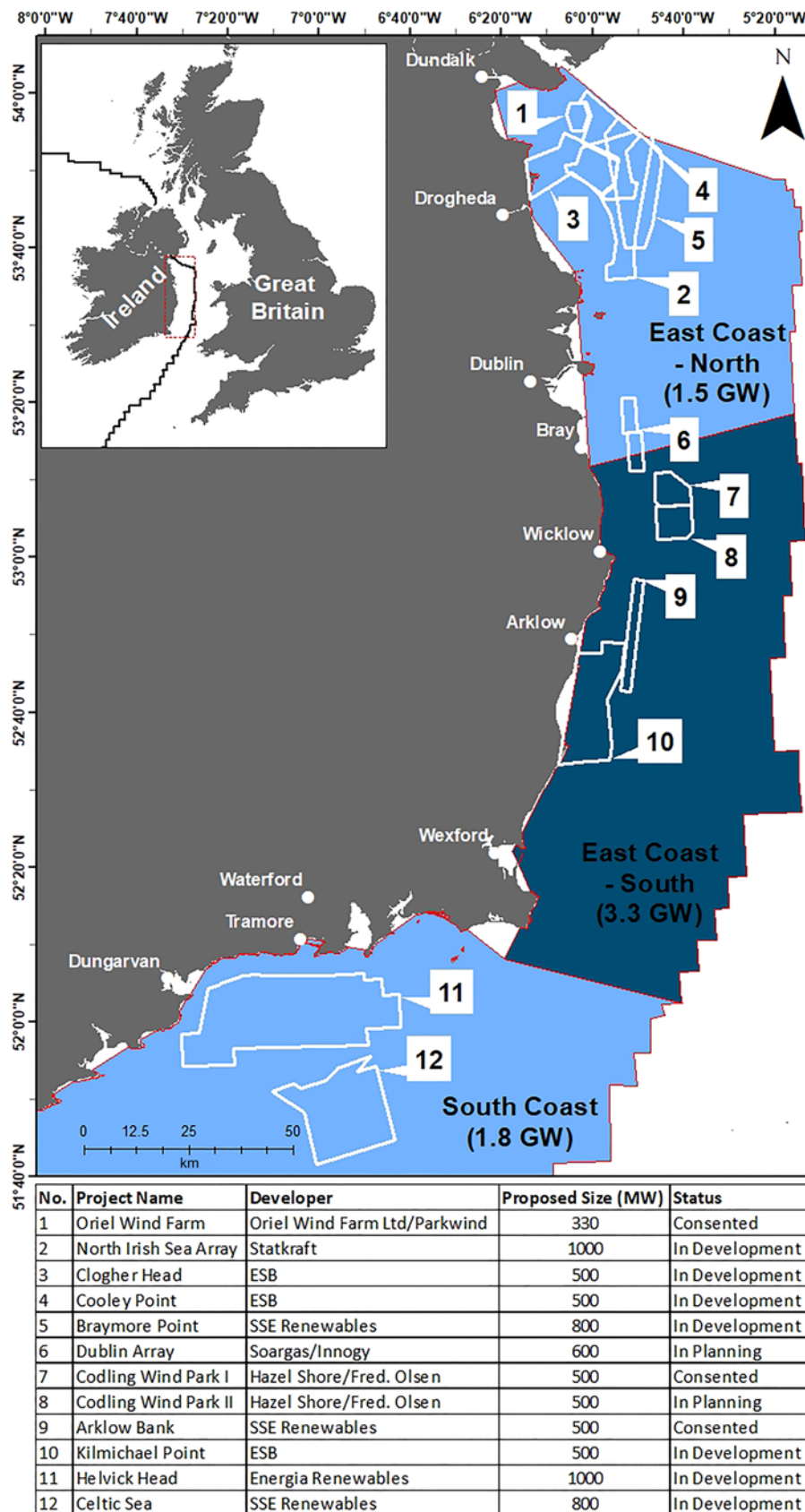
### Case study 1: Irish seabed substrate data for offshore wind energy development accessed via the EMODnet Geology data portal

With its energetic wind regime and relatively shallow water depths, the Irish Sea and its approaches has many advantages for developing offshore wind generation and has been technically recognized as being able to support up to 4.8 MW of fixed offshore wind ‘without any likely significant adverse effects on the environment’ (DCENR 2014; Figure 1). However, since its construction in 2004, the Arklow Bank Wind Park remains the only offshore wind farm in Ireland and consists of seven turbines rated with a total capacity of 25 MW. Since 2004, the cumulative grid-connected wind capacity in Europe has reached 18.5 GW, with 2.7 GW (1 GW = 1000 MW) installed alone in 2018 using, on average, 6.8 MW rated turbines (Wind Europe 2019). Electricity from offshore wind generation is increasingly being considered as an economic and efficient technology to help Ireland achieve its current and future renewable energy targets. Most recently, under Action 25 of its Climate Action Plan 2019, the Irish Government has set a target of 3.5 GW of electricity from offshore renewable sources by 2030 (DCCAE 2019). Moreover, under Action 26 of the Plan, the Irish Government has promised to support emerging marine technologies, including exploring for test locations for such technologies (DCCAE 2019). By 2019, an increasing number of licence applications were being made to the planning and consenting process (Fig. 6). This includes

a number of Irish-based developers in addition to some significant European entities. Proposed project sizes range from 300 to 1000 MW, with locations across the Irish and Celtic seas. Given the volume of projects and the nascent nature of the industry in Ireland, there is likely to be a strong demand for seabed data to support various stages of project development.

Seabed characterization using geological and environmental data is a crucial early-stage activity in the siting and development of offshore wind farms. Geological and geophysical data strongly underpin our understanding of the geotechnical ground conditions on which offshore wind turbines and their associated infrastructure are anchored or placed. For example, turbines require foundations that are fixed to the seabed using a variety of foundation options. These include monopiles, which are suitable for a variety of substrates, and gravity bases, which are more suited for areas with hard substrates at or near the surface (e.g. bedrock). Furthermore, electrical cabling is used to bring the generated power to shore for distribution. These cables often need to be sited along kilometres of seabed, where they are susceptible to scour and therefore need to be placed under scour protection or be entrenched into the seabed. Scour is also a significant issue for turbine foundations (Whitehouse *et al.* 2011).

Offshore wind farms have been deployed in the UK sector of the Irish Sea, with *c.* 2.7 GW successfully installed. However, a number of key projects have encountered adverse geological ground conditions that have resulted in their discontinuation (e.g. the



**Fig. 6.** Ireland's Exclusive Economic Zone in the Irish Sea with Offshore Renewable Energy Development Plan designations (east coast–north, east coast–south, south coast) and current projects planned for the area with their development stage.

Celtic Array). Similarly, Ireland's only offshore wind farm to date (Arklow Bank) encountered significant scour issues in the months following its construction (Whitehouse *et al.* 2011). Therefore, as Ireland looks to further develop its offshore wind capacity, understanding the seabed sediments and subsurface structure with regard to siting offshore renewable energy is a first-order

requirement and the first stage of assessment towards a sustainable national marine energy development strategy. Underpinning this strategy is the need for robust, multi-scale geological and environmental data. INFOMAR data in the EMODnet Geology data portal provides key baseline data to identify not only potential sites for the development of offshore renewable energy (ORE), but



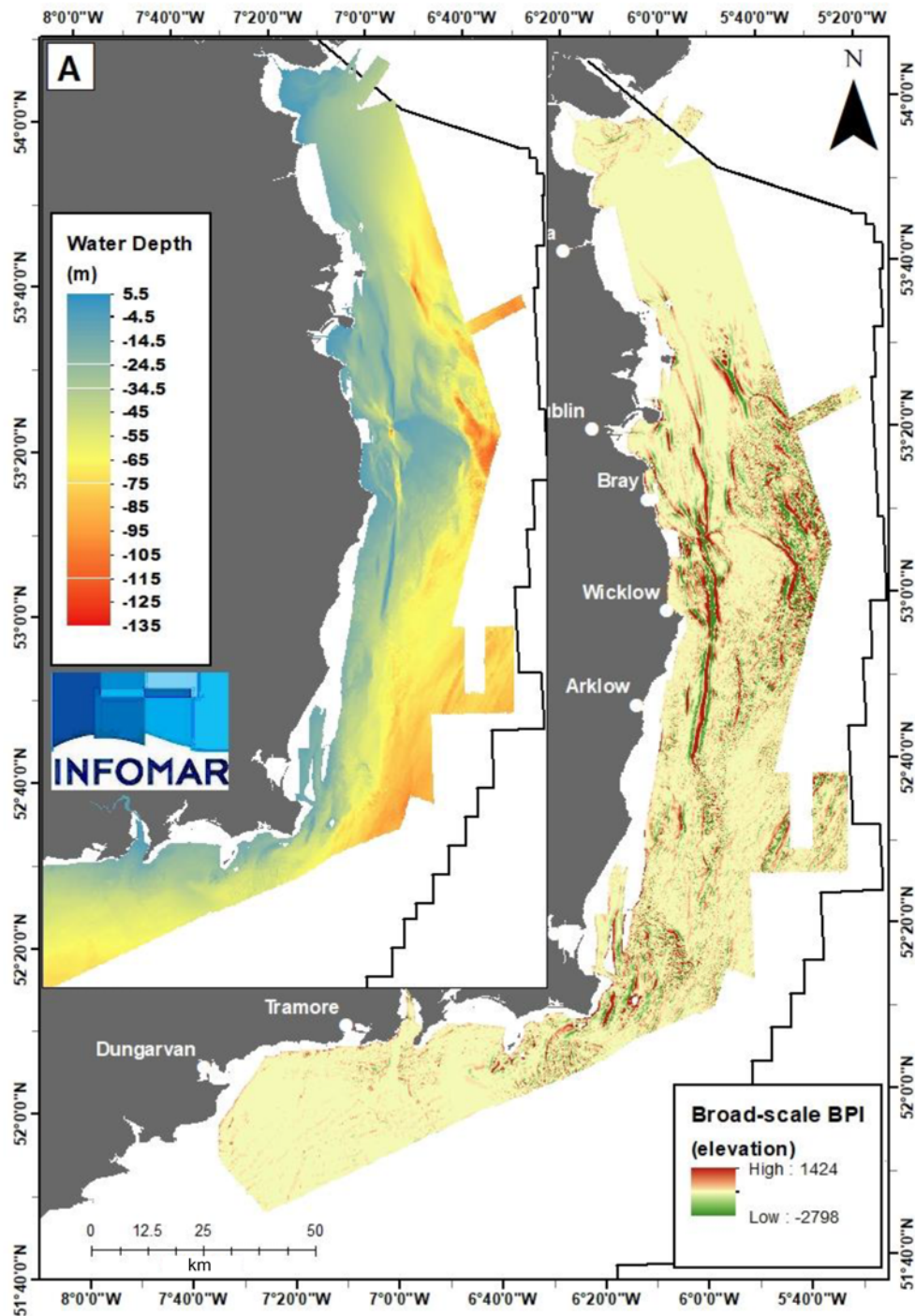


Fig. 7. (a) Multibeam echo sounder bathymetry data for the Irish Sea acquired by the INFOMAR programme and (b) derived broad-scale bathymetry position index data.

also potential geological constraints associated with the projects, such as sediment mobility and problematic geological deposits.

### *Irish Sea offshore setting*

The Irish Sea is a tidal basin located between southern Scotland, Wales, England and Ireland and extends from the northern approaches of the Celtic Sea in the south to the North Channel separating the north of Ireland from SW Scotland (Fig. 6). It is a formerly glaciated shelf and last experienced glaciation from *c.* 34 ka BP until the end of the Last Glacial Maximum at *c.* 17 ka BP, with shallow glaciomarine to marine conditions potentially between 21.0 and 16.0 cal. ka BP (Lambeck 1996; Peltier *et al.* 2002).

During the glaciation episode, ice sheets merged across much of northern Britain and Ireland, heading south through the Irish Sea. This acted as a conduit for the erosion and transport of sediments, blanketing much of the Irish Sea with glaciogenic deposits (Eyles and McCabe 1989; Jackson *et al.* 1995). Following disintegration of the ice sheet at the end of the Last Glacial Maximum, the sea-level rose and there was an incursion into the Irish Sea area, creating modern day marine conditions.

Quaternary sedimentation in the Irish Sea subsequently deposited a drape over the underlying bedrock. These Quaternary sediments have variable thickness, generally in the range of tens of metres to absent (Jackson *et al.* 1995; Mellet *et al.* 2015). These sediments mainly consist of reworked glacial and post-glacial sediments that

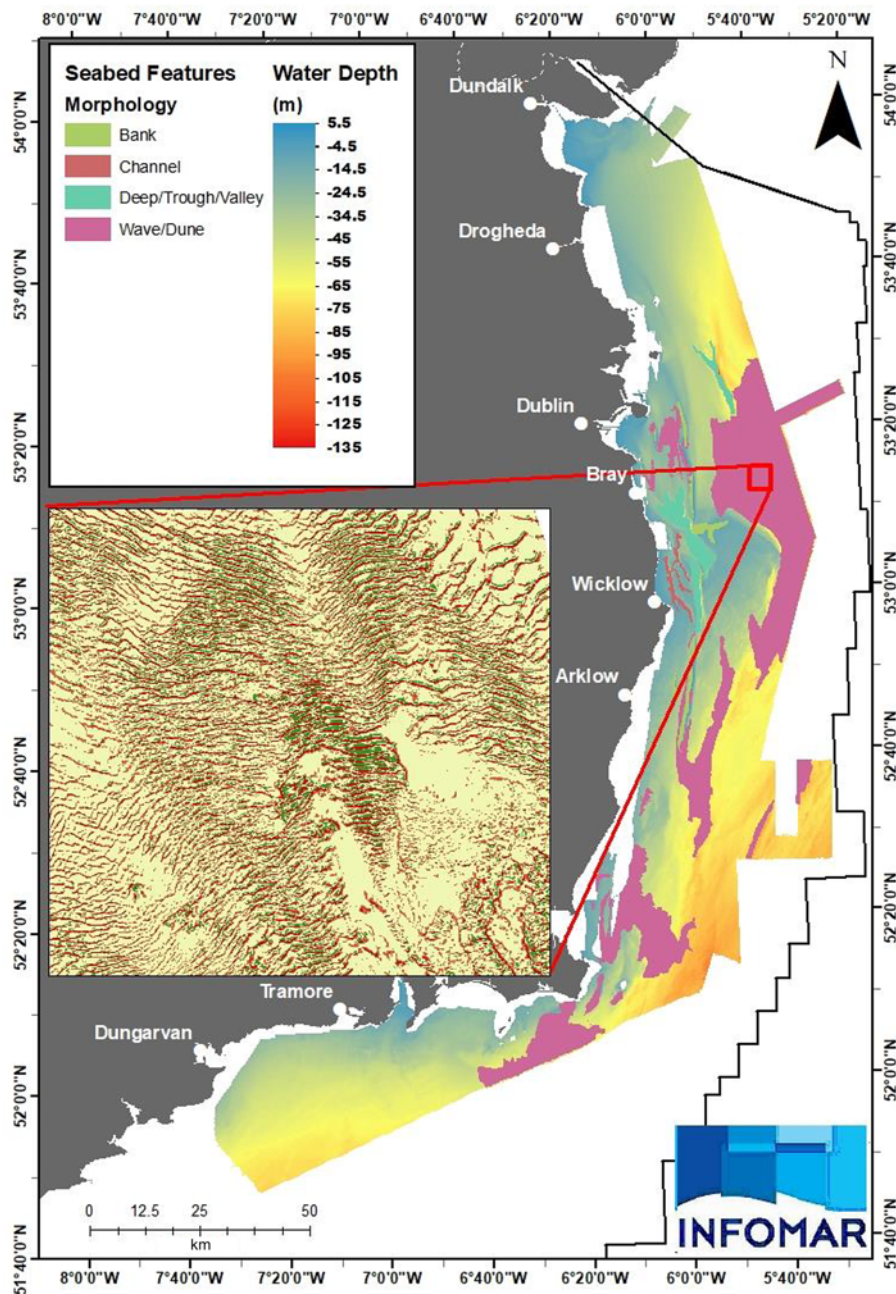


Fig. 8. Geomorphological map of the Irish Sea with highlighted sediment waves on fine-scale bathymetry position index.

form a complex distribution of various sediment types (Belderson 1964; Dobson *et al.* 1971; Jackson *et al.* 1995). Past ice sheet dynamics and modern day conditions have a significant role in determining the morphology of the seabed, with submarine channels and quasi-stable sediment banks (Whittington 1977; Warren and Keary 1988; Jackson *et al.* 1995; Wheeler *et al.* 2001; Van Landeghem *et al.* 2009a). Areas of peak spring tidal currents show a strong correlation with the distribution of coarser sediments. At present, the sea has access to the Atlantic Ocean through the North Channel to the north and St George's Channel to the south, with a central connecting trough running through the Irish Sea. It is through these two channels that tides enter the Irish Sea, which, for the most part, exceeds the energy thresholds that allow sediment to be actively eroded or induced to transport. In areas of strong currents, gravely sediments dominate and sandy sediments can be mobile, forming sand waves and ripples (Belderson and Stride 1966; Jackson *et al.* 1995; Van Landeghem *et al.* 2009b). As a result, the seafloor sediments of the Irish Sea can be divided into three types: lag or modern day erosion; sediments in transport; and present day deposits

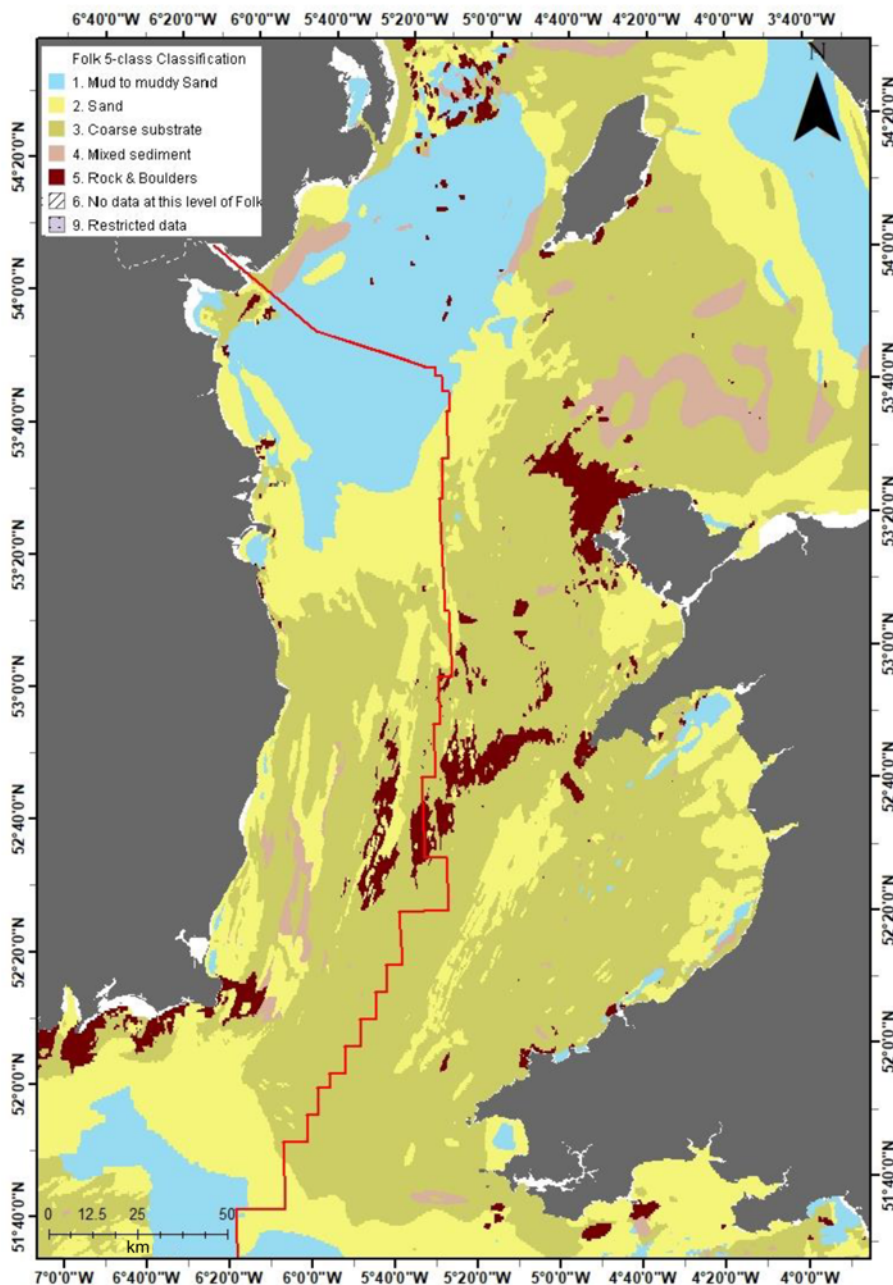
(Holmes and Tappin 2005). Once in motion, these sediments follow well-defined transport pathways around the Irish Sea (Holmes and Tappin 2005; Van Landeghem *et al.* 2009a; Ward *et al.* 2015). Sediments are known to accumulate in two areas located at the end of these sediment transport pathways in the west and east, referred to as the western and eastern Irish Sea mud belts (Belderson 1964).

## Methods

### MBES data

The MBES datasets were obtained from the INFOMAR Interactive Web Data Delivery System. A total of 36 raster tiles were used to build a mosaic. Given that the data were collected by different vessels and systems and gridded to different resolutions, the data needed to be at a common resolution (cell size) before they could be combined. Therefore the raster tiles were re-sampled to a 5 m cell size using the Resample Tool in the ArcGIS Data Management Toolbox. Once all the raster tiles had been re-sampled, they could





**Fig. 9.** Seabed substrate map from the EMODnet Geology data portal showing substrate type for the area of interest in the Irish Sea. Red line indicates Ireland's Exclusive Economic Zone. EMODnet Geology, 2016 seabed substrate 1: 250 000 – Europe © EMODnet Geology, European Commission, 2016. Available at [www.emodnet-geology.eu/geonetwork/srv/fin/catalog.search#/home](http://www.emodnet-geology.eu/geonetwork/srv/fin/catalog.search#/home) (last accessed September 2019).

then be combined into a single seamless file using the Mosaic to New Raster tool in the ArcGIS Data Management Toolbox (Fig. 7). This allowed for easier use of the data and the generation of subsequent bathymetric derivatives using elements of the ArcGIS ArcToolbox and the Benthic Terrain Modeler. This tool is a plug-in extension for ArcGIS that can be used to calculate fine- and broad-scale bathymetric position indices (BPIs) Walbridge *et al.* (2018). The BPI can be used to define the elevation of a particular location relative to the overall grid area. Therefore it is a useful tool in defining positive topographic features such as banks, as well as negative topographic features (e.g. troughs and channels). In this study, the broad-scale BPI was calculated with an inner search radius of 25 m and an outer search radius of 250 m, giving a scaling factor of 1000. The fine-scale BPI was calculated using an inner search radius of 3 m and an outer search radius of 25 m to give a scaling factor of 100 (Fig. 7). These datasets were then standardized to allow the easier comparison of outputs. Features were subsequently described using the two-part geomorphological classification system of Dove *et al.* (2016) (Fig. 8).

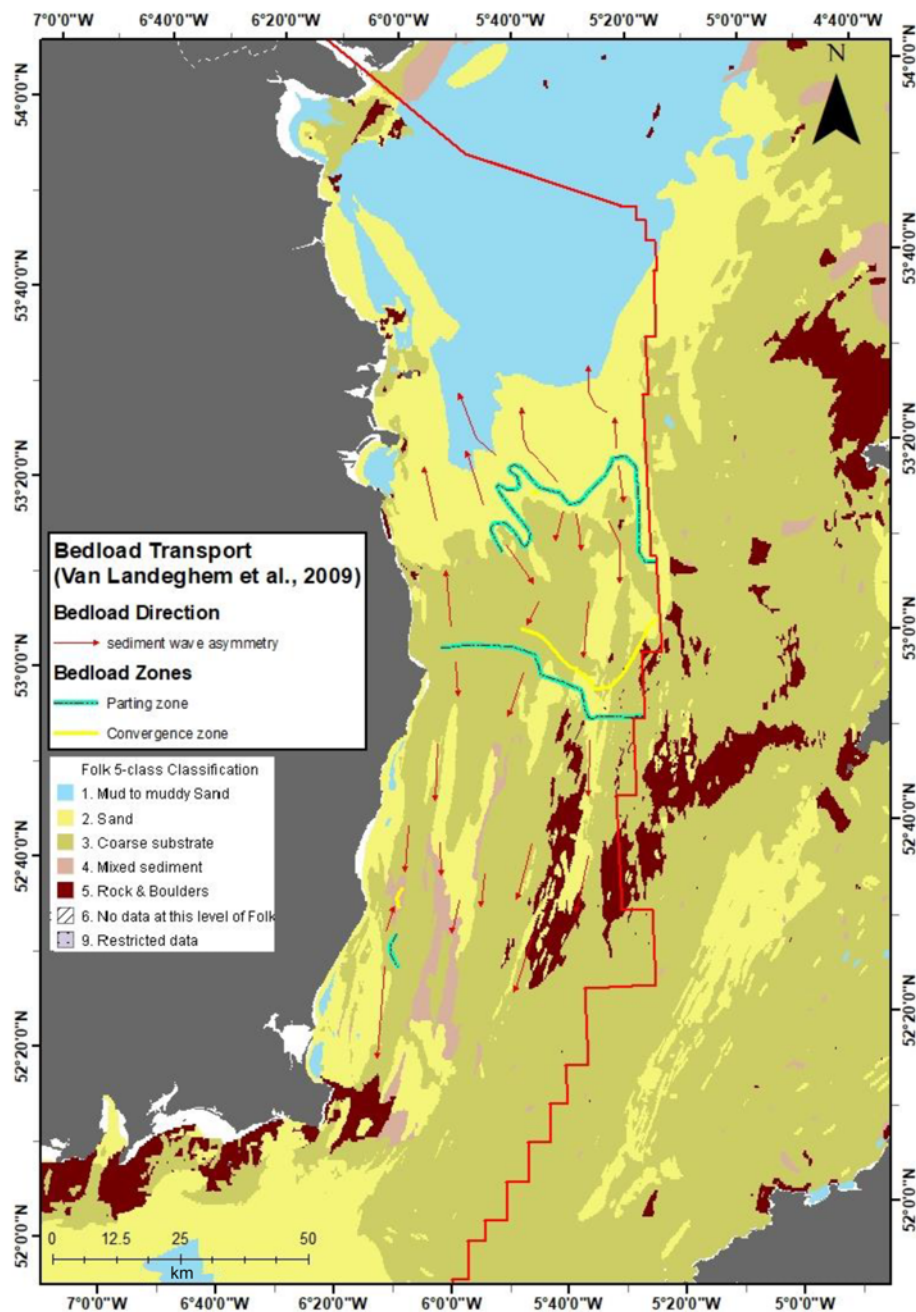
### *Seabed substrate*

A seabed substrate map of the European marine areas (including the Irish Sea) has been collated and harmonized from seabed substrate information as part of the EMODnet Geology project. This EMODnet reclassification scheme includes at least five seabed substrate classes, with four substrate classes defined on the basis of the modified Folk triangle (mud to muddy sand, sand, coarse sediment and mixed sediment) and one additional substrate class (rock and boulders) (Fig. 9). The substrate classification was accessed from the EMODnet Geology data portal at a scale of 1:250 000.

### **Results**

#### *Geomorphology*

The generally shallow and flat seafloor topography of the Irish Sea is punctuated by distinct bathymetric features, which are well defined by the BPI dataset (Fig. 8). The east coast (south) area



**Fig. 10.** Sediment distribution and dynamics in the Irish Sea. Main layer shows EMODnet seabed substrate map. Red line indicates Ireland's Exclusive Economic Zone. Overlain on this are the dominant seabed transport features in the Irish Sea. Adapted from Van Landeghem *et al.* (2009a). EMODnet Geology, 2016 seabed substrate 1: 250 000 – Europe © EMODnet Geology, European Commission, 2016. Available at [www.emodnet-geology.eu/geonetwork/srv/fin/catalog.search#/home](http://www.emodnet-geology.eu/geonetwork/srv/fin/catalog.search#/home) (last accessed September 2019).

shows the highest degree of heterogeneity, with a series of bank structures aligned roughly parallel to the coast. These banks can be as shallow as 2 m b.s.l. Also readily highlighted are topographic lows on the seabed, related to glacially incised channels, which, in this area, are up to 82 m b.s.l. and 50 m lower than the relative seabed. Fine-scale BPI data readily identified extensive sediment waves in this area. The seabed has a generally flatter topography in the east coast (north) area. Some bank, sediment wave and channel features were identified in the southern part, albeit less extensive than the east coast (south) area.

#### *Sediments and seabed mobility*

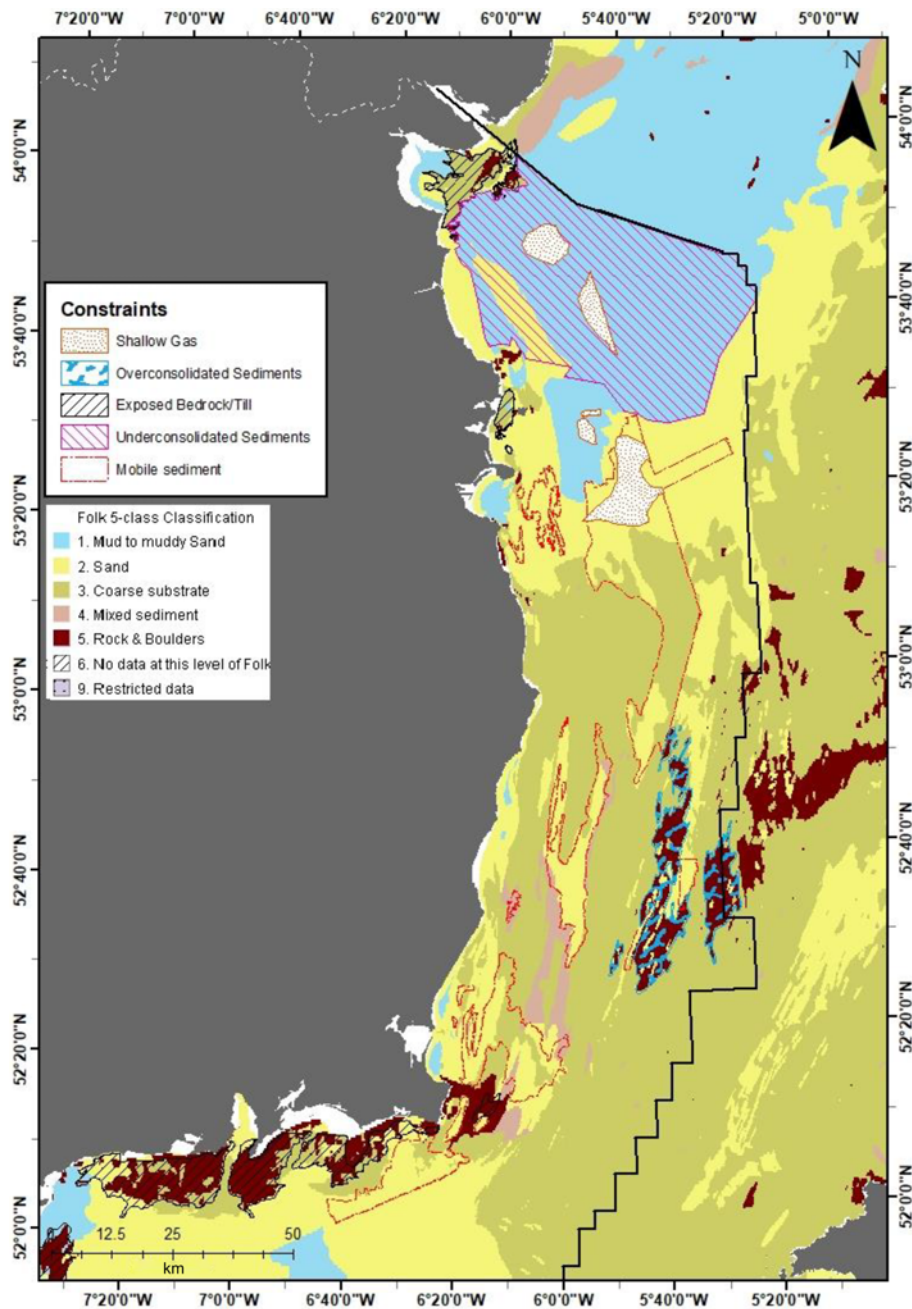
Sediment distribution is strongly related to active hydrodynamic processes (Fig. 10). Sediment parting zones identified by Van Landeghem *et al.* (2009a) correspond well with areas of coarse sediments and sands that are potentially mobile (Fig. 10). Subsequently, the east coast (south) area is dominated by a heterogeneous distribution of coarse-grained sediment and mixed sediments. This is reflective of the strong hydrodynamic regime in

this area, driven mainly by tidal currents, which is significant enough to mobilize coarse sediments into sediment waves (as identified in the bathymetric data) and strip the seabed of unconsolidated material exposing the underlying rock and/or till (Figs 10 and 11). Bank structures coincide with areas composed predominately of sand. Channels are observed to be infilled by mixed sediments. In the east coast (north) area, where tidal currents and sediment transport away from bedload parting zones are less intense, the substrate is composed primarily of varying degrees of sand and mud, with coarser sediments typically close to shore where the wave climate can have a stronger influence (Fig. 10). At the termination of this transport pathways is a relatively large area of fine-sediment accumulation, composed of mud to sandy mud, referred to in the north Irish Sea as the western Irish Sea mud belt (Belderson 1964).

#### *Constraint mapping*

Several geological factors can constrain the siting and installation of offshore wind infrastructure, including fixed turbine foundations





**Fig. 11.** Constraints map of the Irish Sea. Main layer shows EMODnet seabed substrate map. Black line is Ireland's Exclusive Economic Zone. Overlain on this are potential geological constraints to the siting and construction of offshore wind infrastructure. Adapted from Mellet *et al.* (2015) (Table 1).

(Mellet *et al.* 2015). The results of the geomorphological mapping (Fig. 11) were combined with the inferred sediment distribution to delineate and digitize areas where there are potential geological implications for the siting and construction of ORE infrastructure based on an adapted table from Mellet *et al.* (2015) (Table 1). In particular, contemporary seabed dynamics and active seabed processes can affect the infrastructure following its completion, either by burial through bedform migration or instability caused by the removal of sediment (i.e. scour) (Kenyon and Cooper 2005; Whitehouse *et al.* 2011). Gas hosted in Quaternary sediments near the seabed has been identified throughout the Irish Sea (Croker *et al.* 2005). This gas can migrate to the seabed, where it can form methane-derived authigenic carbonates, a hard substance difficult to penetrate by piling, or pockmarks, which are fluid-escape structures that create seabed instability. Areas where bedrock or over-consolidated sediments (e.g. diamicton) occur at or near the seabed can offer substrates that are hard and subsequently difficult to pile foundations into (Mellet *et al.* 2015). Under-consolidated sediments, by contrast, are typically soft sediments that, in significant thicknesses, are unlikely to support traditional piled foundations.

## Discussion

The ORE resource of the Irish Sea is significant. This resource is vital for Ireland to meet its climate change targets under Action 25 of the Climate Action Plan 2019 (DCCAE 2019). Shallow sand banks may be preferable for offshore wind development, with some progressed as projects to date based on fixed-bottom technology (i.e. the Arklow Bank, Codling Bank and the Dublin Array). However, the surface and shallow geology of the Irish Sea can offer significant constraining factors to the installation and subsequent stability of offshore infrastructure, such as wind turbine foundations, as demonstrated previously at Arklow Bank (Whitehouse *et al.* 2011). Fixed foundation technology is typically constrained to water depths <40 m for economic reasons. With offshore floating wind technology becoming increasingly affordable, it is opening up the possibility of deeper water sites (i.e. >40 m) becoming viable for ORE development. Such projects could be located in the seabed channel areas of the Irish Sea where suitable water depths for floating wind technology occur, which are also relatively close to shore. Such areas have also been assessed for tidal energy

conversion devices as a result of their strong current profiles (Dorschel and Wheeler 2012). Therefore understanding the geological conditions in these areas is key in appraising mooring and anchoring options.

Strong sediment dynamics in some areas of the Irish Sea will prove problematic, not only for ORE foundation and mooring options, but also for the associated cabling to bring the energy ashore. The provision of INFOMAR MBES bathymetry, used in conjunction with sediment distribution maps, becomes a useful support tool to identify areas of active sediment migration (through the delineation of sediment wave features) and potential sediment mobility for future, targeted surveys. In addition, areas of significant sediment erosion can expose the underlying till and bedrock, which can prove difficult for cable trenching. In the north part of the Irish Sea, the flat, relatively featureless topography of the seabed suggests a suitable area for the installation of a variety of foundation types, such as monopile and gravity-based solutions. However, from sediment distribution data, the widespread occurrence of fine-grained, possibly under-consolidated sediments offers a potentially strong constraining factor as a result of their low bearing capacity (Mellet *et al.* 2015; Coughlan *et al.* 2019). These fine-grained sediments are also known to host accumulations of shallow gas, which can have significant effects on the properties of sediments and the stability of the seabed (Yuan *et al.* 1992; Mellet *et al.* 2015; Coughlan *et al.* 2019).

### Conclusions

The high-resolution seabed imagery derived from MBES data for the Irish EEZ that is available from INFOMAR and the harmonized broad-scale seabed substrate information from the EMODnet Geology data portal are both crucial in robustly evaluating areas of seabed for ORE development. These data may be used throughout the development process, including: potential site identification; evaluating geological constraints at sites; preparing environmental impact assessments; siting cable routes associated with ORE projects; and panning targeted surveys for advanced site investigation. Accessing the data assembled in a central portal where it can be viewed with other data at varying scales provides a dynamic tool for regional zonation and site-specific assessments for ORE development.

### Case study 2: transboundary initiative supporting MSP in the Celtic Seas

In 2014, the European Parliament and the Council of the European Union adopted Directive 2014/89/EU (<https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0089&from=EN>) establishing a framework for MSP. The purpose of MSP is to ensure the sustainable development of marine resources. It aims to balance different marine activities with the need to protect the marine environment and provides a mechanism for transparent, sustainable and evidence-based decision-making. MSP is a cross-cutting policy tool enabling public authorities and stakeholders to apply a coordinated, integrated and transboundary approach. All EU Member States must have a Marine Spatial Plan in place by March 2021. The Supporting Implementation of Maritime Spatial Planning in the Celtic Seas (SIMCelt) project (2016–18) ([www.simcelt.eu](http://www.simcelt.eu)) has supported the implementation of the MSPD in the Celtic Sea. The project aims specifically promote and develop cross-border cooperation, addressing data gaps and issues and the assessment of best practice for data sharing and the joint use of data. The SIMCelt project examined the potential impact and interaction of maritime sectoral activities and informed the range of factors potentially impacting on the marine area within the Celtic Sea, their cumulative impact and projected future trends, and

**Table 1.** Summary of geological constraints. Adapted from Mellet *et al.* (2015)

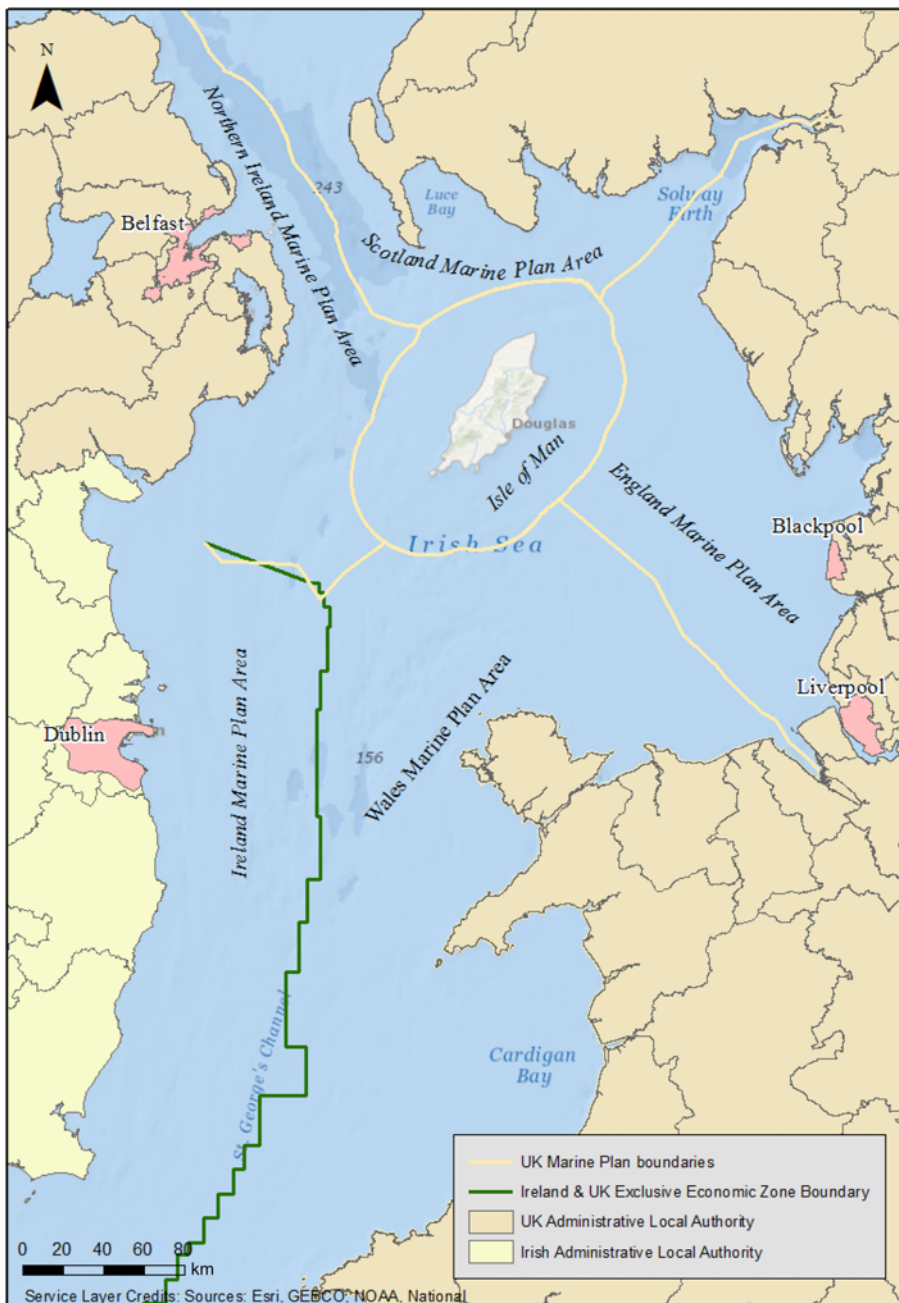
| Geological feature                           | Potential constraint  |
|--|---|
| Shallow gas                                  | Affects seabed instability (e.g. pockmark formations) and long-term behaviour of sediments (e.g. differential settlement)<br>Can create hard substrates at surface (i.e. methane-derived authigenic carbonates) |
| Over-consolidated sediments (e.g. diamicton) | High shear strength values make it difficult to pile<br>High levels of heterogeneity  |
| Exposed bedrock                              | Hard substrate restrictive to some foundation types   |
| Under-consolidated sediments                 | Low shear strengths affect bearing capacity<br>Implications for differential settlement<br>Prone to scour   |
| Mobile sediments                             | Can bury structures<br>Can erode sediment at the base of structures, causing instability (e.g. scour)<br>Affect seabed levels   |

examined stakeholder challenges to transboundary cooperation on MSP and possible approaches to addressing these. Part of this project is to determine how to manage spatial uses and conflicts in marine areas and addressing cumulative effects is therefore an essential part of this process. Cumulative effects assessment (CEA) is a systematic procedure for identifying and evaluating the significance of effects from multiple human activities.

INFOMAR seabed substrate data in the EMODnet Geology portal was a key dataset in helping to address the issues and challenges associated with implementation of the MSPD. The majority of published CEA studies relate to impacts on the benthic environment (Korpinen and Andersen 2016). The extent of the EMODnet Geology data in the Celtic Sea was especially valuable in understanding spatial uses and conflicts in marine areas in a transboundary region. As island nations, the countries bordering the Irish Sea (Fig. 12) rely on shipping for the import and export of goods and passenger transport. In recent years, there has been substantial offshore wind development in the Irish Sea, with increased development largely driven by international commitments and EU obligations to reduce greenhouse gas emissions. Offshore wind farm development has been most intense in the waters of NW England. Pipelines and cables traverse the seabed of the Irish Sea, with submarine energy cables transporting electricity through interconnectors, driven by offshore wind energy requirements and cross-border energy infrastructure linking Northern Ireland to Scotland and Ireland to Wales. The marine space is also used for aggregate extraction, with the largest use of marine-dredged aggregates in the construction industry in the UK (Highley *et al.* 2007).

### Access to transboundary harmonized data and CEA

To undertake a CEA, it was necessary to collate the best available data to assess both the spatial pattern and temporal change in individual human pressures. For the CEA, it is important to have high-quality and high-resolution data on benthic habitats and the sensitivity of the receiving environment. The EMODnet Geology substrate data were used to assess the receiving environment. A habitat sensitivity map was generated using the substrate data, which considers both the exposure to the activity and the capacity of the receiving environment to assimilate the pressure. The EMODnet Geology substrate reclassification scheme provides harmonized



**Fig. 12.** Map of Irish Sea showing the Exclusive Economic Zones of the six neighbouring countries: Ireland, Wales, Scotland, Northern Ireland, the Isle of Man and England.

data across the European seas, including the Celtic and Irish seas with most relevance to the SIMCelt project.

Access to, and use of, maritime spatial data across all jurisdictions in the Irish Sea was essential for the CEA. There are six different jurisdictions around the Irish Sea (Ireland, Northern Ireland, Scotland, England, Wales and the Isle of Man), in addition to a large number of different planning authorities (Fig. 12) and, in a transboundary context, this can lead to technical complications. Each jurisdiction has distinct data access and management procedures for their MSP data. In general, data are available through national or regional portals and are focused on a single jurisdiction. The MSPD states that EU Member States make use of the best available data and information by encouraging the relevant stakeholders to share information and by making use of existing instruments and tools for data collection. Integrated data are vital for sustainable economic development in the Irish Sea and the widest possible level of cooperation is required. With this in mind, accessing INFOMAR seabed substrate data harmonized with data from the adjoining sea areas in the EMODnet Geology data portal was a key factor.

### *Transboundary data harmonized in a single data portal*

Through improved data coherence, the EMODnet data initiative enables future transboundary work on MSP. Data use and sharing, as well as cooperation among EU Member States, are key objectives of the MSPD (Articles 10 and 11), increasing awareness of data and information in other jurisdictions, what exists and how to access it. The Directive on open data and the re-use of public sector information, also known as the Open Data Directive (Directive (EU) 2019/1024) entered into force in 2019. Member states have to fulfil new requirements around the availability and re-use of public sector data and a concomitant need for an integrated marine data use and sharing service. The EMODnet initiative provides a mechanism for data harmonization for MSP through standards for data use agreements and data citation, naming conventions, reporting quality of data or styling. In this study, the EMODnet Geology portal provided a single point of access to reliable and accurate information about the marine environment and maritime activities. Specifically, INFOMAR seabed substrate data harmonized with substrate data from the adjoining sea areas was crucial in planning



for MSP. It is a remarkable source of cross-boundary datasets, which is essential in the development of marine plans.

## Discussion

### Data challenges

Integrating datasets from multiple sources presents data harmonization issues. EMODnet Geology addresses these issues by ensuring a number of steps are adhered to, whereby data are identified, harmonized, generalized and then compiled. The harmonization step required all Irish data to be classified into a shared, international classification system, which was chosen to be Folk. INFOMAR sediment samples undergo particle size analysis and the results are classified according to the Folk system. Differences in grain size ranges made it challenging to translate the Irish data. Generalization involves reducing the amount of detail in the data and this is a necessary step in EMODnet Geology to deliver pan-European data at similar scales. This results in the loss of important detail – for example, in areas of high seabed heterogeneity, broad-scale data do not highlight important seafloor features. However, the broad-scale representation captures the entire transboundary seabed substrate for the European seas on a scale that is relevant to governments and stakeholders. The data can be readily visualized by querying the metadata of any dataset, the user can identify the source of the data and, although the data are included at a broad scale, the associated metadata directs the user to the original data source (i.e. the INFOMAR data viewer).

### Extent of INFOMAR data coverage and gaps

EMODnet Geology provides important information on marine geological data coverage for the European seas, with the aim of identifying data gaps and deficiencies at different scales. This information can be used to guide future data acquisition and survey efforts. In the current phase of the project, for the first time, substrate data are being delivered at multiple scales to include INFOMAR's fine-scale seabed substrate information. The work presented here contributes to the assessment of the extent of seabed substrate data and highlights areas for future survey effort to inform proposals addressing such data deficiencies. Although the 1:1 000 000 substrate map covers 65% of the European maritime areas, at a scale of 1:250 000, overall coverage for the partner countries is poor at 19% (Kaskela *et al.* 2019). However, in the Celtic Sea region, which encompasses the majority of the Irish offshore area, seabed substrate data extend to 79% coverage. This figure reflects the comprehensive surveying conducted over the past 20 years as part of Ireland's national seabed mapping programme, which has mapped >80% of the Irish designated area.

### Irish data in a European context

The key benefit of involvement in EMODnet Geology is that Irish data are visible and available for download in a pan-European data portal. Irish seabed substrate data have previously been included in marine data projects encompassing a smaller geographical extent. The MESH project gave Ireland the first opportunity to show the extent of Irish substrate data (translated to EUNIS) in relation to other European sea regions (JNCC 2007). Following on from MESH, the MESH Atlantic project (between 2010 and 2013) further promoted harmonized seabed substrate collation and the data acquired during the INSS and INFOMAR programmes were the primary sources of data used in the generation of a collated seabed substrate layer. The original classes assigned to the data were translated to a modified Folk class to facilitate a seamless reclassification of the data to the EUNIS classification system. The substrate types, together with data collated from other habitat

mapping projects and seabed surveys, were integrated to produce a single, harmonized layer of substrate distribution within the currently designated Irish continental shelf of the North Atlantic Ocean. These data have now been incorporated into EMODnet's Seabed Habitats portal and the data portals for MESH and MESH Atlantic no longer exist.

It is a decade since EMODnet was first initiated as a long-term marine data initiative, making it one of the longest running marine data projects in Europe. EMODnet is currently entering a new phase and will continue sourcing new data until 2021. The strategic approach of EMODnet to identify and target key datasets for the benefit of a range of marine data users – including policy-makers, scientists, private industry and the public – has secured its position as Europe's largest marine data initiative. The vision is that EMODnet will continue to proactively engage with organizations beyond 2020 as a fully operational and user-focused data service (Martín Míguez *et al.* 2019).

The Central Portal offers user-oriented data services comprising a geoviewer, a metadata catalogue, a query tool and documentation on how to access data and data products using web services. This provides a platform for collaboration across Europe, where a wide range of professional users, government bodies and the general public have access to explore and visualize the Irish data. The query tool is designed to allow marine spatial planners to query multiple datasets across the different thematic portals via one single interface. The value from an Irish perspective is that the data are easily accessible and interoperable, adding value to the INFOMAR dataset. For the future, EMODnet aims to improve data coverage, quality and resolution and, at the same time, improve coherence, harmonization and interoperability for different thematic areas (Martín Míguez *et al.* 2019). By strengthening the connectivity between existing programmes and data initiatives, EMODnet remains well-funded and supported by other long-term initiatives and operations within national strategies related to the marine environment, ensuring it continues as a long-term permanent service.

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**Author contributions** **JG:** conceptualization (lead), formal analysis (equal), investigation (lead), methodology (equal), project administration (supporting), validation (equal), writing – original draft (lead); **CM:** conceptualization (supporting), formal analysis (equal), methodology (equal), validation (equal), writing – review and editing (supporting); **EO:** formal analysis (supporting), methodology (supporting); **XM:** formal analysis (equal), methodology (equal), project administration (lead), supervision (supporting), writing – review & editing (supporting); **FS:** formal analysis (equal), methodology (equal), supervision (lead), writing – review and editing (supporting); **MC:** writing – original draft (supporting); **CNA:** writing – original draft (supporting); **CM:** conceptualization (supporting), formal analysis (equal), methodology (equal), validation (equal), writing – review and editing (supporting)

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**Data availability statement** The broad-scale datasets generated during and/or analysed during the current study are available in the EMODnet Geology data portal ([www.emodnet-geology.eu](http://www.emodnet-geology.eu)). The INFOMAR data are freely available from [www.infomar.ie](http://www.infomar.ie).

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