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Human pressures on UK seabed habitats: a cumulative impact assessment

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ABSTRACT: European Member States are required to assess the status of marine waters, including analysis of cumulative effects. We developed a methodology for evaluating the impact of several human activities that constitute 4 direct pressures on the UK (England and Wales) seabed community: smothering, abrasion, obstruction (sealing), and extraction. The method was tested by mapping the spatial extent of individual and cumulative activities for 2007 by habitat type, quantifying the intensity of activities, and estimating impact using published recovery times. More than half (134 400 km^2) of the seabed was directly affected by human activities, of which only 165 km^2 (<0.1 %) was occupied by multiple activities. Benthic fishing accounted for 99.6 % of the spatial footprint. Sensitivity to the pressures of human activities varied by habitat type, with estimated recovery times ranging from <1 mo for otter trawling in sand, to ~15 yr for co-occurring aggregate extraction and dredge material disposal in low-energy gravel habitat. Fully integrated, dynamically-linked environmental assessments are generally considered desirable for greater scientific understanding of an ecosystem. The methodology we present for quantifying cumulative effects is a step towards this. However, our findings indicate that a limited number of activities were the predominant cause of widespread, long recovery times of benthic fauna. This suggests that when time and resources are limited, single sector assessment rather than detailed evaluation of cumulative effects, can still usefully guide management. As the observed cumulative effects were primarily related to a few activities, it might reasonably be argued that management effort should be focused on spatially extensive activities, such as benthic fishing to mitigate most of the human impact on the UK seabed.

KEY WORDS: Abrasion · Cumulative impact · Extraction · Marine habitats · Obstruction · Recovery · Smothering · UK seabed

INTRODUCTION

The UK has commitments to monitor and assess the condition of the marine environment under several international conventions and Directives, including the United Nations Convention on biological diversity (UNEP 1992), the OSPAR Convention for the protection of the North-East Atlantic, and the Habitats (EU 1992), Birds (EU 2010) and Water Framework (EU 2000) Directives. Added to these is the new European Marine Strategy Framework Directive (MSFD), which requires member states to make an assessment of their marine waters with a requirement to achieve Good Environmental Status by 2020 (EU 2008). The recently published Charting Progress 2 (CP2) report was compiled to address many of the obligations under these initiatives and regulations by providing robust evidence for the current and projected state of the marine environment (Defra 2010). However, the conclusions that could be drawn were limited. The authors reported that they had low confidence in the assessment of shallow subtidal sediment habitats and that this was because of a lack of knowledge, data and assessment tools. These habitats, defined as sand, gravel, mud and mixed sediments that are affected by wave action, constitute the majority of the seabed of

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England and Wales (Fig. 1). Only 10% of the seabed was assessed using habitat maps and the remainder was modelled. Furthermore, the authors highlighted the severe lack of understanding regarding the links between human activities and the marine environment. Most significantly there was little understanding of the cumulative impact of several activities in one area and the ability of a species or habitats to recover once a pressure has been removed.

In this paper we address some of these knowledge gaps, with particular reference to the requirements of the MSFD. The Directive requires member states to assess predominant pressures and impacts, including cumulative and synergetic effects. Apart from naturally occurring near-bed currents and wind-induced waves (Hall 1994), the major sources of seabed disturbance in UK waters are caused by human activities (Foden et al. 2010). Under the MSFD, human activities are grouped into generic pressure types, which are useful because ecosystems respond to types of pressure rather than specific activities. Pressures directly affecting the seabed are physical loss (smothering and obstruction) and physical damage (siltation, abrasion, and extraction). The MSFD defines and lists examples of activities causing such pressures. From these we considered the following 4 pressures caused by 12 activities which occur in UK (England and Wales, E&W) waters:

- Smothering: covering the natural seabed habitat with a layer of material which, under some circumstances, might be expected to disperse. Smothering activities include disposal of dredged material and cuttings from oil and gas exploration
- Obstruction (termed 'sealing' in the MSFD): permanent structures fixed on the seabed. Obstruction activities include oil and gas platforms, well heads, oil and gas pipelines, telecommunication and power cables, wind turbines, and wrecks
- Abrasion: scouring and ploughing of the seabed. Abrasion activities include benthic fishing using trawl gear, burying activity during telecommunication and power cable laying, and wind turbine scour
- Extraction: exploitation by removal of seabed resources. Aggregate extraction is the only activity in this pressure type.

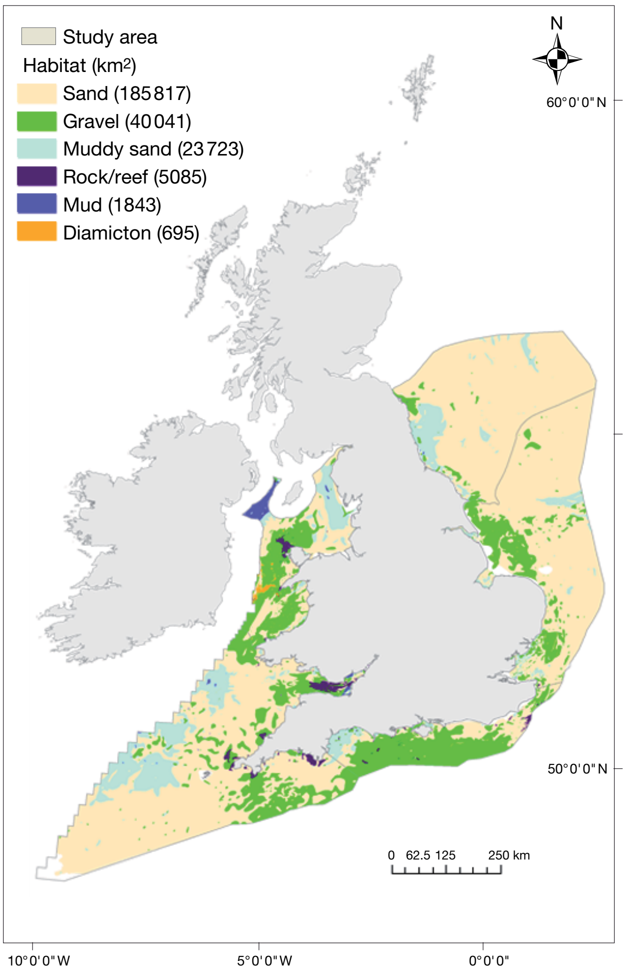

Fig. 1. Study area. UK (England and Wales) seabed habitat types — Charting Progress reporting area

Habitats vary in their sensitivity to disturbance from different pressures. Investigations of seabed recovery rates following disturbance provide a method of quantitatively estimating habitat sensitivity (Desprez 2000, Cooper et al. 2007, Foden et al. 2009, 2010). Habitats requiring long recovery periods might be considered more sensitive than those with more rapid recovery rates. If a pressure occurs too frequently for a habitat to recover, the benthic community's biomass and productivity decline (Hiddink et al. 2006a) and sustainability may be jeopardised. Defining benthic recovery from any type or scale of pressure is problematic. Ecosystem recovery is complex with a range of definitions and metrics used, and existing scientific studies have limitations in their scope (Gilkinson et al. 2005, Hall et al. 2008). This is because complete recovery would be the return of an ecosystem to its original, pre-disturbance state, whereby the abundance, diversity, structure and functioning of the biological community are the same as prior to the disturbance (Hiscock & Tyler-Walters 2006). However, this is unrealistic and most studies focus on the recovery of the key species, assemblages and components of the ecosystem (Hall et al. 2008).

The cumulative effects of coinciding pressures can be additive, antagonistic, or synergistic. Antagonism is a cumulative impact value lower than the sum of individual impacts, and synergy is a value greater than the sum of individual impacts (Folt et al. 1999). These can be difficult to predict (Crain et al. 2008, Darling & Côté 2008). Consequently, with a few notable exceptions (e.g. Stelzenmüller et al. 2010), most previous regional and global scale studies have been limited to assuming cumulative pressures are additive and have presented relative, rather than actual, impacts (e.g. Halpern et al. 2008b). Quantifying the capacity for habitats to withstand pressures has been identified as a critical step for better understanding of ecosystem resilience (Ban et al. 2010) and will help inform decision-makers in facilitating an ecosystem approach to marine management.

Our study builds on the innovative earlier work of Eastwood et al. (2007), who mapped human activities in UK (England and Wales) waters, and Stelzenmüller et al. (2010), who analysed spatial pressures and marine habitat sensitivity by running scenarios to estimate risk of cumulative impacts. Our objective was to develop a method for examining whether cumulative effects are of spatial or temporal concern in UK waters. To do this, we conducted a 'dynamically linked ecosystem assessment' (Foden et al. 2008) for a range of different sectors by (1) mapping the spatial extent of human activities in 2007 at a high resolution; (2) using data on habitat recovery periods as indicators of sensitivity and estimating the proportion of habitats in which recovery would be possible at 2007 levels of activity; (3) investigating where pressures coincided, potentially giving rise to cumulative impacts on the seabed; and (4) where pressures overlap, estimating overall recovery times for 4 cumulative effects scenarios — greatest, additive, antagonistic, and synergistic (e.g. Crain et al. 2008, Darling & Côté 2008, Halpern et al. 2008a, Foden et al. 2010).

METHODS

Study area and habitats. The study area (Fig. 1) comprised the marine waters of the UK (E & W), as delineated for environmental status reporting under Charting Progress (Defra 2005). Five habitat types were identified, based on the largest proportion of constituent particle size: mud, muddy sand, sand, gravel, and reef/rock (including biogenic habitats constructed or composed primarily of living biota). These incorporate European Nature Information System (EUNIS) habitats A5.1, A5.2, A5.3, A5.4, A5.5 and A5.6 (EEA 2004). The habitat types are relevant to the impact of human activities on the seabed (Collie et al. 2000, Kaiser et al. 2006, Pitcher et al. 2009, Foden et al. 2010). Together the habitats constitute >99% of the UK seabed with diamicton (matrix of large and fine grains) or unclassified sediment accounting for the remainder.

Spatial data and processing. To conduct a pressure assessment of human impacts on the seabed, spatial data were collated for 4 pressures and associated activities listed above (Table 1). We used data from 2007 for compatibility with previous impact assessment work (Foden et al. 2009, 2010). Records for each activity were joined to British Geological Survey sediment types (Folk 1954) using the ESRI ArcGIS Geographical Information System (ESRI) and grouped to the habitat types listed above.

The 2 main causes of smothering in UK waters are the disposal of material from harbour dredging (creating dredging spoils) and the discharge of drill cuttings at oil and gas platform drilling rigs. Disposal occurs in defined licensed areas and licensees are generally guided to dispose of material in the centre of the site in an attempt to restrict plumes (S. Pacitto pers. comm.). When an oil or gas well is drilled, waste cuttings are separated on the platform and are normally discharged to the seabed (Kingston et al. 1987, Breuer et al. 2004). By January 2001 oil- and synthetic-based muds could no longer be released into the environment (OSPAR Commission 2000, 2009). We assumed that during the intervening decade, recovery from drilling with these muds will have occurred (Daan & Mulder 1996). Consequently only the effects of water-based muds (WBM) cuttings were considered for well heads and platforms in operation during or since 2001. Although cuttings piles will vary in size and shape, WBM-contaminated cuttings have been reported to reach approx. 100 m from the well (Daan & Mulder 1996, Currie & Isaacs 2005, Zuvo et al. 2005), which we used as a standard dimension.

Potential causes of obstruction in UK waters include oil and gas platforms, well head protective structures, pipelines, exposed cables, wind farm turbines, and wrecks. Individual platforms, well head structures, wind turbine scour protection, and wrecks vary in size and shape, but as specific information was not available, we used standard dimensions to generate representative footprints (spatial extent estimates) for these activities (Table 1). Dimensions were available for individual pipelines and armoured telecommunication cables overlying rock so their footprints could be accurately represented. In soft sediment telecommunication cables are generally buried, but to account for the remainder, we assumed ~20% was exposed and used a standard cable width (R. Hill pers. comm.).

Abrasion in UK waters is caused by benthic fishing, wind turbine foundation scour, and burial of power cables. The most important human pressure, in terms of spatial extent and level of impact, results from fishing using benthic trawl gear such as beam trawlers, otter trawlers, and shellfish dredges (e.g. Collie et al. 1997, Rijnsdorp et al. 1998, Dinmore et al. 2003, Stelzenmüller et al. 2008). Recovery from fishing is gear-dependent and may also depend on frequency of trawl passes (Kaiser et al. 2006, Hall et al. 2008). We used published estimates of spatial variability and intensity

Table 1. Pressures and activities affecting the UK seabed. Data provided in WGS 84 (world geodetic system 1984) projection in decimal degrees (6 decimal places; Cefas, SPIRE, SeaZone, UKHO), or British National Grid eastings and northings at ordinate resolution 0.0001 m (UK DEAL). Cefas: Centre for Environment Fisheries and Aquaculture Science; SPIRE: Shared Spatial Information Services (https://secure.services.defra.gov.uk/); UK DEAL: United Kingdom Offshore Oil & Gas Industry, Common Data Access Ltd. (www.ukdeal.co.uk); UKCPC: United Kingdom Cable Protection Company (www.ukcpc.org.uk); SeaZone: British Crown and SeaZone Solutions Limited; UKHO: United Kingdom Hydrographic Office

Pressures and activities	Data source & description	Activity description	Manipulation in GIS and footprint area	References
Smothering				
Disposal of dredged material	Cefas, SPIRE. Licence area polygons	Disposal occurs within >150 licensed sites. Licensees deposit material over the centre of sites	Dimensions of licensed disposal sites, without buffers	Bolam et al. (2006), Birchenough et al. (2010), S. Pacitto (pers. comm.)
Cuttings from oil and gas exploration	SPIRE, UK DEAL. Point data	Cuttings are produced during drilling. Cuttings are separated and disposed to sea. Since 2000 only water-based fluid has been permitted for drilling	Circular buffers of 100 m radius applied to platform and well head data. Area of ~31500 m^2 per point	OSPAR Commission (1993, 2000, 2009), Daan & Mulder (1996), de Groot (1996), Currie & Isaacs (2005), Eastwood et al. (2007), R. S. Rowles (pers. comm.)
Obstruction (sealing)				
Oil and gas platforms	SPIRE, UK DEAL. Point data	Four- or 6-leg steel structures, each 2 m diameter. Plus associated drilling and production gear	Circular buffers of 7.5 m radius applied. Area of 180 m^2 per platform	UKOOA (2002), Eastwood et al. (2007)
Well heads	SPIRE, UK DEAL. Point data	Protective structures built over well heads	Circular buffers of 25 m radius applied to point data. Area of ~2000 m^2 per well head	Eastwood et al. (2007)
Oil and gas pipelines	SPIRE, UK DEAL. Line data	Pipelines resting on the surface of seabed	Exact dimensions of pipelines	Eastwood et al. (2007)
Telecommunication and power cables	SPIRE, SeaZone, UKHO. Line data	Exposed cables on rock are armoured to a maximum diameter of 50 mm. Approx 20% cables in soft sediment are not buried	Buffers 50 mm wide for cables on rock substrate and 25 mm on soft sediment	Kogan et al. (2006), Carter et al. (2009), R. Hill (pers. comm.), UKCPC
Wind turbines	Crown Estate, SPIRE, SeaZone. Point data	Monopile foundations 4–5 m in diameter with scour protection of 30 m diameter	Circular buffers of 15 m radius applied. Area of ~700 m^2 per turbine	OSPAR Commission (2006), Rees (2006)
Wrecks	SPIRE, SeaZone, UKHO. Point data	Sizes of individual wrecks unknown. Nominal spatial extent used	Circular buffers of 17.5 m radius applied. Area of 962 m^2 per wreck	Eastwood et al. (2007)
Abrasion				
Benthic fishing using trawl gear	Cefas. Point data	Vessels ≥ 15 m. Satellite-based Vessel Monitoring Systems (VMS) point data. UK logbook data and the European vessel register for type of gear deployed; grouped as otter trawls, beam trawls or shellfish dredges	Estimates of spatial extent of fishing for each VMS record based on vessel speed, VMS interval and width of fishing gear. Data gridded in 1 km^2 cells. Intensity calculated from annual number of trawl passes	Collie et al. (1997), Rijnsdorp et al. (1998), Dinmore et al. (2003), Stelzenmüller et al. (2008), Foden et al. (2010)
Telecommunication and power cables	SPIRE, SeaZone, UKHO. Line data	Fibre-optic cables 17–21 mm diameter, protected to a total diameter of 30 mm. Buried in soft sediment by sea plough or water jet	Buffers 5 m wide representing the mean width of trench disturbance	Allan (1998), Carter et al. (2009), Drew & Hopper (2009), UKCPC
Wind turbine scour	Crown Estate, SPIRE, SeaZone. Point data	Waves and tides around turbines cause scour pits in mobile sediment, up to 10 times the diameter of the obstruction	Circular buffers of 50 m radius applied. Area of ~7850 m^2 per turbine, minus area of scour protection (see Obstruction)	Rees (2006)
Extraction				
Aggregate extraction	Crown Estate, Cefas, SPIRE. 50 × 50 m polygons	Electronic Monitoring Systems (EMS) data in 50 × 50 m (2500 m^2) cells showing location and hours dredged per year	EMS 50 × 50 m cell locations and dredge intensity	Dickson & Lee (1972), Kenny & Rees (1994), Newell et al. (1998), Boyd et al. (2004), BMAPA (2006, 2008), Foden et al. (2009, 2010), K. O'Shea (pers. comm.)

of fishing activity in UK waters in 2007 (Foden et al. 2010). Intensity was accounted for as follows: e.g. if a beam trawler sweeps the entire area of a 1 km^2 cell 4 times a year, fishing intensity was set to be 4.0 and the mean recovery time for the cell was estimated as the recovery time from one pass × 4 (sensu Foden et al. 2010). Abrasion caused by hydrodynamics around individual turbine foundations can create scour pits of 100 m diameter (Rees 2006), which we used as a standard footprint for all turbines. The majority of offshore cables in UK waters are buried using sea-ploughs or water jets (Allan 1998, Carter et al. 2009, Drew & Hopper 2009). The overall disturbance strip ranges from 2 to 8 m (Carter et al. 2009), and we used a mean width for all buried cables.

Aggregate dredging for mineral resources constitutes extraction pressure in UK waters. We used published estimates of aggregate extraction effort in UK waters during 2007 (Foden et al. 2009).

With GIS, estimations were made of the location and areas of seabed habitats affected by individual and by coincidental activities. Activities were also grouped by the 4 pressure categories to estimate the location and areas affected by individual or cumulative pressures. The footprint estimates of each activity were attributed a confidence rating on a scale of 1 to 3: 1 indicating the highest confidence rating in which location and extent of an activity's footprint were accurately known, 2 indicating known location but estimated extent, and 3 indicating the lowest confidence based on estimations of location and extent (sensu Eastwood et al. 2007).

Recovery. We estimated seabed habitat sensitivity to different anthropogenic activities by determining recovery rates of the benthic community following cessation of an activity, and based on the activity's distribution and intensity. Recovery was characterised as having occurred when the abundance, species richness or biomass of benthic biota was equivalent to a 20% reduction or less in the pre-impact value (Kaiser et al. 2006) or a return of benthic resources to either a baseline (pre-impact) or reference condition (Wilber et al. 2008). Recently published estimates of habitat recovery after aggregate extraction (Foden et al. 2009) and benthic fishing (Foden et al. 2010) were used. A review was conducted of scientific literature for recovery of the benthos from the remaining human activities. Our study area is in temperate waters where primary and secondary production are high with strong seasonal patterns, so data from studies conducted in this, or similar areas, were used. UK waters have a long history of high levels of human activity, with many pressures tending to repeatedly target the same grounds year after year (Kaiser et al. 2002, Hiddink et al. 2006b). For some habitats therefore, the point at which recovery is deemed to have occurred is a point in a constant disturbance cycle and not disturbance of a pristine benthic community.

For some activities the date of occurrence can be important when determining a site's stage of recovery. The timing of different activities was known with varying levels of precision (e.g. day or month) for 4 activities: dredge material disposal, fishing, cable burial, and aggregate extraction. This information was used to estimate the degree of recovery already reached by 2007 and to filter out activities old enough for full recovery to be assumed. Drilling dates were not available for well heads and the spatial extent of resultant cuttings piles is likely to be an overestimation, as recovery was probably well underway at sites were dispersal had occurred. Date of installation is irrelevant for areas of the seabed permanently sealed by some obstruction activities, as no recovery is possible for the duration of the activities' presence. Similarly, date of wind farm construction was not relevant for scour pits associated with turbines, as they represent a constant abrasion pressure.

Cumulative impact. The size and location of multiple activities and pressures were identified as described above. We considered activities representing obstruction pressure to be exclusive of in-combination effects. Where the seabed has been effectively sealed by an installation, benthic recolonisation is prevented and extra activities cannot have further impacts. For example, disposal may occur on top of a wreck, or a benthic fish trawl may pass over a wellhead but they can create no more damage. Within each habitat, the size and location of areas where activities coincided were estimated; the estimation of total recovery times is described below.

Where activities were coincident we estimated cumulative recovery times according to the intensity of the activity and habitat in which they occurred. Estimates were made under 4 different cumulative effects scenarios: single greatest, additive, antagonistic, and synergistic (Halpern et al. 2008a, Foden et al. 2010). This allowed us to determine the sensitivity of the scenarios to different measures of impact estimation according to habitat type. The premise for Scenario I was that the single worst or dominant pressure takes precedence over the others in determining combined effects, with lesser pressures having no additional impact. For Scenario II, multiple pressures were assumed to act independently within the system, and therefore, overall recovery time was the sum of all pressures (e.g. Halpern et al. 2008a, Ban et al. 2010).

The purpose of Scenarios III and IV was to show a range in the sensitivity of habitats to impacts that interact. Scenario III estimated cumulative impacts as the antagonistic effects of multiple pressures. Previous investigations have found marine landscapes to be more sensitive to some human activities than others. If pressures are applied consecutively to marine habitats, then the impact of the primary pressure may pre-condition the habitat to be less sensitive to the secondary pressure. To estimate total recovery time we used a linear calculation sensu Stelzenmüller et al. (2010): recovery time from the primary pressure + 50% recovery time from the secondary pressure, + 0% from the third pressure. Total recovery times were expected to be between those of Scenarios I and II. In Scenario IV synergistic effects were assumed, in which the impact from accumulated pressures was greater than the sum of the individual parts, the assumption being the first pressure lessens the resilience of a habitat, making it more sensitive to subsequent pressures. Therefore in Scenario IV, we estimated total recovery time using the same linear relationship: recovery from the primary pressure + 150% recovery time from secondary pressure + 200% from the third, with the expectation of total times greater than for the other 3 scenarios. A rank order of pressures needed to be determined for Scenarios III and IV. Stelzenmüller et al. (2010) scored the sensitivity of UK marine landscapes to a range of pressures and found that, in general, landscapes were most sensitive to extraction and were slightly more sensitive to smothering than abrasion pressures.

RESULTS

Spatial distribution of pressures

Aggregate extraction and 3 obstruction activities — pipelines, cables, and wind turbines — were all at the highest confidence level (Table 2) because their location and extent were available from the data source

Table 2. Estimates of spatial extent of human activities and pressures affecting the UK seabed (km^2) in 2007. Percentages of habitat and seabed affected are in *italics*. Confidence in spatial data: 1, known location and extent; 2, known location and estimated extent; 3, estimated location and extent

Pressure	Human activity	Confidence	Footprints per habitat: Sand	Gravel	Muddy sand	Reef	Mud	Footprints on UK seabed: Per activity	Per pressure (overlapping activities merged)
Smothering	Dredge material disposal	3	110.8	89.6	61.0	21.9	0.2	283.5	346.01
			0.06	*0.22*	*0.26*	*0.43*	*0.01*	*0.11*	*0.14*
	Cuttings from well heads and platforms	2	52.6	6.2	3.6	0.03	0.1	62.6	
			0.03	*0.02*	*0.02*	*<0.01*	*0.05*	*0.02*	
	Smothering per habitat (overlapping activities merged)		**163.4**	**95.8**	**64.5**	**21.9**	**0.34**		
Obstruction	Oil and gas platforms	2	0.8	<0.1	<0.1	0.0	0.0	0.8	21.1
			<0.01	*<0.01*	*<0.01*	*0.00*	*0.00*	*<0.01*	*<0.01*
	Well heads	2	4.2	0.5	0.3	<0.1	<0.1	5.0	
			<0.01	*<0.01*	*<0.01*	*<0.01*	*<0.01*	*<0.01*	
	Oil and gas pipelines	1	3.1	0.7	0.2	0.0	<0.1	4.0	
			<0.01	*<0.01*	*<0.01*	*0.00*	*<0.01*	*<0.01*	
	Submarine cables	1	0.2	<0.1	<0.1	<0.1	0.0	0.3	
			<0.01	*<0.01*	*<0.01*	*<0.01*	*0.00*	*<0.01*	
	Wind turbines	1	0.1	0.1	0.1	0.0	0.0	0.2	
			<0.01	*<0.01*	*<0.01*	*0.0*	*0.00*	*<0.01*	
	Wrecks	2	6.7	3.4	1.7	0.4	0.1	12.4	
			<0.01	*<0.01*	*<0.01*	*<0.01*	*<0.01*	*<0.01*	
	Obstruction per habitat (overlapping activities merged)		**14.4**	**4.4**	**1.9**	**0.4**	**0.1**		
Abrasion	Benthic fishing	2–3	93946.2	19893.4	18088.2	647.3	1324.7	133899.7	133909.59
			50.56	*49.68*	*76.25*	*12.73*	*71.89*	*52.2*	*52.20*
	Wind farm scour pits	2	0.6	0.6	0.5	0.0	0.0	1.7	
			<0.01	*<0.01*	*<0.01*	*0.00*	*0.00*	*<0.01*	
	Submarine cable burial	2	12.3	4.2	1.4	0.0	0.1	18.0	
			<0.01	*<0.01*	*<0.01*	*0.00*	*<0.01*	*<0.01*	
	Abrasion per habitat (overlapping activities merged)		**93952.3**	**19896.8**	**18089.3**	**647.3**	**1323.9**		
Extraction	Aggregate extraction	1	51.9	92.4	1.9	0.0	0.0	146.3	146.3
			0.03	*0.23*	*<0.01*	*0.00*	*0.00*	*0.05*	*0.05*
Footprint of all pressures, per habitat			**94182.0**	**20089.5**	**18157.6**	**669.6**	**1324.3**		
			50.69	***50.17***	***76.54***	***13.17***	***71.87***		

(Table 1). The location of dredge disposal is only accurate to licence areas not the exact dumping site and this was assigned the lowest confidence rating. The location of benthic fishing vessels is provided at a 2 hourly frequency from VMS. However, in this time vessels can cover up to 12 nautical miles whilst fishing (Lee et al. 2010) and, as an estimate of the exact tracks of vessels was required for this work, confidence was rated as 2 to 3 (intermediate-to-low). Data for the remaining activities were at the intermediate confidence level because their locations were known, but the extent of impact was estimated.

The total area affected by human activity was 134 400 km^2, constituting 52% of the UK seabed (Table 2). Abrasion was the main pressure. Specifically, benthic fishing accounted for most of the abrasion pressure, affecting an area up to 3 orders of magnitude greater than for any other activity in any habitat. The total area affected by obstruction, extraction and smothering pressures was only 513.4 km^2, constituting ~0.2% of the study area. Smothering was the second largest pressure, mainly accounted for by dredge material disposal. The majority of mud and muddy sand habitats were affected by human activities, with an estimated >70% of their area affected. Human activities occurred in approximately half of the area of sand and gravel and only 13% of reef habitats. Benthic fishing was the major cause of human pressure but its confidence rating was 2 to 3; thus, in general, overall confidence in the location and extent of human activity on the UK seabed in 2007 could be classed as intermediate-to-low.

In total only an estimated 166 km^2 (0.07%) of UK seabed was affected by cumulative pressure (Table 3). Smothering, abrasion, and extraction pressures were coincident in relatively small proportions of habitat areas. Smothering and abrasion accounted for the largest areas of in-combination pressures. These 2 pressures coincided in 71 km^2 (<0.1%) of sand, and 45 km^2 (0.2%) of muddy sand. In all other cases, 2 or 3 combined pressures were coincident in <0.1% of habitat areas.

Table 3. Estimated areas of coincidental pressures (km^2) affecting UK seabed habitats (percentage of habitat area affected in *italics*)

Coincidental pressures	Habitat				
	Sand	Gravel	Muddy sand	Reef/ rock	Mud
Smothering + abrasion	71.1 *0.04*	10.2 *0.03*	44.6 *0.19*	0.7 *0.01*	0.1 *0.01*
Abrasion + extraction	13.6 *0.01*	18.5 *0.05*	0.0 *0.00*	0.0 *0.00*	0.0 *0.00*
Extraction + smothering	2.2 *<0.01*	3.7 *0.01*	0.0 *0.00*	0.0 *0.00*	0.0 *0.00*
Smothering + extraction + abrasion	0.1 *<0.01*	0.9 *<0.01*	0.0 *0.00*	0.0 *0.00*	0.0 *0.00*

Recovery

For reasons stated above, no recovery estimates were made for areas where the seabed was sealed by obstructions. Therefore recovery estimates are not given for locations in which oil and gas platforms, wellheads, pipelines, wind turbines, wrecks or surface laid cables were present. The precision of published recovery rates of the benthic community from the other commonly occurring human activities was variable, e.g. quoted as days, months or years. We rationalised these as months or years, so that recovery rates in Table 4 are in the range <1 mo to 9 yr.

The impacts on the benthos from smothering are site-specific. Recovery from dredge material disposal is context dependent and thus does not conform to a single ecological model (Bolam & Rees 2003, Bolam et al. 2006, Whomersley et al. 2010). In general, communities adapted to strongly hydrodynamic environments recover significantly more rapidly than those in weakly hydrodynamic environments (Bolam & Rees 2003, Bolam et al. 2006, Wilber et al. 2008). The recovery rates quoted in Table 4 are based on salinity, hydrodynamics and water depth of the receiving environment. Our estimates of recovery from cuttings contaminated with WBM were based on recovery from physical smothering, because these are quantified in the literature. However, WBM drilling wastes may contain free oil, dissolved aromatic hydrocarbons, heavy metals and radionucleides, and recent studies suggest the response of the benthic community may be through oxygen depletion (e.g. Trannum et al. 2010). However, benthic recovery has yet to be quantified. Recovery rates from physical smothering depend on particular combinations of sediment characteristics, the local hydrodynamic regime, receiving habitat, and benthic community (Kröncke et al. 1992, Daan et al. 1994, Holdway 2002, Kröncke & Bergfeld 2003, Breuer et al. 2004). Although recovery rates were only available for sand and gravel environments, 94% of cuttings piles in the UK are in these habitats (Table 2).

Abrasion pressures may be caused by regularly-occurring, constant, or one-off activities (Table 4). Recovery rates from bottom-fishing were summarised from Foden et al. (2010), who estimated recovery of the benthos by

Table 4. Recovery times for habitats by seabed pressure (smothering, abrasion, or extraction) and activity. Strong hydrodynamics: shallow (≤20 m), strong wave action or tidal currents, low residence time (~days), high turbidity and sediment movement. Weak hydrodynamics: >20 m deep, non-turbulent, low circulation sites. n/d: no data available; n/r: no recovery until the activity ceases; n/a: not applicable (the activity does not occur in the habitat, in UK waters)

Pressure	Human activity		Environment			
			Estuarine (polyhaline)		Coastal (euhaline)	
Smothering	Dredge material disposal	Strong hydrodynamics	1–9 mo[a,b]		≤1 yr[a,b]	
		Weak hydrodynamics	≤2 yr[a]		1–4 yr[a,b,c,d]	
		Habitat				
		Sand	Gravel	Muddy sand	Reef	Mud
	Oil and gas cuttings	<1 yr[e,f]	>11 mo (well advanced)[g]	n/d	n/d	n/d
Abrasion	Beam trawling	<6 mo[h]	n/d	<8 mo[i]	n/d	n/d
	Otter trawling	<1 mo[i]	<1 yr[j]	>7 mo[k]	>8 yr[i]	<1 mo[i]
	Shellfish dredging	>8 yr[i,l]	>8 yr[i]	1.6 yr[i]	3.2 yr[i]	n/d
	Wind turbine scour	n/r	n/r	n/r	n/a	n/a
	Cable burial	1–12 mo[m,n]	<1 yr[n]	<1 yr[n]	n/a	<4 mo[o]
Extraction	Aggregate extraction	7.3 yr[p]	9.0 yr[p]	n/d	n/a	n/a

[a]Bolam & Rees (2003), [b]Wilber et al. (2008), [c]Borja et al. (2009), [d]Wilson et al. (2009), [e]Daan & Mulder (1996), [f]Daan et al. (1994), [g]Currie & Isaacs (2005), [h]Kaiser et al. (1998); [i]Kaiser et al. (2006); [j]Kenchington et al. (2006); [k]Ragnarsson & Lindegarth (2009); [l]Gilkinson et al. (2005), [m]Guerra-García & García-Gómez (2006), [n]Andrulewicz et al. (2003), [o]Sparks-McConkey & Watling (2001), [p]Foden et al. (2009)

fishing gear-type and intensity. The evidence for the effects of fishing frequency is mixed, i.e. within a single habitat type the same frequency of trawl events can lead to differing responses of the benthos in different locations. Therefore we used a minimum recovery time of 1 yr in Table 5, which also allows for seasonality in the ability of the benthic community to recover (Hall et al. 2008, C. L. J. Frid pers. comm.). The habitat–gear combinations for which there were no recovery rates only represent approximately 1 % of the area subjected to benthic fishing in 2007. Scour pits around the foundations of wind turbines are likely to be a constant abrasion pressure. Routine sampling is not possible within 50 m of a turbine (OSPAR Commission 2008), so we assumed no benthic recovery is possible from scour during the lifetime of wind farms. Wind farms are licensed for 25 yr (A. Judd pers. comm.) and to date none have been decommissioned in UK waters. Outside the scour zone, between turbines, there is little or no evidence for benthic disturbance caused by the wind farm (NPower Renewables 2008, Degraer & Brabant 2009, Cefas 2010). Cable installation is of limited spatial and temporal extent unless a submarine cable is damaged, and recolonisation may be rapid (Guerra-García & García-Gómez 2006). No data were available specifically on recovery from cable burial in mud habitats. However, a study of low intensity benthic trawling effects in a low-energy 60 m deep mud environment was appropriately comparable as it mirrors the mud habitat in UK waters.

The only activity representing extraction pressure is aggregate dredging. Recovery estimates in Table 4 for this activity were taken from Foden et al. (2009).

Cumulative impact

Co-occurring activities were found in all habitat types (Table 5). The footprints of coinciding activities were largest in sand (87.2 km^2) and smallest in mud (<0.1 km^2) habitats. However, these constitute <0.5 % of each of the 5 habitat types. Values are stated to an accuracy of 0.1 km^2 to reflect the variation in confidence levels in the locational accuracy of activities and the spatial extent of their impact (from Table 2). Some combinations of activities were not found. For example, in weakly hydrodynamic estuarine environments, disposal did not occur where there were extraction or abrasion pressures. Wherever abrasion coincided with extraction or smothering, benthic fishing was the causative activity of abrasion pressure. Submarine cables and wind farm scour pits were exclusive of any other activity.

Cumulative recovery rates across the 4 scenarios ranged from ≤1 to 15 yr. In Scenario I, recovery time estimates were ≤4 yr for all combinations of smothering and abrasion activities, but estimates doubled (7.3 to 9 yr) where extraction comprised one of the co-occurring activities. A similar pattern was repeated for Scenarios II, III and IV; aggregate extraction consis-

Table 5. Impact from human activities in UK waters, in 2007. Recovery period estimates for individual activities and cumulative impact recovery estimates for 4 scenarios: I: longest recovery period; II: additive recovery period; III: antagonistic recovery period (100% 1st pressure + 50% 2nd pressure + 0% 3rd pressure); IV: synergistic recovery period (100% 1st pressure + 150% 2nd pressure + 200% 3rd pressure). Fishing gear, mean fishing intensity (where 1 = entire 1 km^2 cell is fished yr^{-1}) and period of recovery from fishing are taken from Foden et al. (2010), with a minimum recovery period of 1 yr (C. L. J. Frid pers. comm.). BT: Beam trawl; OT: otter trawl; SD: shellfish dredge

Habitat	Cumulative pressures	Recovery estimates for individual activities	Affected area (km^2)	Recovery estimates for cumulative impact scenarios (yr) I	II	III	IV
Sand	Smothering + abrasion	Disposal (estuarine strong dynamics) 0.75 yr, BT (intensity 1.86)[a] 1 yr[b]	4.0	1	1.8	1.3	2
		Cuttings & disposal (coast strong dynamics) ≤1 yr, BT (intensity 0.81)[a] 1 yr[b]	18.3	1	≤2	≤1.5	≤2.5
		Disposal (coast weak dynamics) 1–4 yr, BT (intensity 1.11)[a] 1 yr[b]	35.6	≤4	≤5	≤4.5	≤5.5
		Cuttings & disposal (coast strong dynamics) ≤1 yr, OT (intensity 1.07)[a] 1 yr[b]	8.2	1	≤2	≤1.5	≤2.5
		Disposal (coast weak dynamics) 1–4 yr, OT (intensity 1.41)[a] 1 yr[b]	3.3	≤4	≤5	≤4.5	≤5.5
		Cuttings & disposal (coast strong dynamics) ≤1 yr, SD (intensity 0.18)[a] 1.4 yr	1.8	1.4	≤2.4	≤1.7	≤3.1
	Extraction + abrasion	Extraction 7.3 yr, BT (intensity 0.89)[a] 1 yr	11.6	7.3	8.3	7.8	8.8
		Extraction 7.3 yr, OT (intensity 0.38)[a] 1 yr	1.5	7.3	8.3	7.8	8.8
		Extraction 7.3 yr, SD (intensity 0.19)[a] 1.5 yr	0.6	7.3	8.8	8.1	9.6
	Extraction + smothering	Extraction 7.3 yr, Disposal, coast strong dynamics ≤1 yr	2.2	7.3	8.3	7.8	8.8
	3 pressures	Extraction 7.3 yr, Disposal, coast strong dynamics ≤1 yr, BT (intensity 0.27)[a] 1 yr[b]	0.1	7.3	≤9.3	≤7.8	≤10.8
Gravel	Smothering + abrasion	Cuttings & disposal (coast strong dynamics) ≤1 yr, BT (intensity 1.16)[a] 1 yr[b]	0.2	1	≤2	≤1.5	≤2.5
		Disposal (coast weak dynamics) 1–4 yr, BT (intensity 0.85)[a] 1 yr[b]	2.9	≤4	≤5	≤4.5	≤5.5
		Cuttings & disposal (coast strong dynamics) ≤1 yr, OT, (intensity 0.72)[a] 1 yr[b]	1.0	1	≤2	≤1.5	≤2.5
		Disposal (coast weak dynamics) 1–4 yr, OT (intensity 1.58)[a] 1.6 yr	5.9	≤4	≤5.6	≤4.8	≤6.4
		Cuttings & disposal (coast strong dynamics) ≤1 yr, SD, (intensity 0.40)[a] 3.2 yr	0.2	3.2	≤4.2	≤2.6	≤5.8
		Disposal (coast weak dynamics) 1–4 yr, SD (intensity 0.01)[a] 1 yr[b]	<0.1	≤4	≤5	≤4.5	≤5.5
	Extraction + abrasion	Extraction 9 yr, BT (intensity 0.62)[a] 1 yr[b]	5.9	9	10	9.5	10.5
		Extraction 9 yr, OT (intensity 1.26)[a] 1.3 yr	3.0	9	10.3	9.7	11
		Extraction 9 yr, SD (intensity 0.35)[a] 2.8 yr	9.6	9	11.8	10.4	13.2
	Extraction + smothering	Extraction 9 yr, disposal (coast strong dynamics) ≤1 yr	1.9	9	10	9.5	10.5
	3 pressures	Extraction 9 yr, disposal (coast weak dynamics) 1–4 yr	1.9	9	13	11	15
		Extraction 9 yr, disposal (coast strong dynamics) ≤1 yr, BT (intensity 0.18)[a] 1 yr[b]	0.9	9	11	9.5	12.5
Muddy sand	Smothering + abrasion	Disposal (coast strong dynamics) ≤1 yr, OT (intensity 1.5)[a] 1 yr[b]	44.6	1	≤2	≤1.5	≤2.5
Reef	Smothering + abrasion	Disposal (coast weak dynamics) 1–4 yr, SD (intensity 0.15)[a] 1 yr[b]	0.7	≤4	≤5	≤4.5	≤5.5
Mud	Smothering + abrasion	Cuttings only (no data), OT (intensity 1.03) [a]1 yr[b]	<0.1	1[c]	1[c]	1[c]	1[c]

[a]Foden et al. (2010).
[b]Minimum recovery period of 1 yr for all fishing gears and fishing intensity.
[c]No recovery period for one of the activities, therefore values for Scenarios II, III and IV are for one pressure only

tently accounted for the longest cumulative recovery times. Consequently, sand and gravel habitats were estimated to have the longest recovery periods for Scenario IV, at up to 10 or 15 yr, respectively, because there was no aggregate extraction in the other 3 habitats. Cumulative recovery estimates were most rapid for all scenarios in muddy sand habitats (up to 2.5 yr), where disposal and otter trawling in a strongly hydrodynamic environment were the only coincidental activities. From the values given in Table 4 reef habitats might have been expected to recover slowly, but recovery from coincidental activities was estimated at up to 5.5 yr. The likely explanation is that scallop dredging was at the very low intensity of 0.15 (i.e. approx. once per km^2 every 7 yr), which could allow for the benthos to begin recovering between trawls and dredge material disposal events. Mud habitat was least affected by cumulative activity (<0.1% of habitat). Benthic recovery from drill cuttings in mud was not known, so cumulative times could not be estimated for combined smothering and abrasion pressures in this habitat. However, mud habitat only represents an area <0.1 km^2.

DISCUSSION

This study builds on previous assessment of human activities causing direct, physical pressure on the UK seabed (Eastwood et al. 2007) in 3 key ways: by quantifying the intensity of relevant activities, by linking the spatial extent of activities to habitat type, and by estimating their cumulative impact using published recovery times. Our methods and findings are relevant to several European and global obligations to assess and report marine environmental status, principally those commitments requiring greater knowledge and understanding of individual and cumulative effects from different human activities. We provide a snapshot of the spatial extent of human activities acting on the UK seabed in 2007 by applying the framework for evaluating individual and cumulative impacts proposed by Foden et al. (2010). Where activities were coincidental, 4 impact scenarios were applied to assess the range of possible consequences.

In 2007, cumulative activities were relatively rare, in total affecting an area of only 166 km^2 (<0.1% of the study area). The majority of the footprint of human activities was caused by the activity of single, rather than multiple, sectors. Abrasion had the largest spatial extent of the 4 pressures and just one activity, benthic trawling, accounted for 99.99% of abrasion by area. Benthic fishing affected more than half of UK (E & W) waters, as compared with 0.2% affected by all the other 11 activities combined. Inter-annual change in this pattern is predicted to be small. Previous work examining temporal changes in fishing pressure in UK waters found strong spatio-temporal correlation in fishing intensity between 2006 and 2007 (Pearson's $r = 0.405$, $p < 0.001$) (Foden et al. 2010). The other human activities are of more restricted spatial extent, e.g. pipelines, dredge disposal licence areas, oil and gas platforms. Therefore the locations and sizes of coincident activities are unlikely to be highly variable over time. To control the consequences of human pressures on the marine environment, it could reasonably be argued that in terms of extent, the assessment and control of spatially limited cumulative impacts is relatively unimportant. The remaining concern relates to consequences of these combined activities on benthic recovery, and the extent to which they are sustainable.

Estimates of recovery rate for single sector activities were <1 mo to 9 yr, while recovery ranged from 1 to 15 yr for cumulative activities under the 4 scenarios. The largest activity–habitat combinations were beam and otter trawling in sand and gravel, where recovery of the seabed community might reasonably be expected within 1 yr. In contrast, the recovery rates from aggregate extraction were substantially greater, although the spatial footprint was very restricted, comprising only <0.01% that of benthic fishing. In the small areas where cumulative effects occurred, abrasion and smothering in sand and muddy sand habitats accounted for the majority of coinciding pressures. These pressure–habitat combinations had recovery estimates of up to 5.5 yr, while other cumulative impact scenarios suggested the benthic community would require a decade or more to recover. Wherever recovery estimates were ≥9 yr, aggregate extraction accounted for the largest proportion of that time period.

These results provide quantitative estimates of spatial extent and recovery times of habitats, which are an important addition to the assessment of UK marine ecosystems already undertaken (Defra 2010). This national assessment of benthic habitat condition was based on expert judgement and drew upon limited evidence from monitoring studies and research. Its conclusion states 'large areas of subtidal sediments in most regions have been adversely affected by mobile fishing gears such as bottom trawls and dredges [...] [and] locally, extraction of aggregates has damaged the seabed in the Eastern Channel and Southern North Sea' (Defra 2010, p. 31). Given the large footprint of benthic fishing and the slow recovery rate estimates from aggregate extraction, it might be reasonable, at least in the short term, for management measures to focus on these 2 activities if impact on the seabed is to be mitigated and marine status improved. Indeed, aggregate extraction is already highly regulated and very spatially restricted (DCLG 2002). New statutory regulations for aggregate licensing (DCLG 2007) require the Marine Management Organisation to consider the Habitats and Environmental Impacts Assessment Directives (EU 1992, 2003) in their decisions. Consequently, decision-making on site licences is already moving towards an ecosystem approach. Furthermore, it has been argued by some commentators that the loss of seabed can be balanced by the socio-economic need for aggregate, especially when sites are selected within an ecosystem-based management system (Petterson 2008, Rabaut et al. 2009). This argument is more difficult for extensive activities such as fishing, which is amongst the most important factors affecting the ecological state of many marine ecosystems (Jennings & Kaiser 1998, Watling & Norse 1998), and for which management is widely considered to be a high priority (e.g. Pauly et al. 2005, Pitcher & Lam 2010). However, in the UK there has been a recent move toward regionalisation with the establishment of Regional Advisory Councils, which have the potential to improve fisheries management.

The methodology for analysing individual and cumulative impacts of human activities on the seabed and its application presented herein are likely to be appropriate for other locations. Indeed the literature reviews of recovery rates, here and from previous work (Foden et al. 2009, 2010), included international studies with similar environmental conditions to the UK, based on this *a priori* assumption. Waters of the wider European region have comparable pressures as well as environmental characteristics to the UK, and similar responses to those pressures would be expected. The basic framework would also be amenable for use in examining the impact of different kinds of pressures affecting regions of contrasting environmental conditions, although literature reviews or empirical studies of pressure effects would need to be focused on the same characteristics of the region under investigation.

Cumulative impact assessment as a discipline is still in its early stages. Recent studies have mapped spatial extent and intensity of multiple human activities (e.g. Ban & Alder 2008, Halpern et al. 2008b, Selkoe et al. 2009), but few have considered their impact on the receiving habitat (e.g. Ban et al. 2010). These studies are at a variety of scales and in all cases identified greater proportions of overlapping pressures than in this study, generally because they considered pressures on the entire marine ecosystem such as shipping, recreation, aquaculture, and pelagic fishing. Our detailed, quantitative study is an important step on which a holistic ecosystem assessment could be based. However, the more complex and highly integrated the assessment, the more difficult it can be to indicate causality and to predict future scenarios (Foden et al. 2008). For example, recent assessments using multiple parameters to model present and future states are variable in producing quantitative or qualitative conclusions (e.g. Culp et al. 2000, Link et al. 2002, Choi et al. 2005, Chang et al. 2008), which can have consequences for management practices. A compromise is needed between the complexity of a fully integrated ecosystem assessment and its utility for directing management.

There are limitations to this work, for example related to the quality of broad scale habitat maps and the lack of ground-truthing of recovery times, which have been faced by many previous regional scale assessments (e.g. Halpern et al. 2009, Ban et al. 2010). Recovery rates for single activities, summarised in Table 4, are based on empirical evidence, but there are too few studies of recovery from the effects of combinations of activities to estimate recovery. For this reason we presented 4 scenarios of cumulative effects from multiple activities. Ideally the scenarios would also have been run to investigate cumulative impact from repeat events of the same activity. However, it was not possible to present this within the confines of a single paper, although it would be an interesting area for future study. The use of confidence ratings for our data has been a useful step, particularly for those activities for which the exact locations or the spatial extent of their impact was unknown. Confidence was generally low where generic spatial dimensions were used, e.g. for cuttings piles (sensu Eastwood et al. 2007). In reality a markedly patchy distribution of cuttings around production platforms has been noted, depending on site-specific sediment grains size and local hydrography (Kingston et al. 1987). Comparative *in situ* observations of cuttings from oil and gas production would improve size estimates of area affected and biological impacts from smothering, by habitat type. Similarly, the development of scour pits around turbines will be in the direction of local, prevailing hydrodynamics and such site-specificity could not be taken into account for each structure.

Finally, we assumed that recovery of the natural benthic community could not take place where obstructions were present. However, it is possible that some structures, such as surface-laid cables and pipelines, have either self-buried or are themselves used as a structure for future colonisation. Nevertheless, they might also be subject to damage and therefore be re-exposed for maintenance, and it was not possible to account for these differences in our analyses. Other semi-permanent structures such as wellheads, wrecks, and turbines might provide a hard substrate offering new habitat for benthic fauna and flora (Kogan et al. 2004, 2006, Danish Energy Authority 2006). Such subtle changes in habitat can have implications for higher trophic levels by providing shelter and feeding opportunities for predators. There is some evidence that the artificial reefs created by obstructions such as offshore wind farms can enhance fish populations in 2 ways, by increasing the availability of prey species living on the turbines and excluding some types of fishing activity from the region effectively creating a no-take zone (Punt et al. 2009, Reubens et al. 2011). Consideration of these types of trade-offs among different activities may be an interesting extension of cumulative impact assessment. Nonetheless, establishment of fauna associated with these hard substrates represents changes in populations, not re-establishment of the ambient benthic community which we defined as recovery.

The response of the benthic community to all human activity was found to be strongly dependent on the type of receiving habitat. This highlights the necessity for accurate, high resolution habitat maps, essential for more precise estimations of impact for effective management and control (Defra 2010). Similarly, higher resolution spatial data would more closely link activities to the receiving habitat. For example, whilst 2 hourly VMS signals from fishing vessels are suitable for management purposes at the UK scale, for estimating cumulative effects more frequent data would improve the accuracy in locating coinciding activities. Further scientific observations of the immediate and long-term footprint on the benthos from all human activities are necessary to determine which of the 4 scenarios is the most likely in the natural environment.

This work is a rigorous, quantitative assessment of direct individual and cumulative anthropogenic impacts on the seabed. It contributes towards understanding the links between humans and the marine environment by assessing the spatial and temporal effects of anthropogenic activities on the benthos. For future assessment and management purposes, in terms of the impact we have examined in this UK-based study, perhaps the most significant finding is that cumulative pressures on the seabed were very spatially restricted in 2007. Recovery times were comparable to some single sectors; therefore, single sector activities remain the predominant cause of direct human impact on the benthos. Nevertheless, there is still a need to develop scientific understanding of the linkages across those aspects of the marine environment not considered herein, e.g. water column pollution, pelagic fisheries, shipping and underwater noise. How such considerations might modify our findings is yet to be determined. To implement a full ecosystem-based approach to management would require a coherent and holistic assessment of all such interconnections, some of which may lead to cumulative impacts greater than those we have been able to consider (Foden et al. 2008). Nevertheless, we have addressed some of the knowledge, data and assessment tool gaps identified in recent national status assessments (Defra 2010), with regard to human pressure and impact on the benthic community. We hope that this approach to assessing the state of marine habitats will enable a more quantitative approach in future reporting against European and international commitments.

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