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JNCC Pressure Mapping Methodology

Physical Damage (Reversible Change) – Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion

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Summary

There are a growing number of human activities occurring within the marine environment. Concern over the possible impacts of these activities on the marine and coastal environment has led to the development of national, regional, and global commitments that aim to preserve, and, where possible, to mitigate impacts on marine environments (UKMMAS, 2010).

Different human activities exert a variety of pressures and these pressures will, in turn, have different levels of impact on habitats and species. To enable management of these impacts, we need to better understand how human activities and biodiversity interact spatially and temporally. We can then assess the sensitivity of the habitats and species that are exposed to these activities, and thus the associated pressures. When combined, exposure and sensitivity provide an indication of a habitat's 'vulnerability' to impacts.

To support this vulnerability assessment approach, JNCC are developing methods for creating geospatial pressure datasets for use at a regional and national scale. These datasets are created using a GIS to delineate their spatial extent and all activities that are known to exert the pressure are considered. In the UK one of the priority pressures on benthic habitats is Physical Damage – "Habitat structure changes - abrasion & other physical damage" hereafter referred to as 'abrasion', which is described as the "disturbance of sediments where there is limited or no loss of substrate from the system".

Activities known to exert the pressure of abrasion were evaluated in this pressure mapping method. Demersal fishing was identified as being the most spatially extensive activity associated with the pressure, and thus smaller contributing activities were not included. To create the pressure dataset, two types of data for demersal fishing were considered: anonymous VMS 'ping' data for UK vessels only, supplied by the Marine Management Organisation (MMO); and, aggregated VMS data grids for UK and EU vessels. Both determined the location and type of fishing gear deployed.

Swept area was calculated per grid cell using recommended gear widths multiplied by vessel speed and the time. This was aggregated by grid cell and then divided by the area of the grid cell to determine the swept area ratio, which is the proportion of the estimated swept area to the area equivalent to each grid cell. For each year, two raster layers were created from an R script using the swept area ratio per grid cell for surface and subsurface abrasion. The data is provided in a 0.05 x0.05 decimal degree grid.

The production of the abrasion pressure layers is based on a range of assumptions, and thus has a number of limitations, mainly that they are primarily for areas beyond the 12 nautical mile limit for use at a regional and national scale. Mobile demersal fishing for ≥12/15m is the only activity used here due to the difficulty in assessing contact area from static gear activities. For mobile gears, there is an assumption that fishing is occurring if the vessel is travelling between 1 and 6 knots. Furthermore, only VMS data that can be linked to gear type either by skipper logbook or EU vessel register could be used.

The current method is less appropriate for assessing swept area inshore as non-VMS inshore fisheries data was not included owing to a mismatch with VMS data. In the future new initiatives may enable the tracking of small fishing vessels (<12m) and it is hoped that a combined method that better reflects the pressure that fishing exerts on the seabed can be found.

Contents

1   Introduction

1.1 Background

This report was prepared from data available and research initiated in 2013. The extent of the Continental shelf has since been amended and further data for the subsequent years is now available.

Marine pressures can be defined as the mechanism through which an activity has an effect on any part of the ecosystem. The nature of the pressure is determined by activity type, intensity and distribution (Robinson *et al* 2008). As such, pressure does not equate to impact in this context.

Concern over the possible impacts of anthropogenic pressures on the marine and coastal environment has led to the development of national, regional, and global commitments that aim to preserve, and, where possible, to mitigate impacts on marine environments (UKMMAS 2010). Of relevance to the UK is the Marine Strategy Framework Directive (MSFD, 2008/56/EC) and the EC Habitats (92/43/EEC), which both require assessment of human activities within the marine environment. As such, determining the distribution and intensity of pressures is a key step in understanding the potential impacts of human activities.

An assessment of impact can be undertaken through a vulnerability assessment approach. Different human activities exert a variety of pressures and these pressures will, in turn, have different levels of impact on habitats and species. A vulnerability assessment essentially evaluates where, spatially, activities occur within the marine environment, and thus what level of 'exposure' marine habitats or species have to pressures associated with these activities. By ascertaining how sensitive each marine habitat and species is to these pressures it is then possible to predict their vulnerability. Exposure x Sensitivity = Vulnerability.

1.2 Pressures prioritisation

A prioritisation exercise was undertaken by JNCC to identify the relative importance of different pressures acting on benthic habitats in order to focus efforts on data collection and mapping for those pressures. This exercise reviewed a list of ranked pressures developed for Charting Progress 2 (CP2) (UKMMAS 2010), and compared this to other assessments of anthropogenic pressures (e.g. Scotland's Marine Atlas and the 2010 OSPAR Quality Status Report (Baxter *et al* 2011; OSPAR 2010)) to see if similar pressures were ranked in a comparable order. No evidence could be found to justify re-ranking the priority pressures, and as such the priority pressure list for seabed habitats at a UK scale is based on the CP2 assessment. In prioritising anthropogenic pressures on benthic habitats, consideration was given to their spatial extent, coincidence with features, and the intensity/significance of their effect on the features.

From this exercise, pressures were identified as high, medium, low and very low priority (JNCC 2011). The three highest priority pressures on seabed habitats were considered to be:

- Biological Pressures – "Removal of target species"
- Physical Damage – "Habitat structure changes - removal of substratum (extraction)"
- Physical Damage – "Habitat structure changes - abrasion & other physical damage"

Methodologies for pressures mapping are being developed for both of the physical damage high priority pressures. This report focuses on the pressure **"Habitat structure changes - abrasion & other physical damage" (hereafter referred to as "abrasion")**. Please note, following the prioritisation exercise, the pressure name subsequently changed to "Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion" (OSPAR 2011).

1.3 Aims

The aim of this paper is to present a recommended method for the creation of a standard UK-wide geo-data layer showing the intensity of abrasion on substrate caused by human activities, focusing on the area beyond 12 nautical miles (nm) from the coast. It is hoped that this method and the metrics and parameters used (fishing gear types and associated trawl widths and speeds) might be adopted as common approaches, to aid comparison between studies in the future. Updates with more recent data can, and should, be made as and when new datasets become available.

The method presented can be used to map abrasion pressure but does not consider the relative vulnerability of seabed habitats to this pressure. Habitat type and associated sensitivity to the abrasion pressure are not considered within this report. The geo-spatial pressure layers developed as a result of this method would need to be used in association with sensitivity and prevailing conditions information before any assessment of vulnerability is made.

Moreover, the geo-data layers for abrasion are two in a series of pressure layers, and may be used alongside these other pressure layers to support monitoring and assessment of impacts from a variety of marine activities.

2   Abrasion

2.1 Definition of abrasion and potential impacts

This paper adopts the definition of the pressure 'Physical damage (Reversible Change)' provided by the Marine Strategy Framework Directive (MSFD, 2008/56/EC) and further developed by the OSPAR Intercessional Correspondence Group on Cumulative Effects (OSPAR 2011). 'Physical damage (Reversible Change) - Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion' has been defined as: *"The disturbance of sediments where there is limited or no loss of substrate from the system. This pressure is associated with activities such as anchoring, taking of sediment/geological cores, cone penetration tests, cable burial (ploughing or jetting), propeller wash from vessels, certain fishing activities, e.g. scallop dredging, beam trawling. Agitation dredging, where sediments are deliberately disturbed by gravity, and hydraulic dredging where sediments are deliberately disturbed and moved by currents could also be associated with this pressure type. Compression of sediments, e.g. from the legs of a jack-up barge could also fit into this pressure type.*

Abrasion relates to the damage of the seabed surface layers (typically up to 50cm depth). Activities associated with abrasion can cover relatively large spatial areas and include: fishing with towed demersal trawls (fish & shellfish); bio-prospecting such as harvesting of biogenic features such as maerl beds where, after extraction, conditions for re-colonisation remain suitable or relatively localised activities including: seaweed harvesting, recreation, potting, aquaculture."

Abrasion can be split into two sub-types: Surface abrasion, defined as "*Damage to seabed surface features*" and sub-surface abrasion, defined as "*Damage to seabed surface and penetration*" (Tillin & Tyler-Walters 2010). These definitions relate to the parts of the gear that are in contact with the seabed.

Abrasion of seabed substratum has the potential to impact marine systems in a number of ways. Direct physical effects include the homogenisation of habitat topography through the modification of substrate and the displacement/damage of emergent structures such as boulders and reefs which can in turn result in the loss of habitat-dependant populations (Jennings & Kaiser 1998; Greive *et al* 2015; Johnson 2002). Abrasive activities can also influence the abundance of individuals within a benthic community through displacement and mortality (Rose *et al* 2000). Sessile and emergent epifauna are most vulnerable to being crushed or buried as a result of abrasion, whilst infauna are at risk of being excavated from their burrows and exposed to the seabed where they may be predated upon (Collie *et al* 1997; Johnson 2002). All of these above effects can result in community composition changes which in turn can have ecosystem-level consequences. It is these ecosystem-level consequences that are the basis for many concerns regarding the impact of abrasion in the marine environment.

2.2 Relationships between activities and pressures

In order to understand how activities exert pressures on the marine environment, it is first necessary to consider what activities contribute to a given pressure. To identify the links between activities and the pressures they exert, a matrix has been created (JNCC 2013). This matrix uses the standardised list of pressures (OSPAR 2011) and a corresponding standardised list of activities to be considered (JNCC 2014) and was based on a review by JNCC of the five most significant pressure/activity matrices (Annex II).

The scale at which any geo-data pressure layer is used helps determine which activities data are appropriate to include. For instance, for regional and national (i.e. broad-scale, regional sea, UK-wide) assessments, the contribution of some activities to the overall pressure footprint will be negligible and may compromise the use of other information (e.g. measures of intensity or frequency), may complicate the generation of pressure-data layers, or may limit the operational application in assessments. Under these circumstances, it is recommended that the activities used to generate the abrasion layer be prioritised to use only those that are of greatest importance in terms of spatial footprint. In contrast, at smaller spatial scales, e.g. within Marine Protected Areas, activities with a smaller footprint will likely have a larger effect on any overall assessment of impact and may need to be considered within smaller scale geo-data pressure layer development.

2.3 Activities to include in the pressure layer

Many studies that look at mapping abrasion pressure focus on either the single greatest activity or an additive of one or more activities (Halpern *et al* 2008; HELCOM 2010; Korpinen *et al* 2012). The most spatially extensive activity associated with the pressure physical abrasion is demersal fishing (both demersal trawling and dredging activities) (Eastwood *et al* 2007; UKMMAS 2010; Tillin *et al* 2010). When mapping such a spatially extensive activity at a national or regional scale there is little added value in the addition of smaller contributing activities. As such, the decision was made to create a geo-data layer showing demersal fishing activity only. All activities associated with abrasion that are not considered within this UK study are listed in Annex II. Other activities may need to be considered for studies that are conducted at a finer spatial scale or undertaken for a particular feature type.

3   Existing methodologies to map abrasion pressure

Many studies utilise the European Commission Vessel Monitoring System (VMS) data to measure fishing activity. VMS is a legal requirement for fishing vessels over a certain length in EC waters (Council Regulation (EC) No 1224/2009). It transmits a signal ('ping') at a minimum of two hour intervals that generates information on position, speed, heading and vessel identity. This information can also be linked to the vessels' logbooks to provide additional information on the gear type used, catch and landings. From 2006 it was a condition on vessels ≥15m, but as of 2013 this was extended to include vessels ≥12m in length.

Techniques have been developed over the last few years to translate VMS into an indicator of fishing activity (Lee *et al* 2010). VMS data includes positional information for each data point or 'ping'. As an alternative to presenting the pings as data points, methods have been progressed to either interpolate between or to aggregate these points. Interpolation methods attempt to model the path of the vessel between the VMS data points (Mills *et al* 2007; Eastwood *et al* 2007), whilst the aggregation method sums the data points onto a raster grid (Dinmore *et al* 2003; Lee *et al* 2010; Foden *et al* 2011). Jenkins *et al* (2015) undertook a detailed review of the different options for interpreting fishing activity data in the production of abrasion geo-data layers and tested different options for the purposes of seabed monitoring. A review of recent literature (Foden *et al* 2010; Dinmore *et al* 2003; Piet *et al* 2006; Mills *et al* 2007; Gerritsen *et al* 2013; Korpinen *et al* 2012; Eastwood *et al* 2007) shows that an aggregated grid is the most consistently used approach. This is largely because of the high levels of uncertainty associated with track interpolation. Though gridding VMS data is a common approach, there is some variation in the grid size used and a recent alternative approach proposes using a nested grid methodology (Gerritsen *et al 2013)*. Since exposure to pressures associated with demersal fishing tends to be at the scale of fishing grounds or trawl scars, and not arbitrary statistical grids, relating values of hours fished per annum in a generalised grid creates some difficulties. Studies such as Jennings *et al* (1999) and Korpinen *et al* (2012) looked at fishing in terms of hours fished or presence/ absence (footprint) of effort rather than translating fishing activity into pressure on the seabed. Most academic studies on fishing impacts, rather than activity, are in relation to the number of times an area of seabed has been fished. One common method for trying to relate VMS data to the large number of impact studies is through presenting the abrasion pressure as a 'swept area' of seabed. The swept area method takes into account the many varied types of mobile demersal fishing gear used and how the varying widths of gear types penetrate the sediment to different depths, hence exerting different levels of abrasion pressure.

Swept area is generally considered to be an estimation of the area of seabed in contact with the fishing gear and is a function of gear width and vessel speed, so requires information on both these parameters. Some previous studies have used expert judgement (Barnard & Boyes 2013) to define gear widths and speeds in their analysis (Table 1). For instance, Gerritsen *et al* (2013) applied their method to demersal otter trawl data in the Celtic Sea and varied the gear width per region based on the main fishery industry in the area. Several studies (Dinmore *et al* 2003; Eastwood *et al* 2007; Mills *et al* 2007; Gerritsen *et al* 2013) had access to the actual speed a vessel was travelling recorded at the ping, so assumptions about the average speed a vessel was travelling per gear type were not required. In the absence of actual speed data, estimates were based on the range of vessel speeds routinely recorded for given fishing activities. However, data on gear width is not routinely collected and there can be significant variation between vessels in the gear employed.

We consider swept area to be the best method of converting fishing activity data into a metric that better represents the pressure on the seabed. Different gear types interact with

the seabed in different ways and subsequently exert different levels of abrasive pressure both in terms of the area of substrate affected and the penetration depth. These considerations are central to the recommended method because gear width (determined by gear type) is a key component of the swept area calculation and contributes to the area estimates of surface and subsurface abrasion. Being able to consider the varying amounts that different gears penetrate the sediment allows us to relate this to the potential impact on the infauna and epifauna, hence allowing calculation of both a surface and subsurface abrasion layer. Our research into using swept area has shown there is an absence of a standard swept area calculation method. A standard list of recommended gear types, widths and vessel speeds would allow easier comparison between studies and a better understanding of context.

This methods paper presents currently available gear categories from UK logbooks and recommends a method for the creation of a standard abrasion data layer at a UK-wide scale. The method subsequently describes how to convert commercial VMS fishing activity data (of specific and most relevant gear types) into swept area for use as an abrasion pressure layer.

Table 1. Literature comparison of current methods for calculating seabed abrasion from fishing gear.

Reference	Gear	Gear Width	Vessel Speed	Data	Swept Area Calculation (SWA)	Notes	Scale	Location	Date
Foden *et al* 2010	Beam trawl	2 x 12m	Recorded vessel speeds	Grid	SWA calculated per point and aggregated in grid cells. SWA = width (km) x Speed (km per hour) x hrs since last ping.	SWA was used to inform a cumulative impact assessment. Foden *et al* (2011) furthered this work by using additive techniques to combine SWA with windfarm scours and tele-communication/ power cables footprints to create an abrasion GIS layer.	1km^2 grids	England & Wales	2006 & 2007
	Scallop dredges	2 x (9 x 1m)							
	Mechanised dredges	3m							
	Otter trawl	24m							
	Nephrops trawls	60m							
Dinmore *et al* 2003	Beam trawl	2 x 12m	6 knots	Grid	SWA calculated per point and aggregated in grid cells. Each point was assigned two hours of effort.		1 x 1nm 2 x 2nm 4 x 4nm 8 x 8nm	North Sea	1st July 2000 – 30th June 2002
Piet *et al* 2006	Beam trawls (outside 12nm)	2 x 12m	6 knots	Grid	SWA estimated from: number of days recorded at sea, the mean vessel speed and width of beam trawl.	SWA used to create potential pressure indicators for fish mortality from beam trawling. This paper compared different methods for measuring fishing pressure.	ICES Rectangles		
	Beams trawls (inside 12nm)	2 x 4m							
Mills *et al* 2007	Beam trawl	2 x 12m	6 knots	Track Lines	SWA of track line calculated from gear width. Points were converted to track lines using 3 interpolation methods:				

					1) straight line for minimum 2) maximum ellipse 3) best estimate				
Gerritsen *et al* 2013	Beam trawl	18m	Recorded vessel speeds	Nested Grid	SWA calculated per point and aggregated in nested grid cells. SWA divided by the area of the cell to get a comparative swept area ratio.		Nested grid cells ranging from 0.11km^2 - 220km^2	Ireland (Celtic sea)	
	Dredges	16.5m							
	Otter Trawl Aran and Irish Sea	60m							
	Otter Trawl Irish Continental Shelf	100m							
Korpinen *et al* 2012				Grid	Calculation based on catch amounts (tonnes)/ gear type/ species/ cell.		ICES rectangles		2007 & 2008
Eastwood *et al* 2007	Beams trawl	2 x 12m	Recorded vessel speeds	Track Lines	The spatial extent of fishing activity was calculated using track lines from VMS which were buffered to the width of the differing gear widths for trawling and dredging.	This study analysed physical pressure on the seabed from a number of activities including fishing.			
	Otter trawl doors	2 x 2m							

3.1 Data availability

Two types of data were available for this study:

- anonymous VMS 'ping' data (2009-2012), UK vessels only.
- aggregated VMS data grids (2006-2009), UK and EU vessels.

Anonymous VMS ping data are not currently available to all data users, due to their commercially sensitive nature. Data are sometimes aggregated to a grid before release, to anonymise the movements of individual fishing vessels. Both ping and gridded data were considered in this study to make the approach relevant to most users.

The anonymous VMS ping data were provided by the Marine Management Organisation (MMO) following a request from JNCC in 2013. The VMS ping data were only available for 2009-2012 and for UK-registered vessels at this time (i.e. no VMS ping data was available for vessels registered outside the UK).

The aggregated VMS data grids were provided to JNCC through a Defra marine biodiversity research project[1], for the UKCS designated area (set out in orders made under section 1(7) of the Continental Shelf Act 1964) within the British fisheries limit. The aggregated VMS data were derived from VMS ping data for 2006–2009 per gear type and were available for UK and non-UK registered vessels. These aggregated data grids were created using ping data as follows:

- VMS ping data for UK vessels were linked to skipper logbook information in order to determine location and the type of fishing gear being deployed.
- VMS ping data for non-UK registered vessels were linked to the primary gear listed in the EU vessel register unless skipper logbook information for actual gear being used was available. For most of the non-UK fleet such logbook information is not available.
- A speed filter was used to select boats travelling between 1-6 knots as this was considered indicative of active fishing (Mills *et al* 2007; Lee *et al* 2010).
- Duplicate pings were removed and the time interval between successive records was calculated in order to assign hours since last ping to each record.
- Point data representing VMS pings were aggregated to raster grids at a resolution of 0.05 decimal degrees (Geographical Coordinate System World Geodetic System 1984 (GCS WGS84)) i.e. unprojected. The grid was aligned to, and was a subdivision of, larger ICES rectangles to allow comparison with catch data that are collected at this scale (Lee *et al* 2010).
- Within each grid cell, the number of pings was summed based on the interval of time between each ping, which produced an estimated total time for fishing associated with the cell.
- This information was provided to JNCC per annum and per gear type for 2006-2009.

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[1] Further development of marine pressure data layers and ensuring the socio-economic data and data layers are developed for use in the planning of marine protected area networks (MB0106). *Report No. 1: Objective 1 Provision of geo-database containing standardised layers showing the distribution of specified activities, sites and resources with associated metadata and comments.* See Lee *et al* 2010.

3.2 Gear types

A list of fishing gears was developed from the available gear types listed within the Defra MB0106 project (Cefas & ABPmer 2010; Lee *et al* 2010). The predominant activities associated with physical abrasion, in terms of extent and intensity, are demersal trawling and dredging. Table 2 lists the gear types associated with these fishing activities that were included in the method for both UK and non-UK vessels. Only towed gears are recommended for inclusion within this method since VMS and log book data do not currently enable a good representation of the effort of static gear.

While gear types for UK vessels can be derived from associated log book data, based on Food and Agriculture Organization of the United Nations (FAO) gear codes, for non-UK (EU only) vessels logbook information is rarely available. Instead, information on fishing gear can be obtained from 'primary gear' entries in the EU vessel register. This does mean if the vessel has a secondary gear type in use that is not assigned the same gear width as the primary gear, the gear width could be incorrectly assigned.

The gear entries in the EU vessel register include gear codes for different gear types, similar to the UK logbook information. However, the aggregated European vessel data layers available for this study were only provided with demersal, beam and dredge gear categories, which reduced the ability to estimate gear widths for the individual trawl types for these layers e.g. Otter Twin Trawl.

Table 2. List of gear types included within the method.

	Fishing Activity	**Gear Code**	**Gear Type**
UK Vessel data layers	Demersal Trawling	TBB	Beam Trawl
		TBN	Nephrops Trawl
		PTB	Pair Trawl
		SPR	Pair Seine[2]
		OTB	Otter Trawl
		OT	Otter Trawl (Unspecified)
		OTT	Otter Twin Trawl
	Dredging	DRB	Shellfish dredger
European Vessel data layers	Demersal (EU)		All otter trawls
	Beam (EU)		Beam trawl
	Dredge (EU)		Shellfish dredger

3.3 Estimating surface and subsurface abrasion

The gear types were assigned to surface and subsurface abrasion based on the physical interaction of the gear with the seabed. Due to the variation in gear sizes employed by fleets, both within and between different mobile bottom-contact fishing gears, there is no simple set of published estimates of the extent of bottom-contact gears. As such, for this method, minimum and maximum gear widths and average trawling speed parameter values were derived from three sources:

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[2] A single boat seine is also likely to create some surface abrasion, but these are not included because it is poorly understood and not in common use.

- previous studies (Krost *et al* 1990; Rose *et al* 2000; Dinmore *et al* 2003; Eastwood *et al* 2007; ICES 2010);
- relevant legislation pertaining to maximum permissible sizes/number of specific gears/gear components (e.g. beam trawl/scallop dredge), and;
- seafish estimates of gear dimensions (Seafish 2005).

The surface and subsurface gear widths are given in Table 3 and Table 4 respectively. These show the likely minimum and maximum gear widths and vessel speeds associated with VMS-capable vessels operating in UK waters, as well as the gear widths and speeds that are proposed for use within this method.

This method recommends that surface and subsurface abrasion are assumed to be:

- the same for beam trawls;
- the same for dredges; and
- different for otter trawling.
  - Subsurface abrasion is considered to be exerted by the otter trawl doors; and
  - Surface abrasion is considered to be exerted from both otter trawl doors and ground gear (including sweeps/bridles).

Table 3. Surface abrasion gear widths and speeds used in method validation.

Gear Type	Minimum		Maximum		Proposed[3]	
	Width (m)	Speed (knot)	Width (m)	Speed (knot)	Width (m)	Speed (knot)
Beam Trawl	8	1	24	6	18	4.5
Nephrops Trawl	50	1	100	6	60	3
Pair Trawl & Seine	200	1	300	6	250	3
Otter Trawl	50	1	100	6	60	3
Otter Trawl (Twin)	60	1	200	6	100	3
Boat dredge	6.8	1	23.8	6	12	4
Otter (Other)	50	1	100	6	60	3
Demersal (EU)	50	1	100	6	60	3
Beam (EU)	8	1	24	6	18	4.5
Dredge (EU)	6.8	1	23.8	6	12	4

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[3] Proposed gear widths and speeds for this method, made after discussion with JNCC fisheries advisers.

Table 4. Subsurface abrasion gear widths and speeds used in method validation.

Gear Type	Minimum		Maximum		Proposed	
	Width (m)	Speed (knot)	Width (m)	Speed (knot)	Width (m)	Speed (knot)
Beam Trawl	8	1	24	6	18	4.5
Nephrops Trawl	0.5	1	4	6	2	3
Otter Trawl	0.5	1	4	6	2	3
Otter Trawl (Twin)	1	1	5	6	3	3
Pair Trawl & Seine	n/a	n/a	n/a	n/a	n/a	n/a
Boat dredge	6.8	1	23.8	6	12	4
Otter Other	0.5	1	4	6	2	3
Demersal (EU)	0.5	1	4	6	2	3
Beam (EU)	8	1	24	6	18	4.5
Dredge (EU)	6.8	1	23.8	6	12	4

3.4 Pre-processing data for analysis

The anonymous VMS ping data for UK vessels were pre-processed in the same way the aggregated grids had been provided, to prepare them for further analysis:

- ping data was linked to skipper logbook information in order to determine the type of fishing gear being deployed;
- duplicate pings were removed and the time interval between successive records was calculated in order to assign minutes since last ping to each record;
- locations in or close to port were removed;
- a speed filter was also applied to select vessels travelling between 1-6 knots as a proxy of active fishing (Mills *et al* 2007; Lee *et al* 2010).

The data were then filtered to the gears of interest and the chosen gear widths were associated with each ping. Speed information was converted from knots to metres per minute to aid further calculations.

A blank grid was created at a resolution of 0.05 decimal degrees (dd) (200 per ICES rectangle, WGS84) to be used to aggregate the ping information. Within the WGS84 geographical co-ordinate system the grid cell sizes vary, therefore the Albers equal-area conic[4] projection was used to determine the area of each cell within this grid.

3.5 Swept area ratio for each gear type

The area of seabed swept by a vessel was calculated per gear type per annum. The swept area method was applied to both aggregated VMS and VMS pings. This calculation was carried out for each demersal and dredging fishing gear type:

1   For the aggregated VMS, the fishing area swept was calculated per grid cell and is referred to as 'Swept area', SA, (m^2.cell^{-1}). It was calculated by multiplying the 'width of fishing gear', w, (m) by the 'average vessel speed', v, (m.hr^{-1}) and the 'time fished', e, (hr) to get an estimate of area covered per gear (Equation 1). The resulting swept area was

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[4] Adjusted parallel 1 = 50.2 and parallel 2 = 58.5

calculated as m^2, per cell, per annum (m^2.cell^{-1}.yr^{-1}). This was done per gear per year on a cell-by-cell basis from 2006–2009 for the UK and non-UK vessel data that were available.

2   For the VMS pings, 'Swept area', *SA*, (m^2) was calculated per ping, by multiplying the 'width of fishing gear', w (m), by the 'recorded speed', *v* (m.min^{-1}) and the 'time fished' (each ping representing the area swept since the last recorded ping), *e* (min), to get an estimate of area covered per gear, per ping (Equation 1). The pings were then aggregated by summing on a pre-prepared grid at 0.05dd (which aligned with the aggregated VMS data). The resulting swept area was calculated as m^2, per cell, per annum (m^2.cell^{-1}.yr^{-1}). This was done per year from 2009–2012.

Equation 1 – *Swept Area calculation*

$$SA = \sum wve$$

Where SA is the swept area, w is total width of fishing gear (m) causing abrasion, v is average speed vessel (m/min), e is the number of minutes between pings.

A swept area ratio, *SAr*, was then calculated to account for the varying cell size of the GCS WGS84 grid. To produce the swept area ratio (i.e. area swept in terms of the proportion of the cell fished within the time period, measured as a ratio of the area of the cell), *SA* was divided by the actual grid cell area as previously created in Albers equal-area conic[5], *CA* (Equation 2).

Equation 2 – *Swept Area 3.4.1 ratio calculation*

$$SAr = \frac{SA}{CA}$$

Where SA is the swept area, CA is cell area and SAr is swept area ratio (equivalent of the number of times the cell was swept).

3.6 Mapped products

For each year, two raster layers were created using the swept area ratio per grid cell for surface and subsurface abrasion (Figures 1 and 2 show 2012 data as an example). The swept area ratio represents the proportion of each cell swept per annum. Note that this value may be larger than '1' if parts of the cells are swept more than once. A cell score of '1' means that an area equivalent to the size of that cell has been swept that year; this could mean that the whole cell has been swept once (though unlikely in reality), or that half the cell has been fished twice, or that a quarter of the cell has been fished four times, and so on. Looking at the maps of surface and subsurface abrasion for each year and across years it shows there are different distributions of pressure and different hotspots for vessels ≥15m. Surface and subsurface abrasion show different information and it will be important to consider which product is most appropriate in any given future use. For instance, when considering potential impacts on erect epifauna it may be more appropriate to consider

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[5] Adjusted parallel 1 = 50.2 and parallel 2 = 58.5

surface abrasion and when considering impacts on infauna it might be better to use subsurface abrasion.

Another consideration, particularly in terms of benthic impact studies, is the historic fishing effort within a region. With this in mind, a map was produced of standard deviation across four years (2009-12) for surface abrasion (Figure 3). This map shows areas where fishing effort is patchy across years (larger deviation), and also areas where fishing effort is more consistent (smaller deviation). We recommend that a map of variation in fishing effort over multiple years is viewed in conjunction with a map of swept area, as it could be misleading to look at data for a single, perhaps atypical, year.

Surface Swept Area Ratio (2012) (UK vessels only)
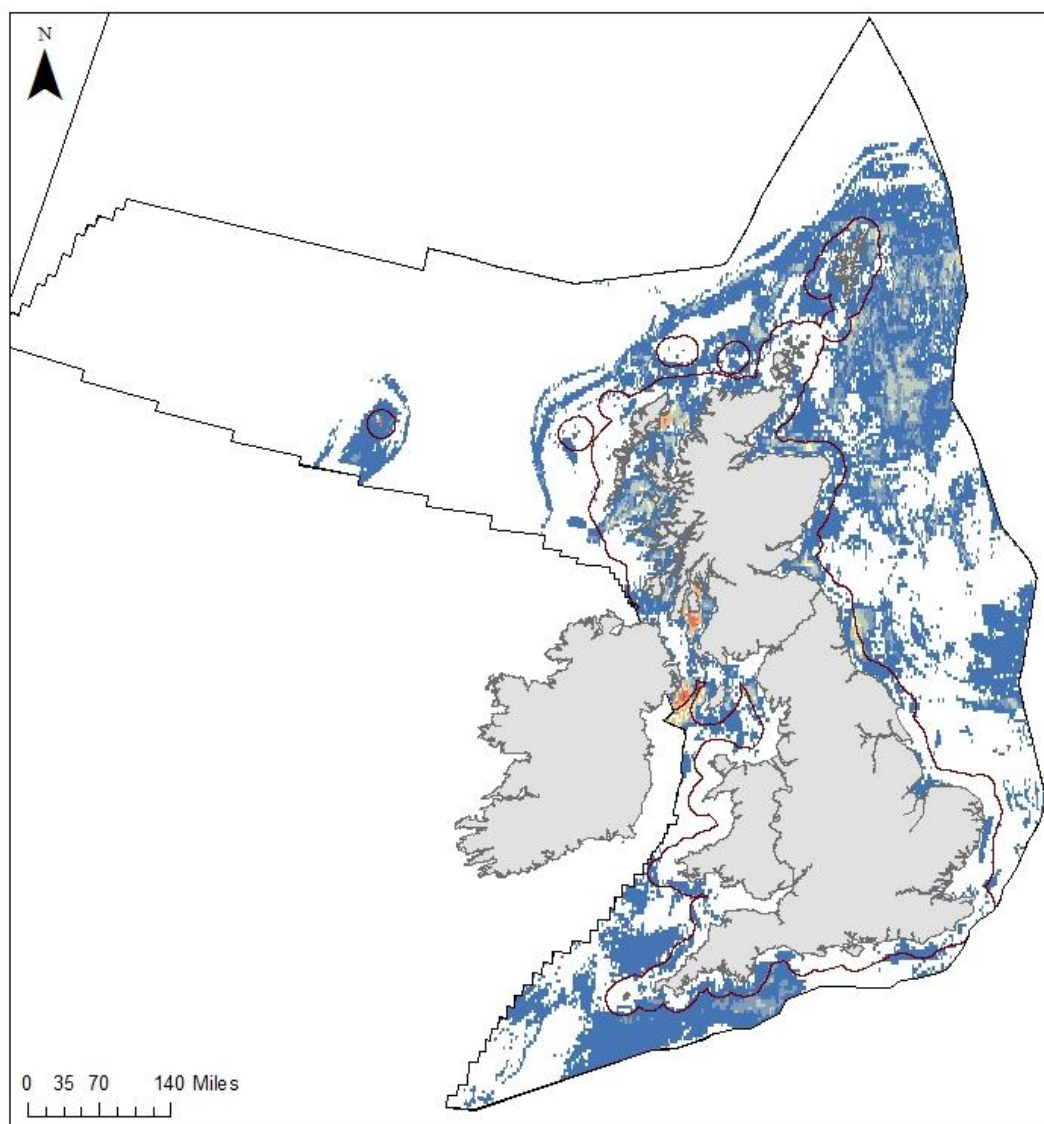
Legend

Surface Swept Area Ratio (2012)
(number of times cell swept)
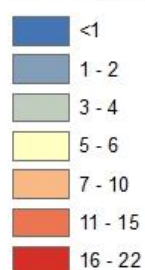
■ <1	
■ 1 - 2	
■ 3 - 4	
■ 5 - 6	
■ 7 - 10	
■ 11 - 15	
■ 16 - 22	

□ UK & Ireland Coastline
— UK Continental Shelf
— UK 12nm Limit

12nm © British Crown. All rights reserved. The exact limits of the UK Continental shelf are set out in orders made under section (17) of the Continental shelf Act 1964 (© Crown Copyright). The Continental Shelf Act (Designation of Areas) Consolidation Order 2000. The Continental Shelf Act (Designation of Areas) Order 2001. World Vector Shoreline © US Defence Mapping Agency. Not to be used for navigation. © JNCC 2014

Figure 1. Surface swept area ratio for UK vessels (≥15m) in 2012. Swept area ratio is the area of the swept area as a proportion of the area of cell.

Sub-surface Swept Area Ratio (2012) (UK vessels only)

Legend

Sub-surface Swept Area Ratio (2012)
(number of times cell swept)

0.01 - 0.1	UK & Ireland Coastline
0.2 - 0.5	UK Continental Shelf
0.6 - 0.9	UK 12nm Limit
1	
2	
3	

12nm © British Crown. All rights reserved. The exact limits of the UK Continental shelf are set out in orders made under section (17) of the Continental shelf Act 1964 (© Crown Copyright). The Continental Shelf Act (Designation of Areas) Consolidation Order 2000. The Continental Shelf Act (Designation of Areas) Order 2001. World Vector Shoreline © US Defence Mapping Agency. Not to be used for navigation. © JNCC 2014

Figure 2. Subsurface swept area ratio for UK vessels (≥15m) in 2012. Swept area ratio is the area of the swept area as a proportion of the area of cell.

Standard Deviation in Surface Swept Area Ratio Between Years (2009-2012) (UK Vessels Only)
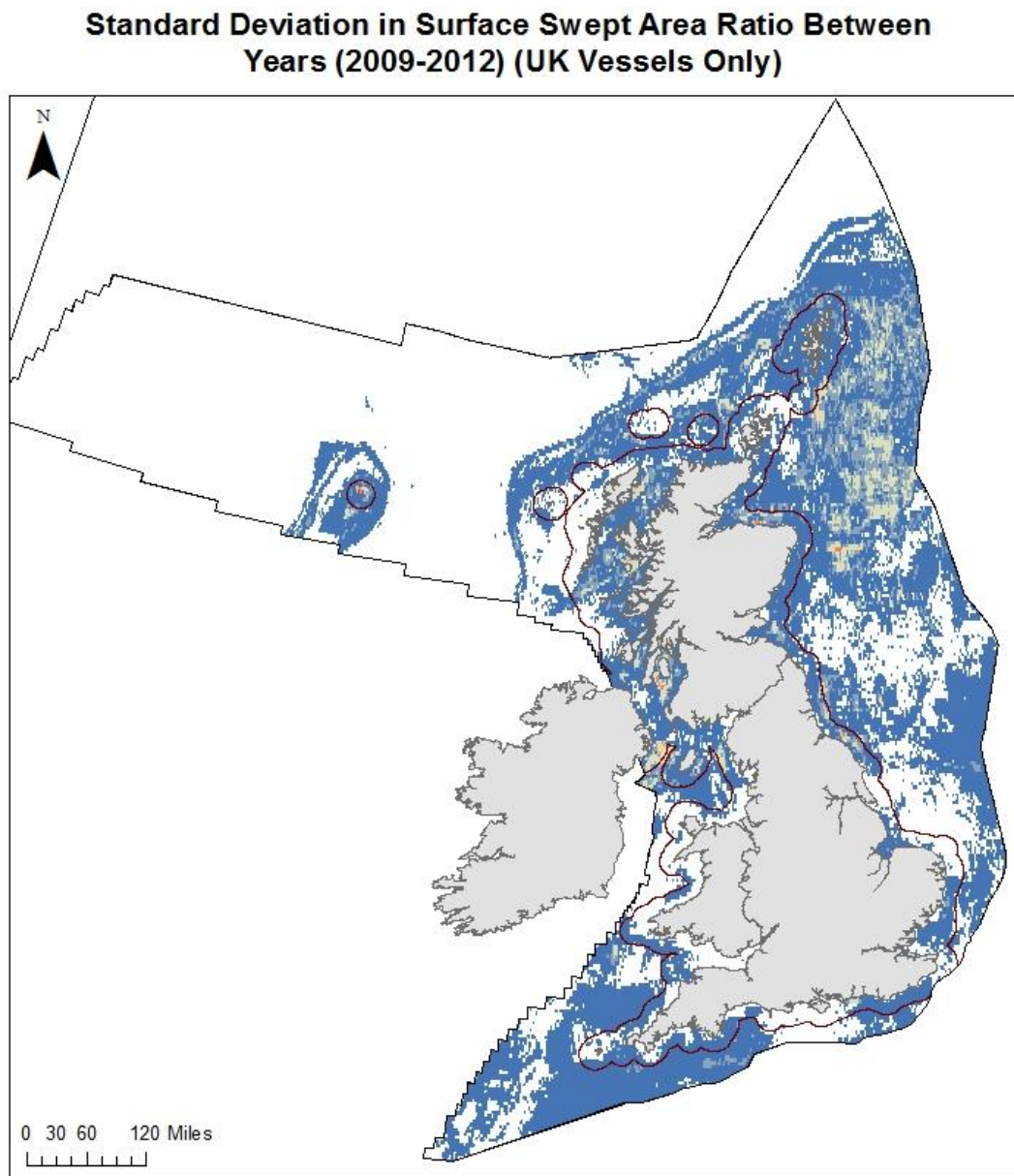
Legend

Surface SWA Ratio Standard Deviation

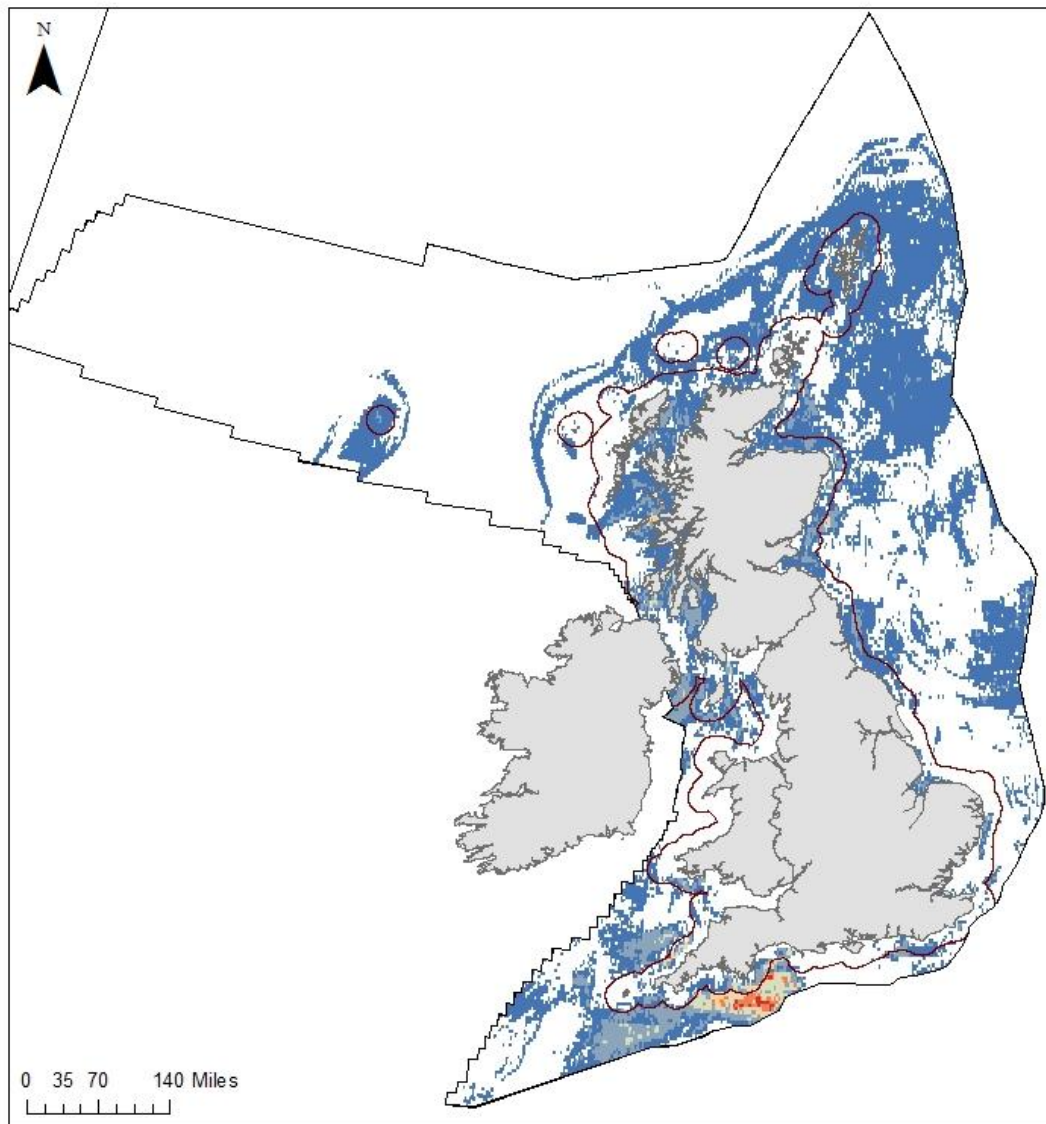|	
■	< 1
■	1 - 2
■	3 - 4
■	5 - 6
■	7 - 10
■	>10

▢	UK & Ireland Coastline
——	UK Continental Shelf
——	UK 12nm Limit

12nm © British Crown. All rights reserved. The exact limits of the UK Continental shelf are set out in orders made under section (17) of the Continental shelf Act 1964 (© Crown Copyright). The Continental Shelf Act (Designation of Areas) Consolidation Order 2000. The Continental Shelf Act (Designation of Areas) Order 2001. World Vector Shoreline © US Defence Mapping Agency. Not to be used for navigation. © JNCC 2014

Figure 3. Surface swept-area ratio standard deviation for UK vessels (≥15m) from 2009–2012. Number of standard deviations from the average (mean) swept area ratio per grid cell for 2009–2012.

4   Summary of recommended method to map abrasion

Based on the steps taken in Existing methodologies to map abrasion pressure the following method is recommended as a standard for producing an abrasion pressure geo-data layer (See Figure 4). It is recommended that, in order to best represent abrasion pressure and take into account the relative effects of lighter and heavier gears, both surface and subsurface abrasion data layers are created. If a footprint of overall abrasion is required, without consideration of sediment penetration or frequency, then surface abrasion could be used to indicate presence-absence on a cell-by-cell basis.

4.1 Data preparation

When processing raw VMS ping data, it is recommended that the steps presented in Lee *et al* (2010) are followed:

1. Remove duplicate records.
2. Remove locations in or close to port.
3. Calculate the time interval between successive records; JNCC recommends removal of records that have a time interval greater than the required regularity of VMS pings (currently at least every two hours) ie pings >120 minutes apart are removed as these may be misrepresentative of fishing.
4. Establish the fishing gear used by each vessel and exclude (or categorize as 'Unassigned') any VMS locations for which fishing gear cannot be established.
5. Differentiate between fishing and non-fishing records based on reported speed [(1-6 knots as fishing)].
6. Estimate the spatial distribution of fishing effort (i.e. intensity) from these records.

ICES have developed an R software package specifically to process and analyse VMS derived data called VMSTools (Hintzen *et al* 2012). The tool allows users to combine VMS and logbook data, automates the cleaning and processing of the VMS data, contains interpolation methods for VMS tracks, calculates indicators (e.g. percentage area trawled) at different spatial scales and includes a procedure to calculate area swept. These tools (Hintzen *et al* 2013) can also be used to implement the method recommended in this report.

4.2 Swept area

Once the data have been prepared, the VMS ping data points can be aggregated based on the spatial scale of the study. For use at a national or regional-sea scale, a cell size of 0.05dd (GCS WGS84) is recommended (Lee *et al* 2010). This is a function of the distance a vessel can travel in the time between VMS pings, based on average fishing speeds. If a more localised analysis is required, a smaller cell size or nested grid approach is likely to be more appropriate. Point data and interpolated tracks are not recommended as, particularly in deeper waters, there is a large degree of uncertainty associated with them (Gerritsen *et al* 2013).

The raster cell size (at the 0.05dd size) should be created for the study area in GCS WGS84 and then converted into a projected co-ordinate system to convert area into metres[6]. For the UKCS designated area, Albers Equal Area conic should be used[7] .

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[6] Esri Arc GIS FISHNET tool.
[7] Adjusted parallel 1 = 50.2 and parallel 2 = 58.5

If VMS point data are not available and aggregated VMS data grids (with time as a unit) are, then the swept area should be calculated at the grid level.

Before calculating the swept area, it is important to ensure the metrics are in the same units, i.e. if speed is in metres per hour, gear width should also be metres and time should be in hours. Swept area is calculated by taking the width of fishing gear that could exert an abrasion pressure (width as recommended in Estimating surface and subsurface abrasion 3.3, also see below) and multiplying it by effort (time) and the speed of the vessel to get the total area swept per gear for a given time period (Equations 1 and 2 – Swept area ratio for each gear type). To calculate the swept area ratio per annum, the total area swept must be divided by the area of the cell per gear, per year.

4.2.1 Recommended gears and speeds

The following gears, gear widths and speeds are recommended for use in the swept area calculation in UK waters for vessels ≥15m registered to that gear type (Table 5). These should only be used when known fishing vessel speeds and/or gear widths are not available.

Table 5. Recommended gears for inclusion, gear widths and speeds

Gear Type[8]	Surface Gear width (m)	Subsurface Gear width (m)	Speed (knot)
Beam Trawl	18	18	4-5
Nephrops Trawl	60	2	3
Pair Trawl & Seine	250	n/a	3
Otter Trawl	60	2	3
Otter Trawl (Twin)	100	3	3
Boat dredge	12	12	4
Otter Other	60	2	3
Demersal (EU)	60	2	3
Beam (EU)	18	18	4-5
Dredge (EU)	12	12	4

The calculation should be completed for each demersal and dredging fishing gear type for UK vessels. The layers are comparable between gear types, allowing for them to be combined into a single layer: one for surface abrasion and one for subsurface abrasion.

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[8] EU listed gear types should be used for non-UK vessels where FAO gear codes (EU level 4 métier gears) are unknown.
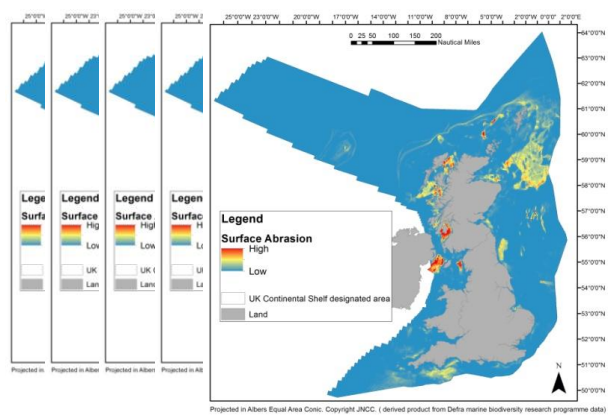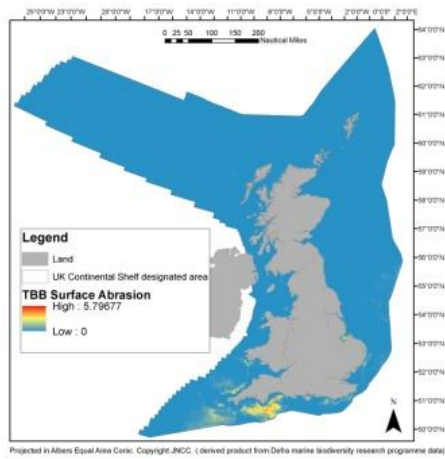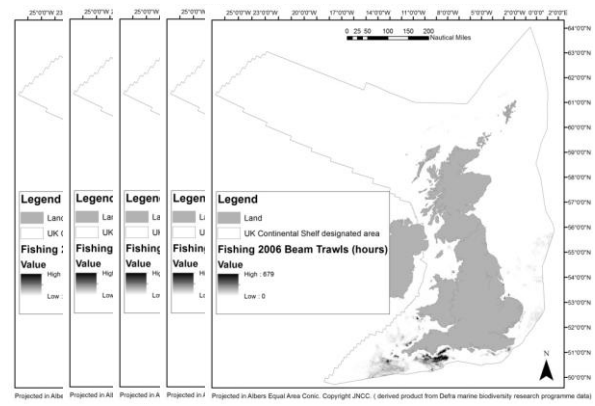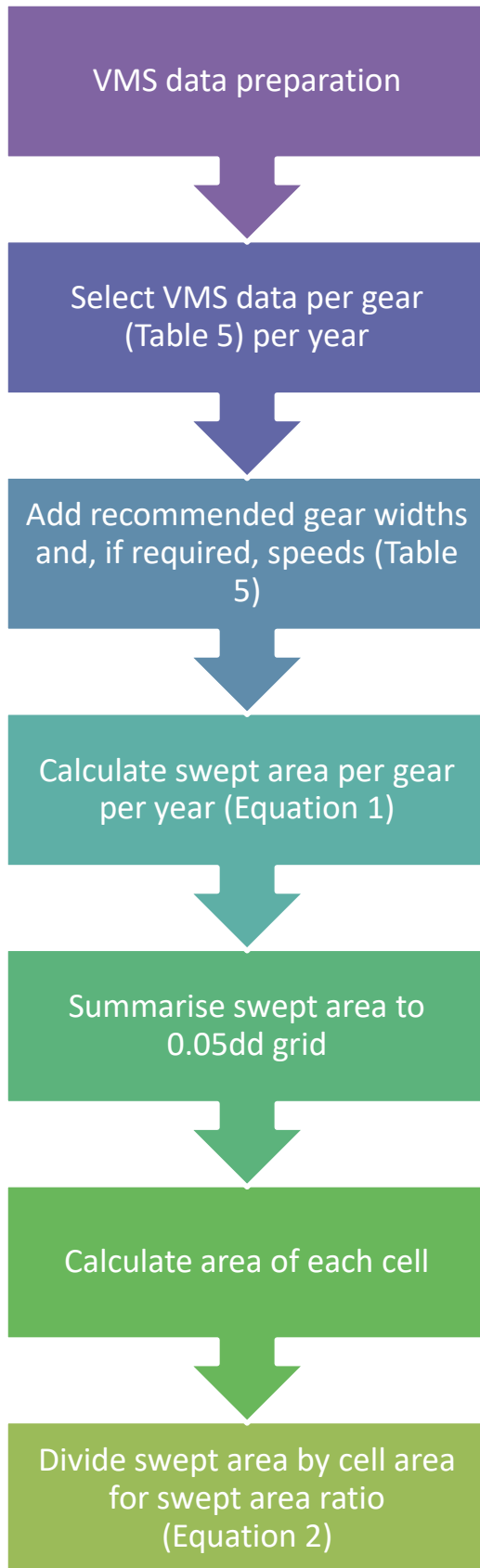
Figure 4: Work flow diagram of recommended method for creating abrasion pressure geo-data layers.

4.3 Quality assurance

It is recommended that all aggregated swept area layers are quality assured after creation to ensure that the raster grid and associated abrasion scores reflect the underlying raw data. For example, VMS pings filtered by the speed rule can be plotted over the aggregated abrasion geo-data pressure layer to check that:

- the distribution and spread of the ping data are reflected in the abrasion data layer;
- all cells with pings have an associated abrasion score;
- all cells without pings have no associated abrasion score;
- cells with more VMS pings have relatively higher abrasion scores than cells with fewer VMS pings;
- there is variation in abrasion layers between years, if data are available for different years;
- there are no cells that contribute a disproportionately high abrasion score; if this is the case, the underlying data can be explored to see whether this is a true representation of the data or a product of the method;
- areas of known high fishing intensity are reflected in the abrasion layers and that these regions are different for surface and subsurface abrasion (here, we had JNCC fisheries experts sense check the geo-data pressure layers); and ensure metrics are consistent.

JNCC has an Evidence Quality Assurance policy (JNCC 2015), which along with an associated set of Evidence Quality Guidance Notes provide a standard for JNCC staff to follow to help ensure that the quality of JNCC scientific advice and evidence is fit for purpose. The development of this report and the abrasion geo-data layer have followed the JNCC evidence quality assurance (EQA) process.

4.4 Limitations and assumptions

The production of abrasion pressure layers from activities data is based upon a number of assumptions and the resulting geo-data layers have several limitations associated with their use. This method is recommended for creating abrasion layers for use at a regional and national scale for areas beyond the 12 nautical mile limit and has prioritised the inclusion of human activities data to those that are of greatest importance in terms of spatial footprint, namely mobile demersal fishing. Other activities that cause abrasion (see Annex II) may need to be considered for studies that are conducted at a finer spatial scale or undertaken per feature type.

Mobile demersal fishing for ≥12/15m vessels is the only activity considered here, due to the difficulty in assessing contact area from static gear activities. However, due to the mobility of trawl gears, the relative area swept per unit fishing is inherently higher than that for static gears, thus the current method is likely to encompass the overwhelming majority of area swept by all fishing gears at a regional and national scale. Due to the current mismatch between VMS data and data associated with smaller vessels (predominately fishing inshore), a decision was made to only include VMS data. In the future, with the increase in VMS use to smaller vessels (≤12m), new initiatives may enable the tracking of small fishing vessel activity and it is hoped that a combined method that better reflects the pressure that fishing exerts on the UK seabed can be found. As a result of this, the current recommended method will be less appropriate for assessing swept area inshore.

For mobile fishing gear, it is common practice to use a speed filter to identify vessels that are actively fishing. However, for static gear, vessel activity is less likely to reflect fishing effort. Lee *et al* (2010) recognised that 'for trawled gears, the values within the raster grids

indicated estimated hours fished. For non-trawled gears this could not be taken as being fully representative of the intensity of fishing as no indication was given of the time that set nets/pots *etc* remained *in situ*. Rather, it gave an indication of the spatial extent affected by these gears and the likely intensity based on time spent setting and retrieving gear'. For some vulnerable marine ecosystems, such as deep-sea sponge aggregations, there may be a requirement to consider other gear types, such as longlines, static gear, overlap of static gear sites with mobile gear (which can result in the static being dragged by the mobile gear), in any assessment of potential impact; this cannot currently be accommodated into the proposed method.

In order to calculate a swept area ratio, it was necessary to rely on assumptions of gear dimensions and fishing speed. The two categories, surface abrasion and subsurface abrasion also relied on assumptions about sediment penetration associated with different components of the mobile gear. Due to the variation in both gear dimensions and operation, there is no single set of generalised estimates for the extent of bottom contact of individual gear codes (EU level 4 métier gears). We acknowledge that the proposed estimates of gear widths are largely based on informed judgement. These estimates could be refined in the future if our resolution of gears deployed increases (e.g. bespoke métiers). Though there may be some disagreement about the assumptions made in the current work, the Pearson's correlation coefficients showed broadly that changing the metrics would have a negligible effect on the final abrasion scores. Although they would have an absolute value change, these changes were relative and any targets set to this data would therefore also be relative.

The use of a grid system suggests a homogeneous distribution of effort across each raster grid cell. Care must be taken to articulate that a cell with a score of 1 means that an area equivalent to the area of the cell has been swept per annum rather than simply meaning the cell has been swept once. Though this is rarely the case in reality, as fishermen typically target known tows repeatedly for safety/economic reasons, it better reflects our confidence in the spatial data, given the frequency of the ping data, than point data or track interpolation.

4.5 Uses and next Steps

The objective of this report is to provide a recommended and standardised method for the development of pressure layers for surface and subsurface abrasion. JNCC intends to produce updated surface and subsurface layers every year, using combined UK and non-UK vessels data supplied by the Marine Management Organisation, which will be made available via the JNCC website (for download and through Web Services).

The abrasion layers have been used for a number of projects to date, and provide a range of future uses including:

- planning offshore monitoring surveys within areas of a fisheries pressure gradient to test for effects of fishing activity on benthic communities;
- development of the common MSFD indicator 'BH3 - Extent of Physical damage to predominant and special habitats';
- initial development of a cumulative effects assessment tool to support offshore MPA condition assessment and reporting requirements and provision of advice to industry on in-combination effects of industry projects;
- supporting the development of MPA management measures;
- development of UK monitoring options under MSFD;
- supporting development of advice on operations for MPA conservation advice packages.

This work came about as part of a drive to improve efforts on data collection and mapping for pressures to support understanding the potential impacts of human activities. A method and data layer has also been created by JNCC for the pressure 'Physical Damage – Habitat structure changes - removal of substratum (extraction)' (Peckett *et al* 2016*)*. Methods papers have also been prepared by Cefas for five additional pressures: Marine Litter (Jenkins 2014); Non-Indigenous Species (Breen & Murray 2014); Organic and Nutrient Enrichment (Koch *et al* 2014); Physical change (to another seabed type) and physical loss to land and freshwater (Goodsir & Koch 2014) and Siltation Rate Changes (Frost *et al* 2014).

In the longer term, it is hoped that UK-wide pressure layers for priority pressures will be produced to support longer term studies of impacts of human activities and monitoring and assessment obligations under national, European and international legislative instruments.

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6 Annex I: A description of the studies considered within the combined JNCC pressure-activities matrix

Project Title	Description	Reference
Business as Usual Projections of the Marine Environment, to inform the UK implementation of the Marine Strategy Framework Directive.	The Marine Strategy Framework Directive (MSFD) 'Business as Usual' (BAU) study uses Drivers-Pressures-Status-Impacts-Response (DPSIR) framework to identify how drivers and pressures change over time and how this may lead to changes in environmental state.	ABPMer 2012
MarLIN marine and coastal activities to environmental factors matrix.	This list of maritime and coastal activities and environmental factors was derived from the Marine Conservation Handbook (Eno 1991) as amended by Cooke & McMath (2001) and discussion with the Marine Information Team (JNCC), and the MarLIN Biology & Sensitivity Key Information Sub-programme technical advisory group.	MarLIN 2003
Options for developing Ecosystem Based Management (ODEMM) linkage framework.	The ODEMM linkage framework builds on the DPSIR approach (Driver-Pressure-State-Impact-Response) (EEA 1998), which systematically organises information to assess which management responses might help to reduce impacts on the state of the environment.	Koss *et al* 2011
SNH and JNCC Features, Activities, Sensitivities Tool (FEAST).	A pressures-activities matrix created by SNH and JNCC's Scottish MPA Project team. This matrix is based on the Natural England and JNCC matrix produced for the MCZ process. Refinements were made to some activity categories (most notably fishing) to reflect practices in Scotland. The matrix has been merged with the pressures-features matrix (also refined based on the original MB102 matrix) and has been published as an online interactive resource called FEAST (Features, Activities, Sensitivities Tool).	The Scottish Government, 2013
Natural England and JNCC simplified pressures activities matrix.	A pressures-activities matrix produced by Natural England and JNCC for use in the designation of Marine Conservation Zones (MCZ).	JNCC unpublished

7   Annex II: A list of all the activities associated with abrasion that were excluded from this study

Category	Activity	Reason for Exclusion
Food Production	Aquaculture - finfish	Insufficient data – Available datasets only represent the spatial locations of the actual aquaculture farms and not the associated underwater infrastructure that links to an abrasion pressure (extent and intensity).
	Aquaculture - shellfish	
Habitat Modification	Beach replenishment	Insufficient data – No known UK wide publicly available datasets exist for this activity.
Extraction – Non Living Resources	Extraction - navigational dredging (capital, maintenance)	Extraction as a pressure is considered separately (physical damage – removal of substratum). To avoid double counting it was excluded from this methodology.
	Extraction - sand & gravel	
Extraction – Living Resources	Bio-prospecting	Insufficient data – No known UK wide publicly available datasets exist for these activities.
	Extraction - maerl	
	Fishing - crab tiling/bait digging	
	Fishing - hand gathering (and tractor dredging)	
	Fishing - hooks and lines that use anchors	This activity can cause abrasion due to anchoring, but unquantifiable from data sources
	Fishing - nets setting with anchors	
	Fishing - potting/creeling	This activity can cause abrasion but unquantifiable from data sources
	Fishing - recreational	Insufficient data – No known UK wide publicly available datasets exist for these activities.
	Fishing - Seines with anchors	This activity can cause abrasion due to anchoring, but unquantifiable from data sources
	Fishing - Seines without anchors	This activity can cause abrasion due to anchoring, but unquantifiable from data sources
	Fishing - shellfish harvesting	Insufficient data – No known UK wide publicly available datasets exist for these activities.
	Harvesting - seaweed	
	Fishing – mechanized dredging	This activity can cause abrasion however the intensity is more related to the pressure of physical damage - extraction
Man-made structures	Infrastructure - artificial reefs	It is the installation and decommissioning of infrastructure that is most associated with abrasion. Compared to other activities these phases of development operate over relatively short timescales. Currently it is beyond our ability to capture this temporal variability in activities. The
	Infrastructure - cables (Installation)	
	Infrastructure - cables (Operation)	
	Infrastructure - coastal (ports, marinas, leisure facilities)	
	Infrastructure - coastal defence & land claim	
	Infrastructure - offshore (oil & gas	

Category	Activity	Reason for Exclusion
	platforms)	pressure footprint of man-made infrastructure is considered as part of the pressure category 'physical loss, physical change' as such, at this time, the decision was made to exclude infrastructure from the abrasion method.
	Infrastructure - offshore (wind & wave & tidal turbines)	
	Infrastructure - Pipelines (Installation)	
	Infrastructure - pipelines (Operation)	
	Infrastructure- Carbon Capture Storage at Sea (gas storage)	
	Infrastructure- natural gas storage	
Military	Military	Insufficient data – Available datasets relate to large polygon areas where certain Ministry of Defence (MOD) activities can occur, but not the exact spatial location of these actual activities for MOD security reasons.
Survey & Research	Survey - biological, oceanographic (research, education)	Insufficient data – No known UK wide publicly available datasets exist for these activities.
Recreation	Tourism & recreation	Insufficient data – links between recreational activities and abrasion are still poorly understood
Transport	Transport - shipping	Footprint of activity thought to be minimal

8   Annex III - R code

8.1   R code for anonymous VMS to swept area

```r
#================================================================
#R code for anonymous VMS to Swept area # e.g. Using 2009 data
#================================================================

#necessary packages and functions

library(utils)
necessary = c('shapefiles', 'rgdal',  'raster', 'GISTools')     # add name of package here to install
installed = necessary %in% installed.packages()[, 'Package']
if (length(necessary[!installed]) >=1)
install.packages(necessary[!installed], dep = T)

library(shapefiles)
library(rgdal)
library(raster)                 #raster library
library(GISTools)          #GIS library
setwd ("D:/SWA")          #set working directory where your data will save
                          # read in text files of VMS points

VMSdata<- read.csv("D:/R code test/VMS data/JNCC FULL 2009.txt")

View(VMSdata) # check which data fields are of interest

#================================================================
#Speed filtering
#================================================================

VMSdata <- subset (VMSdata, VMSDAta$speed >= 1 & VMSdata$speed <= 6) # speed filter

#check data summary and that filtering worked
summary (VMSdata$gear)

#converts speed from knots to metres per min
VMSdata$mmin <- (VMSdata$speed * 30.8666666664) # converting metres per min

## create new data set containing  just the gears we are interested in for each year
a <- VMSdata [VMSdata$gear == "OTB",] ##otter trawls only
b <- VMSdata [VMSdata$gear == "TBB",] #beam trawls only
c <- VMSdata [VMSdata$gear == "TBN",] #nephrops trawls only
d <- VMSdata [VMSdata$gear == "PTB",]
e <- VMSdata [VMSdata$gear == "OT",]
f <- VMSdata [VMSdata$gear == "OTT",]
g <- VMSdata [VMSdata$gear == "DRB",]
h<- VMSdata [VMSdata$gear == "SPR",]
VMSdata<- rbind (a,b,c,d,e,f,g,h)

### add in gear widths into a new column for each year
VMSdata$gearm  [VMSdata$gear == "OTB"] <- 60
VMSdata$gearm  [VMSdata$gear == "TBB"] <- 18
```

```
VMSdata$gearm  [VMSdata$gear == "TBN"] <- 60
VMSdata$gearm  [VMSdata$gear == "PTB"] <- 250
VMSdata$gearm  [VMSdata$gear == "DRB"] <- 12
VMSdata$gearm  [VMSdata$gear == "OT"] <- 60
VMSdata$gearm  [VMSdata$gear == "OTT"] <- 100
VMSdata$gearm  [VMSdata$gear == "SPR"] <- 250


VMSdata$gearmSub  [VMSdata$gear == "OTB"] <- 2
VMSdata$gearmSub  [VMSdata$gear == "TBB"] <- 18
VMSdata$gearmSub  [VMSdata$gear == "TBN"] <- 2
VMSdata$gearmSub  [VMSdata$gear == "PTB"] <- 0
VMSdata$gearmSub  [VMSdata$gear == "OT"] <- 2
VMSdata$gearmSub  [VMSdata$gear == "OTT"] <- 3
VMSdata$gearmSub  [VMSdata$gear == "DRB"] <- 12
VMSdata$gearmSub  [VMSdata$gear == "SPR"] <- 0
```

#remove records >120 minutes as they are misrepresentative of fishing for 2hr ping interval
VMSdata <- subset (VMSdata, VMSdata $pingtime <=120)

#calculate the swept areas
VMSdata$SWA <- VMSdata$mmin * VMSdata$gearm * VMSdata$pingtime   # SWA calculation
VMSdata$SWAsub <- VMSdata$mmin * VMSdata$gearmSub * VMSdata$pingtime   # subsurface SWA calculation

# create raster of area of interest at 0.05 decimal degree (dd) intervals
r1<- raster(nrows=340, ncols=680, xmn=-24, xmx=10, ymn=47, ymx=64)   # new raster 0.05dd

#==
#Export raster
#==

a <- data.frame (VMSdata [,6]) ## create table of only the XYcoords for use in analysis ([,1:2] = all rows 2 columns). You can check that it is columns 1 and 2 by using "summary (p)"

b <- data.frame (VMSdata [,7])
p <- data.frame (cbind(b,a))

#Create Raster
rVMSdata<- rasterize(p, r1, VMSdata$SWA, fun= "sum", background=NA,
mask=FALSE, update=FALSE)
r <- writeRaster(VMSdata, filename="SWAdata.tif", format="GTiff", overwrite=TRUE)

rVMSdata<- rasterize(p, r1, VMSdata$SWAsub, fun= "sum", background=NA,
mask=FALSE, update=FALSE)
r <- writeRaster(VMSdata, filename="subSWAdata2009.tif", format="GTiff", overwrite=TRUE)
###This can then be repeated for all relevant years

#==
#SWA RATIO
#==
p1 <- rasterToPoints(r1)   # create centroids of raster grid
pp <- data.frame (p1 [,1:2])
files <- list.files(path= "D:/SWA", pattern = ".tif", full.names=TRUE) #import rasters from location
UK Fishing (should list the files in the directory - check it worked)

```
sta <-stack (files)
exr<-extract(sta ,pp)
areapoly<- readShapePoly ("D:/GIS tests/RasterGridPolygon.shp") # import polygon Grid of Area
proj4string(areapoly) <- CRS("+proj=aea +lat_1=50.2 +lat_2=58.5 +lat_0=30 +lon_0=10 +x_0=0
+y_0=0 +ellps=intl +units=m +no_defs" )
#you can use http://spatialreference.org/ref/esri/102013/ to find the correct code for your projection

summary (areapoly)
swa <-cbind (pp, areapoly[,3], exr)
summary(swa)
swa[is.na(swa)] <- 0

#calculate swa ratio for each year e.g.2009-2010
swa$swaRatio2009 <-  swa$subSWAdata2009/swa$F_AREA   ## SWA divided by area
swa$swasubRatio2009 <- swa$SWAdata2009 /swa$F_AREA

swa$swaRatio2010 <-  swa$subSWAdata2010 /swa$F_AREA
swa$swasubRatio2010 <- swa$SWAdata2010 /swa$F_AREA  ### etc....

#calculate the average mean over the years of the ratio (this can also be done for the absolute SWA)
swaratio$swaMean <- (swa$swaRatio2009   + swa$swaRatio2010 + swa$swaRatio2011 +
sswa$swaRatio2012 )/4    # Years added up and divided by number of years
swaratio$swaSubMean <-(swa$swasubRatio2009   + swa$swasubRatio2010 + swa$swasubRatio2011
+ sswa$swasubRatio2012 )/4

#calculate the variance over the years of the ratio (this can also be done for the absolute SWA)
swaratio$swaVAr <- (((swaratio$swaRatio2009  - swaratio$swaMean)^2) + ((swaratio$swaRatio2010
- swaratio$swaMean)^2) + ((swaratio$swaRatio2011 - swaratio$swaMean)^2) +
((swaratio$swaRatio2012- swaratio$swaMean)^2))
swaratio$swaSubVAr <- (((swaratio$swasubRatio2009  - swaratio$swaMean)^2) +
((swaratio$swasubRatio2010 - swaratio$swaMean)^2) + ((swaratio$swasubRatio2011 -
swaratio$swaMean)^2) + ((swaratio$swasubRatio2012- swaratio$swaMean)^2))

#calculate the standard deviation of the ratio (this can also be done for the absolute SWA)
swaratio$swaSD <- sqrt (swaratio$swaVAr)
swaratio$swaSubSD <- sqrt (swaratio$swaSubVAr)

#create and export new rasters of the ratios, the standard deviation and the variance
ra<- rasterize(pp, r1, swaratio$swasubRatio2009, fun= "last", background=NA,
mask=FALSE, update=FALSE)
rf <- writeRaster(ra, filename="swasubratio2009.tif", format="GTiff", overwrite=TRUE) ##etc for all
years and SD and VAr
```

8.2   R Code for Aggregated VMS

```
#==============================================================
#R Code for Aggregated VMS# e.g. using 2008 data #
#==============================================================

#necessary packages and functions
library(utils)
necessary = c('shapefiles', 'rgdal',  'raster', 'GISTools')          # add name of package here to install
installed = necessary %in% installed.packages()[, 'Package']
if (length(necessary[!installed]) >=1)
install.packages(necessary[!installed], dep = T)

library(shapefiles)
library(rgdal)     #GIS library
library(raster)    #Raster library
library(GISTools)
setwd ("D:/SWA")  #Set working directory where your data will save to

#===================
##import rasters####
#===================

ls()                                #List files in project
r1 <- raster("D:/SWA/rasters/r1.tif")  # import largest extent raster  (this could be the largest extent
raster or a created grid. (Check location)

files <- list.files(path= "D:/SWA/rasters/UK", pattern = ".tif", full.names=TRUE )  # import rasters
from location UK Fishing
files                                            #should list the files in the directory - check it worked

files2 <- list.files(path= "D:/SWA/rasters/NonUK", pattern = ".tif", full.names=TRUE )  # import
rasters from location NON UK Fishing
files2

FAUK <-stack (files)                              # stack rasters listed in files
FAnon <-stack (files2)                            # stack rasters listed in files2

#===================================
##Creating centroids from raster####
#===================================
p <- rasterToPoints(r1)    # used the raster to point function to create a table of centroids for each cell
and values of a raster using extent raster r(double checked centroids below)
plot  (p)                                  # plot to check it worked

pp <- data.frame (p [,1:2])  # create table of only the XYcoords for use in analysis ([,1:2] = all rows 2
columns). You can check that it is columns 1 and 2 by using "summary (p)"

ncol (p) # checks to compare the numbers of rows and column to ensure it worked.  Should be the
same number of rows as pp.
ncol (pp)
nrow (pp)
nrow (p)
```

```
#=========================
#Import Area  data#
#=========================
areapoly<- readShapePoly ("D:/GIS tests/RasterGridPolygon.shp") # read in polygon of area
proj4string(areapoly) <- CRS("+proj=aea +lat_1=50.2 +lat_2=58.5 +lat_0=30 +lon_0=10 +x_0=0
+y_0=0 +ellps=intl +units=m +no_defs" )  ## you can use http://spatialreference.org/ref/esri/102013/
to find the correct code for your projection


summary (areapoly)
proj4string(areapoly)                  #tells you the co-ordinate system of the data


#=======================
##Extracting raster data#
#=======================


exr<-extract(FAUK ,pp)
# extracts values of each raster in the file list for those locations UK VMS
exr2<-extract(FAnon ,pp)
# extracts values of each raster in the file list for those locations NON UK VMS



FAallxy <-cbind (pp, areapoly[,3], exr, exr2) # binds the table of raster information with the xy co-
ordinates

summary  (FAallxy)  #note  there are some NAs this is because of the different extents of some
rasters.  These need converting to 0 to allow for calculations to take place.  Do it is should be noted
that some areas do not have values for all years.
names (FAallxy)

FAallxy[is.na(FAallxy)] <- 0     #This turns all N/A values to 0 so that equations can be run on them

FAallxy$areakm2 <- FAallxy$F_AREA  / 1000000    # turns the square meter areas to square km



#==================
#SWA calculation#
#==================

##############################
#####Surface Abrasion ###########
##############################


FAallxy$SWA2008_DRB <- FAallxy$X2008_DRB * 12 * 5.55588
#data$swept_area_km2 <- effort * gear_width * VesselSpeed_kmhr
FAallxy$SWA2008_ALL_Dredge <- FAallxy$X2008_ALL_Dredge * 12 * 5.55588
FAallxy$SWA2008_OT <- FAallxy$X2008_OT * 60 * 8.334
FAallxy$SWA2008_OTT <- FAallxy$X2008_OTT * 100 * 8.334
FAallxy$SWA2008_OTB <- FAallxy$X2008_OTB * 60 * 8.334
FAallxy$SWA2008_ALL_Demersal <- FAallxy$X2008_ALL_Demersal * 60 * 8.334
FAallxy$SWA2008_TBB <- FAallxy$X2008_TBB * 18* 8.334
FAallxy$SWA2008_TBN <- FAallxy$X2008_TBN * 60* 8.334
FAallxy$SWA2008_PTB <- FAall$X2008_PTB * 250* 5556
FAallxy$SWA2008_ALL_Beam  <- FAallxy$X2008_ALL_Beam  * 18* 8.334
```

```
FAallxy$SWA2008_SPR<- FAall$X2008_SPR * 250* 5556
summary (FAallxy)


#===================
###SWA Summations####
#===================
FAallxy$SWA2008_demersal <-  FAallxy$SWA2008_TBN +  FAallxy$SWA2008_OTT +
FAallxy$SWA2008_OTB +  FAallxy$SWA2008_OT + FAall$SWA2008_PTB +
FAall$SWA2008_SPR  #UK demersal trawls

FAallxy$ALL_demersal <- FAallxy$SWA2008_demersal + FAallxy$SWA2008_ALL_Demersal
# UK and NON uk demersal trawls

FAallxy$ALL_Beam <- FAallxy$SWA2008_TBB  + FAallxy$SWA2008_ALL_Beam
#UK and Non UK beam

FAallxy$ALL_Dredge <- FAallxy$SWA2008_DRB  + FAallxy$SWA2008_ALL_Dredge
#UK and Non UK dredged

FAallxy$SWAallSurfaceAV <-  FAallxy$ALL_Beam  + FAallxy$ALL_Dredge +
FAallxy$ALL_demersal                    #All UK and Non UK

#===================
 ###SWA RATIO####
#===================

FAallxy$swaRatio_Surface  <- FAallxy$SWAallSurface/FAallxy$areakm2

#############################
#####Subsurface Abrasion ##
#############################

FAallxy$SWA2008_DRB <- FAallxy$X2008_DRB * 12 * 5.55588
#swept_area_km2 <- effort * gear_width * VesselSpeed_kmhr
FAallxy$SWA2008_ALL_Dredge <- FAallxy$X2008_ALL_Dredge * 12 * 5.
FAallxy$SWA2008_OT <- FAallxy$X2008_OT * 2 * 8.334
FAallxy$SWA2008_OTT <- FAallxy$X2008_OTT * 3 * 8.334
FAallxy$SWA2008_OTB <- FAallxy$X2008_OTB * 2 * 8.334
FAallxy$SWA2008_ALL_Demersal <- FAallxy$X2008_ALL_Demersal * 2 * 8.334
FAallxy$SWA2008_TBB <- FAallxy$X2008_TBB * 18* 8.334
FAallxy$SWA2008_TBN <- FAallxy$X2008_TBN * 2* 8.334
FAallxy$SWA2008_ALL_Beam  <- FAallxy$X2008_ALL_Beam  * 18* 8.334

summary (FAallxy)

#===================
 ###SWA Summations####
 #===================
FAallxy$SWA2008_demersal <-  FAallxy$SWA2008_TBN +  FAallxy$SWA2008_OTT +
FAallxy$SWA2008_OTB +  FAallxy$SWA2008_OT #UK demersal

FAallxy$ALL_demersal <- FAallxy$SWA2008_demersal + FAallxy$SWA2008_ALL_Demersal
# UK and NON UK demersal trawl
```

```r
FAallxy$ALL_Beam <- FAallxy$SWA2008_TBB  + FAallxy$SWA2008_ALL_Beam
#UK and Non UK beam

FAallxy$ALL_Dredge <- FAallxy$SWA2008_DRB  + FAallxy$SWA2008_ALL_Dredge
#UK and Non UK Dredge

FAallxy$SWAallsubsurface  <-  FAallxy$ALL_Beam  + FAallxy$ALL_Dredge +
FAallxy$ALL_demersal  # Subsurface SWA

#==================
###SWA RATIO####
#==================

FAallxy$swaRatio_subsurface   <- FAallxy$SWAallsubsurface /FAallxy$areakm2

######################
#####Export raster###
######################


setwd ("D:/SWA/AbrasionResults")

rACSurface<- rasterize(pp, r, FAallxy$SWAallSurface, fun= "last", background=NA,
             mask=FALSE, update=FALSE)
rf <- writeRaster(rACSurface, filename="SWAallSurface.tif", format="GTiff", overwrite=TRUE)
# create surface abrasion


rACSubSurface<- rasterize(pp, r, FAallxy$SWAallSubSurface, fun= "last", background=NA,
                        mask=FALSE, update=FALSE)
rf <- writeRaster(rACSubSurface, filename="SWAallsubSurface.tif", format="GTiff",
overwrite=TRUE)
 # create subsurface abrasion

##### Repeat for subsurface and surface SWA ratio and for all years.
```