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Report of the Workshop to evaluate regional benthic pressure and impact indicator(s) from bottom fishing (WKBENTH)

28 February–3 March 2017

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Executive summary

The workshop to evaluate regional benthic pressure and impact indicator(s) from bottom fishing (WKBENTH) chaired by Adriaan Rijnsdorp (the Netherlands), met at ICES Headquarters on 28 February - 3 March 2017. The workshop was attended by 24 participants from 8 countries, including representatives from various ICES Working Groups, the fishing industry and experts involved in regional sea's convention (RSC) work.

WKBENTH is part of a series of three workshops that ICES has organised to address an advice request from European Commission to "Evaluate indicators for assessing pres-sure and impact on the seafloor from bottom-contacting fishing. Using this assessment, demonstrate trade-offs in catch/value of landings relative to impacts and recovery po-tential of the seafloor". The three workshops and advice process outcomes as a whole were published as ICES Advice and delivered to the EU on 26 June 2017. Indicators approaches developed in WKBENTH were further refined based on input from a stakeholder workshop on the production of operational guidance on assessment of benthic pressure and impact from bottom fishing (WKSTAKE, 23 March 2017). WKSTAKE looked into the operational challenges of the suggested indicators to assess impact and the usefulness of the indicators in a management context. This fed into the last workshop in which methods to evaluate trade-offs between the impact on seafloor habitats and provisions of catch/value of the fisheries were explored (WKTRADE, 28-31 March 2017).

The specific task of the WKBENTH workshop was to evaluate different modelling approaches (of combining pressure, habitat map and sensitivity layers) to assess the extent of impacts at the (sub)regional scale. ICES has recommended in 2016 to apply a mechanistic, quantitative approach based on biological principles. In this report the performance of two such approaches – the longevity and population dynamic approach, were explored and compared to the BH2 and BH3 approach used in OSPAR. Details of the methodology and corresponding indicators were described and the differences and critical assumptions were reviewed. This overview is useful in guiding the continued development of work within Regional Sea Conventions for the Baltic Sea (HELCOM) and North-East Atlantic (OSPAR), as well as for the Mediterranean (Barce-lona Convention) and Black Sea (Bucharest Convention).

In advance of WKBENTH, a core group of experts prepared material. At WKBENTH indicators of both 1) pressure, footprint of bottom trawling on the seafloor, and 2) impact, combining pressure and underlying sensitivity of habitats, were produced as worked examples for the Celtic and North Sea ecoregions. Maps and footprint indicators per habitat and ecoregions of trawling intensities (surface and subsurface abrasion) were prepared, based on VMS and logbook data. WKBENTH further reviewed the ecosystem functions of the benthic ecosystem and explored possibilities of including ecosystem function in the impact assessment methods. Although arbitrary GES thresholds were used in the worked out examples, WKBENTH explored the ecological basis for setting threshold levels in relation to specific management objectives. The quality of the indicator assessment methods were evaluated using frameworks developed in ICES.

Impact maps of the different assessment approaches differed in the absolute value. Nevertheless, a comparison of the maps suggested a similarity across methods in the location of areas with either high or low impact, although locally discrepancies were found, suggesting that impact is mainly determined by gradients in fishing pressure than gradients in sensitivity. Only one of the longevity approaches showed a different

pattern of impact, which is due to the fact that the method predicts low impact of trawling in shallow waters and in habitats that are exposed to high bed shear stress.

None of the methods provided a final solution how to best assess benthic impacts. BH3 is already put into practice and provides an initial assessment for the OSPAR 2017 IA but uses a categorical approach that does not provide a continuous pressure – impact – state relationship recommended by ICES. The longevity and population dynamic approaches are designed to provide continuous relationships. Longevity is both theoretically and practically a very attractive way to capture sensitivity to trawling. It can capture interactions between environmental and trawling disturbance well and can in theory capture many different environmental stresses. The parameterisation, however, is based on a data set that does not cover the full range of environmental conditions, regions and habitats, and, poorly reflects the epifaunal community. The results of the impact assessments using the longevity and population dynamic approaches, therefore, are preliminary and the application of the methods beyond the domain of environmental variables, or in other regions, is uncertain and needs to be validated and ground truthed. The BH2 approach performed a quantitative benthic status assessment by means of Margalef diversity. This index calculation needs ideally be based on local data input, which hampers extrapolation of the scores to other habitats and regions.

As the assessments were focussed on the regional scale, application on the local scale may be less appropriate because it may not include specific conditions of the environment or benthic community that deviate from the regional model.

None of the methods account for small-scale habitat structures beyond the c-square level. BH3 partly considers this by incorporating additional information from habitats classified at small scales and biotope data. Regional indicators can provide only limited information for local assessments, as e.g. habitat heterogeneity cannot be considered appropriately. On a sub-regional scale, different methods or adaptations of methods may be useful and as such, need a separate evaluation.

The population dynamic approach using continuous environmental variables was used for a worked example for the North Sea for WKSTAKE and WKTRADE. The anal-ysis showed that bottom trawling is aggregated in a relatively small part of the total area trawled. The benthic status of the intensively trawled fishing grounds was poor, but the catch rate per unit of impact was higher than in the peripheral fishing areas. These peripheral areas had a higher status, while they had a relatively small contribu-tion to the overall landings and revenue. The relative high catch per unit of impact in the core fishing grounds implies that a reduction of fishing impact might be achieved with a lower cost in landing reduction by limiting fishing pressure in the peripheral grounds as compared to a reduction of fishing in the core fishing grounds.

A comparison of the impact assessments between métiers needs to be interpreted with caution because of the simplifying assumption that the impact is determined by the swept area ratio (surface or subsurface) only, ignoring the differences in the penetration profiles resulting in differences in the impact per unit swept area across métiers.

1 Definitions in the context of WKBENTH

Fishing pressure:

The physical abrasion of the seabed by bottom-contacting fishing gears. The pressure is expressed as the ratio between the sum of the area swept by the fishing gear (with components having a surface or subsurface penetration) per year and the total area of the site (swept-area ratio - SAR).

Species sensitivity:

The intolerance of a species or habitat to damage from an external factor and the time taken for its subsequent recovery.

Resistance:

The ability of a receptor to tolerate a pressure without changing its character

Recoverability (or resilience):

The time that a receptor needs to recover from a pressure, once that pressure has been alleviated

Fishing impact:

The effects (or consequences) of fishing pressure on an ecosystem component. The impact is determined by both exposure and sensitivity to a pressure.

Fishing intensity indicator:

A characteristic of the footprint of the fisheries, on either spatial or temporal scales (or both).

Benthic impact indicator:

A characteristic of a benthic habitat that can provide information on ecological structure and function

2 Introduction

Member countries and Regional Sea Conventions (RSCs) are developing indicators of impacts on benthic habitats from anthropogenic activities, particularly bottom-trawling, for MSFD purposes (D1 biodiversity and D6 seafloor integrity). EU projects are also developing approaches across European seas (including the Mediterranean and Black Sea). As part of this process, in 2016 ICES organized a workshop (WKFBI 2016) that contributed towards the ICES advice to the EU "*guidance on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats*" (ICES 2016).

In 2017, the EU (DG ENV) requested advice from ICES to "*evaluate indicators for assessing pressure and impact on the seafloor from bottom-contacting fishing. Using this assessment, demonstrate trade-offs in catch/value of landings relative to impacts and recovery potential of the seafloor*". To address this request for advice, ICES ran three workshops. The first workshop (WKBENTH) evaluated different modelling approaches (of combining pressure, habitat map and sensitivity layers) to assess the extent of impacts at the (sub)regional scale. Using this evaluation, a stakeholder workshop (WKSTAKE) was organized to discuss the operational challenges of the suggested indicators to assess impact and the usefulness of the indicators in a management context. The last workshop (WKTRADE) used the assessment indicators developed in the above two workshops, to explore the trade-offs between benthic impact and the landings or revenue of the fisheries. All workshop report were reviewed by the Working Group on Ecosystem Effects of Fishing Activities (WGECO) and formed the basis of advice published as ICES Advice to the EU on 26 June 2017.

Under the EU's Marine Strategy Framework Directive (for both Descriptors 1 and 6) condition metrics are required for widespread habitats and communities that can ensure structure and functions of ecosystems are safeguarded and that benthic ecosystems are not adversely affected. WKBENTH has used EUNIS level 3 habitats (of the 2004 version of EUNIS), this is further elaborated on in Annex 6 and Annex 9 of this report. ICES advised in 2016 that maps of seabed habitat are combined with those of fishing intensity for assessing the state of seabed habitats. This also requires an assessment of the sensitivity of the communities associated with each habitat. Developing both fishing footprint and impact maps into operational indicators at the regional scale will require exploring end-user requirements for managers and fisheries as stakeholders.

Using a procedure (see Figure 2.1), WKBENTH has proposed best practices to assess pressure on and impact from bottom fishing on the seafloor at the broader scale. The regional scale assessment methods considered by WKBENTH have been developed using mechanistic and/or expert understanding of how bottom trawling impacts the benthic community typical for each habitat. By exploring the relationship between trawling intensity and benthic structure and function we can help define threshold levels for GES. Threshold levels can be proposed to help inform the process of setting the level at which the benthic community can be considered in a poor state relative to policy objectives. In producing worked examples (as maps and indicators), different scenarios and management options can more easily be explored. Importantly assessment method will also need to inform managers about the relationships, and therefore trade-offs, between benthic impacts and the landings or revenue of the fisheries.

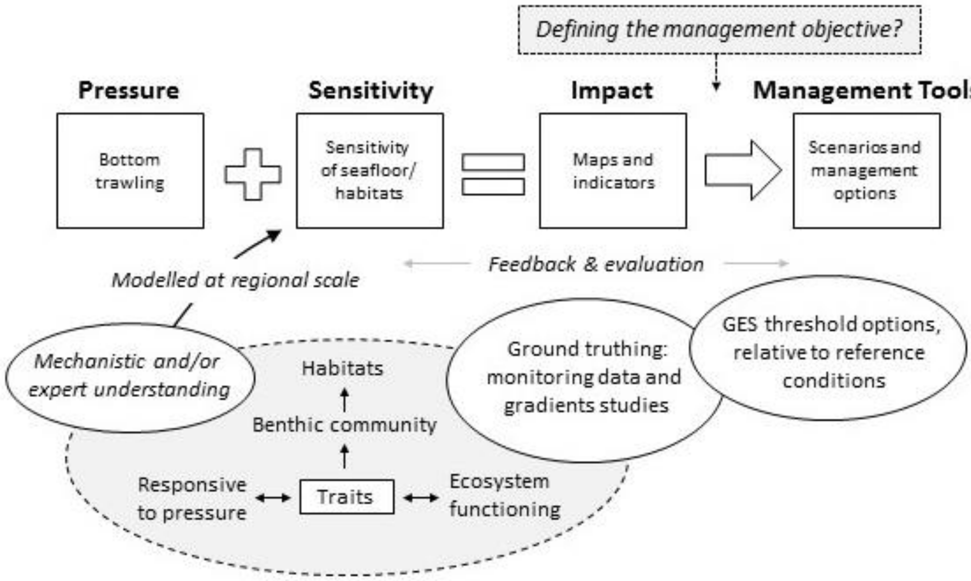


Figure 2.1. Conceptual diagram of the steps taken in developing management tools for assessing pressure and impact on the seafloor from bottom-contacting fishing.

This WKBENTH report begins with an exploration of our understanding of the functional response of the benthos to bottom fishing (Chapter 3). Specific traits of benthic species can be linked to either "*affect on*" ecosystem functioning or,"*response to*" the pressure (i.e. bottom fishing). This chapter on functionality is followed by suggesting operational ways forward in setting GES (good environmental status) thresholds, based on reference conditions and on our understanding of how bottom trawling impacts the seafloor (Chapter 4).

Within this context, worked examples of benthic pressure and impact assessment from bottom fishing at the broader scale of the (sub)region, across a 6-year period are prepared at the scale of the MSFD (sub)regions for the Baltic, North and Celtic Sea. Thus in Chapter 5, fishing footprint indicators and maps to estimate pressure from bottom fishing as SAR (swept area ratios) are presented. While in Chapter 6, different methods to assess seafloor/habitat sensitivity are presented. Combined with pressure as SAR, indicator and maps are produced to estimate impact for the North and Celtic Sea.

The outputs of regional fishing footprint and modelled sensitivity and impact scores are compared in Chapter 7, using empirical data from monitoring and gradient studies. This ground-truthing is required to ensure relationships can be scaled-up and to identify gaps in monitoring data for parametrizing models across different regions. Based on this, Chapter 8 explores the differences between the output of respective assessment methodologies, as well as, with respect to their underlying assumptions. Such insight is essential in guiding the continued development of work within Regional Sea Conventions for the Baltic Sea (HELCOM) and North-East Atlantic (OSPAR), as well as for the Mediterranean (Barcelona Convention) and Black Sea (Bucharest Convention).

In Chapter 9, the adaptability of assessments (maps and indicators) as management tools is presented with respect to being able to explore different fishing pressure scenarios, alternative management options and associated trade-offs in catch/value of the fisheries. This is prepared as input to WKSTAKE and WKTRADE. In chapter 10 the main findings from WKBENTH are presented as input to the advice drafting group (ADGFBT) in response to the EU request to ICES.

3 Functional response of seafloor habitats to bottom fishing

3.1 Functional effect and response traits

3.1.1 The importance of seabed for ecosystem functioning

The Convention on Biological Diversity (CBD, 2001) defines an ecosystem as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" (Article 2 of the Convention). An ecosystem may be considered as a unit within which an assemblage of living organisms interact with each other and with the chemical and physical environment, resulting in natural processes and establishment of a series of complex ecological balances. Ecosystems may operate at a wide range of spatial and temporal scales, from long-term global systems, to very small, localised or ephemeral systems. It is the interactions and processes within ecosystems that afford the delivery of a wide range of environmental goods and services. Given the extent to which ecosystems are connected across different spatial and temporal scales it is often difficult to define precise boundaries between ecosystems, especially when applied to the development of management measures. To overcome some of the fuzzy nature of ecosystem boundaries, spatial management units have tended to be defined on the basis of their physiographic and habitat features first, followed then by a definition of their associated biology.

There has been, and still is, a large amount of confusion between the terminology of properties, processes, functions, goods and services in the marine literature. Here, ecosystem processes refer to mechanistic processes (e.g. bioturbation, bioirrigation, decomposition) that are carried out by the biota; ecosystem functions are those functions mediated by ecosystem processes and incorporate pools and fluxes (rates) of materials and energy (e.g. carbon and organic matter pools, nutrient cycling, primary productivity). Ecosystem functions must be considered as a subset of ecological processes (e.g. the processes drive the functions) and ecosystem structures that provide specific goods and services (de Groot, 1992). While the distinction between these terms is implicitly important within an ecological context, we must attempt to understand how seabed biological assemblages contribute to them. To answer this, we need to clearly define what we aim to preserve, minimise impacts to, or restore following bottom fishing and understand that each of these are likely to be habitat-specific.

In this respect, we may refer to goods and services provided by the marine ecosystem; an increasingly common method of classifying exactly what we may gain and/or lose when we exploit the environment (Holmlund and Hammer, 1999). There are a number of methods used for classifying goods and services, and although the typology devised by Groot *et al*. (2002) was primarily based on terrestrial functions, it aids us to classify those pertinent to the marine environment in a clear manner. The main goods and services we would consider those most important for marine policy to safeguard for shelf seas are listed in Table 3.1. While the relative importance of each of these will vary between different habitats, additional functions may be regarded as essential in some situations. We must also be mindful that managing trawling to minimise impacts to one function may result in enhanced impacts to another function of that habitat (Beaumont and Tinch, 2003). For example, managing the seabed to enhance food availability for commercial fish may result in decreased biodiversity and/or reduced benthic-pelagic coupling in some habitats.

Table 3.1. The main functions, ecosystem processes and goods and services of marine ecosystems that are particularly pertinent to trawling impacts on sedimentary habitats.

FUNCTIONS	Ecosystem Processes	Goods and Services
Regulation functions		
Nutrient regulation	Role of fauna in storage and re-cycling of nutrients (e.g. N, P, S)	Enhanced benthic-pelagic coupling and maintenance of healthy systems
Gas/climate regulation	Role of fauna in carbon fluxes, CO_2 sequestration	Maintenance of favourable climate for humans
Habitat functions		
Refugium function	Suitable living space for some species	Maintenance of biodiversity and some commercially harvested species
Nursery function	Suitable habitat for some species to reproduce	
Sediment stability	Stabilisation or destabilisation through direct (e.g., tubes) or indirect (e.g., diatom predation) processes	Reduced temporal shift in sediment balance within coastal areas.
Production functions		
Food provision	Conversion of energy to prey for animals	Enhanced fishing industry

3.1.2 Biological traits

It has been widely accepted, in both the marine, freshwater and terrestrial realms, that the roles played by the biological components of ecosystems are better described by embracing what the organisms do as opposed to their taxonomic phylogeny. While structural approaches have proven indispensible for assessing biological status and the drivers of change in biological assemblages, they are somewhat limited in terms of inferring the role played by a given assemblage affecting any of the important functions they perform. Recent advances in biological traits analyses (BTA) have proved of some utility in this respect. Correlations between species distributions and habitat characteristics have limited potential for mechanistic understanding of ecological patterns since analyses based on taxonomic grounds alone do not provide confirmation of assembly rules independent of species biology (Statzner *et al.*, 1994). Species assemblage distributions are only patterns, and patterns are phenomena arising from unknown mechanisms, a mechanism being a comprehensive interplays between variables (Rosenzweig and Ziv, 1999). Biological traits can be used to understand why different taxonomic entities (e.g. species, genera) occur in similar habitats (Dray and Legendre, 2008), as organism performances result from common adaptations to environmental forces (Greenslade, 1983; Southwood, 1988). Hence, the use of multiple traits, as variables describing species performances, enable the generation of laws, patterns with mechanisms, and consequently can support the development of theoretically-sound applications. In this respect, the intrinsic advantage of using biological traits in indicator development is the strength of theoretical implications; there is no reliable indicator without theoretical biology.

A biological trait is simply a description of a particular characteristic of an individual (often defined for the species). The number of traits that may be classed for a group of species is potentially large, although many tend to be invariably correlated and/or are covariates. For marine benthic invertebrate assemblages, Table 3.2 lists those that have been commonly used in published studies (although individual studies tend to encompass only a subset of these). Biological traits may be grouped, according to functional classification ecology, into two broad categories (Hooper et al., 2004). Functional effect traits are those which affect ecosystem properties while functional response traits are those which affect a species' response to changes in the environment such as disturbance, resource availability or climatic shifts (Lavorelle and Garnier, 2002).

Violle *et al*. (2007) highlighted that there has been wide confusion in the use of these terms. However, an understanding of the distinction between these two types of traits is of utmost importance as functional response traits may vary independently from functional effects traits. For example, in terrestrial plants, regeneration traits (seed size, number of seeds per plant, dispersal mode) which often affect response to disturbance (i.e., functional response traits), tend to be only loosely correlated with vegetative characteristics, which have more direct effects on process rates (i.e. functional effect traits) (Diaz and Cabido, 1997). The extent to which this de-coupling or separation of traits into these two groups is widespread across various biological groups and/or differing ecosystems (the marine ecosystem, for example) is not presently known (Pakeman, 2011). However, because traits that affect response to disturbance also affect individuals or populations sensitivity to recover from disturbance or stress, they may indirectly influence an ecosystem process or function under consideration (Hooper *et al*. 2004).

Ultimately, both components of trait classes are theoretically important with respect to ecosystem dynamics and ecological functioning. However, advancing our understanding of which traits are important for affecting the ability of benthic assemblages to affect certain ecological functions and processes is our primary goal. It follows that for any indicator of assemblage status to have the capacity to reflect functionality it must be based, in part, on functional effects traits.

There have been a number of published studies in the marine realm where trait compositional changes have been observed along an environmental gradient (e.g. Oug et al., 2012; Paganelli *et al*., 2012) or following a temporal and/or spatial disturbance gradient (de Juan and Semestre, 2012). Significant progress with respect to our understanding of the identity of a number of functional response traits has been made. For example, taxa exhibiting sedentary and/or soft-bodied traits have been shown to be particularly vulnerable to trawling (Thrush *et al*., 1995; Blanchard *et al*., 2004) and Dimitriadis *et al.* (2012) found that traits associated with filter feeding (i.e. 'plankton', 'suspended organic matter' and 'filter feeders') were favoured in regions of high primary productivity. These studies ultimately describe patterns in functional response traits, although functional changes resulting from such patterns are often implied. In recognition of the distinction between functional response traits and functional effects traits, these assumptions may only hold if the observed functional response traits also act (wholly or partly) as functional effects traits. Unfortunately, this level of understanding regarding functional effects traits is currently lacking and while such studies (above) may indeed describe trait patterns, inferences regarding functional alterations associated with such patterns must be made with a degree of caution. Some attempts have been made to categorise benthic traits as response or effects traits (e.g., Beauchard *et al*., 2017; see Table 3.2) but these are, largely, based on expert opinion. As Pakeman (2011) recently pointed out, "identification of traits that mediate the response of plants to the environment is well established, but identification of effects traits, and the linkage between the two sets, is less developed"

Table 3.2. Examples of biological traits commonly used in marine benthic studies. Indication of whether the trait may be regarded as a response or effects trait is also indicated (Beauchard et al., 2017).

TRAITS	MODALITIES	FUNCTIONS AND PROCESSES	RESPONSE	EFFECT
Motility	Attached/Sessile Tubicolous Crawler Crawler-Swimmer Swimmer Flyer	Foraging mode, ability to escape predation, migratory requirements, dispersal	+	
Body length	Length classes	Sensitivity (small) or resistance (large) to predation, thermal resistance, fecundity increase, metabolic oxygen consumption rate	+	+
Trophic mode	Deposit feeding Deposit-Suspension feeding Suspension feeding Carnivory Omnivory	Food acquisition, growth requirements, demographic control (predation), nutrient cycling	+	+
Lifespan	Age classes	Longevity increases reproductive successes over time	+	
Age at sexual maturity	Age classes	Early age at maturity increases demographic resilience in adverse environmental conditions	+	
Annual fecundity	Number of eggs/propagules classes	Dispersal, resource to higher trophic levels	+	+
Egg/Propagule size	Size classes	Juvenile survival and recruitment success	+	

Reproductive frequency	Seasonal Continuous	Continuous reproduction can support demographic resilience in adverse conditions	+	
Assexuality	None Assexual seasonal Assexual continuous	Most of time, auxiliary advantage to sexual reproduction (heterogamy) to ensure demographic resilience in adversity or temporary dispersals	+	
Early development	Direct development Larval pelagic stage duration classes	Juvenile survival, dispersal potential	+	
Egg Propagule protection	None Brooding/Bearing Capsule Gel	Juvenile survival and recruitment success	+	
Structural robustness	Fragile Intermediate Robust	Sensitivity to physical damage (e.g. storm, predatory aggression)	+	
Burrowing depth	Sediment depth classes	Foraging mode, protection against epibenthic and benthopelagic predators, biogeochemical impacts	+	+
Resistance form	None Body regeneration Poison	Survival against abiotic damages and biotic aggressions	+	
Habitat creation ability	None Below sediment 3D structures	Biogeochemical requirements, niche creation, refuge, nursery, below sediment oxygenation	+	+

	Above sediment 3D structures Both			
Sediment mixing	None Diffusion Advection Regeneration	Food acquisition, impact on biogeochemistry, organic matter re-distribution, habitat provision	+	+
Irrigation	None Water flushing	Food acquisition, survival against hypoxia, organic matter re-distribution, impacts on biogeochemistry	+	+

3.1.3 Identifying traits of functional importance

There are a large number of potential traits which may be derived to describe the life history, behavioural and morphological characteristics of marine benthic species (Table 3.2), and published studies have generally used a sub-set of those listed (Bremner *et al*., 2004; Tillin *et al*., 2006; Verissimo *et al*., 2012; Van der Linden *et al*., 2012). The final traits list usually encompassed within published studies regarding marine invertebrate assemblages is based on a perceived or assumed association with ecological functionality (Tillin *et al*., 2006; Dimitriadis *et al*., 2012) and/or loosely based on data availability (Paganelli *et al*., 2012). Ultimately, the selection of biological traits to be included for any analysis using biological traits analysis (BTA) is important. The traits included in any analyses has the potential to affect the way benthic assemblages are assessed, so the number and type of traits chosen for BTA should not be an arbitrary decision. Development of BTA, particularly where functional effects traits are implicitly or explicitly the foci, must include an assessment of which traits provide the most useful description of ecological functioning so that selection is optimised (Bremner *et al*., 2006). Van der Linden *et al*. (2012) indicated that the selection of traits and categories must be made a priori on the basis of evidence of their importance in ecosystem functioning, i.e., where a mechanistic link between the trait and function has been demonstrated.

Petchey and Gaston (2006) suggested that the correct number of traits is the number that is functionally important. This is, of course, intuitively correct but inherently assumes an understanding of which traits are functionally important (and their relative importance) and which ones are not. Within terrestrial systems, comprehension of the links between biological traits and ecological functioning is comparatively well developed; a result of focussed experimental and field observational studies over a number of decades. However, in the marine environment, although progress has been made regarding the influence of a small number of traits and benthic-pelagic coupling (with implications for nutrient and carbon fluxes, etc.) and the importance of body size trait for trophic transfer (Jennings *et al*., 1998; Blanchard et al., 2008), understanding is far behind that for terrestrial ecosystems. Chapin *et al*. (1997) stated that traits with powerful effects on ecosystem processes (via their ecological functions) are those that; (i) "modify the availability, capture and use of soil resources such as water and nutrients, (ii) affect the feeding relationships (trophic structure) within a community, and (iii) influence the frequency, severity and extent of disturbance. Traits, therefore, that affect resource use (including energy and nutrients) and feeding interactions are fundamentally important for ecosystem functioning while traits related to habitat modification (i.e. bioturbators and habitat modifiers) are also recognised for their functional importance by way of modifying ecosystem processes (Graf and Rosenberg, 1997; Pearson 2001). These three categories are both very comprehensive and wide-ranging making the number of traits important for functioning of bed assemblages potentially very large.

Traits can be selected based on the requirements and aims of the individual study, whether it is to describe assemblage functioning, identify the extent and magnitude of anthropogenic impacts, or a combination of both. In this way, we can choose to incorporate effects traits or response traits only, or explicitly (and knowingly) include a combination of both. In this respect, we may consider traits more associated with life history to reflect response traits while those reflecting behaviour and morphology to represent effects traits (Bremner *et al*., 2004; Tillin *et al*., 2006). Although this method of segregating response traits from effects traits appears a convenient mechanism for rationalising the number and identity of traits, it must be adopted with great caution until we understand more about relationships between traits and functioning, or more specifically, which traits fall into which trait group. Bolam *et al*. (2014) considered life history traits to be more associated with recovery from trawling (i.e., long term or chronic response) while a number of behavioural and morphological traits pre-disposed invertebrate taxa to the direct or acute effects of trawling (i.e. describing the likelihood of death or removal via trawling). Thus, species exhibit differing responses to anthropogenic disturbance because their responses to environmental change is determined by their morphological, behavioural and life history characteristics they possess, not only one group. That is, some morphological traits (commonly associated with effects traits) also predispose a species to being more vulnerable to the direct impacts of fishing (Tyler-Walters *et al*., 2012; Bolam *et al*., 2014). It follows, therefore, that there may be an important distinction in response traits; those that provide some longer term adaptation to persistent sets of environmental conditions in which case the response traits ensures the survival of the species, whereas those traits which favour the survivability of the individual e.g. they can resist the effects of fishing are much shorter term and act on the individual and not the species. Translated into relevance to minimising trawling impacts, we may arguably regard survival of the individual to be more important than that of the species, so functional response as a measure of individual resistance may be more pertinent from a functional perspective.

It is well documented that infaunal invertebrates exhibit significant influence over benthic sedimentary geochemical environments in soft sediments through bioturbation, i.e. the mixing of sediment and particulate materials carried out during foraging, feeding and burrow maintenance activities, and the enhancement of pore-water and solute advection during burrow ventilation (Rhoads, 1974; Volkenborn *et al*., 2010). These actions influence oxygen, pH and redox gradients (Pischedda *et al*., 2008; Queirós *et al*., 2011), sediment granulometry (Montserrat *et al*., 2009), pollutant release (Gilbert *et al*., 1994; Granberg *et al* 2008), macrofauna diversity (Volkenborn et al., 2007), bacterial activity and composition (Mermillod-Blondin and Rosenberg, 2006; Gilbertson et al., 2012) and metal (Teal *et al*., 2009), carbon (Kristensen, 2001), nutrient and nitrogen cycling (Kristensen, 2008; Bertics *et al*., 2010). Hence, assessments of faunal bioturbation can contribute to a better understanding of how these ecosystem processes and coupled functions are mediated by biological activity. However, there are presently a number of hurdles which encumber our understanding of direct links. Firstly, published studies (e.g. Solan *et al*., 2004) have generally applied a metric of bioturbation based on body mass and two traits (mobility and bioturbation mode); consequently there has been little appraisal of the potential influence of other traits. Secondly, similar bioturbation metric values may result from taxa displaying very different bioturbation mechanisms and, thus, different functional effects. Thirdly, observed correlations between a bioturbation metric and a measure of processes or functionality may not signify cause-and-effect; there have been no published studies where species have been placed into functional groups based on a measure of functioning (e.g., nutrient flux). Finally, while some biogeochemical studies have traditionally tended to focus on quantifying the relationships between redox and carbon content with processes (e.g., pollutant release, bacterial activity, oxygen gradients), other biogeochemists have centred on understanding the drivers of carbon remineralisation (by bacteria) and the links between bioturbation and redox/carbon degradation have often been reduced; studies explicitly addressing the relationship between biological traits and biogeochemical process have not yet been undertaken (Figure 3.1).

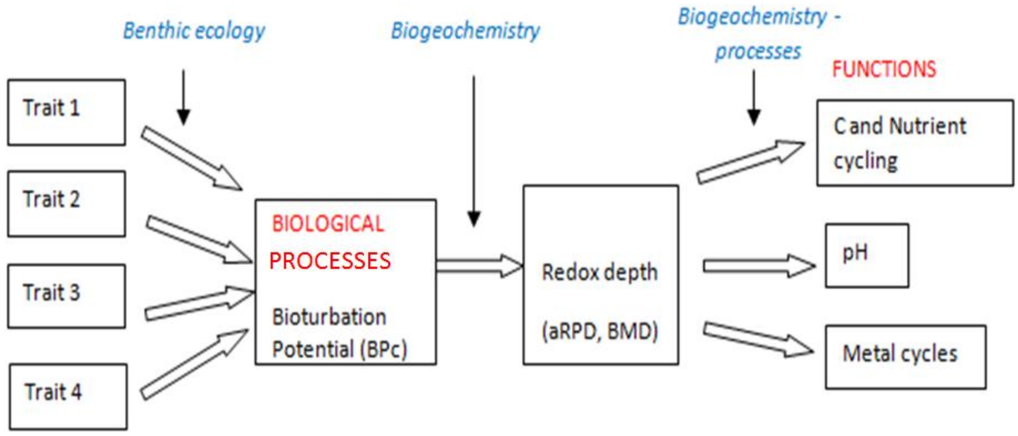


Figure 3.1. Relationship between biological (effects) traits, bioturbation potential metrics and sediment biogeochemical processes and benthic functioning. The blue text refers to the nature of the different scientific approaches applied to address the various steps.

3.2 Assessing functional implications of the proposed metrics

Six approaches have been proposed by WKBENTH to provide potential indicators of benthic status in response to bottom fishing. The aim here is to discuss each of these approaches with respect to their capacity to imply functional capacity of the benthic assemblages. For example, while GES as determined for a particular indicator implies that the ecological status of the benthos is representative of an unimpacted state, does it also imply that the benthos has a 'greater functionality' than one of an impacted state? We discuss whether their formulation allows such inferences to be made.

3.2.1 BENTHIS Longevity approach

The longevity approach assesses impact of trawling to the benthic assemblage as a whole by considering the longevity of benthic invertebrates in relation to trawling intensity (Rijnsdorp *et al*., 2016a). It makes the assumption that taxa with a longevity that exceeds the average interval between two successive trawling events will be impacted by bottom trawling. By first establishing the relationship between the cumulative biomass and longevity in different sea floor habitats, defined by either the EUNIS classification system or by continuous environmental variables, the indicator of the trawling impact is estimated given the observed trawling intensity by grid cell.

By considering the longevity of the organisms in a habitat, in addition to the biomass, the index captures potentially relevant aspects of benthic functioning. However, since the trait is used as a proxy for the recovery time of the benthic assemblage to trawling, and not to specifically link any particular function or ecological process, the index provides little additional understanding with regard to any change in function due to fishing. However, by using the longevity composition of a subset of taxa representing an ecological function, the method can be directly used to assess the impact of bottom trawling on ecosystem function (Rijnsdorp *et al*., 2016).

In addition, considering longevity as a proxy for recovery time is challenging, especially when considering EUNIS habitat levels, since the longevity of biogenic structures will be more important than the longevity of the individual organisms.

3.2.2 Population dynamics approach

The population dynamic approach (PDA) assesses recovery from trawling disturbance using metrics of benthic biomass, carrying capacity, recovery rate and trawling intensity (Hiddink *et al.*, in prep). The approach quantifies biomass recovery, following an impact due to trawling. The recovery is quantified as a proportion of the assumed full carrying capacity, % of K (biomass/carrying capacity) and a recovery rate r. Both r and K are assumed to be longevity-specific and the age-classes recovery curves are then integrated to scale up to full community recovery curves.

The PDA method estimates the recovery dynamic of a relative biomass index. While absolute biomass values could be more directly related to several facets of function (e.g. secondary production, bioturbation potential), relative biomass, in that case, only reflects a state relative to K (e.g. 50% of K). However, using longevity-specific K and r values, to then infer an overall community recovery curve, ensures that the community at full recovery, following a disturbance (100% of K), reflects an asymptotic, stable state of the system's maturity. As such, K may be inferred as a maximum maturity state associated to a fully functioning system. The level of maturity does not, however, refer to any specific function and needs to be approached from a holistic angle. Some description of functionality may only be inferred on both ends of the recovery curve (no functioning at 0% of K and full function at 100% of K). Any tentative description from intermediate state of recovery needs to be done with caution as the relationship between B/K and functions is not known and likely to differ depending on the function of interest.

To assess the impact of bottom trawling on ecosystem function, longevity-specific K and r values can be derived for a selection of taxa representing the ecosystem function of interest (Rijnsdorp *et al.*, 2016) and used to assess the impact of bottom trawling on ecosystem function.

3.2.3 BH2

The BH2 indicator has been developed based on an approach that assesses sensitivity to several pressures (fisheries, organic enrichment, sedimentation etc.) The index is based on a combination of indices evaluated through an index optimization tool BENMMI. The tool contains a suite of commonly used benthic indices (species richness per sample, Margalef diversity (D), SNA, Shannon index, PIE index (Probability of Interspecies Encounter), AMBI and ITI), which can be combined by the tool using Multi-Linear Regression and tested for their performance (sensitivity and precision) in regard to a pressure. The pressure data are introduced into the BENMMI tool combined with the benthos data at the sample level.

Of the indices included in this approach, only AMBI and ITI (the Infaunal Trophic Index) could provide any additional reference to functionality compared to the traditional indices focused on species richness or density (abundance or biomass). The AMBI index (Borja *et al.* 2000) is based on ecological groups of species along a sensitivity-tolerance gradient, while the ITI index (Maurer *et al.* 1999, Word 1979) is a numerical representation of the distribution of dominant feeding groups of benthic fauna. In the index, species are assigned to four feeding groups encompassing feeding on suspended material to deposited material, translated into a range from 0 (only subsurface deposit feeding) to 100% (only suspension feeding). It is noteworthy that for example predation, scavenging, parasitism and herbivory, additional feeding types of benthic invertebrates are not included in the index and thus only a subset of trophic interactions is possible.

Margalef D has proven to be the index that performs best in terms of sensitivity and precision for the pressure fisheries, and thus the one index put forward to be used for the regional scale. However, of the species sensitivity and biological trait indicators, the ITI index shows the best sensitivity and precision for fisheries (van Loon *et al*., 2013), but has not been evaluated in this advice.

The Margalef D index put forward provides insight into the impact on diversity from fishing, however it does not reflect functioning per se or link to any specific function, other than that a high diverse area has a higher probability to include a broader functional composition and functional resilience and resistance. However, the relationship between diversity and ecosystem function has been shown to be idiosyncratic (Emmerson *et al*., 2001; Bolam *et al*., 2002), and thus inferences for function based on this indicator are limited. The inclusion of the ITI index may theoretically provide a greater functional relevance, and, based on the feeding traits included, would most closely refer to the process of organic material cycling. However, whether this function is the most relevant for fishing impact can be discussed.

3.2.4 BH3

The BH3 index combines a pressure map (abrasion) with a sensitivity map to derive an assessment of fisheries impact (disturbance map). The sensitivity layer indicates species or (when information on species level does not exist) habitats, defined to be sensitive to physical damage (fishing). In assigning sensitivity, ecological groups are defined, which essentially also encompass and delineate different biological traits (Tillin and Tyler-Walters, 2014). For example, a number of groups such as "group 1a Sea pens (erect, large, longer-lived epifaunal species with some flexibility), "group 1c Small epifaunal species with robust, hard or protected bodies, soft-bodied or flexible epifaunal species" or "group 9 Burrowing hard bodied species", are defined.

As the index implicitly incorporates the underlying functional composition of assemblages by a multitude of what may arguably be termed response traits, it does not allow for any assessment of a particular ecosystem function. The traits used to delineate the ecological groups essentially indicate the species ability to persist in a given condition and these traits are not necessarily the same that support the performance of a particular process or function (Solan *et al*., 2004). The link to function is thus indirect and can only highlight the state of the benthic community using underlying hypotheses that the most affected species are those characterizing a "mature" state.

3.3 Discussion

One of the fundamental requirements of a suitable indicator is that it tracks changes in a given pressure, e.g., bottom fishing for WKBENTH. The six approaches presented under WKBENTH each fulfil this basic indicator premise (see Section 8.1). Complex numerical improvements and subsequent empirical testing have been undertaken during the derivation of each of these approaches. Fundamentally, these approaches are founded on aspects of assemblages which respond to imposed bottom fishing and, therefore, whether implicitly or explicitly, rely on response traits. A species' response traits depict whether that species responds to bottom fishing, and, when scaled up to all the species within an assemblage, changes due to these response traits result in altered assemblage structure (Bolam *et al*., 2016).

It is becoming increasingly recognised (see section 3.1) that the role benthic assemblages play in altering or contributing to ecosystem function is governed by the effects traits combined across its component species. It is the effect of these traits which have direct and/or indirect implications for ecological functions which underpin important ecosystem services. While the approaches tested under WKBENTH fulfil their roles as indicator of ecological status they are presently limited in their capacity to distil information regarding, or quantify differences in, ecological functioning. This situation may, however, be improved by subsequent incorporation of relevant effects traits that pertain for specific functions. Currently, the relationship between effects traits and function is at a very early stage and some progress is presently being made to address this knowledge gap (Beauchard *et al.*, 2017). While the biomass-dependent basis of some of the proposed approaches (e.g., PDA, Long-SB-1, Long-LL-1) may result in their indicator values correlating with BPc, an estimate of community bioturbation potential, a mechanistic link between BPc and bioturbation rate has not yet been demonstrated at large spatial scales.

Based on their effect traits, taxa can be selected representing specific ecosystem functions and their longevity composition can be estimated. Using the ecosystem function specific longevity distribution (Rijnsdorp *et al.*, 2016), the population dynamic and longevity approaches can be applied to obtain an estimate of the potential impact of bottom trawling on ecosystem function. Recently, Beauchard *et al.* (2017) reviewed the use of biological traits in marine community ecology. Among the many theoretical and technical aspects encountered in BTA, they argued that the high analytical expertise required in BTA curbs the development of ecological indicators derived from biological traits. The nature and the number of traits used were argued to be critical aspects for two reasons. Firstly, the functional relevance of traits strongly depends on the research context. Response traits enable to explain why species are habitat specific (e.g. species can be naturally adapted or not to stress or disturbance). Effect traits are more relevant when studying ecological engineering and the consequent services. There is still no evidence of correlation between response and effect traits, the ultimate goal of an organism being to express its fitness through growth, survival and reproduction (Darwin, 1859), the performances of its effect traits being simple consequences of fitness expression (e.g. oxygenating actively the sediment ensures survival to an organism, this function being not designed to benefit to other organisms). Hence, combining both response and effect traits for a common objective remains theoretically difficult, methodologically uncertain in terms of causality, and potentially statistically noisy due to the large number of traits.

Secondly, absence of biological significance has been evidenced for many traits in marine studies. For instance, the use of morphology can be questionable in several studies on benthic communities including several phyla when the trait modalities are so closely linked to taxonomy that they become a proxy for the taxonomy of the underlying community. The ambiguity here is that BTA aims to mask taxonomy by emphasizing what is functionally common among distant taxa (growth, survival and reproduction). In the specific case of morphology, this does not mean that morphology does not deserve any interest in BTA, the problem being how to express it in order to make it relevant in a research context. External features of an organism like “soft-protected (tube/tunic)”, “exoskeleton”, “shell” or scaling or shield structures may be much less relevant in expressing the survival of an organism to beam trawling effect than simply expressed through “Fragile”, “Intermediate” and “Robust” characterizing body fragility which is also a morphological aspect, but less taxonomically discriminant and encapsulating more sharply the process of damage and instantaneous mortality. This morphological illustration, although relatively specific, is valuable for any hypothetical trait which can be flexibly designed, whatever response or effect. The traits that should be objectively considered when studying response are well documented as their expression is driven through fitness requirements (Charnov, 1993). By contrast, nothing precisely defined is supposed to drive the sea-floor functioning so that traits that should be considered when studying effect remain less clearly defined in quality and number. At least, Table 3.1 displays explicitly the functions and processes in which those traits should be involved. Table 3.2 suggests some of them, but unlike sediment mixing, the main constraint nowadays lies in the large absence of documentation on species ability to irrigate the sediment, especially in benthic habitats sensitive to trawling, and especially regarding the holistic nature of this highly important function resulting from many species interactions and which makes sense only at the community level.

There is an array of important functions that sedimentary habitats perform to meet the needs of ecosystem services which are commonly the fundamental foci of marine policy (Table 3.1). It is important to appreciate that different benthic habitats, and the functional role of the benthic assemblages, vary with respect to their capacity to deliver each of these ecosystem services. For example, the role of macrofaunal assemblages affecting nutrient regulation via benthic-pelagic coupling has been shown to depend largely on the physical setting of the environment (Mermillod-Blondin *et al.*, 2006). In deep, muddy environments with low velocity bottom flows, benthic-pelagic coupling is almost exclusively dependent on the bioturbative activities of the resident invertebrate assemblages. The sediment mixing and bio-irrigation functions these organisms perform as part of their feeding, respiratory or locomotive behaviours greatly affect the oxidative conditions of the surficial sediments. These conditions vastly affect the microbial community activities and biogeochemical processes in turn driving nutrient fluxes and the capacity of such sediments to act as nutrient sources or sinks. However, these processes are overwhelmingly driven by physical processes in less-muddy, more dynamic habitats where oxygenation of surficial sediments results from higher bed shear stresses. Similarly, secondary production, and the capacity of benthic assemblages to provide energy to higher trophic levels, is governed by not only the amount, timing and quality of food reaching the bed, the amount of carbon recycling within the sediments, but also the turnover rates of the benthic assemblages. These processes differ naturally between sedimentary habitats under dissimilar physical settings. As the functional roles of the benthic assemblages vary between habitats it follows that the effects traits needed to carry out these functions will vary (Figure 3.2). Thus, any indicator formulated to distil information regarding the functional integrity of the seabed must, therefore, be habitat-specific, adapting the indicator in view of the importance of different traits to fulfil different functions in different habitats.

3.4 Conclusion

A clear outcome of this review is that the important functions and services that benthic communities provide to the whole marine ecosystem are complex and can be difficult to quantify, especially regarding biogeochemical fluxes (i.e. rates over time). In general, the reviewed indicators have a limited potential to inform us regarding sea-floor functions as a response to bottom fishing. The relevance of using biological traits, in particular the effect traits, to explore these sea-floor functioning is feasible. Future research needs to focus on the relationship between effects traits and specific sea-floor functions.

For the time being, response traits comprise the fundamental basis of indicators since they clearly express why a species is found in a habitat; as illustrated by the life history approach, indication of trawling impact is more easy to understand and to scientifically support based on direct effects (damage and/or instantaneous mortality) whereas quantifying sea-floor functions through effect traits is more indirect and may induce more uncertainty in terms of measurements and reference level assessment (i.e. functions depend on the presence of organisms specifically adapted to habitats)..

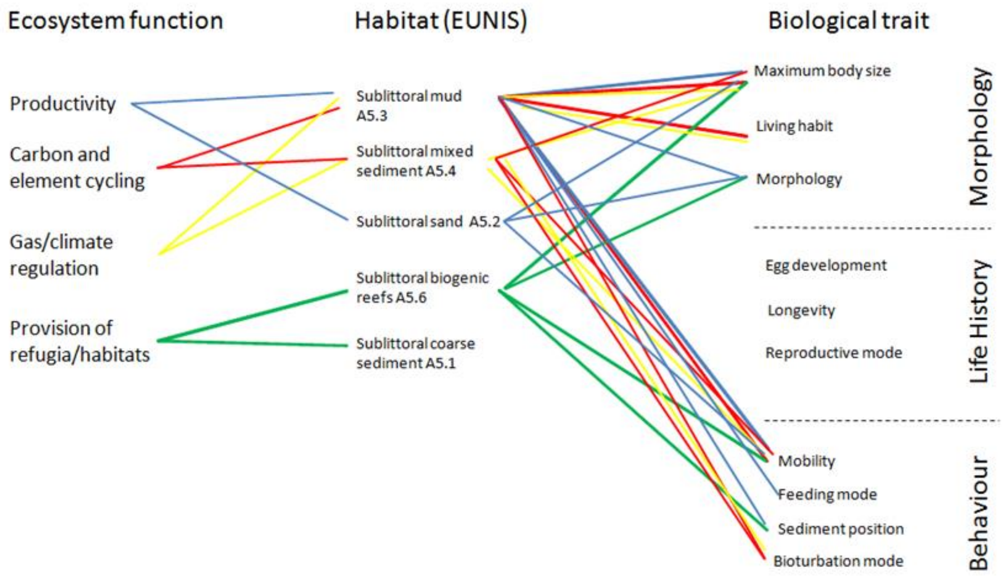


Figure 3.2. Schematic illustration of the relationships between traits, habitats and important ecological functions. This is not designed to be complete and the links highlighted may not be supported by observations; this figure serves to indicate that for any habitat there is likely to be a number of important ecological functions and/or processes, these may vary between habitats, and the traits required to describe the role benthic assemblages to undertake these are likely to be habitat and function specific. The traits are likely to reflect effects traits and empirical data are urgently needed to provide greater confidence of the nature of these traits. Some habitats (e.g. sublittoral coarse sediments), although they may provide important ecological functions, these are not mediated by benthic invertebrate traits. For others, the importance of traits may only become relevant under certain physical characteristics of the sediments. For example, bioturbation (or the traits which underlie bioturbation) is important for nutrient cycling and carbon flux in sublittoral mixed or muddy sediments but these processes are mediated by physical advective currents in coarser substrata

4 Indicators reference values and GES (good environmental status) threshold

The TOR a) ii) of WKBENTH is to map and provide indicator(s) of the area **impacted** by bottom fishing (in the same 6-year periods), and the proportion (%) of each MSFD broad habitat type **impacted** per subdivision.

Under criterion D6C3 of the revised Commission Decision Document (to be published in 2017), an **adverse effect** is described in terms of a habitat's change in "structure and function (species composition and their relative abundance, absence of particularly sensitive or fragile species or species providing a key function, size structure of species)". This document confirms that Member States are required to cooperate at regional or subregional level to establish **threshold values for adverse effects**. Threshold values for adverse effects of demersal fishing should be defined in relation to a reference state or conditions of the habitat in question.

Threshold values for adverse effects can be defined in several ways. One way of defining an impact is establishing where the effects of fishing disturbance go beyond the natural variation of a habitat in the absence of pressure. Any demersal gear use can cause an impact, but this impact may be minor (depending on the gear and the habitat), and may not exceed GES threshold values for "adverse effects". Another way of defining impact is in relation to recovery i.e. whether a habitat can recover within a reasonable timescale.

The definition of threshold values will be related on the management objectives set. Various thresholds have been set in relation to impact and recovery by scientists, policy makers and NGOs in the context of natural resource management, which may provide guidance for the setting of GES thresholds for the benthic ecosystem. In fisheries management, fish stock biomass limits of 10 to 20% of B_0 (unfished biomass), below which population collapse and recruitment limitation may occur, are used, and B_{MSY} at 50% of B_0 is often targeted. Thresholds can also be set from the perspective of the ecosystem services, such as the food provisioning for fisheries resources which is maximized at B_{MSY} which tends to be around 50% of B_0. Another example is the threshold set by the Marine Stewardship Council for a serious or irreversible harm as "reductions in habitat structure and function such that the habitat would be unable to recover at least 80% of its structure and function within 5-20 years if fishing on the habitat were to cease entirely". In a similar way, GES thresholds could be defined as i) a tolerable level of degradation of a habitat when exposed to a chronic pressure and ii) an expected reasonable recovery time once a pressure has been alleviated.

Any GES thresholds (degree of degradation and recovery time) relating to habitat quality or condition should be applied uniformly to every habitat. This may result in very different intensities of pressure being acceptable in different areas, depending on the sensitivity of the habitat type in question.

4.1 WKBENTH definitions of reference and threshold values

Reference state

The reference conditions/state is defined as the unimpacted state of a habitat in the absence of anthropogenic pressures under existing climatic conditions (i.e. as opposed to the pristine state/areas of habitats). Reference conditions include a quality element (the condition of a habitat) and a quantity element (the area of the habitat) under an unimpacted scenario.

GES threshold for adverse effects

We applied a range of arbitrary threshold levels for the reduction of the indicator value relative to the unimpacted state for two reasons. First, multiple objectives result in multiple GES thresholds. Second, we lack a solid ecological basis for setting GES threshold levels. If non-linear relationships exist between state (or impact) and pressure, the inflection point in these relationships (i.e. when a significant change in the relationship occurs) could be used to help define thresholds of "adverse effects". However, at the current time, such inflection points have not been identified for relationships between biomass or species richness and demersal fishing pressure.

General considerations

As reference values and GES threshold levels are an integral part of the assessment methodology, they cannot be directly compared across assessment methods which use different indicators.

It is noted that the exposure to other (fishing and non-fishing) pressures can affect both the impact of fishing and the rate of recovery of a habitat to a demersal fishing event.

It would be appropriate to set GES threshold levels for ecosystem functioning (EF, rather than just structure), but the ability to model ecological functioning in response to pressures is currently lacking. Metrics to define EF and indicate when EF has been impeded by demersal fishing are needed: structural aspects such as biodiversity and biomass are currently assumed to be proxies for EF. Which aspects of ecosystem functioning (EF) are most relevant to measure (e.g. changes in bioturbation/nutrient cycling) also requires further research.

5 Fisheries Benthic Pressure – fishing footprint maps and indicators

5.1 Introduction

Spatial fisheries data are essential to understand interactions between fisheries and the ecosystem and thus have become a key issue in European maritime policies. In order to describe the spatial and temporal distribution of fishing activities – and simultaneously considering their characteristic ecological footprint – the Working Group on Spatial Fisheries Data (WGSFD) uses data from the Vessel monitoring system (VMS) and fisheries logbook data provided by participating countries. In the past a high amount of effort was spent to data compilation, quality control and harmonization. As part of the ongoing OSPAR requests in 2014-2016 the group further investigated fishing pressure in relation to benthic communities, i.e. from mobile contacting gears such as beam trawls, demersal otter trawls and dredges. To quantify the direct impact of fishing on the seabed the penetration depth as well as the swept-area, i.e. the area covered by the specific gear needs to be estimated. WGSFD revised and improved the method proposed under BH3 to assess swept-area ratio within c-squares for the calculation of surface and subsurface pressure layers. It defined best practices and workflows in R for data analysis and data call submission, and developed indices, e.g. representing fishing intensity on different spatial scales, which is now part of the BH3 technical specifications for the calculations of fishing pressures. In 2016 WGSFD compiled and analysed the data to update fishing abrasion pressure maps used now as basis for WKBENTH impact assessments.

5.2 Methods to estimate SAR

To estimate benthic impacts it is necessary to provide a spatially resolved index of fishing intensity for mobile bottom contacting gears. WGSFD defined fishing intensity as the area swept per unit area, i.e. the area of the seabed in contact with the fishing gear in relation to a surface area of the grid cell. For this VMS and fisheries logbook data from the Northeast Atlantic and the Baltic Sea were collected from 2009-2015 following a data call from 15th January 2016. In its raw format, VMS data are geographically distinct points, so-called "pings", providing information about the vessel, its position, instantaneous speed and heading. VMS transmits at regular intervals of approximately 2 hours, but with higher polling rates for some countries. VMS data points can be linked to logbook data in order to get additional information about the ship, the applied gear and eventually also the catch. Following some analytical steps to identify e.g. misreported pings, the vessel state (steaming, fishing or floating) has to be identified using the actual speed information. Only data, which were assumed to represent fishing activity, were then assigned to a 0.05 x 0.05 degree grid, about 15 km² at 60°N latitude, using the approach of C-square reference (Rees, 2003). Finally, national data were reported in a gridded and anonymized form summing the number of pings within each grid cell based on the time interval between successive pings, and including information about vessel flag country, gear code (equivalent to DCF level 4), fishing activity category (DCF level 6), average fishing speed, fishing hour, average vessel length, average kW, total landings weight and total value of all species caught. Therefore, estimates on total fishing time within each grid cell and métier are available for the years 2009-2015. In order to calculate swept-area values certain assumptions about the spread of the gear, the extent of bottom contact and the fishing speed of the vessel needed to be made and thus a number of working steps were necessary (Figure 5.2.1, for further details, see ICES WGSFD Report (ICES 2015)). First a full quality assessment of all submitted data were performed (Step 1). Submitted VMS datasets usually contained information on the gear based on standard DCF métiers (from EU logbooks, usually at the resolution of métier level 6) and the gear-specific fishing speed, but not on gear size and geometry. Therefore, vessel size-gear size relationships developed by the EU FP7 project BENTHIS project (Eigaard *et al*., 2016a) were used to approximate the bottom contact (e.g. gear width). To do this, it was necessary to aggregate métier level 6 to lower and more meaningful gear groups (so-called "Benthis métiers"), for which assumptions regarding the extend of bottom contact were robust (Step 2). Following this, fishing effort (hours) was calculated and aggregated per c-square for each métier and year (Step 3). Fishing speeds were based on average speed values for each métier and grid cell submitted as part of the data call, or, where missing, a generalized estimate of speed was derived (Step 4). Similarly, vessel length or power were submitted through the data call, but where missing average vessel length/power values were assumed from the BENTHIS survey (Eigaard *et al*., 2016a) (Step 5). Parameters necessary to fulfil steps 2, 4, and 5 are listed in table 5.2.1. The resulting bottom contact values (m) were finally used to calculate swept-areas (SA) per gear group, grid cell and year (Step 6).

For towed gears (Otter trawls, beam trawls, dredges): $\boldsymbol{SA = \sum evw}$,

For Danish seines (SDN_DMF): $\boldsymbol{SA = \sum(pi * (w/2pi)\hat{}2 * (e/2.591234))}$,

For Scottish seines (SSC_DMF): $\boldsymbol{SA = \sum(pi * (w/2pi)\hat{}2 * (e/1.9125) * 1.5)}$,

where *SA* is the swept-area, *e* is the time fished (h), *w* is the total width (m) of the fishing gear (gear group) causing abrasion, and *v* is the average vessel speed (m/h).

The swept-area information was additionally aggregated across métiers for each gear class (otter trawl, beam trawl, dredge, demersal seine) with two layers, one for surface abrasion and one for subsurface abrasion (as proportion of the total area swept, see table 5.2.1). To account for varying cell sizes of the GCS WGS84 grid, swept-area values were additionally divided by the grid cell area:

$\boldsymbol{SAR = SA/CA}$

where *SAR* is the swept-area ratio (number of times the cell was theoretically swept), *SA* is the swept-area, and *CA* is the cell area.

Finally effort and swept-area maps were generated at appropriate scales (Step 7 and 8).

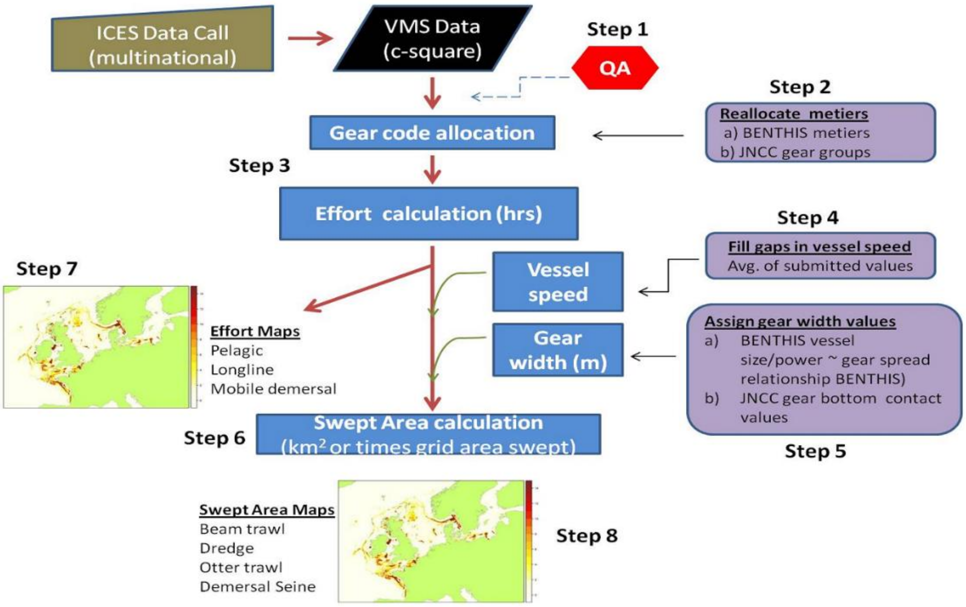


Figure 5.2.1. Workflow for production of fishing effort and swept-area maps from aggregated VMS data (0.05° x 0.05° C-square resolution) (from ICES 2015). Please note that for pressure estimates used in this Workshop all métiers and vessel size/ gear spread relationships were derived from BENTHIS and not from JNCC sources.

Table 5.2.1. Parameter estimates of the relationship between vessel size (as length (m) or power (kW)) and gear width, the average width of fishing gear causing abrasion (surface and subsurface), the corresponding proportion of subsurface abrasion, and the average fishing speed for each BENTHIS Métier (derived from Eigaard et al. (2016a) and ICES (2015)).

Gear class	BENTHIS métier	Model	Average gear width (m)	Subsurface proportion (%)	Fishing speed (knots)
Otter trawl	OT_CRU	$5.1039*(kW^{0.4690})$	78.92	32.1	2.5
	OT_DMF	$9.6054*(kW^{0.4337})$	105.47	7.8	3.1
	OT_MIX	$10.6608*(kW^{0.2921})$	61.37	14.7	2.8
	OT_MIX_CRU	$37.5272*(kW^{0.1490})$	105.12	29.2	3.0
	OT_MIX_DMF_BEN	3.2141*LOA+77.9812	156.31	8.6	2.9
	OT_MIX_DMF_PEL	$6.6371*(LOA^{0.7706})$	76.21	22	3.4
	OT_MIX_CRU_DMF	3.9273*LOA+35.8254	113.96	22.9	2.6
	OT_SPF	0.9652*LOA+68.3890	101.58	2.8	2.9
Beam trawl	TBB_CRU	$1.4812*(kW^{0.4578})$	17.15	52.2	3
	TBB_DMF	$0.6601*(kW^{0.5078})$	20.28	100	5.2
	TBB_MOL	$0.9530*(LOA^{0.7094})$	4.93	100	2.4
Dredge	DRB_MOL	$0.3142*(LOA^{1.2454})$	16.97	100	2.5
Demersal seines	SDN_DMF	$1948.8347*(kW^{0.2363})$	6536.64	5	NA
	SSC_DMF	$4461.2700*(LOA^{0.1176})$	6454.21	14	NA

5.3 Results – maps and indicators per ecoregion and habitat

5.3.1 Maps of fishing intensity

Maps describing fishing pressure on benthic habitats are based on swept-area ratio estimates (SAR) calculated as annual grid cell averages covering the years 2009–2015. Surface and subsurface abrasion are considered separately and visualised for the three ICES ecoregions, i.e. Baltic Sea, North Sea and Celtic Sea. Due to a legislation change, vessels of 12–15m total length are only included in the estimates since 2012. We therefore show maps averaging SARs from the years 2012–2015. Maps of yearly estimates can be found in Annex 7.

Celtic Sea

The fishery with bottom-contacting gears in the Celtic Sea concentrates along the shelf break as well as, in the south, on the shelf, i.e. in water depth of less than 200m (Fig. 5.3.1, 5.3.2). Otter trawls are the prevailing gear type but locally dredging and seining can be important (see WKFBI report, ICES, 2016). Spatial patterns of surface and subsurface abrasion are similar but with subsurface abrasion being at least an order of magnitude lower than surface abrasion. Deep-sea areas beyond the shelf are hardly fished.

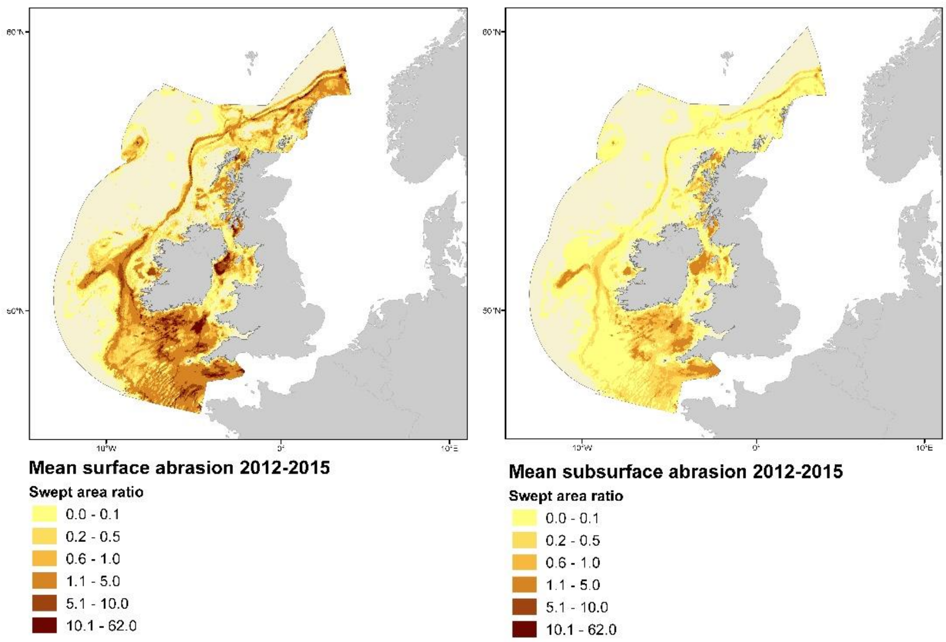


Figure 5.3.1. Average swept area ratios (SAR) from the years 2012–2015 separated into surface (left) and subsurface abrasion (right) in the Celtic Sea.

North Sea

The North Sea, including the Skagerrak and Kattegat area, is Europe's main fishing ground with highest efforts spend in the shallow southern part, i.e. at water depths less than 50m (Annex 5). Beam trawling on flatfish as well as on shrimps, the latter concentrating in the Wadden Sea, plays an important role. Due to the different groundgear subsurface abrasion rates are relatively high in areas where the flatfish fishery operates. Along the Norwegian Trench and in the Skagerrak area otter board trawling prevails, while in the north-west off the coast of Scotland, fishing effort and therefore also surface and subsurface abrasion is very low (i.e. below 0.1 SAR).

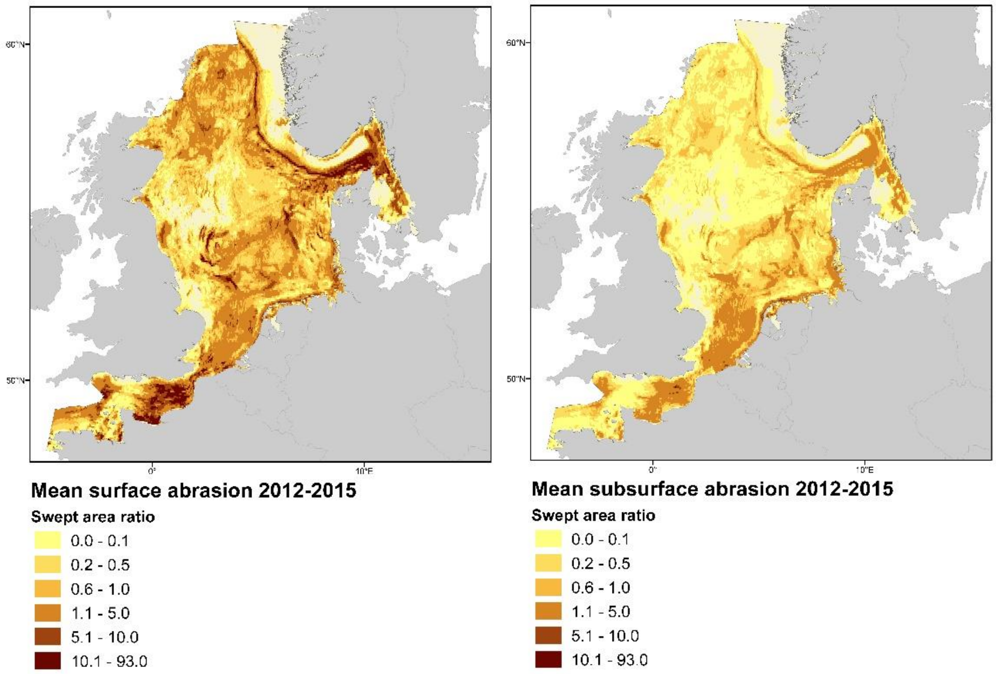


Figure 5.3.2. Average swept area ratios (SAR) from the years 2012–2015 separated into surface (left) and subsurface abrasion (right) in the North Sea.

Baltic Sea

The fleet structure in the Baltic Sea is different from the North Sea and Celtic Sea with many small boats operating close to the shore. Not all of them are included in VMS, but many of the small boats use rather static than bottom-contacting gears. According to the VMS data, surface and subsurface abrasion is highest in the southern part of the Baltic and concentrates especially in the Arkona and Bornholm Sea (Fig. 5.3.3). Otter trawling and to a smaller extend seines are the main bottom-contacting fishing gears, mainly targeting cod.

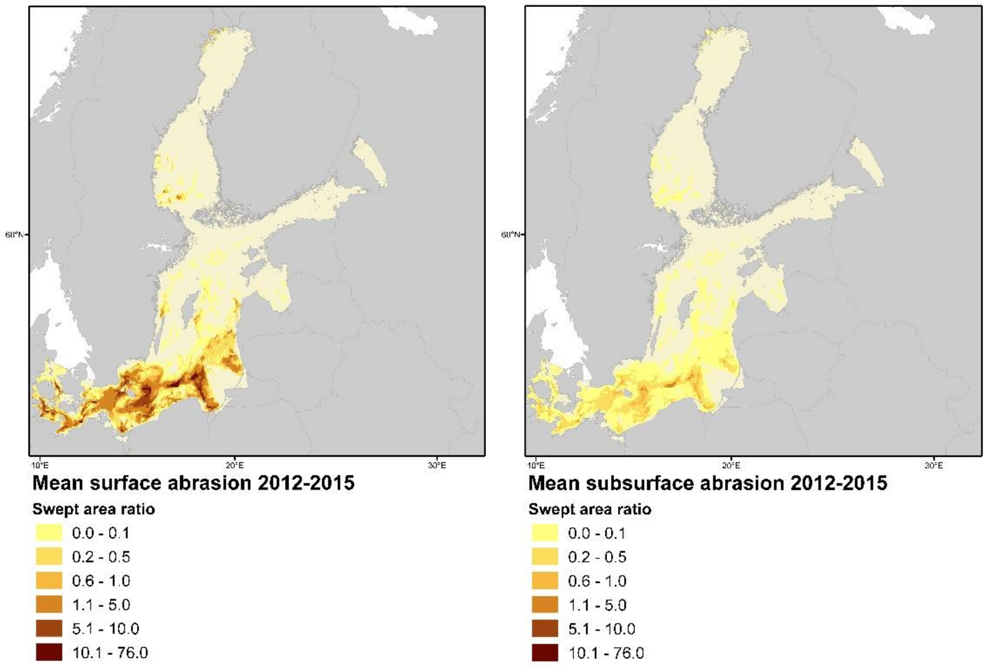


Figure 5.3.3. Average swept area ratios (SAR) from the years 2012–2015 separated into surface (left) and subsurface abrasion (right) in the Baltic Sea.

5.3.2 Fishing intensity indicators (fisheries footprint)

The calculation of fishing footprint indicators is based on Eigaard *et al*. (2016b). They are calculated by ICES Ecoregions (Celtic Sea, Greater North Sea, Baltic Sea) and by depth interval (0–200 m, 200–1000 m, >1000 m) for the years 2009–2015.

The percent c-squares affected by mobile bottom contacting gears (MBCG) are calculated as the total number of squares within an ICES Ecoregion and depth interval compared to the number where the fishing effort from MBCG are larger than 0.

To calculate the percent c-squares affected by the 90% highest fishing effort, the fishing effort is ordered by c-square with decreasing fishing effort, and the number of c-squares with the 90% highest fishing effort is compared to the total number of c-squares.

For calculation of the % footprint area on the seabed, the surface swept area is used. If the swept area in a c-square is larger than the area of the c-square, the swept area is set to the area of the c-square. The total swept area in an ICES Ecoregion and depth interval is compared to the area of the ICES Ecoregion and depth interval to calculate the % footprint on the c-square.

The same calculations are made by ICES Ecoregion and EUNIS habitat using the average fishing effort and surface swept area for the years 2009–2015.

Celtic Sea

In the Celtic Sea fishing with mobile bottom contacting gears mainly takes place on the shelf or at the shelf break. Consequently, more than 60% of the shelf area and more than 50 of the shelf break are affected (Table 5.3.1) with little variation between years.

The overall footprint amounts to ~28% on the shelf and ~23% on the shelf break. Compared to that, the footprint area in water depths >1000m amounts to only ~1% with a clear decreasing trend over time.

The habitats, which suffer from the biggest footprint (in %) by mobile bottom contacting gears are A5.3 (Sublittoral mud) and A4.3 (Atlantic and Mediterranean low energy circa littoral rock) (Table 5.3.2). However, these are not the dominating habitats as sublittoral coarse and sand habitats (A5.1-5.2) cover vast areas, while the footprint is relatively high (39.1-54.3%). Further, deep sea habitats that are already found at the slope and also fished by mobile bottom contacting gears have a footprint between 11.7-21.8%.

Table 5.3.1. Fishing intensity indicators for mobile bottom contacting gears (MBCG) in the Celtic Sea as percentage of the area affected in relation to shallow (<200m) and deep water layers (>200m).

	0–200 m			200–1000 m			>1000 m		
	% c-squares affected by MBCG	% c-squares affected by the 90% highest fishing effort	% footprint area on seabed	% c-squares affected by MBCG	% c-squares affected by the 90% highest fishing effort	% footprint area on seabed	% c-squares affected by MBCG	% c-squares affected by the 90% highest fishing effort	% footprint area on seabed
2009	63.4	28.9	47.4	59.2	26.2	37.1	7.1	2.7	2.3
2010	64.4	29.5	48.3	58.0	24.8	36.0	5.9	2.1	1.8
2011	59.4	27.0	44.0	50.3	21.2	31.4	4.5	1.8	1.7
2012	62.7	28.6	48.4	50.0	21.9	33.3	5.0	2.1	1.5
2013	62.5	28.8	48.2	49.7	22.7	34.9	4.4	1.5	1.2
2014	64.6	28.1	47.7	50.9	22.8	35.2	2.4	0.9	0.8
2015	62.8	27.7	46.5	52.6	23.8	36.6	2.1	0.8	0.6

Table 5.3.2. Fishing intensity indicators for mobile bottom contacting gears (MBCG) in the Celtic Sea as percentage of the area affected in relation to EUNIS habitats level 3.

Ecoregion	EUNIS code	EUNIS name	Habitat number of c-squares	Habitat total area (km2)	% c-squares affected by MBCG	% c-squares affected by the 90% highest fishing effort	% footprint area on seabed
Celtic Sea	A3.1	Atlantic and Mediterranean high energy infralittoral rock	503	6,378	11.5	1.8	2.6
	A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	230	2,991	37.8	13.0	12.5
	A3.3	Atlantic and Mediterranean low energy infralittoral rock	90	858	20.0	8.9	8.0
	A4.1	Atlantic and Mediterranean high energy circalittoral rock	169	2,745	30.8	9.5	6.3
	A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	1,371	24,014	66.1	24.6	40.7
	A4.3	Atlantic and Mediterranean low energy circalittoral rock	872	15,546	80.0	43.9	66.7
	A5.1	Sublittoral coarse sediment	6,594	114,620	70.6	27.2	39.1
	A5.2	Sublittoral sand	6,540	112,128	79.0	37.8	54.3
	A5.3	Sublittoral mud	1,836	31,416	85.5	46.7	77.8
	A5.4	Sublittoral mixed sediments	2,018	32,915	65.5	29.0	43.8
	A6.1	Deep-sea rock and artificial hard substrata	155	2,502	27.7	14.8	20.4
	A6.2	Deep-sea mixed substrata	3,734	58,317	40.6	18.2	21.8
	A6.4	Deep-sea muddy sand	8,034	140,058	30.1	11.8	15.7
	A6.5	Deep-sea mud	14,387	248,588	20.2	7.3	11.7
	NA	Data not available	7,403	124,752	57.6	26.5	46.7

North Sea

In the North Sea most of the fishery operates in shallow water areas. Thus, around 40% of all areas with water depths from 0-200m are affected by mobile bottom contacting gears, with little variation between years (Table 5.3.3). Deeper water layers (200-1000m) are found in the northern North Sea along the Norwegian Trench. Here, approximately 25% of the area is affected.

In the North Sea sublittoral habitats dominate and also suffer from the highest fishing pressure (SAR) with more than 45% of the total area affected by mobile bottom contacting gears (Table 5.3.4). Circalittoral rock habitats, although less common, also get a significant amount of pressure, and here A4.2 (Atlantic and Mediterranean moderate energy circalittoral rock) is the habitat with the highest footprint estimate (~45%).

Table 5.3.3. Fishing intensity indicators for mobile bottom contacting gears (MBCG) in the North Sea as percentage of the area affected in relation to shallow (<200m) and deep water layers (>200m).

	0-200 m			**200-1000 m**		
	% c-squares affected by MBCG	**% c-squares affected by the 90% highest fishing effort**	**% footprint area on seabed**	**% c-squares affected by MBCG**	**% c-squares affected by the 90% highest fishing effort**	**% footprint area on seabed**
2009	73.0	31.6	55.1	36.6	9.9	20.4
2010	72.2	30.0	54.1	35.4	7.9	16.6
2011	68.3	26.6	47.8	42.8	17.3	29.8
2012	72.1	28.0	52.4	40.7	12.7	23.9
2013	72.7	28.4	52.6	39.5	15.6	26.9
2014	71.8	27.1	50.8	37.5	13.7	24.7
2015	73.6	29.1	53.0	38.0	15.6	24.9

Table 5.3.4. Fishing intensity indicators for mobile bottom contacting gears (MBCG) in the North Sea as percentage of the area affected in relation to EUNIS habitats level 3.

Ecoregion	EUNIS code	EUNIS name	Habitat number of c-squares	Habitat total area (km2)	% c-squares affected by MBCG	% c-squares affected by the 90% highest fishing effort	% footprint area on seabed
North Sea	A3.1	Atlantic and Mediterranean high energy infralittoral rock	226	3,119	45.6	18.1	21.4
	A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	150	1,978	49.3	18.7	25.6
	A3.3	Atlantic and Mediterranean low energy infralittoral rock	7	82	71.4	71.4	42.3
	A3.5	Baltic moderately exposed infralittoral rock	2	6			
	A4.1	Atlantic and Mediterranean high energy circalittoral rock	127	2,050	69.3	24.4	25.9
	A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	659	11,956	89.2	33.8	54.5
	A4.3	Atlantic and Mediterranean low energy circalittoral rock	476	7,525	79.0	42.0	42.6
	A4.5	Baltic moderately exposed circalittoral rock	2	18			
	A5.1	Sublittoral coarse sediment	5,147	91,461	83.4	32.5	53.4
	A5.2	Sublittoral sand	21,706	366,852	89.0	36.3	58.4
	A5.3	Sublittoral mud	4,270	69,862	93.0	49.1	78.0
	A5.4	Sublittoral mixed sediments	2,218	33,493	65.6	19.2	57.0
	A6.1	Deep-sea rock and artificial hard substrata	59	920	33.9	23.7	18.9
	A6.2	Deep-sea mixed substrata	258	3,936	18.2	5.8	6.5
	A6.4	Deep-sea muddy sand	759	9,179	41.4	22.0	40.8
	A6.5	Deep-sea mud	3,333	51,998	48.9	15.6	27.2
	NA	Data not available	2,367	14,789	10.8	5.4	14.5

Baltic Sea

In the Baltic Sea less than 20% of the total area is affected by mobile bottom contacting gears (Table 5.3.5), and most of the effort is spend in the western Baltic and in the Baltic Proper (See section 5.3.1). Therefore, 90% of the highest fishing effort is concentrated in only around 6.5% of the total area (<200m) with little variation around years. In recent years fishing in the deep basins below 200m water depth ceased, and currently these deep areas are not affected by mobile bottom contacting gears at all.

Sublittoral mud and mixed sediments are the dominating habitats in the Baltic Sea. However, sublittoral sand and coarse sediments sustain a higher percentage of affected areas (Table 5.3.6). In terms of the overall footprint, sublittoral sand is the habitat that is mainly fished by bottom-contacting gears, followed by sublittoral mud and coarse sediments. Little abrasion has been detected in infra- and circalittoral rock habitats as well as on sublittoral mixed sediments.

Table 5.3.5. Fishing intensity indicators for mobile bottom contacting gears (MBCG) in the Baltic Sea as percentage of the area affected in relation to shallow (<200m) and deep water layers (>200m).

	0–200 m			200–1000 m		
	% c-squares affected by MBCG	% c-squares affected by the 90% highest fishing effort	% footprint area on seabed	% c-squares affected by MBCG	% c-squares affected by the 90% highest fishing effort	% footprint area on seabed
2009	15.6	6.3	9.7	11.6	9.6	0.6
2010	15.6	6.7	10.8			
2011	16.0	6.7	11.1	0.7	0.7	0.1
2012	16.1	6.4	12.2	4.8	3.4	0.3
2013	15.9	6.4	11.8			
2014	17.2	6.6	12.3			
2015	16.1	6.2	11.5			

Table 5.3.6. Fishing intensity indicators for mobile bottom contacting gears (MBCG) in the Baltic Sea as percentage of the area affected in relation to EUNIS habitats level 3.

Ecoregion	EUNIS code	EUNIS name	Habitat number of c-squares	Habitat total area (km2)	% c-squares affected by MBCG	% c-squares affected by the 90% highest fishing effort	% footprint area on seabed
Baltic Sea	A3.5	Baltic moderately exposed infralittoral rock	376	4,207	4.3	0.8	2.0
	A4.5	Baltic moderately exposed circalittoral rock	343	4,928	3.2	2.0	1.2
	A4.6	Baltic sheltered circalittoral rock	1	16			
	A5.1	Sublittoral coarse sediment	921	13,959	30.3	13.0	10.0
	A5.2	Sublittoral sand	3,557	52,586	46.1	18.9	27.8
	A5.3	Sublittoral mud	10,408	159,638	25.1	10.5	18.4
	A5.4	Sublittoral mixed sediments	10,474	148,381	11.7	3.8	4.5
	NA	Data not available	1,055	5,972	0.4	0.2	0.2

5.4 Caveats and indicator methods documentation and reproducibility (TAF)

Vessel monitoring systems are primarily intended for compliance and monitoring purposes and the data collected were not specifically designed to enable effort map-ping. As such, there remain some data quality issues and caveats. These have been identified by WGSFD (ICES 2016) and the most important aspects are shortly listed below:

- The outputs can only reflect the data submitted and data from some countries were still missing (Spain, Iceland, Greenland, Faroe Islands, Russia) or some parameters, e.g. fishing speeds were not fully submitted. Looking at the quality control summaries of WGSFD (ICES 2016) the outputs appear to be consistent over time, but fishing pressure in certain areas may have been underestimated.
- Up to 2011 only vessels larger than 15 meters were obliged to have VMS on board. In 2012 the legislation changed, and data from vessels larger than 12 meters became available. However, due to differences between countries how vessel length categories were reported, it was not always possible to partition this segment and therefore make the data directly comparable before and after 2012. This is likely to be relevant when examining trends in effort for inshore areas.

- Similarly, in nearshore areas and for some countries substantial fleets of smaller vessels not equipped with VMS exist (< 15 m prior to 2012, < 12 m thereafter). For these, only logbook data are available, which is at the spatial resolution of ICES rectangles and is consequently not considered here.
- For calculating fishing intensities, as well as surface and subsurface abrasion, fishing hours, gear widths and fishing speeds are used as input. Gear widths are an estimate based on BENTHIS project relationships between gear widths and vessel lengths or engine power (Eigaard *et al*., 2016a). Information on vessel lengths and engine power is available as an average per grid cell; if missing, very broad assumptions on average vessel sizes and engine power had to be made in order to estimate gear widths.
- Corresponding fishing speeds were mostly available and, where missing, were replaced by average fishing speeds on the same or similar gears.
- Although standard routines (using R for statistical computing and the related VMS-tools package (Hintzen *et al*., 2012)) were defined, aggregation methods and the identification of fishing activity from VMS data may still vary between countries.
- Gear coding in logbooks is not typically suited for quantitative estimations of seabed pressure, i.e. the exact gear type (width/spread and weight) is un-known. The calculation of swept-areas and the corresponding surface and subsurface abrasion can therefore only be an approximation of the actual values.
- The group partly encountered the problem of misreported gear groups: E.g. Scallop dredging in some countries seems to be reported as HMD, but should be coded as DRB (DRB_MOL). Locally this would cause differences in abrasion. For the UK fishery the values were changed accordingly. Further Otter twin trawling is often reported as OTB (and not OTT).

To illustrate the extent of fishery by vessels smaller than 15 m, the maps in figures 5.4.1 show the average fishing effort for the years 2012–2015 (after it became mandatory for vessels with length 12–15 m to have VMS on-board) in hours for vessels larger than 15 m and for vessels 12–15 m in the North Sea, Celtic Sea and Baltic Sea. It shows that the effort for the vessels of 12–15 m is mainly close to coasts, and that the UK has not submitted VMS data for vessels < 15 m. See ICES (2016) for details on data submissions.

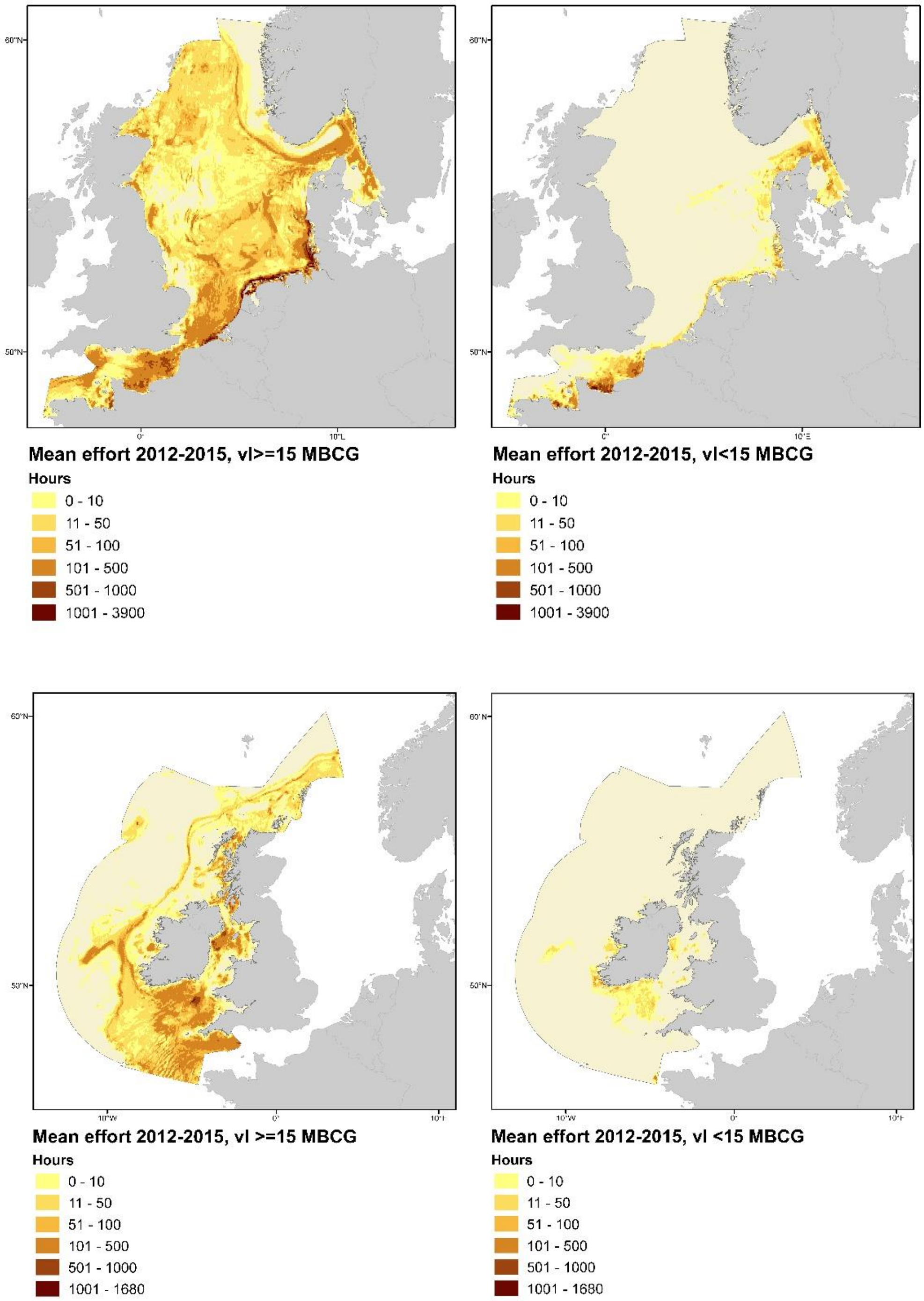


Figure 5.4.1: Average effort in hours 2012-2015 for vessel lengths larger than 15 m and vessel lengths less than 15 m for the North Sea, the Celtic Seas and the Baltic Sea (Part 1).

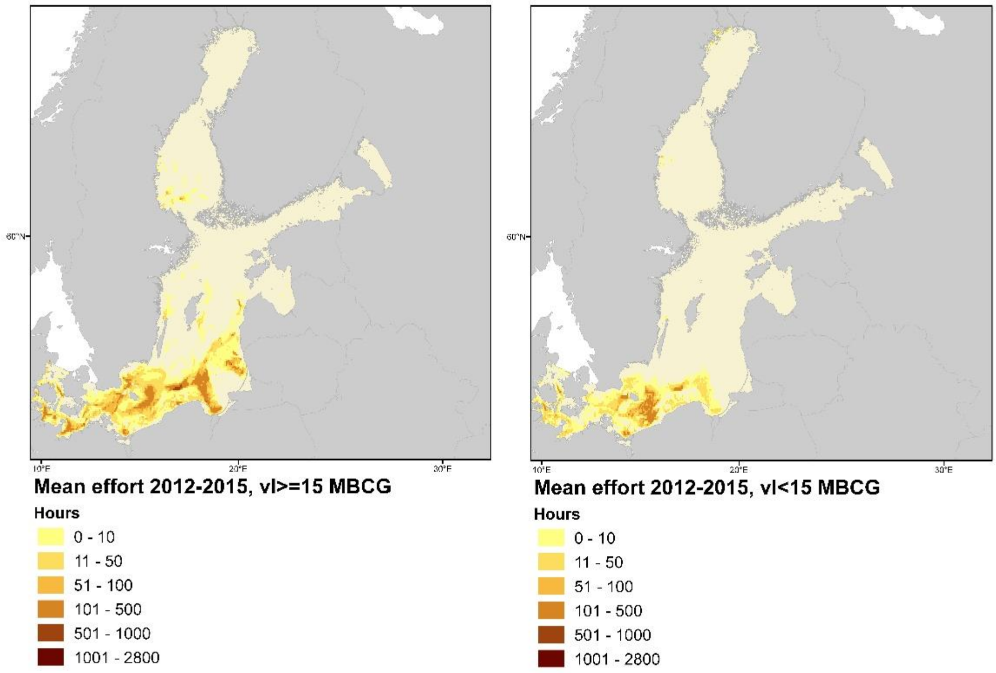


Figure 5.4.1: Average effort in hours 2012-2015 for vessel lengths larger than 15 m and vessel lengths less than 15 m for the North Sea, the Celtic Seas and the Baltic Sea (Part 2).

6 Fisheries Benthic Impact – seafloor impact maps and indicators

6.1 Introduction

To convert patterns of fishing pressure into patterns of bottom trawling impact ICES has recommended to apply a mechanistic, quantitative approach based on biological principles. In this chapter the performance of two such approaches – the longevity and population dynamic approach, developed in the FP7-project BENTHIS and the Trawling Best Practice project - are explored and compared to the BH2 and BH3 approach used in OSPAR. In addition, a method developed in the FP7-project DEVOTES is included as this method may provide another possibility.

Table 6.1.1 provides an overview of the different methods used with the main differences. The methods estimate the impact in terms of a reduction in population biomass (PDA), a reduction in the proportion of the community biomass potentially impacted (Long-SBI, Long-LL), a reduction in a diversity index (BH2) or a categorical impact score (BH3). Methods also differ in the selection of taxa included and the information used for habitat (EUNIS level; continuous habitat variables) and trawling pressure (surface or subsurface swept area ratios). Impact is analysed for the total community (PDA, Long-SBI, BH2) or a selection of taxa (Long-LL: long-lived species; BH3: typical and/or sensitive species). In the sections below, details of the methods will be described.

6.2 Different methods to estimate sensitivity

6.2.1 Longevity

There is ample evidence that bottom trawling shifts the species composition of benthos from long lived taxa to short lived taxa, suggesting that longevity may be used as a proxy of the sensitivity of the community for trawling pressure (Thrush *et al.*, 2005). Since longevity is also related to other relevant life history characteristics such as the age at first reproduction and population growth rate, this information may be useful in developing indicators for trawling impact.

In FP7-project BENTHIS, longevity distributions were both analysed in relation to the Eunis habitats and continuous habitat variables. The estimated longevity distributions are used to estimate indicators for trawling impact (Rijnsdorp *et al.*, 2016 BENTHIS D1.3).

Table 6.1.1 Overview of the assessment methods explored to estimate the impact of bottom trawling on the sea bed.

METHOD	VARIABLE	INDICATOR	RESPONSE SCALE	UNCER TAINTY	BENTHOS	HABITAT	PRESSURE	COMMENT
PD1	rel.biomass.medan_categorical	Relative biomass	Continuous (0–1)	yes	Community	Eunis-3	surface abrasion	Longevity composition (untrawled reference) used to estimate recovery parameter distribution
PD2	rel.biomass. median_continious	Relative biomass	Continuous (0–1)	yes	Community	Continuous habitat	surface abrasion	Longevity composition (untrawled reference) used to estimate recovery parameter distribution
Long-SBI-1	SBI1	Relative biomass of taxa with longevity > trawling interval	Continuous (0–1)	no	Community	Eunis-3	subsurface abrasion	longevity approach simple: worst case estimate (untrawled reference)
Long-SBI-2	SBI2	Relative biomass of taxa with longevity > trawling interval	Continuous (0–1)	no	Community	Continuous habitat	surface abrasion	longevity approach (trawled reference)
Long-LL-1	impact.ratio.2	Relative biomass	Continuous (0–1)	no	Long-lived taxa	Continuous habitat	surface abrasion	longevity approach with empirical effect of trawling (untrawled reference)
Long-LL-2	marginal.impact.ratio.	Relative biomass (marginal decrease)	Continuous (0–1)	no	Long-lived taxa	Continuous habitat	surface abrasion	longevity approach with empirical effect of trawling (trawled reference)
BH2	Margalef	Margalef	Continuous	no	Community diversity	Eunis-3	surface abrasion	Reference community adjusted to fishing pressure
BH3	BH3	Impact categories	Categorical score 0–9	yes	Selection of sensitive / typical taxa	Eunis-4 and higher	surface abrasion	

6.2.1.1 Benthic samples.

The longevity composition of the benthic community was estimated using benthic samples collected in the North Sea and English Channel with 0.1 or 0.078 m2 grabs or box-cores (Figure 6.2.1). These sampling gears provide a quantitative estimate of the biomass of the smaller epi- and infaunal part of the benthic community. One data set comprises samples taken in UK waters between 2000–2010 (Bolam *et al*., 2014) The second data set comprises annual benthic samples taken in the Dutch part of the North Sea together with samples taken along different trawling gradients across the North Sea as compiled by (van Denderen *et al*., 2015a; van Denderen *et al*., 2014). A total of 403 stations were sampled at least once with replicates (between 2 and 6) for 97 stations. In total 392 replicate samples were taken. Some sampling stations had replicates while others were sampled annually over multiple (replicate) years. All samples were sieved over a 1 mm mesh sieve and the retained organisms were identified to the lowest taxonomic level possible. In most sampling stations, biomass per taxonomic grouping was estimated in wet weight, while the samples in the Dutch part of the North Sea were estimated in grams ash free dry weight. These differences in methodology will have limited effects on our outcome as the longevity approach only use proportional data to predict the longevity composition of a benthic community at each sampling location.

For each sampling station, the sediment characteristics (%gravel, %sand, %mud) and depth were recorded and used to determine EUNIS habitat. The trawling intensity for each station was estimated as the average annual swept area ratio (surface abrasion) of the corresponding 1x1 minute grid cell for all bottom trawl métiers in the period 2010-2012 (Eigaard *et al*., 2017). Figure 6.2.2 shows the range of environmental conditions covered by the 403 sampling stations.

6.2.1.2 Longevity distribution by EUNIS habitat

Taxa were classified into longevity classes <1 year, 1–3 years, 3–10 years, >10 years (Bolam *et al*., 2014). The longevity composition for the total community is estimated as the cumulative biomass (B) longevity relationship fitted by the following logistic mixed effect model:

B ~ intercept + log(longevity) + habitat + log(longevity)*habitat + log(trawling) + log(trawling)*habitat + error_1 + (random(station intercept/replicates) + error_2)

We used a mixed effect model to take account of the dependency of the cumulative biomass estimates for each station. Error_1 represents a binomial error. Error_2 represents the normally distributed error of the random effect on the intercept and slope by station and the replicates nested within the stations. The habitat parameter represents either the EUNIS habitat class assigned to the stations. Trawling intensity, depth and tidal shear stress were log-transformed to improve the model fit. A value of 10-2 was added to the trawling intensity and shear stress estimates, close to the minimum observed value, to avoid taking the log of zero. The mixed effect model was estimated using library lme4 in R version 3.02.

The longevity composition of the benthos differed across EUNIS-3 habitats and was significantly affected by trawling intensity (Table 6.2.1). Bottom trawling shifted the longevity curves towards the left reflecting a relative decrease in long lived taxa and a relative increase in short lived taxa (Figure 6.2.3). Coarse sand (A5.1) and mixed sediments (A5.4) were characterised by relatively greater proportion of long lived taxa as compared to sandy (A5.2) and muddy (A5.3) sediments.

Table 6.2.1. Parameter estimates of the of the effects log$_e$ trawling intensity and Eunis-3 habitat class on the cumulative biomass – longevity relationship as given by the selected mixed effect model with the random intercept (station/replicates)

Fixed effects:	Estimate	Std Error	Z value	Pr(>|z|)	
(Intercept)	-4.47878	0.37264	-12.019	< 2e-16	***
Loge(longevity)	2.85119	0.22092	12.906	< 2e-16	***
as.factor(Eunis)A5.2	-1.22175	0.45169	-2.705	0.006834	**
as.factor(Eunis)A5.3	-0.13806	0.80792	-0.171	0.864311	
as.factor(Eunis)A5.4	0.30105	1.06435	0.283	0.777290	
Loge(trawling intensity)	0.13699	0.03693	3.709	0.000208	***
Loge(longevity):as.factor(Eunis)A5.2	0.91707	0.26663	3.440	0.000583	***
Loge(longevity):as.factor(Eunis)A5.3	1.10317	0.64105	1.721	0.085273	.
Loge(longevity):as.factor(Eunis)A5.4	0.14503	0.64778	0.224	0.822844	

Signif. codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**

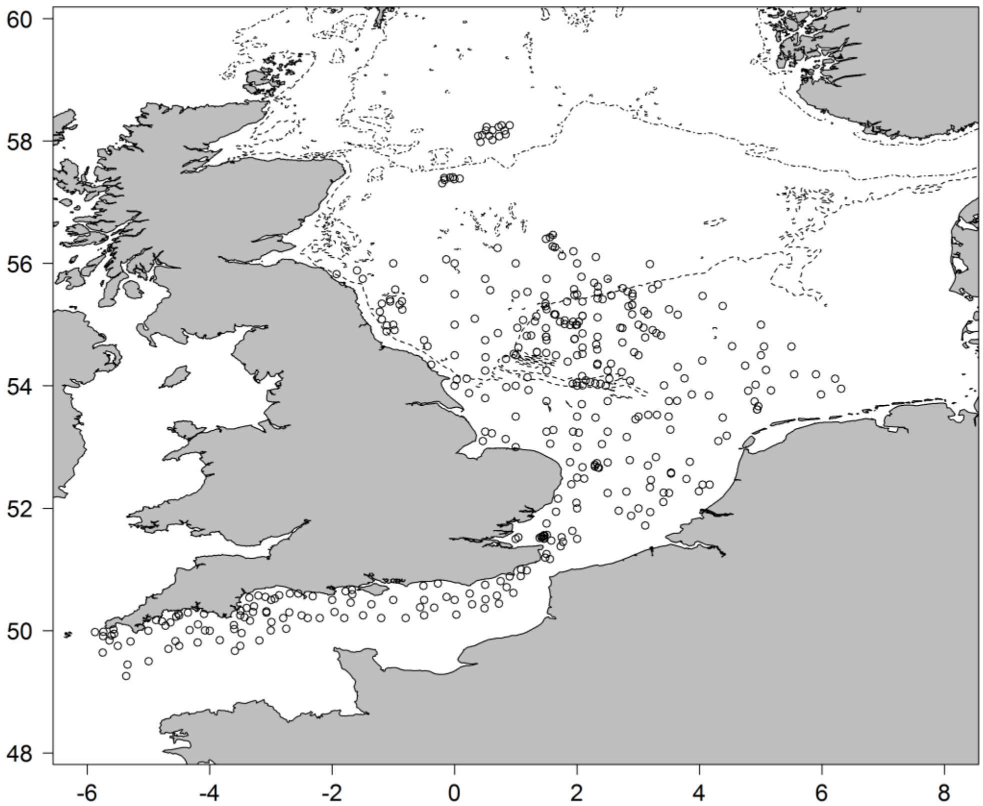


Figure 6.2.1. Location of the sampling stations of the infauna used in the longevity analysis

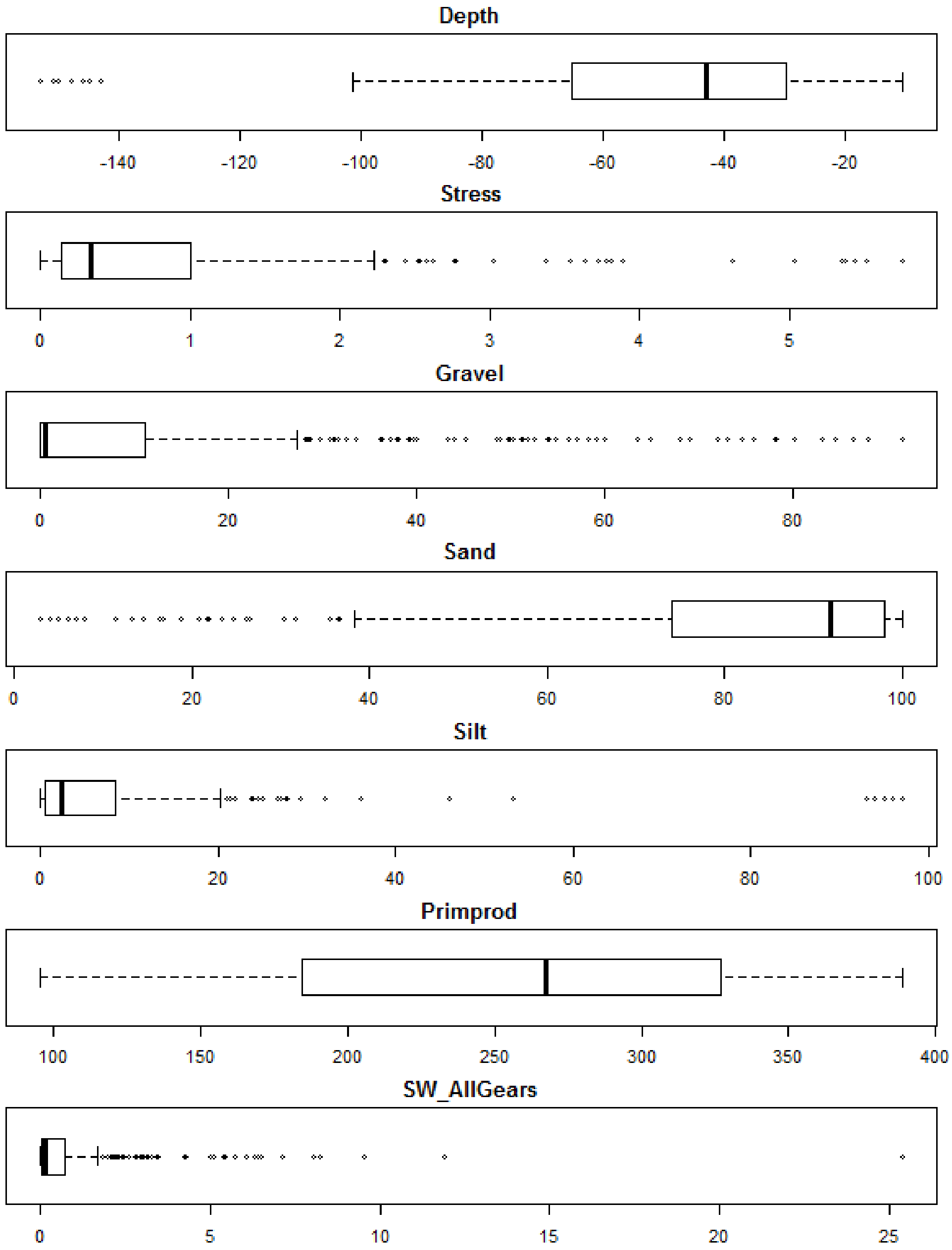


Figure 6.2.2. Box plot of the range of environmental conditions of the sampled stations.

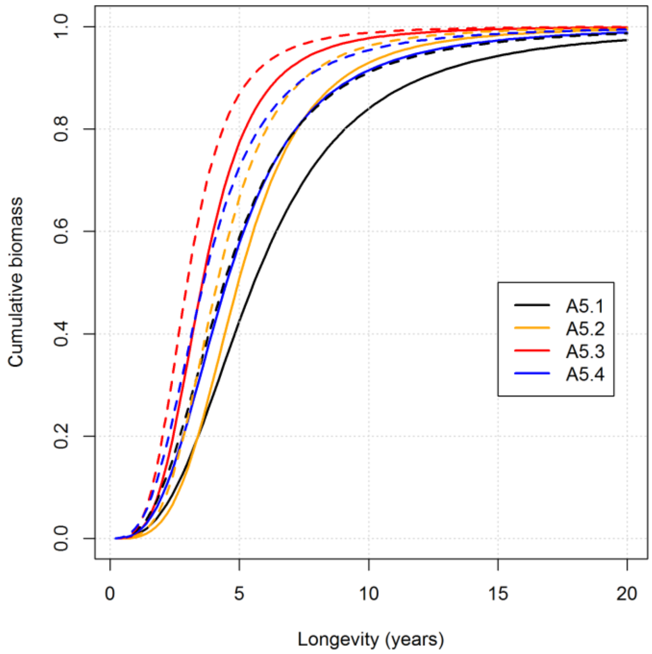


Figure 6.2.3. Cumulative biomass (proportion) - longevity (years) relationship as predicted by the generalised additive mixed effect model for four Eunis-3 habitats at an annual trawling intensity of zero (full lines) and one (hatched lines). A5.1 – Coarse sediment, A5.2 – Sand; A5.3 – Mud; A5.4 – Mixed sediment (BENTHIS Deliverable 1.3).

6.2.1.3 Longevity distribution by functional groups

The cumulative biomass longevity relationships are also estimated for a selection of functional groups for the four Eunis habitats. Taxa living on the surface of the seabed are dominated by short-lived taxa in all habitats (Figure 6.2.4). The longevity composition of the taxa living on or within the top 5cm of the seabed is close to the composition of the total community. Suspension feeders are more long-lived than bio-turbators. The community of coarse sediments (A5.1) and mixed sediments (A5.4) comprise of a larger proportion of long-lived taxa. The effect of habitat is significant for the surface and the surface + subsurface habitat subsets but not for the two functional groups (Table 6.2.4). Trawling intensity reduced the proportion of long-lived taxa although this effect was only significant for bioturbators and the subset of surface taxa.

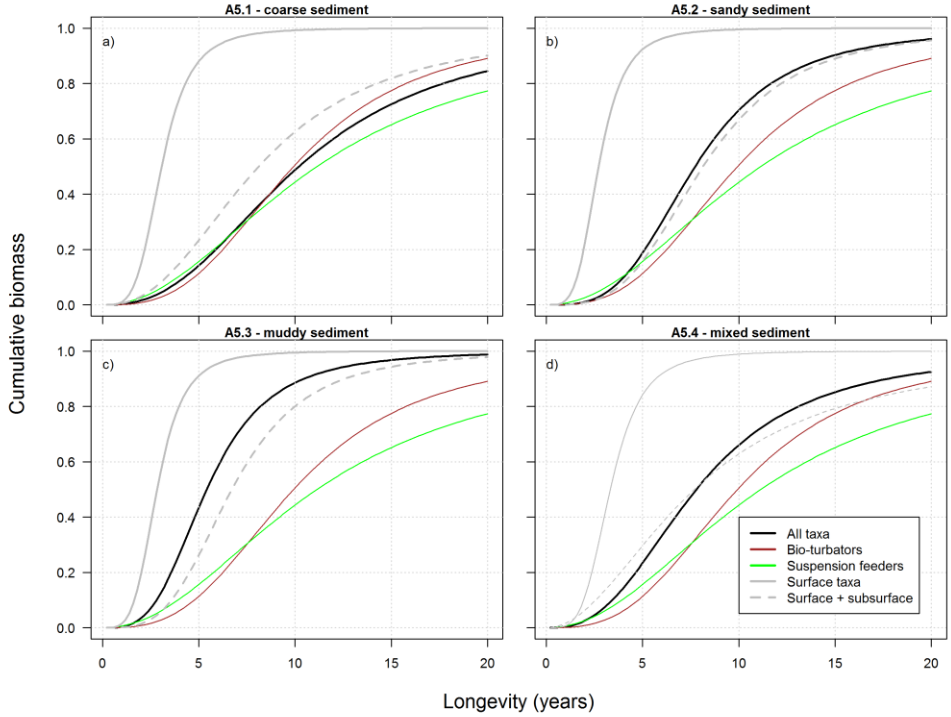


Figure 6.2.4. Cumulative biomass (proportion) - longevity (years) relationship for all taxa as well as subsets of two functional groups (bioturbators, suspension feeders) and two habitat groups (surface: taxa that live on the seabed; surface + subsurface: taxa that live on the seabed or in the top 5cm of the seabed) for Eunis-3 habitats: a) A5.1 – coarse sediment; b) A5.2 – Sand; c) A5.3 – Mud; d) A5.4 – Mixed sediment. (BENTHIS Deliverable 1.3).

6.2.1.4 Longevity distribution in relation to continuous habitat variables

The cumulative biomass (B_{lht}) of the total community is also fitted as a logistic function of continuous habitat characteristics. Since sediment variables gravel, sand and mud are correlated, it was decided to only include gravel because it is important for sessile epibenthic taxa. Furthermore, mud was significantly correlated with depth.

Table 6.2.2 shows the parameter estimates of the most parsimonious model based on the AIC and BIC[1]. The analysis showed that the longevity composition of the benthic community is affected by both depth, gravel and tidal shear stress. Trawling affects the longevity distribution and its effect is habitat dependent. Figure 6.2.5 shows as an illustration the cumulative biomass distributions for a number of different habitats (Figure 6.2.5). The proportion of long lived taxa increases with depth and gravel, and decreases with tidal shear stress. The effect of trawling reduces the proportion of long lived taxa. The effect of trawling is reduced at high levels of shear stress and in shallow waters.

[1] In the BENTHIS Deliverable, a slightly different model was used including a 3-way interaction term of loge(stress)*loge(depth)*loge(trawling). According the AIC this model was slightly better.

Table 6.2.2. Parameter estimates of the selected mixed effect model of the cumulative biomass in relation with loge(longevity) and the environmental variables log(depth, gravel%, log(trawling intensity) and log(tidal shear stress). (BENTHIS).

```
Fixed effects:

               Estimate Std. Error z value Pr(>|z|)
(Intercept)   -8.461840   0.787589 -10.744  < 2e-16 ***
ll             3.391591   0.158234  21.434  < 2e-16 ***
ldepth         0.888672   0.194269   4.574 4.77e-06 ***
Gravel         0.013581   0.011573   1.173  0.24061
lfreq         -0.700110   0.301009  -2.326  0.02002 *
lstress       -0.030685   0.117816  -0.260  0.79452
ll:Gravel     -0.017213   0.006082  -2.830  0.00465 **
ldepth:lfreq   0.195986   0.083486   2.348  0.01890 *
lfreq:lstress -0.089926   0.040885  -2.199  0.02784 *
---
```

Signif. codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**

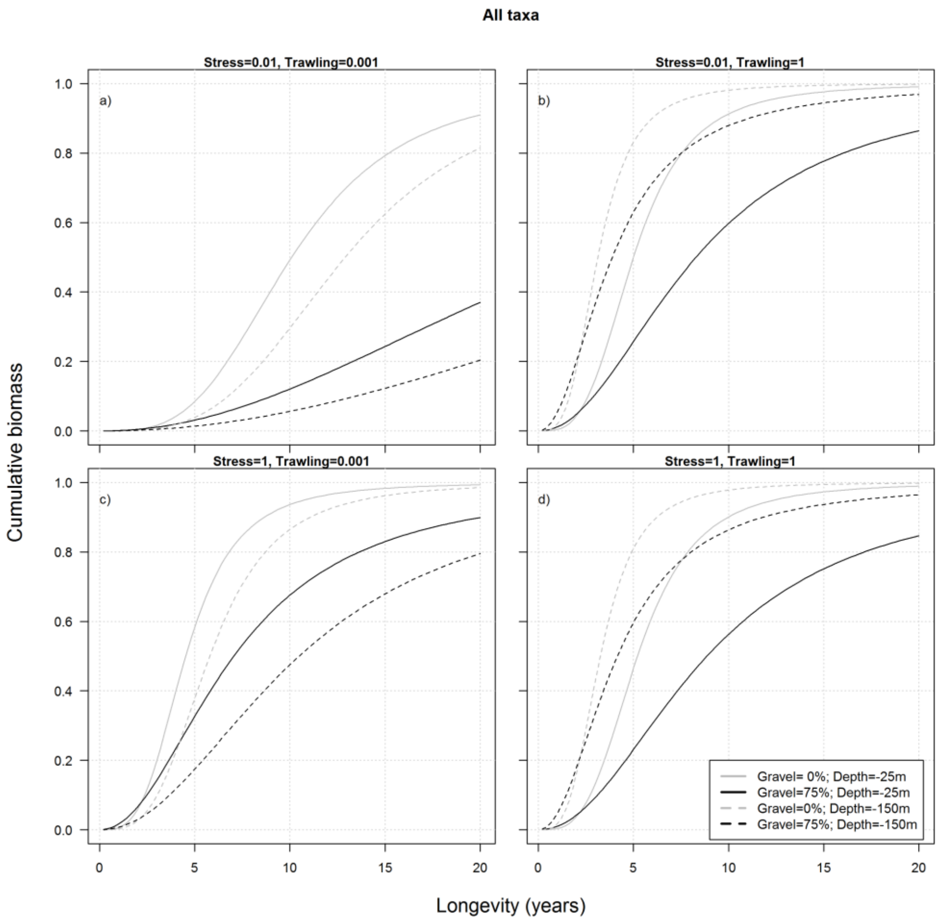


Figure 6.2.5. Cumulative biomass – longevity distributions for a range of different combination of habitat variables (%gravel, depth, tidal shear stress) and trawling intensity (BENTHIS Deliverable 1.3).

6.2.1.5 Longevity community indicator (Long-SBI-1 and Long-SBI-2)

In the first application of the longevity approach, the impact of bottom trawling is estimated assuming that taxa will potentially be impacted if the interval between two successive trawling events is shorter than the life span (Rijnsdorp *et al.* 2016). The interval between two successive trawling events can be estimated from the reciprocal of the swept area ratio (see 6.1.1). Once the relationship between the cumulative biomass and longevity is known, the trawling impact, and corresponding status of the sea floor, can be estimated given the observed trawling intensity in a grid cell. Grid cell estimates can be mapped or aggregated to calculate an index of trawling impact by habitat or management area.

Indicator SBI1 (simple longevity approach) is estimated using the longevity distribution for the untrawled situation provides a worst case situation as it assumes that taxa trawled during their life span will be impacted. Eigaard *et al* (2017) applied this approach to trawling pressure data for the North Sea and Adriatic Sea assuming a single longevity composition for all sea floor habitats.

Indicator SBI2 is estimated using the longevity distribution for the observed trawling intensity at each grid cell.

6.2.1.6 Longevity long lived taxa (Long-LL1, Long-LL2)

The impact of trawling can also be evaluated for the long-lived taxa. We selected the relative change in the biomass of taxa with a longevity of 10 years or more as an appropriate indicator.

Two indicators of trawling impact were calculated. The first indicator Long-LL-1 estimated the decrease in the biomass of long-lived taxa for each grid cell as a ratio of the untrawled biomass using the parameter estimates of the longevity relationships fitted (Table 6.2.2). Trawling intensity showed a significant interaction with depth and tidal shear stress predicting a stronger decrease in long-lived biomass at increasing depth or decreasing tidal shear stress. In shallow areas and areas with a high shear stress, where the model predicted a positive effect of trawling on the biomass of long lived taxa, the change in biomass was set at zero.

The second indicator Long-LL-2 estimated the decrease in biomass of long-lived taxa if bottom trawling would sweep the grid cell one time more (marginal impact). This indicator may be particularly useful when exploring the trade-off between the impact of trawling and the yield of the fishery (see 6.2.1.7).

6.2.1.7 Explorations of the longevity approach

Below we include some of the results of explorations of the longevity method from the BENTHIS project (Rijnsdorp *et al.*, 2016b). In BENTHIS the data on trawling intensity were available at a resolution of 1x1 minute grid cells. Because no data layers at this resolution were available for the sediment characteristics and seabed stress, we assigned the mean value estimated from the benthic data set for each Eunis-4 habitat type. For the grid cells of habitat types that were missing, an overall mean value was assigned.

6.2.1.7.1 Critical trawling intensity

The fitted cumulative biomass – longevity relationships can be used to estimate the trawling intensity at which the biomass of long-lived taxa is reduced to a percentage of the untrawled biomass. This trawling intensity reflects the sensitivity of the community for bottom trawling. Figure 6.2.6 shows how the critical trawling intensity is affected by depth, gravel and shear stress. Figure 6.2.7 shows that according the longevity method that takes account of the habitat dependent effect of trawling on the benthic community composition, the sea floor in the shallow parts of the southern North Sea is insensitive for the impact of trawling.

6.2.1.7.2 Sea floor integrity

Figure 6.2.8 shows a map of the sea floor integrity expressed as the relative status of the biomass of long-lived taxa estimated with the Long-LL-1 method.

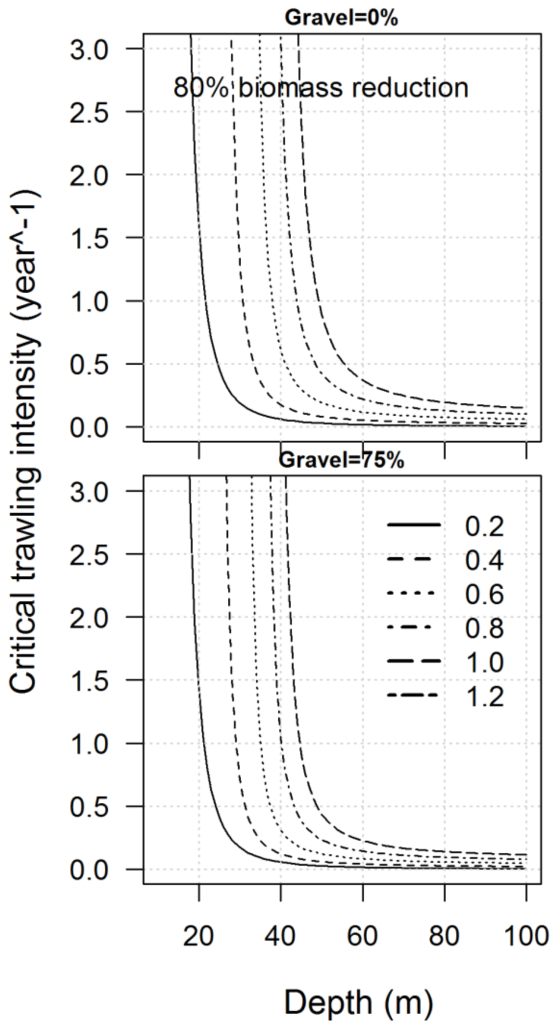


Figure 6.2.6. Critical trawling intensity at which the biomass of long-lived taxa (10 years or more) is reduced to 80% in relation to depth for a seabed with 0% or 75% gravel and tidal shear stress levels between 0.2 and 1.2 unit (BENTHIS Deliverable 1.3).

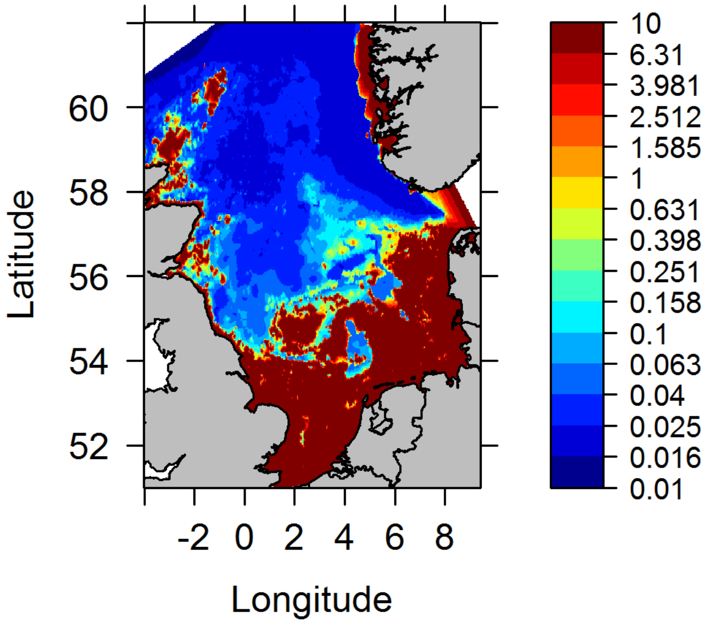


Figure 6.2.7. Critical trawling intensity at which the proportion of long lived taxa (life-span of 10 years of more) is reduced to 80% of the untrawled biomass (BENTHIS Deliverable 1.3).

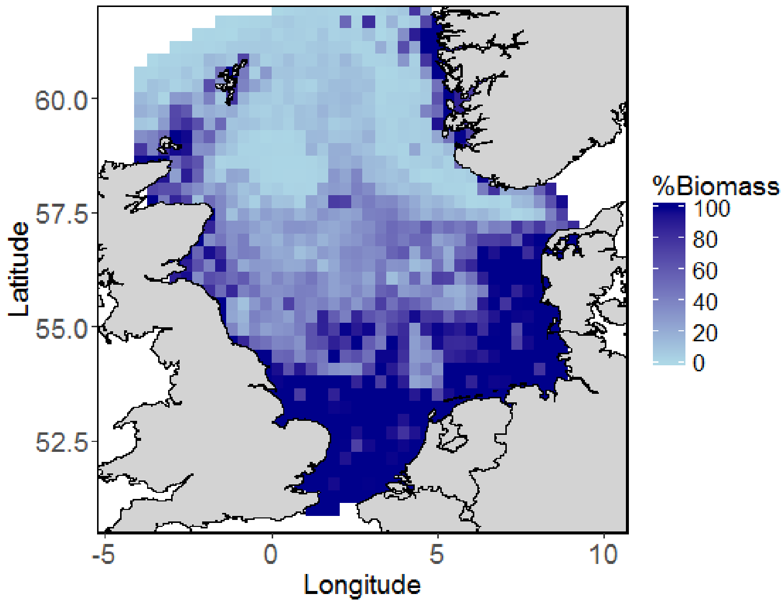


Figure 6.2.8. Reduction in the biomass of long-lived taxa (>10 years) given the observed annual trawling intensity in the period 2010-2012 estimated with the longevity approach using continuous habitat variables (BENTHIS Deliverable 1.3).

6.2.2 Population dynamic approach

6.2.2.1 ICES WKBENTH population dynamics assessment model

This assessment methodology relies heavily on the longevity analyses in 6.2.1 and Hiddink and al. (In prep) and methodologies developed and described in Hiddink *et al.* (Submitted) and its supplementary information. The assessment methodology is explained in detail in Pitcher *et al.* (2017) and Ellis *et al.* (2014).

The logistic growth equation (Schaefer) was used to describe recovery of benthic fauna because it provides an effective abstraction of the complex recovery dynamics of populations and communities and can be fitted to available data (e.g. McClanahan *et al.*, 2007; Ellis *et al.*; Lambert *et al.*, 2014). If we assume the recovery of biomass of biota *B* following trawling is described by the logistic growth equation, then the equilibrium solution can be used to estimate *B* in an environment subject to chronic fishing disturbance (Pitcher *et al.*, 2017) as:

$$B = K\ (1 - F\ d/r) \quad \text{(eq. A1)}$$

where *F* is trawling frequency, *d* is the depletion of biota caused by each trawl pass (expressed as a proportion) and *r* is rate of increase, interpreted here as the recovery rate and *K* is the carrying capacity of the ecosystem. At equilibrium, the effect of trawling on *B* is a linear function of *F* with slope equal to minus the ratio *d/r*. Equation A1 only requires estimates of *K*, *F*, *d* and *r* to estimate biomass *B* (Pitcher *et al.*, 2017). Trawling frequency *F* is defined as the swept area ratio, which is the area trawled annually divided by the studied area ($km^2\ km^{-2}\ y^{-1}$, simplified to y^{-1}). Different gears will have different levels of seabed contact or penetration and these factors will influence *d*.

Here we model the effect of trawling on the biomass of each longevity class, and present the overall effect of trawling as the biomass summed over all longevity classes. For this assessment we therefore need *F*, *d*, *K* and *r* for each c-square in the assessed area, for each longevity class. The values of *K* depend on the habitat type or local environmental conditions, and the values of *d* depend on the fishing gears used in each square.

Carrying capacity *K* is expressed for each longevity class (<1 y, 1–3 years, 3–10 years, >10 years) as the fraction of the biomass of the class of the total biomass and this fraction is habitat specific, and derived from Rijnsdorp *et al.* (2016), based on the longevity distribution of infaunal invertebrates. This was done based on a EUNIS habitat level for the first method (called *population dynamics - EUNIS*) (K estimates given in Table 6.2.3), and based on continuous environmental variables (% gravel, tidal shear stress and depth) for the second method (called *population dynamics – continuous environmental variables*) (relationships between cumulative K and the variables given in Rijnsdorp *et al.* (2016)). Because we are examining fractions of the total, the sum of *K* for all longevity classes equals 1 and the overall summed *B* is a relative value that scales between 0 and 1 (although if the *K* estimates were available, this approach could readily be used with absolute *K* estimates)

Table 6.2.3 The predicted fraction of biomass in untrawled areas in different EUNIS habitats, by longevity class, from Rijnsdorp *et al.* (2016).

EUNIS CATEGORY	0-1Y	1-3Y	3-10Y	>10Y	HABITAT DESCRIPTION
A5.1	0.006	0.116	0.689	0.189	Sublittoral coarse sediment
A5.2	0.002	0.099	0.812	0.087	Sublittoral sand
A5.3	0.005	0.283	0.691	0.021	Sublittoral mud
A5.4	0.008	0.172	0.710	0.110	Sublittoral mixed sediments

Depletion *d* was estimated in Hiddink *et al.* (Submitted) for otter trawls OT, beam trawls BT, towed dredges TD and hydraulic dredges HD. These gears were matched to the EU gear types as specified in Table 6.2.4. Hiddink *et al.* (Submitted) found a strong correlation between *d* and the penetration depth of a trawl gear, so an alternative approach to estimate *d* for each fishing gear could be to estimate penetration depth for each gear, from empirical measurements or from models (Ivanovic *et al.*, 2011; O'Neill & Ivanović, 2016) and this may be particularly useful for fishing gears where no measurements of *d* are available, such as demersal seines.

Table 6.2.4. Matching of gear types from Hiddink *et al.* (Submitted) with EU gears, and estimates of depletion *d* for each.

GEAR GROUP	GEAR CODE	DEPLETION *D* (FRACTION)		
Hiddink *et al.* (Submitted)	EU	5%	Median	95%
OT – otter trawl	OTB, OTT, PTB, SSC, OT, TBN, SDN	0.02	0.06	0.16
BT – beam trawl	TBB, TBS, TB	0.07	0.14	0.25
TD – towed dredge	DRB	0.13	0.20	0.30
HD – hydraulic dredge	HMD	0.35	0.41	0.48
Not grouped	FPO, GNS, PTM, GN, LHP, LLD, NA, OTM, GTR, TMS, PS, SPR, SV, SX, LHM			

Recovery rate *r* was estimated for each longevity class (Table 6.2.5). The estimates of *r* presented here are local estimates and these were corrected to a grid-scale *R* as specified by Pitcher *et al.* (2017) and Ellis *et al.* (2014) in this assessment, assuming a random distribution of fishing effort within each c-square. When assuming a random distribution of fishing effort within each c-square, the local estimate of *d* is effectively equal to the grid scale *D* and was therefore not corrected.

Table 6.2.5. Estimates of recovery rate *r* by longevity class

LONGEVITY CLASS	MEAN LONGEVITY (Y)	*R* (PERCENTILE)		
		5%	50%	95%
0-1y	0.53	0.31	1.24	4.59
1-3y	2.10	0.22	0.87	3.21
3-10y	6.45	0.12	0.47	1.76
>10y	12.56	0.07	0.29	1.06

When attempts are made in future assessments to apply this methodology to particularly long-lived organisms for which the >10 y r estimate does not seem appropriate, then if a measure of time it takes for recovery in biomass up to a near equilibrium state, either from known recovery after impact or complete recolonization, is available, you can generate the *r* using this equation:

$$r = T \Big/ \left(\frac{ln(\phi\ d)}{(1-d)(1-\phi)} \right)$$ (Hiddink *et al.*, Submitted) (eq. A2)

Trawling frequency *F* was estimated as the swept area ratio (y^{-1}) for each c-square for each gear type. If multiple gear types were active in a single square, the *F* was summed for all the gears, and a compound *d* was calculated as the *d* of the individual gears weighed by the *F* of each of the individual gears. An alternative approach (which was not implemented) could use the *d* ~ penetration depth correlation, by creating a penetration depth ~ *F* histogram (based on whole gears or gear components) for each c-square, estimating *d* for each penetration depth, and applying equation A1 for each fraction of the c-square that had a unique *d-F* combination, and then finally summing *B* over the whole c-square.

Equation A1 was applied for each longevity class in each c-square, and the relative total biomass *B* in each c-square was calculated as the sum of the biomass of the four longevity classes. Figure 6.2.9 gives an example of this. Both *r* and *d* were estimated with uncertainty and this uncertainty was propagated into the estimates of *B* as specified in Hiddink *et al.* (Submitted). We report the 5, 50 and 95% percentiles of our *B* estimates.

The recovery time (T) of the community was estimated using equation A2. Given the depleted status of each longevity class corresponding to the observed swept area ratio, the recovery of the biomass was estimated as the sum of the biomass of the four longevity classes. Recovery time was estimated as the time required for the total biomass to reach 90% of K. As the model implies that a longevity class will not recover when fully depleted, we assumed a minimum biomass of 0.001 to allow the longevity class to recover.

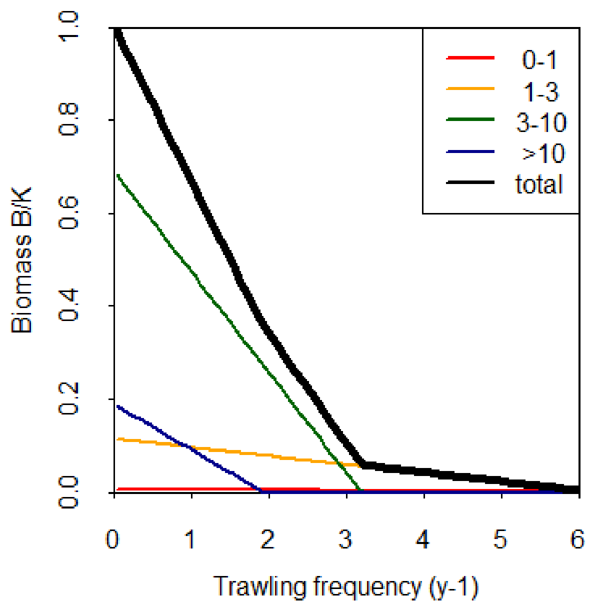


Figure 6.2.9. Example of the relationship between the predicted B/K for all four longevity classes, and the total *B/K* for all classes combined, which is used as the response variable in this assessment. Example for BT on EUNIS habitat A5.1. *B/K* at *F* = 0 equals *K* for each longevity class, while the slope of the relationship equals -*d*/*r* for the gear-longevity combination.

6.2.2.2 Limitations and strengths

A strength of this approach is that it has been parameterised using on all available evidence using a systematic review of the literature, that it uses a biologically meaningful mechanistic, quantitative model to make predictions, and that uncertainty is quantified.

A limitation of the current implementation of the model is that the estimation of *K* for the different longevity classes has been carried out based on infauna from the Greater North Sea only. The longevity distributions for epifaunal organisms are likely to be skewed towards longer-lived biota, and important variation in K may exist within habitats. A final limitation is that the gear classification is simplistic and would benefit from *d* estimates with a higher gear resolution. In particular, brown shrimp trawls in the coastal zone are now assumed to have the same *d* as larger beam trawls and this may overestimate their impact.

6.2.3 BH3

The aim of this indicator is to evaluate to what extent the sea floor and its associated ecology, species and habitats are being damaged by human activities. The indicator is designed to assess all subtidal habitat types at a sub-regional level i.e. predominant habitats and MSFD special habitats, including OSPAR Threatened and/or Declining habitats (OSPAR Agreement 2008-6). It uses a combination of spatial analyses to extrapolate data and knowledge from local studies to larger areas, and therefore it is regarded as particularly useful for assessing large sea areas where currently only limited data are available.

The indicator will build upon two types of underlying information, i) the distribution and sensitivity of habitats (resilience and resistance), and ii) the distribution and intensity of human activities and pressures that cause physical damage, such as mobile bottom gear fisheries, sediment extraction and offshore constructions. These two sources of information (pressure and sensitivity) are combined to calculate the potential damage to a given seafloor habitat, and the trends across the six-year period

At present the focus of the work is on predominant habitats according to the Marine Strategy Framework Directive (MSFD) and how to incorporate special consideration of those habitats listed under the OSPAR threatening and declining list. The EUNIS (European nature Information System)[2] level 3 classification has been used as a proxy for the MSFD predominant habitats. Biogeography has been taking into account for the development of this indicator in order to assess variations of sensitivity and disturbance within a sub-regions containing similar physical and biological characteristics.

The methodology used have been thoroughly tested and reviewed by national and OSPAR experts and through focus workshops, and it represent a realistic approach to assess the distribution of impacts across the regions based on current knowledge and using all evidence available. However, it is important to note that the strength of any assessment is dependent on the quality of the data, and this will in turn dictate the power and utility of the resultant information

The indicator is still under development. The following limitations should be noted:

- Distribution and proportionality of partial indicator pressure data used at this stage. Using data from >12m vessels, limits the dataset to waters largely beyond 6/12nm and therefore will underestimate impact on those geographical areas where inshore fleets are based;
- Pressure type, limited to sea bed abrasion from fishing and not including the other pressures which result in physical damage Impacts from small vessels and information from other activities causing physical damage will be added at a later stage.;
- Parts of the indicator calculations are based on categorical approaches. Development of a quantitate approach to assess sensitivity and disturbance for large scale assessment is currently under development;
- The indicator is not able to assess historical damage, which had caused the deterioration and modification of habitats in the past;
- Calculation of a final physical damage index per habitat type and sub-region needs to be developed;

Assessment Scale

The spatial assessment of this indicator is presented at EUNIS level 3, and has been prepared by combining the sensitivity and pressure[3] data from habitats, biotopes and species within the EUNIS level 3 habitat polygons. For this assessment the OSPAR regions have been subdivided following biogeographic boundaries (OSPAR, 2016) into: Southern North Sea (SNS) and Northern North Sea (NNS); Southern Celtic Sea (SCS) and Northern Celtic Sea (NCS), English Channel (CH) and Bay of Biscay/Iberian Peninsula. Please note that for Region IV, only a partial assessment has been possible in this assessment, as at present insufficient habitat and sensitivity data on the deep seafloor areas are available.

[2] Eunis classification: http://eunis.eea.europa.eu/habitats-code-browser.jsp

Two temporal scales are used:

- Annually to calculate the distribution of disturbance within a year and,
- Within an MSFD cycle (6 years) to calculate the total aggregated values for a whole cycle.

The temporal aggregation across a cycle of 6 years is calculated using the aggregation of values from the pressure and disturbance. The method used to assess habitat and sensitivity data does not have a temporal scale associated with the spatial layers, although within the sensitivity results the resilience values are based mainly of the longevity of habitats and species as it is one of the key elements to assess their recoverability

Please note the aggregation method within the MSFD cycle is currently under the development

Spatial Analysis and trend analysis

The indicator method is based on a series of analytical steps to combine the distribution and intensity of physical damage pressures with the distribution and range of habitats and their sensitivities. The indicator will use an additive approach for future inclusion of multiple other pressures.

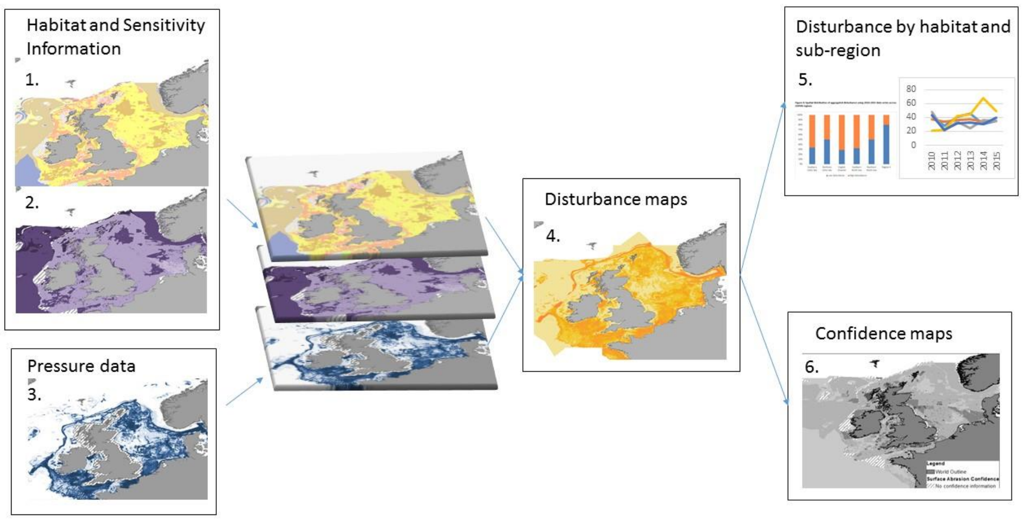


Figure 6.2.10. Conceptual overview of the indicator showing the different components of the indicator.

An overview of the concept is showing in Figure 6.2.10, illustrating the main results produced under each of steps of the analysis. A detailed description of each of the steps is described below:

Step 1: Extent and distribution of habitats

An important component of this indicator is the production of a composite habitat map showing the extent and distribution of predominant and special habitats and their associated sensitivities. This map is produced using a combination of benthic survey data and modelled habitat maps. As a basis for the assessment, a full coverage EUNIS level 3 habitat map has been produced for the OSPAR Maritime Area, integrating maps from surveys and broad-scale models. Please note that at present, the new EUNIS classification has not been taken into consideration as it has not been published

The EUNIS habitats are mapped at different levels of detail, from level 3 physical habitats to level 6 biological communities and then aggregated to EUNIS level 3 where more detail is provided. The majority of the habitat maps were obtained from the European Marine Observation and Data Network (EMODnet) Seafloor Habitats portal[4], including the broad-scale physical habitat map, EUSeaMap (EMODnet, 2010 & 2016), and more detailed habitat maps created from survey data available through EMODnet, or as part of OSPAR habitat data calls. The information on the coverage and type of data have been taken into account for the calculation of confidence maps (see step 6). The specification for a habitat map for the assessment of BH3 included the following conditions:

- To contain information on the relevant EUNIS habitat/biotope type at any level between levels 3 and 6;
- To refer data on biotopes to Level 3 of the EUNIS habitat classification system;
- To use the broad-scale modelled map, EUSeaMap at EUNIS level 3 when higher resolution maps from surveys are not available
- To use the best available evidence on habitat data;
- To cover the greatest possible area of the OSPAR North-East Atlantic region;
- To contain no overlaps.

Mapping rules were established in order to decide objectively which of the overlapping datasets would be the sole occupant in the overlapping area. Where a EUNIS habitat map developed from survey data overlapped with a broad-scale predictive habitat map, a threshold confidence score of 58 % was used as a simple rule for deciding whether or not to favour the habitat map from survey. This threshold was based on the MESH protocol (Mapping European Seabed Habitats) (EMODnet, 2010). Within the MESH scoring system, for any map to have a score greater than 58 %, the survey techniques must have used a combination of remote sensing and ground-truthing to derive the habitat types, hence physical and biological elements are included for its production. Therefore, 58 % was deemed to be the lower threshold at which an overlapping survey map is considered to be of higher quality than the broad-scale predictive map. Pre-processing conditions and rules for the combining of data are outlined in Annex 1 of the Indicator JAMP, the output can be seen in Figure 6.2.11.

[4] EMODnet Seafloor Habitats portal: www.emodnet-seafloorhabitats.eu/webgis

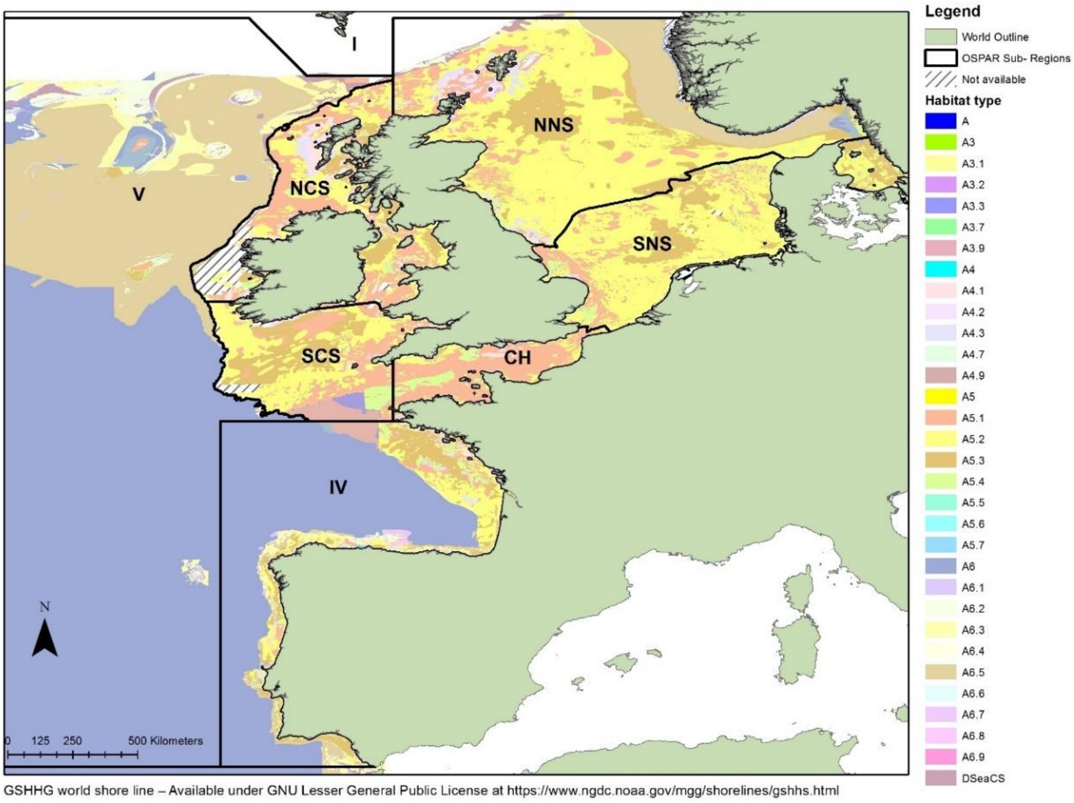


Figure 6.2.11. OSPAR-scale full-coverage EUNIS level 3 benthic habitat map, integrating maps from surveys and broad-scale models. OSPAR Region/ Sub-Region Codes: NNS= Northern North Sea, SNS= Southern North Sea, CH= English Channel, NCS= Northern Celtic Sea, SCS= Southern Celtic Sea, I= Region I- Arctic Waters, II= Region IV- Bay of Biscay and Iberian Peninsula, V= Region V- Wider Atlantic.

Step 2: The assessment of habitat sensitivity

The sensitivity of benthic habitats is determined based on a combination of the resistance (tolerance) and resilience (recoverability) of key structural, functional and characterising species of the habitat in relation to a defined intensity of each pressure Tillin *et al*, 2010; BioConsult, 2013; Tillin and Tyler Walters, 2014). Due to data limitations, the sensitivity scores are defined using a categorical scoring approach (Tillin *et al*, 2010). Sensitivity assessments for ecological groups have also been undertaken using Bray-Curtis cluster similarity analysis and Multidimensional Scaling, where resistance and resilience scores are assigned to groups of species with similar biological traits (e.g. burrowers) (Tillin and Tyler Walters, 2014). Resistance and resilience values were assigned using the definitions in Tables 6.2.6 and 6.2.7, from a mixture of literature based evidence and expert judgement.

Table 6.2.6. Assessment scale used for determining resistance of a species or habitat

RESISTANCE	DESCRIPTION
None	Severe decline and/or physical-chemical parameters also affected e.g. removal of habitat that could cause a change of habitat type. A severe decline/ reduction relates to the loss of more than 75 % of the extent, density or abundance of the selected species or habitat element.
Low	Significant mortality of species with some effects on physical-chemical character of habitat. A significant decline/reduction relates to the loss of 25%-75% of the extent, density or abundance of the selected species or habitat element.
Medium	Some mortality of species without change to habitat type. 'Some mortality' relates to the loss of up to 25% of the extent, density or abundance of the selected species or habitat element.
High	No significant effects to the physical-chemical character of habitat and no effect on population viability of species but potential effects to biological processes like feeding, respiration and reproductive rates.

Table 6.2.7. Assessment scale for resilience

RESILIENCE	DESCRIPTION
Very Low	At least 25 years to recover structure and function
Low	Full recovery within 10–25 years
Medium	Full recovery within 2–10 years
High	Full recovery within 1–2 years
Very high	Full recovery within 1 year

Sensitivity matrix (combination of resistance and resilience)

The resistance and resilience scores are combined to produce an overall sensitivity score for a species or habitat. A matrix is used to automate this combination and results in a category of sensitivity, ranging from 1 to 5 (with 5 being the most sensitive). This matrix can be applied to different sensitivity assessments (Table 6.2.8).

Table 6.2.8. Sensitivity matrix combing resistance and resilience scores to produce a sensitivity score ranging from 1 to 5, where 5 is the most sensitive.

Sensitivity		**Resilience**				
		very low (>25 yr.)	low (>10-25 yr.)	medium (>2-10 yr.)	high (1-2 yr.)	very high (<1 yr.)
Resistance	none	5	4	4	3	2
	low	4	4	3	3	2
	medium	4	3	3	2	1
	high	3	3	2	2	1

The sensitivity map is created with three steps (Figure 6.2.12), using best available evidence where present

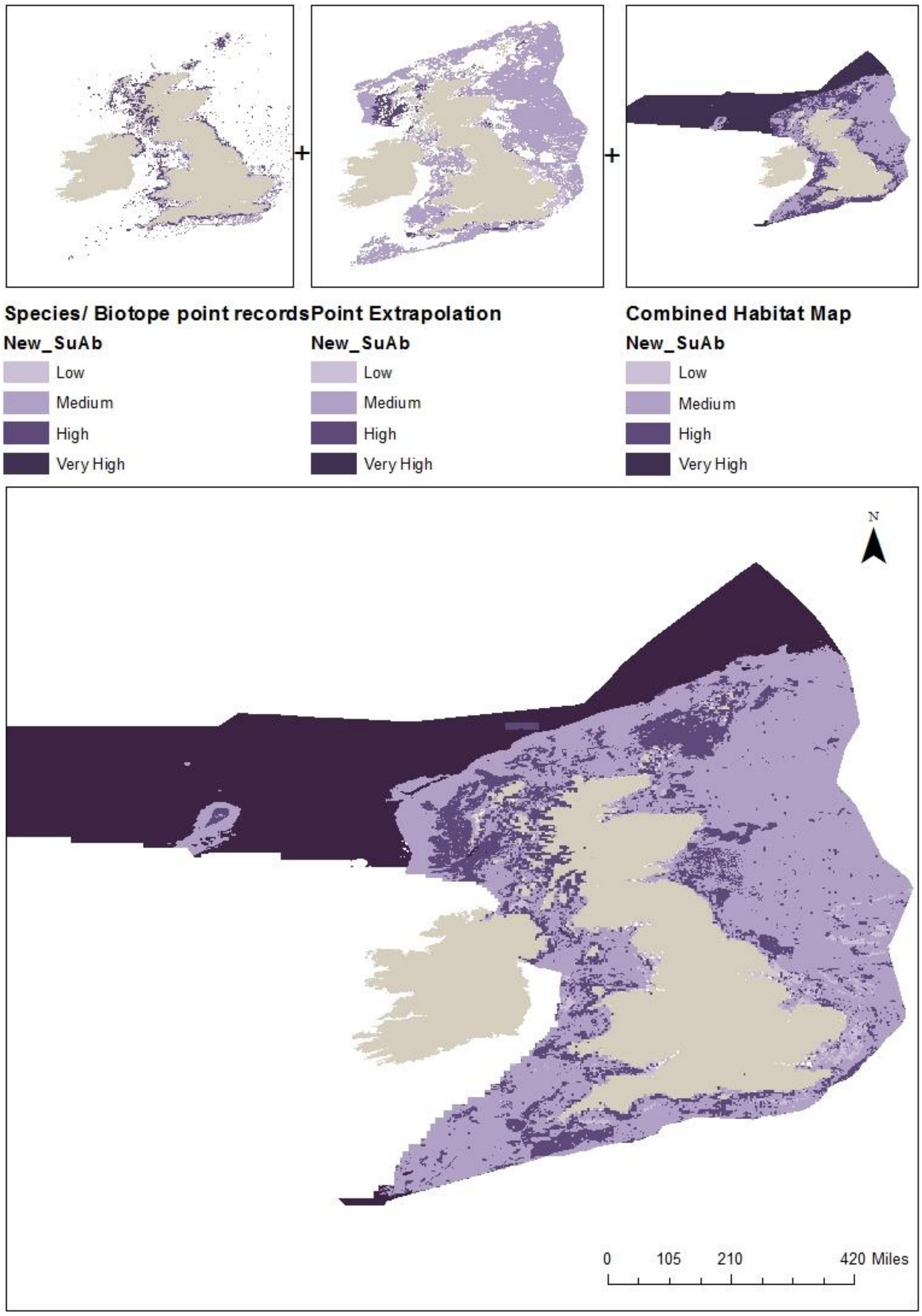


Figure 6.2.12. 3-step method for creation of sensitivity map.

Species records from survey data, that match a list of species assigned to specific ecological groups, are mapped using their maximum sensitivity value (based on the combination of resilience and resistance). Data are plotted as the intersection between the habitat polygon and a 0.05° grid;

If there is a high enough density of species recorded (I sample point per 20km^2) and agreement between the species and the underlying habitat, the sensitivity from the same species records used in step one are used to assign a modal sensitivity to the surrounding habitat polygon. For example, if data coverage is sufficient, and the substrate and habitat type in the surrounding polygons are the same, then the same sensitivies are applied to these areas;

Finally, in order to act as a background map, and to fill in areas not covered by the first two steps, the habitat map outlined in Step 1 is used to assign EUNIS level 3 benthic habitat sensitivities to the whole area. The sensitivities used in this step are often a range (from very low sensitivity to very high), in which case the maximum sensitivity is selected.

The maps are then combined geographically to show the highest confidence information across all regions. The resulting sensitivity maps for surface and sub-surface abrasion are shown in Figures 6.2.13 and 6.2.14.

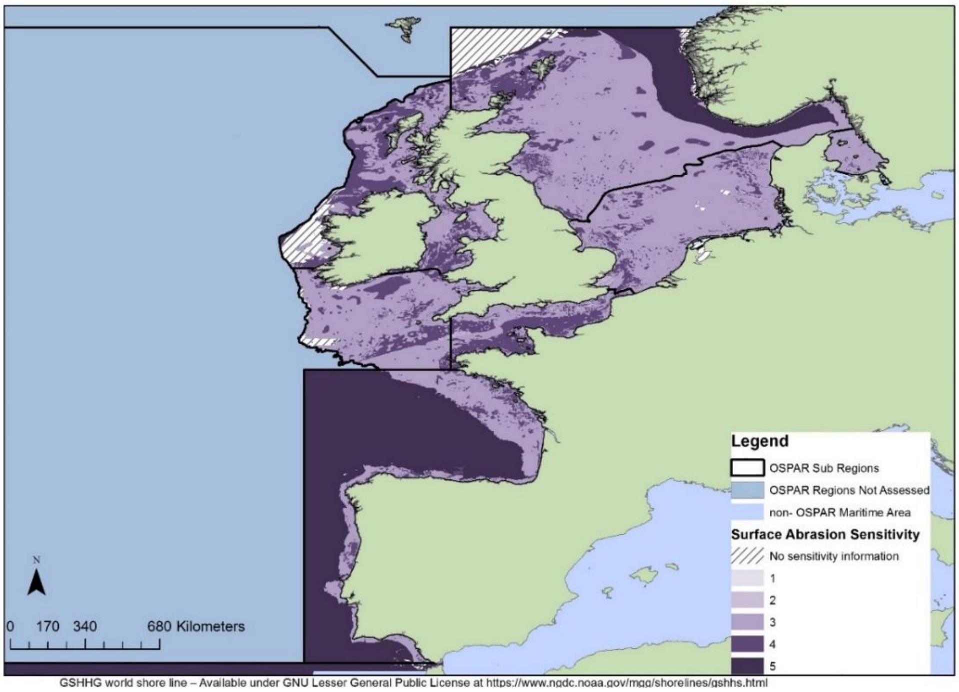


Figure 6.2.13. Extent and distribution of habitat and benthic species sensitivities (based on resilience and resistance) to surface abrasion combined within EUNIS Level 3 benthic habitat types. Sensitivity is expressed in categories from 1-5, where 1 is the least sensitive and 5 is the most sensitive

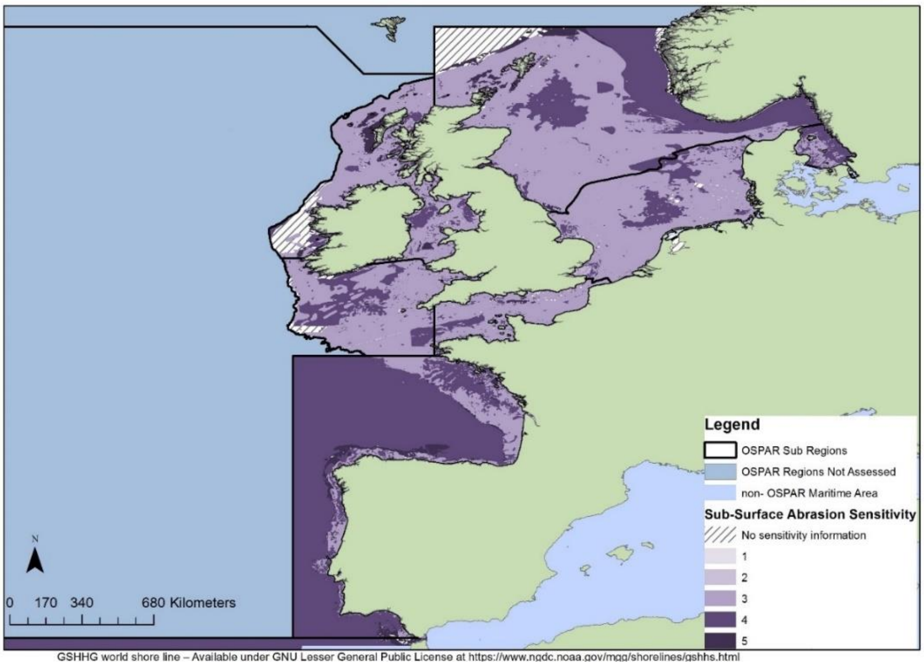


Figure 6.2.14. Extent and distribution of habitat and benthic species sensitivities (based on resilience and resistance) to surface abrasion combined within EUNIS Level 3 benthic habitat types. Sensitivity is expressed in categories from 1-5, where 1 is the least sensitive and 5 is the most sensitive

Step 3: The assessment of the extent and distribution of physical damage pressures

Fishing pressure maps are used for the years 2010 to 2015. Swept Area Ratio (SAR) is assigned to 5 categories to represent biologically relevant levels of disturbance from fishing (Table 6.2.9).

Table 6.2.9. Classification of the swept area ratios per grid cell for a year.

None (0)	0
Very Low (1)	>0.00 – ≤0.33
Low (2)	>0.33 - ≤0.66
Medium (3)	>0.66-≤1.00
High (4)	>1.00-≤3
Very High (5)	> 3

For assessments across a cycle (6 years): Several statistical approaches were explored in order to analyse the variability on the level of fishing across years, including regression analysis and the use of percentiles, e.g. 95-percentile. However, these approaches were not deemed suitable due to not only the limited number of years available, but also the high level of variable on the SAR values.

A simple analysis of variance is used with the classified surface and sub-surface yearly results, in order to differentiate between cells with low and high SAR variability. This analysis allows the distinction between areas where fishing intensity seems to be consistent or at similar levels across years, from those where fishing intensity levels fluctuates. A grid cell was considered to be 'variable' when the variance analysis showed a change in three or more categories of the classified SAR across all years. The resulting map showing variable cells can be seen below (Figure 6.2.15).

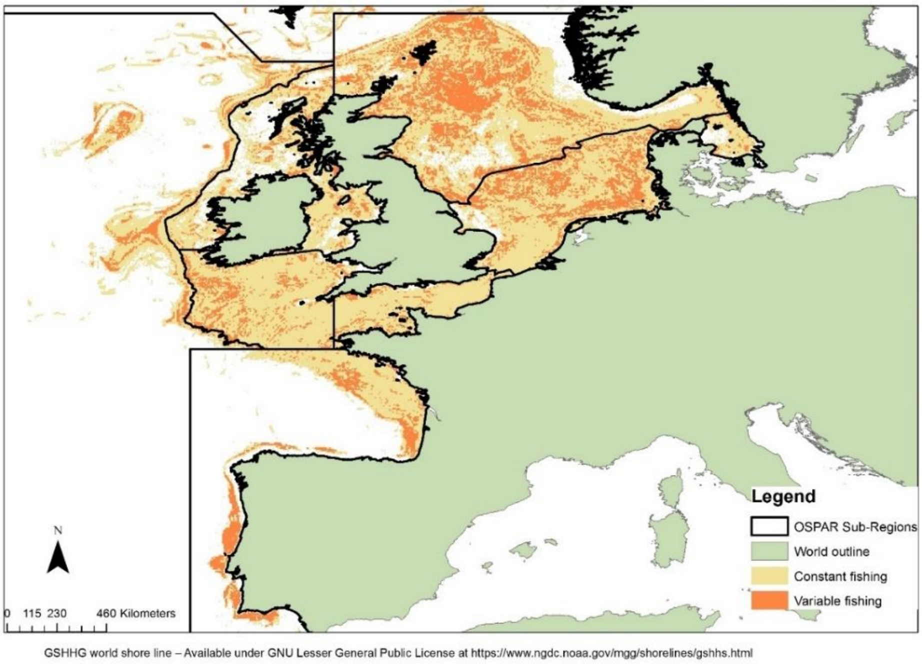


Figure 6.2.15. Spatial distribution of variable and constant fishing using 2010–2015 data series. Variable fishing is defined when a grid has a change of three or more pressure categories.

In order to produce a layer showing the aggregated surface and subsurface pressures that took into account the variations on fishing pressures across years, a generic rule was used:

- For cells with *low variability* (consistent fishing: i.e. constantly under a similar fishing pressure) the mean of SAR across all years is calculated,
- For cells with *high variability* (i.e. fishing pressure variable) the highest SAR value across all years is selected to define the pressure category as it represents the maximum level of exposure within the cycle.

The resulting fishing pressure maps applying this method are shown for surface abrasion (Figure 6.2.16) and Sub-Surface Abrasion (Figure 6.2.17).

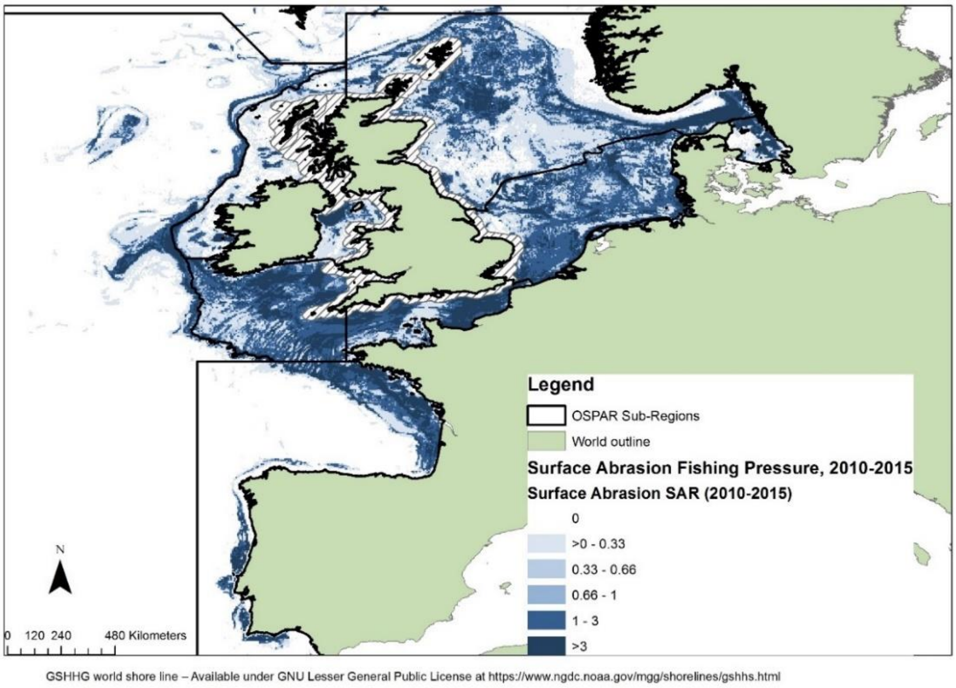


Figure 6.2.16. Aggregated Surface abrasion pressure using 2010–2015 data series. Pressure unit is swept area ratio (the proportion of grid cell swept by fishing gear). The hatched area around the UK showing the areas where inshore fisheries activity from vessels < 12m is higher than those >12m.

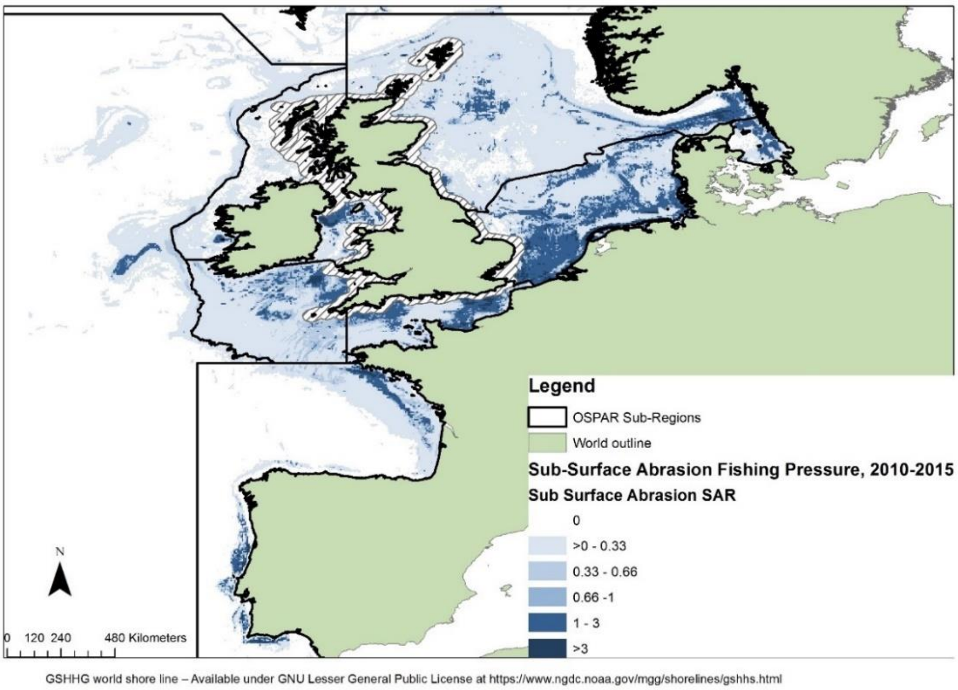


Figure 6.2.17. Aggregated Sub-Surface abrasion pressure using 2010–2015 data series. Pressure unit is swept area ratio (the proportion of grid cell swept by fishing gear). The hatched area around the UK showing the areas where inshore fisheries activity from vessels < 12m is higher than those >12

Step 4: The combination of pressure intensity and habitat sensitivity

The degree of disturbance of a habitat is a prediction based on the spatial and temporal overlap of its sensitivity and exposure to a specific pressure. As a first approach to set up a disturbance matrix for the pressure 'abrasion', the modelling results of Schroeder *et al*. (2008) using fishery-induced mortality rates of selected benthic species with different ecotypes (r- and K-selected species) for the fishing gears beam and otter trawl were used as a basis. The decrease in abundance was averaged over the different species and gears to obtain a logarithmic curve for the physical impact of bottom trawling. The values derived from the function were applied to create a disturbance matrix combining sensitivity and extent of pressure (BioConsult, 2013).

The results from the sensitivity and pressure spatial layers are combined via this matrix, producing ten categories of disturbance (0-9, where 0 is no disturbance, and 9 is the greatest amount of disturbance possible) (Table 6.2.10). The matrix is used to calculate the disturbance for each surface and sub-surface abrasion per year. The highest value from both disturbance categories is then selected to calculate the combined disturbance values.

Table 6.2.10. Disturbance matrix combining extent of pressure and habitat sensitivity.

Disturbance matrix		Habitat sensitivity 1	2	3	4	5
	0	0	0	0	0	0
Extent of pressure	1	1	2	3	4	6
	2	1	2	4	6	7
	3	1	3	5	7	9
	4	1	4	6	8	9
	5	2	4	7	9	9

At present other activities which could cause physical damage pressures are not included. It is anticipated that due to the different nature of the pressures 'selective extraction', 'abrasion' and 'changes in siltation', separate disturbance matrices or algorithms will be required which will take into account the spatial distribution of pressures and the temporal effects. This information is not currently available and will be included on the next round of assessments for an overall calculation of disturbance caused by physical damage.

Step 5: Disturbance aggregation method and trend analysis

Surface and Sub-Surface disturbance were combined by selecting the highest disturbance in each given area. Disturbance values across years are combined using the aggregated fishing pressure spatial layers, developed in step 3 above. Results are used to calculate trend between years in those grid cells or c-squares identified as variable. This allows the variation of disturbance across years per habitat type to be assessed. The trend analyses are simple plots over the six-year period, rather than a linear regression which was not possible due to the small number of years assessed. For the purpose of the aggregation a simple rule was chosen based on expert judgment using the moderate disturbance values as the middle point for the split. Using this rule the disturbance categories were aggregated into two groups:

- Disturbance categories 0 to 4, representing lower levels of disturbance;

- Disturbance categories 5-9, representing higher levels of disturbance.

Results from the assessment can be seen in figures 6.2.18-20 below.

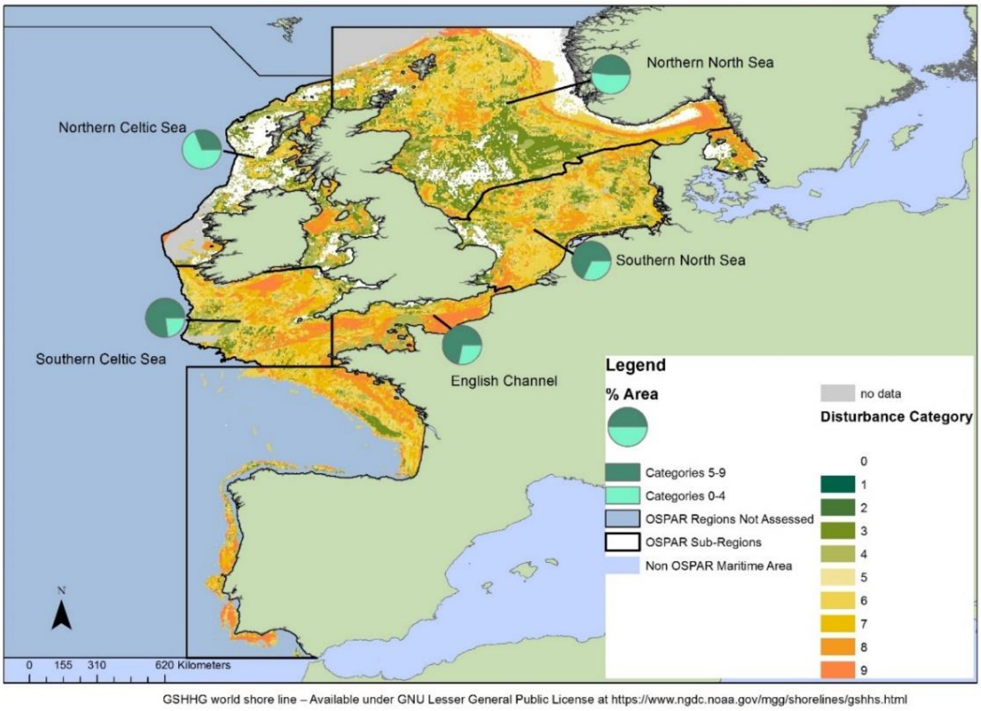


Figure 6.2.18. Spatial distribution of aggregated disturbance using 2010–2015 data series across OSPAR sub- regions. Disturbance categories 0–9, with 0= no disturbance and 9= highest disturbance. Plots show percentage area of OSPAR sub-regions in disturbance categories 0–4 (none or low disturbance) and 5–9 (high disturbance) across reporting cycle (2010–2015).

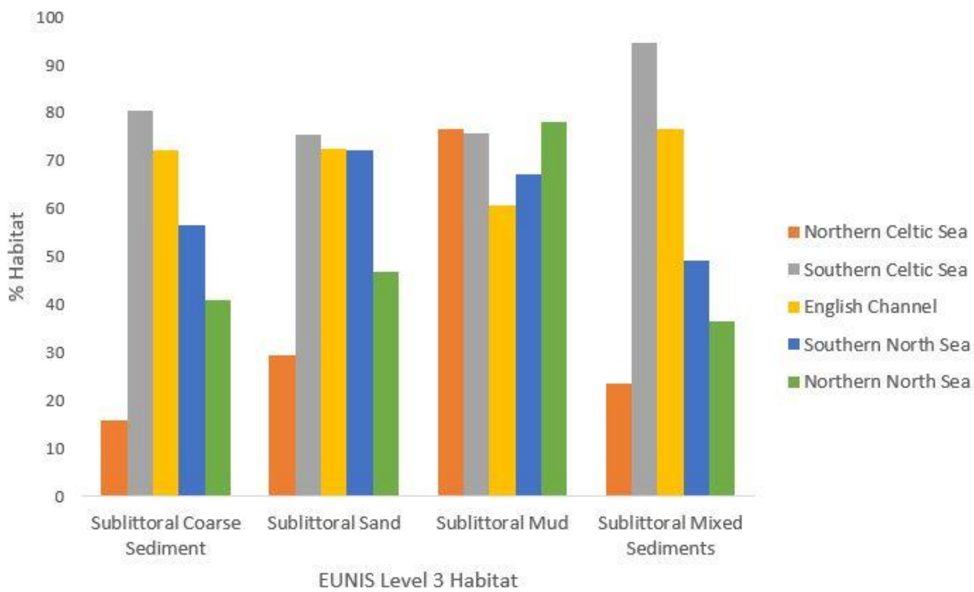


Figure 6.2.19. Percentage of habitat with disturbance category 5–9 in OSPAR sub-regions for coarse, sand, mud and mixed sediments

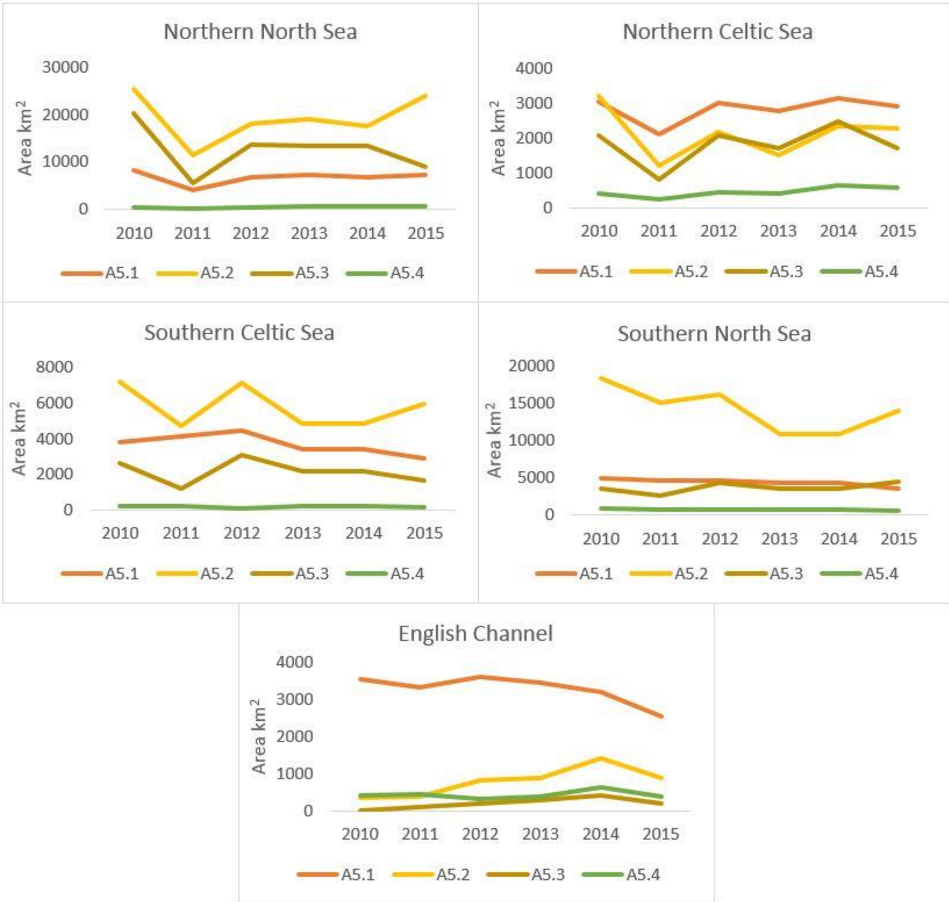


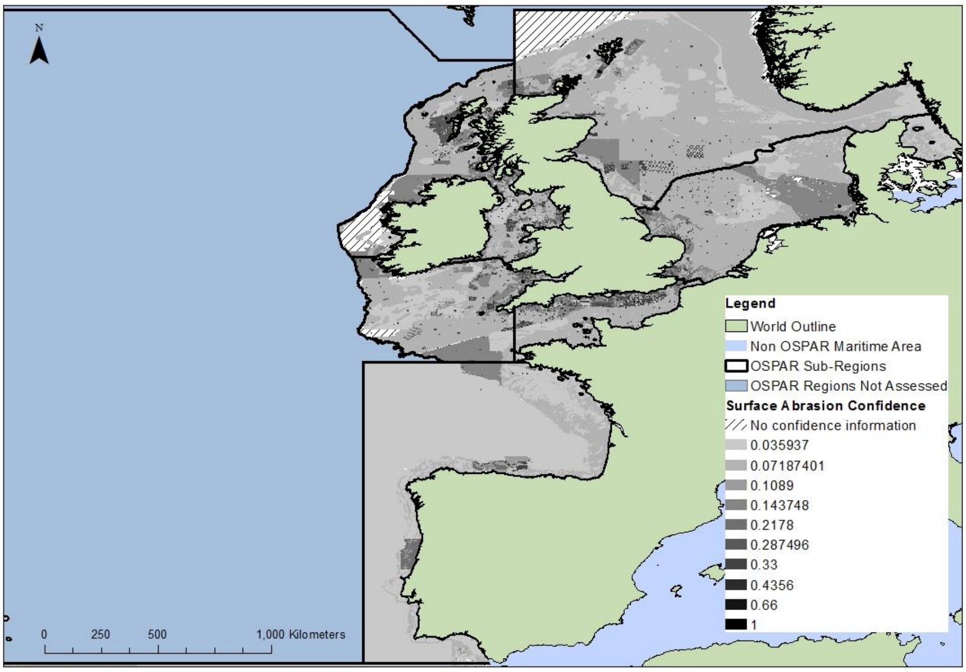
Figure 6.2.20. Trend analyses for a selection of habitats (A5.1- Sublittoral Coarse Sediment, A5.2- Sublittoral Sand, A5.3- Sublittoral Mud and A5.4- Sublittoral Mixed Sediments) per sub region for area (km²) with disturbance in categories 5-9. Only cells with high variability in fishing pressure are shown

Step 6: Confidence assessments

In order to spatially represent confidence in the available data, a numeric method of calculating confidence was adapted from OSPAR (2015). The method multiplies relative measures of confidence on a scale of 0 to 1, where there is a difference in confidence between categories or classes used in a data layer.

A numerical score (0.33, 0.66 or 1) was manually assigned by the assessor to each of the different attributes used to create the sensitivity layer. A high confidence score was given a numeric value of 1, medium 0.66 and low 0.33. The different methods used to create the sensitivity layer were taken in turn and a numeric confidence score was assigned to each of the attributes: confidence based on underlying data; confidence within data source (such as MESH confidence for habitats); and confidence in the sensitivity of the habitat to a pressure.

The resulting confidence map can be seen in Figure 6.2.21.



GSHHG world shore line – Available under GNU Lesser General Public License at https://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html

Figure 6.2.21. Spatial distribution of confidence assessments for the physical damage indicator.

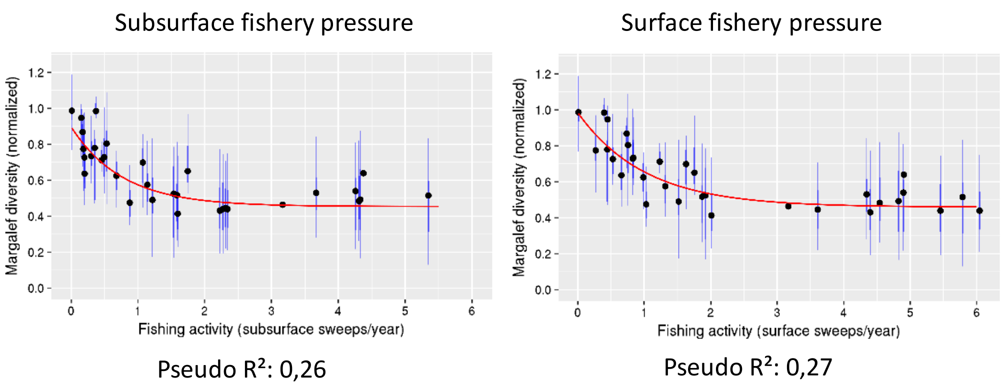
6.2.4 BH2 – multimetric index

The BH2 is an assessment approach that develops (a) a common benthos assessment method, which is the most sensitive and precise for common pressures in the Southern and Northern North Sea, especially fisheries and organic enrichment, (b) is the most precise to model reference values, (c) shows the best assessment precision and (d) is suitable for use as a common method within the Southern North Sea, and potentially in other European marine regions (van Loon et al. submitted). Margalef diversity appeared to be the best performing benthic index regarding these 4 criteria, even better than several MMI combinations with e.g. AMBI and the Infaunal Trophic Index. Therefore, this relatively simple and very practical index and reference estimation method was selected as benthos assessment method for European OSPAR and MSFD applications, and applied to the benthos data from the Southern North Sea in the period 2010–2015. The results show in general lower normalized Margalef scores in coastal waters, and higher normalized Margalef scores especially in the deeper offshore water.

Reference values of the tested benthic indexes (species richness, Margalef diversity, SNA index, Shannon index, PIE index, AMBI, ITI) were estimated using index values from a 6 year period, and an improved variable percentile method, in which the percentile value used is adjusted to the average ICES fishing pressure in the period 2009-2013. The percentile values used were 75 (low fishing pressure), 95 (medium fishing pressure) and 99 (high fishing pressure). The estimated reference values obtained using this method appeared to correlate quite well with the median depth of the assessment areas, with model precisions of R^2 0.86 for Margalef (sigmoid model) and R^2 0.95 for SNA (linear model). It appeared that this depth-reference value of Margalef was quite useful to assist in the estimation and confirmation of reference values, for example in the case of insufficient benthos data within an assessment area.

For the fisheries-index testing normalized index values were used (index value divided by estimated reference value), because it was assumed that the same level of fisheries pressure has a larger absolute effect on more biodiverse and deeper living benthic communities compared to more robust benthic communities in the coastal zone, but that the relative effect, tested using normalized index values, is comparable. A clear exponentially decreasing relation (R2 0.26, $p < 0.00001$) between both subsurface and surface fishing activity and normalized (assessment value divided by reference value) Margalef diversity values was found, with an asymptotic normalized Margalef value of approximately 0.45 at a fishing activity >2.3 subsurface sweeps/year. This asymptotic value is predominantly found in coastal waters, and probably shows that the naturally already more robust benthic communities have transformed into resilient benthic communities, which are not sensitive any more to increasing fishing pressure (Figure 6.2.22).

The results of the above analysis need to be interpreted with caution, since the reference values were set in dependence of the observed trawling intensity, the response variable (Margalef diversity) is arithmetically dependent on the predictor variable (trawling intensity). Hence the observed relationship with trawling intensity may be (partially) related to the setting of reference values in relation to trawling intensity.



	subsurface	Surface
function	Y=b0+b1*exp(b2*X)	Y=b0+b1*exp(b2*X)
B0	0.4547636	0.4601551
B1	0.4429882	0.5260321
B2	-1.3004540	-0.9873331

Functions: Y is EQR(d) en x is fishery induced pressure.

Figure 6.2.22. Relationship between the Margalef diversity indicator and trawling intensity for surface and sub-surface abrasion

6.2.5 Life history approach

This method was developed in FP7-project DEVOTES. This developing approach (Beauchard *et al.*, in preparation) is based on the Habitat Templet Concept that considers species-habitat specificity (Southwood, 1977; Southwood, 1989): complex combinations of traits expressing reproduction, motility, trophy and resistance form can translate species ability to survive in specific conditions. These traits formally express the three facets of fitness, growth, survival and reproduction (Darwin, 1859). Resistant species are supposed to be adapted to physical stress and may provide strong reproductive allocation (e.g. continuous reproduction to sustain reproductive success), other species may remain resilient to disturbance (e.g. dispersal capability for re-colonisation), whereas some others from stable environment may be more adapted to biotic interactions (e.g. predation, competition). Here, only response traits matters as they express performances under different kind of natural environmental variability such as disturbance, stress and favourableness. This approach indicates beam-trawl impact simply through individual, biomass or species density depletion.

An application example from Dutch marine waters is provided as an illustration on what could be generalized over entire shelves. Twelve response traits of 183 taxa widely distributed over the European north-west shelf were compiled. Taxa were clustered after a multivariate ordination of the taxa × traits matrix, and the subsequent typological groups were used as community descriptors indicating the degree of species adaptation to natural constraints (e.g. shear stress or storm). Then, the functional nature of a community (at a sampling location) can be expressed by the relative densities of the different groups (in terms of individual or biomass density). Figure 6.2.23 displays the resulting typology and its coherence with theoretical considerations.

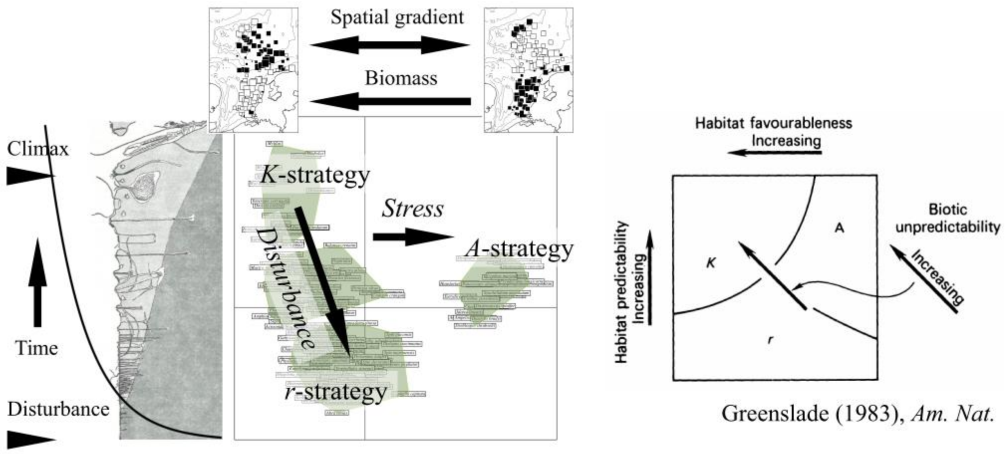


Fig. 6.2.23. Typological groups resulting from the clustering of the taxa × traits table ordination (right) and comparison to the Habitat Templet Concept (left). The horizontal axis opposes environmental conditions favouring biomass production (left) to stressed conditions (right); above maps indicate in black where these habitats and associated fauna occur. In non-stressed conditions, the vertical axis ordinates taxa according to marine benthic ecological successions following a disturbance (Pearson and Rosenberg, 1978).

Although four groups were identified by the clustering, three functional poles can be distinguished as three life history strategies:

- A-strategy ("A" for adversity selection; Greenslade, 1983) in stressed conditions (continuously oscillating abiotic conditions); organisms has a short life span, an early maturity, continuously reproduce and release progenies with a high degree of survival;

- r-strategy; these species are largely documented in the marine literature, and mainly consist in pioneer and opportunistic organisms of fast growth with local dispersal;

- K-strategy; these species succeed to the previous one along ecological successions and exhibit the most vulnerable functions such as slow growth, late sexual maturity and absence of parental care.

For obvious reasons, the taxa exhibiting the K-functionalities are those used to identify the habitats the most vulnerable to physical damage induced by beam-trawling. Beam-trawling is supposed to mimic natural variability (bottom water currents and storms), and its effects on A- and r-strategists were hypothesized to be neutral or positive whereas they were hypothesized to be negative on K-strategist densities (second and third groups along the second axis of Figure 6.2.23). These theoretical considerations involve an adequate vocabulary to avoid any confusion. In the process of impact, two functional abilities can be distinguished; "sensitivity" characterises the species response through either absence of response, damage or death; complementary, the temporal nature of "recoverability" expresses the ability of a population to survive after damage and/or to recolonise after mortality. Following these definitions, a vulnerable species logically represents what should be expected from a reliable indicator (Table 6.2.11).

Table 6.2.11. Species typology in response to the effect of beam-trawling.

Functional ability	Species type		
	Resistant	Resilient	Vulnerable
Sensitivity	None	Low or High	High
Recoverability	Not applicable	High	Low

The test area, the Dutch EEZ, comprises two contrasting habitats, a shallow and hydrologically stressed habitat and a deep and non-stressed habitat (Fig. 6.2.23). The relevance of the life history approach is assessed by bivariate relationships between response variables and trawling intensity after removing environmental effect according to the procedure described in ground-truthing page X. Three metrics can be considered: individual and biomass densities, and species richness, expressing the demographic, productive and compositional dimensions of organism communities, respectively. Several tested variables can be considered of potential interest as indicator of beam-trawling impact as (1) they respond significantly to fishing intensity ($p < 0.05$) and (2) as the sign of variation is consistent with the theoretical predictions illustrated in Figure 6.2.23: positively in the case of r- and A-strategists, and negatively in the case of K-strategists (Fig. 6.2.24). This supports the resistant and resilient nature of the first ones, and the vulnerable nature of the latter.

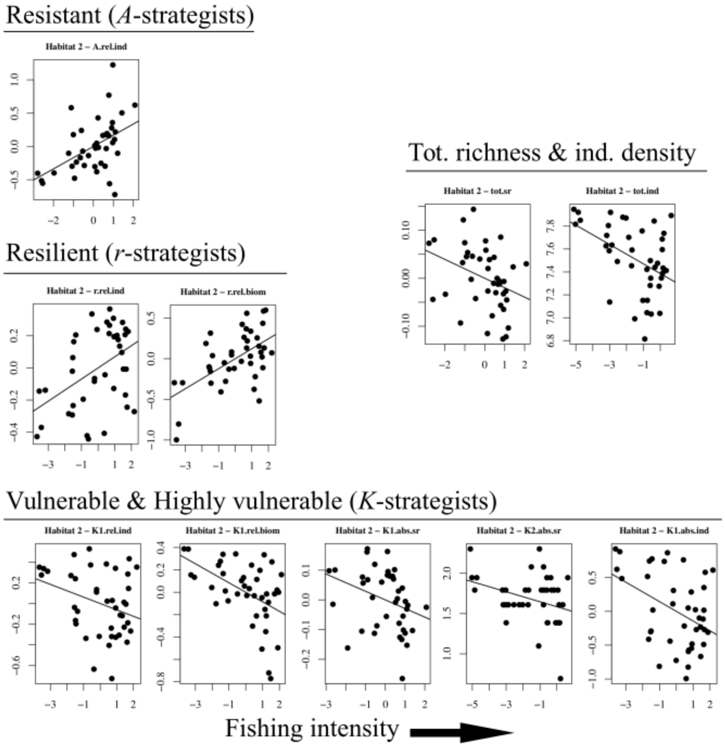


Fig. 6.2.24. Significant responses to trawling intensity ($p < 0.05$) among all the tested biological variables in the deep habitat (non-exhaustive list). Each response variable resulted from the aggregation of species densities from each sampling location according to their typological group. Explained variance by fishing intensity ranges from 3 to 24 %.

Reference conditions can be easily assessed when a pressure on the sea-floor like beam-trawling is largely dominant among others. Reference indicator values were computed from the conditional relationships between each indicators and trawling intensity (after removing environmental influence); the amount of biological information (i.e. individual or biomass density, or number of species) depleted by trawling was quantified by the difference between response predictions and response value for which trawling intensity equals zero (Fig. 6.2.25). Then, this depleted value was added to the observed field value. Note that impact (ratio depletion/reference) can be also assessed in this way.

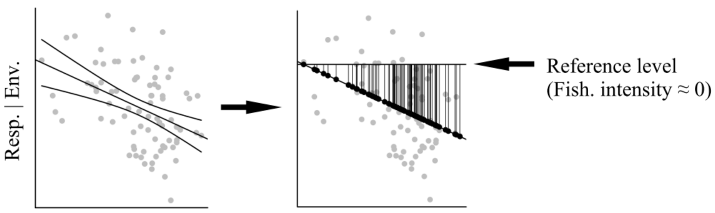


Fig. 6.2.25. Computation of the reference level for any variable responding significantly to trawling intensity. The deviation between the predictions (black dots) and the y-value for which trawling intensity is null (horizontal line) represents the biological depletions specifically caused by trawling since colinearity with environmental descriptors is removed from both dependent and explanatory variables. This depletion is then added to the raw observed field value.

Illustrations of resulting patterns are provided by four indicators responding significantly to trawling intensity over the whole area (Fig. 6.2.26). The first three indicators clearly point to the higher sensitivity of the deep habitat compared to the naturally stressed one in the shallow area. However, the pattern can slightly differ depending on the metrics expressed in the indicator, depending on individual density, biomass density or species density. Additionally, the fourth indicator, expressing the biomass ratio of vulnerable species over the sum of resistant and resilient ones, highlights local sensitivities in community structure.

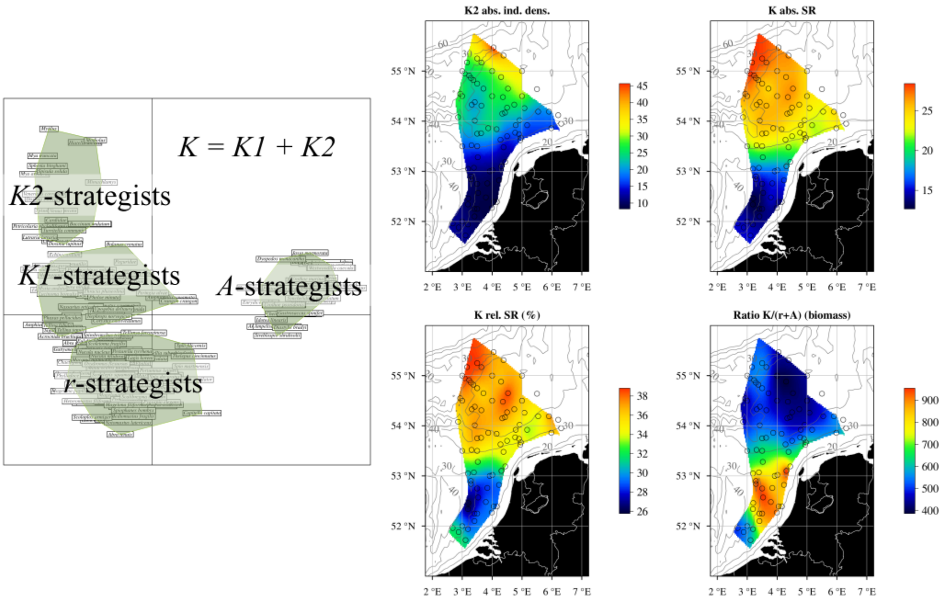


Fig. 6.2.26. Illustrations of reference patterns from four selected variables found to respond significantly to trawling pressure. "abs." refers to absolute density of individual ("ind."), "rel." to relative density and "SR" to species richness. See "section 7.2.5." for description of the functional nature of the four different strategist groups.

Ecological indicator development is challenging as it requires a strong understanding of ecological functioning in species communities. Therefore, theoretical biology remains a prerequisite before any applied development. The advantage of the life history approach is that it directly takes the theoretical constraint into account. Although this approach does not inform on the sea-floor functions that can be affected by trawling, it may be relevant in this respect as functions depend on organisms that are themselves habitat-specific as demonstrated by the approach. Implicitly, the approach assumes that species and/or biomass loss is functional loss.

The development presented in the example from the Dutch waters fulfils several general quality criteria required in ecological indicator development:

- mechanistically understandable

- theoretically-sound based

- possibility to compute a reference level

- possibility to assess the degree of impact in respect to the reference level

Also, the approach is not spatially limited as the 12 involved traits are now documented for more than 300 species distributed over the north-west shelf.

Developments on an indicator expressing explicitly sensitivity and recovery potential based on a selection of specific traits are ongoing as part of the ICES WGBIODIV working group. The provisional outcomes clearly evidence the advantage of using several traits over the use of individual traits. A recovery component integrating age at sexual maturity is shown to have a dominant significance over all tested components and sub-components; combined with a sensitivity component, indicator responsiveness is improved. Although this mechanistic investigation shows that tested variables were found to respond significantly over the whole study area, they were mostly responsive in the deep habitat, with a large absence of significance in the stressed habitat; this last results provides coherence with the provisional outcomes of the longevity approach. For the time being, important environmental descriptors used in this test-area were not available over the whole shelf. Optimal predictions will be done in the course of 2017 after getting appropriate data available at both spatial scales. Nevertheless, some similar outcomes from both approaches in shallow stressed habitats seem to appear. In any case, the longevity approach provides a practical applied advantage in decision making (time of fishing exclusion in order to enable recovery), but the mechanistic reliability of life span as indicator of recovery will deserve some theoretical and analytical explorations.

6.3 Comparison of sensitivity maps across assessment methods

6.3.1 Sensitivity maps

Assessment methods are compared using the sensitivity maps of the benthic habitats. Sensitivity maps have been developed for the BH3 method, but sensitivity is also implicit in the other methods, if the fishing pressure is kept constant throughout the area. Depending on what value is chosen for the constant fishing pressure, the sensitivity will change. For the Population Dynamics models, the swept area ratio is set to 1, and for the Longevity methods, the swept area ratio is set to 0.2 to find the largest variation sensitivity.

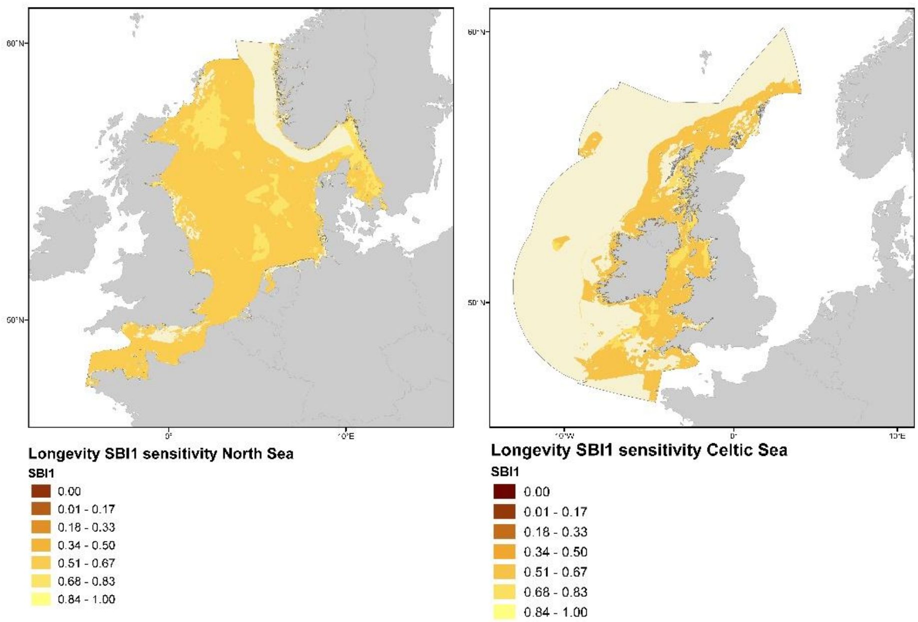


Figure 6.3.1: Sensitivity of the longevity Long-SBI-1 method if using a constant swept area ratio of 0.2, Greater North Sea and Celtic Seas.

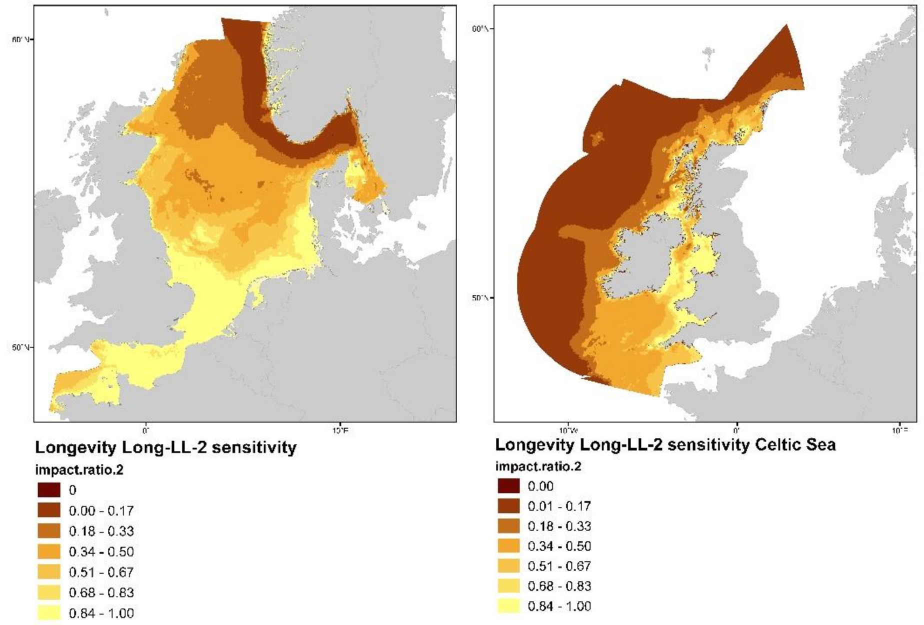


Figure 6.3.2: Sensitivity of the longevity Long-LL-2 method if using a constant swept area ratio of 0.2, Greater North Sea and Celtic Seas.

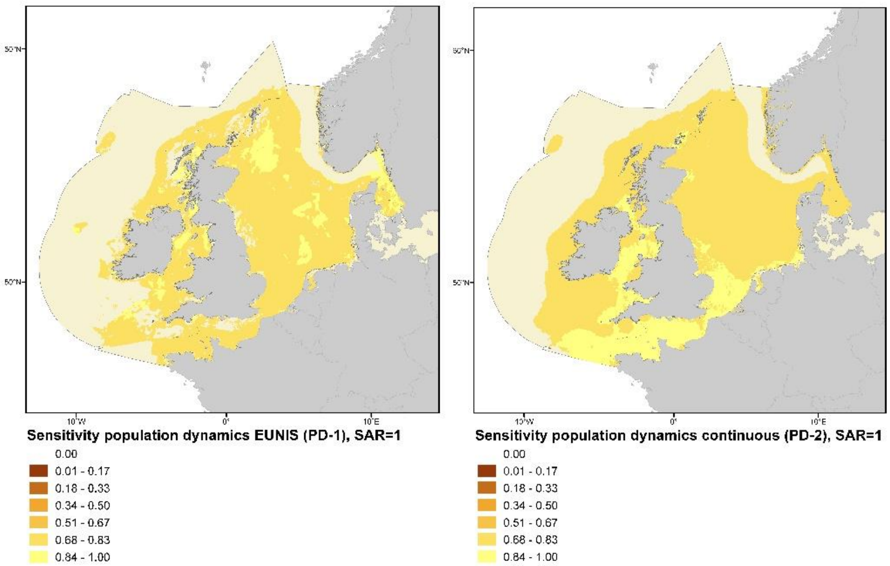


Figure 6.3.3: Sensitivity (B/K at SAR = 1 y-1) for population dynamics method based on EUNIS habitats (PD-1left) and continuous habitat variables (PD-2 right).

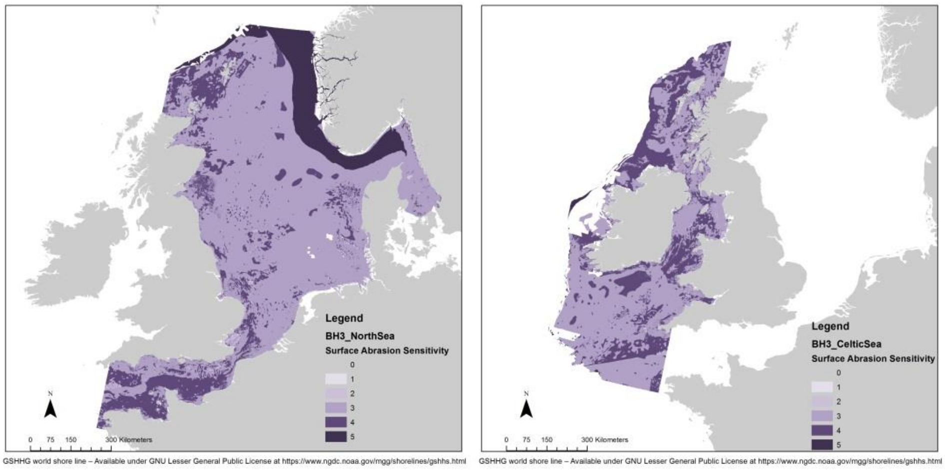


Figure 6.3.4: BH3 Surface Abrasion sensitivity maps for the Greater North Sea (Left) and Celtic Seas (right).

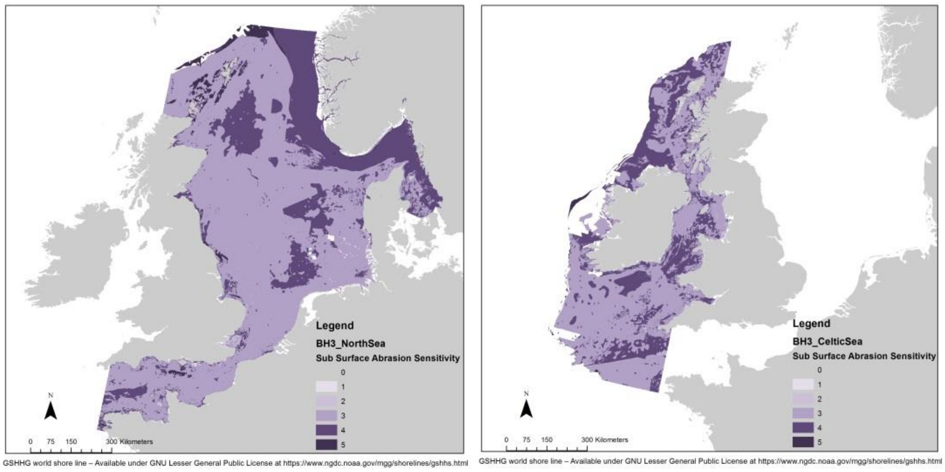


Figure 6.3.5: BH3 Subsurface Abrasion sensitivity maps for the Greater North Sea (Left) and Celtic Seas (right).

6.3.2 Cross correlation of sensitivities

To facilitate the comparison of the sensitivity maps, a cross correlation analysis was carried out between the sensitivity scores per grid cell.

In pre-analysis, it was noted that no major difference were detectable between the results for the two considered sea regions (Greater North Sea and the Celtic Sea). Therefore, results are presented solely for the Greater North Sea.

The correlations were executed both for a subset of EUNIS habitats and the full coverage of the Greater North sea (n=230 110) in R (basic cor/cortest function) using Spearman rank (for comparison with categorical scores) and Pearson correlation. Eight different assessments were considered (see Table 6.1.1). Sensitivity scores were available for PD1, PD2, Long-SBI1 and SBI2, Long-LL1 and LL2 and BH-3.

Results

Sensitivity scores were continuous (range 0.1) for PD1, PD2, Long-LL1 and LL2 and Long-SBI1 and SBI2, whereas sensitivity is expressed categorical (classes 0-9) in BH-3. However, single sensitivity values were assigned to individual habitats in approaches

PD1 and long-SBI1 (Table 6.3.1). Despite a continuous approach, also in PD2 the variation of the sensitivity within the EUNIS-2-habitats is low. The assignment of the sensitivity for BH-3 was done based on higher EUNIS-Level (4 or 5). Consequently, the sensitivity score range within the broad-scale habitats is rather large. Highest variability in sensitivity was found in the LL-approach. Almost the full range from low to high sensitivity was covered within EUNIS-habitats A4.3 A5.2 and A5.3, respectively.

Table 6.3.1. Sensitivity scores for selected EUNIS-habitats in the Greater North Sea presented as median and range (in brackets).

EUNIS HABITAT	PD2	PD1	LL	SBI1	BH3
A4.2	0.83 (0.75–0.84)	NA	0.82 (0.19-1)	NA	3.5 (0–4)
A4.3	0.81 (0.72–0.83)	NA	0.37 (0.09-1)	NA	3.5 (0–5)
A5.1	0.82 (0.71–0.84)	0.81	0.81 (0.14-1)	0.52	3.5 (0–5)
A5.2	0.82 (0.71–0.84)	0.83	0.54 (0.09-1)	0.58	3.5 (0–5)
A5.3	0.81 (0.73–0.84)	0.85	0.39 (0.10-1)	0.71	3.5 (0–5)
A5.4	0.81 (0.71–0.84)	0.83	0.66 (0.11-1)	0.66	3.5 (0–4)
A6.5	0.78 (0.74–0.82)	NA	0.11 (0.05-0.26)	NA	5 (3–5)

NA: not available for this habitat

Comparing the sensitivity scores for the different habitats within the individual indicators, it becomes apparent that the scores hardly vary at all in many indicators. In PD1 and PD2 the sensitivity score for all habitats is about 0.8. Long-SBI1 and BH-3 consider a median sensitivity for all habitats (Long-SBI1 range 0.52 – 0.71). Consequently, for all indicators basing on these sensitivity scores the calculated impact values strongly depend on the pressure layers and are highly correlated among each other (Table 6.3.2). A spearman-rank correlation was used for the correlation analysis. This was chosen as the analysis included one categorical approach (BH-3) and some of the other approaches were obviously not normally distributed. All comparisons indicated significant correlations between all indicators ($p < 0.05$). Correlation coefficients were highest comparing the EUNIS-based approaches (Long-PD1 and Long-SBI1) and the indicators using a continuous habitat approach (Long-PD2 and Long-LL2), respectively. The correlation between PD1 and PD2 was surprisingly weak keeping the very similar sensitivity values in mind showing the importance of the variability in environmental variables (depth, shear stress) within the EUNIS habitats. Nevertheless, as the range of sensitivity scores within the data set is rather narrow (0.71 – 0.84), small differences in sensitivity might lead to large differences in ranking.

Table 6.3.2. Spearman-rank-correlation for sensitivity scores in the Greater North Sea.

	PD2	PD1	LONG -LL (BOTH)	LONG-SBI1	BH3
PD2		-0.30	**0.70**	-0.31	-0.22
PD1			-0.42	**0.77**	**0.58**
LONG-LL (BOTH)				-0.36	-0.23
LONG-SBI					0.48
BH3					

As mentioned above, correlation between the impact scores was high between most of the indicators (Table 6.3.3) as the sensitivity highly correlated (Table.6.3.2) and the pressure map was identical for all approaches. However, the longevity approach with an empirical relationship between trawling and the longevity distribution of the community (Long-LL2) showed lowest correlation with the remaining indicators.

Table 6.3.3.: Spearman-rank-correlation for impact scores in a subset of the Greater North Sea (n=31 135).

	PD2	LONG_LL2	LONG_LL1	LONG_SBI2	LONG_SBI1	BH2	BH3_SURF	BH3_SUB
PD2		0.18	**-0.61**	**0.93**	**0.94**	**0.97**	**0.80**	**0.69**
LONG_LL2			0.46	0.23	0.04	0.07	0.16	0.03
LONG_LL1				-0.59	**-0.66**	-0.36	-0.50	-0.47
LONG_SBI2					**0.85**	**0.94**	**0.72**	**0.60**
LONG_SBI1						**0.86**	**0.70**	**0.73**
BH2							**0.77**	**0.64**
BH3_SURF								-0.54
BH3_SUB								

6.4 Impact scores and diversity indexes in case study areas

6.4.1 Comparison of impact maps

The various methods for estimating fishing impact on the sea-floor described above, have been applied at a regional scale to the ICES Ecoregions Greater North Sea and Celtic Seas for the time period 2009–2015 (BH3 2010–2015), using the same input data, described in chapter 6. The resulting maps for 2015 are found in figures 6.4.1-6.4.7 below, while maps for the whole time-series can be found in Annex 10.

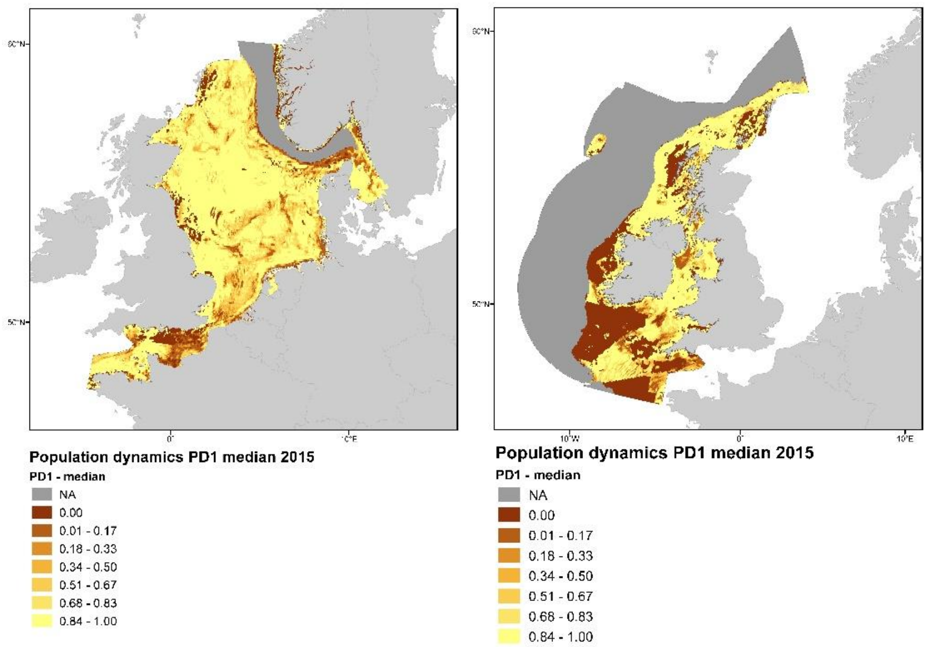


Figure 6.4.1: Population dynamics PD1 median 2015 Greater North Sea (left) and Celtic Seas (right) based on EUNIS habitats. Only applies to depths less than 200 m.

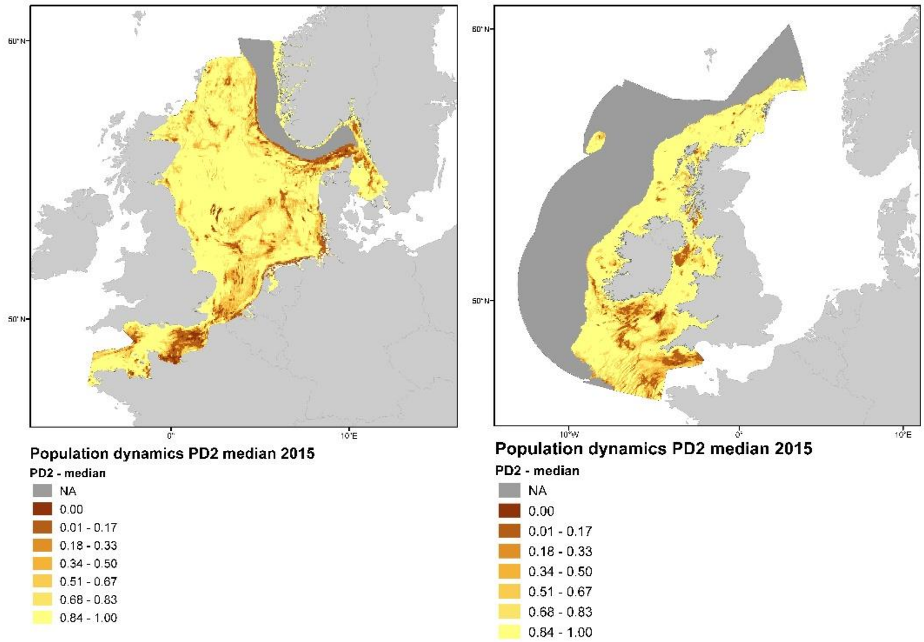


Figure 6.4.2: Population dynamics PD2 median 2015 Greater North Sea (left) and Celtic Seas (right) based on continuous habitats. Only applies to depths less than 200 m.

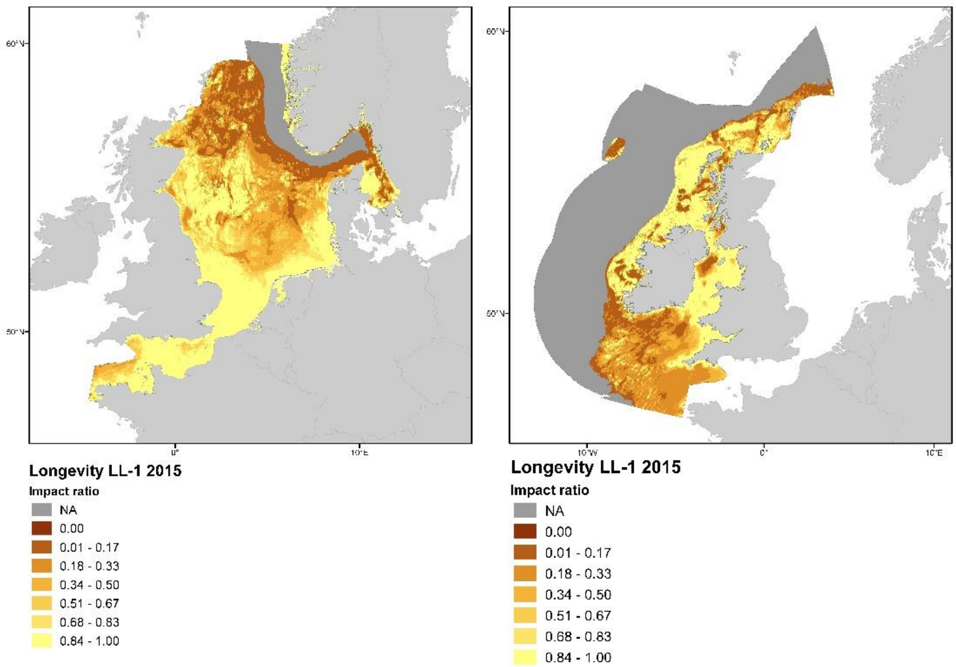


Figure 6.4.3: Longevity Long-LL-1 2015 Greater North Sea (left) and Celtic Seas (right) based on continuous habitats. Only applies to depths less than 200 m.

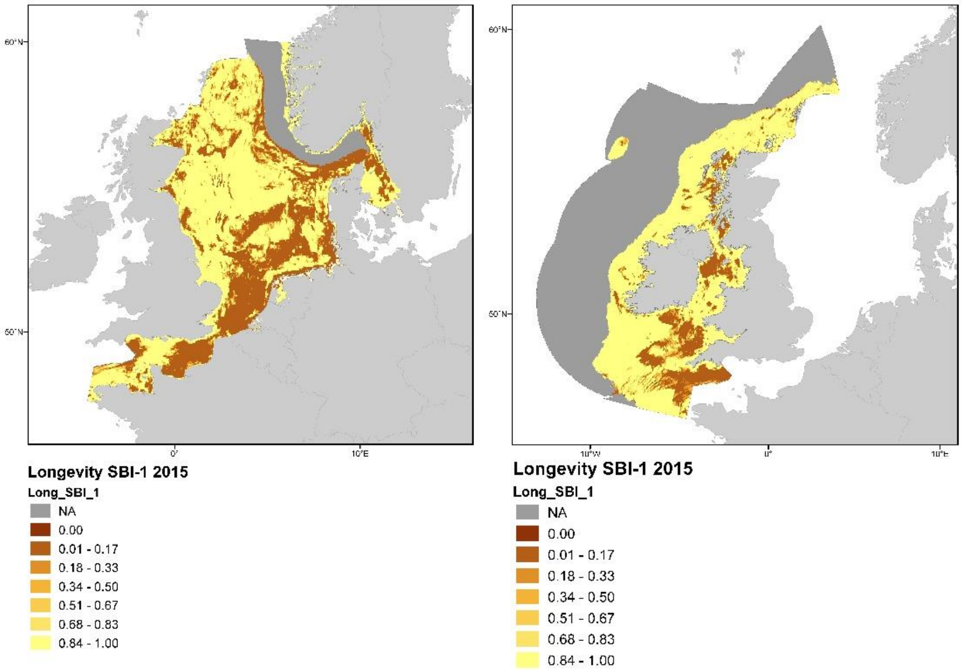


Figure 6.4.4: Longevity Long-SBI-1 2015 Greater North Sea (left) and Celtic Seas (right) based on EUNIS habitats. Only applies to depths less than 200 m.

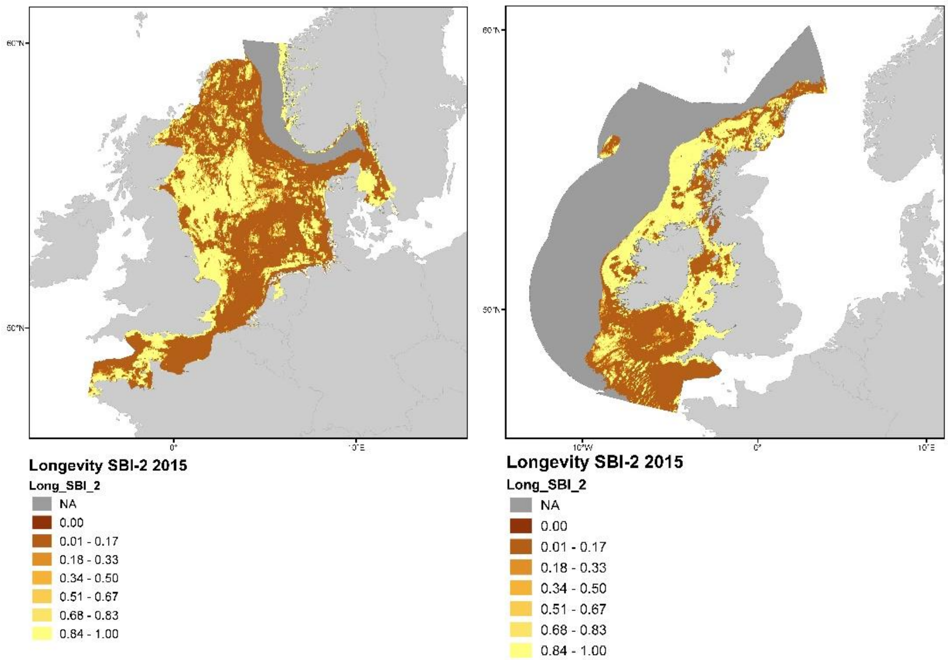


Figure 6.4.5. Longevity Long-SBI-2 2015 Greater North Sea (left) and Celtic Seas (right) based on continuous habitats. Only applies to depths less than 200 m.

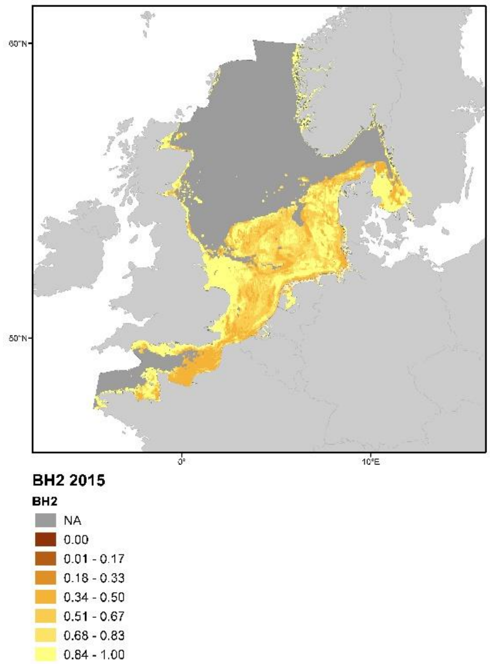


Figure 6.4.6 : BH2 (Margalef) 2015 Greater North Sea based on continuous habitats. Only applies to depths less than 50 m.

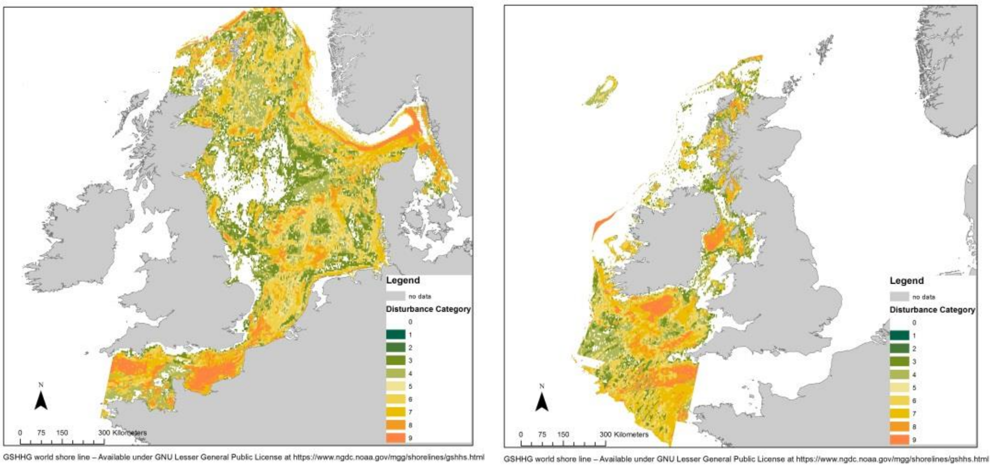


Figure 6.4.7: BH3 2015 Greater North Sea (left) and Celtic Seas (right).

6.4.2 Distribution of predicted benthic state values.

Figure 6.4.8 and 6.4.9 show the distribution of benthic state values for our different assessment models for the Greater North Seas and Celtic Sea in 2015. These histograms help in understanding how different GES threshold affect the area that is above and below the threshold. All widespread habitats exhibit the full range of possible state scores from 0 to 1. A large fraction of habitats are in a state close to 1 for each of the assessment methods because a substantial fraction of most habitats is not or very lightly fished. Some of the assessment methods seem to predict a binary response to trawling with mostly very low or very high state values (Long.SBI.1 &Long.SBI.2, and Long.LL.1 to a lesser extent), and for such methods the choice of GES threshold will have virtually no effect on the area that is in GES at a regional scale. To a lesser extent, this pattern is found for most assessment methods.

There exist distinct difference in the benthic state of different habitats, with mud bottoms (A5.3 and to a lesser extent A6.5) standing out as having a higher fraction of c-squares scoring low.

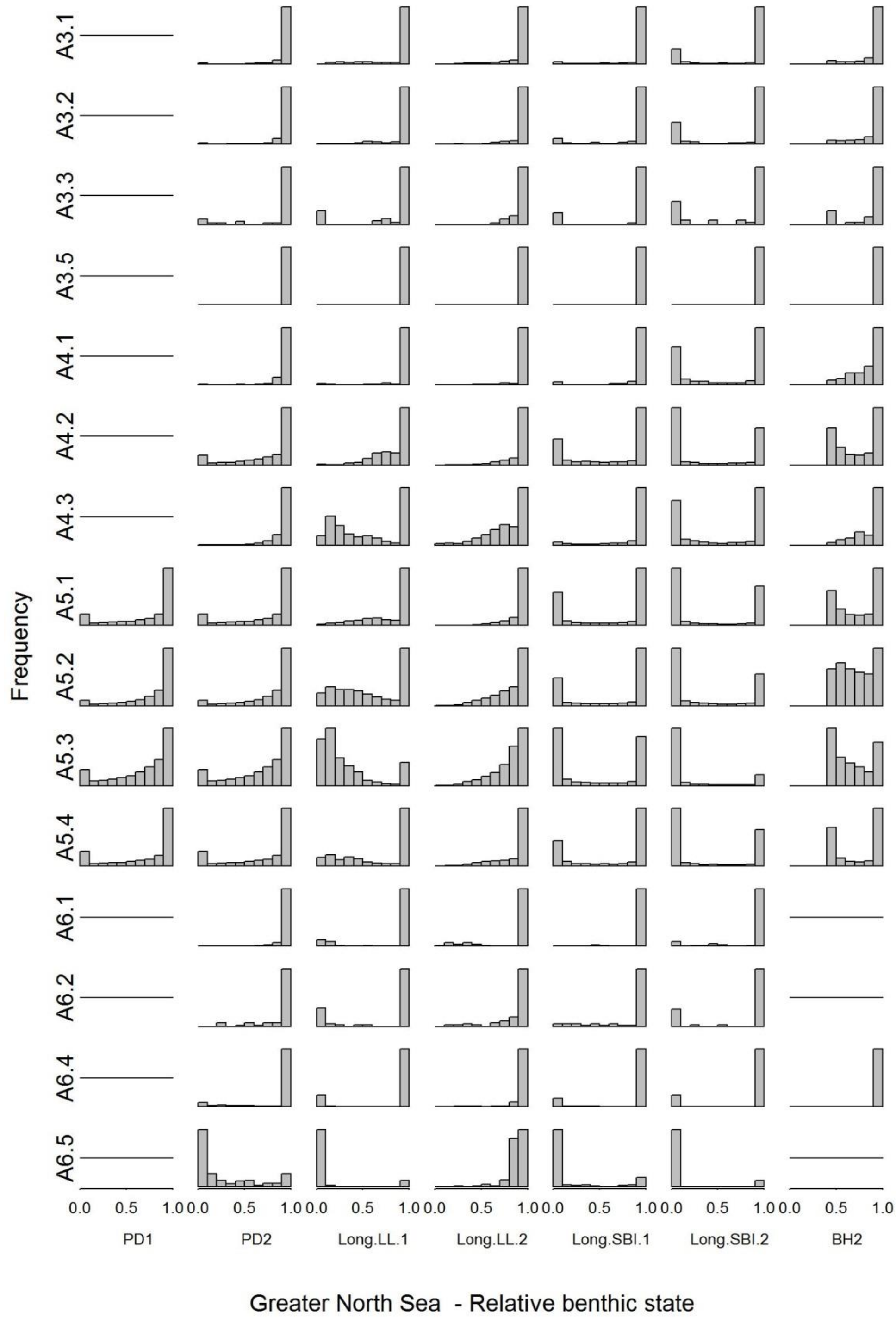


Figure 6.4.8: Histograms showing the relative benthic state by habitat for the Greater North Sea

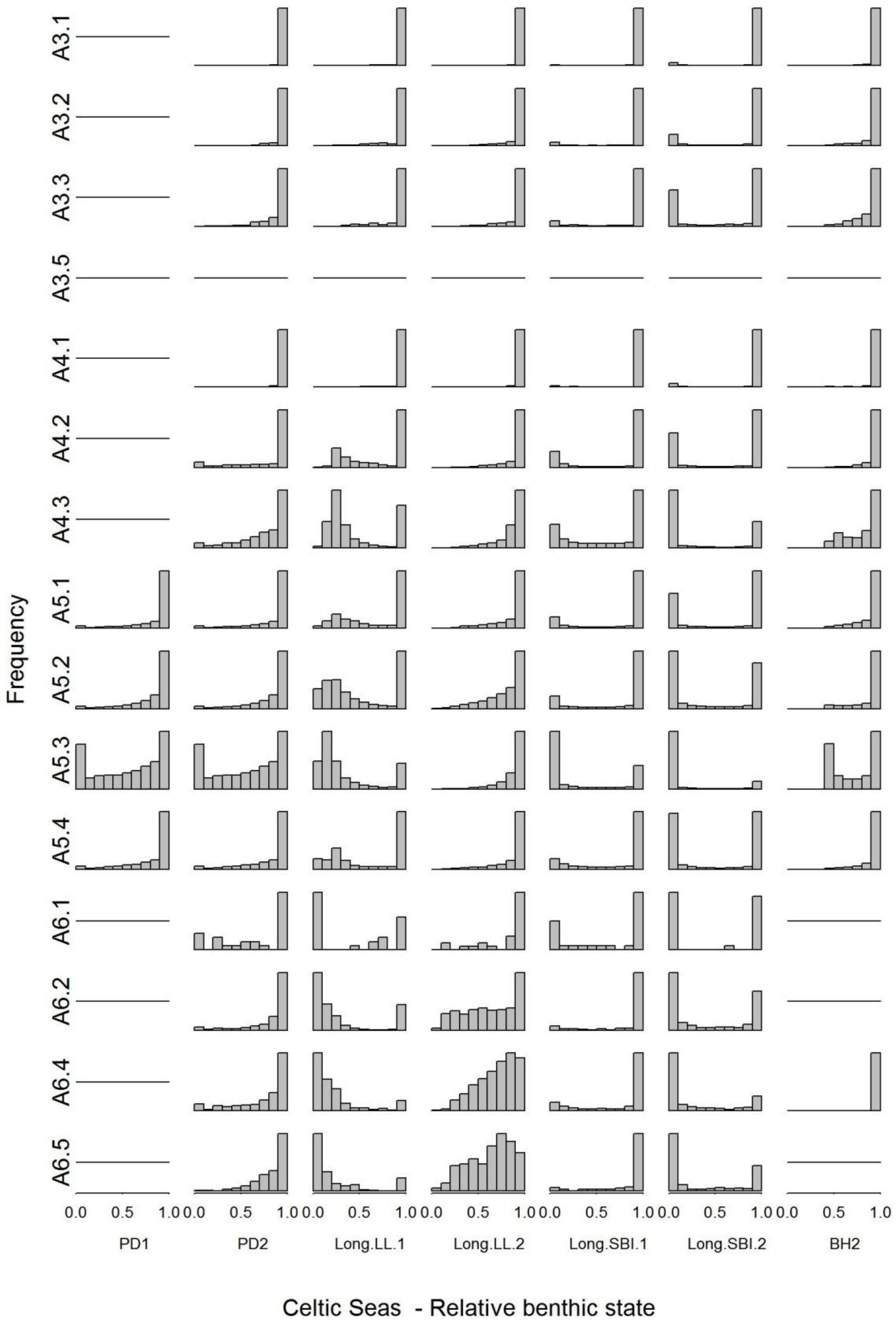


Figure 6.4.9: Histograms showing the relative benthic state by habitat for the Celtic Seas

6.5 Results: maps and indicators per ecoregion and habitat

Comparison of the sensitivity maps based on the longevity composition with the sensitivity maps from the BH3 showed a general correspondence between the sensitivities estimated by expert judgement (BH3) and those estimated from the longevity composition, except for the sea floor in shallow waters and habitats exposed to a high shear bedstress. The difference in the sensitivity estimate between the methods is due to the incorporation of a habitat dependent effect of trawling which was included in the longevity-2 (LL2) method but not in the others.

Comparison of the impact maps showed significant positive correlations between all methods, except for the longevity method LL2. A significant correlation was also observed with the Margalef index of species richness of the BH2 approach estimated from benthic samples in the North Sea in shallow waters (down to 50m). BH2 approach suggests that trawling reduces the margalef index but it is uncertain whether this result is influenced by the setting of reference values. The main differences observed between the impact maps are in shallow waters and areas exposed to high tidal shear bedstress by the longevity (LL2) method. This methods takes account of the reduced impact of bottom trawling in shallow waters and areas exposed to a high tidal shear stress. The overlapping impact maps produced by the different methods reflect that the gradients in fishing pressure are stronger than the gradients in sensitivity.

7 Ground-truthing indicator using empirical data sets

Ground-truthing is important to test the observations, assumptions and predictions of the different indicators and should be done with independent datasets across regions and habitats. In this chapter, a start is made on how to ground truth, based on available information and expertise among the WKBENTH participants. In a first section, we describe what need to be done, how and what is needed (criteria) for this process. In a second section, some case studies were described that focus on certain ground-truthing aspects. In the last section, a correlation analysis is made between the different indicator approaches to test their comparability.

7.1 Parameterization and data gaps – what's needed and where

Ground-truthing/ validation of the suitability of the available indicator outcomes should cover the full range of all underlying assumptions and data. Therefore, four specific levels of ground-truthing/ validation needs can be identified, based on the available indicators properties:

- The pressure maps,
- The underlying sensitivity maps,
- The final impact maps, resulting from a combination of the pressure and sensitivity maps
- The input data for pressure - impact relationships.

For all these levels, it has to be clear before ground-truthing (a) which aspects should be covered, (b) how to cover them (methods) and (c) which criteria are essential to focus on.

In general, for all steps/approaches of ground-truthing, the design, regarding temporal and spatial scale as well as sampling strategy of acquired ground truth data have to be considered in relation to those used by the indicator. Beside it, it has to be ensured if the indicators are sensitive in relation to other critical pressures (both natural environmental gradients and other large scale anthropogenic influences such as eutrophication), especially with respect to the scale of the ground-truthing study. A suitable method to define the operational scale of the indicator and habitat and to test the impact of other parameter on the variation explained is variance partitioning (see e.g. Annex 8 and 12).

With regard to the **pressure maps**, the underlying VMS-data should be checked considering the following criteria:

- Is the coverage/representativeness of the included fleet/ gear types similar throughout the full spatial range and for all habitats (including e.g., biogenic habitats)?
- What is the uncertainty or unknowns of VMS and log book-data and does this influence the results in a biased way?
- "Post aggregation of data" and how this is executed for the different sub-datasets (data in regard to space & time, national data)

As the pressure map analyses are comparatively well established for the moment, the focus in ground-truthing should lay on the indicators and the aspects of sensitivity and impact.

Ground-truthing of the estimated impact maps is not straight forward as they are based on **maps on the sensitivity of habitats/species.** These sensitivity estimates are based on expert judgement (BH3) or derived from the analysis of the effect of bottom trawling on the biomass or community composition of the benthic community (other methods).

Hence, ground-truthing / validation should focus on the underlying sensitivity maps as well as on the scientific basis for the quantification of the effect of trawling, including the métier specific impact. The ground-truthing of the sensitivity maps can be done considering the following criteria:

- What habitats are covered by the ground-truthing data set in relation to those covered by the indicator?
- Is a relevant trawling gradient covered for each habitat / combination of environmental variable to estimate the habitat dependent impact for the relevant métiers, in particular are comparable untrawled areas included?
- Is the ground truth data range in space and time suitable for the responsiveness of indicator?

Improvement of the assessments can be achieved by extending the empirical basis of the underlying sensitivity maps. Performing specific ground-truthing surveys is recommended. Future research should be focused on the collection of benthos data along environmental gradients and trawling gradients in areas and habitats where the data are scarce or not available, as well as experimental studies to study causality (e.g. link between differential outputs of indices) and to the scale (regional/local/grain size) in relation to impacts & scale in relation to habitats. They may either be designed as (1) BACI-studies on a local scale, (2) as comparisons between MPAs vs. fished areas (ideally covering the full fishing gradient) or (3) as monitoring of benthic succession after closure of specific areas for fisheries (with focus on recoverability).

Beside the relationships and maps also the pressure or impact thresholds generated from the different indicators need to be compared and ground truthed.

Ground-truthing gaps

Several WKBENTH reported indicators have been developed based on data from a particular region (mostly the North Sea). Therefore, ground-truthing / validation is essential for testing their applicability in other ecoregions (Mediterranean, Black Sea, Iberian coast, Baltic Sea), which is currently lacking. Some ground-truthing of assessing fishing impacts is performed based on certain Baltic case-studies (Kattegat, Fehmarn belt, Baltic Proper). With regard to indicator "BH-3", it should be mentioned that a similar (but not identical) approach is currently under development under HELCOM (status: pre-core indicator). In addition, instead of a Margalef-Index (BH2), BQI (Benthic Quality Index) has been chosen to assess the state of soft-bottom communities in the Baltic Sea. A first case-study from the Kattegat (Denmark) revealed that a weak but significant correlation between fishery pressures and BQI exists. However, BQI has not explicitly been developed for assessment of fishing pressure and intensive ground-truthing studies are crucial.

The ground-truthing in this report is mainly focusing on the relation of certain parts of the indicators (longevity, diversity) and the fishery pressure. Beside this, it is also essential to ground truth if the degree of impact or degradation in status in a certain area corresponds with these predicted by the models. Therefore, a benthic monitoring program with appropriate spatial and temporal scale in relation to fishery pressure is necessary, which is currently lacking in all areas. As in this report only parts of the indicators were ground truthed, more investment is needed to cover all aspects. Ideally, such process is executed on regional level by a comprehensive, independent dataset.

7.2 Ground-truthing of empirical relations

In this chapter, some case studies were described that focus on ground-truthing aspects, mainly related to longevity and simple benthic descriptors (density, biomass, Margalef diversity).

- Southern North Sea case study: testing longevity relationships in "unfished" areas for different habitats.
- Southern North Sea (NSBS dataset)
- Kattegat (Denmark): testing response of different benthic parameters and longevity against fishery pressure & linking with BH3 approach
- Kattegat & Gotland: testing response of longevity classes against fishery pressure
- Femern Belt area: Habitat specific impacts of fishery compared to natural stressors on benthic invertebrate community parameters

7.2.1 Southern North Sea (OSPAR dataset)

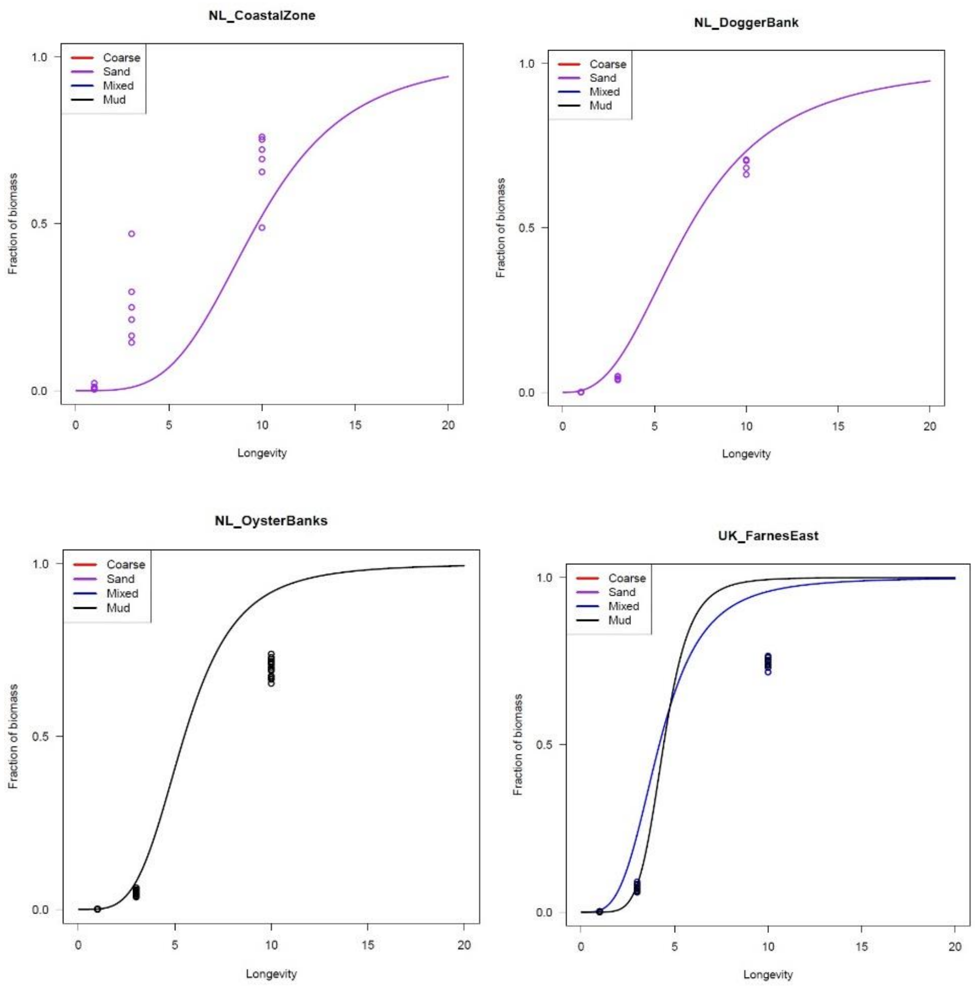
Table 7.2.1. Overview of amount of taxa covered by traits and individual AFDW information in each area.

AREA	Total taxa	Covered taxa by traits	Covered taxa by traits and biomass
BE_NorthSea	139	0,885	0,791
NL_DoggerBank	97	0,979	0,784
NL_Offshore	116	0,897	0,741
NL_OysterBanks	150	0,940	0,633
UK_HoldernessOffshore	155	0,929	0,555
NL_FrysianFront	130	0,908	0,646
NL_CoastalZone	90	0,844	0,811
UK_MarkhamsTriangle	152	0,875	0,592
UK_FarnesEast	318	0,843	0,384
UK_NEFarnesDeep	252	0,849	0,433
UK_SwallowSand	268	0,854	0,425
UK_NNorfolkSandbanks	139	0,914	0,576

Approach

Dataset with 1247 station in the Southern Bight of the North Sea from Belgium, Netherlands, UK) for the period 2010–2015. The data set contains 985 taxa, for which 90% of the taxa could be coupled with traits information. None of those missing taxa occurs in more than 5% of the samples. Some general taxa were excluded from the data, as Actinopterigii, Amphipoda, Bivalvia, Crustacea, Nemertea, Nematoda, Copepoda, Tubellaria. Biomass is determined based on mean individual Ash Free Dry Weight (AFDW), determined on benthic data from Belgium and the Netherlands. For 505 taxa (51,2%), a AFDW value was available. An overview of the amount of information available is given in Table 7.2.1. Fishing pressure data is coming from the surface and sub-surface abrasion estimates made on data of 2010–2015. With this dataset, the longevity curve in "unfished" habitat is tested with those predicted by the BENTHIS models.

Results: In Figure 7.2.1, the predicted distribution of longevity in "unfished" areas is ground truthed with the OSPAR BH2 data for certain areas and habitats. There seems to be a quite good comparability, except that the curves are more steep and seems to contain fewer long living species as in the predictions (except UK Holderness Offshore). As this is based on few data points (due to low amount of unfished locations), no strong conclusions can be made of it. But, it at least shows that it is necessary to ground truth this relation, especially for other habitats or regions.



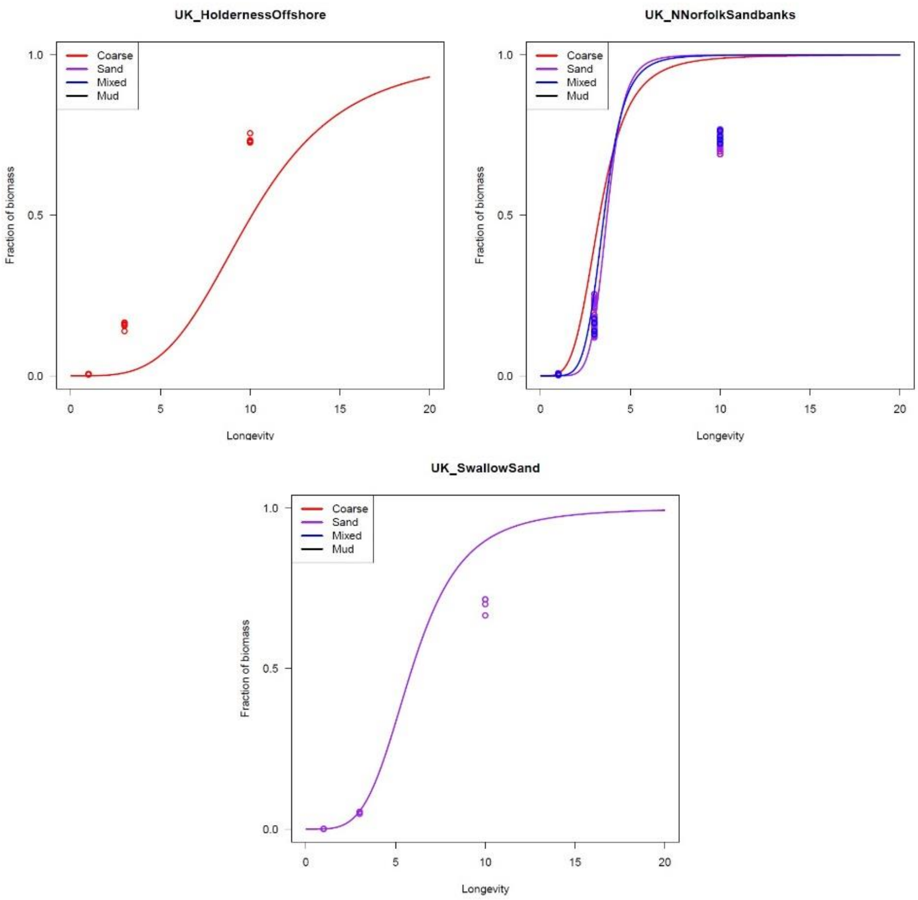


Figure 7.2.1. Longevity curves of certain areas/habitats in "unfished" areas. The dots in the plot show the predicted fraction of biomass by the BENTHIS model for these sampling stations, while the curve is predicted from the data from OSPAR.

7.2.2 Southern North Sea (NSBS dataset)

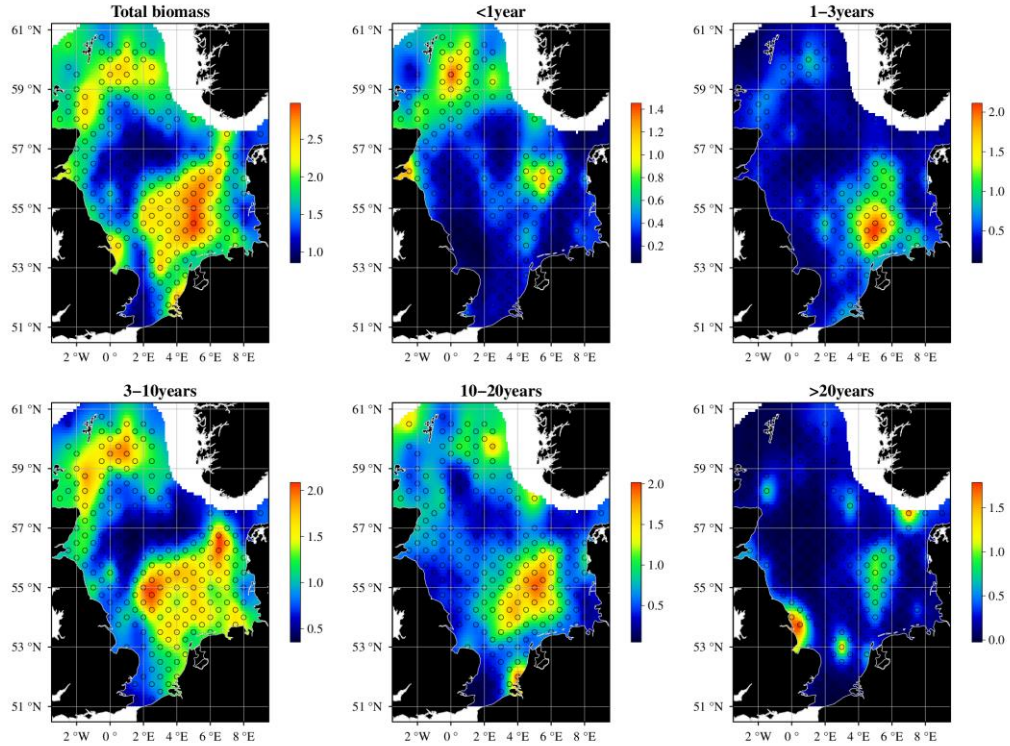


Figure 7.2.2. Absolute biomass per sample (log-transformed values of ash-free dry weight m^{-2}). Points represent the sampling locations.

The North Sea Benthos Survey data (NSBS; Heip *et al.*, 1992) were used for mapping biomasses per longevity class. The advantage of this data set is that it covers the entire North Sea and results from a highly harmonized sampling protocol using box-corer (Anonymous, 1986). Although biomass densities at the species level are not available in the NSBS data, individual species biomasses (ash-free dry weight) of 260 taxa sampled from 1991 to 2012 as part of the yearly monitoring of the Dutch EEZ (Daan and Mulder, 2009) were combined with the individual densities of the NSBS data (nb. individuals m^{-2}) to approximate biomass densities (ash-free dry weight m^{-2}). The taxa documented for both biomass and life span are widely distributed over the North Sea, encompass a largely dominant part of the total biomass and enabled to reproduce consistently Figure 1 in Heip et al. (1992). Figure 7.2.2. and Figure 7.2.3 displays the absolute and relative biomasses per class of life span, respectively.

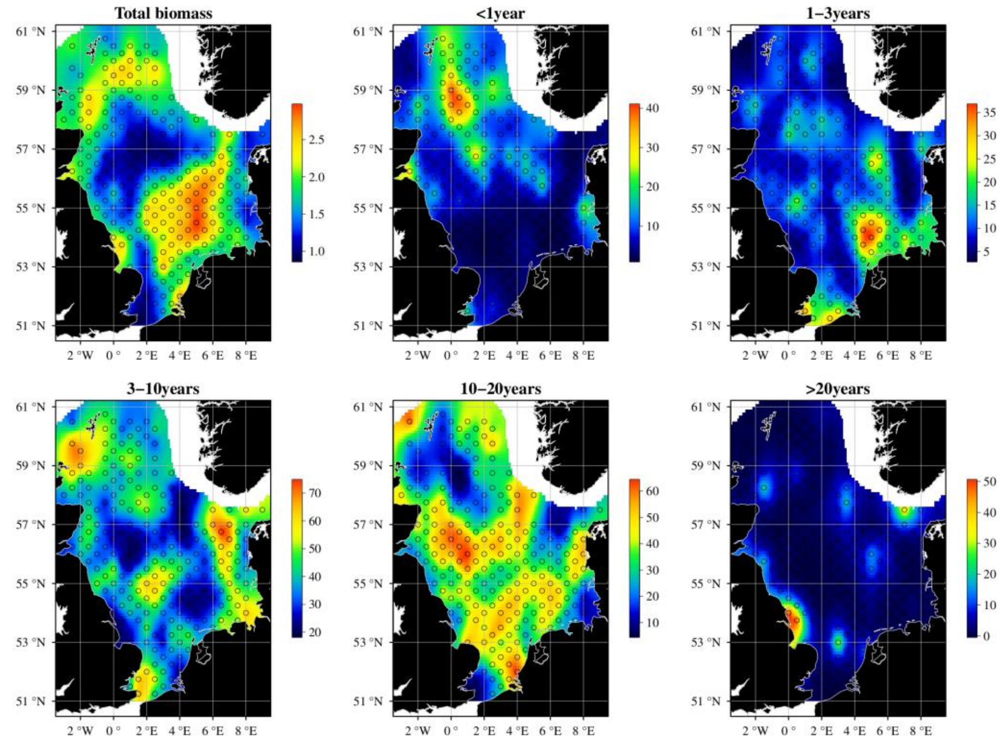


Figure 7.2.3. Relative biomass per age class in % of total sample biomass (ash-free dry weight m^{-2}) displayed in the top left corner. Points represent the sampling locations.

7.2.3 Kattegat, Denmark

The Kattegat and Danish straits harbors a bottom trawl fishery for Nephrops with surface abrasion ratios from more than 20 in the northern part down to zero values in Øresund where trawling has been prohibited since 1932. Data on macrobenthos species composition and density were available from 22 fixed station sampled in April-May over 7 years with a total of 5 replicate HAPS bottom corer samples collected per sampling event. Trawling intensity was estimated at each station and year from VMS and logbook data and cumulated for each sampling station within a circle with 2 km radius centered on the sampling station. Footprint estimates for the different gear types and vessel groups were taken from Eigaard *et al.* (2016). For each station average near bottom salinity, depth and seabed habitat classified at Eunis level 3 into coarse sand, sand, mud and mixed sublittoral sediments were available.

The impact of bottom trawling was analyzed to reveal how fishing affected the abundance of individuals in the four different longevity classes (<1y, 1–3y, 4–10y and >10y) used in the longevity approach (SBI1) and in the species sensitivity categories (high, medium, low) used in the BH3. In addition the Margalef index (BH2) was calculated and analyzed. Data on SBI1 longevity were available at the species or genus level covering 90% of the individuals in the samples while the BH3 sensitivity could only be assigned to 15% of the individuals in the data. The Margalef index was calculated for all of the samples.

A log linear mixed effects model was fitted to the response variables. The model used habitat, log salinity, log depth and log trawling intensity as independent fixed variables and year and station as random variables:

$$logresponsevariable = logtrawl + habitat + logsalinity + logdepth + \varepsilon_{station} + \varepsilon_{year} + \varepsilon_0$$

Insignificant variables were removed by backwards elimination. Results are presented in Table 7.2.2.

The total number of individuals per station, N_{sum}, was significantly negatively related to trawling. Regarding the SBI1 indicator and longevity class <1 year only habitat type was significant. Coarse sediments contained significantly more individuals than sandy, muddy and mixed sediments. For the 1–3 year longevity class the effect of trawling was negative and highly significant, and so was habitat type where the intercept was significantly lower for mud than for coarse sediments. For the 4–10 year longevity group the number of individuals was significantly negatively related to depth, but not to other variables. For the longevity >10 year group log numbers were not significantly related to any of the independent variables. This longevity group was heavily dominated by the brittle star *Amphiura filiformis*, which occurred in most of the samples and appeared to be unaffected by trawling.

Table 7.2.2. Kattegat. Result from fitting a linear mixed effects model with year and station as random variables and habitat, logdepth, logsalinity and logtrawling as fixed independent variables to total benthos density, density by longevity group, by sensitivity group and Margalefs index. Only significant parameter estimates were included in the final model and in the table. *:P<0.05; **:P<0.001; ***P<0.0001. Log stands for natural logarithm.

		Log(Nsum)	Log(N<1y)	Log(N1-3y)	Log(N4-10y)	Log(N>10y)
Intercept		4.86(0.17)***			5.84(1.09)***	
Logtrawling		-0.29(0.09)*		-0.49(0.14)**		
Logsalinity						
Logdepth					-0.76(0.35)*	
EUNIS habitat	Coarse		2.96(0.59)***	4.56(0.70)***		
	Sand		0.73(0.21)**	4.17(0.27)***		
	Mud		0.30(0.39)	2.75(0.53)***		
	Mixed		0.53(0.18)**	3.77(0.26)***		
		Loglow	**Logmed**	**Margalef**		
Intercept		5.29(1.06)***	-9.83(4.06)*	0.20(0.02)**		
Logtrawling		-0.34(0.14)*		-0.49(0.14)**		
Logsalinity			3.72(1.19)**			
Logdepth		-0.94(0.36)*				
EUNIS habitat	Coarse					
	Sand					
	Mud					
	Mixed					

Regarding the BH3 indicator there were no species in the Kattegat data that could be assigned to the high sensitivity category. Surprisingly, the density in the low sensitivity class responded significantly negatively to fishing and depth, while the density of the medium sensitivity class was significantly positively related to salinity, but did not respond to trawling. Examining the link between the species sensitivity and longevity class, most of the individuals from the low sensitivity category were in the 4 to 10 years longevity category (Table), while most of the individuals from the medium sensitivity category were in the more than 10 years longevity category (Table). The less than 1 years longevity category seems to be restricted to amphipods. Noticing that only 15% of the individuals could be assigned to one of the two sensitivity classes, this result may be caused by encountering too few classified taxa in the Kattegat data. Also the variation is high between the stations, as shown by the high standard deviations in Table 7.2.3.

Finally, Margalefs index which assumes a semi-logarithmic relationship between species richness and density was significantly negatively related to trawling, Table 7.2.2.

Table 7.2.3. For low and medium sensitivity genera from BH3, number of individuals were summed across all stations for a certain longevity class. Mean number and standard deviation is calculated.

Longevity cat.	Sum of low sensitivity individuals	Mean number at each station	Standard deviation
<1 year	100,5	0,688356164	2,524630674
1–3 year	559,8	3,83390411	6,587951214
4–10 year	878,8	6,018835617	5,443507949
>10 year	14,0	0,095890411	0,247466563
Longevity cat.	**Sum of medium sensitivity individuals**	**Mean number at each station**	**Standard deviation**
<1 year	0	0	0
1–3 year	160,5	1,099315068	2,08493766
4–10 year	1091,5	7,476027397	12,2956864
>10 year	2667	18,26712329	19,4809513

7.2.4 Kattegat & Gotland, Sweden

The Baltic Sea, Kattegat

The dataset is from 58 stations sampled 2009–2011 and 2014 and comprised of 261 different taxa of benthic macrofauna sampled quantitatively by SmithMcIntyre grab (0.1 m^2). The sampling design was stratified to soft seafloor sandy/silty-mud, and to depths exploited by the bottom trawling fleets targeting *Nephrops norvegicus* and a mix of *Nephrops* and demersal fish, i.e. 23–58 m which is below the halocline and in full marine conditions.

The effects of fishing were examined on the benthic community by testing how the proportion long-living organisms varied across the fishing gradient. This was done for species biomass. All species were classified according to their maximum longevity (using a trait-based approach from BENTHIS).

<u>Results:</u>

- The longevity distribution showed no trend along the trawling intensity gradient examined when analysed for all species in the dataset (Figure 7.2.4).
- The macrofauna assemblage was dominated by the brittlestars *Amphiura filformis* and *Amphiura chiajei*. Together these two species represented 50 % in the overall number of individuals, and 58 % of the biomass. *A. filiformis* was present in 98 % and *A. chiajei* in 83 % of the samples. These two species are long-lived and apparently resilient to bottom trawling (Sköld *et al.* in prep.), and thus eliminate the potential from other species in responding to the trend in bottom trawling intensity.
- Removing these two dominant species indicate that there is a potential negative trend for biomass of species with longevity > 10yrs and trawling intensity (Figure 7.2.4 right plot). However, the pattern is strongly influenced by

large individuals of the heart urchins *Brissopsis lyrifera* and *Echinocardium cordatum* and the bivalve *Actica islandica*.

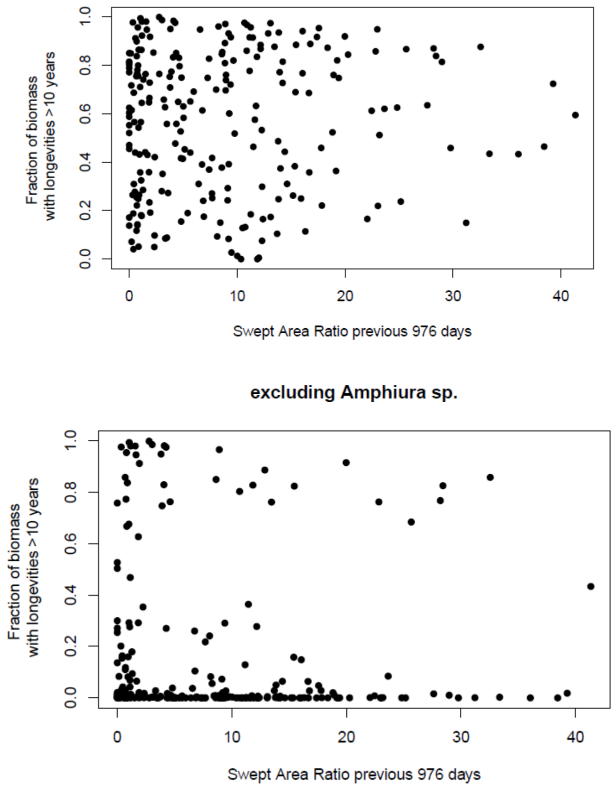


Figure 7.2.4. Scatter plot of fishery pressure (swept area ratio previous 976 days) and fraction of biomass of longevity class (>10 years). Left plot is including all species, whereas right plot is excluding Amphiura spp.

The Baltic Sea, Gotland (Baltic Boost/SLU dataset)

Data from the national Swedish benthic monitoring programme was examined for effects of bottom trawling along bottom trawling gradients within the HELCOM BOOST project. Conclusive results for effects on benthic fauna composition along a trawling intensity gradient were seen for a monitored cluster of sampling stations south-east of the island Gotland in the central Baltic Sea. The effects of fishing were examined on the benthic community by testing how the proportion long-living organisms varied across the fishing gradient. This was done for species biomass and abundance.

All species were classified according to their maximum longevity (using a trait-based approach from BENTHIS, adjusted by Anna Törnroos to include Baltic-specific species traits). There were no species with maximum longevities larger than 10 years in the dataset. This limited the data to three longevity groups: <1 year, 1–3 year and 3–10 years. Since there were only few species in the <1 year group, we decided to combine this group with the 1–3 year group.

<u>Results:</u>

- The fraction of biomass and abundance of species with longevities between 3 and 10 years was negatively related to bottom fishing disturbance.

- The shorter-living organisms (with longevities < 3 years) increased with increasing bottom fishing intensity (note that the data is proportional, hence this does not directly mean that there is an absolute increase).
- No effects between species longevity (both biomass and abundance) and depth were found (Figure 7.2.5).

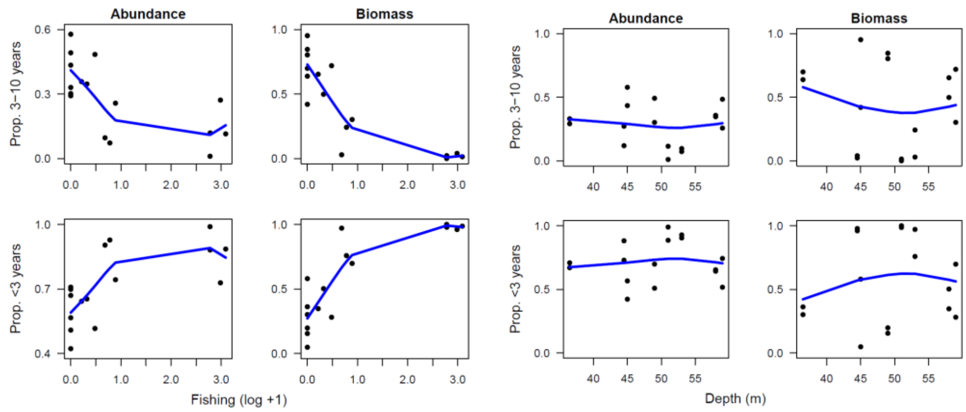


Figure 7.2.5. Relation in abundance and biomass with fishing (left graphs) and depth (right graphs) for longevity classes <3 year and 3-10 year.

7.2.5 Femern Belt area

Habitat specific impacts of fishery compared to natural stressors on benthic invertebrate community parameters

Approach: This report gives a summary of a comprehensive case study evaluation of fishery impacts on the benthic habitats in the Femern Belt area of the Western Baltic Sea during a 2 year period from 2009 to 2010 compared to impacts from natural stressors on different EUNIS Level 3 benthic habitats using multi-variate statistical analyses (J. Rasmus Nielsen *et al*., 2017).

Factors analysed: The analyses cover 1027 benthic invertebrate samples with Van Veen Grab and Frame where the sampling gears cover a sampling area of approximately 0,1 m^2. The sampling covers a standardized and systematic grid design with repeated samplings of the stations in the grid by year and season (Figure 7.2.6). These samples with high resolution in time and space have undergone faunistic classification with phylogenetic and species determination, as well as density and biomass estimation (wet and dry weight) by benthic species group, which all have been quality controlled. The benthic community parameters estimated and analysed are biodiversity (BD) as total number of species per sample, density (N) as total number of individuals counted per sample (or by species group by sample), biomass (B) as total biomass in dry weight per sample (or by species group by sample), and average individual mean weight B/N estimated as average for all individuals by sample in the benthic invertebrate community, i.e. on the overall community level (or as average for all individuals by species for selected indicator species by sample). An area conversion factor by sampling gear was used to standardize the analyzed number of individuals and the dry weight per species, but not the biodiversity parameter. The latter should be noted because there is observed a correlation between the number of species (BD) and the number of individuals (N) per sample. The differences between the covered areas of the different sampling gears are, however, so small (between 0.098 m^2 and 0.117 m^2) that there is no significant effect to be expected on BD by the different sampling areas. The majority of the data samples (69 % where FP>0, and 85% where FP>=0) have been area corrected.

All species in the marine benthic invertebrate data were categorized in longevity classes established according to genus as a trait based measure. In the current dataset we use 4 longevity categories, i.e. categories of how old the different groups (genuses) can be (how high an age they can obtain). That is respectively groups which have only an annual life span (0–1 year), groups with a bi-annual lifespan of 1–3 years, multi-annual groups with lifespans of 3–10 years, and long lived benthic invertebrate groups with a lifespan > 10 years. Some genera have species which belong to several of those longevity categories. Accordingly, we have identified 8 longevity classes (4 pure and 4 hybrid). For the statistical analyses different class variables of longevity was tested, and in the final analyses the longevity class variable were organized in 3 clusters. That is in clusters respectively above and below 3 year life span, and with a hybrid cluster between those (Cluster A: 0–3 years; Cluster C: >3 years; Cluster B: Hybrid 1–3 & 3–10). The rationale is that the benthic organisms having a longevity between 0-3 years are generally smaller than benthic organisms having longer longevity of above 3 years which are generally bigger. It is expected that fishing impacts will be different on the smaller and more short-lived organisms compared to the larger more long lived organisms in general.

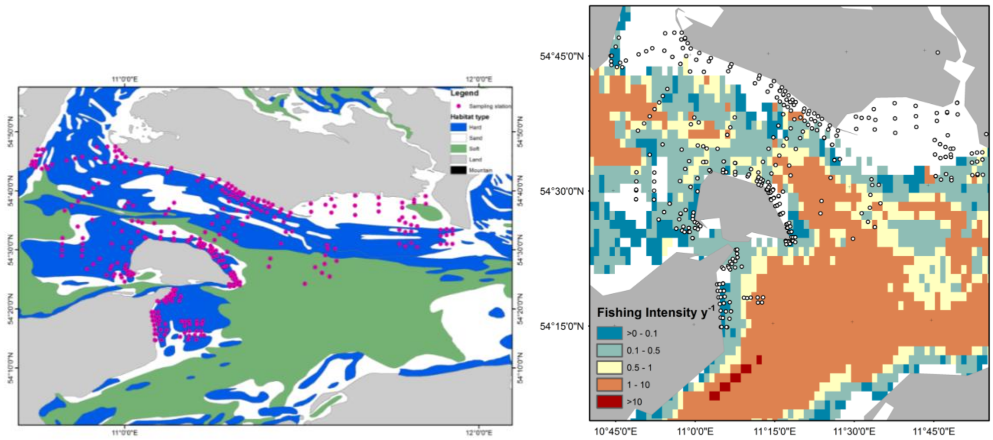


Figure 7.2.6. Left) Grab and Frame sampling stations under the benthic invertebrate monitoring program and survey design (conducted by a consortium under the Femern Belt A/S in 2009–2010) according to different types of benthic sediment types (physical habitats). Soft bottom is fine grained sublittoral mud (sediment type 1), sand is sublittoral sand (sediment type 2), and hard bottom is sublittoral mixed sediments (sediment type 3). Right) Example of fishing intensity (cumulated FP) by Danish, German (and Swedish) vessels (>= 15 m length) fishing with towed gears in the Femern Belt area in 2010. The Femern Belt invertebrate sampling stations are included in the map as well.

Hydrographical data, bottom depth, and sediment physical characteristics are obtained from two databases and a physical hydrodynamic model processing data available from the Danish Meteorological Institute (DMI). The used data have been extracted, processed and compiled by DTU Aqua. The physical data are produced by a Baltic-North Sea ocean-ice model HBM (HIROMB-BOOS Model) in the operational setup by DMI. The extracted hydrographical parameters estimated and analyzed are near seabed temperature (t, °C), salinity (s, psu), oxygen concentration (o, mmol O_2/m^3 where 1,0 mmol O_2/m^3 = 0,032 mg O_2/l), and current speed (u, m/sec) as well as bottom depth (m). Monthly minima (t_min and s_min and o_min as minimum bottom temperature, salinity and oxygen concentration, respectively) and maxima (u_max as bottom maximum current speed) for these parameters have been used in the analyses for the different benthic invertebrate sampling station positions according to sampling time.

Seafloor sediment data together with depths were extracted by DTU Aqua from the EUNIS level 3 databases processed and compiled for the benthic invertebrate sampling positions using EU-FP7-BENTHIS standards described in Eigaard *et al*. (2017). Three EUNIS level 3 habitats at location of benthic invertebrate sampling were relevant here (Fig. 1): 1 Sublittoral mud (A5.3), 2 Sublittoral sand (A5.2) and 3 Sublittoral mixed sediments (A5.4).

The fishing intensity or fishing pressure (FP) data comprise Danish and German VMS (satellite monitoring) fishing effort registration for vessels of 15 m length and longer using demersal hauled gears (mainly otterboard trawlers and otterboard pair trawlers, but also seiners and dredgers). The fishing effort data have been extracted from national VMS databases and compiled and aggregated by DTU Aqua (Danish fishery data) and TI (German fishery data). The FP data resolution, processing and aggregation for estimating FP is following the EU-FP7-BENTHIS standards, and the EU FP7 BENTHIS WP2 methods and software have been used for the process of estimating FP as described in Eigaard *et al*. (2017) which is also based on previous work published in Bastardie *et al*. (2010) and Hintzen *et al*. (2012). Fishing effort is accumulated within a radius of 1000 m around each of the benthic invertebrate sampling stations during the previous 3 months of the benthic invertebrate sampling date. That is 3 months before the current month of the sampling date. The resulting cumulated FP (fishing intensity) is estimated as the fraction of the area (ratio of surface) covered by fishery, i.e. accumulated fishing effort, in this 1000 m radius and 3 month period of time. That is, the total swept area inside a circle with radius 1000 m centered around each benthic sampling station coordinate so the FP is expressed as the swept area ratio per quarter in form of the relationship between the area fished (swept) divided by the total station area. The surface areas of the circles were computed from UTM coordinates. Accordingly, if the cumulated FP parameter is 0.5 then only half of the 1000 m radius area is swept during the previous 3 month period which is the same as the full area is swept once after every second 3 month period. If the FP is 2 then the full area is swept by fishery 2 times within a 3 month period, i.e. 8 times within a year. The relevant fishing effort and VMS data have been extracted and compiled according to unique identifiers based on position and time, and do take into account 0 FP as well. The FP data used for present analyses are from 2008–2010 with the calculated cumulative FP 3 months previous to the benthic invertebrate sampling (or in current month).

Model: A general additive model (GAM) with mixed effects was used in the statistical analyses of the data which were merged using unique identifiers of date, position, and station number. Selected models are shown in Table 1 below. For the BD and N integer (count) dependent variables a negative binomial distribution and log as the link function was used with the possibility of estimating over-dispersion. The negative binominal distribution was used as this model does not assume dependency between the mean and the variance in the distribution. For the continuous B and B/N dependent variables a tweedy distribution was used. A mixed models design was used for all models with year as a random effect and with the other explanatory variables as fixed effects (Table 1). We have evaluated the short term impacts over a 2 year period considering seasonal effects as well. The yearly differences and variability as well as the interactions between years for all factors are taken into account by including year as fixed effect in the mixed model. It is more robust to evaluate on the short term because the short term impacts are expected to be most visible and not as much influenced by noise and variability in different interactions from other influencing factors as in long term data. A spatial component with spline (s) or tensor (te) between longitude and latitude was added allowing inclusion of the spatial and station variability, i.e. the variability between observations. Alternative model versions were compared.

Table 7.2.4. Overview of selected tested statistical models with different types of dependent and explanatory variables included, as well as model settings. The overall R-square of the model, the number of observations, the model AIC and the deviance (the proportion of the variability) in the data explained by the model are given. The models have been run with data both including and excluding samples with zero fishing pressure at the sampling stations (Incl. or Excl. 0 FP). Also, model runs have been performed for data excluding the large mussels (LM) Mytilus edulis and Arctica islandica for samples including zero fishing pressure as especially the former occur in high number in the samples (Excl. LM).

Model Number	Mixed GAM Model analysed within the R statistical software	Model R2 & N			Deviance Explained & AIC		
		Excl. 0 FP	Incl. 0 FP	Excl. LM	Excl. 0 FP	Incl. 0 FP	Excl. LM
Model 6 **(BioDiv, Int. Act. Eff.)**	Biodiv ~ log(N_ind) + t_min + s_min + o_min + u_max + quarter * sed_type * FP_cum + s(year,bs=re) + s(lon,lat,k=75) *(Incl. interactions between season, sed. type and FP)*	0,98	0,86 37408	0,84	97,0%	85,8% 239025	82,6%
Model 6.3 **(BioDiv, Int. Eff., No N)**	Biodiv ~ t_min + s_min + o_min + u_max + quarter * sed_type * FP_cum + s(year,bs="re") + s(lon,lat,k=75) *(Incl. interactions; Not considering N)*	0,97	0,84 37408	0,84	96,2%	82,0% 247716	82,0%
Model 14 **(BioDiv, Int. Act. Eff., Longevity)**	Biodiv ~ log(N_ind) + t_min + s_min + o_min + u_max + quarter * sed_type * Longevity * FP_cum + s(year, bs="re") + s(lon,lat,k=75) *(Incl. interactions between season, sed.type, longevity and FP)*	-	0,86 36255	0,82	-	85,5% 232625	83,1%
Model 10 **(Density, Int. Eff.)**	N_ind ~ t_min + s_min + o_min + u_max + quarter * sed_type * FP_cum + (year,bs="re") + s(lon,lat,k=75)	0,68	0,26 37408	0,26	74,9%	40,2% 524634	40,1%
Model 15 **(Dens., Int. Eff., LongE.)**	N_ind ~ t_min + s_min + o_min + u_max + quarter * sed_type * Longeviety * FP_cum + (year,bs="re") + s(lon,lat,k=75) *(Incl. interactions between season, sed.type, longevity and FP)*	-	0,26 36255	0,41	-	40,6% 507780	50,7%
Model 11a **(Biom., Int. Eff., No N)**	Biomass ~ t_min + s_min + o_min + u_max + quarter * sed_type * FP_cum + (year,bs="re") + s(lon,lat, k=75) *(Not considering N)*	0,02	0,02 32867	0,01	9,0%	11,4% -230968	9,9%

Model 16 **(Biom., Int. Eff., LongE.)**	Biomass ~ t_min + s_min + o_min + u_max + quarter * sed_type * LongE * FP_cum + (year,bs="re") + s(lon,lat, k=75) *(Not consid. N; Incl. int.act. btw. season, sed, longev. and FP)*	-	(0,04) 31929	0,04	-	47,6% -249624	42,0%
Model 13 **(MW, Int. Act. Effect)**	Biomass/N_ind ~ s_min + o_min + u_max + quarter * sed_type * FP_cum + (year,bs="re") + s(lon,lat,k=75)	0,51	0,31 37408	0,31	67,3%	54,1% -181083	53,0%
Model 17 **(MW, Int. Eff., LongE.)**	Biomass/N_ind ~ s_min + o_min + u_max + quarter * sed_type * LongE * FP_cum + (year,bs="re") + s(lon,lat,k=75) *(Incl. interactions between season, sed.type, longevity and FP)*	-	0,31 36255	0,39	-	52,3% -169339	57,3%

Main Results and Conclusions:

- Benthic invertebrate Density and Biodiversity (and also Average Individual Mean Weight) are rather strong indicators for impacts of fishery on the benthic invertebrate community with respect to different levels of fishing intensity. In general, the higher Fishing Pressure the significantly lower Density and Biodiversity and Average Individual Mean Weight on community level.
- These results are consistent when also taking into account the influencing natural physical stressors (pressures), as well as the interactions between impacts of fishing pressure, benthic habitats, benthic invertebrate longevity groups, and seasons of year.
- Benthic invertebrate Biomass seems not to be a strong indicator on community level in relation to fishing impacts on benthic invertebrates. When including longevity in the analyses of biomass it increases the proportion of the variability in the data explained by the model (because of the long lived species with high biomass influences this), however, the model residuals still show strong trends indicating that the biomass per longevity group is not a good descriptor for fishery impact.
- The biomass naturally also influences the Average Individual Mean Weight (=Biomass/Density) indicator, even though this indicator performs better than biomass alone on community level.
- The type of habitat significantly influences biodiversity, density, biomass, and mean individual weight between different habitats. In general, highest number of species (BD), individuals (N), and biomass (B) in the benthic invertebrate community is found in habitat 3 with sublittoral mixed sediment (hard bottom) while it is more similar between habitat 1 (sublittoral mud) and habitat 2 (sublittoral sand) except for biomass that is lower in habitat 2.
- There are strong and significant interaction effects, and the Fishing Pressure has different impacts on the Biodiversity and Density and Average Individual Weight (and Biomass) in different benthic habitats and for different longevity groups also dependent on season of the year. There are strong significant interactions between FP, Habitat, Longevity Group and Season.
- There are significant impacts of natural stressors on biodiversity, density, biomass and mean individual weight. Especially, there are observed positive correlation between BD and bottom maximum current strength (U-max) and bottom minimum salinity (S-min), while there is negative correlation between BD and minimum oxygen concentration (O-min). Overall, it seems that the influence of Natural Physical Stressors is in the same order of magnitude as the impacts of Fishing Pressure on the benthic community BD, N, and MW.
- There are interactions between the hydrographical parameters and depth and, accordingly, the model was also tested with depth alone. In the Baltic, it cannot be assumed that natural stress is only related to depth because some of the hydrographical stress factors are positively correlated with depth, others are negatively correlated, and some are not correlated with depth, which is shown in present study. As depth is not expected to determine occurrence of benthic species by itself, which is rather determined by the tolerances to hydrographical and other physical habitat parameters, and because the models including depth alone did not explain more of the variability in the data as the models including all hydrographical parameters or the hydrographical parameters individually, and finally, because of the adverse significant correlations (and interactions) between depth and the hydrographical factors, then depth should in general be used with care in such models. Depth has been excluded in present analyses.

- It is evident that the positive correlation and impact of Density on Biodiversity needs to be taken into consideration when evaluating impacts on Biodiversity.
- Different thresholds of impacts from different levels of FP (in discrete steps/ranges of 0,1) can be identified for the different indicators, especially for density, and the thresholds for the indicators are also different for different benthic habitats and benthic longevity groups.
- More analyses are ongoing and necessary on selected single invertebrate species with respect to impact of FP, e.g. *Arctica islandica*, to finally conclude on this. Research is ongoing on this.
- Finally, it will be an advantage to describe the potential influencing processes, i.e. the causality in the observed results and functional relationships, for the impacts of the FP and natural stressors.

7.3 Main findings and conclusion

- Ground-truthing is important for testing the observations, assumptions and predictions of the different approaches and should ideally be done systematically with independent datasets across regions and habitats.
- On a large scale the different indicators applied were comparable in relative trends, but locally discrepancies were found. The indicators identify the same areas as being impacted, except for the continuous longevity approach (considering only the long-lived class) where the southern North Sea is resilient to seabed abrasion.
- Currently, the results and relations of all indicators are mainly based on North Sea settings, so there applicability needs to be ground truthed in other regions or missing habitats. In WKBENTH only some Baltic testing was executed, whereas it is lacking for all other regions (Celtic, Mediterranean, Iberian coast).
- The natural physical stress to the benthic fauna deviates between regions where natural stress strongly overlap with bottom trawling (e.g. Baltic = salinity and oxygen deficiency; North Sea=shear stress), which makes the applicability of indicators incorporating relationships with continuous environmental variables not straightforward (new models need to be created using local estimates of important environmental relationships such as shear stress, oxygen and salinity).
- For ground-truthing, most datasets lack "real" undisturbed conditions for the prevailing environment, which hamper setting the theoretical values (or reference). Currently, we mostly rely on data from the least fished areas to set the theoretical background.
- Complete, and not partial, data containing the whole pressure gradient should be used to ground truth the indicator response against pressure in any given area.
- The ground-truthing of models revealed locally discrepancies. In the Kattegat analysis, the abundance of both longevity (SBI1) and sensitivity groups (BH3) did not respond as expected to changes in fishing pressure, while the Margalef index (BH2) did.
- Ground-truthing the models on independent data should ideally be presented by showing the raw data beside the modeled relationships (theoretical and empirical). The curves and data need than to be statistically compared, which is currently not done.

- Certain long-living dominant species seem tolerant, and have strategies to cope the disturbance (e.g. *Amphiura spp.*). The assumption that long-living species are all sensitive does not hold, as also vice versa (short living species can be sensitive). For instance, certain biogenic reefs (cf *Lanice conchilega*) are generated and inhabited by short living species, but the reef structure is vulnerable and can takes long to regenerate when physically damaged. Overall the results need to be handled with care, as the longevity and biomass based models rely on biomass only and certain large species can influence the relations strongly.

8 Evaluation and comparison of impact indicators

8.1 Evaluation of indicators against selection criteria

To assess the suitability of indicators describing the impact of bottom-contacting gears on benthic communities, a number of quality criteria were defined based on previously proposed frameworks (ICES 2002, Rice and Rochet 2005, Queiros *et al.* 2016) (table 8.1.1). Prior to the process of evaluating the indicators, criteria were weighted according to their importance, i.e. in how far a criterion is necessary to be able to fulfil the user needs. Criteria rated as essential are viewed as "one-out-all-out" criteria; i.e. if an indicator does not meet its standards, it should be not taken into account for impact assessments. The remaining criteria were further classified as of high or minor importance. Here, the weighting can certainly vary depending on the user group addressed. Currently, several of the impact assessment methods are not yet fully developed and most likely also perform differently depending on the spatial context. We thus avoided scoring and ranking of indicators. Essential criteria were met for all approaches and consequently all indicators were basically eligible.

For each of the main criteria a number of sub-criteria were defined, which were used to qualitatively compare the different impact indicators. These sub-criteria were not given a weight but were solely descriptive. They were assessed individually for each of the indicators, and thus can be compared case by case (table 8.1.1). The overall performance of indicators on different spatial scales (on a regional or sub-regional level) needs to be evaluated in a separate step.

Tab 8.1.1: Criteria to assess indicator quality defined by WKBENTH and based on frameworks developed in ICES (2002), Rice and Rochet (2005), and Queiros et al. (2016). In terms of their importance to the overall assessment, weightings are associated with each of the main criteria (in grey): Essential, high, or of minor importance. Essential criteria are viewed as "one-out-all-out" criteria; i.e. if the indicator does not meet the requirement it should be not taken into account for impact assessments. Sub-criteria are used to aid direct comparison between impact indicators. In total four impact indicators are evaluated (Chapter 6.2.1-6.2.5). The two methods developed in the BENTHIS project each have one further refinement. The longevity-based approach (Chapter 6.2.1) is further distinguished into SBI1 (Simple benthic indicator based on an untrawled reference) and LL1 (Long-living species indicator); the population dynamic approach (Chapter 6.2.2) is either based on EUNIS habitats only (PD1) or includes additional information of the longevity distribution (PD2).

Criterion	Description Sub–criteria	Priority	Impact indicators Longevity–based approach	Population dynamic approach	BH2	BH3
Variable type			Relative biomass of 1. taxa with longevity > trawling interval (SBI1) 2. long-living taxa (LL1)	Relative biomass (PD1/ PD2)	Relative biodiversity (normalised Margalef Index)	Impact categories (9 levels)
Theoretical basis	Scientific evidence must provide a clear basis linking ecosystem features to impacts from bottom contacting fishing gears that are relevant to the achievement of objectives	Essential	Applies	Applies	Applies	Applies
	A) Does the indicator relate to features of the benthic community?		SBI1: Biomass composition across longevity classes LL1: Proportion of long-living species (>10y)	Total biomass of the benthic community	Biodiversity	Community composition and substratum type
	B) Is there evidence linking pressure to ecosystem features?		longevity composition of the community linked to average frequency of trawling	Linked by depletion and recovery rates derived from meta-analyses	Linked by a reduction of biodiversity due to trawling pressure	Linked by resistance and resilience of the community

Criterion	Description sub-criteria	Priority	Impact indicators Longevity-based approach	Population dynamic approach	BH2	BH3
Sensitivity	Trends in the indicator should be sensitive to changes in the pressure	Essential	Applies	Applies	Applies	Applies
	A) Is the indicator responsive to changes in pressure?		Consistent reduction of long-living species	Consistent reduction of total biomass	Consistent reduction of biodiversity	Consistent change based on expert judgement (impact matrix)
	B) Can the indicator be used to measure progress in time (e.g. GES in MSFD)?		Dependent on the underlying pressure layer	Dependent on the underlying pressure layer	Yes, assessment data needed as input	Dependent on the underlying pressure layer
	C) Does the indicator represent tolerance/ resistance and recovery/resilience aspects?		SBI1: considers only recovery; LL1: additionally includes resistance (proportion of long-living species)	Explicit	Implicit	Explicit
Specificity	Indicators should respond to the properties they are intended to measure (and it should be possible to disentangle the effects from other factors)	Essential	Applies	Applies	Applies	Applies

Criterion	Description sub-criteria	Priority	Impact indicators Longevity-based approach	Population dynamic approach	BH2	BH3
	A) Does the indicator solely relate to fishing disturbance or can fishing effects be disentangled?		SBI1: considers environmental variability between EUNIS 3 level habits, LL1: considers depth, tidal sheer stress, gravel content.	PD1: considers variability between EUNIS 3 habitats + gear specific depletion rates PD2: additionally considers longevity distribution (+ information on depth, tidal sheer stress, gravel content)	Due to indicator normalisation environmental variability between EUNIS 3 habitats are considered.	Theoretically effects are solely related to abrasion. Environmental variability is implicitly taken into account by habitat classification level.
	B) Can the method quantify uncertainty?		Uncertainty of model estimates known.	Uncertainty for depletion and recovery rates available.	Uncertainty of model estimates known	Confidence layers combining the type and quality of habitat data, confidence scores from the sensitivity to physical abrasion benchmarks
Quality of underlying data	The underlying data layers should be adequate	High				
	A) What is the type of data for indicator development?		Empirical data	Meta-analyses	Empirical data	Literature review/ expert judgement

Criterion	Description sub-criteria	Priority	Impact indicators Longevity-based approach	 Population dynamic approach	 BH2	 BH3
	B) Is the spatial coverage of underlying data appropriate for indicator development?		Extrapolation of impact estimates beyond areas, for which the model was parameterised, is highly uncertain	Extrapolation of recovery estimates beyond areas, for which the model was parameterised, is highly uncertain	Restricted to southern North Sea (<50m water depth)	Approved for North Sea and Celtic Sea, but not yet sufficient information for other areas
	C) Are broad-scale habitat types represented?		SBI1: based on four EUNIS 3 habitats (5.1 – 5.4); LL1: based on environmental parameters only, but parameterised by data from 5.1-5.4	PD1: based on four EUNIS 3 habitats (5.1 – 5.4); PD2 based on environmental parameters, but parameterised by data from 5.1-5.4	EUNIS 3 habitats (5.1 – 5.4), Southern North Sea	Yes
	D) Are all relevant bottom-contacting fishing gears included?		Pressure data layers based on VMS mobile bottom contacting gears (SAR)			
				Gear-dependent depletion rates		
	E) Is the output quantitative, semi-quantitative, or qualitative?		Quantitative	Quantitative	Quantitative	Semi-quantitative (ordinal)
Reference state	An appropriate reference informs the model	High				
	A) Is a reference state used to inform the indicator?		Longevity distribution from recently untrawled areas	Biomass from recently untrawled areas	Biodiversity estimates from recently untrawled areas	Does not apply. Refers to the present state.

Criterion	Description sub-criteria	Priority	Impact indicators Longevity-based approach	Population dynamic approach	BH2	BH3
	B) Is an unimpacted reference state in relation to condition used to inform the indicator?		Unimpacted (~pristine) state not available for any of the regions and indicators			
Precautionary capacity	The indicator includes mechanisms that adhere to the precautionary principle	High				
	A) Is a precautionary margin included in the indicator		No	No	No	Possible to apply in the aggregation of sensitivity scores.
	B) Is the indicator sensitive to keystone functions/species		Yes, sensitive to longevity distribution	Yes, sensitive to total biomass	Yes, sensitive to biodiversity	Yes, explicitly addressed in sensitivity layers
Cost effectiveness	The indicator is cost effective	Minor				
	A) Is more empirical data required to apply the indicator to all broad-scale habitat types.		Yes	Yes	Yes	No. More expert judgement of sensitivity for Baltic and Black Seas needed (part Mediterranean)
	B) Is ongoing habitat monitoring required for indicator refinements?		Not necessary for the indicator maintenance, but monitoring is required to ground-truth/ calibrate results and to record the current ecosystem state			
Possibility to include other pressures	The indicator is able to include other pressures or cumulative effects	Minor				
	A) Can cumulative physical abrasion be included?		Yes	Yes	Yes	Yes

Criterion	Description sub-criteria	Priority	Impact indicators Longevity-based approach	 Population dynamic approach	 BH2	 BH3
	B) Can other pressures be included in the indicator?		Yes, but needs model redefinition	Yes, but needs model redefinition	Yes, but needs model redefinition	No, but separate impact matrices and disturbance maps can be produced
Cross-regional applicability	The indicator should be broadly applicable and comparable across regions	Minor				
	A) Does the indicator cover all relevant broad-scale benthic habitats types?		No (only soft-bottom habitats, EUNIS 5.1-5.4)	No (only soft-bottom habitats, EUNIS 5.1-5.4)	No (only southern North Sea)	No (applicable to all OSPAR regions but only Atlantic and partial Mediterranean currently covered)
	B) Does the indicator allow cross-regional comparison?		Yes (potentially)	Yes (potentially)	Yes (potentially)	Yes (potentially)

8.2 Comparison of indicator performance

Large progress has been made in the past few years in developing indicators to describe the impact of trawling on benthic communities. Within this workshop a suite of impact indicators were calculated on a c-square basis for the three ICES ecoregions Celtic Sea, North Sea and Baltic Sea by using the same pressure layer and thus making them directly comparable to each other. Four types of indicators could be distinguished (see table 8.1.1), and two of them have further variants (chapter 6.2). Each of the indicators represents different features of the community. BH3 (Chapter 6.2.4) shows sensitivity and impact using matrices of expert judgements based on Schroeder et al. (2008). Resilience and resistance of benthic communities are evaluated separately on a categorical scale, whereas the other methods provide continuous measures of community sensitivities. BH2 (Chapter 6.2.5) concludes on overall biodiversity changes in relation to fishing pressure, population dynamic approaches (Chapter 6.2.2) on total biomass reductions and the longevity approaches (Chapter 6.2.1) on the proportion of long-living species in soft-bottom communities. Two indicators were mapped for the longevity approach. The simple one (SBI1), expressing the cumulative biomass from taxa with a life-span longer than the estimated trawling frequency, was characterised by a distinct inflection point in the underlying relationship. This led to the observation that nearly all areas, which experience a fishing pressure above 1 SAR, are classified as impacted and all below as not impacted, resulting virtually in a binary response, rather than a continuous impact value. The longevity approach informed with additional environmental parameters (LL1) reversed this observation. Near coastal areas, which experience a high level of fishing pressure, become largely unaffected due to co-occurring high natural disturbance rates. Patterns visible on the disturbance maps from any of the ICES ecoregions thus clearly diverge from those of the other indicators, which show a high degree of spatial congruence among each other. These shallow areas aside, although the scales differ across indicators, very similar areas are identified as highly impacted. This is not surprising as EUNIS level 3 habitats are used as background information for all of these indicators, and, in case of a higher resolution of habitat classes, these are still nested within EUNIS 3. The spatial patterns further resemble the output from the pressure layer (Chapter 5.3), which indicates that the spatial gradient of the pressure has a bigger influence on the impact than the gradient of the underlying sensitivity layer. For the impact indicator based on the biomass of long-living taxa (LL1) the opposite applies. Here, the biomass of long-living species seems to be strongly related to the environmental parameters used in the model (i.e. gravel content, tidal shear stress, water depth), creating a strong sensitivity gradient especially from near-coastal to deeper water areas. Consequently, areas which are only marginally affected by tidal shear stress could be strongly affected by relatively low levels of trawling activities and vice-versa.

Although impact maps were produced for the North Sea, Baltic Sea and Celtic Sea, interpretations need to be made with care. In relation to spatial coverage BH3 currently has the largest applicability and provides impact estimates for the entire OSPAR area (which amidst the Mediterranean and Black Sea). The other methods are still spatially limited. BH2 currently provides values for the southern North Sea only (<50m water depth), whereas the approaches developed in the BENTHIS project provided extrapolations for the three ICES ecoregions. However, data used for model developments represented EUNIS habitats 5.1 -5.4 only. For model parameterisation the population dynamic approaches used world-wide meta-data information, whereas longevity approaches are based on data exclusively collected in the North Sea. It thus remains to be evaluated in how far an extrapolation beyond the model domain is feasible.

All impact indicators investigated in WKBENTH are currently based on the same underlying pressure layer. Thus, activities causing the same type of pressure, i.e. surface or subsurface abrasion, can be considered by any of the methods. Other pressures, such as contamination or eutrophication, cannot be directly included. However, modelling approaches can parameterise other pressures as long as strong relationships between the pressure and the sensitivity measure exist. This also applies to additional environmental variables in order to disentangle natural structures from anthropogenically driven effects. Further, uncertainty estimates can be provided from modelling results. Categorical indicators such as BH3 have a limited flexibility. If other types of pressures should be considered it either needs a revision of the expert judgement taking into account pressure interactions or pressures must be evaluated separately, meaning that no common integrative indicator can be developed.

8.3 Indicator output comparison

Indicators of the area impacted by bottom fishing by year for the period 2009–2015 and broad habitat type have been made by calculating the area impacted/un-impacted if reducing the impact to thresholds of 20%, 40%, 60% and 80% by removing the cells with lowest impact. This has been done with the various applied methods for estimating fishing impact. Figures 8.3.1 and 8.3.2 illustrates the thresholds by habitat and year for seven impact estimation methods.

Maps illustrating the extent of the area impacted using the 4 thresholds are shown in Figure 8.3.3 for the PD2 approach. Results for the other methods can be found in Annex 11. As the BH3 method is categorical the same method can't be directly applied so instead thresholds were set at disturbance categories 4–9.

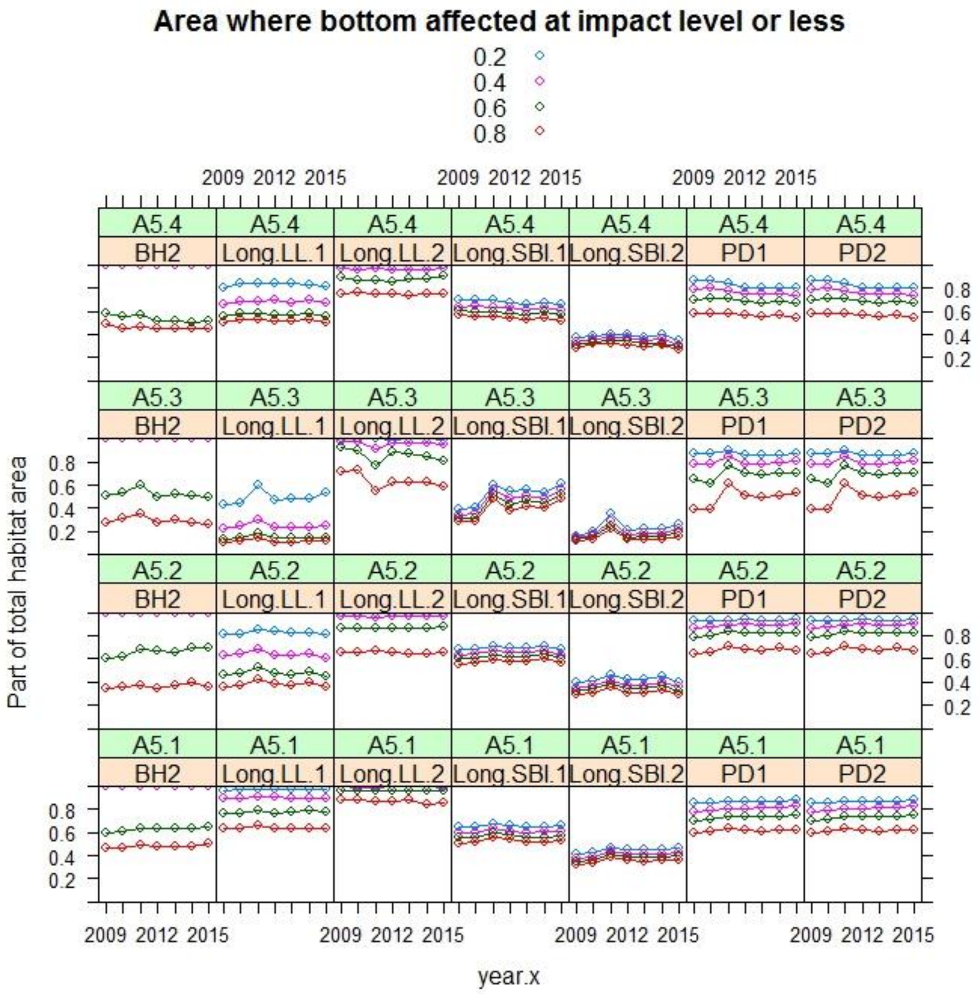


Figure 8.3.1: Figure showing the proportion of the area impacted in the North Sea if reducing the impact to thresholds of 20%, 40%, 60% and 80% by removing the cells with lowest impact, by habitat and year for the applied impact estimation methods.

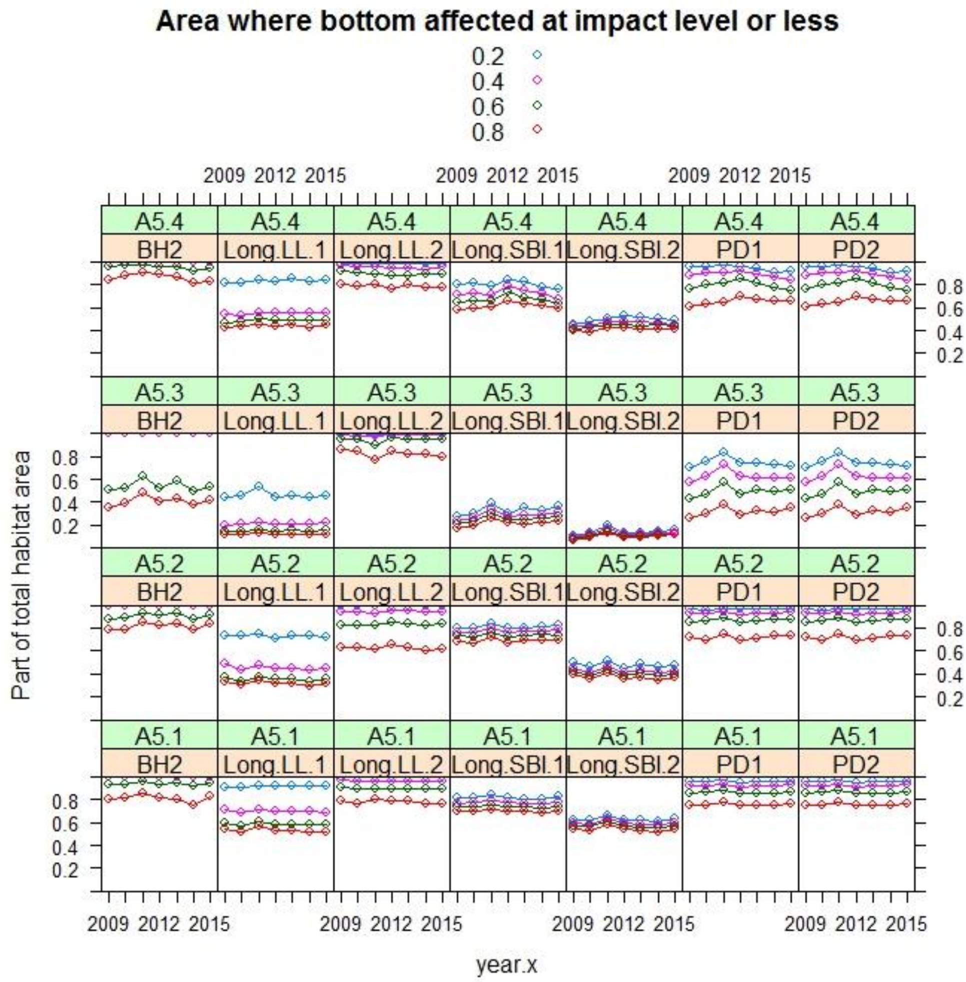


Figure 8.3.2: Figure showing the proportion of the area impacted in the Celtic Sea if reducing the impact to thresholds of 20%, 40%, 60% and 80% by removing the cells with lowest impact, by habitat and year for the applied impact estimation methods.

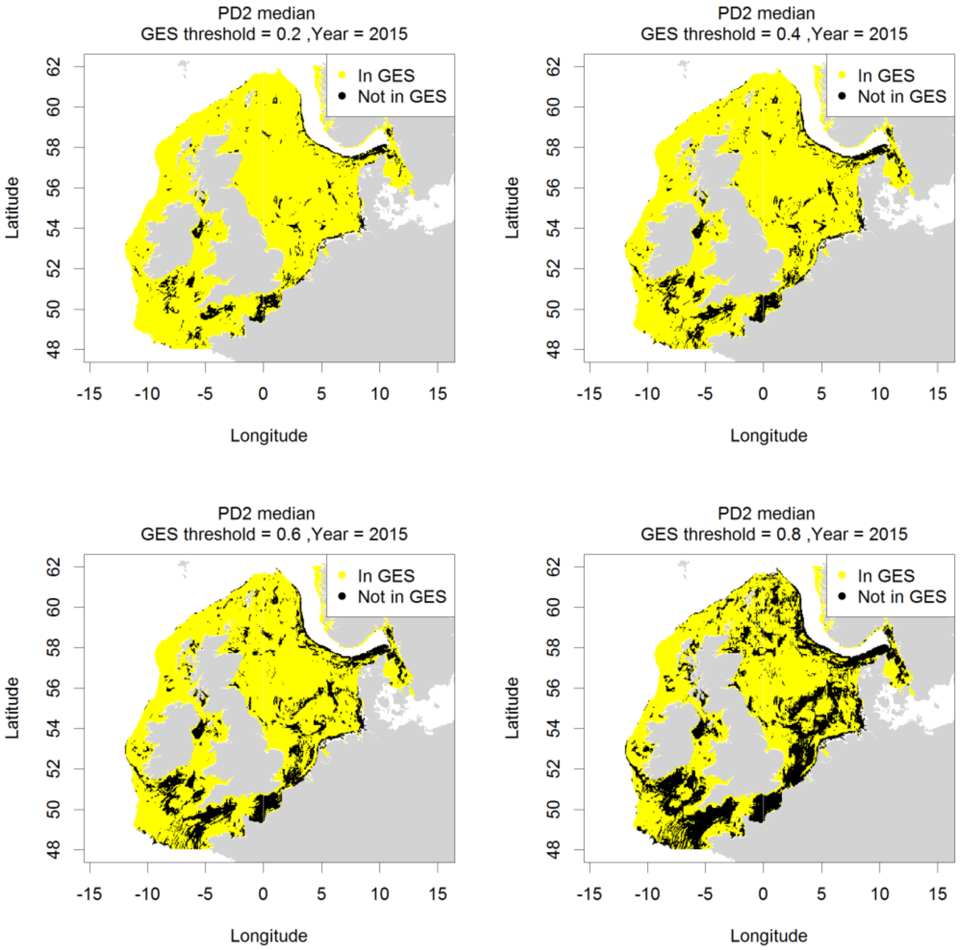


Figure 8.3.3: Maps showing the extent of the seafloor estimated to be in GES given GES threshold levels of 20%, 40%, 60% and 80% using method PD2.

8.4 Scenarios for changing fishing pressure

Four scenarios of alternative fishing effort were generated to explore the behaviour of the indicators (Figure 8.4.1). The scenarios were based on estimates of the surface swept area ratio (SAR) based on VMS data from 2015 in the Greater North Sea and the Celtic Seas. The sum of the SAR from all bottom contacting gear in each c-square was rescaled to simulate four scenarios:

a) 10 % fishing effort increase: the SAR in each c-square was increased 10%

b) 10 % fishing effort decrease: the SAR in each c-square was decreased 10%

c) 10 % fishing effort reallocation: the sum of the SAR in the c-squares holding the lowest 10% of the cumulative SAR was allocated proportionally to the other c-squares. This was done separately for the Greater North Sea and the Celtic Seas.

d) 20 % fishing effort reallocation: similar to c), but reallocating the lowest 20% of the cumulative SAR

The BH3 method for calculating physical disturbance has been applied for the scenario's for increasing and decreasing the swept area ratio's by 10%. The resulting maps can be found in figure 8.4.2.

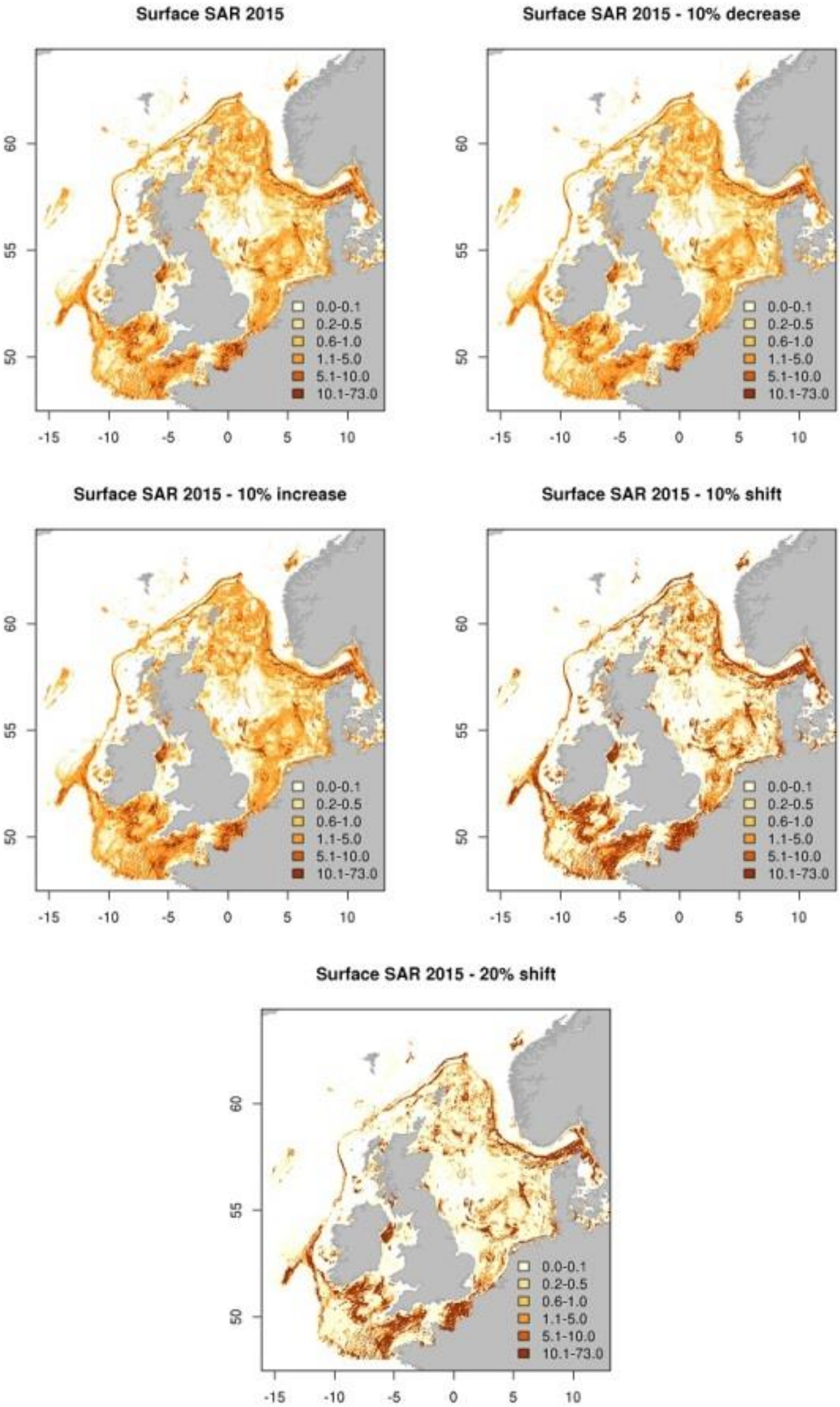


Figure 8.4.1: Maps showing the fishing pressure (surface swept area ratio) changing with the four different scenarios.

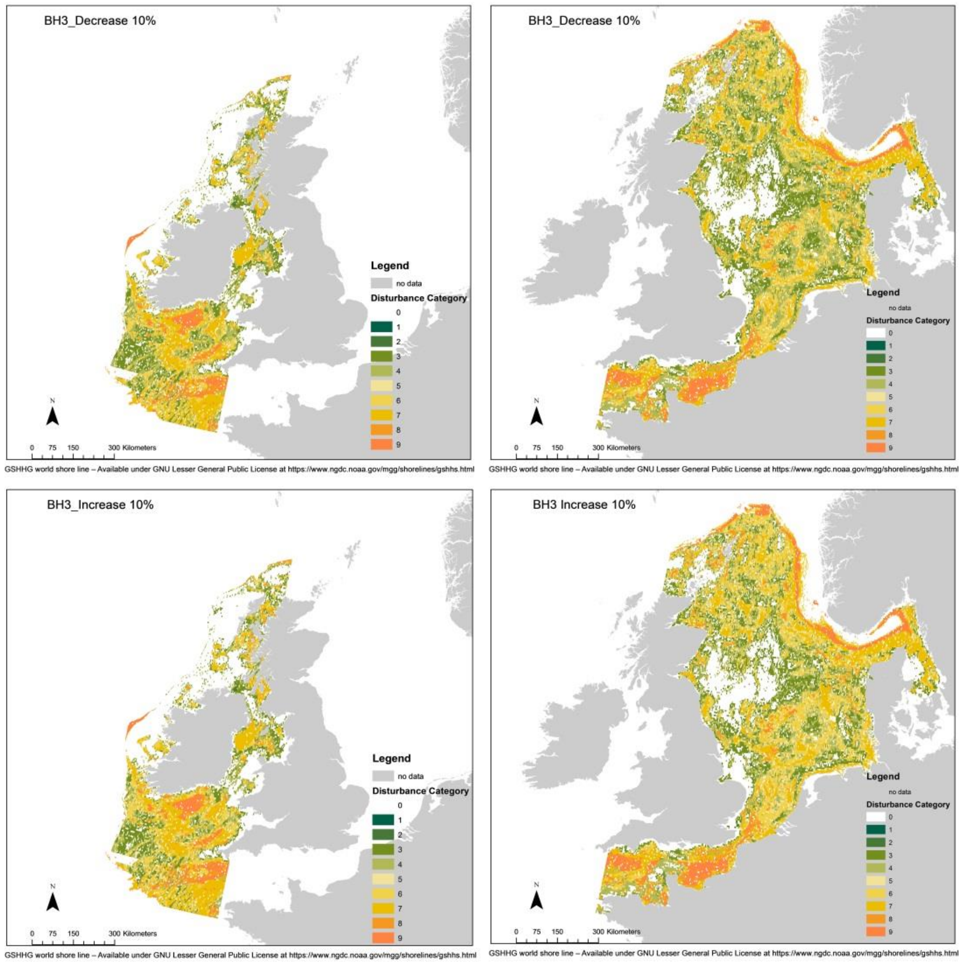


Figure 8.4.2: Maps showing the resulting BH3 disturbance if using fishing pressure scenarios increasing/decreasing by 10%

8.5 Challenges and recommendations

Because management in relation to achieve GES of benthic communities will be done spatially and not on the overall effort level, the development of integrated indicators can supplement the assessment but a spatially explicit viewing is essential. Here, all indicators can be mapped at the resolution of the pressure layer, i.e. 0.05°*0.05°. However their outputs clearly differ, which is related to the respective feature of the benthos community that is considered. The usefulness of the indicators thus depends on the underlying question. Further, the performance in the spatial context might differ but this needs further investigations and ground-truthing exercises that were beyond the scope of this workshop. For the interpretation of indicators, users need to be aware of a number of constraints as well as about options for indicator improvement. Below we list a number of caveats, challenges and recommendations related to separate components of the indicators.

Pressure layer:

- Pressure estimates as surface and/or subsurface abrasion may be inappropriate in terms of the different gears used (e.g. light and heavy beam trawls). So far only the population dynamic approach incorporates gear specific effects due to gear-dependent depletion rates.

- Using data from >12m vessels, limits the dataset to waters largely beyond 6/12nm and therefore will underestimate impact on those geographical areas where inshore fleets are based;
- Technical innovations of gears are so far not considered in the pressure layer (e.g. the use of pulse beam trawls). Information about exact gear specifications are lacking from logbooks but should be provided in the future. Further, when new gear types are commonly used, impact studies are necessary to inform either sensitivity matrices or model parameters.
- All methods rely on the pressure layer with a 0.05°*0.05° C-square resolution. However, this does not consider small-scale patchiness of trawling, as e.g. parts of the grid cell are more intensively fished whereas other parts may remain unaffected. A higher resolution of fishing pressure data requires higher polling frequencies (currently: ~2h-1). Further, national data need to be provided on the ping level rather than being aggregated on the C-square level.

Sensitivity layer:

- So far all approaches, aside from BH3, consider only infaunal communities. Impact estimates of e.g. benthic epifauna probably differ and should be considered in future assessments.
- The quality and spatial coverage of data to develop sensitivity layers is crucial for their applicability. BH2 and the methods based on the longevity distribution of communities are currently strongly driven by samples from soft-bottom habitats in the south-western North Sea. In contrast to this, the population dynamic approach is based on meta-data information from various regions but is still limited to EUNIS 5.1 -5.4. An extrapolation beyond this area and especially to different habitats or ecoregions thus leads to a high degree of uncertainty.
- None of the methods account for small-scale habitat structures beyond the c-square level. BH3 partly considers this by incorporating additional information from habitats classified at small scales and biotope data.
- EUNIS 3 is not a sufficient resolution for sensitivity maps. In the future habitat heterogeneity should be taken into account at least at EUNIS level 4 (e.g. hard-substratum, cobble reefs). Here BH3 provides the finest resolution taking reefs etc. into account.

Impact layer:

- Currently, none of the methods provide a final solution how to best assess benthic impacts. BH3 was already put into practice and provides an initial assessment for the OSPAR 2017 IA.
- The ensemble of impact maps, each based on different sensitivity layers, provides the most comprehensive view on fisheries benthic impacts.
- Extrapolation of continuous impact models (longevity approach, population dynamic approach, BH2) beyond the domain of the underlying data is probably not suitable and involves a high degree of uncertainty. At the moment an extrapolation is only feasible to soft-bottom habitats of EUNIS 5.1 – 5.4.
- For the Celtic Sea and Baltic Sea impact assessments of modelling approaches must be still tentative. Here BH3 has the largest spatial coverage (entire OSPAR area aside from Mediterranean and Black Sea)

- New benthos data need to be obtained to improve the relationships used for modelling approaches, make reasonable predictions for areas beyond the North Sea, and ground-truth the outputs from any of the methods.
- Modelling approaches are dependent on input layers of e.g. gravel content and tidal shear stress. In the future these data layers should be based on the best available information.
- Regional indicators can provide only limited information for local assessments, as e.g. habitat heterogeneity cannot be considered appropriately. On a sub-regional scale different methods or adaptations of methods may be useful and as such, need a separate evaluation.

9 Input to WKSTAKE and WKTRADE

9.1 Operational worked examples

Following the ICES (2016) advice, the impact of bottom trawling was assessed using the population dynamic approach based on continuous habitat variables (PD2). This assessment method is mechanistically based and can be applied on regional scale. The impact indicators are estimated on a continuous scale and can be linked to the landings and the value of the fishing activities.

9.1.1 Impact assessment North Sea bottom trawl fisheries in 2015

The assessment is based on the swept area ratio by grid cell of all bottom trawl métiers in the North Sea in 2015.

First we analysed how the intensity of the fishing pressure is distributed within the footprint of the fisheries. Grid cells were sorted according an increase in trawling impact and the cumulative landings, value and effort was plotted against the rank of the grid cell (Figure 9.1.1a). The analysis revealed that landings and revenue are originating from a relatively small part of the footprint. ~65% of the landings originate from 20% of the footprint, whereas the status in these core fishing grounds is reduced to less than 0.6. The recovery time to a status of 0.9 is estimated to be at least 5 years and increases steeply with the reduction in the status (Figure 9.1.1b). The peripheral fishing areas, comprising 80% of the footprint, produces only 35% of the landings. The status of the sea floor in these peripheral grounds is above 0.6 and the recovery time to a status of 0.9 is less than 5 years.

Figure 9.1.1c and d shows how the CPUE and the marginal impact of trawling are related to the status. Results show that the CPUE in the low status grid cells is slightly lower than in the high status grid cells. The marginal impact, defined as the decrease in status due to an increase in SAR by 0.01, is low in low status grid cells, and highest in grid cells with a high status. Relating the catch to the marginal impact in a grid cell reveals that the grid cells with a poor status produce a higher catch per unit of impact than the grid cells with a high status (Figure 9.1.1g).

Figure 9.1.1e and f shows how the absolute landings and value decrease with increasing grid cell status. Because the differences in CPUE are relatively small, these patterns mainly reflect the decrease in fishing effort going from low to high grid cell status.

Figure 9.1.1h illustrates how the GES threshold for status (B/K) affects the proportion of the area fished (footprint) that is in GES and the proportion of the effort (swept area) and landings in these grid cells. The percentage of the sea floor in GES decreases to about 65% when the threshold level is increased to 0.8K. Increasing the threshold further results in a steep decrease in the percentage seafloor in GES. The dashed lines showing the proportion of the landings or value taken in the grid cells is GES show again that a large part of the landings (value) is taken in grid cells that are not in GES.

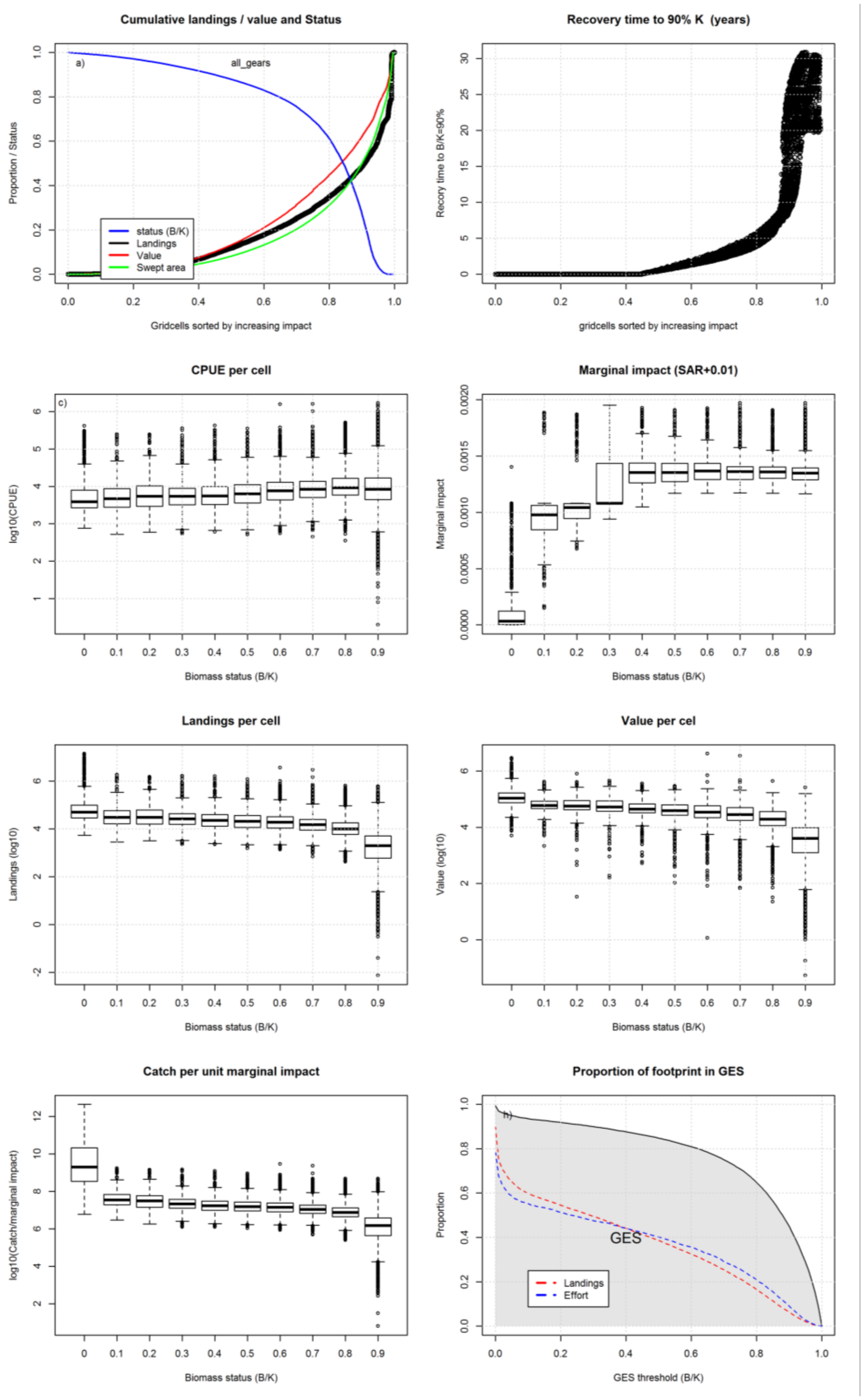


Figure 9.1.1 Summary of the impact assessment of the impact of bottom trawling on the sea floor using the PD2 method.

9.1.2 Assessment of a selection of métiers

Métiers differ substantially in the value of their target species and their footprint (Eigaard *et al*. (2016). The otter trawl fisheries targeting industrial species is a high volume (landings) and low value fisheries. The other side of the spectrum we have fisheries targeting high value species like sole, roundfish or nephrops. Separate impact assessments were carried out for four métiers reflecting different type of fisheries. We analysed the otter trawl fisheries for industrial species (OT_DEM <70mm), the otter trawl fisheries for a mix of demersal species (OT_DEM >70mm), the otter trawl fisheries for Nephrops and Pandalus (OT_CRU) and the beam trawl fishery for flatfish (TBB_DEM >70mm).

The results (Table 9.1.1) of the analysis showed a consistent pattern across métiers that was similar to the results obtained for the pooled bottom trawl fisheries (section 9.1.1).

Table 9.1.1. Overview of the footprint of the four métiers in the North Sea in 2015. Footprint is expressed in the number of c-squares fished. SAR is the mean swept area ratio (km2/km2), GES gives the proportion of grid cells with a status B/K>0.5.

fp.metier	MBCG	OTB_CRU	OTB_DEF_<70	OTB_DEF_>70	TBB_DEF_>70
			All habitats		
Swept area (1000km^2)	333	87	24	140	73
Weight (10^6 kg)	1085	41	541	87	70
Value (10^6 €)	982	128	113	175	236
Footprint (ngrid)	41741	10486	3465	17654	9096
SAR (mean)	1.43	1.24	1.25	0.78	0.55
Grid cells in GES	0.53	0.90	0.91	0.97	0.93
			Coarse sediments (A5.1)		
Swept area (1000km^2)	45	2	4	25	13
Weight (10^6 kg)	87	1	23	10	13
Value (10^6 €)	159	2	5	21	48
Footprint (ngrid)	3851	349	924	2466	1580
SAR (mean)	2.47	0.67	0.41	0.99	0.61
Grid cells in GES	0.72	0.95	0.98	0.97	0.89
			Sandy sediments (A5.2)		
Swept area (1000km^2)	197	51	14	73	53
Weight (10^6 kg)	817	25	501	53	51
Value (10^6 €)	567	62	105	103	167
Footprint (ngrid)	17410	6545	1676	10504	6334
SAR (mean)	1.73	0.90	1.96	0.61	0.57
Grid cells in GES	0.81	0.95	0.86	0.99	0.93
			Muddy sediments (A5.3)		
Swept area (1000km^2)	48	29	3	23	3
Weight (10^6 kg)	95	13	16	13	3
Value (10^6 €)	111	56	2	26	9

Footprint (ngrid)	3795	2804	338	2947	569
SAR (mean)	2.64	2.17	1.42	0.69	0.33
Grid cells in GES	0.70	0.79	0.86	0.98	0.99
			Mixed sediments (A5.4)		
Swept area (1000km^2)	19	3	2	13	2
Weight (10^6 kg)	37	1	1	7	2
Value (10^6 €)	88	4	1	16	6
Footprint (ngrid)	1354	491	298	960	371
SAR (mean)	3.98	0.79	0.50	2.24	0.32
Grid cells in GES	0.63	0.94	1.00	0.85	0.95

9.2 Main findings – recommendations – caveats

Trawl fisheries are aggregated in only a small part of their footprint. Although the status of the sea floor in these heavily trawled areas is low, these areas produce the bulk of the landings. Since the benthic status in these areas is low, the effect of a change in fishing pressure is low in comparison with a similar change in fishing pressure in areas where the status is high. This asymmetry between the status and the marginal impact offers the possibility for reducing trawling impact at a low cost in landings or revenue.

A full worked out example of an impact assessment is presented using the population dynamic approach (PD2) with a longevity composition estimated using continuous environmental variables. The impact assessment estimates the proportion of the sea floor in GES. Although GES thresholds can be founded on ecological arguments given a clear management objective, no GES thresholds have been set. WKBENTH, therefore, explored the effect of different GES threshold levels on the proportion of the sea floor in GES (see chapter 9) and the importance of these areas for the fishery landings and revenues.

Given the fishing pressures recorded in 2015 and under the arbitrary assumption of a 80% GES threshold, the proportion of the seafloor estimated to be in GES ranges between 57% (mixed sediment) and 79% (sandy sediment), with muddy sediments and coarse sediments were at 71% and 72%, respectively. For the total North Sea 76% of the seafloor is in GES.

The worked example illustrates the potential of the population dynamic method to convert the continuous pressure into a continuous impact / status to monitor changes in the status of the seafloor and the impact of the bottom trawl fisheries on a regional scale. The biological basis facilitate the setting of GES threshold levels based on ecological processes, such as the minimum biomass required to sustain recruitment or the biomass corresponding to the maximum sustainable management of the target fish species. The relative simplicity contributes to the transparency of the methodology. PD2 was chosen as an example, and the longevity method could be a useful alternative, although its methods are based on statistical estimates of the effect of trawling on the benthic community and does not provide an estimate of the biomass of the benthos that is relevant in terms of setting GES thresholds. Both methods can potentially be used to address the impact on ecosystem functioning.

Further work is required on strengthening parameterisation of the models, in particular the estimation of the longevity composition in habitats and regions which have not been covered in the current parameterisation. Particular attention is needed on the habitat dependent impact of bottom trawling.

10 Main findings and discussion – advice highlights for ADG

ICES advised in 2016 that maps of seabed habitat are combined with those of fishing intensity for assessing the state of seabed habitats. This also requires an assessment of the sensitivity of the communities associated with each habitat. As part of this process, ICES recommended to apply a mechanistic, quantitative approach based on biological principles.

Building on previous advice, in 2017 ICES was requested to suggest a procedure how to best operationalize indicators for assessing both fishing footprint and impact on the seafloor at the regional scale. Part of this process required feedback and a critical exploration of the different methodologies available. By producing worked examples (as maps and indicators), different scenarios and management options were explored. Threshold levels were (arbitrarily) proposed to help inform the process of setting the level at which the benthic community can be considered in a poor state relative to policy objectives.

Importantly, any proposed assessment method will also need to inform managers about the relationships, and therefore trade-offs, between benthic impacts and the landings or revenue of the fisheries. This process involved careful consideration of end-user requirements, for managers and fisheries as stakeholders (see WKSTAKE and WKTRADE). This will be useful in guiding the continued development of work within Regional Sea Conventions for the Baltic Sea (HELCOM) and North-East Atlantic (OSPAR), as well as for the Mediterranean (Barcelona Convention) and Black Sea (Bucharest Convention).

Assessment approaches

All the assessment methods evaluated comply with indicator evaluation criteria, but they differ in their underlying scientific basis. The longevity and population dynamic approaches are in line with ICES Advice to the EU in 2016. They are based on a mechanistic relationship, are parameterised with empirical data, and allow the estimates of trawling pressure to be converted into an estimate of impact on a continuous scale. Although both the longevity and population dynamic methods require further development, both approaches can consistently assess trawling impact across habitats and can provide indicators and reference levels for good environmental status. The population dynamics and longevity methods are conceptually simple, use few parameters and can provide indicators for the community, as well as, specific subsets of the community (e.g. bioturbators, suspension-feeders). The sensitivity layer for both methods is based on a statistical prediction of the longevity distribution of the benthic community. Longevity is both theoretically and practically a very attractive way to capture sensitivity to trawling. It can capture interactions between environmental and trawling disturbance well and can in theory capture many different environmental stresses.

Both approaches have been compared to worked examples of the BH3 and BH2 approaches developed and applied in OSPAR. As concluded in the ICES Advice to the EU in 2016, BH3 is using a categorical scoring approach to assess sensitivity that is based on science based expert judgement. As such, it cannot capture the continuous gradients of sensitivity and subsequent impact. BH2 is developed to estimate the benthic status from empirical observations and is not intended to extrapolate status beyond the observation area.

The assessment models are focussed on the regional scale and are parameterised using broad scale data, the application of the regional models at a local scale may be less appropriate because it may not include specific environmental conditions/species that determine variation in sensitivity to trawling at a local scale.

Impact estimates

Impact maps of the different assessment approaches differed in the absolute value. Nevertheless, there is large similarity across methods in areas with either high or low impact, although locally discrepancies can be found. The overall similarity in impact across the methods highlights that gradients in fishing pressure determine impact much more than gradients in sensitivity. Only one of the longevity approaches (Long-LL_2) showed a different pattern of impact, which is due to the fact that the method predicts low impact of trawling (even at relatively high fishing pressure) in shallow waters and in habitats that are exposed to high bed shear stress.

The impact indicators across methods were largely stable across the years.

WKBENTH concluded that the ensemble of impact maps, each based on different sensitivity layers, is currently providing the most comprehensive view on benthic impacts from bottom fisheries.

Ground-truthing

Ground-truthing is important to test the assumptions and predictions of the different approaches and should be done with independent datasets covering large spatial scale, including a broad range of environments and habitats across regions. A comparison of different assessment methods is best done through comparison of sensitivity maps rather than impact maps, because otherwise fishing pressure layers may obscure the differences.

Both the population dynamics and longevity methods are based on a statistical prediction of the longevity distribution of the benthic community. The use of such a layer requires extensive data over the full range of environmental variables and regions. The current longevity distributions are estimated from infaunal sampling data collected in the English Channel and southern North Sea and this may limit the applicability outside the range of environmental variables or regions for which the longevity distributions were estimated. This particularly applies to the impact estimates below 100 meters and beyond the North Sea region. Benthic data from other areas and regional seas are necessary to improve and/or ground-truth the methods and allow extrapolation.

The applicability to other regions (and missing habitats) needs to be examined and ground-truthed. In WKBENTH only some ground-truthing of the longevity distribution was done for the Baltic Sea region, whereas it was lacking for all other regions (Celtic, Mediterranean, Iberian coast). Still, it became clear that the natural stressors to the benthic fauna will deviate between regions. For example, salinity will largely determine the longevity distribution of the benthic community in the Baltic Sea, whereas shear stress is more important in the North Sea. This highlights that further work needs to be done to broaden the range of environmental variables (including salinity, wave shear stress, productivity, hypoxia) and regions to improve the longevity – habitat relationships.

The trawling impact or benthic state estimated by the assessment methods are expressed in relative terms and are based on regional scale relationships which have averaged out the well-known variability in benthic samples. Predictions from the regional models, therefore, may be difficult to compare with local observational data. Still, ground-truthing of the predicted longevity distributions showed that most areas fit the expected patterns, i.e. fewer long-lived species in trawled and naturally disturbed areas. However, there were some significant exceptions and this may imply that the average patterns used on the regional scale may not be the best predictor of the local situation. Local patterns may be determined by few dominant taxa which may respond differently to trawling disturbance. For example, certain long-living dominant species may be tolerant to relatively high trawling pressures (Amphiura spp. in the Kattegat area) or have strategies to cope with disturbance (deep-burrowing species).

The parameterisation of the population dynamic approaches is based on all available information from the literature so cannot be improved on substantially. The underlying assumption that the longevity distribution changes with environmental conditions and is skewed towards more short-lived organisms in more naturally disturbed habitats could be tested through sampling over environmental gradients.

Importantly, most datasets lack "real" undisturbed conditions for the prevailing environment and this both hampers setting the reference condition to be used in the assessment, as well as, ground-truthing of sensitivity and impact.

GES threshold

The GES thresholds explored in WKBENTH were chosen arbitrarily. Thresholds, however, can be based on scientific arguments and linked to specific objectives. In fisheries management, limit reference levels for stock biomass below which population collapse and where recruitment limitation may occur are set at 10% to 20% of the unfished biomass, while a target reference of sustainable exploitation is set at a Bmsy of 50%. The latter reference is also related to the objective of the food provisioning ecosystem service. If the objective is to protect the habitat provisioning function, protection of biogenic habitat would call for a much higher threshold. Thresholds can also be defined in terms of the recovery of the habitat, i.e. whether a habitat can recover within a certain time period.

Future work

The empirical basis of the quantitative assessment methods (population dynamic and longevity approach) needs to be broadened and tested, in particular with regard to benthic data sets from habitats currently not included, and epibenthic data sets. Attention should be given to the interaction of trawling and natural disturbance, which is responsible for the large discrepancy in predicted impacts of most assessment methods and Long_LL2. More work is also needed on the vulnerability of groups of benthic taxa to trawling, which can be included in the model.

The use of continuous environmental variables rather than the EUNIS habitat classification seems more promising for assessing impact as they result in larger gradients in the sensitivity layer. Data layers for these continuous environmental variables need to be improved/produced. Effort should first be concentrated on sediment characteristics (%gravel, %sand, %silt) tidal shear bedstress, wave shear bedstress, salinity and hypoxia across regions.

The current methods assume that impact is directly proportional to the swept area at the surface of subsurface layer but no information is available to convert the surface or subsurface abrasion into impact of the different métiers. The population dynamic approach has incorporated gear-specific estimates of depletion and these could be used to capture effects of the different métiers in future work. Still, further work is needed to refine the impact estimates of the different gears deployed in the bottom fisheries, including pulse/beam trawl, passive gears and from fishing vesssels <12m (mainly fishing within the inshore 6/12 nm zone). A higher resolution of fishing pressure data would also be beneficial for assessments. This requires higher polling frequencies in the VMS system (e.g. one ping per 30min). Further, national data would need to be submitted on the ping level rather than being aggregated on the C-square level.

The quantitative assessment methods explored (population dynamic and longevity approach) did not provide an estimate of the impact of bottom trawling on specific ecosystem functions. The methods, however, are technically capable to estimate this. Further work to estimate the parameters required in the assessment methods for the selected ecosystem functions, will allow a consistent and comparable assessment of the bottom trawling impact on the benthic community, as well as, on specific ecosystem functions. These impact estimates will then reflect the reduction in biomass or community composition and will hence indicate the potential effects of trawling on selected ecosystem functions.

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Annex 2 Agenda

Introduction

The EU (DG ENV) have requested advice from ICES to "Evaluate indicators for assessing pressure and impact on the seafloor from bottom-contacting fishing. Using this assessment, demonstrate trade-offs in catch/value of landings relative to impacts and recovery potential of the seafloor". This work will be published as ICES Advice and delivered to the EU on 26 June 2017.

Member countries and Regional Sea Conventions (RSCs) are developing indicators of impacts on benthic habitats from anthropogenic activities, particularly bottom-trawling, for MSFD purposes (D1 biodiversity and D6 seafloor integrity). EU projects are also developing approaches across European seas (including the Mediterranean and Black Sea). As part of this process, in 2016 ICES organized a workshop (WKFBI 2016) that contributed towards the ICES advice to the EU "guidance on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats" (ICES 2016).

In 2017, to address the request for advice by EU (DG ENV), ICES is running three workshops. The first workshop (WKBENTH) will evaluate different modelling approaches (of combining pressure, habitat map and sensitivity layers) to assess the extent of impacts at the (sub)regional scale. Using this evaluation, a stakeholder workshop (WKSTAKE) will be organized to discuss the operational challenges of the suggested indicators to assess impact and the usefulness of the indicators in a management context. The last workshop (WKTRADE) will use the assessment indicators developed in the above two workshops, to explore the trade-offs between benthic impact and the landings or revenue of the fisheries.

WKBENTH

In preparation of WKBENTH the Chair Adriaan Rijnsdorp and the ICES secretariat, with a small group of workshop participants have been preparing worked examples for the Celtic, N. Sea and Baltic (see below agenda). A first draft of the WKBENTH report has also been prepared. This is to encourage workshop participants to identify how they can best contribution with regard to the expected outcomes of WKBENTH (see workshop TORs). Participants are also encouraged to familiarize themselves with the 2016 ICES advice and workshop report prior to WKBENTH.

Agenda for WKBENTH

The workshop will start at 10.00, on Tuesday 28 February and ending 15.00, Friday March 3, 2017. Other days we expect to start at 9.00 and finish by 18.00, and breaking for lunch (13.00–14.00) with morning and afternoon coffee breaks. On the first day, we will organize an icebreaker at the ICES secretariat and a joint dinner in Copenhagen on the evening of Wednesday, 1 March. Both events will be at own expense.

WKBENTH Agenda	Tue – 28 Feb	Wed – 1 March	Thurs – 2 March	Fri – 3 March
9.00	*Presentations (start 10.00)* A. Fishing pressure and footprint indicator	*Plenary (9.00-9.30)* *Sub-groups* A-D, all themes drafting text (9.30-11.00)	*Plenary (9.00-9.30)* *Sub-groups* A-C	*Plenary (9.00-9.30)* *-decide what needs doing to finalize report*
11.00-11.30	**COFFEE**	**COFFEE**	**COFFEE**	**COFFEE**
11.30 – 13.00	*Presentations (continued)* B. Impact assessment methods and (potential) benthic impact indicators	*Plenary reporting* (11.30-12.30) TAF transparent assessment framework New *sub-groups* A-C, organize afternoon work (12.30-13.00)	*As required,* *sub group work*	*As required,* *sub group work*
13-14.00	**LUNCH**	**LUNCH**	**LUNCH**	**LUNCH**

14.00 – 16.00	*PLENARY* (14-14.30) *SUB-GROUPS A-D*, SCOPING FOR ALL THEMES (14.30-15.30) *PLENARY REPORTING* 15.30 – 16.30	*SUB-GROUPS* A-C	*AS REQUIRED,* *SUB GROUP WORK*	*AS REQUIRED,* *SUB GROUP WORK* PLENARY (END 15.00)
16.00-16.30	**COFFEE (16.30)**	**COFFEE**	**COFFEE**	
16.30 – 18.00	*One theme 1-4 per Sub-group A-D* (16.45-18.00)	*Sub-groups* A-C (end 17.00)	*As required,* *sub group work* *Plenary reporting* (17.30 -18.00)	
18.00	**ICE BREAKER**	**DINNER**		

Tue-Wed - all four A-C sub-groups to discuss and report on "theme 1-4", 15 min per theme.

Group A (Theme 1)	Group B (Theme 2)	Group C (Theme 3)	Group D (Theme 4)
Jan Geert Hiddink* Andreas Lunn Bastian Schuchardt Dorothee Kopp Jeppe Olsen Mattias Sköld Olivier Beauchard Stefan Bolam	Rabea Diekmann* Philip Boulcott Adriaan Rijnsdorp Anna-Grethe Underlien Pedersen Bryony Meakins Julian Burgos Laurene Merillet	Alexander Darr* Gert Van Hoey Anna Tornroos Annabelle Aish Guillaume Bernard J. Rasmus Nielsen Pascal Laffargue	Wouter van Broekhovern* Josefine Egekvist Anita Carter Clement Garcia Daniel van Denderen Henrik Gislason Patrik Jonsson Sebastian Valanko

*Chair of sub-group discussions. The sub-group should appoint a person to report in plenary and another to take note.

Theme 1 (15 min) – task: *using scenarios, produce a bullet list description of "un-impacted" and "impacted"*

- What does impact mean - link structure to functioning for benthic ecosystem (what is missing?)
- How to compare impact estimates?
- Practical way forward for setting reference values?

Theme 2 (15 min) – task: *produce a bullet list of criteria to assess footprint and impact indicators against*

- What selection criteria should WKBENTH use to evaluate indicators (see Rice and Rochet, 2005)?

- How to ensure regional and cross regional comparability, impact assessment in selected regions (various methods, same underlying data)?

Theme 3 (15 min) – task: *produce a bullet list of 1) ground truth indexes, and 2) modelled indicator scores – that can be compared*

- How to best ground-truth assessment methods/indicators with field data in WKBENTH?
- How do we compare impact estimates from various methods, what do they mean?

Theme 4 (15 min) - task: *in the context of WKSTAKE and WKTRADE, produce a bullet list of principles to assess fishing impact on benthic habitats*

- What guidance can WKBENTH propose on how to assess fishing impact on benthic habitats?
- How to prioritize methods/indicators that can be used in WKSTAKE and WKTRADE?

** Rice, J. C., and Rochet, M-J. 2005. A framework for selecting a suite of indicators for fisheries management. e ICES Journal of Marine Science, 62: 516e527. Link.

Wed-Thurs – theme specific sub-group work (to be decided).

Group A (Biscay)	Group B (Atlantic room)	Group C (Cadiz room)	Group D (Atlantic room)
Henrik Gislason* Adriaan Rijnsdorp Josefine Egekvist Philip Boulcott Bastian Schuchardt Anna-Grethe Underlien Pedersen Wouter van Broekhovern Annabelle Aish Julian Burgos J. Rasmus Nielsen Sebastian Valanko	Gert Van Hoey* Clement Garcia Mattias Sköld Stefan Bolam Andreas Lunn Dorothee Kopp Alexander Darr Anna Tornroos Guillaume Bernard Laurene Merillet Pascal Laffargue	Jan Geert Hiddink* Bryony Meakins Anita Carter Rabea Diekmann Jeppe Olsen Daniel van Denderen Patrik Jonsson Olivier Beauchard	*if required*

*Chair of sub-group discussions. The sub-group should appoint a person to report in plenary and another to take note.

Sub Group A – conduct an operational evaluation of presented footprint and impact indicators, using output from sub group theme work and the 8 step method in Rice, J. C., and Rochet, M-J. 2005. A framework for selecting a suite of indicators for fisheries management. e ICES Journal of Marine Science, 62: 516e527. Link. Evaluation should consider how indicators are operational in the context of WKBENTH and WKTRADE. 2003, 2005 and 2012 reports of the Working Group on the Ecosystem Effects of Fishing Activities (WGECO) may also be useful source.

Sub Group B – technical work to ground truth, taking into account input from sub group discussions – especial on traits and ecosystem functioning, reference value and impact

Sub Group C - technical work still required to prepare both footprint and impact worked examples and indictors, taking into account input from sub group discussions

Sub Group D – if required (e.g. split up work within Group A)

Annex 3 ToRs

WKBENTH – Workshop to evaluate regional benthic pressure and impact indictor(s) from bottom fishing 2017/2/ACOM40 The **Workshop to evaluate regional benthic pressure and impact indictor(s) from bottom fishing** (WKBENTH), chaired by Adriaan Rijnsdorp*, The Netherlands, and Josefine Egekvist* (TBC), Denmark will meet in Copenhagen, Denmark, 28 February – 3 March 2017 to:

a) Building on 2016 ICES Advice to the EU "guidance on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats", compare a set of maps/indicators for assessing both physical disturbance pressures from bottom-contacting fishing gears and their environmental impacts on seabed habitats/sea-floor integrity. Worked examples (e.g. Baltic Sea, N. Sea and/or Celtic Sea) at the scale of MSFD (sub)region should be prepared, that include:

- i) Map and indicator(s) of fishing intensity (physical disturbance), for the most recent 6-year period (and for earlier periods where possible); and
- ii) Map and indicator(s) of the area impacted by bottom fishing (in the same 6-year periods), and the proportion (%) of each MSFD broad habitat type impacted per subdivision.

b) With the above (TOR a) in mind, compare impact estimates (maps and associated indicators) by exploring:

- i) how impact scores per c-square (lowest spatial resolution) are aggregated spatially into a subdivision-scale score (e.g. by considering fragmentation, average, maximum, cumulative) per habitat type;
- ii) how overall impact scores compare to other benthic community composition indicators of impact, and where possible use a ground truth data set across a trawling gradient;
- iii) explore the impact indicator's flexibility to also incorporate other types of pressures that may simultaneously impact the benthos (e.g. hypoxia due to nutrient enrichment or physical disturbance from gravel extraction)
- iv) how the current indicators perform against previous ICES advice on what constitutes a good indicator.

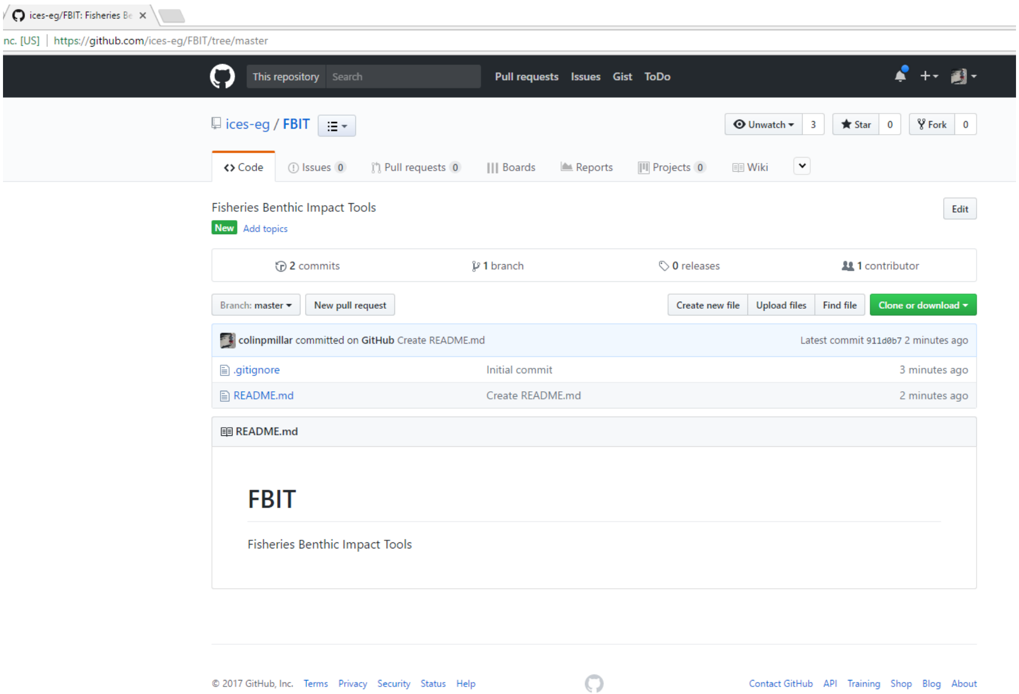
c) With TOR b in mind, suggest how the guidance relates to the continued development of work within the Regional Sea Conventions. The assessment scale of indicators should be suitable biogeographic subdivisions of the MSFD regions and subregions, and per MSFD broad habitat type (or more finely-defined habitat types).

In preparation for the workshop, the Chair, Adriaan Rijnsdorp, The Netherlands, will facilitate coordination and consolidation of work on TOR a-b, as well as help ensure the workshop's objectives TOR are met and that the workshop report is finalized. WKBENTH will provide a draft report to WKSTAKE by 13 March 2017, and based on feedback, finalize the report by 31 March 2017 for the attention of the ACOM Committee.

Supporting information Priority	High, in response to a special request from DGENV on the Common Implementation (CIS) of the MSFD. The advice will feed into ongoing efforts to provide guidance on the operational implementation of the MSFD.
Scientific justification	Member countries and Regional Sea Conventions (RSCs) are developing indicators of impacts on benthic habitats from anthropogenic activities, particularly bottom-trawling, for MSFD purposes (D1 biodiversity and D6 seafloor integrity). EU projects are also developing approaches across European seas (including the Mediterranean and Black Sea). As part of this process, ICES has in 2016 provided as advice to the EU "guidance on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats". The next challenge is for impact score(s) derived on the basis of a mechanistic, quantitative approach (e.g. developed in BENTHIS) to be evaluated in terms of robustness as an indicator in assessing the state of the seabed for MSFD purposes (WKBENTH). In addition to indicators describing pressure from bottom-fishing activity, indicators of the ecological impact of bottom fishing are required and could include a measure of the 'reduction in the surface area where the community, or a specific functional group, is in its undisturbed reference state'. By setting threshold impact values per habitat type/ subdivision, the approach should enable quantification of a real extent of impacted and not impacted seafloor. Furthermore, the benthic pressure and impact assessment indicators (or derived parameter) should enable exploration of the trade-offs between the proportion of impact on seafloor habitats and provisions of catch/value (WKTRADE). From an EBFM (ecosystem-based fisheries management) perspective, there is a need to inform managers about the interlinkages, and therefore possible trade-offs, between benthic impacts and the landings or revenue of the fisheries. To do this, an analysis of fishing intensity and the catch achieved (by weight or value) should be compared to the degree of habitat impact (taking account of the resilience of the habitat and whether there is any recovery of it between bottom-fishing events). Undertaking the analysis per unit area (c-square) and per fishery should aim to show which areas are most productive for each fishery and which areas are least productive but have high costs in terms of environmental impact. The outcomes should offer a possible way to inform managers of such trade-off scenarios. Developed indicator procedures and tools to evaluate trade-off in a management context should support continued development of work within the Regional Sea Conventions. To ensure this dialogue a stakeholder workshop (WKSTAKE) will be organized, which WKBENTH and WKTRADE will contribute to.
Resource requirements	ICES secretariat and advice process.
Participants	Workshop with researchers and RSCs investigators If requests to attend exceed the meeting space available ICES reserves the right to refuse participants. Choices will be based on the experts' relevant qualifications for the Workshop. Participants join the workshop at national expense.
Secretariat facilities	Data Centre, Secretariat support and meeting room
Financial	Covered by DGENV special request.
Linkages to advisory committees	Direct link to ACOM.
Linkages to other committees or groups	Links to CSIMSFD-EA and SCICOM.
Linkages to other organizations	Links to RSCs and EC.

Annex 4 Indicator methods documentation and reproducibility (TAF)

https://github.com/ices-eg/FBIT



Annex 5 EUNIS habitats and environmental conditions

For the evaluation of fishing pressure and the subsequent impact studies information about the underlying habitats and depth bands are essential. In the following maps of EUNIS level 3 habitats as well as water depths are shown for three ICES ecoregions, namely the Celtic Sea, the Greater North Sea and the Baltic Sea.

Celtic Sea

The Celtic Sea cannot be clearly separated from the open North Atlantic. To the west the shelf sharply drops to water depths below 1000m (Fig. 1). There large areas are dominated by deep-sea mud and muddy sand (Fig. 2). On the shelf EUNIS habitat information is lacking especially south-west of Ireland. Where information is available sand, mud, and coarse sediments, as well as rocks alternate on small-spatial scales.

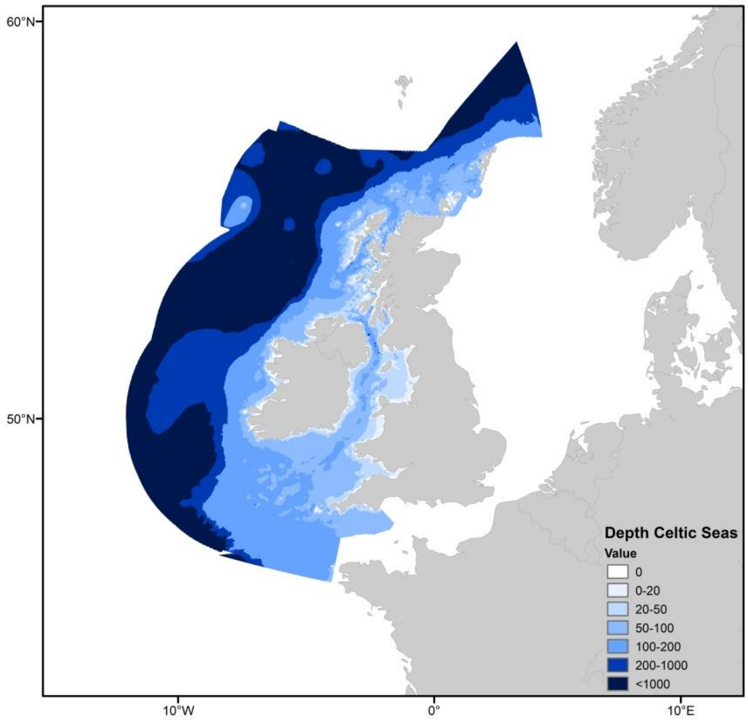


Figure 1. Major depth bands in the Cetic Sea area used for indicator development and fishing impact studies. Source: http://www.gebco.net/

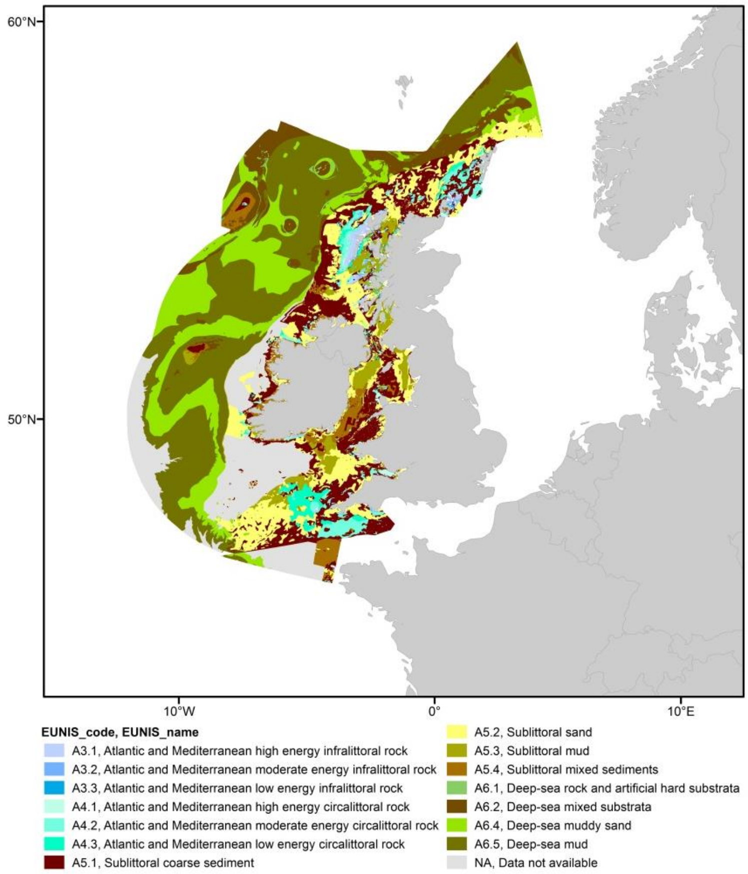


Figure 2. EMODnet EUNIS level 3 habitat map of the Celtic Sea area used for indicator development and fishing impact studies. Data combined under BENTHIS project, Eigaard et al. 2017.

North Sea

The North Sea is a marginal sea of the Atlantic Ocean with major water inflows from the south through the English Channel and from the north through the Norwegian Sea. It is a shallow sea with water depths of 20-50m in the south and increasing water depth up to 100-200m to the north (Fig. 3). In the Norwegian Trench water depth can reach ~700m. Vast areas of the North Sea are covered by sand and mud (Fig. 4). Coarse sediments and rocks are found mainly along the British coast as well as in the English Channel. The Norwegian Trench is characterised by deep-sea mud.

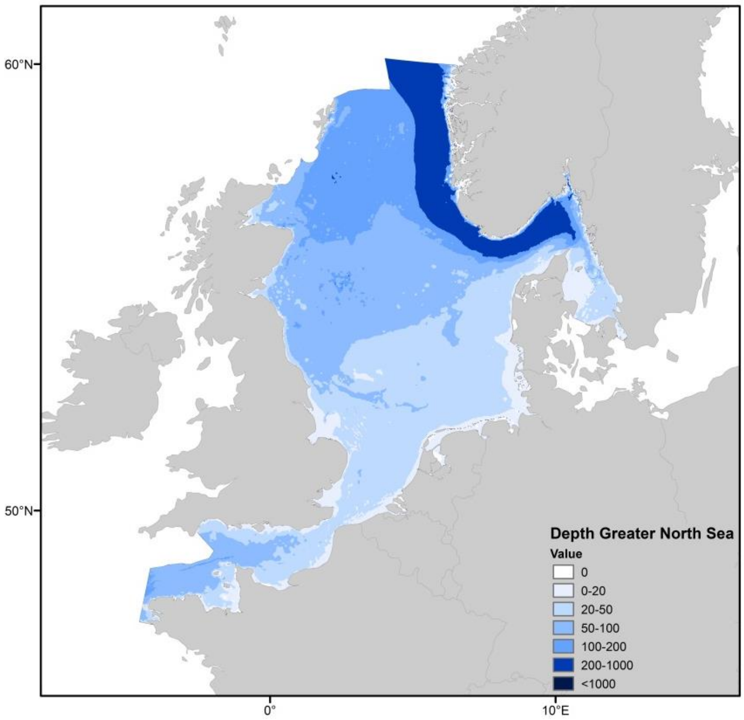


Figure 3. Major depth bands in the Greater North Sea used for indicator development and fishing impact studies. Source: http://www.gebco.net/

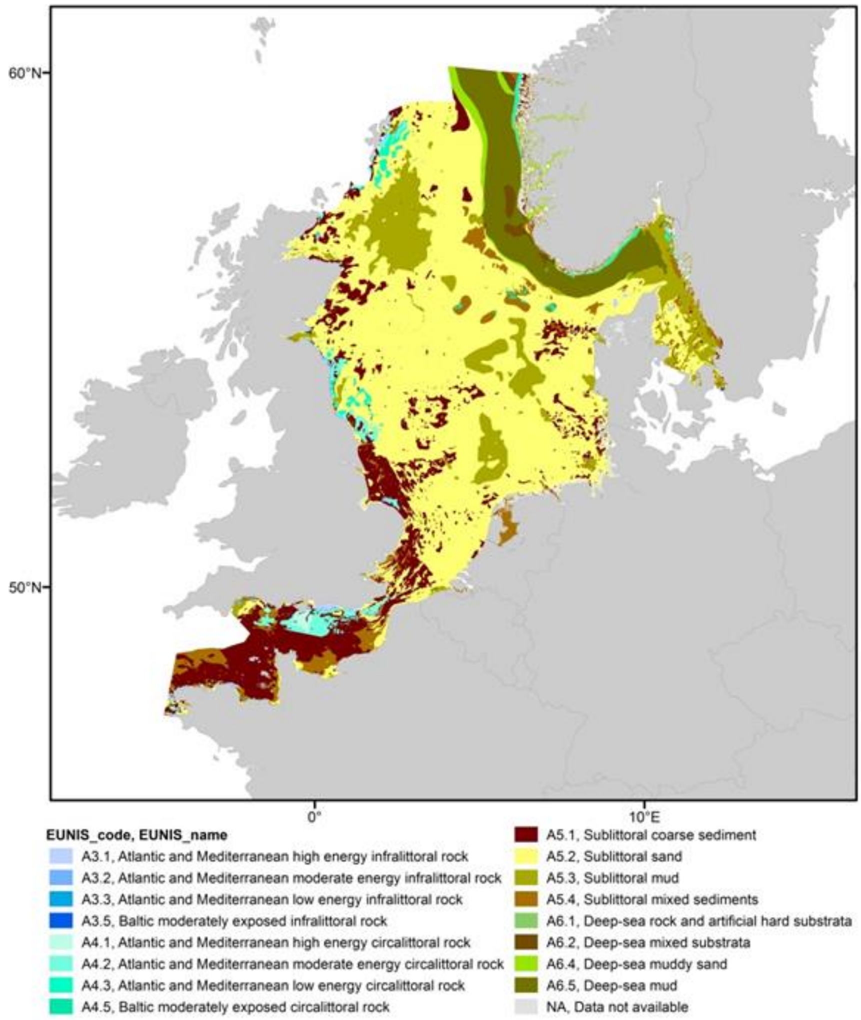


Figure 4. EMODnet EUNIS level 3 habitat map of the Greater North Sea used for indicator development and fishing impact studies. Data combined under BENTHIS project, Eigaard et al. 2017.

Baltic Sea

The Baltic Sea is a semi-enclosed brackish sea. It is characterised by a number of deep basins, such as the Bornholm Basin and Gotland Basin with a maximum water depth of 459m, as well as shallow sills, that limit the exchange with salty North Atlantic waters (Fig. 5). The habitats are dominated by sublittoral muddy or mixed sediments, but in the southern Baltic Sea as well as in the Bothnian Sea sandy and coarse sediments prevail (Fig. 6).

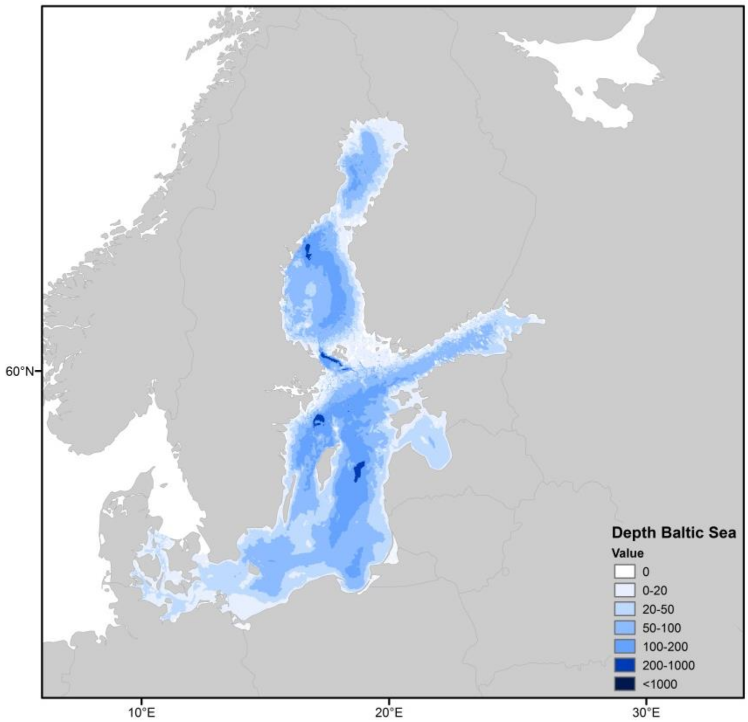


Figure 5. Major depth bands in the Baltic Sea used for indicator development and fishing impact studies. Source: http://www.gebco.net/

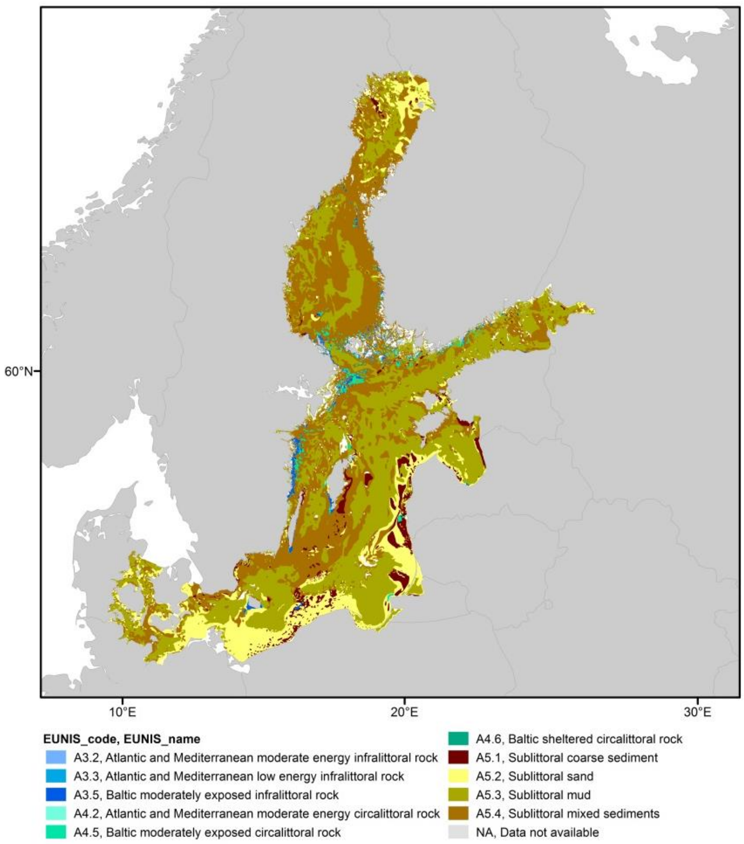


Figure 6. EMODnet EUNIS level 3 habitat map of the Baltic Sea used for indicator development and fishing impact studies. Data combined under BENTHIS project, Eigaard et al. 2017.

Other input data needed for running the methods based on continuous habitats are the sea-floor gravel content and tidal shear stress. Different options for accessing those inputs on a spatial scale for the North Sea and Celtic Seas were explored. It was chosen to base the gravel content on values by EUNIS level 4 habitat provided by Stefan Bolam. These values were added to the EUSeaMap 2016 (http://www.emodnet-seabedhabitats.eu/) to get the maps shown in figure 8.

Table 1: Mean and standard deviation of two environmental variables by Eunis-4 habitat of the benthic sampling stations of Bolam et al. (2014) and van Denderen et al. (2015).

		% Gravel		Stress	
EUNIS LVL 4	NO. STATIONS	AVERAGE	STDDEV	AVERAGE	STDDEV
A5.13	9	34.6	26.1	0.5	0.4
A5.14	149	17.5	25.8	1.2	1.1
A5.15	51	15.2	15.1	0.6	0.8
A5.23	280	0.4	1.1	0.2	0.1
A5.24	1	4.2	-	0.2	-
A5.25	88	0.8	1.1	0.8	0.8
A5.26	21	0.4	0.7	0.5	0.5
A5.27	91	0.4	1.0	0.4	0.5
A5.35	79	0.3	0.2	0.2	0.2
A5.37	78	0.0	0.1	0.1	0.3
A5.43	3	14.5	14.9	0.1	0.0
A5.44	20	31.4	14.7	0.9	0.8

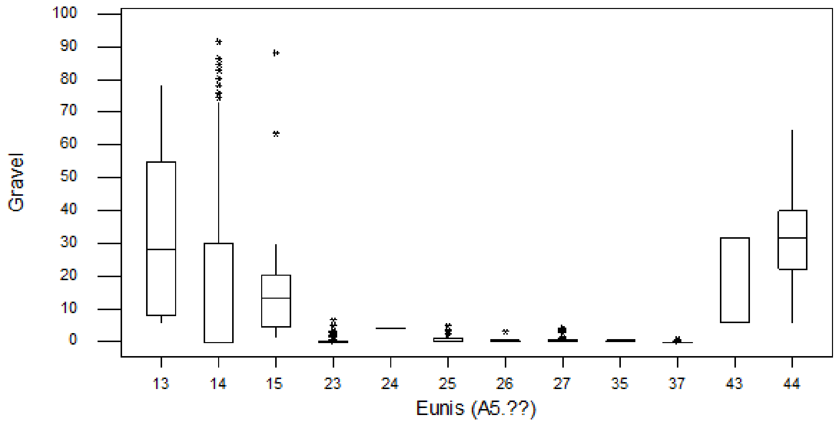


Figure 7: Percentage gravel per EUNIS habitat

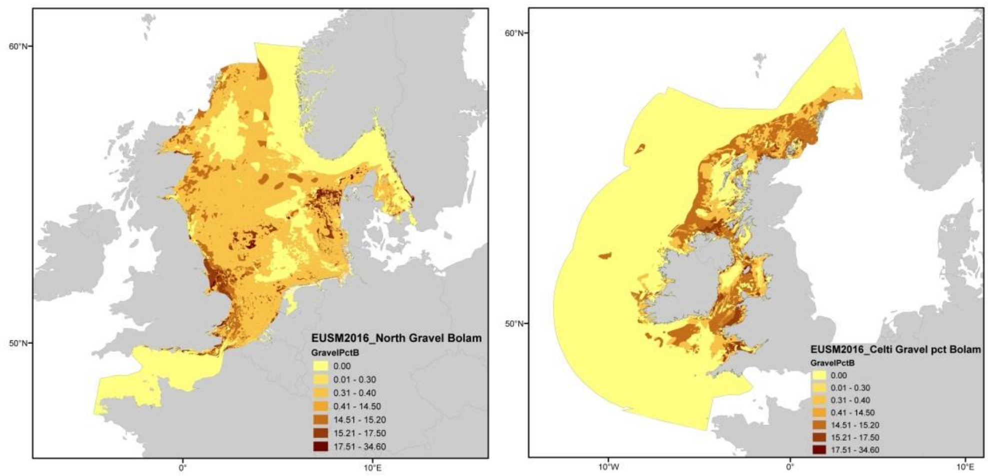


Figure 8: Gravel % by EUNIS level 6 habitat from Bolam applied to EU SeaMap 2016 (http://www.emodnet-seabedhabitats.eu/) for the North Sea (left) and Celtic Seas (right).

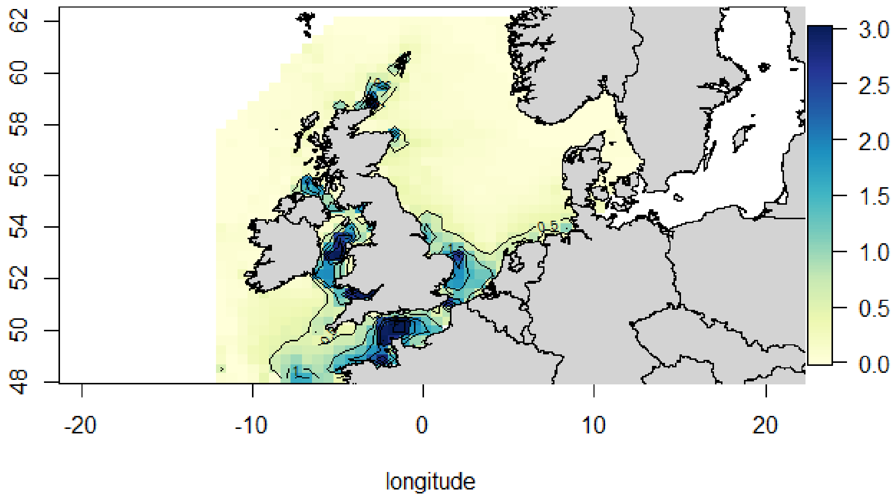
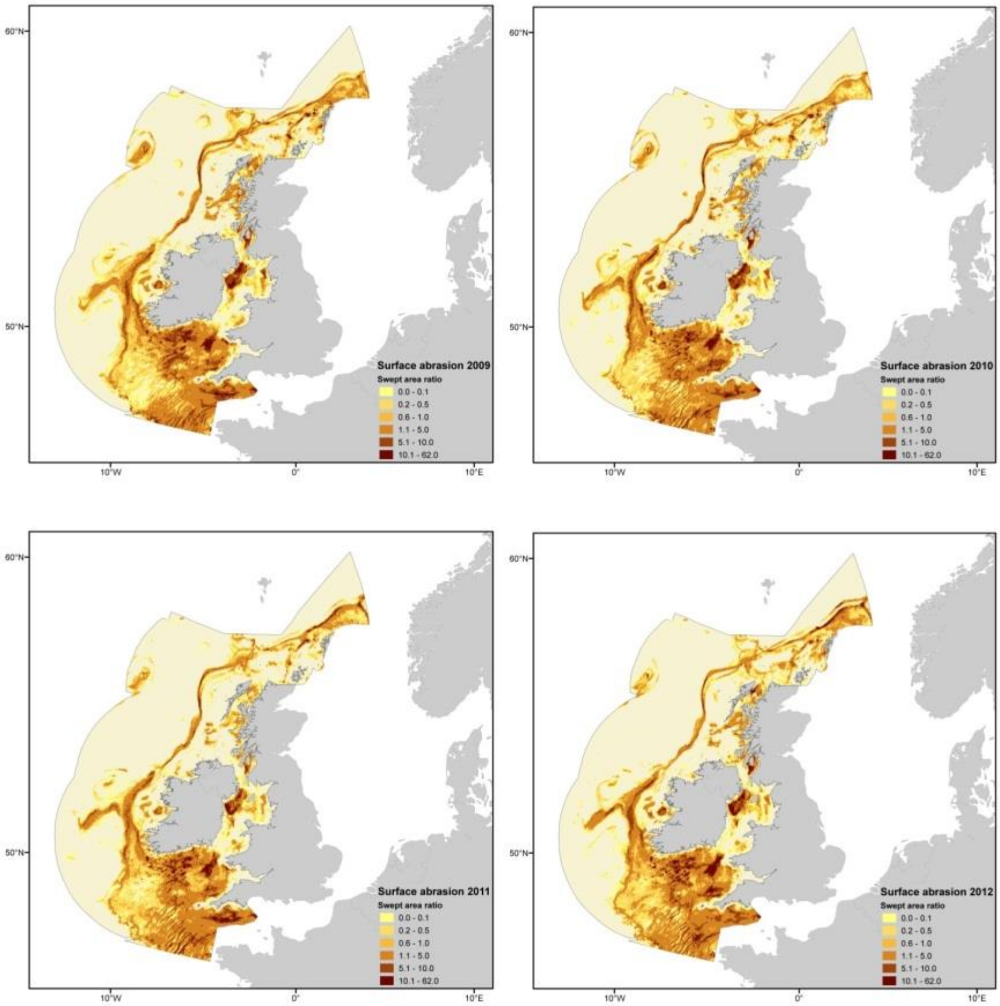


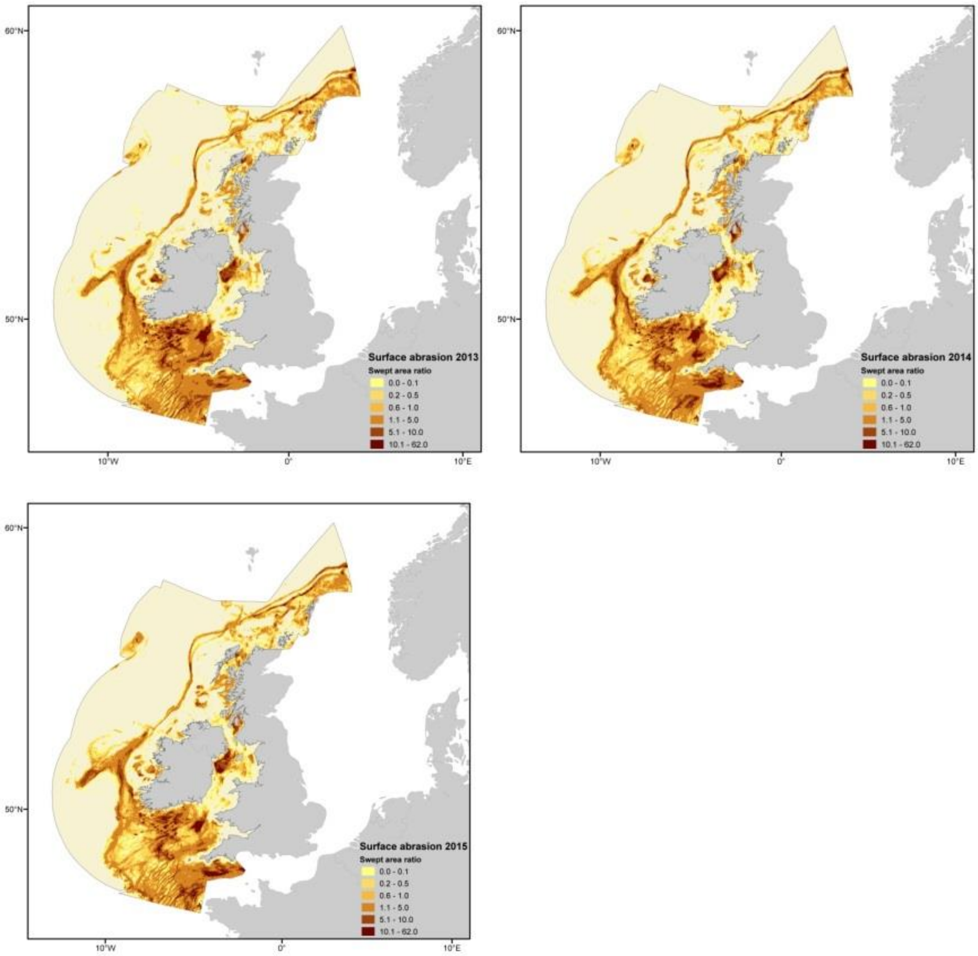
Figure 9: Tidal shear stress based on model output from John Aldridge (CEFAS) (Hiddink et al, 2006; van Denderen et al., 2016). Tidal-bed shear stress was estimated using a 2-dimensional hydrographic model. This model predicts shear stress (the force per unit area exerted on the seabed by the tidal currents: N m–2) on a 1/8° longitude by 1/12° latitude spatial scale.

Annex 6 Annual fishing pressure maps

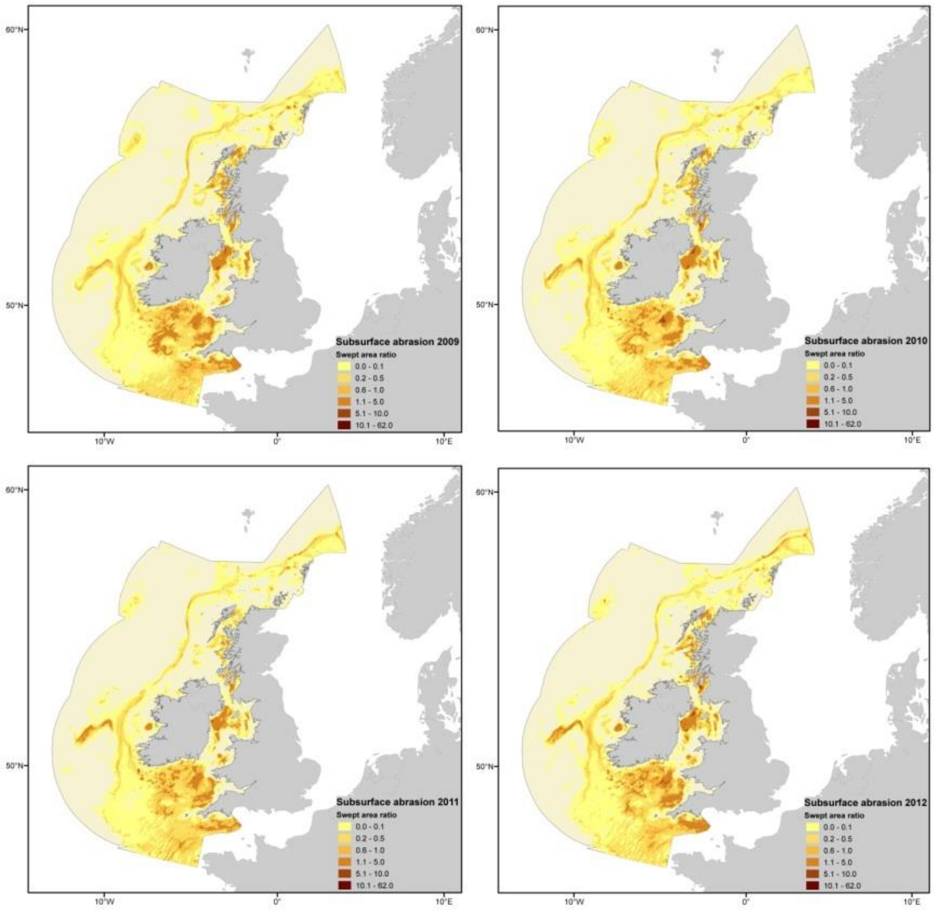
Celtic Sea



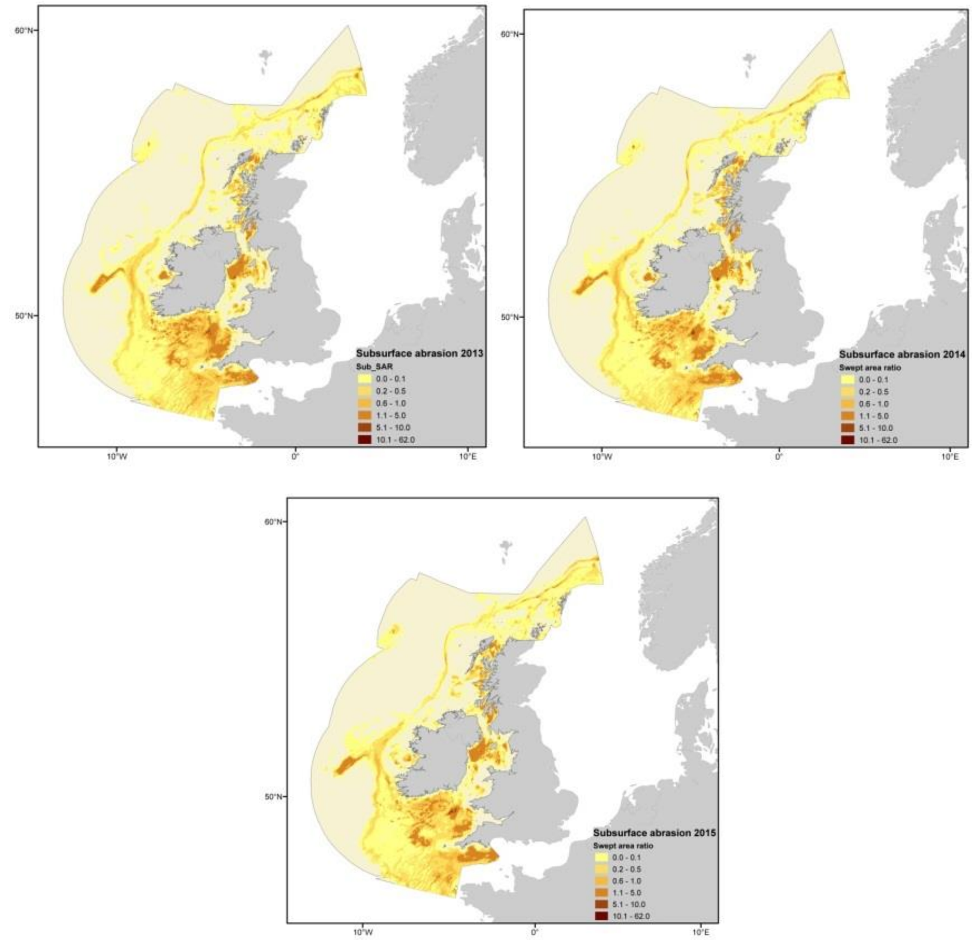
Average annual swept area ratios (SAR) from 2009 (top) to 2015 (bottom) in relation to surface abrasion in the Celtic Sea (Part 1)



Average annual swept area ratios (SAR) from 2009 (top) to 2015 (bottom) in relation to surface abrasion in the Celtic Sea (Part 2).

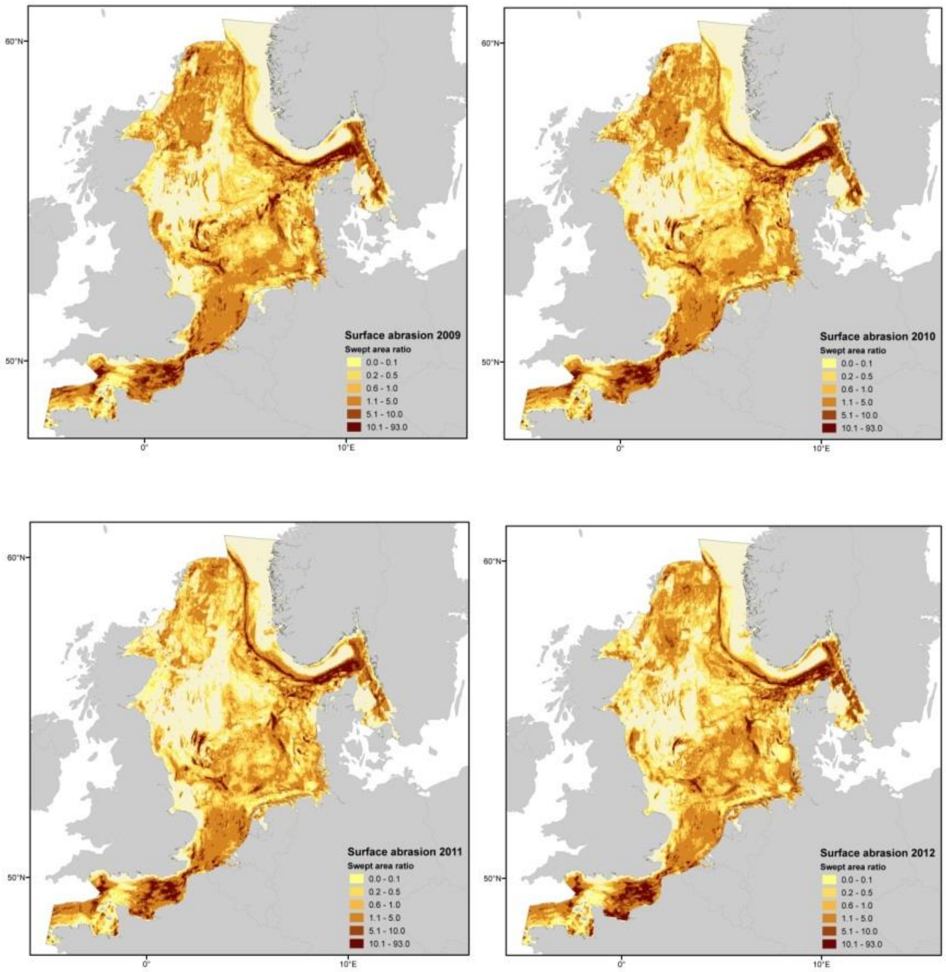


Average annual swept area ratios (SAR) from 2009 (top) to 2015 (bottom) in relation to subsurface abrasion in the Celtic Sea (Part 1).

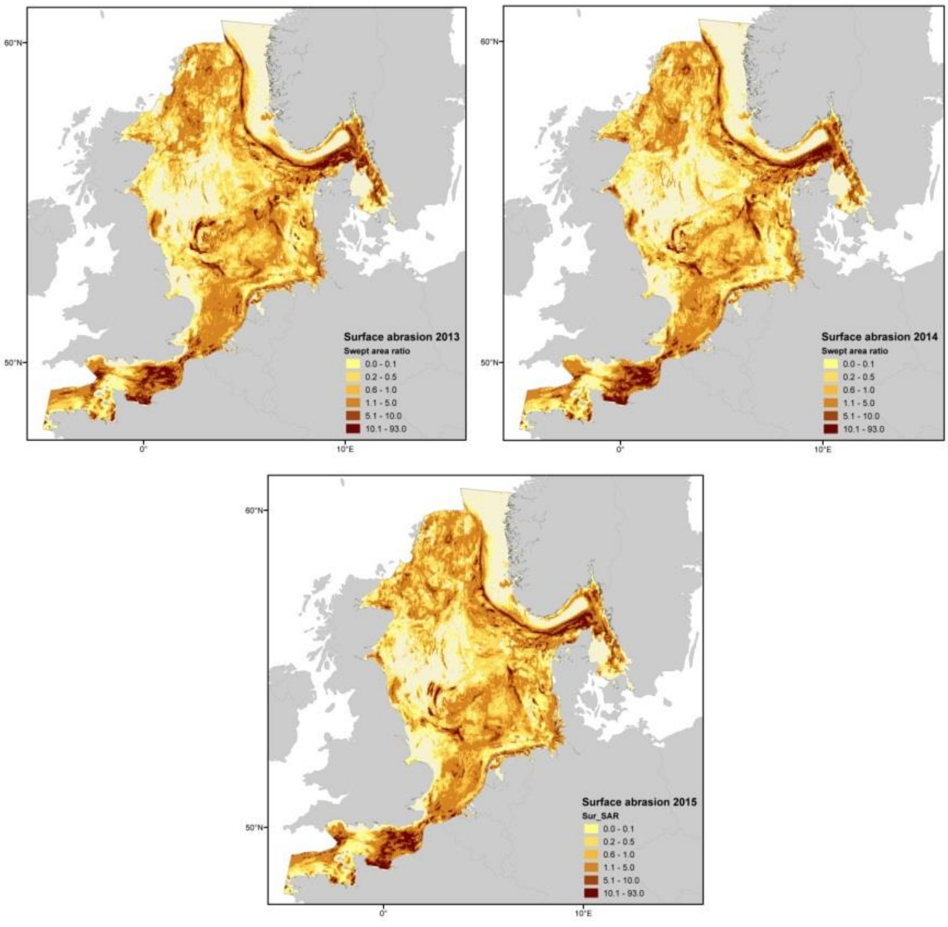


Average annual swept area ratios (SAR) from 2009 (top) to 2015 (bottom) in relation to subsurface abrasion in the Celtic Sea (Part 2).

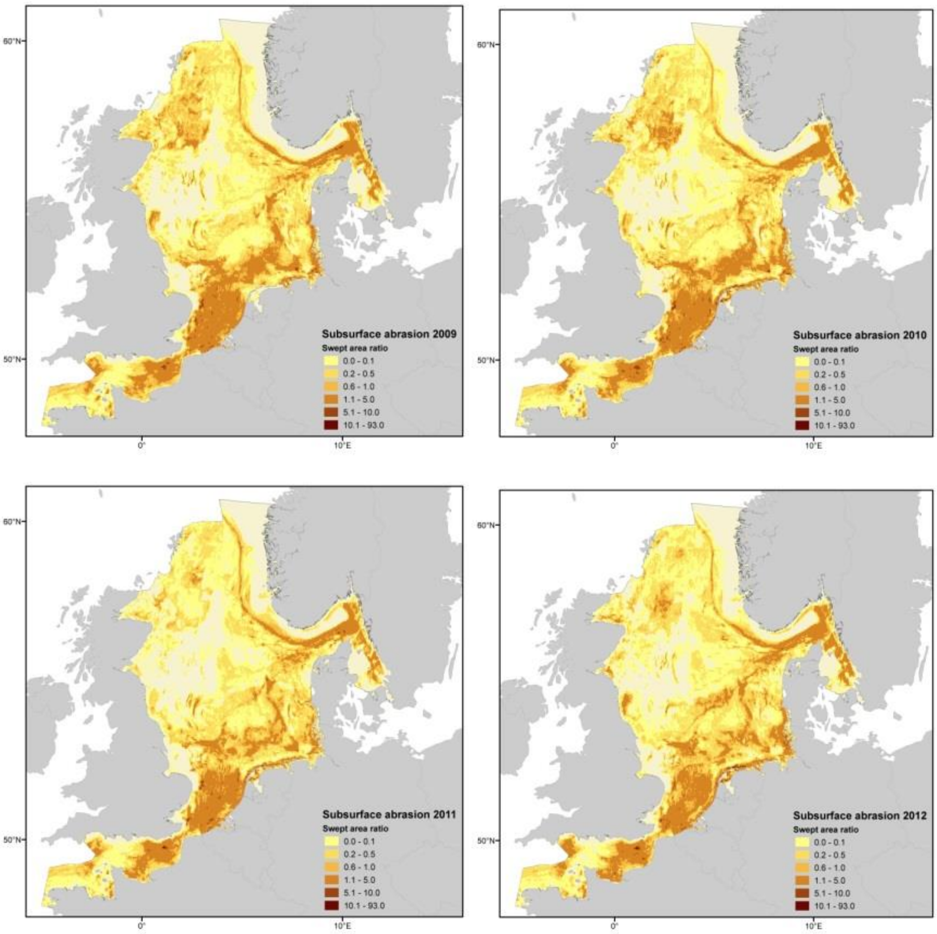
North Sea



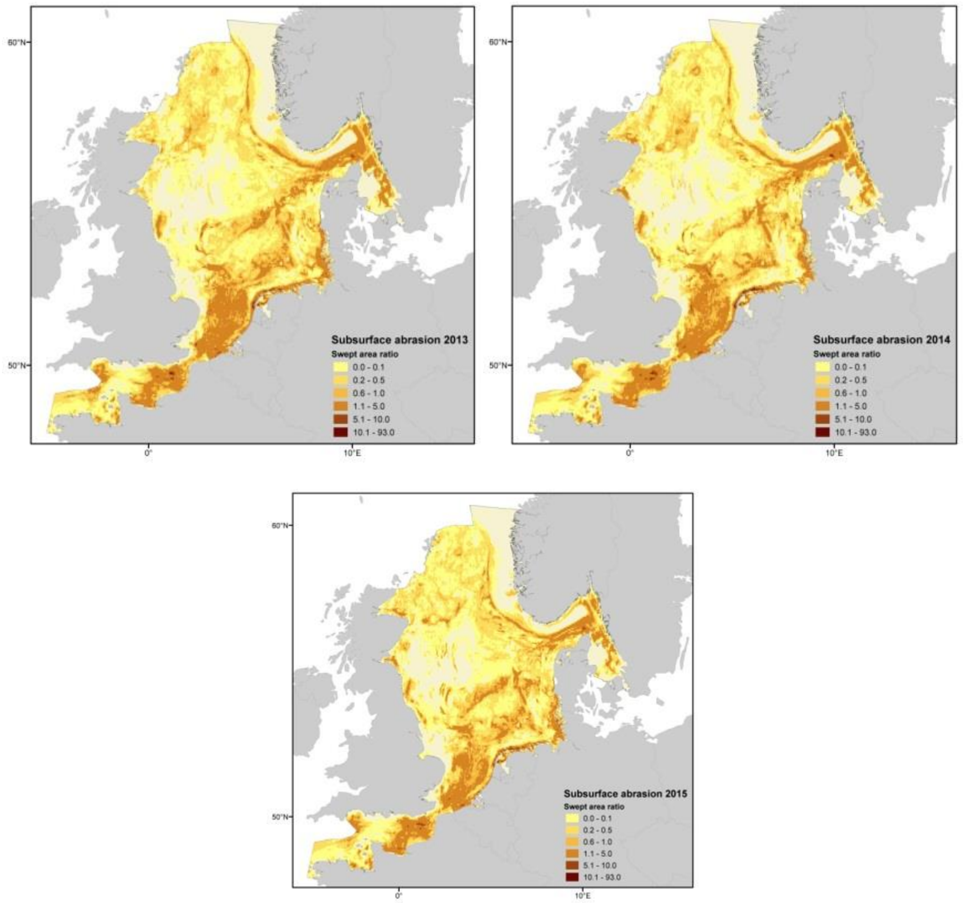
Average annual swept area ratios (SAR) from 2009 (top) to 2015 (bottom) in relation to surface abrasion in the North Sea (Part1).



Average annual swept area ratios (SAR) from 2009 (top) to 2015 (bottom) in relation to surface abrasion in the North Sea (Part 2).

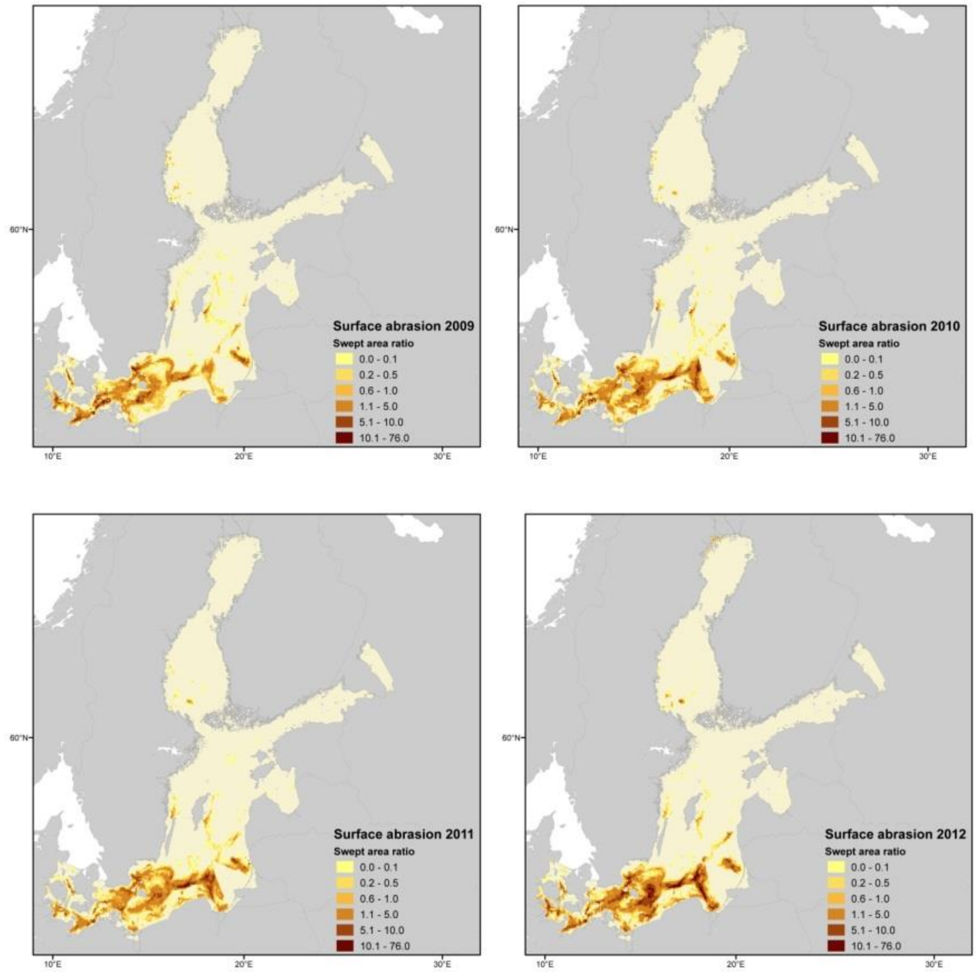


Average annual swept area ratios (SAR) from 2009 (top) to 2015 (bottom) in relation to subsurface abrasion in the North Sea (Part 1).

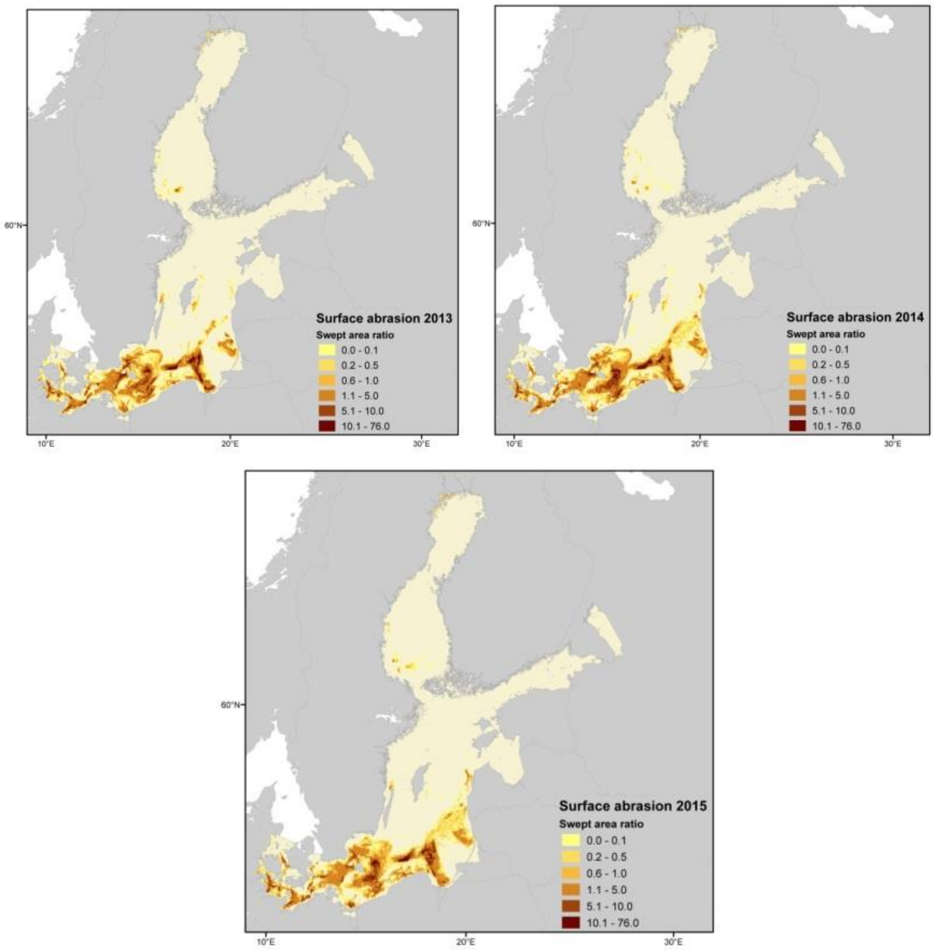


Average annual swept area ratios (SAR) from 2009 (top) to 2015 (bottom) in relation to subsurface abrasion in the North Sea (Part 2).

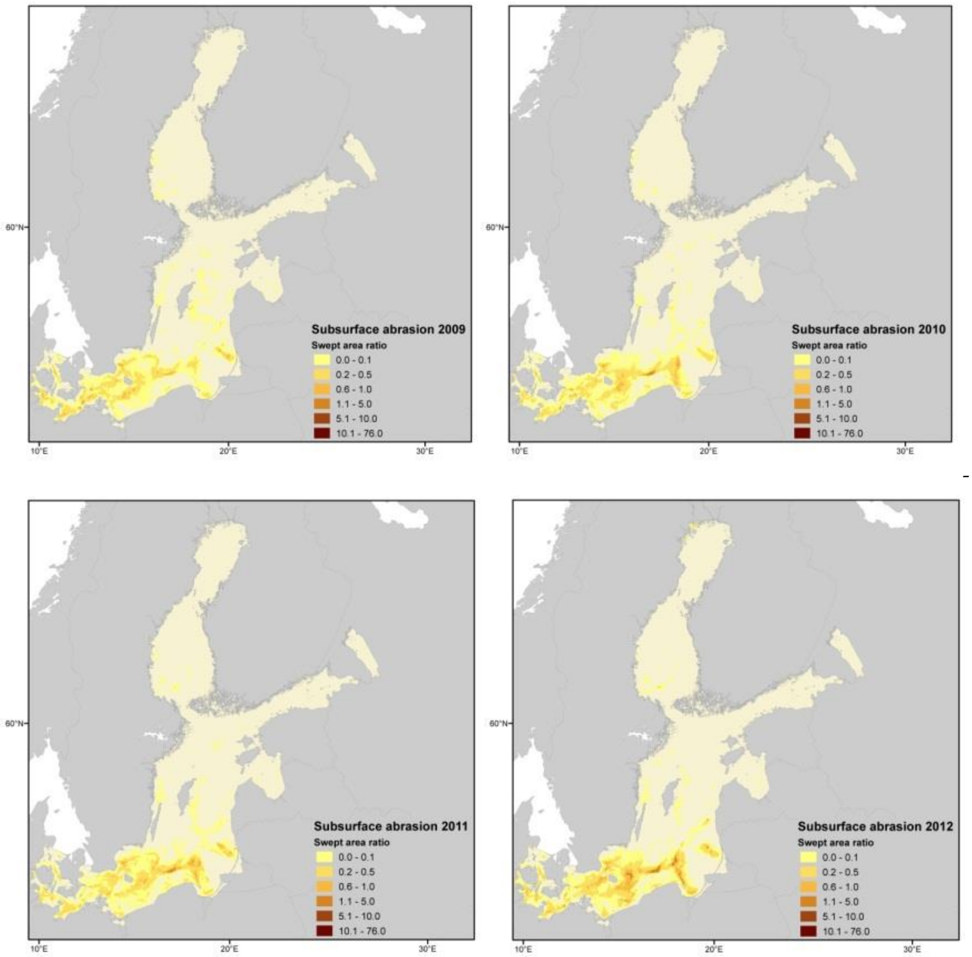
Baltic Sea



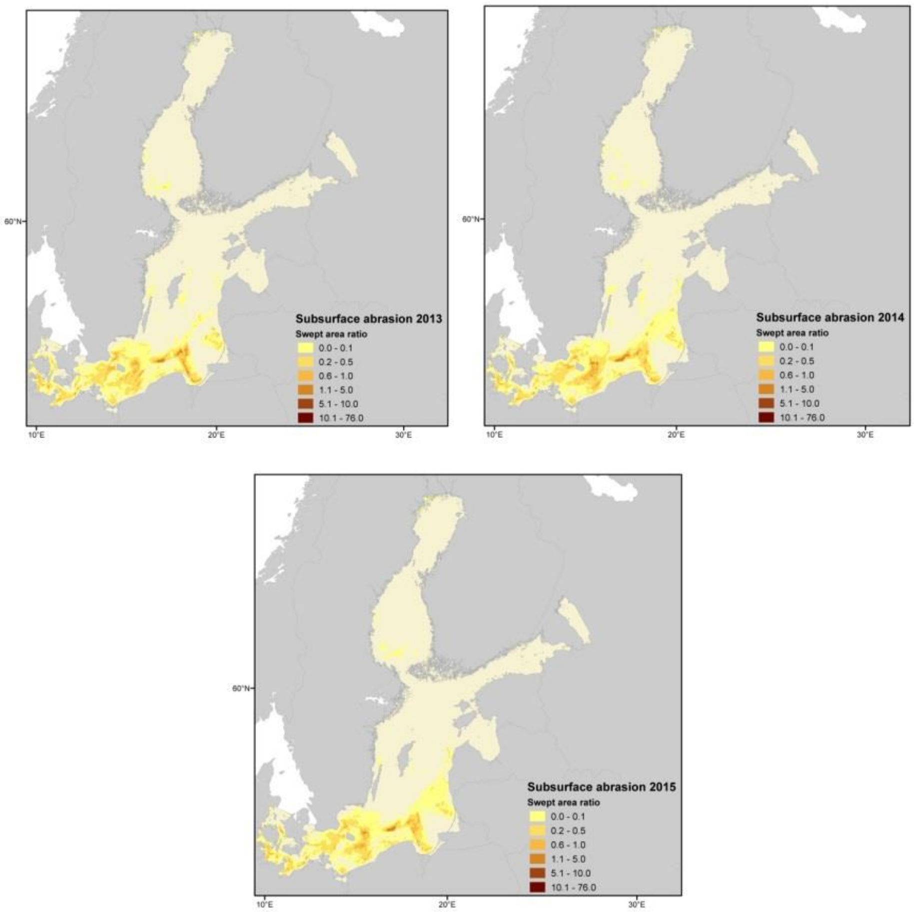
Average annual swept area ratios (SAR) from 2009 (top) to 2015 (bottom) in relation to surface abrasion in the Baltic Sea. (Part 1)



Average annual swept area ratios (SAR) from 2009 (top) to 2015 (bottom) in relation to surface abrasion in the Baltic Sea (Part 2).



Average annual swept area ratios (SAR) from 2009 (top) to 2015 (bottom) in relation to subsurface abrasion in the Baltic Sea (Part 1).



Average annual swept area ratios (SAR) from 2009 (top) to 2015 (bottom) in relation to subsurface abrasion in the Baltic Sea (Part 2).

Annex 7 Confounding effects and variance partitioning

1. Variance partitioning

The problem of confounding effects is not recent and methods for overcoming it have been proposed a long time ago (Borcard *et al*, 1992). This can be easily illustrated in the basic case of three variables. In Figure 1, the circles represent the variances of three variables:

- X1, first explanatory variables

- X2, second explanatory variables

- Y, response variable

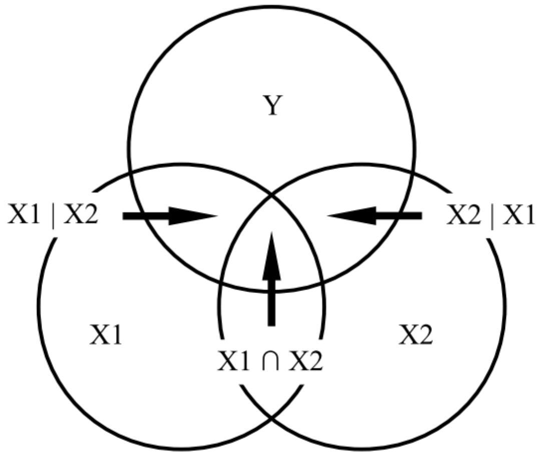


Fig. 1. Illustration of variance common among three variables and that can lead to confounding effects in statistical modelling.

An overlap represents variance in common which is the amount of variance of a variable that can be linearly explained by an overlapping variable (notations in Fig. 1):

- X1 | X2, the variance of Y explained by X1 when removing the effect of X2

- X1 ∩ X2, the variance of Y commonly explained by X1 and X2 (confounding effect)

- X2 | X1, the variance of Y explained by X2 when removing the effect of X1

Overlaps are variance sub-spaces that can be additively handled. For instance, the maximum amount of variance of Y that can be linearly explained by using both X1 and X2 is the sum of the three above sub-spaces (multiple linear regression of Y on X1 and X2). Adjusted *R*-squared is used as an unbiased estimator of each sub-space of which the significance can be tested again the null hypothesis with adapted *F*-statistics (Peres-Neto *et al*, 2006; Borcard *et al*, 2011; Legendre and Legendre, 2012).

In the applied case of ecological indicator development, the conditional effect (X1 | X2 or X2 | X1) is the one of interest. Suppose that both trawling intensity (variable X2) and a given ecological indicator (Y) are both correlated to a gradient of productivity (variable X1), the true trawling effect on the indicator can be disentangled from the productivity effect based on partial correlations consisting in the extraction of residual values from the relationships among the variables (Fig. 2). It is important to note that this procedure can include more than two explanatory variables, which is extremely relevant in the case of several co-dominant human pressures in a given area (e.g. Baltic Sea where eutrophication can parallel trawling).

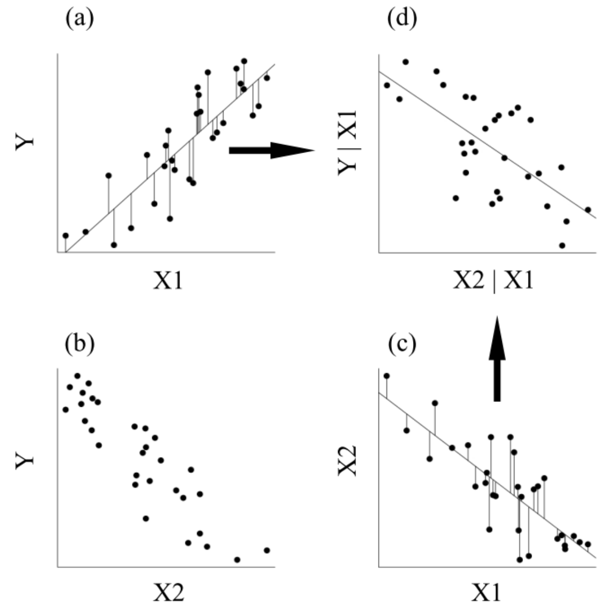


Fig. 2. Illustration of partial correlation to disentangle a confounding effect of two variables X1 and X2 on a third one Y correlated to X1 (a) and to X2 (b). Removing the effect of X1 on Y to isolate the pure effect of X2 consists in retrieving the the residual values from the relationships (a) and (c) in order to create two new variables Y | X1 and X2 | X1 independent of X1 (d). This operation provides the sign of variation of the considered conditional relationship. See Legendre and Legendre (2012) for more details and application examples.

In the example illustrated in Figure X, Y responds negatively to X2 through simple regression (b) and also through partial regression (d). However, in other examples, Y could also respond negatively to X2 (simple regression), but could respond positively after retrieving residuals (partial regression). Hence, given the objective causality required in ecological indicator development, partitioning the variance should be mandatory in cases of colinearity to avoid spurious or flawed conclusions.

References

Borcard D., Gillet F., Legendre P., 2011. Numerical Ecology with R. Springer, 306 p.

Borcard D., Legendre P., Drapeau P., 1992. Partialling out the spatial component of ecological variation. Ecology 73:1045–1055.

Legendre P., Legendre L., 2012. Numerical ecology, Third Edition. Elsevier, 1006 p.

Peres-Neto P., Legendre P., Dray S., Borcard D., 2006. Variation partitioning of species data matrices: estimation and comparison of fractions. Ecology 87:2614–2625.

Annex 8 Broad habitats defined

Broad habitats defined

The TOR a ii) of WKBETH refers to ii) Map and indicator(s) of the area impacted by bottom fishing (in the same 6-year periods), and the proportion (%) of **each MSFD broad habitat type** impacted per subdivision. The most up to date list of **broad habitat types** is presented in the European Commission revised « Decision document » on criteria and methodological standards (2017, as yet unpublished).

Table 1: Broad habitat types including their associated biological communities (relevant for criteria under Descriptors 1 and 6) presented in the EC 2017 revised "Decision document".

Ecosystem component	Broad habitat types	Relevant EUNIS habitat codes (version 2016[2017])
Benthic habitats	Littoral rock and biogenic reef	MA1, MA2
	Littoral sediment	MA3, MA4, MA5, MA6
	Infralittoral rock and biogenic reef	MB1, MB2
	Infralittoral coarse sediment	MB3
	Infralittoral mixed sediment	MB4
	Infralittoral sand	MB5
	Infralittoral mud	MB6
	Circalittoral rock and biogenic reef	MC1, MC2
	Circalittoral coarse sediment	MC3
	Circalittoral mixed sediment	MC4
	Circalittoral sand	MC5
	Circalittoral mud	MC6
	Offshore circalittoral rock and biogenic reef	MD1, MD2
	Offshore circalittoral coarse sediment	MD3
	Offshore circalittoral mixed sediment	MD4
	Offshore circalittoral sand	MD5
	Offshore circalittoral mud	MD6
	Upper bathyal[12] rock and biogenic reef	ME1, ME2
	Upper bathyal sediment	ME3, ME4, ME5, ME6
	Lower bathyal rock and biogenic reef	MF1, MF2
	Lower bathyal sediment	MF3, MF4, MF5, MF6
	Abyssal	MG1, MG2, MG3, MG4, MG5, MG6
Pelagic habitats	Variable salinity[13]	
	Coastal[14]	
	Shelf	
	Oceanic/beyond shelf	

The EC states that these broad habitat types including their associated biological communities (relevant for criteria under Descriptors 1 and 6) equate to one or more habitat types of the EUNIS classification. They clarify that the **2017 version of EUNIS** (as yet unpublished) has been used to categorise these broad habitat types, and that updates to the EUNIS classification should be reflected in the broad habitat types used for the purposes of Directive 2008/56/EC and of this Decision.

The EUNIS level 2 habitat types referred to in Table 1 are presented below in Table 2. This table is drawn from a summary record of a European Topic Centre for Biodiversity (ETC/BD) meeting regarding the revised version of EUNIS[5], which will be published in 2017.

Table 2: EUNIS level 2 habitat types (2017)

Zone		Substrate					
		Hard/firm		Soft			
		Rock*	Biogenic habitat*	Coarse	Mixed	Sand	Mud
Phytal gradient / hydrodynamic gradient	Littoral	MA1	MA2	MA3	MA4	MA5	MA6
	Infralittoral	MB1	MB2	MB3	MB4	MB5	MB6
	Circalittoral	MC1	MC2	MC3	MC4	MC5	MC6
Aphytal/ hydrodynamic gradient	Offshore circalittoral	MD1	MD2	MD3	MD4	MD5	MD6
	Upper bathyal	ME1	ME2	ME3	ME4	ME5	ME6
	Lower bathyal	MF1	MF2	MF3	MF4	MF5	MF6
	Abyssal	MG1	MG2	MG3	MG4	MG5	MG6

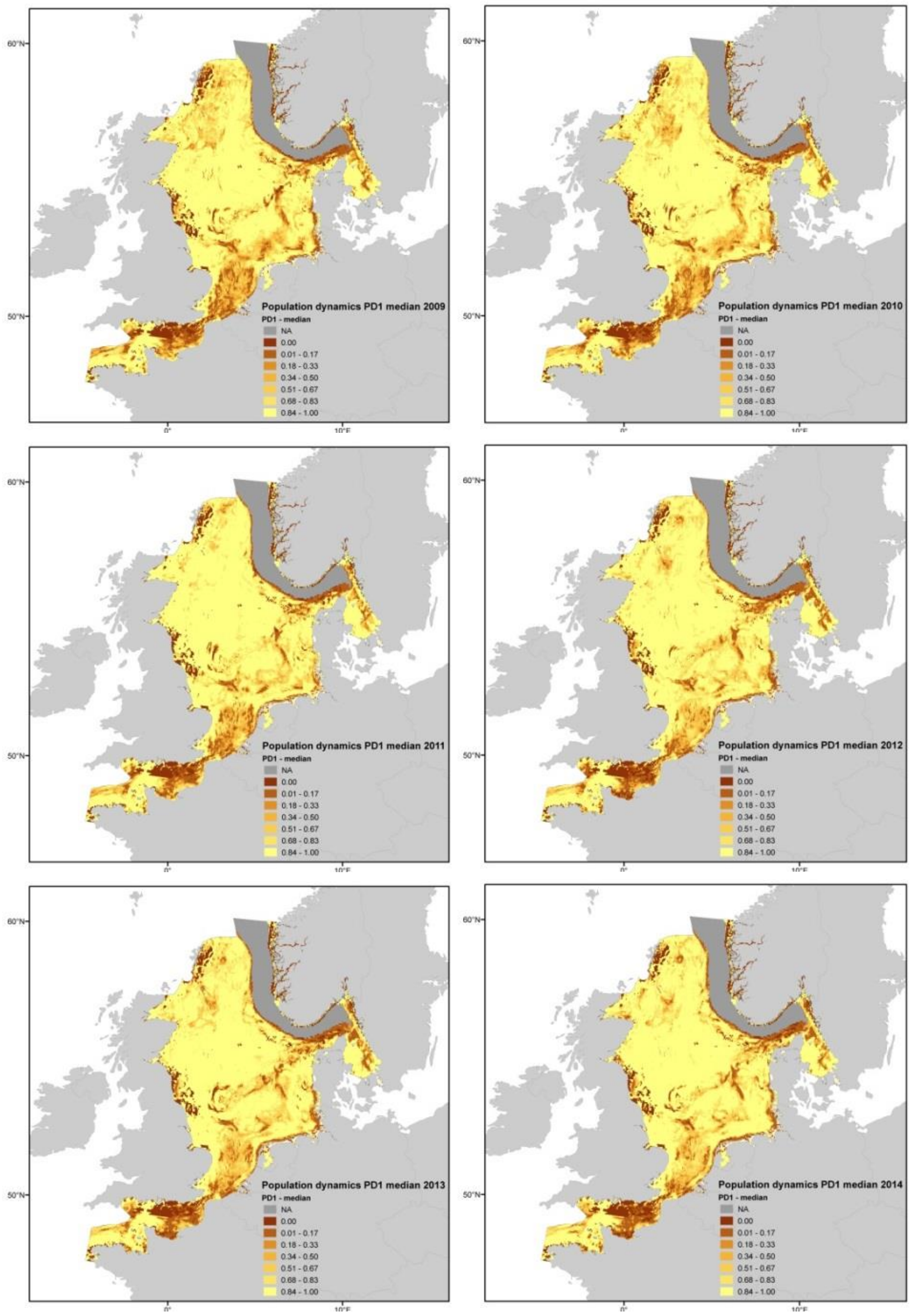
Given that neither the revised Commission Decision Document nor the revised EUNIS classification have been formally published, WKBENTH preferred not to refer to or use these lists in its advice to the Commission under TOR a ii). In addition, most of the work to date on assessing the impact of human pressures on broad habitat types has been based on EUNIS level 3 habitats of the 2004 version of EUNIS (see Table 3). This is due, in part, to most contiguous maps of European seabed habitats being available at EUNIS 2004 level 3 (EUSeaMap etc.). It was therefore decided that, in the context of WKBENTH advice, these EUNIS level 3 (2004) habitats would be used.

5 Revising the marine section of the EUNIS Habitat classification - Report of a workshop held at the European Topic Centre on Biological Diversity, 12 & 13 May 2016 ETC/BD Working paper N°A/2016 http://bd.eionet.europa.eu/Reports/ETCBDTechnicalWorkingpapers/Revising_marine_section_EUNIS_Hab_classification

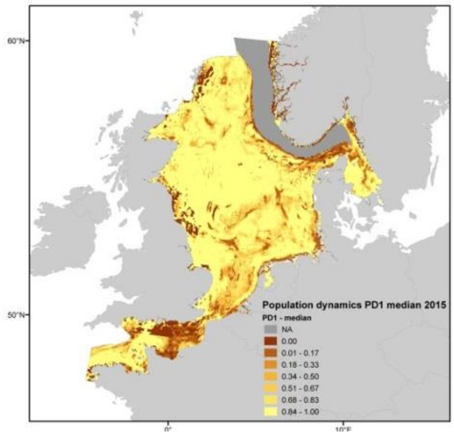
Table 3: EUNIS level 3 habitats and codes (EUNIS 2004)

High energy intertidal rock	**A1.1**
Moderate energy intertidal rock	A1.2
Low energy intertidal rock	A1.3
Intertidal coarse sediment	A2.1
Intertidal sand and muddy sand	A2.2
Intertidal mud	A2.3
Intertidal mixed sediments	A2.4
Coastal saltmarshes and saline reedbeds	A2.5
Intertidal sediments dominated by aquatic angiosperms	A2.6
Intertidal biogenic reefs	A2.7
High energy infralittoral rock	A3.1
Moderate energy infralittoral rock	A3.2
Low energy infralittoral rock	A3.3
High energy circalittoral rock	A4.1
Moderate energy circalittoral rock§	A4.2
Low energy circalittoral rock§	A4.3
Subtidal coarse sediment	A5.1
Subtidal sand	A5.2
Subtidal mud	A5.3
Subtidal mixed sediments	A5.4
Subtidal macrophyte-dominated sediment	A5.5
Subtidal biogenic reefs	A5.6
Deep-sea rock and artificial hard substrata	A6.1
Deep-sea mixed substrata	A6.2
Deep-sea sand	A6.3
Deep-sea muddy sand	A6.4
Deep-sea mud	A6.5
Deep-sea bioherms	A6.6
Raised features of the deep-sea bed	A6.7
Deep-sea trenches and canyons, channels, slope failures and slumps on the continental slope	A6.8
Vents, seeps, hypoxic and anoxic habitats of the deep sea	A6.9

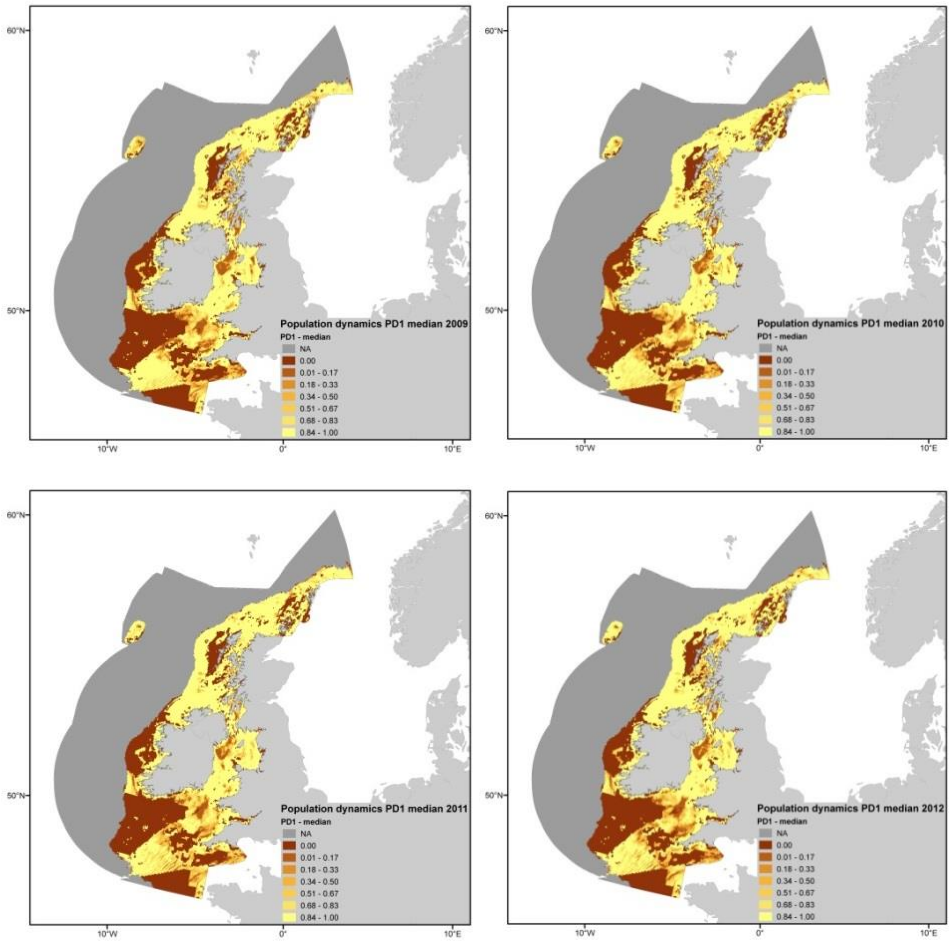
Annex 9 Annual impact maps using various impact methods



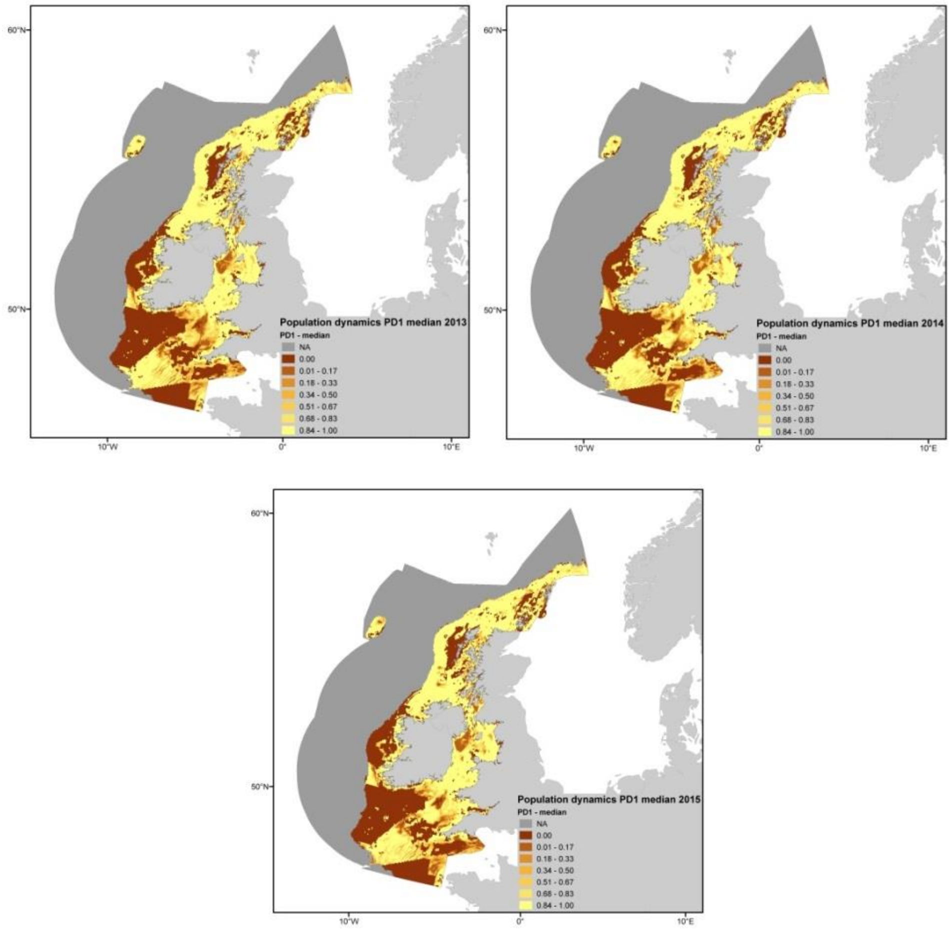
Population dynamics PD1 median 2009-2015 North Sea, EUNIS habitats. Only applies to depths less than 200 m (Part 1).



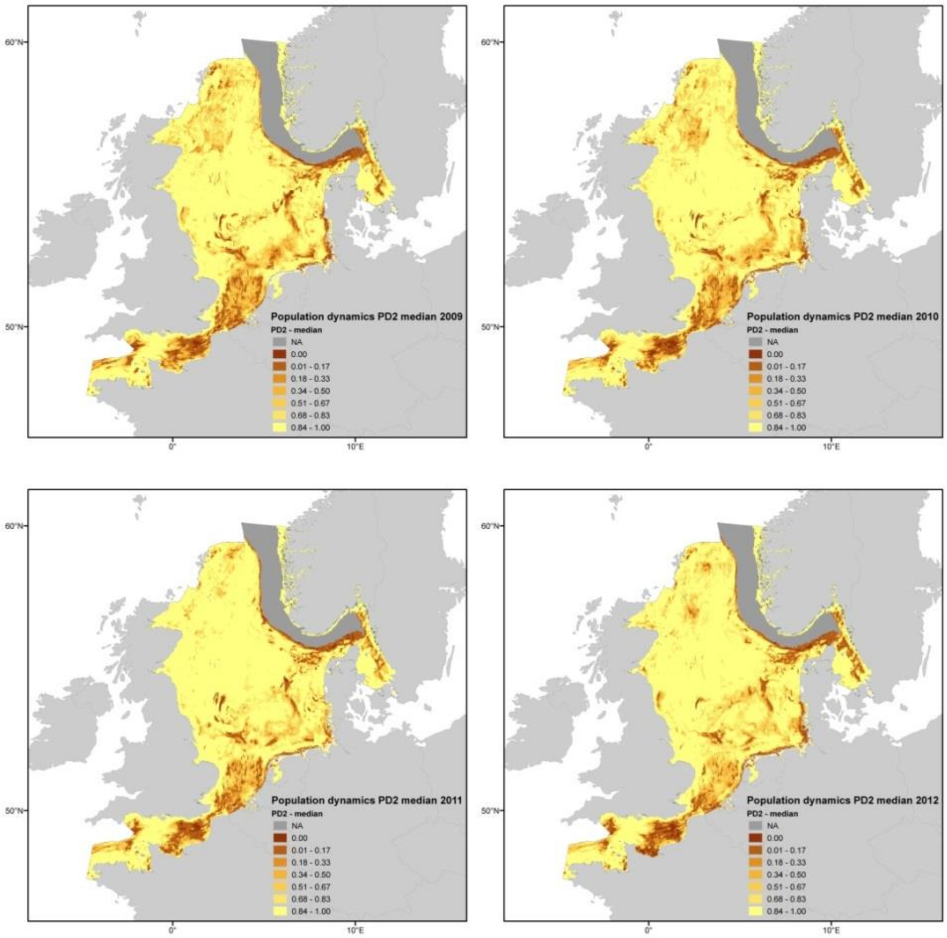
Population dynamics PD1 median 2009-2015 North Sea, EUNIS habitats. Only applies to depths less than 200 m.



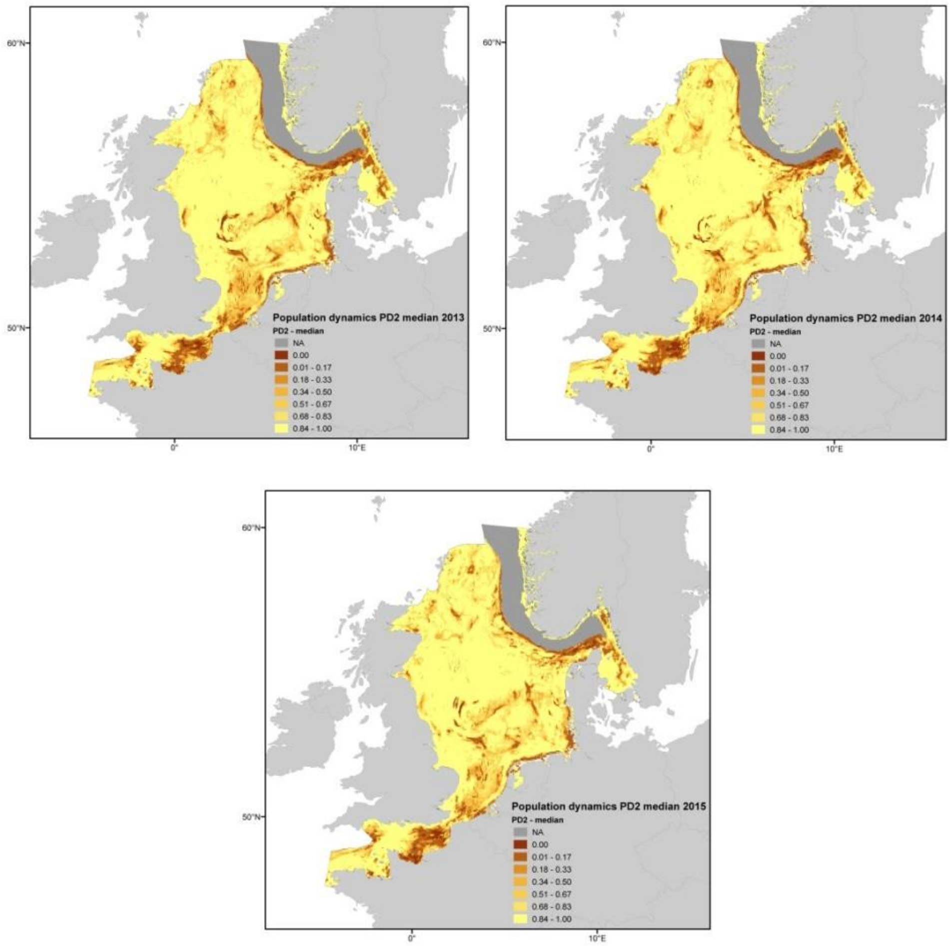
Population dynamics PD1 median 2009–2015 Celtic Sea, EUNIS habitats. Only applies to depths less than 200 m. (Part 1)



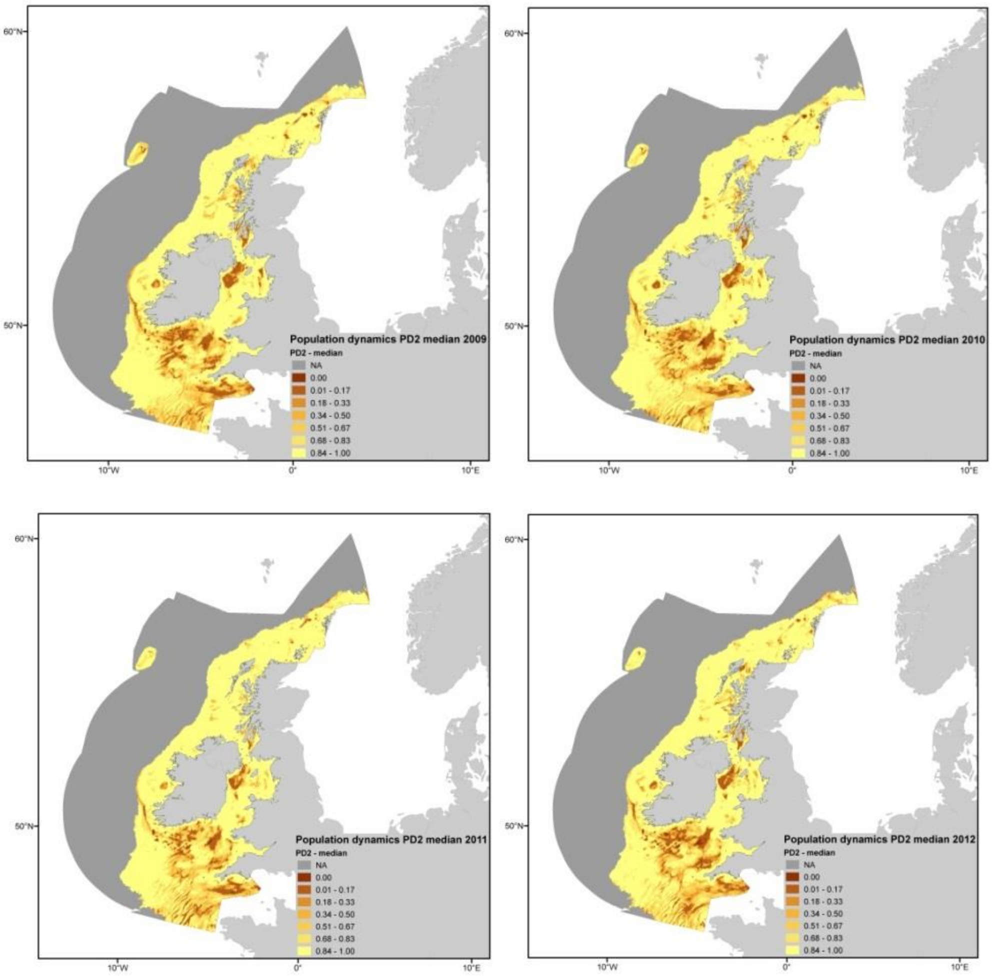
Population dynamics PD1 median 2009–2015 Celtic Sea, EUNIS habitats. Only applies to depths less than 200 m (Part 2).



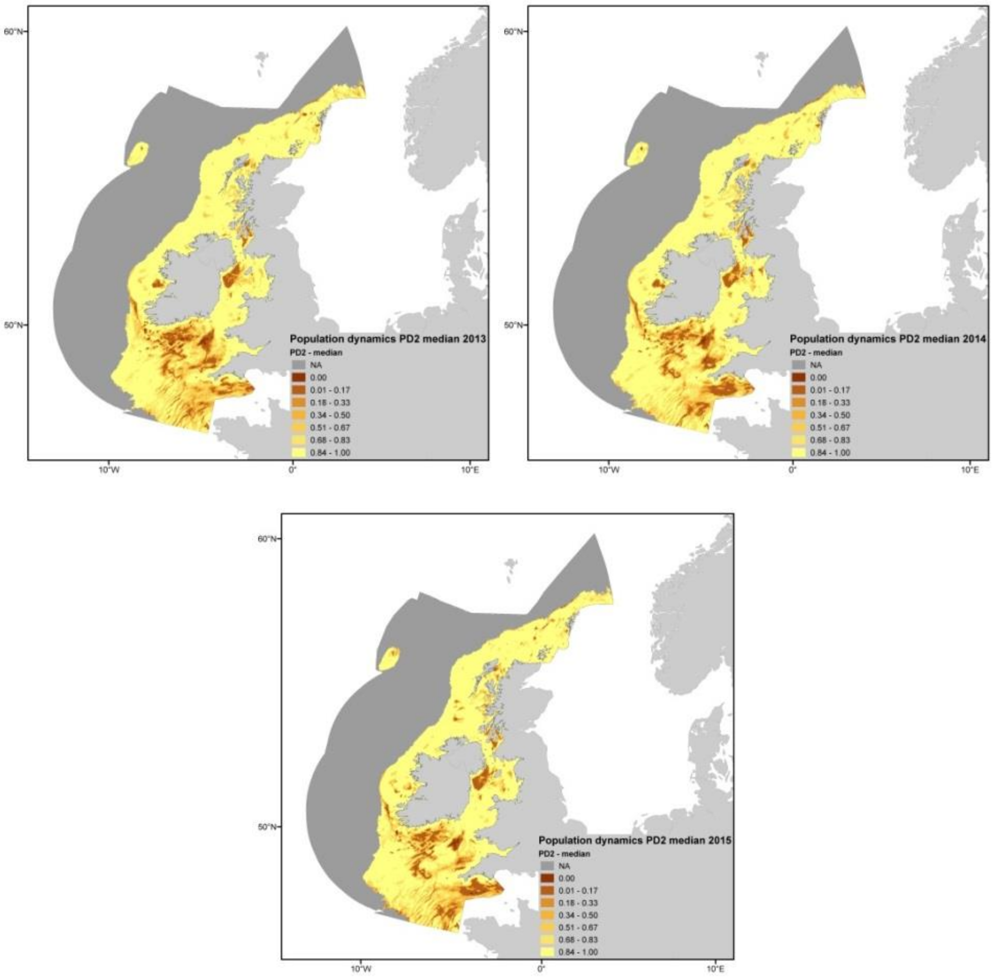
Population dynamics PD2 median 2009–2015 North Sea, continuous habitats. Only applies to depths less than 200 m (Part 1).



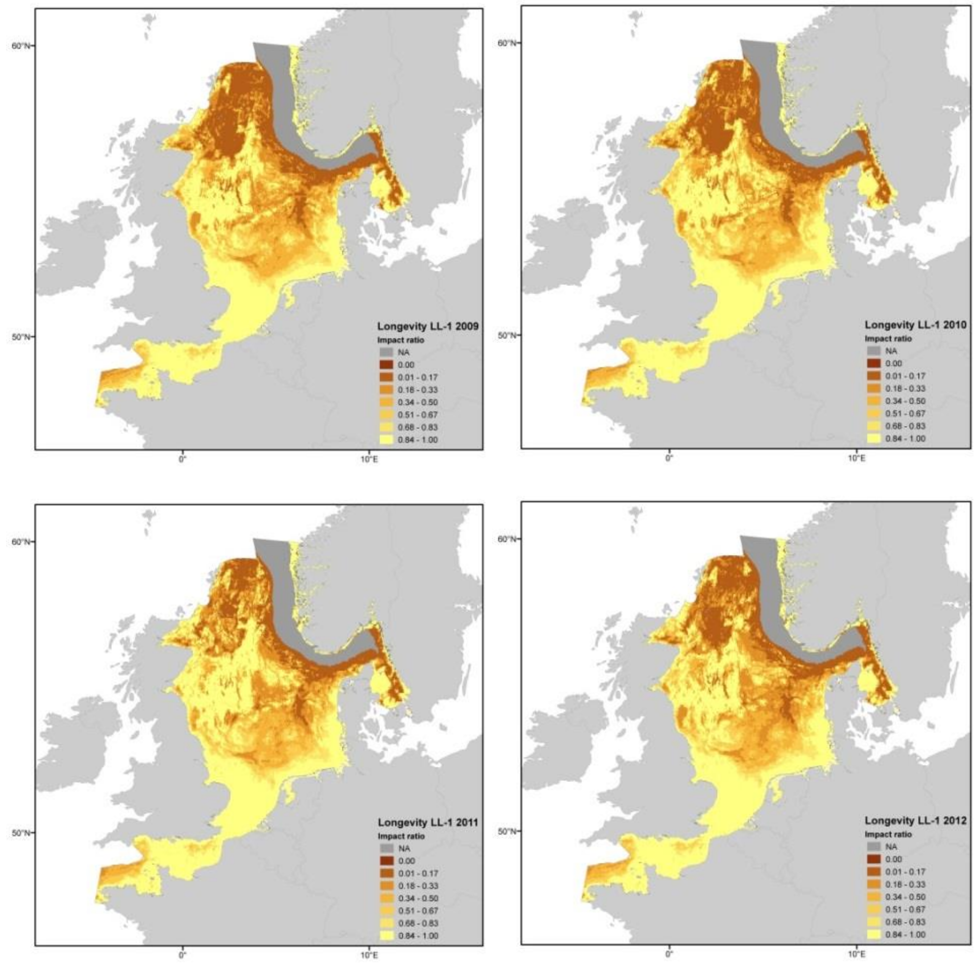
Population dynamics PD2 median 2009–2015 North Sea, continuous habitats. Only applies to depths less than 200 m (Part 2).



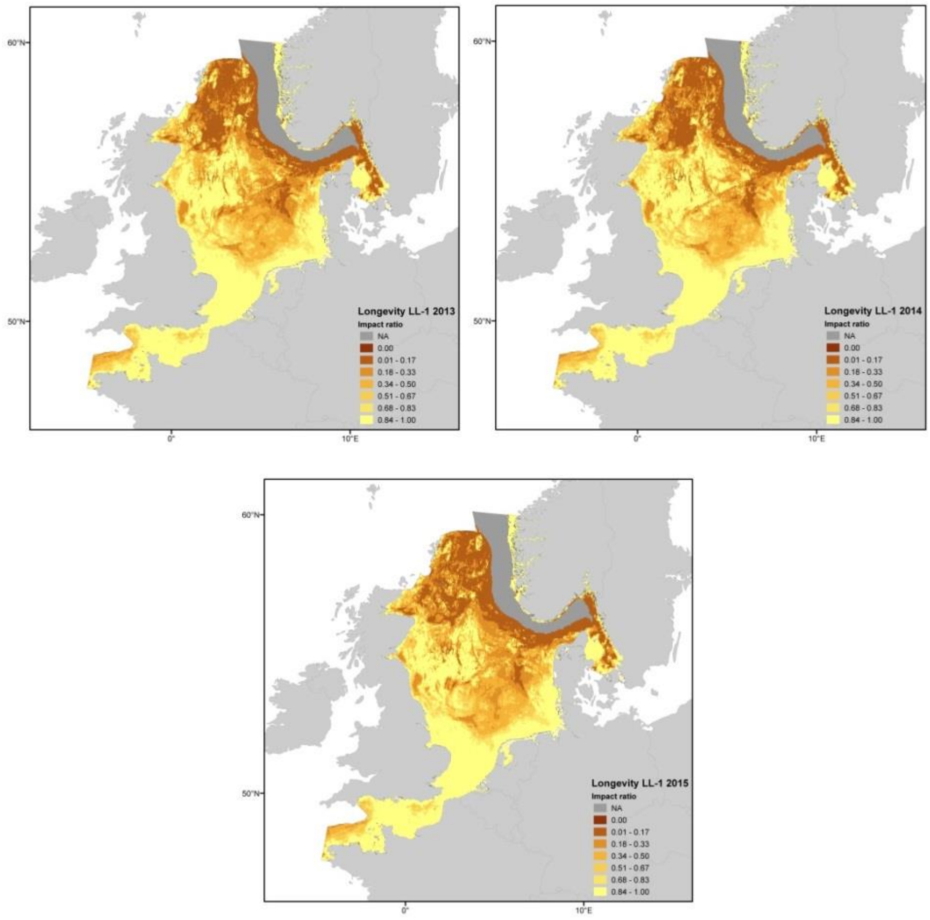
Population dynamics PD2 median 2009–2015 Celtic Sea, continuous habitats. Only applies to depths less than 200 m (Part 1).



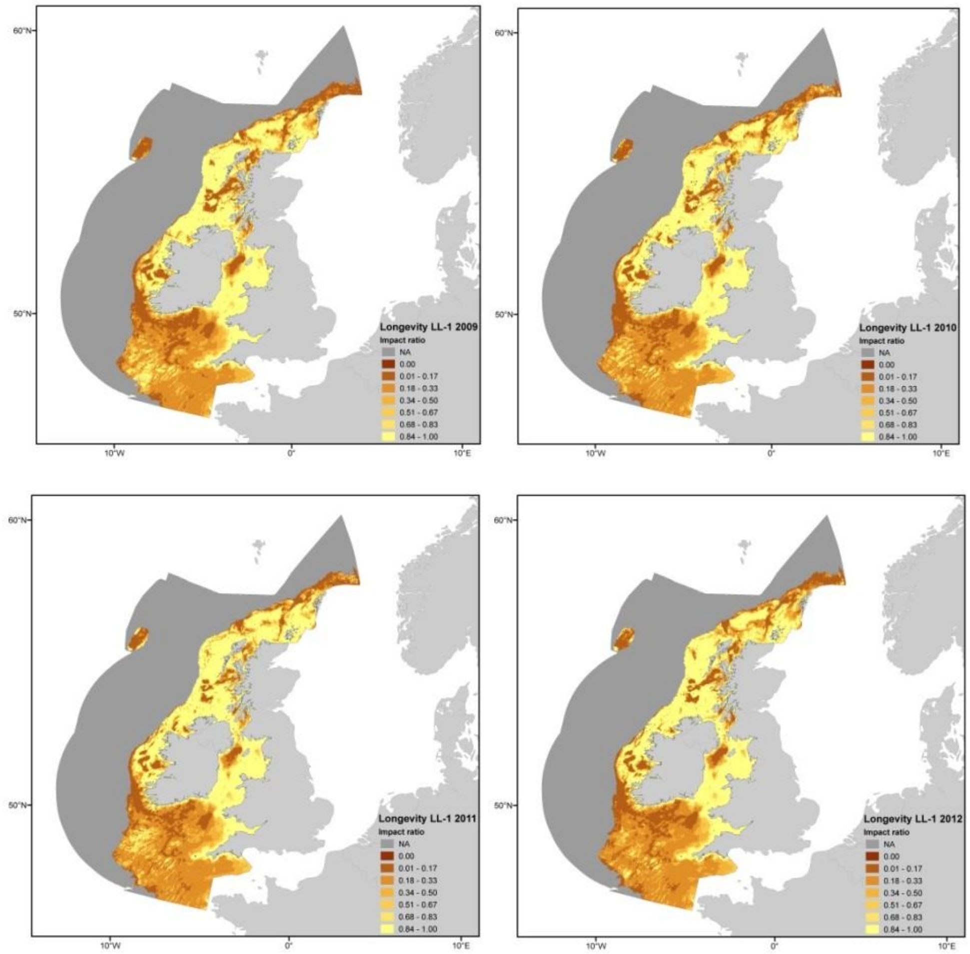
Population dynamics PD2 median 2009–2015 Celtic Sea, continuous habitats. Only applies to depths less than 200 m (Part 2).



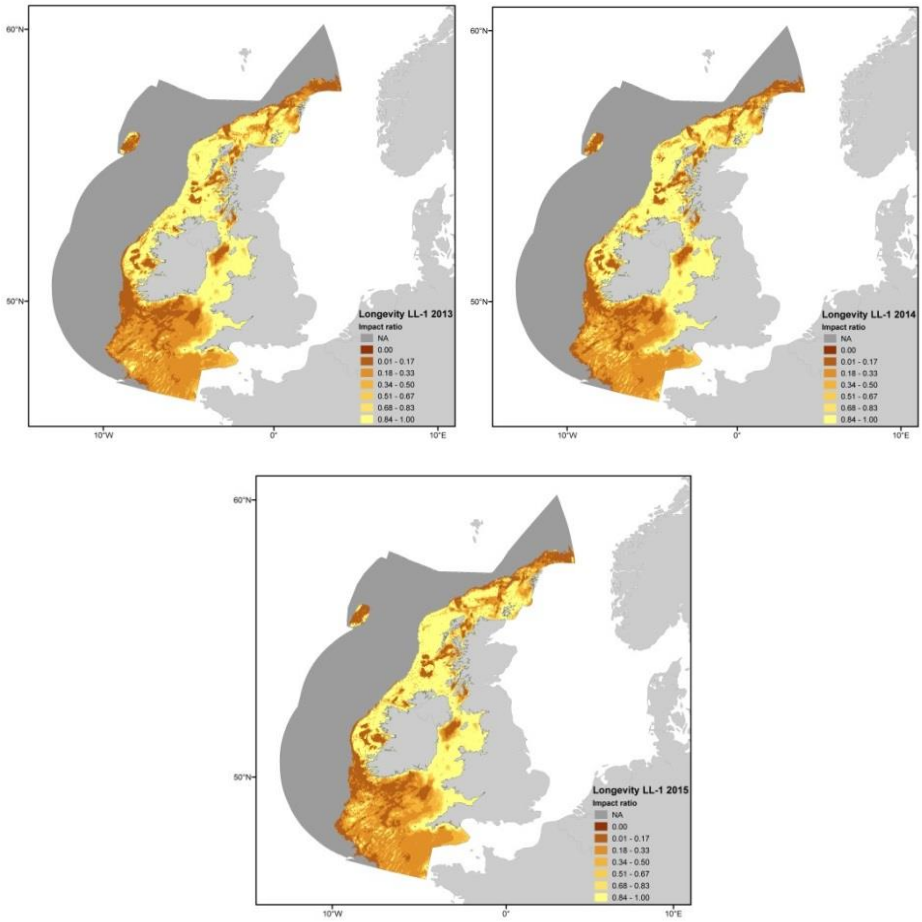
Longevity LL-1 2009–2015 North Sea, continuous habitats. Only applies to depths less than 200 m (Part 1).



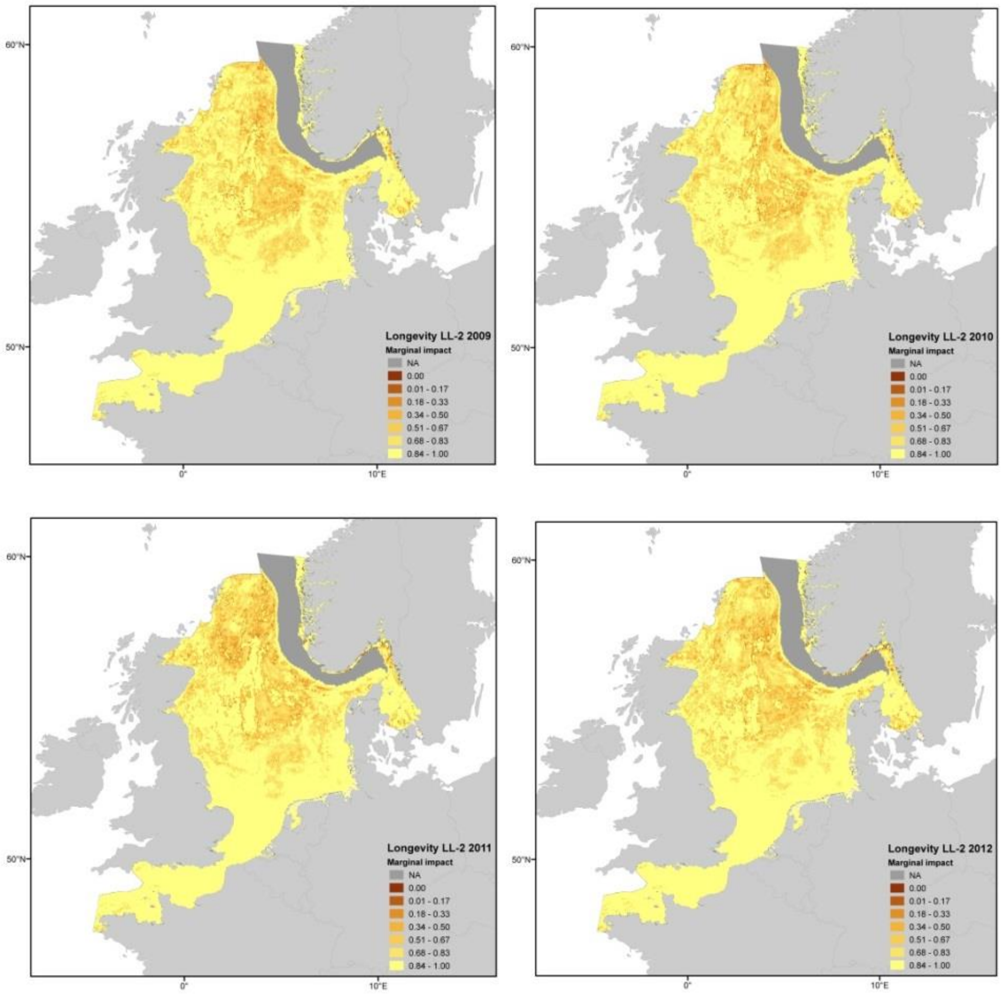
Longevity LL-1 2009–2015 North Sea, continuous habitats. Only applies to depths less than 200 m (Part 2).



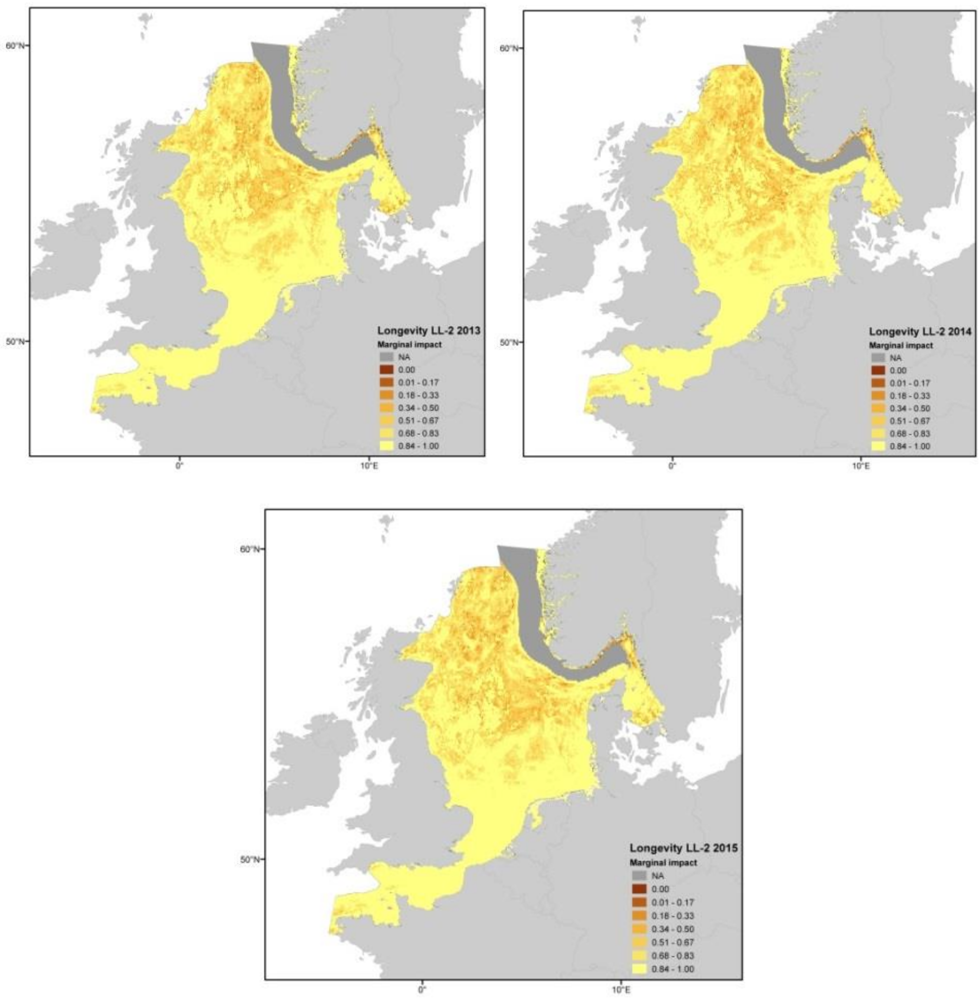
Longevity LL-1 2009–2015 Celtic Sea, continuous habitats. Only applies to depths less than 200 m (Part 1).



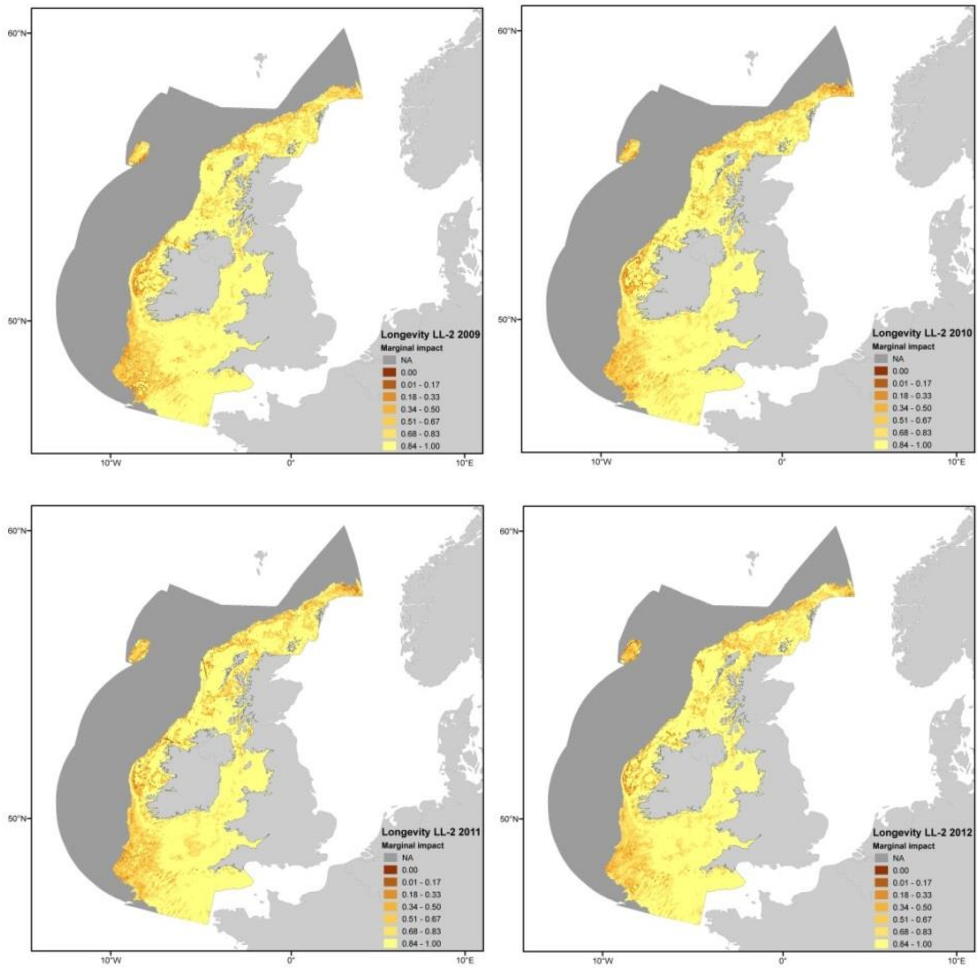
Longevity LL-1 2009–2015 Celtic Sea, continuous habitats. Only applies to depths less than 200 m (Part 2).



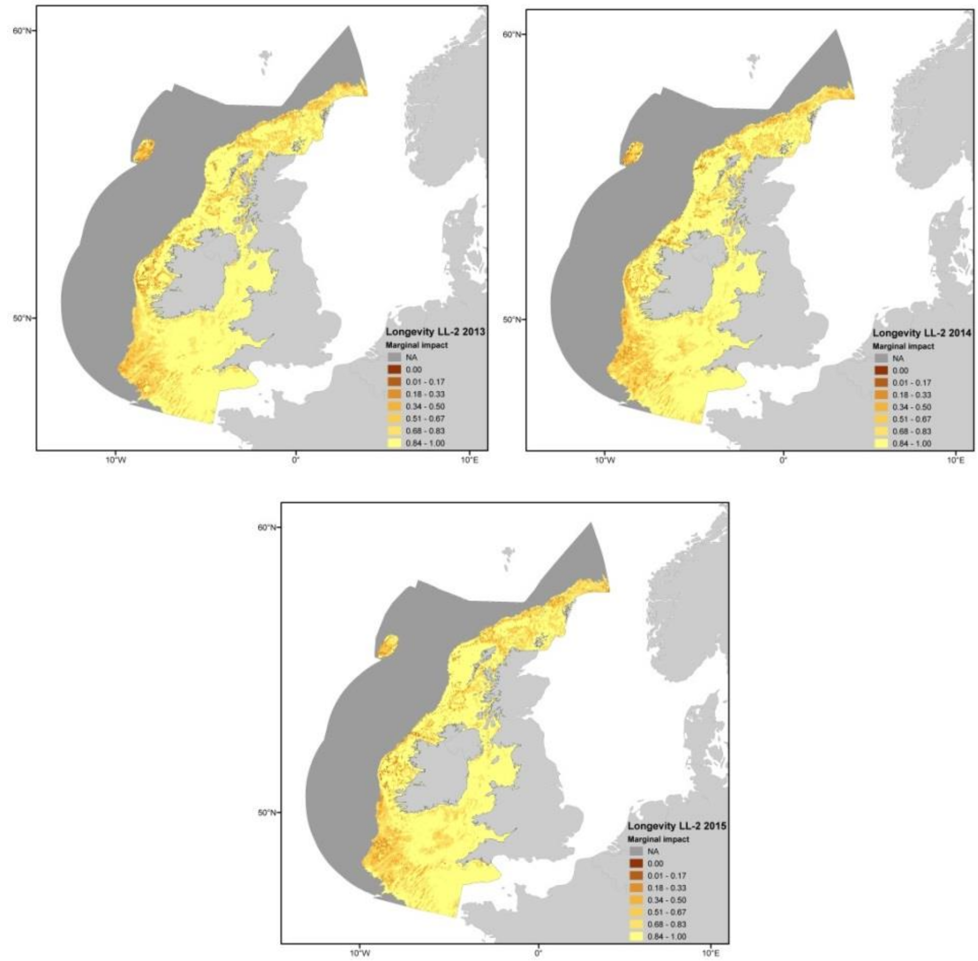
Longevity LL-2 (marginal impact) 2009–2015 North Sea, continuous habitats. Only applies to depths less than 200 m (Part 1).



Longevity LL-2 (marginal impact) 2009–2015 North Sea, continuous habitats. Only applies to depths less than 200 m (Part 2).



Longevity LL-2 (marginal impact) 2009–2015 Celtic Sea, continuous habitats. Only applies to depths less than 200 m (Part 1).



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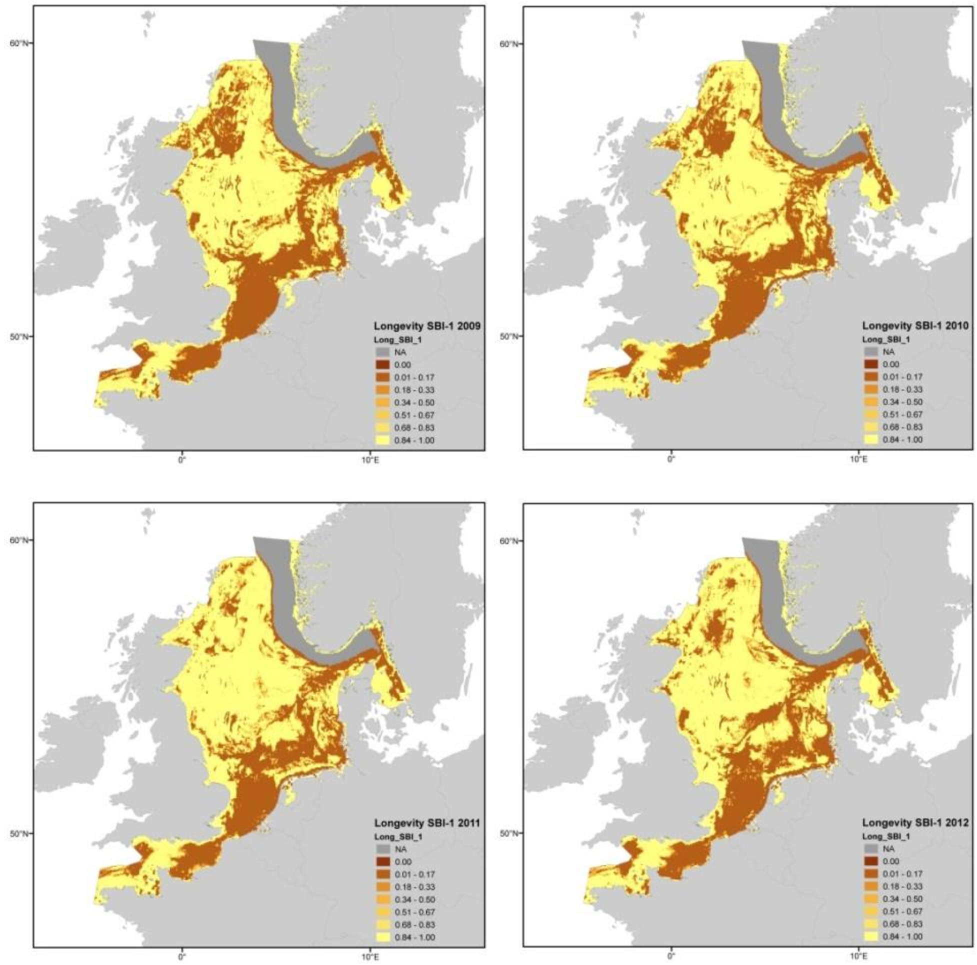
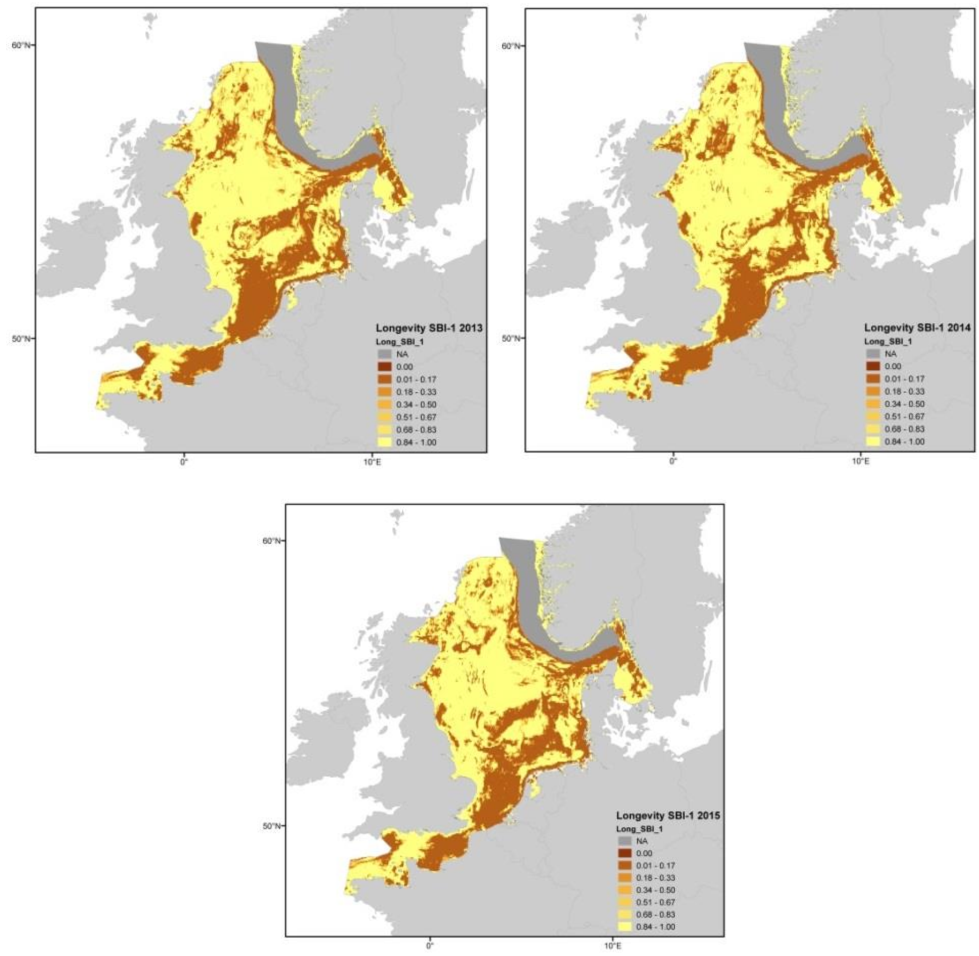
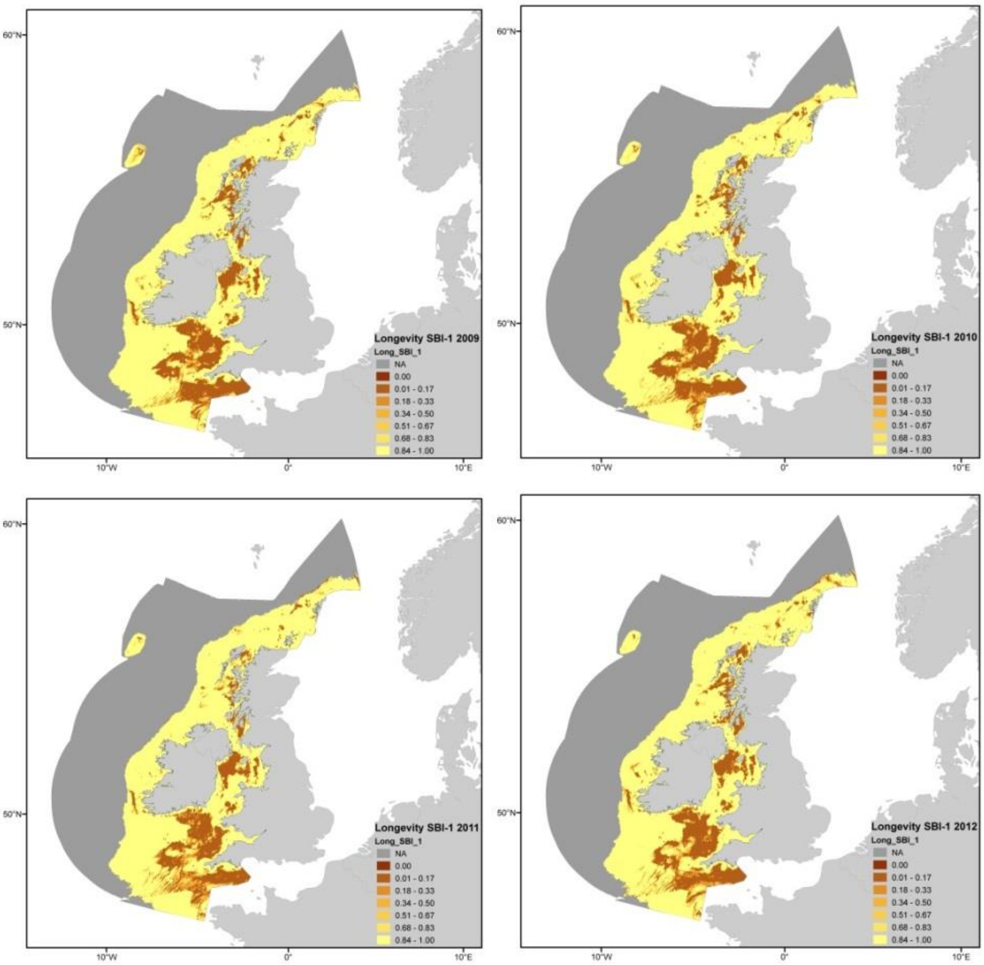


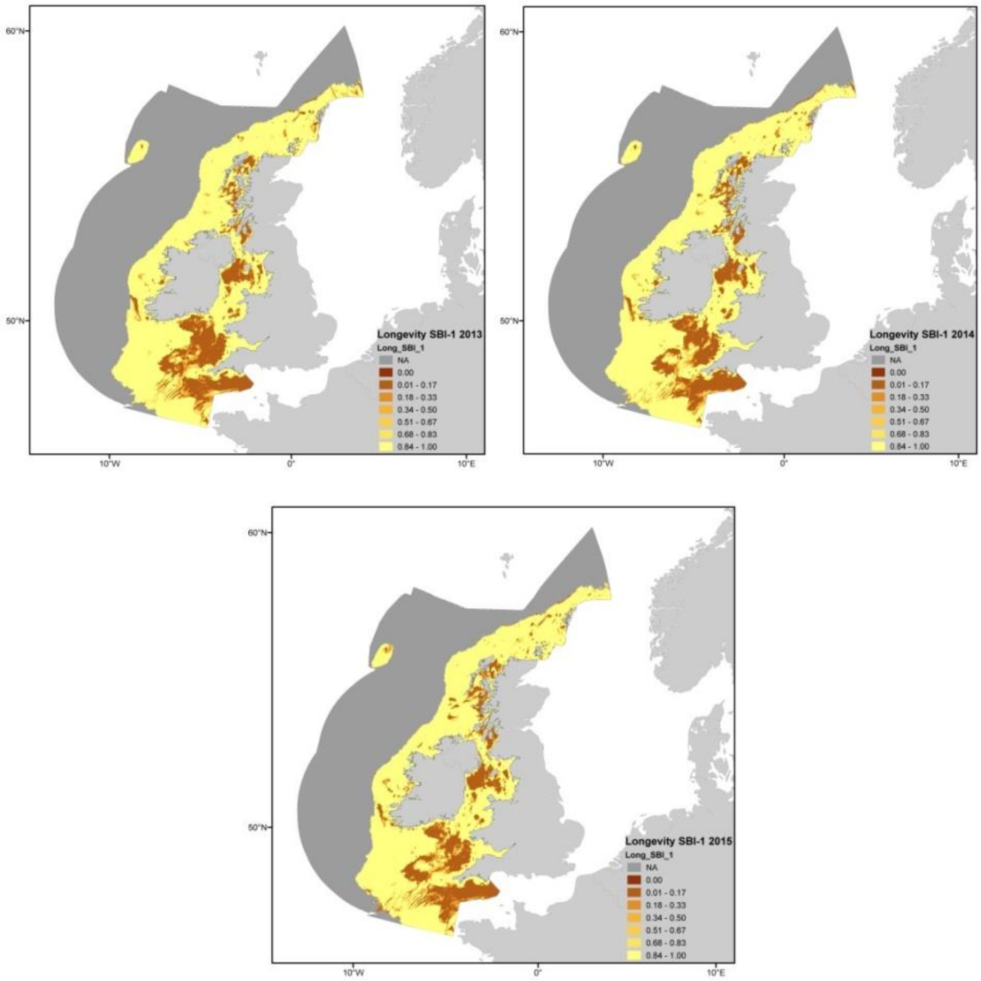
Longevity SBI-1 2009–2015 North Sea, EUNIS habitats. Only applies to depths less than 200 m (Part 1).



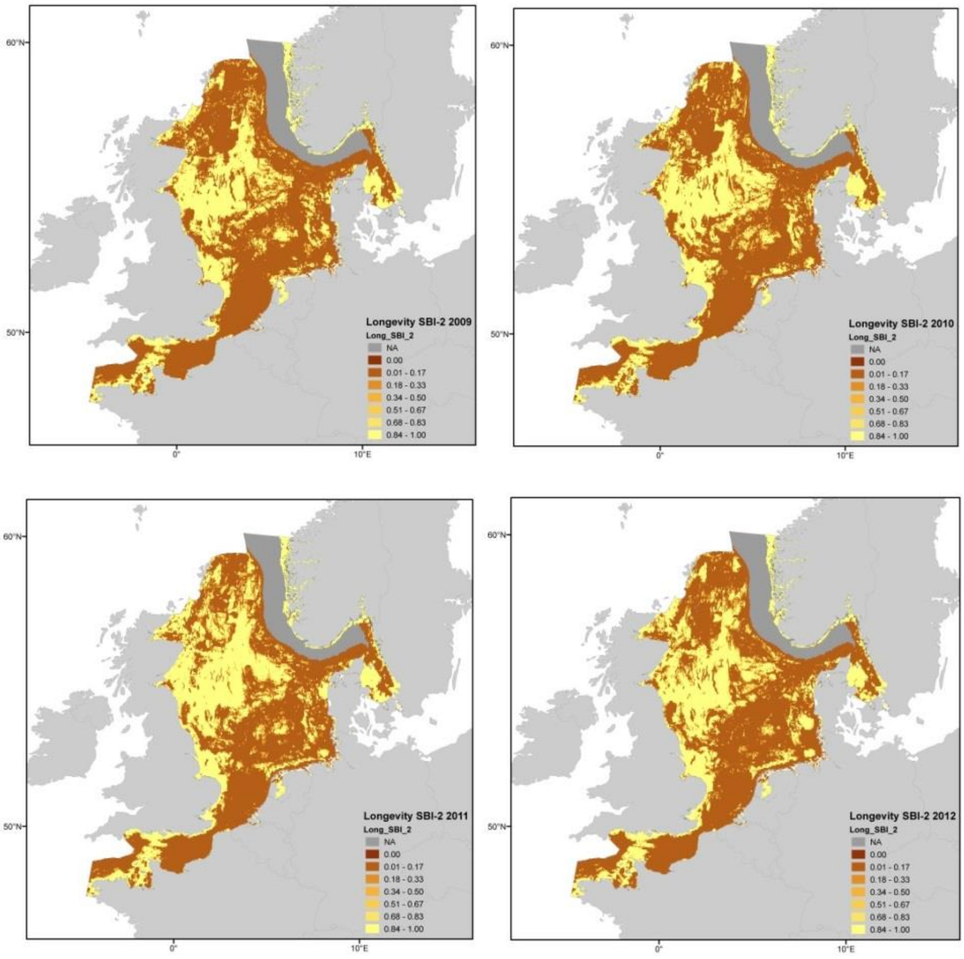
Longevity SBI-1 2009–2015 North Sea, EUNIS habitats. Only applies to depths less than 200 m (Part 2).



Longevity SBI-1 2009–2015 Celtic Sea, EUNIS habitats. Only applies to depths less than 200 m (Part 1).



Longevity SBI-1 2009–2015 Celtic Sea, EUNIS habitats. Only applies to depths less than 200 m (Part 2).



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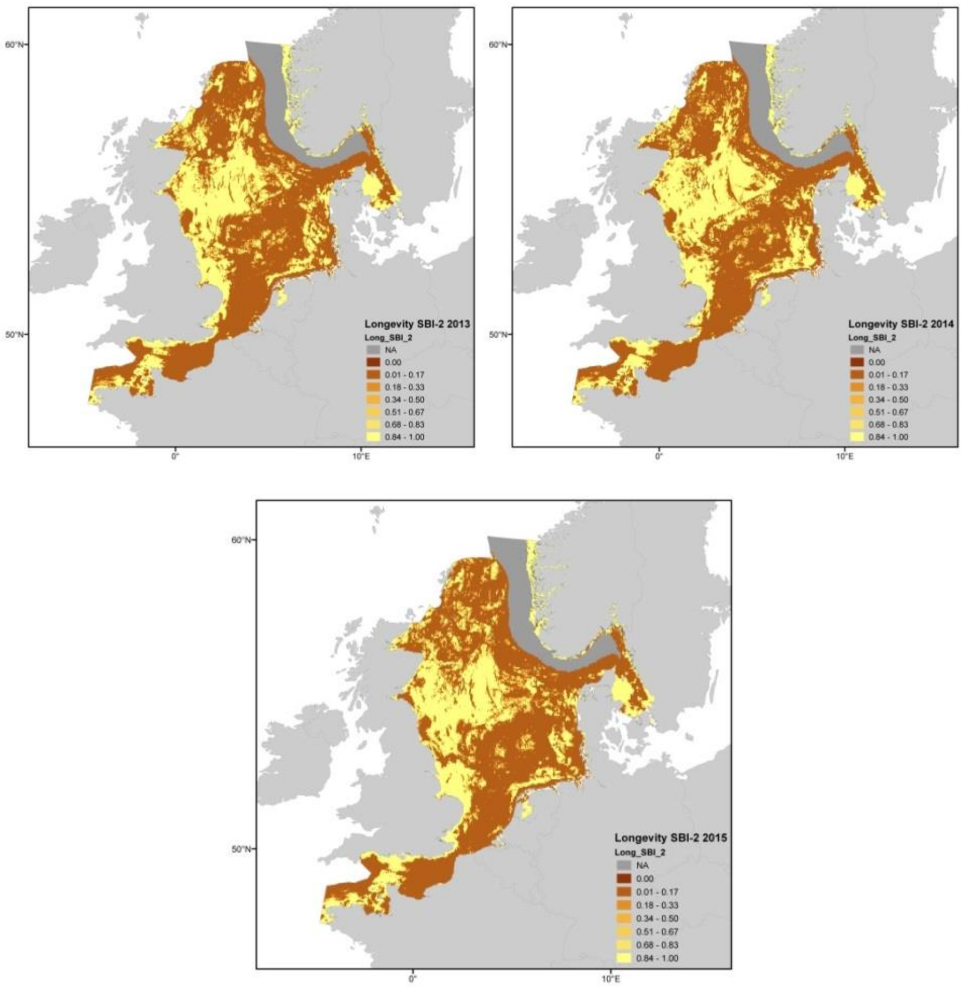

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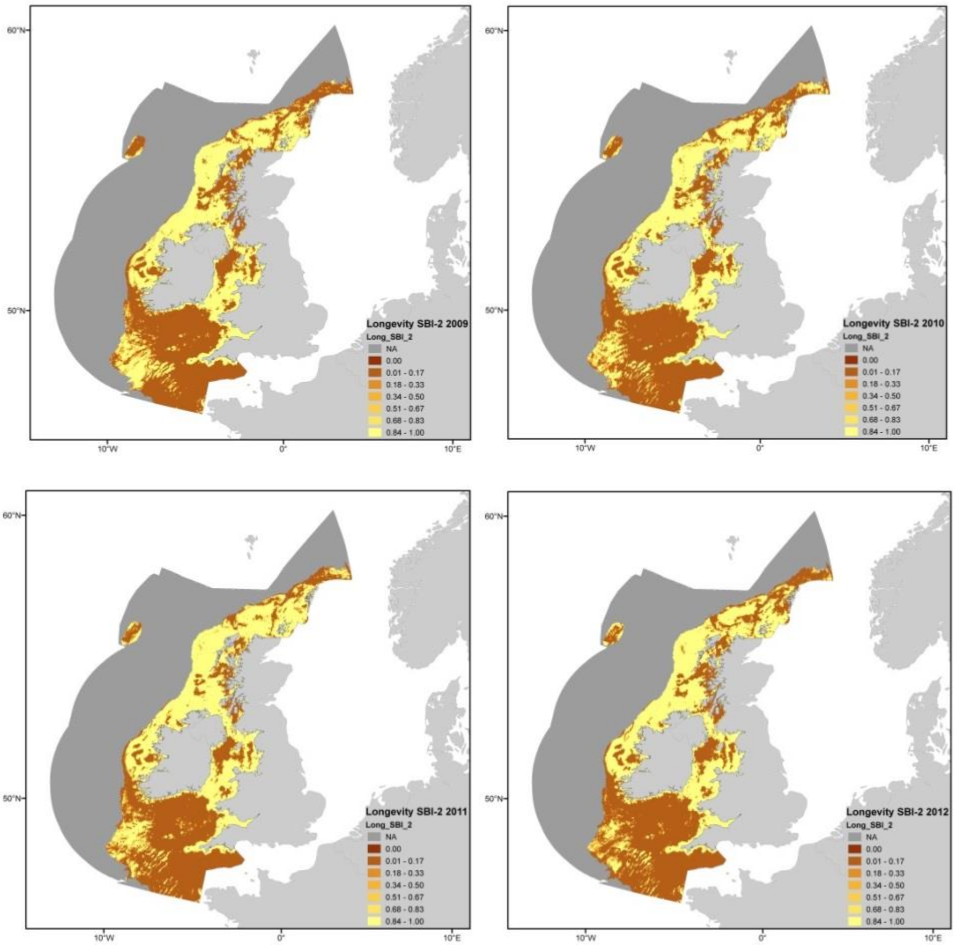
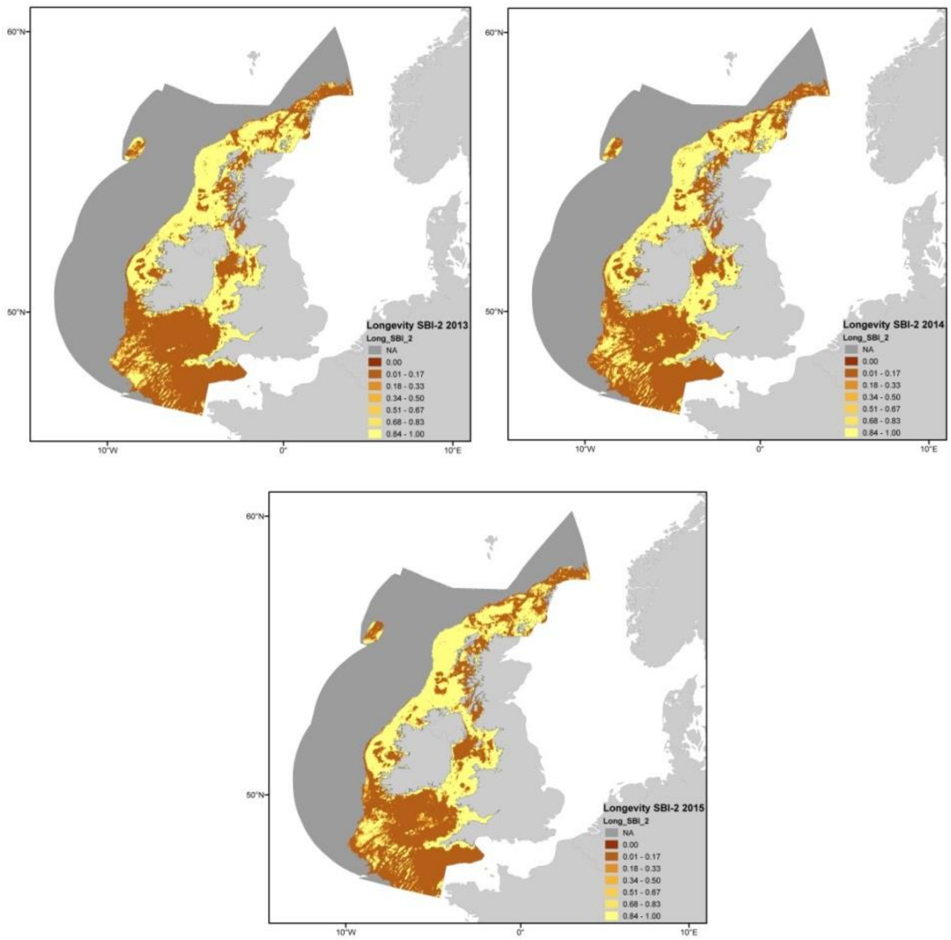
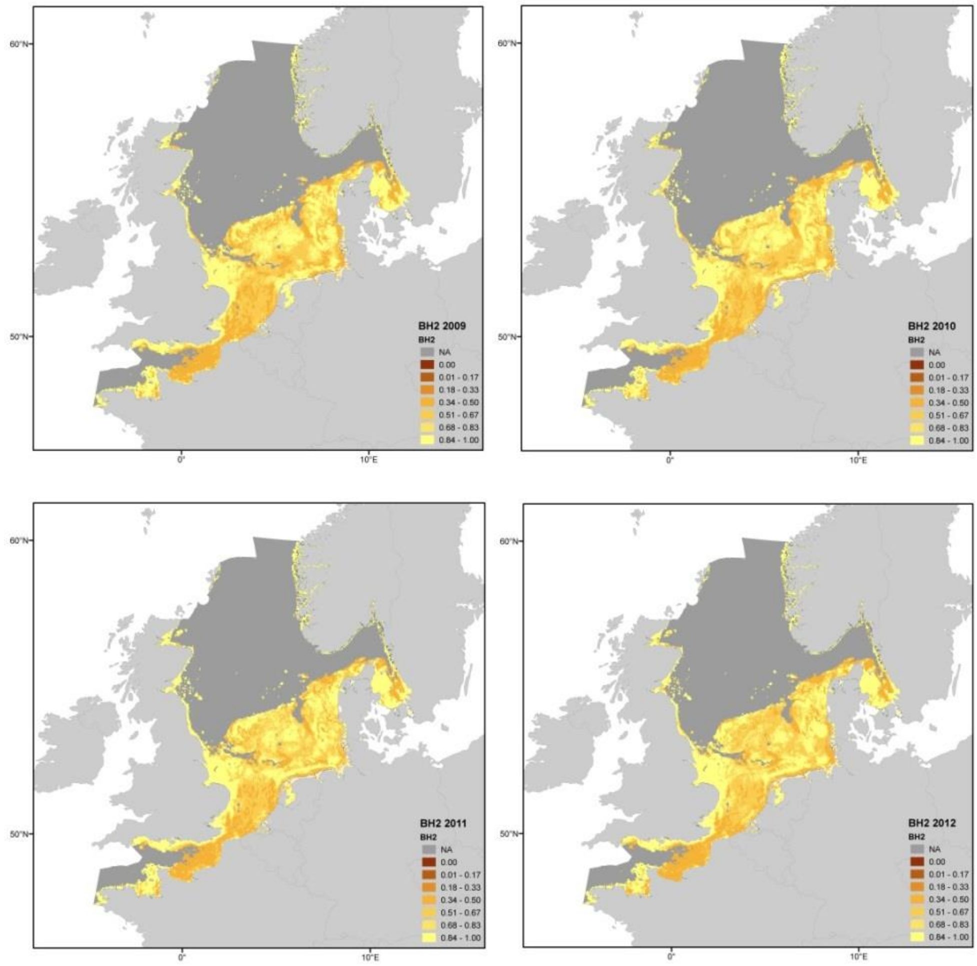


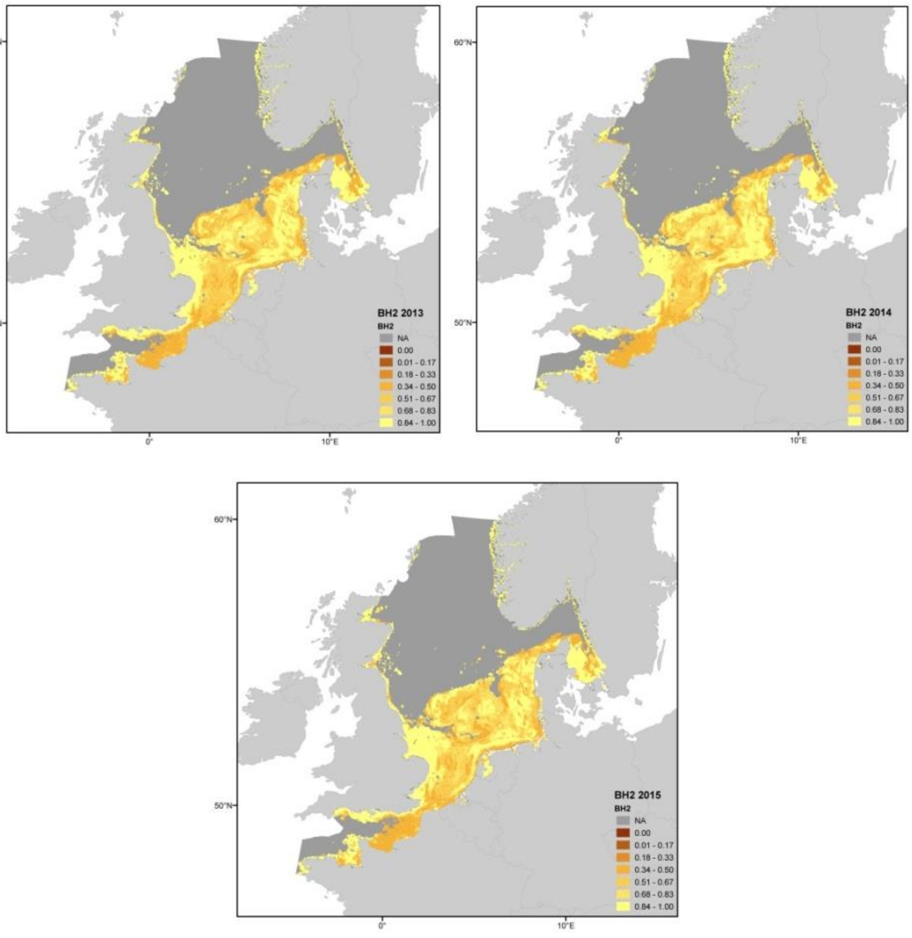
Longevity SBI-2 2009–2015 Celtic Sea, continuous habitats. Only applies to depths less than 200 m (Part 1).



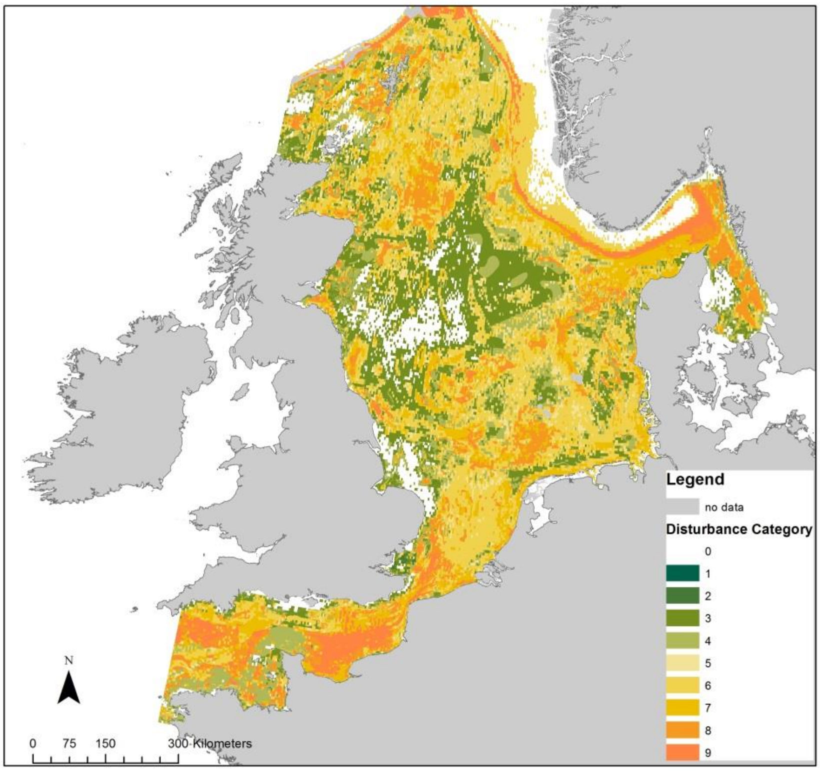
Longevity SBI-2 2009–2015 Celtic Sea, continuous habitats. Only applies to depths less than 200 m (Part 2).



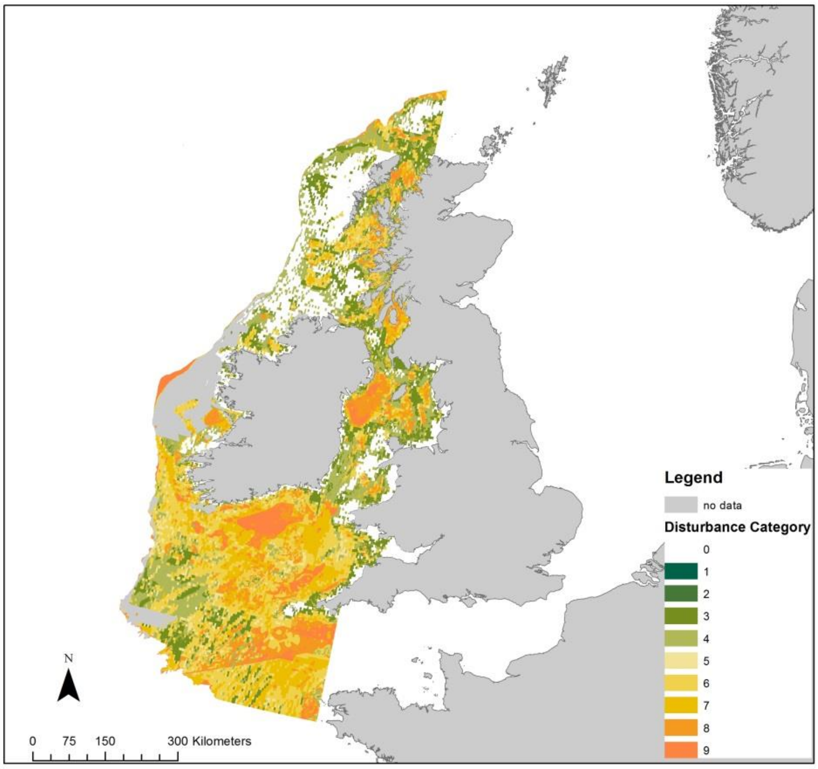
BH2 (Margalef) 2009–2015 North Sea. Only applies to depths less than 50 m (Part 1).



BH2 (Margalef) 2009–2015 North Sea. Only applies to depths less than 50 m (Part 2).



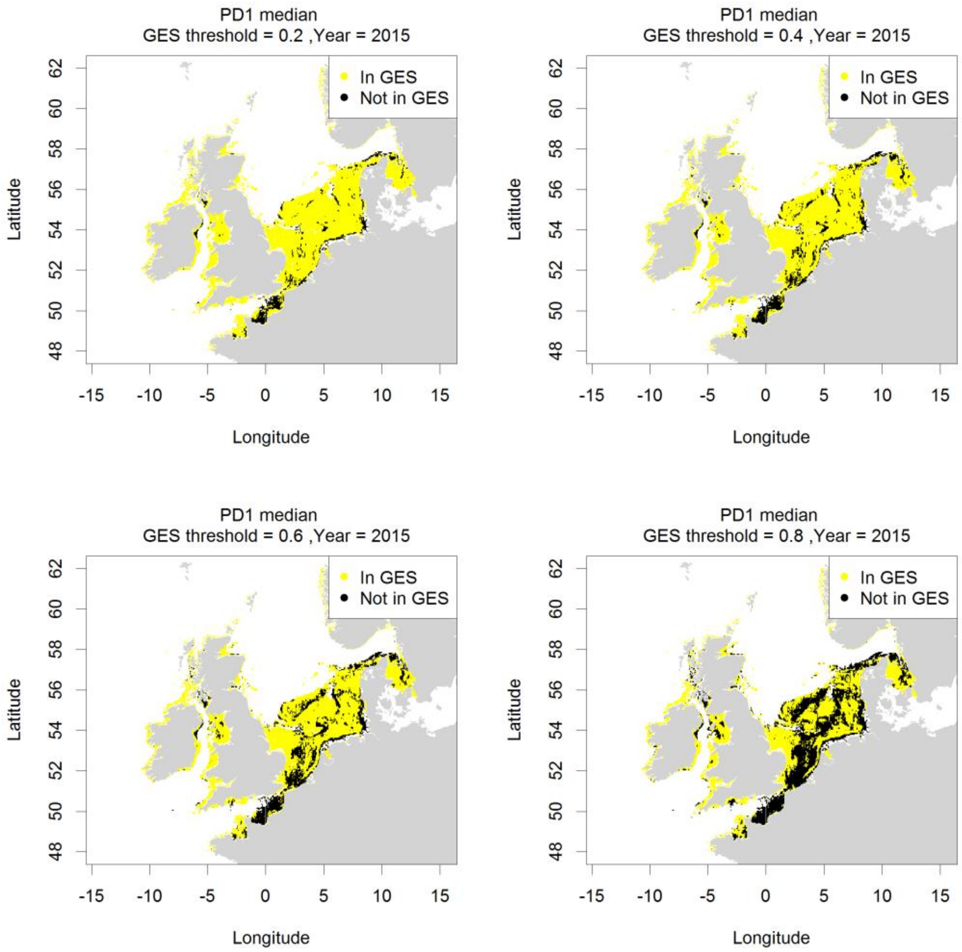
GSHHG world shore line – Available under GNU Lesser General Public License at https://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html



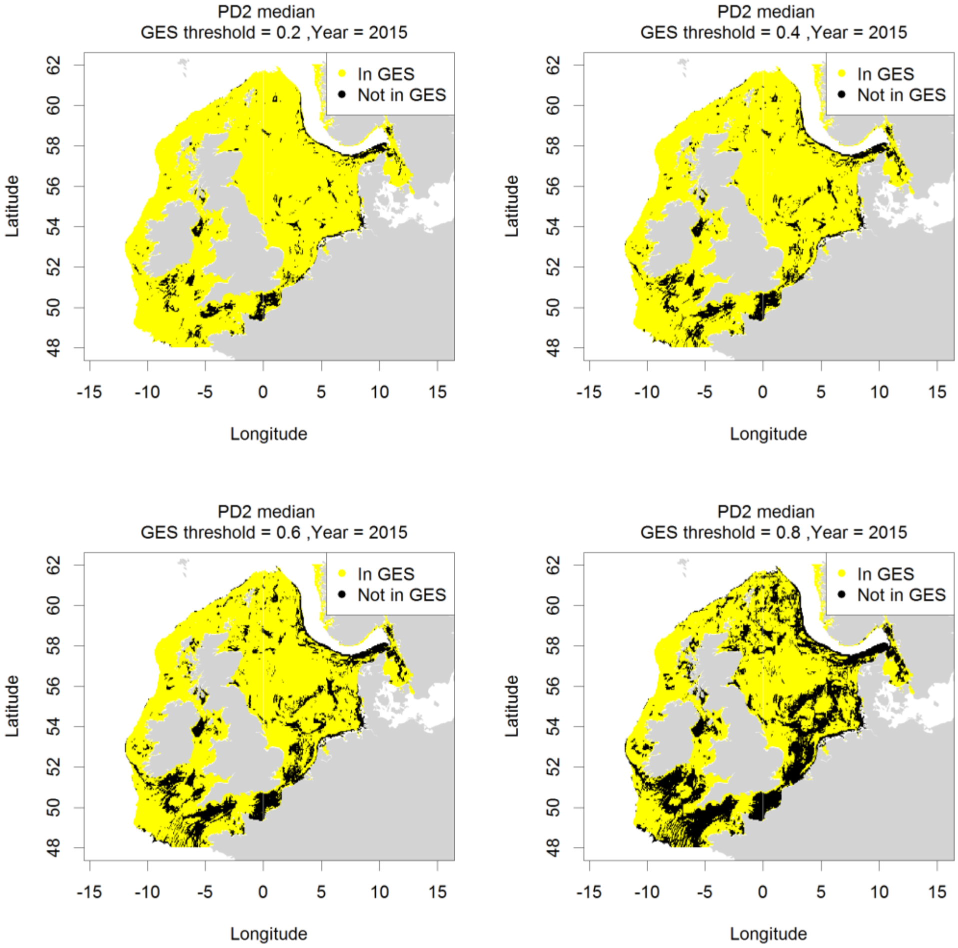
GSHHG world shore line – Available under GNU Lesser General Public License at https://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html

BH3 average disturbance 2010–2015

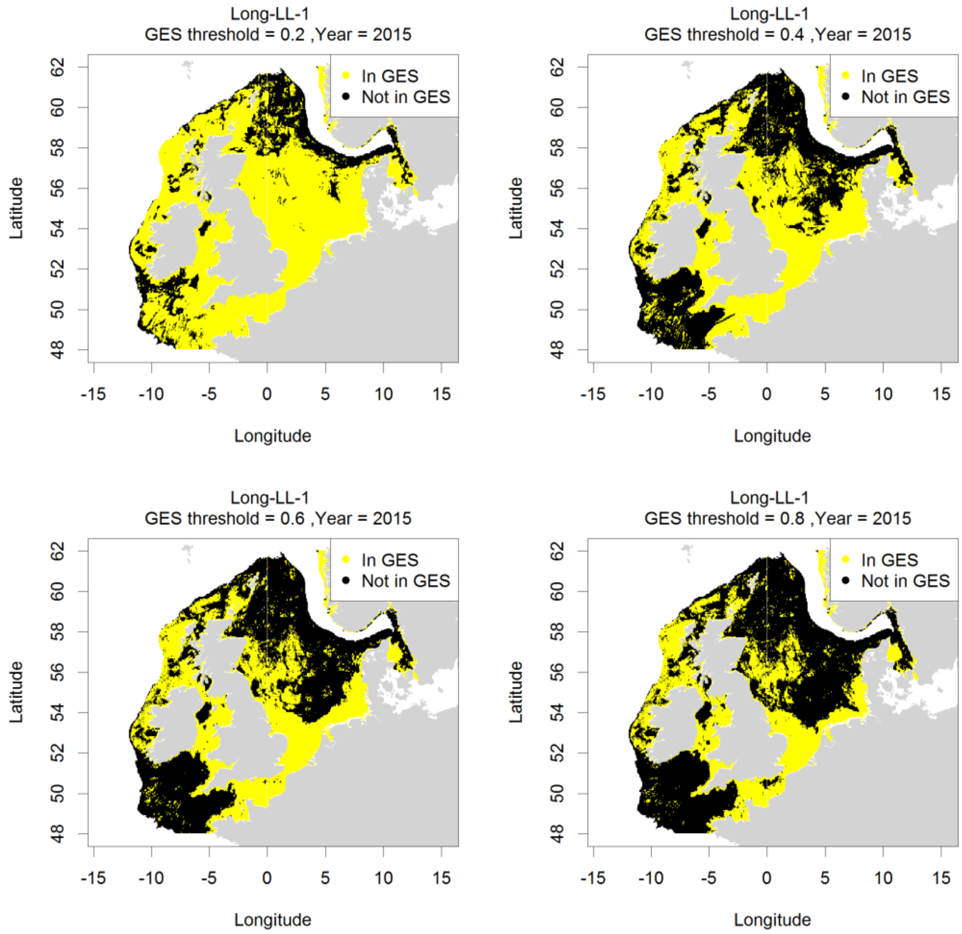
Annex 10 Impact thresholds using various impact methods



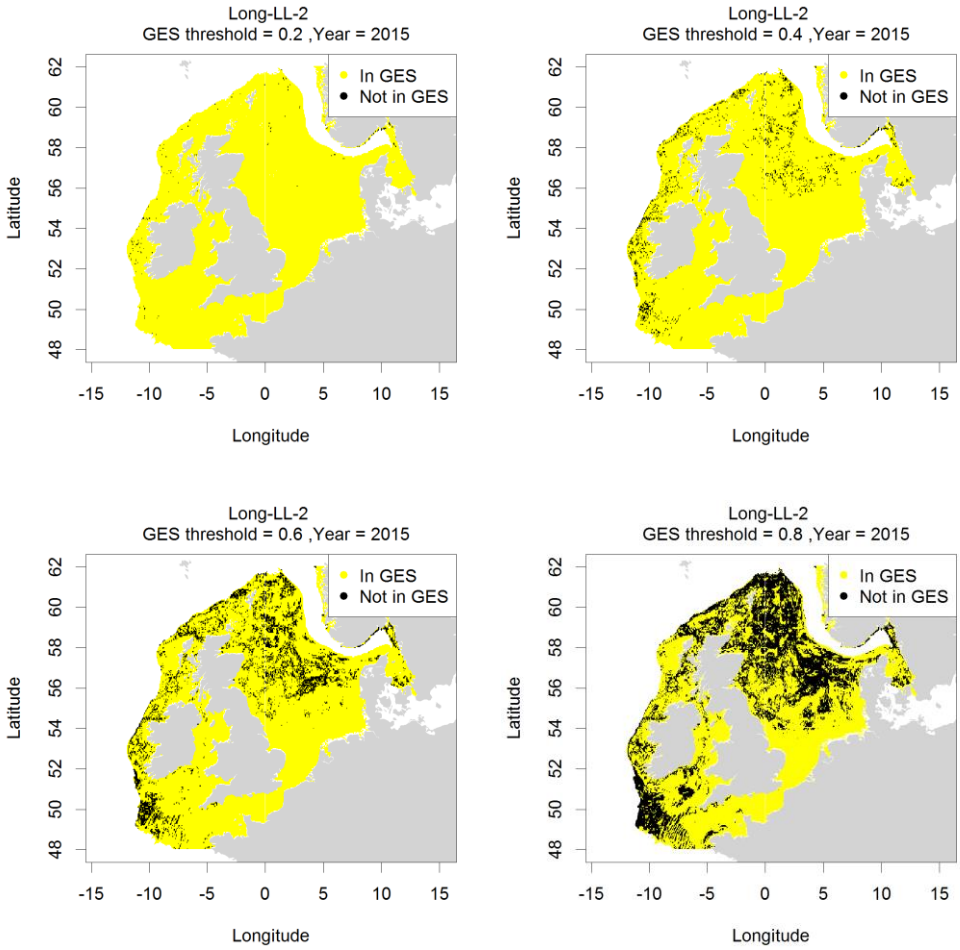
Maps showing the extent of the PD1 median if it is reduced to 20%, 40%, 60% and 80% by removing the cells with lowest impact.



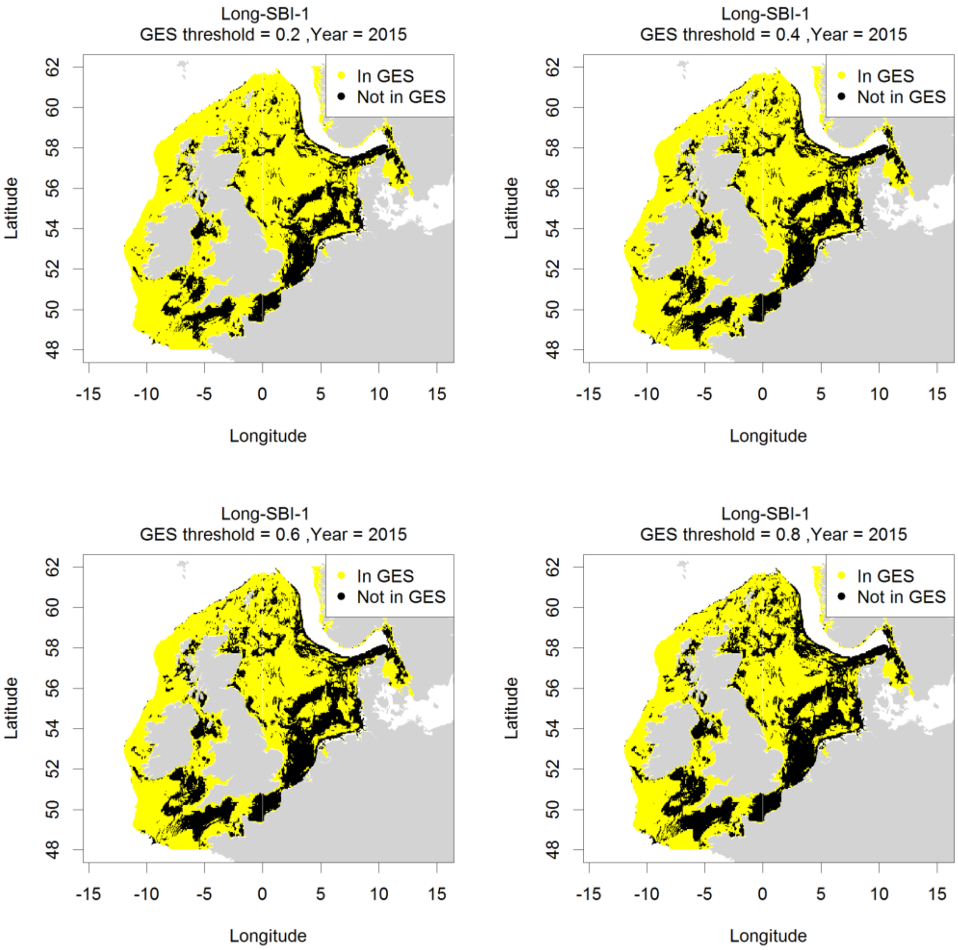
Maps showing the extent of the PD2 median if it is reduced to 20%, 40%, 60% and 80% by removing the cells with lowest impact.



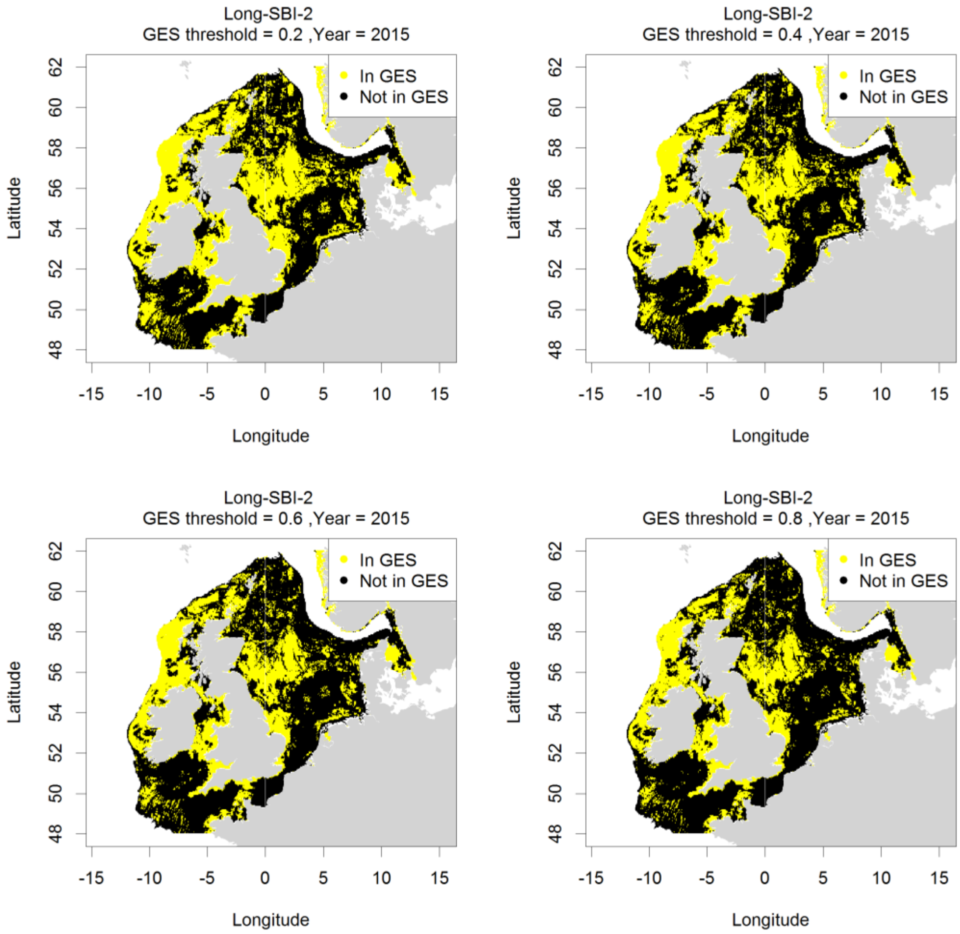
Maps showing the extent of the Longevity LL-1 impact if it is reduced to 20%, 40%, 60% and 80% by removing the cells with lowest impact.



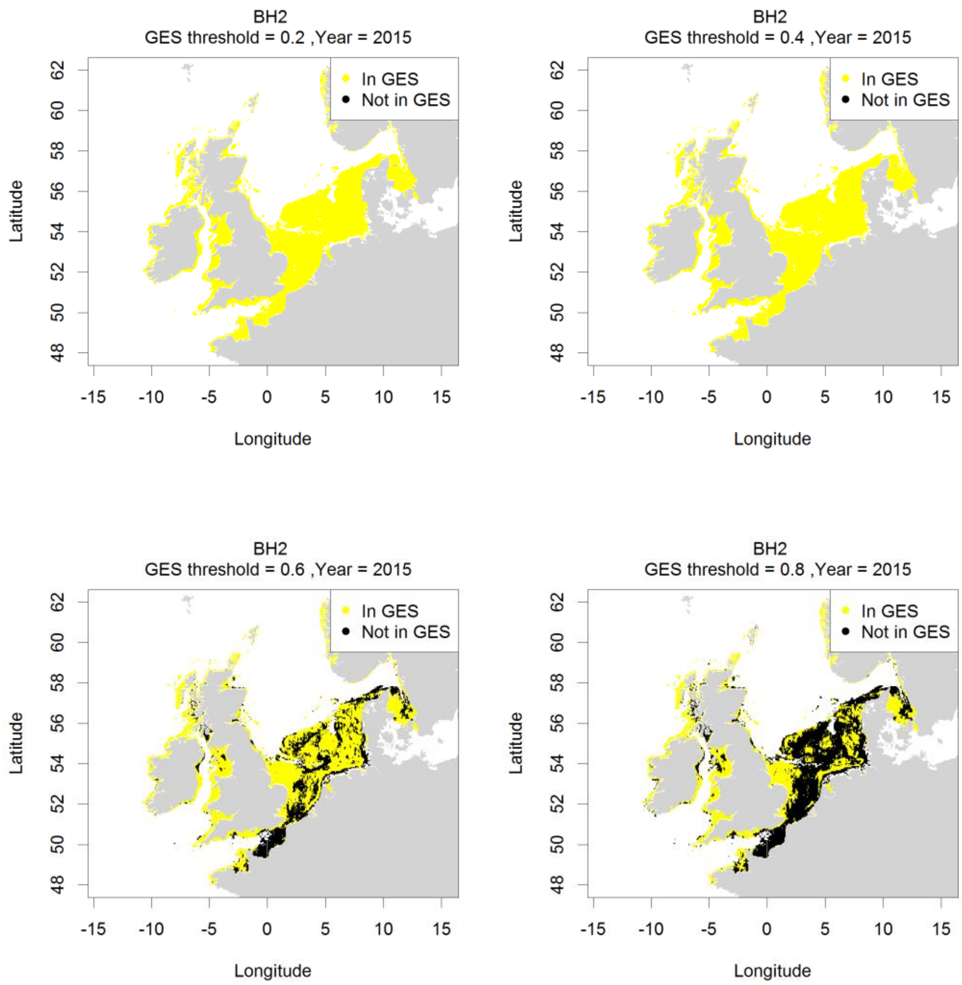
Maps showing the extent of the Longevity LL-2 impact if it is reduced to 20%, 40%, 60% and 80% by removing the cells with lowest impact.



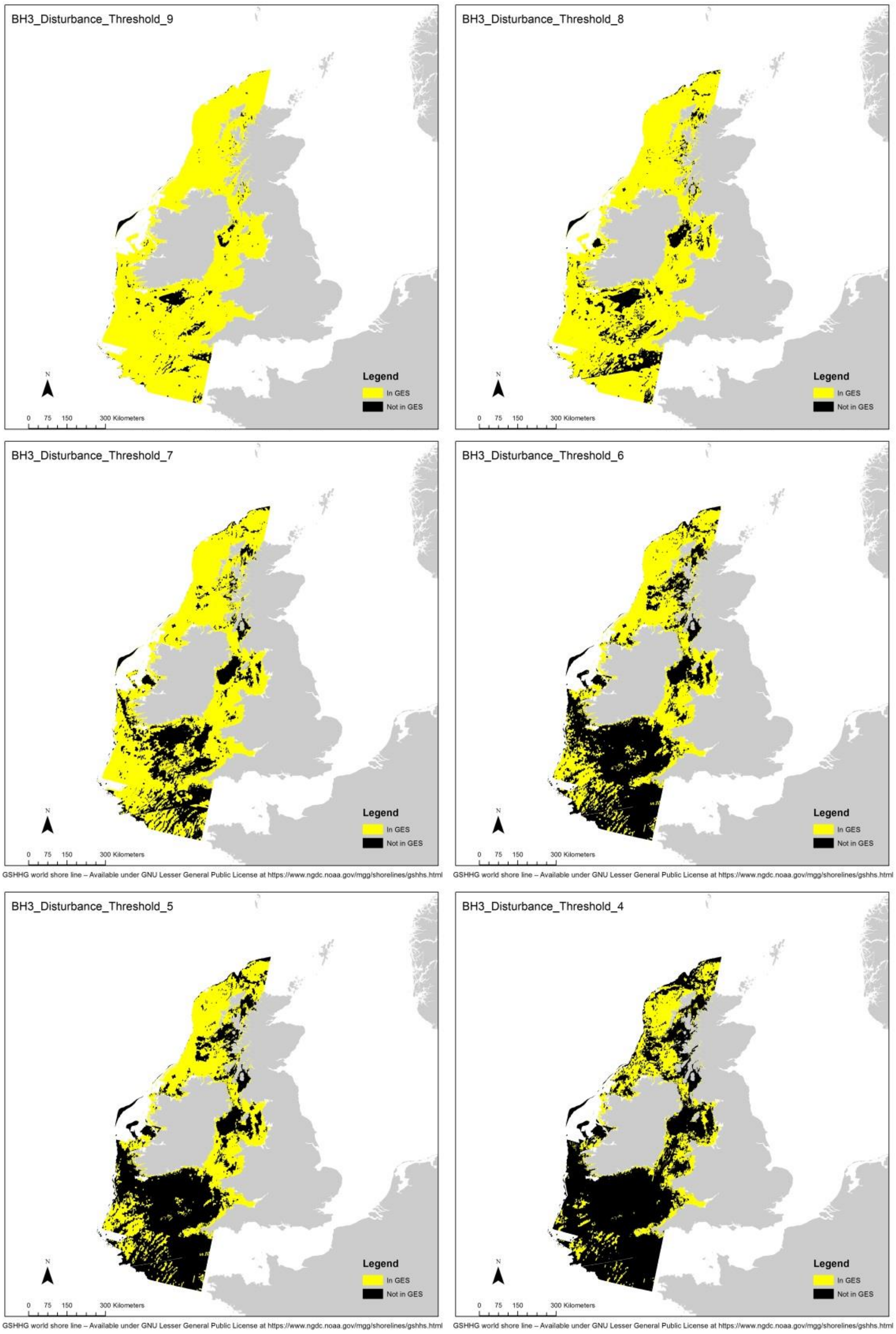
Maps showing the extent of the Longevity SBI-1 impact if it is reduced to 20%, 40%, 60% and 80% by removing the cells with lowest impact.



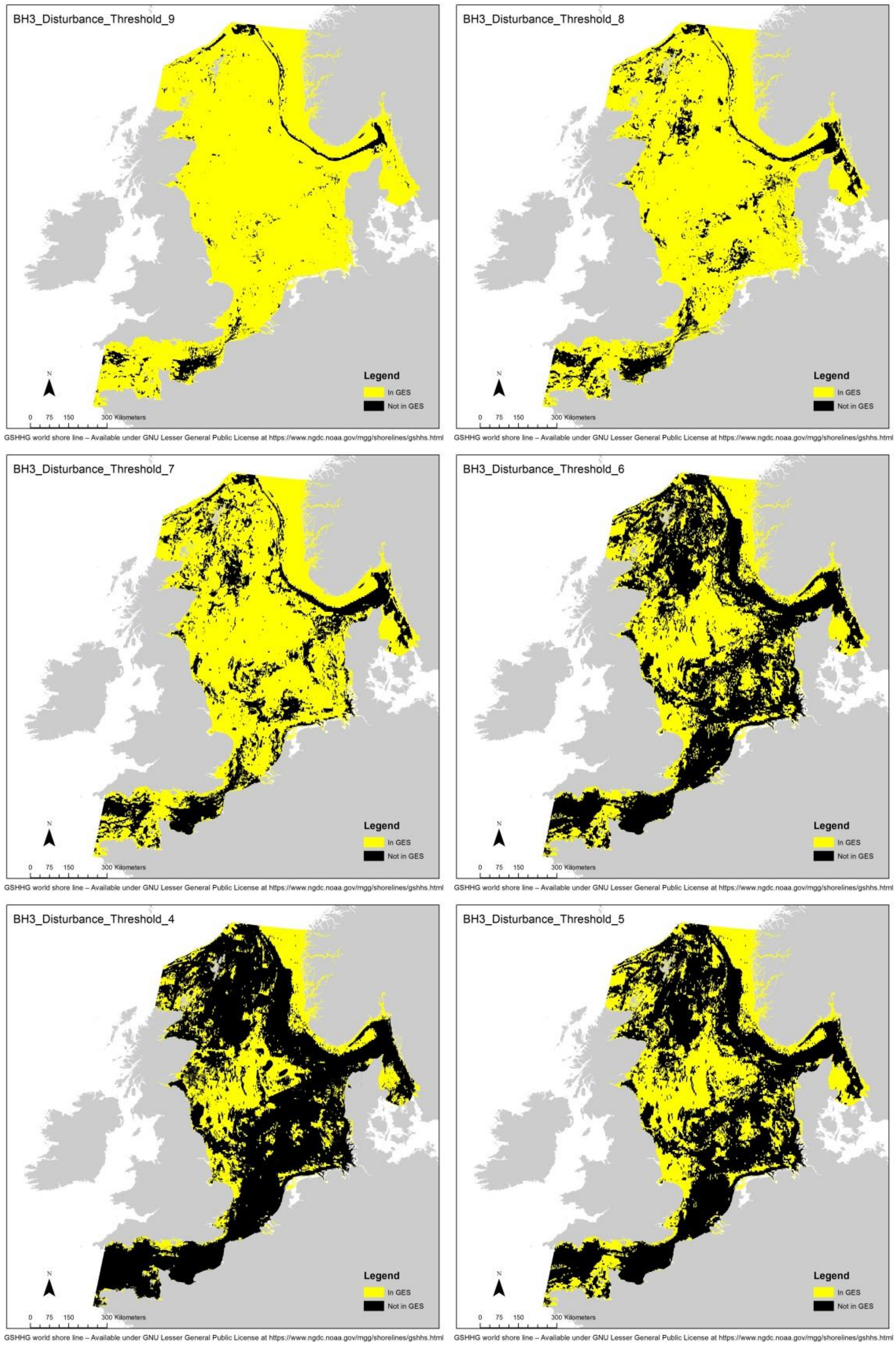
Maps showing the extent of the Longevity SBI-2 impact if it is reduced to 20%, 40%, 60% and 80% by removing the cells with lowest impact.



Maps showing the extent of the BH2 impact if it is reduced to 20%, 40%, 60% and 80% by removing the cells with lowest impact.



Maps showing the extent of the BH3 impact if it is reduced to threshold 9, 8, 7, 6, 5 and 4 in the Celtic Seas

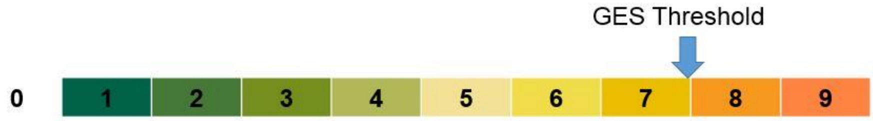


Maps showing the extent of the BH3 impact if it is reduced to threshold 9, 8, 7, 6, 5 and 4 in the Greater North Sea

Table 1. % Areas Above and Below GES for 4 sub-tidal habitats with a threshold set at disturbance category 7

CELTIC SEA	% AREA NOT IN GES	% AREA IN GES	NORTH SEA	% AREA NOT IN GES	% AREA IN GES
A5.1	38	62	A5.1	54	46
A5.2	15	85	A5.2	50	50
A5.3	43	57	A5.3	69	31
A5.4	30	70	A5.4	52	48

<u>Threshold = 8</u>



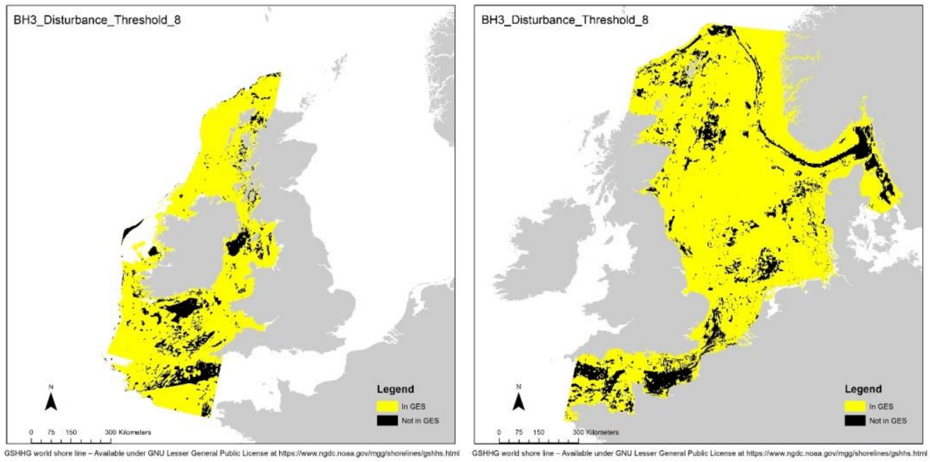
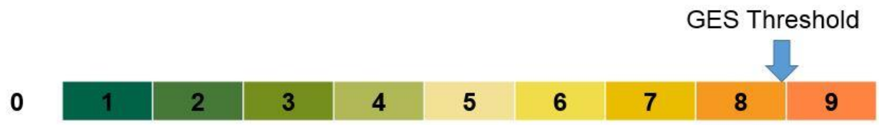
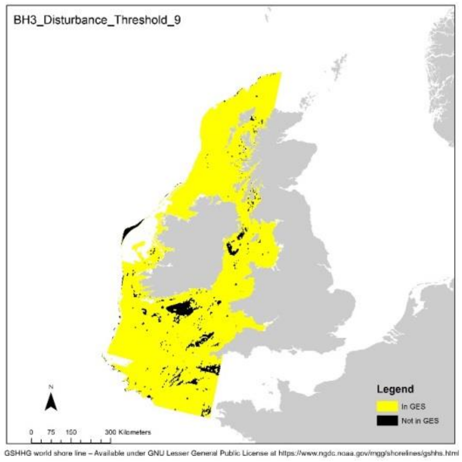


Table 2. % Areas Above and Below GES for 4 sub-tidal habitats with a threshold set at disturbance category 8

CELTIC SEA	% AREA NOT IN GES	% AREA IN GES	NORTH SEA	% AREA NOT IN GES	% AREA IN GES
A5.1	29	71	A5.1	44	56
A5.2	1	99	A5.2	14	86
A5.3	21	79	A5.3	39	61
A5.4	7	93	A5.4	28	72

<u>Threshold=9</u>





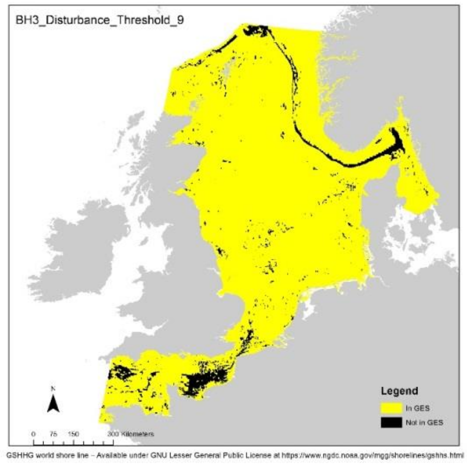


Table 3. % Areas Above and Below GES for 4 sub-tidal habitats with a threshold set at disturbance category 9

Celtic Sea	% Area not in GES	% Area in GES	North Sea	% Area not in GES	% Area in GES
A5.1	12	88	A5.1	23	77
A5.2	0	100	A5.2	0	100
A5.3	5	95	A5.3	27	73
A5.4	1	99	A5.4	15	85

Annex 11 Habitat specific impacts of fishery compared to natural stressor on benthic invertebrate community parameters (results)

Habitat specific impacts of fishery compared to natural stressors on benthic invertebrate community parameters

J. Rasmus Nielsen*,1, Berthe J.M. Vastenhoud*,1, Sieme Bossier*,1, Flemming Møh-lenberg*,2,

Francois Bastardie*,1, Asbjørn Christensen*,1, Grete Dinesen*,1, Rabea Diekman*,3,

Henrik Gislason1, Ole Eigaard1, Christina Pommer1, et al.

1 DTU Aqua, Charlottenlund (DK); 2 DHI, Hørsholm (DK); 3 vTI, Hamburg (D); *Authorship equal;

Correspondence: J. Rasmus Nielsen, rn@aqua.dtu.dk

Resulting tables and figures from the Femern Belt area case study.

Table 2. Results, parametric coefficients, **and estimates of the statistical analyses with model 15 (Density) including samples with zero FP and excluding quarter 3.**

```
Family: Negative Binomial(1.898)      Link function: log


N_ind ~ t_min + s_min + o_min + u_max + FP_cum * sed_type * Quarter * Longevit
y.Cluster +
        s(YEAR, bs = "re") + s(lon, lat, k = 75)


Parametric coefficients:
                                              Estimate Std. Error z value Pr(
>|z|)
(Intercept)                                  4.1095019  0.1346639  30.517  < 2
e-16 ***
t_min                                        0.0805544  0.0038546  20.898  < 2
e-16 ***
s_min                                        0.0338772  0.0017407  19.462  < 2
e-16 ***
o_min                                         0.0021843  0.0002928   7.460 8.6
6e-14 ***
u_max                                        -0.1839491  0.0984000  -1.869 0.0
61567 .
FP_cum                                       -0.0275022  0.0182264  -1.509 0.1
31319
sed_type1                                   -0.7661295  0.0440236 -17.403  < 2
e-16 ***
sed_type2                                   -0.6310546  0.0410002 -15.391  < 2
e-16 ***
Quarter2                                      0.0122224  0.0250578   0.488 0.6
25714
```

```
Longevity.ClusterC                        0.0430415  0.0144046   2.988 0.0
02808 **
FP_cum:sed_type1                          0.2247948  0.0640718   3.508 0.0
00451 ***
FP_cum:sed_type2                         -1.3782053  0.1488537  -9.259  < 2
e-16 ***
FP_cum:Quarter2                           0.4416395  0.1388096   3.182 0.0
01465 **
sed_type1:Quarter2                        0.3431727  0.0490884   6.991 2.7
3e-12 ***
sed_type2:Quarter2                       -0.1130971  0.0509242  -2.221 0.0
26358 *
sed_type1:Longevity.ClusterB              0.1231791  0.0601566   2.048 0.0
40595 *
FP_cum:sed_type1:Quarter2                -1.6284339  0.5792104  -2.811 0.0
04932 **
FP_cum:Quarter2:Longevity.ClusterB       -0.5288212  0.2313393  -2.286 0.0
22259 *
sed_type1:Quarter2:Longevity.ClusterB    -0.1958912  0.0762018  -2.571 0.0
10150 *
FP_cum:sed_type1:Quarter2:Longevity.ClusterB  1.4602022  0.8451939   1.728 0.0
84050 .

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

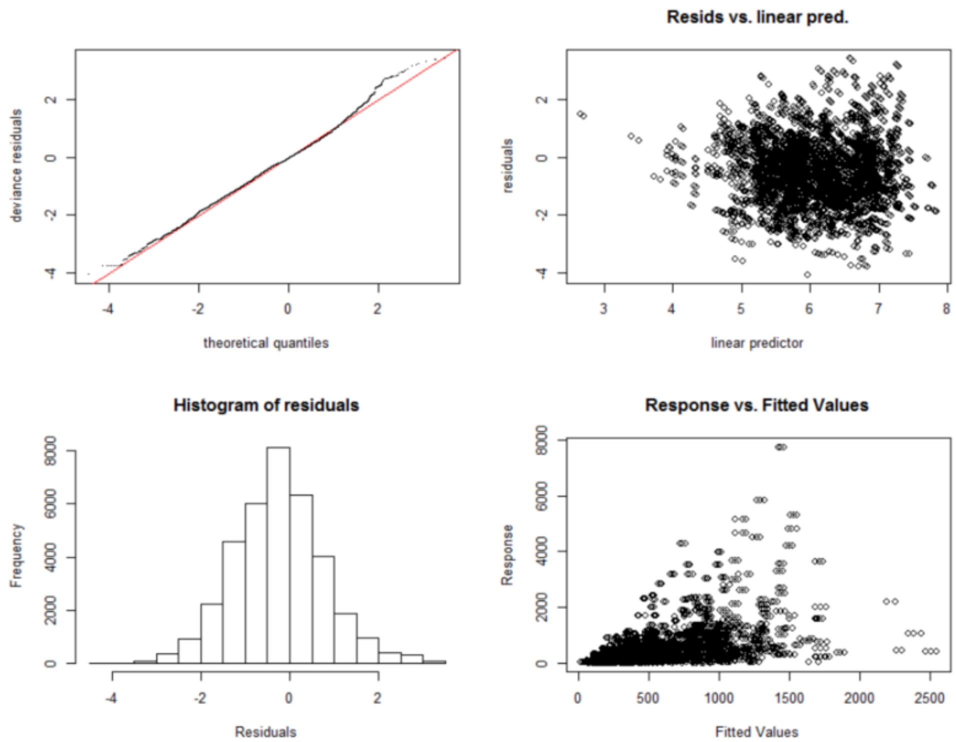


Figure 3. Residuals analysis of the model 15 statistical analyses.

Table 3. Results, parametric coefficients, and estimates of the statistical analyses with model 14 (BioDiversity) including samples with zero FP and excluding quarter 3.

```
Family: Negative Binomial(181.832)            Link function: log


Biodiversity ~ log(N_ind) + t_min + s_min + o_min + u_max + FP_cum * sed_type *
Quarter *
               Longevity.Cluster + s(YEAR, bs = "re") + s(lon, lat, k = 75)


Parametric coefficients:
                                              Estimate Std. Error z value Pr(
>|z|)
(Intercept)                                  2.518e+00  3.678e-02  68.459  < 2
e-16 ***
log(N_ind)                                   1.269e-01  1.349e-03  94.067  < 2
e-16 ***
t_min                                        5.505e-03  1.092e-03   5.042 4.6
1e-07 ***
s_min                                        4.539e-03  4.500e-04  10.086  < 2
e-16 ***
o_min                                        2.863e-05  8.039e-05   0.356  0.
72179
u_max                                       -2.775e-01  2.514e-02 -11.040  < 2
e-16 ***
FP_cum                                      -2.268e-02  4.729e-03  -4.795 1.6
2e-06 ***
sed_type1                                   -1.444e-02  1.292e-02  -1.118  0.
26345
sed_type2                                   -1.105e-02  1.470e-02  -0.752  0.
45196
Quarter2                                    -2.096e-02  6.777e-03  -3.093  0.
00198 **
Longevity.ClusterC                          -9.377e-03  3.815e-03  -2.458  0.
01398 *
Longevity.ClusterB                           9.962e-03  5.360e-03   1.858  0.
06311 .
FP_cum:sed_type1                            -1.079e-01  1.921e-02  -5.618 1.9
3e-08 ***
FP_cum:Quarter2                              1.578e-01  3.373e-02   4.678 2.8
9e-06 ***
sed_type1:Quarter2                           1.041e-01  1.394e-02   7.462 8.5
0e-14 ***
sed_type2:Quarter2                           8.330e-02  1.788e-02   4.660 3.1
7e-06 ***
FP_cum:Longevity.ClusterC                    1.323e-02  6.151e-03   2.151  0.
03151 *
sed_type2:Longevity.ClusterB                -5.405e-02  2.979e-02  -1.814  0.
06965 .
Quarter2:Longevity.ClusterC                  1.142e-02  5.281e-03   2.162  0.
03064 *
FP_cum:sed_type1:Quarter2                   -1.245e+00  1.545e-01  -8.057 7.7
9e-16 ***
```

```
FP_cum:sed_type2:Quarter2                     -6.442e+00  2.056e+00  -3.133  0.
00173 **
FP_cum:sed_type1:Longevity.ClusterC           -4.451e-02  2.350e-02  -1.894  0.
05818 .
FP_cum:sed_type2:Longevity.ClusterB            1.884e-01  8.997e-02   2.094  0.
03627 *
sed_type1:Quarter2:Longevity.ClusterB         -6.250e-02  2.136e-02  -2.926  0.
00343 **
sed_type2:Quarter2:Longevity.ClusterB          7.221e-02  3.517e-02   2.053  0.
04005 *

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

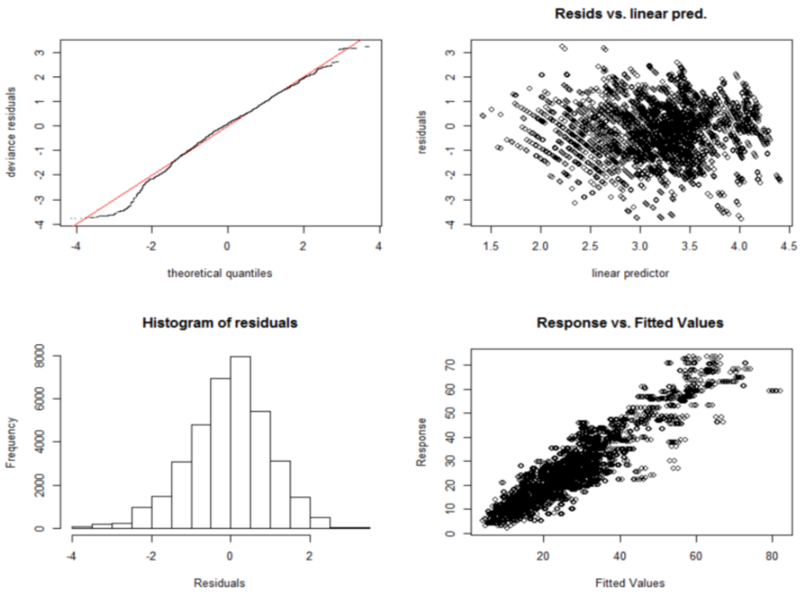


Figure 4. Residuals analysis of the model 14 statistical analyses.

Table 4. Results, parametric coefficients, and estimates of the statistical analyses with model 16 (Biomass) including samples with zero FP and excluding quarter 3.

```
Family: Tweedie(p=1.968)              Link function: log

Biomass ~ t_min + s_min + o_min + u_max + Longevity.Cluster * FP_cum * sed_typ
e * Quarter +
          s(YEAR, bs = "re") + s(lon,  lat, k = 75)

Parametric coefficients:
                                              Estimate Std. Error t value Pr(
>|t|)
(Intercept)                                  -8.307e+00  4.045e-01 -20.534  <
2e-16 ***
t_min                                         4.119e-02  1.151e-02   3.577 0.0
00348 ***
s_min                                         4.654e-03  5.314e-03   0.876 0.3
81172
o_min                                         4.675e-03  8.739e-04   5.350 8.8
8e-08 ***
u_max                                        -1.668e+00  2.949e-01  -5.658 1.5
4e-08 ***
```

```
Longevity.ClusterC                              5.630e+00  4.279e-02 131.569  <
2e-16 ***
Longevity.ClusterB                              1.847e+00  6.052e-02  30.516  <
2e-16 ***
FP_cum                                         -1.463e-01  5.447e-02  -2.686 0.0
07226 **
sed_type1                                      -2.740e-01  1.309e-01  -2.094 0.0
36296 *
sed_type2                                       7.122e-01  1.225e-01   5.813 6.2
0e-09 ***
Quarter2                                       -3.534e-01  7.536e-02  -4.689 2.7
5e-06 ***
Longevity.ClusterC:FP_cum                       6.692e-01  6.858e-02   9.758  <
2e-16 ***
Longevity.ClusterB:FP_cum                      -2.444e-01  8.711e-02  -2.806 0.0
05026 **
Longevity.ClusterC:sed_type1                    1.453e+00  1.443e-01  10.068  <
2e-16 ***
Longevity.ClusterB:sed_type1                    6.522e-01  1.742e-01   3.745 0.0
00181 ***
Longevity.ClusterC:sed_type2                   -9.069e-01  1.455e-01  -6.233 4.6
3e-10 ***
Longevity.ClusterB:sed_type2                   -1.117e+00  2.668e-01  -4.184 2.8
7e-05 ***
FP_cum:sed_type1                                2.544e+00  1.819e-01  13.981  <
2e-16 ***
Longevity.ClusterC:Quarter2                     4.914e-01  6.109e-02   8.045 8.9
3e-16 ***
Longevity.ClusterB:Quarter2                     3.779e-01  8.762e-02   4.313 1.6
1e-05 ***
sed_type1:Quarter2                              8.320e-01  1.498e-01   5.556 2.7
8e-08 ***
Longevity.ClusterC:FP_cum:sed_type1            -2.882e+00  2.185e-01 -13.193  <
2e-16 ***
Longevity.ClusterB:FP_cum:sed_type1            -3.121e+00  2.585e-01 -12.073  <
2e-16 ***
Longevity.ClusterC:FP_cum:sed_type2             1.275e+00  6.148e-01   2.074 0.0
38041 *
Longevity.ClusterB:FP_cum:Quarter2             -3.265e+00  6.902e-01  -4.731 2.2
5e-06 ***
Longevity.ClusterC:sed_type1:Quarter2          -1.147e+00  1.874e-01  -6.120 9.4
7e-10 ***
Longevity.ClusterB:sed_type1:Quarter2          -1.995e+00  2.268e-01  -8.799  <
2e-16 ***
Longevity.ClusterB:sed_type2:Quarter2           5.587e-01  3.358e-01   1.664 0.0
96145 .
FP_cum:sed_type1:Quarter2                      -8.058e+00  1.771e+00  -4.549 5.4
0e-06 ***
Longevity.ClusterC:FP_cum:sed_type1:Quarter2  9.035e+00  2.143e+00   4.216 2.4
9e-05 ***
Longevity.ClusterB:FP_cum:sed_type1:Quarter2  1.972e+01  2.543e+00   7.756 9.0
1e-15 ***
Longevity.ClusterC:FP_cum:sed_type2:Quarter2 -4.465e+01  1.363e+01  -3.276 0.0
01056 **

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

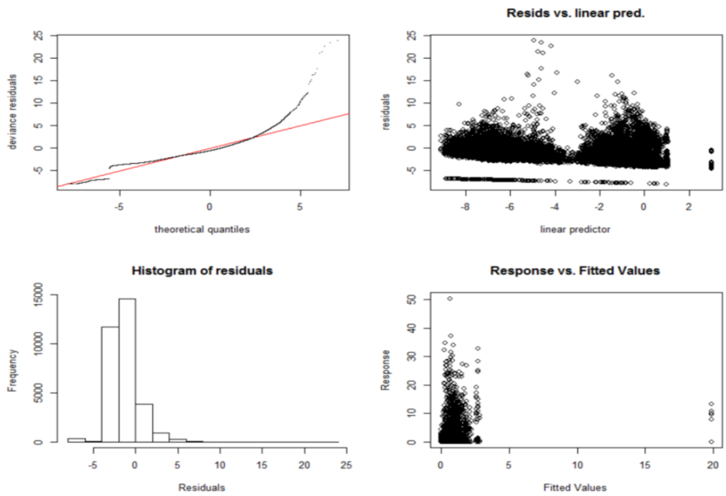


Figure 5. Residuals analysis of the model 11 statistical analyses.

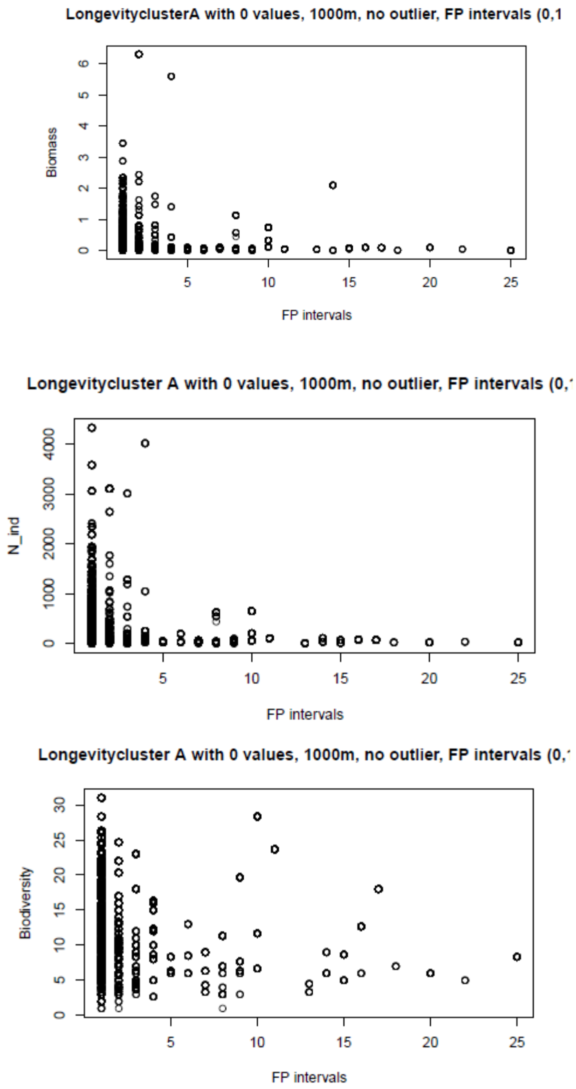


Figure 6.Correlation between benthic invertebrate community density (N), biodiversity (BD), biomass (B) and fishing pressure (FP) for longevity cluster A (0-3 years) where averages for N, BD and B are estimated for FP in discrete steps of 0,1 (discrete scale) for samples covering stations with zero fishing pressure. At the scale of the FP-axis then 1 correspond to FP=0,0–0,1, 2 corresponds to FP=0,1–0,2, etc, i.e. 10 corresponds to FP=0,9–1,0.

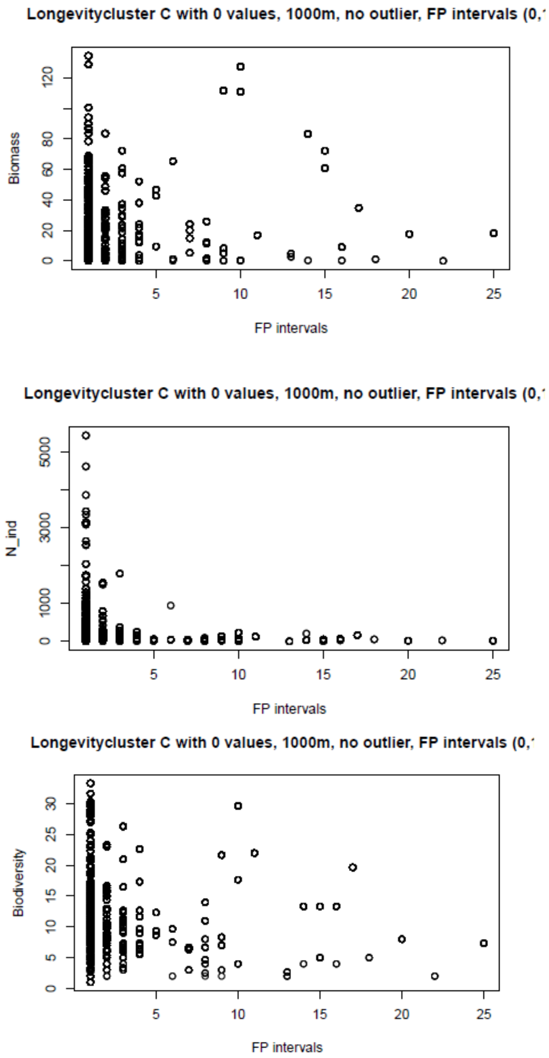


Figure 7.Correlation between benthic invertebrate community density (N), biodiversity (BD), biomass (B) and fishing pressure (FP) for longevity cluster C (>3 years) where averages for N, BD and B are estimated for FP in discrete steps of 0,1 (discrete scale) for samples covering stations with zero fishing pressure. At the scale of the FP-axis then 1 correspond to FP=0,0–0,1, 2 corresponds to FP=0,1-0,2, etc, i.e. 10 corresponds to FP=0,9–1,0.

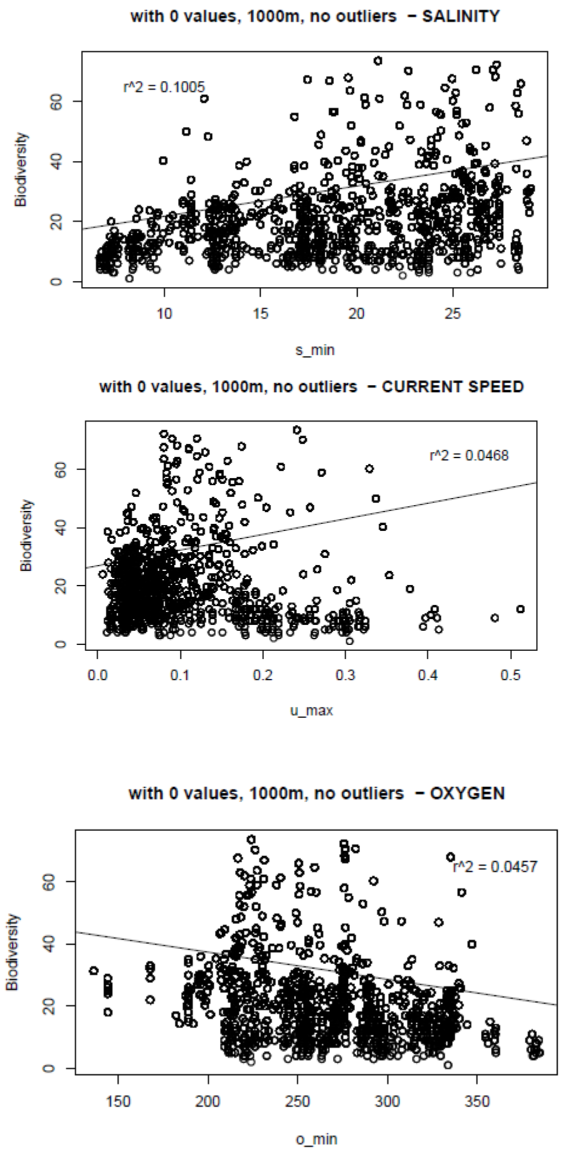
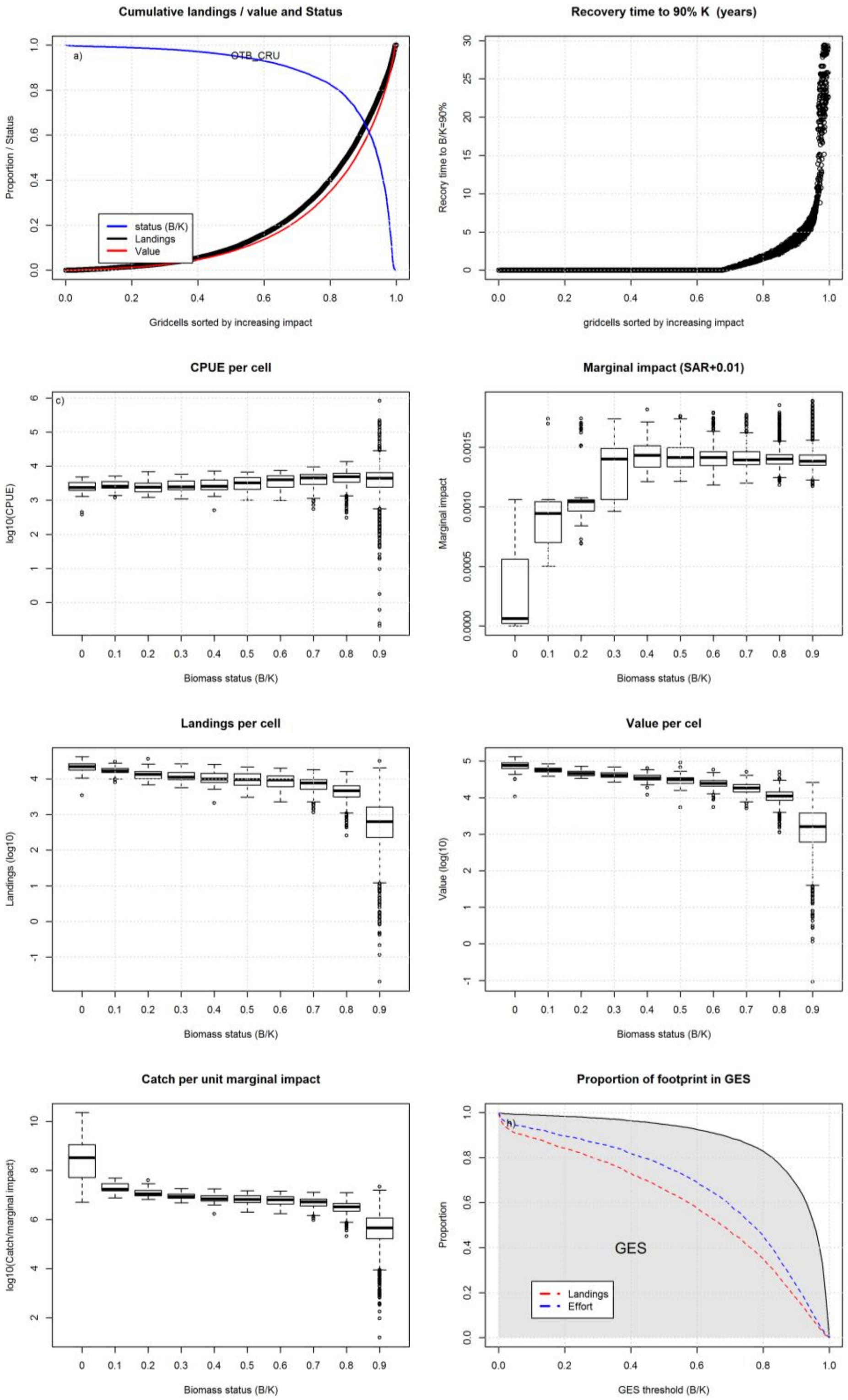


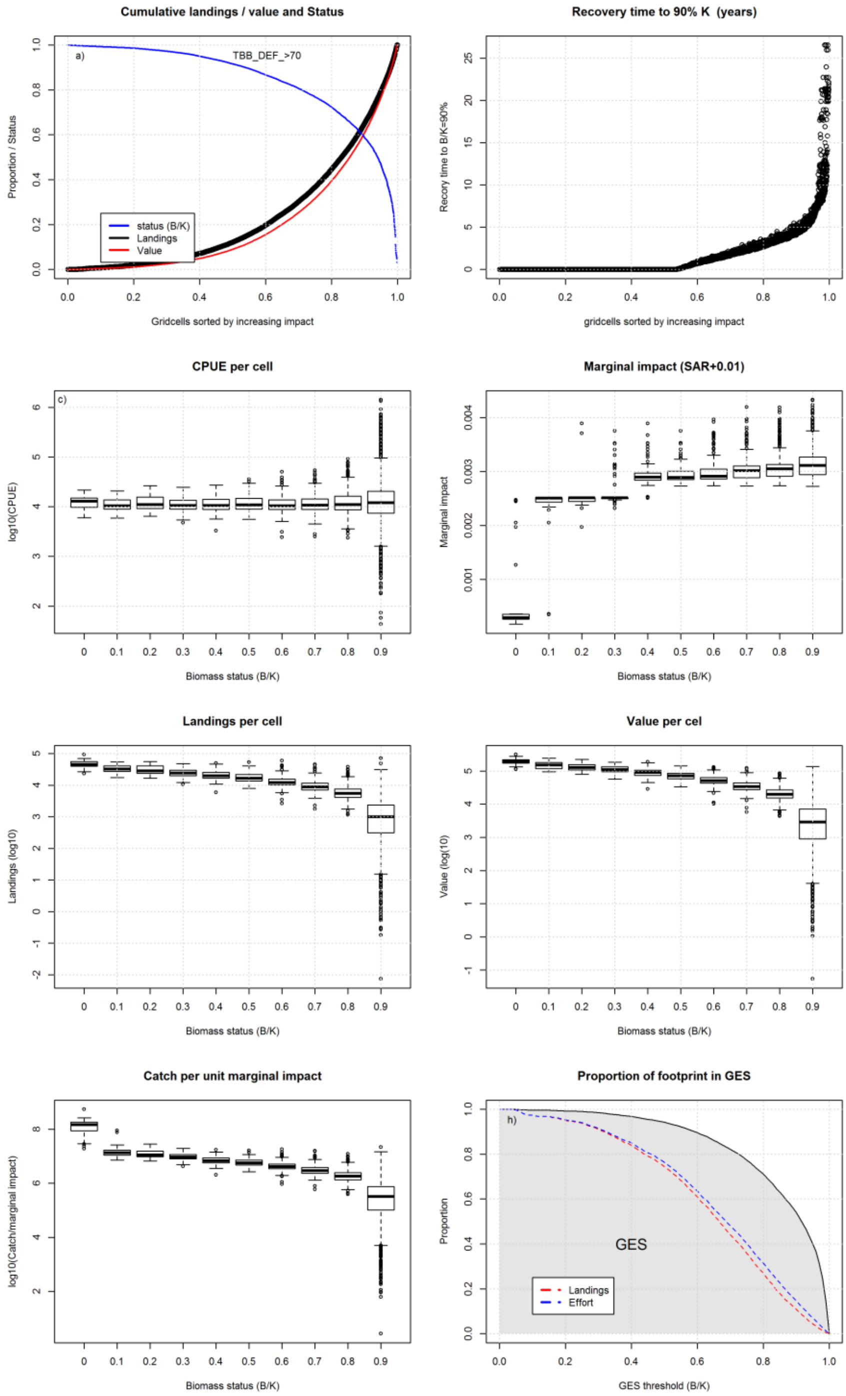
Figure 8. Correlation between benthic invertebrate community species richness (biodiversity, BD) and selected hydrographical factors (S-min, U-max, and O-min) on a continuous scale for samples covering stations with zero fishing pressure.

Annex 12 Standard output of the impact assessment by metier

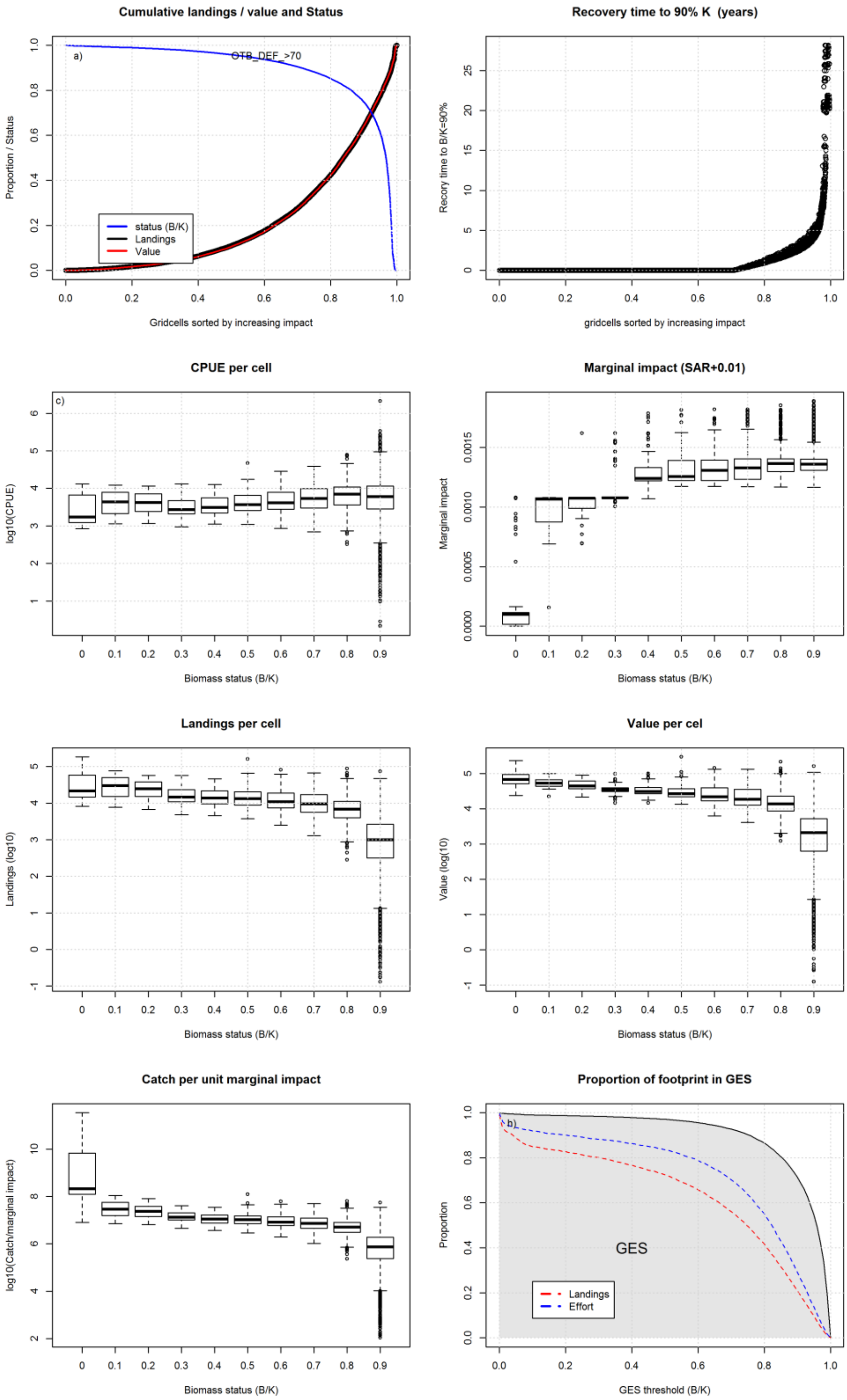
OTB_CRU



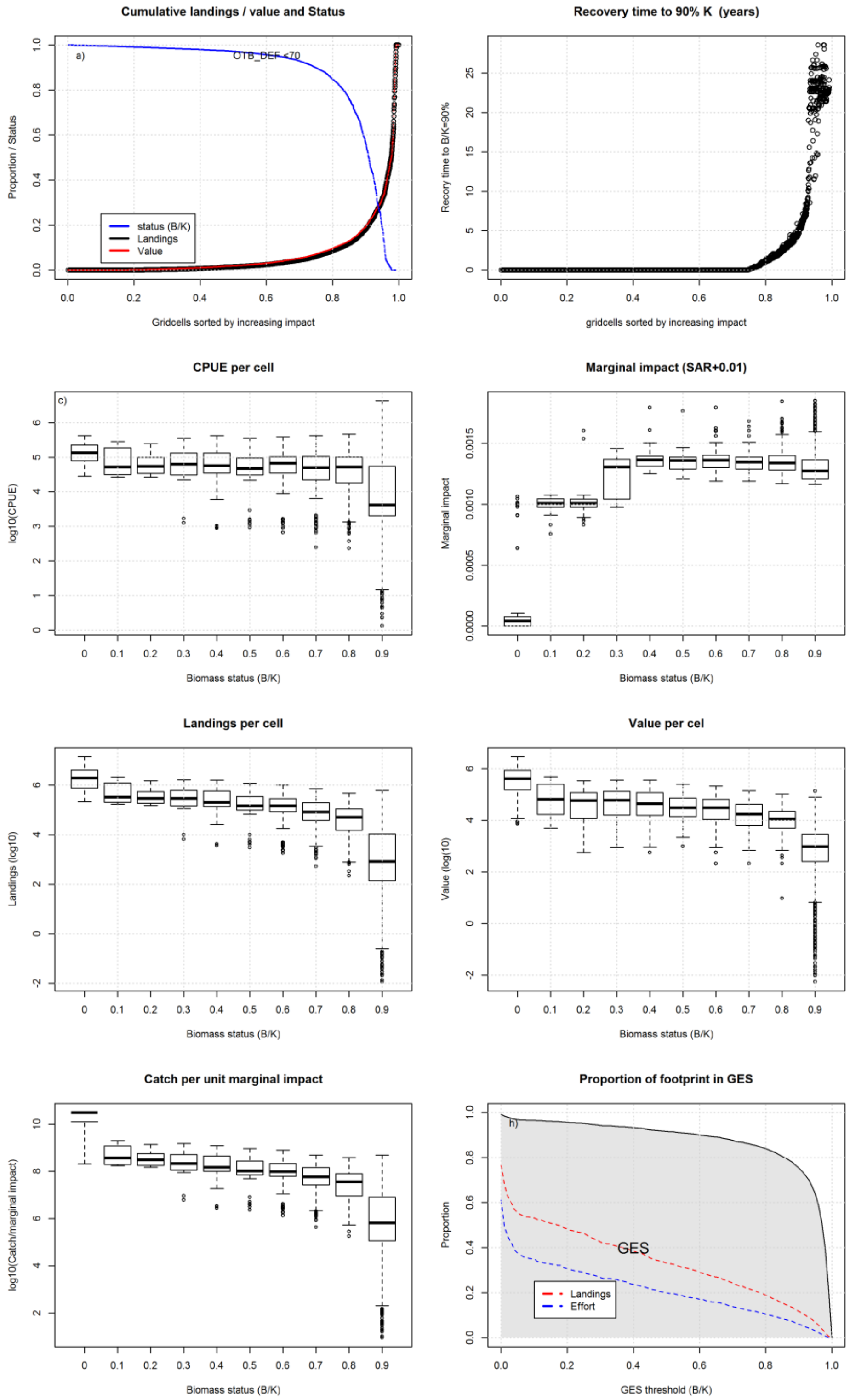
OTB_DEF_<70


Cumulative landings / value and Status
a)
TBB_DEF_>70
status (B/K)
Landings
Value
Proportion / Status
Gridcells sorted by increasing impact
Recovery time to 90% K (years)
Recory time to B/K=90%
gridcells sorted by increasing impact
CPUE per cell
c)
log10(CPUE)
Biomass status (B/K)
Marginal impact (SAR+0.01)
Marginal impact
Biomass status (B/K)
Landings per cell
Landings (log10)
Biomass status (B/K)
Value per cel
Value (log10)
Biomass status (B/K)
Catch per unit marginal impact
log10(Catch/marginal impact)
Biomass status (B/K)
Proportion of footprint in GES
h)
GES
Landings
Effort
Proportion
GES threshold (B/K)

OTB_DEF_>70


Cumulative landings / value and Status
a)
OTB_DEF_>70
status (B/K)
Landings
Value
Proportion / Status
Gridcells sorted by increasing impact
Recovery time to 90% K (years)
Recovy time to B/K=90%
gridcells sorted by increasing impact
CPUE per cell
c)
log10(CPUE)
Biomass status (B/K)
Marginal impact (SAR+0.01)
Marginal impact
Biomass status (B/K)
Landings per cell
Landings (log10)
Biomass status (B/K)
Value per cel
Value (log(10)
Biomass status (B/K)
Catch per unit marginal impact
log10(Catch/marginal impact)
Biomass status (B/K)
Proportion of footprint in GES
b)
GES
Landings
Effort
Proportion
GES threshold (B/K)

TBB_DEF_>70mm



Cumulative landings / value and Status
a)
OTB_DEF <70
status (B/K)
Landings
Value
Proportion / Status
Gridcells sorted by increasing impact
Recovery time to 90% K (years)
Recory time to B/K=90%
gridcells sorted by increasing impact
CPUE per cell
c)
log10(CPUE)
Biomass status (B/K)
Marginal impact (SAR+0.01)
Marginal impact
Biomass status (B/K)
Landings per cell
Landings (log10)
Biomass status (B/K)
Value per cel
Value (log10)
Biomass status (B/K)
Catch per unit marginal impact
log10(Catch/marginal impact)
Biomass status (B/K)
Proportion of footprint in GES
h)
GES
Landings
Effort
Proportion
GES threshold (B/K)

Annex 13 Technical minutes by WGECO

WGECO is requested to review three ICES workshop reports, WKBENTH (28 Feb – 3 March 2017), WKSTAKE (23 March 2017), and WKTRADE (28–31 March 2017) (ToR f)

WGECO interpreted the request as capturing two aspects of the advisory work:

1) Assessment of fishing pressure and seafloor status, which is reflected in the first part of the request, i.e. "Evaluate a set of indicators for assessing physical disturbance pressures from bottom-contacting fishing gears and their environmental impacts on seabed habitats/sea-floor integrity". This aspect is based on WKBENTH. For the evaluation of the indicators WGECO considered the available knowledge base to calculate indicators for:
   - Physical disturbance pressures
   - The impact of fishing on seabed habitats/sea-floor integrity based on the methods to determine habitat sensitivity
2) Guidance for management to mitigate this pressure and its impact, which is reflected in the second part of the request, i.e. "develop an approach on how to demonstrate the trade-off between catch/value of landings per unit area and the environmental impact and recovery potential of the seafloor". This aspect is based on WKSTAKE and WKTRADE.

WKBENTH

The report is very comprehensive but still seems like a work in progress. Several potentially useful approaches are presented. In summary, the physical disturbance indicators appear to be sufficiently well advanced to be used for advice whereas the impact indicators have often not matured to the point where they can be used for advice. There are several impact indicator variants and the methodological difference between them is often minor. As yet, there is insufficient scientific basis for choosing one over the other, but the choice of indicator produces vastly different results.

Physical disturbance pressures

For the pressure "physical disturbance caused by fishing" it appeared that different names were used to describe the same indicator, i.e. "fishing intensity", "fishing effort", "mean abrasion", expressed as the area swept per unit area. The same name should be used consistently for the indicator. WGECO considers that the most likely candidate is fishing intensity as fishing effort usually refers to hours fishing or days-at-sea while abrasion caused by fishing is only one of the pressures that make up physical disturbance. The indicator was calculated as the area of the seabed in contact with the fishing gear relative to the surface area of the grid cell ("c square"). The workflow to produce these fishing intensity maps is given in Figure 6.2.1 in the WKBENTH report. From these maps three pressure indicators (1-3) were calculated:

1. The percent of c-squares affected by mobile bottom contacting gears (MBCG) is calculated as the total number of squares within an ICES Ecoregion and depth interval compared to the number where the fishing effort from MBCG is larger than 0. The indicator provides information on the proportion area impacted by fishing. As every c-square touched by fishing is included, this is likely to provide an overestimate of the physical disturbance, which is expected to be higher at coarser spatial resolution. The indicator can be calculated for any spatial sub-unit within the Ecoregion and we assume that the

(arbitrary) decision to estimate this indicator by depth interval rather than EUNIS habitat is just intended as an example.

2. To calculate the percent of c-squares affected by the 90% highest fishing effort, the fishing effort is ordered by c-square with decreasing fishing effort, and the number of c-squares with the 90% highest fishing effort is compared to the total number of c-squares. This indicator adds information on the aggregated nature of fishing. Again, to provide information by habitat, it will need to be estimated by habitat.
3. For calculation of the %footprint area on the seabed, the surface swept area is used. If the swept area in a c-square is larger than the area of the c-square, the swept area is set to the area of the c-square. The total swept area in an ICES Ecoregion and depth interval is compared to the area of the ICES Ecoregion and depth interval to calculate the %footprint on the c-square. Note that this indicator uses the term footprint to denote a different indicator than the footprint referred to in WKTRADE, which describes the number of c-squares where the swept area is >=1 divided by the total number of c-squares. This ambiguity in naming is confusing to the reader.

All the above indicators describe the fishing effort in terms of its interaction with the seafloor. An additional indicator could be one that reflects the fishing pressure in terms of its *potential* to disturb the seafloor:

4) total swept area of the fishing fleet, not taking account of how this is distributed over any c-squares, possibly distinguishing between surface and subsurface.

The calculation of these indicators per depth-range and/or per habitat provides a comprehensive assessment of the fishing pressure, i.e. physical disturbance. The data quality issues and caveats spelled out in section 6.4 are considered comprehensive and relevant.

A general point is that the value of these indicators depends on the spatial and temporal resolution applied. Now the choice was to use c-squares (0.05 x 0.05 degree grid, about 15 km² at 60°N latitude) but higher resolution will give overall lower pressure values and result in a smaller impacted area. Therefore, WGECO recommends that any reporting of pressure indicators should be accompanied by the resolution at which they were derived, even in cases where the resolution of habitat maps are coarser. High resolution fishing effort data is essential to evaluate fishing pressures accurately at fine spatial resolution.

Fishing impact indicators

The WKBENTH report presents a suite of benthos indicators that were developed to assess bottom-trawling impacts of northern boreal habitats (ICES, 2017). Three sets of benthic indicators (i.e. Long-LL 1-2, Long-SBI1-2 and PD1-2) which evaluate changes in benthos relative biomass alone or combined with species longevity were discussed. Two additional indicators applied by OSPAR were also discussed; the BH2 which uses conventional quantitative diversity indices (e.g. Margalef's D, AMBI, and Shannon-Wiener's H'), and the BH3 which uses categorical impact scores based upon expert judgements. These indicators are presented with the relevant information pertaining to their suitability to calculate fishing impact on the benthic community.

Table 8.1.2.1. Relevant characteristics of the indicators proposed by WKBENTH

INDICATORS	APPROACH AND INFORMATION USED	SENSITIVITY ASPECT DISTINGUISHING BETWEEN RESISTANCE/DEPLETION AND RESILIENCE/RECOVERY	PART OF THE COMMUNITY COVERED AND CALCULATED VARIABLE
PD1 quantifies biomass recovery as a proportion of the assumed full carrying capacity, % of K (biomass/carrying capacity) and a recovery rate, r. PD1 evaluated the recovery rate from bottom trawling in relation to individual EUNIS Level 3 habitats.	Mechanistic based on meta-analysis	Both	Whole community biomass
PD 2 similarly estimated biomass recovery from bottom trawling but using continuous habitat variables (%gravel, tidal shear stress, depth).	Mechanistic based on meta-analysis	Both	Whole community biomass
SBI1 (simple longevity approach) is estimated using the longevity distribution for the untrawled situation and provides a worst case situation as it assumes that taxa trawled during their life span will always be impacted.	Correlative using trait-based information	Resilience/Recovery only	Whole community biomass
SBI2 is estimated using the longevity distribution for the observed trawling intensity at each grid cell.	Correlative using trait-based information	Resilience/Recovery only	Whole community biomass
LL1 estimated the decrease in the biomass of long-lived taxa for each grid cell as a ratio of the untrawled biomass using the parameter estimates of the longevity relationships fitted (Table 7.2.2). The method attempts to take account of depth and tidal shear stress.	Correlative using trait-based information	Resilience/Recovery only	Subset, long-lived only, biomass
LL2 estimated the decrease in biomass of long-lived taxa if bottom trawling would sweep the grid cell one time more (marginal impact). This indicator may be	Correlative using trait-based information	Resilience/Recovery only	Subset, long-lived only, biomass

particularly useful when exploring the trade-off between the impact of trawling and the yield of the fishery (see 7.2.1.7).			
BH2 was developed based on an approach that assesses sensitivity to several pressures (fisheries, organic enrichment, sedimentation etc.). Margalef D is a biodiversity index that performs best in terms of sensitivity and precision for the pressure caused by fisheries and was used as the indicator.	Correlative using trait-based information	None	Whole community, species richness based on abundance
BH3 creates a sensitivity layer indicating species or (when information on species level does not exist) habitats, defined to be sensitive to physical damage (fishing).	Categorical, based on expert judgement	Both	Subset: predominant species or special habitats, qualitative

Review of the presented information on impact indicators

The following general observations apply to the work presented:

1) The rationale for the parameterization of these indicators is often poorly documented, their pros and cons rarely are provided, and there is limited guidance for which situations (e.g. habitat settings) these should be used.

2) The trends in the distribution of sensitivity and impact scores in time and space can vary greatly between some methods. In many cases, the choice of parameters is not logical and may affect comparability and evaluation of their performance.

3) While the specific attributes of these indicators are compared, there is no attempt to evaluate their operational ability.

4) The methodology for calculating the two indicators based on longevity (LL1 and LL2), differ only slightly. There is limited comparison of the performance of these two indicators and little guidance provided when they should be used and why. In Table 7.3.1 the sensitivity scores of both these indicators are combined, but it is uncertain how and why that was done.

5) The strength and weaknesses of these methods are not compared. The WKBENTH Table 9.1.1 states that it uses various well established criteria to evaluate the indicator performance. However, it appears that the table provides baseline information on the specific properties of each of these indicators but does not evaluate their performance.

6) The indicators are not grouped according to which aspects of benthic impact they reflect. This makes the evaluation difficult as an indicator may be the best available for a specific aspect of the benthic community though it

performs worse in the evaluation than an indicator for another of those aspects.

7) The quantitative benthos indices were all developed based on grab or corer samples collected in soft sediments (ICES, 2017; Rijnsdorp et al., 2016). The densities of larger bodied species, deep-burrowing infauna and mobile epifauna, and species that are highly patchily distributed, are thus underestimated (Eleftheriou and Moore, 2013).

8) The WKBENTH comments in Table 9.1.1 on whether the different indicators reflect trends over time seem to be based on the assumption that habitat maps are well known and remain static. This may not necessarily be true as may be discovered if habitat sampling is continued.

Considerations on the suitability of proposed indicators

The following issues and considerations apply to the suitability of the proposed methods and their indicators. Each of these has relevance to the information presented in Table 8.1.2.1.

- There are restrictions on the applicability of the different methods. The quantitative indices were applied to what are often the most common habitats, i.e. A5.1 – Coarse sediment; A5.2 – Sand; A5.3 – Mud; A5.4 – Mixed sediment, but cannot be applied to other habitat types (ICES, 2017), such as pebbles, boulders, bedrock and biogenic habitats (e.g. sponge bottoms, bivalve and cold-water coral reefs and limestone deposits).
- All the quantitative benthos indices were based on biomass measures (i.e. biomass in the samples), except for BH2, which was based on abundance (i.e. density of individuals in the samples).
- The BH2 uses the Margalef diversity index, although this index is sensitive to density (i.e. sampling effort), (Gamito, 2010). Furthermore, the reference values were set so the Margalef diversity index results were dependant on trawling intensity (ICES, 2017). Species richness is highly correlated with density of individuals. Thus, without accounting for species accumulation curves reflecting how changes in macrobenthos density affects the number of species recorded at individual sites, classical species richness and diversity indicators are likely to be subject to variation due to inter-annual changes in recruitment success (Gislason et al., 2017).
- In general, WKBENTH prefers quantitative continuous methods over qualitative methods. While WGECO agrees that this is appropriate for data rich systems, it may not be possible in all areas and in areas without data, expert judgement may still be required in the parameterization of the methods. Therefore BH3 may serve as the 'best available information' of benthos and benthic habitats in data poor areas, and for sediment habitats not properly represented or covered by the above quantitative benthos indices.
- For all methods, the change over time is determined by the underlying pressure layer. However, only the mechanistic approach can be expected to give a realistic progress in time as this approach includes the actual speed of recovery. For example a sudden major decrease in pressure would cause a sudden increase in the indicator which, notably for the LL1 representing species with very slow (<10 yr) recovery, is not expected in reality.
- Methods that explicitly include both Resistance/Depletion and Resilience/Recovery can be considered more specific to the physical disturbance

pressure as recovery applies to any pressure causing additional mortality. Methods only including recovery are not specific to physical disturbance.

- There is an element of gear specificity in the estimation of fishing pressure, which is reflected in the contribution of different gears to the total swept area, distinguishing surface and subsurface. However, when calculating impact based on the fishing pressure estimates there are distinct differences between the methods in terms of their capacity to handle different gears. The SBI1/LL1/BH2/BH3 methods do not distinguish between gears when calculating impact based on fishing intensity. In contrast, the PD method distinguishes fishing gears in terms of the depletion they cause based on their penetration depth.

The quantitative indicators (or rather methods) all have their merits and flaws. For example, the population dynamics (PD) approaches appear to be more useful in integrated assessments as they are specific for one pressure, i.e. physical disturbance. The problem with the PD approaches is that they only provide information on the total biomass of the benthic community, which is only one aspect of seafloor integrity and not necessarily the most appropriate one to assess fishing impact. The PD method is a more generic method as its parameters are based on a global meta-analysis but suffers from the assumption that each habitat is a homogenous unit. In contrast, the correlative approaches can be based on empirical data (if available) but there is an issue applying formulas from one (part of an) Ecoregion to another.

Set reference levels

The use of GES and non-GES to signify which c-squares are impacted is confusing and premature as the methodologies are not sufficiently developed and the knowledge base is lacking for the identification or setting of any GES thresholds.

WKSTAKE

The methods are well explained (with the exception of the lack of naming of chairs and facilitators) in the report. However, the link to original task and the objectives of the discussion is unclear. The introduction does not mention the same purposes of the workshop as the request: 1) operational challenges of the suggested indicators, 2) regional (RSC) and cross-regional (EEA) requirement of the assessment, 3) scientific robustness of procedure, and 4) usefulness of indicators in a management context. WGECO therefore decided to evaluate the general input from WKSTAKE to the workshop process instead of the progress on ToRs and objectives.

WKSTAKE identifies that caveats should be clearly listed in advice, maps should be in compatible formats and that colour schemes should not convey value (e.g. red-yellow-green). Priority actions were:

- identify uncertainty associated with maps and how to communicate this uncertainty,
- the development of sophistication so that local specifics can be taken into account,
- the need to consider the displacement of vessel activity and gear changes,
- the lack of coverage of smaller (<12m) vessels, and recreational fisheries.

Effort is required to build in further industry input, greater dialogue with stakeholders standardization across countries. Finally, the ideal approach should accommodate the possibility and consequences of gear changes.

WKTRADE

The objective of WKTRADE was to propose approaches on how to inform managers about trade-offs between benthic impacts and the landings or revenue of the fisheries, considering both spatial and temporal aspects for MSFD broad habitat types. The intention was to provide guidance on methods that would allow managers to explore the trade-offs between the provision of catch/value and the impact on seafloor habitats.

WGECO specifically reviewed and suggested edits for the draft advice format, as this was the approach suggested to inform managers. The draft advice sections were identified as difficult to understand for stakeholders when WGECO members found them difficult to interpret.

Draft advice format (WKTRADE Section 5)

Overall, the advice sheet looks sensible and contains the necessary information. There are, however, several places where the advice can be made easier to understand and more precise in its use of terms. Further, while WGECO appreciates that the example provided was only meant to illustrate what the advice format could look like for one aspect of the benthic community (in this case biomass), other aspects (e.g. biodiversity) may also need to be covered. This necessity for several indicators is addressed in detail in WKBENTH, which also concludes that it is necessary to ensure that spatial management measures do not encourage the reallocation of effort into previously lightly or non-impacted areas. This issue should be repeated in the advice format to avoid the possibility that focusing on single indicators (i.e. less than half of the biomass left compared to undisturbed) encourages closure of medium fished areas causing effort to move to currently unfished areas.

The figures and text refer to pressure, impact and state indicators more-or-less at random, and the draft advice does not use these terms consistently. WGECO considers that it is preferable to use pressure and impact or pressure and state in a consistent manner. From the request, pressure and impact seem to be most relevant, but for consistency with other indicators under the MSFD, pressure and state seems preferable, particularly as this allows the importance of different areas to be judged according to their biomass. However, as only relative estimates of state and impact are available, an area with a carrying capacity (assumed undisturbed biomass) K of 2 which is impacted by 0.5 (resulting biomass 1) will be judged as having a lower state than an area with a K of 200 impacted by 0.25 (resulting biomass 50).

There are numerous abbreviations in the report which are not explained, and which furthermore seem unnecessary as they are generally only mentioned once. WGECO has suggested simplifications to focus the entire document on the pressure indicators 'times swept per year' and 'trawled footprint', together demonstrating overall pressure and concentrated pressure, and on the impact indicators landings, value and benthic impact. Benthic impact indicators are presently not considered sufficiently developed to be used in operational advice; however, once indicators become available, the description should be applicable to any method. To identify high management cost/benefit areas, the ratio of value to swept area is used for each habitat. This corresponds to assuming that impact of swept area is identical in all parts of the habitat. Using value downplays the leverage of the high biomass-low price per kg industrial fisheries.

As information, Table 5.1 is very good and could be given in the summary, removing the 'state' row and replacing the c-squares with area fished (swept area in km^2).

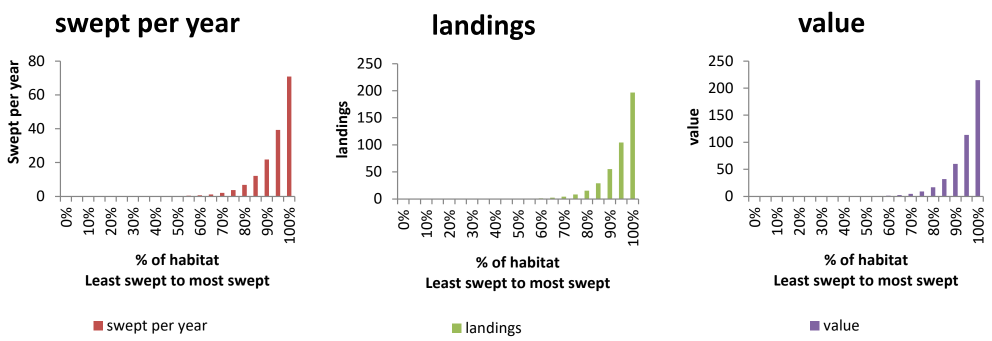
Pressure

All figure numbering in this section refers to numbers in the example advice sheet at the very end of Section 5 of the WKTRADE report (p. 22 onwards).

Fig 1. The left panel inserted key does not describe what all colours mean and this should be added. The insert on the right panel is unlikely to mean much to the recipient of advice and is furthermore too small to make out. Star in the caption is not explained. As the annual footprint may vary in particular locations, it would be informative to include both the annual swept area map and the five-year summed swept area map, as this may be of relevance to longer lived species and also demonstrates that areas currently appearing not to be trawled may have been impacted in other years. Furthermore, when making decisions on spatial management measures, using the final year map only is clearly inadequate. Other time periods could also be considered, but having a short period limits the effects of poorer coverage in the early years of vessels between 12 and 15 m.

Fig. 2. Add one more panel showing times swept per year per habitat (left) and footprint per habitat on the right. The current figure legend text is difficult to understand and it is suggested to be rephrased as: "The figure shows the footprint area as a proportion of the habitat area in the region for each year and habitat type for habitats A5.1 – Coarse sediment; A5.2 – Sand; A5.3 – Mud; and A5.4 – mixed sediments and across all habitats (including other habitats). Footprint is defined as the areas swept more than once, on average, in a year." As no trend is apparent, it could be considered to replace Fig. 2 with a bar chart or table showing the footprint for each habitat.

The left panel of Fig. 3. is confusing (as it excludes non-fished areas) and is difficult to interpret for both scientists and non-experts. Further, having state indicators in this section on pressures is confusing (Fig. 3 right panel) and cumulative curves are difficult to understand for non-experts. WGECO assumes that the main message of this figure is the aggregation of fishing effort and suggests replotting of Fig. 3 to show on separate panels, the total swept area/landings/value as a function of area bins, as shown in the hypothetical panels below:



This shows the uneven distribution of fishing – if all areas had almost the same fishing effort, the columns would be almost the same size. It could also be considered whether value and landings are both needed or one would be sufficient as this would simplify the figure. There should be one figure for each habitat since the request is specific about the need for habitat based indices. To link these figures to the concept of footprints, the columns could be shaded where Swept area ratio>1. Further, the five-year summed values could be inserted as bars in each plot to show if the currently unfished areas have been consistently unfished in the previous period.

Impact

Fig. 4. This figure should show impact, not state, to make it consistent with the section header. The left figure (a) is very strange – how can the average status be substantially lower than the status of the individual habitats which make up most of the habitat? The message of the right figure is not clear to non-experts (including WGECO). WGECO suggests showing, for each habitat, the average impact on the left panel and on the right panel, the area impacted by more than e.g. 0.5 and not calling this footprint, as footprint is defined above as something different. We have used 'impacted area' below as a suggestion.

Fig. 5. Making the figures refer to changes only within the impacted area is confusing unless the figures are shown in pairs (one showing % impacted area, another average impact within impacted area), and even then, stakeholders will not find these easy. WGECO suggests to keep the focus on habitats and make the panels each show one habitat, with the fleets appearing as different lines and then adding a summed line for the habitat.

Page 24, below the figure: "Time series of the footprint where the seafloor status is above a GES threshold value (once a GES threshold has been set)": These proposed time series figures can be replaced by inserting a reference line in the panels showing impacted area with the agreed reference level (which WGECO agrees is a policy decision to define).

Status across habitats

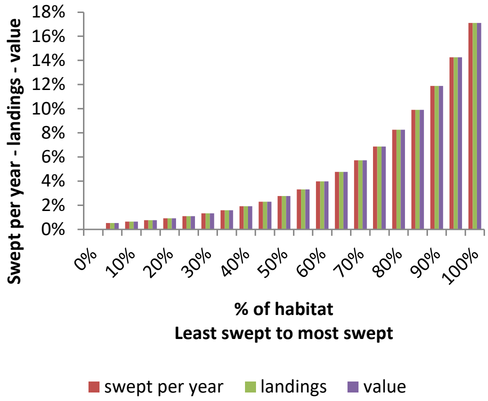
The naming of B/K as Blim should be avoided as the phrase is already used in a fish assessment context. Further, it is unclear why there would be a B-*target* – would we then aim to impact more if B/K exceeded this value?

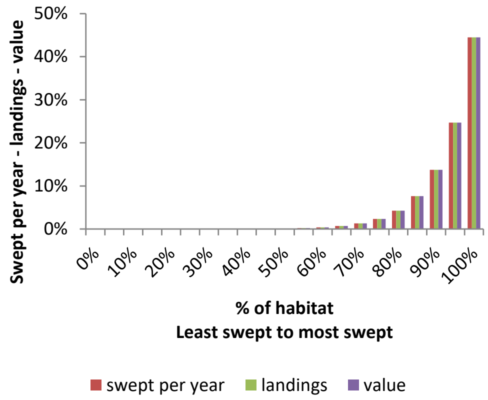
The figures integrating trade-offs in a single figure are difficult to interpret (Fig. 3 left panel) and stakeholders tend to want to see a map. A possible way to demonstrate the area which is currently lightly fished would be to show two figures with maps similar to Fig. 4.6 but based on 5-year averages. The first figure could show black squares depicting the least value/swept area c-squares which together account for 5% or 10% of the total swept area for each habitat. By using value/swept area to rank the c-squares, areas with high value are given priority for continued fishing over those with low value if swept area is the same. Similarly, areas with low swept areas are given priority for continued fishing over areas with high swept areas when value is the same. Alternatively, ranking can use value directly, but this would not account for differences in high value/low impact and high value/high impact areas.

The figures could show the distribution of effort of the fleets in separate panels from top to bottom overlayed with the areas (which are defined across all fleets). A table below could give the summed area, effort, landings and value by each fleet and habitat for each of the 5% and 10% swept area decreases in the above figures. It will be key to keep the number of presented percentages low, as the number of habitats and fleets on their own means that the number of maps is already rather large.

In addition to the maps, the information currently in Fig. 3 right panel can be given. These figures cannot show the actual trade-off between total swept area and value when closing increasingly large areas starting from the least cost/benefit (value/swept area). However, they do give some indication of the maximum order of magnitude of loss and gain (losses and gains can be less as fleet redistributes or if areas are located differently) and can be presented as such 'envelope' estimates, stating the caveats in drawing conclusions on actual losses and gains clearly. The figures should be based on c-squares ordered according to value/swept area similar to the maps to avoid seemingly conflicting results. They should show value, swept area and the ratio between the two, and to link to the new figure 3, they could be given as bar charts.

The suggested figures will encourage thinking about protecting low-impact areas as first suggested by managers and industry (industry refers to areas not fished due to other activities, but the results should be the same) in WKSTAKE. They will also give a perception of how the patchy nature of the fisheries and impact means that to obtain significant decreases in impact. Protecting very large areas may be impractical where fishing is very aggregated (right plot below) but smaller areas can be protected where fishing is more evenly distributed (left plot below). For the two examples below, the least value areas resulting in 5% of the impact cover 30% and 75% of the area, respectively.





If the focus on the footprint indicator becomes too large, there is a danger that to improve this indicator, medium fished areas are suggested for closures, causing reallocation of effort into both previously heavily and lightly impacted areas.

It should be clear in the advice that these figures are not to be used to suggest closed areas without evaluating the effects of redistribution of the fleet (the effort scenarios suggested by the industry at WKSTAKE) and habitat characteristics of the proposed closed area. The annexes of the report suggest several methods which are specifically designed to address this issue, and these methods would seem relevant in an evaluation of spatial management measures. WGECO would recommend a gradual introduction of closed areas as part of an adaptive approach to spatial management. The maps can be seen as a starting point for discussions.

Incorporation of WKSTAKE advice

WKSTAKE identifies that caveats should be clearly listed in advice. They also suggested to depict uncertainty (particularly about the habitat map), and to include effects of changes of gear and redistribution of the effort. These recommendations have not been addressed.

Lines 1171-1181: These methods specifically fail to take account of the dynamics of fishing effort distribution and gear choice, two important issues pointed out by WKSTAKE. The reason for assigning the descriptions of models capable of evaluating these aspects to the appendix is not clear.

Conclusions and the way forward

Several indicators have been put forward for the assessment of fishing pressure and seafloor status to provide guidance for management.

The indicators for the assessment of fishing pressure affecting the seafloor, i.e. physical disturbance, are sufficiently well developed to be used as basis for advice. The suggested impact indicators can provide a different perspective to fishing pressure and as such should be considered complementary. It seems unlikely that one indicator will be sufficient to address all desired aspects of the benthic status, and therefore, a suite of indicators will probably be necessary.

The potential indicators for seafloor integrity and how it is impacted by physical disturbance from fishing, have not matured to the point that they can be used as basis for advice. The different indicators are based on different methods, each with their pros and cons and there is insufficient scientific basis to select among them. WGECO supports the recommendation that the quantitative methods should be used whenever sufficient data are available. However, the expert judgement-based method (BH3) can be applied in data-poor situations or for those habitats (e.g. VMEs) where the parameters required to apply the quantitative methods are lacking. The quantitative indicators (or rather methods) all have their merits and shortcomings. As a way forward WGECO recommends that the process to (further) develop these indicators should focus on combining, where possible, the strengths of the different methods. A first attempt to explore this is presented in ToR a.

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