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Report on benthic ecosystem processes and the impact of fishing gear

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Key benthic ecosystem processes:

Relationships between macroinvertebrate biological traits and sea bed functioning in European waters

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Summary

Over the past decade, there have been a number of studies aiming to improve our knowledge of the functional impacts of trawling on the sea bed using Biological Traits Analysis (BTA). BTA is an ecological approach that looks beyond the mere zoological identity of taxa and the species composition of communities by focusing on the form and function of the biota; that is to say 'what they do' rather than 'who they are'. Essentially, BTA uses a series of life history, morphological and behavioural characteristics of species present in assemblages to indicate aspects of their ecological functioning. However, our ability to use this approach to address the functional impacts of trawling is currently hindered by a number of conceptual and methodological factors, the main ones being;

- a lack of appreciation of the distinction between 'response traits' (i.e. those which vary along an environment gradient and/or disturbance regime) and 'effects traits' (i.e. those which have an effect on an ecosystem process),
- a current lack of quantified relationships between benthic invertebrate effects traits and ecosystem processes regarding the sea bed, and
- a serious lack of basic biological information (life-history, morphology, behaviour) regarding benthic invertebrate taxa.

This report introduces a list of traits that may be considered as those particularly relevant for inclusion within the subsequent broadscale biological traits analysis being undertaken on benthic invertebrate assemblage data under WP3. The ten traits include a number of life-history, behavioural and morphological characteristics and, in combination, are likely to reflect relationships with a range of important ecosystem functions (e.g. nutrient fluxes, carbon storage, benthic-pelagic coupling, secondary production). Finally, we advocate that a focus on acquiring accompanying metrics of functioning (e.g. sediment biogeochemistry, secondary production) aligned with traits information would significantly improve our ability to determine both the identity and importance of effects traits for specific ecosystem processes.

1 INTRODUCTION

Human activity has comprehensively altered marine ecosystems and will continue to do so, with some workers reporting 41 % of marine areas are strongly affected by multiple anthropogenic perturbations (Halpern et al., 2008). Coastal and marginal seas are particularly susceptible as they host a disproportionately large fraction of productivity and, because of the economic benefits that humans accrue from living in close proximity to the coast, such regions tend to be densely populated (Gray, 1997; Hinrichsen, 2010). Ecosystem function and biodiversity of coastal and shelf seas are, therefore, under pressure from a multitude of threats such as pollution, eutrophication, physical modification and habitat loss (GESAMP, 1990; Gray, 1997). One of the most widespread yet manageable pressures we impose on the seabed is disturbance of the substrate by towed demersal fishing gear (bottom trawling and dredging). Watling and Norse (1998) calculated that an area equivalent to the world's continental shelf is swept by trawlers every two years. In UK waters, the footprint of trawling far exceeds that of other direct impacts such as aggregate extraction and offshore constructions (Eastwood et al., 2007) and is reckoned to account for over 99 % of the footprint of all human pressures on the UK seabed (Foden et al., 2011). It follows, therefore, that if current and future management of trawling activities can be based on an improved scientific rationale, potentially large improvements in the sustainability of this activity may be observed for continental shelf seas.

Over the past forty to fifty years, there has been a considerable number of studies specifically aiming to understand the impacts of the various bottom trawling gear on seabed communities (e.g. Dayton et al., 1995; Jennings and Kaiser, 1998; Hall, 1999; Kaiser et al., 2000; Jennings et al., 2001; Bergman et al., 2002; Queiros et al., 2006). Such studies have shown that bottom trawling can have dramatic effects on the structure of marine ecosystems although impacts tend to be wide-ranging, depending upon the gear, intensity, spatial area and the nature of the seabed habitats (Hall, 1999; Kaiser and de Groot, 2000; Smith et al., 2000; Tillin et al., 2006). One notable feature regarding such studies, however, is their focus on structural impacts. It has been observed that, following both natural and anthropogenic stressors, functional impacts and functional recovery trajectories are not always matched by their structural counterparts (Cooper et al., 2008; Grilo et al., 2011; Wan Hussin et al., 2012; Bolam, 2012). Conserving marine ecosystems, the *raison d'etre* of the ecosystem approach, requires knowledge of not only how species may be affected by ecosystem change, but of how the system works and the effects of multiple and potentially interacting pressures on the functioning ecosystem. The ecosystem approach, therefore, must aim to safeguard function as well as biodiversity, but trawling impacts on benthic community function need to be understood before they can be managed.

Recently, a number of studies have attempted to address this deficiency in our knowledge of the functional impacts of trawling using Biological Traits Analysis (BTA) (e.g. Tillin et al., 2006; de Juan et al., 2007; Frid, 2012). BTA is an ecological approach that looks beyond the mere zoological identity of taxa and the species composition of communities by focusing on the form and function of the biota; that is to say 'what they do' rather than 'who they are'. Essentially, BTA uses a series of life history, morphological and behavioural characteristics of species present in assemblages to indicate aspects of their ecological functioning (Bremner, 2008). While the approach has, to date, afforded new and exciting insights regarding trawling impacts, a limited understanding of the relationships between biological traits and functionality currently restricts our ability to make unequivocal statements regarding effects of trawling on important sea bed functions.

This report aims to review our current knowledge of how BTA may be applied to improve our understanding of the effects of bottom trawling on important sea bed functions. The compilation of our contemporary knowledge of this subject is of inherent strategic importance to BENTHIS. That is, it is envisaged that the information gleaned will aid decisions regarding the number and type of biological traits that should be studied to increase our understanding of the functional impacts of trawling for a range of habitats. Focussing on traits linked to functions should allow a more relevant assessment of benthic species assemblages in relation to sustaining the marine ecosystem resources valued by society e.g. fisheries yield and species diversity, together with a number of other important functions of the sea bed (e.g. benthic-pelagic coupling). Basically, we should observe more meaningful and useful benthic ecological patterns of variation in space and time that allow more effective management of resources. BTA was initially derived for, and applied to, terrestrial systems and the approach and methodology only relatively recently applied to the marine realm. As a consequence, relevant published studies pertaining to the seabed using this approach are comparatively primitive both in terms of their theoretical and methodological developments and their functional significance. Marine benthic researchers are, in essence, approximately 20 years behind terrestrial scientists attempting to understand the links between biological traits and ecological functioning. Consequently, this review occasionally makes reference to the terrestrial literature, and theoretical developments in that field. Furthermore, this review briefly touches upon relevant background concepts to ensure a sound definition of some important, and yet widely mis-represented terms; this ensures that such ambiguity is minimised under the auspices of BENTHIS.

2 ECOLOGICAL PROCESSES AND FUNCTIONS

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 functions. 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 processes, functions and services in the marine literature (M. Solan, pers. comm.). 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 are implicitly important within an ecological context, the central element of this review is that we attempt to understand which traits are important in delivering what we deem significant within a management framework, in other words, we need to be explicit regarding what processes and/or functions are germane to BENTHIS. Put another way, while what we consider as particularly important in safeguarding from trawling may be a combination of both processes and functions, it is how biological traits are responsible for contributing to them which is of central importance to this report. Firstly, therefore, we need to clearly define what we aim to preserve, minimise impacts to, or restore following trawling and these are likely to be habitat-specific.

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 aimed at 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 fisheries managers to safeguard are listed in Table 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 sea bed to increase secondary production may result in decreased nursery/refuge functioning and/or reduced benthic-pelagic coupling in some habitats.

Table 1. Ecosystem processes, functions and goods and services of marine ecosystems that are particularly pertinent to trawling impacts.

Process	Function	Goods and services
	Regulation functions	
Bioturbation	Nutrient fluxes	Maintenance of primary production Water purification
Filter feeding	Benthic-pelagic coupling	
Bioturbation	Carbon storage	Climate regulation
	Habitat functions	
Production of biogenic structures	Nursery & refuge function	Recruitment and survival of commercially important species Presence of high biodiversity areas
	Production functions	
Photosynthesis, herbivory and predation	Secondary production of invertebrates and fish	Fish catches

A complete list of of all goods and services affected by the trawling industry could be very lengthy (Beaumont and Tinch, 2003), so only those goods and services directly associated with the marine benthic environment are included here.

3 FUNCTIONAL TRAITS

A biological trait is simply a description of a particular characteristic of an individual (often defined for the species), for example body size, feeding mode and reproductive mode. The number of traits of an individual is large, although many traits tend to be correlated and/or are covariates. For marine benthic invertebrate assemblages, Table 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). Voille 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., are *functional response* traits), tend to be only loosely correlated with vegetative characteristics, which tend to 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). If tightly correlated, disturbances will greatly affect functioning as species with similar functional traits will be removed/affected by the disturbance. Alternatively, if effects and response traits are not linked then those species affected by disturbance will range in their effects traits and functioning will be less affected.

Trait	Potential categories
Maximum size	Millimetres, centimetres - categories dependant on range in dataset
Maximum growth rate	Grams year^{-1}, % change, productivity/biomass ratio - dependent on range in dataset
Longevity	0-3y, 4-7y, 8-11y, 12+y
Time to maturity	Months - categories dependent on range in dataset
Reproductive method	Asexual, sexual-shed eggs, sexual-brood eggs
Fecundity	Oocytes per individual - categories dependent on range in dataset
Propagule dispersal	Pelagic, benthic
Body design	Soft, soft-protected (tube/tunic), exoskeleton, shell
Living habit	Tube, permanent burrow, temporary burrow, crevice/hole, epizoic/epiphytic, free
Living location/environmental position	Surface, interface, 0-5cm, 6-10cm, >10cm
Exposure potential	Low (infauna/flat), moderate (mound surface/interface), high (erect surface/interface dwellers)
Degree of flexibility	$<10^{o}$, $10\text{-}45^{o}$, $>45^{o}$
Degree of attachment	None, temporary, permanent
Strength of attachment strength	None, low, moderate, high
Resource capture method	Suspension feeder, deposit feeder, opportunist/scavenger, active predator, symbiosis, producer
Food type	Detritus, carrion, living material-benthic, living material-planktonic, chemicals in solution
Energy transfer efficiency	Low, moderate, high
Bioturbation mode	Upwards conveyor, downwards conveyor, diffusive mixer, surface depositor
Defence strategy	None, escape, autotomy/evisceration, aperture closure, combat-physical, combat-chemical
Movement method	None, swim, crawl/creep/climb, burrow/bore, jump
Mobility	Sessile, motile
Water column migration	None/no evidence, irregular/single, regular-seasonal/reproductive, regular-diel
Horizontal migration	None/no evidence, irregular/single, regular-seasonal/reproductive, regular-diel
Intra-specific sociability	Singular, occasionally-gregarious, permanently-gregarious, colonial
Predictability of dynamics	Predictable, unpredictable
Recruitment variability/success	Low, moderate, high

Biogenic habitat provision	None, settlement/attachment site, shelter, sediment accretion, sediment removal
Scale of habitat provision	Ephemeral, moderate, long-lasting

Table 2. Examples of biological traits commonly used for marine benthic assemblages.

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). For instance, a seed disperser or pollinator that has little direct effect on ecosystem processes may be essential for the persistence of a canopy species that has greater direct ecosystem impact. Incidentally, such unknown indirect effects are often cited by ecologists as justification for the importance of species diversity, however, there is currently no theoretical framework to predict when these indirect effects are important. 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 the primary aim of this review under BENTHIS and, in consequence, identifying functional effects traits will be the primary goal for work conducted under WP3.

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 (Papageorgiou et al., 2009; de Juan and Semestre, 2012). Indeed, there has been significant progress with respect to our understanding of the identity of a number of functional response traits. 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; de Juan et al., 2007; Bolam et al., 2013) 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. We must be conscious of the fact that 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, we may only infer functional changes from alterations to response traits if those functional response traits also act (wholly or partly) as functional effects traits. Unfortunately, our understanding of which traits fall into each of the two trait categories is limited. While we may regard 'bioturbation mode' as an effects trait and 'brittleness' as a response trait, the distinction for other traits is less clear. 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*". One of the key aims of BENTHIS is to address this current gap in understanding, ultimately resulting in an improved understanding of the functional impacts of trawling in European shelf waters.

4 FUNCTIONAL EFFECTS TRAITS

4.1 Current understanding of effects traits

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), macrofauna diversity (Volkenborn et al., 2007), bacterial activity and composition (Mermillod-Blondin and Rosenberg, 2006; Gilbertson et al., 2012) and metal (Teal et al., 2008; 2009), carbon (Kristensen, 2001), nutrient and nitrogen cycling (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 1).

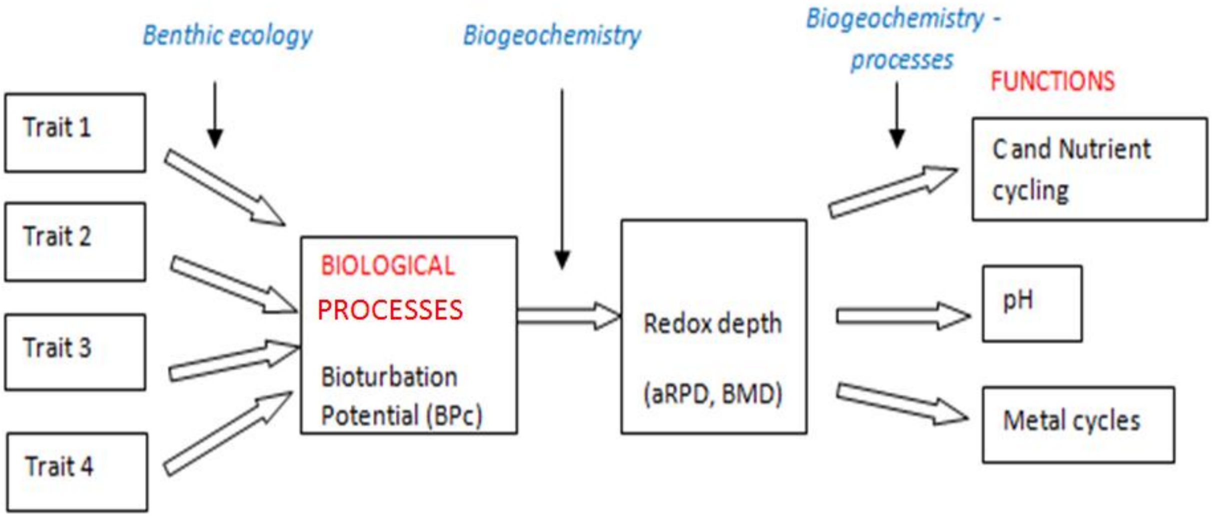

Figure 1. Relationship between biological traits, bioturbation potential metrics and sediment biogeochemical processes and benthic functioning. The blue text refers to the nature of the different scientific approaches applied to address the various steps. Bioturbation potential is a metric used as a proxy for bioturbation and is affected by a number of biological traits. The process of bioturbation affects the redox depth of sediments which, in turn, has important effects on important ecosystem functions such as carbon and nutrient cycling.

4.2 Trait selection

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 2), and published studies have generally used a sub-set of those listed (Bremner et al., 2004; Tillin et al., 2006; de Juan et al., 2007; Cesar and Frid, 2012; Verissimo et al., 2012; Van der Linden et al., 2012). More often than not, the final traits list 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 BTA study is important as it has the potential to affect the way benthic assemblages are assessed: it should not be an arbitrary decision. Development of BTA, particularly where functional effects traits are implicitly or explicitly the foci, must therefore include an assessment of which traits provide the most useful description of ecological functioning (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. Bremner et al. (2004) found that including as many traits as possible gave a more informative picture of overall ecological functioning and, conversely, limiting the number of traits minimises the ability of the approach to accurately describe the functioning of an assemblage. Moreover, these authors postulated that studies which include few biological traits risk providing a misleading view of sea bed functioning. But how do we attempt to refine a list of traits to those deemed more pertinent to address an (or set of) ecological function and/or process? A number of studies have indicated that infaunal invertebrate traits reflecting behavioural and morphological characteristics are likely to be more relevant to functioning (and termed 'functional traits'; Tillin et al., 2006; Dimitriadis et al., 2012) as opposed to life history traits which describe the ability to respond to, or recover from, physical disturbance (Tillin et al., 2006; Bolam et al., 2013). However, as Bremner et al. (2004) found during an experimental cockle-fishing study, traits grouped according to this rationale do not always respond in such a predictable manner.

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 (Blanchard et al., 2004), understanding is far behind that for terrestrial ecosystems. Chapin et al. (1997) stated that traits with powerful effects on ecosystem processes 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 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). The three categories put forward by Chapin et al. (1997) 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. (2013) 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., 2009; Bolam et al., 2013). 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 (the response traits ensuring the survival of the population), and those traits which favour the survivability of the individual to acute impacts and affect the survivability of the individual as opposed to the population.

Frid et al. (2008) approached the issue of defining which traits should be incorporated into analyses to describe the functional attributes of benthic assemblages. Focussing on two habitats off the English coast; a subtidal sandbank and a rocky reef, they firstly defined the ecological functions for which the two habitats were regarded as being important (Table 3). Secondly, they indicated which biological traits they considered were required for the benthic assemblages to fulfil these functions (an example is given for one function in Table 4). The final list of traits (Table 5) represents the combination of those regarded as being influential for the ten functions listed in Table 3. It was highlighted that not all traits would be regarded as of equal importance; some traits may be indicators of more than one aspect of functioning. It was agreed that all traits should be included in the analysis of ecological functioning, although particular traits may be further considered in isolation if this was considered appropriate for a particular dataset, e.g., if a particular function was regarded as being of great importance (Frid et al., 2008).

In view of the relative paucity of quantified relationships between biological traits and ecological functioning in the marine realm compared with that of terrestrial systems, the approach adopted by Frid et al. (2008) may be regarded as appropriate. However, there are some limitations. Firstly, the relationships between the traits indicated as being important for a given function have not yet been quantified: their involvement was essentially based on best professional judgement by a small number of scientists. Secondly, when one expands this approach to a wider number of habitats and/or functions then the potential number of traits becomes almost prohibitive (Bremner, 2008). Thirdly, in addition to those currently recognised, there is always the possibility of further functionally-important traits yet to be identified. Finally, trait selection will ultimately be constrained by the amount of information available (Gayraud et al., 2003) and the costs of processing it; this issue relates to terrestrial studies and, arguably, is a far greater problem for studies in marine systems.

Table 3. Important ecological functions of two marine habitats; a rocky reef and subtidal sandbank (Frid et al., 2008).

1	Energy and elemental cycling (carbon, nitrogen, phosphorus, sulphur)
2	Silicon cycling
3	Calcium carbonate cycling
4	Food supply/export
5	Productivity
6	Habitat/refugia provision
7	Temporal pattern (population variability, community resistance and resilience)
8	Propagule supply/export
9	Adult immigration/emigration
10	Modification of physical processes

4.3 Limitations to trait inclusion

In a recent study of benthic invertebrate and fish data from UK waters, Tyler et al. (2011) highlighted the inherent problem facing marine scientists attempting to improve present knowledge of the links between biological traits and ecological functioning. They stated, based on their findings, that the lack of trait information for benthic and fish species was "*startling*" and reflected a deep ignorance of the basic biology of a well-studied fauna. Their conclusions were fitting with the concerns of many other authors whose studies were constrained by a lack of basic biological information (e.g. Tyler-Walters et al., 2009). Based on eight fundamental (and commonly used) biological traits (i.e. body size, feeding mode, diet, longevity, reproduction, fecundity, larval dispersal, adult dispersal), 20% of the species studied by Tyler et al. (2011) completely lacked any data, full trait information was only found for 9% of species, and biological knowledge tended to be correlated with biogeographic knowledge (i.e., less biological information exists for less ubiquitous species). The implications of the latter point regarding our understanding of ecosystems may depend entirely on the extent to which common/widespread species dominate community properties and ecosystem functioning (Gaston and Fuller, 2008; Gaston, 2010). If certain combinations of traits were considered to be key to ecosystem functioning, they could perhaps best be maintained by directing management efforts at common species which possess those traits (Gaston and Fuller, 2008). However, rare species may possess unique and possibly functionally important traits, or occupy the indirect links to important ecosystem processes and functions (see reference to pollinating insects for canopy species mentioned earlier); the poor state of biological knowledge for rare species documented by Tyler et al. (2011) means that we simply do not know if this is the case for UK marine benthic species or not.

It is clear, therefore, that trait inclusion within a particular study, both in terms of type and number (and how they are weighted during analyses), must be carefully considered in the context of the questions being asked to ensure that the approach most effectively provides the 'true' answers and not simply the answers we are seeking. This may seem logical, but the reality is that these two aspects of trait analyses (i.e., trait type and number) are constrained; we presently do not have the scientific understanding to know which traits we need to include, and the number is fundamentally constrained by basic biological knowledge. Multi-trait analyses of marine benthic assemblages are data- and time-consuming tasks and large numbers of species must often be identified and the corresponding trait information gathered for each before BTA can be applied (Bremner, 2008). A number of published studies have opted to reduce this problem by restricting the dataset to a reduced number of taxa; either the numerical or biomass dominants (e.g. Tyler-Walters et al., 2009) or those highlighted (*a posteriori*) as being responsible for characterising faunal assemblages or particular areas (e.g. Frid, 2012). However, Bremner (2008) cautions the adoption of such data reductions; although data reductions appear to have little effect on univariate or multivariate (Somerfield and Clarke, 1995; Clarke and Warwick, 1998; Vellend et al., 2008) descriptions of assemblage structure, implications of this for traits analysis rest on whether trait composition behaves the same way as species structure. Indeed, as Bremner (2008) pointed out, Ellingsen et al. (2007) found that a subset of the most widespread species in New Zealand sedimentary assemblages did not encompass all traits present within the complete dataset. The authors considered that each of the non-represented traits were functionally important, indicating that traits analysis based on a subset of species may not provide an appropriate depiction of ecological functioning. Rare species may possess unique and possibly functionally important traits (or combinations of traits); the poor state of biological knowledge for rare species as documented by Tyler et al. (2011) for the UK means that we simply do not know if this is the case or not.

Table 4. Getting from function to traits, an example for productivity.

	Key Function	Trait	Description
Import	Primary production	Resource capture method	Primary producers
		Size, growth rate, longevity	Amount of materials/energy fixed
		Allochthonous input	N/A (passive physical process)
Intra-system	Secondary production	Energy transfer efficiency	How well productivity is transferred between organisms
		Body design	Proxy for palatability (affect likelihood of consumption and transfer of productivity) [1]
		Defence mechanisms	Proxy for palatability
		Resource capture method, food type, growth rate, longevity	Amount and rate of transfer (includes symbiosis)
	Turnover	Growth rate, longevity	
		Tissue components	Proxy for litter quality (affect rate of decomposition) [1]
		Body design	Proxy for litter quality (affect rate of decomposition) [1]
Export	Living production	Attachment degree and strength	Affects likelihood of export
		Living location	Affects likelihood of export
		Propagule dispersal	Planktonic reproductive phase affects supply of production
		Fecundity	Affects supply of production
		Time to maturity	Affects supply of production
		Migration	Affects export of production
	Non-living production	Movement type	Release of non-living materials from substrate

[1] Some biotic characteristics may be the result of a combination of other traits. For example, palatability is determined by the design of an organisms body (e.g. hard or soft) and the expression of behavioural defence mechanisms, etc. Additionally, some traits may be difficult to measure directly, proxies may be used instead. [2] May require decision tree approach as determined by the expression of a number of trait categories such as body design and living location (e.g. organisms with shells or exoskeletons living on the substrate surface provide settlement sites) or sociability and living location (e.g. organisms forming beds, patches or reefs in the interface (partially buried) or on the substrate surface provide refugia, modify currents and trap sediments). (Taken from Bremner et al., 2006).

Table 5. Biological traits considered relevant to the various ecological functions of two benthic habitats; a rocky reef and subtidal sandbank (Frid et al., 2008).

1	Maximum size	15	Resource capture method
2	Maximum growth rate	16	Food type
3	Longevity	17	Energy transfer efficiency
4	Time to maturity	18	Tissue components
5	Reproductive method	19	Defence strategy
6	Fecundity	20	Movement method
7	Propagule dispersion	21	Mobility
8	Body design	22	Water column migration
9	Living habit	23	Horizontal migration
10	Living location	24	Intra-specific sociability
11	Exposure potential	25	Predictability of dynamics
12	Degree of flexibility	26	Recruitment variability/success
13	Degree of attachment to bed	27	Biogenic habitat provision
14	Strength of attachment to bed	28	Scale of habitat provision

The list of 28 traits here are those in total deemed relevant for the ten ecological functions listed in Table 3.

5 IMPLICATIONS FOR FUTURE WORK UNDER BENTHIS

Under WP3 within BENTHIS, a large dataset comprising benthic invertebrate data from a number of independently-conducted, disparate studies will be analysed using BTA to model the relationships between trait composition and environmental parameters. These data will encompass a range of habitats, and sampling locations will vary in a number of important characteristics including sample acquisition (e.g. sampling devices) and sample processing methods (e.g. sieving, identification) and trawling history (intensity, frequency, trawl gear, etc.). One key goal of this analysis will be to assess the functional impacts of trawling for any given habitat which, given the extent of the data being analysed, should make a significant contribution to advance our understanding of this paradigm. Implicitly, given the findings of the current review, insightful and transparent decisions regarding the ecological functions and/or processes to be considered important for a given habitat will need to be made. Decisions regarding which traits are to be incorporated within the analysis will also need to be scientifically defensible (Figure 2). We are ultimately constrained by, and required to make a final decision based on a compromise based on, both our understanding of trait relevance and the availability of comparative biological information. We do not currently have sufficient understanding to indicate with certainty which traits should be included, and which we may discount, for a particular ecological function and/or process.

Based on this review of the traits (particularly functional traits) which have been commonly used within comparable studies, together with an informed appreciation of biological information availability, we propose to adopt the traits presented in Table 6 as those targeted under WP3. In combination, they reflect life-history (longevity, larval development and egg development modes), morphology (maximum body size, body morphology) and behavioural (sediment position, mobility, living habit, feeding mode, bioturbation type) characteristics of infaunal invertebrates. We believe this list of traits reflects a balanced compromise between the need to include a wider suite of traits as possible whilst acknowledging a serious paucity of basic biological trait information pertaining to benthic invertebrates. The latter issue is aided, to a certain extent, by the recent compilation of biological information for 777 genera sampled across the English sector of the Greater North Sea (North Sea and English Channel) encompassing a number of EUNIS habitats (Figure 3; Anon, 2013; Bolam et al., 2013). Figure 4 reveals that the composition of trait categories varies between EUNIS habitats within the Greater North Sea for a number of traits (Anon, 2013).

This review has highlighted a notable lack of knowledge regarding quantified relationships between biological traits and ecological functioning, an issue which in part will be addressed by BENTHIS. The implication of this is that while the analysis of the large dataset from habitat studies planned under WP3 will permit us to describe trait patterns as a consequence of varying trawling intensities, our capacity to ascertain the functional significance of such patterns will initially be limited to those sites where there has been a comprehensive and integrated programme of benthic measurements describing structure, process and function. These studies are, however, likely to represent a very small subset of those available. In response to this, we propose that survey work being undertaken under the case studies under BENTHIS needs to explicitly incorporate a significant component of observational data regarding sediment functional and state attributes. For example, a link is presently assumed between changes in bioturbation (trait, or a metric such as BPc) with biogeochemical functioning but few studies (Solan et al., 2004; Solan et al., 2012) have linked these changes to a proxy of bioturbation (e.g. mixing depth, redox depth, carbon storage). Indeed, changes in a metric/trait are often assumed to directly deliver a change in functionality but this assumption, the trait combinations underlying them and the relationships between them have rarely been validated with real observations (Figure 1). This tracking of parallel changes in metric/trait and links to observed sediment functions and state will be a priority under BENTHIS. This will result in an improved understanding of the metric/trait and function relationships within various sediment habitats, between them and potential impacts as a result of trawling impact. It should also identify areas where the metrics/traits do not directly drive ecosystem functions and those functions, as a result, which are more resistant to trawling pressure. Therefore, only if the resulting biological trait data are accompanied by relevant sediment functional information can we start improving our capacity to model the relationships between trait patterns and processes.

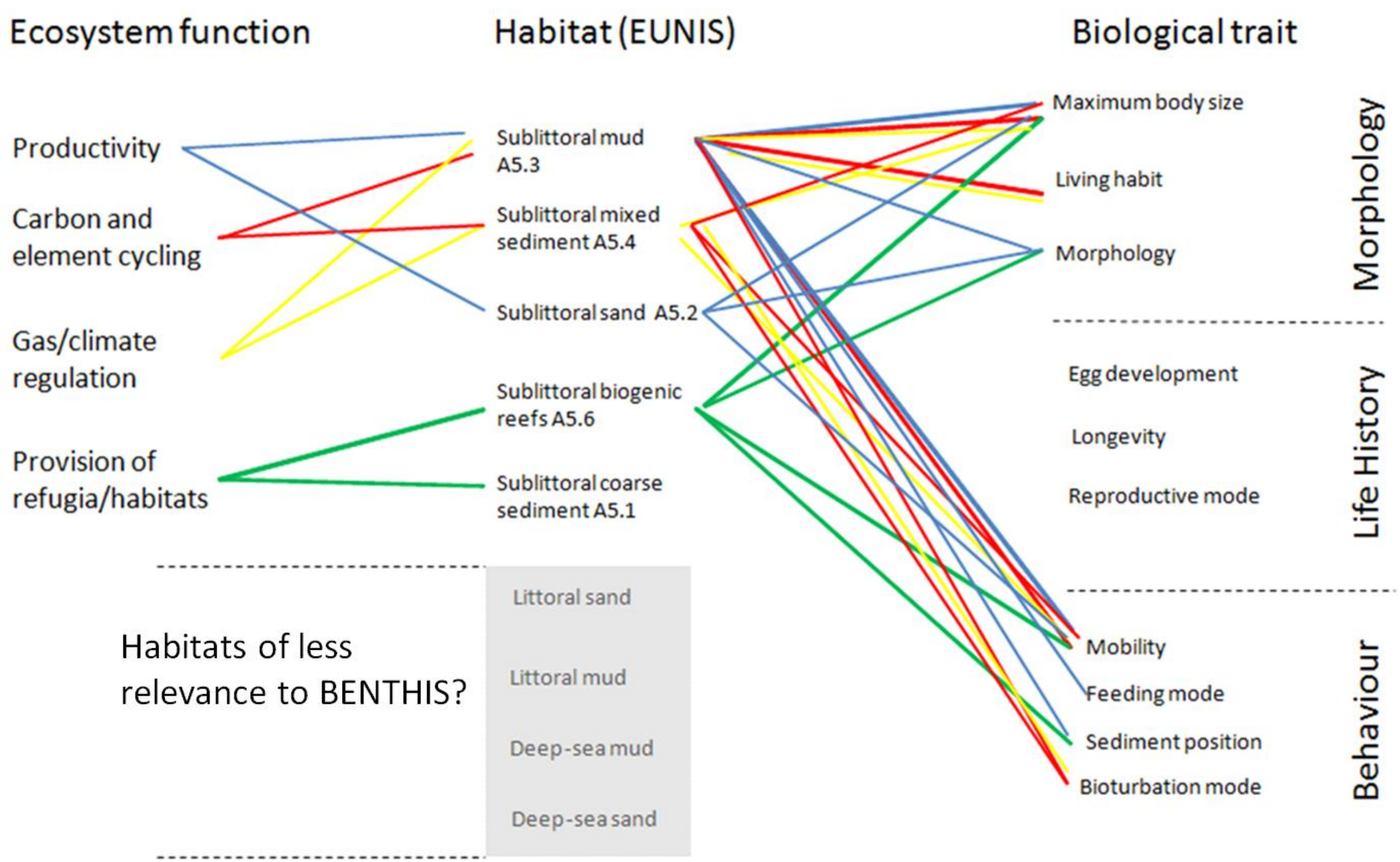
Ecosystem function
Habitat (EUNIS)
Biological trait
Productivity
Carbon and element cycling
Gas/climate regulation
Provision of refugia/habitats
Sublittoral mud A5.3
Sublittoral mixed sediment A5.4
Sublittoral sand A5.2
Sublittoral biogenic reefs A5.6
Sublittoral coarse sediment A5.1
Habitats of less relevance to BENTHIS?
Littoral sand
Littoral mud
Deep-sea mud
Deep-sea sand
Maximum body size
Living habit
Morphology
Morphology
Egg development
Longevity
Reproductive mode
Life History
Mobility
Feeding mode
Sediment position
Bioturbation mode
Behaviour

Figure 2. Schematic illustration of the relationships between traits, EUNIS habitats and important ecosystem functions. The linkages shown on this conceptual figure are not truly representative of our current understanding; this figure serves to indicate that for any EUNIS habitat in European waters, there is likely to be a number of important ecosystem functions and/or processes, these may vary between habitats, and the traits required to describe the ability of the bed assemblages to undertake these are likely to be habitat and function specific. The relative importance of behavioural and morphological traits over life history traits is emphasized in the illustration.
This figure also highlights that some EUNIS habitats (e.g. sublittoral coarse sediments) provide important ecosystem functions, but these may not be greatly mediated by benthic invertebrate traits. For others, the importance of traits may only become relevant under certain conditions. For example, bioturbation (or the traits which affect bioturbation) is important for nutrient cycling and carbon flux in sublittoral mixed sediments when the silt/clay content is more than approximately 5-8% (Parker et al., in prep) but these processes are mediated by physical advective currents in less silty sediments.
Under BENTHIS, we may focus efforts on improving our understanding of the links between traits and functions for habitats which are either spatially dominant in European waters and/or experience the greatest impact, or where data are particularly amenable to acquire. Thus, we need to screen our efforts to ensure that we model the relationships between habitat functioning and trawling impacts for the most pertinent functions and/or habitats.

Table 6. Proposed list of traits (and potential categories) to be included for BTA under WP3.

Trait	Category (example)
Maximum Size	<10mm 10-20mm 21-100mm 101-200mm >201mm
Morphology	Soft Tunic Exoskeleton Crustose Cushion Stalked
Maximum Longevity	<1 year 1-3 years 3-10 years >10 years
Larval Development Location	Pelagic Planktotrophic Pelagic Lecithotrophic Benthic (direct)
Egg Development Location	Asexual / budding Sexual – shed eggs (pelagic) Sexual – shed eggs (benthic) Sexual – brood eggs
Living Habit	Tube-dwelling Burrow-dwelling Free-living Crevice/hole/under stones Epi/endo zoic/phytic Attached to substratum
Sediment Position	Surface Shallow infauna (0-5cm) Mid-depth infauna (5-10cm depth) Deep-infauna (>10cm)
Feeding Mode	Suspension Surface deposit Sub-surface deposit Scavenger / opportunist Predator Parasite
Mobility	Sessile Swim Crawl/creep/climb

	Burrowers
Bioturbation Mode	Diffusive mixing
	Surface deposition
	Upward conveyor
	Downward conveyor
	None

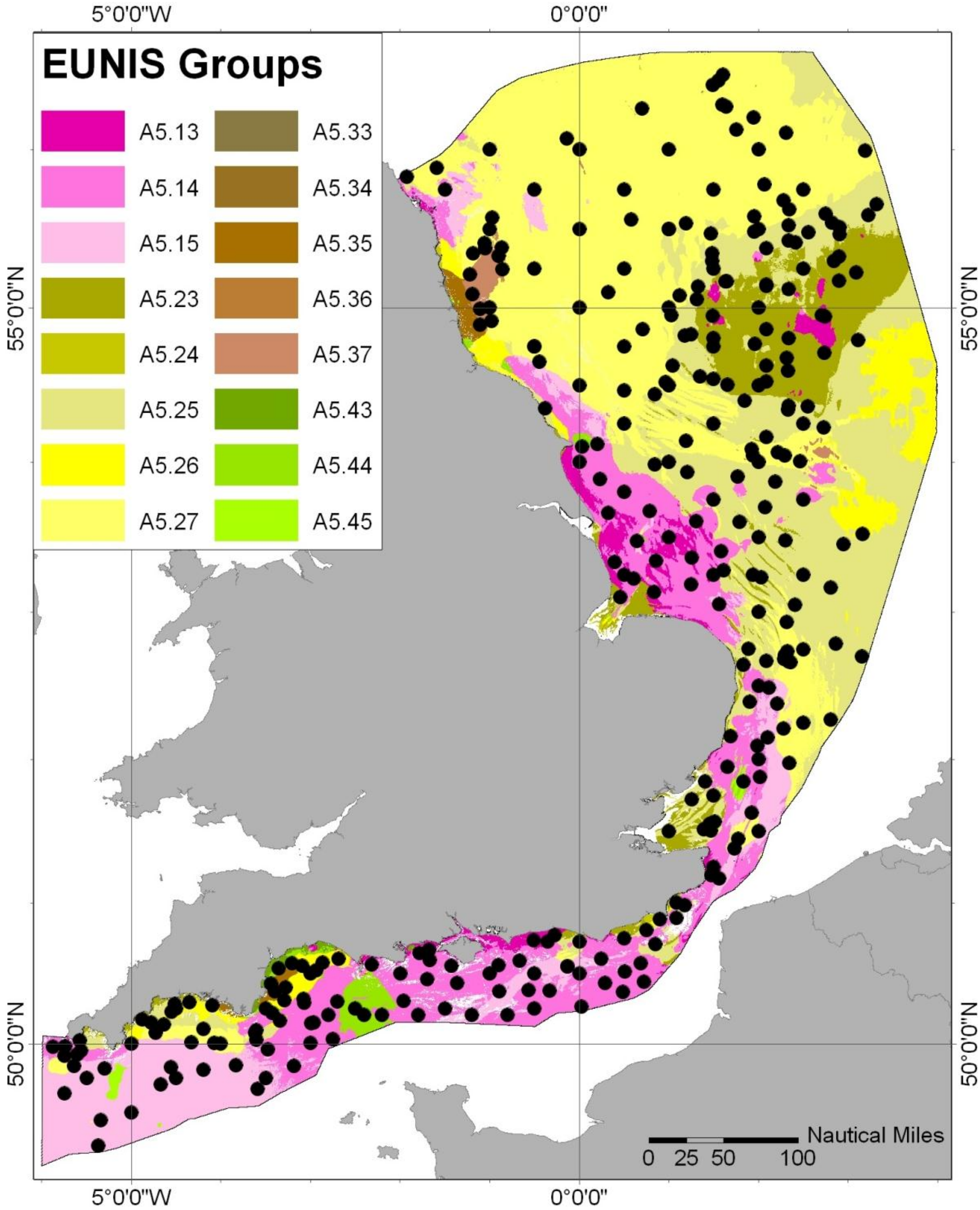

Figure 3. Location of 327 stations for which biological traits information (at the genus level) of the infaunal taxa are available (Anon, 2013).

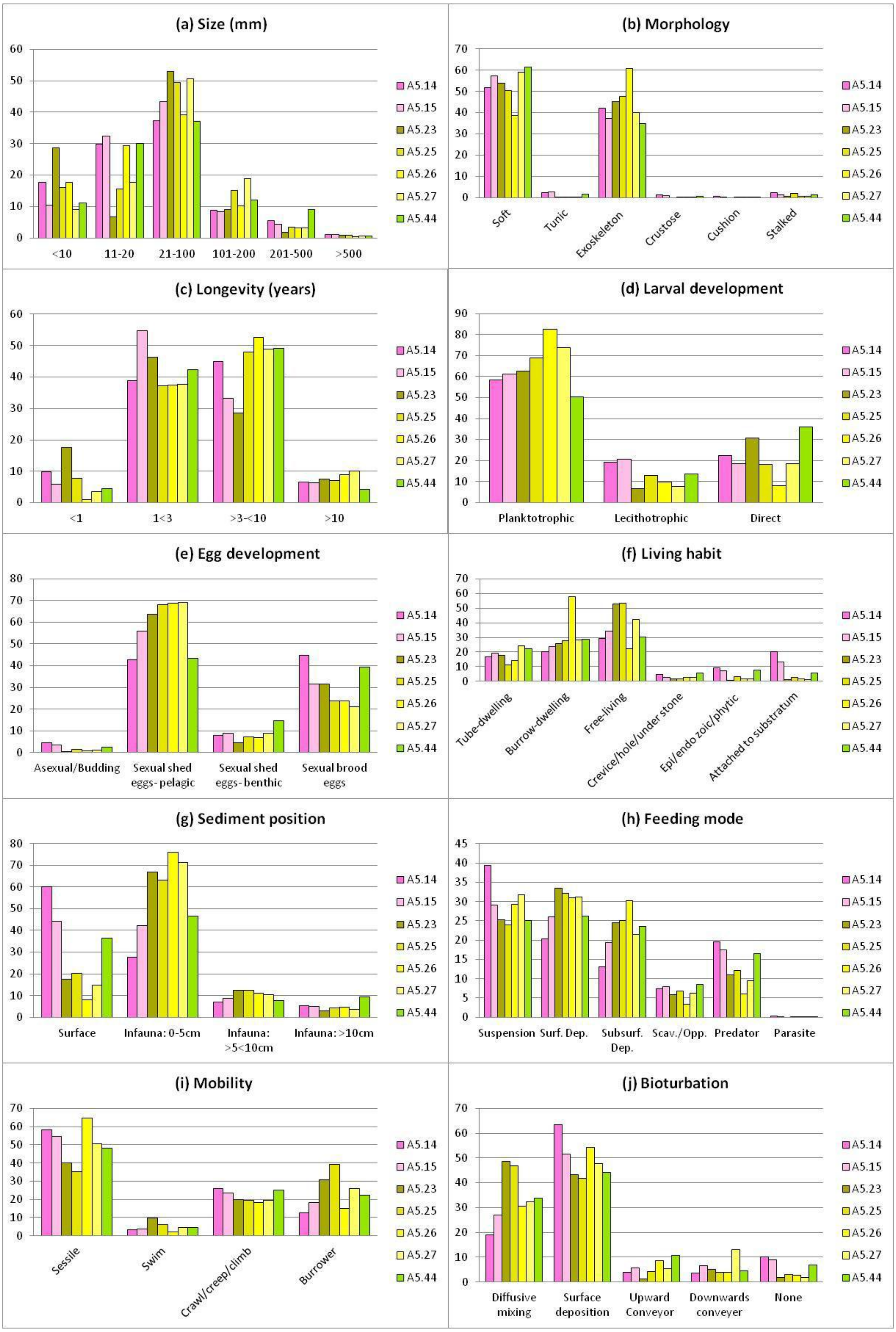

Figure 4. Biological trait composition of invertebrate assemblages of the most common EUNIS habitats in the Greater North Sea (percentage of total number on y-axis). Data are based on fuzzy-coded traits data using transformed abundance data as the enumeration method (Anon, 2013).

6 CONCLUSIONS

This review has highlighted a number of key messages that are germane to BENTHIS and, in particular, are of central importance regarding further work under this project. We regard these as being;

- there is currently a lack of clarity in some of the terminology germane to BTA. Work under the auspices of BENTHIS needs to ensure commonality to minimise the potential for ambiguity during the conduct and interpretation of subsequent all data,
- the distinction between 'response' and 'effect' traits is clearly important and we must ensure that we fully understand this difference when interpreting and making conclusions based on traits data,
- the difference between population (long-term) and individual (short-term) response traits, and how these relate to fishing impacts, deserves spatial attention. While the former refers to resilience (or chronic impacts) the latter relates to population resistance (acute impacts). Importantly, it is likely that the traits responsible for these two vary,
- there is presently a real lack of understanding of cause-and-effect relationships between traits and functioning. Most (if not all) links are presently not quantified and based on theoretical relevance, and
- we need to ensure that we focus on the appropriate traits for any given set of analyses. Fundamentally, we need to be clear on what function we deem important for a given habitat and ensure that the most appropriate functional traits are used. Acquisition of new observational data, to allow our understanding of the latter to be improved, should be a priority under BENTHIS.

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Deliverable 1.1b

Benthic impact from the perspective of the fisheries

Due date of deliverable: month 13 (Oct 2013)
Actual submission date: month 15 (Dec 2013)

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SEVENTH FRAMEWORK PROGRAMME

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Summary

The fisheries of the BENTHIS case study areas represent a variety of fleet segments which have very different effects on the benthic ecosystem depending on fishing methods and target species. In the following, effort and landings of the commercial fisheries of the case study areas are reviewed and summarized with starting point in the official effort and landing statistics collected by the EU Scientific, Technical and Economic Committee for Fisheries (STECF) supplemented with information of Turkish effort and Landings data provided by CFRI (the Central Fisheries Research Institute in Turkey). Following a general regional based description of the fisheries, a review and classification of impact mechanisms allows for a grouping of vessels and gear types according to expected level of seabed impact. The relative importance of these groups, in terms of contributions to total effort and landings of the case study fleets, is summarized and forms the basis for a prioritisation of the gear types and impact mechanisms that will be the focus of the fishing pressure mapping in WP2.

The benthic impacts of demersal otter trawlers, demersal seines, beam trawlers and dredges were identified as the most significant, and the major effects and mechanisms of impact were assessed to be: 1) Mortality of benthic organism from direct gear- sea bed gear contact during fishing, 2) food subsidies from discards and gear track mortality, 3) habitat alterations through disturbance of sediments and biogenic habitats, and 4) geo-chemical processes from disturbance of sediment. Although food subsidies from discards are acknowledged to be an important benthic impact mechanism, the task of mapping discards was not assessed to be feasible within BENTHIS WP2 due to the poor availability (lack of coverage) of discard data from the European fisheries (the effects of discards will, however, be dealt with in WP4). Therefore the mapping efforts in WP2 will prioritize the mechanisms of direct physical seabed impacts of demersal fishing activities.

Following this prioritisation, the four gear types are described and broken down into individual components. The gear-seabed contact by component is conceptualised in “gear footprints” of each gear. These footprints form the basis of an industry questionnaire designed to deliver information of the dimensions of the individual gear components for those gears currently in use in European and Turkish fisheries. The industry information is combined with VMS and logbook data of fishing effort and activity in WP2 in BENTHIS to provide fine-scale mapping of fishing pressure from physical gear-seabed interactions for each case study region. The questionnaires are appended to this report, and the further implementation of questionnaire data and the developed BENTHIS WP2 methodology for mapping of fishing pressure on the benthic habitats is described in detail in Deliverable 2.1.

Table of contents

1. Introduction and regional fisheries description

Commercial fisheries represent a variety of vessels and gears, which have very different levels of contact with the sea bed and impact the ecosystem through a number of mechanisms. In BENTHIS the objective is to go into detail with those gears/fisheries that have the largest impact on the benthic ecosystem. I.e. the gear types/fisheries that have a high level of sea bed impact and at the same time contributes significantly to the total fishing effort in the case study regions. These are the fisheries that should be in focus of the subsequent BENTHIS work, and the starting point of this prioritisation has been the official effort and landing statistics collected by the EU Scientific, Technical and Economic Committee for Fisheries (STECF). These official statistics, as reported by the member states, are used by STECF to give an annual report on the EU fishing fleets. Information from the STECF 2012 annual report has been used together with Turkish effort and landings data provided from CFRI (the Central Fisheries Research Institute in Turkey), to give a general regional based description of the fisheries in terms of days at sea, landed weight and landed value by country gear type and gear size. Following this general description of the fisheries, a review and classification of impact mechanisms allows for a grouping of vessels and gear types according to expected level of seabed impact. The relative importance of these groups, in terms of contributions to total effort and landings, is summarized and forms the basis for a prioritisation of the mechanisms that will be the focus of the fishing pressure mapping in WP2.

In the STECF statistics the following abbreviations are used for the different *mobile gear types*: Beam trawl (TBB); Demersal trawl and Demersal seiner (DTS); Pelagic trawl and seiner (PTS); Dredges (DRB); Polyvalent mobile gears (MGP); Other mobile gears (MGO); Purse seiners (PS) and Pelagic trawlers (TM).

The following abbreviations are used for *passive gear types*: passive gears for vessels smaller than 12 meters (PG); Gears using hooks (HOK); Drift nets and fixed nets (DFN); Pots and traps (FPO); polyvalent passive gears (PGP); other passive gears (PGO)

The following abbreviations are used for vessels using *both passive and active gears*: Combining mobile and passive gear (PMP).

The Baltic Sea

According to the 2012 Annual Economic Report on the EU Fishing Fleet (STECF-12-10) the Baltic Sea is covered by ICES areas IIIb, IIIc and IIId, which is slightly different from the BENTHIS regional case study definition, where also IIIa-south (Kattegat) is included. Eight Member States were involved in the Baltic Sea fisheries in 2011. These countries were Denmark, Sweden, Finland, Estonia, Latvia, Lithuania, Poland and Germany. The total days at sea amounted 421.4 thousand. The weight and value of landings amounted to 569 thousand tonnes and €230 million, respectively. Finland, Germany and Poland accounted for around 67.5% of the total days at sea (mostly generated by small scale fisheries). In terms of landed weight, Finland (120 thousand tonnes), Poland (111 thousand tonnes) and Sweden (108 thousand tonnes) were the leading countries followed by Denmark, Estonia and Latvia. The charts in Figure 1.1 show the proportion of days at sea, landings weight and value attributable to each Baltic Sea Member State, gear type and vessel size groups in 2011.

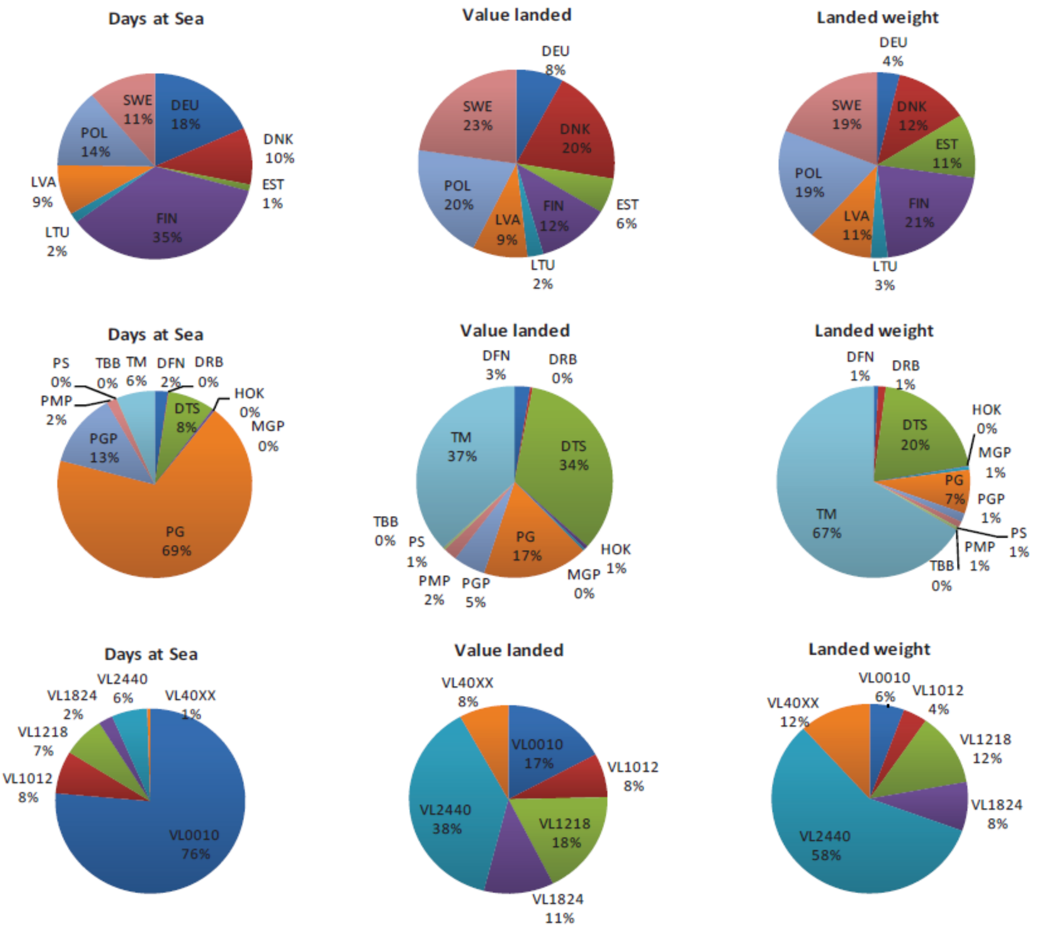
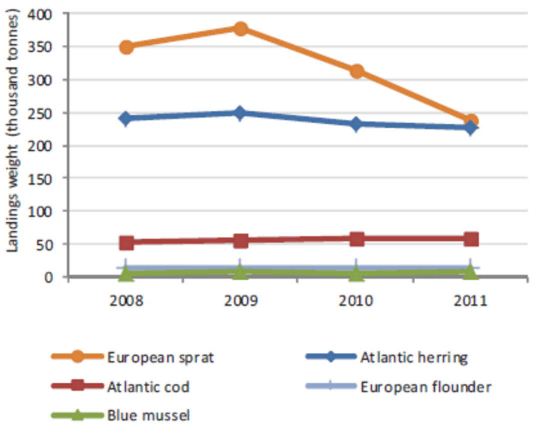


Figure 1.1. EU Baltic Sea fleet effort and landings by member state (top row), gear type (middle row) and length class (bottom row) in 2011. Figure from page 45 in the 2012 annual Economic Report on the EU Fishing Fleet (STECF-12-10).



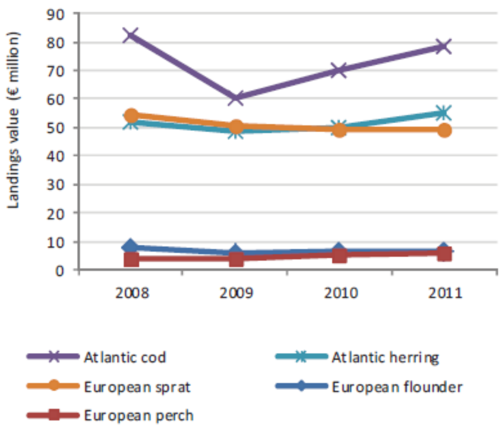


Figure 1.2. EU Baltic Sea fleet landings weight and value by species from 2008 – 2011. Figure from page 46 in the 2012 annual Economic Report on the EU Fishing Fleet (STECF-12-10).

Measured in days at sea, the Baltic demersal fisheries are dominated by passive gears fished from small vessels targeting mainly cod, but when measured in catches and values the demersal fishery is dominated by larger trawlers catching also cod (Figure 1.1 and 1.2.) In the Kattegat otter trawlers targeting Nephrops in soft sediment habitats is the dominating fleet segment. These otter trawl fisheries both impact the seabed, as well as produce substantial amounts of discards. In addition to cod the gill net fisheries target a variety of demersal fish such as plaice, flounder, turbot and brill, but are supposed to have minor impacts on the benthos. In coastal waters bivalves are exploited using shellfish dredges. The Western Baltic Sea including Kattegat (WBS) offers a unique opportunity to analyse the benthic effects of fishing thanks to the closure of Øresund to towed gears since the 1920s, the introduction of the Kattegat MPA in 2008 (including cod closure) and the WBS Natura-2000 areas. Furthermore an extensive benthic national monitoring and data collection effort has taken place in the area over a number of years, which can be used to investigate spatial and temporal differences in the development of benthic communities in (chronically) trawled/dredged/seined and non-trawled/dredged/seined areas

The North Sea

In the 2012 Annual Economic Report on the EU Fishing Fleet (STECF-12-10) the North Sea catches of member states are treated jointly with member state effort and landings in the Eastern Artic area (ICES areas I and II), but the latter area contributes relatively little to the total effort and landing statistics. Note that for this analysis there were no effort, landings volume or value data available for Spain. Based on the data available, a total of 22,239 vessels indicated landings from the North Sea and Eastern Arctic area in 2010. The majority of these vessels either wholly or partially operated in other areas such as the Baltic Sea and North Atlantic. In 2010 the total effort (days at sea) spent by EU vessels in the North Sea and Eastern Arctic was an estimated 494 thousand days. In the demersal fishery with active gears the otter trawler fleet had the highest share of total days (30%), followed by the beam trawlers (18%) and the Dredges (5%) (Figure 1.3). The total volume landed by the EU fleet in the North Sea and Eastern Arctic in 2010 was 1,396 million tonnes of seafood. The demersal otter trawler fleet had the highest share of the total volume (62%), due to large yearly catches of sandeels and sprat with this gear type, followed by the pelagic trawler fleet (12%) and then the TBB fleet (8%). The total value of landings by the EU fleet in the North Sea and Eastern Arctic in 2010 was €1,462 million. The UK fleet had the highest share of the total value (29%), followed by the Danish fleet (23%) and then the Dutch fleet (18%) (Figure 1.3)

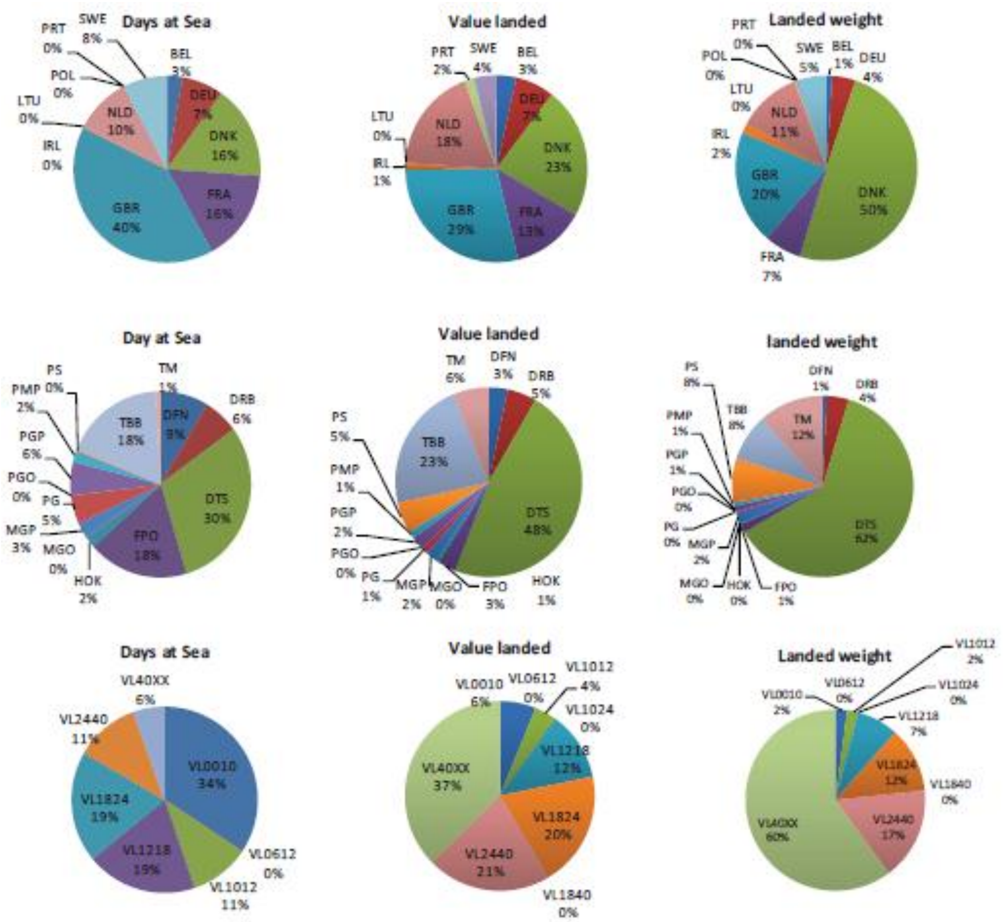


Figure 1.3. EU North Sea and Eastern Artic (ICES area I and II) fleet effort and landings by member state (top row), gear type (middle row) and length class (bottom row) in 2011. Figure from page 69 in the 2012 annual Economic Report on the EU Fishing Fleet (STECF-12-10).

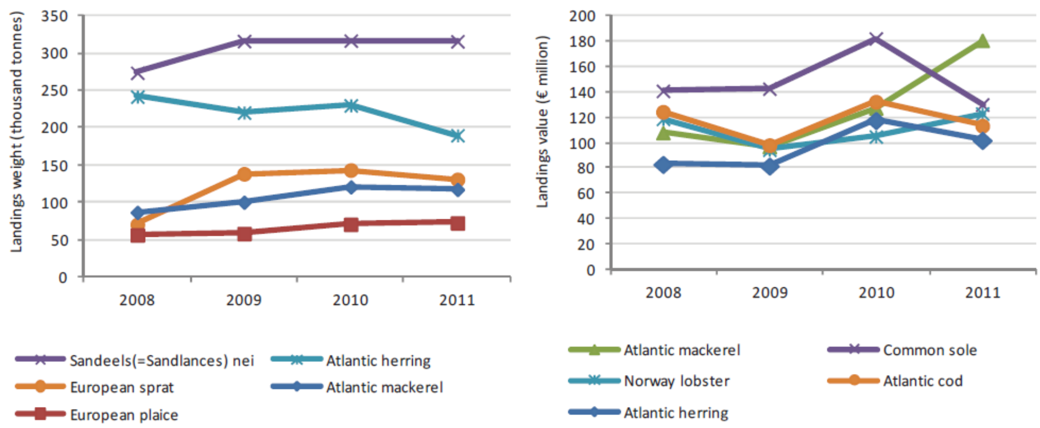


Figure 1.4. EU North Sea and Eastern Artic (ICES area I and II) landings weight and value by species from 2008 – 2011. Figure page 70 in the 2012 annual Economic Report on the EU Fishing Fleet (STECF-12-10).

Both in terms of effort days, landing weights and landing values the North Sea demersal fisheries are dominated by otter trawlers targeting roundfish, flatfish and crustaceans and Beam trawls targeting flatfish (Figure 1.3 and 1.4). Both the ottertrawls and the flatfish beam trawl, deployed with tickler chains that penetrate into the sea bed and a mesh size of 80 mm, produce considerable amounts of fish and invertebrate bycatch. In the coastal waters there is a fishery for brown shrimps using small meshed gear that produces considerable amounts of discards.

The Western Waters

In the 2012 Annual Economic Report on the EU Fishing Fleet (STECF-12-10) the Western Waters fisheries statistics of member states are treated jointly with member states effort and landings in some additional parts of the North Atlantic (ICES areas V, X and XII), but the latter areas only contribute relatively little to the combined effort and landings statistics. Fisheries in the Western Waters are undertaken by vessels from 11 different EU countries, namely: Belgium, Denmark, France, Germany, Ireland, Lithuania, Poland, Portugal, Spain, The Netherlands and United Kingdom. For the 2012 report data on effort, landings volume and value by species were not available for Spain. Therefore, the following overview does not include Spanish data.

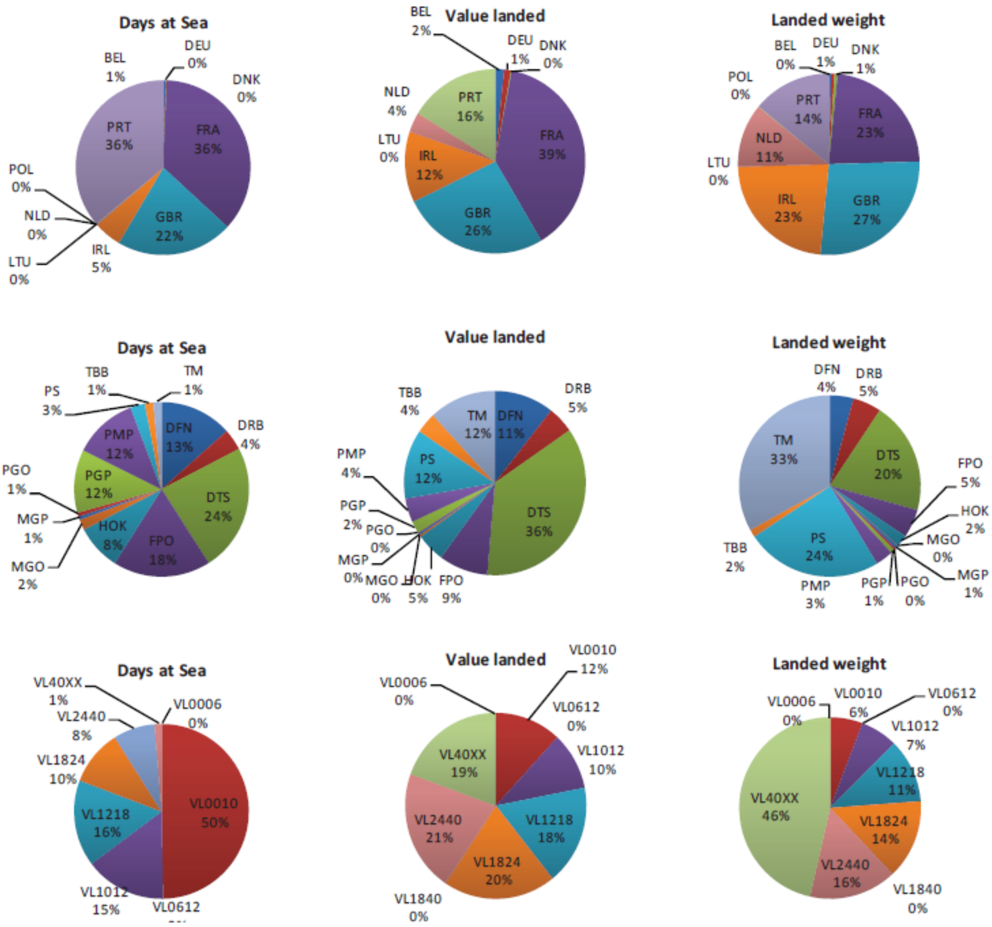


Figure 1.5. EU Western Waters and North Atlantic (ICES areas V, X and XII) fleet effort and landings by member state (top row), gear type (middle row) and length class (bottom row) in 2011. Figure from page 69 in the 2012 annual Economic Report on the EU Fishing Fleet (STECF-12-10).

More than 10 million days at sea (DAS) were recorded by the EU fleets fishing in the North Atlantic in 2010, with France (36%), Portugal (36%), UK (22%) and Ireland (5%) being the major contributors (Figure 2.5). Almost 1,094 million tonnes of seafood were landed by the EU fleet operating in the Western Waters and ICES areas V, X, and XII in 2010, with demersal trawls (20%) and dredges (5%) being the major demersal contributors. Excluding data on the Spanish fleet, the remaining EU fleet operating in the North Atlantic generated landings valued at more than €1,480 million in 2010. In terms of volume landed, the main demersal species are of minor importance, but in terms of landing value Norway lobster (€135 million), common sole (€81 million), monkfish (€67 million) and Great Atlantic scallop (€63 million) are major contributors to the total (Figure 1.5). In the western waters a broad variety of fishing techniques is being used. Important fisheries impacting the benthic ecosystem are the scallop fisheries using dredges and the otter trawl fisheries for a wide variety of demersal species. Fisheries impact will be particularly strong in biogenic habitats such as cold water coral reefs. The fisheries using static gear, pots or traps are expected to have less impact.

The Mediterranean

EU Member States fishing in Mediterranean waters include Spain, France, Italy, Slovenia, Greece, Malta, Cyprus and Portugal. Bulgaria and Romania fish exclusively in the Black sea and compared to the Mediterranean effort and landings values are marginal (< 1%) and the following EU statistics for both areas combined are almost exclusively driven by the Mediterranean fishery. In terms of data availability, Greece did not submit any data. Spain did not submit any data on volume and value of landings by species, fishing effort or capacity. Slovenia did not submit data on effort and landings for 2008 and 2009 for the Mediterranean area. For Portugal, only data on landings (volume and value) and effort for 2010 (and very few data for 2008) has been submitted while information on the fleet consistency is completely missing. As a result of missing Greek and Spanish data (known to be major Mediterranean players), Italian production appears to represent the major part of the totals (see following graphs). A fully comprehensive and realistic analysis could therefore not be carried out. Based on the submitted data, the European fleet fishing in the Mediterranean and Black Sea consisted of around 21,179 vessels, with a total gross tonnage (GT) of 228 thousand tonnes and total kilowatts (kW) of 1.43 million in 2010. The Italian fleet accounted for around 71% of the total number of vessels followed, at a very long distance, by the Bulgarian fleet (13%) (Figure 2.6).

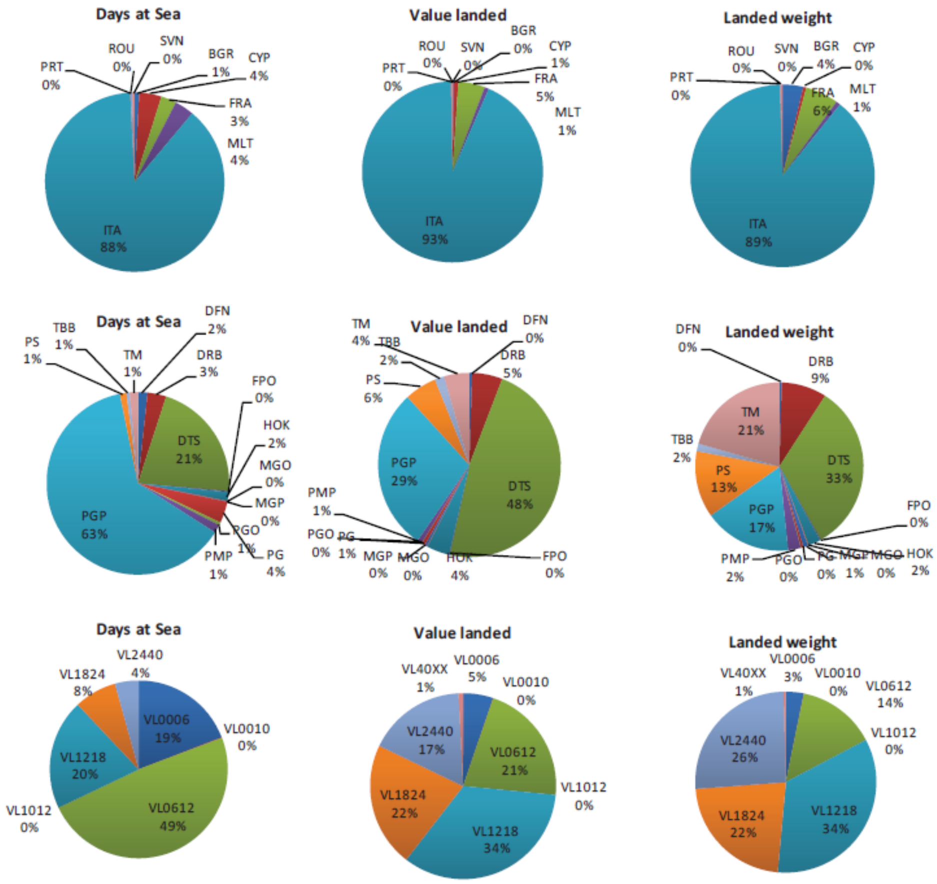


Figure 1.6. EU Mediterranean and Black Sea fleet effort and landings by member state (top row), gear type (middle row) and length class (bottom row) in 2011. Figure from page 52 in the 2012 annual Economic Report on the EU Fishing Fleet (STECF-12-10).

The EU Mediterranean and Black Sea fleet (with the exception of Spain and Greece) spent a total of around 2 million days at sea in 2010, and an average of 89 days per vessel. Of the countries who submitted data, the Italian fleet accounted for 88% of the total number of days, followed, at a distance, by the Cypriot and Maltese fleets (both 4% of the total). Based on the data submitted, the total volume and value of landings achieved by the member states fleet in 2010 (excluding Greece and Spain) were 1,184 thousand tonnes and €251 million respectively. It should again be outlined that the lack of Spanish and Greek data does not allow for a very realistic analysis of the member state Mediterranean and Black Sea fishery fleet production. The passive gears are the most important gears in terms of effort, accounting for 63% of the total and followed by the demersal trawlers (21%). Demersal trawlers are, instead, the most important in terms of both weight and value of landings (33% and 48%, respectively) (Figure 1.6).

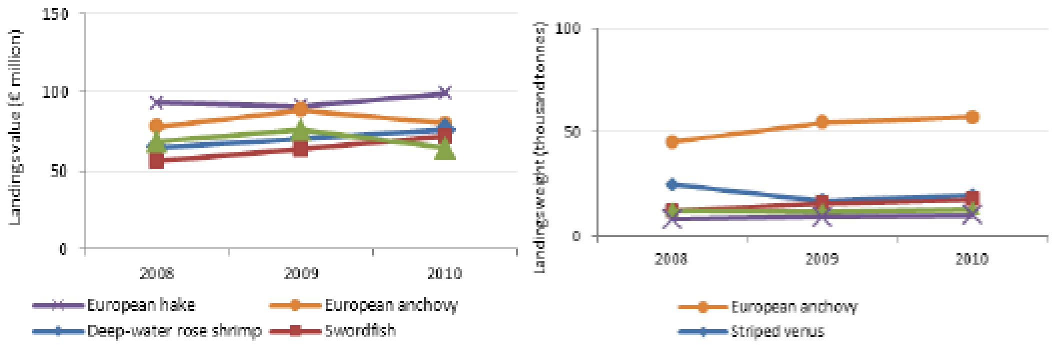


Figure 1.7. EU Mediterranean and Black Sea landings weight and value by species from 2008 – 2011. Figure from page 53 in the 2012 annual Economic Report on the EU Fishing Fleet (STECF-12-10).

Excluding data on the Greek and Spanish fleet, the 5 most important species landed in terms of volume in 2010 were European anchovy, sardine (pilchards), deep water rose shrimp, clams (striped venus) and European hake (Figure 1.7). In 2010 the total volume of clams landed was around 19 thousand tonnes (8% of total landings). This species is mainly landed in the Adriatic Sea by Italian dredgers. Sardines (European pilchards) were the third most important species in terms of volume landed in 2010, amounting to 17.7 thousand tonnes (7% of total landings). Excluding data on the Greek and Spanish fleets, the five most important species in terms of value were hake, deep water rose shrimp, cuttlefish, anchovy, and swordfish. In 2010 the value of hake landed was the highest of all species, amounting to €99 million, 8% of the total value of landings in 2010.The second most important species in terms of value is anchovy, which amounted to €79 million (7% of the total value) in 2010. Deep water rose shrimp were the third most important species at €75 million (6% of the total value). None of these species account for more than 8% of the total value of landings, highlighting the fact that the Mediterranean and Black Sea fisheries are highly diversified and not overly dependent on any one particular species at the regional level.

In the Mediterranean fleet characteristics are also very varied with multiple gear types and a wide range of vessel sizes fishing a variety of habitats such as sea grass beds and coral reefs. Discards are characterised by extremely high species diversity (there may be ~100 species in a bottom otter trawl and of these ~40 retained) with a high percentage of non-commercial catch (commercial portion of catch may range from 30-80%) and high variability in total discard rate due to seasonality. Endangered species are frequently caught and benthic flora is often hauled up with catch, some of which is from sensitive benthic. Due to the effort based management regime in force in the Mediterranean, with exception of blue fin tuna, no over-quota discarding occurs. Catches are discarded primarily because of low commercial value of the species concerned. High-grading of small fish is a recent occurrence as traditionally smaller fish were eaten, but larger sized fish now fetch a higher market price, resulting in a high grading incentive. Bottom trawling fleets predominate in many fisheries and are responsible for a high share of total catches and, in many cases, yielding the highest earnings among all the fishing sub-sectors (Luchetti and Sala, 2009). These bottom trawl fleets are rather unselective.

The Black Sea

In the Black Sea the fishing fleets are dominated by relatively small vessels mainly operating in coastal waters. In the northern waters along the coasts of Romania and Bulgaria, bottom trawling is forbidden, and demersal fish resources such as turbot are being exploited by gill net fishers. Trawl fisheries are the main fishing method in the southern Black Sea and the main effort in this area comes from the Turkish otter trawler and beam trawl fleet. The Black Sea ecosystem has been heavily impacted by anthropogenic factors such as eutrophication and hypoxia that degraded coastal ecosystems and had negative impacts on open-sea populations (Daskalov, 2003). Recently the ecosystem was impacted by the spread of the invasive predatory mollusc, the rapa whelk (*Rapana venosa*). The species is a major predator of benthic invertebrates and has impacted the benthic community and food web (Daskalov et al., 2010), in particular the blue mussel (*Mytilus galloprovincialis*) and the striped venus clam (*Chamelea gallina*). Due to the increase in abundance, rapa whelks have gained commercial important since the 1980s in the eastern Black Sea (Samsun shelf area: Kızılırmak-Yeşilırmak). Rapa whelks are exploited with beam trawls (algarnas) that have a negative impact on benthic habitats and benthic ecosystem. The fishery is also characterised by an important bycatch of juvenile fish species such as *Psetta maxima*, *Solea nasuta*, *Arnoglossus laterna*, *Pleuronectes flesus*. The adverse impact of bottom trawling on commercial and non-commercial benthic/demersal fauna is a major concern in Turkey and has raised many speculations often without any firm scientific basis. Along the southern coasts there are two Fishery Restricted Areas: (i) Kizilirmak-Yesilirmak Shelf Area (KYSA) restricted for trawling between May and October; (ii) Melet River Shelf Area (MRSA) is restricted for trawling throughout all year.

2. Effects and mechanisms of benthic impacts from fishing

Fishing can affect benthic ecosystems in many ways, by modifying the sedimentary habitats, increasing or decreasing nutrient fluxes, killing benthic invertebrates and through the redirection of energy from discards to the seabed. These changes in turn lead to changes in the functioning of the benthic ecosystem and the availability of food for commercial fish species. The different pathways by which fishing may impact the benthic ecosystem is summarised in Table 3.1 distinguishing between the mechanism and the ecological effect.

Table 3.1. BENTHIS Framework for distinguishing between the impact mechanisms and effects of demersal fisheries.

Impact	Effect	Mechanism
Direct	Mortality	Gear contact
	Food subsidies	Discarding and trawl track mortality
	Habitat alterations	Disturbance of sediment
	Geo-chemical processes	Disturbance of sediment
Indirect	Changes in predator-prey interactions, including feeding of commercial fish species	Changes in species or size composition
	Changes in competition for food or space	Changes in species or size composition
	Changes in bioturbation, nutrient fluxes, bentho-pelagic coupling	Changes in species or size composition
Chronic effect	Changes in habitat	Disturbance of sediment or biogenic organisms

Commercial fisheries utilise a wide variety of fishing gears ranging from passive gears such as pots and trammel nets, to bottom trawl that are towed over the sea bed. Passive gears may damage benthos, for instance when a long line deployed on a reef may tear off branches of the reef, but it is generally assumed that bottom trawls will have a much larger impact on benthic ecosystems than passive gear because a) they cause higher mortality rates of benthos and higher habitat modification rates and b) because the footprint of towed gears will be many orders of magnitudes larger than those of passive gears (Jennings and Kaiser 1998).

The impact of a bottom trawl will depend on the size of the gear components, their penetration depth as well as the speed and distance over which the gear is towed. For example, in an otter trawl, the sweeps only touch the surface of the sea bed, whereas the otter boards dig a furrow into the sediment. Many modern trawl doors are the result of initial designs, improved through practical trials until they work well enough to be used commercially. Modern door designs are more advanced and sophisticated as a result of increasing fuel costs and the necessity to minimize impact on the environment. Meeting these challenges has led to significant improvements in the way new otterboards are designed and tested (Sala et al., 2009). In a beam trawl the tickler chains that are mounted between the shoes penetrate into the sediment and disturb the upper layer as well the benthic organisms that live in the sediment. The penetration depth depends on the number of tickler chains and depends on the sediment type (Ivanovic et al. 2011).

The disturbance of the sediment may cause changes in the geo-chemical processes in the seafloor (Duplisea et al. 2001). Resuspension of organic material (Durrieu De Madron et al. 2005; Pilskaln et al. 1998) may affect the nutrient and carbon fluxes from the sediment, and consequently affect primary production and eutrophication. O'Neill & Summerbell (2011) have demonstrated that, for a given sediment type, there is a relationship between the hydrodynamic drag of the gear element and the mass of sediment entrained behind it (O'Neill et al. 2013b).

The direct mortality imposed to organisms that are hit by a fishing gear has been estimated in field experiments. Mortalities vary between species, fishing gears and sediment type and are on avergaearound 50% (but range between 0% and 95%) for a single passage of a trawl, with the highest mortality rates observed on biogenic reefs and muddy sand.(Kaiser et al. 2006). Beam trawls and scallop dredges on average cause higher mortality rates than an otter trawl. Biogenic habitat building species were more vulnerable than infaunal invertebrates. However, for many benthic organisms and bottom trawl gears, no direct mortality estimates are available and we are currently lacking the ability to make predictions for species that fall outside current studies and regions for which no research exists (Kaiser et al. 2006).

Fisheries generate carrion as a result of material discarded at sea from fishing boats (Fonds and Groenewold, 2000). It is unclear whether the increases in the population sizes in scavenging seabirds that have been partially attributed to discarding practices might be mirrored in changes in the populations of benthic scavengers. As discarding has been on-going for decades benthic ecosystems that are reliant on discards as a food source may have developed (Kaiser and Hiddink 2007). As a discarding ban will reduce the energy flow to the seabed, it is necessary to understand what changes this may cause to benthic ecosystems, and to do this it is necessary to quantify to flow of energy from fisheries to the seabed, and to assess what effect this has on seabed ecosystems.

The modification of the seabed habitat, mortality of invertebrates and flow of discards to the seabed has resulted in long-term changes to the functioning of benthic ecosystems. Fishing will result in changes in the species and size composition of the benthic community due to differential mortality across species and size classes, and due to the food subsidies provided by the trawl track mortality and the discards and offal that sink to the sea bed. Community changes will influence the ecosystem functioning affecting geo-chemical fluxes as well as trophic interactions (Dayton et al. 1995; Kaiser et al. 2000; Tillin et al. 2006). Few studies have been carried out to evaluate how the effects of large scale commercial fisheries results in geo-chemical and community changes and how these translate into effects on measures of ecosystem functioning such as bioturbation, nutrient fluxes and bentho-pelagic coupling. Furthermore, we are currently lacking the ability to evaluate the effect of large-scale chronic trawling on the food availability for benthivorous fish such as plaice, cod and haddock. Such reductions in food availability may reduce secondary production in fisheries (Hiddink et al. 2011).

Little is known on how fishing indirectly affects bioturbation, nutrients fluxes and bentho-pelagic coupling through changes in benthic community composition. Trawling has been shown to reduce the abundance of bioturbating species and this is likely to affect nutrient fluxes (Widdicombe et al. 2004). Trimmer et al (2005) found that biogeochemical processes in the upper layers of sediment, both oxic and suboxic, seemed unaffected by trawling in the long-term. In deeper anoxic sediment, however, mineralisation via sulphate reduction may be stimulated by the extra disturbance, at least in areas with little tidal energy.

Many important commercial fishes, such as flatfish and gadoids, feed on benthic invertebrates for part of or all their life-history. Bottom trawling thus not only reduces the population size of fish through direct removal, but also reduces the abundance of their prey (Auster and Langton 1999). Recent studies have shown that this may results in reduction of the growth of flatfish species (Shephard et al. 2010), and could therefore reduce the sustainability of fisheries. These results contrast with the hypothesis that bottom trawling may promote the typical small benthic organisms on which small-mouthed flatfish species like sole and plaice feed (Hiddink et al. 2008). These conflicting results may be due to the difference in bottom-up and top-down regulated ecosystems (van Denderen et al., 2013).

3. Prioritisation of fisheries in relation to benthic impact

With reference to the established BENTHIS framework (Table. 2.1) for distinguishing between the mechanism and the ecological effect of the benthic impacts from commercial fishing, the benthic impacts of demersal otter trawlers, demersal seines, beam trawlers and dredges were a-priori identified as potentially high impact gears, and the major effects and mechanisms were assessed to be: 1) Mortality of benthic organism from direct gear- sea bed gear contact during fishing, 2) food subsidies from discards and gear track mortality, 3) habitat alterations through disturbance of sediments, and 4) geo-chemical processes from disturbance of sediment. Food subsidies from discards were acknowledged to be an additional important benthic impact mechanism of fisheries, but the task of mapping discards was not assessed to be feasible within BENTHIS WP2 due to the poor availability (lack of coverage) of discard data from the fisheries. Therefore the mapping efforts in WP2 will prioritize the mechanisms of direct physical seabed impacts of demersal fishing activities.

When considering the physical gear-seabed interaction as the primary impact mechanism, the contribution to the overall benthic impact from pelagic fisheries is assessed to be marginal.

Passive gears also have physical interactions with the seabed, for instance when a gill net is set and hauled, and also during soaking time, the anchors and the ground rope of bottom set gill nets will impact a small area of the sea bed. It is, however, generally assumed that bottom trawls will have a much larger impact on benthic ecosystems than passive gear because a) they cause higher benthos mortality and habitat modification rates and b) because the footprint of towed gears is many orders of magnitudes larger than those of passive gears (Jennings & Kaiser 1998).

The total fishing effort according to the STECF statistics was aggregated into the below six vessel groups according to expected level of benthic impact and compared in terms of relative contributions to total yearly days of fishing and landings (Figure 3.1).The other group comprises mainly polyvalent mobile gears (e.g. combined pelagic trawlers and purse seiners or combined otter trawlers and gill netters).

1. Demersal trawl and seines (high level of gear-seabed contact)
2. Dredges (high level of gear-seabed contact)
3. Beam trawls (high level of gear-seabed contact)
4. Pelagic fisheries (insignificant gear-seabed contact)
5. Passive gears (low level of gear-seabed contact)
6. Other (low level of gear-seabed contact)

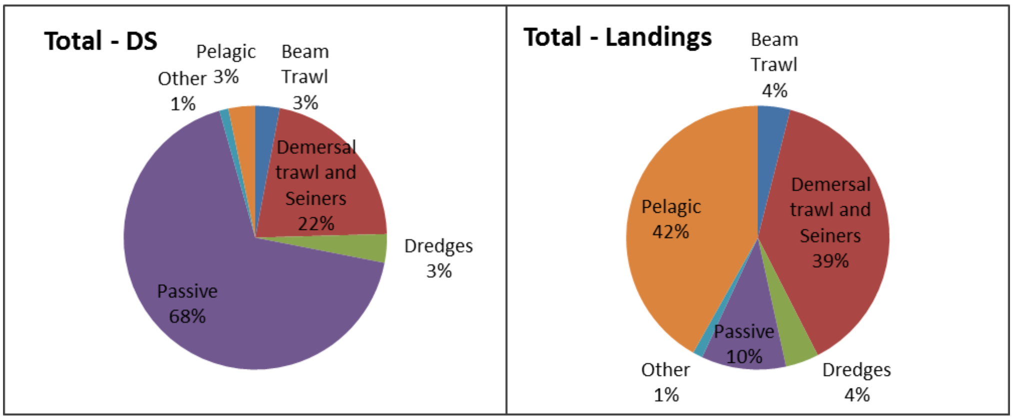


Figure 3.1. Proportion of total yearly days at sea (DS, left panel) and landing weight (Landings, right) of member states in 2010 split on vessel groups according to benthic impact level (data from STECF-12-10).

In terms of effort (days at sea) the 2010 fishery with passive gears by the EU member state vessels is almost three times as large as the effort with the three high level benthic impact gears defined above (Figure 3.1 left). This picture is, however, completely reversed, when the gear groups are compared in terms of total landings, where the demersal trawlers and seiners, the beam trawlers, and the dredgers land almost five times as many fish as the passive gear group (Figure 3.1, right). The other gear group has less than 1% of both the fishing days and the landings, whereas the pelagic fleet has approx. 3% of the effort, but 42% of the landings.

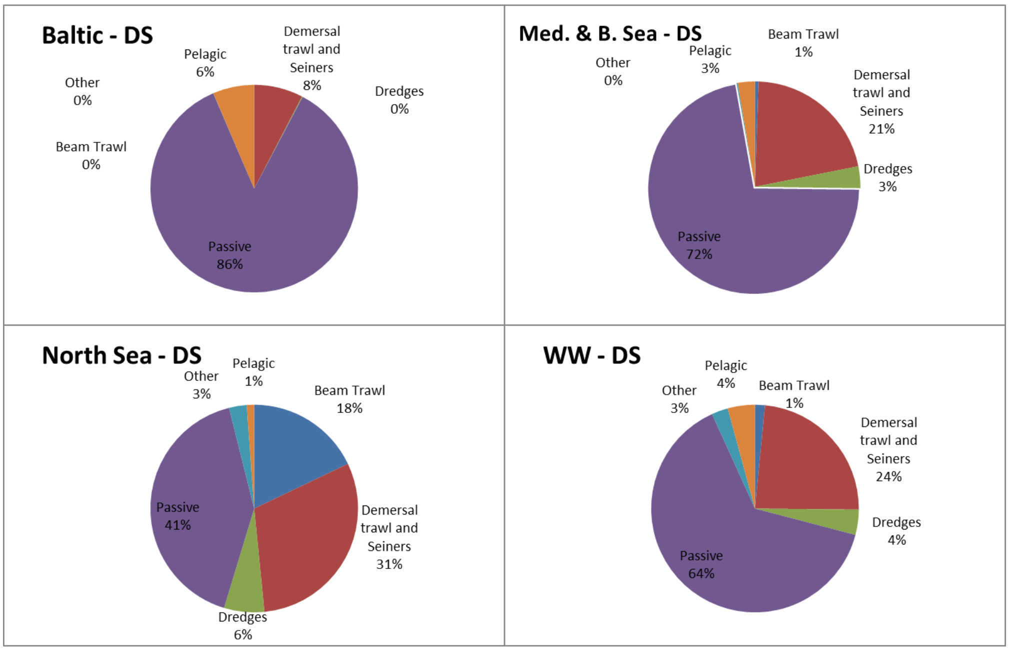


Figure 3.2. The proportion of total yearly days at sea (DS) of member states in 2010 split on regions and vessel groups according to expected benthic impact (data from STECF-12-10)

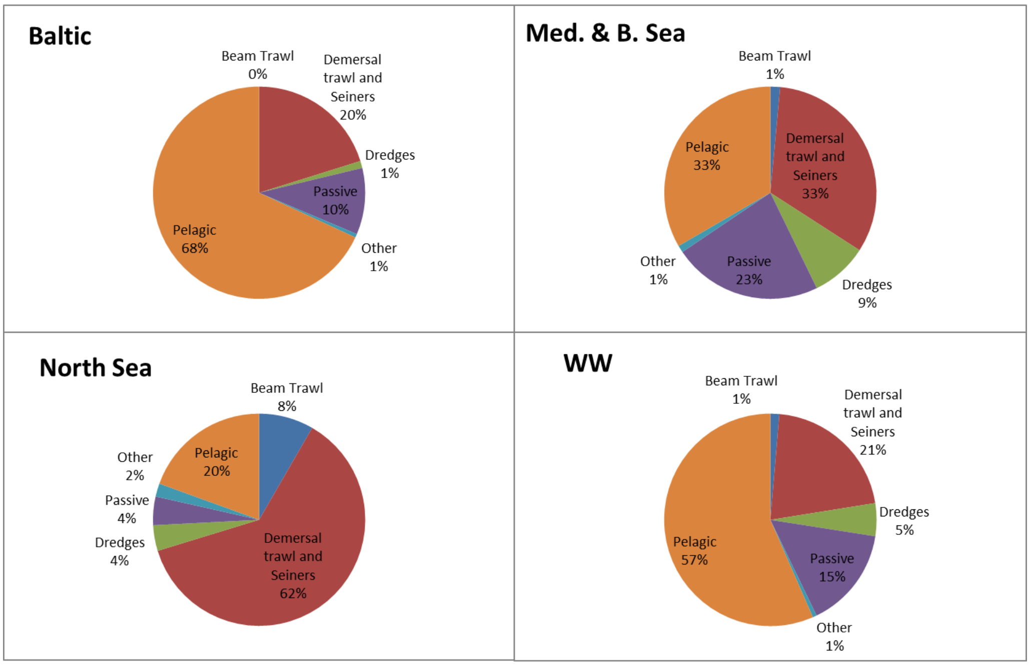


Figure 3.3. The proportion of total yearly landings of member states in 2010 split on regions and vessel groups according to expected benthic impact (data from STECF-12-10).

This pattern is almost the same across all case study regions (Figure 3.2 and 3.3) although smaller variations do exist between the regions. In all cases, however, the fishing effort (days at sea) with passive gears is substantially larger than the effort with mobile demersal gears, but completely reversed when measured in landings. This is mainly a result of the vessels fishing with passive gears being much smaller than the vessels fishing mobile gears.

Based on the above summary of the effort and landings of the vessel groups with a high level of gear-seabed contact (demersal trawlers and seiners, beam trawlers, and dredges), the vessel groups with a low level of gear-seabed contact (passive gears and other polyvalent/mobile gears) and the vessel groups with insignificant gear-seabed contact (pelagic gears), it is assessed that a prioritisation of the high-level impact group will include the bulk of benthic fishing pressure from the EU fleet. In addition to the EU fleet statistics, effort and landing information for the bulk of the Turkish commercial fishery with trawlers and beam trawlers in the Black Sea are available to the future BENTHIS work through CFRI (the Central Fisheries Research Institute in Turkey) who are partners in the project.

The total 2010 fishing days and landings and the main target species for the three high-level impact fisheries are summarized below (Table 3.1).

Table 3.1. Effort, landings and main target species for EU member states in the case study regions in 2010. Black Sea data are purely Turkish and provided by CFRI.

	2010	Demersal otter trawls and seines	Dredges	Beam trawl
Baltic Sea	Days at sea	32800	500	100
	Landings (tonnes)	130400	7000	100
	Main species	Cod	Blue mussels	Plaice
North Sea*	Days at sea	150700	31000	88500
	Landings (tonnes)	864600	54600	116400
	Main species	Cod, Nephrops, sandeel	Scallops	Sole, plaice
Western Waters**	Days at sea	238900	39800	15600
	Landings (tonnes)	235000	55700	15100
	Main species	Nephrops, sole, monkfish	Scallops	Sole, plaice
Mediterranean***	Days at sea	403700	62900	10300
	Landings (tonnes)	82000	21800	3700
	Main species	Hake	Clams	Sole, brill, turbot
	Days at sea	58200		28615
	Main species	Whiting, red mullet, turbot, bluefish, shad		Sea snail

*) also including ICES area I and II

**) also including ICES areaV, X and XII

***) no data available for Spain, xxxx

4. Demersal otter trawling, demersal seining, beam trawling and dredge fishing

Demersal otter trawling

Demersal otter trawls (or bottom trawls) are essentially conical nets that are dragged along the sea floor. The trawl net is held open using trawl floats, ground gear and trawl doors (Figure 4.1). The trawl doors that are used by the biggest vessels can each weigh up to 5-6 tonnes. The trawl is dragged along the bottom at a speed of between two knots (shrimp trawling) and five knots (fish trawling). The trawl doors are connected to the net by sweeps made of steel wire or chain. These can be 30-150 m long. Under the net there is the ground gear, which is designed to protect the net against wear, and to help it across rough terrain. There are various designs of ground gears, as shown in Figure 4.2. In traditional bottom trawling, the trawl doors, sweeps and ground gear all come into contact with the ground during trawling. Depending on the length of the sweeps, the width of seabed affected by a single bottom trawl can vary between 40 and 200 m. Assuming a speed of four knots, and a width of 100 m at the trawl doors, this equates to 740,800 m^2 of affected seabed for each hour of trawling. In modern bottom trawling, multi-rig trawling is also used, which involves two or three trawls being tied together so that they can be dragged side by side (Figure 4.3). Twin rig trawling involves the use of two trawl doors, two trawls and a weight located between the middle warp (towing cable) and the sweeps going to each of the trawls. The weight is approximately 30 per cent heavier than the trawl doors. Twin rigs are mostly used for shrimp and Nephrops trawling. A third type of bottom trawling is pair trawling, where two vessels drag a single trawl (Figure 4.4). In that case there are no trawl doors, but there may be weights at the transition between the warps and sweeps.

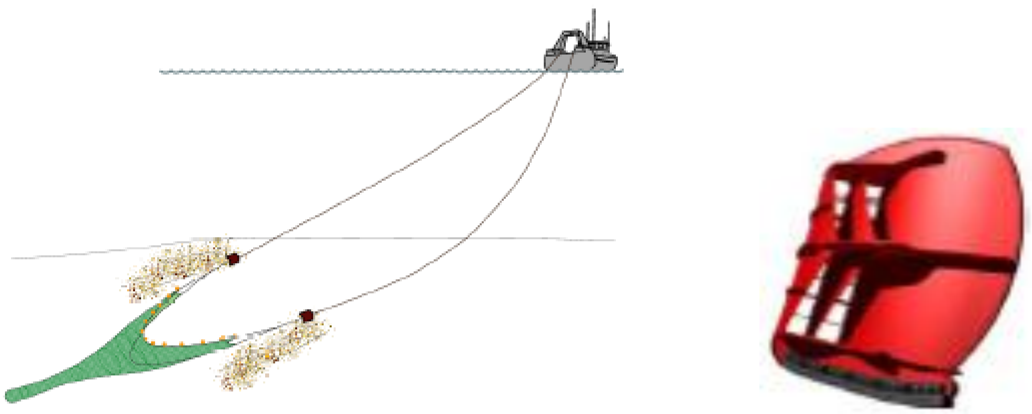


Figure 4.1.Left: illustration of bottom trawling using a single trawl and right: typical bottom trawl door (Illustration from Buhl-Mortensen et al. 2013).

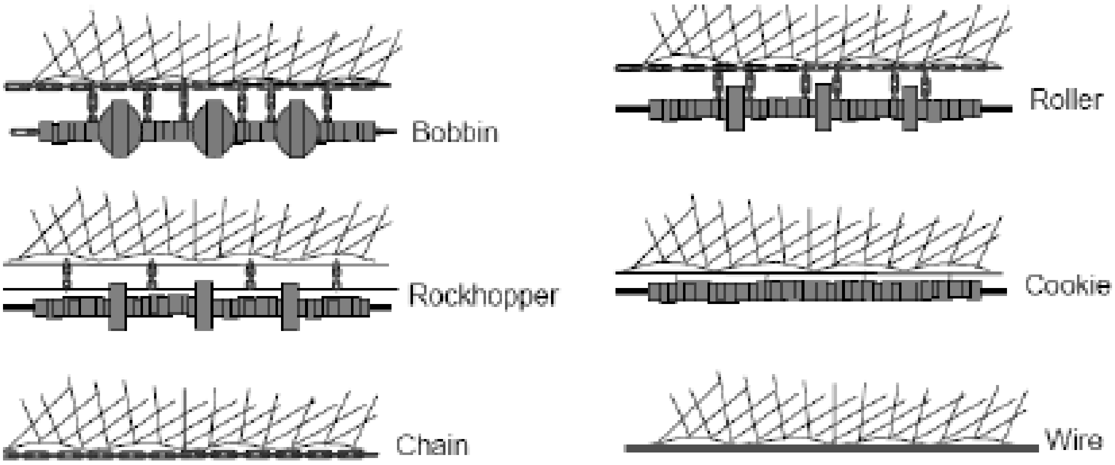


Figure 4.2. Examples of ground gear designs for bottom trawling. (Illustration from Buhl-Mortensen et al. 2013).

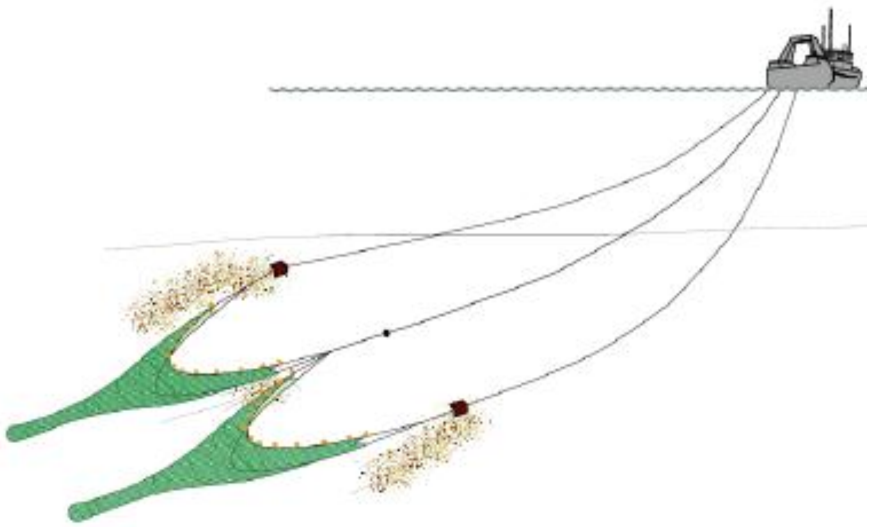


Figure 4.3. Bottom trawling using two trawls (twin rig trawling). (Illustration from Buhl-Mortensen et al. 2013).

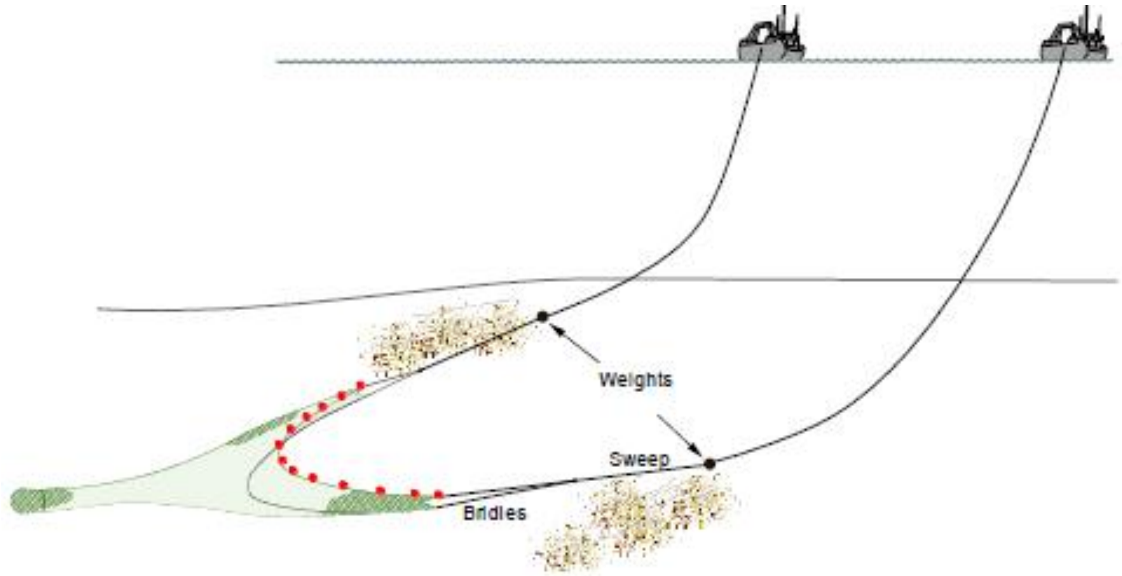


Figure 4.4. Pair trawling with a bottom trawl. (Illustration from Buhl-Mortensen et al. 2013).

Demersal seining

When fishing with Danish (or anchored) seine the gear is laid out in roughly a triangular area on the seabed using very long ropes that are hauled by an anchored vessel (Figure 4.5). As the two ropes are hauled in the net gradually closes, and towards the end of the haul it moves forwards in the same way as a trawl. Scottish seining (or flyshooting) is a more engine power demanding variation of Danish seining, where the vessel moves forward while at the same time hauling in the ropes. Flyshooting can be considered a hybrid between anchored seining and demersal otter trawling.

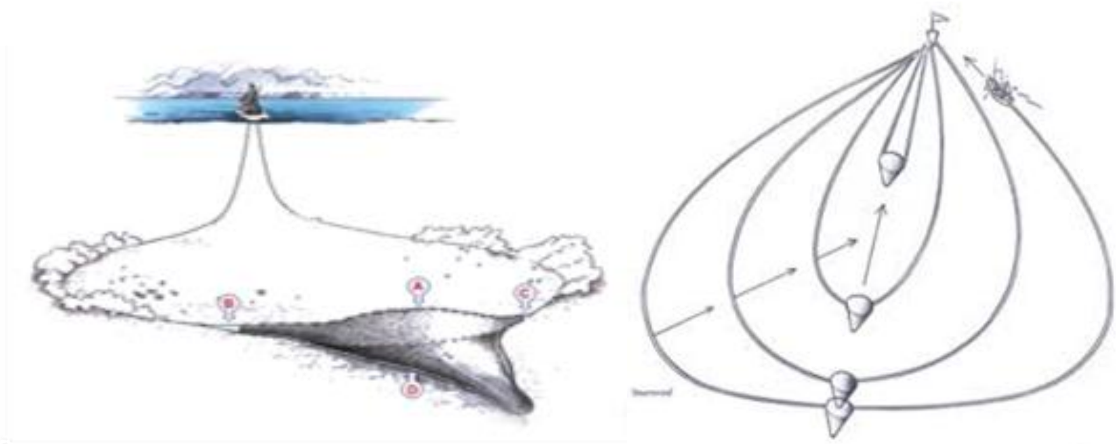


Figure 4.5. Left: Illustration of three steps in an individual anchored seine haul.

Beam Trawling and dredge fishing

Both beam trawls and scallop dredges are used to target species that stay on the bottom or that are partly buried in the sediment. Accordingly, the tickler chains of a beam trawl (Figure 4.6) and the teeth or shearing edge (knife) of a dredge (Figure 4.7) are specifically designed to disturb the sea bed surface and penetrate the upper few centimetres of the sediment. Chains, teeth and shearing knife, respectively, are mounted along the whole width of the two gears (beam trawl width roughly varies between 4 to 12 m, and scallop dredges from 0.75 to 3 m, according to FAO Fisheries Technical Paper No. 472). The beam trawl fishery for brown shrimps utilise beam trawls without tickler chains. Typically two beam trawls are towed per vessel, but as for dredgers variation in towing methods and numbers can be quite large (Figure 4.7). Recently, a number of beam trawlers in the North Sea flatfish fishery have replaced the tickler chains by electrodes to chase flatfish from the seabed. These pulse trawl are more selective for the main target species sole and have a lower bycatch of discards (van Marlen et al., 2014).

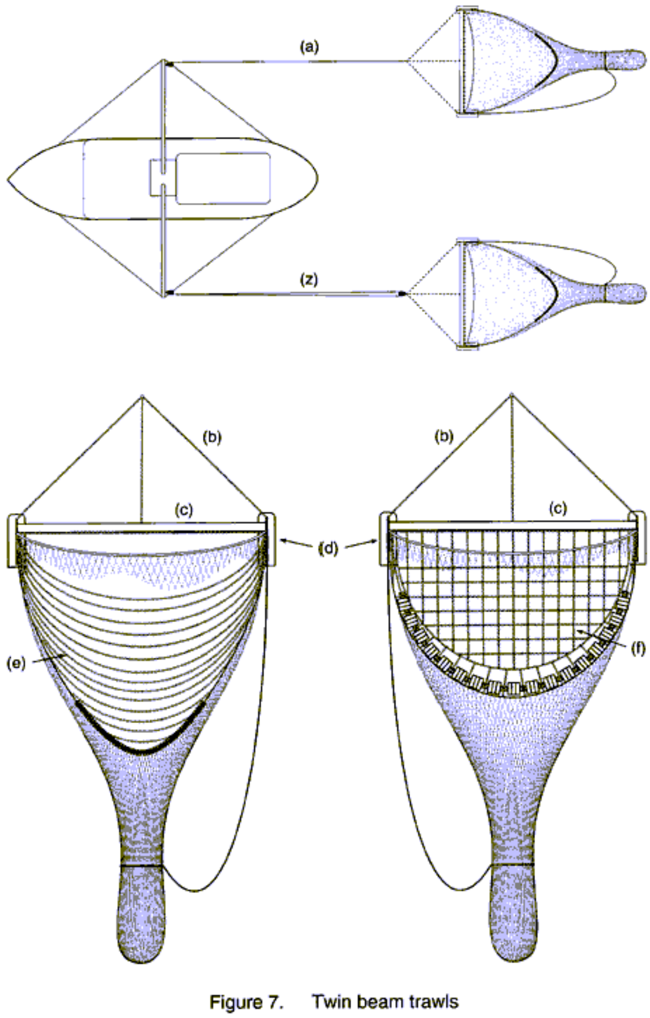
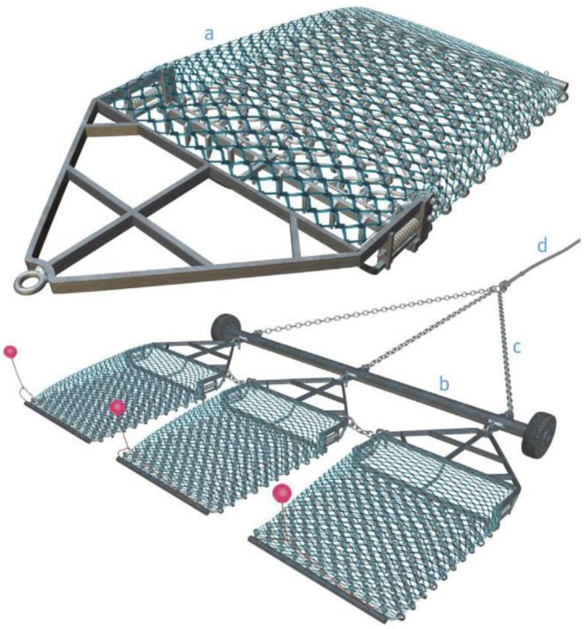


Figure 4.6. Top: towing two beam trawls: Bottom: bema trawls with different design of ground gear.



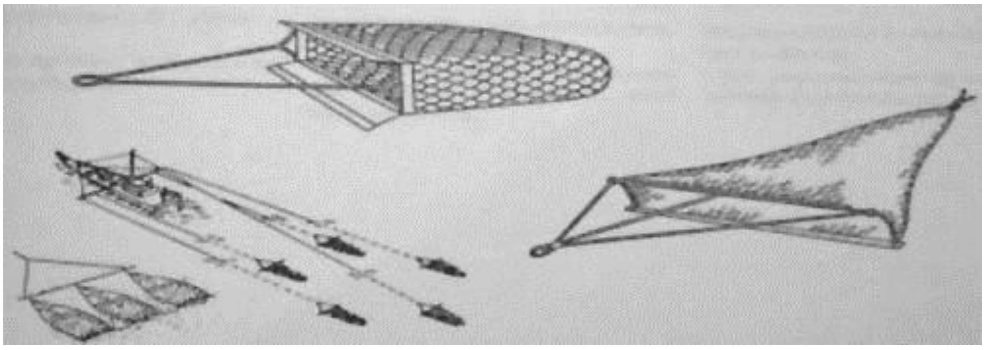


Figure 4.7. Different dredge types, with and without with shearing edge and teeth, and towed in different ways and numbers (drawings from O'Neill 2013 (top) and FAO Fisheries Technical Paper No. 419(bottom))

5. Gear and sediment interactions of demersal otter trawls, demersal seiners, beam trawls and dredges

In order to assess the direct physical impact on the seabed when fishing with different types of bottom gears, it is necessary to distinguish between the bottom impacts of the individual gear components.

Demersal otter trawls

For a traditional single otter trawl there are three main types of sea bed impact during a trawl haul: 1) from the otter boards, 2) from the sweeps and 3) from the trawl itself (the trawl ground gear). Of these three impacts the one from the otter boards is the most severe but also the impact with the narrowest track/path of impact (Figure 5.1).

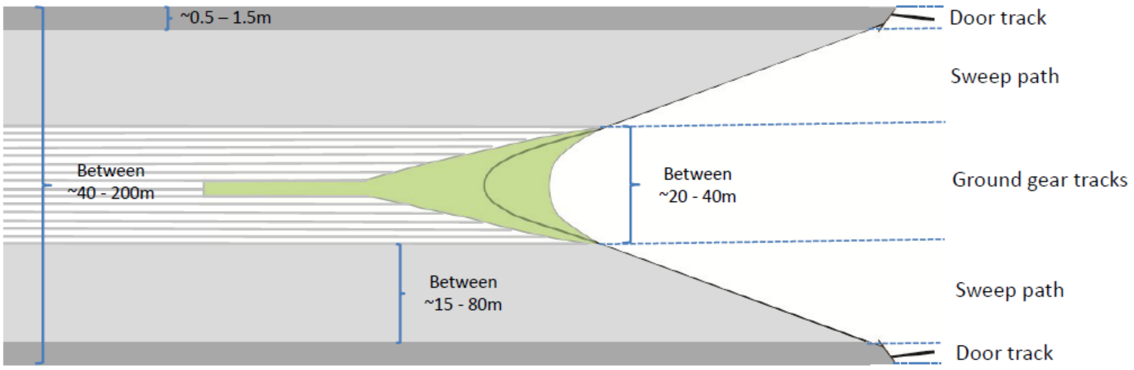


Figure 5.1. Conceptual footprint from standard otter trawls with three types of sea bed impacts: 1) the track affected by the otter boards (Door track), 2) the track influenced by the sweeps (Sweep tracks) and 3) the track affected by the trawl/groundgear itself (Ground gear tracks) (Illustration Buhl-Mortensen et al. 2013).

Studies have been performed in Norway and Scotland, as part of the DEGREE project, to measure the dimensions of the marks left by these components on the sea floor (DEGREE 2010) (Figure 5.2).

Figure 5.2. Left: marks created by the door of a rock hopper trawl in soft mud in Varangerfjorden. Right: Marks created by the ground gear of a rock hopper trawl in soft mud in Varangerfjorden. The distance between the red laser lights is 10 cm (from DEGREE 2010).

In Scotland divers compared areas of the seabed (with different substrates) before and after the trawl had passed. Photos of examples of the marks left by each component are shown for mud and sand bottoms in Figure 5.3. By using laser scanning techniques, the divers were able to obtain exact measurements of the sea bottom topography before and after trawling (see e.g. Figure 5.4).

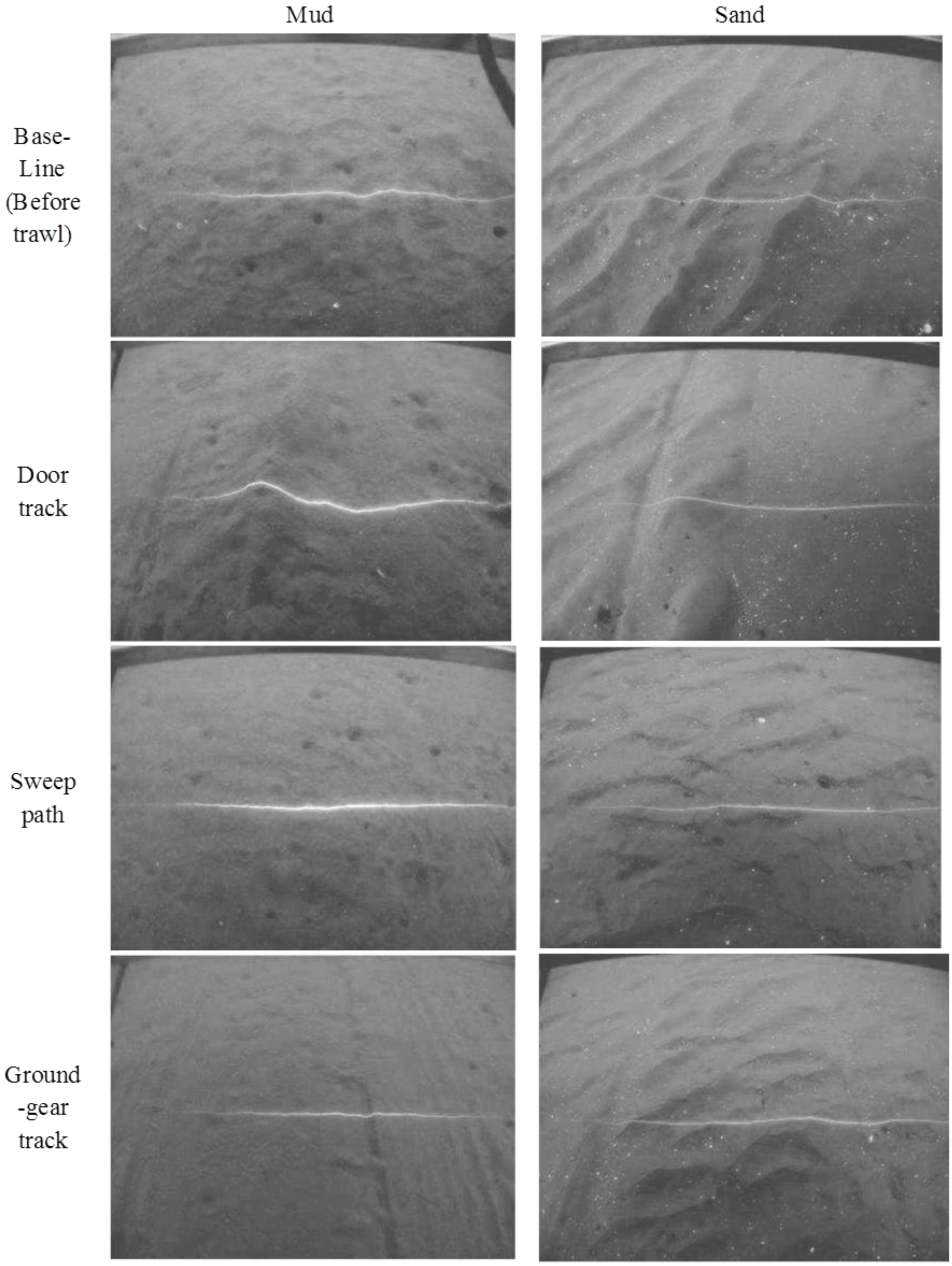


Figure 5.3. Photos of sediments before and after contact with various components of the trawl in mud and sand. Each photo also shows a laser profile (from DEGREE 2010).

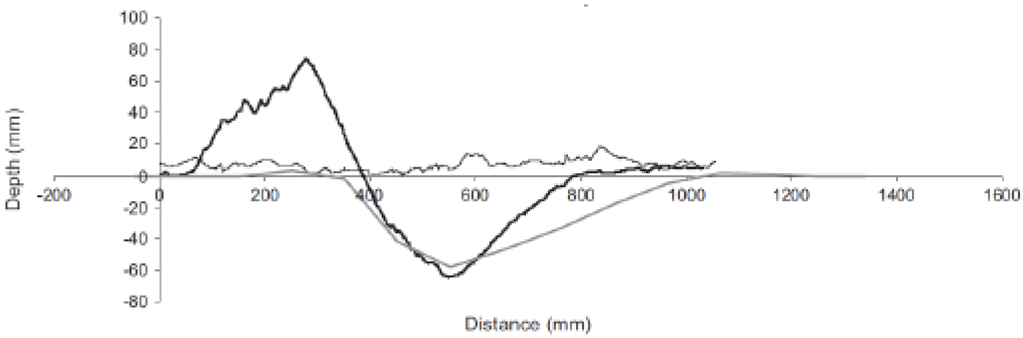


Figure 5.4. Laser readings before (dotted line) and after (solid black line) contact with a trawl door in muddy sand, compared with the predictions of a classic FE model of plasticity (solid grey line) (from O'Neill et al. 2010).

Based on the photos it was possible to calculate what proportion of its path each trawl component affected, and the depth of the marks they left in the substrate.

In terms of the proportion of the path affected, there was no doubt that the trawl doors had the biggest impact, although the path was relatively narrow (~0.5-1.5 m). The trawl doors dug up a trench/furrow that was up to 20 cm deep in Norway (10 cm in Scotland), and transferred large amounts of sediments onto either side of their path. The furrow was not always continuous, as the trawl doors sometimes floated up off the bottom, depending on the topography and sea state. Italian experiments demonstrated trawl door furrows of up to 35 cm (Luchetti and Sala 2012).

The sweeps represented the biggest proportion of the trawl path, but they appeared to have little impact on mud bottoms. On sand there is more contact due to waves in the sand, but the impact is limited to the top 2 centimetres of sediment. However, it is important to remember that this component can destroy any structures that rise up more than a few centimetres above the surrounding sea floor. Sweep chains impacted the top 5 centimetres of the sediment (Buhl-Mortensen et al. 2013).

In the DEGREE experiment the ground gear affected the sea bed very unevenly due to the heterogeneous composition of rock hopper gears, but in some places the top 10 cm of the sediment was impacted (DEGREE 2010).

The roller clump of twin trawls has been shown to create furrows of up to 12 (O'Neill et al. 2009) and 15 cm (Ivanovic et al. 2011).

Beam Trawls

For a beam trawl the footprint is more homogenous than for otter trawls and can be separated in two types of paths/tracks: one type of track being affected by the shoes of the beam and the second type being affected by the ground gear of the beam trawl and before that, by the tickler chains of the trawl if such chains are deployed (Figure 5.5). Both tickler chains and beam shoes have been demonstrated to inflict furrows of up 10 cm depth in the sediment (Kaiser et al. 1996). The impact of the pulse trawl will be less than that of tickler chain beam trawls (van Marlen et al., 2014) and will be studied in more detail in field trials in BENTHIS WP7.

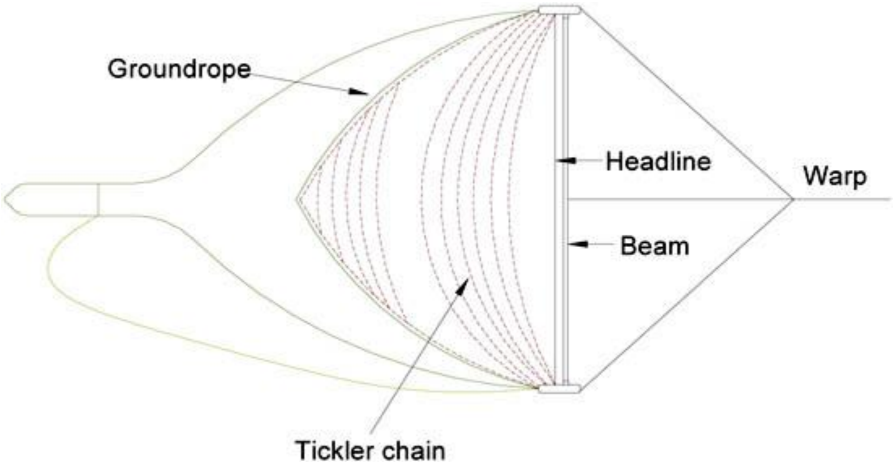


Figure 5.5. Drawing of beam trawl with warp, beam, shoes, tickler chains and ground gear (illustration from FAO Fisheries Technical Paper 472)

The sediment mobilisation from beam trawling can also be substantial (Figure 5.6) as demonstrated with Side Scan Sonar (SSS) technology by Luchetti and Sala (2012).

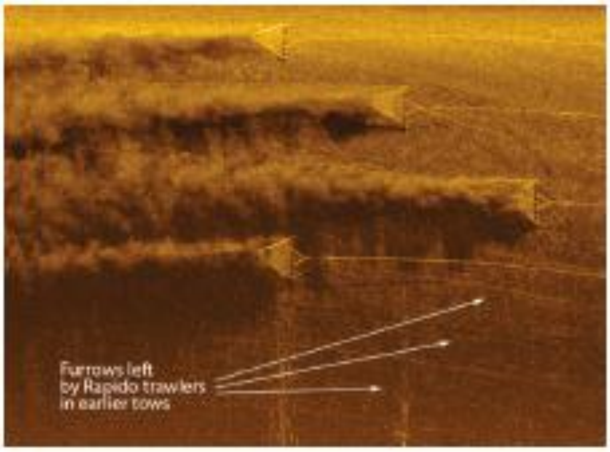


Figure 5.6. Resuspension of sediments caused by Rapido beam trawling in the Adriatic Sea. Evidence of the furrows left by Rapido trawls in earlier tows can be seen in the lower part (image from Luchetti and Sala 2012)

Dredges

Dredges used for catching molluscs such as scallops, mussels and oysters, typically either have a very homogeneous can be expected to have a more uniform gear footprint than beam trawls in that often the ground gear does not vary much in structure across the entire width of the dredge (Figure 4.7). This does, however, depend highly on the presence/absence of dredge teeth which are not uncommon and produce a more uneven sediment furrow (Figure 5.7, 5.8 and 5.9). Dredges have been demonstrated to create furrows of up to 6 cm depth in soft sediments (Pranovi et al. 2000). The hydro-dredges used for infauna bivalves in the Adriatic Sea have been demonstrated to create up to 15 cm deep furrows in the sediment (Luchetti and Sala 2012)

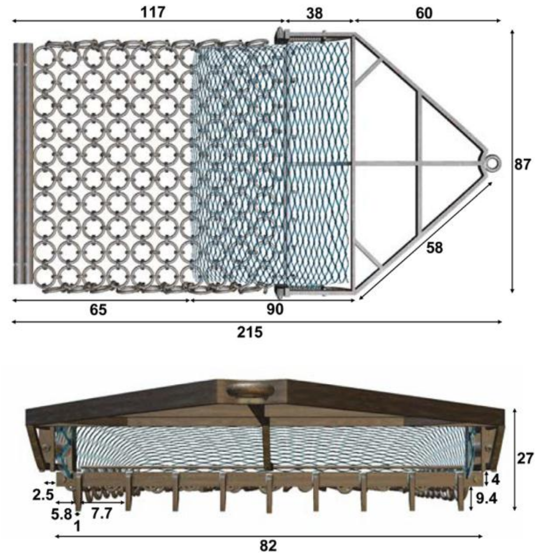


Figure 5.7. Front and top view and dimensions (mm) of scallop dredges in use in Scotland (O'Neill et al 2013)

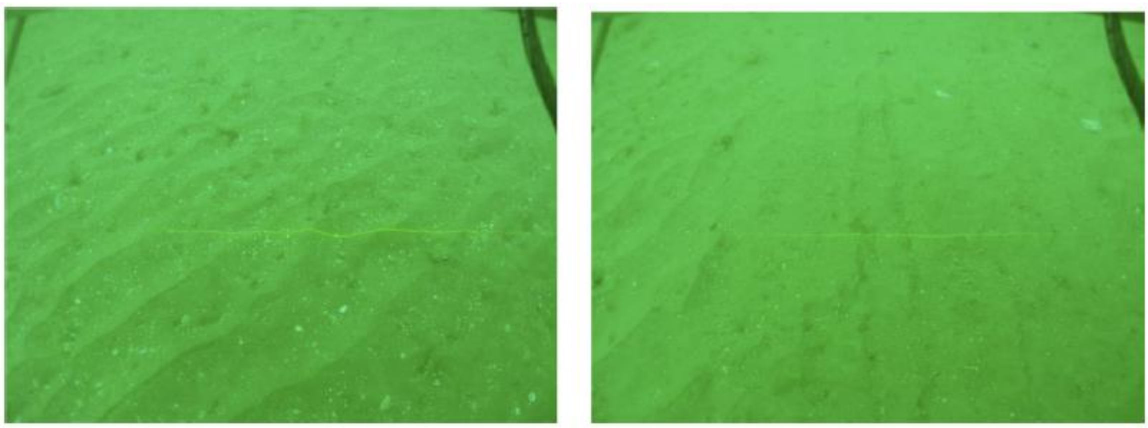


Figure 5.8. On the left is the un-impacted seabed, whereas on the right is the seabed after the passage of a scallop dredge. The marks left by the dredge teeth can clearly be seen (O'Neill et al 2013).

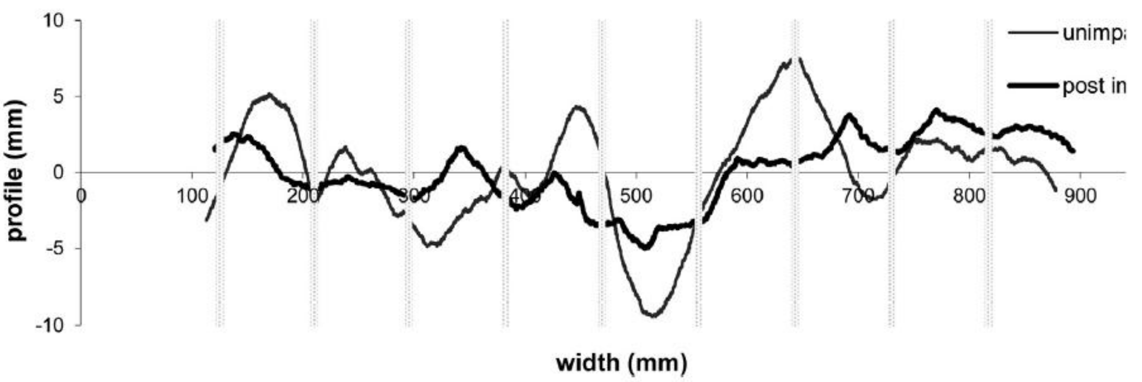


Figure 5.9. Profile of un-impacted and post impacted seabed measured using the laser stripe profiler. The vertical lines represent the possible position of the scallop dredge teeth and coincide with local minima of the post impact profile (O'Neill et al 2013).

Demersal seiners

No studies have been done to document the physical impact of either Danish or Scottish seining on seabed habitats, but presumably the effect is smaller for Danish seines than for bottom trawling, since there are no trawl doors and the ground gear is lighter. The impact level of Scottish seining (or flyshooting) is probably somewhere in between the two other gear types as flyshooting can be considered a hybrid between anchored seining and demersal otter trawling. The biggest impact (largest area of impact) is from the ropes, when they are pulled together in the first phase of the operation (Figure 5.10). Since this kind of fishing is dependent on the ropes not getting caught on obstacles during the herding phase, there are clear limitations on the sediment types where it can be used. Presumably the ropes have a physical impact similar to that of the sweeps of a trawl.

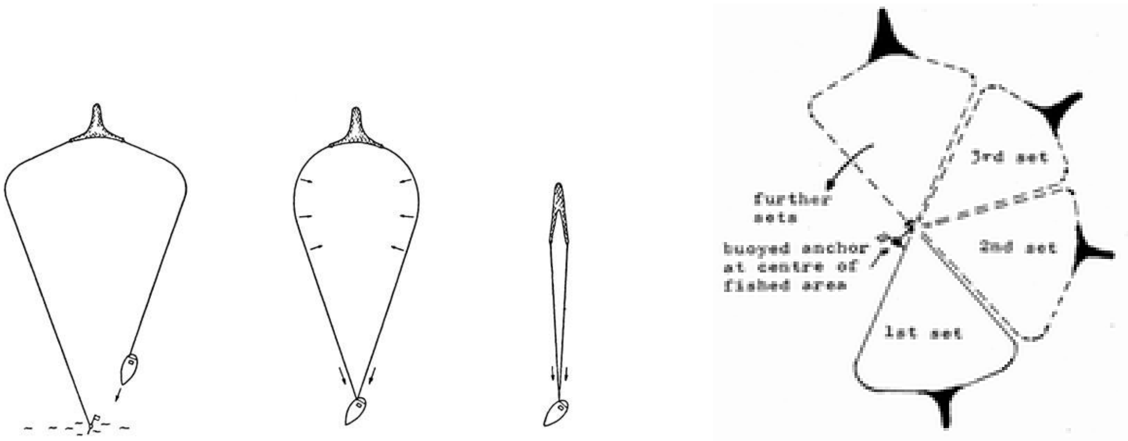


Figure 5.10. Left: Illustration of three steps in an individual anchored seine haul, Right: the combined gear footprint of a series of four seine hauls (illustration from http://www.fao.org/fishery/geartype/203/en)

6. Conclusions and implementation in the further BENTHIS work

Following the review of the fisheries in the European Union, the analyses of impact mechanisms and effects, the a-priori segmentation into high and low- impact fisheries, the prioritisation based on total EU effort and landings, and the subsequent breakdown of high-impact gear types into individual components, the following main conclusions are drawn:

- The combined effort of the four prioritised vessel types with a high level of gear-seabed contact during fishing (demersal otter trawlers, demersal seiners, beam trawlers and dredges) will capture the bulk of benthic fishing pressure from the EU fleet.
- The major effects and mechanisms of impact for these groups were assessed to be: 1) Mortality of benthic organism from direct gear- sea bed gear contact during fishing, 2) food subsidies from discards and gear track mortality, 3) habitat alterations through disturbance of sediments, and 4) geo-chemical processes from disturbance of sediment.
- Food subsidies from discards are acknowledged to be an important benthic impact mechanism, but the task of mapping discards was not assessed to be feasible within BENTHIS WP2. This is mainly due to the poor availability (lack of information) of discard data from the European fisheries (the mechanism of discards impact on the benthic ecosystem will, however, be analysed in WP4).
- The efforts in WP2 will be focused on mapping the area and severity of seabed impact of the above identified four gear types.
- The severity of impact is highly variable between gear types, between gear components, and in a few cases even within components (e.g. otter trawl ground gear) and also varies with sediment type and target species. Based on results from the scientific literature a summary of sediment impact depth by gear and component is given below (Table 6.1)

Table 6.1. Sediment impacts by gear type and components and approximate proportion of total impact area that can be ascribed to each component, for the four gear types prioritized in the future WP2 work
.

Gear types	Gear components	Depth of gear impact	Proportion of total area of gear impact
Demersal otter trawl	Sweeps and bridles	< 1cm	approx. 45 – 80 %
	Sweep chains	≤ 5 cm	approx. 1 – 2 %
	Trawl doors	≤ 35 cm	approx. 0.5 – 2 %
	Multirig clump	≤ 15 cm	approx. 0.5 – 2 %
	Ground gear	≤ 2 cm	approx. 20 – 45 %
Demersal seine	Seine ropes*	(< than trawl sweep impact)	approx. 75 - 95 %
	Ground gear*	(< trawl ground gear impact)	approx. 5 – 25 %
Beam trawl	Shoes	≤ 10 cm	approx. 2 – 5 %
	Tickler chains	≤ 10 cm	approx. 95 – 98 %
	Ground gear	< 1cm	approx. 95 – 98 %
Dredge	Ground gear	< 15cm	approx. 100 %

*No experimental data exist for demersal seine gear components.

The main implication for the further BENTHIS work has been the integration of the above prioritisation of gear types into the workflow of the WP2. The detailed gear footprints of the four high-impact gears established in this review have formed the basis of an industry questionnaire survey designed to deliver information of the dimensions of the relevant gear types currently in use by the European fishing industry. These gear specifications are central in the further work with fine-scale mapping of fishing pressure from physical gear-seabed interactions, where the industry information is merged with VMS and logbook information of fishing effort and activity. The four questionnaires are appended to this report (Figure 6.1, 6.2, 6.3 and 6.4) and the further implementation of questionnaire data and the developed BENTHIS methodology for fine scale mapping of EU fishing pressure on the benthic habitats is described in detail in Deliverable 2.1.

Figure 6.1 Industry questionnaire (demersal otter trawl) designed from the above fisheries review and prioritisation and subsequent break down of gears into different components.

Country:			
Fishing area:			**Bottom trawls**
Date:			*BENTHIS-2013*
vessel:			(partner)
Trawl	type and name		
Trawling mode*	one or two vessels (single or pair trawling)		
Rigging	number of trawls per vessel		
Net maker	company name		
Codend	stretched mesh size (mm)		
Target species[1] (single)	only single species fisheries		
Primary species[1]	only mixed/multi-species fisheries		
Secondary species[1]	only mixed/multi-species fisheries		
Third species[1]	only mixed/multi-species fisheries		
Bottom type	bedrock, hard bottom, sand, hard clay, mud		
Vessel	engine power in kW		
	tonnage in GRT		
	Loa: overall length in metres		
Trawl circumference	number of meshes		
	stretched mesh size (mm)		
Trawl	Trawl height (metres)		
	Wing spread (metres)		
Doors	pelagic or bottom		
	number		
	producer and model		
	length (m)		
	height (m)		
	weight (kg)		
Door spread	door spread (metres)		
Sweeps	sweep length (metres)		
Bridles	number and length (metres)		
Tickler chains/lines	number		
	total weight of each chain or line (kg)		
Groundgear	length of groundgear (metres)		
	type, e.g. rockhopper, bobbins, discs, etc.		
	diameter of ground-gear (mm)		
	total weight of ground gear (kg)		
Clump	type (e.g. chain or roller)		
	weight of clump (kg)		
Other chains in gear	number and location in gear		
	total weight of each (kg)		

[1] please inform both common name and FAO 3-Alpha Species Codes (ASFIS)

Trawling speed (knots):	
Steaming speed (knots):	
Fuel consumption trawling (litres/hour):	
Fuel consumption steaming (litres/hour):	
Consumption other activities (litres/hour and activity):	

Figure 6.2. Industry questionnaire (beam trawls) designed from the above fisheries review and prioritisation and subsequent break down of gears into different components.

Country:			
Fishing area:			**Beam trawls**
Date:			*BENTHIS-2013*
vessel:			(partner)
Trawl type	conventional beam trawl, pulse-trawl, sum-wing, hydrorig, etc.)		
Total trawl number	number of trawls per vessel		
Net maker	company name		
Codend	stretched mesh size (mm)		
Target species[1] (single)	only single species fisheries		
Primary species[1]	only mixed/multi-species fisheries		
Secondary species[1]	only mixed/multi-species fisheries		
Third species[1]	only mixed/multi-species fisheries		
Bottom type	bedrock, hard bottom, sand, hard clay, mud		
Vessel	engine power (kW)		
	tonnage (GT)		
	overall length (m)		
Warp/depth ratio	(1 / x)		
Warp	warp diameter (mm)		
Beam	beam width (m)		
	complete beam weight in air (kg)		
Beam shoes	number		
	width (mm)		
	length (mm)		
Sumwing	width (m)		
	corde length (mm)		
	complete wing with nose weight in air (kg)		
Sumwing nose	width (mm)		
	total length (mm)		
	contact plate length (mm)		
Tickler chains	number		
	total weight of each (kg)		
Chain mat	total weight (kg)		
Groundgear	length of groundgear (m)		
	type, e.g. bobbins, rubber discs, chain, etc.		
	diameter of ground gear (mm)		
	total weight of ground gear (kg)		
Electrodes	number		
	electrode length (m)		
	electrode diameter (mm)		
	electrode type		

[1] please inform both common name and FAO 3-Alpha Species Codes (ASFIS)

Trawling speed (knots):		
Steaming speed (knots):		
Fuel consumption trawling (litres/hour):		
Fuel consumption steaming (litres/hour):		
Consumption other activities (litres/hour and activity):		

Figure 6.3. Industry questionnaire (demersal seines) designed from the above fisheries review and prioritisation and subsequent break down of gears into different components.

Country:			
Fishing area:			**Demersal seines**
Date:			*BENTHIS-2013*
vessel:			(partner)
Seine type	flyshooter/Scottish seine or anchored/ Danish seine		
Net maker	company name		
Codend	stretched mesh size (mm)		
Target species[1] (single)	only single species fisheries		
Primary species[1]	only mixed/multi-species fisheries		
Secondary species[1]	only mixed/multi-species fisheries		
Third species[1]	only mixed/multi-species fisheries		
Bottom type	bedrock, hard bottom, sand, hard clay, mud		
Vessel	engine power (kW)		
	tonnage (GT)		
	overall length (m)		
Seine circumference	number of meshes in circumference		
	stretched mesh size (mm)		
Seine height	height of seine (metres)		
Seine rope	total rope capacity (total length in metres)		
	rope diameter in (mm or inches)		
	rope weight (kg per meter rope)		
Groundgear	length of groundgear (metres)		
	type, e.g. bobbins, rubber discs, chain, etc.		
	diameter of groundgear (mm)		
	total weight of ground gear (kg)		

[1] please inform both common name and FAO 3-Alpha Species Codes (ASFIS)

Steaming speed (knots):		
Fuel consumption steaming (litres/hour):		
Fuel consumption fishing (litres/hour):		
Duration of haul/fishing operation (hours):		
Consumption other activities (litres/hour and activity):		

Figure 6.4. Industry questionnaire (dredges) designed from the above fisheries review and prioritisation and subsequent break down of gears into different components.

Country:			
Fishing area:			**Dredges**
Date:			*BENTHIS-2013*
vessel:			(partner)
Dredge	type and name		
Total dredge number	number of dredges per vessel		
Net maker	company name		
Codend	stretched mesh size (mm)		
Target species[1] **(single)**	only single species fisheries		
Primary species[1]	only mixed/multi-species fisheries		
Secondary species[1]	only mixed/multi-species fisheries		
Third species[1]	only mixed/multi-species fisheries		
Bottom type	bedrock, hard bottom, sand, hard clay, mud		
Vessel	engine power (kW)		
	tonnage (GT)		
	overall length (m)		
Warp/depth ratio	ratio of warp length and fishing depth (1 /x)		
Warp	warp diameter (mm)		
Dredge	total width (m)		
	total weight (kg)		
[1] please inform both common name and FAO 3-Alpha Species Codes (ASFIS)			
Trawling speed (knots):			
Steaming speed (knots):			
Fuel consumption trawling (litres/hour):			
Fuel consumption steaming (litres/hour):			
Consumption other activities (litres/hour and activity):			

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