Detecting ecological-economic effects of marine spatial plans from displacing the bottom fishing pressure

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List of abbreviation

AIC	Akaike's information criterion
DF	Deposit Feeders
DMU	National environmental research institute of Denmark
DTU-	Technical University of Denmark
EAF	Ecosystem based Approach for Fisheries
EBM	Ecosystem Based Management
EMMCMSP	Erasmus Mundu Master Course on Marine Spatial Planning
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
ICES	International Council for the Exploration of the Sea
MRE	Marine Renewable Energy
MSP	Marine Spatial Planning
SF	Suspension Feeders
VMS	Vessel Monitoring System
WoRMS	World Register of Marine Species

SUMMARY

Bottom fishing is expected to have significant effects on benthic fauna, while these impacts are likely to vary according to gear type, fishing intensity and between seafloor habitats. We tested spatial scenarios for mitigating benthic fauna depletion caused by fishing, while evaluating likely effects on the economy of local fisheries. We first identified and mapped gradients of fishing pressure (FP, swept area. y^{-1}) and evaluated the sensitivity of functional fauna groups (deposit feeders and suspension feeders) related to different FP within pre-defined habitat types. Functional relationships were obtained from the coupling of vessel-based VMS data, logbooks and core sampling of benthic fauna within the Kattegat (ICES IIIas) over the period 2008-2012. We then applied the previously published DISPLACE model (Bastardie et al., 2014) , to provide fishery policy makers and sector-specific stakeholders with an evaluation of likely effects of spatial planning when FP is displaced to different fishing grounds and thereby impact other areas and habitats. This empirical study showed that response to FP is more pronounced for both deposit and suspension feeders associated with muddy substrate compared to harder substrates. Areas with lower fishing pressure had a significantly higher abundance of benthic fauna. Fleet modelling showed that a FP restriction of 60% in the most sensitive habitat results in 4% increase in overall profit (due to change in fuel costs, underlying stock developments, and landing composition). Offshore wind farm development in Kattegat also potentially increases the overall fishery profit by 5%. Interestingly, the scenarios led to positive or negative individual profit depending on the type of vessels and fishing activities. By looking back at our empirical study of benthic fauna, we found that the displaced spatial closure in Scenario 1 will lead to an 1% increase in overall benthic fauna abundance (+3 % in the sensitive habitat), while wind farm implementation in Kattegat could likely reduce overall benthic fauna abundance by 2%. Modelling approaches are required to anticipate potential adverse effects on fisheries and underlying habitats from effort displacement. Further development of modelling framework that includes the dynamics of both the fisheries and benthic fauna community are essential to meet public demands for ecosystem based fisheries management.

Keywords

Marine Spatial Planning; Agent-based Modelling; Benthic Fauna; Displaced Fishing Effort; Ecological Economic Evaluation; Scenario Evaluation

1.0 Introduction

The promotion of blue growth in Europe has made many countries concentrate on development of new marine activities that are more economically appealing (ECORYS Nederland BV, 2012; European Commission, 2012, 2014). Development of new activities in the marine space may constrain spaces for already existing activities. Fisheries is one of the traditional uses of marine spaces, and in recent times it has been competing for spaces with emerging marine activities like offshore wind farms(Rodmell and Johnson, 2003; de Groot et al., 2014). Marine Spatial Planning (MSP) is being promoted as a new policy tool to bring soundness in marine spaces(European Parliament, Council of the European Union, 2014; European Commission, 2013) . MSP is involved with allocation of spaces for different uses. Although MSP encourages multiple uses of spaces for efficiency some activities are incompatible and have to utilize different spaces, e.g. offshore windfarms and fisheries. For mobile activities like fisheries, some of these emerging activities not only restrict them from using existing spaces but also from reaching other potential fishing areas, and as a result at times fishers are forced to reallocate to other places. How the fishing effort will be redistributed is not always uniform and will depend on fisheries economics and ecological factors. Most of the time fishermen will want to concentrate fishing effort in area where they get more profits in terms of the value of catches or in places where they use less operational costs. The productivity of an area is also related to ecological characteristics. Increased fishing activities of certain gears like bottom trawls might lead to increased detrimental effects on fish stocks and benthic fauna. New management regime encourages an ecosystem based management (EBM) which requires ensuring resources are exploited in sustainable manner and without negative impacts on the environment.

Conducting an environmental impact assessment is required by the EU for any new uses of the sea (European Parliament, Council of the European Union, 2001) it is therefore essential for any MSP regimes to also consider likelihood impacts on ecosystem that may happen when a marine activity is moved to other places. Indeed, article 5 of the EU MSP Framework Directive (European Parliament, Council of the European Union, 2014) obliges member states to implement MSP with the objective of achieving a sustainable development of the fisheries. However there is a gap in research that has a holistic look at the subject of fishing effort allocation. The majority of research done typically focus on one subject area either on the fishery economics or on the environmental impacts. The opportunity to combine datasets from different fields to have a holistic view of the ecosystem is gradually being possible given the increasing emphasis of EBM.

This study looks at the possible effects of fishing activities displaced from an area as consequence of MSP on fish stock and benthic fauna' dynamics. The general objective of this study is to predict the induced effects of MSP from the perspective of the fisheries, by mapping the effort allocation, predicting the effort displacement in space and time, and deducing the probable induced change on fish stocks and marine benthic ecosystems. This is done by coupling the fine-scale fishing pressure modelling to the modelling of the fish stocks and benthic fauna dynamics.

1.1 Study Context and conceptual framework

It is required by law that vessels greater than 12 m operating in the EU to give their position to authorities while operating in the EU waters using the Vessel Monitoring System as a result it has been possible to map fishing effort distribution. DISPLACE intends to serve as a basis for decision support tools for (fishery) manager and was established to help integrate fishermen's decision-making processes when they face changes in fishery management, economic factors influencing the fishery, economic viability, and underlying stock conditions (Bastardie et al., 2014). Some of the capabilities of DISPLACE is evaluating the effects of smaller and larger marine area restrictions on stocks and fisheries. At the same time ecological studies have been going on at the study area for almost 10 years. The ultimate goal here is to identify areas where benthic fauna will be largely impacted if fisheries spatial restrictions are introduced. The results of the study aim to contribute to policies associated with development and implementation of marine spatial plans.

In this study we put our focus in Western Baltic and Kattegat areas of the Baltic Sea when both high resolution data for DISPLACE and benthic fauna datasets were available. We adopted a conceptual model as outlined in Figure 1.

First we examine the responses of benthic fauna communities collected in fixed sampling stations (divided as suspension feeders and deposit feeders) that experience different amount of trawling impact in different habitats types in Kattegat area, where we achieve a long term (9 years) evaluation of trawling impacts on benthic fauna. We compare how the impacts vary within and among the four benthic habitat types.

We then used this information to predict possible impacts on benthic fauna from fishing impacts when some sections in the study area are closed for fishing using displaced model, first by closing imaginary areas with habitats showing most response of fishing pressure gradient on benthic fauna. The final part is the assessment of a real case of proposed area for offshore windfarm in the study area to see what impacts it would have on vessel and environment.

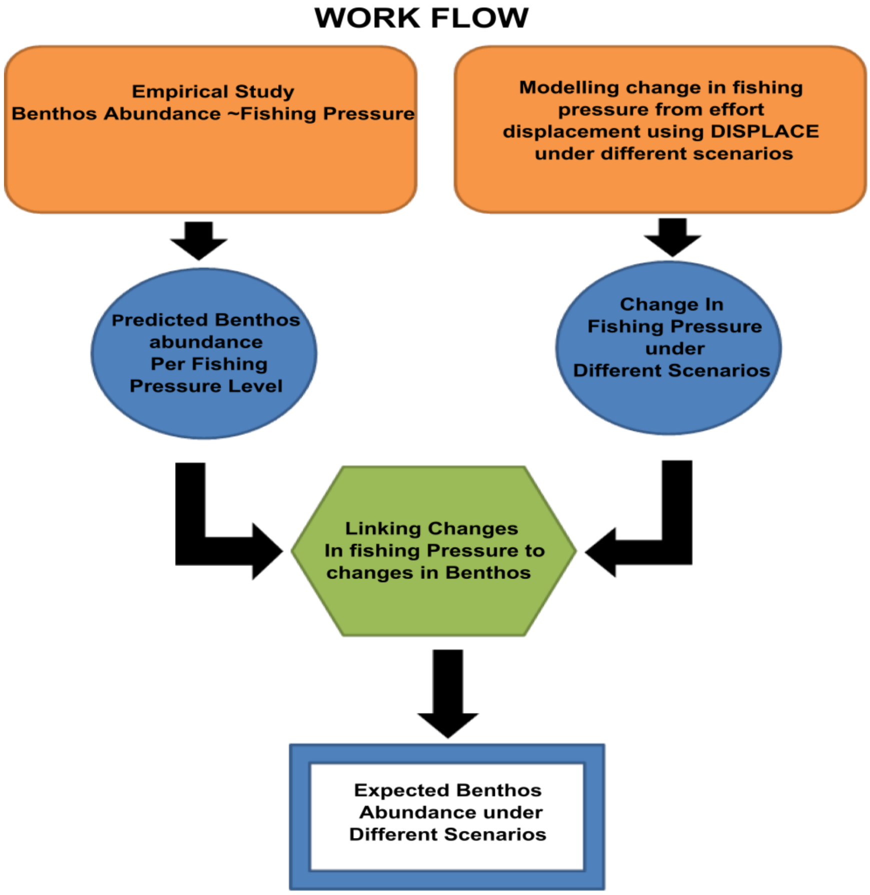

Figure 1: Conceptual framework adopted for the study

1.2 Problem Statement and justification

In recent times there has been is an increase in marine activities due to the increase focus on blue growth. It is estimated that the growth of some sector like wind energy will increase by 6000% in the next 20 years. The Development of new activities in the marine space may constrain spaces for already existing activities. In most cases this will likely lead to increase in fishing effort to new area or increase fishing pressure in already existing places, as a consequence this will aggravate the impact of fishing especially by bottom touching fishing methods. While the promotion of marine spatial plan is to bring a balance in the use marine spaces especially by promotion of multi-use space practices, the biggest challenge for marine managers is to bring a balance of maintaining economic gains whilst maintaining a sound ecological condition of the of marine spaces. Understating the interaction between fisheries economic goals in relation to the ecological impacts on benthic communities is important to help us predict the like hood impacts of management plans both to the economy and to the environment. Evaluation of impacts at individual vessel level help to see possible outcomes and management measures than can be taken at individual vessel level. Understating how benthic fauna abundance will behave under projected marine spatial planning scenario has a potential to be used as a criteria for evaluation of marine spatial plans to enable the reduction of impact on marine benthic fauna

1.3 Research Hypothesis

1.3.1 Hypothesis 1

Fishing methods that come into contact with the bottom marine habitat have been reported to have a great impact on benthic fauna, the intensity of the impact can be different in different areas depending on magnitude of fishing pressure and habitat type. First we investigate the role of fishing pressure level on benthic fauna abundances and also the effect habitat type on the relationship between fishing pressure and Benthic fauna abundances

H_0: Benthic fauna abundances are higher in areas experiencing high fishing pressure

H_1: Benthic fauna abundances are lower in areas experiencing low fishing pressure

H_0: Variation in benthic fauna abundance is explained sufficiently by fishing intensity only

H_1: Variation in benthic fauna abundance is explained sufficiently by not only fishing intensity but also by habitat type.

1.3.2 Hypothesis 2

Here we investigate changes in vessels dynamics when different scenarios on fishing spatial restriction are implemented.

H_0: Vessels dynamics do not change when different fisheries spatial restriction are implemented

H_1: Vessels dynamics change when different fisheries spatial restriction is implemented

1.3.3 Hypothesis 3

Here we investigate changes in benthic fauna abundances when different fishing spatial restrictions Scenarios are implemented.

H_0: Benthic fauna abundances do not change when different fisheries spatial restriction are implemented

H_1: Benthic fauna abundances change when different fisheries spatial restriction is implemented

2.0 Literature Review

The European commission is giving a focus to "Blue Growth", looking on ways on how Europe's coasts, seas and oceans can potentially be a source of new jobs and boost the income of its member nations. The focus of blue growth is on marine activities that have a potential for new jobs and growth and include aquaculture, coastal tourism, marine biotechnology, ocean energy, seabed and mining (European Commission, 2012, 2014). The development of new activities such as marine renewable energy (MRE) may have some impacts on fisheries (de Groot et al., 2014)

MSP is gaining increasing popularity in many parts of the world as a way of bringing harmony in management of marine spaces (Foley et al., 2010). MSP is associated with allocating spatial and temporal distribution of human activities in maritime zones to achieve environmental, economic and social objectives (Ehler and Douvere, 2009). Although many of the marine spatial plans advocate for integration of activities for multiple use in an area, some activities are not compatible with one another and are competing for ocean space or have adverse effects on each other. For example, marine renewable energy platforms may be well compatible with aquaculture activities (Buck et al., 2004). Fisheries activities like trawling may cause damage to both the MRE installation devices and to other fishing gears (Rodmell and Johnson, 2003). The development of new activities will increase pressure on the existing users (Alexander et al., 2013). Fisheries being a traditional use of the marine space will most likely be affected by spatial restrictions, such as exclusion zones placed around energy extraction installations (Alexander et al., 2012). These installations will lead to the displacement of fishing effort.

The dynamics of fishing effort displacement is not only in the restriction of fishermen from accessing their traditional fishing grounds but the closed area might also affect the access routes for the fishermen to reach other fishing grounds. This can affect travelling (steaming) time between harbours and fishing grounds, which can lead to significant change in fuel costs and vessel economy (Bastardie et al., 2010a). The choice of where fishermen will relocate their effort can depend on fisheries dynamics (Valcic, 2009) and potential profitability, where for example fishermen concentrate their effort in nearby fishing grounds with potentially larger catches and higher revenue (Bastardie et al., 2010b). With more activities in the offshore areas anticipated in the coming years (Douvere and Ehler, 2009) this will in turn lead to more fishing effort displacement. DISPLACE is a spatial individual vessel-based model, which accounts for parameters determining fishermen's decisions and offers projections of fishing effort displacements based on expected revenues and operating costs (fuel costs) and in response to assumed spatial planning measures (Bastardie et al., 2014, 2013b).

The focus of studies on fishing effort displacement has mostly been to evaluate the economic impacts on the fisheries (Bastardie et al., 2013a, 2013b; de Groot et al., 2014). Nevertheless the impacts of these activities on the marine environment (Douvere, 2008) is also a concern. In most cases when fishing is restricted in an area the fishing effort will be displaced to other fishing grounds where they are bound to increase the fishing pressure of the area, in both cases this might have an impact on the ecosystem through trophic cascades and alteration of benthic habitats (Valcic, 2009). Ecosystem based management (EBM) is being prioritized in efforts to rebuild marine ecosystems (Levin et al., 2009) and specifically ecosystem based approach for fisheries (EAF) (FAO, 2003; Sinclair et al., 2002). EAF emphasizes the consideration of the consequences of any fisheries management action (Link, 2002), For example it's important to evaluate the consequences of fishing effort displaced to previously unfished areas (Dinmore et al., 2003a). The magnitude of the effect of fishing on benthic fauna varies greatly across fishing gears and the type of habitat where the gear is operating (Kaiser et al., 2006). Some fishing activities like demersal trawling can have detrimental impacts on the seabed (Eastwood et al., 2007) . The effect may include reduction of biomass, production and diversity for benthic species (Kaiser and Groot, 2000). Benthic fauna will be affected differently under different levels of fishing pressure levels (de Juan and Demestre, 2012) . The impacts of trawling on benthic species can be profound in previously untrawled area while the magnitude will also depend on the frequency and intensity of natural disturbance (Duplisea et al., 2002; Hiddink et al., 2006). Hence, the ecological characteristics of the benthic fauna also define how these communities will be affected by different fishing activities. For example large and slow-growing species are particularly vulnerable to trawling disturbance (Lambert et al., 2014), Both deposit and suspension-feeders are vulnerable to scallop dredging across gravel, sand and mud habitats, while their response to beam-trawling is dependent upon habitat type; Benthic organisms in soft-sediments are more susceptible to fishing pressure effects and take more time to recover. (Kaiser et al., 2006; Eno et al., 2013; Grabowski et al., 2014)

Several authors have suggested methodologies for effective mapping of fishing effort and deducing displaced fishing effort (Bastardie et al., 2010c, 2013b; Mills et al., 2007; Lee et al., 2010; Miethe et al., 2014), and specifically for displacement from MSP measures (Bastardie et al., 2015). Coupling the fishing effort displacement data with benthic fauna dynamics can provide useful information for assessing the environmental consequences of fishery management actions and inform management decision-making as part of EAF (Hiddink et al., 2006).

3.0 Objectives

The overall objective of this study is to evaluate the importance of the interaction between ecological and economic factors when implementing marine spatial plans. Interaction of both ecological factors (benthic fauna) and economic factors (fisheries gains), will be investigated by combining both Empirical study and Modelling Techniques in Kattegat and Western Baltic area of the Baltic Sea and Assessment and how future marine spatial planning Scenarios will impact these interaction. An attempt will be made to establish area within the study area where less impact will be experienced when fishing spatial restriction area established. Recommendations will be made to marine spatial planners to possibly incorporate modelling techniques that integrate both ecological and economic objectives when establishing marine spatial plans.

The specific objectives of the study were;

1. Evaluating the effects of fishing pressure on benthic fauna abundance in the different habitat across Kattegat and western Baltic area of Baltic Sea.
2. Evaluating the effects of fishing spatial restriction on fisheries dynamics (vessels economy, fishing effort)
3. Determine the likelihood impacts on benthic fauna by different scenarios on spatial restriction of fisheries

4. 0 Methodology

4.1 Study site

The study and analysis focus was on Kattegat and Western Baltic Sea area, covering an area of approximately 66500 km^2 as shown in Figure 2. Fishing activities in the area are a mixture of small scale fisheries and large industrial commercial fishing, fishing for crustaceans' species (*Nephrops* and *Pandalus*), gadoid (cod), flatfish (plaice and sole) and pelagic species (sprat and herring). The analysis primarily focuses on the large commercial vessels (because only these ones are equipped with VMS, see below) using fishing gears that get into contact with the sea bottom during fishing operation mostly trawls.

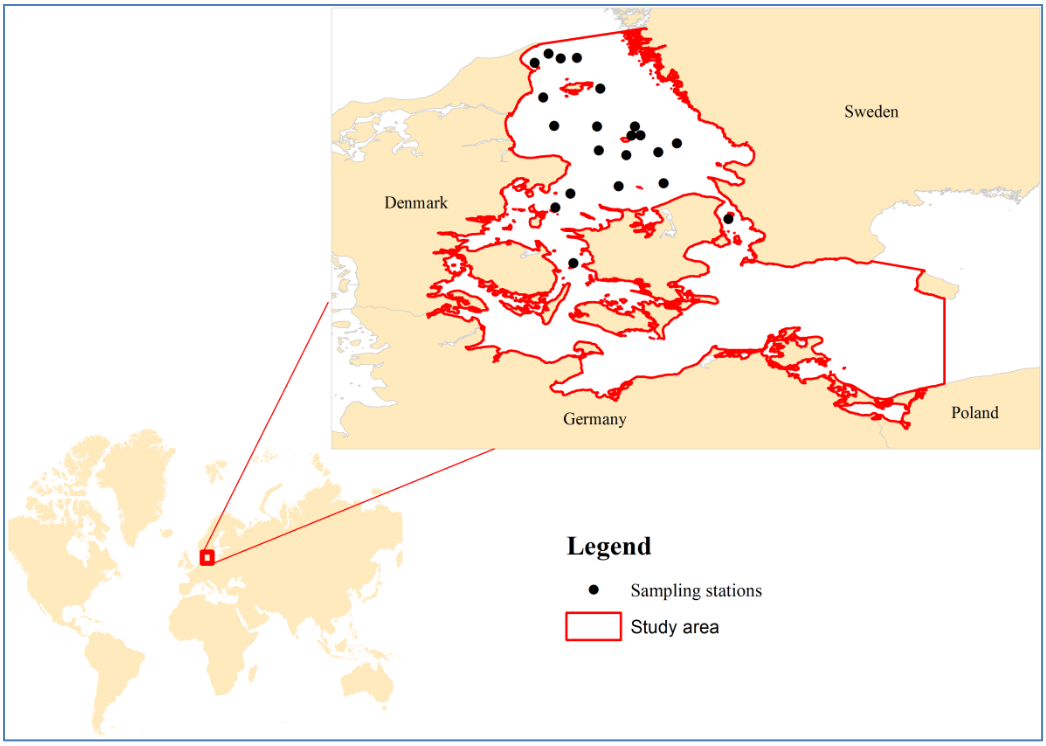

Figure 2: Map of study region Kattegat and Western Baltic area (red area) together with the spatial distribution of sampling sites (black dots)

4.2 Data type and sources and analysis

Key data sets for the study include benthic habitat map, fishing effort data and benthic fauna' data.

4.2.1 Habitat maps

Habitat maps were derived from map Balance project benthic marine landscapes (Piekäinen and Korpinen, 2008), available at balance-eu.org on request. These are maps of marine landscapes and including 60 broad scale habitat types which are defined according to different combinations of bottom substrate, photic zone and salinity level. There is a large gradient of salinity that exists in the Baltic Sea and explains a large part of the structuration of the benthic fauna. Bottom substrates are divided into five classes, bottom substrate: 1= bedrock, 2 = hard bottom, 3 = sand, 4 = hard clay, 5 = mud. Zonation according to photic level are in two classes, photic zone =1and aphotic zone= 2. Salinity zonation was divided into six classes: 1 = 0-5 psu, 2 = 5 - 7.5 psu, 3 = 7.5 -11 psu, 4 = 11 - 18 psu, 5 = 18-30 psu, 6 = <30. In this report for ease of reference, we refer the habitats with their balance project codes; Balance 525 means a habitat in mud substrate and aphotic zone with salinity of between 18-30 psu. The description of the habitat type where the benthic fauna sampling stations were located are presented in Table 1. A complete summary of the physical and environmental characteristics of the station are presented in appendix 1.

Table 1: Description of the habitat types where the benthic fauna sampling stations were Located

Habitat	Description	Number of stations in Habitat
225	hard bottom, aphotic, 18-30 psu,	2
315	Sand, photic, 18-30 psu	2
325	Sand, aphotic, 18-30 psu	1
326	Sand, aphotic, <30 psu	6
525	Mud, aphotic, 18-30 psu	5
526	Mud, aphotic, <30 psu	5

4.2.2 Fishing effort data

Since 2012, it is required by law for vessels greater than 12 m operating in the EU to give their position to authorities while operating in the EU waters using the Vessel Monitoring System (VMS). Fishing pressure was estimated using Danish vessel monitoring system (VMS) data obtained from the Danish (DK) Fishery Directorate in raw and un-interpreted form for all vessels cruising in the study area during 2005–2013, and was processed by the National Institute of Aquatic sciences (F. Bastardie, DTU Aqua). Prior to 2012 only vessels with length greater than 15 m, were required to give their positions. For the analysis we excluded data for vessels less than 15 for comparison purposes. Corresponding logbook data was also acquired. Data processing and analysis for estimation of fishing pressure followed the procedure by(Bastardie et al., 2010c; Hintzen et al., 2012) and further expanded in (Eigaard et al., 2015), and were done using the VMStools package in R.

4.2.3 Benthic fauna

Observation data of benthic fauna from 21 stations across the study area were obtained from National Environmental Research Institute of Denmark (DMU). Data sets were collected using grab core sampler. In each sampling year, three samples were collected at each of the sampling sites and these were put together and the total number of individuals standardized to sampling surface are of 0.0715 m^2.

In our attempt to evaluate the relationship between benthic fauna and fishing pressure we investigated different variable combinations in order to find the right level of the variable that gave the better responses. For example, we investigated the use of benthic fauna individual counts as opposed to individual weight versus abundance, etc., use of Balance level 2 to Balance level 3, functional groups as compared to family or individual taxa.

The response of abundance we adopted the use of benthic fauna abundances as suggested by better (Kaiser et al., 2006) and (Mangano et al., 2014) and confirmed in our exploratory analysis. For the benthic groups we decided to consider functional groups as in (Kaiser et al., 2006). The benthic fauna samples were divided into two groups based on feeding modes either as deposit feeders (DF) or suspension feeders (SF). Species information on feeding modes obtained from the world register of marine species (WoRMS) http://www.marinespecies.org/. We also examined the response of specific re-analyzed sensitive taxa i.e. benthic fauna were scoring from high to low susceptibility to fishing pressure because of their biological traits e.g., feeding, reproduction, body size was done. Species scoring high as sensitive include Astarte, Onoba, Prada, Pagurus and Arctica. We also investigated the response of benthic fauna at family level, simper analysis was done to determine the most important families based on their abundances (done in R using simper {vegan} package). We couldn't get much relationship between fishing pressure and benthic fauna. Although we provide analysis of the functional the response of sensitive taxa and families is provided in the Appendix 2 and 3.

Another point of consideration was the right level of the habitat resolution to work on. A combination of the three habitat parameters would give of habitat type bottom substrate, light penetration and salinity i.e. level 3 would give 48 different combinations of habitat type as shown in Figure (4.) These would be 48% of the habitat while considering analysis at bottom substrate, light penetration (level 2) would cover 84% and considering habitat only i.e. (level 1) would cover 96% of the habits. Although aggregation of the data at level 3 gave a little representation of the study area it gave the best response. The response of benthic fauna abundance is influenced by many factors including depth and salinity (Gray, 1981). Our analysis using habitats that combines bottom substrate, light penetration and salinity gives a better resolution of the analysis in trying to find out specific area of the ecosystem that are impacted. Light penetration is correlated with depth and provides important information for fisheries management and ecosystem based management.

Fishing pressure values were categorized into five or three categories to check the response of benthos under the different mode of categorization. All fishing pressure values were then divided into five classes A, B, C, D, E with 20%, 40%, 60%, 80% and 100% percentiles as the upper limits of the classes or as no, low and high fishing..

4.2.4 Environmental Data

Environmental variables used in this work were gathered as raster layers from the HELCOM website; BALANCE, variables include bathymetry and energy.

4.3 Statistical Modelling of relationship between benthic fauna and fishing pressure

We employed a mixture of methods to understand the relationship between displaced fishing effort and benthic fauna, most of the methods were done in ArcGIS and R software. Generalized linear models (GLM), generalized additive models (GAM) and linear mixed models (LME) were explored to draw functional relationship between abundance of benthic fauna functional groups and fishing pressure in the different habitat types.

4.4 Modelling change in fisheries dynamics using DISPLACE

In this section we aimed to evaluate the ecological-economic effects impacts of creation of spatial restriction to fishing effort. We applied the DISPLACE model (Bastardie et al., 2014) to provide the fishery sector-specific stakeholders and policy makers with an evaluation of the likely effect of the spatial planning.

The DISPLACE model aims to provide a fishery sector-specific way of an evaluating the likely effect of the spatial planning by modelling spatial explicit fishery dynamics and quantifying how the effort displacement will affect the (i) the vessel overall economy and (ii) the other benthic habitats where the pressure is increased. The model includes a consideration of several factors affecting fisheries when accounting for decision making including seasonal conditions, fish and fuel prices, weather conditions and spatial plans. The description of how DISPLACE works are well illustrated in http://displace-project.org/blog/

DISPLACE simulations are based on creation of scenario on fishing activities over a certain period of time, in our analysis our simulations were based on a full calendar year with an hourly time step. The operation of the fishing activities in the simulations are based on the decision making of individual vessels based on spatial temporal changes e.g. stock fluctuations and available space for fishing. For example, under normal time without any restriction, fishermen tend to focus their effort in high profit grounds (among the fishing grounds they know best), the effort allocation will change when seasonal changes occur for the most profitable grounds, changes in effort distribution will also occur when some areas are closed for fishing. The tool enables users to modify the different variables in order to test different management actions. For our case we were interested in evaluating the change in areas available to fish, motivated by creation of some new marine activities that are not compatible with fishing. We created two spatial scenarios; Scenario 1 and 2 are shown Figure 3 A and B respectively as described in the data section and shown in Figure 19a.

The reason for selecting the two scenarios was based on several factors, the first scenario was a closure of an area of habitat. Largely dominated by habitat 525- muddy substrate, in aphotic placed with salinity levels of between 18-30, this habitat indicated to be the most sensitive habitat form our first part of the empirical study on the relationship between fishing pressure and benthic fauna, closing this area will have role of protecting the benthic fauna (conservation goal). Scenario 2 evaluates case a real proposal for spatial restrictions that would create in areas proposed for offshore wind parks... The two scenarios gave us the possibility of comparing different aspects of closed area, for example by comparing impacts of closing big versus small area, sensitive versus insensitive habitats, closing area with conservation goal versus closing area with economic goal.

The results from the tool include the area fished, amount of fishing hours in trips, catches and revenues. Thus the tools gives us the possibility to evaluate the impacts these closures will have both to the economy of the vessel and the ecosystem. In order to achieve robust results we performed 30 stochastic replicates per scenario and averaged the results of each variable.

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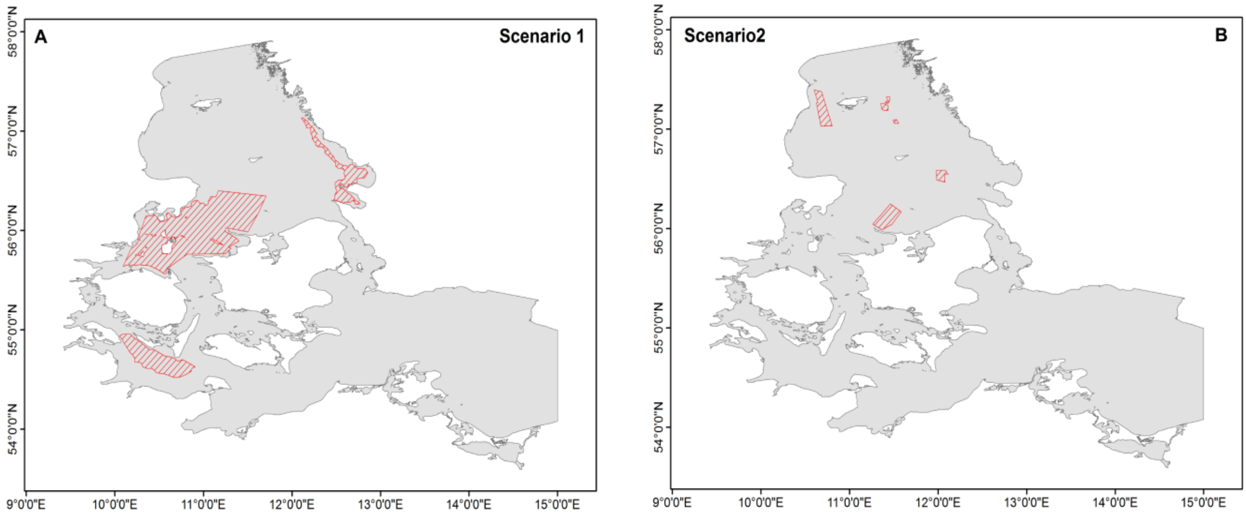


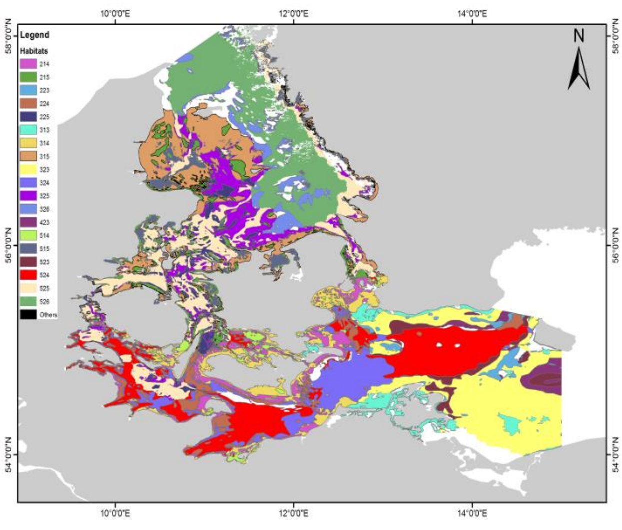
Figure 3: A map showing a representation of fish restriction areas by Scenario 1(A) and Scenario2 (B)

5.0 RESULTS

5.1 Relationship between the fishing pressure and the benthic fauna per habitats (mitigating by the habitat effect)

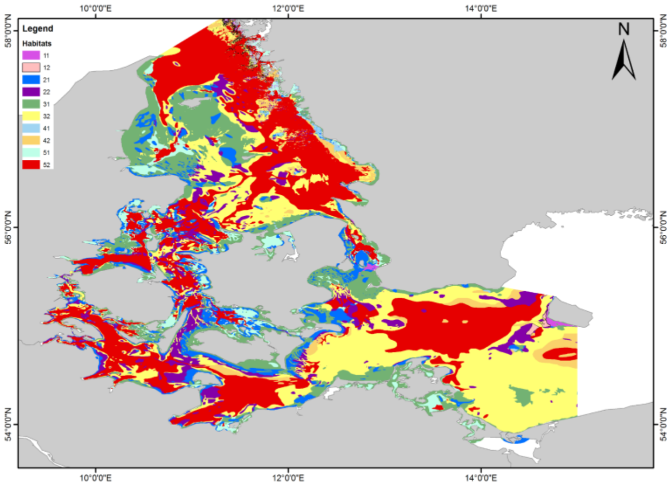
5.1.1 Spatial distribution of habitats in the study area

Habitat types were resumed at three levels Figure 4. (bottom substrate, Photic zone and salinity) and the corresponding coverage in the study area. The habitats highlighted in grey correspond to those that are represented in the benthic fauna sampling stations. The listed habitats represent most of the habitats (over 90%) while the small habitats are aggregated as others. Figure 5 shows the habitats in the study area aggregated to Level 2 (bottom substrate and Photic zone) and Figure 6 shows the habitats in the study area aggregated to Level 1 (bottom substrate only).



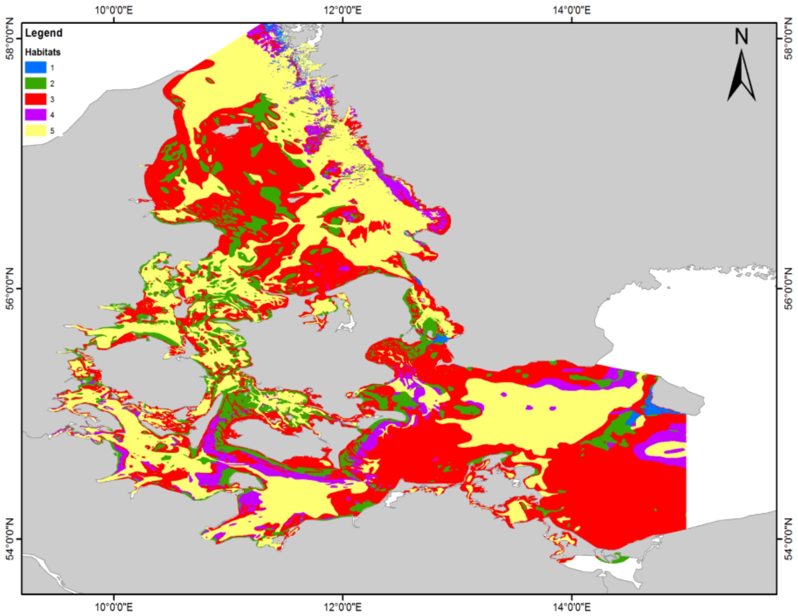
Habitat	AreaKm^2	% Cover
524	7840.57	11.8
323	7661.62	11.6
526	7357.17	11.1
315	5520.02	8.3
525	5418.67	8.2
324	3983.54	6.0
325	3618.57	5.5
314	3033.19	4.6
215	2240.25	3.4
214	2227.94	3.4
224	1909.17	2.9
326	1795.61	2.7
313	1779.94	2.7
225	1663.08	2.5
515	1572.32	2.4
523	1183.34	1.8
423	851.14	1.3
223	752.11	1.1
514	716.03	1.1

Figure 4: Habitats in study area at level 3



Habitat	AreaKm^2	% Cover
52	21861.22	33.0
32	17632.88	26.6
31	11233.16	16.9
22	4930.32	7.4
21	4841.40	7.3
51	2720.62	4.1
42	2311.08	3.5
41	267.42	0.4
11	258.86	0.4
12	246.05	0.4

Figure 5: Habitats in study area at level 2



Habitat	AreaKm^2	% Cover
1	504.91	0.8
2	7862.55	11.9
3	28866.04	43.5
4	4487.67	6.8
5	24581.84	37.1

Figure 6: Habitats in study area at level 1(habitat 1= bottom substrate: 1= bedrock, 2 = hard bottom, 3 = sand, 4 = hard clay, 5 = mud

5.1.2 Environmental Variables analysis in Study Area

Pearson correlation was computed to examine the relationship between all the environmental variables Figure (7). The figure shows the correlation chart, with scatterplot matrix, histograms, kernel density overlays, absolute correlations, and significance asterisks (0.05*, 0.01**, 0.001***). There was a high correlation between energy and bathymetry, in that case we dropped Energy and only retained bathymetry in our analysis. There was no relationship between bathymetry and habitat type thus both variable were considered in the analysis, since habitat level types were similar we retained habitat level three for our analysis at it constituted more habitat information.

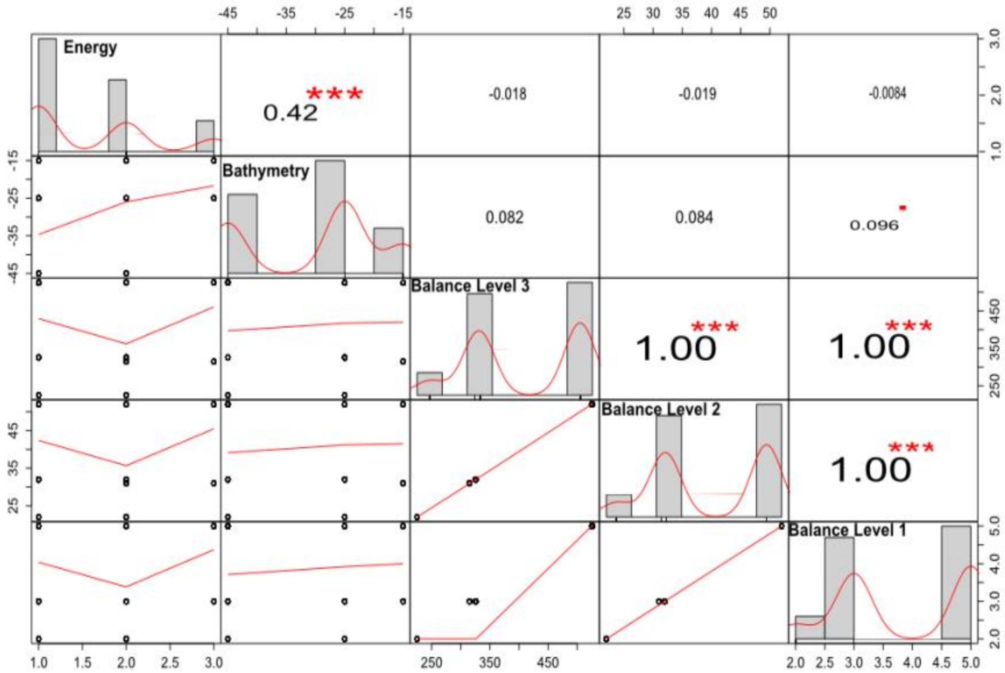


Figure 7: Pearson correlation of environmental variables

5.1.3 Trends in Fishing pressure in the study area.

The total fishing pressure exhibited a decreasing trend between 2005 and 2009, a fairly stable trend between 2009 and 2012 and a sharp drop between 2012 and 2013 (Figure 8).

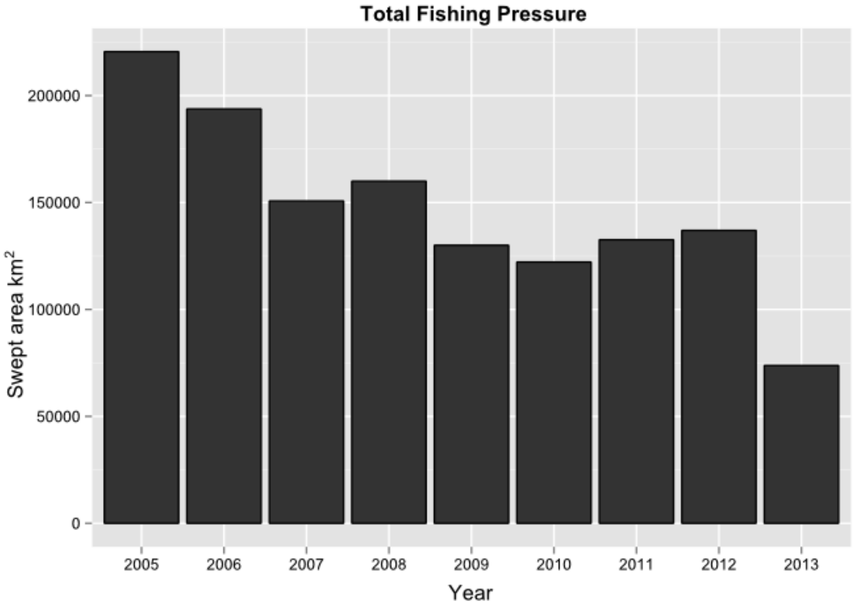


Figure 8: Trends in the total fishing pressure estimated by swept area km2

5.1.4 Trends in fishing pressure in the different habitant levels

We summed up the fishing pressure in the different balance habitats both at level 1, 2 and 3 as described earlier. The Aim here was to see if the trend in the total fishing pressure was similar in all the habitats types. For level 1 there is a steady trends in the sand and hard bottom habitats, fishing pressure in the mud habitats is exhibiting a decrease between 2005-2007 and a steady trend thereafter similar to the one on total fishing pressure (Figure 9). Although most of the fishing pressure is in the mud bottom habitat, the dominant habitat in the study area is sand bottom (see Figure 6). Same trends are exhibited at level 2 and 3. (Figure 10 and 11)

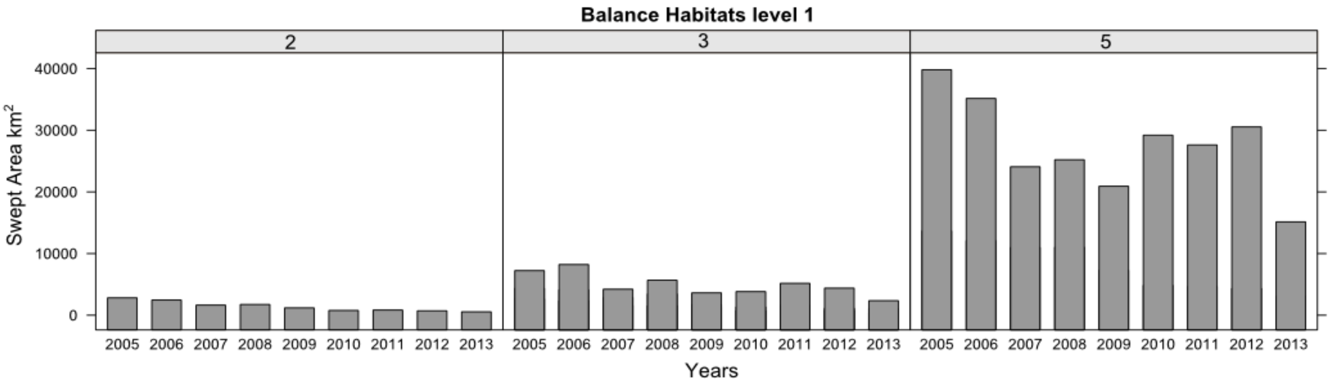


Figure 9: Trends in total fishing pressure at balance habitats level 1, 2=hard bottom, 3=sand bottom , 5=mud bottom

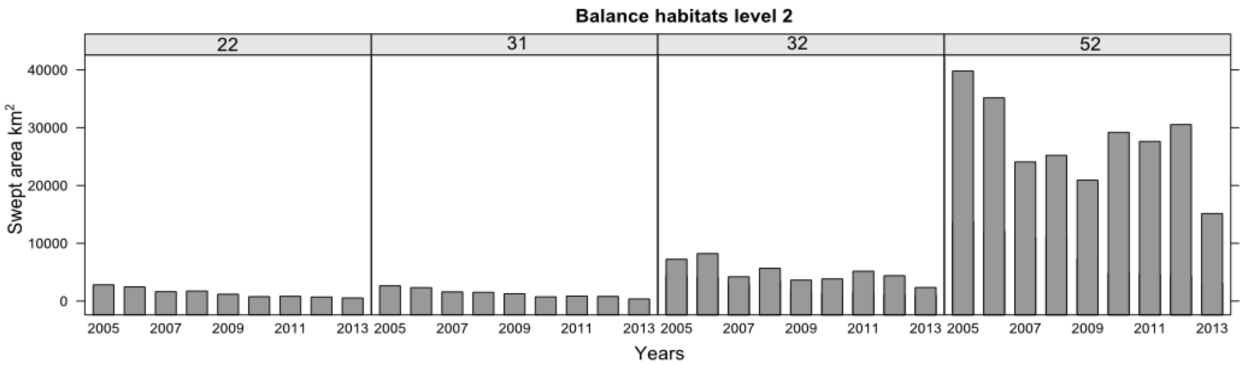


Figure 10: Trends in total fishing pressure at balance habitats level 2, 22=hard bottom-aphotic, 31=Sand bottom-photic, 32=Sand bottom-aphotic,52=Mud bottom-aphotic

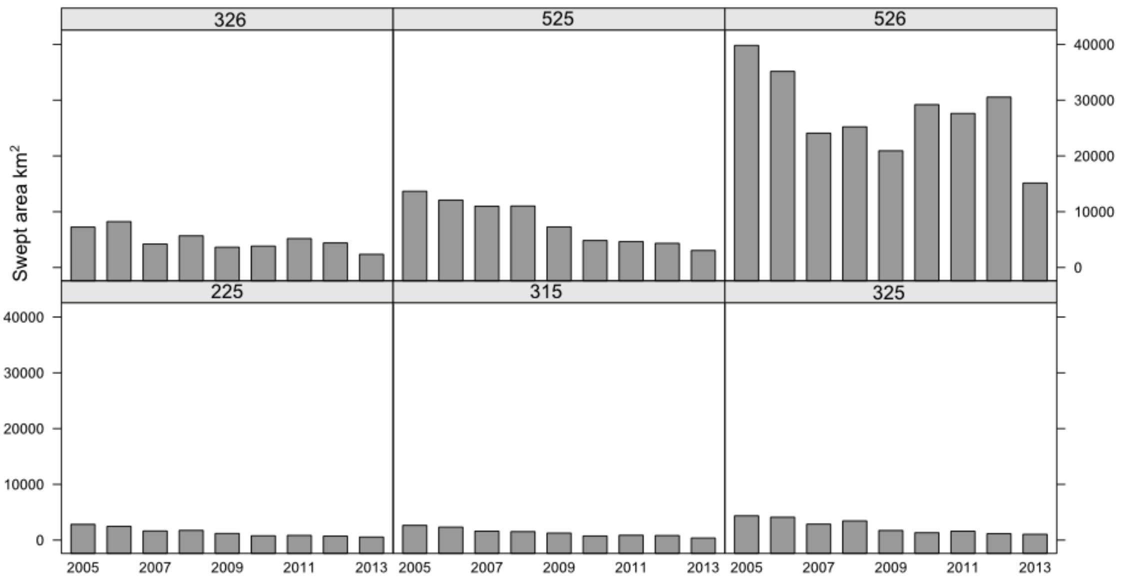


Figure 11: Trends in total fishing pressure at balance habitats level 3, 225=Hard bottom-aphotic-18-30 psu, 315-Sand bottom-aphotic-18-30 psu, 325= Sand bottom-aphotic-18-30psu, 326=Sand bottom-aphotic -<30 psu, 525 mud bottom-aphotic-18-30 psu

5.1.5 Response of benthic fauna to fishing pressure

An analysis of the whole study of the total abundances of the benthic fauna revealed that the number of individual was significantly different ($p<0.001$) across the different categories of fishing pressure. The abundances values showed a decreasing trend as you move from area of high fishing intensity to area of low fishing intensity (Figure 12). The trend seems to be the same for all the functional groups as shown in Figure 13 and 14. Highest abundance values were area with low fishing pressure although suspension feeders did not show a significant difference between high fishing pressure and low fishing pressure indicating that the fishing impacts might be more pronounced on suspension feeders than on deposit feeders.

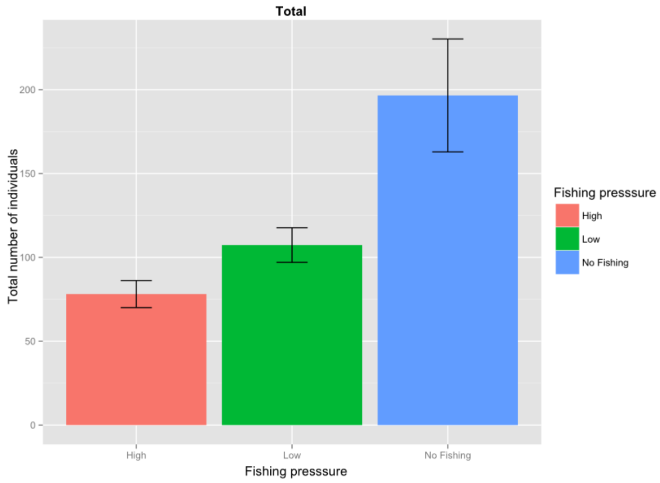


Figure 12: Response of the total number of individuals (all taxa) along a gradient of fishing pressure from high fishing pressure to no fishing (0 fishing pressure)

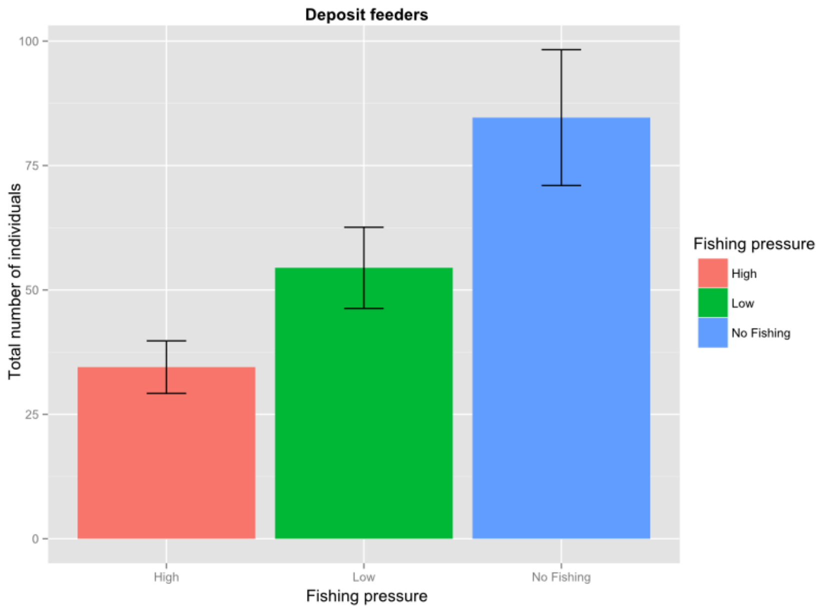


Figure 13: Response of the total number of individuals (deposit feeders) along a gradient of fishing pressure from high fishing pressure to no fishing (0 fishing pressure)

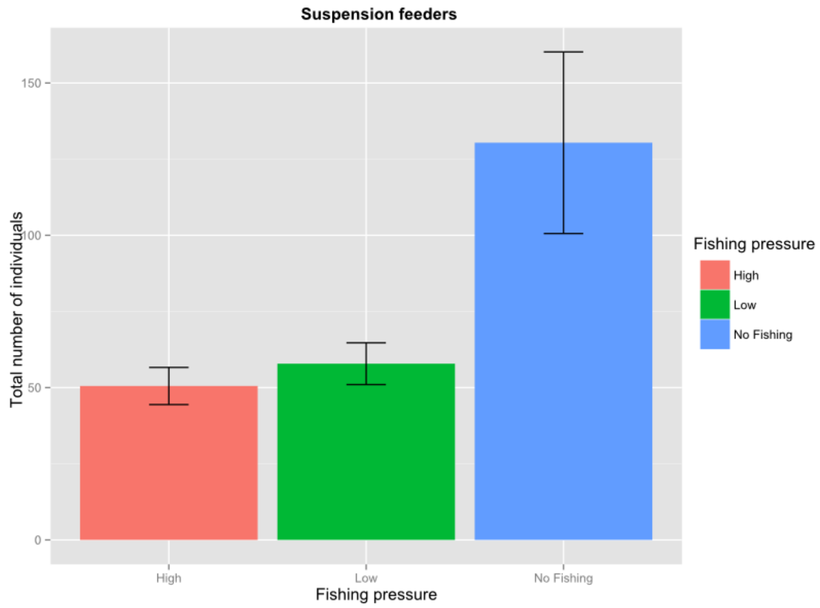


Figure 14: Response of the total number of individuals (suspension feeders) to a gradient of fishing pressure from high fishing pressure to no fishing (0 fishing pressure)

Most of the sampling stations were in habitats 326 (sand in aphotic zone with salinity <30 push), 525 (mud in aphotic zone with salinity of between 18-30 psu) and habitat 526 (mud in aphotic zone with salinity of<30 psu) (Table 1). The amount of fishing pressure was more concentrated in habitat 525 and 526 as shown in Figure 11.

When we used wet weight data the response of the benthic fauna to fishing pressure was very marginal as shown in Figures 15, 16, and 17. Although comparatively habitat 526 showed the lowest wet weight values for the benthic fauna , In habitat 525 there is a huge reduction in benthic fauna abundance moving from area of no fishing pressure to area with fishing pressure but the difference seem to level out as more fishing pressure is increased (Figure 18). This initial impact seems to be stronger for suspension feeders than for deposit feeders (Figure 19 and 20). The same trend can be observed in habitat 225 and habitat 215 and habitat 315. Some habitat seem to have missing values in some fishing pressure categories, it should be noted that the fishing pressure class are a computation of the swept area for the previous year on a station, the stations are uniform for all the habitats, but some habitats had more stations than others Table 1. Also we have some stations which did not experience same trends in fishing pressure.

Habitat 526 did not show any trends on the response of both benthic fauna wet weight to fishing pressure for both functional groups (Figure 15 and 16).

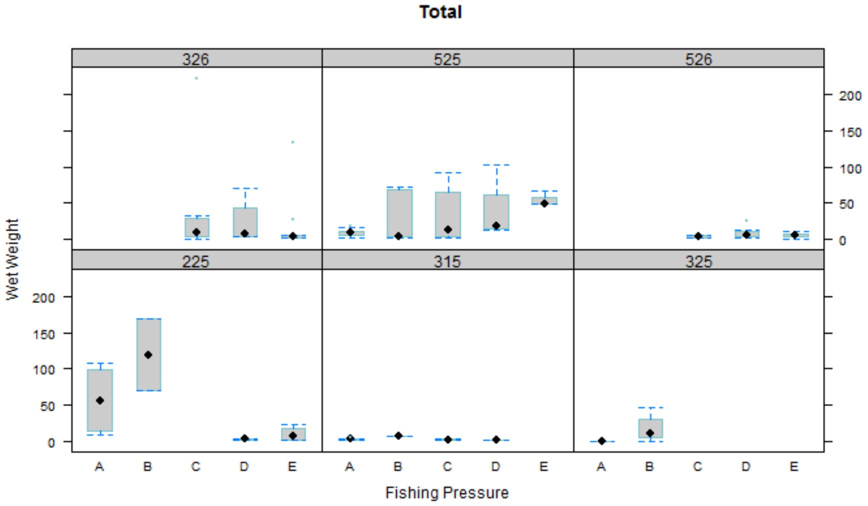


Figure 15: Response of the total wet weight of (all taxas) to a gradient of fishing pressure from A (zero fishing Pressure), B (low fishing pressure) to E (high fishing pressure), grouped per balance habitat at level 3

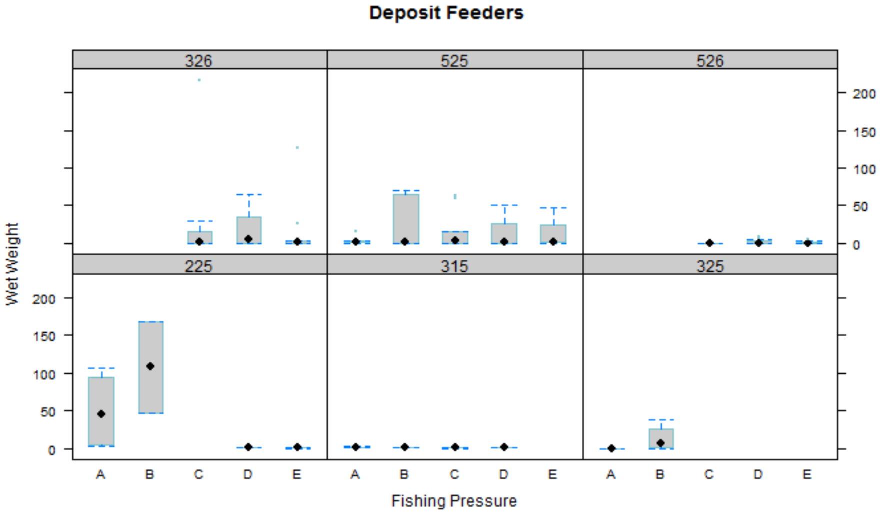


Figure 16: Response of the total wet weight of (deposit feeders) to a gradient of fishing pressure from A (Zero fishing Pressure), B (low fishing pressure) to E (high fishing pressure), grouped per balance habitat at level 3

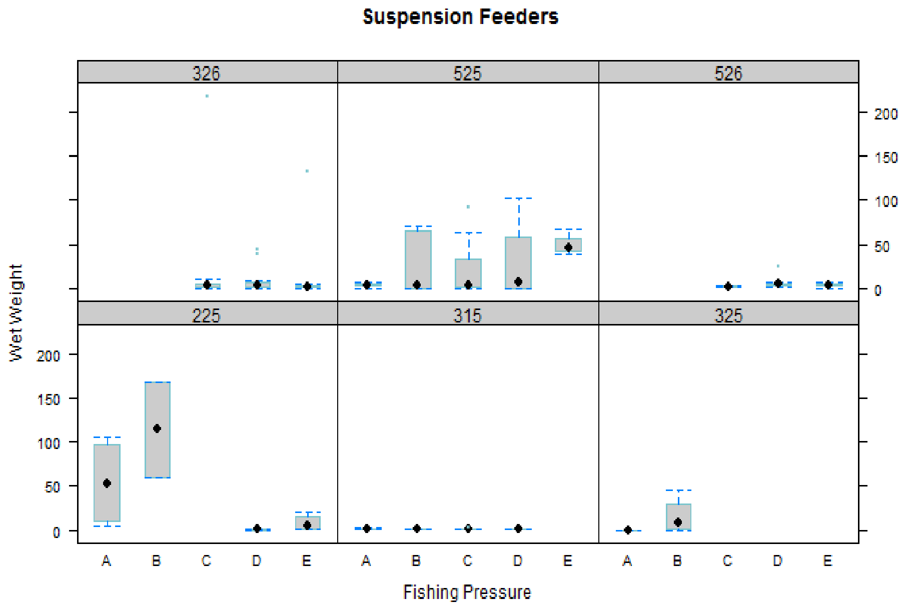


Figure 17: Response of the total wet weight of (Suspension feeders) to a gradient of fishing pressure from A (Zero fishing Pressure), B (low fishing pressure) to E (high fishing pressure), grouped per balance habitat at level 3

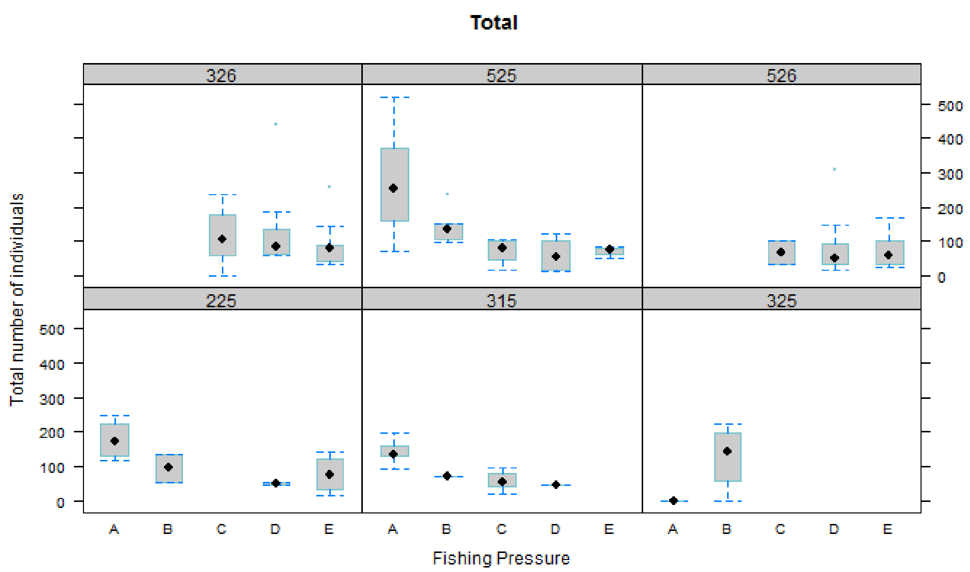


Figure 18: Response of the total number of individuals (all taxa) to a gradient of fishing pressure from A (zero fishing Pressure), B (low fishing pressure to E (high fishing pressure), grouped per balance habitat at level 3

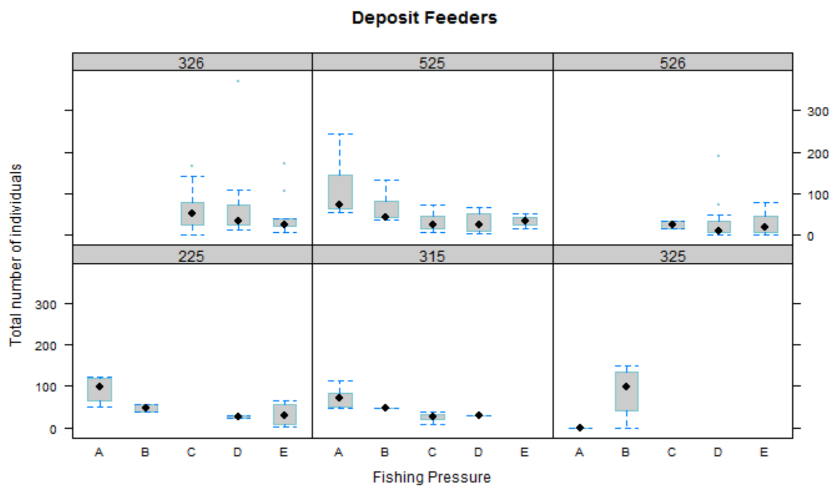


Figure 19: Response of the total number of individuals (deposit feeders) to a gradient of fishing pressure from A (zero fishing Pressure), B (low fishing pressure to E (high fishing pressure), grouped per balance habitat at level 3

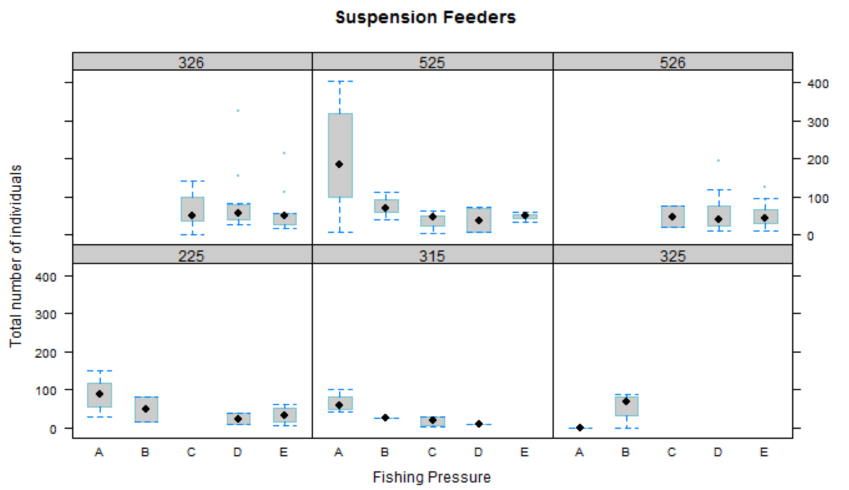


Figure 20: Response of the total number of individuals (suspension feeders) to a gradient of fishing pressure from A (zero fishing Pressure), B (low fishing pressure to E (high fishing pressure), grouped per balance habitat at level 3

Visualising the plots on the effect of fishing pressure to benthic fauna in the previous section, it was evident that areas experiencing higher fishing pressure have low abundances of benthic fauna. The relation is not the same for all the habitats for example habitat 525 revels highest benthic fauna abundance when the fishing pressure is zero. This reveals that other effects of other variables affect the relationship between fishing pressure and benthic fauna abundance. Our main objective here was to use modelling methods (linear models and mixed models) to quantify this relationship between fishing pressure and benthic fauna abundance, for example this allowed us to predict how much benthic fauna abundance would expect in areas where sampling was not done just by using known values of fishing pressure values and other variables.

We used example of similar studies and data available to us to evaluate variables that may affect the relationship. Some of the variable evaluated included habitat, energy and bathymetry. According to Tabachnick and Fidell (2001) the independent variables with high relation (collinearity) should not be included in regression models. We used this criterion to exclude some of the variables e.g. energy which showed a high correlation with bathymetry (Figure 7).

Linear models

We aimed for the simplest models to quantify the relationship between fishing pressure and benthic fauna. We used linear models (McCullagh and Nelder, 1989). The results of the linear model are presented in Table 2. In the models we tested the effects of different variable included habitats and bathymetry.

Table 2: Results of the linear model

Independent Variable	Group	Predictor	Pvalue	R squared
wet weight	Total	Fishing pressure	0.134	0.018
	DF	Fishing pressure	0.069	0.027
	SF	Fishing pressure	0.167	0.015
	Total	Fishing pressure+Habitat	***0.181***	0.027
	DF	Fishing pressure+Habitat	0.034*	0.053
	SF	Fishing pressure+Habitat	0.246	0.023
	Total	Fishing pressure+Habitat +Bathymetry	0.000*	0.438
	DF	Fishing pressure+Habitat +Bathymetry	0.000*	0.3715
	SF	Fishing pressure+Habitat +Bathymetry	0.000*	0.396
Abundance	DF	Fishing pressure	0.038*	0.034
	SF	Fishing pressure	0.105	0.021
	Total	Fishing pressure	0.303	0.009
	DF	Fishing pressure+Habitat	0.101	0.036
	SF	Fishing pressure+Habitat	0.195	0.026
	Total	Fishing pressure+Habitat	0.185	0.027
	DF	Fishing pressure+Habitat +Bathymetry	0.000*	0.236
	SF	Fishing pressure+Habitat +Bathymetry	0.000*	0.182
	DF	Fishing pressure+Habitat +Bathymetry	0.000*	0.2161

The response of wet weight and abundances of all the total benthic fauna and individual functional groups did not show any significant result. The relationship seem to be influenced by habitat type and bathymetry considering the significant values p value < 0.05 as shown in Table 2. Although some of linear models gave significant results, the R squared values were very low. When using linear models the best results that show significance should produce low p values and a high R-squared value. The low p-values and low R-squared values indicates that changes in the fishing pressure are related to changes in the benthic fauna abundances but the models do not explain a lot of the benthic fauna variability. Our model was weak indicating high-variability of the data around the regression line (Faraway, 2005). This can be interpreted from the box plot in (Figures 18, 19 and 20) above, of the relationship between benthic fauna and fishing pressure.

We also note from these figures that at low or on no fishing the number of benthic fauna is very low and as the fishing pressure increases there is a drastic change at first but later there is little change as more fishing pressure is increased. This may assume a decreasing quadratic curve. Adding more variables to a model may help to improve model results. Our dataset had station and year as fixed variables and we opted to add them in our model using linear mixed models instead of linear model as mixed models are good in explaining datasets that have both fixed and random effect (Faraway, 2005).

Linear mixed model

We used linear mixed effect models to assess relationships between benthic fauna abundances and to estimate the abundances of benthic fauna in the whole of the study area. Our hypothesis here was that the variation in the abundance of the benthic fauna was heavily influenced by fishing pressure and also by benthic habitats and bathymetry and that the interaction is different in each sampling station that was repeatedly sampled over the sampling yearWe used R (R Development Core Team 2015) and the lme4 (De Boeck et al. 2011) packages to perform linear mixed effects analyses of the relationships among benthic fauna counts, fishing pressure, habitat type We investigated different models to test the significance of different fixed and random effects. The fixed effects considered were habitats, Interaction and bathymetry and random effects tested were sampling station and time (Year). We started testing the model by adding all the fixed and random effects and sequentially dropping non-significant terms from the full model. We choose to keep in the model random effects that attributed to variance and dropped those that contributed too little variation (see Appendix 4).

Our choice of model involved the performing analysis of variance between two models and comparing the akaike's information criterion AIC (Akaike, 1974), where model with smaller AIC was preferred (De Boeck et al., 2011). Our final selected model with the Best AIC used (fishing pressure *balance) as fixed effects and sampling station as the random effect. Our predicted parameters values using our model are shown Table 3 and a summary of the Chi-square values and the corresponding p-values were obtained from hypothesis tests using the likelihood ratio statistic (Table 4).

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Table 3: Results of the linear mixed-effects bathymetry and sampling station as a random variable

Linear mixed model fit

Abundance ~ FP* Balance + (1 | Station)

	All		Deposit feeders		Suspension feeders	
Fixed Effects	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
(Intercept)	65.31	34.19	61.96	43.48	70.65	30.21
FP_1yr	-4.15	4.65	-3.36	6.18	-5.59	5.15
Balance315	-23.40	47.61	-24.16	60.48	-21.29	41.84
Balance325	-72.44	57.93	-68.00	73.60	-78.87	51.25
Balance326	14.49	40.07	20.87	51.04	5.05	35.84
Balance525	19.44	39.68	39.04	50.37	-1.86	34.70
Balance526	-20.28	41.28	-1.75	52.66	-40.56	37.40
FP:Balance315	3.80	24.69	0.92	32.96	0.16	28.34
FP:Balance325	881.55	251.64	697.26	339.04	1066.48	310.75
FPr:Balance326	-1.47	6.17	-1.21	8.21	-0.68	6.94
FP:Balance525	-0.70	5.48	-0.53	7.30	-0.40	6.18
FP:Balance526	3.23	5.41	1.65	7.21	5.41	6.15

Table 4::Chi-square values and the corresponding p-values obtained from hypothesis tests

	All		Deposit feeders		Suspension feeders	
Fixed Effects	Chi-square	*P* -value	Chi-square	*P* -value	Chi-square	*P* -value
(Intercept)	3.40	0.07	1.95	0.16	4.96	0.03
FP_1yr	0.79	0.37	0.29	0.59	1.16	0.28
Balance315	0.24	0.62	0.16	0.69	0.26	0.61
Balance325	1.51	0.22	0.84	0.36	2.27	0.13
Balance326	0.13	0.72	0.17	0.68	0.02	0.89
Balance525	0.24	0.62	0.59	0.44	0.00	0.96
Balance526	0.24	0.62	0.00	0.97	1.15	0.28
FP:Balance315	0.02	0.88	0.00	0.98	0.00	1.00
FP:Balance325	11.96	0.00	4.15	0.04	11.16	0.00
FP:Balance326	0.06	0.81	0.02	0.88	0.01	0.92
FP:Balance525	0.02	0.90	0.01	0.94	0.00	0.95
FP:Balance526	0.36	0.55	0.05	0.82	0.77	0.38

With the modelling of benthic fauna response to interaction between fishing pressure and habitat it was possible to get various slopes per habitat and compare the performance of the benthic fauna in each habitat.

5.2 Assessing impacts of scenarios on fisheries dynamics

5.2.1 Changes in fishing Effort

Results from DISPLACE model for the spatial restriction caused by Scenario 1 would lead to an overall loss of 10% of area available for fishing while Scenario 2 will lead to overall loss of 1% of study area available for fishing. Changes in area km^2 of fishing area for Scenario 1 and Scenario 2 for the habitats studied for benthic fauna dynamics are shown in (Figure 21) while a summary of the changes for all the habitats in the study area are presented in Appendix 5.

Our fleet modelling showed that fishing effort (in swept area) will reduce by 2% over all under Scenario 1 while, Scenario 2 presents no important changes(<1%) in fishing effort (swept area). For the habitats that were studied for benthic fauna abundance fishing effort (swept area) will be reduced in habitat 525 which is was the target habitat closure for this scenario while the greatest gain in fishing effort will be in habitat 315 (+33%) (Figure 22).

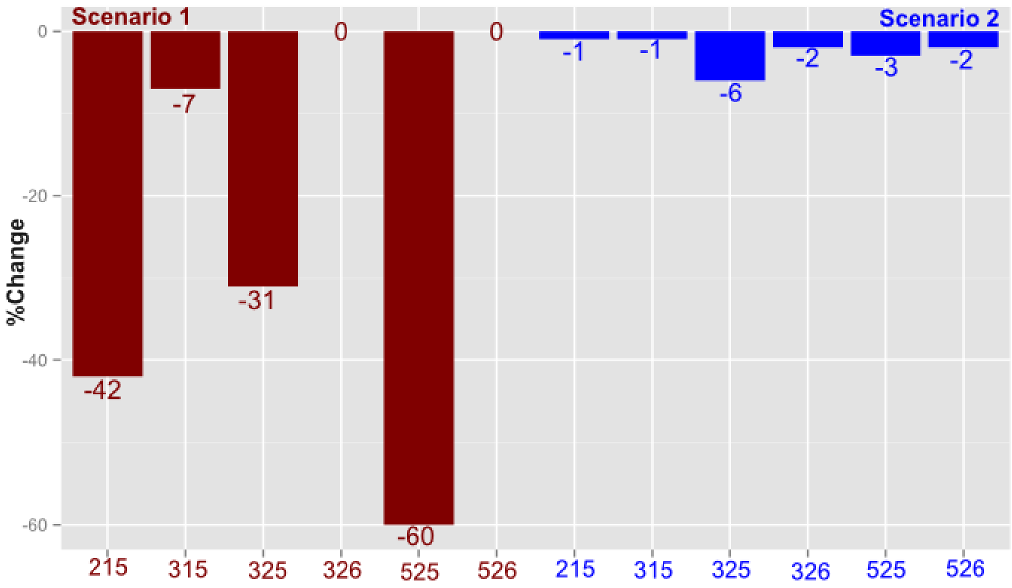

Figure 21: Changes in area (km^2) of fishing area, for the habitats studied for benthic fauna' dynamics

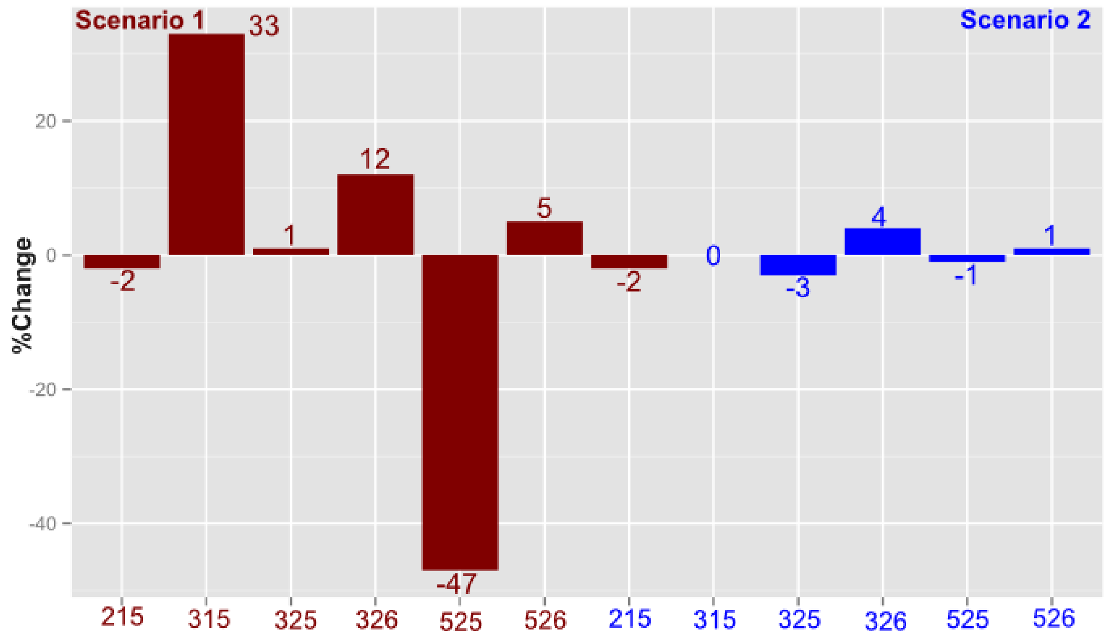

Figure 22: Changes in swept area year $^{-1}$,) (Scenario 1 and 2), for the habitats studied for benthic fauna' dynamics

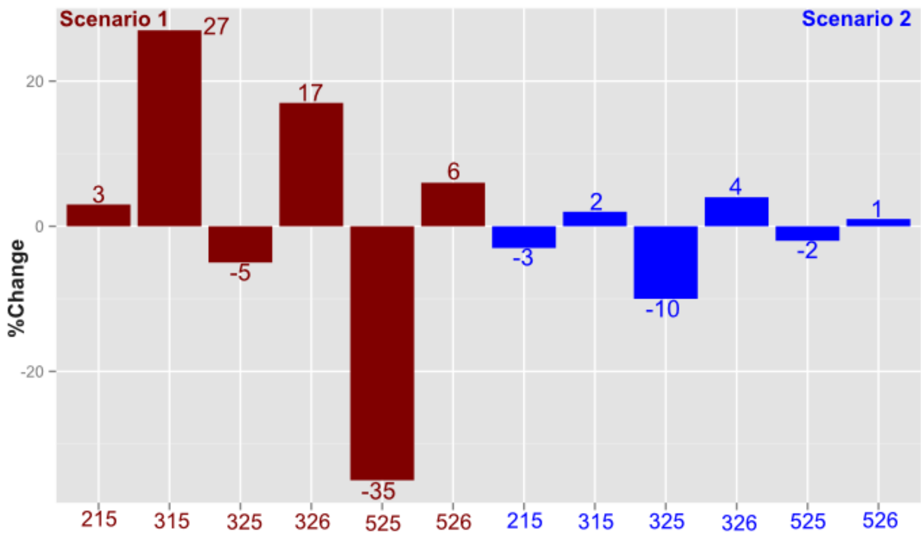

Figure 23: Changes in fishing effort (hours fished) (Scenario 1 and 2), for the habitats studied for benthic fauna dynamics

Habitat 525 will experience the largest reduction in the number of hours fished and the largest increased in fished hour will be habitat 315(Figure 23)

The changes in the spatial distribution of the effort are shown in Figure 24. A pattern of decrease of fishing effort inside the closure and an increase in fishing pressure in area close to the closed area is evident especially for Scenario1. Scenario 2 depicts less changes spatially for the swept area probably because the spatial restriction is much smaller in size compared to Scenario 1. Interestingly the distribution of changes are not concentrated in the area near the closures, area far much further from the closure are and experiencing both positive and negative changes likely due to a change in target species for some of the impacted vessels.

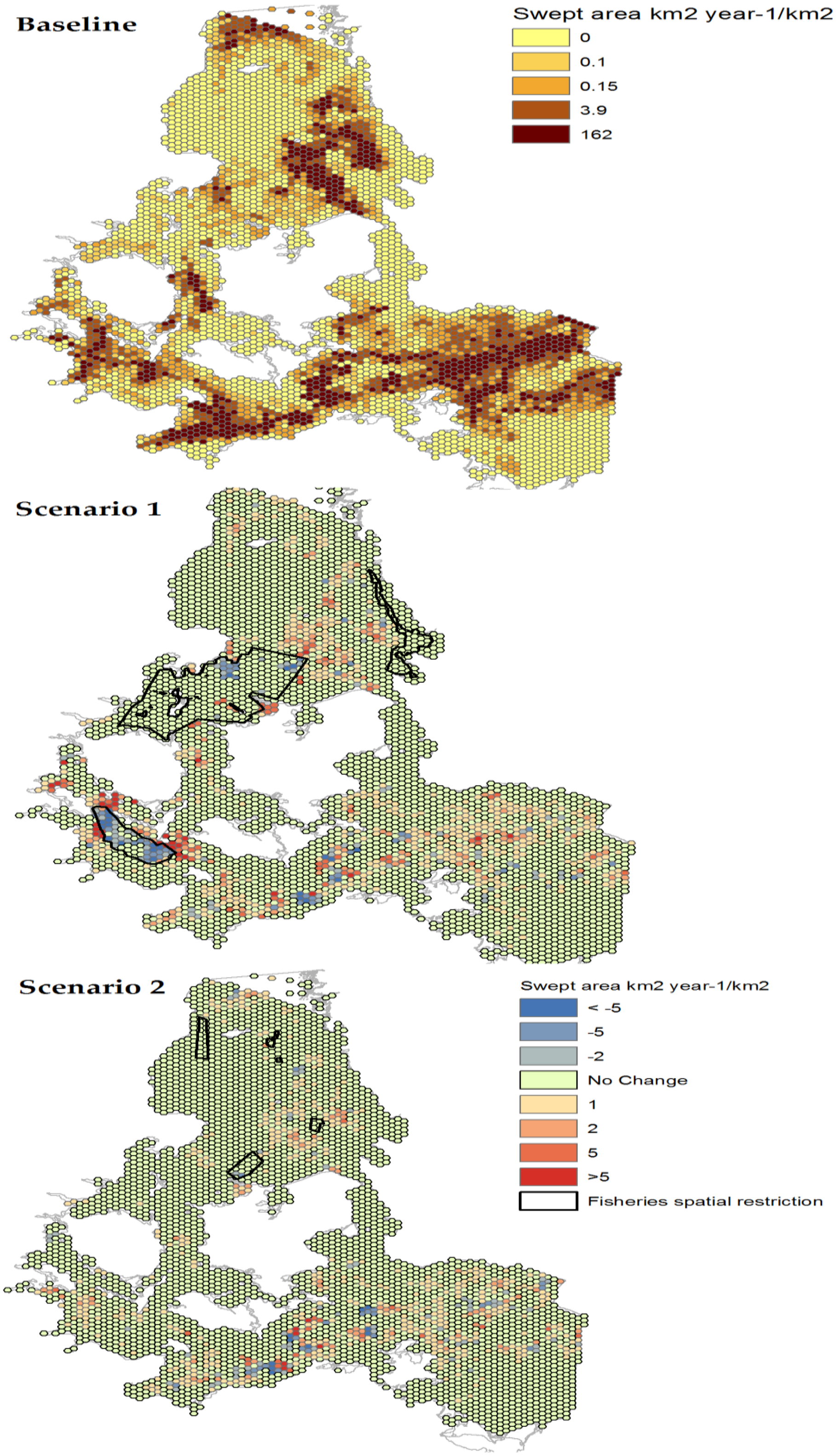

Figure 24: Spatial distribution of the displaced fishing effort

5.2.2 Changes in vessels revenues

Our fleet modelling showed that the spatial restriction caused by Scenario 1 would lead to an overall loss of profit increase of 4%. In this scenario most vessels are bound to make some profits as shown in Figure 25. A small proportion of the vessel will be adversely affected (over 100,000 euros loss) while of the vessels will experience huge gains (over 100,000 euros loss) (Figure 25).

For Scenario 2 the fleet modelling showed that it overall increases the profits by 5%. In this scenario most of the vessels will potentially make profits. A few vessels fall in the extreme ends of adverse profits or loss as shown in Figure 25.

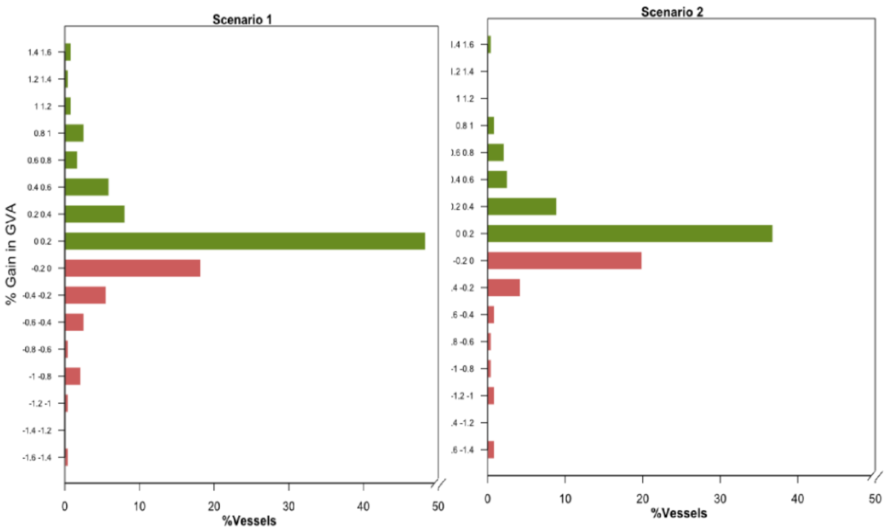

Figure 25: Percentage of vessels experiencing various economic gains under the two scenarios (Log-ratio of the gross added value (GAV) compared to the baseline GAV)

The changes in the gains by the vessels could be attributed to change in fuel costs, underlying stock developments, and a change in landing composition when the catches are made out of different target species.

The changes in the vessels gains did not vary much among the scenarios (Figure 26), despite the large area closed in Scenario 1; this is because not that many vessels were used to visit this zone before the closure. There was some large gain and losses in gross added value for some of the vessels, but most of the vessels experienced little changes in the vessel economy. If there are losses in some in some individual economy, the spatial restriction of some areas did not actually have an impact on the overall economy; there was little difference in the overall revenue from the three scenarios as indicated by Figure 26. This is the result of the gains in some vessels cancelling out the losses in our vessels bringing the balance in the total profit.

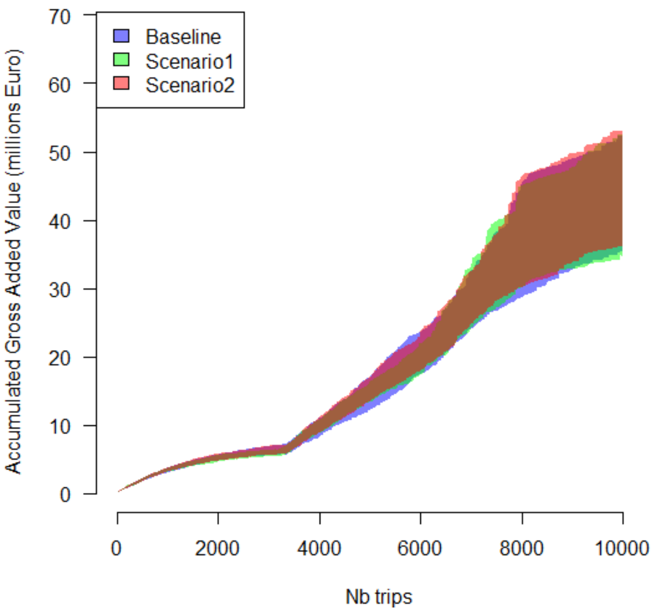

Figure 26: Accumulated gross added value by Scenarios

5.3 Linking scenario to change in benthic fauna abundances.

The final step of our study was to estimate the abundance of benthic fauna under the different scenarios. We recall the model of the relationship between the abundance of benthic fauna and fishing pressure as described in the first section. Our model based on the empirical data of both gave the benthic fauna as

$$63.079 + C - 3.408 * \frac{swept\ area}{6.25}$$ …………..Equation 1

Where *C* is the y intercept of the benthic fauna abundance in individual habitat type from the mixed model result (Table 3).

When we substitute the value of swept area with the simulated swept area values under the different scenarios in equation 1 and the y intercept of the benthic fauna in each habitat studied in the we get the predicted benthic fauna abundance values under the different scenarios per habitat. Figure 27 show the expected changes for simulated data in Scenarios 1 and 2 for the benthic fauna abundance in each of the habitat

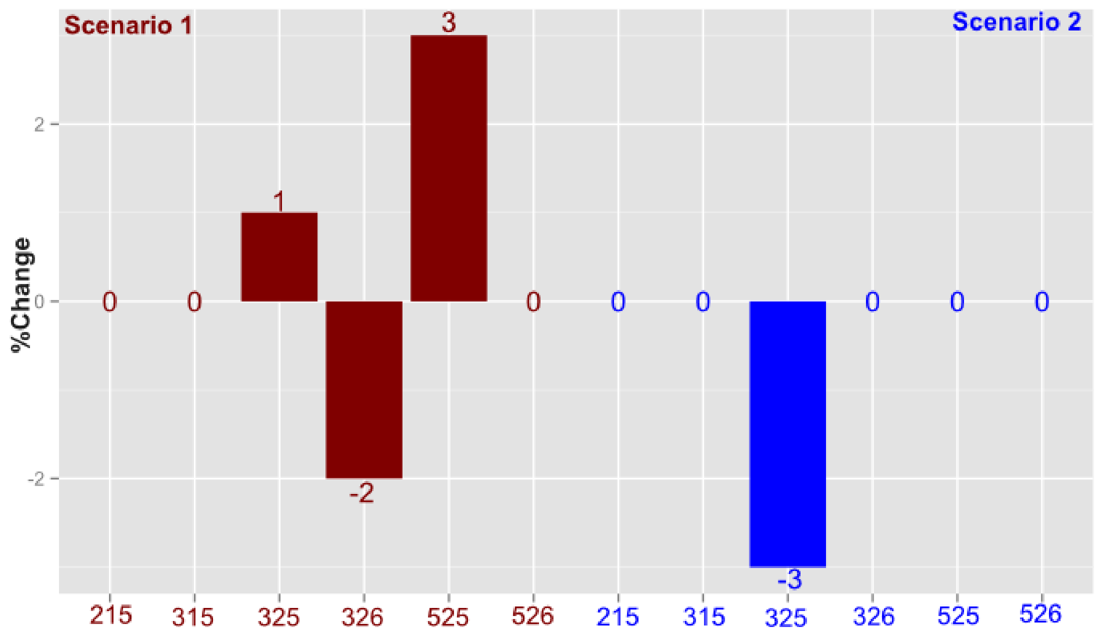

Figure 27: Expected benthic fauna abundances under the Scenario 1 and 2in the studies habitats

By relating these results to changes in both fishing area, effort, economic and our empirical study on relationship between benthic fauna and fishing pressure we are able to have a close look at the impacts of each scenario on different management components. Example for Scenario 1 we see that displaced pressure could result in 1% increase in overall benthic fauna abundance (but +3 % in the sensitive habitat), while wind farm implementation in Kattegat could likely not change the overall be benthic fauna abundance but decrease the benthic fauna abundance in sensitive habitat 325 by 3% (Figure 27).

Figures 28 and 29 present a summary of all the results for the different aspects of fisheries change under the two scenarios.

A summary of the results of summary changes

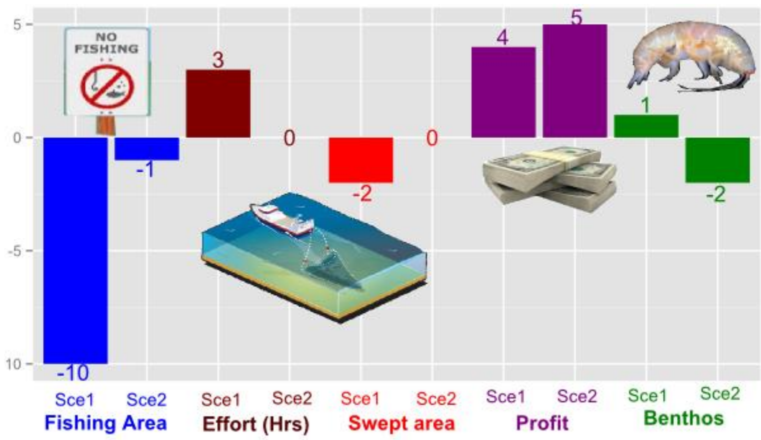

Figure 28: Summary of the overall changes

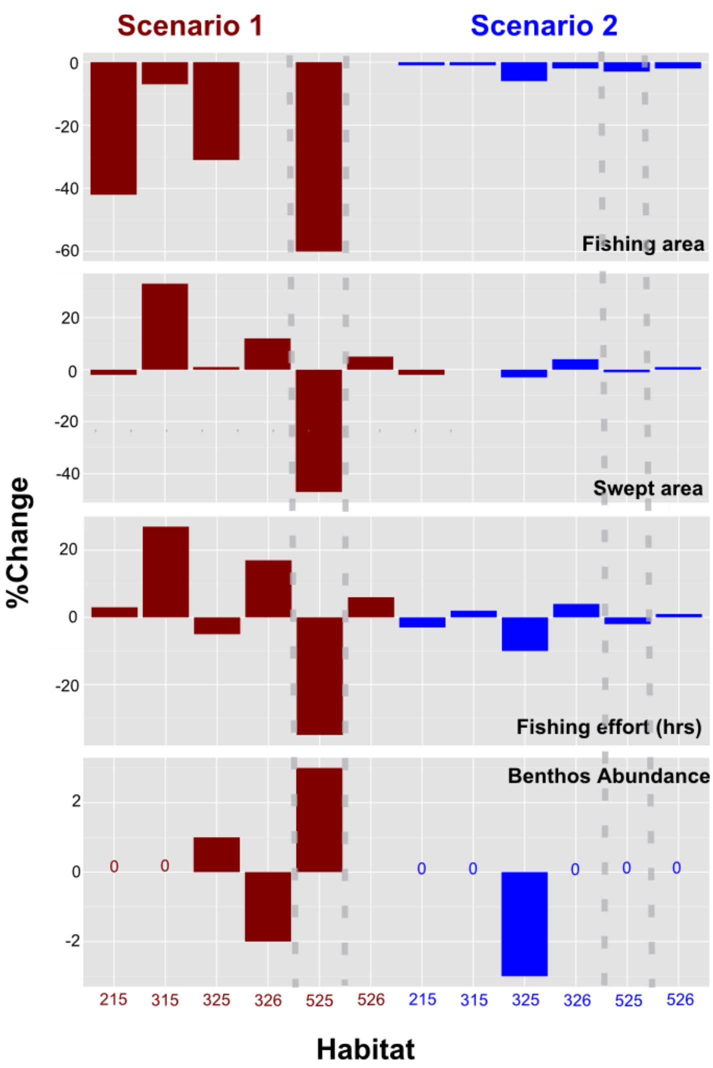

Figure 29: Summary of changes per Balance habitat

6.0 Discussion

6.1 Impact of displaced fishing pressure of benthic fauna

With the increase in competition for marine space, we can anticipate for a reduction of areas available for fishing in favour of other emerging marine activities. Displaced fishing effort will impact fish populations and the environment elsewhere (Dinmore et al., 2003). Our study demonstrates that fishing pressure is negatively related to benthic fauna in some habitats. On the other hand, the impacts of fisheries spatial restriction depends on a case to case basis and depends on the biology of the target species and the dynamics of the fishery (Dinmore et al., 2003). It's there necessary therefore marine managers to develop tools to help evaluate spatial restriction on fisheries on a case to case basis. Our methodological approach has enabled us to estimate the potential impacts of displaced fishing effort both on the vessel economy and on benthic fauna in two contrasting scenarios. Our Scenarios 1 is and 2 represent a closure of 10% and 1% of the study area respectively, and results showed that this leads to an overall increase in benthic fauna abundance by 1% and a decrease of 2% respectively. This latter result firmly demonstrates that the amount of area closed does not necessarily correspond to the magnitude of the change on other ecosystem components, e.g. the overall benthic fauna abundance, and advocate for the use of models capable of anticipating those effects.

MSP involves foreseeing and expressing what conditions are desirable for the future and putting on measures to meet the objectives (Gilliland and Laffoley, 2008). Our approach could be used to assess the impacts of different marine spatial planning scenarios especially in evaluating fisheries-related objectives. The interesting finding from our study is that displacement of fisher effort does not necessary cause overall harm benthic fauna in all cases. This gives an opportunity for planners to make decision that will make optimal decision when making spatial restrictions measures.

6.2 Winners and losers' in marine spatial planning

Contrary to the expectation of many stakeholders the spatial allocation of activities e.g. (wind farms, marine reserves) under marine spatial planning is not a win, when activities are allocated there will be winners and losers (Ehler, 2012). The decision of who wins and who loses depends on the long term plans of the marine spatial plan (Gilliland and Laffoley, 2008). The European union directive for the establishment of a framework for marine spatial planning encourages the promotion of MSP that minimizes conflict, promotes economic growth whilst releasing a good environmental status (European Parliament, Council of the European Union, 2014). This leaves big challenges to environmental managers and planners of realizing a plan that incorporates both environmental gain and economic gains.

Our scenario evaluation brings out a comparison of two important aspects of marine management (economic gains and environmental conservation). Scenario 1 primarily involves spatial restriction of sensitive habitats (conservation goal) while Scenario 2 are spatial restriction for development of windfarms (economic goal). Scenario 1 leads to an overall loss of increase of 4% in fisheries profit and an increase in benthic fauna in the sensitive habitat by 3%. On the other hand, Scenario 2 leads to a total increase of 5% of fisheries profit but would reduce the benthic fauna by 2%. The two scenarios offer different situations to consider when making decisions of either to make economic gains or protect the benthic fauna.

Several methods have been employed to help decide the best option for spatial allocation of activities, e.g. tradeoff analyses (White et al., 2012). The criteria for the choice of scenario would be to choose the scenario that does not lead to irreversible environmental changes. However, if we identified relationships between fishing pressure quantifications and local benthic fauna abundances, our study cannot address yet the full dynamic of it, some biological processes being still lacking (e.g. the recovery rate of benthic fauna abundance after pressure occurrence).

6.3 Advancing ecosystem based management under marine spatial planning

The findings from our study have potentially important implications for the role of marine spatial planning in promoting the conservation key ecosystem functions; specifically when making spatial decision that will lead to the redistribution of fishing effort to other habitats. Redistribution of fishing effort is highly influenced by economic factors and underlying stock developments (Bastardie et al., 2014). In such a scenario where a certain amount of effort is displaced e.g. in Scenario 1 as discussed, the focus of the fishers will be to improve profitability. The results here reinforce the need to carefully think of modelling scenarios of behavioural responses of fishers both in economic terms and their likelihood impacts on the ecosystem. Such studies that combine both economic and ecological impacts are scarce. The issues to consider when assessing the impact of spatial restriction are complex; For example from our empirical study in Figure 18 we can see that as fishing pressure increases, the population of benthic fauna abundance decreases. The effects of fishing pressure on benthic fauna is highest in the first trawling event scenario, in subsequent trawling events the effects is much lower, the graph of the response of benthic fauna abundance to fishing pressure take a big drop in the beginning and gets less steep as the fishing pressure increases, this results are consistent with other similar studies on benthic fauna (Kaiser et al., 2006). This implies that a scenario that displaces effort to pristine areas has a much bigger impact than displacing effort to already impacted areas (Kaiser, 2005; Jennings et al., 2001).

Although some of the factors that come into play when evaluating the impact of bottom trawling on benthic ecosystem, e.g. the recovery of benthic fauna in different habitats (Lambert et al., 2014), production of benthic fauna in area of effort restriction (Hiddink et al., 2006), habitat fragmentation (Eggleston et al., 1999) and other ecosystem factors were a limitation in our study, the results points out that balancing ecological, economic, and social goals and objectives is important when making marine spatial planning decision.

6.4 Evaluating future conditions based on the scenarios

Both of our scenarios lead to the overall slight increase of vessels economy in average. The interesting part of the results is that despite the overall increase of the vessels gains, at individual scale some vessels are making huge profits while some vessels will make massive loses. This shows that in the case of this scenario of spatial restrictions some vessels are becoming more efficient and making more profits at the expenses of the other making losses (Bastardie *et al*., 2013). When fishermen experience huge losses they may be forced out of business (Abernethy *et al*., 2010). If the losses happen to a huge number of vessels it can lead to collapse of even a fishing community (Stead, 2005). It is estimated that the windfarms farms will increase by 6000% by the year 2030 (WWF, 2010) in the study area. This increase will hugely reduce significantly the fishing vessels in the Baltic. Does a reduction in number of fishing vessels signify fewer impacts on the benthic fauna? Our evaluation of Scenario 2 has shown that reduction in fishing effort doesn't necessary mean a positive effect on the benthic fauna. Fisheries are regulated by the EU quota levels, a decrease in fleet may mean increased quotas to fewer vessels which may imply same impacts (WWF, 2010).Thus the efficiency of the remaining vessels will increase (Bastardie *et al*., 2013). Furthermore the construction phase and implementation phase of windfarm installation may have negative impacts on benthic fauna which will ultimately affect the fisheries (Rodmell and Johnson, 2003) which may aggravate the impacts.

Our approach of analysis enable marine managers and planners to understand who and where negative and positive impacts are bound to occur, this is critical in making sure that measures are taken to counter the negative impacts of the planning scenario , example planning for a compensation mechanism for the adversely affected vessels for the scenarios

For the areas which are going to experience increased fishing pressure, the effects might be detrimental. Some habitats are able to recover from extreme events of trawling disturbances while for others it may take quite a long time. benthic fauna have a different way of responding to fishing pressure, e.g. slow growing species will take much longer to recover than short growing species (Kaiser et al., 2006). The removal of benthic fauna by fishing related events, does not only affect benthic fauna structure, reproductive state and recovery, but also other ecosystem services that the organism were offering (Reiss *et al*., 2014).

It is therefore important for assessment to be conducted and caution be taken when allocating activities that may lead to fisher displacement to areas where they can be more harmful to the ecosystem. The possible impact on benthic fauna' effects should be explicitly considered if enhanced ecosystem function is the overall goal of the marine spatial plan.

7. Conclusion and Recommendations

7.1 Conclusion

The assessment of the potential impact of marine spatial planning scenarios on benthic environmental individual vessels level provides a new approach for marine managers to effectively evaluate different scenarios and consider the most feasible option during the initial planning period.

The opportunity to combine datasets from fisheries and benthic fauna communities is rare and enables us to tend toward a holistic evaluation of the ecosystem. This study has presented us with an opportunity to employ modelling techniques in evaluating planning scenarios in a really simplistic way that can easily be understood by stakeholders and decision makers.

The study has shown that variations in benthic fauna abundances in the study area can be explained by the different levels of experienced fishing pressure on sites. A much sensitive variation is revealed in habitats with muddy substrate. Future scenarios of fisheries economy can be successfully simulated at individual vessels level with information on stocks and fuel costs to provide insights of the impacts of planned fisheries spatial restriction on benthic fauna. Our study also showed that non-linear effects from the displacement of fishing effort on components of the marine ecosystem are to be expected, which makes the use of modelling tools for anticipating them very valuable.

It is difficult when doing marine plans to maintain a win-win situation for all sectors; ordinarily there will be winners and losers. It is the responsibly of the planner to evaluate the scenario based on the desired goals of the plan to strike a balance between economic gains and conservation goals. The management measures to be taken should be then evaluated for their effectiveness, efficiency and ability to meet the expectations of the stakeholders before implementation.

7.2 Recommendations and options for future work

- Develop of modelling framework that includes the dynamics of both the fisheries and benthic fauna community are essential to meet public demands for ecosystem based fisheries management,
- Encourage marine spatial planners and managers to use models that integrates all aspects of the ecosystems in management,
- Conduct benthic fauna sampling in a manner they will enable representation of most of the habitats

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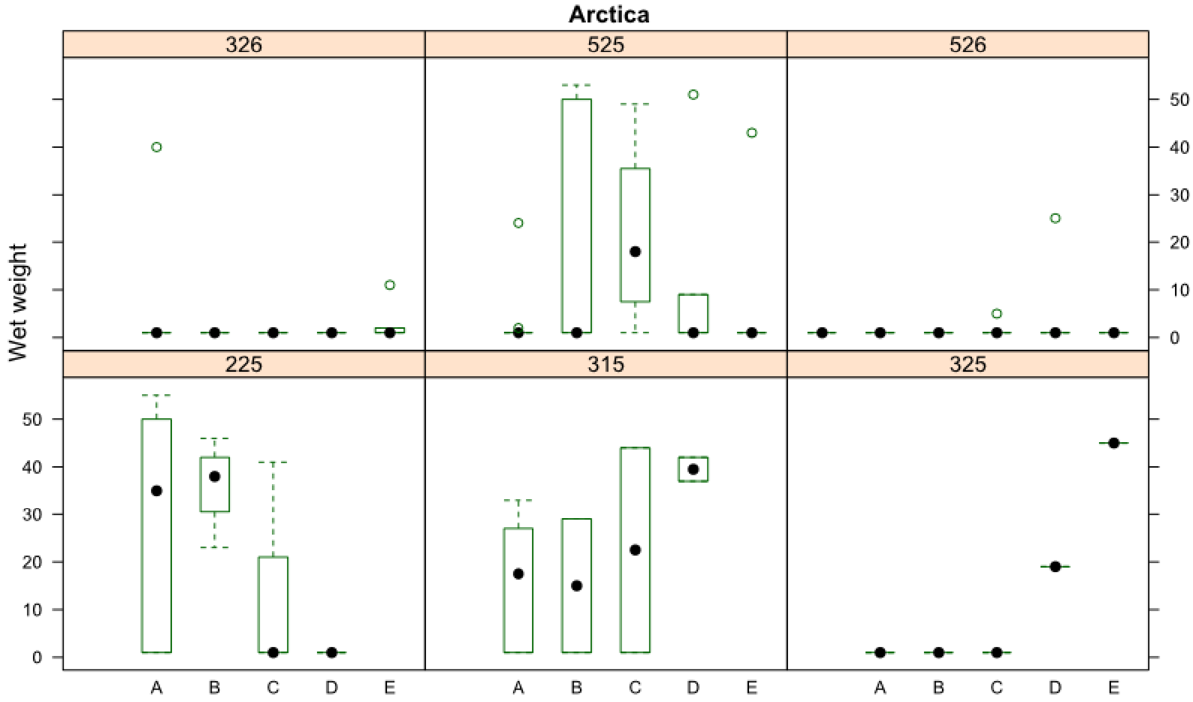
Appendices

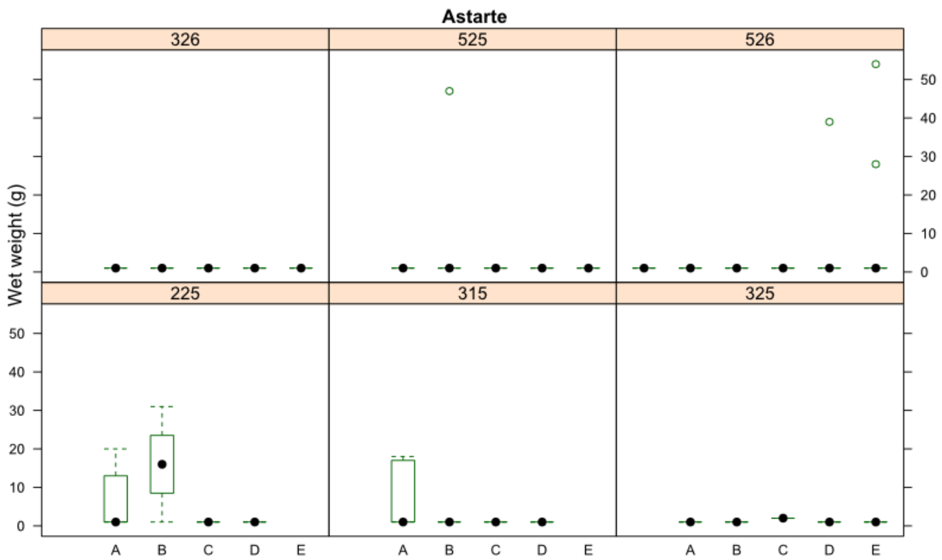
Appendix 1. Summary data for the sampling station

Station	Latitude	Longitude	Balance Level 3	Bathymetry
14	55.9762	10.8038	225	-16.11
42	56.7500	11.6234	315	-27.43
49	56.7547	11.7223	326	-19.06
150	56.5920	11.2732	325	-16.54
155	56.8508	11.2537	315	-13.39
158	57.9170	11.0358	526	-89.19
409	56.8567	10.7917	525	-14.37
413	56.6687	12.1154	526	-46.96
939	55.3753	10.9977	225	-34.4
1402	56.2379	11.9723	326	-27.06
1416	57.6366	10.7317	526	-23.69
31S	55.8534	12.6690	525	-15.73
BF16N21	57.5834	10.8609	526	-27.39
P11	57.2588	11.2903	326	-24.9
P21	57.1639	10.6735	525	-11.99
P23	56.1262	10.9653	525	-22.89
P26	56.8491	11.6625	326	-17.89
P35	56.2059	11.4877	525	-22.41
P46	57.5346	10.5807	526	-16.12
P6	56.5736	11.9155	326	-31.04
P9	56.5400	11.5688	326	-29.05

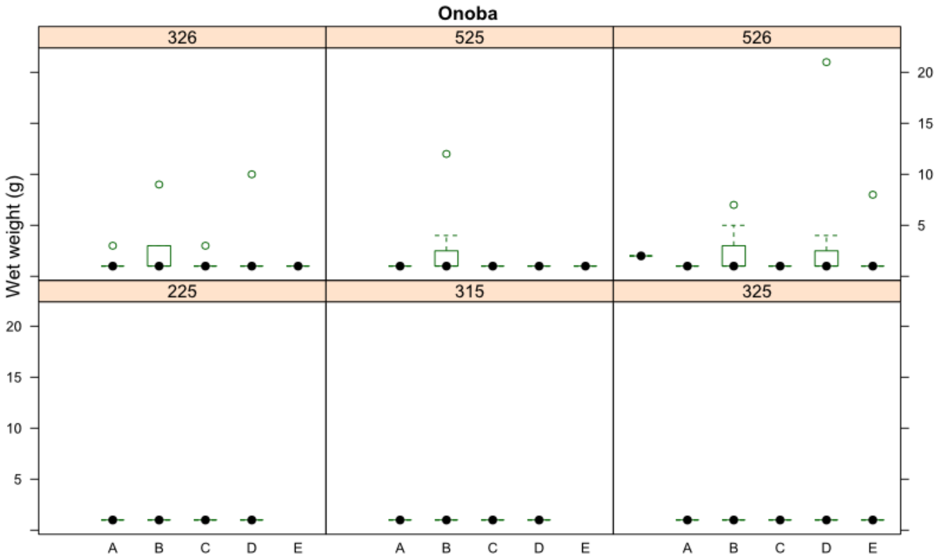
Appendix 2. Reponses of sensitive species to fishing Pressure



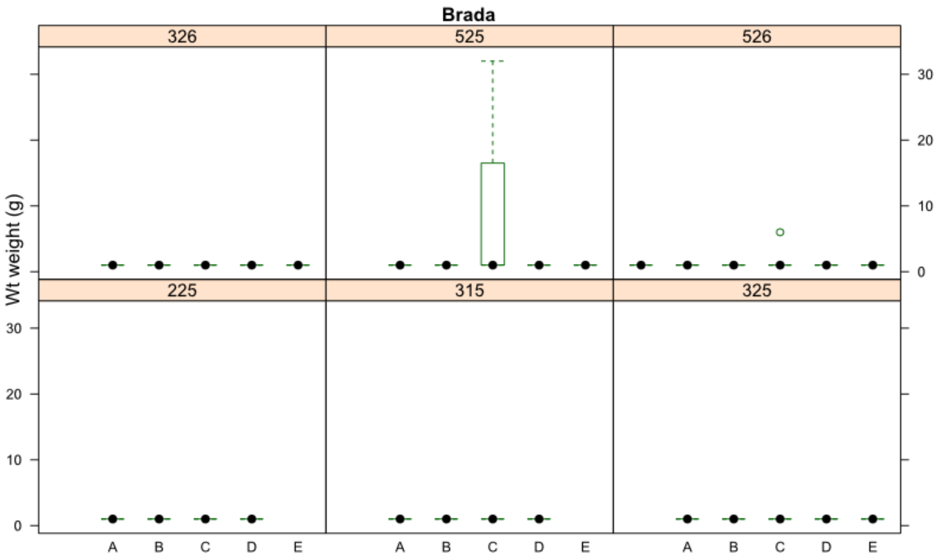
Response of total wet weight of (Arctica taxa)to a gradient of fishing pressure from A (low fishing Pressure) to E (high fishing pressure), grouped per balance habitat at level 3



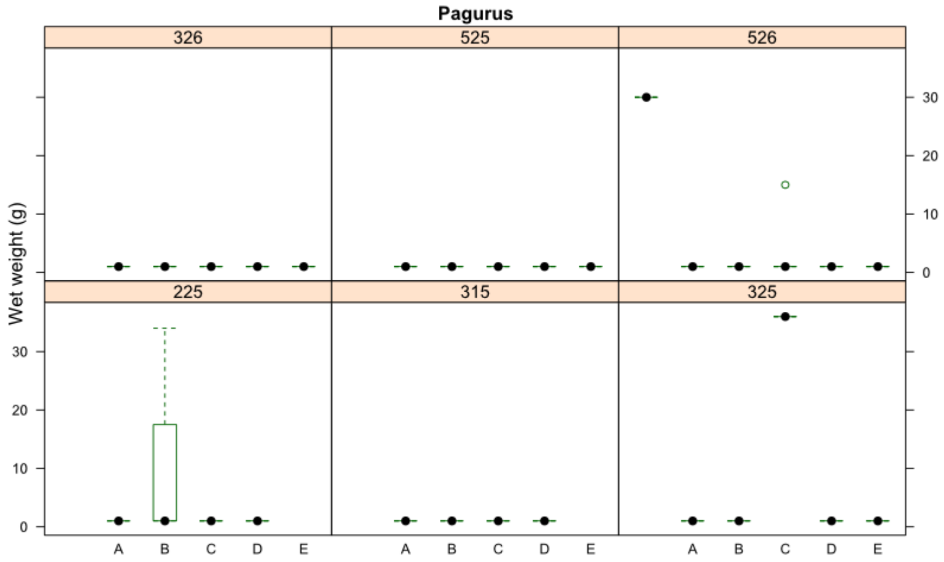
Response of total wet weight (Astarte taxa) to a gradient of fishing pressure from A (low fishing Pressure) to E (high fishing pressure), grouped per balance habitat at level 3.



Response of total wet weight (Onoba taxa) to a gradient of fishing pressure from A (low fishing pressure) to E (high fishing pressure), grouped per balance habitat at level 3.



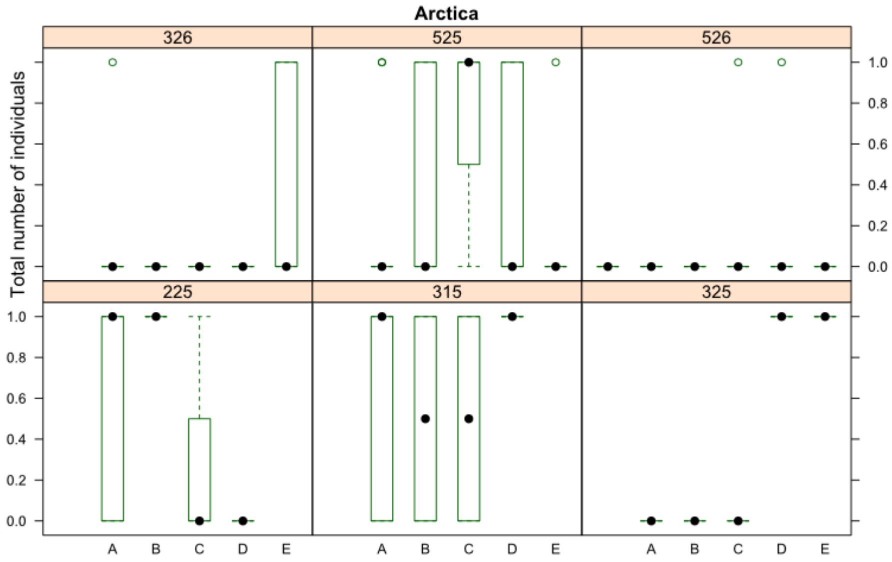
Response of total wet weight (Brada taxa) toa gradient of fishing pressure from A (low fishing pressure) to E (high fishing pressure), grouped per balance habitat at level 3



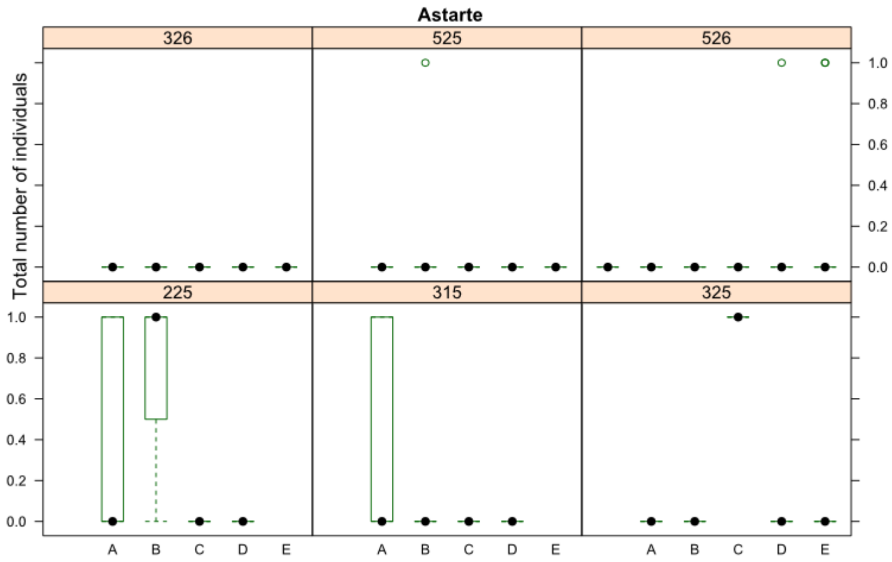
Response of total wet weight (Pagurus taxa) to a gradient of fishing pressure from A (low fishing pressure) to E (high fishing pressure), grouped per balance habitat at level 3.

Summary of regression analysis of Total wet weight of sensitive taxas response to fishing pressure gradient (one year prior fishing pressure). Significant differences are indicated by *p <0.05

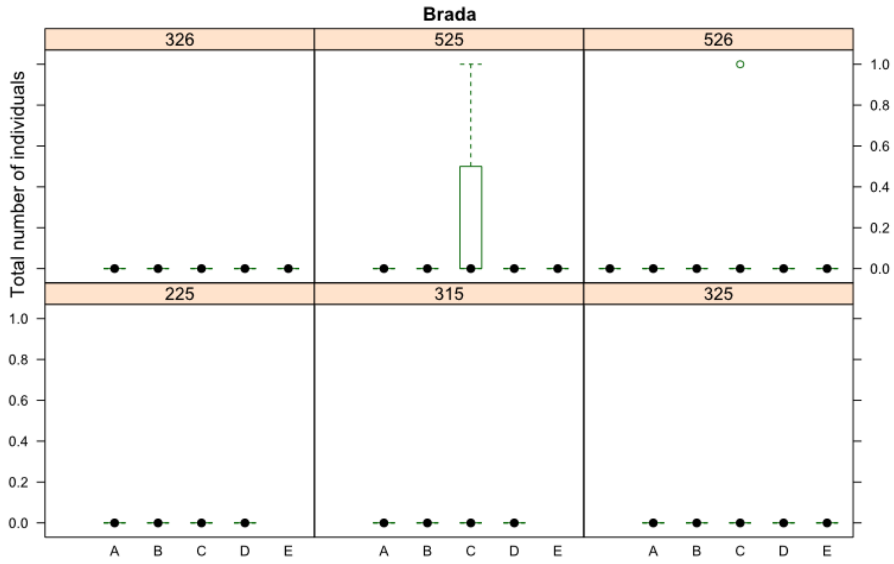
Regression	**FP Class**		**FP+Balance**	
Wet Weight (g)	**P value**	**R-squared**	**P value**	**R-squared**
Arctica	0.001*	0.114	0.000*	0.239
Astarte	0.050*	0.044	0.118	0.042
Brada	0.182	0.018	0.396	0.004
Onoba	0.145	0.023	0.590	-0.012
Pagurus	0.029	0.030	0.004*	0.102



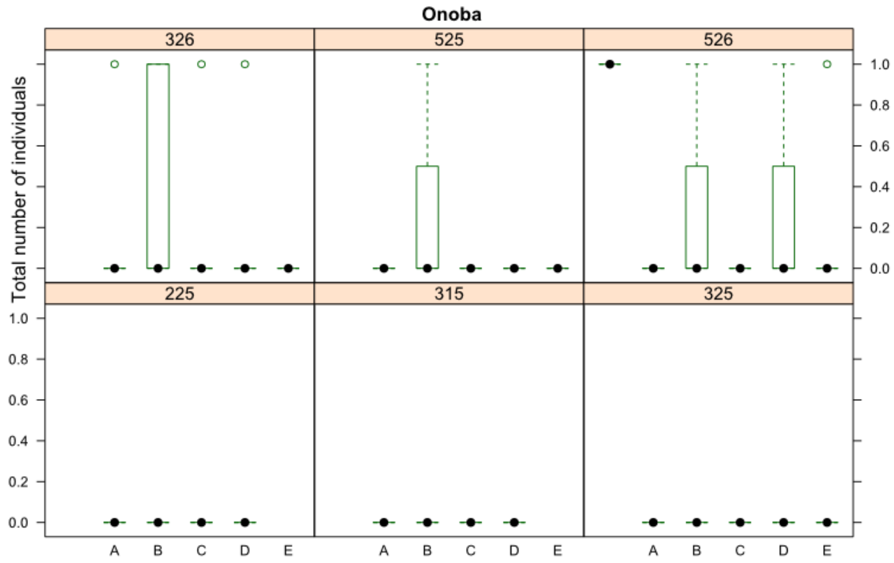
Response of the total number of individuals (Arctica taxa) to a gradient of fishing pressure from A (low fishing pressure) to E (high fishing pressure), grouped per balance habitat at level 3.



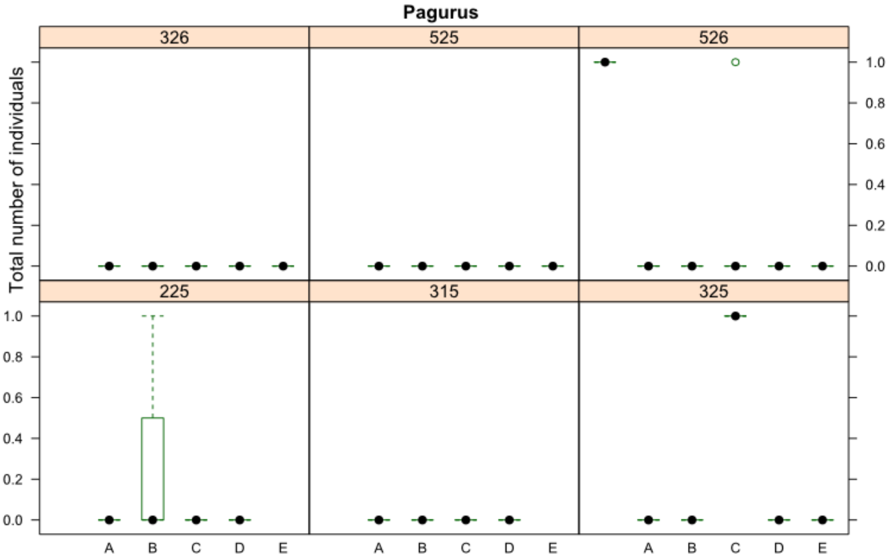
Response of the total number of individuals (Astarte taxa) to a gradient of fishing pressure from A (low fishing pressure) to E (high fishing pressure), grouped per balance habitat at level 3.



Response of the total number of individuals (Brada taxa) to a gradient of fishing pressure from A (low fishing pressure) to E (high fishing pressure), grouped per balance habitat at level 3.



Response of the total number of individuals (Onoba taxa) to a gradient of fishing pressure from A (low fishing pressure) to E (high fishing pressure), grouped per balance habitat at level 3.



Response of the total number of individuals (Pagurus taxa) to a gradient of fishing pressure from A (low fishing pressure) to E (high fishing pressure), grouped per balance habitat at level 3

Summary of regression analysis of Total number of individuals of sensitive taxas response to fishing pressure gradient (one year prior fishing pressure). Significant differences are indicated by *p <0.05

Regression	**FP Class**		**FP+Balance**	
Abundance	**P value**	**R-squared**	**P value**	**R-squared**
Arctica	0.001*	0.106	0.000*	0.230
Astarte	0.004*	0.087	0.006*	0.113
Brada	0.046*	0.046	0.297	0.014
Onoba	0.021	0.026	0.370	0.007
Pagurus	0.017	0.037	0.015*	0.078

Appendix 3. Response of benthic fauna to fishing pressure at family Level

Summary of regression analysis of Total number of individuals (Taxas grouped at family level) response to fishing pressure gradient (one year prior fishing pressure) . Significant differences are indicated by *p <0.05

Regression	FP Class		FP+Balance	
Wet_Weight	**P value**	**R-squared**	**P value**	**R-squared**
Amphiuridae	0.000*	0.140	0.000*	0.274
Arcticidae	0.000*	0.180	0.000*	0.281
Bathyporeiidae	0.012*	0.072	0.000*	0.175
Capitellidae	0.110	0.029	0.195	0.029
Cirratulidae	0.002*	0.101	0.006	0.113
Echinocyamidae	0.015*	0.067	0.000*	0.388
Maldanidae	0.283	0.009	0.002*	0.138
Montacutidae	0.173	0.020	0.425	0.002
Nephtyidae	0.109	0.029	0.088	0.051
Nuculidae	0.451	-0.002	0.536	-0.008
Opheliidae	0.009*	0.078	0.000*	0.444
Orbiniidae	0.000*	0.234	0.000*	0.213
Oweniidae	0.009*	0.077	0.001*	0.147
Pholoidae	0.239	0.013	0.171	0.033
Rissoidae	0.285	0.009	0.419	0.002
Semelidae	0.597	-0.010	0.335	-0.010
Spionidae	0.002*	0.100	0.000*	0.218
Tellinidae	0.096	0.032	0.000*	0.153
Terebellidae	0.656	-0.013	0.000*	0.280
Thraciidae	0.018*	0.018	0.000*	0.533
Thyasiridae	0.129	0.026	0.123	0.085
Trichobranchidae	0.464	-0.003	0.223	0.025
Urothoidae	0.009^*	0.078	0.000*	0.186
Veneridae	0.050*	0.046	0.001*	0.147

Appendix 4. Summary of model linear mixed model choice

Model	Model	BIC	Random Effects Variance %			
			Station	Balance	Bathymetry	Year
M1	Abundance ~ FP_1yr + (1 | Station.x)	2694	51			
M2	Abun~FP_1yr+(1|Station.x)+(1|Balance)	2700	51	0		
M3	Abun ~ FP_1yr + (1 | Station.x) + (1 | BathClass)	2700	50		0.5	
M4	Abun~FP_1yr+(1|Station.x)+(1|Year.y)	2681				5.6
M5	Abun~FP_1yr+FG+(1|Station.x)+(1|Year.y)	2678	52			5.9
Model 4	Abun~FP_1yr+FG+BathClass +(1|Station.x)+(1|Year.y)	2685	47			6.5

Appendix 5: Summary of changes of the different aspects studied in all the habitats

Available area for fishing		
Habitat	**%Change Scenario 1**	**%Change Scenario 2**
113	0.00	0.00
114	0.00	0.00
115	-0.29	0.00
116	0.00	0.00
123	0.00	0.00
124	0.00	0.00
125	-0.81	0.00
126	0.00	0.00
212	0.00	0.00
213	0.00	0.00
214	0.00	0.00
215	-15.58	-0.03
216	0.00	-2.17
222	0.00	0.00
223	0.00	0.00
224	-0.32	0.00
225	**-41.97**	**-1.02**
226	-0.27	-2.15
311	0.00	0.00
312	0.00	0.00
313	0.00	0.00
314	0.00	0.00

315	**-7.41**	**-0.51**
316	0.00	0.00
322	0.00	0.00
323	0.00	0.00
324	-0.09	0.00
325	**-31.37**	**-5.95**
326	**-0.09**	**-1.60**
413	0.00	0.00
414	0.00	0.00
415	-0.10	0.00
416	0.00	-12.59
423	0.00	0.00
424	0.00	0.00
425	-18.66	0.00
426	-0.56	-2.82
511	0.00	0.00
512	0.00	0.00
513	0.00	0.00
514	0.00	0.00
515	-12.69	-0.61
516	0.00	-5.86
522	0.00	0.00
523	0.00	0.00
524	-1.36	0.00
525	**-60.29**	**-3.38**
526	**-0.15**	**-2.10**

Fishing effort (swept area)		
Habitat	**%Change Scenario 1**	**%Change Scenario 2**
113	8	-3
114	17	-50
116	NA	NA
123	15	0
125	NA	NA
126	NA	NA
212	-46	169
213	-78	2

214	138	-2
215	33	3
216	-9	-4
223	9	-2
224	37	-3
225	-2	-2
226	3	-2
311	NA	NA
312	-57	-25
313	-2	-2
314	13	5
315	33	0
316	5	6
322	-20	-10
323	-3	2
324	3	-1
325	1	-3
326	12	4
413	NA	NA
414	-1	12
415	-87	-49
416	-67	-100
423	1	0
424	4	4
425	5	-13
426	-18	-8
511	NA	NA
512	NA	NA
513	18	10
514	-2	-5
515	183	46
516	321	-42
522	79	11
523	1	-3
524	7	-1
525	-47	-1
526	5	1

Fishing effort (time,hrs)		
Habitat	%Change Scenario 1	%Change Scenario 2
113	10	-1
114	-12	16
116	NA	NA
123	17	4
125	NA	NA
126	NA	NA
212	-46	169
213	-79	5
214	103	-1
215	7	-3
216	-9	-4
223	12	-1
224	36	-2
225	3	-3
226	4	-1
311	NA	NA
312	-57	-25
313	-1	1
314	21	5
315	27	2
316	5	7
322	-4	-15
323	-3	2
324	11	-1
325	-5	-10
326	17	4
413	NA	NA
414	-3	11
415	-87	-49
416	-67	-100
423	1	1
424	-1	0
425	5	-13
426	-17	-8
511	NA	NA
512	NA	NA
513	14	6
514	-1	-5

515	59	14
516	325	-50
522	79	11
523	5	-2
524	8	0
525	-35	-2
526	6	1

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