14 February 2017

Appendix 3 - Supporting material

BalticBOOST final report
15.9.2015 - 14.12.2016

Baltic Sea project to boost regional coherence of marine strategies through improved data flow, assessments, and knowledge base for development of measures

Co-funded by
the European Union

Supporting material

Content:

Theme 3: Physical loss and damage to seabed habitats

This report is supporting material to the BalticBOOST WP 3.1 deliverable "Estimating physical disturbance on seabed". The BalticBOOST project that was coordinated by HELCOM and co-financed by the European Union in 2015-2016 as part of the programme DG ENV/MSFD Action Plans/2016.

WP 3.1 Supporting material 1: Case study Gulf of Finland

Impacts of Vuosaari harbor construction works on the coastal ecological status east of Helsinki

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Contents

1. Introduction

Several studies have focused on the impacts of different human activities related to harbor construction work (Rosenberg 1977, Wildish & Thomas 1985, Witt et al. 2004, Simoninia et al. 2005, Ware et al. 2010). Among the prominent activities are dredging, land fill and disposal of dredged material. The impacts of sediment disposal on zoobenthos depend on the amounts, quality and structure of the masses. The essential factors causing stress to bottom habitats originate in forming of covering beds, increasing turbidity and changes in sediment structure as well as the chemical properties of the sediment (Witt et al. 2004). However, more information is still needed on the pressure-impact relationships and the magnitude of pressures benthic habitats can tolerate to support the implementation of the Water Framework Directive (WFD) and environmental target setting in the Marine Strategy Framework Directive (MSFD).

To study the impacts of human activities connected to construction work and relate the impacts to environmental status, a case study on the construction of Vuosaari harbor in Helsinki, Gulf of Finland, was carried out. Extensive data were collected during the construction phase as part of the an environmental impact assessment (Vatanen et al. 2012). These data, together with regular monitoring data from the area were utilized to investigate the impacts of the construction works and relate them to good environmental status indicatorsin the coastal environment. The construction works, carried out during 2003-2008, included dredging and filling of the harbor, sediment dumping and sand extraction, as well as some small scale contamination dredging in the harbor's second phase area. The impacts on the coastal water system and fishery were monitored in compliance with the monitoring programme approved by the Livelihood, traffic and environment Centre of Uusimaa (formerly the Environment Centre of Uusimaa). The monitoring was related to the permission of the Vuosaari Harbor and its navigable route. The data and results on water and sediment sampling, turbidity surveys, water quality, zoobenthos and seabed vegetation surveys have been reported by the Vuosaari Construction Project (Niinimäki et al. 2004, Vatanen and Haikonen 2007, 2008, 2009; Vatanen et al. 2006, 2012), the data being partly available in the environmental data system of SYKE.

According to Vatanen et al. (2012), the most important impact of the construction works on the water system and fishing industry were the increase in sedimentation due to risen turbidity and elevated concentrations of suspended solid matter. The area affected by increased turbidity near the bottom has extended as far as 2.5 km from the sediment filling area but the influence has weakened since 2005 (Vatanen et al. 2012, Figure 1). However, turbidity levels have decreased very swiftly to close to background levels when no dredging and disposal work was done.

In aim of this study was to assess the impacts of the Vuosaari Harbor construction works on the ecological status of coastal waters east of Helsinki based on the zoobenthos and phytobenthos data gathered during the Vuosaari Construction Project in 2003-2008 and from routinely monitored stations.

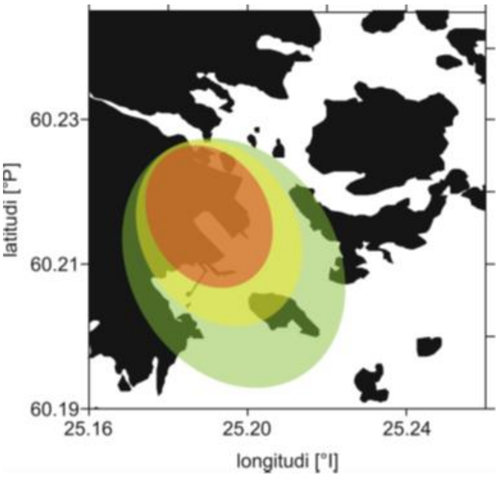

Figure 1. Intensity and frequency of turbidity in the surface water layer in the Harbor and its surrounding areas in 2003 - 2007. In the read areas, the influence of turbidity was strong and the turbidity clouds occurred frequently. Weaker but regular influences of turbidity were observed in the yellow areas, whereas separate and occasional influences of turbidity were recorded in the green areas. Source: Vatanen et al. (2012).

2. Material and methods

The data originated mainly from the Vuosaari Construction project carried out in 2003-2008.Long term water quality data was derived from the Hertta data system of SYKE and long term macrozoobenthos data from Helsinki Environment Centre was also used. The pressure data, including Secchi depth, turbidity and suspended solid matter, were picked in the HERTTA data system, whereas the data on the zoobenthos and growth limit of *Fucus* zone and sedimentation rate were derived from the above-mentioned Vuosaari reports. During the Vuosaari Project, sedimentation was measured three times per year, in early summer, middle summer and late autumn, the data of which were here averaged on annual basis. The Brackish Water Benthic Index (BBI) developed by Perus et al. (2007) was used to classify the ecological status of the zoobenthic community. Similar to BBI, the lower growth limit of *Fucus* zone is an operational indicator in the ecological classification of Finnish coastal waters (Bäck and Ruuskanen 2000). Here, the ecological status was assessed based both on BBI and the lower growth limit of *Fucus* zone using the class boundaries given in Aroviita et al. (2012). The pressure-effect relationships were carried out using simple linear and logarithmic regression analyses.

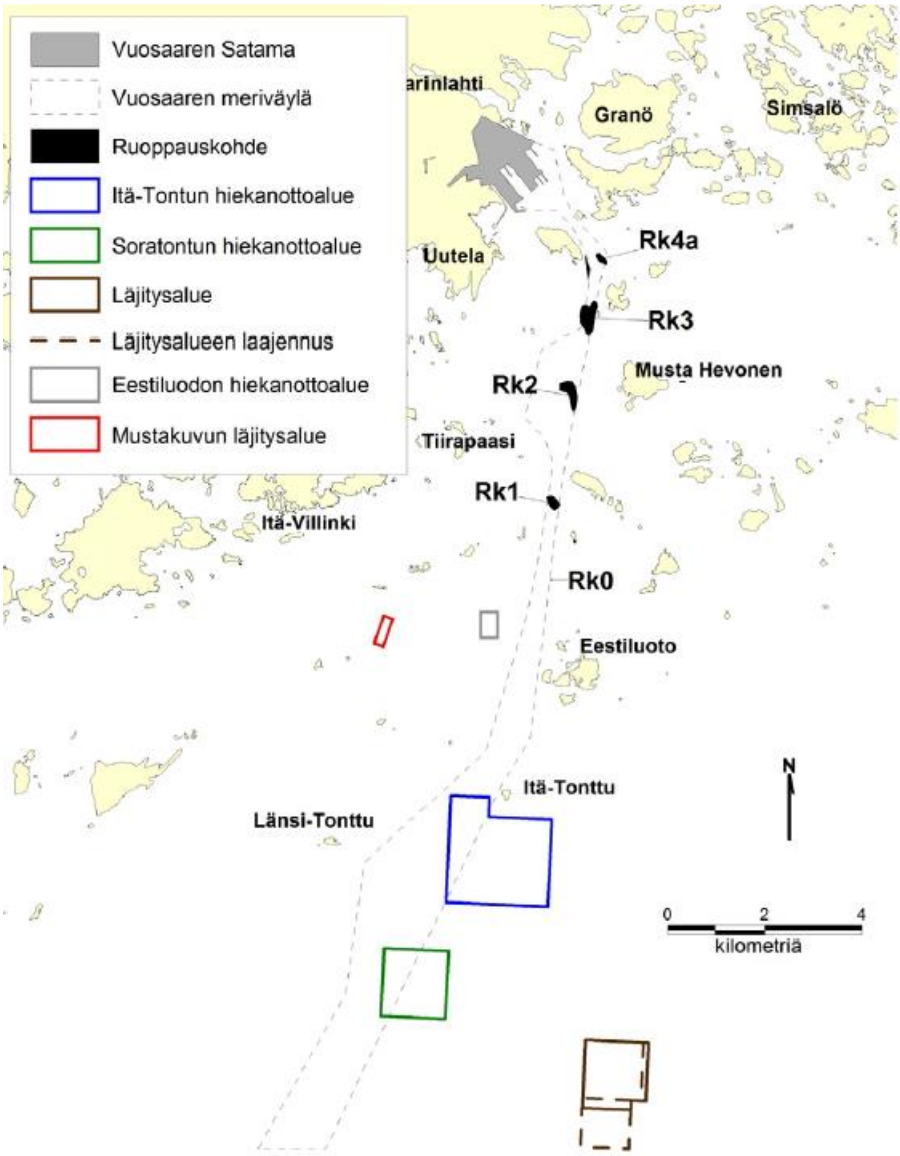

Figure 2. The Vuosaari Harbor (grey), navigable route (broken line), dredging areas (black), sand extraction areas (blue=Itä-Tonttu, green=Soratonttu, grey=Eestiluoto), sediment filling areas (brown=sea filling area, red=Mustakupu). Source: Vatanen et al. 2012.

3. Description of the construction work areas

The construction works in the Vuosaari Harbor included dredging, sand extraction and filling. Dredging was carried out both in the Harbor area and in the navigable route in five spots (Figure 2). Altogether 6.6 million m^3 TA (theoretical amount) material was dredged (Table 1). To estimate the impact of dredging on BBI, we used three zoobenthos and the corresponding water quality sites in 2005 and 2008, three of the sites locating inside and one outside the dredging areas (Table 2, Figs. 3 - 4). The last-mentioned site (Granö 113) in Granofjärden locating about 3 km distance north-east apart the Harbor was used as a reference site. To estimate the impact on *Fucus*, we used nine phytobenthos lines and the corresponding water quality sites (Table 3, Figure 3 and 5). The phytobenthos lines covered the inner, middle and outer archipelago areas.

The sand extraction areas Itä-Tonttu and Soratonttu located in the outer archipelago about 12 km from the Harbor area (Figure 2). The zoobenthos data between 2004 and 2009 were available for nine sites, of which one was located inside and the others in the distances varying from 150 m to 1000 m from the abstraction areas (Table 2, Figure 6). The water quality data were derived from the near-by Länsi-Tonttu, being included both in the programmes of Finland's national monitoring and the monitoring of Helsinki City since the 1970s. Altogether 6.3 million lighter-m^3 of sand have been lifted between 2003 and 2008 (Table 1). In 2006, elevated concentrations of suspended solids were observed in SW corner of Soratonttu in the depth of 40 m near the bottom during the first week of sand uptake.

Sediment masses originated from the dredging areas have been piled south of Eestiluoto Skerry in the open sea about 20 km distance apart from the Harbor (Figure 2). The filling of material totaling altogether 5.2 million m^3 TA was carried out between 2003 and 2008 but it was greatest during 2004 and 2006 (Table 1). The zoobenthos sampling points were located inside and outside the filling areas in the distance varying from 100 to 700 m from the filling area. Unfortunately, there were no water quality sites available to test the impact of pressures like turbidity to BBI.

Sedimentation caused by the constructions works in the Harbor and navigable route as well as in filling area and sand extraction has been monitored in several sites, of which we used two to study the impact of sedimentation on BBI and three to study the impact on *Fucus*, in respectively (Table 4, Fig 7). The sediment site S1 is located north of the Granö Island forming a reference for the possible impacts. The three other sites are in the sphere of influence of the Harbor construction works.

Table 1. Amounts of sea sediments handled during the Vuosaari Harbor construction works in 2003-2008. The dredged material originated (i) from the harbor and (ii) from the navigable route (numbers in cursive). Codes: *, purified sediment from tributyltin (TBT); TA, theoretical amount. Source: Vatanen et al. 2012.

Year	**Season**	**Dredged clay (million lighter-m^3 / m^3 TA)**	**Placed in the Harbor (million lighter-m^3 / m^3 TA)**	**Placed in sea filling area (million lighter-m^3 / m^3 TA)**	**Sea sand extraction (million lighter-m^3)**		
					Itä-Tonttu	Soratonttu	Total
2003	IV-XII	0.35 / 0.30		0.35 / 0.30			
2004	IV-XII	2.08 / 1.88 *0.003 / 0.003*	*0.67*	2.08 / 1.88 *0.003 / 0.003*	1.65		1.65
2005	IV-XII	2.17 / 1.74 *0.28 / 0.22*	0.45* *0.25*	2.17 / 1.74 *0.28 / 0.22*	0.08	2.39	2.47
2006	IV-XI	1.25 / 0.99		1.25 / 0.99	1.42	0.78	2.2
2007	I-V	0.088 / 0.007		0.088 / 0.007			6.32
2008	V-XII	0.05 /0 .04		0.05 /0 .04			
		5.86 / 4.96	0.45* *0.92*	5.86 / 4.96			12.64

Table 2. The zoobenthos sites and the corresponding water quality sites, human activities, pressures and the attributes used in estimating the impacts. Codes: * means that the site is located inside the activity area.

Zoobenthos sampling sites	**Corresponding or nearby water quality sampling sites**	**Human activities**	**Pressures**	**Attributes to impacts**
174* 1742* 1741	174* 106* 113	Dredging in the Harbor	Turbidity	Secchi depth, Suspended solid matter
HI1, HI2, HI3*, HI4, H15 and HS1, HS2, HS3, HS4	Länsi-Tonttu 114	Sand extraction	Turbidity	Secchi depth
				Distance from the activity area
V1, V2, V3	180*	Dredging in the navigable route	Turbidity	Turbidity, Suspended solid matter
L1*, L2, L3*, L4, L5, L6*	(no corresponding site)	Sediment filling	Turbidity	(no water quality data)

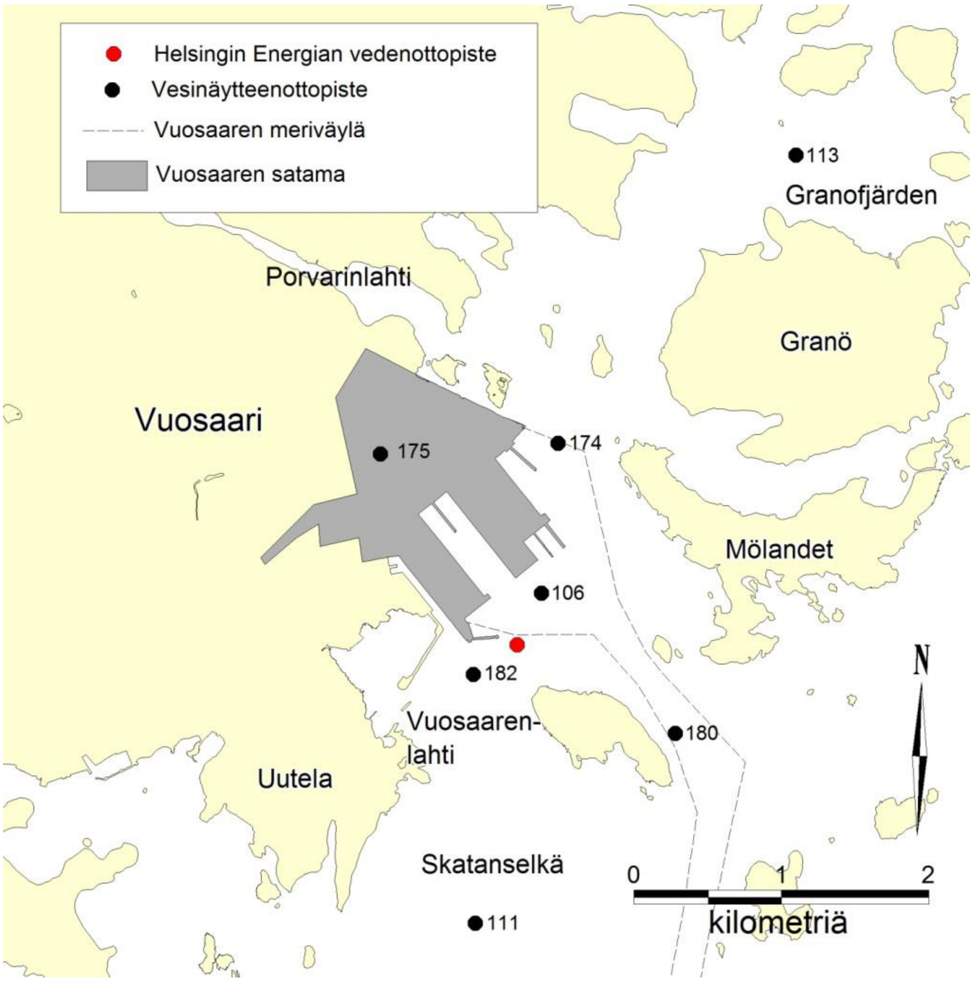

Figure 3. The Vuosaari Harbor (in grey) and the water quality monitoring sites. See the correspondence of the zoobenthos and water quality sites in Table 2. Source: Vatanen et al. 2012.

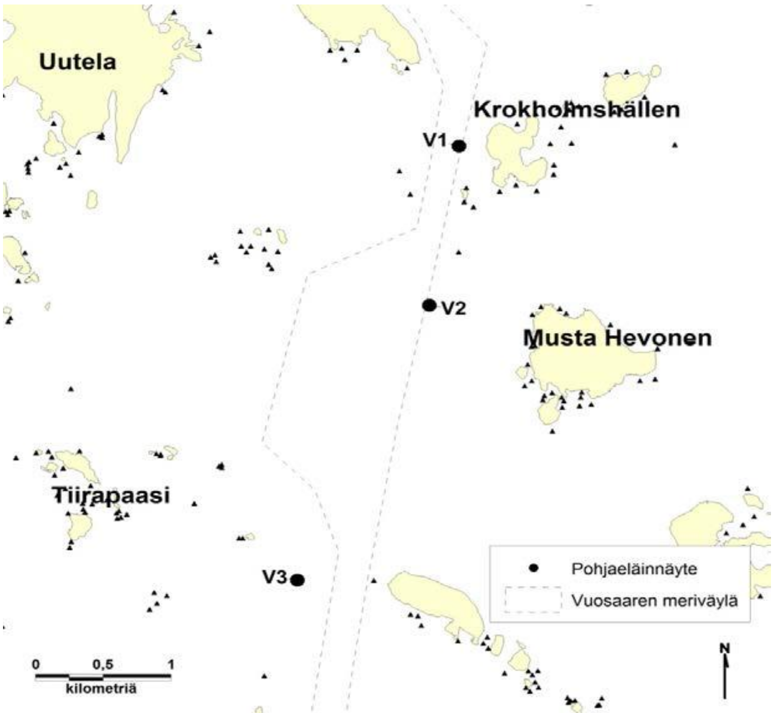

Figure 4 The zoobenthos sites (V1, V2 and V3) of navigable route. See the correspondence of the zoobenthos and the water quality sites in Table 2. Source: Vatanen et al.2012.

Figure 5. The diving lines to define the growth limit of Fucus vesiculosus zone The lines K31 and K32 were so called "joker" lines, of which locations were decided based on turbidity clouds caused by dredging. Codes: S, inner archipelago; K, middle archipelago; U= outer archipelago; M, Offshore zone. Source: Vatanen et al. 2012.

Table 3. The phytobenthos sites and the corresponding water quality station, the human activities, pressures and attributes used to estimate the impacts. Codes: * means that the site is located inside the activity area.

Phytobenthos sampling line	Nearby water quality sampling sites	Zone	Human activities	Pressures	Attributes to impacts
K1	174*	Inner arch	Dredging	Turbidity	Secchi depth, Suspended solids
K2	106*				
K3	180*	middle arch			
K5	111				
K14	113	inner arch	Reference		
K31,K32	182		Dredging		
K13, K21, K22	Länsi-Tonttu	outer arch / offshore	Reference		

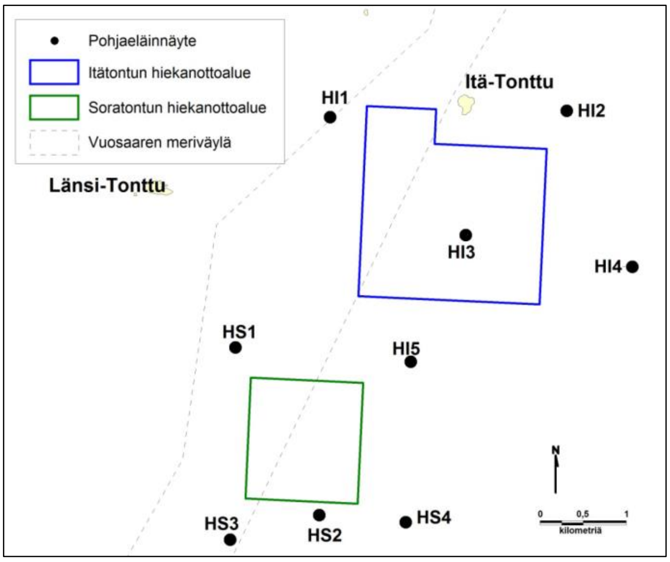

Figure 6. The sand extraction areas Itä-Tonttu (blue) and Soratonttu (grey) as well as the zoobenthos sampling sites. The water quality site Länsi-Tonttu is located east of the sand extraction area of Itä-Tonttu (see Table 2). Source: Vatanen et al. 2012.

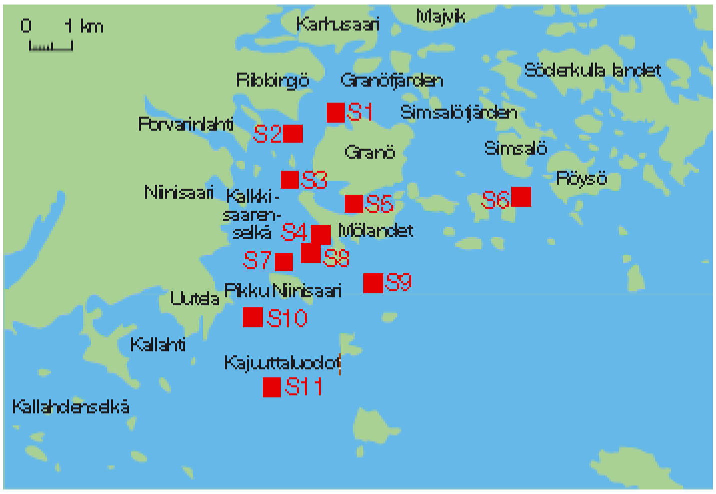

Fig 7. The sedimentation sites in the influence of the Harbor construction works. See correspondence of the phytobenthos lines and the water quality sites in Table 4. Source: Vatanen et al. 2012.

Table 4. Sedimentation sites and the corresponding near-by zoobenthos and phytobenthos sites, the pressure and its attribute.

Sediment site	Zoobenthos site	Phytobenthos line	Pressure	Attribute to impacts
S1	1741		Sedimentation	Sedimentation rate (g/m2/d)
S3	174*	K1		
S7	1742	K2		
S10		K31, K32		

4. Results and discussion

4.1 Impacts of pressures on BBI index

As a consequence of the Harbor construction works, turbidity and concentrations of suspended solid matter increased as a result of accelerating sedimentation (Vatanen et al. 2012), which affected the occurrence and success of the zoobenthos communities. Near the dredging areas, turbidity varied from 4.6 to 14.9 FTU and suspended solid matter from 5.5 to 14.5 mg/l in 2005 and 2008. BBI ranged from 0.13 (bad status) to 0.78 (good status). Near the sand extraction areas, turbidity varied from 1.5 to 2.3 FTU and BBI varied from 0.4 (moderate status) to 1.12 (high status) in 2005, 2008 and 2009. As a comparison, in the inner reference area (site 113) the annual average turbidity near the bottom has ranged from 1.3 to 8.9 FTU since the 1980s and suspended solid matter from 1.3 to 11 mg/l since 1991, in respectively (data from the HERTTA data system in SYKE), revealing that occasional elevated values are conceivable in the inner archipelago outside the direct influence of the Harbor construction works, too.

In the dredging areas, suspended solid matter was the best predictor, explained 58% in the variation of BBI based on the data in 2005 and 2008 (Fig 8). Instead, BBI was weakly linked to turbidity (Figure 9). Accordingly, based on BBI it seemed that near the Harbor the overall ecological status weakened with increasing suspended solid matter and turbidity. The analyses were, however, hindered by a low number of zoobenthos data, covering only two years. Comparing the sites, the ecological status deteriorated to poor in all but one site (174) where the status class surprisingly improved from bad to good between 2005 and 2008, suggesting a possible recovery of the community.

In the sand extraction areas, the link between BBI and the pressure data could not be proved (Figure 10). Additionally, there was no clear connection to distance from the sand extraction areas, although the ecological status seemed weakly to be improved along the increasing distance between 2005 and 2009 (Figure 11). For filling areas, the analyses with BBI could not be performed due to lack of the corresponding water quality sites and data.

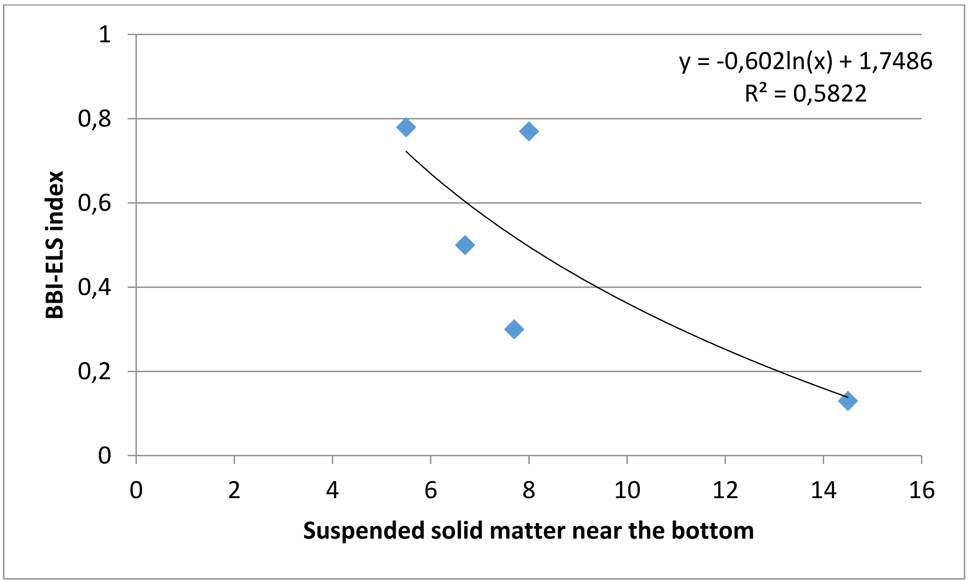

Figure 8. The relationship between BBI index (BBI-ELS) and the annual average of suspended solid matter (mg/l) near the bottom in the dredging areas in 2005 and 2008.

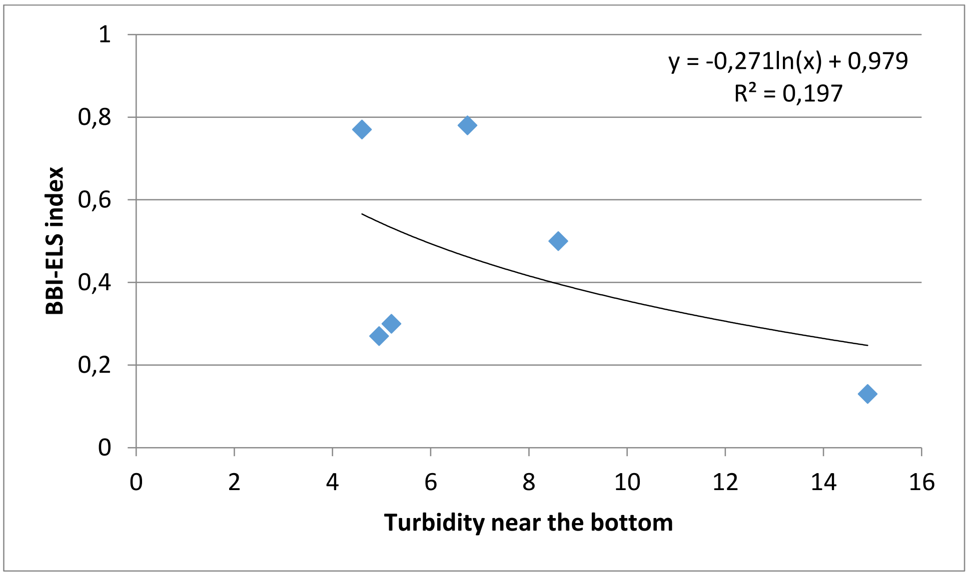

Figure 9. The relationship between BBI index (BBI-ELS) and the annual average turbidity near the bottom in the dredging areas in 2005 and 2008.

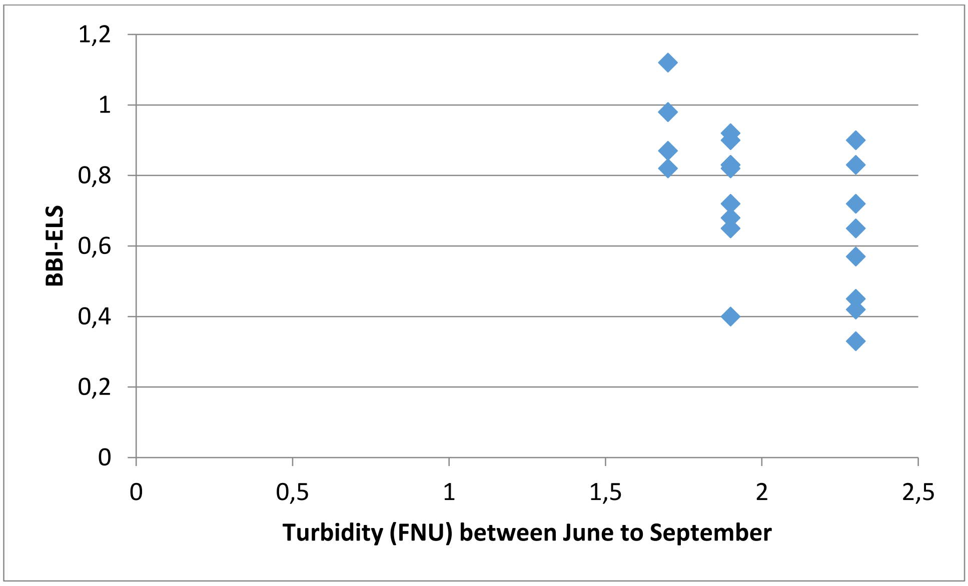

Figure 10. The relationship between BBI-ELS and summer turbidity (June to September) in sand extraction areas in 2005, 2007 and 2009. See the zoobenthos sites and the corresponding water quality site in Table 2.

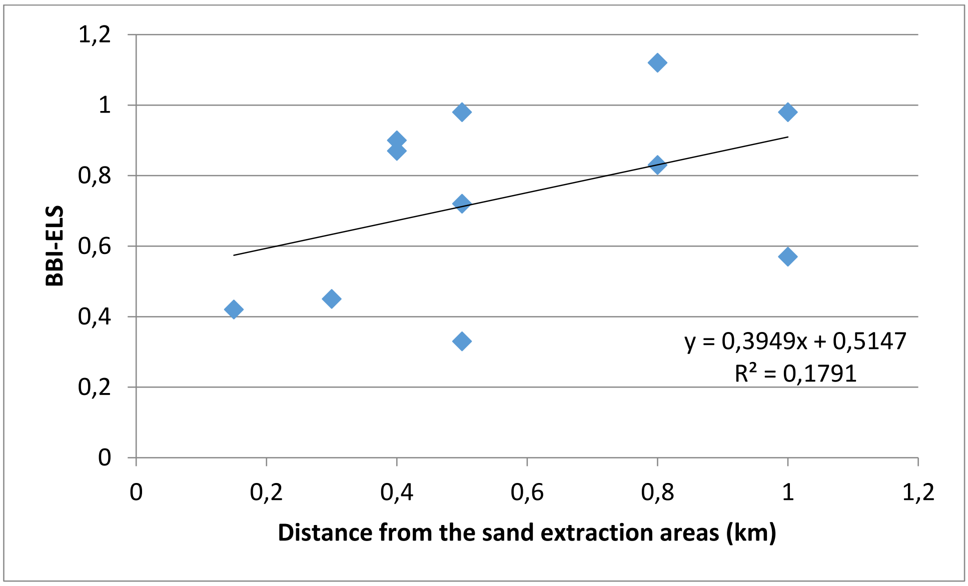

Figure 11. Relationship between BBI-ELS and the distance from the sand extraction areas in 2007 and 2009.

4.2 Impact of the Harbor construction works on the growth limit of *Fucus* zone

Secchi depth is used as a general pressure indicator for the growth limit of *Fucus* zone (Bäck & Ruuskanen 2000, Commission Decision 2013). In the influence of the Harbor dredging area (Figure 3), the growth limits of *Fucus* zone varied from 1.0 to 3.5 m in 2003 - 2008, and Secchi depth from 1.1 to 5.4 m, in respectively. In the reference offshore area near the Island of Länsi-Toukki, the corresponding *Fucus* zone ranged from 2.9 to 5.1 m and Secchi depth from 3.8 to 4.2 m (Figure 6). In the middle archipelago of Skatanselkä, outside the direct influence of dredging, the corresponding ranges were 2.7 to 3.3 m for *Fucus* zone and 1.8 to 3.2 m for Secchi depth.

Based on Secchi depth, the status near the Harbor was poor or moderate during the construction works while in the navigable route in the sphere of influence from the Harbor, the status seemed to vary from bad to high. The high Secchi values at 3K (5.4 and 5.7 m in 2005 and 2007) representing the high status there are unconvincing. The observations on *Fucus* were too scarce to assess the tendency in status during the construction works.

Considering the whole study area, Secchi depth explained 30% in the variation of the growth limit of *Fucus* zone (Figs. 12). The *Fucus* zone appeared to increase along with increasing Secchi depth, excluding the two cases mentioned above (Table 3, Figure 3). If the high Secchi values over 5 m are true, the explanation might be that *Fucus* did not had time to recover from the deterioration of the habitat by then. When leaving out the two odd samples, the Secchi depth would account for 56% of the variation of the growth limit of *Fucus* zone, which is in accordance with the EU intercalibration results (R^2=6.8) in Finnish coastal waters (see Karup et al. 2012). Similarly, a weak negative link was found between the *Fucus* zone and suspended solid matter (R_2=0.22). Also in this case the relationship was weakened by the same samples from 2005 and 2007; without these data, the correlation would have been better.

It must be taken into account that Secchi depth and suspended solid were measured at the near-by water quality sites and not exactly at the same sites than *Fucus* zones (Figs. 3 and 5, Table 3). Hence, it could be assumed that Secchi depth were lower and suspended solid matter higher in the sites of the navigable route (sites 180 and 174) than those in the near-by phytobenthos lines. However, water quality data were not available to prove this assumption. Additionally, it was difficult to quantify the influence of natural variation and the impact of shipping to the changes in *Fucus* zone based on this small dataset.

Overall, based on *Fucus* the ecological status was worst NE of the Harbor dredging areas in the vicinity of site 174 and best in the outer archipelago near Länsi-Tonttu during the Harbor construction works in 2003 - 2008.

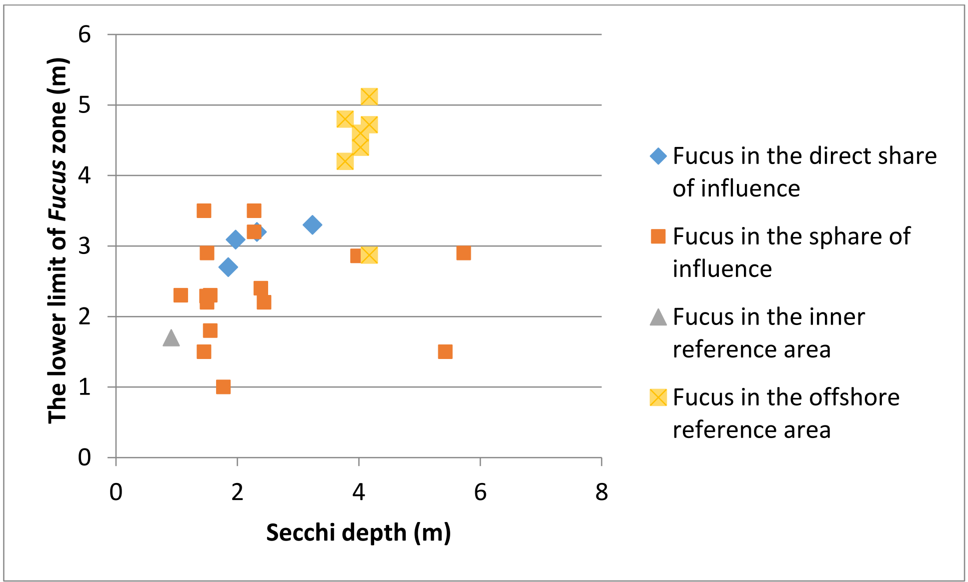

Figure 12. The relationship between the lower limit of the Fucus zone and Secchi depth in the influence area of the Vuosaari Harbor constructions in 2003 – 2008. The direct sphere of influence was limited to the inner archipelago and the sphere of influence in the middle archipelago. The line K14 was a reference area in the inner archipelago and K13, K21 and K22 the reference areas in the outer archipelago or offshore areas.

4.3 Impact of sedimentation on BBI and the growth limit of *Fucus*

The annual sedimentation rate near the dredging areas was on an average 29.5 g/m^2/d varying from 6.3 to 79.8 g/m^2/d during 2003 -2007. On an average, seasonal sedimentation rate did not vary a lot: the lowest values (27.4 g/m^2/d) were measured in June and the highest (32.1 g/m^2/d) in August. The growth limit of *Fucus* zone did not correlate either with the annual or seasonal average sedimentation rate near the Harbor (Figure 13, Table 4). Unfortunately, there were not enough concurrent data to test the connection between BBI and sedimentation rate.

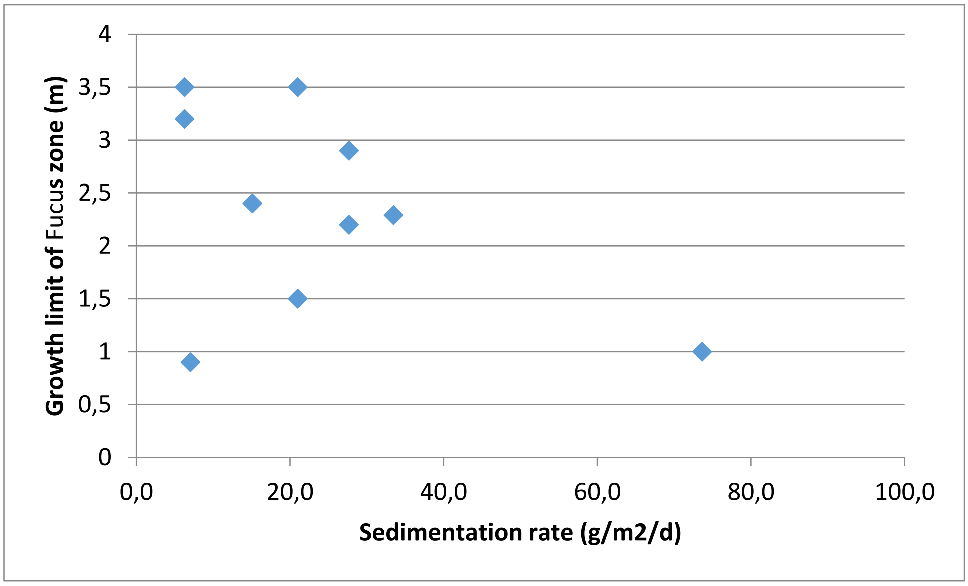

Figure 13. Relationship between the growth limit of Fucus zone (m) and sedimentation rate (g/m2/d) near the Vuosaari Harbor between 2004 and 2008.

5. Concluding marks

The impacts of the Vuosaari Harbor construction work on BBI and the growth limit of *Fucus* zone were strongest in the sphere of influence of turbidity in the distance of about 2 km apart from the coast. The data was too limited to draw any far-reaching conclusion. However, suspended solid accounted for 58% of the variation in BBI, whereas Secchi depth explained 56% of the variation in the growth limit of Fucus zone. In general, the ecological status in the vicinity of the Harbor seemed to be weakened along the increasing suspended solid matter and turbidity.

6. References

Aroviita, J., Hellsten, S., Jyväsjärvi,J., Järvenpää, L., Järvinen, M., Karjalainen, S.-M., Kauppila, P., Keto, A., Kuoppala, M., Manni, K., Mannio, J., Mitikka, S., Olin, M., Perus, J., Pilke, A., Rask, M., Riihimäki, J., Ruuskanen, A., Siimes, K., Sutela, T., Vehanen, T. & Vuori, K.-M. 2012. Ohje pintavesien ekologisen ja kemiallisen tilan luokitteluun vuosille 2012 - 2013 – päivitetyt arviointiperusteet ja niiden soveltaminen. Ympäristöhallinnon ohjeita 7/2012. Suomen ympäristökeskus, 144 s.

Bäck, S. & Ruuskanen, A. 2000. Distribution and maximum depth of *Fucus vesiculosus* along the Finnish coastline. Marine Biology 136(2): 303-307.

Karup, H., Krause-Jensen, D., Dahl, K., Wurgler, H. Kaire, T., Ruuskanen, A., Bäck S., Furhaupter, K., Karez, R., Jermakovs, V., Bucas, M., Brzeska, P., Blomqvist, M. & Bonne, W. Macroalgae an angiosperms. Technical Report Coastal Waters, Baltic Sea GIG.

Niinimäki, J., Paasivirta, L., Heitto, A., Oulasvirta, P. & Vatanen, S., A. 2004. Vuosaaren satamahankkeen vesistö- ja kalatalousseuranta 2003. Vuosaaren satamahankkeen julkaisuja 1/2006. Helsinki, 120 s.

Simoninia. R., Ansaloni, I., Cavallini, F., Graziosi, F., Lotti, M., Massamba N´Siala, G., Mauri, M., Montanari, G., Preti, M. & Prevedelli, D. 2005. Effects of long-term dumping of harbour-dredged material on macrozoobenthos at four disposal sites along the Emilia-Romagna coast. Marine Pollution Bulletin 50: 1595-1605.

Perus, J., Bonsdorff, E., Bäck, S., Lax, H.-G., Villnäs, A. & Westberg, V. 2007. Zoobenthos as indicators of ecological status in coastal brackish waters: a comparative study from the Baltic Sea. Ambio 36(2-3): 250-256.

Rosenberg, R. 1977. Effects of dredging operations on estuarine benthic macrofauna. Marine Pollution Bulletin 8: 102–104.

Vatanen, S., Niinimäki, J. & Haikonen A. 2006. Vuosaaren satamahankkeen vesistö- ja kalatalousseuranta 2005. Vuosaaren satamahankkeen julkaisuja 1/2006. Helsinki, 120 s.

Vatanen, S. & Haikonen A. 2007. Vuosaaren satamahankkeen vesistö- ja kalatalousseuranta 2006. Vuosaaren satamahankkeen julkaisuja 1/2007. Helsinki, 120 s.

Vatanen, S. & Haikonen A. 2008. Vuosaaren satamahankkeen vesistö- ja kalatalousseuranta 2007. Vuosaaren satamahankkeen julkaisuja 1/2008. Helsinki, 104 s.

Vatanen, S. & Haikonen A. 2009. Vuosaaren satamahankkeen vesistö- ja kalatalousseuranta 2008. Vuosaaren satamahankkeen julkaisuja 1/2009. Helsinki, 100 s.

Vatanen, S., Haikonen A. & Piispanen, A. (toim.) 2012. Vuosaaren sataman rakentamisen aikaisen (2003-2008) vesistö- ja kalataloustarkkailun yhteenvetoraportti. Kala- ja vesimonisteita nro 57. Kala- ja vesitutkimus Oy, 198 s.

Ware, S., Bolam, S. & Rees, H. 2010. Impact and recovery associated with the deposition of capital dredging at UK disposal sites: Lessons for future licensing and monitoring. Marine Pollution Bulletin 60: 79–90.

Wildish, D. J. and Thomas, M. L. H. 1985. Effects of dredging and dumping on benthos of Saint John harbour, Canada. Marine Environmental Research 15: 45–57.

Witt, J., Schroeder, A, Knust, R. & Arntz, W.E. 2004. The impact of harbour sludge disposal on benthic macrofauna communities in the Weser estuary. Helgol Marine Research 58: 117–128.

Theme 3: Physical loss and damage to seabed habitats

This report is supporting material to the BalticBOOST WP 3.1 deliverable "Estimating physical disturbance on seabed". The BalticBOOST project that was coordinated by HELCOM and co-financed by the European Union in 2015-2016 as part of the programme DG ENV/MSFD Action Plans/2016.

WP 3.1 Supporting material 2: Case study Mecklenburg Bight

Partner: The Leibniz Institute for Baltic Sea Research (Leibniz-Institut für Ostseeforschung Warnemünde, IOW)

Author: Kai Hoppe

Contents

1. Introduction

The case studies in BalticBoost WP 3.1 for non-fisheries pressures affecting seabed habitats are not meant to be exact analyses of localized impacts and do not claim to be exhaustive. They are exemplary calculations based on readily and “not-so-readily” available data from HELCOM, ICES or national data services. Also, they intend to test some rather debatable assumptions regarding the concept of damage and loss. No consideration was given to the temporal aspect of data availability, because up-to-date information was only available in very few cases. As a result we can, together with the findings from WP 3.2, explore potential pathways for developing joint principles for defining environmental targets for seafloor integrity.

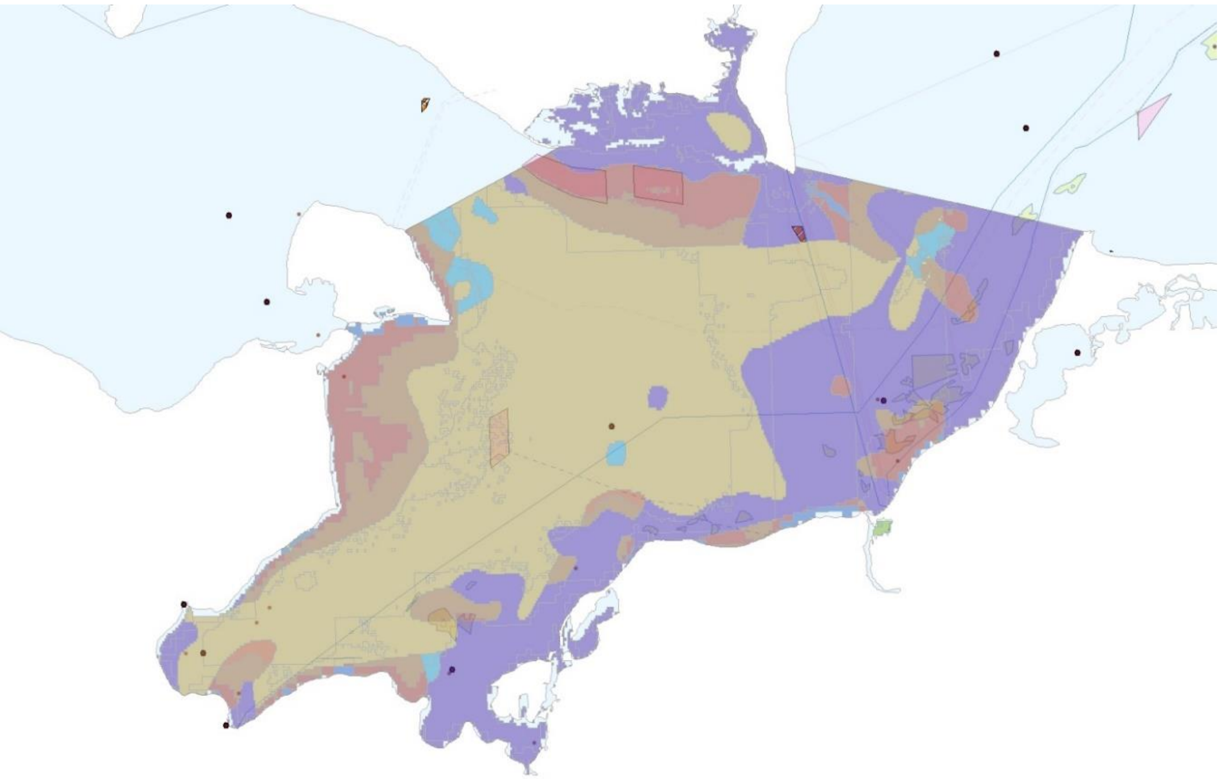

Figure 1: Mecklenburg Bight with broad scale habitat map (EUSeaMap 2011) and representations of human activities.

The case study Plantagenetgrund aims at exploring information from sources, that are publicly available, applied to a broad scale habitat map. It is meant to explore ways to assess (non fisheries) physical impacts from human activities on a scale comparable to the approach expected to be taken by the upcoming MSFD assessment.

2. Human activities

The first step of selecting the relevant human activities already leaves us with decisions that cannot be completely satisfactory. In their GES advice, the European Commission lists the following activities relevant for D6:

1) Coastal infrastructures (ports, defenses against erosion, etc.) and offshore installations (oil and gas platforms, wind farms, etc.);
2) Offshore mining and sand extraction;
3) Release of dredged sludge;
4) Moorings;

5) Some fishing practices (trawling, dredging, etc.);
6) Aquaculture (unused fish feed, fish feces, etc.);
7) Introduction of non-indigenous species (trough ballast water for instance);
8) Pollution (chemical pollution, litter);
9) Changes in riverine inputs (organic enrichment of particulate matter, etc.);
10) Sediment remobilization by fishing equipment (trawls, dredges);
11) Changes in freshwater riverine inputs as a consequence of damming and irrigation;
12) Changes in solid matter riverine inputs; and
13) Release of large quantities of warm (power plant cooling) or salty water (from desalination facilities)

source: http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-6/index_en.htm; 08.06.2016)

Of these, only points 1 - 6 and 10 directly apply to physical damage and loss, but moorings and coastal infrastructure have not been included in this study (see **I.e.** and **f.**). Several other activities (ship traffic, tourism etc.) have also been considered, but not selected here. Even if we exclude eutrophication, pollution and other non-physical pressures, a totally comprehensive evaluation of seafloor integrity is not achievable at the moment and we have to restrict ourselves to the estimation of the most relevant effects.

2.1 Wind farms

Detailed information about wind farms is readily available, most current on 4coffshore.com, often including number of engines, details of constructions, length of cables, etc.. However, some assumption have to be made for the 1100 turbines deployed or planned to be deployed in the Baltic in the near future. Whereas in early wind farm projects various foundation designs were employed, lately it seems that monopiles will be the by far most commonly used type of construction.

For the case study I selected not only the fully commissioned Danish farms (*Nysted* I and II), but also the German *Beta Baltic*, that is in an advanced planning stage. However, *Vineta* and *Beltsee* were excluded, because their planning is in a stage much too premature for consideration.

The area covered by the constructions themselves is determined mainly by the amount of scour protection in place. The area sealed can definitely considered to be lost, even though it is "transformed" to a new habitat type (typically from sand to rock) and the new habitat may have a higher biodiversity than the old one. OSPAR (2008) described an average of 30 m diameter per turbine (or 5 times the piling diameter) and this number was confirmed by data from Nysted I (Danish Energy Authority 2006). It is futile to try and determine each and every foundation in the park individually. The numbers are only fractional amounts of the wind farm area, and the wind farm itself typically only covers part of a suitable sand bank or other ecosystem component.

Table 1. Wind farms in Mecklenburg Bight

Name	country	turbines	area (km²)	loss (m²)	loss of windfarm area (%)
Nysted	DK	72	26	50.400	0,2
Nysted II	DK	90	34	63.000	0,2
Baltic Beta	*DE*	*50*	*12*	*35.000*	*0,3*

2.2 Cables

There are two types of wind farm cables. First there is an array of cables connecting the turbines to each other and to a converter station and second the converter station sends the current to a terrestrial receiver station on shore. Often, several wind farms are interconnected and share a common shore cable. In addition to these there are a number of sea cables for electricity or data connecting countries through the Baltic Sea.

Several methods are used to protect the cables from damage by anchoring ships or ground-touching fisheries. On hard bottoms cables can be covered by concrete or steel casings, and most often they are buried at 1 to 2 m depth in sediments. Depending on the burial technique, cable trenches can be visible as 2 m wide disturbances after decades, indicating a long term change of sediment characteristics. Therefore, for the sake of this broad scale study, cables are considered to lead to loss of original habitats. Modern entrenching methods may have less of an imprint on the seafloor by covering the cables with the (more or less) original sediment. In those cases the temporary (several months to one year) damage to the seafloor has to be assessed. However, compared to North Sea sediments the seafloor in the Baltic Sea is much less uniform, so that boulders, clay deposits etc. often prohibit the use of more environmentally friendly cable laying methods.

Table 2. Cables in Mecklenburg Bight, connecting wind farm to the mainland and Germany to Danmark and Sweden.

Name	Country	Length to shore (km)	Array length (km)	Windfarm area (km²)	Area affected m²	Compared to windfarm area (%)
Nysted	DK	21,5		26	43.000	0,2
			55		110.000	0,4
Nysted II	DK	56		34	112.000	0,3
			80		160.000	0,5
Baltic Beta	*DE*	ca. 37,5		*12*	*75.000*	*0,6*
(not yet in operation)			*ca 25*		*50.000*	*0,4*
cable to Baltic I	DE	41		-	82.000	-
DE-DK	DE/DK	44			88.000	-
DE-SE	DE	94	-		188.000	-

2.3 Extraction

Areawise, in Mecklenburg Bight the most intense physical use of seafloor habitats is (was) the exploitation of fossil sediment deposits. Several size classes of sand and gravel are of interest for industrial use and coastal protection (dyke building and beach replenishment). The layers need to be strong and pure enough, close enough to harbor facilities and in acceptable water depths to be considered as “industrial deposits”. Of these, according to Schwarzer (2006) in 2004 already all deposits in Germany (Mecklenburg-Westpommerania) had been exploited by 31 % and deposits in the eastern Gulf of Finland by 45 % (for building purposes in St. Petersburg and Leningrad). Intuitively, this should have a significant effect on the abundance of certain habitat types. However, on a larger scale (EUNIS level 3) the percentage loss of habitats may not be as obvious.

Still, it is very hard to judge what kind of physical loss and damage is caused by sediment extraction. On a broad scale extraction fields do not differ from the surrounding areas of fine or mixed sediments. Also, regulations in Germany (and HELCOM Recommendations) state that the deposits are not to be depleted to the underlying clay or till layer. Also, the older, more harmful methods of stationary dredging with the resulting 8 - 10 m deep holes, which can lead to permanent oxygen deficiency, have been banned for a long time. The use of trailing suction hoppers is supposed to be more environmentally friendly by more gradually reducing the wanted layer and leaving undisturbed areas in between the extraction lanes, which can help with the resettlement of newly exposed layers.

Still, during the extraction process the sediments are treated in several ways. The hopper itself is protected by a mesh cage, which stops larger particle and rocks from entering and damaging the device. Finer particles are dispersed on the ground during the process and also released directly as in the ship hold´s overflow. Finally, undesired size fractions are sieved and released from the ship. Most of those sediments fall directly back to the extraction area, but some particles are subject to transportation with local currents. Therefore, a degree of change in sediment composition is unavoidable.

No information is available for the detailed spatial extent of sediment extraction. The ICES working group WGEXT only collects yearly tonnage of national extraction on a voluntary basis. In Germany, extraction fields are known with an expected amount of usable sediment and statistics as to how much has been extracted to date (in our case until 2012). We could assume that for example 50 % of sediment extraction will result in the use of 50 % of the area in question, but this may lead to overestimation, if some deposits have been harvested to a greater depth than others. Likewise, it is also possible that all the area has been used, but only to half the depth possible. In fact, the extraction companies are encouraged to utilize rather all the surface layer in a field instead of taking all the sediment in one part of the field at a time.

Table 3. Extraction fields in Mecklenburg Bight (to my knowledge no extraction in Danish waters, inquiry to Danish authorities pending)

Name	**Area km²**	**Volume (industr.) m³**	**Extracted m³**	***impact (until 2012) km² (approx.)***
Wismargrund	93,64	591.928	560.058	*88,6*
Trollegrund	7,15	1.236.250	357.650	*4,1*
Kühlungsborn	6,58	639.500	150.000	*3,1*
Heiligendamm	21,5	1.068.020	444.272	*17,9*
sum	*128.87*	*3.535.698*	*1.511.980*	***ca. 113,7***

For the purpose of this case study, we have taken an "assumed percentwise approach". This means that three of the fields that have been harvested to 29, 23 and 42 %, respectively, of the volume are assumed to have lost twice the percentage of surface. However, the biggest extraction field in Mecklenburg Bight (Wismargrund, now closed), where 95 % of the "industrial deposits" has been extracted, is assumed to have lost 95 % of the surface, because it is not likely that 100 % the area can indeed be reached in the extraction process. Wismargrund is also by far the most relevant case for physical loss or damage in Mecklenburg Bight, with approximately 88,6 km² of sandy habitat lost or damaged. This equals more than 84 % of the affected seafloor in this study.

2.4 Disposal

Dredging and dumping is an important subject for HELCOM policies and the information available for the amount of dredged and dumped material is better than for sediment extraction. Many locations of dredged harbor channels or deposit sites etc. are available, but the timeliness, sufficiency and accuracy of the information were found to be questionable. Data for dredged areas was hard to verify and this case study concentrates on the physical effect of dumping sites. Even in local administrative accounts inconsistencies in reporting appeared, for example due to partial use of dredged sediments in construction. One has to be aware, that the amount of dumped materials is given in differing units. Numbers from the HELCOM data service are given in tons of dry weight, whereas maritime agencies often calculate in cubic meters, a more practical unit when it comes to accounting for shiploads of sediments. The conversion factors vary depending on the minerals and the water content. As a rule of thumb, for “sea sand” a density of 1,66 t /m³ is assumed (Bergamt MV).

The spatial effect of dumping varies very much with the methods employed, with local conditions and the accuracy of the barge pilots. More environmentally friendly methods have been invented in the last decades, but no information about their availability and actual use is readily available. Typically, the material is carried in several shiploads to a more or less exact position and dumped at once. In low current situations almost all the sediment will be deposited in “one place” and only small amounts of fine sediments will affect habitats in the vicinity. According to local authorities (pers. com.) an area up to 400 m from the deposit “point” will be measurably “affected” and after 500 m no effects can be observed at all.

For the case study, a radius of 400 m has been calculated for the points of minor dumping and 500 m for the larger amounts of deposited sediments. It is not possible to calculate the thickness of the resulting layer and to approximate the likely difference between original sediment structure and the new layer. Therefore, for the time being the affected areas are considered as lost, due to the application of a precautionary ecosystem approach. The disproportionate error margin is considered to be negligible (for the time being), because total numbers are very small.

The Danish dumping site is treated differently due to the large amount of material dumped there and to the exact areal information provided by HELCOM.

Table 4. Disposal sites in Mecklenburg Bight (according to HELCOM maps and data service), DE area approximated in 2 classes, 400 and 500m m, respectively; DK area provided by HELCOM

Name	**Country**	**Year**	**Amount (t dry weight)**	***Area (until 2013) m² (approx.)***
Approach channel of Timmendorf	DE	2006 - 2008	4.300 - 10.800	*125.660*
Approach channel of Timmendorf/Poel	DE	2012	8.265	*125.660*
Ancora Marina Neustadt/ Bay of Mecklenburg	DE	2009	20.757	*125.660*
Trave (approach Luebeck)	DE	2010 - 2011	21.120 - 217.536	*196.344*
Harbour Rostock-Warnemuende	DE	2006 - 2013	5.250 - 93.835	*196.344*
Gedser Færgehavn Indsejling, map sign 196	DK	2010	798.994	*1.800.000*
sum				***ca. 1 km²***

2.5 Coastal infrastructure

The discussion, whether all coastal construction like port facilities, dredging of harbor approaches, groynes, piers etc. should also be assessed, has not been concluded yet, but for the time being damage and loss from these pressures is not included in the case study.

2.6 Beach replenishment

For coastal protection and recreational beach use large areas on and in front of beaches are covered with sediments stemming from **l.c.**, some of them regularly following erosion after storm surge events. They are not subject to this case study, because they often concern areas outside the scope of the MSFD and typically affect areas of natural rearrangement of substrates. Furthermore, data for this pressure are not at all easily accessible.

3. Habitat maps

3.1 Scale

For the evaluation of habitat damage and loss precise maps of benthic maps are necessary. Fairly precise maps are available for German Baltic waters and they will be used in the second case study Plantagenetgrund. In this broad scale case study however, sediment maps comparable to EUNIS level 3 (EUSeaMap 2011) are used due to several reasons. They are the "lowest common denominator", having been modeled for all Baltic waters and allowing for a regional assessment. Also, the MSFD assessment is supposed to be based on this very low resolution scale (i.e. "broad scale habitats"). The case studies are expected to demonstrate the possibilities and shortcomings of this approach by comparing two types of maps.

3.2 The map

A Baltic Sea map is available at the EUSeaMap data portal (http://www.emodnet-seabedhabitats.eu/default.aspx?page=1974&LAYERS=HabitatsEnBaltic). However, a big part of Mecklenburg Bight is missing there. The reason for this is that Mecklenburg Bight areas were modelled as part of the original North and Celtic Sea dataset back in 2011, but it looks like these areas were erroneously missed when the model was run back in 2012. The Emodnet project provided the 2011 data layer (many thanks go to Graeme Duncan at JNCC England). This map gives a very rough picture of sediment distribution. For example, in the sediment extraction field the seafloor is partly mapped as "sublitoral mud", but we know that only sand and gravel have been extracted there and the numbers have been applied accordingly in the calculation. The map is expected to be substituted by a better model in the near future and a prototype is available, but not used here due to several shortcomings.

3.3 Calculation

Calculations were based on an ESRI ArcView GIS containing data from HELCOM, Emodnet, BSH and others. Most numbers were taken manually with the "Measure"-tool for distance (cables) and area (wind farms etc.), habitat area was calculated using the clip tool inside ArcView.

Table 5. Broad scale habitats affected by physical impacts.

EUNIS 3 habitat/ area in MB (km^2)	**Affected by sediment extraction (m^2)**	**Affected by dumping (m^2)**	**Loss from wind turbines (m^2)**	**Affected by cables (m^2)**	**Sum (m^2)/ percentage**
sublittoral sand / 1432,7	113.700.000	2.122.004	-	706.600	116.528.604/ **8,1**
sublittoral mud / 2075,4	-	447.664	35.342	401.400	884.406/ **0,04**
sublittoral mixed sediments/ 72,3	-	-	-	18.400	18.400/ **0,03**
shallow sublit. rock/biogenic reef/ 867,6	-	-	114.508	270.000	384.508/ **0,04**
sublittoral till / 4,09	-	-	-	106.800	106.800/ **2,6**

4. Conclusion

The results for sublittoral mud, sublittoral mixed sediments and sublittoral rock (the broad scale habitats available in this map) are in line with the expectation, that human activities on this scale affect the habitats to a very low extent. However, the “rare” habitat type sublittoral till is potentially damaged to a degree relevant for GES discussion. However, the biggest surprise was that spatially largest sediment type, sublittoral sand, is affected to a comparably large extent by one human use targeting this sediment. A GES boundary of 5 % loss, which has been discussed (and rejected) at EU level, would have been reached in this respect, so that a more rigorous discussion of sediment extraction should be initiated. Also, this may mean that physical damage and loss of non-fisheries human activities has been underestimated in comparison to fisheries effects in the Baltic Sea.

Theme 3: Physical loss and damage to seabed habitats

This report is supporting material to the BalticBOOST WP 3.1 deliverable "Estimating physical disturbance on seabed". The BalticBOOST project that was coordinated by HELCOM and co-financed by the European Union in 2015-2016 as part of the programme DG ENV/MSFD Action Plans/2016.

WP 3.1 Supporting material 3: Plantagenetgrund

Partner: The Leibniz Institute for Baltic Sea Research (Leibniz-Institut für Ostseeforschung Warnemünde, IOW)

Author: Kai Hoppe

Contents

1. Introduction

The case studies in BalticBoost WP 3.1 for non-fisheries pressures affecting seabed habitats are not meant to be exact analyses of localized impacts and do not claim to be exhaustive. They are exemplary calculations based on readily and "not-so-readily" available data from HELCOM, ICES or national data services. Also, they intend to test some rather debatable assumptions regarding the concept of damage and loss. No consideration was given to the temporal aspect of data availability, because up-to-date information was only available in very few cases. As a result we can, together with the findings from WP 3.2, explore potential pathways for developing joint principles for defining environmental targets for seafloor integrity.

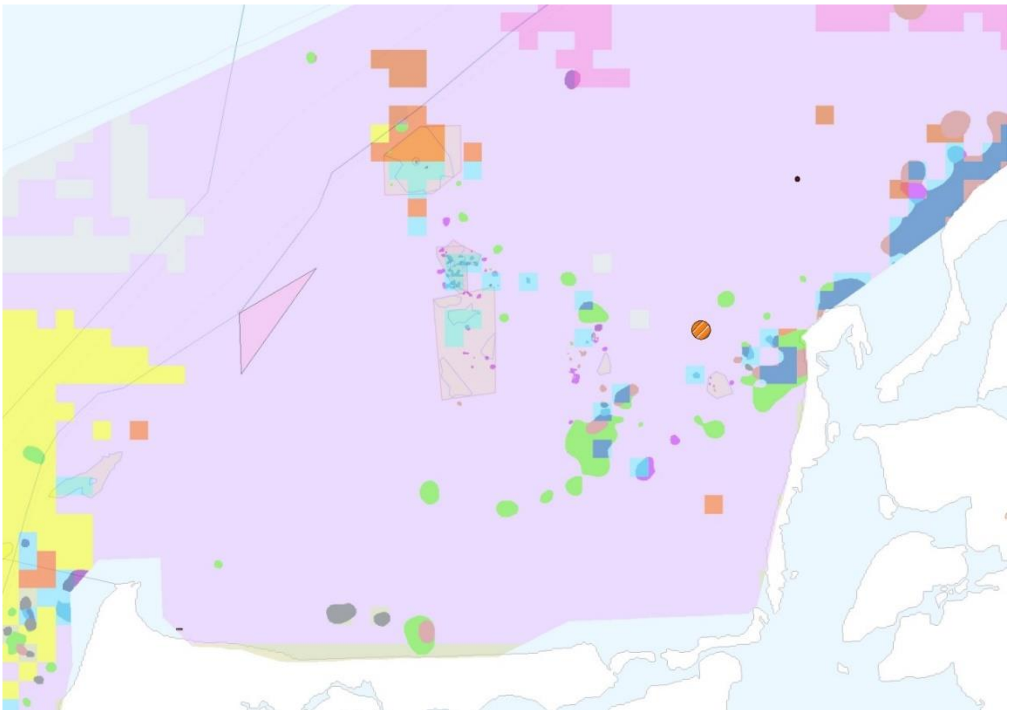

Figure 1: Plantagenetgrund with fine scale habitat map (Schiele et al 2015) and representations of human activities

The case study Plantagenetgrund aims at exploring information from sources, that are not usually publicly available, applied to the most accurate small scale habitat map. However, even though voluminous EIAs (environmental impact analyses) for construction or excavation projects are accessible upon request, the underlying data, like species or biomass tables, are not. Therefore no concrete comparison between communities in affected or unaffected areas can be carried out and the analyses have to remain on a theoretical level.

2. Human activities

The first step of selecting the relevant human activities already leaves us with decisions that cannot be completely satisfactory. In their GES advice, the European Commission lists the following activities relevant for D6:

1) Coastal infrastructures (ports, defenses against erosion, etc.) and offshore installations (oil and gas platforms, wind farms, etc.);

2) Offshore mining and sand extraction;
3) Release of dredged sludge;
4) Moorings;
5) Some fishing practices (trawling, dredging, etc.);
6) Aquaculture (unused fish feed, fish feces, etc.);
7) Introduction of non-indigenous species (trough ballast water for instance);
8) Pollution (chemical pollution, litter);
9) Changes in riverine inputs (organic enrichment of particulate matter, etc.);
10) Sediment remobilization by fishing equipment (trawls, dredges);
11) Changes in freshwater riverine inputs as a consequence of damming and irrigation;
12) Changes in solid matter riverine inputs; and
13) Release of large quantities of warm (power plant cooling) or salty water (from desalination facilities)

source: http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-6/index_en.htm; 08.06.2016)

Of these, only points 1 - 6 and 10 directly apply to physical damage and loss. Several activities (ship traffic, tourism etc.) have also been considered, but not selected here. The area was chosen to evaluate wind farm construction, cables, sediment extraction and dumping grounds. Even if we exclude eutrophication, pollution and other non-physical pressures, a totally comprehensive evaluation of seafloor integrity is not achievable at the moment and we have to restrict ourselves to the estimation of the most relevant effects.

2.1 Wind farms

Detailed information about wind farms is readily available (most up-to-date on http:\\www.4coffshore.com), often including number of engines, details of constructions, length of cables, etc.. The wind farm Baltic I was completed in 2010, but construction at the converter station seems to be ongoing.

Figure 2: Wind farms are notoriously hard to capture from sea level. However, this perspective gives an idea about the low density of installations in the area

Figure 3: Maintenance work (here at the converter station in 2016) can also lead to seafloor damage.

The area covered by the constructions is determined mainly by the amount of scour protection in place. The sealed area can definitely considered to be lost, even though it is “transformed” to a new habitat type (typically from sand to rock) and the new habitat may have a higher biodiversity than the old one. Even though detailed information about possible construction types were examined in the project application documents, the finally employed technique is not known. The turbines themselves are grounded by monopole constructions, which supposedly need scour protection in place.

OSPAR (2008) described an average of 30 m diameter per turbine (or 5 times the pile diameter) and this number was confirmed by data from Nysted I (Danish Energy Authority 2006). This number was used here. Similarly, effects of the electrical cables in Baltic I have to be approximated. There are two types of wind farm cables. First there is an array of cables connecting the turbines to each other and to a converter station and second the converter station sends the current to a terrestrial receiver station on shore. Baltic I shares its shore cable with another wind farm that in turn will be connected to a station in Sweden.

Table 1. Wind farm Baltic I

Name	Country	Turbines	Area (km²)	Loss (m²)	Loss compared to windfarm area (%)
Baltic I	DE	21	2	14.844	0,2
Cables		length (km)	depth (m)	affected area (m²)	
Array cable	DE	21	unknown	42.000	0,6
Shore cable	DE	122	1,5	244.000	-

During the process leading to the installation of the wind farm Baltic I, extensive impact analyses and prediction have been produced, including an evaluation of impacts on the seafloor in the construction areas for several types of turbine foundations, cable trenches etc.. The overall result was that the impact can be considered not to be severe and rather short-lived. Disappointingly, the investigation was not continued in the construction phase, nor were the prognoses reviewed afterwards. Also, the construction methods finally chosen from a number of possibilities were not documented. And whereas the project application is accessible (with a special application process), the underlying data are not.

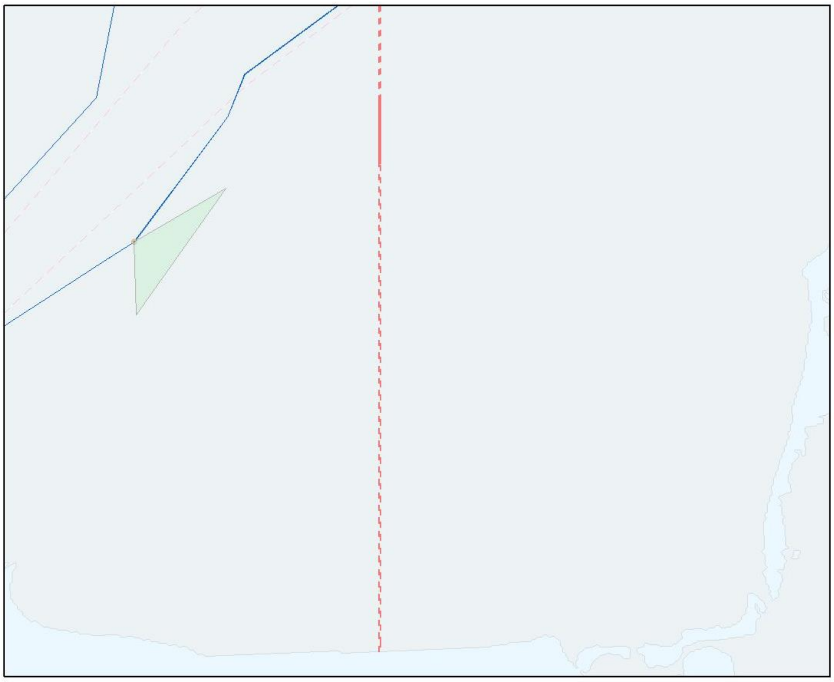

Figure 4. Wind farm and cables at Plantagenetgrund (green triangle - wind farm, blue lines - power cables, red lines - data cables, vertical red line from an undocumented cable found in an EIA (solid line) and theoretically continued dotted line))

2.2 Cables

In addition to the wind farm cables a number of data cables can be found in the case study area. Again, the exact nature of the impact they have is unknown, so that for the sake of this study they are presumed to have been established decades ago, using even more invasive methods than used nowadays.

Several methods are used to protect the cables from damage by anchoring ships or ground-touching fisheries. On hard bottoms cables can be covered by concrete or steel casings, and most often they are buried at 1 to 2 m depth in sediments. Depending on the burial technique, cable trenches can be visible as **2 m wide disturbances** after decades, indicating a long term change of sediment characteristics.

In addition to "known" cables an investigation for sediment extraction permits identified two "lost" cables in the study area bathymetrically and by side scan sonar.

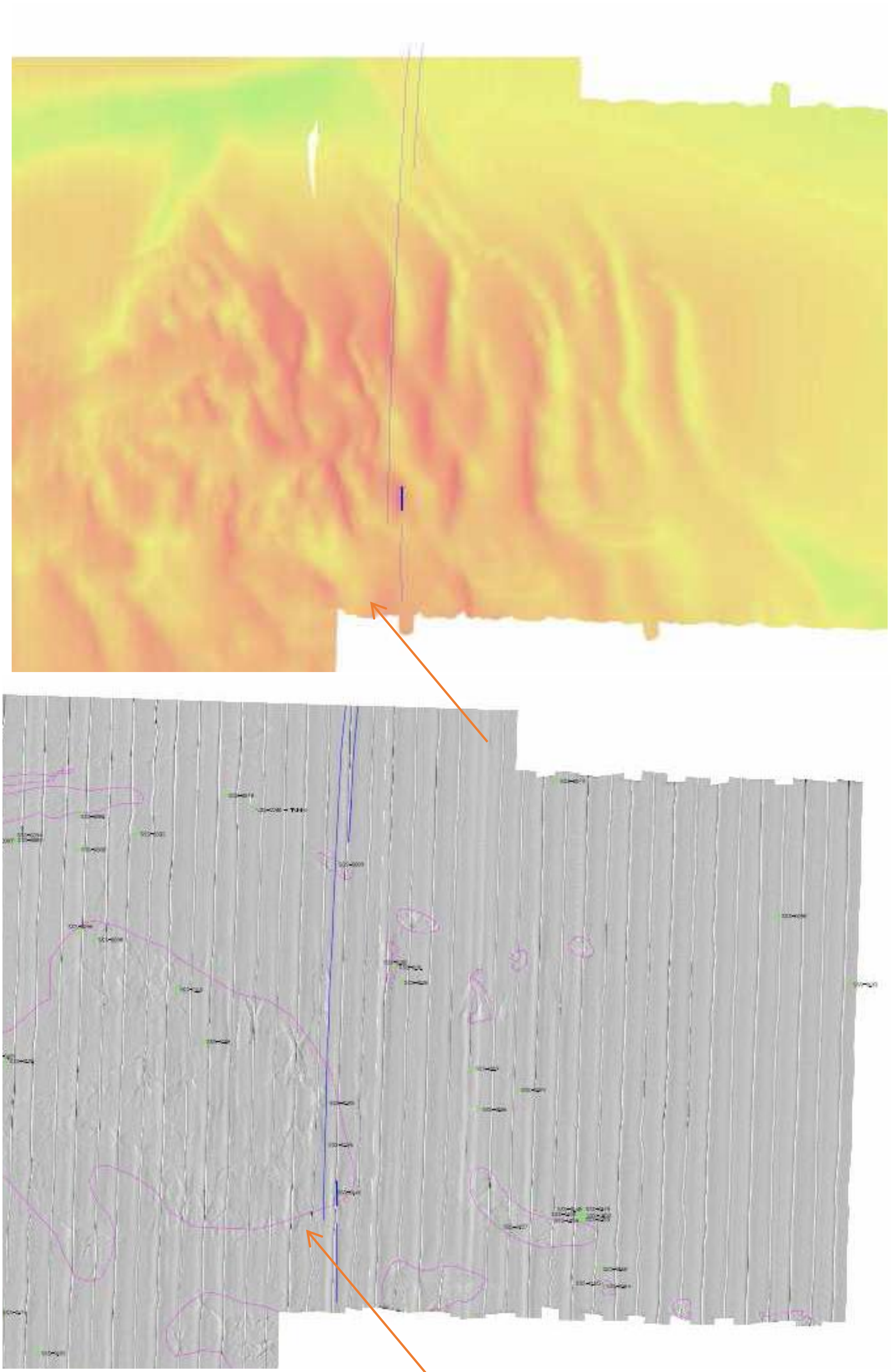

Figure 5 and 6. Bathymetric and side scan sonar images showing two parallel cables (arrows) in the Plantagenetgrund NW sand extraction area (corresponding to the full part of the vertical red line in Figure 4).

Even though information about the origin of the cables is missing, they nicely demonstrate that cable can have a lasting impact on the seafloor. Experts at the national maritime organization were surprised, that cables, which supposedly were buried deep enough not to be an obstacle, are now, decades later, (partly) visible and affecting the seafloor.

Table 2. Data cables in Plantagenetgrund area.

Name	**Country**	**Length (km)**	**Length in cs area (km)**	**Area affected (m²)**	**Comment**
BalticCable	DE/DK/SE	279	10,5		
“lost cable”	DE/DK?	?	2 x 29,1	117.280	assumed, based on records for 2,8 km in EIA
SE-D4	DE/SE	44	13,8	27.600	out of use
SE-D5	DE/SE	94	21	41.960	null

2.3 Extraction

Areawise, in north-eastern Germany the most intense physical use of seafloor habitats is the exploitation of fossil sediment deposits. Several size classes of sand and gravel are of interest for industrial use and coastal protection (dyke building and beach replenishment). The layers need to be strong and pure enough, close enough to harbor facilities and in acceptable water depths to be considered as “industrial deposits”. Of these, according to Schwarzer (2006) in 2004 already all deposits in Germany (Mecklenburg-Westpommerania) had been exploited by 31 %. Intuitively, this should have a significant effect on the abundance of certain habitat types. However, on a broad scale (EUNIS level 3) the percentage loss/damage may not be as obvious. Permits for sediment extraction are subject to a range of environmental impact assessments, and the results are part of a public consultation process, during which they are available in the internet. However, after the process these data are hard to get.

It is very hard to judge what kind of physical loss and damage is caused by sediment extraction. On a broad habitat scale extraction fields do not differ from the surrounding areas of fine or mixed sediments. Also, regulations in Germany (and HELCOM Recommendations) state that the deposits are not to be depleted to the underlying clay or till layer. The older, more harmful methods of stationary dredging with the resulting 8 - 10 m deep holes, which locally lead to permanent oxygen deficiency, have been banned for a long time. The use of trailing suction hoppers is supposed to be more environmentally friendly by more gradually reducing the wanted layer and leaving undisturbed areas in between the extraction lanes, which can help with the resettlement of newly exposed layers.

Still, during the extraction process the sediments are treated in several ways. The hopper itself is protected by a mesh cage, which stops larger particle and rocks from entering and damaging the device. Finer particles are dispersed on the ground during the process and also released directly as in the ship hold´s overflow. Finally, undesired size fractions are sieved and released from the ship. Most of those sediments fall directly back to the extraction area, but some particles are subject to transportation with local currents. Therefore, a degree of change in sediment composition is unavoidable.

The extraction area “Plantagenetgrund” consists of several extraction fields with slightly differing uses and granulometric distributions. It has been in use for several decades and Plantagenetgrund SE in the south has almost been depleted (2012). The northern and middle east (the irregular red polygon in Figure 7) fields have assumedly not been used yet and exploitation of the field in the middle (Plantagenetgrund NW) is ongoing until 2050. The two additional polygons (yellow in Figure 7) are potential extraction fields for use in coastal protection.

According to a data point in the CONTIS online information system, the northernmost field is also used as a dumping ground for dredged materials (see I.d). However, upon closer inspection no information about dumping dates and amounts of material were forthcoming (yet?) from the responsible offices for maritime or mining affairs.

For the purpose of this case study, we have taken an assumed percent-wise approach (see also Case Study Mecklenburg Bight) for Plantagenetgrund SE. Unfortunately, this can only be applied to one of the extraction fields, where information for the amount of harvested material was available.

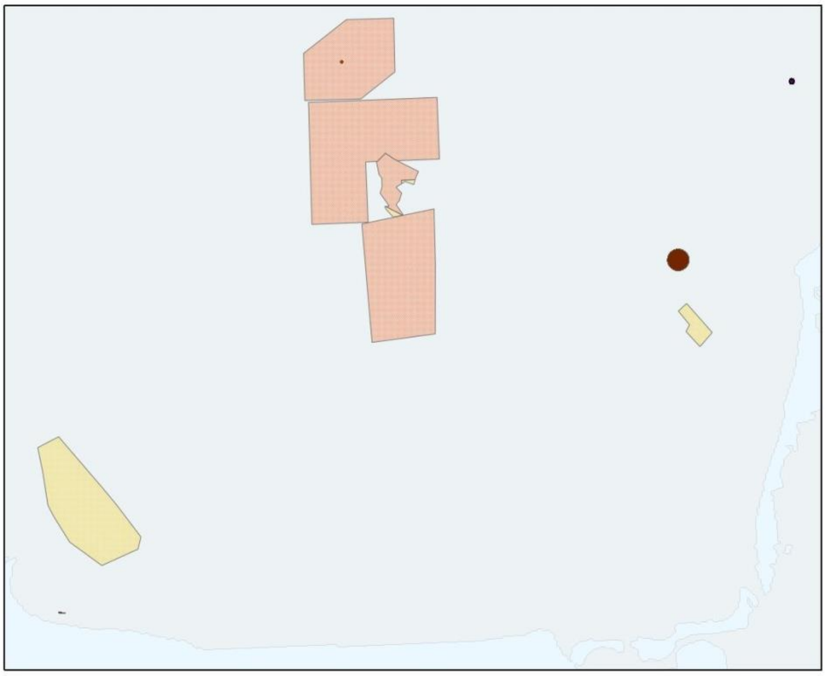

Figure 7. Extraction fields (yellow and red polygones) and dumping grounds (dark brown points and one tiny polygone in the lower left) at Plantagenetgrund

In addition to the known exploitation status of the sediment fields a second calculation covers the potential impact should all industrial deposits be depleted. At least for the largest extraction field "Plantagenetgrund NW" a license for exploitation exist until 2050, so that this assumption is not very far-fetched.

Table 3. Extraction fields in Plantagenetgrund.

Name	Area km²	Volume (industr.) m³	Extracted m³	*Impact km² (approx.)*
Plantagenetgrund Nord	18,4	10.620.000	0	*0*
Plantagenetgrund NW	26,2	40.970.000	?	*?*
Plantagenetgrund SE A	2,7	?	?	*?*
Plantagenetgrund SE	17,5	2.919.996	2.715.025	*16,2*
Ostsee-4-6-Sa-V2 / SWK: S 3	13,5	?	?	*?*
Ostsee-5-6-Sa-V1 / SWK: S 3	1,3	?	?	*?*
sum	*128.87*	*3.535.698*	*1.511.980*	***16,2 (up to ca. 110)***

2.4 Disposal

Dredging and dumping is an important subject for HELCOM policies and the information available for the amount of dredged and dumped material is better than for sediment extraction. Many locations of dredged harbor channels or deposit sites etc. are available, but the timeliness, sufficiency and accuracy of the information were found to be questionable. Even in local administrative accounts inconsistencies in reporting appeared, for example due to partial use of dredged sediments in construction. One has to be aware, that the amount of dumped materials is given in differing units. Numbers from the HELCOM data service are given in tons of dry weight, whereas maritime agencies often calculate in cubic meters, a more practical unit when it comes to accounting for shiploads of sediments. The conversion factors vary depending on the minerals and the water content. As a rule of thumb, for “sea sand” a density of 1,66 t /m^3 is assumed (Bergamt MV).

The spatial effects of dumping vary very much with the methods employed, with local conditions and the accuracy of the barge pilots. More environmentally friendly methods have been invented in the last decades, but no information about their availability and actual use is readily available. Typically, the material is carried in several shiploads to a more or less exact position and dumped at once. In low current situations almost all the sediment will be deposited in “one place” and only small amounts of fine sediments will affect habitats in the vicinity. According to local authorities (pers. com.) an area up to 400 m from the deposit “point” will be measurably “affected” and after 500 m no effects can be observed at all.

For the case study, areas affected by dumping were available from the HELCOM data service for two cases (“northern approach to Stralsund” and „Join_ID 22013165“). A third dumping site, “Wieker Bodden/Arcona Sea”, was approximated by comparing it to „Join_ID 22013165“. The last site, „dumpin_p (OID 375)“, originates from an probably outdated data set by CONTIS and could not be verified.

It is not possible to calculate the thickness of the layers resulting from the disposal and to approximate the likely difference between original sediment structure and the new layer. Therefore, for the time being the affected areas are considered as lost, due to the application of a precautionary ecosystem approach. The disproportionate error margin is considered to be negligible (for the time being), because total numbers are very small.

Table 4. Disposal sites in and around Plantagenetgrund

Name	**Country**	**Year**	**Amount (t dry weight)**	***Area (until 2013) km² (approx.)***
Northern approach to Stralsund	DE	2006	139.263	0,785
Wieker Bodden/Arkona Sea	DE	2009	33.110	*0,009*
„Join_ID 22013165“	DE	2013	68.645	0,019
„dumpin_p (OID 375)“ (located in extraction field Plantagenetgrund Nord)	DE	"in use"	-	-
sum				***ca. 0,8km²***

The shipping channel leading from our case study area to Stralsund (see **I.e.** below) has to be maintained by almost yearly dredging (*Tab. 5*). The numbers available for the years 1990 - 2013 show, that the amount deposited at the dumping site “Northern approach to Stralsund” varies a lot from year to year. Also, the one number given in the GIS system for 2006 does not exactly match the number derived from the local authority (WSA Stralsund), nor does it at all match an average yearly number (66.000 m³). The area of 0,785 km² is consistent, however, so that a permanently disturbed area of this size can safely be accounted for. The channel itself can be approximated by comparing satellite images to the GIS maps.

Table 5. Material dredged for "Northern approach to Stralsund".

year	amount (m³)	year	amount (m³)	year	amount (m³)
1990	54.377	1997	-	2004	-
1991	85.483	1998	69.115	2005	178.043 (100.000 for construction)
1992	13.118	1999	38.859	2006	103.158
1993	98.643	2000	82.994	2007	87.776
1994	130.369	2001	60.172	2008	200.000 (all for dyke construction)
1995	40.975	2002	101.337	2009	200.000
1996	47.551	2003	-	2010 - 13	0

2.5 Coastal infrastructure

The Darß area and the island of Hiddensee, that border the case study are in the East and South, are subject to coastal erosion on one hand and recreational use on the other. Therefore, of ca. 56 km of coastline about 24,1 km are protected by wooden groyne systems and rocks, significantly changing the naturally variable near shore habitats. Even though the groynes extend only about 100 m perpendicularly into the sea, they are supposed to alter the sediment transport regime much further. In addition to this, there are two piers and an artificial harbor. For this harbor and for the connection to the harbor of Stralsund two shipping lanes have been dredged and are maintained by more or less continuous dredging (see **I.d.** above). For coastal infrastructure an assessment is under discussion and not added here yet, because the conceptual basics are missing.

Figure 8. Coastal infrastructure in cs area: brown - groyne systems (dotted = inactive), black - enrockment, lilac - piers, blue - dredged channels

2.6 Beach replenishment

For coastal protection and recreational beach use large areas on and in front of beaches are covered with sediments stemming from **l.c.**, some of them regularly following erosion after storm surge events. They are not subject to this case study, because they often concern areas outside the scope of the MSFD and typically affect areas of natural rearrangement of substrates. Furthermore, data for this pressure are not at all easily accessible. Anyway, it is not likely that beach replenishment is needed in the case study area.

2. Habitat maps

3.1 Scale

For the evaluation of habitat damage and loss precise maps of benthic maps are necessary. Fairly precise maps are available for German Baltic waters and they will are used in this case study. In a broad scale study however, sediment maps comparable to EUNIS level 3 (EUSeaMap 2011) are used due to several reasons. They are the “lowest common denominator”, having been modeled for all Baltic waters and allowing for a regional assessment. Also, the MSFD assessment is supposed to be based on this very low resolution scale (i.e. “broad scale habitats”). The case studies are expected to demonstrate the possibilities and shortcomings of this approach by comparing two types of maps.

Figure 9. Plantagenetgrund with fine scale habitat map (Schiele et al 2015, left) and EUSeaMap broad scale habitats (right, only partly covering the area)

3.2 The maps

The habitat map by Schiele et al (2015) is currently the finest map available in Mecklenburg. In contrast, the versions of the EU Seamap project from 2011/2012 only represent habitats in a very broad resolution (http://www.emodnetseabedhabitats.eu/default.aspx?page=1974& LAYERS= HabitatsEnBaltic). In some places its accuracy is questionable, for example some sand extraction areas are represented as mud habitats. A preliminary version of the forthcoming new version (2016) yielded a different, but also not satisfying result (not demonstrated in the case study).

3.3 Calculation

Calculations were based on an ESRI ArcView GIS containing data from HELCOM, EmodNet, IOW, BSH, MV data service and others. Most numbers were taken manually with the “Measure”-tool for distance (cables) and area (wind farms etc.), habitat area was calculated using the clip tool inside ArcView.

Table 5. "Fine scale" habitats affected by physical impacts; worst case is a situation when all designated extraction fields have been exploited.

Habitat, HUB code level 6 (where possible)	**Area in German Baltic waters (km^2)**	**Area in cs (km^2)**	**Affected area in cs (km^2)**	**Percentage**	**Affected area in cs (km^2) ("worst case")**	**Aercentage ("worst case")**
mixed bivalves CMM, AA.J3L9	2304	872,1	18,43	**2,11**	61,90	**7,10**
mixed bivalves CMM, AB.J3L9	1923,1	43,6	0,0062	0,01	0,006	0,01
AA.J3L	596,8	16,7	0,0258	0,15	0,03	0,15
AA.M1C/S	541,6	19,1	0,0012	0,01	0,400	2,10
Mytilidae, AA.J1E1	*243,3*	*18,5*	0	0	9,753	**52,72**
AA.J3	194,6	13,1	0,0032	0,02	0,003	0,02
Mya arenaria, AA.J3L4	160,7	4,9	0,01	0,18	0,01	0,18
mixed bivalves CMM, AA.I3L9	47,2	1,9	0,0045	0,24	0,004	0,24
Ophelia/Travisia , AA.J3L11	127,9	11,46	0,0066	0,06	5,650	**49,30**
AB.M1	172,5	0,14	0,0009	0,65	0,001	0,65
AA.M*1	*136,1*	*3,5*	*0*	0	0,013	0,36
AA.G	*5,2*	*2,1*	-	-	-	-
sum	*6453*	*1.007*	18,49	1,84	77,77	**7,72**

Table 6. "Broad scale" habitats affected by physical impacts (by summing Tab. 5 l6 habitats to broader typology); worst case is a situation when all designated extraction fields have been exploited.

Broad scale habitat	**Area in German Baltic waters (km^2)**	**Area in cs (km^2)**	**Affected area in cs (km^2)**	**Percentage**	**Affected area in cs (km^2) (worst case)**	**Percentage (worst case)**
photic sand	4357,4	963,36	18,48	**1,92**	77,76	**8,07**
aphotic sand	2095,6	43,74	0,007	0,016	0,007	0,016

3. Conclusion

When comparing the status quo in Tab. 5 and 6 we can see that in the end both results are not dramatically different. We can see that the more rare communities like mussel beds have so far been spared from damage, presumably due to recommendations stemming from the Environmental Impact Assessments, which are part of the permission process. If we classify the impacts as loss, they are with a proportion of about 2 % fairly substantial in this small assessed area, but not yet in a magnitude where the Good Ecological Status may be compromised. However, we have to keep in mind that additional effects from fishing and coastal installations have not been included in this consideration.

This situation changes, should a complete exploitation of fossil sediment layers be contemplated (worst case scenario). On a small scale, half of two rarer habitats will then be affected, likely wiped out. More relevant for MSFD purposes, even on a broad scale a severe impact on about 8 % of photic sands can be expected. If the responsible agencies are not bound by national regulations in this respect anyway, they will have to also keep the larger MSFD point of view regarding damage and loss of seabed habitats in mind.

Theme 3: Physical loss and damage to seabed habitats

This report is supporting material to the BalticBOOST WP 3.1 deliverable "Estimating physical disturbance on seabed" and WP 3.2 deliverable "Fisheries Impact Evaluation Tool (FIT) with Application to Assess the Bottom Fishing Footprint in Western Baltic Sea". The BalticBOOST project that was coordinated by HELCOM and co-financed by the European Union in 2015-2016 as part of the programme DG ENV/MSFD Action Plans/2016.

WP 3.1 and WP 3.2 Supporting material 4: Case study Femern Belt

Influence of fishing pressure on benthic invertebrate species diversity and density in the Western Baltic Sea and evaluation of robust indicators for this taking into consideration hydrographical and physical habitat characteristics (initial results)

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Contents

1. Introduction

The aim of the study is to evaluate ecological side effects of fishery with hauled gears in relation to impacts on the benthic environment, habitats and communities.

The following 0-hypotheses are tested:

- The species richness (biodiversity=BD), the number of individuals (density=N), the BD given N, the biomass (B), and the B given N, respectively, of marine benthic invertebrates, are not affected by fishery and not dependent on different levels of fishing pressure (FP);
  - The above hypothesis is tested for several parameters (indicators):
    - BD or BD given N in benthic invertebrate community,
    - N (density of full benthic invertebrate community or by species for selected indicator species),
    - Biomass in dry weight (B in DW) given N (for full benthic invertebrate community or by species for selected indicator species),
    - Average individual mean weight B/N (estimated as average for all individuals in the benthic invertebrate community, i.e. on the overall community level, or as average for all individuals by species for selected indicator species);
- There is no difference between different benthic habitats (seabed hardness types with different sediment grain sizes and types) and impacts of FP levels on biodiversity, density, biomass, or mean weight for marine benthic invertebrates;
- All species and species groups of marine benthic invertebrates are equally affected by different levels of FP;
- It is from the present data not possible to obtain robust (statistical highly significant) indicators for impacts of different levels of FP on the benthic invertebrate community level (species groups) or for selected single invertebrate indicator species;
- It is from the present data not possible to identify clear threshold levels in FP according to biodiversity and density in the benthic invertebrate community or for selected single invertebrate indicator species.

2. Materials and methods

2.1 Benthic Invertebrate Community Data

Under the Environmental Impact Assessment (EIA) of a potential fixed link between Denmark and Germany benthic invertebrate fauna and community data were sampled and compiled by a consortium under the Femern Belt A/S (Danish Ministry of Transport) lead by the Danish Hydrological Institute (DHI) with participation of among other Institute of Oceanography in Warnemünde (IOW). The Femern Belt A/S has granted full access to these data in present scientific investigation context with data analyses and evaluations conducted by DTU Aqua. The benthic monitoring program covered benthic fauna stations sampled under a carefully planned survey design with intensive, standardized, and repeated grab and frame sampling on seasonal basis during 2009 and 2010 on different types of benthic habitats and bottom depths in the Femern Belt area of the Western Baltic Sea (Figure 1; Tables 1-2). Overall, 315 locations have been sampled throughout the first, second and third quarter of the year, and in total 1032 unique samplings have been taken under the monitoring program. The data sampling, the subsequent faunistic classification with phylogenetic and species determination, as well as the density and biomass estimation (wet and dry weight) by benthic (species) group, have been quality checked and controlled by several independent faunistic experts to ensure high data quality.

Different types of invertebrate sampling gears were used, and each gear has different observation coverage area as shown in Table 1. The small Rahmen frame type which samples an area of 0.0625 m^2 was specifically used to sample only blue mussels (*Mytilus edulis).* The data obtained with this sampling method are analyzed separately and not included in the current study. Two parallel sets of analyses have been made. One is covering all 1090 benthic samples disregarding the FP value, i.e. including also sampling stations with no fishery and accordingly zero fishing pressure values (upper part of Tables 1 and 2). Another set covers only the 100 samples on stations where there has been fished, i.e. where FP>0 (lower part of Tables 1 and 2). Both investigations have excluded the directed blue mussel sampling with specific blue mussel sampling dredgers, however, blue mussels sampled with the other sampling gears have naturally been included in the analyses. The stations included in the respectively 58 and 6 samples with the dredge were also covered by Van Veen Grab sampling, and the dredge sampling did not provide any other information than the occurrence (presence/absence) of a species (Table 1). Accordingly, the data from these 58 and 6 samples, respectively, were excluded. Finally, 97 and 2 samples, respectively, that are on the sediment type 4 ("outside polygons") have been excluded from the analyses (Table 2). Consequently, there are respectively 935 (=1032-97) and 92 (=100-8) samples analysed which provide quantitative FP and benthic invertebrate data.

The benthic community parameters estimated and analysed are biodiversity (BD) as total number of species per sample, density (N) as total number of individuals counted per sample (or by species group by sample), biomass (B) as total biomass in dry weight per sample (or by species group by sample), and average individual mean weight B/N estimated as average for all individuals by sample in the benthic invertebrate community, i.e. on the overall community level (or as average for all individuals by species for selected indicator species by sample).

An area conversion factor by sampling gear was used to standardize the analyzed number of individuals and the dry weight per species (Table 1), but not the biodiversity parameter (Table 1). The latter should be noted because there is observed a correlation between the number of species (BD) and the number of individuals (N) per sample. The differences between the covered areas of the different sampling gears are, however, so small (between 0.098 m^2 and 0.117 m^2) that there is no significant effect to be expected on BD by the different sampling areas. The majority of the data samples (69 % where FP>0, and 85% where FP>=0) have been area corrected. See Tables 1 and 2 for overview of samples.

Table 1. Overview of benthic sampling gears used, their sampling area, the area standardization and correction factor by gear, as well as the number of samples conducted with each gear and method. The upper table covers all benthic samples including the samples on stations where there is not fishing, i.e. where the fishing pressure is 0, while the lover table only covers the samples where there is fishing , i.e. where the fishing pressure is above 0, (FP>0).

Sampling gear	Sampling area (m^2)	Area corrected	Number of samples
Van Veen Grab	0,0980	1,00	73
Van Veen Grab	0,1166	0,84	161
Dredge	0,1166	0,84	57
Dredge	0,1152	0,85	1
Kautsky frame	0,10	0,98	570
Rahmen (0.1 m^2 mit Netzbeutel)	0,10	0,98	186
Van Veen Grab	0,10	0,98	24
Van Veen grab	0,1152	0,85	2
Van Veen Greifer (0.1 m^2)	0,10	0,98	16

Sampling gear	Sampling area (m^2)	Area corrected	Number of samples
Van Veen Grab	0,0980	1,00	14
Van Veen Grab	0,1166	0,84	35
Dredge	0,1166	0,84	6
Kautsky frame	0,10	0,98	31
Rahmen (0.1 m^2 mit Netzbeutel)	0,10	0,98	9
Van Veen Grab	0,10	0,98	3
Van Veen Greifer (0.1 m^2)	0,10	0,98	2

Table 2. Overview of the benthic invertebrate samples and categories used in the present analyses including their spatio-temporal coverage. Furthermore, average fishing pressure by quarter by category is indicated, and the minimum and maximum FP observed at stations in given category, i.e. the FP range included in the analyses. In the lower part of the table the range (min, max, mean) of number of species and individuals per sampling in each category. The two upper tables are covering all samples also including stations with zero fishing pressure, while the two lower tables are covering samples at stations where the fishing pressure were above zero. Values in brackets indicate inclusion of 1 sampling outlier.

	No. of Samples	**Total No. of Species (BD)**	**Total No. of Individuals (N)**	**Total Biomass (B, g)**	**Average FP, Abrasion**	**Minimum FP, Abrasion**	**Maximum FP, Abrasion**
All samples also including stations with zero fishing pressure							
All Samples	1032	363	745643	8561,93	0,07	0	2,49 (6,27)
2009	544	336	441744	4430,71	0,06	0	2,49
2010	488	292	303899	4131,23	0,07 (0,08)	0	1,93 (6,27)
Season 1	519	326	312609	4292,71	0,11 (0,12)	0	2,49 (6,27)
Season 2	429	323	392398	4251,66	0,02	0	0,55
Season 3	84	66	40636	17,56	0,03	0	2,18
Habitat 1	80	194	49511	2948,23	0,23	0	1,93
Habitat 2	172	174	65932	257,62	0,03	0	0,89
Habitat 3	683	352	586629	5316,94	0,07 (0,08)	0	2,49 (6,27)
Habitat 4	97	105	43571	39,14	0,01	0	0,34

	Min. BD per station	**Max. BD per station**	**Mean BD per station**	**Min. N per station**	**Max. N per station**	**Mean N per station**	**Mean N per station excl. Mytilus edulis**
All samples also including stations with zero fishing pressure							
All Samples	1	74	19	1	7746	470,72	
2009	1	70	19	1	7746	532,86	
2010	2	74	18	3	4827	402,52	
Season 1	2	72	19	1	5832	393,71	
Season 2	2	74	21	7	7746	555,80	
Season 3	1	24	13	3	2868	483,76	
Habitat 1	7	44	24	1	868	209,79	
Habitat 2	3	43	12	3	1923	323,20	
Habitat 3	1	74	21	1	7746	560,30	
Habitat 4	2	32	13	3	2510	449,19	

Table 2. (Continued).

	No. of samples	Total No. of Species (BD)	Total No. of Individuals (N)	Total Biomass (B, g)	Average FP, Abrasion	Minimum FP, Abrasion	Maximum FP, Abrasion
Samples with fishing pressure FP>0							
All Samples	92	239	60032	2540,91	0,35	0,01	1,93
2009	50	215	29491	1090,93	0,27	0,01	1,56
2010	42	175	30541	1449,98	0,44	0,03	1,93
Season 1	63	218	35783	1765,63	0,46	0,01	1,93
Season 2	29	178	24249	775,28	0,10	0,04	0,55
Habitat 1	35	135	23650	1790,65	0,44	0,05	1,93
Habitat 2	3	55	977	21,36	0,39	0,03	0,87
Habitat 3	54	228	35405	728,90	0,29	0,01	1,78

	Min. BD per station	Max. BD per station	Mean BD per station	Min. N per station	Max. N per station	Mean N per station	Mean N per station excl. *Mytilus edulis*
Samples with fishing pressure FP>0							
All Samples	3	71	21	1	1851	301,67	
2009	3	63	20	1	1791	310,43	
2010	5	71	22	26	1851	293,66	
Season 1	3	71	20	1	1851	255,60	
Season 2	7	42	22	64	1791	411,00	
Habitat 1	10	38	24	5	664	229,61	
Habitat 2	5	32	18	26	262	139,57	
Habitat 3	3	71	20	1	1851	397,81	

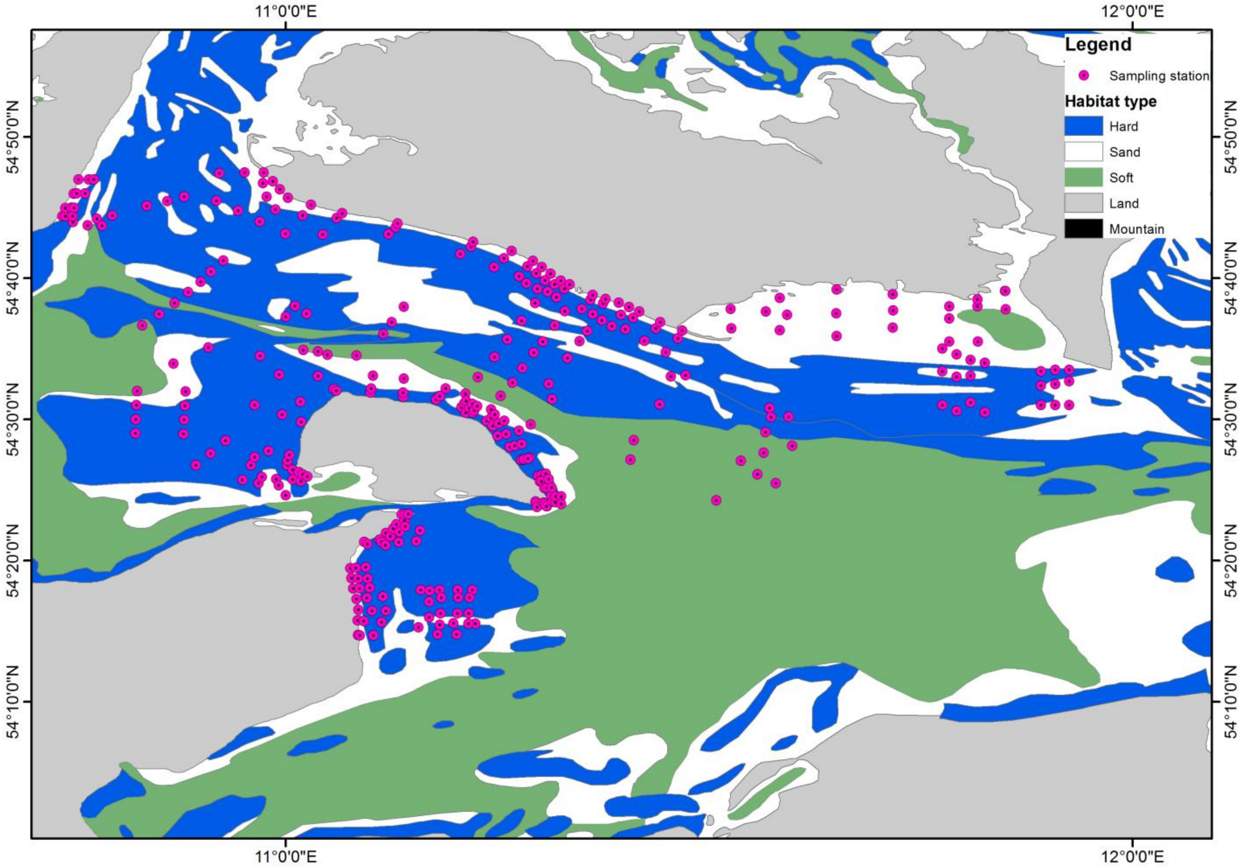

Figure 1. Grab and Frame sampling stations under the benthic invertebrate monitoring program and survey design (conducted by a consortium under the Femern Belt A/S in 2009-2010) according to different types of benthic sediment types (physical habitats). Soft bottom is fine grained sublittoral mud (sediment type 1), sand is sublittoral sand (sediment type 2), and hard bottom is sublittoral mixed sediments (sediment type 3).

2.2 Fishing Intensity Data

The fishing intensity or fishing pressure (FP) data comprise Danish and German VMS (satellite monitoring) fishing effort registration for vessels of 15 m length and longer using demersal hauled gears (mainly otterboard trawlers and otterboard pair trawlsers, but also seiners and dredgers). The fishing effort data have been extracted from national VMS databases and compiled and aggregated by DTU Aqua (Danish fishery data) and TI (German fishery data). FP estimates are obtained by processing the raw VMS data and making further coupling to fishery logbook data and to questionnaire surveys of fishermen and net makers with estimates regarding the dimensions of the different gears by applying the methodology described in Bastardie et al. (2010), Hintzen et al. (2012), and combined in Eigaard et al. (2016; 2017). The relationships between gear dimensions and vessel size (e.g. trawl door spread and vessel engine power (kW)) for different gear groups were used to assign quantitative information of bottom contact (e.g. width of gear) to each logbook trip, and the extended logbook data were combined with interpolated vessel tracks based on VMS data (Hintzen et al., 2012). The required vessel size information, in terms of engine power (kW) and overall vessel length, was collected, together with the gear specifications in a pan-European industry-based questionnaire survey (Eigaard et al., 2016). This study enabled statistical modelling of the vessel size or vessel engine power ~ gear size relationships for different métiers (combinations of gear types and target species) to deduce the width of the sweep of each of the (VMS interpolated) fishing event taking place across the stations.

Fishing effort is accumulated within a radius of 1000 m (and alternatively 1500 m) around each of the benthic invertebrate sampling stations during the previous 3 months of the benthic invertebrate sampling date. That is 3 months before the current month of the sampling date (and alternatively only during the current month of the sampling date). The resulting cumulated FP (fishing intensity) is estimated as the fraction of the area (ratio of surface) covered by fishery, i.e. accumulated fishing effort, in this 1000 m radius and 3 month period of time. That is, the total swept area inside a circle with radius 1000 m centered around each benthic sampling station coordinate so the FP is expressed as the swept area ratio per quarter in form of the relationship between the area fished (swept) divided by the total station area. The circles surface areas were computed from UTM coordinates. Accordingly, if the cumulated FP parameter is 0.5 then only half of the 1000 m radius area is swept during the previous 3 month period which is the same as the full area is swept once after every second 3 month period. If the FP is 2 then the full area is swept by fishery 2 times within a 3 month period, i.e. 8 times within a year. The FP data resolution, processing and aggregation for estimating FP is following the EU-FP7-BENTHIS standards, and the EU FP7 BENTHIS WP2 software has been used for the process of estimating FP as described in Eigaard et al. (2017) which is also based on previous work published in Bastardie et al. (2010) and Hintzen et al. (2012).

An example of the FP data for hauled gears in 2010 in the Femern Belt Area is shown in Figure 2. The relevant fishing effort and VMS data have been extracted and compiled according to unique identifiers based on position and time, and do take into account 0 FP as well. The FP data used for present analyses are from 2008-2010 with the calculated cumulative FP 3 months previous to the benthic invertebrate sampling (or in current month). Finally, the FP data have been merged with benthic invertebrate and physical habitat data by DTU Aqua using unique identifiers of date, position, and station number.

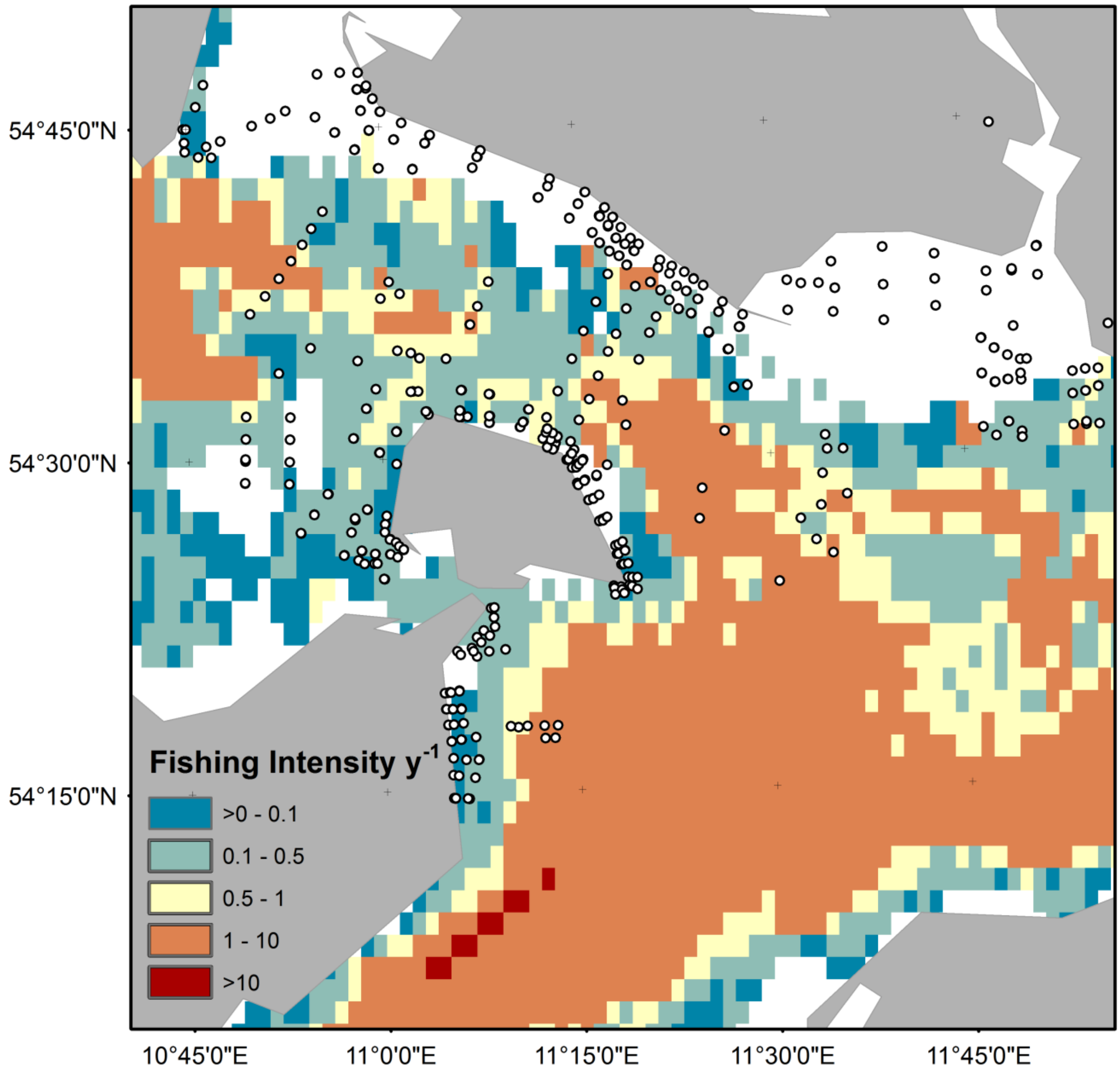

Figure 2. Fishing intensity (cumulated FP) by Danish, German (and Swedish) vessels (>= 15 m length) fishing with towed gears in the Femern Belt area in 2010. The Femern Belt invertebrate sampling stations are included in the map as well.

2.3 Physical habitat data: Hydrographical Data and EUNIS Level 3 Benthic Habitat Data

Hydrographical data, bottom depth, and sediment physical characteristics are obtained from two databases and a physical hydrodynamic model processing data available from the Danish Meteorological Institute (DMI). The used data have been extracted, processed and compiled by DTU Aqua. The physical data are produced by a Baltic-North Sea ocean-ice model HBM (HIROMB-BOOS Model) in the operational setup by DMI. A biogeochemical module (ERGOM) is dynamically embedded in the HBM. HBM is a three-dimensional, free-surface, baroclinic ocean circulation and sea ice model. The model allows for fully two-way nesting of grids with different vertical and horizontal resolution, as well as time resolution. The HBM setup for the present hydrographic dataset has a horizontal grid spacing of 6 nautical miles (nm) in the North Sea and in the Baltic Sea. In the vertical grid the model has up to 50 levels in the North Sea and the Baltic Sea with a top layer thickness of 2 m. At the surface, the model is forced with atmospheric data from the numerical weather prediction model HIRLAM (DMI) with 10 m wind fields, sea level pressure, 2 m temperature and humidity and cloud cover. Furthermore, freshwater runoff from the 79 major rivers in the region is obtained from a mixture of observations, climatology (North Sea rivers) and hydrological models (Baltic Sea). The extracted hydrographical parameters estimated and analyzed are near seabed temperature (t, °C), salinity (s, psu), oxygen concentration (o, mg O_2/l), and current speed (u, m/sec) as well as bottom depth (m). Monthly minima and maxima as well as the daily mean values for these parameters have been extracted for the different benthic invertebrate sampling station positions according to sampling time.

Seafloor sediment data together with depths were extracted by DTU Aqua from the EUNIS level 3 databases processed and compiled for the benthic invertebrate sampling positions using EU-FP7-BENTHIS standards described in Eigaard et al. (2017). Three EUNIS level 3 habitats at location of benthic invertebrate sampling were relevant here: 1 Sublittoral sand (A5.2), 2 Sublittoral mud (A5.3) and 3 Sublittoral mixed sediments (A5.4). Some stations did not have sediment data available and they were categorized as 'outside polygons' and this category only includes 2 samples where FP was above 0 (not used).

2.4 Initial two-way correlation analyses

Initial stage two-way correlations were investigated between biodiversity BD, density N, biomass B, cumulative FP, bottom temperature, oxygen concentration, and salinity (all as minima within the sampling month), and current speed (maximum within the sampling month), as well as the season and the type of habitat / sediment classified in the above 3 categories 1-3. Furthermore, single species correlations were investigated for selected species between FP and both N, and B (but naturally not for BD in these cases), however the single species analyses are not dealth with in this report. The methods used was partly a two-way Lowess nonlinear correlation analysis on natural scale for all parameters (shown in form of combined / multiple parameter plots) and linear correlation analysis on natural and log-log scale shown as regression plots for selected parameters. All two-way correlation analyses were performed in R (R Core Team 2015). The analyses are shown on Figs. 3-9.

2.5 Statistical analyses and model for multi-variate analysis of variance with a mixed GAM model

A general additive model (GAM) with mixed effects was used in the statistical analyses of the same parameters (Table 3) and data (including the one outlier) as investigated in the initial correlation analyses. The dependent variables in the mixed model on benthic community level were BD, N, B, and B/N, respectively, and the explanatory variables were FP, habitat type (spatial explicit), season, year, individual hydrographical parameters, and depth (Table 3). For the BD and N integer (count) dependent variables a negative binomial distribution and log as the link function was used with the possibility of estimating over-dispersion. The negative binominal distribution was used as this model does not assume dependency between the mean and the variance in the distribution. For the continuous B and B/N dependent variables a tweedy distribution was used. A mixed models design was used for all models with year as a random effect and with the other explanatory variables as fixed effects (Table 3). A spatial component with spline (s) or tensor (te) between longitude and latitude was added allowing inclusion of the spatial and station variability, i.e. the variability between observations. Alternative model versions were compared (Table 3). Significant effects were identified for each model using backwards elimination of insignificant model terms, and their statistical significance was estimated (Tables 4-7). Furthermore, model estimates of the dependent variable according to the impact of the explanatory effects were provided (Tables 4-7). The overall variability in the data explained by the model (estimation of deviance) was also estimated (Tables 3-7). Over-dispersion according to the negative binomial distribution, residual plots, and Q-Q plots were inspected for deviations from homoscedasticity and homogeneous distribution (Figs. 11-14). Variance inflation factors were inspected to check for collinearity. All analyses were performed in R (R Core Team 2015) using the package lme4 and lmerTest (Bates et al. 2015).

The most important statistical models tested so far are listed in Table 3. Some of the models tested FP with a smoother effect (not shown), which slightly increased the fraction of the variability in the data explained by model and slightly improved the residuals, but as those models give no direct estimate of the FP effect on the dependent variable they are not used. The models have also been tested with interactions between factors – especially interactions in BD, N, B and B/N between habitat (sediment) type, season, and fishing pressure (models 6, 6_new3, 10, 11a, and 13). When interactions were tested the models were reduced to only include statistical significant interactions. Interactions were especially observed between hydro-graphical parameters, and between sediment types, seasons and FP. As expected there were interactions between the hydrographical parameters and depth and, accordingly, the model has also been tested with depth alone (not shown), and the individual hydrographical parameters separately (not shown) besides with all hydrographical parameters together excluding depth (all shown models). As depth is not expected to determine occurrence of benthic species in itself, which is rather determined by the tolerances to hydrographical and other physical habitat parameters, and because the models including depth alone did not explain more of the variability in the data as the models including all hydrographical parameters or the hydrographical parameters individually, and finally because of the adverse significant correlations (and interactions) between depth and the hydrographical factors, then the depth parameter has been excluded from the analyses (see also results and discussion sections). Seasonal differences were also tested in all models.

Table 3. Overview of selected tested statistical models with different types of dependent and explanatory variables included, as well as model settings. The overall R-square of the model and the deviance (the proportion of the variability) in the data explained by the model are given as well. The models have been run with data both including and excluding samples with zero fishing pressure at the sampling stations (Incl. or Excl. 0 FP). Also model runs have been performed for data excluding the large mussels (LM) Mytilus edulis and Arctica islandica for samples including zero fishing pressure as especially the former occur in high number in the samples (Excl. LM).

Model Number	Mixed GAM Model analysed within the R statistical software	Model R^2			Deviance Explained		
		Excl. 0 FP	Incl. 0 FP	Excl. LM	Excl. 0 FP	Incl. 0 FP	Excl. LM
Model 2 (BioDiv, Main Effects)	**Biodiv ~ log(N_ind) + FP_cum + t_min + s_min + o_min + u_max + quarter + sed_type + (1|year) + s(lon,lat,k=75)** *(Incl. quarter + all hydrographical factors; N log-transformed; Smoother on spatial component with k=75)*	0,97	0,86	0,86	96,3%	85,5%	85,4%
Model 6 (BioDiv, Inter-action Effects)	**Biodiv ~ log(N_ind) + t_min + s_min + o_min + u_max + quarter * sed_type * FP_cum + (1|year) + s(lon,lat,k=75)** *(Incl. interactions between season, sed. type and FP)*	0,98	0,86	0,84	97,0%	85,7%	82,6%
Model 6.3 (BioDiv, Inter-act. Eff., No N)	**Biodiv ~ t_min + s_min + o_min + u_max + quarter * sed_type * FP_cum + (1|year) + s(lon,lat,k=75)** *(Incl. interactions; Not considering N)*	0,97	0,84	0,84	96,2%	82,0%	82,0%
Model 10 (Density, Inter-action Effects)	**N_ind ~ t_min + s_min + o_min + u_max + quarter * sed_type * FP_cum + (1|year) + s(lon,lat,k=75)**	0,68	0,26	0,26	74,9%	40,1%	40,1%
Model 9a (Biomass, Main Effects)	**Biomass ~ N_ind + FP_cum + t_min + s_min + o_min + u_max + quarter + sed_type + (1|year) + s(lon,lat, k=75)** *(Considering N; Continous variable => tweedies => N not log transformed)*	0,02	0,02	0,01	8,8%	11,2%	9,9%
Model11a (Biomass, Int. Eff., No N)	**Biomass ~ t_min + s_min + o_min + u_max + quarter * sed_type * FP_cum + (1|year) + s(lon,lat, k=75)** *(Not considering N)*	0,02	0,02	0,01	9,0%	11,3%	9,9%
Model 13 (Mean Weight, Interact. Eff.)	**Biomass/N_ind ~ s_min + o_min + u_max + quarter * sed_type * FP_cum + (1|year) + s(lon,lat,k=75)**	0,51	0,30	0,31	67,3%	53,5%	53,0%

3. Results

3.1 Initial correlation analyses using merged datasets

The results from the two-way correlation analyses shown in Figure 3 (Lowess smother non-linear correlation analysis) and Figs. 4-7 (linear correlation analysis on natural and log-log scale) show that there generally seems to be a very small but significant negative correlation between fishing pressure (FP) and benthic invertebrate community density, N (Figs. 3-4), while there seems to be a very small and less significant positive correlation between FP and benthic invertebrate community biodiversity, BD when including season in the two-way analyses (Figs. 3 & 5), however, the linear correlation plots including zero-values of FP on the log scale does not indicate a positive correlation (Fig. 5). When excluding season in the two-way correlation analyses, there is a small but highly significant negative correlation between FP and BD (not shown). This should be seen in context of a strong correlation between FP and season of year (as well as in relation to hydrographical factors and depth) with highest FP in the third quarter of the year compared to the other quarters. Strong correlations between FP and hydrographical factors are observed, e.g. the lower minimum temperature (t-min) the higher FP, and the higher minimum oxygen concentration (o-min) the higher FP. (Fig. 3).

Furthermore, there are observed strong correlations between the habitats/sediment types and the hydrographical factors as well as depth. There are as expected observed significant correlations between hydrographical features and depth, i.e. a positive correlation between depth and maximum current speed, minimum bottom salinity and also sediment type, while there is a negative correlation between depth and minimum bottom temperature and minimum bottom oxygen concentration. This is consistent with the bottom inflow of colder and more saline water into the Baltic from the North Sea and outflow of warmer and less saline surface water from the Baltic. A significant negative correlation between N and depth is observed while there is a positive correlation between depth and BD (see reasoning above). (Fig. 3).

The two-way correlation analyses indicate stronger significant correlations between hydrographical factors and the benthic invertebrate community density, N, and the biodiversity, BD, than their correlations to fishing pressure (Figs. 3-6). Especially, there are observed positive correlation between BD and bottom maximum current strength (U-max) and bottom minimum salinity (S-min), while there is negative correlation between BD and minimum oxygen concentaton (O-min).

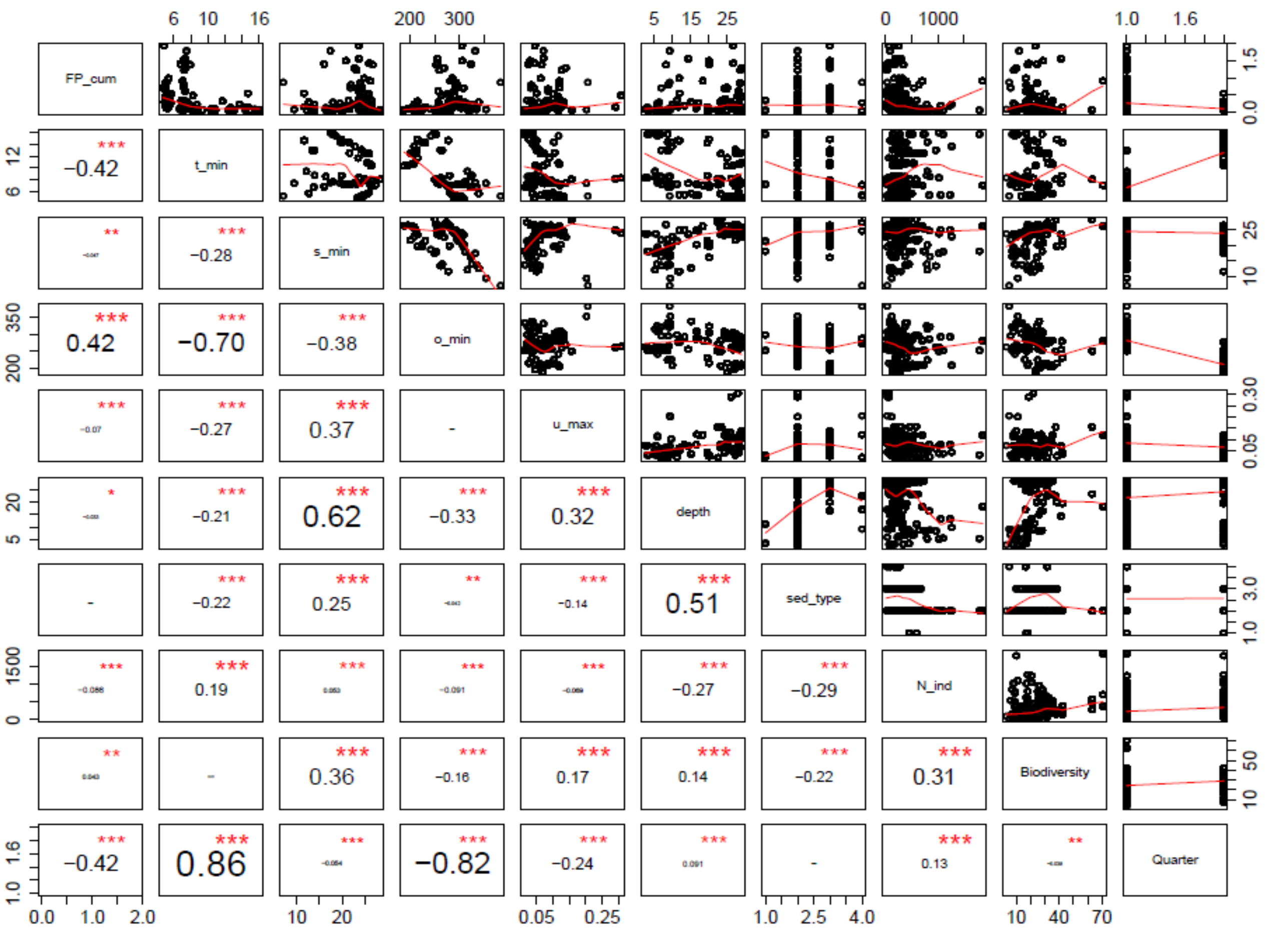

Figure 3a. Two-way correlations (Lowess Smoother) between density, biodiversity, fishing pressure, temperature, salinity, oxygen, current speed, depth and sediment type. Covering samples where FP>0.

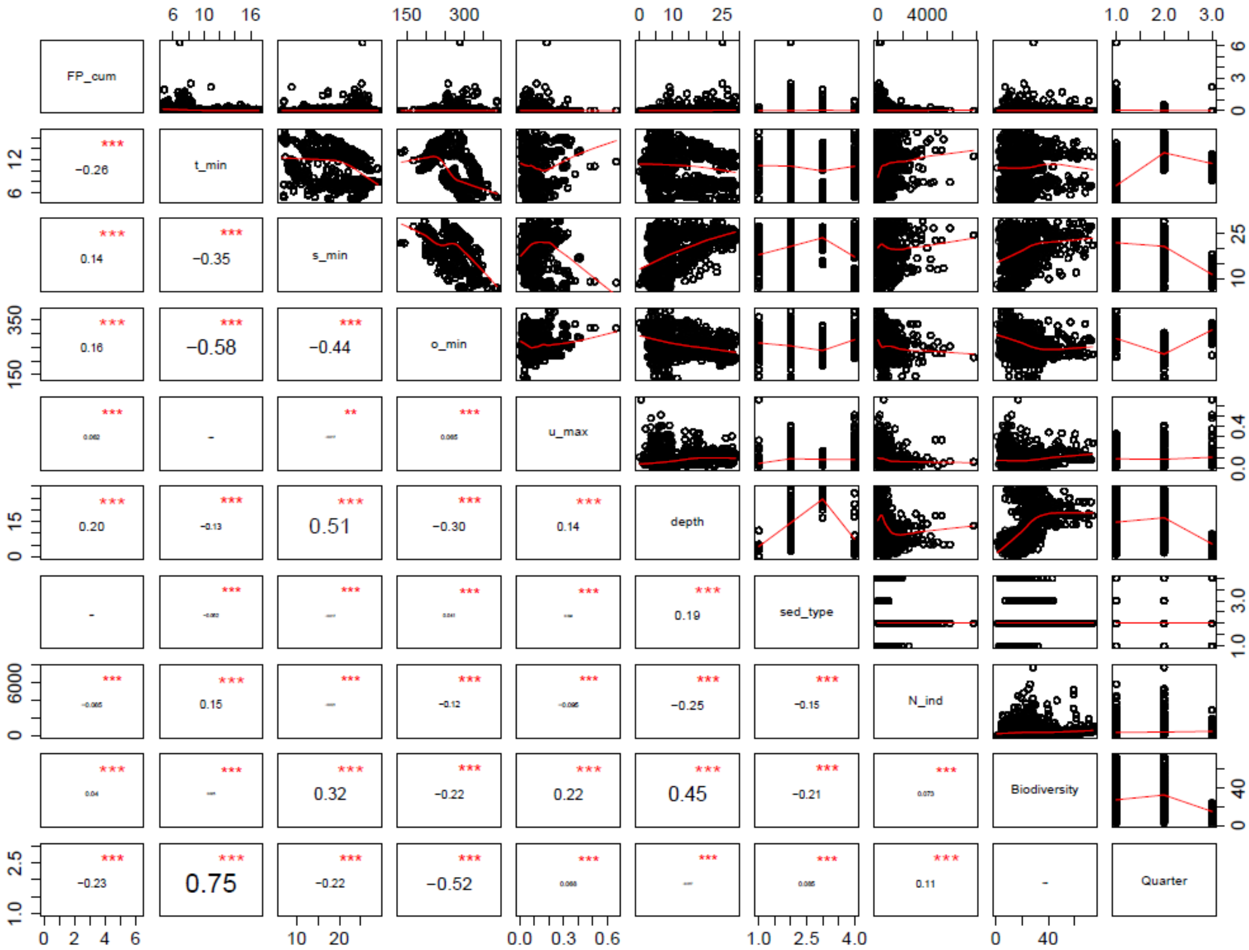

Figure 3b. Two-way correlations (Lowess Smoother) between density, biodiversity, fishing pressure, temperature, salinity, oxygen, current speed, depth and sediment type. Covering samples where FP>=0.

The two-way correlation analyses do not indicate any correlation between benthic invertebrate community biomass, B, and fishing pressure, FP (Fig. 7). Finally, but very important, there is observed a strong positive correlation between BD and N per sample (Fig. 8). Consequently, it is important to take the total number of individuals into account in each sample when analyzing biodiversity. This was accordingly done in the multivariate statistical model analyses (Table 3).

When investigating the seasons separately (not shown), they basically show a negative correlation between FP and both N and BD, however, in the last season these negative correlations are smaller. When looking into the habitats separately (not shown), then a negative correlation between FP and both N and BD is observed for the habitats sublittoral mud and sublittoral mixed sediments. The sublittoral sand habitat has only few observations, and the results from here are rather uncertain. For this habitat type, there is a positive correlation between BD and FP. It should be noted here, that the season effect was not included when investigating the different habitat types separately.

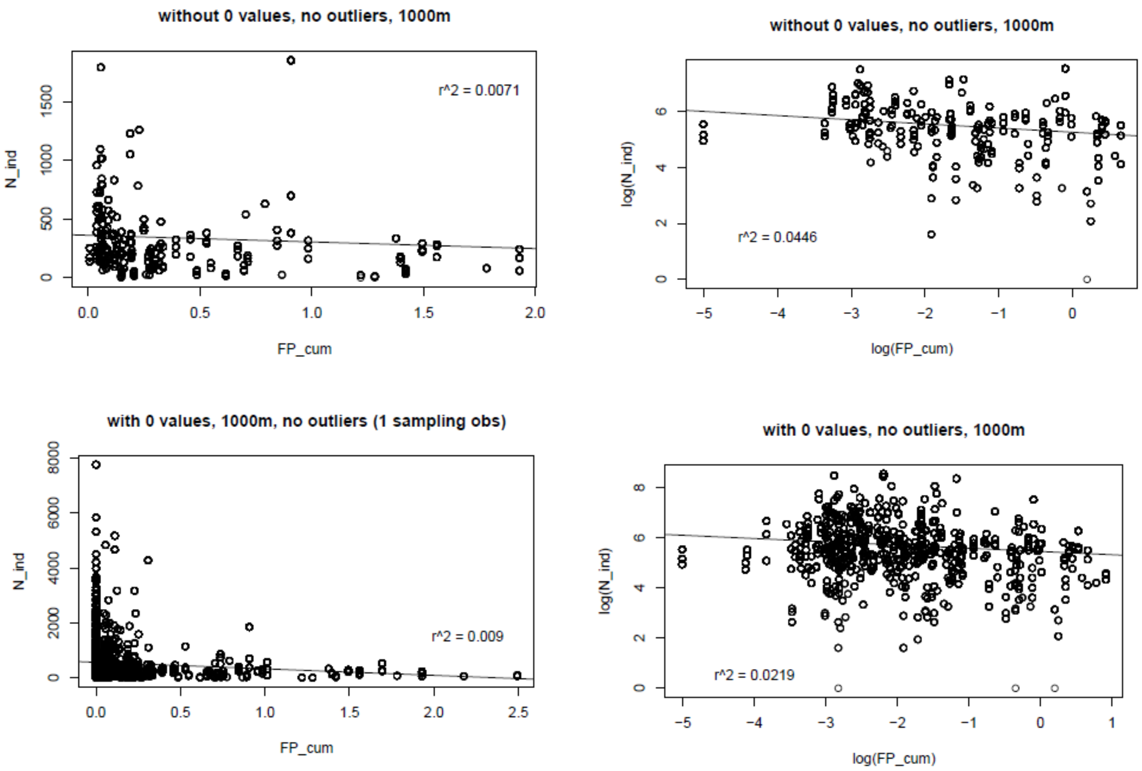

Figure 4. Correlation between benthic invertebrate community density (N) and fishing pressure (FP) on a continuous scale for samples covering stations respectively with and without zero fishing pressure. Shown as both natural and log-log plots.

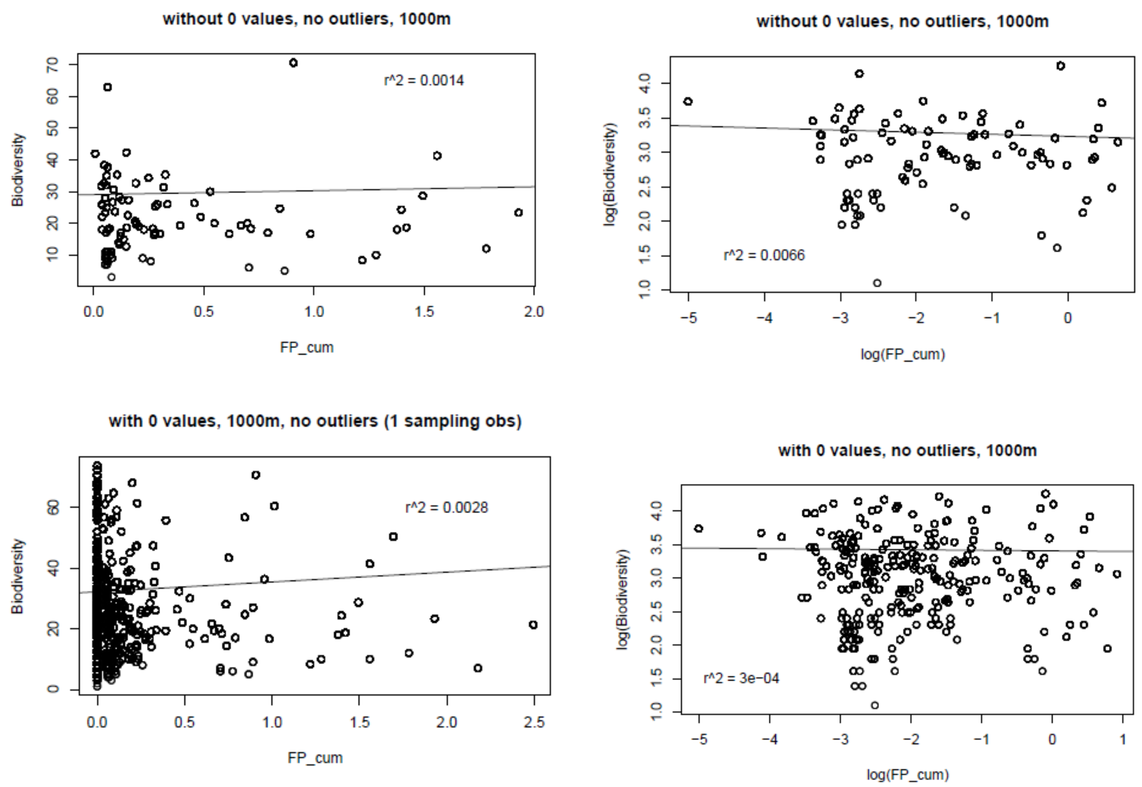

Figure 5. Correlation between benthic invertebrate community species richness (biodiversity, BD) and fishing pressure (FP) on a continuous scale for samples covering stations respectively with and without zero fishing pressure. Shown as both natural and log-log plots.

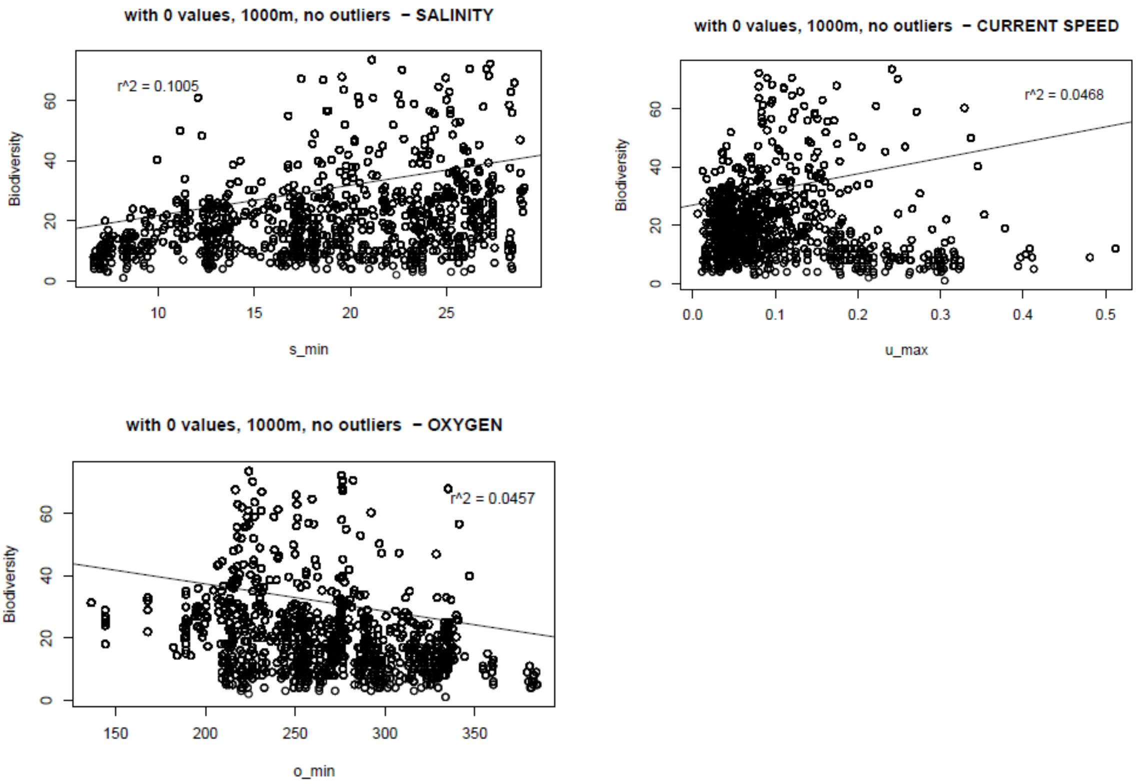

Figure 6. Correlation between benthic invertebrate community species richness (biodiversity, BD) and selected hydrographical factors (S-min, U-max, and O-min) on a continuous scale for samples covering stations with zero fishing pressure.

In general, highest number of species (BD), individuals (N), and biomass (B) in the benthic invertebrate community is found in habitat 3 with sublittoral mixed sediment (hard bottom) while it is more similar between habitat 1 (sublittoral mud) and habitat 2 (sublittoral sand) except for biomass that is lower in habitat 2 (Table 2).

Accordingly, the initial two-way correlation analyses indicate that there are overall different trends and interactions in the impacts of fishing pressure, FP, on benthic invertebrate community density, N, and biodivdersity, BD, according to the different sediment types and the seasons of year. At the same time there are strong correlations between some hydrographical parameters and FP, which complicate analyses of FP impacts on benthic community invertebrates in general. Consequently, multivariate analyses of variance are needed to further explore the impacts and patterns herein.

The same type of two-way correlation analyses were made for selected single species where the relationship between N and B per sample and the FP as well as the hydrographical parameters have been initially investigated. The results obtained so far are in general consistent that there is a negative relationship between FP and both N and B, but this is not shown in the present report.

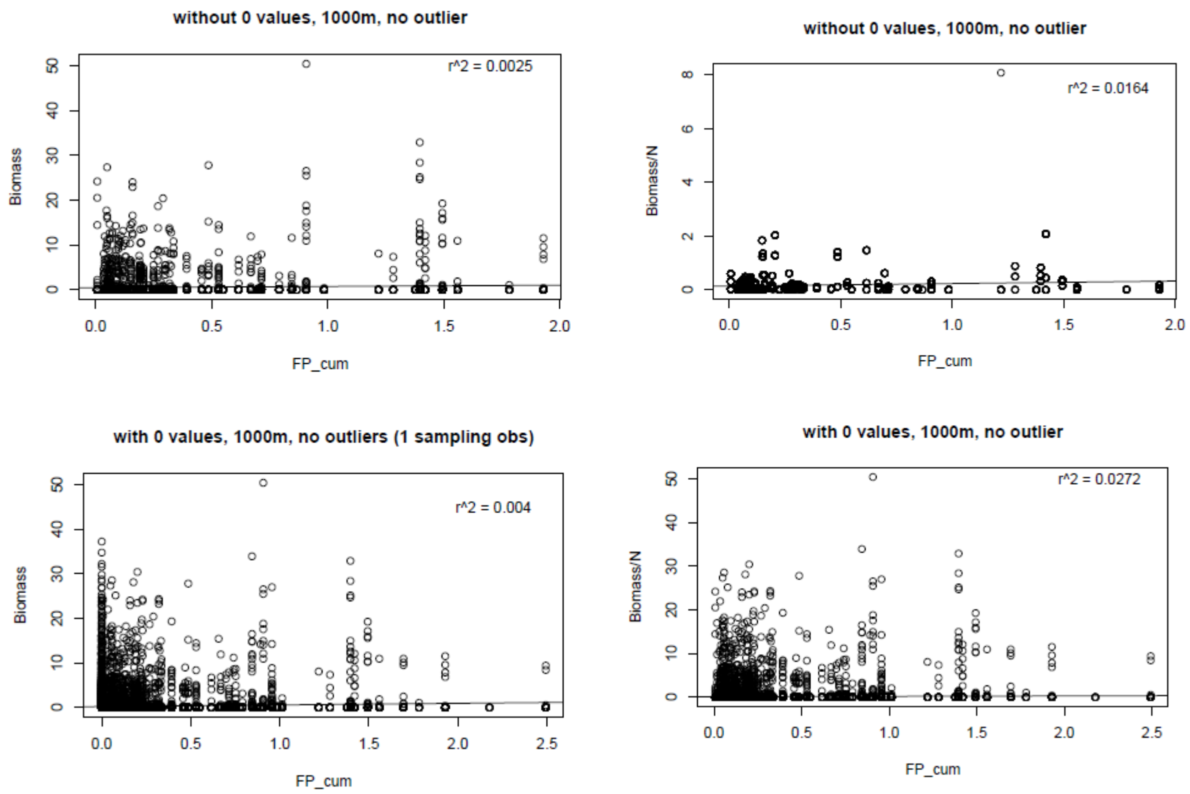

Figure 7. Correlation between benthic invertebrate community biomass (B) as well as average individual mean weight (B/N) and fishing pressure (FP) on a continuous scale for samples covering stations respectively with and without zero fishing pressure.

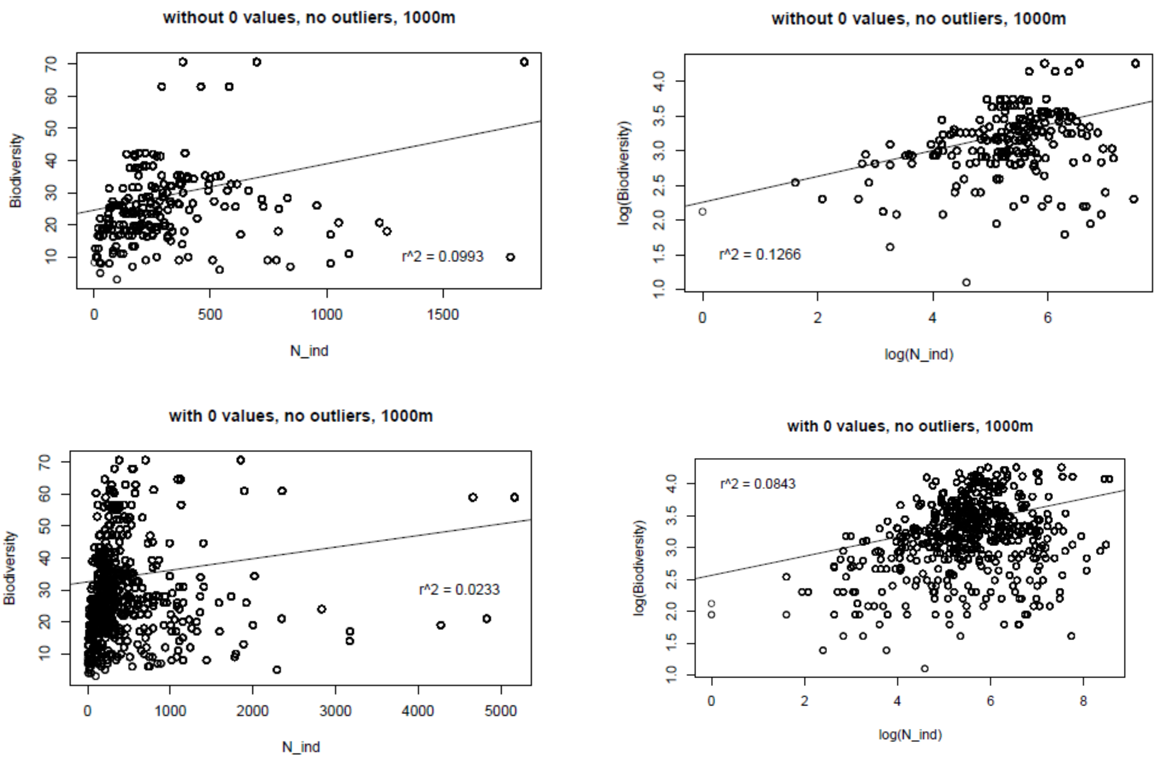

Figure 8. Correlation between biodiversity and density for samples covering stations respectively with and without zero fishing pressure. Shown as both natural and log-log plots.

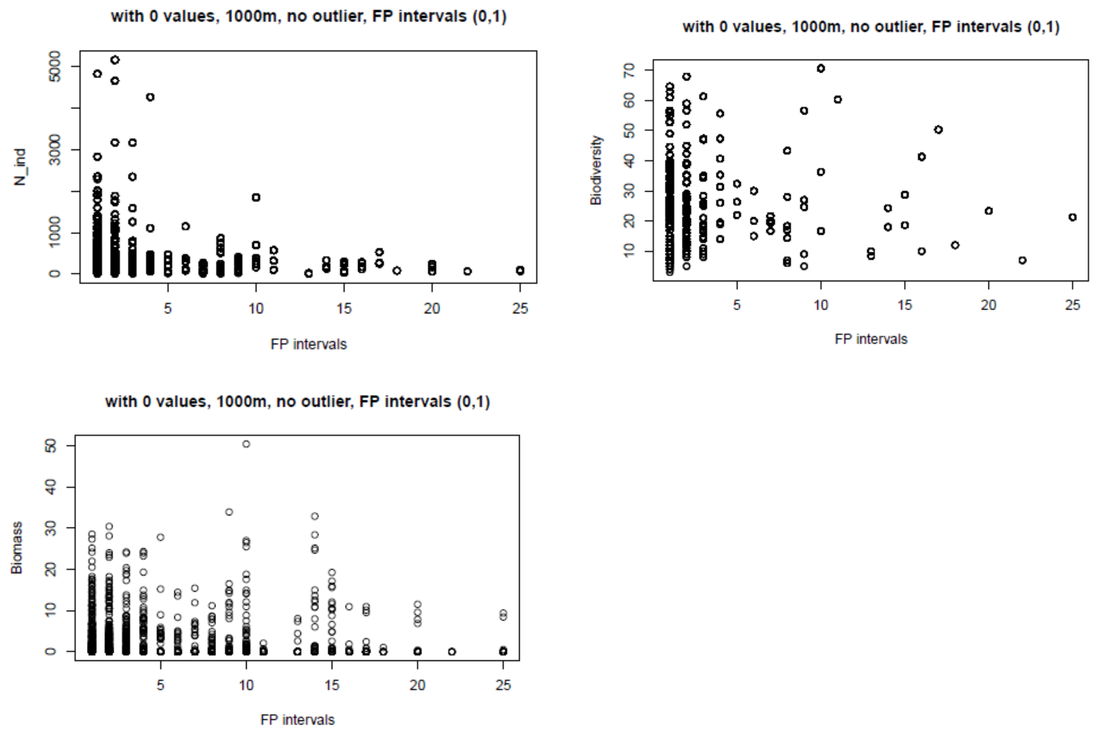

Figure 9. Correlation between benthic invertebrate community density (N), biodiversity (BD), biomass (B) and fishing pressure (FP) where averages for N, BD and B are estimated for FP in discrete steps of 0,1 (discrete scale) for samples covering stations with zero fishing pressure. At the scale of the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

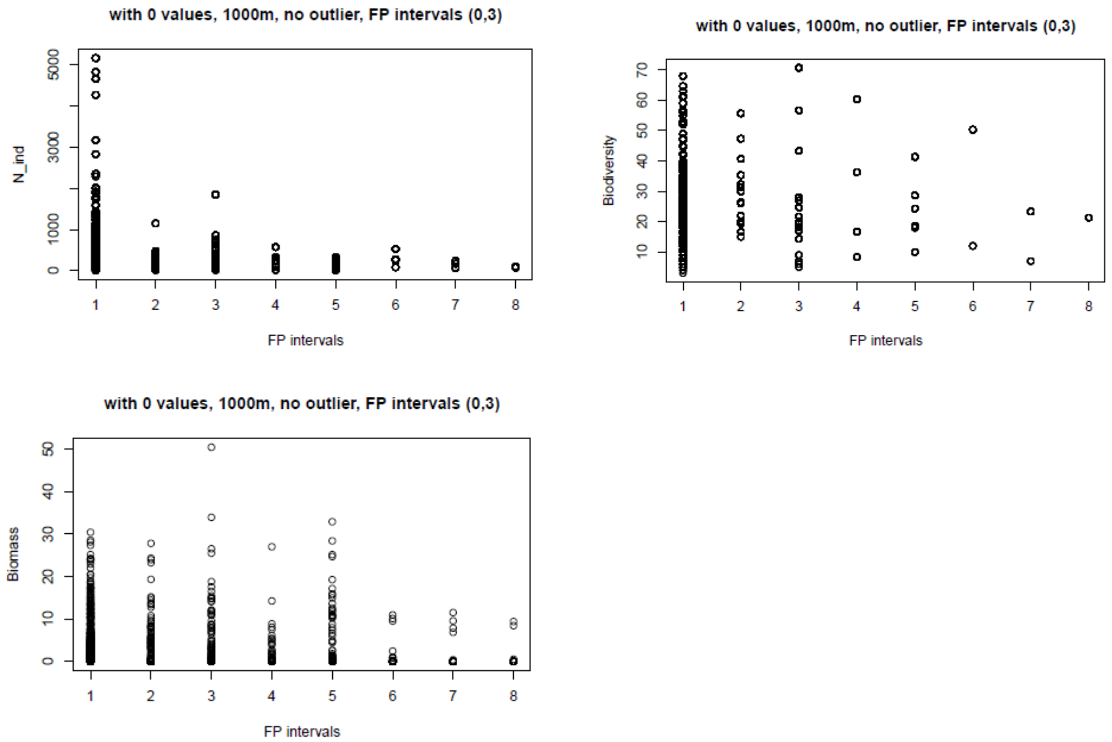

Figure 10. Correlation between benthic invertebrate community density (N), biodiversity (BD), biomass (B) and fishing pressure (FP) where averages for N, BD and B are estimated for FP in discrete steps of 0,3

(discrete scale) for samples covering stations with zero fishing pressure. At the scale of the FP-axis then 1 correspond to FP=0,0-0,3, 2 corresponds to FP=0,3-0,6, etc, i.e. 10 corresponds to FP=2,7-3,0.

In order to identify potential occurrence of threshold values of fishing pressure (FP) according to changes in benthic invertebrate community density (N), biodiversity (BD) and biomass (B) averages for N, BD and B have been estimated for discrete ranges (steps) of FP with steps of respectively 0,1 (Fig. 9) and 0,3 (Fig. 10). It appears from this very initial and uncertain comparison that with quarterly FP values above 0,5, i.e. yearly FP above 2.0, then the highest values of N disappears, while with quarterly fishing pressures above 1,1-1,2 i.e. yearly FP above 4.5, then the highest values of BD disappears, when using discrete FP intervals of 0,1 (Fig. 9). When using discrete FP intervals of 0,3 then the highest values of N disappears when quarterly FP is between 0,3 and 0,6, while the highest values of BD disappears when quarterly FP is above 1,2. For the biomass, then the highest values of B disappears when quarterly FP is above 1,5 when using both FP intervals (Figs. 9-10). Accordingly, there can similar to the plots on continuous scale (Figs 4, 5 & 7) not be identified any robust threshold levels of fishing pressure for changes in benthic invertebrate community density, biodiversity and biomass.

3.2 Results of the statistical modelling and multi-variate analysis of variance with a mixed GAM model

<u>Main effects mixed models</u>: The Baseline model 2 analyses BD under consideration of N and all hydrographical factors, FP, and the 3 sediment types without interaction effects. It explains more than 85% of the variability in the data, and there are no significant trends in the residuals analyses (Table 3). The results show that N and FP highly significantly impacts BD; the higher FP the lower BD, and the higher N the higher BD (not shown). Model 1 gives the same main effects analysis as model 2 except it does not include season (not shown). The results of the analyses with the two models are very similar with respect to significance levels and tendencies in the impacts of the explanatory variables on BD, as well as with respect to the level of variability in the data explained by the model, except that N is not as highly significant in model 2 when including season compared to model 1. Furthermore, the residuals perform slightly better in model 2 compared to model 1 (not shown). This indicates that, the impact of the density N on the BD is to some extent dependent on the season of year.

From the analyses of BD considering only main effects (Table 3) the significance levels and tendencies with respect to impacts of the explanatory variables on BD are consistent (not shown). When running the main effects models with each of the hydrographical factors isolated or with depth instead of the hydrographical factors included the tendency in the impact of sediment type 1 and 2 relative to sediment type 3 reverses from negative to positive impact on BD except for when running with current speed alone. This indicates interactions between the impacts of hydrographical factors and of sediment types on BD. A highly significant impact of all tested hydrographical factors on the BD was observed when running the main effects models (not shown). The lower the current speed or the lower the minimum temperature or the lower minimum oxygen concentration the lower the BD, while the higher minimum salinity the higher BD. These tendencies and significance levels are consistent when running the model with each of the hydrographical factors separately, except for minimum temperature, where the tendency in the impact on BD reverses to result in slightly higher BD when the minimum temperature increases (not shown). Accordingly, there are interactions in the impacts of the hydrographical factors on BD. Finally, the depth factor is highly significant, i.e. the higher depth the lower BD. This should also be seen in context of the higher depth the higher FP as well as in relation to the adverse strong correlations between hydrographical factors and depth described previously in the two-way correlation analyses.

Table 4. Results, parametric coefficients, and estimates of the statistical analyses with model 6.including samples with zero FP.

```
Family: Negative Binomial(175.701)
Link function: log

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

Parametric coefficients:
                           Estimate Std. Error z value Pr(>|z|)
(Intercept)               2.416e+00  3.653e-02  66.144  < 2e-16 ***
log(N_ind)                1.290e-01  1.337e-03  96.514  < 2e-16 ***
t_min                     6.895e-03  1.003e-03   6.874 6.22e-12 ***
s_min                     5.061e-03  4.429e-04  11.426  < 2e-16 ***
o_min                     2.133e-04  7.654e-05   2.787  0.00532 **
u_max                    -3.194e-01  2.456e-02 -13.003  < 2e-16 ***
FP_cum                   -3.581e-02  1.622e-02  -2.208  0.02728 *
sed_type1                -8.263e-02  1.481e-02  -5.579 2.42e-08 ***
sed_type2                -3.727e-02  1.569e-02  -2.376  0.01752 *
Quarter                  -3.420e-03  4.799e-03  -0.713  0.47600
FP_cum:sed_type1          8.773e-01  8.729e-02  10.050  < 2e-16 ***
FP_cum:sed_type2          5.472e+00  1.145e+00   4.781 1.74e-06 ***
FP_cum:Quarter            1.588e-02  1.594e-02   0.996  0.31923
sed_type1:Quarter         7.102e-02  7.851e-03   9.047  < 2e-16 ***
sed_type2:Quarter         3.645e-02  7.938e-03   4.591 4.41e-06 ***
FP_cum:sed_type1:Quarter -9.972e-01  8.668e-02 -11.504  < 2e-16 ***
FP_cum:sed_type2:Quarter -5.531e+00  1.144e+00  -4.836 1.32e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                edf Ref.df Chi.sq p-value
s(YEAR)    1.252e-06   1.00      0  <2e-16 ***
s(lon,lat) 7.360e+01  73.99 139014  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.863   Deviance explained = 85.7%
-REML = 1.1984e+05  Scale est. = 1         n = 37408

                k'      edf  k-index p-value
s(YEAR)    1.00e+00 1.25e-06 9.81e-01    0.09
s(lon,lat) 7.40e+01 7.36e+01 3.45e-01    0.00

> AIC(model06new2)
[1] 239150.7
```

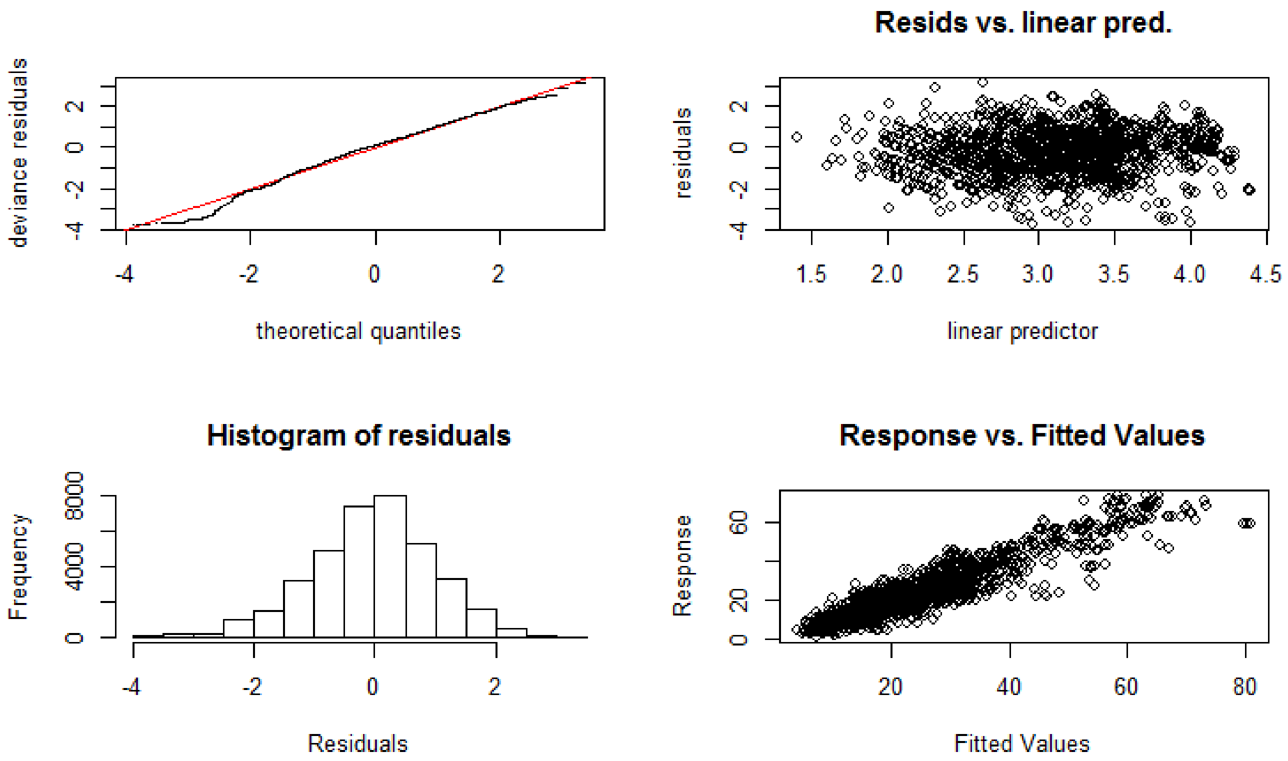

Figure 11. Residuals analysis of the model 6 statistical analyses.

Interaction effects mixed models: When including interaction effects between FP, sediment type and season in the analysis of BD given N (model 6) and keeping all hydrographical factors in then not much more of the variability in the data is explained (86%; Tables 3 & 4), and the residuals only improve slightly (Fig. 11), compared to the main effects models. Also from the interaction models it appears that fishing pressure significantly impacts biodiversity, and the tendency is the same with the higher FP the lower BD, and the higher N the higher BD (Table 4). The FP as main effect is only slightly significant. However, there are significant interaction effects between FP and the sediment types and between FP and season (Table 4). This strongly indicates that FP has different impacts on BD in different habitats dependent on season of year. This should be seen in context of that FP is highly significant in the main effects models for BD (not shown).

Similar to the main effects models the interaction effects models show that the lower the near seabed current speed or the higher the minimum temperature or the higher the minimum salinity or the higher the minimum oxygen concentration the higher the benthic invertebrate community BD. Similar to the main effects models those effects are highly significant in the interaction effect model (Table 4). It is evident from the analyses that the impacts of fishing pressure on the benthic community biodiversity are in the same order of magnitude and equally significant as the influence of natural hydrographical factors on BD such as the current speed (Table 4).

Also in accordance with the main effects models, there appears to be a strong seasonal difference in the BD with a tendency towards significantly higher BD in third quarter compared to the second and fourth quarter of the year (not shown). There is a significant habitat type and according spatial effect on BD both in the interaction effects models which show that BD is significantly different at different habitats with a clear tendency towards higher diversity at more mixed and course sediment types (sublittoral mixed sediment type 3) and lower biodiversity at the more fine grained and soft sand and mud sediment types with lowest biodiversity in the sublittoral mud sediment type 1 (Table 4). There are significant interaction effects between habitat type and season and FP which shows that FP has different impacts in different habitats in different seasons.

It appears that the variability explained in the data by the interaction effects model analyzing BD only decreases slightly (82%) when not considering and including the density, N, in the model (Table 3, Model 6.3). The results concerning the tendencies and significance in impacting effects on BD are the same between model 6 and model 6.3 (not shown). The use of a smoother on the FP, results in a relatively small increase in the proportion of the variability in the data explained by the model, and the tendencies are the same according to all the explanatory factors (not shown). The residuals perform equally well. However, this model does not provide estimates of the FP impact on BD and is accordingly not used.

Table 5. Results, parametric coefficients, and estimates of the statistical analyses with model 10 including samples with zero FP.

```
Family: Negative Binomial(1.885)
Link function: log

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

Parametric coefficients:
                           Estimate Std. Error z value Pr(>|z|)
(Intercept)               4.2168803  0.1319365  31.961  < 2e-16 ***
t_min                     0.0703003  0.0034221  20.543  < 2e-16 ***
s_min                     0.0346434  0.0017077  20.287  < 2e-16 ***
o_min                     0.0020167  0.0002743   7.352 1.95e-13 ***
u_max                    -0.3447448  0.0935588  -3.685 0.000229 ***
FP_cum                    0.0749427  0.0483830   1.549 0.121395
sed_type1                -1.0086282  0.0510868 -19.743  < 2e-16 ***
sed_type2                -0.7839062  0.0461876 -16.972  < 2e-16 ***
Quarter                   0.0640121  0.0154839   4.134 3.56e-05 ***
FP_cum:sed_type1          0.9777646  0.3216205   3.040 0.002365 **
FP_cum:sed_type2         -6.0092060  1.9806282  -3.034 0.002413 **
FP_cum:Quarter           -0.1161761  0.0460472  -2.523 0.011636 *
sed_type1:Quarter         0.2573754  0.0277470   9.276  < 2e-16 ***
sed_type2:Quarter         0.0631896  0.0230420   2.742 0.006100 **
FP_cum:sed_type1:Quarter -0.7210530  0.3201064  -2.253 0.024288 *
FP_cum:sed_type2:Quarter  4.7738110  1.9753834   2.417 0.015664 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                 edf Ref.df Chi.sq p-value
s(YEAR)    9.203e-08   1.00      0  <2e-16 ***
s(lon,lat) 7.324e+01  73.98  15878  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.256   Deviance explained = 40.1%
-REML = 2.6256e+05  Scale est. = 1         n = 37408

                 k'      edf  k-index p-value
s(YEAR)    1.00e+00 9.20e-08 9.38e-01    0.42
s(lon,lat) 7.40e+01 7.32e+01 5.47e-01    0.00
```

The analyses of density, N, alone (model 10, Table 3), show that FP is significantly impacting density (Table 5). However, density as main effect is not statistical significant, but there are strongly significant interaction effects between fishing pressure and habitat type and between fishing pressure and season as well as between fishing pressure, habitat type and season (Table 5). It should be noted that FP is highly significantly impacting N when only main effects models are analysed, and here there is similar highly significant effect of FP on N as for BD, i.e. the higher FP the lower N (not shown). The same tendencies and level of significance of impact of the different hydrographical factors on density are observed (Table 5) as for biodiversity (Table 4). Also here, the analyses show that the impacts of the hydrographical factors on the benthic community density are in the same order of magnitude and equally significant as the influence of fishing pressure on N, especially the current speed (Table 5). The deviance in the data explained by the interaction model for N is less (around 40%; Table 3) when analyzing density, but the residuals perform equally well (Fig. 12) compared to the BD analyses. Similar to BD then inclusion of first order interaction effects between FP, sediment type, and season in the analyses of impact on N does not increase the much compared to the main effects models (not shown). Also when analyzing benthic community invertebrate density, the results on impacts of fishery strongly indicates that the fishing pressure has different impacts on the density in different habitats dependent on the season of the year.

As the large mussels *Mytilus edulis* and *Arctica islandica* are very abundant in the samples, the models were also run exluding those two species from the analyses (Table 3). As can be seen from Table 3 this does not change the model explanation of the variability in the data, and in general the tendencies and significance levels according to different explanatory factors are the same as when including the two species groups (not shown). The same is the case for the models with biodiversity, biomass, and mean weight as dependent variables when excluding those two species (Table 3; not shown).

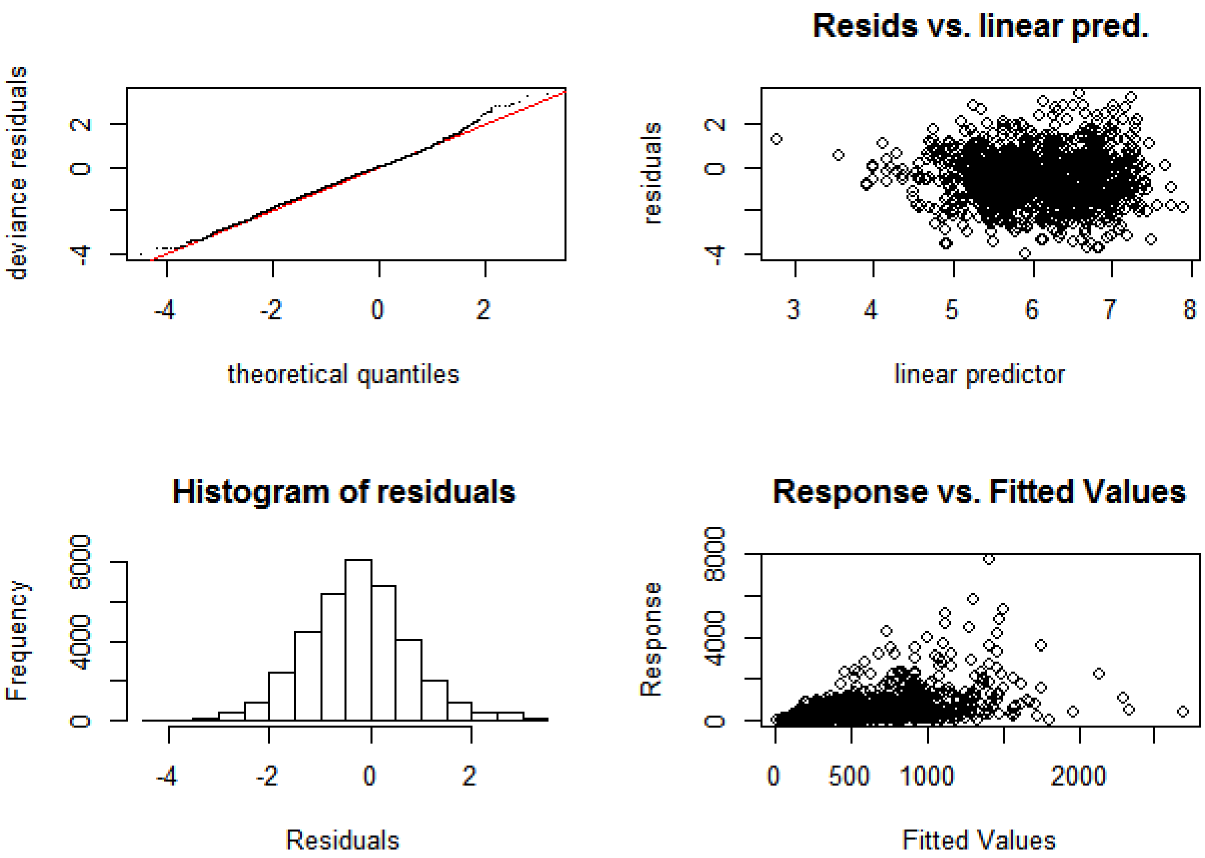

Figure 12. Residuals analysis of the model 10 statistical analyses.

The analyses of biomass, B, show that models with biomass as the dependent variable does not explain more than 11% of the variability in the data (Table 3), and this does not improve when analyzing B given N (model 9a) or when including interaction effects between FP, sediment type and season (model 11a). Furthermore, the analyses of B in all those models show very strong residual trends (Fig. 13). Accordingly, the results shown in Table 6 are very uncertain and should be taken with caution. In general, both the main effects model and the interaction effects model indicate that there is a slightly significant positive correlation between B and FP, but also slightly significant interaction effects between FP and habitat and season of year.

Table 6. Results, parametric coefficients, and estimates of the statistical analyses with model 11 including samples with zero FP.

```
Family: Tweedie(p=1.977)
Link function: log

Formula:
Biomass ~ t_min + s_min + o_min + u_max + FP_cum * sed_type *
    Quarter + s(YEAR, bs = "re") + s(lon, lat, k = 75)

Parametric coefficients:
                           Estimate Std. Error t value Pr(>|t|)
(Intercept)               -3.247128   0.493098  -6.585 4.61e-11 ***
t_min                      0.036788   0.012805   2.873 0.004068 **
s_min                      0.015410   0.006466   2.383 0.017166 *
o_min                      0.002693   0.001019   2.643 0.008227 **
u_max                     -2.254491   0.348147  -6.476 9.57e-11 ***
FP_cum                     0.605692   0.211558   2.863 0.004199 **
sed_type1                  1.370822   0.181276   7.562 4.07e-14 ***
sed_type2                  0.576942   0.174030   3.315 0.000917 ***
Quarter                   -0.065633   0.059550  -1.102 0.270402
FP_cum:sed_type1          -0.820965   1.154793  -0.711 0.477139
FP_cum:sed_type2          24.714255   8.578464   2.881 0.003967 **
FP_cum:Quarter            -0.498838   0.206614  -2.414 0.015769 *
sed_type1:Quarter         -0.297758   0.099807  -2.983 0.002853 **
sed_type2:Quarter         -0.057946   0.088050  -0.658 0.510472
FP_cum:sed_type1:Quarter   0.971811   1.150160   0.845 0.398153
FP_cum:sed_type2:Quarter -25.385319   8.563982  -2.964 0.003037 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                 edf Ref.df    F  p-value
s(YEAR)    2.963e-07   1.00  0.0 2.83e-07 ***
s(lon,lat) 7.034e+01  73.56 78.9  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.0178   Deviance explained = 11.3%
-REML = -1.1792e+05  Scale est. = 6.1009    n = 32867

                 k'      edf  k-index p-value
s(YEAR)    1.00e+00 2.96e-07 4.70e-01    0.82
s(lon,lat) 7.40e+01 7.03e+01 4.17e-01    0.00
```

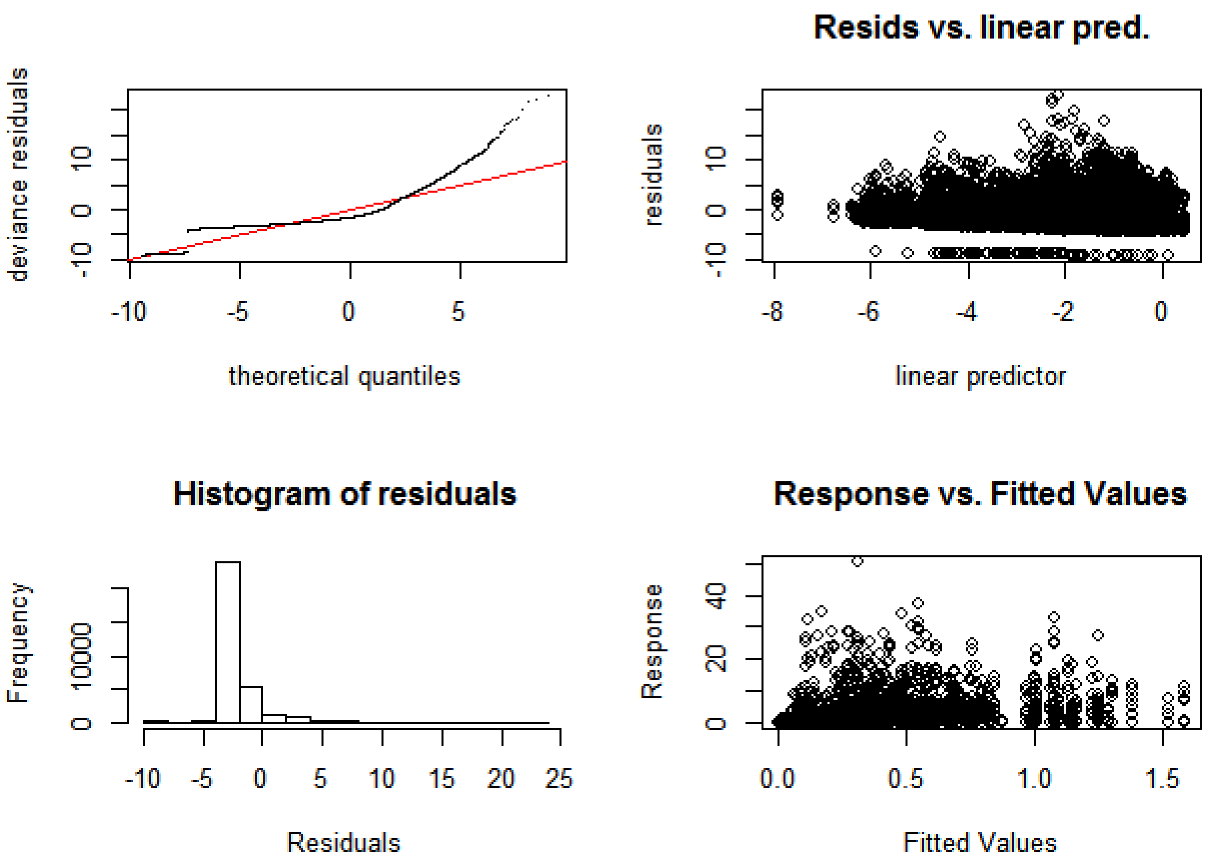

Figure 13. Residuals analysis of the model 11 statistical analyses.

When analyzing average individual mean weight in the benthic invertebrate community, i.e. B/N as the dependent variable (model 13, Table 3) the results again show that FP has a highly significant impact on the benthic community (Table 7) with same tendency as for the BD and density indicators. That is, the higher FP the lower individual mean weight of the organisms in the benthic community (Table 7) even though the main effect is not significant but rather the interaction effects between fishing pressure, habitat type and season of year. For this dependent variable, the model explains only around 53% of the variability in data (Table 3) similar to the analyses of density as the dependent variable, which also is a part of the B/N variable. The residuals perform reasonably well also for the individual mean weight analyses (Fig. 14). There are significant interaction effects for B/N, however, they are difficult to interpret as the interactions both in N and B are in effect here, which make conclusions on this rather difficult. Similar, conclusions on the tendencies in the main effects of the hydrographical explanatory variables for this dependent variable shall be taken with caution because they are influenced on main effects both on the biomass and the density variables.

Table 7. Results, parametric coefficients, and estimates of the statistical analyses with model 13 including samples with zero FP.

```
Family: Tweedie(p=1.955)
Link function: log

Formula:
Biomass_N ~ t_min + s_min + o_min + u_max + FP_cum * sed_type *
    Quarter + s(YEAR, bs = "re") + s(lon, lat, k = 75)

Parametric coefficients:
                           Estimate Std. Error t value Pr(>|t|)
(Intercept)              -1.706e+00  2.103e-01  -8.111 5.15e-16 ***
t_min                    -5.844e-03  5.500e-03  -1.062   0.2881
s_min                    -1.302e-02  2.693e-03  -4.835 1.34e-06 ***
o_min                    -2.744e-03  4.388e-04  -6.253 4.06e-10 ***
u_max                    -3.691e-01  1.470e-01  -2.510   0.0121 *
FP_cum                   -1.099e-02  8.033e-02  -0.137   0.8912
sed_type1                 1.619e+00  7.773e-02  20.830  < 2e-16 ***
sed_type2                -3.252e-01  7.500e-02  -4.336 1.46e-05 ***
Quarter                  -4.467e-01  2.525e-02 -17.691  < 2e-16 ***
FP_cum:sed_type1         -1.008e+00  4.922e-01  -2.047   0.0406 *
FP_cum:sed_type2          1.468e+01  3.334e+00   4.402 1.07e-05 ***
FP_cum:Quarter           -6.248e-02  7.739e-02  -0.807   0.4195
sed_type1:Quarter        -7.452e-01  4.225e-02 -17.637  < 2e-16 ***
sed_type2:Quarter         1.836e-01  3.772e-02   4.868 1.13e-06 ***
FP_cum:sed_type1:Quarter  9.948e-01  4.904e-01   2.029   0.0425 *
FP_cum:sed_type2:Quarter -1.462e+01  3.327e+00  -4.393 1.12e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                 edf Ref.df   F p-value
s(YEAR)    2.039e-07   1.00   0  <2e-16 ***
s(lon,lat) 7.331e+01  73.98 603  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.298   Deviance explained = 53.5%
-REML = -90510  Scale est. = 1.1326    n = 37408

                 k'      edf  k-index p-value
s(YEAR)    1.00e+00 2.04e-07 8.87e-01    0.76
s(lon,lat) 7.40e+01 7.33e+01 5.21e-01    0.00
```

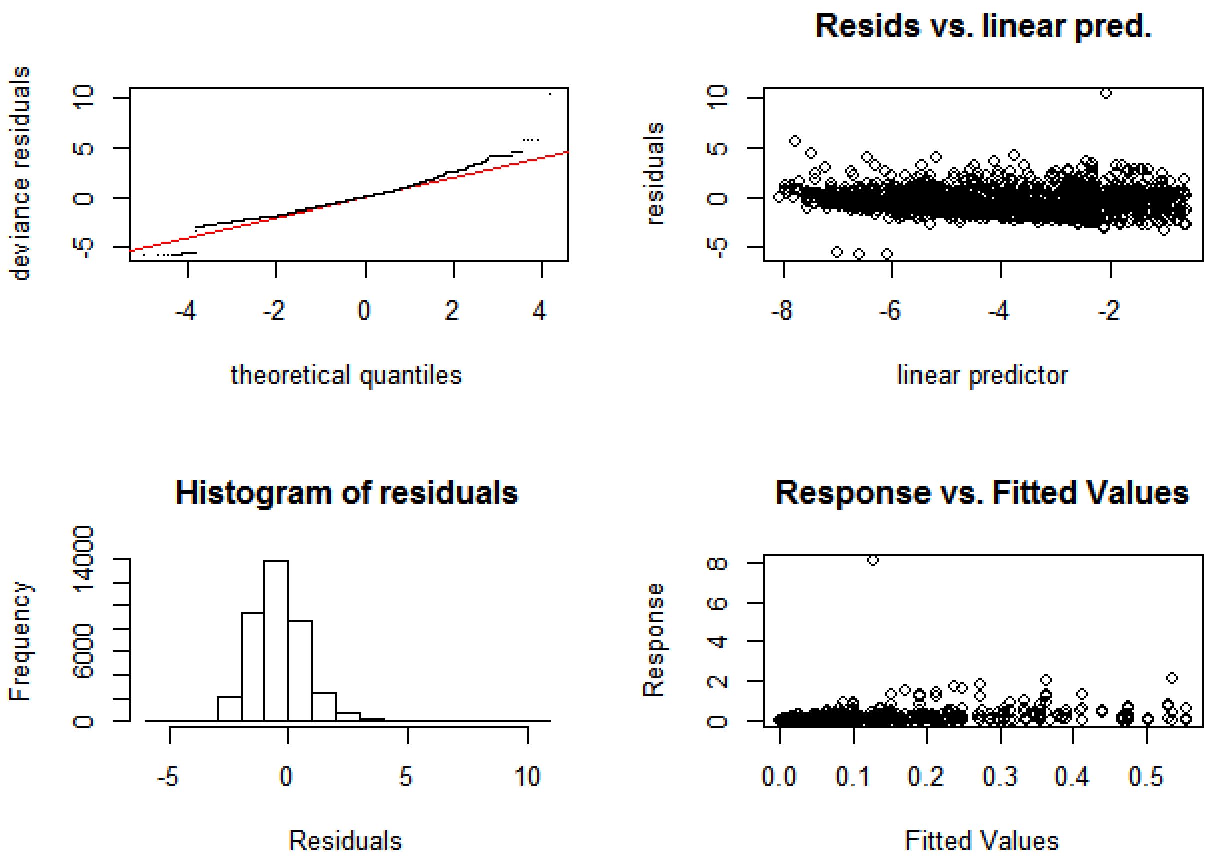

Figure 14. Residuals analysis of the model 13 statistical analyses.

4. Conclusions

Overall, the results indicate that biodiversity and density and mean weight are rather strong indicators for impacts of fishery on the benthic invertebrate community with respect to different levels of fishing intensity, while benthic invertebrate biomass seems not to be a strong indicator on community level in this respect. The latter naturally also influences the mean weight (B/N) indicator. It is evident that there are strong and significant interaction effects and that the FP has different impacts on the biodiversity and density in different habitats dependent on season of the year. Overall, it seems that the impacts of fishing pressure on the benthic community biodiversity and density and mean weight in the benthic invertebrate community is in the same order of magnitude as the influence of natural hydrographical factors, e.g. near bottom maximum current speed and oxygen concentration. Also, it seems necessary to consider the positive correlation and impact of density on biodiversity when evaluating impacts of fishing pressure and other factors on biodiversity.

Time and recovery is not considered, we have only evaluated the short term impacts. It is more robust to evaluate on the short term because the short term impacts are expected to be most visible and not as much influenced by noise as long term level data. We compare impacts of fishery according to a row of parameters and variables to investigate the magnitude of fishing impact compared to impacts of other factors generating natural stress. In the Baltic, it cannot be assumed that natural stress is only related to depth because the hydrographical stress factors are not directly positively correlated with depth. Some are not correlated with depth and some are positively correlated and others are negatively correlated with depth as shown in the present analyses.

In general, there cannot be identified any robust threshold levels of fishing pressure for changes in benthic invertebrate community density, biodiversity and biomass.

The above results suggest that we can reject all the 0-hypotheses listed in the introduction, however, more analyses are necessary, among other on selected single species, to finally conclude on this. Furthermore, future analyses will involve the longevity indicator as well. Finally, it will be an advantage to describe into detail the potential processes, i.e. the causality in the observed results, for the impacts of the hydrographical factors on the biodiversity, density and individual mean weight in the benthic community.

5. References

Bastardie, F., Nielsen, J.R., Ulrich, C., Egekvist, J., and Degel, H. 2010. Detailed mapping of fishing effort and landings by coupling fishing logbooks with satellite-recorded vessel geo-location. Fish. Res. 106: 41-53 pp. doi:10.1016/j.fishres.2010.06.016.

Bates, D., Maechler, M., Bolker, B. & Walker, S. 2015. Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1-48. doi:10.18637/jss.v067.i01.

Eigaard, O.R., Bastardie, F., Breen, M., Dinesen, G.E., Hintzen, N.T., Laffargue, P., Mortensen, L.O., Nielsen, J.R., Nilsson, H.C. O'Neill, F.G. Polet, H., Reid, D. G. Sala, A. Sköld, M., Smith, C., Sørensen, T. K., Tully, O., Zengin, M., Rijnsdorp A. D. 2016. Estimating seabed pressure from demersal trawls, seines, and dredges based on gear design and dimensions. ICES Journal of Marine Science; doi:10.1093/icesjms/fsv099E.

Eigaard O.R., Bastardie F., Hintzen N., Buhl-Mortensen L., Buhl-Mortensen P., Catarino R., Dinesen G.E., Fock H., Geitner K., Gerritsen H., Gonzalez M.M., Jonsson P., Kavadas S., Lafargue P., Lundy M., Mirelis G.G., Nielsen J.R., Papadopoulou N., Posen P., Pulcinella J., Russo T., Sala A., Silva C., Smith C., Vanelslander B., Zengin M., Rijnsdorp, A.D. 2017. Benthic impact of fisheries in European waters: the distribution and intensity of bottom trawling. (In Press ICES J. Mar. Sci.).

Hintzen, N. T., Bastardie, F., Beare, D., Piet, G.J., Ulrich, C., *et al.* 2012. VMStools: Open-source software for the processing, analysis and visualisation of fisheries logbook and VMS data. Fisheries Research, 115: 31–43.

Theme 3: Physical loss and damage to seabed habitats

This report is supporting material to the BalticBOOST WP 3.1 deliverable "Estimating physical disturbance on seabed" and WP 3.2 deliverable "Fisheries Impact Evaluation Tool (FIT) with Application to Assess the Bottom Fishing Footprint in Western Baltic Sea". The BalticBOOST project that was coordinated by HELCOM and co-financed by the European Union in 2015-2016 as part of the programme DG ENV/MSFD Action Plans/2016.

WP 3.1 and 3.2 Supporting material 5: Fishing intensity and effects on benthos in Swedish areas of the Baltic Sea

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Contents

Summary

Bottom trawling has been shown to affect benthos in several studies and therefore this pressure was analysed within five sea areas in the Baltic Sea. In these analyses data from the Swedish national benthic monitoring programme has been analysed together with data on fishing vessel movements and fishing gear impacts. Possible relationships between the two predictor variables fishing intensity and depth, and multivariate and univariate data on benthos assemblages have been explored with distance-based redundancy analysis (dbRDA) in the DistLM routine in the Primer package. Fishing intensity was calculated as the accumulated fishing intensity for four years before sampling of benthos with a 30% reduction each year beginning with year two. With each monitoring station as a centre, fishing intensity was calculated within a circle with the radius 250 meters. In the Baltic Sea there are large areas with anoxic bottom waters and as there are indications that oxygen levels may have been low in the sea area Kalmar between at least the years 2008 and 2012 this area was omitted from deeper analyses. In total four sea regions were analysed for relationships in 2010 and 2012.

Several analyses have been conducted within this study and the results show that there are a number of relationships between different predictors and response variables for the two years. However, the real strength with the analysis should be the comparison of the results for these two years. This comparison show that for multivariate analysis of fourth root transformed abundance of benthos the predictor depth is chosen as the best and only predictor for both 2010 and 2012 in three out of four regions: Scania, Hanö bay west and Blekinge. Fishing intensity was chosen as the best and only predictor in the sea region of Gotland for both years. It is in Gotland sea area that the two most intensely fished stations of all stations in the study occur but scatter plots indicate a change already at low fishing intensity.

Important to note is that collinearity between depth and fishing intensity was high in Scania 2012 and Blekinge 2010 and 2012 and therefore it is in reality impossible to discern if it is depth or fishing intensity which is the most important predictor variable for changes in community structure and thus fishing intensity might be more important in Blekinge and Scania than what has been shown in this study. Collinearity in Blekinge and Scania is largely caused by the fact that there are no monitoring stations

without fishing at greater depths where fishing mainly is occurring. Due to collinearity the results for Scania 2012 and Blekinge 2010 and 2012 are not trustworthy which is the case for both multivariate and univariate analyses.

Analyses of univariate data such as number of species, number of individuals, benthic quality index (BQI) and the W statistic (biomass per individual for the whole sample were also performed). For each year four sea areas and four response variables were analysed (16 analyses altogether). For 2010, if omitting sea area Blekinge which showed to have high collinearity, fishing intensity alone was negatively significant in one analysis, negatively significant together with depth in one and depth alone was negatively significant in one analysis. For 2012 if omitting Scania and Blekinge which showed to have high collinearity, fishing was negatively significant in one analysis and positive in one. Depth was positively significant in one analysis. Only once the same pattern occurred both years which was for fishing intensity which showed a negative relationship with number of species in the sea area of Gotland. These results show that relationships between response and predictor variables can be detected for different years but that these patterns not necessarily are constant over time.

That fishing intensity is significant in Gotland is by necessity due to a strong pattern. However this pattern may also be more distinguishable in Gotland than in other areas due to a lower assemblage variability as stations are located deeper and within a narrower depth range in Gotland compared to other sea areas, and perhaps also due to a lower total number of species which also reduces variability.

Unfortunately not very many stations are available for each sea region and the range of monitoring stations with different fishing intensities is not perfectly distributed within these sea areas. In some sea areas there are a number of stations without fishing intensity but few stations with fishing intensity and in other areas it is the opposite, few or no stations without fishing intensity and many stations with fishing. Additionally the national sampling stations are located at a number of different depths which introduces the effect of depth on the benthic assemblages and thus into the analyses. In many plots it is very clear that depth has an effect on assemblage structure and thus if there are no stations without fishing at the same depths as where fishing is occurring it is often impossible to disentangle if effects are due to depth or due to fishing intensity. This spatial variability necessitates a high number of stations to grasp benthos variability due to depth, salinity and fishing intensity. Thus, it is important to keep in mind that the national monitoring programmes used in this study not are designed to analyse effects specifically due to fishing intensity. Therefore it is encouraged to perform these important analyses in other areas too, and to perform experimental studies with stratified sampling in order to include stations without fishing and stations with a range of fishing intensities at approximately the same depth.

Introduction

Bottom trawling is used within commercial fishing to catch mainly demersal fish, crustaceans and crustaceans. Depending on target species and bottom structure the trawling gears have a range of different adaptions to optimize catch success (Eigaard et al. 2015). Trawls are pulled across the bottom surface and due to fishery specific adaptations the gear penetrates more or less into the bottom and exerts a higher or lower physical pressure (due to weights and chains) on the sediment in order to: keep the gear in contact with the bottom, to protect the gear from wear and to scare fauna into motion. As the trawl moves across the surface both the sediment and species within and on top of the sediment may be impacted. Recent studies show that resuspension from trawling is substantial. It varies with gear and sediment type but a medium resuspension value of 1200 g m^{-2} across several sediment grain sizes has been presented (Oberle et al. 2016). This resuspension of sediments may function as an injection of nutrients into the water column (Dounas et al. 2007). Sediment resuspension by trawling has also been shown to release bioavailable contaminants from contaminated sediments (Bradshaw et al. 2012). Studies have also shown that the deep sea floor surface has become smoother due to trawling and thus lost its original complexity (Puig et al. 2012). The removal of specific macro fauna species has been shown to alter biogeochemical processes in the sediment (Olsgard et al. 2008, Braeckman et al. 2010). The physical relocation of the sediment can affect animals in a number of ways such as causing a general disturbance, relocation, injuries and mortality. Effects that are documented are for example direct mortality of specific species, a decreased abundance of specific species and a decreased diversity (Thrush et al. 2002, Kaiser et al. 2006, Cook et al. 2013, van Denderen et al. 2014, Buhl-Mortensen et al. 2016).

Thus many studies show effects of fishing on benthos but not all (Thrush et al. 2002). When the results are studied in depth it appears that effects are both trawling gear, species and area specific. Effects are often larger on species which are erect, fragile, long lived and large and effects are also more pronounced in specific habitats (Kaiser et al. 2002, Kaiser et al. 2006, Tillin et al. 2006, van Denderen et al. 2014). For example in muddy sediments in the Mediterranean, infauna in trawled areas had a higher abundance of motile burrowing infauna while the un trawled area had a higher abundance of surface infauna (de Juan et al. 2007).

Thus as effects have been shown in several areas it is relevant to analyse possible relationships with fishing pressure and benthos also in the Baltic Sea. Recent advances with positioning advices (VMS) on commercial fishing vessels has enabled a much more precise tracking of the fishing fleet. Thanks to substantial work to analyse and couple VMS positions with logbook data the possibility to calculate fishing intensity for specific vessels has emerged as well as the possibility to calculate area swept and pressure exerted onto the sediment by different types of gears (Bastardie et al. 2010, Hintzen et al. 2012, Eigaard et al. 2015). As effects on benthos may remain for several years (recruitment of species effected may only be successful certain years) this study uses accumulated fishing intensity for four years before sampling.

It is important to underline that a designed experiment has not been conducted and therefore there is a spread of data both regarding the depth of the monitoring stations containing benthic information and the fishing intensity at these stations. The fishing activity did also not commence four years before the benthos was sampled but started long before that, thus potential effects on the benthic assemblage may already have occurred in the past.

These prerequisites complicates and control the analyses that can be done is several ways. It is for example not obvious where the border between low, medium and high fishing intensity should be drawn and therefore such a group analysis was dismissed in favour of the use of fishing intensity as a quantitative predictor variable studied with regression analysis. As also depth (working as a proxy for disturbance, salinity, temperature and sediment structure) may be related to assemblage structure it was included as a second predictor variable in the analyses. As for fishing intensity it is not obvious where the line between shallow, medium and deep water should be drawn and therefore group analysis was dismissed in favour of depth used as a quantitative predictor variable. The task to answer the following questions 1) whether demersal fishing affects the benthic communities in the studied areas and if so, 2) in what way such effects appear and 3) if patterns detected in 2010 also are present in data from 2012, has been regarded more of an exploratory task to analyse different fishing intensity levels than a confirmatory task to tests effects of specific levels of fishing intensity.

Methodology

Sea area considerations

Within the study five areas with different levels of fishing intensity and benthic monitoring data have been analysed. These areas are shown below in Figure 1.

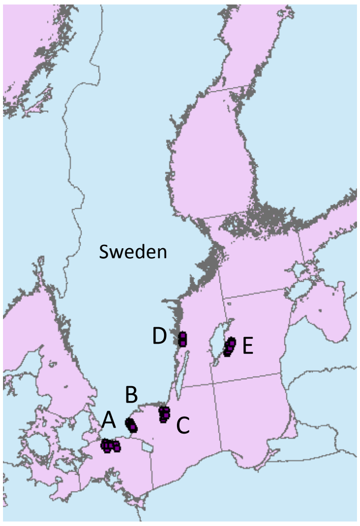


Figure 1. Map of monitoring stations in the Baltic Sea used in the study. A = Scania, B=Hanö bay west, C=Blekinge, D= Kalmar, E=Gotland.

The starting point for this study is the combination of data from three different areas: benthic national monitoring data, fishing activity coupled to logbook data and fishing gear type and area swept by the specific gear. Swedish monitoring data of soft benthic sediment assemblages has been retrieved from sea areas that are known to be covered by a demersal fishery or are close to areas with demersal fishing activities.

Macro fauna in soft sediments can be disturbed by several different pressures. Low oxygen level is such a pressure and low oxygen levels is a problem in vast areas of the Baltic Sea. During national sampling of macro fauna oxygen levels are not measured but sample characteristics such as smell of hydrogen sulphide is noted. In data from 2010 (according to data retrieved from the Swedish Meteorological and Hydrological Institute[1] all macro fauna samples (except from Hanö bay west and some stations very close to the shore in Blekinge) a smell of hydrogen sulphide was noted. Comments on the sediment characteristics could not be found for samples from Hanö bay west and some stations very close to the shore in Blekinge sea area. In data from 2012 none of the samples from Hanö bay west and one of the samples from Blekinge had any comment on a smell of hydrogen sulphide but for all other samples a smell of hydrogen sulphide was noted. Unfortunately the hydrogen sulphide smell does not tell about the oxygen levels at the sediment surface but more of the sediment type and oxygen levels deeper in the sediment. Within other monitoring surveys oxygen levels at different water depths are measured and oxygen deficiency maps are created (Hansson et al. 2011, Hansson et al. 2013). In these surveys the same positions as in the benthos samplings were not used but samplings were conducted more or less in the same regions. According to a *rough* comparison of oxygen maps for 2008-2012 with the location of benthos stations no areas with <2 ml O_2/l were overlapping or very close to benthos sampling stations in Scania, West Hanö bay or Blekinge. Oxygen maps for 2010 however clearly overlapped benthos sampling stations in Kalmar sea area and were close or partially overlapping in 2008 and 2011. Due to these fluctuating oxygen levels and lack of exact data on oxygen levels deeper analyses of Kalmar sea area were omitted. According to a rough comparison of the oxygen maps and benthos stations in Gotland sea area there is no clear overlap but the border to a large area in the east with <2 ml O_2/l and <0 ml O_2/l further to the east seem to lie quite close for the years 2008-2012. A comparison with oxygen monitoring data from 2010 retrieved from the Swedish Meteorological and Hydrological Institute (SMHI) show that the two most southern stations in the sea area Gotland probably have oxygen levels well above at least 62 % oxygen which were recorded at 60 meters

[1] http://www.smhi.se/klimatdata/oceanografi/havsmiljodata/2.2596

depth from oxygen stations not more than 1 km away (data from 2009, 2010 and 2012). The two benthos stations closest to the hypoxic area in the Gotland basin in the map from Hansson et al. are GO 17 at 58 meters and GO13 at 59 meters depth. From these it is 5 km to the closest oxygen sampling stations in the east. At these oxygen sampling stations levels at 60 meters depth (from 2009-2012) are above 39 % saturation which occurred once at one station (median value for 9 measurements is 68%. Thus s data does not indicate that benthos stations in Gotland sea area generally are within the hypoxic area these are included for analysis. However, it is worth to remember that the oxygen deficiency areas in the Baltic fluctuate and that oxygen data from the sea floor at the benthos stations has not been included in the analysis.

Fishing intensity calculation

For each of these national benthic monitoring stations fishing intensity within a circle with a 250 meter radius was calculated based on raw VMS fishing vessel positions for Swedish and Danish boats. Fishing intensity was calculated by coupling geographical VMS positions to logbook data on fishing gear, target species and vessel size according to Bastardie et al. (2010) and Hintzen et al. (2012) in combination with information on swept area and impact due to fishing gear and vessel size according to Eigaard et al. (2016). These calculations produce vessel specific information on bottom area swept by the gear used per unit of time. In this study fishing intensity is the proportion of a circular area with the radius 250 m that is swept. As the effects from fishing potentially may remain over several years, accumulated fishing intensity (FI) was calculated for four years before benthos was sampled in 2012 and 2010 with a 30% reduction each year starting with year two. Thus in this study FI is the proportion of a circular area (r=250 m) that is swept during four years. Thus if FI=1 the whole area is swept once during these four years and if FI=2 the area is swept twice. If FI is less than 1 only parts of the area has been swept during these four years.

Fishing pressure was calculated over several years as potential effects of fishing may remain over several years. This is not surprising as many benthic species have an irregular recruitment success- There are studies indicating that not even five years without fishing (in previously fished areas) is enough to make the unfished area differ significantly from the fished area (Bergman et al. 2015). By using fishing pressure for only one year there is a risk of ignoring important historical pressure levels and thus adding unnecessary variation to the response variable values. By using accumulated fishing pressure over four years we also know that stations with zero fishing intensity at least has had a low very low fishing for four years. By only including fishing pressure for one year these estimates would not have been as secure.

Statistical methods

Analyses have been conducted for several response variables: multivariate assemblage structure based on biomass and abundance and univariate data on species numbers, number of individuals, BQI, and biomass per individual for the whole sample summarized as the W statistics. W was included because for macro fauna it has been shown that disturbance to soft sediment macro fauna can be observed as a decreases in biomass per individual and W is a summary of the relationship of biomass per individual for all species in a specific sample (Clarke et al. 2014).

In all analyses methods within the PRIMER v7 program has been used (Clarke et al. 2014). For the multivariate assemblage structure shadow plots have been used to investigate which part of the data set is enhanced with different sorts of transformations. Plots of both biomass and abundance data indicated that analysis of untransformed data predominantly would reside on a few dominant taxa whereas the 4^{th} root transformation would enhance also species with low biomass/abundance. As it is interesting to analyse possible effects on groups with low biomass the fourth root transformation was chosen as the analysis of most interest. However different transformations may reveal different patterns and therefore the same analysis was also applied to untransformed data of abundances for the year 2012 to look for possible differences. Analyses of abundances was also chosen as the analysis of most interest, but analyses of biomass and abundances may reveal different results and therefore this was also analysed for the year 2012.

As earlier stated it is difficult to draw the line between low, medium and high fishing intensity and therefore mainly quantitative-continuous relationships have been explored with the use of a routine called Distance based linear models (DistLM) using distance based redundancy analysis (dbRDA) for multivariate data described by a resemblance matrix. As there may be differences among the five areas due to salinity gradients the initial analysis however consisted of a test of multivariate differences among sea areas with PERMANOVA and results were visualized with Canonical Analysis of Principal Coordinates (CAP).

As monitoring stations occur at different depths depth may be an important predictor and was added alongside fishing intensity. Before analysis with DistLM the predictor variables were scrutinized with histogram plots. DistLM has no assumptions on predictor variables but they should not be heavily skewed according to the manual. Histogram plots of untransformed, log(x+1) and 4th root transformed data on depth and fishing intensity for all stations and year 2012 showed depth to be somehow ok for untransformed data for all sea areas and was not better with transformations but fishing intensity could not be adjusted with any transformation. Histogram plots of the predictor variables and each of the five sea areas showed no single choice (transformed/untransformed) to be perfect and rarely transformations made the distribution look better. Consequently untransformed data on depth and fishing was used in the analyses of data from the year 2012. However as four predictors were used in analyses for 2010 (untransformed and fourth root transformed depth and fishing intensity as this made some distributions look better) this was also applied for multivariate analysis of 2012 and fourth root transformed abundance data to check for differences in the results. The number of data points for 2010 and 2012 in brackets were for Scania=10, (10), Hanö bay west=11, (12), Blekinge=13, (9), Kalmar=6, (6) and Gotland = 8, (8). Within the DistLM analysis the “Best” selection procedure was chosen together with the selection criteria: AICc (modified Akaike Information Criterion) for model selection and only predictor variables that were significant in marginal tests were selected. Sometimes both predictors were intentionally forced into the model and the dbRDA ordination (although one of them was not significant) to enable the discussion about their contribution to the multivariate pattern.

In summary each multivariate and univariate analysis started with a PERMANOVA analysis of possible differences among sea areas to analyse if all stations could be combined or each sea area had to be analysed separately. This analysis was initiated with Permdisp to analyse for differences in variances among sea areas before PERMANOVA was run. Results from PERMANOVA analysis was visualised with CAP (Canonical Analysis of Principal Coordinates) in one case.

Results

2012 Multivariate analysis of sea areas regarding biomass and abundance

Biomass and abundance data were gathered for in total 45 stations for the year 2012.

As the five different sea areas of interest are located in slightly different salinities, sea areas seemed important to analyse with PERMANOVA before any other analyses were initiated, see

Figure **2**.

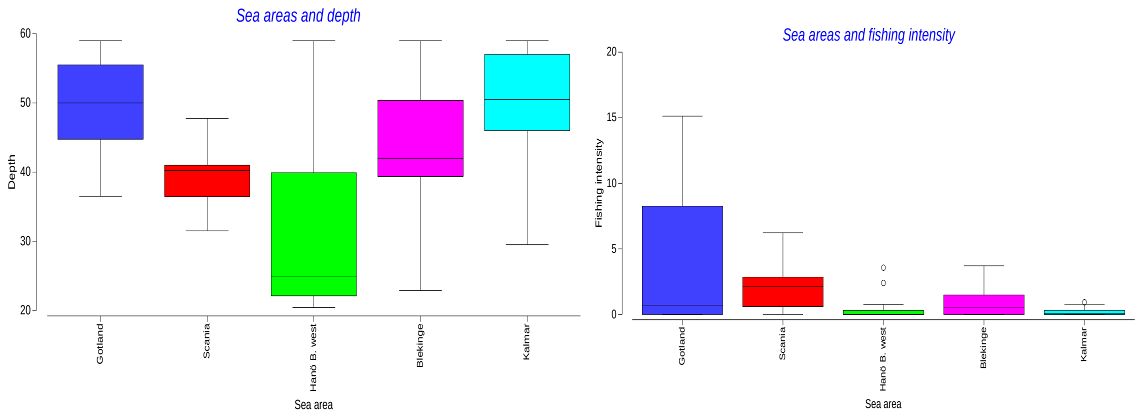


Figure 2. Box plots of depth and fishing intensities within sea areas for 2012. Box extends from first to the third quartile with the median illustrated as the line in the box. Whiskers are minimum and maximum values. If there are values larger than Q3+1.5*IQR (interquartile range) or less than Q1-1.5*IQR these are depicted with o and then whiskers show Q3+1.5*IQR and/or Q1-1.5*IQR.

As PERMANOVA is sensible to differences in variances this was first analysed with Permdisp and sea areas as the only factor which showed to be insignificant for both biomass and abundance (both response variables were fourth root transformed). Subsequent analysis of sea areas with PERMANOVA the same design, unrestricted permutation of raw data and Type III sums of squares showed the factor sea areas to be significant. Pairwise tests of the different sea areas with PERMANOVA showed all sea areas to differ from each other for both biomass and abundance, see **Figure 3** and

Table **1**. As sea areas were significant for fourth root transformed biomass and fourth root transformed abundance, each sea area has been analysed separately with DistLM below. The same Permdisp and PERMANOVA analysis was also performed for untransformed abundance data which showed to be insignificant for Permdisp but significant for PERMANOVA. As six of ten pair-wise comparisons were significant, DistLM analyses for untransformed abundance data were also performed per sea area as shown below. Kalmar sea area was not further analysed do to the risk of anoxic events as mentioned in the methodology.

Table 1. Results from pairwise analysis with PERMANOVA of sea areas and abundance (forth root transf.)

Abundance			Unique	
Sea areas	t	P(perm)	perms	P(MC)
Gotland, Scania	2.5859	0.0004	8952	0.0004
Gotland, Hanö bay west	2.3771	0.0008	9594	0.0016
Gotland, Blekinge	1.9067	0.0118	8142	0.018
Gotland, Kalmar	2.308	0.001	2911	0.0062
Scania, Hanö bay west	2.8778	0.0002	9882	0.0001
Scania, Blekinge	1.542	0.0276	9450	0.0488
Scania, Kalmar	2.0964	0.0002	5635	0.0036
Hanö bay west, Blekinge	2.6495	0.0002	9778	0.0003
Hanö bay west, Kalmar	2.8177	0.0001	7727	0.0003
Blekinge, Kalmar	2.1	0.0005	4306	0.0061

A visualisation of the PERMANOVA result for the five different sea areas is presented with a CAP ordination of biomass and abundance below in Figure 3.

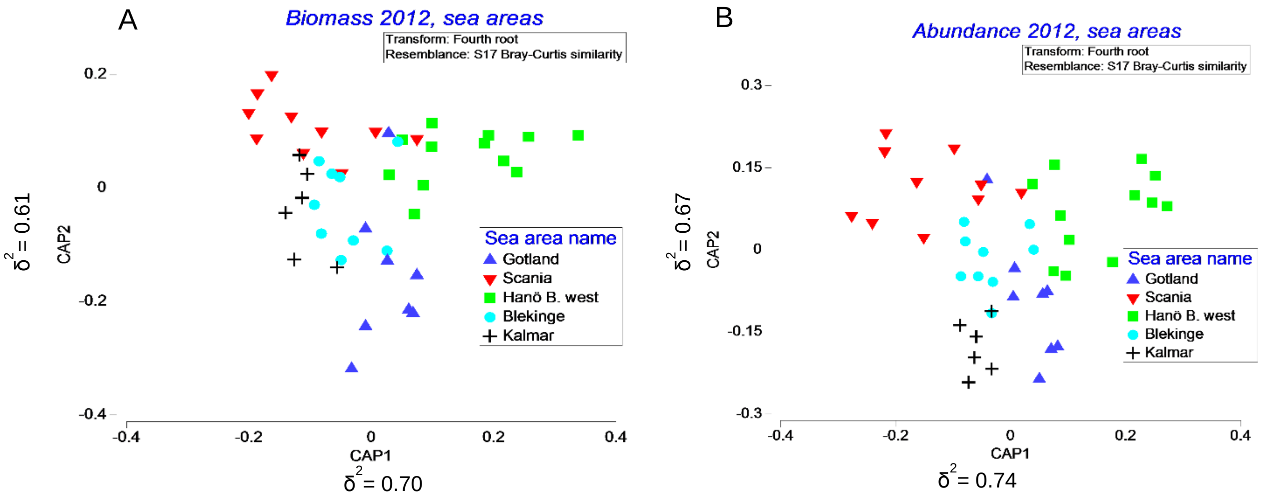


Figure 3. CAP for all five sea areas based on biomass in A and based on abundance in B.

Scania

Depth and fishing intensity untransformed is used and depth is selected as the best model in all tests in Scania although fishing in all analyses also is significant in marginal tests. The correlation among predictor variables is 0.82 and thus above the "threshold" of 0.70 which signals the risk of severely distorted model estimations (Dormann et al. 2013). In Figure 5 it is seen how fishing intensity increases with depth and it is also shown that there is only one station without fishing intensity and this is also the most shallow station. The lack of zero fishing stations at different depths adds to the collinearity which makes it difficult or impossible to evaluate the effect of depth and fishing intensity separately. Thus in this area there is no real test for the effect of these factors separately and the results in the analyses below can not be trusted.

Analysis of biomass (fourth root transformed)

Depth and fishing intensity untransformed. The DistLM analysis of fishing intensity and depth showed both variables to be significant in marginal tests. Depth had a p=0.0012 and an explained variance of 0.29 and fishing intensity p=0.008 and an explained proportion of variance of 0.25. Model selection was performed with best and AICc which selected depth as the best model which explained 29 % of the variation, see Figure 4.

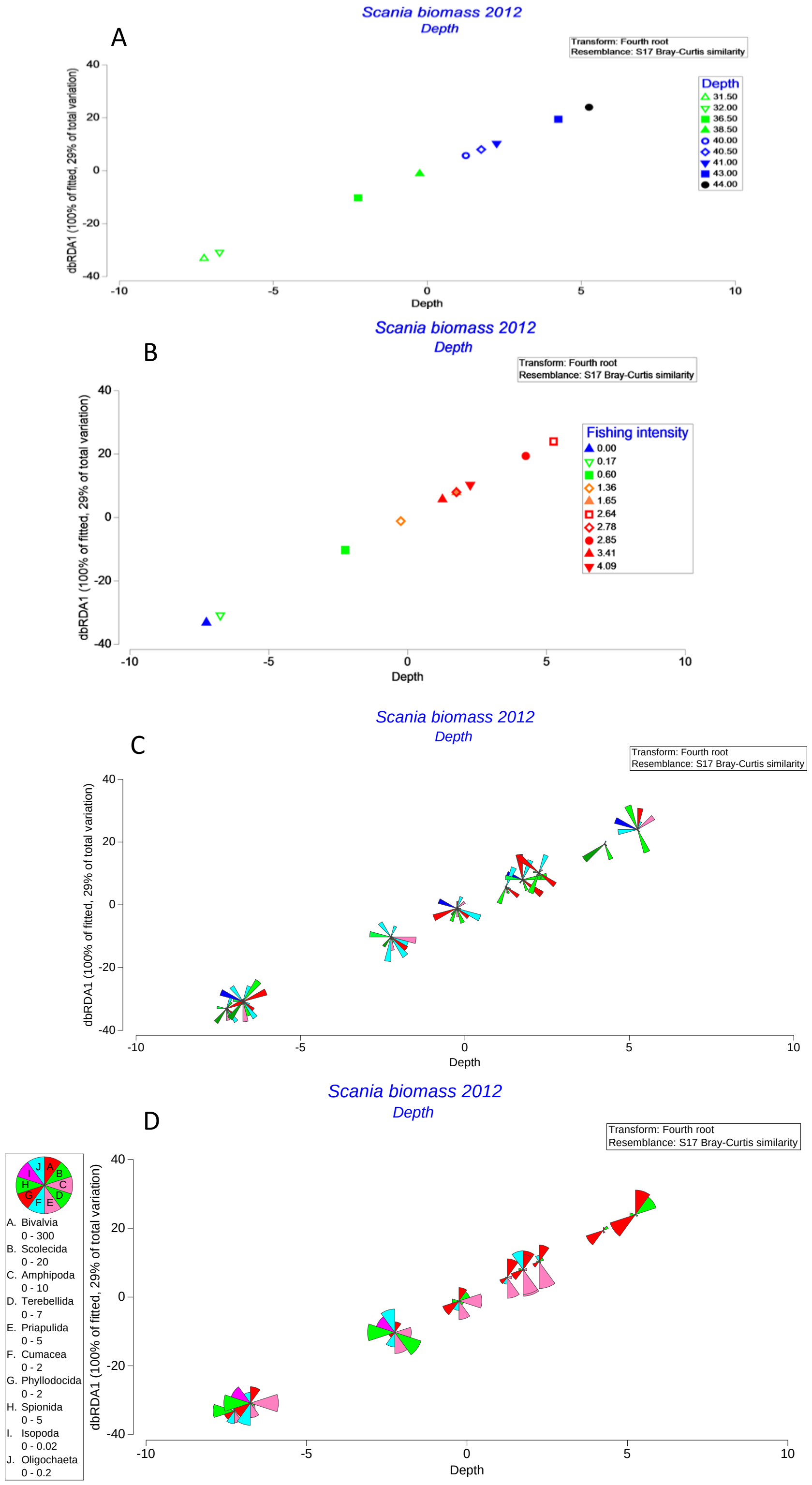


Figure 4. Ordination of Scania according to DistLM analysis of square root transformed biomass and selection of depth as the best model. In A is depth shown and in B fishing intensity. In C the biomass of the different species is overlaid each station (note that the size of each wing representing a species is related to the maximum abundance of that species in the test and therefore wings of the same sizes can represent very different biomass values. In D biomass of species grouped as orders etc. is overlaid each station.

To increase the understanding of the assemblage patterns both predictors were forced into the model and then 41 % of the variation was explained see Figure 5.

Ordination C in Figure 5 indicate that assemblages change inconsistently with both increased depth and fishing intensity but it is depth that is significant.

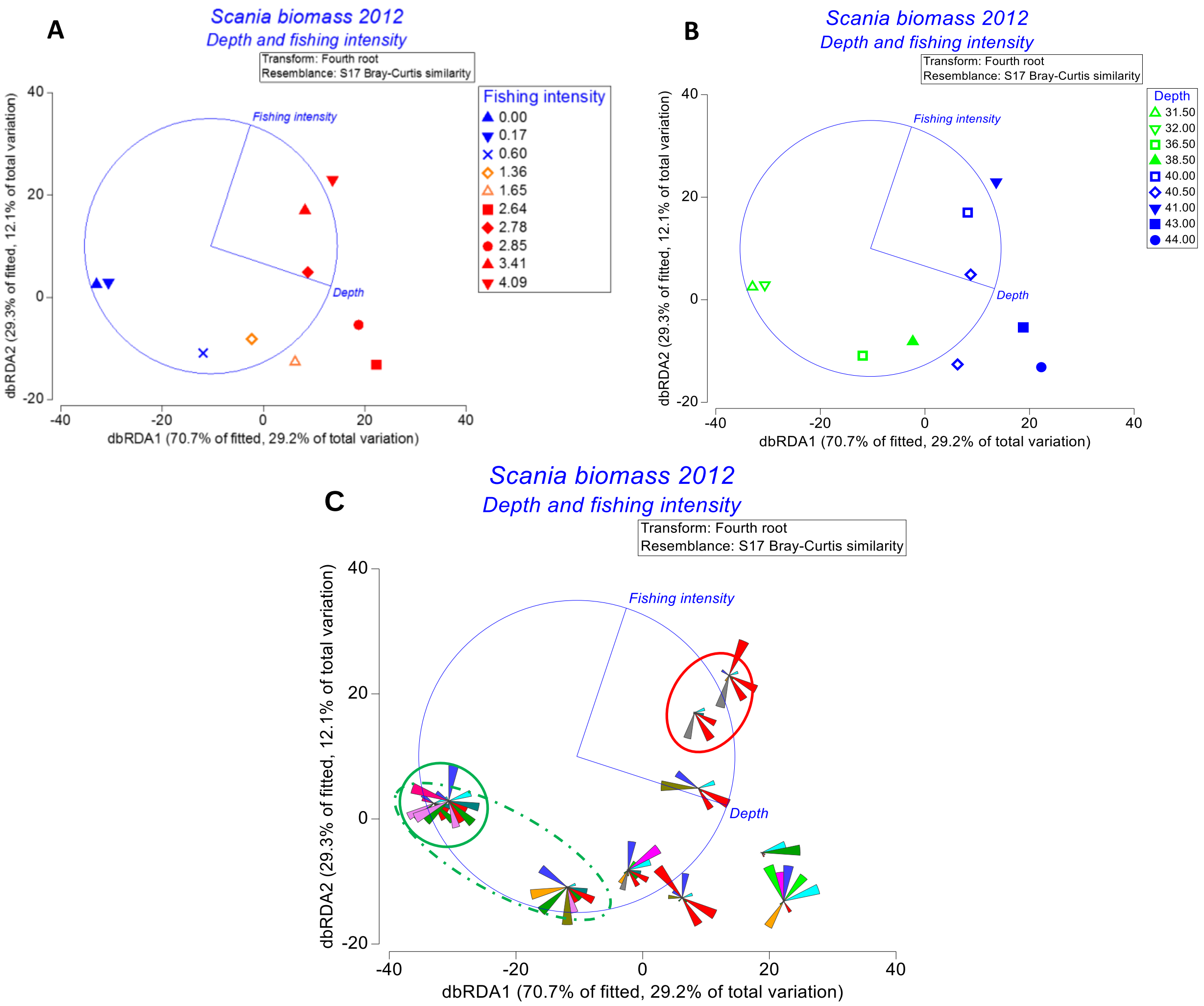


Figure 5. Ordination of monitoring stations in Scania. In A and B fishing intensity and depth is shown. In C the biomass of the different species at the different monitoring stations is shown (note that the size of each wing representing a species is related to the maximum abundance of that species in the test and therefore wings of the same sizes can represent very different biomass values. Within the green ellipse the lowest fishing pressure is found and within the red the highest fishing pressure.

As mentioned above the correlation among predictors is 0.82 and is difficult to say which variable is the most important.

Analysis of Abundance (fourth root transformed)

Depth and fishing intensity both untransformed. The DistLM analysis of abundance and marginal test show both variables to be significant (fishing intensity p=0.004 and explained variance=0.28, depth p=0.001 and explained variance =0.32) as for biomass. The Best analysis with AICc selects depth as the only variable for the best model with 32 % of the variation explained. To increase understanding both variables were forced into the model with the *All* mechanism and then 43 % of the variation is explained in the dbRDA graph which is overlaid with abundance of different orders etc. in Figure 6A. The model results are very much like the results for biomass. (When untransformed and fourth root transformed depth and fishing intensity are analysed in DistLM analysis three out of four predictors are significant in marginal analyses but depth untransformed is still selected as the best predictor).

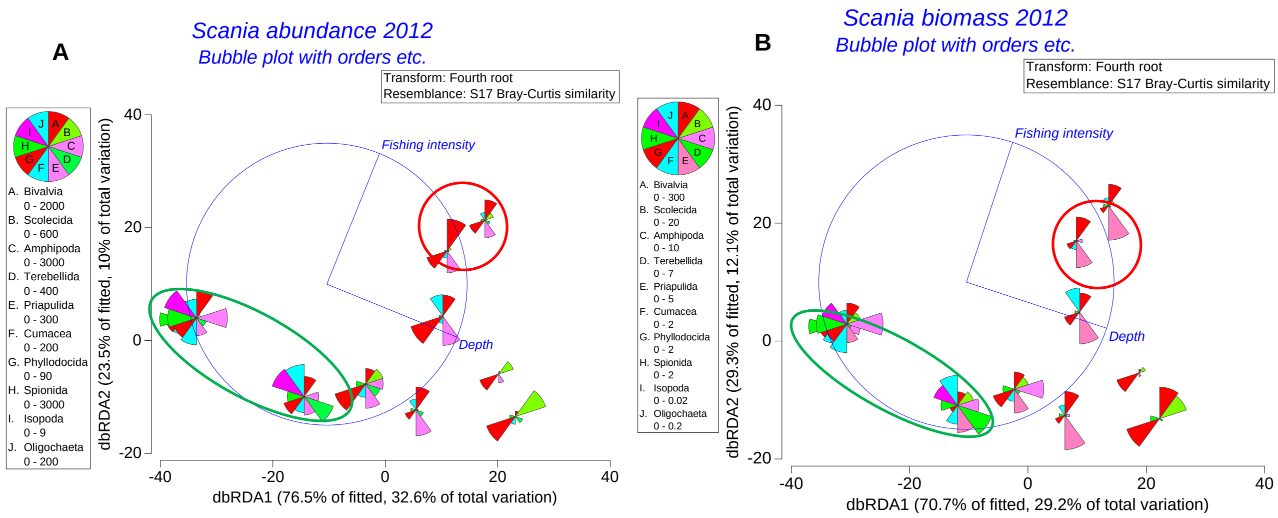


Figure 6. dbRDA ordination with bubble plot overlay of abundance in A and in biomass B of species grouped according to orders etc. to facilitate understanding of effects. Within the green ellipse the lowest fishing pressure is found and within the red the highest fishing pressure.

As mentioned above the correlation among predictors is 0.82 and is difficult to say which variable is the most important.

Analysis of abundance (untransformed)

Depth and fishing intensity untransformed. DistLM analyses of untransformed abundance and marginal test show that both predictors are significant, depth with p=0.006 and fishing intensity with p=0.018. The best selection process with AICc selects depth as the only predictor that explains 28% of the variation (for fourth root transformed data 32% of the variation was explained by depth).

As mentioned above the correlation among predictors is 0.82 and is difficult to say which variable is the most important.

Hanö bay west

Depth and fishing intensity untransformed is used and has a correlation among each other of 0.54. There is collinearity among the predictors but it is below the threshold of 0.70 which indicates severely distorted model estimations.

Depth is selected as the factor describing the assemblage structure the best and due to the presence of stations without fishing at different depths the result seem reasonable. As there are stations without fishing at the same depths as were fishing is occurring the analysis of fishing also seem probable. Fishing is mostly occurring in deep water but due to the high number of stations without fishing at all depths collinearity is "only" 0.54.

Biomass (fourth root transformed to enhance all species)

Depth and fishing intensity untransformed. In the DistLM analysis of marginal tests only depth was highly significant with p=0.0005 and explained variance =0.42 whereas fishing intensity had P=0.09. Thus in the model selection process with best and AICc, depth was chosen as the best predictor which explains 42% of the variation. When fishing intensity is forced into the model (and shown in the ordination below for increased understanding) the two predictors explains 50 % of the variation, see Figure 7.

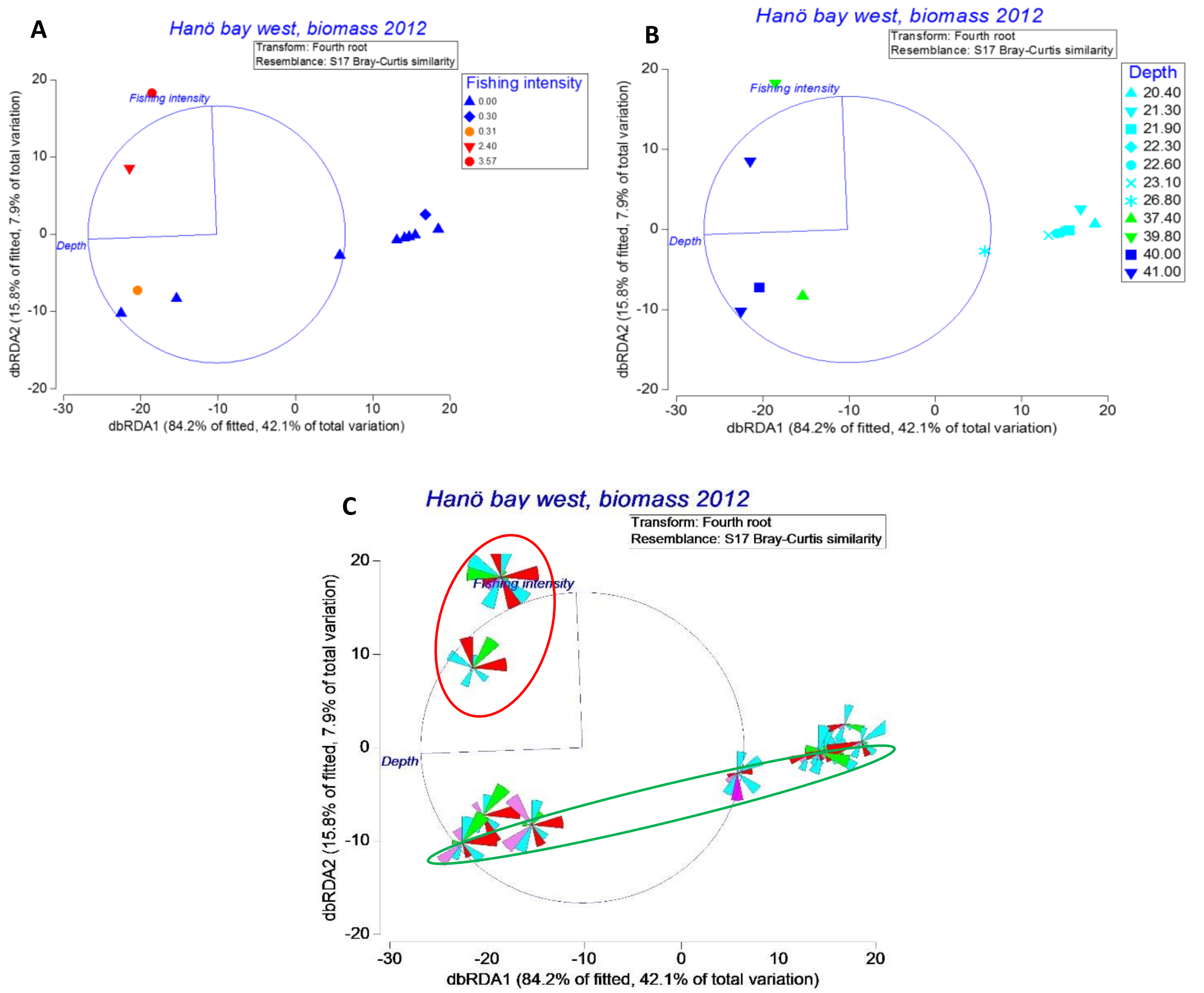


Figure 7. Ordination of monitoring stations In Hanö bay west, along fishing intensity gradients in A upper left and depth in B upper right. In C biomass of the species at the different monitoring stations is shown. Within the green ellipse the lowest fishing pressure is found and within the red the highest fishing pressure.

Fishing intensity was not selected as a significant predictor in the DistLM analysis but to increase understanding it is included in the ordination of assemblage structure in Hanö bay west in Figure 7C which clearly show that the assemblage components change along the depth gradient from shallow to deeper water of about 20 meters to 40 meters. The ordination gives the rough impression that low level of increased fishing intensity (0.30 and 0.31) has no major impact (few stations) but higher levels of fishing (at deeper water) seem to change the assemblage but this is not significant. The ordination in Figure 7C nicely show how assemblage differ between shallow and deep water, this variability however necessitates a high number of replicates from different depths and fishing intensities to be able to make tests and to be able to arrive at significant results.

Abundance (fourth root transformed to enhance all species)

Depth and fishing intensity untransformed. For abundance and DistLM and marginal analysis only depth was significant with p=0.001. With the Best selection method depth was selected and explained 43 % of the variation. With fishing intensity forced into the model 53 % of the variation was explained, see Figure 8B. To deepen the picture of which part of the assemblage has been affected a bubble plot with species abundance and biomass grouped according to orders etc. was overlaid the ordination of Hanö bay west stations, see Figure 8. In this figure it is easier to see that abundance of Nemertea seem to decrease with increased depth and Bivalvia increase. As there are not many stations with fishing intensity in the analysis any hard conclusions are impossible to draw however at the highest fishing intensity levels (only two stations in deeper water) there seem to be some effects although inconsistent between the two stations, see Figure 8. (When untransformed and fourth root transformed depth and fishing intensity are analysed in DistLM, transformed and untransformed depth are significant in marginal analyses but depth untransformed is selected as the best predictor).

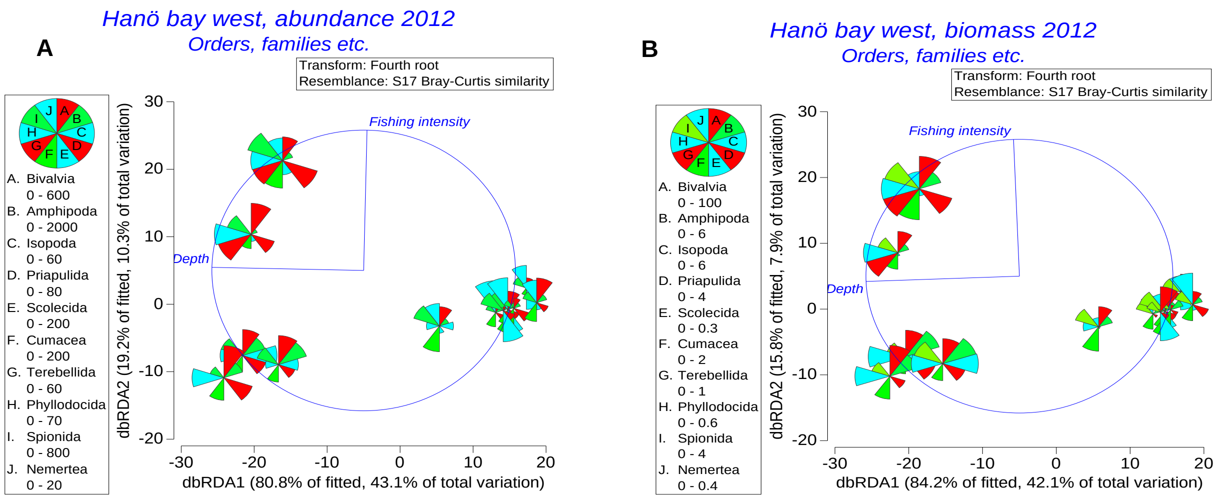


Figure 8. Distance based RDA ordination with bubble plot overlay of species abundance in A and biomass in B grouped according to orders etc. to facilitate overview of effects.

Abundance (untransformed to enhance abundant species)

Depth and fishing intensity untransformed. DistLM analyses of Hanö bay and marginal analyses showed only depth (p=0.001) to be significant as for forth root transformed data. Model selection with Best and AICc chose depth as predictor which explains 32% of the variation in comparison to 43% explained with fourth root transformed data.

Blekinge

Collinearity is present with a value of 0.68 and is due to the fact that fishing intensity increases with depth, the highest fishing intensity is at the two deepest stations and there are no stations without fishing and therefore the results in the analyses below can not be trusted.

Biomass (fourth root transformed to enhance all species)

Depth and fishing intensity untransformed. The outcome of the DistLM analysis show that both predictors are significant in marginal tests with depth p= 0.0001 and explained variance 0.49 and fishing intensity with p=0.02 and explained variance of 0.32. With the model selection procedure Best and AICc, depth is the only predictor variable chosen and explains 49 % of the variation. When both variables are forced into the model with the model selection procedure All 56% of the variation is explained as show in the dbRDA ordination Figure 9. To deepen the understanding of the assemblages bubble plot with species biomass grouped according to orders etc. was overlaid the ordination of Blekinge stations in Figure 10.

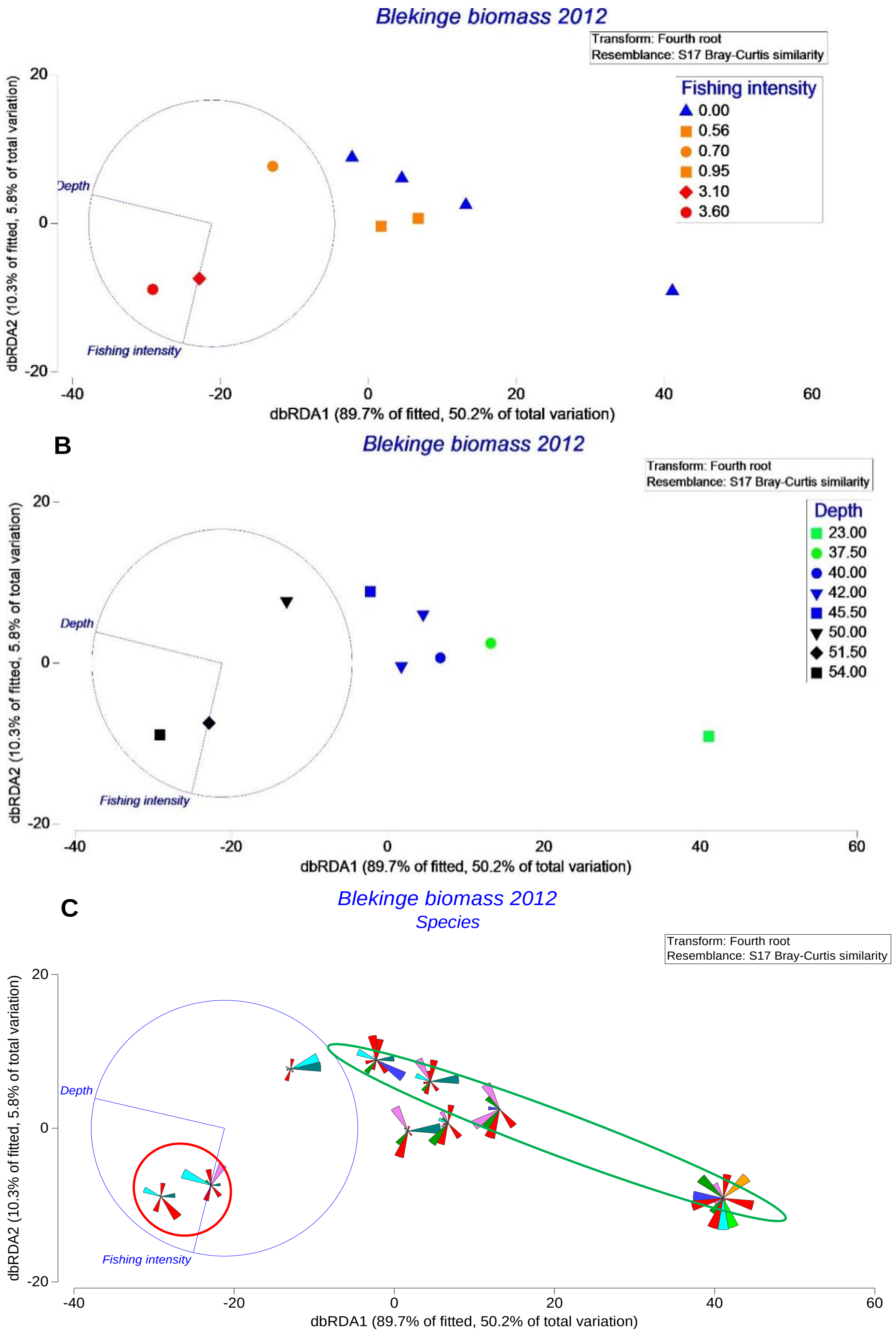


Figure 9. Ordination of monitoring stations in the sea area Blekinge along depth and fishing intensity gradients. Within the green ellipse the lowest fishing pressure is found and within the red the highest fishing pressure.

In Figure 9C both biomass and number of species is highest at the most shallow station which also is without fishing intensity. With increasing depth at stations without fishing intensity there is an indication of a change in assemblage structure but the three deeper stations (37.5, 42 and 45.5 m) without fishing intensity are not consistently alike. Thus when these stations are compared with stations with higher fishing intensity it is difficult to see any consistent patterns.

Abundance (fourth root transformed to enhance all species)

Depth and fishing intensity untransformed. DistLM analysis of abundance and marginal tests shows depth to be significant with p=0.0002. With the selection procedure Best only depth is selected and 47 % of the variation is explained. With both variables forced into the model 53 % of the variation is explained, see Figure 10. To deepen the understanding of the assemblages bubble plot with species abundances grouped according to orders etc. was overlaid the ordination of Blekinge stations, see Figure 10. There are not many stations in the analysis and the ordination gives the impression of an inconsistent change in assemblage structure with increasing depth for unfished stations. Increased fishing also seem to have an effect that is inconsistent between depths. (When untransformed and fourth root transformed depth and fishing intensity are analysed in DistLM untransformed and transformed depth are significant in marginal analyses but depth untransformed is selected as the best predictor).

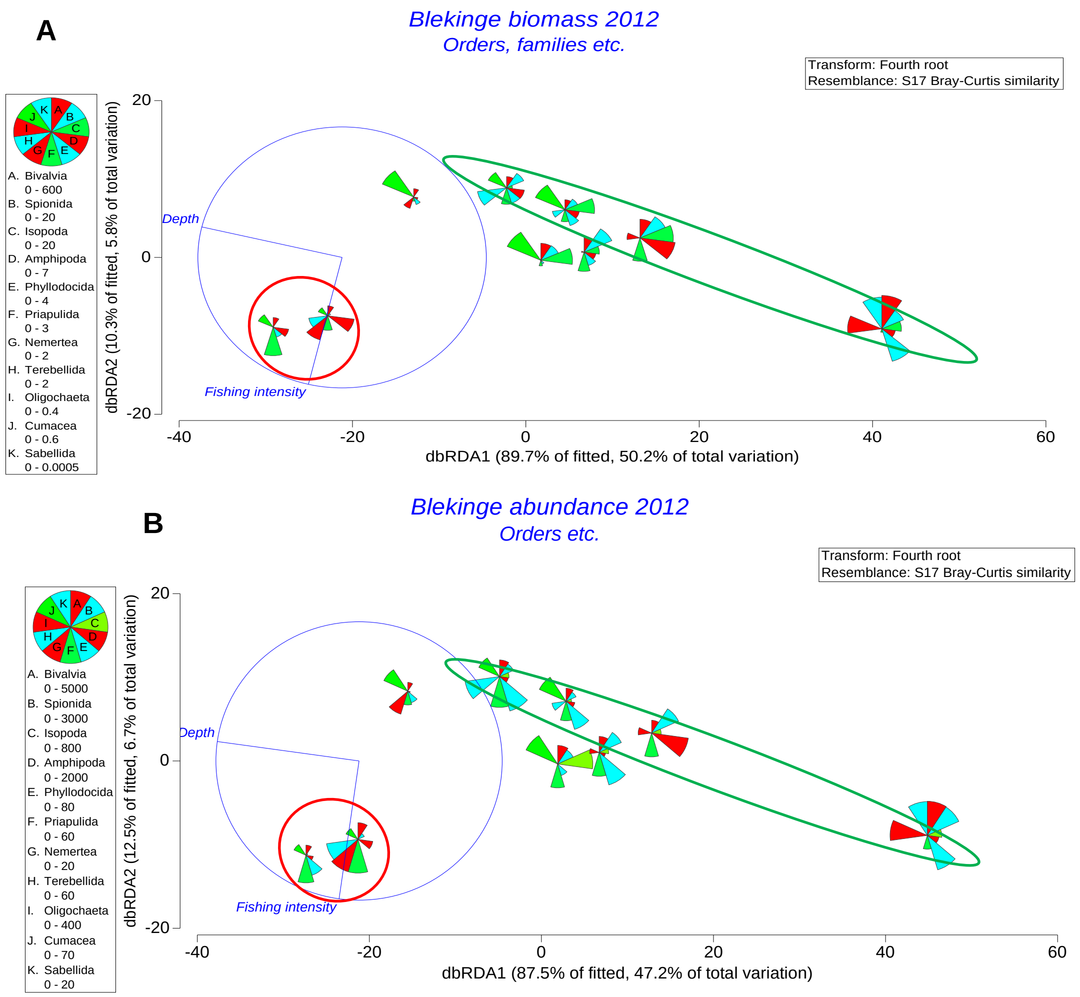


Figure 10. In A and B, dbRDA with biomass and abundances grouped according to orders etc. and overlaid stations within the Blekinge sea area. Within the green ellipse the lowest fishing pressure is found and within the red circle the highest fishing pressure.

Abundance (untransformed to enhance abundant species)

Depth and fishing intensity untransformed. DistLM analyses showed only depth to be significant from marginal analyses with p=0.004 and best selection chose the depth predictor as for fourth root transformed data. 29% of variability was explained compared to 47% explained by fourth root transformed data.

Gotland

Depth and fishing intensity untransformed is used and has a correlation among each other of -0.09. As there are stations without fishing intensity occurring at different depths and as collinearity is very low the tests of depth and fishing intensity and results seem probable.

Biomass (fourth root transformed to enhance all species)

Depth and fishing intensity untransformed. Eight stations lies within the Gotland sea area. The DistLM analysis and marginal tests of fishing intensity and depth show that fishing intensity is highly significant with p= 0.0034 but not depth. With the model selection procedure Best and the model selection criteria AICc, fishing intensity is selected as the only predictor variable and explains 46 % of the variation. This is the only sea area for 2012 for which fishing intensity is significant in the DistLM analysis and it is in this sea area that the two stations with the highest fishing intensity of all sea areas occur. When both predictors are forced into the model and shown in the dbRDA ordination below in Figure 11 they explain 63 % of the variation. In the dbRDA ordination in Figure 11C and Figure 12 the three stations without fishing (within the green ellipse) change somewhat in structure with increasing depth but biomass and number of species of at least two of the stations appear to be very similar. Although dissimilarities within this group of stations without fishing intensity the number of species and biomass is higher compared to stations with higher fishing intensity. The difference is most obvious when comparing unfished stations with the two stations with the highest fishing intensity (within the red ellipse in Figure 11). The fishing intensity at these two stations is the highest of all sea areas.

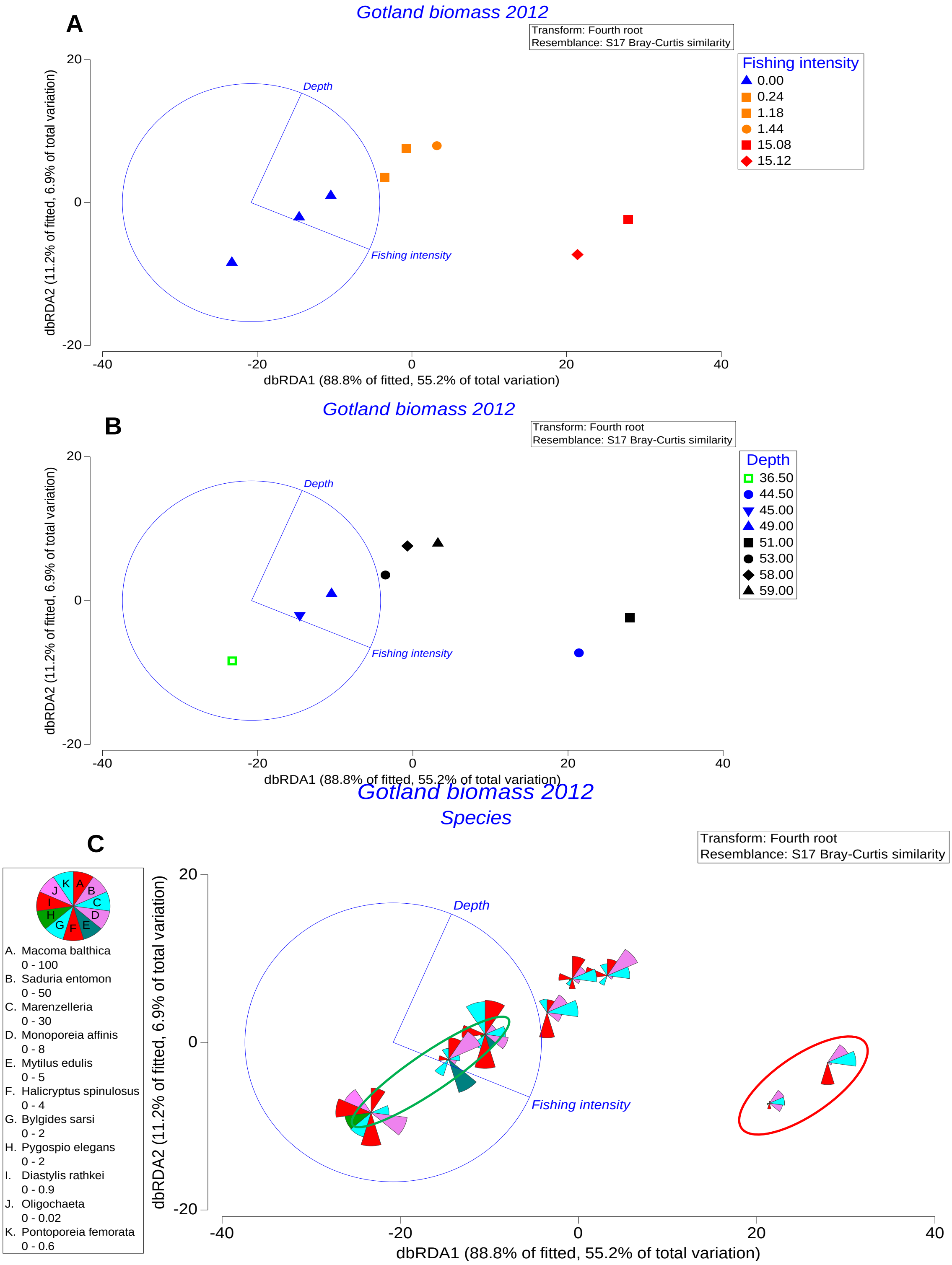


Figure 11. dbRDA ordination of monitoring stations in the sea area Gotland along depth and fishing intensity gradients in A and B and with biomass (untransformed) overlaid each station in C. Green ellipse shows stations without fishing and red ellipse stations with the highest fishing intensity.

Abundance (fourth root transformed to enhance all species)

Depth and fishing intensity untransformed. For abundance the result is the same as for the analysis of biomass thus fishing intensity is the only significant predictor in marginal tests with p=0.03 but this is not significant with Bonferroni adjustments using α=0.025 which however is a harsh correction according to some authors. Probably it is best to see the relationship as on the border between significant and insignificant. Fishing intensity chosen with the Best selection procedure explains 38 % of the variation. With both variables forced into the model 61 % is explained, see Figure 12. (When both untransformed and fourth root transformed depth and fishing intensity are analysed in DistLM analysis untransformed and transformed fishing intensity are significant in marginal analyses and fishing intensity fourth root transformed is selected as the best predictor with explained variance = 51%, (p=0.0042). With Bonferroni adjustments it is only transformed fishing intensity that is significant in marginal tests α=0.0125).

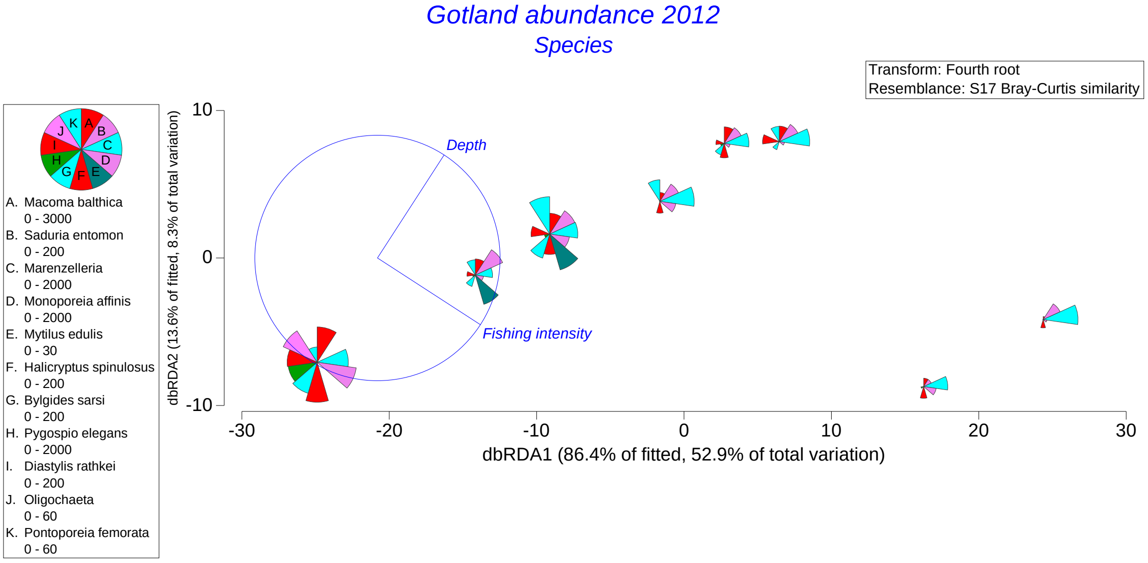


Figure 12. dbRDA ordination of monitoring stations in the sea area Gotland along depth and fishing intensity gradients with abundance (untransformed) overlaid each station. Fishing intensity was the only chosen predictor and fishing intensity is only included in the model and graph to increase our understanding.

Abundance (untransformed) to analyse effects on most abundant species

Depth and fishing intensity untransformed. DistLM analysis show that no predictor is significant in the marginal test.

Summary of model selection using untransformed and transformed predictor variables

As it is interesting to explore the model selection outcome when using both untransformed and transformed predictor variables this was tested using depth and fishing intensity both untransformed and fourth root transformed on abundance data (4^{th} root transformed). The results are presented in Table 2. According to this analysis the same predictor is always chosen in the four sea areas but in Gotland the untransformed predictor is not significant with Bonferroni correction (which by some however is regarded as a harsh correction), the transformed predictor is highly significant and has a higher explained variation.

Table 2. Summary of model selection using four predictor variables (depth and fishing intensity) both untransformed and fourth root transformed in DistLM analysis of abundance (year 2012) fourth root transformed as response variable.

Sea area	Response variable and transformation	Predictor chosen from best selection when any of the predictors are significant in marginal tests	Variation (%) explained with "best" model
Scania	Abundance fourth root	Depth un-transformed	32, the same result as analysis with untransformed predictor variables
Hanö bay west	Abundance fourth root	Depth un-transformed	43, the same result as analysis with untransformed predictor variables
Blekinge	Abundance fourth root	Depth un-transformed	47, the same result as analysis with untransformed predictor variables
Gotland	Abundance fourth root	Fishing intensity square root transformed	51, the same predictor is selected but the untransformed predictor is not significant after Bonferroni correction, the transformed predictor is highly significant and gives a higher explained variance than the untransformed predictor (38%)

Summary and conclusion of DistLM analyses of multivariate data for 2012

DistLM analyses of fourth root transformed biomass and abundance data and untransformed abundance data with untransformed predictor variables generally picks the same predictor or no predictor variable and produces about the same described variability for each sea area, although this is lower for untransformed abundances in Scania and Blekinge, see Table 3. In Gotland where fishing intensity is selected as predictor for both 4th root transformed biomass and abundance, no predictor is selected for untransformed response data. This indicates that it is the combined assemblage with all species that changes with increased fishing intensity and not the most abundant species which are in focus when analysing untransformed assemblage data. With the Bonferroni correction for test of two predictor variables untransformed fishing intensity is not significant in Gotland. However some say Bonferroni is a harsh correction thus valuable to keep in mind is that the significance might be on the border to not significant.

Table 3. Summary of variables used and results from DistLM analyses of two predictor variables (depth and fishing intensity untransformed) and three different response variable datasets. P-values in bold are below α=0.025 with Bonferroni adjustment (α=0.05 and two predictors).

Sea area	Response variable dataset and transformation	Result from marginal test (p-values)	Variable chosen from best selection when any of the predictors are significant in marginal tests	Variation (%) explained with "best" model
Scania High collinearity!	Biomass fourth root	depth=**0.0012**, fishing=**0.008**	Depth	29
High collinearity!	Abundance fourth root	depth=**0.001**, fishing =**0.004**	Depth	32
High collinearity!	Abundance untransformed	depth=**0.006** , fishing **0.018**	Depth	28
Hanö bay west	Biomass fourth root	depth=**0.0005**	depth	42
	Abundance fourth root	depth=**0.001**	Depth	43

Sea area	Response variable dataset and transformation	Result from marginal test (p-values)	Variable chosen from best selection when any of the predictors are significant in marginal tests	Variation (%) explained with "best" model
	Abundance untransformed	depth significant	Depth	43
Blekinge	Biomass fourth root	depth=**0.0001,** fishing =**0.02**	Depth	49
	Abundance fourth root	depth=**0.0002**	Depth	47
	Abundance untransformed	depth=**0.004**	Depth	29
Gotland	Biomass fourth root	fishing =**0.0034**	Fishing intensity	46
	Abundance fourth root	fishing =0.03	Fishing intensity	38
	Abundance untransformed	None	-	-

2012 Univariate analysis of species numbers, number of individuals, BQI and W

As the four different sea areas are located within regions with slightly different salinities and the fact that monitoring stations are from different depths, there is a risk of confounding when building the models if all stations are analysed together see

Figure **2**. Therefore any differences among these sea areas was analysed at the first step. This analysis on differences among sea areas for univariate response variables was conducted with PERMANOVA as conducted for multivariate data above.

The PERMANOVA analysis of differences among sea areas regarding univariate response variables was initiated by separately normalizing: depth and W, depth and BQI, depth and number of species, respectively depth and number of individuals log(x+1). Thereafter similarities among samples based on the Euklidian distance measure was calculated among samples separately for these four pairs. Normalization was done as the variables are on different scales and similarities were calculated with the inclusion of depth to take this factor into account. Euklidian distances were calculated to allow for double zeros. Permdisp analysis on these similarities showed dispersion of species, individuals and BQI to be homogene. Subsequent PERMANOVA analysis for the same four response variables and differences between sea areas showed to be significant for all four. When PERMANOVA and pairwise test were conducted on the four variables regarding differences between specific sea areas, about six out of ten analyses were significant which made separate analyses per sea area relevant to conduct. For W, Permdisp was significant and therefore PERMANOVA analysis was not performed and it was decided to analyse sea areas separately with DistLM.

For all tests the two predictor variables depth and fishing intensity were untransformed following the thoughts described for multivariate analysis above. The DistLM analysis is flexible regarding assumptions on response variables according to the Primer manual. However response variables where still studied with histogram plots of each sea area which showed species number to be ok for all sea regions or not better with log(x+1) or square root transformation. Log(x+1) for number of individuals were ok/quite ok for Scania, Blekinge, Kalmar and Gotland. Untransformed W was Ok for Scania and Hanö bay and quite ok for Blekinge, Kalmar and Gotland. BQI untransformed was quite ok for all sea areas. In conclusion in the analyses the response variables: number of species, BQI and W were untransformed whereas number of individuals were log(x+1) transformed.

Scania

Depth and fishing intensity untransformed is used for all response variables and has a correlation among each other of 0.82. This collinearity makes it difficult to separate the effects from the two predictors from each other and therefore the analyses below can not be trusted.

BQI

Within DistLM analysis and best selection with AICc marginal tests show fishing intensity to be just significant with p=0.049 but not when the Bonferroni correction with α=0.025 is applied. With the best selection method fishing intensity is chosen and explain 40.7 % of the variation. As Bonferroni correction indicates it is not significant the negative relationship between fishing intensity and BQI cannot be trusted. The results are presented as a dbRDA ordination in Figure 13 which shows that there is not a perfect relationship between increased fishing intensity and a lower BQI as the lowest BQI is not found at the highest fishing intensity.

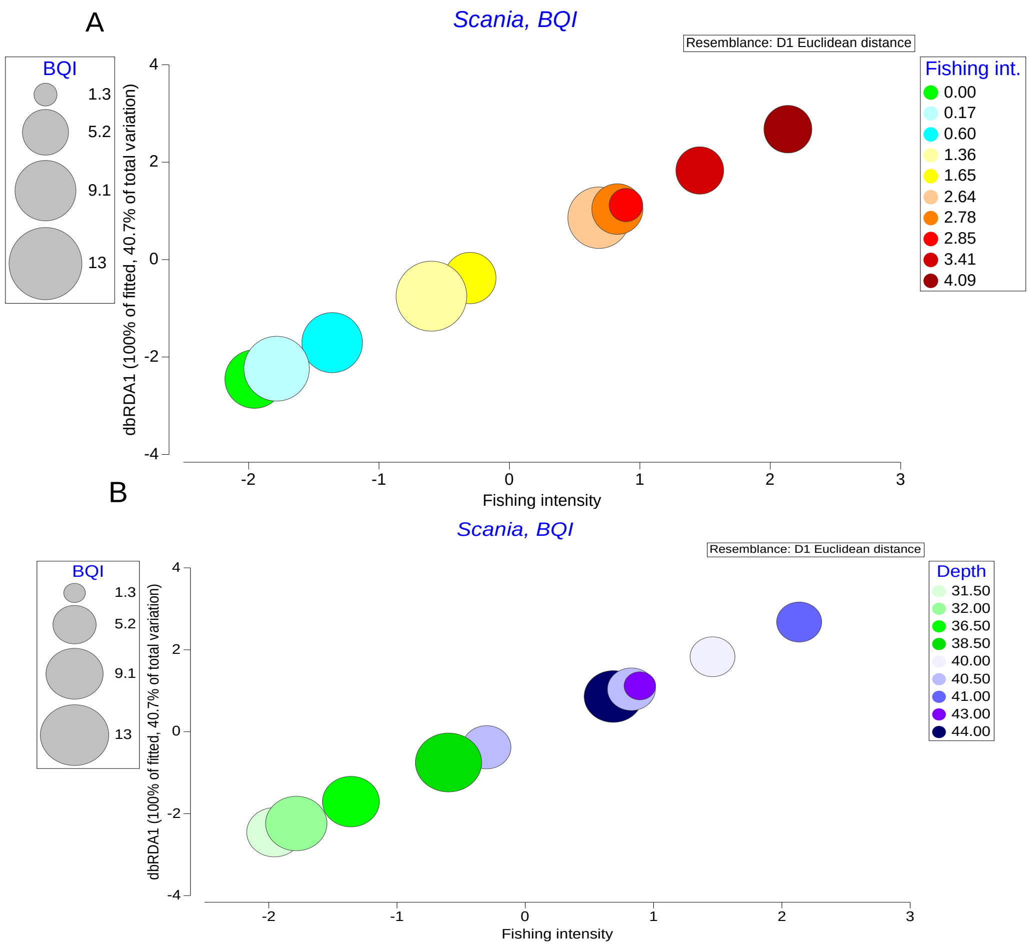


Figure 13. Distance based RDA of BQI predicted by fishing intensity. In A description of fishing intensity, in B description of depth.

Number of species

The analysis of number of species and DistLM and marginal tests shows only fishing intensity to be significant with p=0.024 and also when the Bonferroni correction with α=0.025 is applied. The proportion explained variation is 0.47 and depth almost significant with p=0.053 and explained variation 0.39. With the

Best selection and AICc only fishing intensity is selected and the variance explained is 47 %. In this case a higher fishing intensity is coupled to a lower number of species. The result is presented in a dbRDA ordination where also depth is forced into the model for increased understanding which then explains 48% of the variation, see Figure 14.

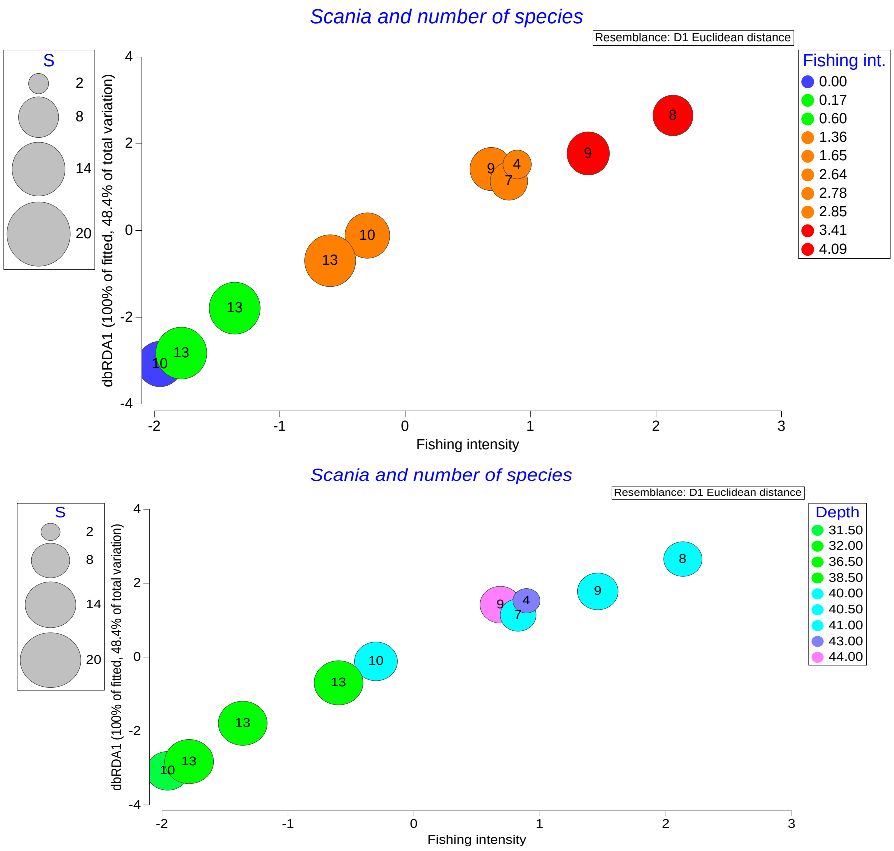


Figure 14. Distance based RDA of number of species predicted by fishing intensity and depth.

Number of individuals

Analysis with DistLM and marginal tests show both variables to be significant with depth and p=0.002 and explained variance = 0.68 and fishing intensity with p=0.032 and proportion explained variance =0.43, with the Bonferroni correction and α=0.025 only depth is significant. With Best as procedure depth is chosen as the only variable with an explained variation of 67.9 %. In the dbRDA ordination fishing intensity only increases the explained variation to 68.1 % but is included to increase understanding as shown in Figure 15.

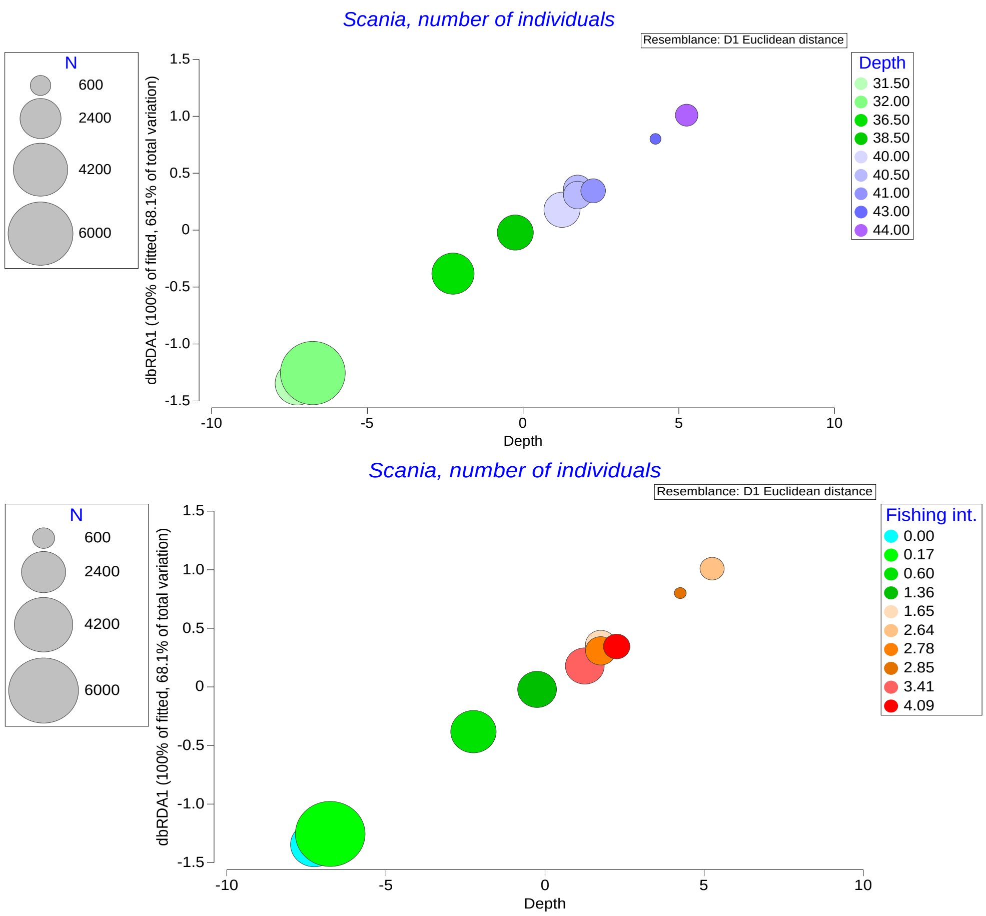


Figure 15. Distance based RDA of number of individuals predicted by depth which was significant. Fishing intensity is forced into the model to increase understanding.

W

From DistLM analysis no predictor was significant in marginal test. Depth with p=0.12 and fishing intensity with p=0.078.

Hanö bay west

Depth and fishing intensity untransformed is used and has a correlation among each other of 0.54. There is collinearity among the predictors but it is below the threshold of 0.70 which indicates severely distorted model estimations.

BQI

DistLM and marginal tests analysis only depth was significant with p=0.03 but not when the Bonferroni correction with α=0.025 is applied. The Bonferroni correction is however harsh and therefore it is probably best to see the relationship as on the border to significant. Depth is selected in best procedure and explained 38% of the variation. Fishing intensity was forced into the model for increased understanding and gives an extra 15 % explained variation in the dbRDA plot, see Figure 16.

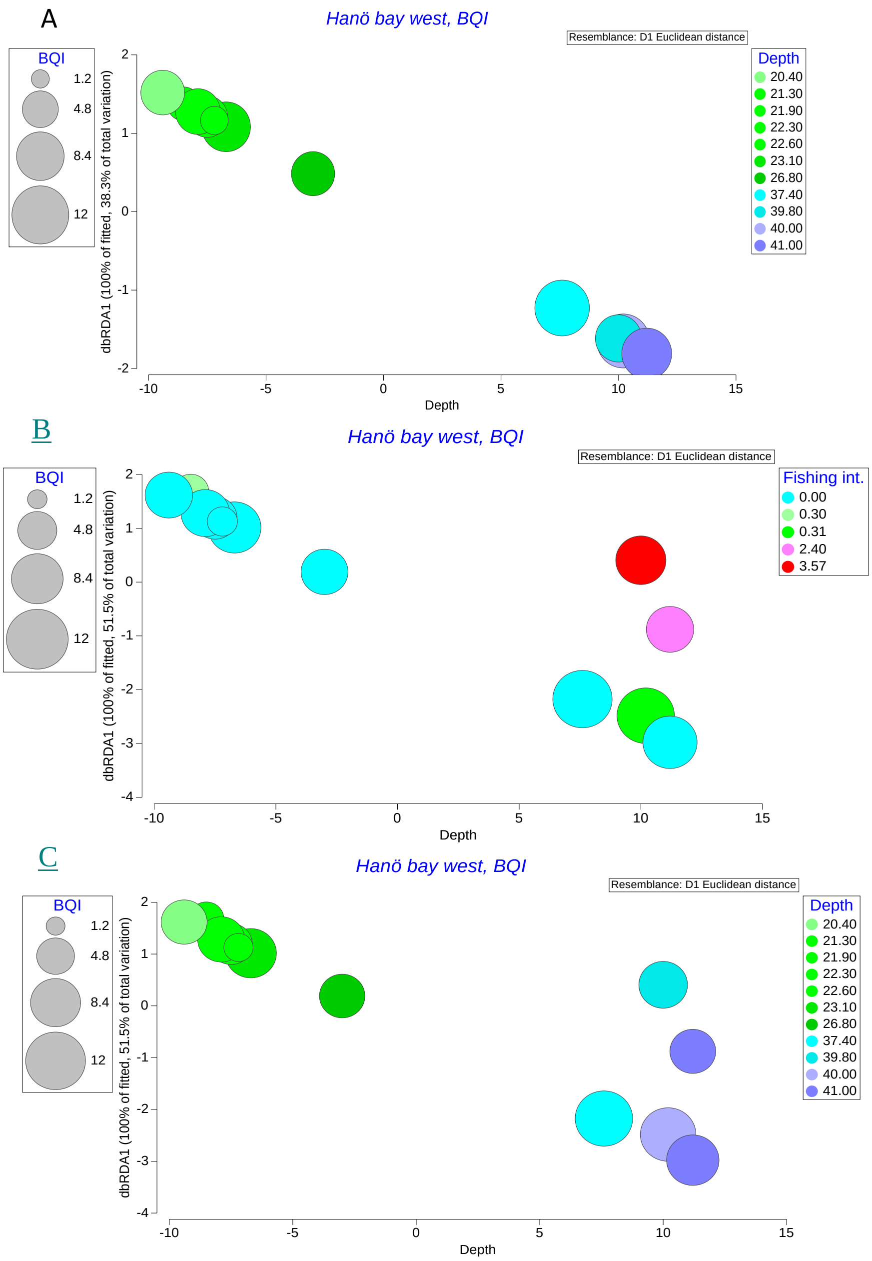


Figure 16. Distance based RDA of number of BQI for Hanö bay. In A is the DistLM selected model where only depth is significant. In B and C fishing intensity is forced into the model for increased understanding.

Number of species

Both predictors were significant in the marginal tests with depth and p= 0.014 and explained variance = 0.47 and fishing intensity with p=0.0048 and explained variance = 0.56 but the best procedure with AICc choose fishing intensity which described 56 % of the variation. In this case increased fishing intensity is coupled to a higher number of species. The result is presented as a dbRDA ordination with depth forced into the model for increased understanding and then 67 % of the variation is explained, see Figure 16.

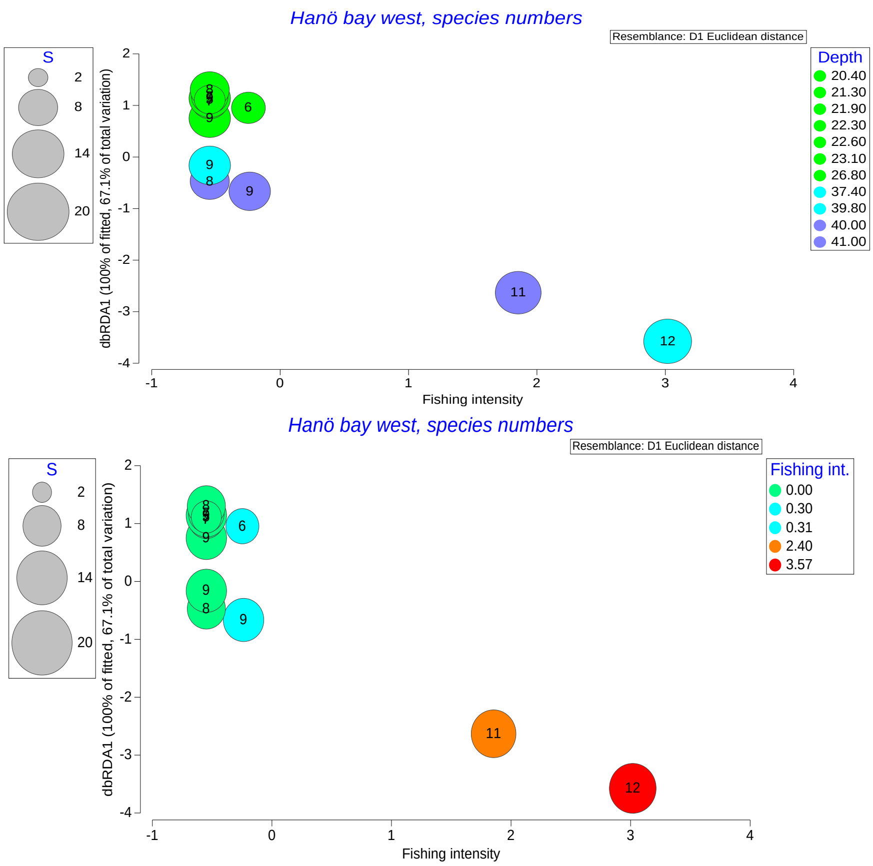


Figure 17. Distance based RDA of number of species predicted by fishing intensity and depth.

Number of individuals

Analysis with DistLM and marginal tests show only depth to be highly significant (p=0.0015) also with the Bonferroni correction with α=0.025 applied. With Best as procedure depth is chosen as the only variable and explained 71 % of the variation. Depth is positively related to number of individuals. In the dbRDA ordination fishing intensity is included to increase understanding as shown in Figure 18 and then explained variability is 72 %.

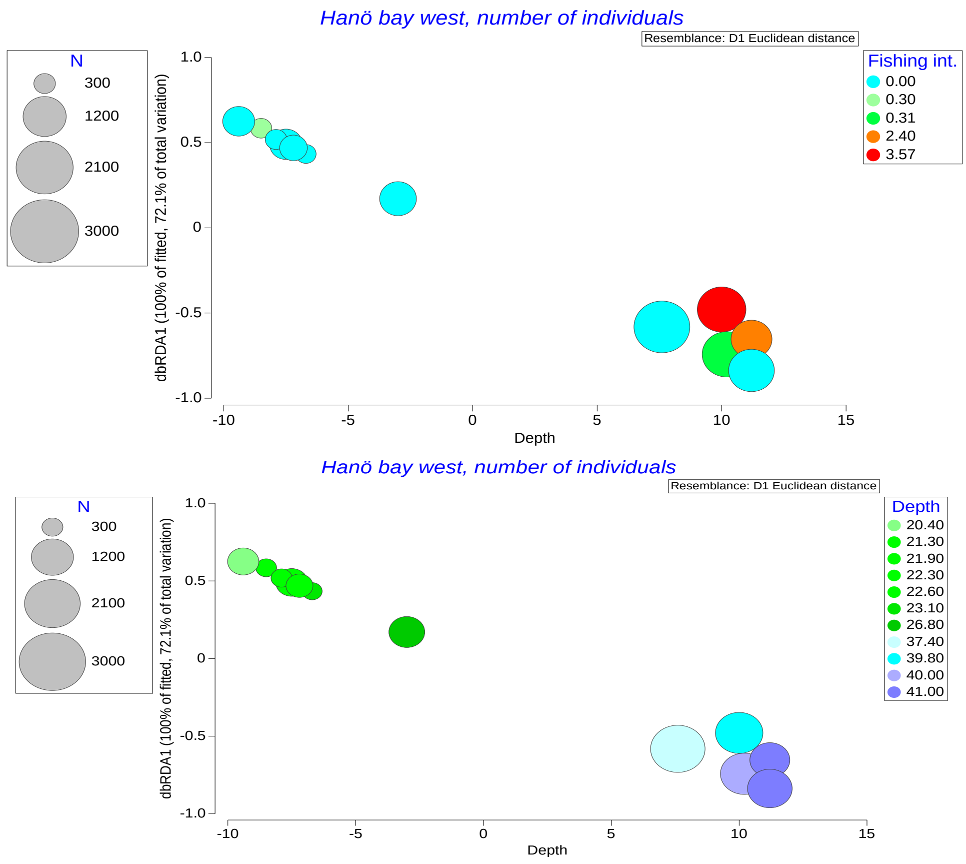


Figure 18.Distance based RDA of number of individuals predicted by fishing intensity and depth.

W

From DistLM analysis no predictor was significant in marginal test. Depth with p=0.43 and fishing intensity with p=0.61.

Blekinge

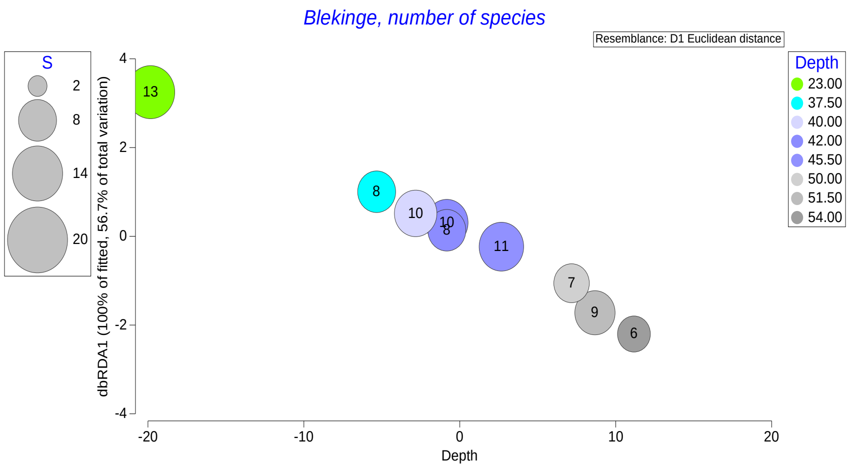
Depth and fishing intensity untransformed is used and has a correlation among each other of 0.68 which is on the border of being too high and thus it is difficult to say which variable is the most important one. Therefore the results in the analyses below can not be trusted.

BQI

DistLM analysis of BQI showed both predictor to be highly insignificant.

Number of species

DistLM analysis showed only depth to be significant in the marginal tests with p= 0.022 and was also chosen in the best procedure with AICc with 56% explained variation. The result is presented as a dbRDA ordination with depth forced into the model for increased understanding and then 56.7 % of the variation is explained, see Figure 19. As seen in the figure the negative relationship between depth and species numbers is strongly dependent on the most shallow station and if this station is exempt from the analysis there is no relationship any longer.



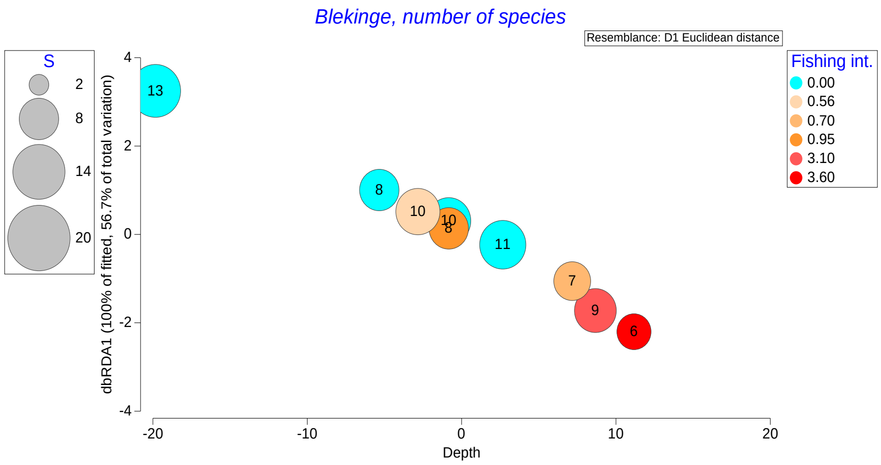
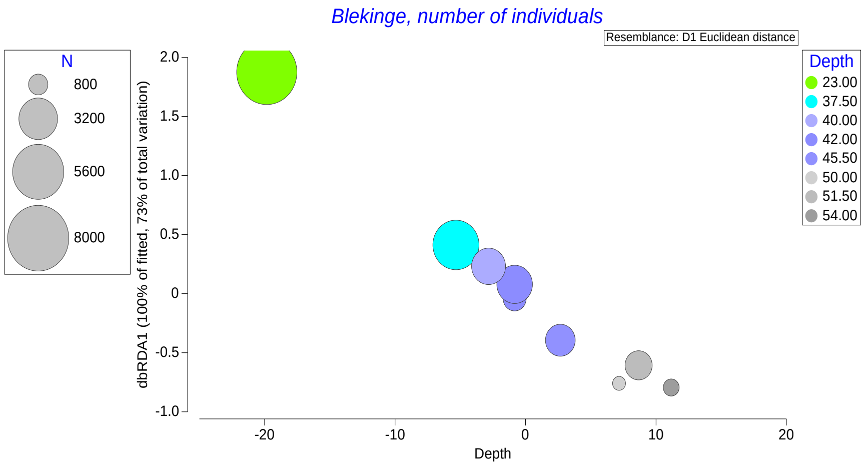


Figure 19. Distance based RDA of number of species with depth as the significant model and fishing intensity is included to increase understanding.

Number of individuals

Analysis with DistLM and marginal tests show depth to be highly significant with p=0.0035. With Best as procedure depth is chosen as the only variable and explained 71 % of the variation and is negatively related to number of individuals. In the dbRDA ordination fishing intensity is included to increase understanding as shown in Figure 20 and then the explained variability is 73 %.



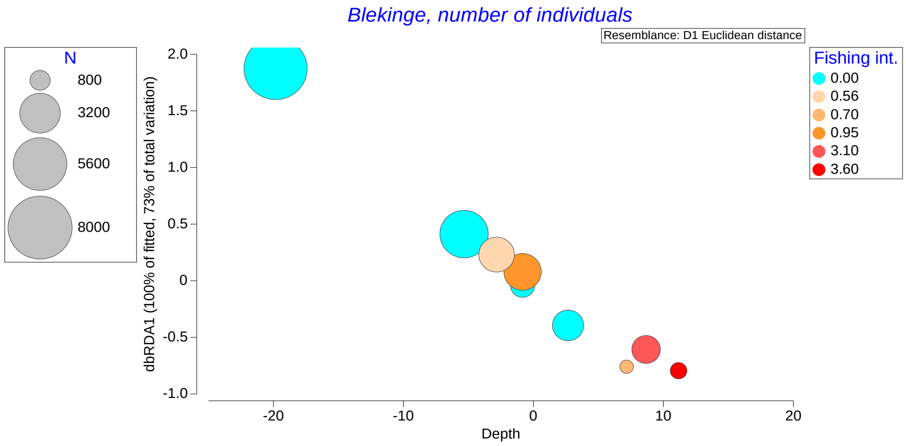


Figure 20.Distance based RDA of number of individuals in Blekinge with depth as the significant model and fishing intensity is included to increase understanding.

W

From DistLM analysis no predictor was significant in marginal test. Depth with p=0.58 and fishing intensity with p=0.71.

Gotland

Depth and fishing intensity untransformed is used and has a correlation among each other of -0.09 and collinearity is thus not a problem.

BQI

DistLM analysis of BQI showed no predictor to be significant with depth and p=0.08 and fishing intensity p=0.12.

Number of species

In DistLM analysis and marginal tests fishing intensity was highly significant with p=0.0047 but depth not at all. In the best analysis fishing intensity was chosen and describes 55% of the variation. In the figure depth is also included in the ordination to increase understanding and then 71% of the variation is explained, see Figure 21.

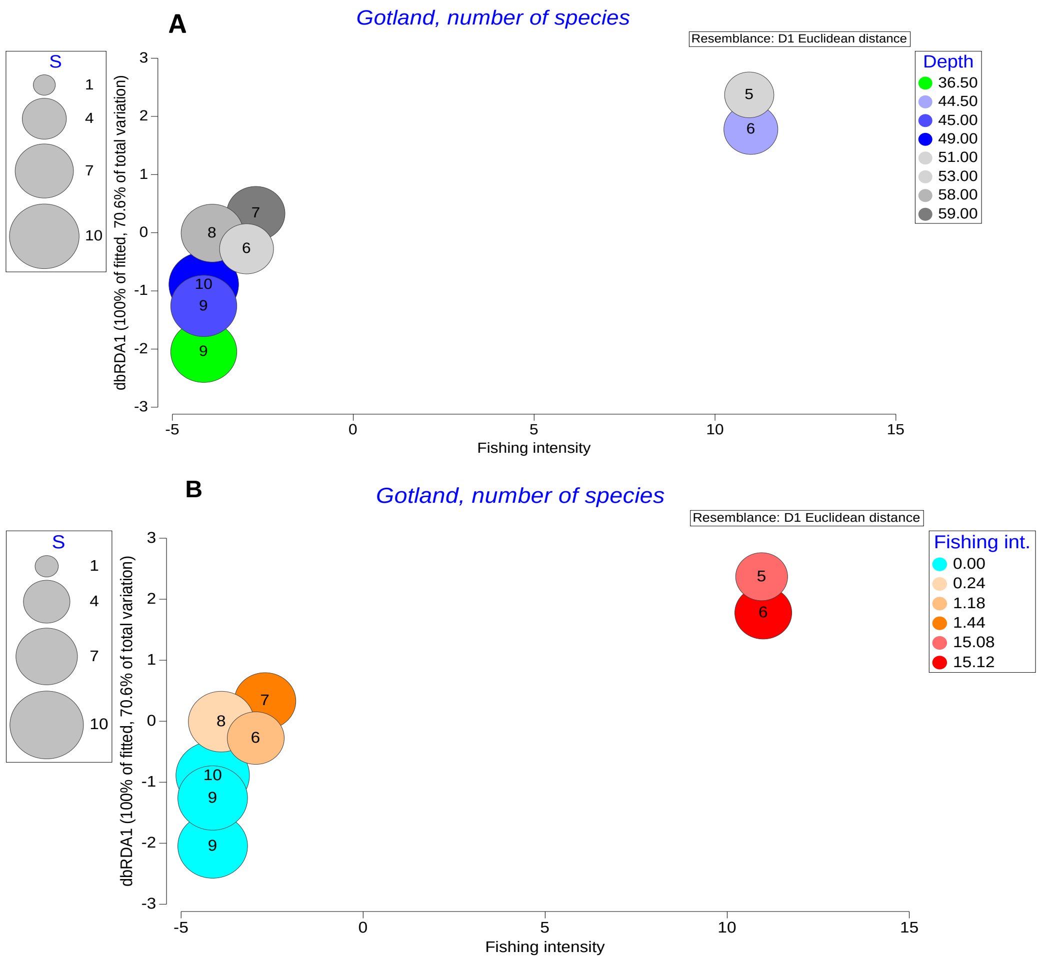
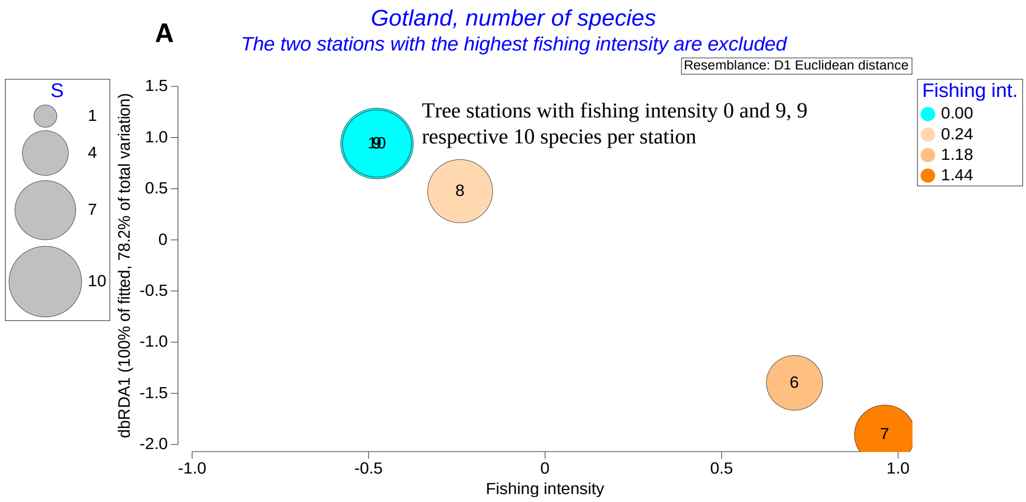


Figure 21. Distance based RDA of number of species for sea area Gotland with depth in A and fishing intensity in B.

As it is interesting to analyse relationships also without the two stations with the exceptionally high fishing pressure these were omitted from an additional analysis. DistLM analysis with these stations omitted showed fishing intensity in marginal test to still be significant with p=0.03. With the best selection procedure fishing intensity explained 78 % of the variation, see Figure 22.



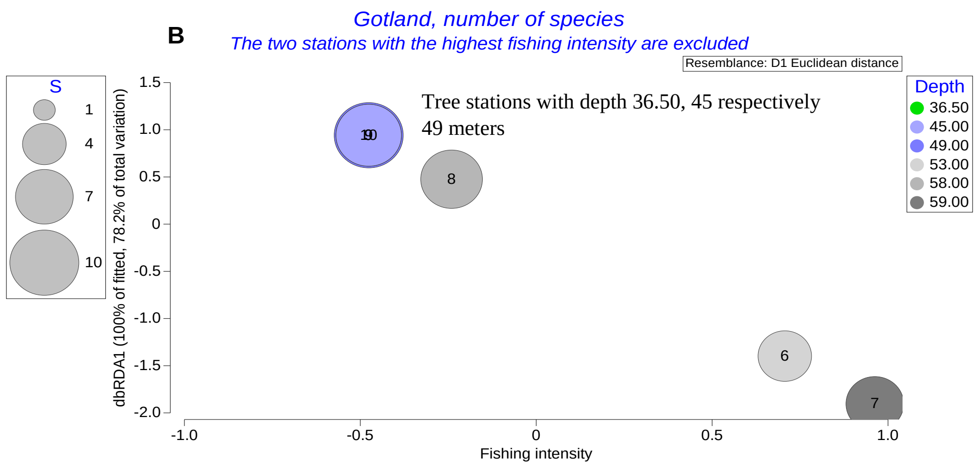


Figure 22. Distance based RDA of number of species for sea area Gotland with depth in A and fishing intensity in B.

Number of individuals

Analysis with DistLM and marginal tests show no factor to be significant, with depth a p=0.23 and fishing intensity p= 0.29. Both variables are forced into the model the dbRDA ordination for increased understanding, see Figure 23.

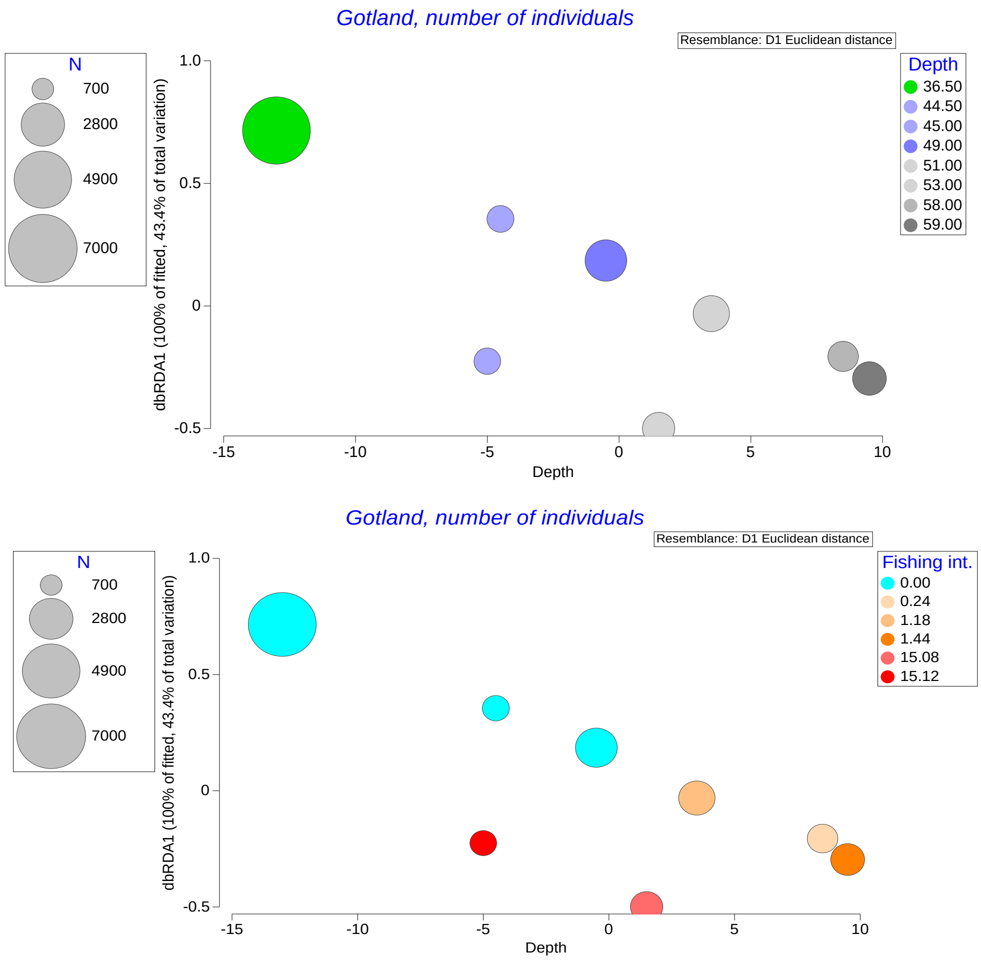


Figure 23.Distance based RDA of number of individuals in Gotland where no predictor was significant but in the figure the predictors are shown for better understanding.

W

From DistLM analysis no predictor was significant in marginal test. Depth with p=0.26 and fishing intensity with p=0.16.

2012 Summary of results from univariate analyses

A summary of results from univariate analyses are presented in Table 4.

Table 4. Results from DistLM analyses of univariate response variables (BQI, Number of species, and W are untransformed and Number of individuals log(x+1) transformed). P-values and predictors in bold are significant at α=0.025 with Bonferroni adjustment.

Sea area	**Response variable**	**Result from marginal test (p-values)**	**Variable chosen from best selection from significance in marginal tests**	**Variation (%) explained with "best" model**
Scania, High collinearity!	BQI	fishing=0.049	fishing, negative	40.7
	Number of species	fishing=**0.024**, depth=0.053	**fishing, negative**	47
	Number of individuals	fishing=0.032, depth=**0.002**	**depth, negative**	67.9
	W	none significant	-	-
Hanö bay west	BQI	depth=0.03	depth, positive	38
	Number of species	fishing=**0.0044**, depth=**0.013**	**fishing, positive**	56
	Number of individuals	depth=**0.0015**	**depth, positive**	71
	W	none significant	-	-
Blekinge	BQI	none significant	-	-
	Number of species	depth=**0.022**, with the most shallow station removed the significance is removed	**depth, negative**	56
	Number of individuals	depth=**0.0035**	**depth, negative**	71
	W	none significant	-	-
Gotland	BQI	none significant	-	-
	Number of species	fishing=**0.0047**, (without two station with highest fishing intensity fishing is still significant)	**fishing, negative,** (without two station with highest fishing intensity fishing is still significantly negatively).	55, (77 without the two stations with highest fishing intensity)
	Number of individuals	none significant	-	-
	W	none significant	-	-

2010 Multivariate analysis of sea areas regarding abundance (fourth root transformed)

Abundance data has been gathered from 48 stations for the year 2010. Abundances were square root transformed to allow for less abundant species to contribute to the analysis and thereafter Bray Curtis dissimilarities were calculated.

The first analysis was Permdisp which showed to be significant as Gotland was different from Blekinge and Scania. PERMANOVA for all sea areas was however performed anyway. This analysis showed to be significant and subsequent pairwise analyses showed all sea areas to be different from one another. These differences indicated that all stations could not be analysed together in a DistLM analysis thus each sea area was analysed separately as for data from 2012.

For DistLM analysis best and AICc was used for selecting the "best" model and four predictors were put in the test: depth and fishing intensity untransformed and the same predictors fourth root transformed as well because histogram plots of transformed predictors were more normally distributed in some sea areas.

Scania

Distlm analyses was used with four predictors which with histogram plots looked more or less normally distributed with or without transformation. Correlation between fishing intensity and depth both untransformed was 0.30. The results with Best selection and AICc showed depth both untransformed and transformed to be significant in marginal test ($p=0.0006$ and $p=0.0007$), also with Bonferroni correction and $\alpha=0.0125$. Fishing predictors were highly insignificant with $p>0.52$. Best selected depth untransformed to be the only predictor with an explained variance of 36%. In the figure both depth and fishing intensity untransformed are forced into the model for added information, see Figure 24. There is not a high collinearity present in the data (0.30), thus fishing intensity does not increase with increasing depth. According to the data it is depth that explains changes in community structure (fishing is not significant and not close to significant). Two drawbacks with the data is however present: 1) there are no stations without fishing thus it is not possible to see if there is a change from no fishing to fishing, 2) as there are no stations without fishing located at different depths, it is not the factor depth in itself that is analysed but depth with different levels of fishing intensity.

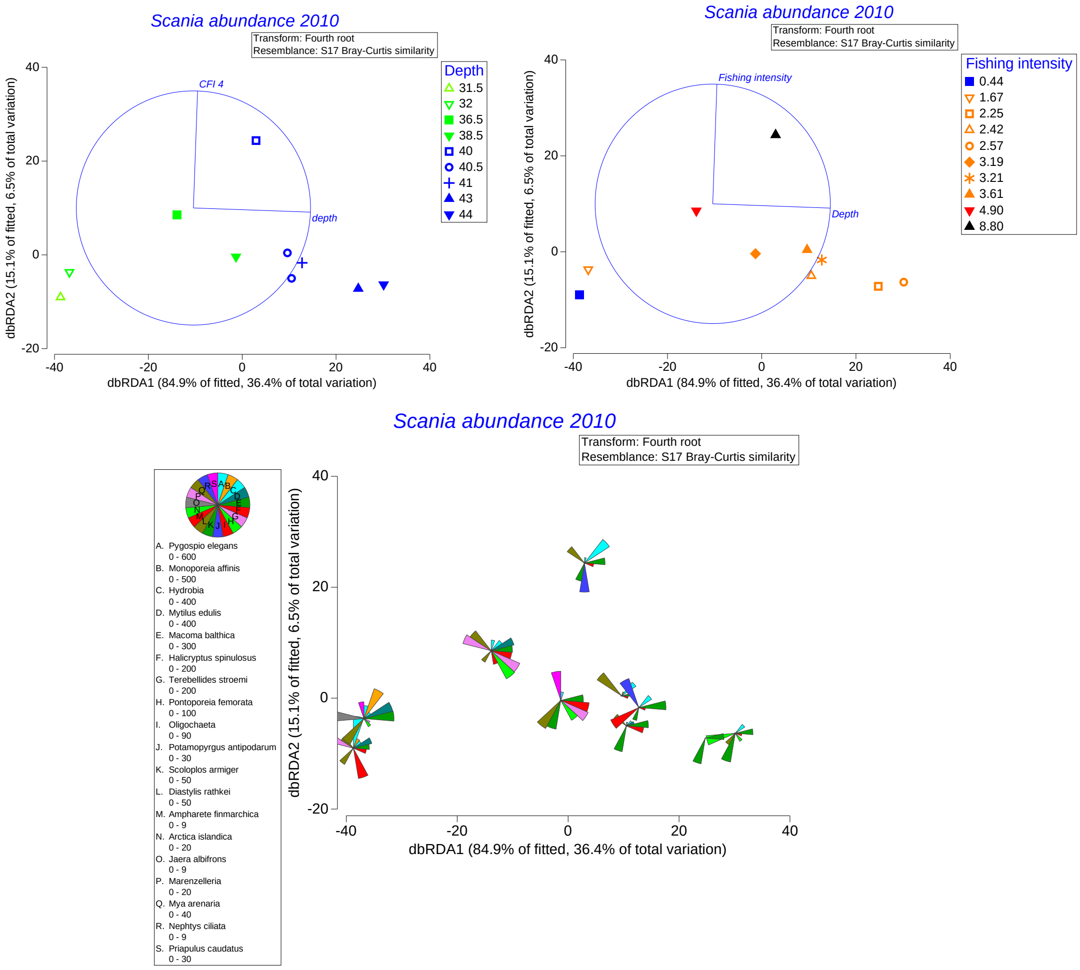


Figure 24. DbRDA ordination of monitoring stations in the sea area Scania along depth and fishing intensity gradients. In the figures above depth and fishing intensity is shown and in the figure at the bottom abundance (untransformed) of species overlaid each station. Note that only depth is significant.

Hanö bay west

Fishing and depth untransformed has a correlation value of 0.54. With the Distlm analysis, best and AICc selection, three of four predictors are significant in marginal tests. Depth untransformed p=0.007, depth transformed p=0.0076, fishing intensity transformed p=0.027 with explained variance 23 %. With Bonferroni correction α=0.0125 only depth untransformed and transformed are significant. Best selects depth untransformed as the only predictor with 25 % of the variability explained. There are several stations without fishing intensity but unfortunately all stations without fishing intensity are located at shallow depth and none in deeper water where fishing intensity mostly is occurring, see **Figure 25**. As shown, shallow stations are grouped separately from deeper stations and some of the shallow stations without fishing have a low number of species and low abundance. When analysing only the deep stations (36.5-41.9m) both depth and fishing is insignificant. This is probably due to the inconsistent change in community structure with increased fishing although the station with the highest fishing intensity seem affected. In summary the data show that there is a change in community structure with increasing depth and DistLM selects depth as the most reliable model. With increased fishing intensity there is an inconsistent change in community structure. A better analysis of fishing intensity would require more stations with and without fishing located in deeper waters.

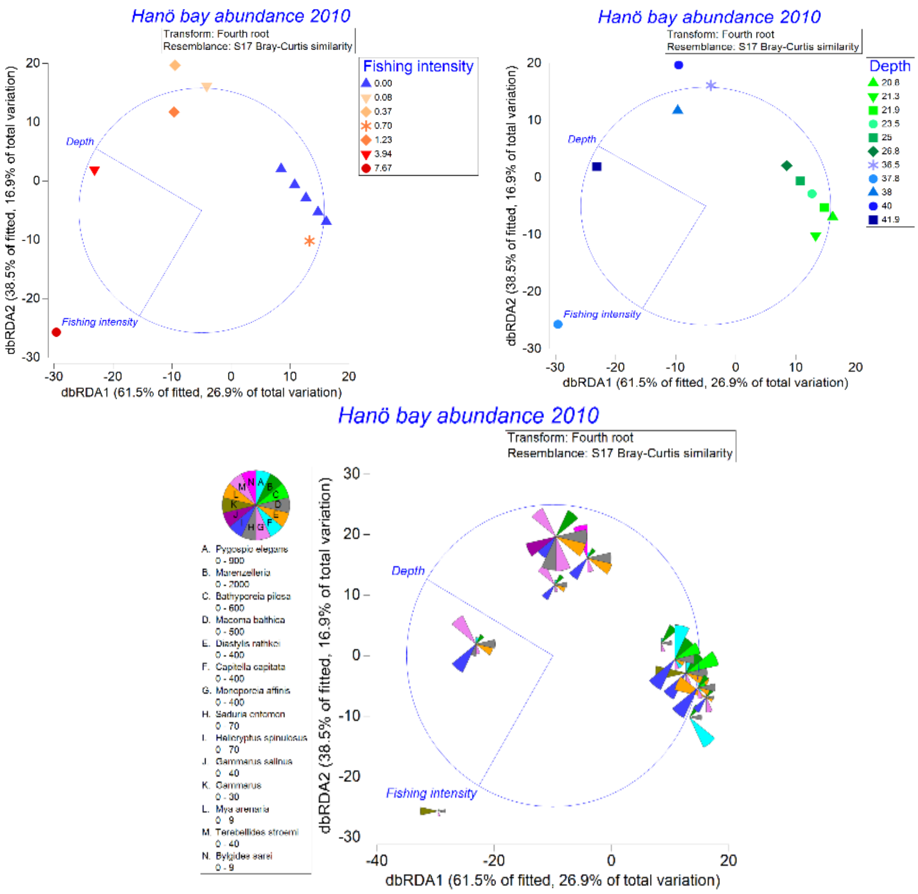


Figure 25. DbRDA ordination of monitoring stations in the sea area Hanö bay along depth and fishing intensity gradients. In the figures above depth and fishing intensity is shown and in the figure at the bottom abundance (untransformed) of species overlaid each station. Note that only depth is significant.

Blekinge

Fishing and depth untransformed has a correlation value of 0.65 and is that high that it is difficult to say which predictor is the truly most important one and therefore the results in the analyses below can not be trusted. Distlm and marginal test shows two of four predictors to be significant after Bonferroni correction with α=0.0125. Values in bold are significant, depth untransf. p=**0.0021**, depth transf. p=0.0154, fishing int. untrans. p=**0.0029** and fishing intensity transformed p=0.0154. However depth untransformed alone is chosen as the best model with 27.7 % explained variation. In the figure both depth and fishing intensity untransformed are forced into the model for added information, see Figure 26. Fishing intensity untransformed has an almost as low p-value and almost the same explained variance as depth and there is a high collinearity present as fishing intensity increases with depth. This makes it difficult to say which factor is most important. There are several stations without fishing in the data and they seem to change with depth which supports the result regarding depth coupled to community structure. However the highest fishing intensity is at the three deepest stations and there are no stations without fishing at the same depths thus it is difficult to say that depth is the only factor affecting community structure. In reality there is no proper test of the fishing effect.

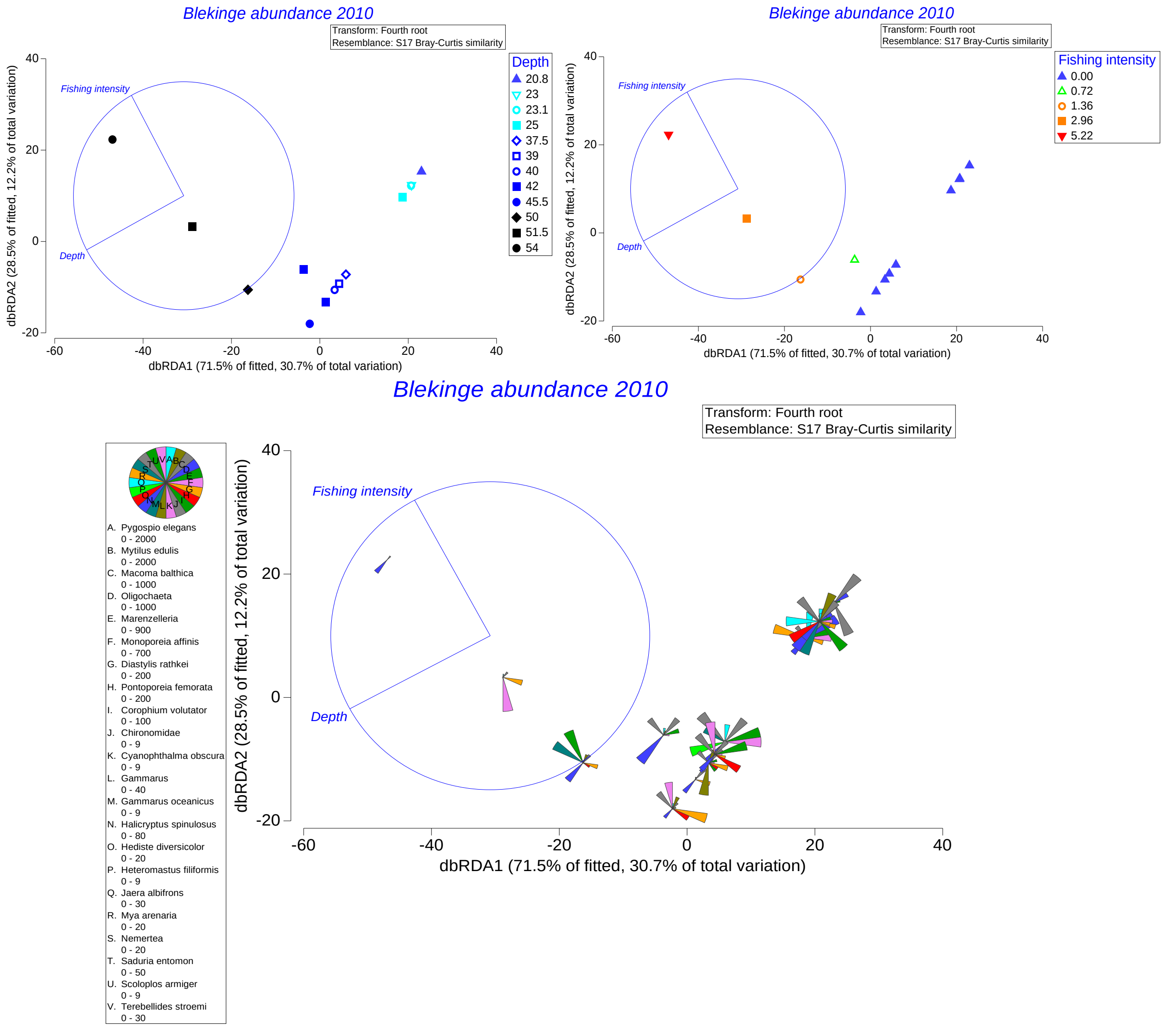


Figure 26. DbRDA ordination of monitoring stations in the sea area Blekinge along depth and fishing intensity gradients. In the figures above depth and fishing intensity is shown and in the figure at the bottom abundance (untransformed) of species overlaid each station is shown. Note that only depth is significant

Gotland

The correlation between fishing transformed and depth untransformed is 0.25. Distlm analysis shows depth transformed to have p=0.04, depth untransformed p=0.034 and fishing intensity transformed to have p=**0.0095** in marginal tests. Numbers in bold are significant after Bonferroni correction and α=0.0125. With best selection fishing intensity square root transformed is the only selected predictor with 35 % of the variance explained, To deepen the understanding both depth and fishing intensity fourth root transformed is forced into the model, see **Figure 27**. There is not a high collinearity among predictors as there are three stations without fishing intensity located from shallow to deeper water and maximum fishing is not found at the deepest stations. It is however only the transformed fishing intensity that is selected. This indicates that distribution of predictors effects the possibility for DistLM to find relationships. Unfortunately the transformed fishing intensity values are not strikingly better (more normally distributed) that untransformed values thus it would probably be difficult to prefer this transformation by looking at the distributions. The fact that the transformations are more important for Gotland 2010 than 2012 might be the fact that the two most intensely fished stations have higher values than the lesser fished stations for this year. The values for these lesser fished stations are without transformations much closer to zero fishing stations than when transformations are applied.

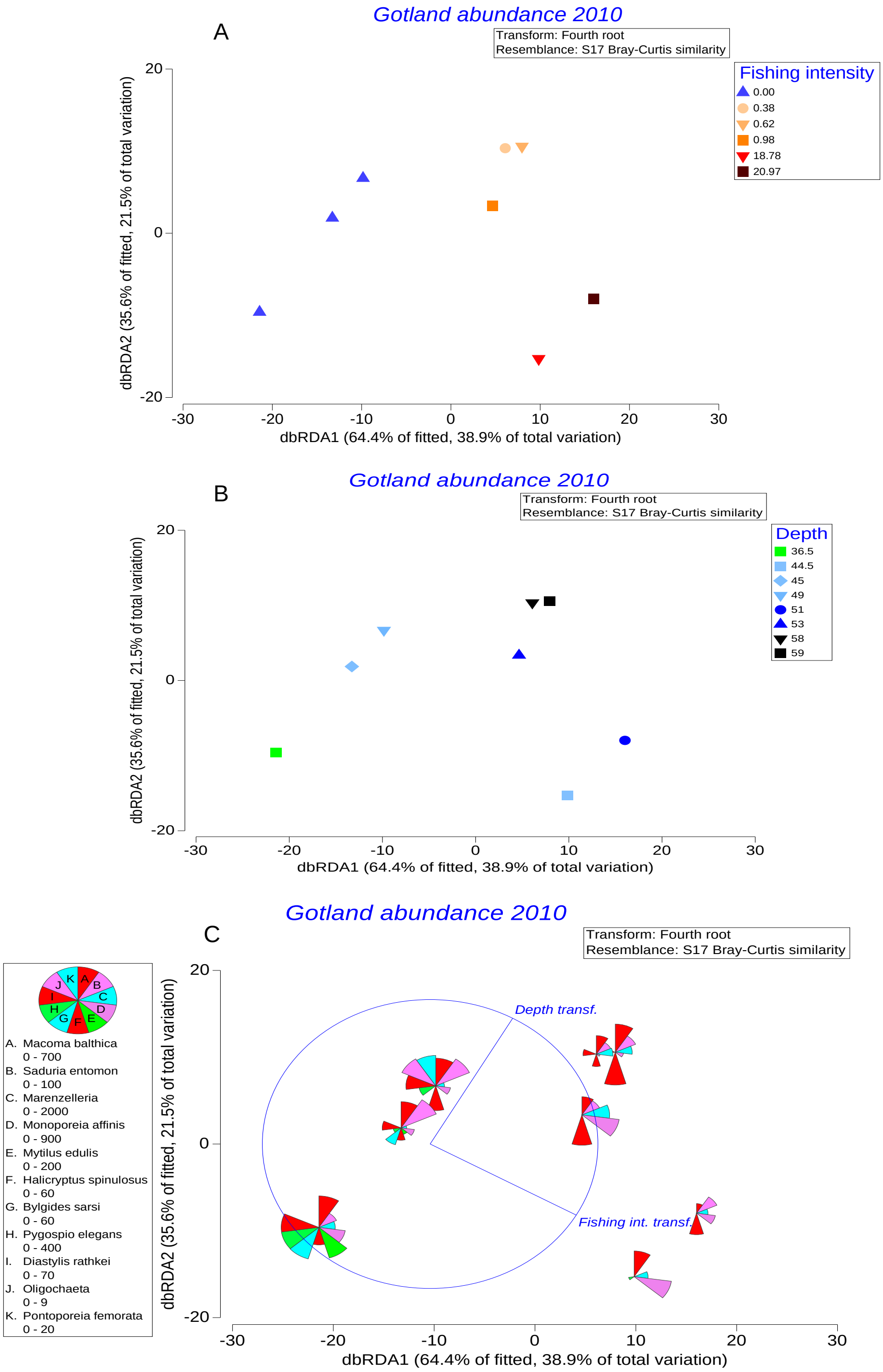


Figure 27. DbRDA ordination of monitoring stations in the sea area Gotland with both fishing intensity and depth forced into the model. In A and B depth and fishing intensity is presented and in C abundance of different species (untransformed) is overlaid each station.

Summary and conclusion of DistLM analyses on multivariate data for 2010

DistLM analyses of fourth root transformed abundance data for 2010 and the four sea areas are summarized in Table 5. Fishing intensity is only chosen as the best predictor variable in the sea area of Gotland.

Table 5. Summary of variables used and results from DistLM analyses for the year 2010 and four predictor variables (depth and fishing intensity both untransformed and fourth root transformed) and fourth root transformed abundance data as the only response variable dataset. P-values in bold are significant at α=0.0125 with Bonferroni adjustment.

Sea area	2010 Result from marginal test (p-values)	2010 Variable chosen from best selection when any of the predictors are significant in marginal tests	2010 Percent variation explained with "best" model
Scania	depth untransformed p=**0.0006**, depth transformed p=**0.0007**	depth untransformed	36
Hanö bay west	depth untransformed p=**0.007**, depth transformed p=**0.0076**, fishing intensity transformed p=0.027	depth untransformed	25
Blekinge	all predictors are significant	depth untransformed	27.7
Gotland	depth transformed p=0.04, depth untransformed p=0.034 and fishing intensity transformed p=**0.0095**	fishing intensity transformed	35

2010 Univariate analysis of species numbers, number of individuals, BQI and W

As multivariate analysis showed sea areas to differ among each other these were analysed separately for univariate analyses also without specific PERMANOVA analyses which was done for data for 2012. Dissimilarities for these univariate response variables were calculated as Euklidian distances to allow for double zeros.

For DistLM analysis best and AICc was used for selecting the “best” model and four predictors were put in the test: depth and fishing intensity untransformed and the same predictors but fourth root transformed as well. This was done as histogram plots of transformed predictors were more normally distributed in some sea areas.

All four response variables were studied with histogram plots for untransformed, square root transformed and log(x+1) transformation for each sea area. Number of species, number of individuals, BQI and W generally were ok untransformed or not better with transformations. However number of species and BQI was log(x+1) transformed for Gotland and number of individuals were log(x+1) transformed for all sea areas.

Scania

Correlation between fishing intensity and depth both untransformed was 0.30 and thus not problematically high.

BQI

Distlm with best and AICc showed the two predictors to be almost significant. Depth untransformed p=0.056 and depth transformed p=0.066.

Number of species

Distlm with best and AICc showed depth untransformed p=0.009 and transformed p=0.0088 to be significant in marginal test. Best selected depth untransformed as the only predictor variable which explained 59 % of the variation. There is a negative relationship between depth and number of species, see Figure 28.

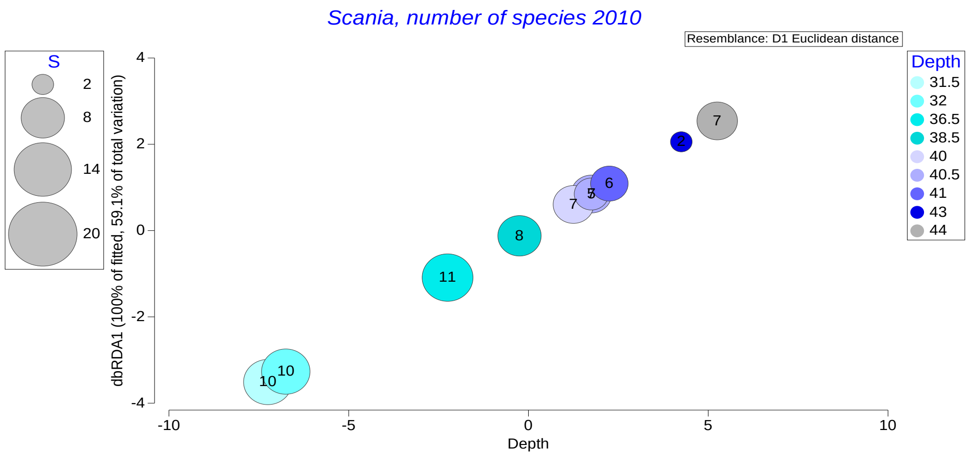


Figure 28. Result from DistLM analysis as dbRDA with Scania and number of species.

Number of individuals log(x+1) transformed

Only depth untransformed and transformed are significant with p=0.0002 and p=0.00004. Best however chooses depth fourth root (76 % explained variance) and fishing intensity fourth root transformed for the best model which has a total of 86% explained variation, see **Figure 29**.

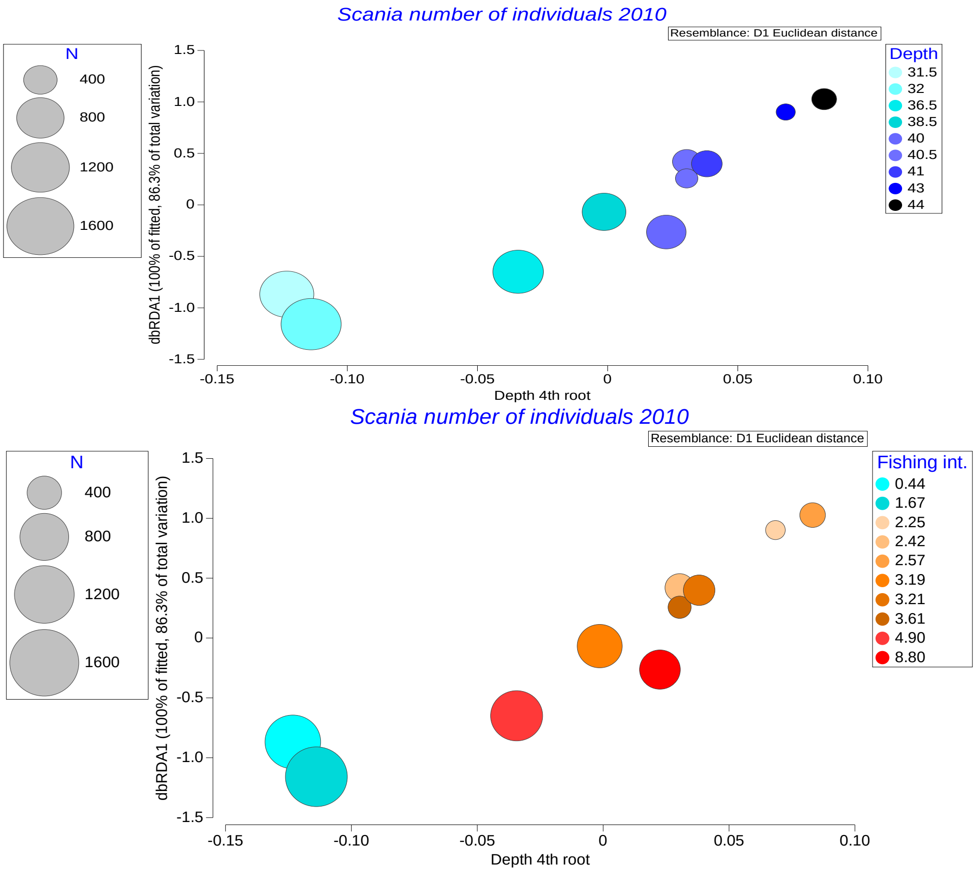


Figure 29. Result from DistLM analysis as dbRDA with Scania and number of individuals.

W

Distlm with best and AICc showed no predictor to be significant in marginal tests.

Hanö bay west

BQI

Distlm with best and AICc showed no predictor to be significant in marginal tests.

Number of species

Distlm with best and AICc showed no predictor to be significant in marginal tests.

Number of individuals log(x+1) transformed

Distlm with best and AICc showed no predictor to be significant in marginal tests.

W

Distlm with best and AICc showed no predictor to be significant in marginal tests.

Blekinge

Fishing and depth untransformed has a correlation value of 0.65 and thus collinearity is that high that it is difficult to say which predictor is the truly most important one and therefore the results in the analyses below can not be trusted.

BQI

Distlm with best and AICc showed fishing intensity untransformed and transformed to be significant with p=0.01 and p=0.045 respectively but with Bonferroni correction and α=0.0125 only fishing intensity untransformed is significant. With fishing intensity transformed removed from the test Best chooses as best model untransformed fishing intensity (51.7 % explained variance) together with transformed depth. This model has 63 % explained variance, see Figure 30.

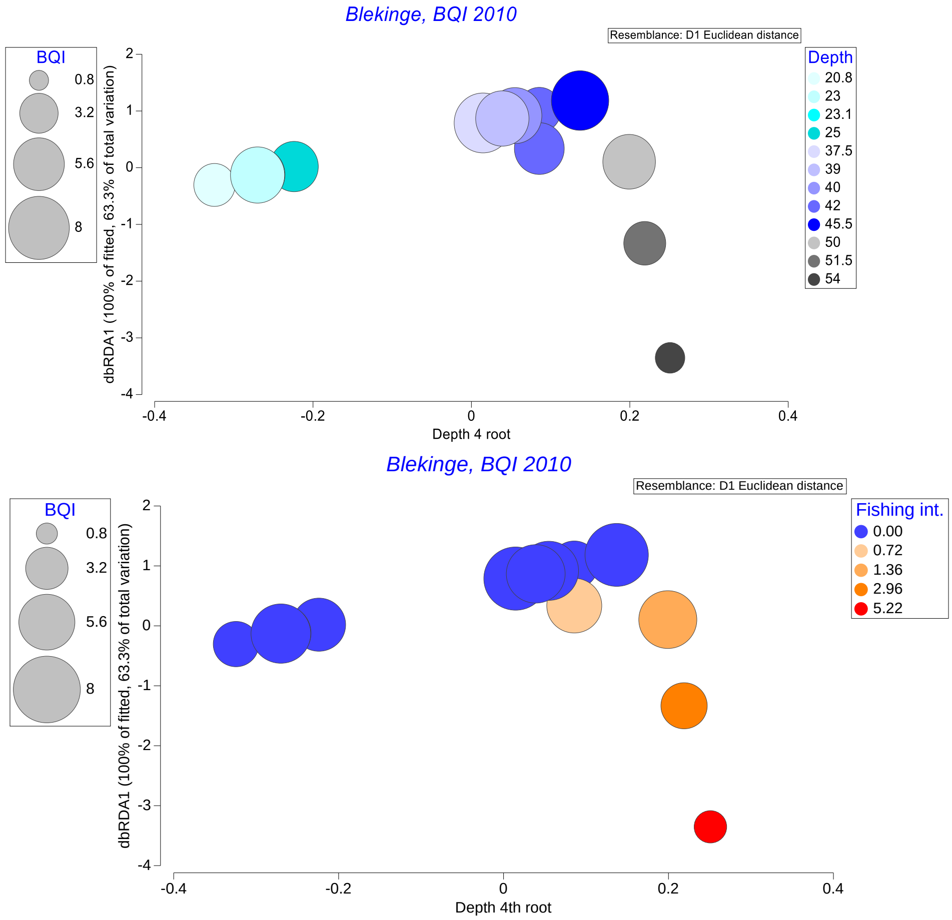
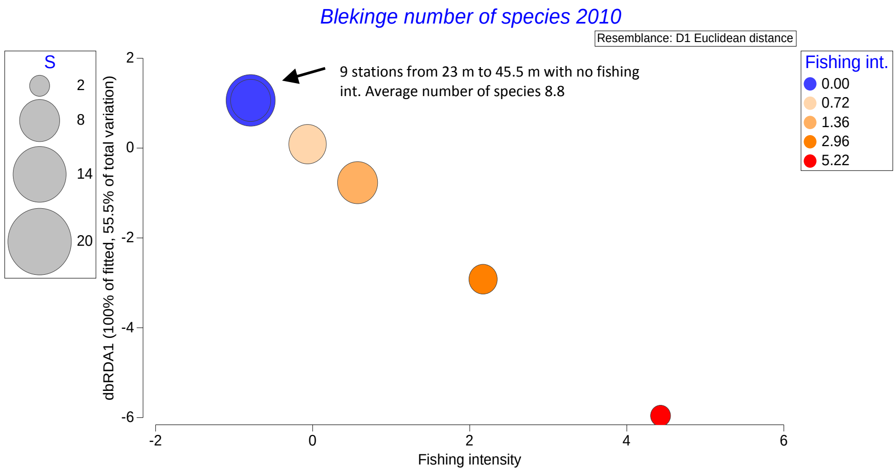


Figure 30. Results from Distlm analysis of untransformed BQI for Blekinge.

Number of species

Distlm with best and AICc showed three out of four to be significant in marginal tests. Depth untransformed p=0.034, fishing untransformed p=0.0027, fishing transformed p= 0.014. With Bonferroni correction and α=0.0125 only fishing intensity untransformed is significant. Best selects fishing intensity untransformed with 55.5% explained variation. With increased fishing intensity the number of species declines, see **Figure 31** and **Figure 32**.



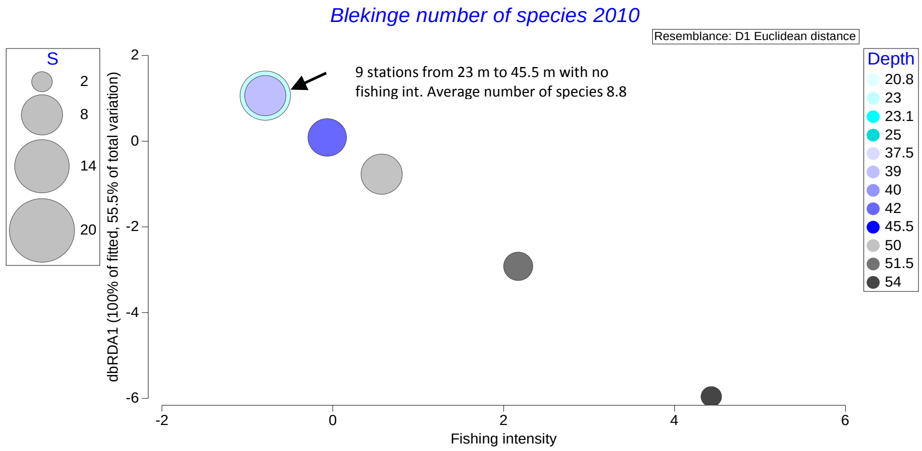


Figure 31.Results from Distlm analysis of untransformed number of species for Blekinge.

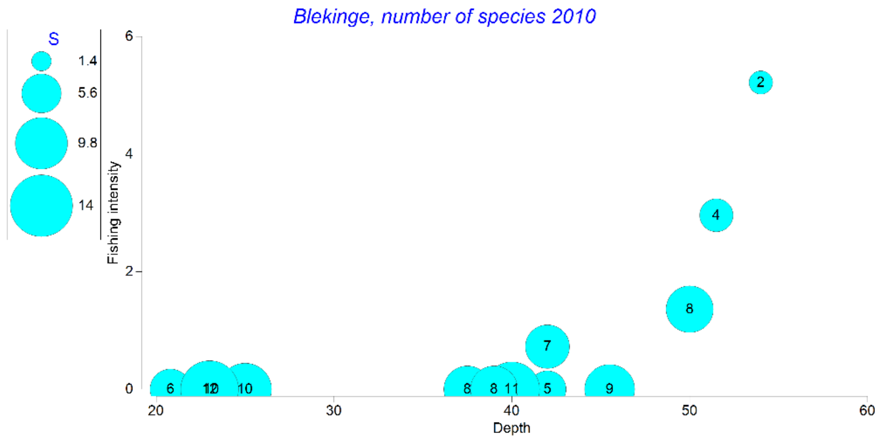


Figure 32. Number of species in Blekinge as bubble plot over scatter plot of untransformed predictors.

Number of individuals log(x+1) transformed

Distlm with best and AICc showed all predictors to be significant in marginal tests. Overall best model choose depth transformed and untransformed and therefore the DistLM analysis was rerun without depth transformed. Fishig intensity untransformed p=0.0003 and depth untransformed p=0.0007. Overall best model chosen was thereafter fishing intensity (proportion 0.73 in marginal test) and depth (proportion 0.64 in marginal test) both untransformed explaining 83% of the variation. In the figure the number of individuals increases from 20.8 meters to 37.5 to then decrease to 45.5 meters depth in unfished areas. Fishing only occurs in 4 locations at stations deeper than 42 meters and the pattern is that the number of individuals decreases with increased fishing intensity.

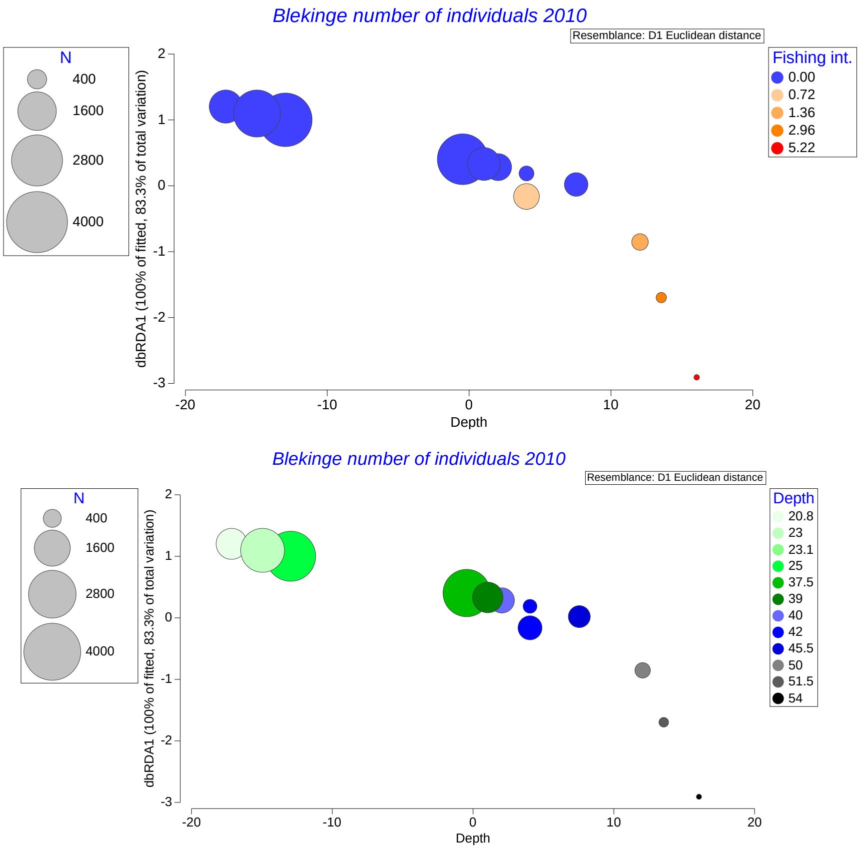


Figure 33. Result from DistLM analysis as dbRDA with Blekinge and number of individual.

W

Distlm with best and AICc showed fishing intensity 4th root to be the only significant predictor in marginal tests with p= 0.047. With the Bonferroni correction and α=0.0125 it is not significant. With the best selection fishing intensity is chosen and explain 31.8 % of the variation but as the p-value is not significant according to Bonferroni adjustments the result is not trustworthy. In the figure depth is forced into the model for increased understanding, see **Figure 34**. In areas without fishing W increases to about 37 meters depth and decreases thereafter. Average W for all unfished areas is 0.22 and W for areas with fishing is larger than for unfished areas at about the same depth.

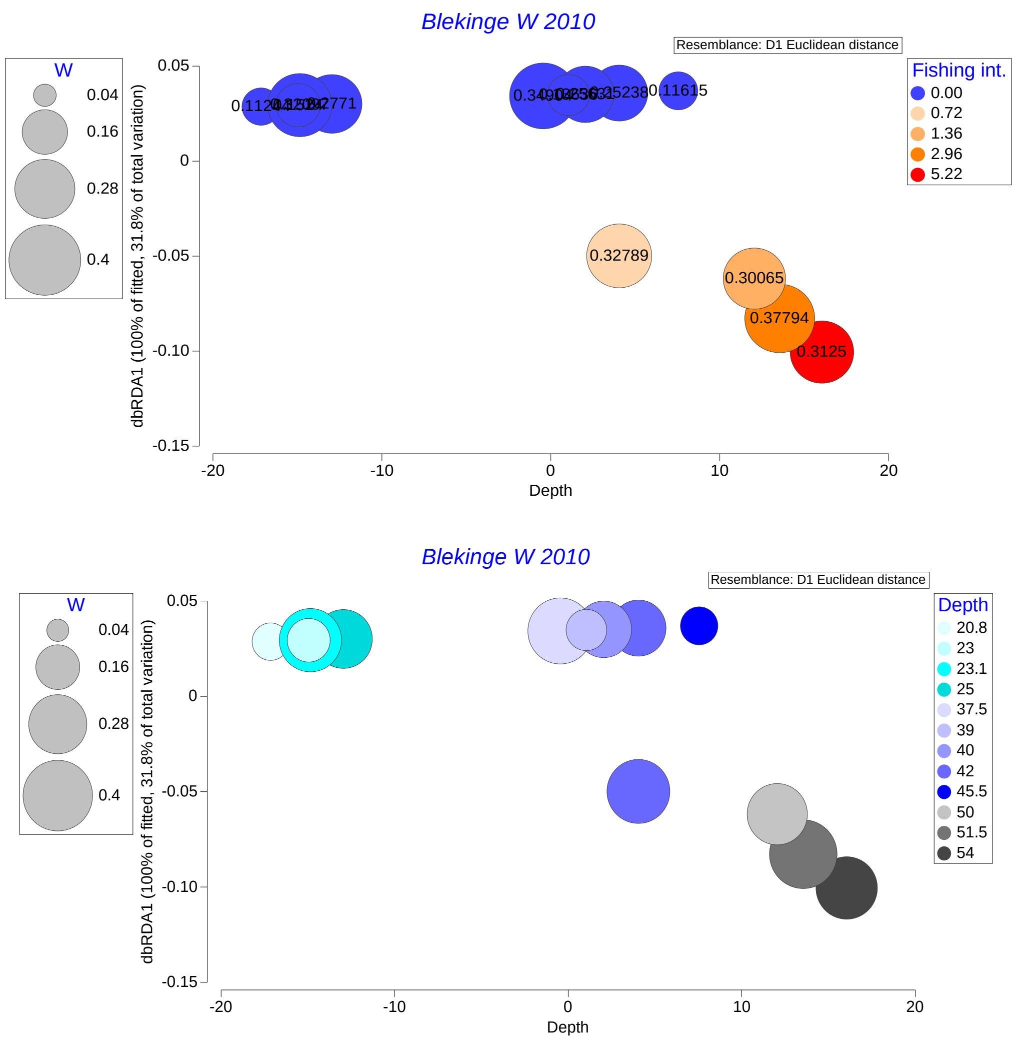


Figure 34. Results from DistLM and Blekinge with untransformed W.

Gotland

The correlation between fishing transformed and depth untransformed is 0.25 and therefore the collinearity is low.

BQI log(x+1) transformed

Both depth untransformed and transformed are significant with p=0.030 and p=0.037. After Bonferroni correction with α=0.0125 depth is not significant and thus the pattern is not trustworthy. Best selects as best model a model with two predictors of the same variable. Therefore DistLM is rerun without depth transformed and the best model is then depth untransformed with 57.8% explained variation, see **Figure 35**.

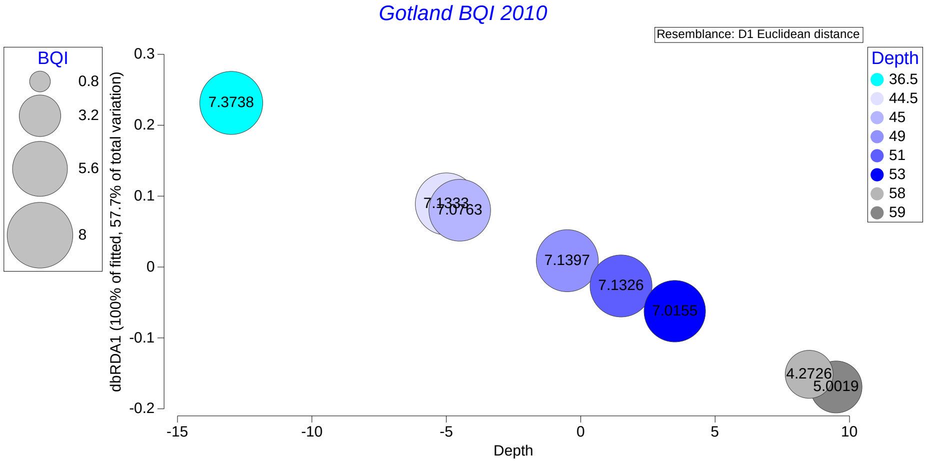
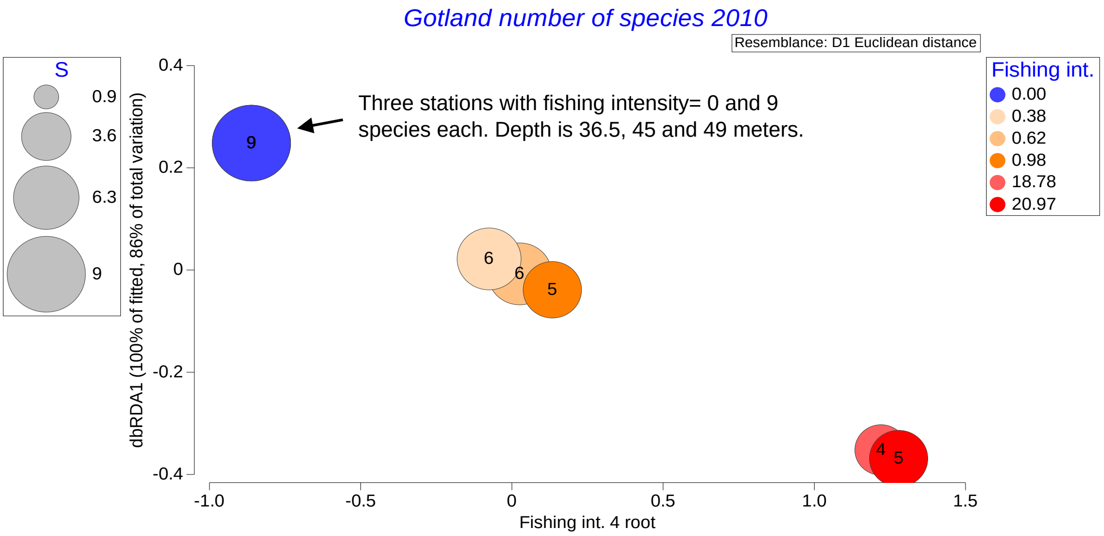


Figure 35. Results from DistLM and Gotland with BQI.

Number of species log(x+1) transformed

Distlm with best and AICc showed fishing intensity transformed to be significant with p=0.0011 and fishing intensity untransformed almost significant with p=0.059. Best selects both fishing predictors as the best model and therefore DistLM is rerun without fishing intensity untransformed. The result is then that the best model is fishing forth root transformed with 86% explained variation, see **Figure 36**.



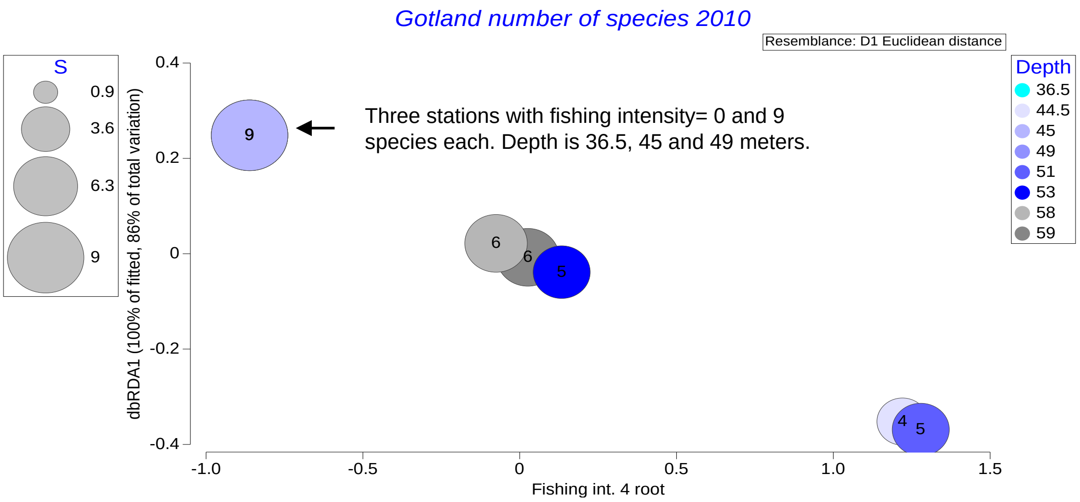


Figure 36. Results from DistLM analysis of Gotland and number of species log(x+1) transformed. Fishing intensity fourth root transformed is negatively related to number of species.

Number of individuals log(x+1)

Distlm with best and AICc showed no predictors to be significant in marginal tests.

W

Distlm with best and AICc showed no predictors to be significant in marginal tests.

2010 Summary of results from univariate analyses

A summary of results from univariate analyses are presented in Table 4.

Table 6. Results from DistLM analyses of univariate response variables. BQI, number of species, and W are untransformed for all sea areas except Gotland. Number of individuals are log(x+1) transformed for all sea areas. Number of species and BQI are log(x+1) transformed for Gotland. P-values in bold are significant at α=0.0125 with Bonferroni adjustment.

Sea area	Response variable and transformation	Result from marginal test (p-values)	Variable chosen from best selection from significance in marginal tests	Variation (%) explained with "best" model
Scania	BQI	No predictor significant	-	-
	Number of species	Depth untransf. p=**0.009**, depth transformed p=**0.0088**	**Depth untransformed, negative**	59
	Number of individuals	Depth untransf. p=**0.0002**, depth transformed p=**0.00004** and explained variance=76%	**Depth transformed** and fishing intensity* transformed, negative	86
	W untransformed	No predictor significant	-	-
Hanö bay west	BQI	No predictor significant	-	-
	Number of species	No predictor significant	-	-
	Number of individuals	No predictor significant	-	-
	W untransformed	No predictor significant	-	-
Blekinge	BQI	Fishing intensity untransformed p= **0.01** and fishing intensity transformed p=0.045	When fishing intensity transformed is removed best selects **fishing int. untransformed** (explained variance 51.7%) and depth transformed.	63
	Number of species	Depth untransf. p=0.034, fishing int. untransf. p= **0.0027** and fishing int. transformed p= 0.014	**Fishing intensity untransformed**. Negative	56
	Number of individuals	All predictors sign.in marginal test. Fishing intensity p=0,0003 and depth p=0.0007. In best selection depth untrans. and transformed is selected and therefore test is rerun without depth transformed.	Fishing intensity (73% explained variation) and depth untransformed (64% explained variation), negative	83
	W untransformed	Fishing intensity transformed p=0.047	Fishing int. transformed, positive	32
Gotland	BQI	Depth untrans. P= 0.03 and depth transformed p=0.037. Best selects both depth predictors and therefore test is rerun without depth transformed.	Depth untransformed, negative	58
	Number of species	Fishing intensity transformed p=**0.001** and fishing int. untransformed p=0.059. Best selects both fishing predictors and therefore test is rerun without fishing int. untransf.	**Fishing int. transformed, negative**	86
	Number of individuals	none significant	-	-
	W untransformed	none significant	-	-

*Fishing intensity was not significant in marginal tests but added described variation to be included in the best selected model.

2010 and 2012 overall result summary

Results from multivariate analyses on 4th root transformed abundance for 2010 and 2012 are summarized in **Table 7** and univariate analyses in Table 8. According to this summary of multivariate analyses fishing intensity is significant for both years in the sea area Gotland. In the other three sea areas multivariate assemblage structure is explained by depth for both years. However in Blekinge 2010 and 2012 and in Scania 2012 collinearity is high making it difficult to disentangle if effects are due to depth and/or fishing the results for these sea areas and years not trustworthy.

Table 7. Results from multivariate analysis of fourth root transformed abundance data from 2010 and 2012.*For Scania 2012 collinearity among predictors is 0.82, for Blekinge 2010 0.65 and for Blekinge 2012 0.68 which makes it impossible to say if community change is due to depth and/or fishing intensity.

Sea area	2010 Variable chosen from best selection when any of the predictors are significant in marginal tests	2010 Percent variation explained with "best" model	2012 Variable chosen	2012 Percent variation explained with "best" model
Scania	depth untransformed	36	depth untransformed, collinearity*	32
Hanö bay west	depth untransformed	25	depth untransformed	43
Blekinge	depth untransformed, collinearity*	27.7	depth untransformed, collinearity*	47
Gotland	Fishing intensity transformed	35	Fishing intensity transformed	51

Results from the multivariate DistLM analyses for Gotland are shown in **Figure 37** below.

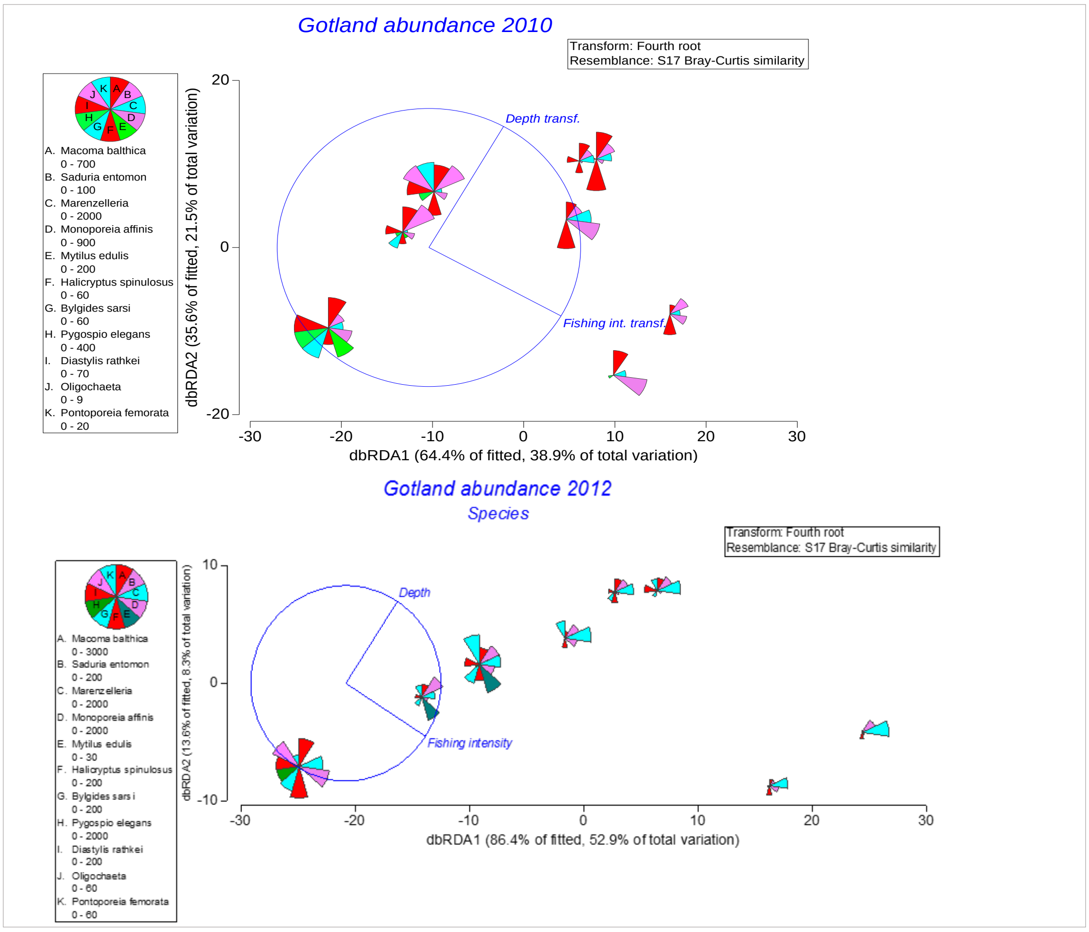


Figure 37. Results from multivariate analyses of 4th root transformed abundance in sea area Gotland where fishing intensity was the only significant predictor. Untransformed abundance values are overlaid each station.

Several species contribute to the multivariate pattern shown in Gotland in 2010 and 2012. Simple pearson correlations between specific species and the two axes can be calculated to understand which species are behind the pattern that is shown. For 2010 the four largest correlation values are for the cumacean *Diastylis rathkei* which has a negative correlation with axis dbRDA 1 (x-axis which is fishing intensity) of -0.85, the polychaete *Bylgides sarsi* -0.78, the polychaete *Pygospio elegans* with -0.74 and the bivalve *Macoma baltica* -0.73. For 2012 *Macoma baltica* has the largest negative correlation with axis dbRDA 1 (x-axis) with -0.79. (Values of *Macoma baltica* abundances are shown in **Figure 38**.) *Bylgides sarsi* has a value of -0.76, *Diastylis rathkei* receives -0.70 and the amphipod *Monoporeia affinis* -0.69. When grouping species for 2012 into “higher” classifications the class bivalvia has a -0.79 correlation with axis dbRDA 1 (x-axis), polychaetes belonging to the order phyllodocida – 0.76 and crustaceans belonging to the order cumacea – 0.70.

Diastylis rathkei is a freely motile cumacean, mainly a deposit feeding located at the surface sediment. *Macoma baltica* is a bivalve and thus rather immobile but does not have a permanent position, it is both a deposit and suspension feeder and is living within the sediment. The polychaete *Bylgides sarsi* is a scavenger, freely motile and bottom dwelling. *Pygospio elegans* is a polychaete which is a surface deposit feeder living in mud tubes. The amphipod *Monoporeia affinis* is a surface deposit feeder located in the surface sediment.

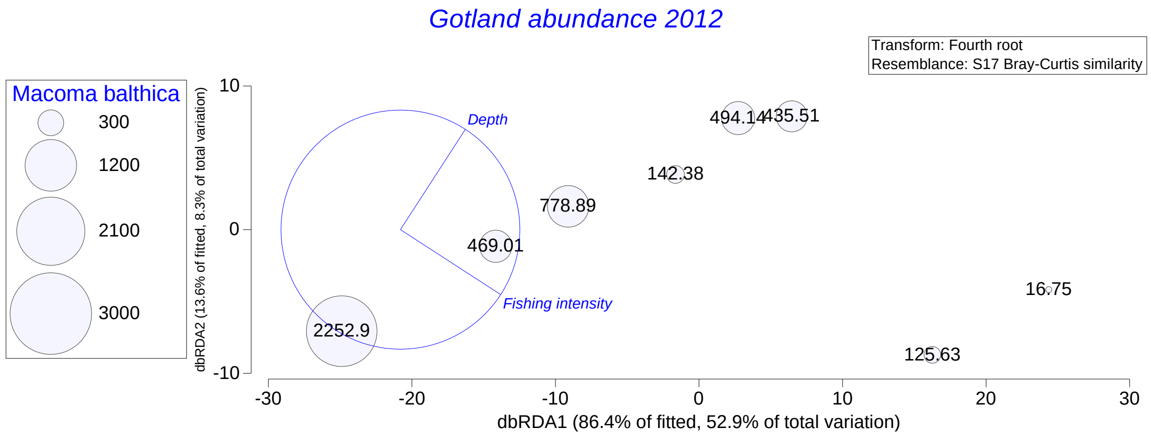


Figure 38. Untransformed abundances of Macoma baltica in sea area Gotland 2012. The length of the vectors for depth and fishing intensity show multiple partial correlations for the two predictors and each of the two axes.

According to the summary of univariate analyses in **Table 8** below it is only in one sea area and for one response variable that the same relationship is clearly shown for both years and that is for number of species in the sea area Gotland which show a negative relationship with fishing pressure. Due to collinearity in Scania 2012 and in Blekinge 2010 and 2012 it is difficult to say if depth and/or fishing intensity is the most important predictor.

Table 8. Summary of results from univariate analyses for 2010 and 2012. Transformations for predictor and response variables for the different years and analyses are given in Table 4 and Table 6. *For Scania 2012 collinearity among predictors is 0.82, for Blekinge 2010 0.65 and for Blekinge 2012 0.68 which makes it impossible to say if community change is due to depth and/or fishing intensity.

Sea area	Response variable	2010 Variable chosen as best model	2010 Variation (%) explained	2012 Variable chosen as best model	2012 Variation (%) explained
Scania	BQI	-	-	fishing, negative (but not sign. with Bonferroni correction)*	40.7
	Number of species	Depth, negative	59	fishing, negative*	47
	Number of individuals	Depth and fishing intensity (10% expl. variation), negative	86	depth, negative*	67.9
	W	-	-	-	-
Hanö bay west	BQI	-	-	depth, positive (not sign. with Bonferroni correction)	38
	Number of species	-	-	fishing, positive	56
	Number of individuals	-	-	depth, positive	71
	W	-	-	-	-
Blekinge	BQI	fishing int. and depth (depth not sign in marginal test) *	63	-	-
	Number of species	Fishing intensity negative*	56	depth, negative*	56
	Number of individuals	Fishing intensity and depth, negative*	83	depth, negative*	71
	W	Fishing int. positive*	32	-	-
Gotland	BQI	Depth, negative	58	-	-
	Number of species	**Fishing int., negative**	86	**Fishing int. negative**, (without two station with highest fishing intensity fishing is still significantly negative).	55, (77 without the two stations with highest fishing intensity)
	Number of individuals	-	-	-	-
	W	-	-	-	-

In **Figure 39** simple scatter plots with untransformed values for fishing intensity and number of species is shown for Gotland in 2010 and 2012 indicating an effect already at low fishing intensity.

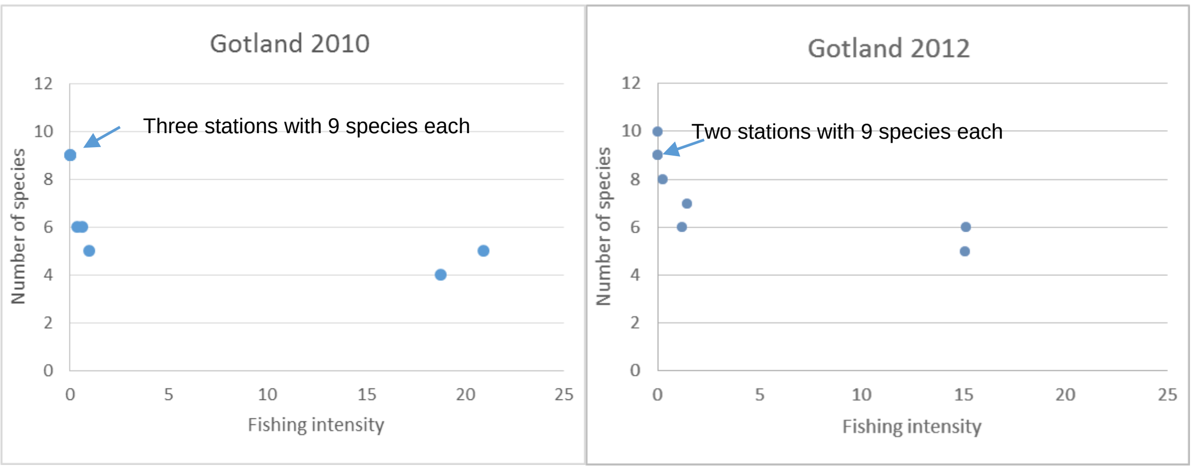


Figure 39. Simple scatterplots of values of untransformed fishing intensity and number of species for the sea area Gotland with 2010 to the left and 2012 to the right. These relationships were significant in the DistLM analyses and the only relationship that was significant for both 2010 and 2012.

Depth was negatively related to number of individuals in Scania in both 2010 and 2012 but as Scania suffers from high collinearity in 2012 (which makes it difficult to say if it is depth or fishing intensity that is the important predictor) the pattern can not be said to be truly consistent for both years. Other relationships between fishing pressure and depth and different response variables were significant but they were never consistent between the two analysed years.

Due to the high collinearity in Blekinge in 2010 and 2012 and Scania 2012 these relationships are not plotted. In the sea area Hanö bay there was a significantly positive relationship between fishing intensity and number of species in 2012, see **Figure 40**.

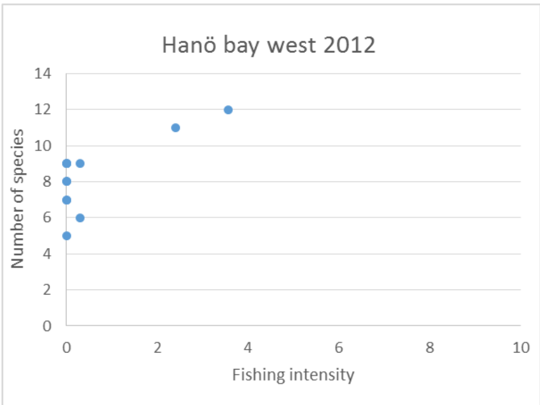


Figure 40. Simple scatterplots with untransformed values for fishing intensity and number of species significant in the DistLM analyses for 2012, (see result summary in Table 8).

Discussion

Several analyses have been conducted within this study and the results show that there are a number of relationships between different predictors and response variables for the two years. However the real strength with the analysis should be the comparison of the results for these two years. This comparison show that for multivariate analysis of fourth root transformed abundance of benthos the predictor depth is chosen as the best and only predictor for both 2010 and 2012 in three out of four regions: Scania, Hanö bay west and Blekinge. Fishing intensity was chosen as the best and only predictor in the sea region of Gotland for both years. It is in Gotland sea area that the two most intensely fished stations of all stations in the study occur but scatter plots indicate a change already at low fishing intensity.

Important to note is that collinearity was high in Scania 2012 and Blekinge 2010 and 2012 and therefore it is in reality impossible to discern if it is depth or fishing intensity which is the most important predictor variable for changes in community structure and thus fishing intensity might be more important in Blekinge and Scania than what has been shown in this study. Due to collinearity the results for Scania 2012 and Blekinge 2010 and 2012 can thus not be considered to be conclusive which is the case for both multivariate and univariate analyses. Collinearity in Blekinge and Scania is largely caused by the fact that there are no monitoring stations without fishing at greater depths where fishing mainly is occurring.

Analyses of univariate data such as number of species, number of individuals, benthic quality index (BQI) and the W statistic (biomass per individual for the whole sample were also performed). For each year four sea areas and four response variables were analysed (16 analyses altogether). For 2010, if omitting sea area Blekinge which showed to have high collinearity and using Bonferroni corrections for multiple predictors, fishing intensity alone was negative significant in one analysis, negatively significant together with depth in one and depth alone was negatively significant in one analysis. For 2012 if omitting Scania and Blekinge which showed to have high collinearity and using Bonferroni corrections for multiple predictors, fishing was negatively significant in one analysis and positive in one. Depth was positively significant in one analysis. Only once the same pattern occurred both years which was for fishing intensity which showed a negative relationship with number of species in the sea area of Gotland. These results show that relationships between response and predictor variables can be detected for different years but that these patterns not necessarily are constant over time.

That fishing intensity is significant in Gotland is by necessity due to a strong pattern. However this pattern may also be more distinguishable in Gotland than in other areas due to a lower assemblage variability as stations are located deeper and within a narrower depth range in Gotland compared to other sea areas, and perhaps also due to a lower total number of species which also reduces variability, see **Figure 41**.

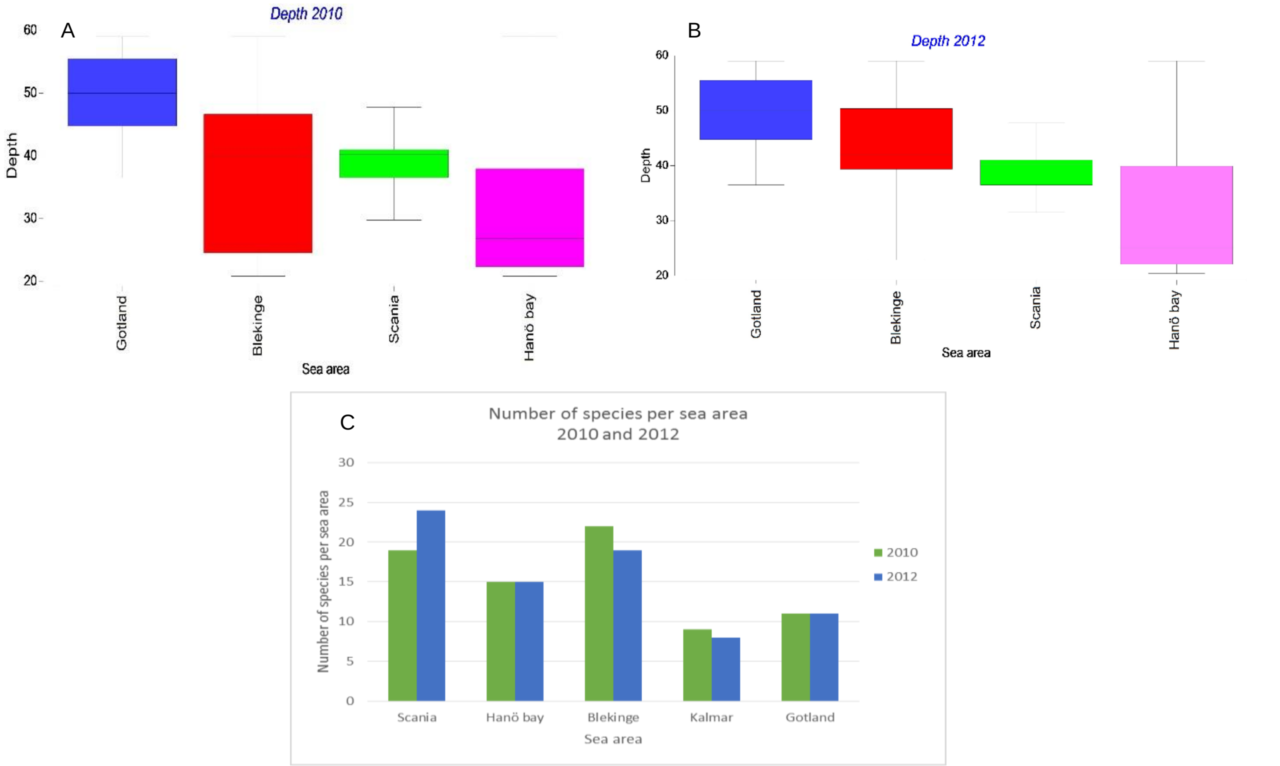


Figure 41. In A and B Box plots of depth in the four sea areas for 2010 and 2012. Box extends from first to the third quartile with the median illustrated as the line in the box. Whiskers are minimum and maximum values. If there are values larger than Q3+1.5*IQR (interquartile range) or less than Q1-1.5*IQR these are depicted with o and then whiskers show Q3+1.5*IQR and/or Q1-1.5*IQR. In C total number of species per sea area (without adjustments due to varying number of locations).

Unfortunately not very many stations are available for each sea region and the range of monitoring stations with different fishing intensities is not perfectly distributed within these sea areas. In some sea areas there are a number of stations without fishing intensity but few stations with fishing intensity and in other areas it is the opposite, few or no stations without fishing intensity and many stations with fishing. Additionally the national sampling stations are located at a number of different depths which introduces the effect of depth on the benthic assemblages and thus into the analyses. In many plots it is very clear that depth has an effect on assemblage structure and thus if there are no stations without fishing at the same depths as where fishing is occurring it is often impossible to disentangle if effects are due to depth or due to fishing intensity. This spatial variability necessitates a high number of stations to grasp benthos variability due to depth, salinity and fishing intensity. Thus, it is important to keep in mind that the national monitoring programmes used in this study not are designed to analyse effects specifically due to fishing intensity. Therefore it is encouraged to perform these important analyses in other areas too and to perform regular experiments with stratified sampling in order to include stations without fishing and stations with a range of fishing intensities at approximately the same depth. As depth is such a prominent structuring factor, analyses of fishing intensity probably should exclude shallow stations (< 25-30m).

References

Bastardie, F., J. R. Nielsen, C. Ulrich, J. Egekvist and H. Degel (2010). "Detailed mapping of fishing effort and landings by coupling fishing logbooks with satellite-recorded vessel geo-location." Fisheries Research **106**(1): 41-53.

Bergman, M. J., S. Ubels, G. A. Duineveld and E. Meesters (2015). "Effects of a 5-year trawling ban on the local benthic community in a wind farm in the Dutch coastal zone." ICES Journal of Marine Science **72**(3): 962-972.

Bradshaw, C., I. Tjensvoll, M. Sköld, I. Allan, J. Molvaer, J. Magnusson, K. Naes and H. Nilsson (2012). "Bottom trawling resuspends sediment and releases bioavailable contaminants in a polluted fjord." Environmental Pollution **170**: 232-241.

Braeckman, U., P. Provoost, B. Gribsholt, D. Van Gansbeke, J. J. Middelburg, K. Soetaert, M. Vincx and J. Vanaverbeke (2010). "Role of macrofauna functional traits and density in biogeochemical fluxes and bioturbation." Marine Ecology Progress Series **399**: 173-186.

Buhl-Mortensen, L., K. E. Ellingsen, P. Buhl-Mortensen, K. L. Skaar and G. Gonzalez-Mirelis (2016). "Trawling disturbance on megabenthos and sediment in the Barents Sea: chronic effects on density, diversity, and composition." ICES Journal of Marine Science: Journal du Conseil **73**(suppl 1): i98-i114.

Cook, R., J. M. Fariñas-Franco, F. R. Gell, R. H. Holt, T. Holt, C. Lindenbaum, J. S. Porter, R. Seed, L. R. Skates and T. B. Stringell (2013). "The substantial first impact of bottom fishing on rare biodiversity hotspots: a dilemma for evidence-based conservation." PloS one **8**(8): e69904.

de Juan, S., S. Thrush and M. Demestre (2007). "Functional changes as indicators of trawling disturbance on a benthic community located in a fishing ground (NW Mediterranean Sea)."

Dormann, C. F., J. Elith, S. Bacher, C. Buchmann, G. Carl, G. Carré, J. R. G. Marquéz, B. Gruber, B. Lafourcade and P. J. Leitão (2013). "Collinearity: a review of methods to deal with it and a simulation study evaluating their performance." Ecography **36**(1): 27-46.

Dounas, C., I. Davies, G. Triantafyllou, P. Koulouri, G. Petihakis, C. Arvanitidis, G. Sourlatzis and A. Eleftheriou (2007). "Large-scale impacts of bottom trawling on shelf primary productivity." Continental Shelf Research **27**(17): 2198-2210.

Eigaard, O. R., F. Bastardie, M. Breen, G. E. Dinesen, N. T. Hintzen, P. Laffargue, L. O. Mortensen, J. R. Nielsen, H. C. Nilsson and F. G. O'Neill (2015). "Estimating seabed pressure from demersal trawls, seines, and dredges based on gear design and dimensions." ICES Journal of Marine Science: Journal du Conseil **73**(suppl 1): i27-i43.

Eigaard, O. R., F. Bastardie, M. Breen, G. E. Dinesen, N. T. Hintzen, P. Laffargue, L. O. Mortensen, J. R. Nielsen, H. C. Nilsson and F. G. O'Neill (2016). "Estimating seabed pressure from demersal trawls, seines, and dredges based on gear design and dimensions." ICES Journal of Marine Science: Journal du Conseil **73**(suppl 1): i27-i43.

Hansson, M., L. Andersson and P. Axe (2011). "Areal Extent and Volume of Anoxia and Hypoxia in the Baltic Sea, 1960-2011. SMHI report 42."

Hansson, M., L. Andersson, P. Axe and J. Szaron (2013). "Oxygen Survey in the Baltic Sea 2012 - Extent of Anoxia and Hypoxia, 1960-2012. Report 46."

Hintzen, N. T., F. Bastardie, D. Beare, G. J. Piet, C. Ulrich, N. Deporte, J. Egekvist and H. Degel (2012). "VMStools: open-source software for the processing, analysis and visualisation of fisheries logbook and VMS data." Fisheries Research **115**: 31-43.

Kaiser, M., K. Clarke, H. Hinz, M. Austen, P. Somerfield and I. Karakassis (2006). "Global analysis of response and recovery of benthic biota to fishing." Marine Ecology Progress Series **311**: 1-14.

Kaiser, M. J., J. S. Collie, S. J. Hall, S. Jennings and I. R. Poiner (2002). "Modification of marine habitats by trawling activities: prognosis and solutions." Fish and Fisheries **3**(2): 114-136.

Oberle, F. K., C. D. Storlazzi and T. J. Hanebuth (2016). "What a drag: Quantifying the global impact of chronic bottom trawling on continental shelf sediment." Journal of Marine Systems **159**: 109-119.

Olsgard, F., M. T. Schaanning, S. Widdicombe, M. A. Kendall and M. C. Austen (2008). "Effects of bottom trawling on ecosystem functioning." Journal of Experimental Marine Biology and Ecology **366**(1): 123-133.

Puig, P., M. Canals, J. B. Company, J. Martín, D. Amblas, G. Lastras, A. Palanques and A. M. Calafat (2012). "Ploughing the deep sea floor." Nature **489**(7415): 286-289.

Thrush, S. F. and P. K. Dayton (2002). "Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity." Annual Review of Ecology and Systematics: 449-473.

Tillin, H., J. Hiddink, S. Jennings and M. Kaiser (2006). "Chronic bottom trawling alters the functional composition of benthic invertebrate communities on a sea-basin scale." Marine Ecology Progress Series **318**: 31-45.

van Denderen, P. D., N. T. Hintzen, A. D. Rijnsdorp, P. Ruardij and T. van Kooten (2014). "Habitat-specific effects of fishing disturbance on benthic species richness in marine soft sediments." Ecosystems **17**(7): 1216-1226.

Theme 3: Physical loss and damage to seabed habitats

This report is supporting material to the BalticBOOST WP 3.1 deliverable "Estimating physical disturbance on seabed" and WP 3.2 deliverable "Fisheries Impact Evaluation Tool (FIT) with Application to Assess the Bottom Fishing Footprint in Western Baltic Sea". The BalticBOOST project that was coordinated by HELCOM and co-financed by the European Union in 2015-2016 as part of the programme DG ENV/MSFD Action Plans/2016.

WP 3.1 and 3.2 Supporting material 6: Case study A quantitative assessment of benthic impact from fishing disturbance in the Baltic Sea using a biological-traits approach

Partner: International Council for the Exploration of the Sea (ICES, Denmark)

Authors: Daniel van Denderen, Sebastian Valanko

Contents

Summary

The assessment of benthic impact from human pressures is often done using expert judgement-based approaches (e.g. BH3 OSPAR, Baltic Sea Impact Index). These approaches are providing a valuable source of information to identify highly sensitive benthic habitats. However, an inherent challenge of these approaches is to consistently scale pressure-impact relationships in benthic habitats that are less vulnerable and able to withstand a certain amount of pressure. For such habitats, quantitative methods that incorporate a mechanistic relationship between pressure and impact/state of the habitat have been recommended as the most useful tool to assess impact and to provide options for management (ICES 2016a, b).

In this project, we have used one such quantitative method for an assessment of the Baltic Sea in relation to fishing disturbance by mobile bottom-contacting fishing gears. We used a trait-based approach to assess the vulnerability of the benthic habitat. Vulnerability was determined for 17 different benthic communities across the Baltic Sea on the basis of the longevity composition of the community. Community vulnerability was predicted to be highest in the western Baltic Sea, where many communities contained long-living animals.

Impact from fishing was calculated from the predicted longevity composition of each benthic community and from fishing intensity estimates of both surface and sub-surface bottom fishing abrasion. Impact was observed in 14 out of the 17 communities, but in most cases only a minor part of the spatial extent of the community was predicted to be impacted. The remaining three communities were predicted to be more heavily impacted. These three communities are all located in the western part of the Baltic Sea.

Using the approach, we were able to quantitatively predict how areas may differ in their sensitivity to bottom trawl fishing disturbance, and, we were able to calculate how much these areas are impacted on a continuous scale. We stress that the approach needs to be developed further before it can be used to assess impact from bottom trawl fishing or to inform management. The outcome can already be compared to expert judgement-based approaches, as well as to other types of benthic indicators (requiring actual monitoring data) that have been and will be developed in HELCOM.

1. Introduction

The assessment of benthic impact from multiple pressures is often done using expert judgement-based approaches (e.g. BH3 OSPAR, Baltic Sea Impact Index). These approaches are used to derive qualitative estimates of the vulnerabilities of benthic habitats and to qualitatively scale pressure-impact relationships for different pressures. An inherent challenge of the expert-judgement based approaches is to consistently scale across pressures and habitats, in order to summarize impact scores in space and time. For that reason, ICES 2016 advice (ICES 2016a, b) recommended mechanistic, quantitative methods to assess impact on benthic habitats. Although this was advised in relation to disturbance caused by fishing with mobile-bottom-contacting gears (hereafter called bottom fishing), it also stated that such methods can provide a way of comparing between the effects of pressures other than fishing, and cumulating these pressures for an overall assessment of the state of seabed habitats.

In this project, we have used one such quantitative method for an assessment of the Baltic Sea in relation to bottom fishing disturbance (combining surface and subsurface abrasion to a predicted fishing impact). We use a trait-based approach to assess the vulnerability of the benthic habitat (following the method developed in Rijnsdorp et al. (2016)). We determine vulnerability for 17 different benthic communities on a Baltic-wide scale. These communities have been described recently in Gogina et al. (2016). The outcome can be compared to expert judgement-based approaches, as well as to other types of benthic indicators (requiring actual monitoring data) that have been and will be developed in HELCOM.

2. Output

The following output is produced:

1) Estimates of the vulnerabilities of 17 benthic communities on a Baltic-wide scale and their predicted threshold values to surface and subsurface abrasion (Figure 3).
2) Impact maps of abrasion by bottom fishing (surface, subsurface) and their combined effect across the Baltic Sea (Figure 4 and Figure 5).
3) Aggregated bottom fishing impact scores per available benthic community (Table 1 and Figure 6).
4) Exploration of the effect of potential management options (Figure 7, Table 2).

3. Methodology

3.1 Benthic invertebrate community data

Impacts of bottom fishing disturbances to the seabed are assessed for 17 different benthic communities across the Baltic Sea. These 17 communities have been defined recently by Gogina et al. (2016) using cluster analysis on species biomass from 2268 sampling locations across the Baltic Sea. In their study, the spatial distribution of these 17 communities has been extrapolated to cover the Baltic Sea (Gogina et al. 2016 and Figure 1). The extrapolation (using a random forests model) incorporated different environmental variables; bathymetric data, near-bottom temperature, salinity and flow speed, categorical sediment data and particulate organic carbon content of the surface sediment.

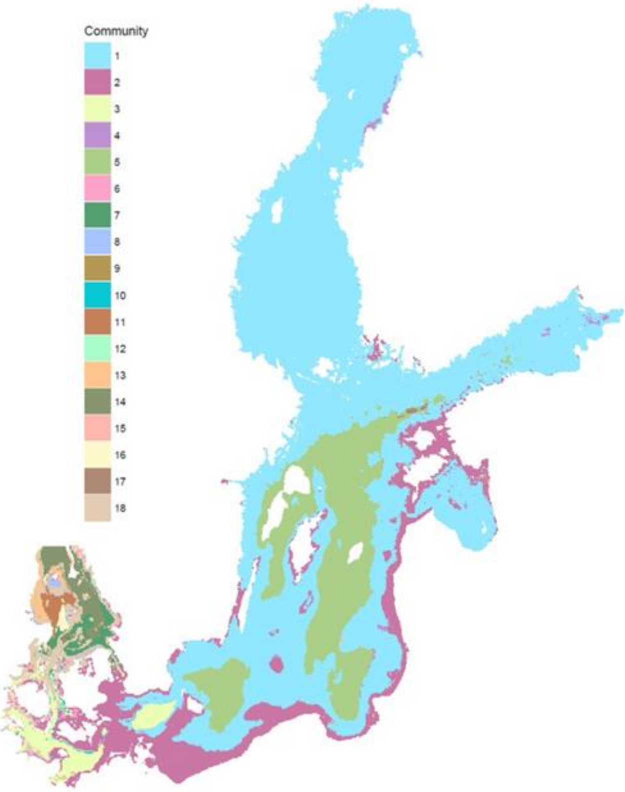


Figure 1. The distribution of the 17 different benthic communities in the Baltic Sea as defined by Gogina et al. (2016) using 2268 sampling stations. Community 18 included all "other" pooled communities.

Benthic biological traits

For each of the sampling locations in Gogina et al. (2016), benthic observations were linked at genus level to a genera-by-trait matrix that included the traits maximum longevity and vertical position in the seabed.

Both the trait longevity and sediment position were derived from Bolam et al. (2014). Data for benthic traits are coming mostly from non-Baltic areas and this may have profound effects on the predicted community longevities (note that the traits have not been re-evaluated by a benthic expert of the Baltic Sea). Longevity was subdivided into four modalities (less than 1 year, 1-3, 3-10 and more than 10 years) and sediment position in two (0-6 cm and >6 cm). For each genera-trait combination, a single modality was assigned a score of 1 when the genus showed total affinity for that particular modality. When the genus could not be assigned unequivocally to a single trait modality, multiple modalities were assigned fractional scores that summed to 1 (see Bolam et al. 2014).

Some genera were not identified in the sampling data and traits were defined for these animals at a higher taxonomic level. Similarly, sampling data identified to species or genera were in many cases unavailable at a similar taxonomic level in the trait table and data were coupled at a higher taxonomic level. From this genera-by-trait matrix (including the higher taxonomic levels), we calculated a table of sampling sites by biomass-weighted modalities. This was done for each sampling site by multiplying the total biomass per taxonomic grouping by the score for the trait modality. These were summed by modality to produce a biomass-weighted trait modality table for all sampling sites.

3.2 Estimating vulnerabilities of the benthic communities

The longevity composition was estimated for the 17 different communities. To derive the vulnerability of the benthic community, the approach needs information on the undisturbed reference state of the benthic community (Rijnsdorp et al. 2016). An estimation of the reference state of the benthic community (its biomass composition across longevity classes) was derived using only these stations that were on average disturbed by the pressure (see pressure layer below) less than once in 20 years; number of sampling stations used varied between 2 and 794 for the different communities. Note that it is likely that most undisturbed sampling stations were not in “pristine” condition and this means that the reference state is based on the “best” condition available for each community. For the relatively undisturbed sampling stations, the cumulative biomass (Cb) in relation to longevity for each community was fitted using the following logistic regression model:

$$Cb \sim intercept + \log(longevity) + community + \log(longevity)*community + \varepsilon 1$$

where longevity is log transformed, community type is a factor and the error term has a binomial distribution. In the study by Rijnsdorp et al. unpub, a logistic mixed effect model, with random intercept and slope by station, was used to statistically predict the cumulative biomass. This could not be achieved with this dataset due to problems with model convergence (possibly due to a high number of communities).

Besides predictions of the cumulative biomass of the total community, we also predicted vulnerabilities for two sediment layers separately using the sediment position trait in the biomass weighted trait modality table. Distinguishing between the two sediment layers helps to determine how much a community is impacted by a pressure that either only affects the surface of the seabed, or also seabed sub-surface. Some species are classified with a vertical position that covers both sediment layers (0-6 cm and > 6 cm) and these were incorporated in the calculation of the upper community layer sensitivity.

3.3 Pressure layers

Two pressure layers were used to test the approach on a Baltic wide-scale. These pressure layers are both related to the effects of bottom fishing disturbance, namely surface and sub-surface bottom fishing abrasion. Both pressure layers describe the average annual fishing intensity (fraction of swept area over a grid cell between 2009 and 2013 (Figure 2), either in the surface layer of the seabed or the sub-surface layer. Since there is an increase in fishing effort observed by VMS, due to the fact that before 2012 only vessels larger than 15 m had to carry VMS, whereas from 2012 onwards the obligation included all vessels larger than 12 m, it is likely that the average intensity values are underestimating total fishing intensity. Still, we assumed that the average abrasion values for both pressures in each grid cell are in a temporal equilibrium state with the benthic community at these grid cells.

The assessment of impact is only including pressure layers related to bottom fishing disturbance but other pressure layers, leading to physical loss and damage to the seabed, could be included as long as there is information on the number of events per year per grid cell.

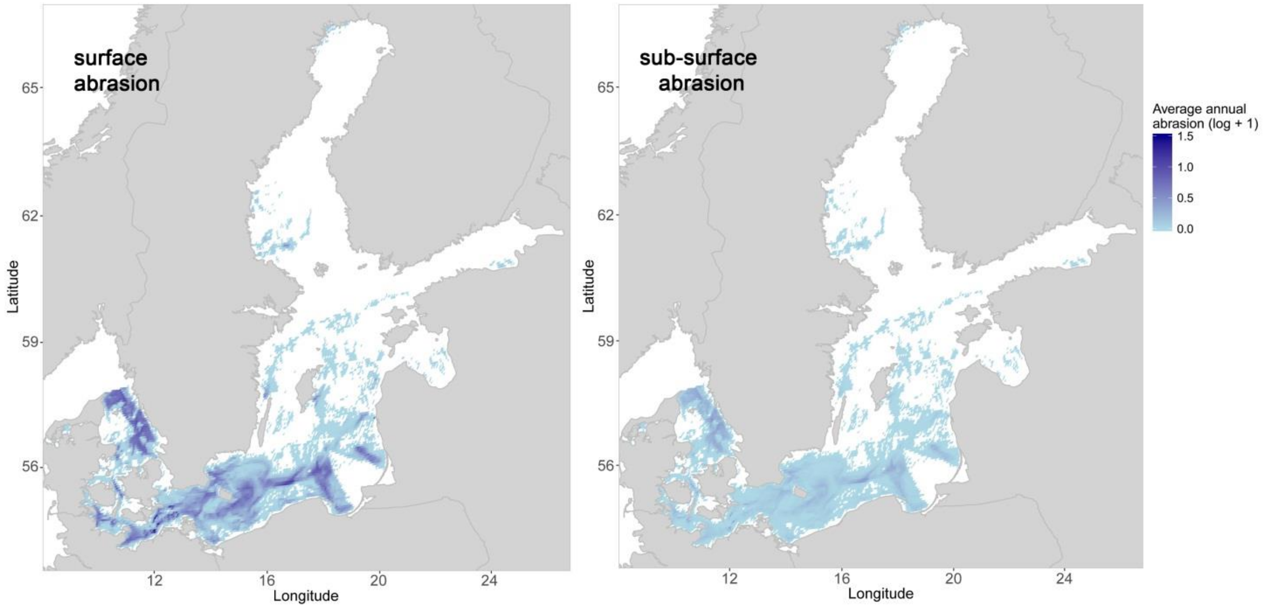


Figure 2. Pressure maps of the average annual intensity from mobile bottom-contacting fishing gears (fraction of swept area over a grid cell) between 2009-2013 for both surface and sub-surface abrasion.

3.3 Predicting impact for surface and sub-surface abrasion and their combined effect

The pressure layers are converted into an estimate of both surface and sub-surface impact from fishing with mobile bottom-contacting gears at the level of the grid cell based on the surface and sub-surface sensitivity of the benthic community at this grid cell. Impact is predicted by estimating the proportion of the benthic community that is impacted by the pressure from the proportion of the biomass comprised by taxa with a life span longer than the average interval between pressure events. As such, impact (for both pressures) is scored for each grid cell on a continuous scale between 0 (unimpacted) to 1 (community is 100% impacted). It is assumed in the assessment that any bottom fishing intensity below 0.05 results in no impact in the community, as the community has, on average, 20 years to recover.

Total impact is the sum of both surface and sub-surface impact weighted by the average biomass proportion of the community in the two sediment layers. The impact scores are mapped and also aggregated per community type to predict the overall biomass decline due to the pressure for each benthic community.

4. Predicting communities' sensitivity and threshold value to impact

For all 17 different communities (and also for community 18 that includes all "other" pooled communities) data were available from sampling stations that were undisturbed (at least during the assessment period). These data were used to calculate the reference condition of both the total community and the two sediment layers separately (Figure 3). The reference condition varies largely between communities. In some communities, species biomass comprises many short-living animals (up to 75% of the biomass is from taxa with longevities less than 5 years, see Figure 3a). These communities are mostly found in the eastern and northern parts of the Baltic Sea. Other communities consist of many long-living animals; with 10 communities having at least 25% of the biomass in taxa with longevities over 10 years. The longevity compositions varied between the surface and subsurface layer (compare figure 3b, c), with relatively more short-living animals in the upper layer.

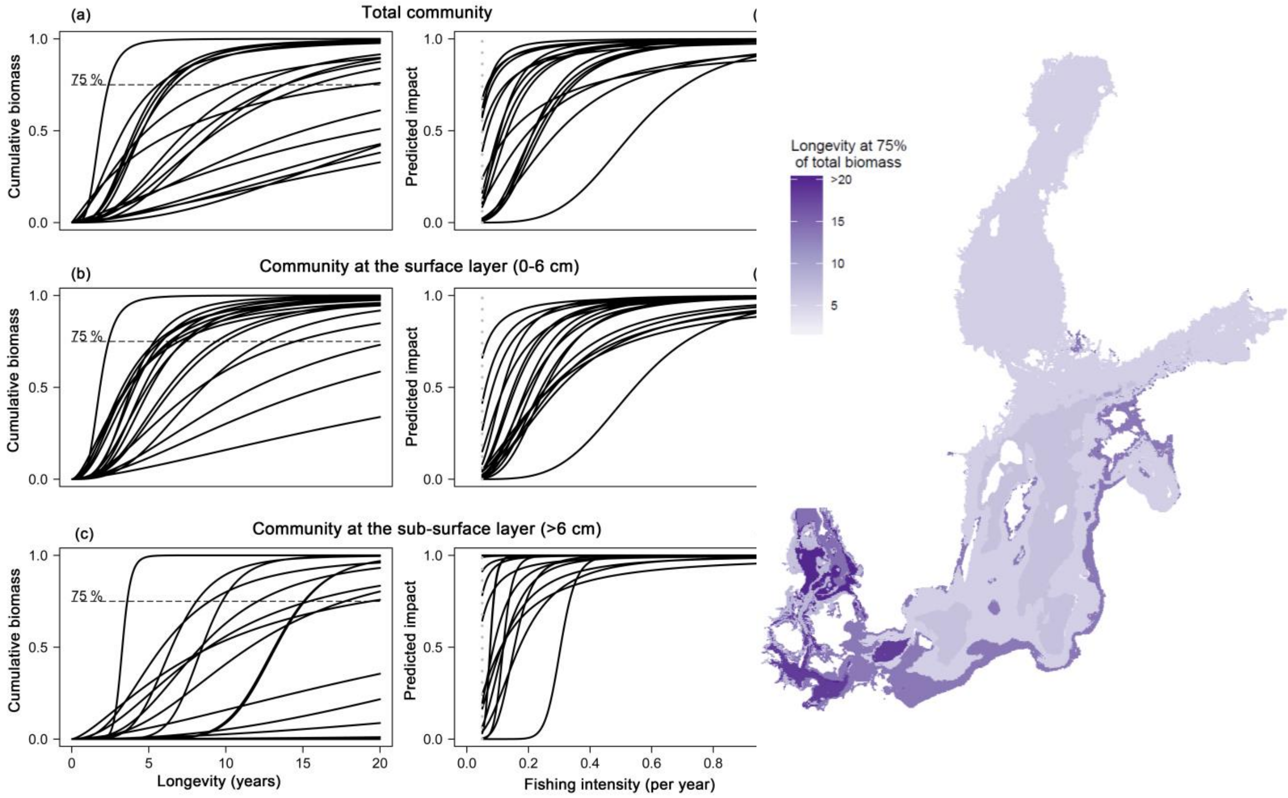


Figure 3. Longevity composition (a-c) across community biomass for the 17 different communities (and also for community 18 that includes all "other" pooled communities), based on all sampling stations that were relatively undisturbed (average pressure intensity <0.05 per year) for the total community (a), the community at the upper layer (b) and at the sub-surface layer (c). The curves in (a-c) provide the reference condition for each community and are used to predict impact from the pressure. Using these curves, impact (i.e. decline in biomass, with no decline at 0 and 100% decline at 1) can be predicted assuming 100% direct mortality from bottom fishing (d-e). The map shows the longevity at 75% of total community biomass and corresponds with the 75% line in (a).

Since the approach assumes 100% direct mortality from fishing, impact can be predicted as a function of fishing using the reciprocal of longevity (Figure 3d-f). This shows the value where fishing intensity will cause an impact in each community. All values are relatively low (the use of longevity gives a worst-case scenario). Still, communities differ in the amount of trawling intensity they can withstand before being impacted. One community is unaffected up to approx. 0.25 times per year and this is because all organisms in this community are relatively short-living.

5. Predicting the effects of bottom fishing disturbance

The reference conditions (Figure 2) can be used to predict impact from both surface and subsurface abrasion. Impact is calculated for each grid cell and community type from the proportion of biomass comprised by taxa with a life span longer than the average interval between pressure events. The predicted impacts of surface, subsurface abrasion from mobile-bottom contacting gears are shown in Figure 4a and b. The total impact is the sum of both surface and subsurface abrasion impact weighted by the average biomass proportion of the community in the two sediment layers (Figure 4c and 5). The impact maps show in many cases high impact in areas that are disturbed by mobile bottom-contacting fishing gears (see Figure 2). Still, the frequency of bottom fishing disturbance in the middle part of the Baltic Sea is generally lower than the lifespan of the organisms and hence no impact is predicted (compare figure 2 and 4).

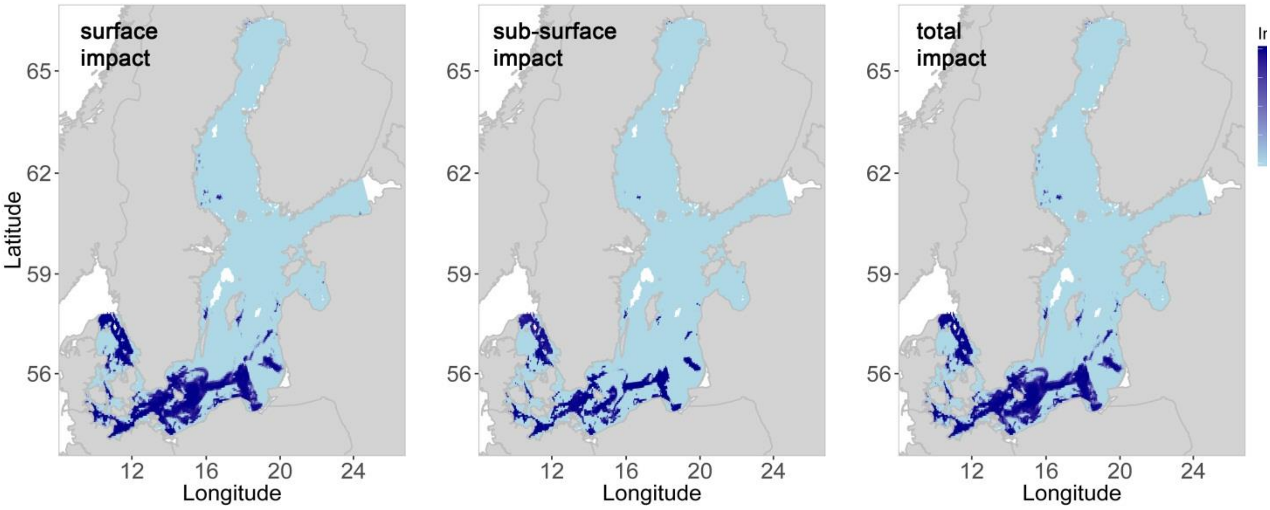


Figure 4. Fishing impact map from mobile-bottom contacting gears for surface (left), sub-surface abrasion (middle) and their combined effect (right). The latter is the sum of both surface and sub-surface impact weighted by the average biomass proportion of the community in the two sediment layers. Impact of 1 means full/maximum impact and impact of 0 means no impact.

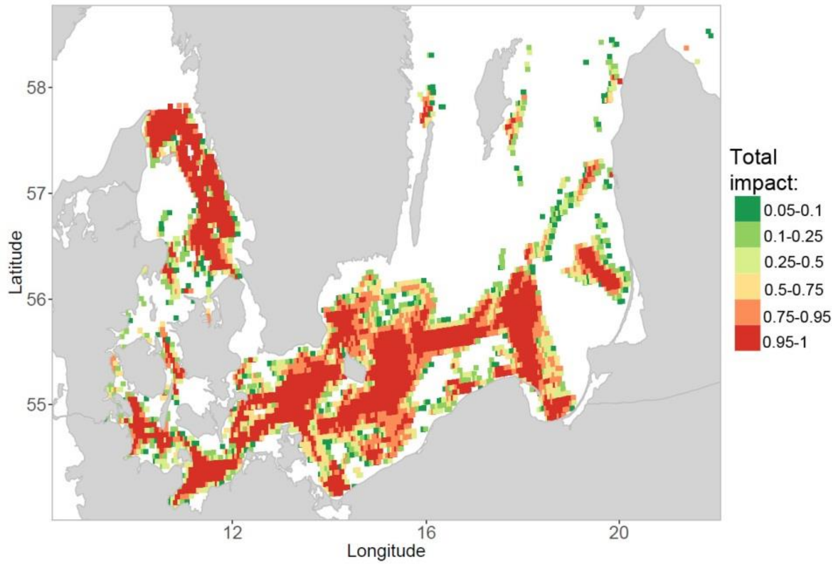


Figure 5. Detailed figure of total fishing impact map (Figure 4c) from mobile-bottom contacting gears. Impact of 1 means full/maximum impact and impact of 0 means no impact.

Total impact is further summarized per community by ordering all grid cells per community type from low to high impact (see Figure 6 and appendix 1). This provides information of the overall impact per community. As shown in Figure 6, some communities are limited affected by the pressure (middle and right panel), while community 3 is predicted to be strongly impacted (left panel).

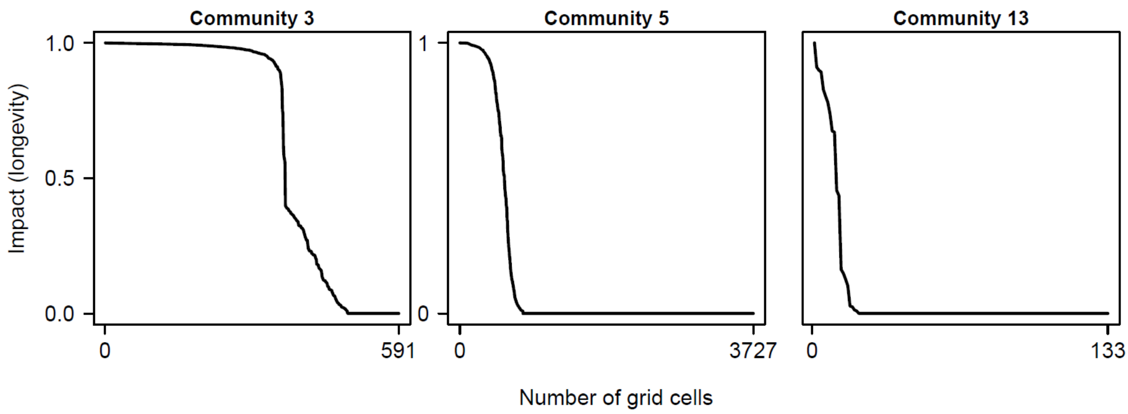


Figure 6 Summarized impact of bottom fishing pressure for three communities across grid cells (all communities are shown in appendix 1). Community 3 (left panel) is stronger impacted than community 5 and 13 (middle and right panel). Communities differ in their spatial coverage (compare number of grid cells).

Information per community type can also be summarized across all grid cells per community type. This is done in table 1 for 1) total community biomass, 2) surface community biomass, 3) sub-surface community biomass. Much of the impact shown in Figure 4 affects community 1 and 2. Since these communities are widespread, overall impact is relatively low. Community 3, 7 and 14 are the most impacted; they consist of taxa that are long-living, while average bottom fishing intensity is relatively high across the grid cells.

Table 1 shows the predicted impact of mobile-bottom contacting gears for both surface and sub-surface abrasion using the trait longevity. The bottom fishing intensity columns show the average annual intensity between 2009 and 2013 (for surface and sub-surface abrasion), averaged across all grid cells per community type. The longevity of the community at 75% of the biomass is similar to the dashed lines in Figure 2b and c.

Community	Total impact	Surface impact	Sub-surface impact	Fishing intensity (surface)	Fishing intensity (sub-surface)	Longevity at 75% of biomass (surface)	Longevity at 75% of biomass (sub-surface)
1	0.07	0.07	0.05	0.79	0.12	5.52	9.78
2	0.15	0.17	0.10	0.53	0.05	9.96	> 20
3	0.64	0.69	0.60	1.33	0.14	7.4	> 20
4	0.02	0.02	NA	0.26	0.04	2.4	NA
5	0.15	0.15	0.03	0.48	0.07	5.84	3.6
6	0.06	0.06	0.04	0.09	0.05	5.36	8.96
7	0.37	0.44	0.33	0.94	0.16	14.52	15.06
8	0.01	0.02	0.00	0.05	0.01	5.76	8.1
9	0.00	0.00	0.00	0.00	0.00	> 20	> 20
10	0.14	0.15	0.09	0.22	0.03	> 20	> 20
11	0.03	0.06	0.01	0.13	0.01	6.34	15.1
12	0.00	0.00	0.00	0.01	0.00	7.28	15.4
13	0.07	0.08	0.01	0.26	0.05	6.56	3.6
14	0.94	0.96	0.83	3.45	0.67	12.56	19.38
15	0.20	0.21	0.19	1.25	0.26	9.38	12.08
16	0.11	0.17	0.07	0.16	0.01	> 20	> 20
17	0.00	0.00	0.00	0.00	0.00	6.96	> 20
18	0.17	0.18	0.13	0.59	0.10	6.6	17.74

6. Management options to reduce bottom fishing impact

Management may aim for a reduction in bottom fishing impact and we explored the effects of two potential management options based on the above results: 1) a spatial limitation of bottom fishing intensity in areas with communities that are most impacted, or, 2) a modification of the mobile bottom-contacting fishing gears to exclude all sub-surface fishing activity.

6.1 Spatial limitation of bottom fishing intensity

Management may aim for a reduction in fishing impact in the communities that are predicted to be most affected by bottom fishing intensity, for example, to a total impact value below 0.25 (based on Table 1, first coloured column). This would mean that on average, across all grid cells, 75% of the benthic taxa, in community biomass, are undisturbed from fishing during their life. Such a target would need protective measures in three communities (community 3, 7, 14) that are all located in the western part of the Baltic Sea (Figure 7)

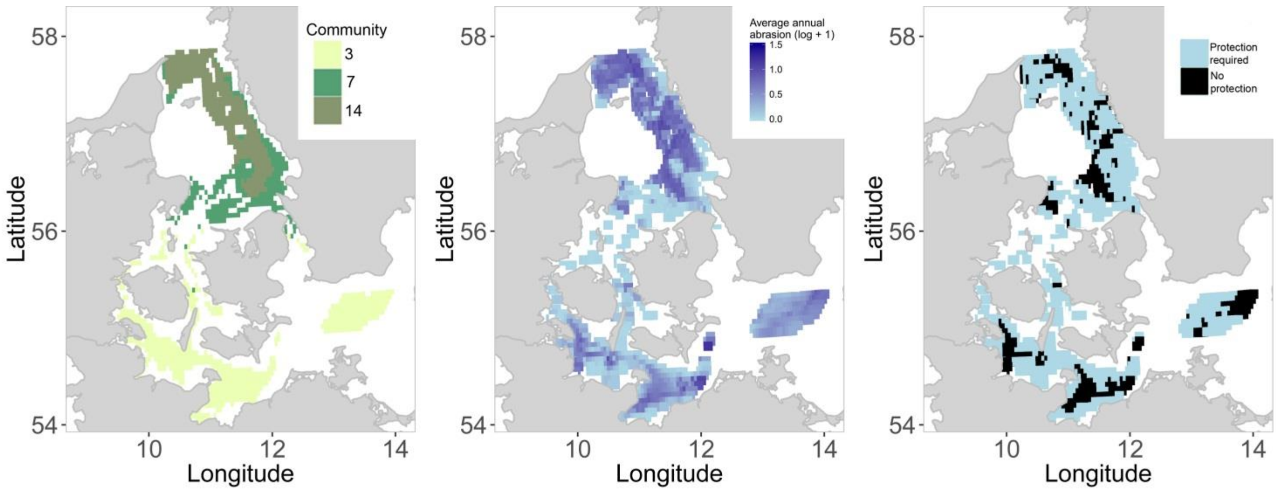


Figure 7. The three communities that have been predicted to be most affected by bottom fishing impact, showing their spatial distribution in the Western Baltic Sea (left panel), the total bottom fishing intensity (surface + sub-surface) (middle panel) and the area that needs protection to reach an impact value below 0.25 (right panel).

The amount of bottom fishing intensity reduction in order to limit impact to 0.25 will vary between the communities as they differ in overall impact, longevity composition and bottom fishing intensity. The non-linearity between impact and bottom fishing intensity gives management the option to protect areas where bottom fishing intensity is relatively low, while impact can be high. Following this scenario, we calculated for each community to what extent bottom fishing intensity (sum of surface and sub-surface abrasion) had to be reduced to limit impact to below 0.25. We did this by first protecting all grid cells that are only incidentally fished (<0.1 per year) and when this did not result in enough impact reduction, we added grid cells in a stepwise fashion, increasing bottom fishing intensity, up to a point where impact was below 0.25. In community 7 all grid cells fished with an average intensity equal or less than 0.95 have to be protected to get an impact score below 0.25. For community 3, this is a bottom fishing intensity of 2.1 times per year, while this is 5.6 times per year for community 14. The consequences of these protective measures are shown in Figure 7c.

6.2 Modification of the mobile bottom-contacting fishing gears to exclude all sub-surface abrasion

Management may also aim for modifications of the mobile bottom-contacting fishing gears to exclude all sub-surface abrasion activity. Since we have separately assessed impact from surface and sub-surface abrasion, we can also examine how such an exclusion of sub-surface abrasion will change impact (Table 3).

Impact is largely reduced in community 3 as a large fraction of the community is positioned below 6 cm in the seabed. Impact is still high in community 14; only a minor part of the community biomass (15%) has a vertical position in the seabed below 6 cm (Table 2).

Table 2. Prediction of impact for the 17 different communities (and also for community 18 that includes all "other" pooled communities) when bottom fishing sub-surface abrasion is excluded. The "Total impact" column is similar as in table 1.

Community	Total impact	Impact (excl. sub-surface abrasion)	Fraction of community biomass > 6 cm in seabed
1	0.07	0.07	0.02
2	0.15	0.12	0.29
3	0.64	0.29	0.59
4	0.02	0.02	0.00
5	0.15	0.15	0.01
6	0.06	0.05	0.20
7	0.37	0.16	0.65
8	0.01	0.01	0.49
9	0.00	0.00	0.01
10	0.14	0.11	0.24
11	0.03	0.02	0.69
12	0.00	0.00	0.44
13	0.07	0.07	0.10
14	0.94	0.82	0.15
15	0.20	0.14	0.30
16	0.11	0.06	0.63
17	0.00	0.00	0.29
18	0.17	0.14	0.20

7. Discussion

7.1 Impact assessment of mobile-bottom contacting gears, a worst-case scenario

The approach adopted in this document implicitly assumed that the disturbance by mobile-bottom contacting gears affected 100% of benthic organisms, while the impact of these gears depended on the maximum longevity of animals in the community. This choice is conservative, because many benthic animals will be able to sustain trawling intervals below their maximum longevity, although at reduced levels of biomass. Still, compared to the previous analysis by Rijnsdorp et al. (2016), we estimated impact for only that part of the community that is likely to be affected by the bottom fishing pressure. This was done using the species trait “vertical position in the seabed” (derived from Bolam et al. 2014). We assumed that surface fishing abrasion is only affecting the upper part of the benthic community (0-6 cm), while sub-surface activity will have an impact on the benthic community that is living deeper in the sediment (> 6 cm). As shown in figure 3b and 3c, the longevity compositions varied between the surface and subsurface community layers, with relatively more short-living animals in the upper layer. This means that the upper layer of the benthic community can withstand higher trawling intensities before it is impacted (figure 3e and 3f). It also means that in areas without any sub-surface abrasion, impact (in terms of decline in species biomass) will never become higher than that part of the community that is living in the upper layers of the sediment.

Dependent on the definition of a healthy status of a benthic population and/or community, it can be argued that it is not species maximum longevity that determines vulnerability, but species age at maturation. The trait age at maturation can be used in a similar way as maximum longevity, but differs as impact will then be defined when a species is disturbed before it is able to reproduce. Generally, benthic species reach their age at maturity 2-4 earlier than their maximum longevity and this directly implies that benthic communities will be able to withstand bottom fishing intensities that are up to 2-4 times higher.

Alternatively, the assessment can be improved by quantifying direct mortality rates for different groups of species across habitats (instead of assuming 100% direct mortality). Such a meta-analysis has been done for bottom trawling disturbance (Collie et al. 2000; Kaiser et al. 2002) and these estimates can possibly be adopted for an assessment of bottom trawl fishing in the Baltic Sea (by lowering direct mortality estimates for different habitat types in the Baltic Sea). Another way to incorporate variation in direct mortality rates across habitats is by statistically predicting the longevity composition of a benthic community as a function of its environmental conditions and bottom fishing intensity. Such an analysis is currently done in the North Sea (Rijnsdorp et al. unpub), but requires high quality sampling data and “clear” trawling gradients across habitats.

7.2 Linking physical pressures that damage the seabed differently

Physical pressures disturbing the seabed (such as mobile-bottom contacting gears, dredging or sediment extraction) may differ in their direct effect. In the report, we assumed that both surface and sub-surface fishing activity with mobile bottom-contacting gears caused 100% mortality on the benthic invertebrate community, while the vulnerability of the benthic habitat was only dependent on its recovery time. However, bottom fishing disturbance does not cause 100% direct mortality of the benthic community and this means that the assessment of impact overestimates the effects. Other types of disturbance, such as sealing of sediment or sediment extraction are potentially more severe in their direct effects and the assumption of 100% mortality could be more realistic.

There are different ways to scale the impact of physical pressures to the benthic community. Ideally, this can be done using a meta-analysis of experimental studies that compare the different physical pressures across habitats and communities. This will lead to estimates of impact across pressures that can be used to parameterize the assessment model (e.g. pressure X is causing 90% direct mortality, pressure Y 10%). Although such a meta-analysis has been done for bottom trawling disturbance (Collie et al. 2000; Kaiser et al. 2002), other types of pressures are less well studied and this makes it hard to quantify the direct mortality of these pressures. If a quantification of the direct effects of different pressures is available, it can be adopted in the approach described in this document (by lowering the direct mortality).

An alternative approach is to assume 100% mortality but only for that part of the community that is affected by a pressure. Such an approach has been used in this study to distinguish between surface and sub-surface abrasion from mobile bottom-contacting gears. Other pressures that cause physical damage to the seabed can be coupled in a similar way (as long as there is information on the number of events per year per grid cell). For example, it may be assumed that sediment deposition will cause mortality to epifaunal organisms, while species that can easily burrow through the new sediment layers are likely to survive such an event. Although this approach still requires information on how the pressure affects the community, it may provide biologically meaningful predictions of impact without having the need to quantify the direct effects for each particular pressure (see Table 3 for different types of pressures). Less severe pressures are harder to incorporate and for these pressures information is needed to quantify their effect. This also includes all pressures that cause only non-lethal effects (non-lethal effects, such as siltation, have still an energetic cost to individuals and this cost can be used to predict the reduction in biomass of the community).

Table 3. Overview of different physical pressures that have severe effects on benthic communities. The species traits in the right column can be used to select only that part of the community that is affected by the pressure.

Pressure	Pressure has an effect on:	Species trait(s) to separate the community
Bottom fishing (surface abrasion)	Epifaunal and top-layer of infauna	Vertical position in the sediment
Bottom fishing (sub-surface abrasion)	Infaunal community	Vertical position in the sediment
Sealing of sediment	Whole + no recovery	-
Sediment extraction	Whole community	-
Sediment deposition	Epifaunal layer (and immobile infauna)	Vertical position in the sediment, mobility

8. References

Bolam, S. G., R. C. Coggan, J. Eggleton, M. Diesing, and D. Stephens. 2014. Sensitivity of macrobenthic secondary production to trawling in the English sector of the Greater North Sea: A biological trait approach. Journal of Sea Research 85:162–177. Journal Article.

Collie, J. S., S. J. Hall, M. J. Kaiser, and I. R. Poiner. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. Journal of Animal Ecology 69:785–798. Journal Article.

ICES. 2016a. EU request for guidance on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats. In Report of the ICES Advisory Committee, ICES Advice 2016, Book 1, Section 1.6.2.4. 5 pp.

ICES. 2016b. Report of the Workshop on guidance on how pressure maps of fishing intensity contribute to an assessment of the state seabed habitats (WKFBI), 31 May 31 May –1 June 2016, ICES Headquarters, Copenhagen, Denmark. ICES CM 2016/ACOM:46. 108 pp.

Gogina, M., H. Nygård, M. Blomqvist, D. Daunys, A. B. Josefson, J. Kotta, A. Maximov, et al. 2016. The Baltic Sea scale inventory of benthic faunal communities. ICES Journal of Marine Science 73:1196–1213.

Kaiser, M. J., J. S. Collie, S. J. Hall, S. Jennings, and I. R. Poiner. 2002. Modification of marine habitats by trawling activities: prognosis and solutions. Fish and Fisheries 3:114–136. Journal Article.

Rijnsdorp, A. D., F. Bastardie, S. G. Bolam, L. Buhl-Mortensen, O. R. Eigaard, K. G. Hamon, J. G. Hiddink, et al. 2016. Towards a framework for the quantitative assessment of trawling impact on the seabed and benthic ecosystem. ICES Journal of Marine Science 73:i127–i138.

Appendix 1. Summarizing impact per community