DTU Aqua
National Institute of Aquatic Resources

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DTU Aqua Report no. 445-2024

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Colophon

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Preface

The project ‘Mapping of seabed habitats and impacts of beam trawling and other demersal fisheries for spatial ecosystem-based management of the Jammer Bay (JAMBAY)’ (Grant Agreement No 33113-B-23-189) was funded by the European Maritime and Fisheries Fund (EMFF) and the Ministry of Food, Agriculture and Fisheries of Denmark.

This Executive Report is the main report for the JAMBAY project and includes the summary of project Work Packages (1 to 4) and Tasks, and the results of Work Package 5. The detailed results of the Work Packages 1 to 4 are presented in 4 independent reports.

This project had a short timeframe to conduct its work, given the magnitude and complexity of the work involved. It started in March 2023 and ended in December 2023. The initial application was accepted and awarded 12 million Danish kr., and in September was expanded to include additional work and an added 14 million Danish kr., to a total of 26 million Danish kr. More than 100 scientists and consultants from several research institutes and private companies were directly involved. Furthermore, the project indirectly involved several stakeholders.

The full data, newly developed methods and models generated during this project have been reported. Part of the work has been disseminated nationally and internationally, but further work is needed to integrate the data and information across the professional fields. Follow up projects have been initiated towards this end. The outputs will inform and provide the opportunity for cross-sectorial, ecosystem-based management.

Kongens Lyngby, February 2024

Grete Elisabeth Dinesen
Senior Consultant

European Union
European Maritime and Fisheries Fund

HAV & FISK

Content

English summary

The focus area of this project was the Jammer Bay area with the overall objective to map seabed habitats and impacts of beam trawling and other demersal fisheries for spatial ecosystem-based management. The specific aims were to: i), geophysically map seabed substrates and habitats (full coverage in the Focus area: 304 km^2; and along transect lines in the screening area: 5230 km^2); and further, for the Screening area; ii), analyse and map the impacts of all mobile bottom-contacting gear types on the seabed habitats, as well as their environmental and climate-related impacts; iii), analyse and map the state of benthic habitat biodiversity and ecosystem functioning and quantify the causal relations to impacts from beam trawls and other mobile bottom-contacting gears; iv), analyse the fisheries resources and socio-economic effects and value chains of all modes of fisheries operating in the Jammer Bay; and v), assess sustainability and trade-offs between fish distribution, socio-economic values, and fisheries impacts on the environmental state of the Benthic Broad Habitat Types (BBHTs) under the Marine Strategy Framework Directive (MSFD).

An important output of this project was the generation of high-resolution bathymetric maps of the seabed in the Jammer Bay area. A total of 2,804 line-km of acoustic remote sensing was completed from vessels, including a Focus area (>300 km^2) with 200 m line spacing, a larger Screening area with 2000 m line spacing, and two parallel lines extending from the coast to the EEZ border. Ground-thruthing was performed using grains size and underwater video information. With these data, seabed maps were generated which enabled the identification of the spatial distribution of the bathymetry, morphology, and different substrate types. The information of seabed morphology and substrate were used to classify Habitat Directive habitats including Sandbanks (1110) and Reefs (1170). Numerous boulder reefs were discovered covering in total an area of ~37 km^2. The information will also be applied for mapping of BBHTs under the MSFD.

Physical fisheries impacts on the seabed were mapped based on new models that enabled estimation of fishing pressure at both medium resolution (~600 x 1000 m) and fine resolution (~60 x 100 m). The Jammer Bay area is intensively fished with bottom-towed gears. A larger area of the deeper, more offshore parts is fished more than 10 times annually. Closer to shore in the shallower areas, fishing intensity is lower, but hot spot areas that are fished more than 10 times annually were located in the central parts of the bay. Danish otter trawling is conducted primarily on mud sediment with a moderate to high fishing pressure in terms of both spatial footprint and penetration depth. Danish seining takes place primarily on sand sediment and is responsible for the broadest spatial footprint but with the smallest penetration depth. The foreign beam trawlers primarily fish on mixed and sand sediments exerting moderate spatial footprints but with the deepest penetration. Experimental results highlighted that high snagging risk in a seabed habitat does not prevent beam trawling as these vessel types with large engine power can turn over boulders when snagging occurs. Most other gear types are generally able to pass the inwards sloping side of small and medium sized boulders, but not the largest boulders. The high-resolution hydrographic dataset for the Jammer Bay and adjacent basins established in this project enabled the assessment of connectivity of plaice habitats and sensitive habitat-forming invertebrate species (the northern horse mussel, *Modiolus modiolus,* and the octocoral, *Alcyonium di-*

gitatum). Furthermore, an index for mobile bottom-contacting gear disturbance of plaice recruitment was defined and assessed for the bay. Two important datasets comprising sandeel larval densities, and lengths using a novel imaging processing tools, were generated. These results contributed to the understanding of the life cycle and recruitment patterns of sandeel (species of Ammodytidae).

Fishery gradient studies are particularly useful in examining long-term (years) and large-scale (kms) impacts of bottom trawling. The Jammer Bay is a data poor area with regards to the benthic macrofaunal communities on the different seabed habitats. With the new gradient data from Van Veen samples (100 x 0.1 m^2 = 10 m^2) and HAPS corer samples (200 x 0.0143 m^2 = 2.86 m^2) we established comprehensive information of the distribution of >300 benthic macrofaunal taxa in the Jammer Bay. Following quality assurance of these new data, the information on the density of species (S), density of individuals (N), wet weight (WW) and ash free dry weight (AFDW), the data will be integrated in the ongoing detailed analyses of fisheries impacts and environmental state of the benthic habitats and trade-offs thereof in the Jammer Bay.

The new data generated in this project will be highly valuable in the upcoming analyses of fisheries impacts on benthic faunal biodiversity, functional traits, and depletion ratios related to individual benthic habitats (BBHTs), hydrographic and climate conditions, hypoxia, and fisheries footprints and trade-offs. The outcome will inform ecosystem-based management and associated designated areas as part of the implementation of the EU Marine Strategy Framework Directive (MSFD), Biodiversity Strategy for 2030 (BDS2030), the Habitats Directive (HD) and Birds Directive (BD) of the NATURA 2000 network, and the EU Common Fisheries Policy (CFP).

Impacts of beam trawling have previously been investigated for Dutch vessels on sandy habitats in the southern North Sea. However, little is known of beam trawling impacts on Circalittoral sand and Circalittoral mixed sediment in Danish waters, including in the Jammer Bay. The two Before-After-Control-Impact (BACI) field experiments retrieved a total of 20 fish and 13 benthic megafaunal invertebrates caught by two beam trawls. The BACI experiment of fisheries impacts of a sumwing beam trawl with 3 tickler chains on Circalittoral sand showed that plaice (*Pleuronectes platessa*), dominated the biomass in all 12 hauls, yet with no clear trends related to impact. However, the biomass of both Dover sole (*Solea solea*), and dab (*Limanda limanda*), clearly increased with the number of impacts. The BACI experiment of fisheries impacts of a chain mat beam trawl on Circalittoral mixed sediment showed an increased biomass of cod (*Gadus morhua*), dab and edible crab (*Cancer pagurus*), with increasing number of impacts. These species were likely attracted to the site by the seabed disturbance and suspension of damaged fauna in the plume of the trawl tracks. The biomass of the attached (sessile) bryozoan colonies (*Flustra foliacea*), and large, mobile sea urchins (*Echinus esculentus*), showed a clear decline in biomass with increased trawling, and both are considered sensitive to bottom trawling.

Most noticeable is the impact on the sensitive octocoral (*Alcyonium digitatum*), that lives attached to boulders and other hard substrates. This octocoral is long-lived (≥28 years) and larger colonies (of heights between 10-20 cm) are ≥10 years old. This species was caught in all chain mat beam trawl hauls on Circalittoral mixed sediment, and with high biomasses (between 14-20 kg in 11 out of the 12 hauls with the chain mat beam trawl). Recovery by recruitment of its pelagic non-feeding (lecithotrophic) larvae is very slow and requires that hard substrates such as stable boulders are present and undisturbed in their habitat. In unfished areas in the Jammer

Bay, this octocoral forms dense beds that function as a biogenic habitat for other species. Thus, this BACI experiment showed that the adverse effects on chain mat beam trawling on Circalittoral mixed sediments are detrimental to structuring seabed fauna, with a high risk of habitat loss.

The Relative Margalef diversity (D_M') index, tested and applied to the Danish part of the North Sea and Skagerrak. This index is expressed as the difference between the value in fished and unfished conditions. Benthos samples from the National Monitoring Programme for Water and Nature (NOVANA) were selected from 2010-2022 and matched with their corresponding MSFD Benthic Broad Habitat Type and assessed for two separate periods (2010-2016 and 2017-2022). In the first period (2010-2016) four out of six habitat types showed low Relative Margalef diversity in the Danish part of the North Sea and Skagerrak, whereas the remaining two were intermediate. Circalittoral sand and Offshore circalittoral mud remained at low relative diversity during the second period (2017-2022), whereas circalittoral coarse and offshore circalittoral sand displayed intermediate relative diversity in both periods. Circalittoral mixed and Offshore circalittoral coarse sediments changed from low to intermediate Relative Margalef diversity. The results may have been influenced by the sampling design of the NOVANA programme, as it was not specifically designed to test the response of benthic communities to various levels of bottom trawling intensity. There were large differences in the number of samples between habitat types and large differences in the number of samples between periods for each habitat type. Furthermore, the NOVANA programme samples with HAPS corers that cover a relatively small area (0.0143 m^2), compared to Van Veen grabs (0.1 m^2) or other types of grabs that are used by other European countries. The HAPS corer tends to underestimate the abundance of larger-sized infauna and epifauna, which are the benthic organisms mostly impacted by physical disturbance from bottom trawling.

The paucity of NOVANA samples in the Jammer Bay area made it difficult to ascertain the state of the benthic seabed habitats using the Relative Margalef diversity index. The additional samples with the Van Veen grab and HAPS corer collected during this project will be of great value to further test the Relative Margalef diversity index and compare its response to fishing with other benthic indicators such as the Benthic Quality Index (BQI) and Relative Benthic State (RBS). A statistical modelling framework can be developed that can account for natural conditions as well as the sampling regime. Such a framework will allow for predicting the index across space, including in areas without sampling, and for estimating reference values of Margalef diversity for habitat types that are currently being under-sampled.

Assessment of Good Environmental State (GES) of the Marine Strategy Framework Directive (MSFD) Benthic Broad Habitat Types (BBHTs) under the Descriptor D6 “Seafloor integrity” Criteria C5 “adverse effects” is planned to include all pertaining pressures. The International Council for Exploration of the Sea (ICES) Fisheries Benthic Impact and Trade-offs (FBIT) working group (WG) has developed a mechanistic benthic indicator, Relative Benthic State (RBS), that assesses bottom trawling impacts and benthic state as the expected benthic biomass reduction relative to unimpacted conditions. The RBS indicator is currently being tested in European marine waters.

In this study, we applied the RBS indicator to assess the environmental state of the BBHTs in the Jammer Bay area. The RBS application was made possible due to the new improved model estimates of trawling intensity, represented as Swept Area Ratio (SAR) at a medium-fine resolution (600 x 1000 m grid cell size) of the physical footprint of the Danish and international vessels fishing with mobile bottom contacting gears in the Jammer Bay area. To distinguish between the pressures of bottom trawling and hypoxia and their adverse effects on BBHTs, we developed a new hydrographic-based model of hypoxia distribution and combined this with the RBS indicator.

For this 1st generation local GES assessment, we used the existing data of the BBHTs from the EMODnet (EU SeaMap ver. Sept 2021), and existing benthic macrofauna data collected by the Danish monitoring programme NOVANA (2014-2022). For the GES Extend Threshold (GES ET), we applied the Article 8 Guidance (by the EU TGSEABED) and adopted a GES ET of ≥75%, (i.e., ≤25% of an area may be adversely affected, incl. ≤2% loss to be assessed as in good state). For the GES Quality Threshold (GES QT), we adopted the ICES WKBENTH2 advice and applied a maximum negative deviation of 0.2 from the maximum RBS value of 1 (i.e., 1 - 0.2 = 0.8).

In the Jammer Bay area, 3 of the 11 BBHTs were in subGES due to adverse effects from bottom trawling in the period from 2014-2016. In the most recent period from 2017-2022, 4 of the 11 BBHTs were in subGES due to bottom trawling. Although RBS was still ≥0.8 in more than 75% of the area of 7 BBHTs, it was considerably lower (i.e., in subGES) in 4 BBHTs. In these 4 BBHTs, RBS ≥0.8 respectively covered 0% of the Upper bathyal sediment, and only ~17% of the Offshore circalittoral mud, ~19% of the Offshore circalittoral sand, but 73.5% of the Offshore circalittoral coarse sediment of each of their total spatial distribution in the Jammer Bay area.

Thus, in the Jammer Bay area, especially 3 of the deeper BBHTs showed a considerable smaller extent of their areas to be in GES than the required minimum of 75% area in GES (GES Extent Threshold), when assessed using the fishery-sensitive benthic indicator, RBS, and hypoxia. However, hypoxia contributed to the subGES of Offshore circalittoral mud by <3%, and thus was of minor importance for the environmental state in this area.

Environmental DNA (eDNA) was successfully extracted and stored for all sampled stations and quantitative PCR assays were developed for two sensitive invertebrate species (*Modiolus modiolus* and *Alcyonium digitatum*). Pilot metabarcoding analyses were performed on samples from six locations to identify biodiversity of fishes and benthic invertebrates.

Analyses of fisheries resources using survey data showed marked shifts in the relative densities of cod and plaice especially at regional scale but also locally. In recent years, the local adult populations of both cod and plaice have declined drastically, impacting the local fisheries in the Jammer Bay. The decline of adult cod was closely correlated to increases of bottom water temperatures in the summer months explained by cod avoidance behaviour. Adult plaice, on the other hand, were caught in areas with warm bottom water temperatures between 2014-2016 indicating that plaice react differently than cod to warming waters. Since 2017, Danish landing statistics showed local fishery was very low. The modelling of fishing intensity showed foreign vessels operating in the area in the same period, but no landing information is accessible. It was thus not possible to identify whether warmer water temperatures, overfishing, another factor, or a combination of factors was the cause for the plaice decline.

The distinct types of fisheries in the Jammer Bay area were identified through relevant features such as vessel lengths, engine sizes, gear types, profitability measures, crew sizes, quota, and ownership. They were categorised into four core groups, which provided a new, operational framework of conceptual models, called “Fishing Cultures”. The conceptual models were applied to identify different connections between cultural life-modes and modes of production in the fisheries, their competition for ecosystem resources and their contributions to value chains and socio-cultural sustenance at the local, national, and international level. Further, a model for assessing the local economic effect of each Fishing Culture was developed.

Each Fishing Culture is a unity of four core features: i), life-mode; ii), mode of operation; iii), fishing methods and iv), community (fishing harbour affiliation). Seven Fishing Cultures were identified: FC 1), Beach landing coastal fishery; FC 2), Dutch demersal beam-trawling; FC 3), Expansive harbour-based fishery; FC 4), Harbour based coastal fishery; FC 5), Specialised gillnet fishery; FC 6), Specialised anchor-seine fishery, and FC 7), Profit-seeking large-scale fishery.

The problematic coexistence of opposite modes of operation and fishing methods were aggravated by the arrival of a fleet of large beam trawlers in 2017 fishing for sole and plaice in the shallow grounds of the Jammer Bay. These beam trawlers subsequently returned to the Jammer Bay during the next 6 years because according to their experience, these target species were no longer available in their home waters of the Southern North Sea.

Fishers (among the interviewed stakeholders) realizing the FCs 1, 4, 5, and 6 find themselves caught in an antagonistic relation to large beam-trawlers realizing FC 2 who operate a long-distance fishery in the Jammer Bay, among other places. Their presence in the Jammer Bay conflicts with local fishers realizing the FCs 1, 4, 5 and 6 because of their inability to share common fishing grounds and fish stocks. The impact by FC 2 on the seabed, marine food webs, and juvenile fish puts, according to the local fishers, pressure on their fishing opportunities at the shallow grounds of the Jammer Bay while the beam trawlers are operating in the area and during a considerable time afterwards.

The Dutch beam trawlers of Fishing Culture 2 operate a downright long-distance fishery without any economic contribution of significance to the local fishing communities in the Jammer Bay area. This is reflected in the considerable differences in the Local Economic Effect (LEE) between the Fishing Cultures and highlights another pattern than would otherwise be obtained from calculations of company profitability in business economic practice. FCs 1, 4 and 5 have the highest LEE, calculated to 49%─56% of the catch value. There is a middle LEE for FC 3 and 6, calculated to around 40%. While the lowest LEE is for FC 7 and FC 2. For FC 7, the calculated LEE is 25%. FC 2 generally does not land fish in any of the Jammer Bay harbours. Thus, the LEE of FC 2 (Dutch beam trawlers) is almost zero.

Unwanted bycatch of nine selected species cod (*Gadus morhua*), whiting (*Merlangius merlangus*), saithe (*Pollachius virens*), haddock (*Melanogrammus aeglefinus*), deep water shrimp (*Pandalus borealis*), Norway lobster (*Nephrops norvegicus*), plaice (*Pleuronectes platessa*), and two species designated as sensitive species, starry ray (*Amblyraja radiata*), and piked dogfish (*Squalus acanthias*), from the sampled fisheries in the Skagerrak, were mapped spatially per year for the period 2018–2022. Further, the fishing effort and the observer coverage from the sampled fisheries in Skagerrak was mapped for the same period.

Electronic Monitoring (EM) data were analysed to show bycatch variability of protected, endangered and threatened species (PETS). Although various oceanographic features were included in the analyses, the main contributor to bycatch probability was fishing effort. Harbour porpoise

(*Phocoena phocoena*), bycatch probability maps highlighted high-risk areas, which varied in both space and time. Spatial distribution maps were estimated for four sensitive fish species, halibut (*Hippoglossus hippoglossus*), spurdog (*Squalus acanthias*), wolfish (*Anarhichas lupus*), and starry ray (*Amblyraja radiata*). For halibut, and particularly spurdog, the overall trend in densities from 1983–2023 was positive, whereas the overall trends for wolfish and starry ray were negative.

The Stochastic Multi-Species (SMS) model developed and maintained by DTU Aqua estimates the predation mortality of the commercially important fish stocks in the North Sea and Skagerrak. This model was updated to include stock assessment input data for 2020-2022. Further, previous estimates of grey seal density and diet were revised, and uncertainties of fish diet estimates were estimated and used in the model likelihood. This work was done in preparation for a week-long meeting of the ICES Working Group on Multispecies Assessment Methods (WGSAM). The output of the updated model quantifies the predator-prey interactions with respect to biomass eaten and predation mortalities and contributes as such to the understanding of the food web for the commercial species in the North Sea.

With the overall aim to demonstrate how different results of this project can be applied in scenario exploration, we implemented a pilot trial of trade-off modelling of fisheries spatial use of seabed habitats and landing values. More explicitly, we combined spatial use of different seabed habitat (MSFD BBHTs) states with economic revenues from the different commercial fisheries métiers. We were able to identify which seabed habitats provided the highest economic value, where fishing grounds are shared and where competition exists between fisheries.

To be environmentally effective, seabed closures require data-based consideration of environmental states and processes that are of importance to the entire ecosystem locally, and to other areas regionally. This also includes an assessment of the closed area functioning and its' potential to achieve and maintain good environmental state, as well as to contribute efficiently as a source area for recruitment to other areas.

Considering the spatial distribution of fisheries with mobile bottom-contacting gears, three scenarios were explored using a 10%, 30%, and 75% spatial closure of the cells from the highest to the lowest Relative Benthic State (RBS) value for each Benthic Broad Habitat Type (BBHT), based on the estimated state under the conditions of the past periods from 2014-2016 and 2017-2022. Cells with RBS values ≥0.8 are considered in a good environmental state (GES); cells with RBS <0.8 to >0.6 are considered in a moderate not good state (subGES moderate), and cells with RBS ≤0.6 are considered in a not good state (subGES). The scenario results show what the state of benthic habitats would have been if the spatial closures were implemented at the end of the first period (2014-2016). In addition, we explored what the state would have been if the spatial closures were first implemented at the end of the second period (2017-2022). Therefore, a decline in average RBS between the two simulated times of closure indicates that delaying closure is detrimental to the habitat resulting in a poorer environmental state.

Scenario 1 explored a 10% strict spatial closure related to the Marine Strategy Framework Directive (MSFD) Descriptor 6 “Seafloor integrity”, Criteria 5 (D6C5) and the EU Biodiversity Strategy for 2030 (BDS2030). The 10% closure of cells with the highest RBS values for each Benthic

Broad Habitat Type (BBHT) showed RBS average values ranged between 1-0.87 and thus are all in good environmental state (GES, RBS ≥0.8). The exception was Upper bathyal sediment with the RBS average of 0.69 in 2014-2016 and a lower average of 0.52 in 2017-2022. For the period 2017-2022, this scenario would have reduced the Danish fisheries income by ≤3.5% for each BBHT, equivalent to a total income loss of ~1 mill DKK, distributed relatively evenly across Offshore circalittoral sand, Offshore circalittoral mud and Upper bathyal sediment.

Scenario 2 explored a 30% spatial closure related to the BDS2030 (i.e., 10% strict closure and an additional 20% closure of total seabed). The results of the spatial closure of the cells with the highest RBS values for each BBHT showed most to be in GES (i.e., with an RBS average range between 0.99-0.87). However, a closure scenario of 30% of Offshore circalittoral sand showed that the RBS average was higher in the first period (0.86 in 2014-2016) than in the second period (0.75 in 2017-2022), with a change from GES to moderate subGES. A closure scenario of 30% of Offshore circalittoral mud showed a decline in RBS average from 0.75 in 2014-2016 to 0.54 in 2017-2022, corresponding to a deterioration from moderate subGES to subGES in the cells with the highest RBS. A closure scenario of 30% Upper bathyal sediment showed a decline in RBS average value from 0.53 in 2014-2016 to as low as 0.29 in 2017-2022, indicating a transition from a deteriorated to a deprived state of the cells with the highest RBS. For the period 2017-2022, this scenario would have reduced the Danish fisheries income by ≤10% for most BBHTs, except for Upper bathyal sediment where the percent income loss was 22.5%. The total loss of the Danish fisheries income was estimated to 12 mill DKK. The scenarios results showed that most of the income loss was related to fisheries on Offshore circalittoral sand (6.5 mill DKK), whereas a smaller proportion of income loss of fisheries was derived from Upper bathyal sediment (1.8 mill DKK).

Scenario 3 considered a scenario, in which fishery with mobile bottom-contacting gears was potentially considered incompatible regardless of métier with the MSFD D6C5 ≥75% Extent Threshold for good environmental state (GES). This closure scenario of 75% of the area of each BBHT showed most BBHTs to be in GES (i.e., RBS average between 0.99-0.89). However, closure of 75% of Offshore circalittoral sand showed a decline of RBS average from 0.65 in 2014-2022 to 0.44 in 2017-2022. This translates to a decline from moderate subGES to subGES of the cells with the highest RBS values. Closure of 75% Offshore circalittoral mud showed a decline of RBS average from 0.37 in 2014-2016 to 0.22 in 2017-2022, indicating a further decline in the subGES level of this habitat. Closure of 75% Upper bathyal sediment showed a decline in the RBS average from 0.45 in 2014-2016 to as low as 0.17 in 2017-2022, reflecting the impoverishment of this habitat type. For the period 2017-2022, this scenario closure would have reduced the overall Danish fisheries income from the Jammer Bay area by 30-62% depending on the métier and BBHT. The percent income loss for Upper bathyal sediment was higher at 72%. However, considering the total loss of Danish fisheries income of 79 mill DKK in the Jammer Bay area, Upper bathyal sediment only contributed to this loss with 6 mill DKK, whereas Offshore circalittoral sand contributed approximately half, approximately 40.5 mill DKK.

It is worth noting, that in all three scenarios of spatial closure, the highest relative percentage loss of fisheries income was derived from closure of the BBHT with the poorest environmental state. In terms of loss in monetary value, the highest fisheries economic loss was derived from BBHT with a better environmental state as measured by the RBS indicator.

The core fishing grounds of the métiers used by the Danish fleet are closely linked to the seabed habitat types. The outer part of the bay consisting of muddy sediments is primarily fished by Danish bottom trawlers for crustaceans (i.e., OT_CRU) and demersal fish (i.e., OT_DEF), as well as Scottish seiners (also known as fly-shooting) (i.e., SSD) and large Danish seiners targeting demersal fish (i.e., SDN). The coastal sandy and coarse habitats in the southern area are fished by small Danish trawlers for demersal fish and occasionally dredgers for collecting molluscs. Small Danish seiners targeting plaice dominate fisheries on the sandy and coarse sediments in the coastal areas of the inner Jammer Bay.

The central part of the Jammer Bay is characterised by mosaic structures of sand, coarse and mixed sediments including multiple reefs with highly complex topography and hydrographic conditions. This large central area provides core fishing grounds on boulder reefs for small Danish gill netters (i.e., GNS) and small Danish seiners (i.e., SDN) on sand targeting demersal fish. Both fisheries are characterised by having relatively low impacts on these habitats. In the central and southern part of this area a few Danish beam trawlers (i.e., TBB) target demersal fish with a higher impact on the seabed.

We estimated the trade-offs of between benthic seabed closure indicators, including extent of each BBHT habitat and biological quality (RBS) as well as the Danish fisheries resource use and value. The pilot scenarios provide examples of how combining environmental and socio-economic data can be used to explore spatial-temporal linkages between ecosystem resource use, environmental impacts and protection requirements, and the potential loss of environmental state and fisheries landings value with different management options. The trade-off scenarios for the Danish fleet can also contribute to dialogue among stakeholders on how to achieve and maintain healthy ecosystems and improve sustainable use of fisheries resources and be implemented in management in the Danish seas.

Core fishing grounds of foreign fleets operating in the same area could not be economically or environmentally assessed individually in the Danish EEZ due to the generic lack of access to logbook and landings information from non-Danish vessels. Hence, it is not possible to conduct a full assessment of the total landings and discards in the Jammer Bay area. This pertains to the landings weights of different target species and their monetary values as well as the bycatch magnitude of prohibited and other unwanted species. Instead, AIS data was used to estimate the spatial fishing pressure as SAR values for the non-Danish vessels. Among the foreign fleet, beam trawlers and Scottish seiners impacted larger areas with high intensity (i.e., high SAR values) particularly in the central parts of the Jammer Bay area. Thus, it may be assumed that their landings and discards, as well as their seabed impacts, are of a magnitude that could negatively impact the ecosystem and the fisheries resources of the Jammer Bay.

Dansk resume

Projektets fokusområde var Jammerbugten (Skagerrak), og det overordnede formål var at kortlægge havbundshabitater og påvirkninger af bomtrawl og andet demersalt fiskeri på havbunden med henblik på en arealbaseret økosystembaseret forvaltning. Projekts formål var at:

i), geofysisk kortlægge havbundssubstrater og habitater (fuld dækning i et fokusområde 304 km^2 og langs transektlinjer i et screeningsområde på 5230 km^2).

og yderligere for screeningsområdet at:

ii), analysere og kortlægge påvirkningerne af de forskellige bundslæbende fiskeriredskabstyper på havbundens habitater såvel som miljø- og klimarelaterede påvirkninger,

iii), analysere og kortlægge status for benthiske habitaters biodiversitet og økosystemfunktioner og kvantificere årsagssammenhængene til påvirkninger fra bomtrawl og andre mobile redskaber med bundkontakt,

iv), analysere fiskeressourcerne og de socioøkonomiske virkninger og værdikæder af de fiskerier, der udføres i Jammerbugten, og ogudbygge metoder til at vurdere bæredygtighed og afvejning mellem udbredelsen af fisk, socioøkonomiske værdier og fiskeriets indvirkning på miljøet og tilstanden af Havstrategidirektivets (HSD) havbundhabitattyper (Benthic Broad Habitat Types, BBHTs).

Et vigtigt aspekt af dette projekt var udarbejdelsen af højopløselige batymetriske kort over havbunden i Jammerbugten. I alt 2.804 linje-km akustisk fjernmåling blev gennemført fra fartøjer, inklusive i et fokusområde (>300 km^2) med 200 m linjeafstand og i et større screeningsområde med 2000 m linjeafstand og to parallelle linjer, der strækker sig fra kysten til grænsen mellem den danske og norske eksklusive økonomiske zone (EEZ). Validering (groundthruthing) blev udført på basis af kornstørrelse af sedimentet og undervandsvideoinformation. Med disse data blev havbundskort genereret, som gjorde det muligt at identificere den rumlige fordeling af batymetri (dybde), morfologi og forskellige substrattyper. Oplysningerne om havbundens morfologi og substrat blev brugt til at klassificere Habitatdirektivets levesteder (HD-naturtyper), herunder Sandbanker (1110) og Stenrev (1170). Der blev opdaget adskillige stenrev, der dækkede et areal på i alt ca. 37 km^2. Oplysningerne kan også anvendes til kortlægning af Havstrategidirektivets havbundshabitattyper.

Fysisk fiskeripåvirkning på havbunden blev kortlagt med nye modeller, der muliggjorde estimering af fiskeriintensiteten både med mellemfin opløsning (0,01°: ca. 600 x 1000 m) og meget fin opløsning (0,001°: ca. 60 x 100 m). Jammerbugten er et område, der bliver fisket intensivt med mange forskellige bundslæbende redskabstyper. Store områder af de dybere dele langt fra kysten (offshore) bliver intensivt fisket mere end 10 gange årligt. Tættere på kysten i de mere lavvandede områder (0-25 m) er fiskeriintensiteten væsentligt lavere, men også i disse områder er der flere fiskeri-hotspot områder i de centrale dele af Jammerbugten, der ligeledes fiskes mere end 10 gange årligt. Dansk bundtrawling med større fartøjer og redskaber foregår primært på mudderbund med moderat til høje fiskeriintensiteter, både i forhold til fisket areal og dybdepåvirkning ned i sedimentet. Dansk snurrevodsfiskeri foregår primært på sandbund og har den største arealpåvirkning, men den mindste fysiske påvirkning på og i havbunden. Udenlandske bomtrawlere (og fly-shootere) fisker på sand og blandet bund (herunder med grus, sten og stenrev). De har en lavere arealpåvirkning per træk end de andre trawltyper, men deres fysiske påvirkning er meget kraftig, både af havbundens større fysiske strukturer (sten), grovere sedimenter (småsten, grus og sand) og finere sedimenter (fint sand, sandblandet mudder).

Resultater af tankforsøg viste tydeligt, at der er høj risiko for, at bomtrawl sætter sig fysisk fast (ved snagging) i havbundens sten af alle størrelser, også store sten. Men dette hindrer ikke bomtrawlerne i at fiske, idet de kraftige redskaber og fartøjer med stor maskinkraft blot kan vælte stenene rundt, når bomtrawlen sætter sig fast. De fleste andre redskabstyper kan undertiden sætte sig fast i mindre sten, men fiskerne undgår typisk områder med mellemstore og store sten, da disse oftest ødelægger trawlene.

De nye høj-opløste hydrografiske data for Jammerbugten og tilstødende havområder, som blev udviklet i dette projekt, muliggjorde analyser af rummelige habitatsammenhænge og spredning af larver af rødspætter (*Platessa pleuronectes*) og to følsomme bundfaunaarter, hestemuslinger (*Modiolus modiolus*) og korallen dødningehånd (*Alcyonium digitatum*). Endvidere definerede vi et indeks for bundslæbende redskabers påvirkning af tilgangen af nye generationer af rødspætter (rekrutteringen) i Jammerbugten. Desuden opbyggede vi to vigtige datasæt for tobislarvetætheder og -kropslængder vha. et nyudviklet billedbehandlingsværktøj. Disse resultater bidrog til en bedre forståelse af livscyklus og rekrutteringsmønstre for tobislarver i Skagerrak.

Fiskerigradient-studier er især vigtige i undersøgelser af effekter af bundtrawling på lang sigt (år) over stor geografisk skala (km). Inden projektet var Jammerbugten et mindre velundersøgt område med relative sparsomme data om makrofaunasamfundene på de forskellige bundhabitater. Med de nye gradientdata fra Van Veen grabbeprøver (100 x 0,1 m^2 = 10 m^2) og HAPS kerneprøver (200 x 0,0143 m^2 = 2,86 m^2) har vi etableret omfattende ny information om fordelingen af over 300 benthiske makrofaunataxa i Jammerbugten. Efter kvalitetssikring af de nye data vil informationerne om antallet af arter (S), antallet af individer (N), vådvægt (WW), og askefri tørvægt (AFDW) blive integreret i de igangværende analyser af fiskeriernes påvirkning og miljøtilstanden af de benthiske habitater og deres interaktioner i Jammerbugten og Skagerrak samt i forhold til fiskeriernes påvirkning i de indre og ydre farvandsområder i den danske eksklusive økonomiske zone (EEZ).

De nye data, som er tilvejebragt i dette projekt, har stor værdi fremadrettet i de nye opdateringer og analyser af fiskeriets påvirkninger på benthisk faunadiversitet, funktionelle træk og dødelighedsrater relateret til Havstrategidirektivets havbundshabitattyper (BBHTs), hydrografi og klimaforhold, iltsvind og fiskeriets fysiske påvirkninger og trade-offs. Data bidrager med vigtige informationer til økosystembaseret marin forvaltning, herunder udpegning af områder til specifikke formål i den danske implementering af EU's Havstrategidirektiv (HSD), Biodiversitetsstrategi for 2030 (BDG2030), Habitat- og Fuglebeskyttelsesdirektiverne (HD og BD) under NATURA 2000 netværket og EU's fælles Fiskeripolitik (CFP).

Påvirkninger af bomtrawling er ikke tidligere undersøgt i danske farvande. De to eksperimentelle fiskerier i forsøgsområderne i Jammerbugt, som undersøgte påvirkning i et kontrolområde og før og efter fiskeri (Before-After-Control-Impact, BACI), viste en samlet fangst på op til 20 fiskearter og 13 megafauna arter afhængigt af bomtrawl- og havbundstype. BACI-eksperimentet med et sumwing-bomtrawl med tre kæder på Circalittoral sand viste, at rødspætte (*Platessa pleuronectes*) dominerede biomassen i alle 12 træk uden nogen klar tendens i påvirkningsgraden målt ved forskellige i biomassen mellem de forskellige træk. Derimod viste biomassen i fangsterne af både gråtunge (*Solea solea*) og ising (*Limnada limanda*) en klar stigning ved et øget antal trawlingspåvirkninger. BACI-eksperimentet med bomtrawl med kædemåtter på Circalittoral blandet bund med sand og sten viste en tendens til øget biomasse af torsk (*Gadus morhua*), ising (*Limanda limanda*) og taskekrabbe (*Cancer pagurus*) ved øget antal bundpåvirkninger af trawlinger. Dette skyldes sandsynligvis, at disse arter tiltrækkes til stedet, som følge af havbundsforstyrrelsen fra fiskeriet og blotlæggelse af beskadigede bunddyr og fisk i trawlsporet og fanen omkring det fiskeripåvirkede område. Biomassen af de fastsiddende (sessile) mosdyrkolonier (*Flustra foliacea*) og store, mobile søpindsvin (*Echinus esculentus*) viste en tydelig nedgang i biomasse med øget antal gange der trawles, og begge arter anses for at være følsomme i forhold til bundtrawling.

Særligt bemærkelsesværdigt er påvirkningen af de følsomme ægte koraldyr, dødningehånd (*Alcyonium digitatum*), der lever fasthæftet på sten og andre hårde overflader på havbunden. Denne art blev fanget i samtlige træk med bomtrawlet med kædemåtter på Circalittoral blandet bund med sand og sten og med de højeste biomasser (mellem 14-20 kg i 11 ud af 12 træk på ca. 500 m). Denne art har en høj levealder (op til eller over 28 år) og kolonier der er 10-20 cm høje er ofte mere end 10 år gamle. Gendannelse ved rekruttering af pelagiske planulalarver er langsom, og larverne kræver, at der er hårdt og stabilt substrat til stede, såsom større sten og andre hårde overflader, som de kan sætte sig på. I de ikke-befiskede områder i Jammerbugten danner koraldyret, dødningehånd, tætte forekomster, der fungerer som biogene habitater for en række andre dyr. Dette BACI-eksperiment på blandet bund viste, at de negative effekter af bomtrawling med kædemåtter på Circalittoral blandet bund med sand og sten er ødelæggende for strukturdannende havbundsfauna, og at der er høj risiko for permanent tab af havbundshabitat.

Biodiversitetsindekset Relativ Margalef diversitet (D_M') blev undersøgt i projektet for den danske del af Nordsøen og Skagerrak. Indekset repræsenterer en relativ værdi for et havbundsområdes diversitet udtrykt relativt i forhold til et lignende havbundsområde, der er lavt påvirket eller upåvirket af fysisk forstyrrelse af fiskeri. Jo lavere tal i indekset, jo dårligere er den relative biodiversitet. Bundfaunadata fra det danske overvågningsprogram for vand og natur (NOVANA) blev udvalgt for perioden 2010-2022 og koblet med de tilhørende seks havbundshabitattyper i Havstrategidirektivet for to vurderingsperioder, 2010-2016 og 2017-2022. I den første periode (2010-2016) viste fire ud af de seks habitattyper lave værdier af Relativ Margalef diversitet, mens værdierne var middelhøje for de to resterende habitattyper. Circalittoralt sand og Offshore circalittoral mudder var ligeledes lave i Relativ Margalef diversitet i den anden periode (2017-2022), mens Circalittoral grov sediment og Offshore circalittoral sand havde middelværdier af Relativ Margalef diversitet i begge perioder. Circalittoral blandet sediment og Offshore circalittoral grov sediment ændredes fra lav til middelværdi i Relativ Margalef diversitet mellem de to perioder. Resultaterne kan være påvirket af NOVANA programmets prøvefordelingsdesign, da det ikke er målrettet undersøgelse af effekter af bundtrawling. Der var således store forskelle i antal prøver for de enkelte havbundshabitattyper og mellem de forskellige år. NOVANA programmet prøvestørrelser varierer også mellem redskaber (HAPS: 0,0143 m^2 henholdsvis Van Veen: 0,1 m^2), hvilket vi har taget højde for i analyserne.

HAPS prøverne dækker et mindre areal end Van Veen prøverne og indsamler færre dyr med stor kropsstørrelse, som ofte er mest påvirkede af bundtrawling. Det sparsomme antal NOVANA prøver i Jammerbugten gør det vanskeligt at vurdere miljøtilstanden af havbundens habitater i området ved anvendelse af indekset Relative Margalef diversitet. De nye indsamlede prøver vil være af stor værdi fremadrettet i de opfølgende undersøgelser af forskellige bundfaunaindikatorer, som Relativ Margalef diversitet og andre indikatorer for havbundshabitater, blandt andet RBS og BQI, og deres respons på fiskeritryk fra bundslæbende redskaber.

Vurdering af god miljøtilstand (GES) af Havstrategidirektivets havbundshabitattyper (Benthic Broad Habitat Types, BBHTs) under Deskriptor D6 ”Havbundens integritet Kriterie C5 ”negativ påvirkning” er planlagt til at omfatte alle relevante presfaktorer. ICES arbejdsgruppen for fiskeriets benthiske påvirkninger og trade-offs (WGFBIT) har udviklet en mekanistisk indikator, RBS (Relative Benthic State), som kan identificere fysisk påvirkning af fiskeri på havbundens habitat-
typer og deres stabilitet ud fra faunabiomassens medianlevetid (L2). RBS-indikatoren er ved at blive implementeret i for de havområder, der hører til EU’s medlemslande.

I projektet anvendte vi RBS-indikatoren til at vurdere miljøtilstanden af Jammerbugtens havbundshabitater (BBHTs). Dette var muligt, fordi vi kunne anvende den nye databaserede fiskeritryksmodel for arealpåvirkningsrate (SAR) i mellemfin opløsning (600 x 1000 m gridcellestørrelse) for fiskeriets fysiske aftryk fra både danske og internationale fartøjer, der fisker med bundslæbende redskaber i Jammerbugten. Med henblik på at skelne mellem negative effekter af henholdsvis bomtrawling og iltsvind på BBHTs miljøtilstande, kombinerede vi RBS-indikatoren med en ny hydrografisk modelbaseret indikator for udbredelsen af iltsvind.

I denne førstegenerations indikatorapplikation af RBS og iltsvind tog vi udgangspunkt i Artikel 8 Vejledningen (udarbejdet af EU TGSEABED) og anvendte GES Areal Tærskelværdien på ≥75% (dvs. GES Areal: max. ≤25% areal negativt påvirket, inkl. ≤2% areal tab for hver BBHT). Endvidere anvendte vi rådgivningen fra ICES WKBENTH2 om at fastsætte GES Kvalitet Tærskelværdien for RBS til max. -0,2 afvigelse fra den højeste værdi på 1 (dvs. RBS GES Kvalitet: ≥0,8).

I Jammerbugten var tre ud af de 11 havbundshabitattyper (BBHTs) ikke i god tilstand (subGES) pga. negativ påvirkning fra bundtrawling i perioden 2014-2016. I perioden 2017-2022 var fire ud af de 11 bundhabitattyper ikke i god tilstand pga. bundtrawling. Selvom RBS var ≥0,8 i mere end 75% af arealet af syv habitattyper, var det betydeligt lavere i de fire habitattyper, der ikke var i god tilstand. I disse fire habitater dækkede områder med RBS-værdier ≥0,8 henholdsvis 0% af Øvre bathyal sediment, ca. 17% af Offshore circalittoral mudder og 19% af Offshore circalittoral sand samt 73,5% af Offshore circalittoral groft sediment (grus og småsten).

I Jammerbugten er arealet af især tre af de dybest beliggende havbundshabitater derfor i væsentlig ringere miljøtilstand end det minimumskrav om GES i mindst 75% af arealet af hver havbundshabitattype, når man vurderer det ud fra den fiskeripåvirkningsfølsomme bundfaunaindikator, RBS. I modsætning hertil påvirker iltsvind kun havbundshabitatet Offshore circalittoral mudder med en meget lille arealandel (<3%) i Jammerbugten.

Miljø-DNA (e-DNA) blev med succes ekstraheret og opbevaret for alle prøvestationer, og kvantitative PCR-assays blev udviklet for to fiskerifølsomme arter af bundyr, hestemuslingen (*Modiolus modiolus*) og korallen dødningehånd (*Alcyonium digitatum*). Pilotanalyser med anvendelse af metabarcoding blev udført på prøver fra seks lokaliteter for at identificere biodiversiteten af fisk og hvirvelløse dyr.

Analyser af fiskeressourcer ved hjælp af fiskeriundersøgelsesdata viste markante ændringer i den relative tæthed af torsk (*Gadus morhua*) og rødspætte (*Platessa pleuronectes*) især på regional skala, men også lokalt. I de senere år er de lokale voksne bestande af både torsk og rødspætter faldet drastisk, hvilket har påvirket det lokale fiskeri i Jammerbugten. Faldet i forekomsten af voksne torsk var tæt korreleret med øgede temperaturer i det bundnære havvand i sommermånederne og kan forklares med, at torskene enten har holdt sig væk eller flyttede sig ud af området. Til gengæld blev voksne rødspætter fanget i de områder, hvor bundvandstemperaturen var høj i 2014-2016. Dansk landingsstatistik viste, at det lokale fiskeri har været meget lavt siden 2017. Modelleringen af fiskeriintensiteten viste, at udenlandske fartøjer opererede i området i samme periode, men VMS (Vessel Monitoring System) og logbogsinformationer om landinger for disse fartøjer er ikke tilgængelige. Det var således ikke muligt at identificere, om rødspætternes tilbagegang skyldes høje vandtemperaturer eller overfiskeri.

De forskellige typer fiskeri i Jammerbugtområdet blev identificeret gennem relevante funktioner såsom fartøjslængder, motorstørrelser, redskabstyper, rentabilitetsmål, besætningsstørrelser, kvoter og ejerskab. De blev organiseret i fire kerneegenskaber, som muliggjorde en ny, operationel ramme af konceptuelle modeller, kaldet "fiskerikulturer". De konceptuelle modeller blev anvendt til at identificere forskellige sammenhænge mellem kulturelle livsformer og produktionsmåder i fiskeriet, deres konkurrence om økosystemressourcer og deres bidrag til værdikæder og sociokulturel, bæredygtig opretholdelse på lokalt, nationalt og internationalt plan. Yderligere blev der udviklet en model til vurdering af den lokale økonomiske effekt af hver fiskerikultur.

Hver fiskerikultur er en enhed af fire kerne-egenskaber i), livsform, ii), driftsform, iii), fangstmetode og iv), tilknytning til fiskerihavn. I Jammerbugten identificerede denne undersøgelse syv forskellige fiskerikulturer (Fishing Cultures, FC): FC 1), Kystfiskeri med strandlanding, FC 2), Hollandsk bomtrawlfiskeri, FC 3), Ekspansivt havnebaseret fiskeri, FC 4), Havnebaseret kystfiskeri, FC 5), Specialiseret garnfiskeri, FC 6), Specialiseret snurrevodsfiskeri og FC 7), Profitsøgende storindustrielt fiskeri.

Den problematiske sameksistens af i), modsatte driftsformer og ii), modsatte fangstmetoder blev forværret af ankomsten af store bomtrawlere i 2017, som fiskede efter tunge og rødspætte på det lavvandede område i Jammerbugten. I løbet af de næste seks år vendte disse bomtrawlere tilbage til Jammerbugten, fordi tunge og rødspætte ikke længere var tilgængelige i deres hjemlige farvande i den sydlige Nordsø.

Fiskere (blandt de interviewede interessenter), der praktiserer FC 1, 4, 5 og 6, oplever at være fanget i en uønsket konflikt med fiskere, der praktiserer FC 2 ved et langdistancefiskeri med store bomtrawlere i blandt andet Jammerbugten. Tilstedeværelsen af FC 2 er i direkte konkurrence med de lokale fiskere, der praktiserer FC 1, 4, 5 og 6 på grund af de manglende muligheder for at dele fælles fiskepladser og fiskebestande. Påvirkning af FC 2 på havbunden, det marine fødenet og juvenile fisk presser, ifølge de lokale fiskere, deres fiskerimuligheder på de lavvandede grunde i Jammerbugten, både mens bomtrawlerne fisker i området og i lang tid herefter.

De hollandske bomtrawlere, der praktiserer fiskerikultur FC 2, driver alene et langdistancefiskeri uden økonomisk bidrag til de lokale fiskerisamfund i Jammerbugtområdet. Dette afspejles tydeligt i de store forskelle i Lokal Økonomisk Effekt (Local Economic Effect, LEE), der er imellem de forskellige fiskerikulturer, der fisker i Jammerbugten. Anvendelse af LEE belyser væsentlige økonomiske forhold, som er forskellige fra de beregninger af virksomhedens rentabilitet, som ofte anvendes i erhvervsøkonomisk praksis. FC 1, 4 og 5 har de højeste beregnede LEE-værdier mellem 49% og 56% af den samlede landingsværdi. De mellemste LEE-værdier er beregnet for FC 3 og 6 til ca. 40% af landingsværdien, mens den for FC 7 er 25%. Den laveste LEE-værdi er beregnet for FC 2. Da de hollandske bomtrawlere (FC 2) generelt ikke lander deres fangede fisk i havnene i Jammerbugtområdet, er deres LEE-værdi tæt på 0%.

Uønsket bifangst af ni udvalgte arter blev kortlagt rumligt pr. år på baggrund af prøver fra fiskeri i Skagerrak. Det drejede sig om torsk (*Gadus morhua*), hvilling (*Merlangius merlangus*), sej (*Pollachius virens*), kuller (*Melanogrammus aeglefinus*), dybvandsreje (*Pandalus borealis*), jomfruhummer (*Nephrops norvegicus*), og rødspætte (*Pleuronectes platessa*) samt to arter, der er udpeget som følsomme, tærbe (*Amblyraja radiata*) og pighaj (*Squalus acanthias*). Ydermere blev fiskeriindsatsen og observatørdækningen fra stikprøverne i Skagerrak kortlagt for perioden 2018-2022.

Elektroniske overvågningsdata blev analyseret for at vise bifangstvariabilitet af beskyttede og truede arter (PETS). Selvom forskellige oceanografiske træk blev inkluderet i analyserne, var fiskeriindsatsen den største bidragyder til sandsynligheden for bifangst. Sandsynlighedskort for bifangst af marsvin (*Phocoena phocoena*) fremhævede højrisikoområder, som varierede i både rum og tid. Rumlige udbredelseskort blev estimeret for fire følsomme fiskearter, helleflynder (*Hippoglossus hippoglossus*), pighaj (*Squalus acanthias*), havkat (*Anarhichas lupus*) og tærbe (*Amblyraja radiata*). For helleflynder og især tærbe er den overordnede tendens i tætheden fra 1983-2023 positiv, hvorimod de overordnede tendenser for havkat og pighaj er negative.

Flerartsmodellen (Stochastic Multi-Species model, SMS), som er udviklet og vedligeholdes af DTU Aqua, estimerer prædationsdødeligheden for de kommercielt vigtige fiskebestande i Nordsøen og Skagerrak. Denne model blev opdateret til at inkludere inputdata for bestandsvurdering for 2020-2022. Desuden blev tidligere estimater for tætheden af gråsæl og dens fødeindtag revideret, og usikkerheder i estimaterne af fisks fødeindtag blev estimeret og brugt i modellens sandsynlighedsberegning. Dette arbejde blev udført som forberedelse til et ugelangt møde i ICES Working Group on Multispecies Assessment Methods (WGSAM). Outputtet af den opdaterede model kvantificerer rovdyr-bytte-interaktionerne med hensyn til prædationsdødelighed, og hvor meget biomasse der er ædt, og bidrager som sådan til forståelsen af fødenettet for de kommercielle arter i Nordsøen.

Med det overordnede formål at demonstrere, hvor forskellige dele af dette projekts resultater kan anvendes til undersøgelse af forskellige forvaltningsscenarier, har vi udført et demonstrationsforsøg med trade-off-modellering af fiskeriers arealanvendelse af havbundshabitater og landingsværdier. Helt konkret har vi kombineret arealanvendelsen af de forskellige havbundshabitattypers (HSD BBHTs) kvalitative tilstand med økonomisk landingsværdi fra de forskellige kommercielle fiskerimétierer. Ud fra dette har vi identificeret, hvilke havbundshabitater der danner grundlag for de højeste fiskeriværdier, hvor og af hvilke fiskerimétierer forskellige fiskepladser deles, og hvor der er konflikter og direkte konkurrence mellem de eksisterende fiskerier.

En af forudsætningerne for, at områdelukninger til beskyttelse af havbundshabitater er miljømæssigt effektive, er inddragelse af data-baserede analyser af miljøtilstand og processer for hele økosystemet, der har betydning både lokalt og for andre områder regionalt. Dette omfatter blandt andet vurdering af det lukkede områdes potentiale til at opnå og bevare god miljøtilstand samt at kunne bidrage effektivt som donorområde med rekruttering til andre områder. Baseret på arealfordeling af fiskerier med bundslæbende redskaber analyserede vi tre forskellige scenarier for fiskerilukning på havbundsarealer af henholdsvis 10%, 30% og 75% af arealerne med de højeste til de lavere værdier af indikatorer Relative Benthic State (RBS) for hvert af Havstrategidirektivets havbundshabitattyper (Benthic Broad Habitat types, BBHTs) estimeret med data-baserede modeller for de to perioder, 2014-2016 (en periode af tre år) og 2017-2022 (to perioder af tre år). Arealerne med RBS-værdier ≥0,8 anses for at være i god miljøtilstand (GES); arealer med RBS fra <0,8 til >0,6 anses for at være i moderat ikke-god miljøtilstand (subGES moderate), og arealer med RBS ≤0,6 anses for at være i ikke-god miljøtilstand (subGES). Scenarieresultaterne viser, hvilken miljøtilstand havbundshabitaterne ville have haft, hvis areallukningerne var blevet indført lige efter den første periode (2014-2016). Endvidere undersøgte vi, hvilken miljøtilstand habitaterne ville have haft, hvis areallukningerne var blevet indført lige efter den anden periode (2017-2022). Det betyder, at et fald i gennemsnitlig RBS-værdi mellem de to simulerede lukningstidspunker indikerer, at en udskydelse af areallukning har en negativ påvirkning på habitatet, hvilket resulterer i en dårlige miljøtilstand.

I scenarie 1 undersøgte vi forholdene ved en 10% streng areallukning af havbunden relateret til Havstrategidirektivets Deskriptor D6 ”Havbundens integritet”, Kriterie 5 (C5) og Biodiversitetsstrategien for 2030 (BDS2030). Resultatet af et scenarie med en 10% areallukning af havbunden af arealer med de højeste RBS-værdier for hver havbundshabitattype (BBHT), viste RBS-værdier mellem 1-0,87 og i god miljøtilstand for de fleste habitater. Undtagelserne herfra var Øvre bathyal sediment (mudderbund på den dybe skrænt i Skagerrak) med gennemsnitlige RBS-værdier på 0,69 (moderat ikke-god miljøtilstand) i 2014-2016 og endnu lavere på 0,52 (ikke-god miljøtilstand) i 2017-2022. For perioden 2017-2022 ville en lukning svarende til scenarie 1 have reduceret de danske fiskeriers landingsværdi med ≤3.5% for hver havbundshabitattype, svarende til et total tab i landingsindtægt på ca. 1 mill. DKK, fordelt jævnt over habitattyperne Dyb circalittoral sand, Dyb circalittoral mudder and Øvre bathyal sediment i Jammerbugt området.

I scenarie 2 undersøgte vi forholdene ved en 30% areallukning af havbunden relateret til Biodiversitetsstrategien for 2030 (BDS2030) (dvs. 10% streng lukning og yderligere 20% generel lukning af havbunden). Resultatet af areallukningen viste ligeledes, at de lukkede arealer for de fleste havbundshabitater ville være i god miljøtilstand (gennemsnitlig RBS mellem 0,99-0,87). Dog viste beregningerne af lukningen af 30% af Dyb circalittoral sand, at den gennemsnitlige RBS-værdi ville være højere i den første periode (0,86 i 2014-2016) end i den anden periode (0,75 in 2017-2022) med et markant fald fra god-miljøtilstand til ikke-god miljøtilstand. Et scenarie med 30% lukning af Dyb circalittoral mudder viste en nedgang i gennemsnitlig RBS fra 0,75 i 2014-2016 til 0,54 i 2017-2022 svarende til en forværring af havbundshabitattypen fra moderat ikke-god til ikke-god miljøtilstand gennemsnitligt for de 30% af arealerne med de højeste RBS-værdier. En 30% lukning af Øvre bathyal sediment viste en nedgang i gennemsnitlig RBS fra 0,53 i 2014-2016 til kun 0,29 i 2017-2022, hvilket viser en væsentlig ændring til det værre fra en forringet til en forarmet ikke-god miljøtilstand gennemsnitligt for de 30% af arealerne med de højeste RBS-værdier. For perioden 2017-2022 ville dette 30% luknings-scenarie i Jammerbugt området have reduceret de danske fiskeriers landingsindtægt med ≤10% for de fleste havbundshabitattyper. Undtagen for Øvre bathyal sediment, hvor landingsindtægten ville være reduceret med

22,5%. Det total tab af de danske fiskeriers landingsindtægt fra Jammerbugt området er estimeret til ca. 12 mill. DKK. Scenarieresultatet viste, at de største tab af landingsindtægter knyttede sig til fiskerier på Dyb circalittoral sand (6,5 mill. DKK), mens en mindre del af tabt indtjening knyttede sig til fiskerier på Øvre bathyal sediment (1,8 mill. DKK).

I scenarie 3 undersøgte vi forholdene ved et scenarie, hvor fiskerier, der anvender en bundslæbende redskabstype uanset métier, potentielt betragtes som uforeneligt med opnåelse af Havstrategidirektivets D6, C5 Areal Tærskelværdi på ≥75% havbundsareal med god miljøtilstand. Dette lukningsscenarie for 75% af arealet af hver havbundshabitattyper viste gennemsnitlige RBS-værdier mellem 0,99-0,89 for de fleste havbundshabitater i Jammerbugt området. For nogle havbundshabitater viste et scenarie med en 75% lukning af Dyb circalittoral sand en væsentlig nedgang i gennemsnitlig RBS-værdi fra 0,65 i 2014-2022 til kun 0,44 i 2017-2022. Dette viser, at en forværring fra moderat ikke-god til ikke-god miljøtilstand i gennemsnit for de 75% af arealerne med de højeste RBS-værdier. Et scenarie med 75% areallukning af Dyb circalittoral mudder viste en nedgang i gennemsnitlig RBS fra 0,37 i 2014-2016 til kun 0,22 in 2017-2022, som viser, at der fra den ene periode til den anden ville ske en yderligere gennemsnitlig forringelse af ikke-god tilstand i de 75% af arealerne med de højeste RBS-værdier. En areallukning af 75% Øvre bathyal sediment viste en nedgang i gennemsnitlig RBS fra 0,45 i 2014-2016 til kun 0,17 i 2017-2022, hvilket er den ringeste miljøtilstand af alle for denne havbundshabitattype i Jammerbugt området. For perioden 2017-2022 ville scenarie 3 have reduceret den totale danske fiskeriindtægt med 30-62% afhængigt af métier og de fleste habitattyper. Det procentvise indtægtstab for Øvre bathyal sediment var højere, nemlig 72%. Men når man ser på det samlede tab for de danske fiskerier på 79 mill. DKK i Jammerbugt området ved scenarie 3, udgør Øvre bathyal sediment et mindre tab på 6 mill. DKK, mens lukning af Dyb circalittoral sand bidrager til godt halvdelen af tabet for de danske fiskerier, ca. 40,5 mill. DKK.

Det er værd at bemærke, at i alle tre scenarier af areallukning af havbundshabitater bidrog lukning af havbundshabitater (BBHTS) med de laveste miljøtilstande til de relative største procentvise tab af indtjening i danske fiskerier i Jammerbugt området. Derimod var det lukning af habitattyper og arealer med en bedre miljøtilstand, målt med RBS-indikatoren, der bidrog til de danske fiskeriers højeste indtægtstab målt i økonomisk værdi af landinger.

De økonomisk vigtigste fiskepladser for de forskellige métiers i den danske fiskerflåde er tæt koblet til havbundens habitattyper, helt generelt og også i Jammerbugt området. Habitaterne i de ydre dele af bugten består især af muddersedimenter. Her fiskes med forskellige danske bundtrawl efter målarter af krebsdyr (métier: OT_CRU) og bundlevende fisk (métier: OT_DEF). Desuden anvendes skotsk vod (SSD) og store snurrevod (SDN) til fiskeri efter bundlevende fisk. De mere kystnære habitater med sand og grove sedimenter (grus) i den indre og sydlige del af Jammerbugten fiskes af mindre danske trawlere efter bundlevende fisk og ind i mellem efter bløddyr. De mindre danske snurrevodsbåde fisker traditionelt især efter rødspætter på de kystnære og centrale havbundshabitater med sand- og grusbunde i Jammerbugten.

Den centrale del af Jammerbugten er karakteriseret ved en for Danmark særlig høj grad af mosaikstrukturer af forskellige habitattyper bestående af sand, grus, småsten og store sten og mange stenrev og stengrunde med blandede sedimenter med groft grus og sten og stenrev, der sammen med en høj topografisk og hydrografisk kompleksitet danner helt særlige forhold i området. Denne central del af Jammerbugten med blandede habitater af stenrev, grus og sand udgør de vigtigste fiskepladser for de små danske garnbåde (GNS), der især fisker på og ved revene efter torsk og andre højværdifisk, og for de mindre snurrevodsbåde (SDN), der især fisker efter fladfisk på de sandede grunde mellem revene. Disse to fiskerimétierer er karakteriserede ved at have en relativ lav påvirkning (bl.a. lav bundfaunadødelighed) på de habitattyper, de fisker på. På grund at fiskerbådenes mindre størrelse og motorkraft er de afhængige af at kunne fiske på disse kystnære fiskepladser. I den centrale del af Jammerbugten er der også nogle få danske bomtrawlere (TBB), der fisker efter målarter af bundlevende fisk med en større påvirkning på de sandbundshabitater, de fisker på.

Vi estimerede trade-offs mellem havbundsindikator relateret til områdelukning, inklusive arealet af hver havbundshabitattype (BBHT) og biologisk kvalitet (mål med RBS-indikatoren), og de danske fiskeriers arealanvendelse af havbundshabitater som fiskepladser og den tilknyttede værdi af landingerne fra de disse. Resultaterne fra de forskellige scenarier for områdelukning viser, hvordan man ved kombinerede analyser af miljødata og socio-økonomiske data kan vurdere komplekse areal- og tidsmæssige sammenhænge. I disse retrospektive scenarioer var fokus på trade-off vurderinger mellem udnyttelse af økosystemernes ressourcer og hensyn til miljøpåvirkninger og beskyttelseskrav og de potentielle tab af henholdsvis miljøtilstand af havbundens habitattyper og af direkte landingsværdi i fiskerierne ved forskellige forvaltningsmuligheder for areallukning af fiskeri med bundslæbende redskaber. Trade-off scenarier kan også bidrage til dialog mellem forskellige interessenter om, hvordan man kan opnå og sikre robuste økosystemer og udvikle bæredygtige fiskerimetoder og forbedre forvaltningen af marin natur og ressourcer i danske farvande.

De samme fiskepladser benyttes intensivt af udenlandske fiskefartøjer, der anvender bomtrawl med kædemåtter eller kraftige kæder (BBT) eller skotske vod (også kaldet fly-shooting) (SSD). Disse fiskepladsers betydning for de udenlandske fartøjers fiskeri i Jammerbugt (og i hele den danske eksklusive økonomiske zone (EEZ) kan ikke vurderes økonomisk og miljømæssigt for de enkelte fartøjer, fordi udenlandske fartøjers VMS- (Vessel Monitoring System) og logbogsinformationer om deres fiskeri i den danske EEZ ikke er direkte tilgængelige for de danske myndigheder. Det var derfor ikke muligt at lave en komplet vurdering af de udenlandske fiskeriers totale landinger og uønsket udsmid (discard) i Jammerbugt området. Dette omfatter især den manglende adgang til data for redskabstype, målarter, landingsvægt og landingsværdi, men også bifangst af illegale og andre uønskede arter, herunder også sårbare arter (såkaldte PETS). I stedet anvendte vi AIS data til at estimere arealfordelingen og hyppighed (målt som Swept Area Ratio, SAR) for de ikke-danske fartøjer. Blandt udenlandske fartøjer var det især store bomtrawlere og fly-shootere, der påvirkede store områder med høj intensitet (høje SAR værdier), særligt i de centrale dele af Jammerbugt området. Ud fra de samlede resultater kan det antages, at de udenlandske fartøjers landinger og udsmid, ligesom deres påvirkning af havbundens habitater, er af et omfang, der kan have negativ påvirkning af økosystemet og fiskeriressourcerne i hele Jammerbugt området.

1. Introduction

A combination of declining fishing opportunities due to BREXIT and declining fish stocks in the Greater North Sea challenged the Danish fisheries sector. BREXIT created uncertainty for the sector and caused a significant loss of quota on several species. Declining fish stocks on the traditional fishing ground due to changes in species distribution and general reduction of some fish populations. Ecosystem and climate changes exacerbate the negative influence on the earning potential for the fisheries sector. This made it necessary to investigate causes and opportunities to inform and help develop ecosystem-based management (EBM). Implementation of the EU MSFD requires development of EBM to achieve good environmental state (GES) ecosystems of European seas. The EU CFP must ensure that fish populations are restored and maintained at levels that secure long-term use for the benefit of society and contribute to food provisioning.

The aims of this project in the Jammer Bay are to: i), geophysically map the seabed substrates and habitats (full coverage in focus area: 304 km2; along transect lines in the screening area: 5,230 km2); and further, for the screening area, to ii), analyse and map the impacts of all individual mobile bottom-contacting gear types on the seabed habitats, as well as their environmental and climate-related impacts; iii), analyse and map the state of benthic habitat biodiversity and ecosystem functioning and quantify the causal relations to impacts from beam trawls and other mobile bottom-contacting gears; iv), analyse the fisheries resources and socio-economic effects and value chains of all modes of fisheries operating in the Jammer Bay; and v), assess sustainability and trade-offs between fish distribution, socio-economic values, and fisheries impacts on the environmental state of the Benthic Broad Habitat Types (BBHTs) under the Marine Strategy Framework Directive (MSFD).

All analyses and model development will be based on existing data and new sampled data for seabed habitat extent and distribution, fisheries physical and biological impacts on seabed habitats and the ecosystem, and fisheries resources and socio-economic value-chains in the Jammer Bay area (Fig. 1.1).

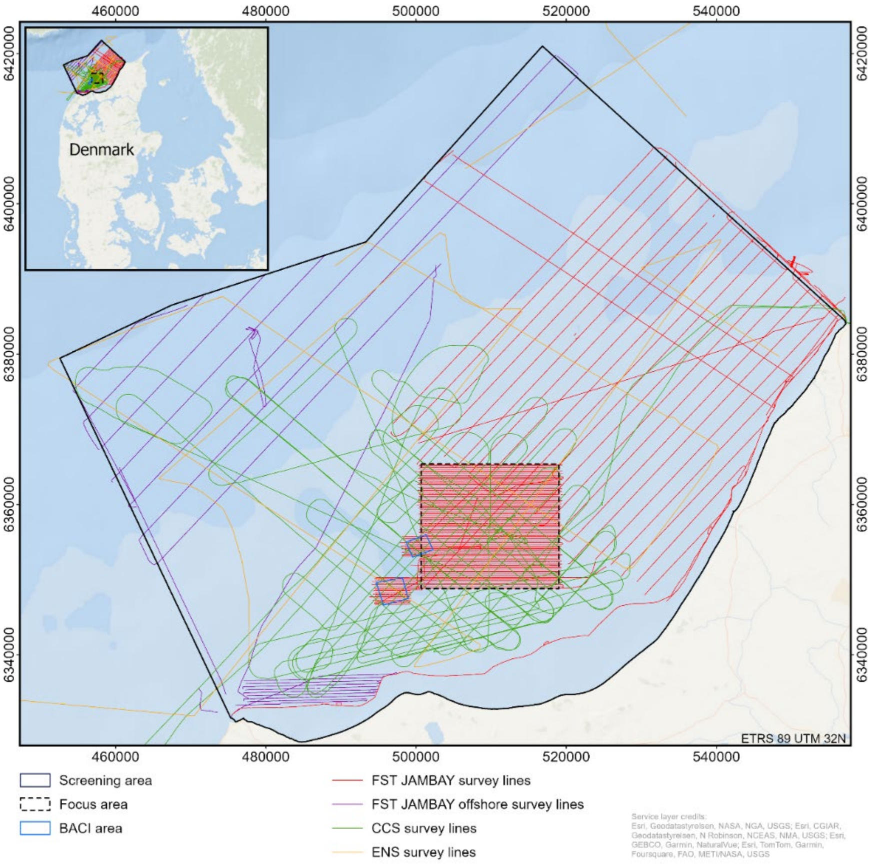

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Figure 1.1. Structure of the project JAMBAY.

The project tasks are grouped into five work packages (WPs):

WP1. Geophysical mapping of seabed substrates and habitats,
WP2. Physical fisheries impacts on seabed habitats,
WP3. Biological fisheries impacts on seabed habitats,
WP4. Fisheries resources and socio-economy,
WP5. Synthesis for ecosystem-based management, dissemination, and project management.

A diagram of the project structure including the Tasks within each WP is given in Fig. 1.2.

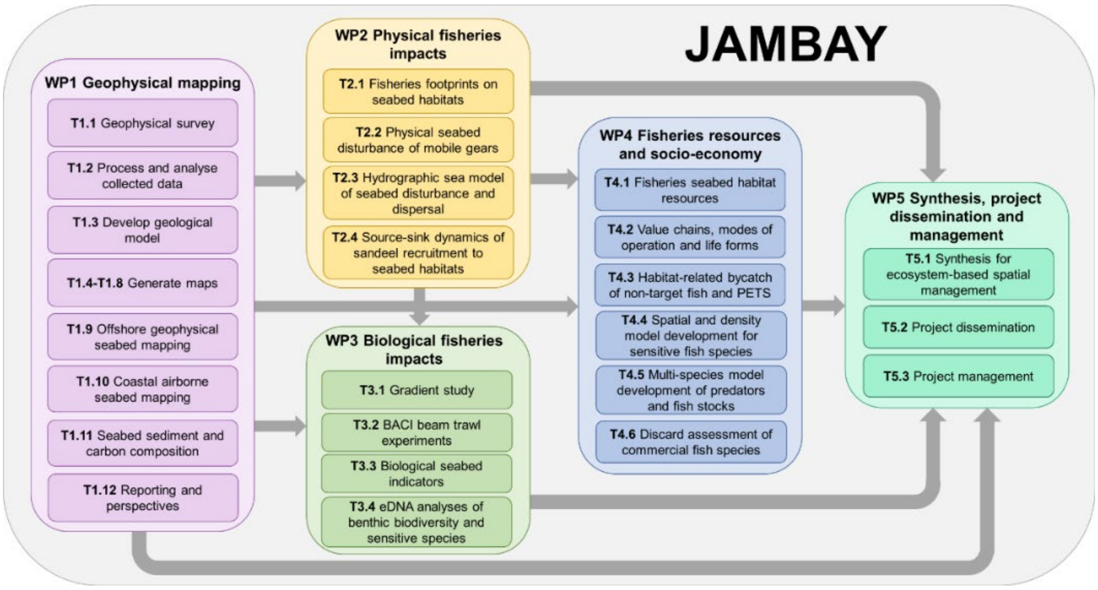

Figure 1.2. Structure of the project JAMBAY.

2. Geophysical mapping (WP1)

2.1 Introduction to WP1

Seabed geology, morphology and substrate constitute the overall components of seabed geodiversity and form seabed habitats and foundation for benthic flora and fauna.

The aims in WP1 were i), to map the seabed within the Jammer Bay Focus area – in the central part of the Jammer Bay – in high spatial resolution and precision, and with full spatial data coverage, in order to create a foundation for analysing the impact of various types of bottom trawling on the seabed surface; and ii), to map the seabed within the Jammer Bay Screening area – covering the area between Hanstholm and Hirtshals from the 10 m depth curve to the EEZ border – in high spatial resolution and precision along the survey lines, with data gaps between survey lines, in order to assess the spatial distribution of seabed substrates and habitats within the Jammer Bay Screening area.

2.2 Geophysical survey (Task 1.1)

Lars Ø. Hansen, Mikkel S. Andersen, Lars-Georg Rödel, Sigurd B. Andersen, Isak R. Larsen, Silas Clausen, Zyad Al-Hamdani, Verner B. Ernstsen

The aim of Task 1.1 was to plan and conduct a geophysical survey using vessel borne multibeam echosounder, side scan sonar and sub-bottom profiler systems. New geophysical data were acquired with side scan sonar (SSS) and multibeam echosounder (MBES) which provided information on substrate and morphology of the seabed surface and with sub-bottom profiler which provided information on the shallow subsurface geology. The survey area was divided into two sub-areas: a Focus area (incl. BACI areas) with 200 m line spacing and a Screening area with 2,000 m line spacing, including two normal to shore parallel lines extending to the EEZ border.

The instruments used for the geophysical survey comprised a pole-mounted Edgetech 6205 combined bathymetry and side scan sonar, a towed Edgetech 4205 side scan sonar, a pole-mounted Innomar SES-2000 medium sub-bottom profiler and an R2Sonic 2024 multibeam echosounder. Primary position and motion were delivered by an SBG Navisight Ekinox GNSS/INS system with an Applanix POSMV Wave Master as backup. Motion input for the sub-bottom profiler was delivered by an SMC IMU-108. Sound velocity profiles were initially measured with a Valeport miniCTD, which was later replaced by a Valeport SWIFT SVP.

Data were collected in the period between 5 June and 21 June 2023. Based on the vessel track line (see Fig. 2.1), including instrument test and calibration lines, turns, and recorded transit lines, a total of 3.255 line-km were completed. Approximately half of the line-km (~1.700 km) were recorded inside the Focus area.

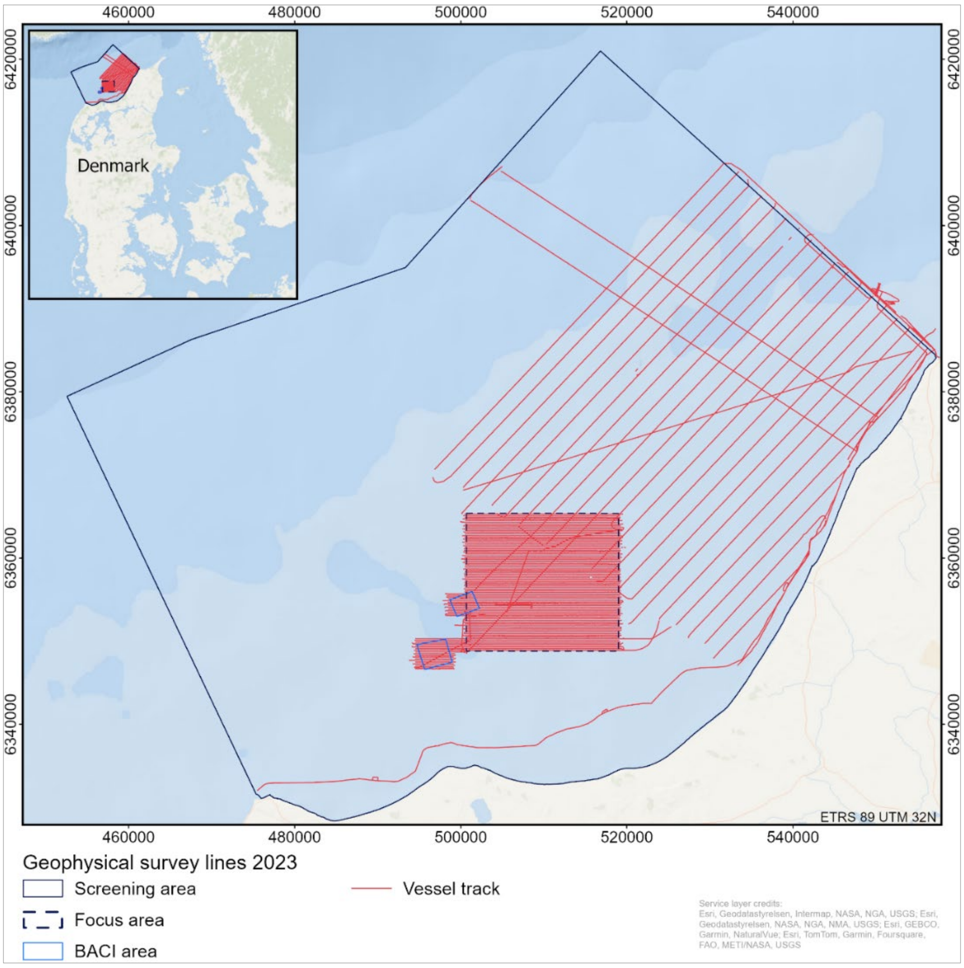

Figure 2.1. Vessel track lines exported from the MBES. Screening and Focus area survey, June 2023.

2.3 Processing and preparation of data (Task 1.2)

Lars Ø. Hansen, Mikkel S. Andersen, Zyad Al-Hamdani, Niels Nørgaard-Pedersen, Nicklas Christensen, Jørgen O. Leth, Sofie Koustед, Isak R. Larsen, Silas Clausen, Jacob R. Jørgensen, Verner B. Ernstsen

The aim of Task 1.2 was to process and prepare the geophysical data for interpretation and generation of maps and models as described in Tasks 1.3-1.8.

Two side scan systems were acquiring data simultaneously during the survey, one was pole-mounted (mostly useful in shallow water), and the other was towed behind the survey vessel (essentially used in deeper water). This setup has its advantage when e.g. one of the side scan systems is not producing optimal side scan images (e.g. due to noise in the water column or in the system). The high and low frequency side scan datasets were loaded to and analysed with the SonarWiz V7 software. The towed side scan data were first corrected for layback using the build in algorithm in the software and the cable-out data registered during acquisition. Subsequently, the side scan imagery positions were fine-tuned and adjusted using data obtained from the multibeam system that produces highly accurately positioned data. The side scan data were then corrected for the water column and the detection of the first seabed return signal using the “bottom track” module in SonarWiz. The software provides different methods for adjusting the setting of the side scan imagery. In this work, we initially applied Empirical Gain Normalisation (EGN), so the side scan image is balanced in intensity across the image swath. When that was not optimal for interpreting the stones distribution across the side scan swath, we applied User-define Gain Control (UGC) and changed the Time Varying Gain (TVG) setting to enhance the side scan image.

The sub-bottom profiler data i.e., Innomar RAW files, were converted into SEG-Y format with Innomar SES Convert software to be used with post-processing software. Depending on data quality (especially wave motion influence/heave compensation), SEG-Y data with insignificant wave motion noise were imported directly to Kingdom seismic interpretation software for further analysis. More noisy data sets were processed with Geosuite Allworks software using trace equalisation, median filter, two times swell filter and time varying gain. Hereafter processed data were likewise imported to Kingdom seismic interpretation software.

The multibeam echosounder data were post-processed in QPS Qimera 2.5.4 software. Post-processing in Qimera is based on sounding editing and a dynamic surface model that continuously updates when an edit is applied. Post-processed kinematics (PPK), i.e. Precise Point Positioning (PPP) solutions were postprocessed in Qinertia software using the SBG Navsight Ekinox navigational data as input to generate SBET (Smoothed Best Estimate of Trajectory) files. The aim of this was to improve the reference point (RP) GNSS positioning by replacing the Real-Time Kinematic (RTK) solution, which frequently drifted during the survey due to signal strength and coverage, with the SBET solution. Sound velocity profiles (SVP) were tied to the sounding files to correct for beam refraction. The SVPs were designated based on spatial and temporal closeness, i.e. the SVP closest in distance and time to a given sounding. A set of automatic filters were applied followed by manual cleaning to remove outliers. The processing steps for MBES data are in Fig. 2.2 as an example.

The acquired side scan .jsf files were imported to the SonarWiz software as .csf files. The .csf files were stored in the SonarWiz project file for interpretation of substrates and human activity (Task 1.7). The processed side scan files were then exported as geotiff side scan mosaic files (georeferenced image files), to be presented and viewed on a GIS platform.

Processed sub-bottom profiler data were imported to Kingdom seismic interpretation software. Seismic units were traced by marking interpreted seismic unit boundaries including the seabed. Unit thicknesses were calculated from two-way travel time data (ms) assuming a constant seismic velocity of 1600 m/s in the unconsolidated sediment sequence. Thickness data were gridded in Kingdom software and exported as grid files for GIS mapping and presentation software.

The accepted soundings of the multibeam echosounder data were exported in ascii xyz format and used to build the bathymetric models.

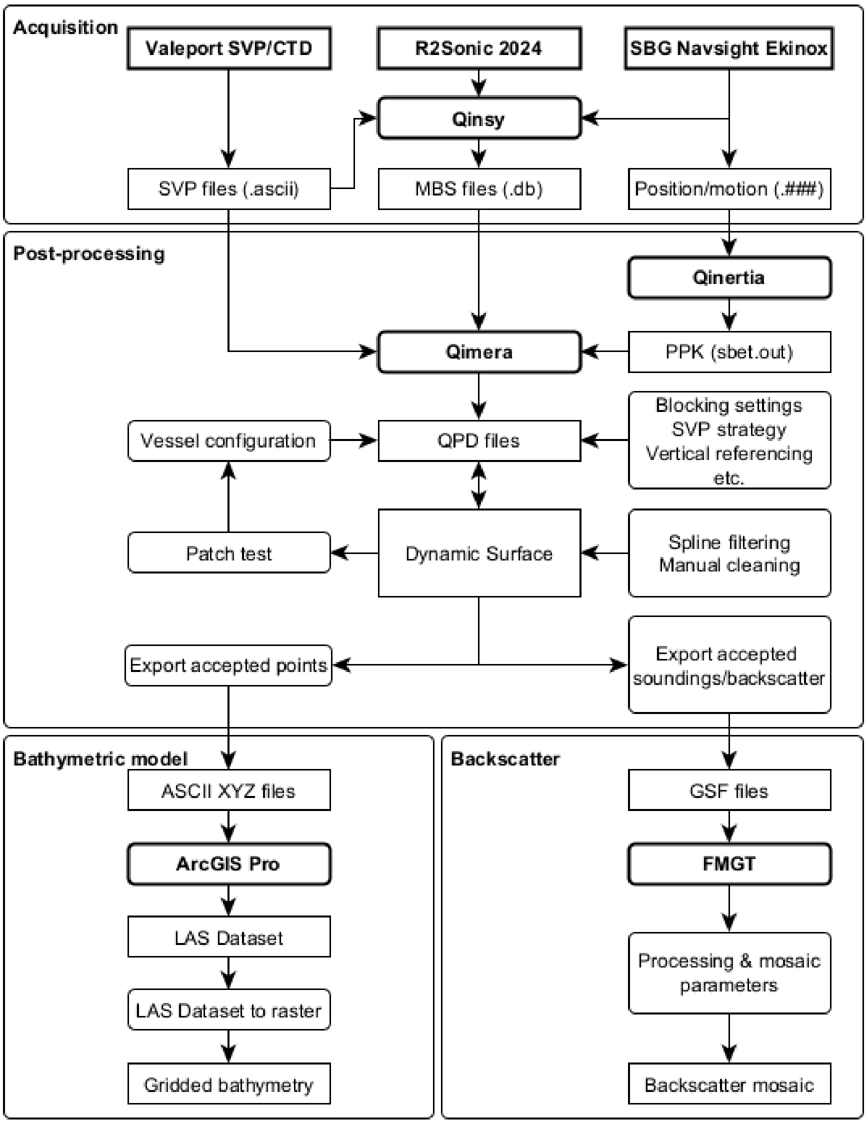

Figure 2.2. Flow chart illustrating the processing steps from acquisition to final products of the multibeam sonar data.

2.4 Geological model (Task 1.3)

Niels Nørgaard-Pedersen, Nicklas Christensen, Jørgen O. Leth, Sofie Kousted, Mikkel S. Andersen, Lars Ø. Hansen, Peter Sandersen, Zyad Al-Hamdani, Verner B. Ernstsen

The aim of Task 1.3. was to develop a geological model of the Jammer Bay. The acquired sub-bottom profiler (SBP) data were integrated with existing seismic data with deeper penetration (Sparker and TOPAS SBP acquisition) and sediment core data to develop a unifying geological model for the entire Jammer Bay area. Seismic interpretation of the data substantiated by vibrocore groundthruthing was the backbone for development of the geological model.

The development of the seismic model was done in the seismic interpretation software IHS Kingdom suite version 2019. The sparker data and selected parts of the SBP data were processed with GeoSuite Allworks software to improve data quality and reduce noise. After processing, sparker data were exported in SEGY format and imported in IHS Kingdom seismic interpretation software for stratigraphic analysis. The seismic interpretation included identification and tracking of stratigraphic boundaries between major stratigraphic units.

Five units were identified (Unit A-E from youngest to oldest) in the available sub-bottom profiler and Sparker seismic data. Unit A, C and D are present across the whole area. Unit B is confined to the northern and deeper part of the Jammer Bay and close to Hanstholm. Unit E can only be identified in the southern parts of the Jammer Bay due to the limited seismic penetration. The geological age and depositional environments of the units were estimated based on existing knowledge from the North Sea to the south of the Jammer Bay (Jensen et al., 2010), onshore radiocarbon and luminescence dating (Larsen et al., 2009), and content of macrofossils in vibrocores.

Figure 2.3 shows a conceptual geological cross-sectional model with identified geological units A-E. The model explains the distribution of characteristic seismic/geological units in the context of existing knowledge of the late Quaternary geological history and the related relative sea level changes in northern Denmark.

This study has revealed that the shallower part of the Jammer Bay has expanded considerably to the west and north due to marine sediment transport and deposition along a growing wedge adjacent to higher-lying pre-quaternary and glacial deposits. This explains the absence of stone reefs in a large part of the outer the Jammer Bay.

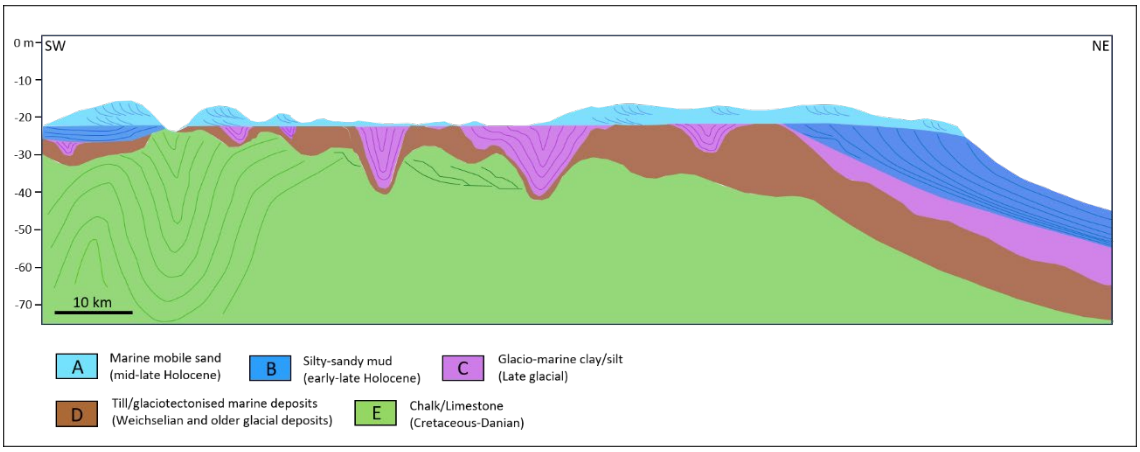

Figure 2.3. Conceptual geological cross section of the Jammer Bay showing major stratigraphic units (A-E) in the upper 50 m below seabed.

2.5 Seabed sediment thickness maps (Task 1.4)

Nicklas Christensen, Niels Nørgaard-Pedersen, Jørgen O. Leth, Sofie Kousted, Mikkel S. Andersen, Lars Ø. Hansen, Peter Sandersen, Zyad Al-Hamdani, Verner B. Ernstsen

The aim of Task 1.4 was to generate seabed sediment thickness maps based on sub-bottom profiler data. Detailed shallow seismic mapping of characteristic sediment units in combination with seabed sediment cores enable the mapping of the thickness of different geological units in 2D and 3D.

Seismic data from new and existing surveys were processed and interpreted by tracing major seismic boundaries, corresponding to seismic unit tops and/or bases. The following units were identified: Prequaternary (mainly chalk), Glacial, Late Glacial, Early Holocene, and Mid-late Holocene (mobile sand). To determine thicknesses of the individual units, the traced horizons (xyz data) were gridded in IHS kingdom suite with the flex gridding algorithm. The horizon grids were converted from two-way-travel time to depth using an average sound velocity of 1,600 m/s for the sediments above the glacial till.

Detailed thickness maps of unit A (mid to late Holocene mobile sand, see Fig. 2.4) and unit C (late glacial deposits) were calculated in the Focus area. In the Screening area, the spatial resolution of the thickness maps is lower, and the uncertainty is higher because of increased line spacing and interpolation.

Mapping the thickness of late glacial typically fine-grained sediments revealed that they appear to be confined to valley-like depressions in the glacial landscape. High data density in the Focus area and parts of the surrounding area enabled detailed mapping of a large late glacial infilled valley or channel with smaller bifurcations, reminiscent of a fluvial drainage system. It is assumed that the late glacial infill represents glaciomarine sediments deposited during relatively high sea level due to the dominant conform character of the fine stratified sediment infill in the valley system.

The thickness distribution of the mobile sand unit in the Jammer Bay shows large coherent areas of thick mobile sand and other areas almost devoid of mobile sand. The distribution likely reflects areas of prolonged sand deposition and accumulation and other areas dominated by erosion and sediment bypassing. The large and thick sand structures on the northwestern margin of the Jammer Bay appear in the mid-late Holocene to have built out on top of the advancing wedge of clinoform structures found on the slope towards deeper water, where accommodation space was available. Large areas in the central Jammer Bay and off Lønstrup and Hirtshals that are characterised by relatively small and thin sand layers with intervening areas of glacial till and late glacial clayey sediments right under the seabed are likely exposed to erosion and sediment bypassing.

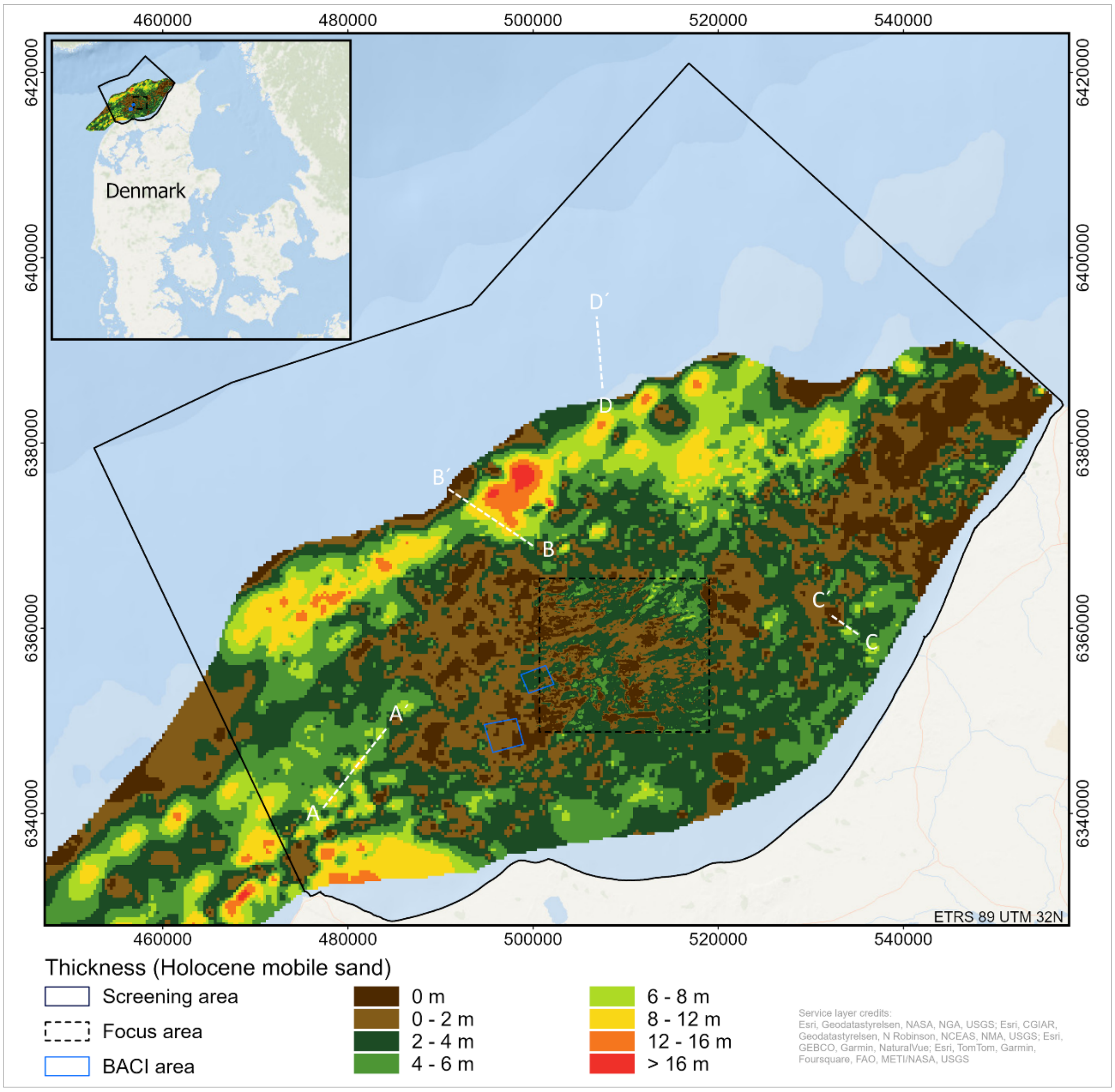

Figure 2.4. Thickness map of the mid-late Holocene sand unit A. The cell size is 20 m in the Focus area and 200 m in the Screening area.

2.6 Bathymetric maps (Task 1.5)

Lars Ø. Hansen, Mikkel S. Andersen, Zyad Al-Hamdani, Nicklas Christensen, Verner B. Ernstsen

The aim of Task 1.5 was to generate bathymetric maps based on multibeam echosounder data.

Bathymetric models, or Digital Elevation Models (DEMs), generated from multibeam echosounder (MBES) data provide information on depth and seabed morphology which is useful in relation to e.g. substrate and habitat mapping as well as geomorphological interpretation and mapping.

The accepted soundings exported in ascii xyz format served as input for production of raster DEMs. The DEM z-values were computed as the mean of all point z-values within each raster grid cell. The actual grid cell size of the DEMs was determined from considerations of point density, along-track sounding spacing, and beam footprint size. The DEMs were produced using ArcGIS Pro.

Two bathymetric models were generated, one covering the Focus area (see Fig. 2.5) and one covering the Screening area. The grid cell resolution was 1 m x 1 m based on the above-mentioned considerations determined for the Focus area.

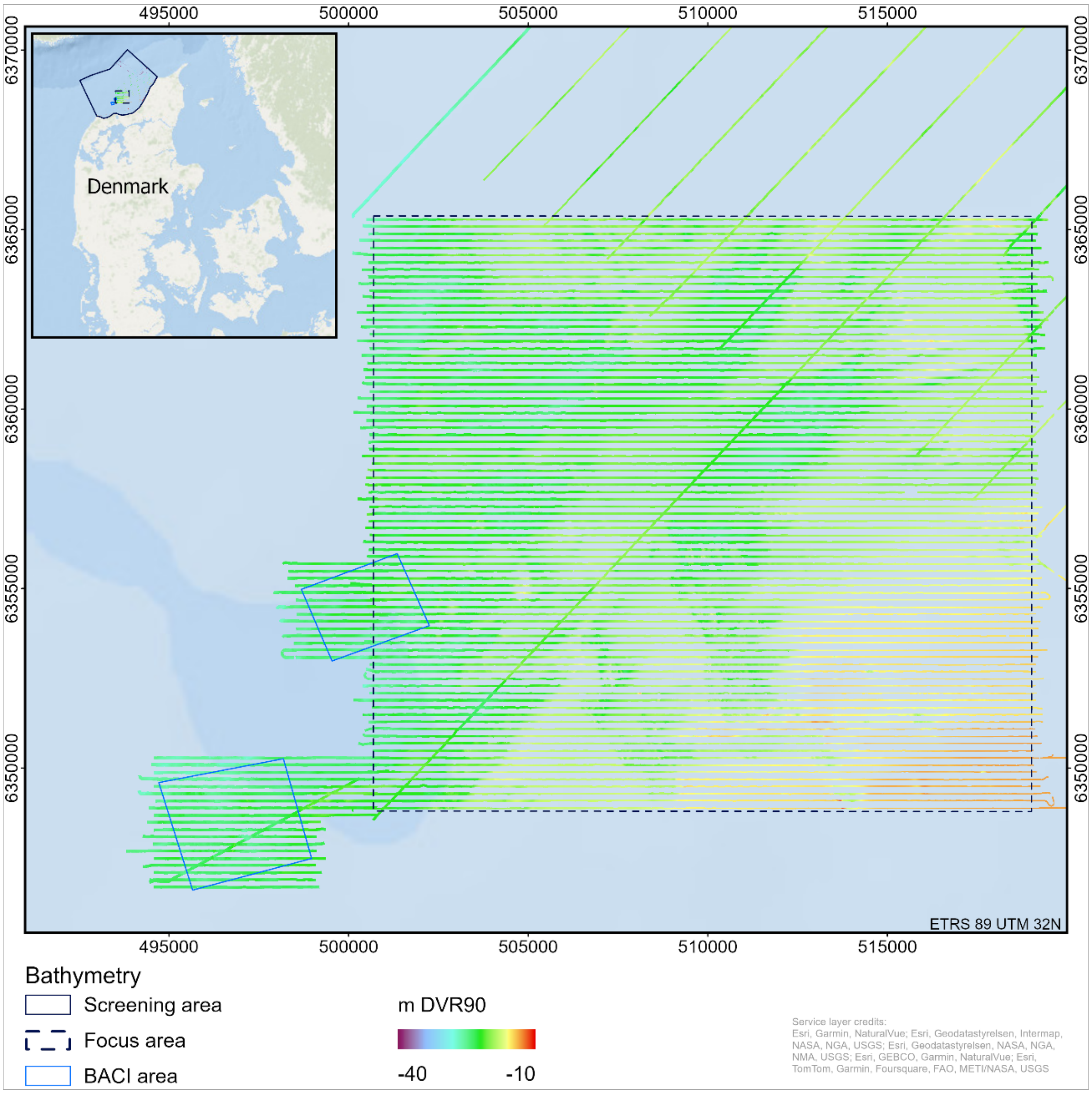

Figure 2.5. Bathymetric map of the Focus area (1 m x 1 m grid cell resolution).

2.7 Seabed morphometric and morphological maps (Task 1.6)

Lars Ø. Hansen, Mikkel S. Andersen, Zyad Al-Hamdani, Verner B. Ernstsen

The aim of Task 1.6 was to generate seabed morphometric and morphological maps based on multibeam echosounder data, supported by side scan sonar and sub-bottom profiler data.

Two distinct DEM-derived geomorphometric entities are surface parameters and surface objects (Pike et al. 2009). These entities can provide information for the delineation and characterization of benthic habitats (Wilson et al. 2007). A surface parameter is a measure of surface form such as slope, curvature, aspect, or rugosity, whereas a surface object is a discrete spatial feature such as a ridge or depression. Morphometric and morphological maps support substrate and habitat interpretations and mapping as described in Tasks 1.7 and 1.8.

DEM-derived seabed surface parameters of slope (see Fig. 2.6), curvature, and aspect (see Fig. 2.7) were generated in ArcGIS Pro using the *surface parameters* tool in the Spatial Analyst toolbox. Slope is a measure of the rate of change in elevation. Aspect is a measure of the downslope direction with the maximum rate of change. Curvature is referred to as the slope-of-slope and measures the convexity/concavity of the surface. Two types of curvature were computed i.e., profile curvature, which is parallel to the direction of maximum slope, describing the rate of change of slope, and the tangential curvature, measures the rate of change perpendicular to the direction of maximum slope.

The morphology of the seabed was mapped using a semi-automatic approach to landform mapping, i.e., Geomorphon Landforms tool in ArcGIS Pro. The geomorphon landform classification was introduced by Jasiewicz and Stepinski (2013) and applies an algorithm that combines elevation differences and visibility concepts to classify terrain into 10 different landforms.

The resulting morphometric and morphological maps provide valuable information for delineation and characterization of the mapped habitats. Whereas slope was used as direct input for delineating sandbanks in Task 1.8.

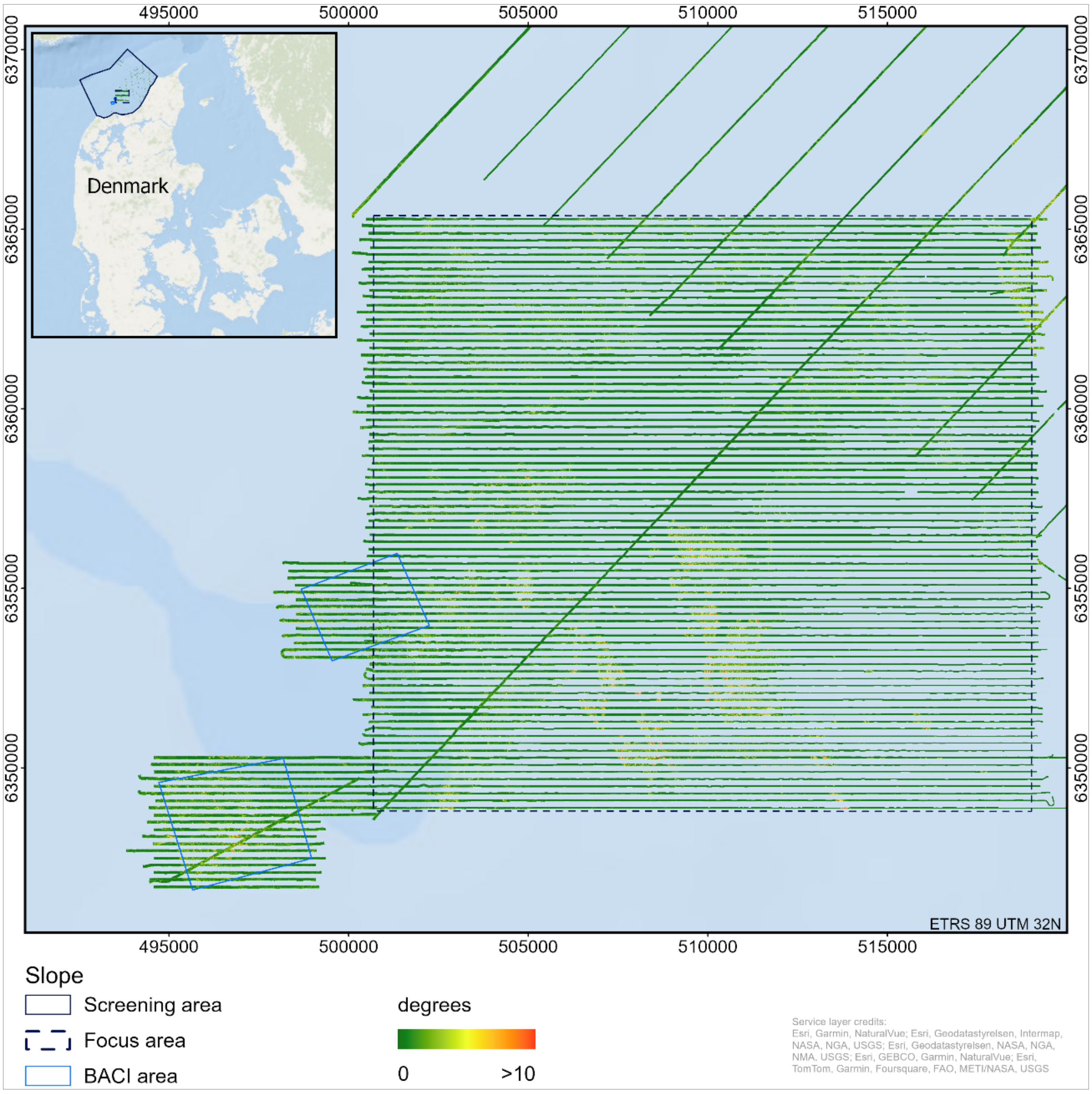

Figure 2.6. Slope map of the Focus area (1 m x 1 m grid cell resolution).

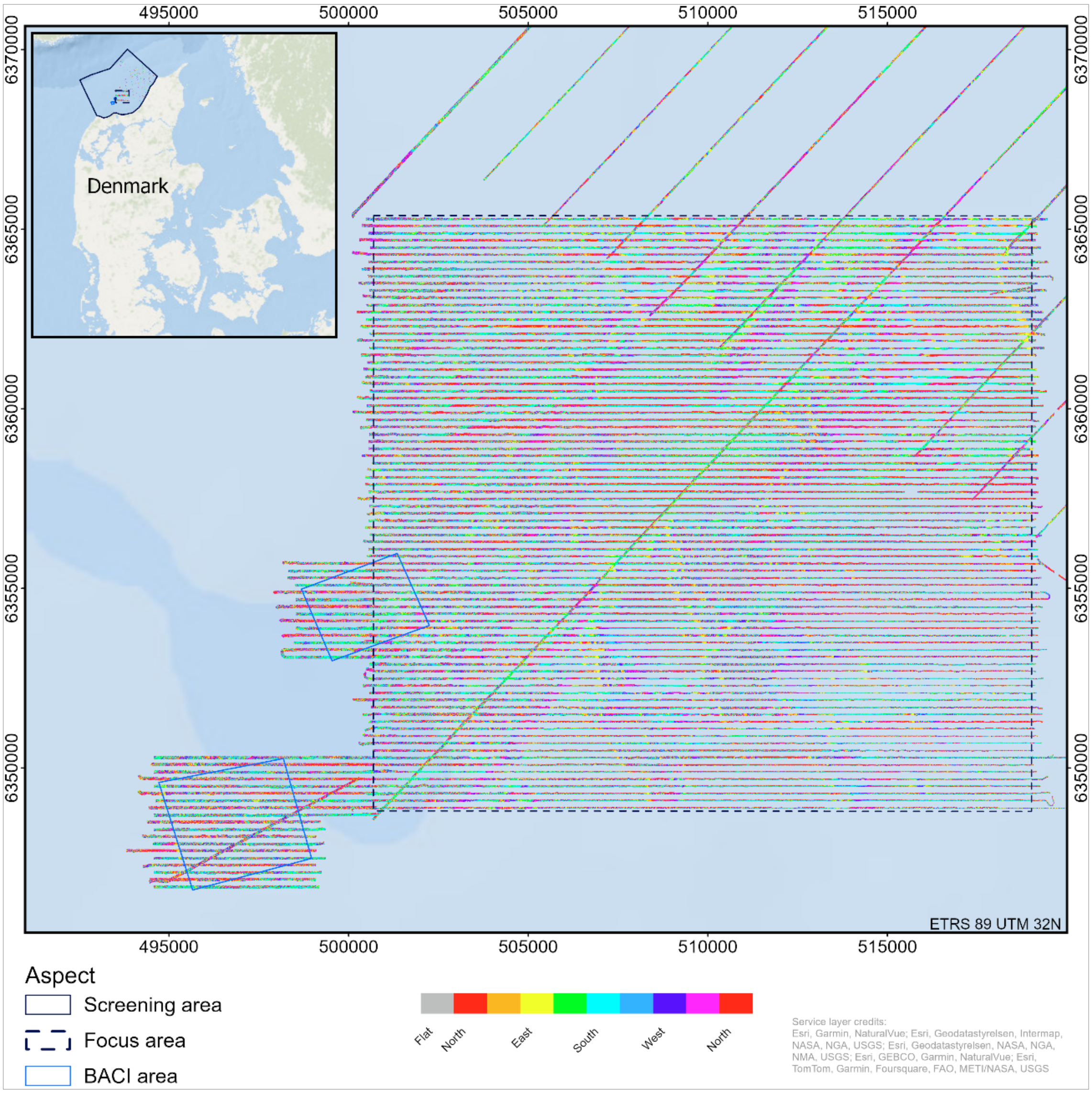

Figure. 2.7. Aspect map of the Focus area (1 m x 1 m grid cell resolution).

2.8 Seabed substrate maps (Task 1.7)

Mikkel S. Andersen, Zyad Al-Hamdani, Isak R. Larsen, Silas Clausen, Jakob R. Jørgensen, Lars Ø. Hansen, Niels Nørgaard-Pedersen, Nicklas Christensen, Jørgen O. Leth, Verner B. Ernstsen

The aim of Task 1.7 was to generate seabed substrate maps based on side scan sonar data, supported by multibeam bathymetry and backscatter data and sub-bottom profiler data, and in combination with knowledge from existing data. Seabed substrates were classified according to the classification system of the Danish Environmental Protection Agency (Miljøstyrelsens substrat-typer in Danish) (Naturstyrelsen 2012). It was also an overall aim of the project to analyse and map the impacts of all individual mobile bottom-contacting gear types on seabed habitats. Hence, trawl marks and other signs of human activities were also mapped based on interpretation of the acquired side scan and multibeam data.

The mapping of seabed substrates in the Jammer Bay was based on 1), Interpretation of geophysical data acquired as part of the JAMBAY project (Task 1.1); 2), interpretation of geophysical data acquired as part of another survey conducted by GEUS for the Danish Energy Agency (ENS); and 3), knowledge from existing data acquired in previous surveys. Data from three different types of instruments were used for the classification of seabed substrates, i.e. side scan sonar, sub-bottom profiler, and multibeam echosounder. The primary data for substrate interpretation was the side scan data as the intensity of the reflected signal from the seabed is directly related to the material and geometry of the seabed.

The mapping of human activity was carried out by manual interpretation of the geophysical data, particularly the side scan data in combination with the multibeam bathymetry data.

The mapped seabed substrates show a diverse spatial distribution of soft and hard substrate types throughout the survey areas (see Figs. 2.8 and 2.9 and Table 2.1). The most dominant substrate types are 1b (sand) covering ~354 km^2 (62% of the mapped area), and 2a (sand, gravel and pebbles) covering ~135 km^2 (24% of the mapped area). Substrate types 4, 3 and 2b (all containing stones larger than 10 cm), together cover ~67 km^2, corresponding to 12% of the mapped area.

An area of 22 km^2 was mapped as trawl marks, of which most were found in the northern part of the Jammer Bay in the Screening area (see Fig. 2.10). Only few trawl marks were found in the Focus area. Five wrecks were observed as well as a few traces from pipelines.

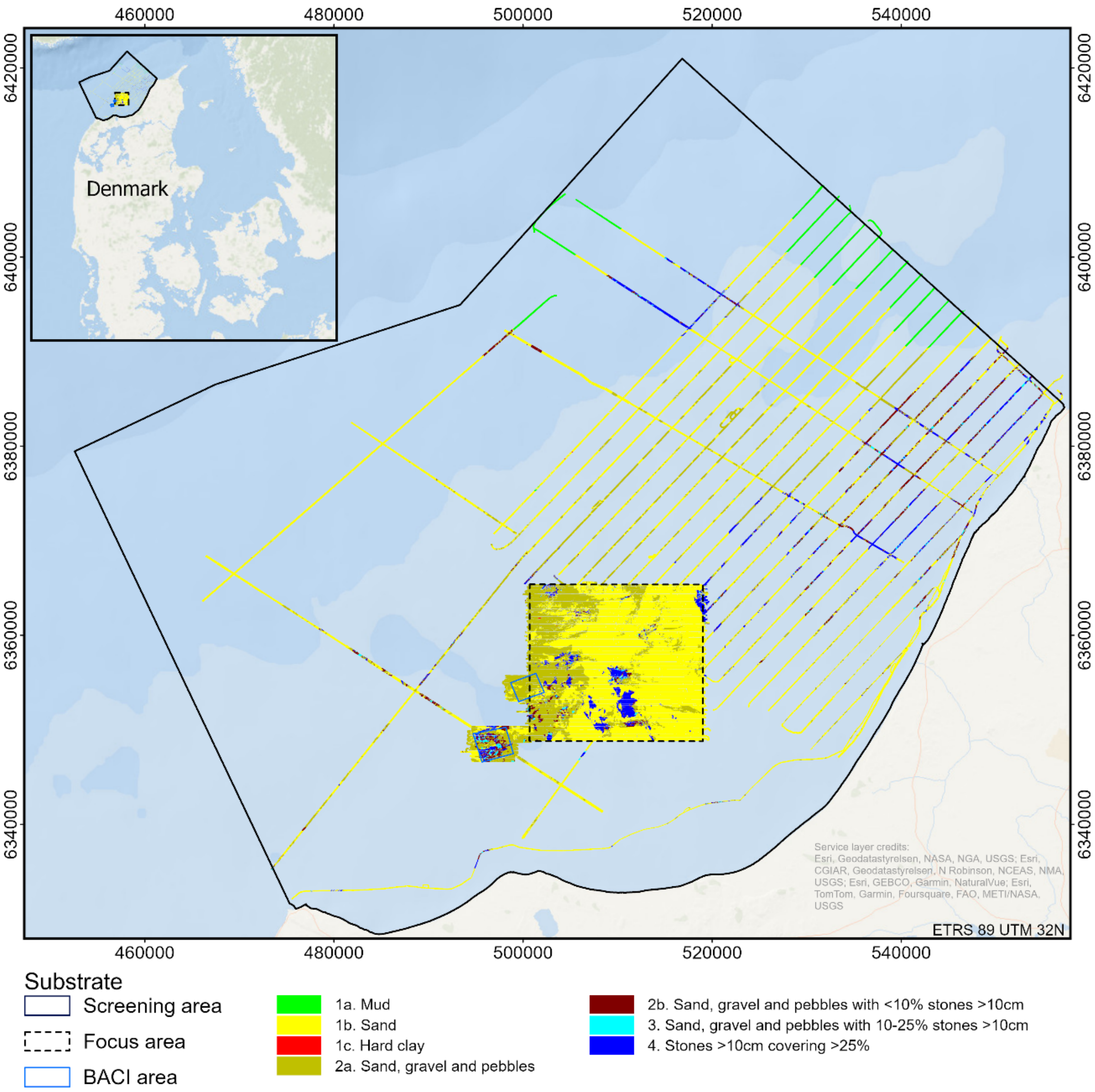

Figure 2.8. Mapped seabed substrates in the Screening area and Focus area.

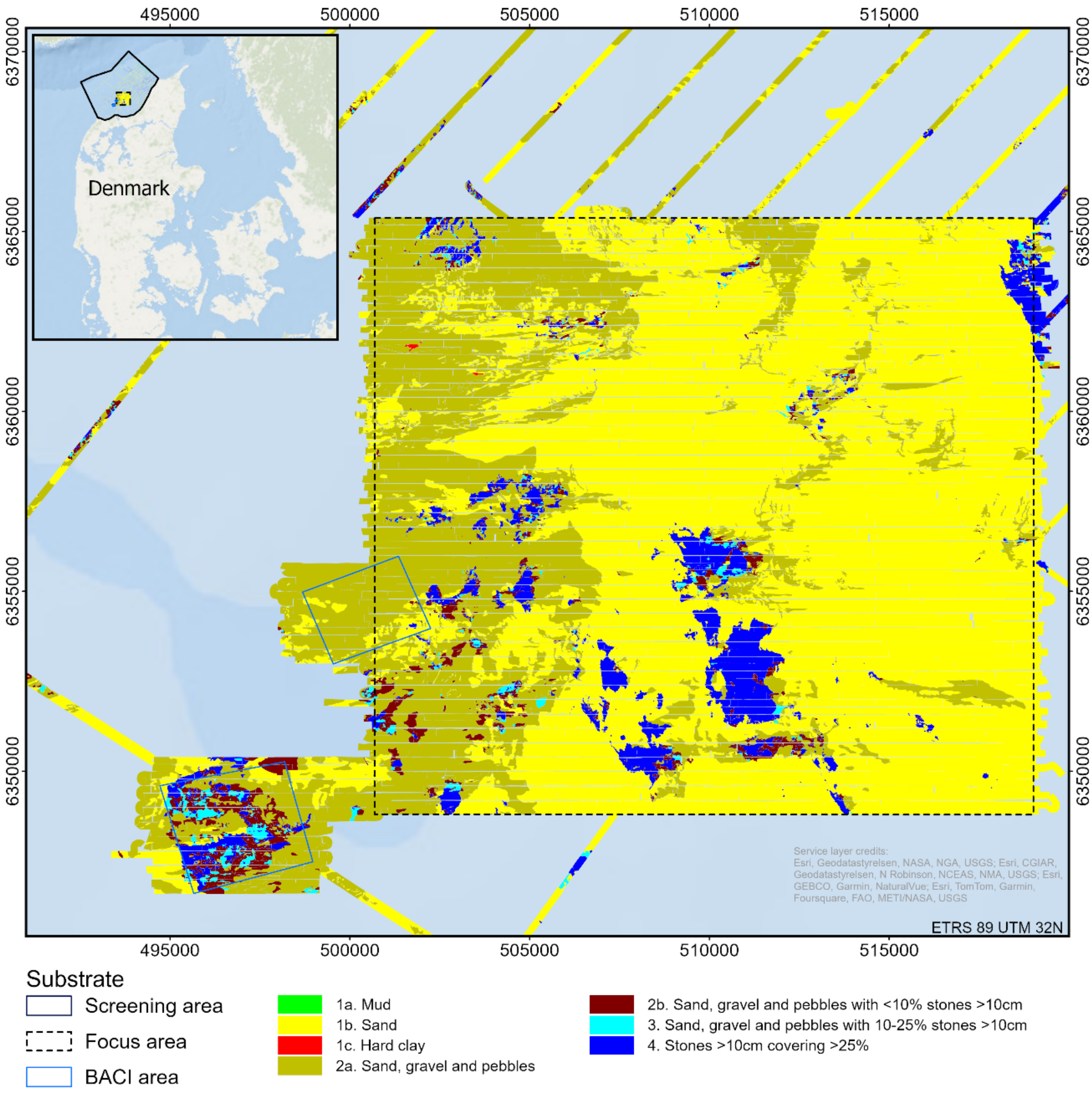

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Figure 2.9. Zoom in on the mapped seabed substrates in the Focus area.

Table 2.1. Areal coverage of each of the mapped seabed substrate types.

	Focus area + BACI			Screening area		
Substrate	**Area (m^2)**	**Area (km^2)**	**Area (%)**	**Area (m^2)**	**Area (km^2)**	**Area (%)**
1a. Mud	0	0	0	17,998,969	18	7
1b. Sand	202,768,779	203	63	151,340,105	151	61
1c. Hard clay	46,341	0	0	20,583	0	0
2a. Sand, gravel and pebbles	94,585,702	95	29	40,257,932	40	16
2b. Sand, gravel and pebbles with (< 10 %) stones >10 cm	8,560,749	9	3	20,007,932	20	8
3. Sand, gravel and pebbles with (10-25 %) stones >10 cm	2,727,671	3	1	3,933,585	4	2
4. Stones > 10 cm covering >25 %	15,912,021	16	5	16,129,129	16	7

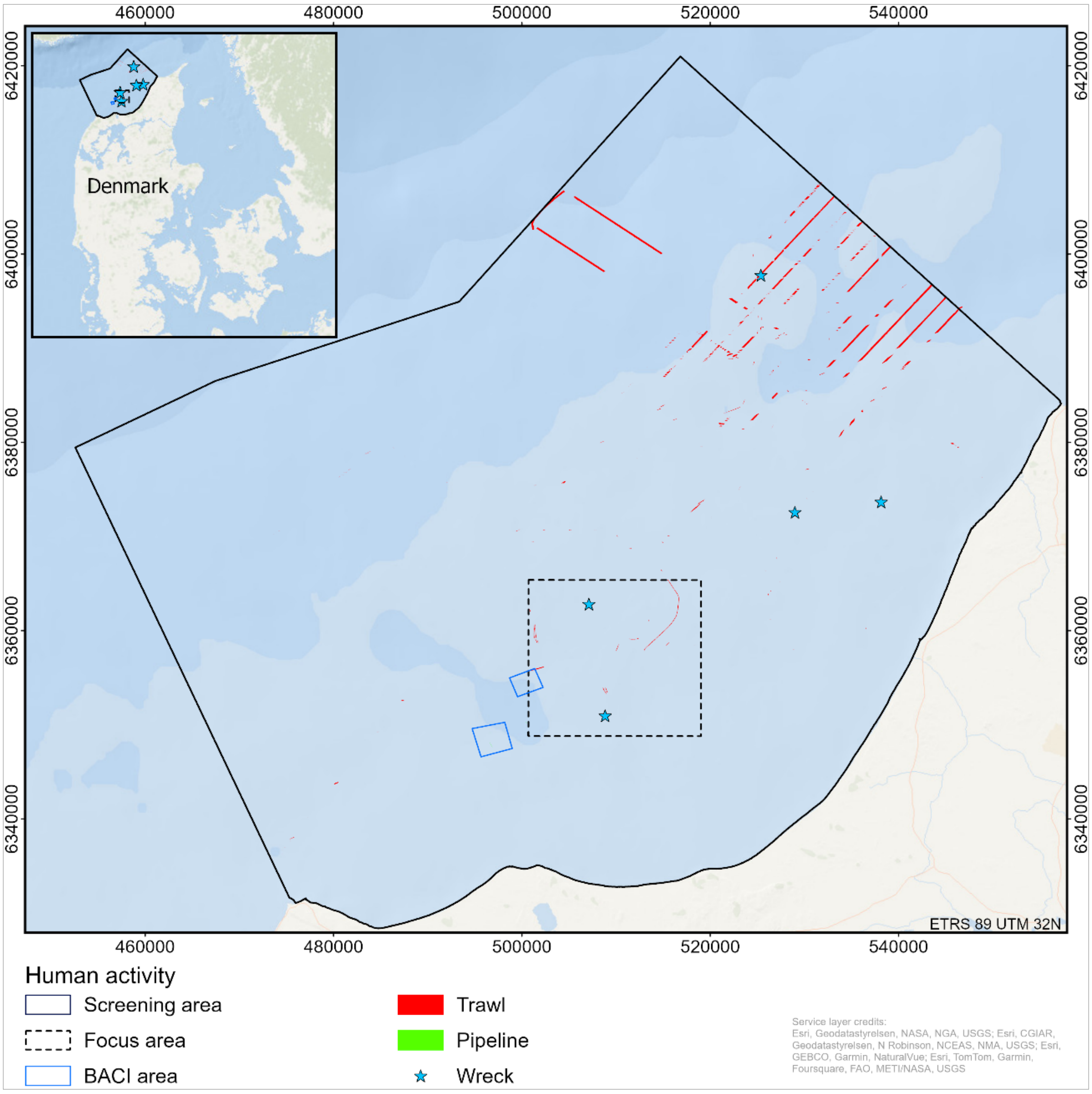

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Figure 2.10. Mapped human activity in the Screening area and Focus area.

2.9 Seabed habitat maps (Task 1.8)

Mikkel S. Andersen, Zyad Al-Hamdani, Isak R. Larsen, Silas Clausen, Jakob R. Jørgensen, Lars Ø. Hansen, Niels Nørgaard-Pedersen, Nicklas Christensen, Jørgen O. Leth, Verner B. Ernstsen

The aim of Task 1.8 was to generate seabed habitat maps based on an integration of seabed substrate and morphology that was derived in previous tasks from multibeam echosounder, side scan sonar, and sub-bottom profiler data. Seabed habitats were classified according to the EU Habitats Directive following the European Commission Interpretation manual of habitats listed under Annex I (EC, 2013) and the associated translation and description by the Environmental Protection Agency (Habitatdirektivets naturtyper in Danish) (Naturstyrelsen 2016; Miljøstyrelsen 2021).

Seabed substrate and morphology were the principal input parameters used in this work for defining the Habitat Directive seabed habitats sandbank 1110 and stone reef 1170. For sandbank habitats, the seabed substrate is 1b (sand). The sandbanks were identified using the criteria by EU international manual and the EPA definition using a semi-automated method in GIS. The method combined the seabed substrate 1b polygon with the morphology layer that exhibits an elevation above the general seabed level and a derived slope of the seabed. The delineation method for stone reef habitats was also semi-automatic where the substrate type 4 and substrate 3 were extracted as polygons in GIS, and stone reef habitat was identified and mapped where substrate 4 exists or where substrate 3 is attached and spatially connected to substrate 4. The results show that both the Focus area and Screening area include many stone reef habitats (see Fig. 2.11 and 2.12). An area of 37 km^2 was mapped as stone reef in total.

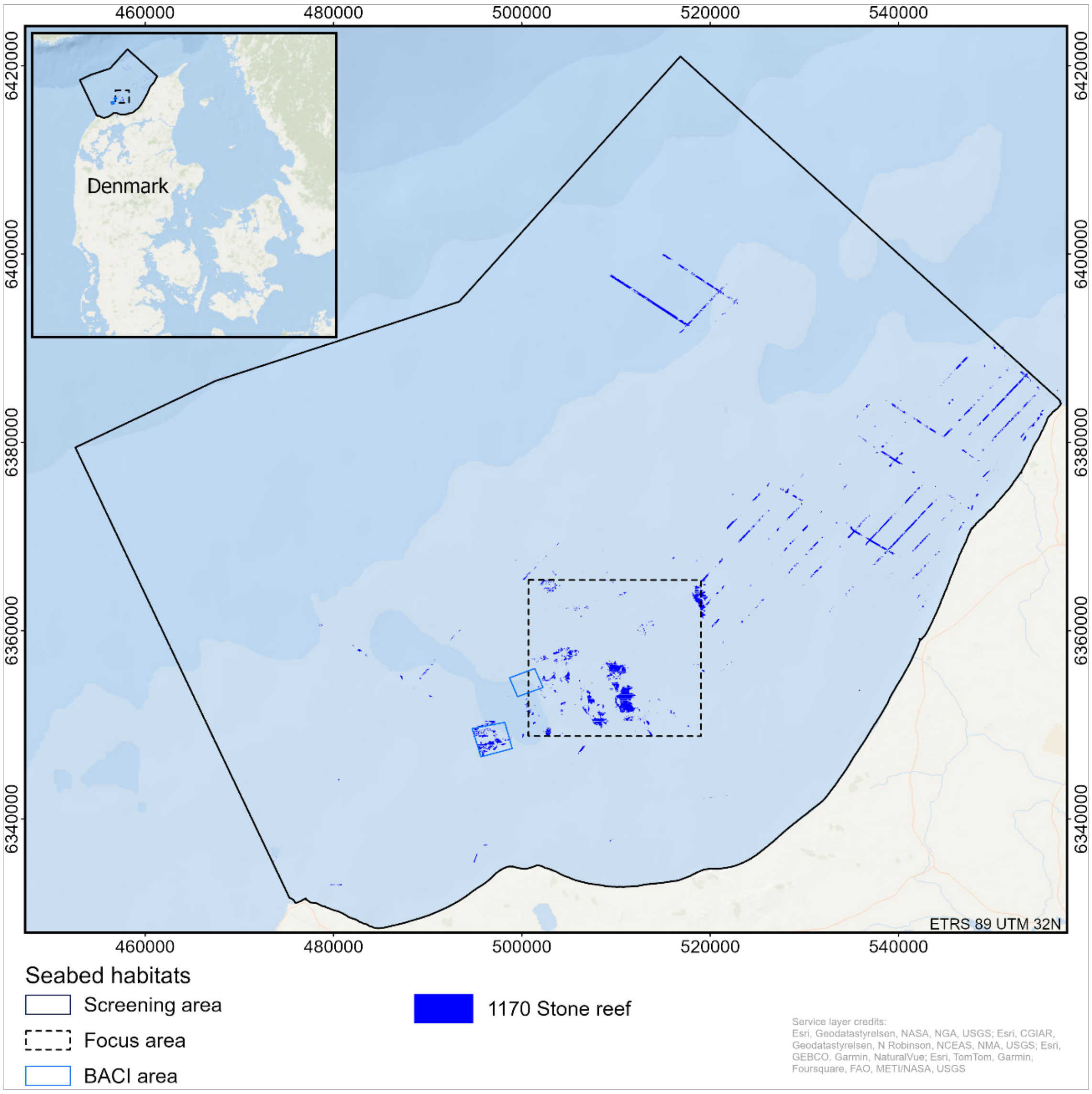

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Figure 2.11. Mapped stone reef habitats (1170) in the Focus area and Screening area.

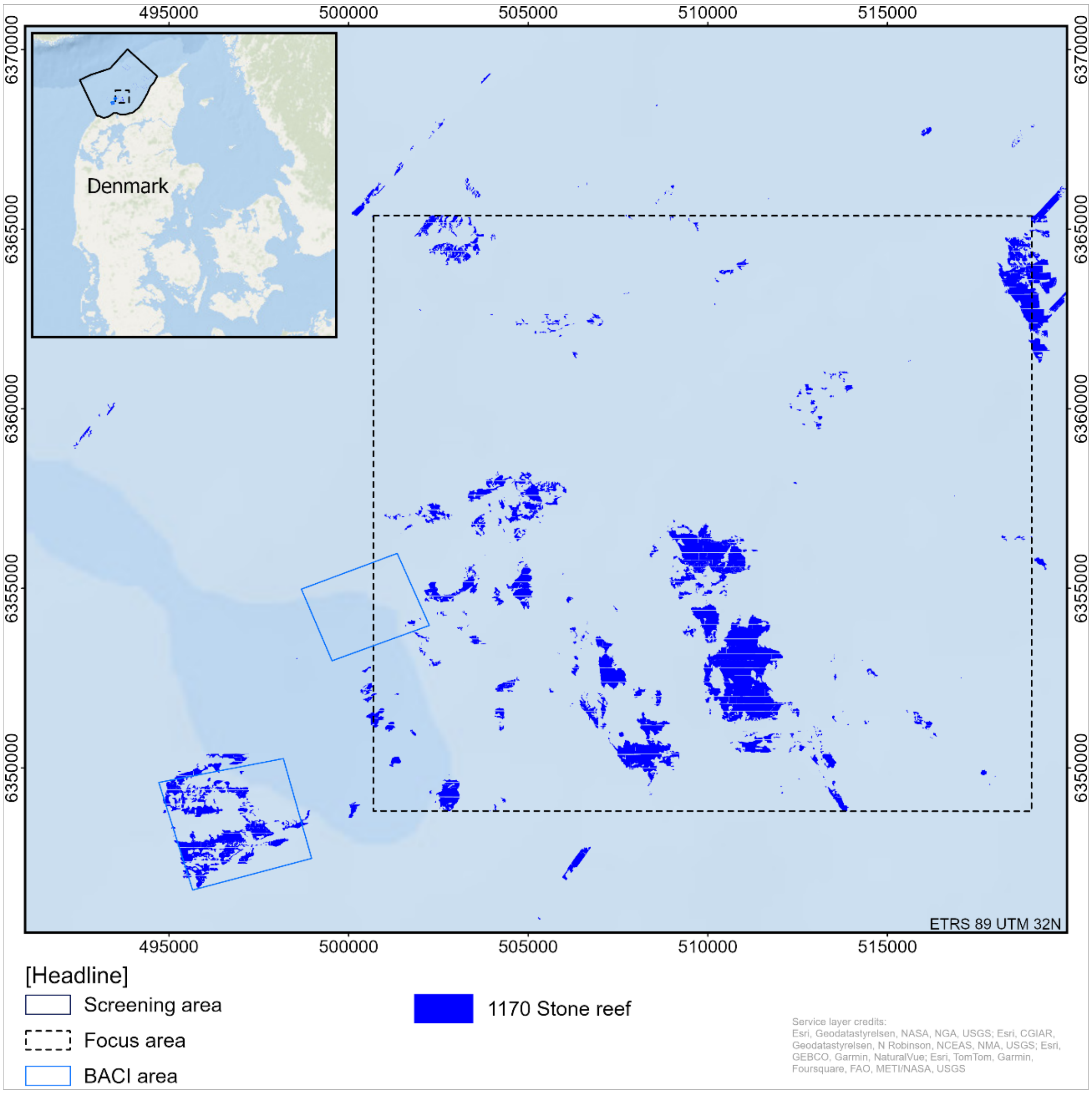


Figure 2.12. Zoom in of the mapped stone reef habitats (1170) in the Focus area.

2.10 Offshore geophysical survey (Task 1.9)

Lars Ø. Hansen, Nicklas Christensen, Sigurd B. Andersen, Lars-Georg Rödel, Sofie Kousted, Silas Clausen, Jakob R. Jørgensen, Mikkel S. Andersen, Zyad Al-Hamdani, Verner B. Ernstsen

The aim of Task 1.9 was to plan and conduct a geophysical survey in the deeper part of the Jammer Bay using vessel borne multibeam echosounder, side scan sonar and sub-bottom profiler systems.

New geophysical data were acquired with side scan sonar (SSS) and multibeam echosounder (MBES) which provided information on substrate and morphology of the seabed surface and with sub-bottom profiler (SBP) which provided information on the shallow subsurface geology. The seabed was mapped in high spatial resolution and precision along the survey lines, with data gaps between survey lines.

The instruments used for the geophysical survey comprised a towed Klein side scan sonar, a pole-mounted Innomar SES-2000 medium sub-bottom profiler and an R2Sonic 2024 multibeam echosounder. Primary position and motion were delivered by an SBG Navisight Ekinox GNSS/INS system with an Applanix POSMV Ocean Master as backup. Motion input for the sub-bottom profiler was delivered by an SMC IMU-108. Sound velocity profiles were measured with a Valeport SWIFT SVP.

Data were collected in the period between 5 December and 9 December 2023. Data were collected along planned survey lines in the offshore Screening area with 4,000 m line spacing. In addition, data were collected near-shore due to poor weather conditions in the offshore area, with 400 m line spacing.

Weather conditions were not optimal in the period of the survey. Approximately 626 line-km inside the Screening area were completed (see Fig. 2.13).

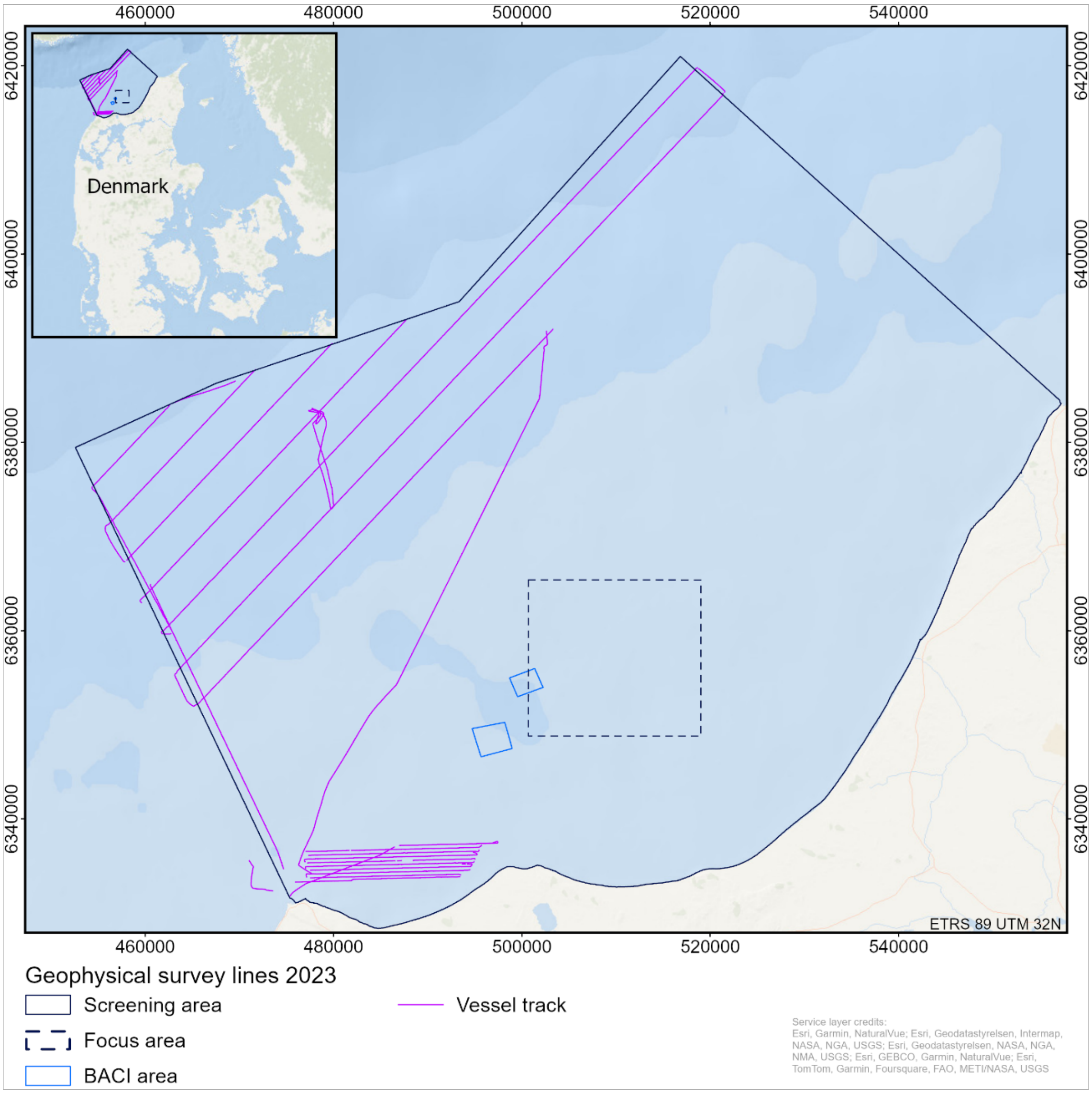


Figure 2.13. Vessel track line exported from the MBES. Screening area survey, December 2023.

2.11 Topobathymetric airborne laser scanning survey (Task 1.10)

The aim of Task 1.10 was to plan and conduct a topobathymetric airborne laser scanning (ALS) survey in the shallow water coastal zone of the Jammer Bay and to process and analyse the acquired ALS data.

Topobathymetric ALS, also commonly known as green lidar (light detection and ranging), utilizes short green laser pulses for high resolution mapping of bathymetry in very shallow waters. It is an active remote sensing technique that is used to create accurate and precise 3D models and visualisations of landscapes and surfaces whether above or below water.

Topobathymetric ALS data is recorded from the coastline towards the 10 m water depth curve in the southern part of the Jammer Bay. Simultaneously, high-resolution RGB-images is recorded. The topobathymetric ALS data is processed to deliver fully processed and classified point clouds as well as digital surface models (DSM) of the water surface and the seabed and digital terrain models (DTM) of the seabed.

The spatial coverage of the topobathymetric ALS data in the coastal zone in the southern part of the Jammer Bay is shown in Fig. 2.14. The ALS data are currently in the preparation stage and will be presented upon completion.

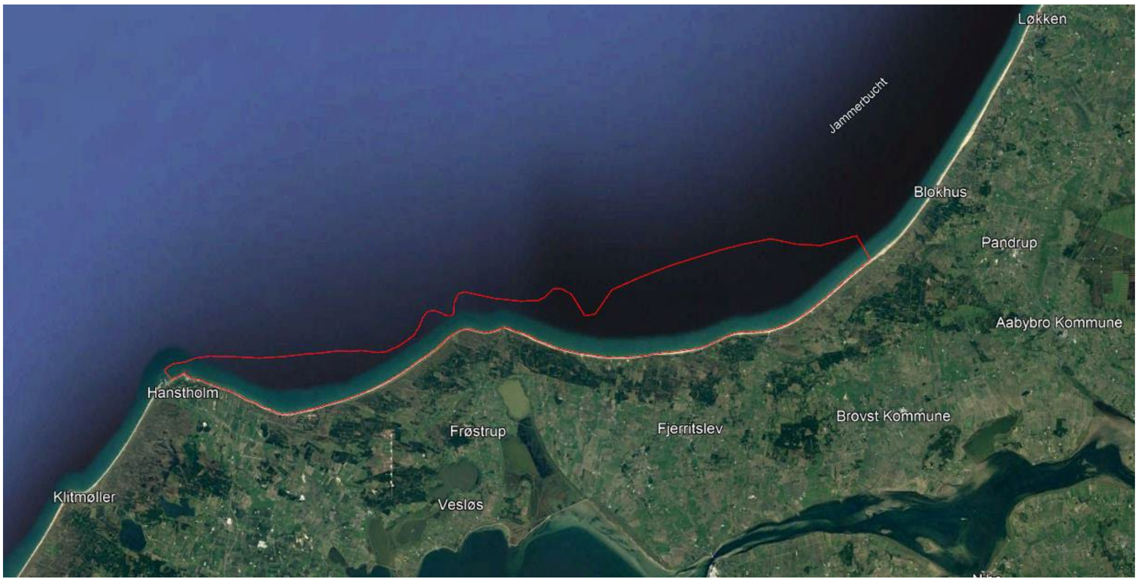


Figure 2.14. Spatial coverage of the topobathymetric ALS data in the coastal zone in the southern part of the Jammer Bay.

2.12 Sediment and carbon analyses (Task 1.11)

Lars Ø. Hansen, Henrik I. Petersen, Pernille Stockmarr, Mikkel S. Andersen, Zyad Al-Hamdani, Verner B. Ernstsen

The aim of Task 1.11 was to perform sediment and carbon analyses to determine seabed sediment and carbon composition.

An ROV video and HAPS sampler survey was conducted to provide additional information on seabed substrates and grain size distributions. HAPS cores were collected at 71 locations in autumn 2023 by WSP (see Fig. 2.15). Subsamples were taken from the upper 2 cm and analysed in GEUS' Sediment Lab to determine water content, organic matter content and grain size distributions by both sieving and laser diffraction that includes the finer fractions <63µm. Furthermore, 60 sediment samples collected by a grab sampler in spring 2023 by DTU Aqua were analysed in GEUS' Sediment Lab to determine organic matter content and grain size distributions by sieving, i.e. only the coarser fractions >63µm. The 60 sediment samples collected in spring 2023 as well as the 71 sediment samples collected in autumn 2023 were analysed in GEUS' Carbon Lab to determine total carbon (TC) and total sulphur (TS) as well as total organic carbon (TOC).

Water content and organic matter content were determined according to the DS 405.11 and DS 204 standards. Grain size distributions of the coarse fraction (>63µm) was determined by dry sieving according to the DS 405.9 standard extended to ½ phi scale. Grain size distributions of the fine fraction (<63µm) were determined by laser diffraction using a Malvern MasterSizer 2000. Based on the dry sieving results, samples for laser diffraction were selected based on weight-% of fine grains, i.e. samples containing >5 % fines were analysed with laser diffraction.

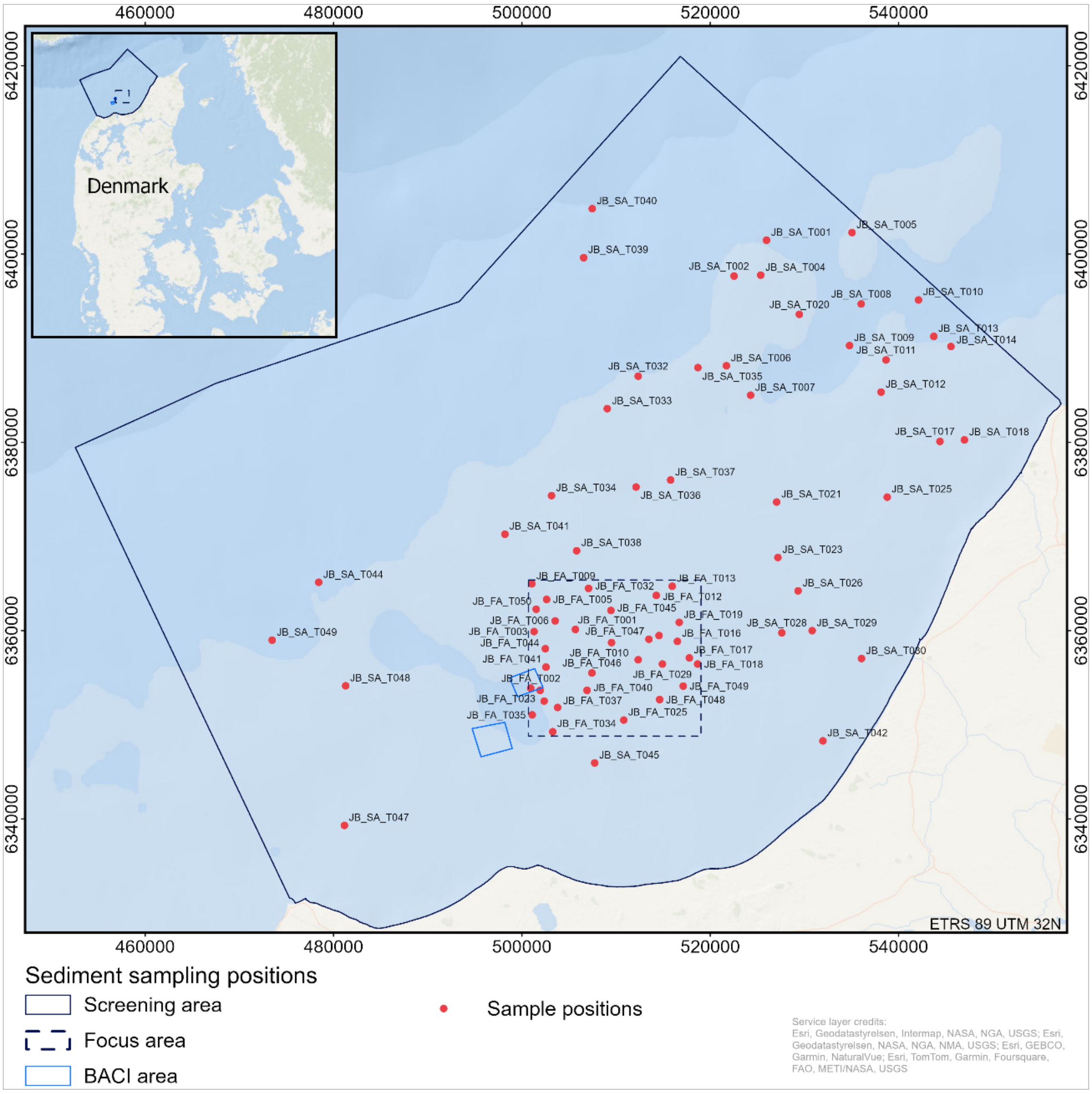


Figure. 2.15. Targeted sample positions of the 71 HAPS cores.

3. Physical fisheries impacts on seabed habitats (WP2)

3.1 Introduction to WP2

Spatial high resolution fishing pressure data for Danish and international fisheries with mobile bottom-contacting gears are important for calculating benthic state indicators. This type of data also allows the calculation of other indicators such as sediment mobilization, fuel use, and direct CO_2 emissions for each fishery.

There were two overarching objectives in this WP; the first was to analyse and map the activities and ecosystem pressures of the different fisheries in the Jammer Bay area, and the second was to analyse the connectivity and recruitment dynamics of selected fish and invertebrate species in the case study area and the surrounding waters.

3.2 Fisheries footprints on seabed habitats (Task 2.1)

Ole R. Eigaard, Jeppe Olsen, Karin J. van der Reijden, Josefine Egekvist, Jonathan Stounberg

The main objective of Task 2.1 has been to improve and apply state of the art methodology for processing fisheries monitoring data, to provide spatial and temporal high-resolution fishing pressure data for both the Danish and the foreign fleets fishing in the Jammer Bay study area. The Jammer Bay fishing pressure data of swept area ratio (SAR), landed catch, fuel-use intensity, and sediment mobilisation were estimated for individual grid cells of 0.001 degrees longitude and latitude (approx. 60 x 100 m). This was made possible through the development of a polygon-based approach to the swept area calculations for individual vessels and a hierarchical use of information in Black Box, AIS, and VMS monitoring data.

The refinement and application of these state-of-the-art methodologies to Danish fisheries monitoring data has enabled the estimation of fishing pressure data in an unprecedented quality and resolution, which is more than 1000 times higher than other publicly available SAR maps and data that are currently used for impact and trade off assessments. For the foreign fleet, AIS data were combined with information on gear type and vessel size in the EU vessel register to provide the SAR, fuel-use, and sediment mobilization estimates per grid cell. Because we did not have access to logbook data for the foreign vessels, landings weight and value per grid cell could not be estimated, and the estimates of SAR, fuel-use, and sediment-mobilisation are substantially more uncertain than the estimates for the Danish fleet.

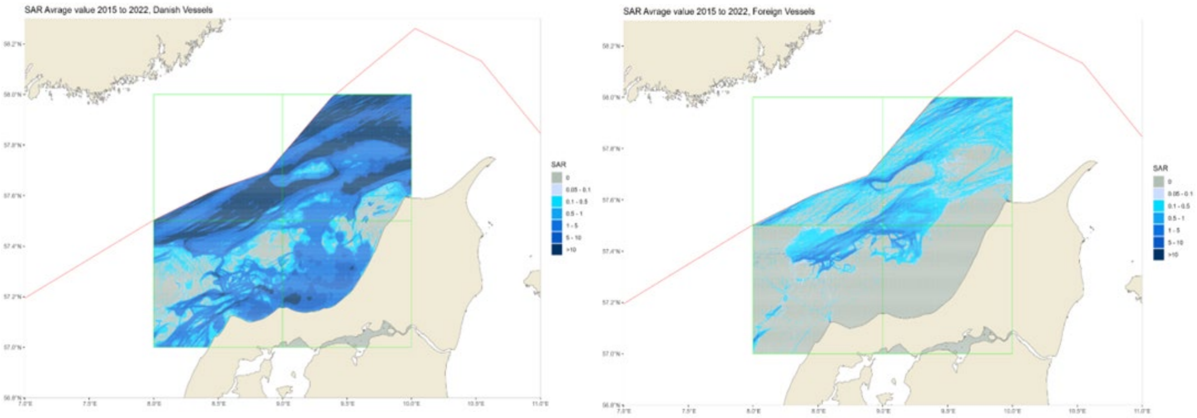


Figure 3.1. SAR values (annual average from 2015-2022 in grid cells of 0.001°) for all mobile bottom contacting gears for the Danish fleet (left) and foreign fleets (right), within the DK EEZ part of the Jammer Bay.

The Jammer Bay study area is intensively fished with mobile bottom contacting gears (Fig. 3.1). When pooling all gear footprints together, the average annual SAR-values from the period 2015-2022 show that larger areas of the deeper, more offshore parts of the case study area are fished more than 10 times annually. In the shallower fishing grounds, closer to shore, the fishing intensity is lower, but also here there are hot spot areas that are fished more than 10 times a year, and a large proportion of the seafloor is fished between 5 and 10 times a year.

Another clear outcome of mapping the SAR estimates by fleet and gear type is that the DK fleet and the foreign fleet are largely complementary in their choice of fishing grounds (Fig. 3.1). The Danish fleet is responsible for the largest fishing pressure on the sandy sediments (Danish seines) and soft sediments (otter trawlers), while foreign vessels (beam trawlers) exert the largest pressure on the coarser sediments.

The spatial distribution of landed catch, fuel-use intensity, and sediment mobilisation closely follows the distribution of fishing intensity, with the highest values per grid cell being found in the grid cells that also have the highest intensity of fishing. There are some deviations between the maps of the different fishing pressures, which are brought about by the price-difference of the species, the difference in the average engine-power of the gear types, and the differences in sediment silt-fractions of the habitat types.

3.3 Physical seabed disturbance of mobile gear components (Task 2.2)

Nurul Huda, Ole R. Eigaard, Barry O'Neill

In this Task, we aimed to get a better understanding of the interaction of towed fishing gears and boulders. This will help fishers choose what gears can be used on certain fishing grounds and will help fisheries managers protect seabed habitats and features. We focused on estimating the snagging probability of different demersal trawls and boulders. We carried out a scaled model flume tank study (i) to identify which gears are more likely to snag on boulders, (ii) to evaluate at which part of a given gear snagging is more likely to occur, and (iii) to determine if there are any characteristic features of a boulder that increases the likelihood of snagging.

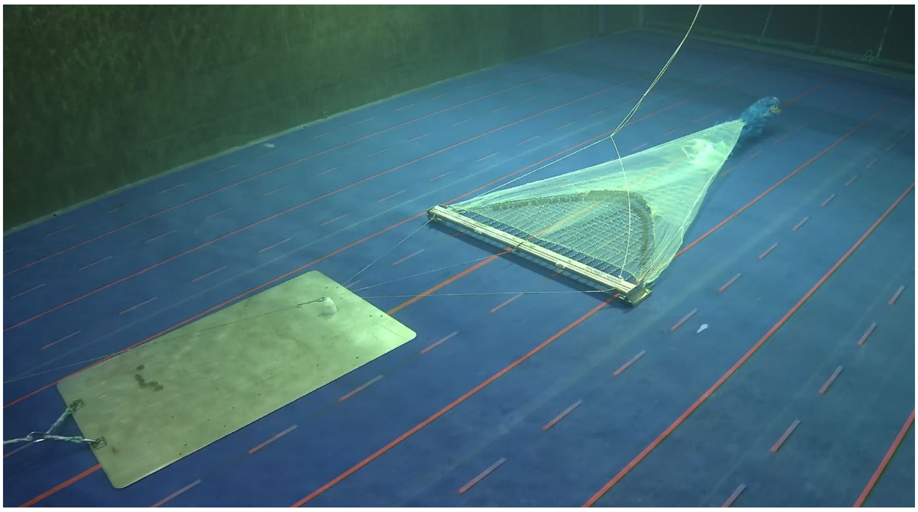


Figure 3.2. The beam trawl with a chain mat approaching the test boulder in the flume tank in Hirtshals.

A central outcome of the study is that tickler chain beam trawls had the highest snagging probability across boulder shapes and sizes, indicating that this gear type is the most restricted in terms of fishable substrate composition. It was expected that Danish seines would have the highest risk of snagging, while tickler chain beam trawls would be better at passing coarse substrate types than both otter trawls and seines. An explanation might be that high snagging risks in a seabed habitat does not per se prevent beam trawling, as these vessel types generally have high engine power and likely can move and turn over boulders when snagging does occur. Even so, our modelling-based results indicate that tickler chain beam trawlers are more restricted in their choice of fishing grounds than generally perceived.

3.4 Hydrographic sea model of seabed disturbance and dispersal (Task 2.3)

Asbjørn Christensen, Henrik Mosegaard

A high-resolution hydrographic dataset covering the Jammer Bay and surrounding basins was established to assess hydrographic control of biological processes in the Jammer Bay area. Interfaces to Python and Lagrangian simulation software were developed to enable cross-disciplinary analyses within the project. Biological modules describing plaice larvae and early life-stages of habitat-forming invertebrates were added.

The connectivity for hydrographic plaice habitats in the Jammer Bay and surrounding basins was assessed by considering drift from known spawning grounds and settlement at coastal nurseries with suitable habitat conditions. The investigations indicated that the recruitment potential has increased slightly in the period 2014-2022, but spatial and temporal fluctuations in recruitment contributions also increased over the period, lowering the stability of the recruitment potential.

Details of settling plaice larval development and the low scope for escape behaviour of the metamorphosing post-larvae together with stage duration define the vulnerability of this recruitment period to mobile bottom-contacting fishing gears. Studies of gear impact on plaice larvae and small juveniles was not found in the literature. Judged from field biology and experimental studies of predator prey interactions, vulnerability peaks at larval lengths of 12-15 mm and exponentially declines until the juvenile has reached about 25 mm.

An index for disturbance of plaice recruitment by mobile bottom-contact gear was defined and assessed for the Jammer Bay. The index described spatio-temporal overlap between Danish/anchor seine fishery and plaice post-larval nurseries, where the relative trend in this index is less sensitive to the current absence of impact quantification studies. The index showed an unfortunate coincidence with peak fishing effort and arrival of newly settled larvae, which stresses importance of future impact quantification studies.

The connectivity for representative habitat-forming invertebrates in the Jammer Bay and surrounding basins was assessed. A representative set of four species with contrasting traits was considered. The species with longer pelagic duration of early life-stages indicated a slight increase in recruitment potential, but also larger spatial and temporal fluctuations, as was found for plaice larvae. Species with shorter pelagic duration of early life-stages did not exhibit similar noticeable increase in recruitment potential.

3.5 Source-sink dynamics of sandeel recruitment to seabed habitats (Task 2.4)

Ole Henriksen, Marie Villefrance, Henrik Mosegaard, Mikael van Deurs

The primary aim of Task 2.4 was to understand the "source-sink dynamics" of sandeel larvae and the connectivity between habitats from the Jammer Bay to the North-Eastern North Sea and Western Skagerrak. The project successfully developed a protocol for measuring sandeel larvae using image-processing tools and created two valuable datasets for larvae densities and lengths. The work involved meticulous re-measurements and recalibration of larvae samples to address initial measurement inconsistencies, ensuring data accuracy. Challenges in completing larval drift and statistical modelling analyses were faced due to time and data readiness constraints. Challenges in completing larval drift and statistical modelling analyses were faced due to time and data readiness constraints. Nonetheless, the project offers significant insights into sandeel recruitment patterns from hatching to settlement and is crucial for effective fisheries management and conservation in marine environments.

Figure 3.3. Illustration of the developed protocol and output for measuring and estimating sandeel larvae lengths and density using image processing tools.

4. Biological fisheries impacts (WP3)

4.1 Introduction

Gradient studies are particularly useful in examining long-term (years) and high-resolution large scale (kms) impacts of bottom trawling (Gislason et al. 2017, McLaverty et al. 2020a, 2020b, 2021, 2023, Rijnsdorp et al. 2020a). These can be supplemented with in situ experimental studies on different substrates to examine trawling impacts. The impact studies can be supplemented with information on benthic (and fish) biodiversity and recruitment of sensitive species in the Jammer Bay using eDNA analyses.

The main objectives of this WP were: 1) to produce various indicators of biodiversity using high spatial resolution seabed habitat and fishing pressure estimates, 2), to conduct experiments to investigate the impacts of beam trawling on different substrates, 3), to examine and compare the responsiveness of biological seabed indicators on biodiversity and ecosystem functioning to bottom trawling and natural pressures in the Jammer Bay, and 4), to analyse benthic and fish biodiversity in the Jammer Bay using eDNA.

4.2 Gradient study and BACI beam trawling experiments (Task 3.1 & 3.2)

Grete E. Dinesen, Anne Mette Kroner, Ciaran McLaverty, Eva Maria Pedersen

Fishery gradient studies are particularly useful in examining long-term (years) and large-scale (kms) impacts of bottom trawling. The Jammer Bay is a data poor area with regards to the benthic macrofaunal communities on the different seabed habitats. With the new gradient data from 100 Van Veen samples (100 x 0.1 m^2 = 10 m^2) and 200 HAPS corer samples (200 x 0.0143 m^2 = 2.86 m^2) we established comprehensive information on the distribution of >300 benthic macrofaunal taxa in the Jammer Bay. Following quality assurance of these new data, the information on the density of species (S), density of individuals (N), wet weight (WW) and ash free dry weight (AFDW), the data will be integrated in the ongoing detailed analyses of fisheries impacts and environmental state of the benthic habitats and trade-offs thereof in the Jammer Bay.

The new data generated in this project will be highly valuable in the upcoming analyses of fisheries impacts on benthic faunal biodiversity, functional traits and depletion ratios related to individual MSFD BBHTs, hydrographic and climate conditions, hypoxia, and fisheries footprints and trade-offs, and can inform ecosystem-based management and associated designated areas in the implementation of the EU Marine Strategy Framework Directive (MSFD), Biodiversity Strategy for 2030 (BDS2030), the Habitats Directive (HD) and Birds Directive (BD) of the NATURA 2000 network, and the EU Common Fisheries Policy (CFP).

Impacts of beam trawling have been investigated for the Dutch vessels on sandy habitats in the southern North Sea. However, little is known of the beam trawling impacts on Circalittoral sand and Circalittoral mixed sediment in Danish waters, including in the Jammer Bay. The two BEFORE-AFTER-CONTROL-IMPACT (BACI) field experiments retrieved a total of 20 fish and 13 benthic megafaunal invertebrates were caught by the beam trawls. The BACI experiment of fisheries impacts of a sumwing beam trawl with 3 tickler chains on Circalittoral sand showed plaice *Pleuronectes platessa*), dominated the biomass in all 12 hauls, however with no clear trends related to impact. On the other hand, the biomass of both Dover sole (*Solea solea*), and dab (*Limanda limanda*), clearly increased with the number of impacts. The BACI experiment of fisheries impacts of a chain mat beam trawl (Fig. 4.1) on Circalittoral mixed sediment showed a trend of increased biomass of cod (*Gadus morhua*), dab (*Limanda limanda*), and edible crab (*Cancer pagurus*), with increasing number of impacts, which are all probably attracted to the site by the seabed disturbance and suspension of damaged benthos and fish in the plume of the trawl tracks. The biomass of the attached (sessile) bryozoan colonies (*Flustra foliacea*), and large, mobile sea urchins (*Echinus esculentus*), showed a clear decline in biomass with increased trawling, and both are considered sensitive to bottom trawling.

Most noticeable is the impact on the sensitive octocoral (*Alcyonium digitatum*) that lives attached to boulders and other hard substrates. This species was caught in all chain mat beam trawl hauls on Circalittoral mixed sediment, and with the highest biomasses (between 14-20 kg in 11 out of the 12 hauls with the chain mat beam trawl). The species is long-lived (>30 years) and the larger colonies (of heights between 10-20 cm) are well over 10 years old. Recovery by recruitment of its pelagic non-feeding (lecithotrophic) larva is very slow, and requires that hard substrates such as stable boulders are present and undisturbed in their habitat. In unfished areas in the Jammer Bay, this octocoral forms dense beds that function as a biogenic habitat for other species. Thus, this BACI experiment showed that the adverse effects on chain mat beam trawling on Circalittoral mixed sediments is detrimental to structuring seabed fauna, with a high risk of habitat loss.

Further analyses of beam trawling impacts on fish and megafaunal density is ongoing, and impacts on the benthic macrofauna at both site is being investigated in detail based on the new Van Veen sediment samples, UW video images of the seabed, and eDNA data from in this project.

Figure 4.1. The beam trawl rigged chain mats used in the BACI experiments on circalittoral mixed sediment in the Jammer Bay.

4.3 Biological seabed indicators – Relative Margalef diversity (Task 3.3A)

Esther D. Beukhof, Jonathan Stounberg, Jeppe Olsen, Ole E. Eigaard, Asbjørn Christensen, Anna Rindorf, Grete E. Dinesen

The adoption of the Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD) in 2000 and 2008, respectively, sparked the development of biological seabed indicators to assess Good Environmental State (GES). In Denmark, the Danish Quality Index (DKI) was developed and has, together with the Swedish Benthic Quality Index (BQI), been applied in Danish coastal and marine waters. Although DKI and BQI have been found to correlate with bottom trawling in some studies, the DKI does not respond to bottom trawling when accounting for the number of individuals sampled and the underlying sampling design. A new generation of biological seabed indicators to detect bottom trawling impacts was developed in recent years by the International Council for the Exploration of the Seas (ICES), as well as the international conventions OSPAR and HELCOM. Here, we tested and applied the Relative Margalef diversity index, an indicator (i.e., the OSPAR indicator BH2b) developed through the OSPAR Benthic Habitat Expert Group (OBHEG), to the Danish part of the North Sea and Skagerrak.

Benthos samples from the National Monitoring Programme for Water and Nature (NOVANA) were selected from 2010-2022 and matched with their corresponding MSFD Benthic Broad Habitat Type (BBHT). Due to the low number of samples for several habitat types, samples were grouped by habitat type into two periods: 2010-2016 and 2017-2022. This led to a final set of six habitat types that were assessed in each period. The Relative Margalef diversity index was calculated by following the methodology of the OSPAR BH2b assessment as closely as possible. First, the standard Margalef diversity (D_M) (number of species – 1 / log(number of individuals)) was calculated per sample, followed by dividing it by the Margalef diversity calculated based on reference conditions. It thus represents an index of Relative Margalef diversity, where diversity is expressed as relative to unfished or low fishing pressure conditions. Reference condition values for Margalef diversity were estimated for each habitat type based on samples from areas with: 1), zero or little bottom trawling, and 2), good oxygen conditions in recent years from 2010-2022. Once the Relative Margalef diversity was calculated, values were classified as representing low (0-0.6), intermediate (0.6-0.8) or high (0.8-1) Relative Margalef diversity.

In the first period (2010-2016) four out of six habitat types showed low Relative Margalef diversity in the Danish part of the North Sea and Skagerrak, whereas the remaining two were intermediate (Fig. 4.2). Circalittoral sand and offshore circalittoral mud remained at low relative diversity during the second period (2017-2022), whereas circalittoral coarse and offshore circalittoral sand displayed intermediate relative diversity in both periods. Circalittoral mixed and offshore circalittoral coarse sediments changed from being low to intermediate Relative Margalef diversity. Overall, the index displays large variation at zero or low bottom trawling intensity, whereas values seemed to decrease at higher trawling intensities. Yet, reference condition values of Margalef diversity were highest in slightly fished areas compared to unfished areas. Further research is needed to investigate what drives the overall variation in the reference conditions for Margalef diversity in terms of environmental conditions and bottom trawling intensity.

The results may have been influenced by the sampling design of the NOVANA programme that was not fully accounted for in this analysis. First, there were large differences in the number of samples between periods for each habitat type, with most samples being available in the second period (2017-2022). Second, there were large differences in the number of samples between habitat types. Both these aspects may have biased the results, with potentially higher Relative Margalef diversity values observed in habitat types and/or periods due to more samples rather than due to truly more species being present. Future analyses should account for these differences where possible, for example by applying species accumulation curves. Third, the NOVANA programme was not specifically designed to test the response of benthic communities to various levels of bottom trawling intensity. Lack of samples from the full range of bottom trawling intensity within each habitat type may therefore not have led to an accurate assessment of fishing impacts on biodiversity. A more even distribution of sampling across habitat types and fishing gradients within in habitat type is needed. Finally, the NOVANA programme samples with Haps corers that cover a relatively small area (0.0143 m^2), compared to Van Veen grabs (0.1 m^2) or other types of grabs that are used by several other European countries. Haps corers mostly sample small-sized infauna and thus underestimate the abundance of larger-sized infauna and epifauna. It is these larger-sized epifauna that have been shown to be mostly impacted by physical disturbance from bottom trawling. Studies like the one conducted here based on HAPS corers may therefore be less effective in capturing fishing impacts. Further research is needed to compare estimates of Relative Margalef diversity based on HAPS corers and Van Veen grabs from the same area and habitat type to study the potential implications on national assessments of benthic diversity based on NOVANA HAPS corers.

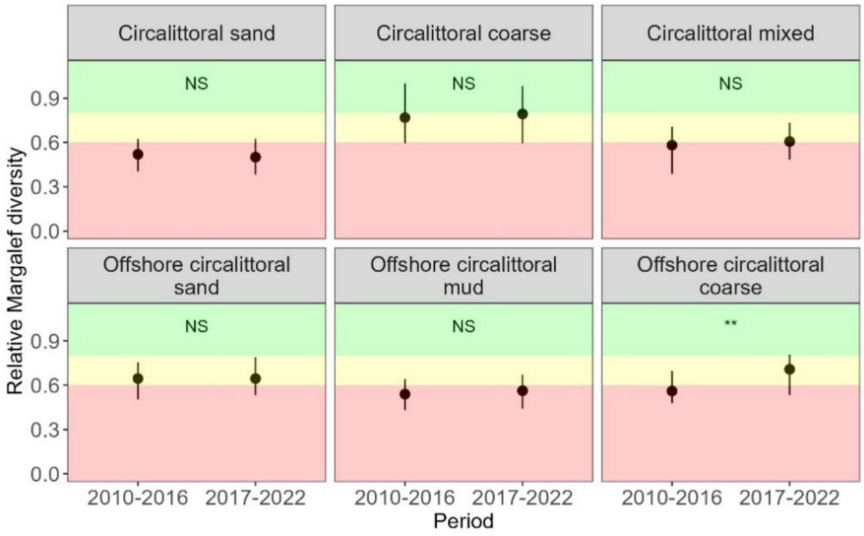


Figure 4.2. Relative Margalef diversity (D_M') by period and MSFD Benthic Broad Habitat Type. Points indicate median values across samples and the edges of the vertical lines the 25th and 75th percentile. Significant difference in D_M' between periods is indicated at the top of each panel: NS = not significant, * = p<0.05, ** = p<0.01, *** = p<0.001.

The NOVANA programme only covers three sampling stations at the periphery of the Jammer Bay, with a total of 401 samples across all years included in this study (2010-2022). It remains therefore uncertain what the state of benthic seabed habitats is in the Jammer Bay in terms of fishing impacts on biodiversity. The Van Veen grab and Haps corer samples collected during this project, JAMBAY, will be of great value in future studies to further test the Relative Margalef diversity index and compare its response to fishing with other benthic indicators (e.g., DKI, BQI, Relative Benthic State). Furthermore, a statistical modelling framework can be developed that can account for natural conditions as well as the sampling regime. Such a framework will allow for predicting the index across space, including in areas without sampling, and for estimating reference condition values of Margalef diversity for habitat types that are currently being under-sampled.

4.4 Relative Benthic State (RBS) as a biological indicator of fisheries and hypoxia impacts in the Jammer Bay (Task 3.3B)

Grete E. Dinesen, Josefine Egekvist, Ole R. Eigaard, Esther D. Beukhof, Asbjørn Christensen, Jeppe Olsen, Jonathan Stounberg, Anna Rindorf

Assessment of Good Environmental State (GES) of the Marine Strategy Framework Directive (MSFD) Benthic Broad Habitat Types (BBHTs) under the Descriptor D6 "Seafloor integrity", Criteria C5 "adverse effects" is planned to include all pertaining pressures (environment.ec.europa.eu). As a first step, indicator development for D6 GES assessment focused on physical pressures mainly including potential adverse effects on benthic habitats from fishery with mobile bottom contacting gears (i.e., bottom dredging, trawling, fly-shooting and seining), hereafter denoted bottom trawling. The International Council for Exploration of the Sea (ICES) Fisheries Benthic Impact and Trade-offs (FBIT) working group (WG) has developed a mechanistic benthic indicator, Relative Benthic State (RBS), that can identify bottom trawling impacts on seabed habitat stability (i.e., biomass median longevity, L2). The RBS indicator is currently being tested in European marine waters.

In this study, we applied the ICES FBIT RBS indicator to assess the environmental state of the BBHTs in marine waters of the Danish Exclusive Economic Zone (EEZ) and zoomed in to assess the detailed impacts of bottom trawling in the Jammer Bay area. To distinguish between impact of the pressures of bottom trawling and hypoxia and their adverse effects on BBHTs, we included a new indicator for oxygen deficiency and combined it with the RBS indicator in this assessment. The RBS application was made possible due to the new data based fisheries intensity model of Swept Area Ratio (SAR) at a medium-fine resolution (600 x 1000 m grid cell size) of the physical footprint of the Danish and international vessels fishing with mobile bottom contacting gears in the Jammer Bay area. The hypoxia indicator was developed in this project (and in collaboration with the EMFF project GESseabed, and the EU project SEAwise).

For this 1st generation local GES assessment, we applied the existing benthic habitat data of the BBHTs from EMODnet (EU SeaMap ver. Sept 2021), and the existing benthic macrofauna data collected by the Danish monitoring programme NOVANA (2014-2022).

In this 1st generation RBS & hypoxia indicator application, we used the Article 8 Guidance (by the EU TGSEABED) and adopted a GES Extend threshold of ≥75%, meaning that maximum ≤25% of an area may be adversely affected, incl. ≤2% loss in order it to be assessed as in good state. Additionally, we adopted the ICES WKBENTH2 advice for the GES Quality threshold for RBS and applied the maximum negative deviation of 0.2 from the maximum RBS value of 1 (i.e., GES Quality: 1 - 0.2 = 0.8).

In the Jammer Bay area, 3 of the 11 BBHTs were in subGES due to adverse effects from bottom trawling in the period from 2014-2016. In the most recent period from 2017-2022, 4 of the 11 BBHTs were in subGES due to bottom trawling. Although RBS was still ≥0.8 in more than

75% of the area of 7 BBHTs, it was considerably lower (i.e., in subGES) in 4 BBHTs. In these 4 BBHTs, RBS ≥0.8 respectively covered 0% of the Upper bathyal sediment, and only ~17% of the Offshore circalittoral mud, ~19% of the Offshore circalittoral sand, but 73.5% of the Offshore circalittoral coarse sediment of each of their total spatial distribution in the Jammer Bay area (Fig. 4.3 and 4.4).

Thus, in the Jammer Bay area, especially 3 of the deeper BBHTs showed a considerable smaller extent of their areas to be in GES than the required minimum 75% area in GES (GES Extent threshold), when assessed using the fishery-sensitive benthic indicator, RBS, and hypoxia. However, hypoxia contributed to the subGES of Offshore circalittoral mud by <3%, and thus was of minor importance for the environmental state in this area.

The new seabed mapping data, generated in this project, is expected to increase the area of mixed sediment, and reduce the area of sand, thereby providing a more accurate evaluation of the BBHTs in question. Moreover, the comprehensive new benthic macrofaunal data, also generated by this project, will be highly valuable in the upcoming 2nd generation GES assessments for the Jammer Bay area, and will contribute to the national and EU assessments of the Greater North Sea.

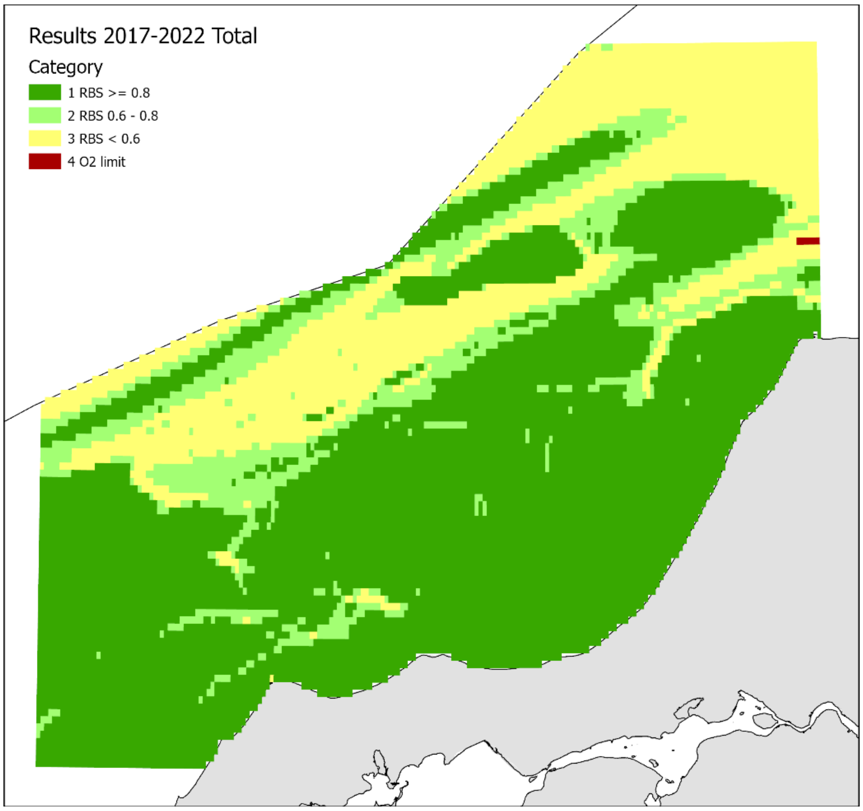


Figure 4.3. The Jammer Bay. Spatial distribution of the Relative Benthic State (RBS) in three categories (RBS: 1-0.8, 0.8-0.6, <0.6) and hypoxia (oxygen categories 3 and 4 combined). Based on SAR from both Danish and foreign vessels (Total vessels) 2017-2022.

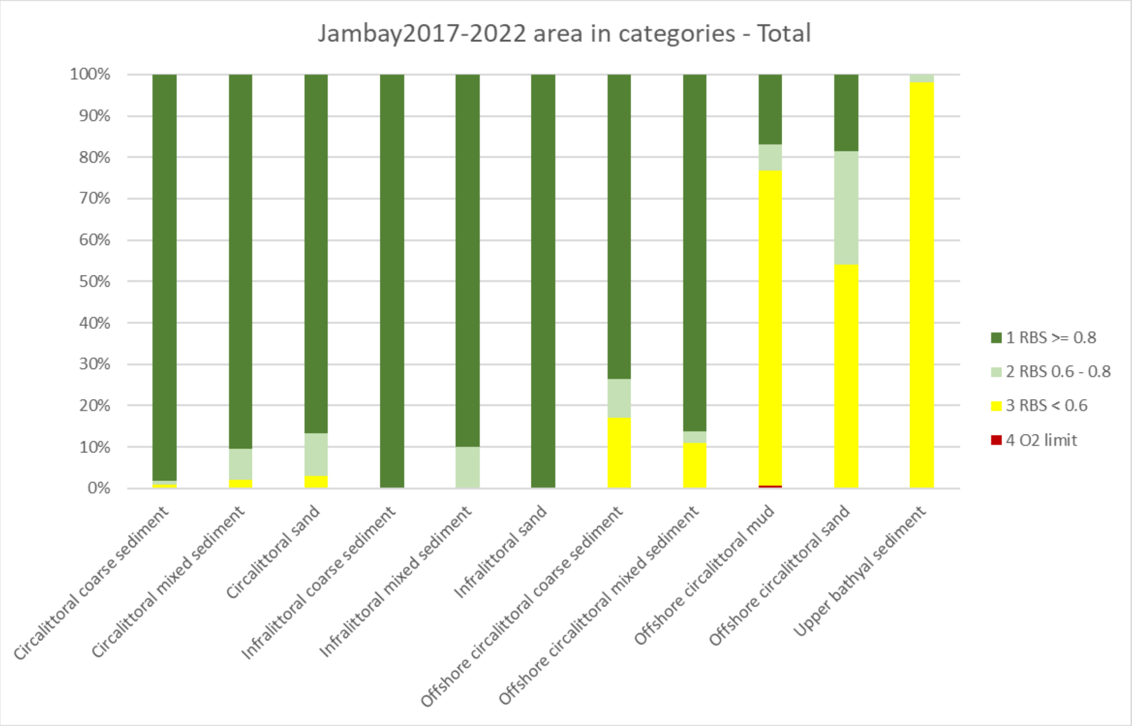


Figure 4.4. The Jammer Bay. Relative Benthic State in three categories (RBS: 1-0.8, 0.8-0.6, <0.6) and hypoxia (oxygen categories 3 and 4 combined) for each BBHT. Based on SAR from both Danish and foreign vessels (Total vessels) 2017-2022.

4.5 eDNA analyses of benthic biodiversity and recruitment of sensitive species (Task 3.4)

Magnus W. Jacobsen, Dorte Bekkevold

Analysis of so-called environmental DNA (eDNA) is an increasingly popular method for assessing species diversity in marine habitats. The primary objective of this task was to extract and secure eDNA from water and sediment samples collected in connection with Task 3.1. and 3.2 to facilitate subsequent downstream analyses of biodiversity in the collected samples and at the different sampling locations. The specific downstream analyses themselves were not part of the allocated task. However, two sub-objectives were to 1), conducting a pilot study utilizing metabarcoding analysis to determine the feasibility for using the collected eDNA to monitor biodiversity in selected samples, and 2), to develop and test a targeted molecular (qPCR) assay for the two sensitive species, namely, the bivalve *Modiolus modiolus* (Danish: hestemusling, English: Horse mussel) and the octocoral *Alcyonium digitatum* (Danish: dødningehånd, English: dead man's fingers).

Environmental DNA (eDNA) was successfully extracted and stored for downstream analyses for all sampled stations and their replicates. The task of developing qPCR assays for the two target species was successful. Preliminary assessments conducted though pilot runs (one analysis per sampling station) showed that the developed assays can be applied to analyse for eDNA from the two species. These results pave the way for comparative evaluations with visual-based methods, thereby assessing the potential for future eDNA-based monitoring of these species.

The pilot run based on metabarcoding was also successful and demonstrated that the approach can be applied to study broad biodiversity of fishes and invertebrates in the collected samples. We observed some differences in biodiversity of fish and metazoans between samples. Specifically, water samples exhibited higher fish biodiversity, while sediment samples exhibited greater metazoan biodiversity. This likely represents a true biological difference between the target groups and their environmental preferences (water vs sediment living species). Notably, for the fish metabarcoding analysis comparisons of water and sediment samples collected from the same location at the same time showed consistency in terms of recorded species, suggesting that either sampling method can be used to assess local species presence/absence. Additionally, the metabarcoding study revealed species differences between reef and sand habitat types, supporting a utility of eDNA for habitat monitoring. For instance, reef-associated species such as Atlantic cod (*Gadus morhua*), Goldsinny wrasse (*Ctenolabrus rupestris*), Norway bullhead (*Micrenophrys lilljeborgii*) and European Pollock (*Pollachius pollachius*) were exclusively observed at rocky sites, aligning with their expected habitat preference. An analysis targeting broader Metazoan biodiversity found that sediment samples exhibited a greater species similarity compared to water samples from the same location. This likely reflects the difference in biodiversity between species living in or in proximity of the seabed versus those residing in the water column.

In summary, our findings support that eDNA-based analysis holds promise as an effective tool for future biodiversity assessment in the Jammer Bay area. The samples collected, stabilised, and archived for further analysis are thus expected to be able to yield detailed information about local-scale biodiversity and to evaluate effects of different exploitation and management regimes.

5. Fisheries resources and socio-economy (WP4)

5.1 Introduction to WP4

The aim of this Work Package is to analyse the fisheries resources, socio-economic effects and value chains of all modes of fisheries operating in the Jammer Bay.

Recent declines in cod quotas and landings and in plaice landings despite increased quotas have given rise for concern to the Danish coastal fishers and related rural towns. The causes for these declines could be due to changes in the distribution of cod and plaice adults in response to climate change or may be the consequence of over-fishing. We therefore investigated fisheries survey data from 2005 - 2022 to examine whether changes in the distribution of cod and plaice have occurred, and if these were connected to changes in the availability of thermal habitats (environmental changes).

Further, we analysed the linkages between fisheries landing values, modes of operation, cultural life-modes, and economic value chains related to vessel nationality and size, gear type, target species, and use of seabed habitats in the wider Jammer Bay.

Together with commercial fishers we investigated relationships between spatial distribution of commercial fisheries, seabed habitat types and of protected, endangered and threatened fish species (PETs) to explore areas of high-risk for bycatch relative to gear type used in the fisheries.

Many fisheries catch species or sizes of fish that are illegal or not desirable to land or sell and are generally discarded at sea. This imposes added mortality that can affect the population development of commercially important species or the population structure or development of sensitive fish species. The discarded amount varies with gear type, fishing area and season; all factors that are necessary for sustainable management. We therefore investigated the discarded amounts in weight and numbers by fishery and related this to landings values in order to explore which fisheries have the lowest relative discard impact relative to the value of the landings.

5.2 Fisheries seabed habitat resources (Task 4.1)

Grete E. Dinesen, Stefan Neuenfeldt, Casper W. Berg, Asbjørn Christensen, Josefine Egekvist, Søren Q. Eliasen, Jonathan Stounberg, Jeppe Olsen, Thomas Højrup, Kirsten Monrad Hansen, Ole R. Eigaard, Josianne G. Støttrup

Historically low landings by coastal fishers in the Skagerrak have been observed in recent years for both cod and plaice. The cod quota and landings were at a low level since the start of this century. On the other hand, the plaice quota, despite it being raised in 2017, could not be utilized by the fishers, and the landings of plaice have further declined indicating lack of fish locally, rather than quota restrictions.

The overall objective of Task 4.1 was to examine whether the perceived decline in coastal cod and plaice occurrences were due to regional or local changes in fish distribution. Such changes could be due to a decline in total stock or decline in the availability of suitable habitats.

The aims of this Task were therefore to identify whether changes in fisheries landings of cod and plaice in the Jammer Bay and Skagerrak from 2000-2022 may be related to changes in: i), quota level and fishery efficiency, ii), fish population structure and distribution or iii), spatial changes of thermally suitable fish habitats. In order to ensure an ecosystem-based approach, we conducted the first steps of the Systems Approach Framework (SAF).

We started with a clear identification of the issue and all relevant stakeholders. Further, system services and human activities and resources were listed for inclusion in the analyses. We then investigated if cod and plaice distribution and population dynamics have changed in response to regional and local population trends. We included fisheries survey data from 2005-2022 for the North Sea, Skagerrak, and Kattegat (ICES DATRAS) and VMS with AIS and logbook information for the Jammer Bay area to identify landings and core fishing grounds linked to habitat conditions.

The fish survey analyses showed a regional shift in the relative cod distribution away from the southern towards the north-western North Sea. For plaice, a shift in the highest relative density was observed from the east towards the north-western North Sea. At the local scale, fish survey data showed significant declines in the large fish populations of both cod and plaice in the Jammer Bay in recent years, while at the same time highlighted the Jammer Bay as an important nursery area for both fish species (Fig. 5.1).

We investigated if the observed changes in relative cod and plaice occurrence was due to changes in thermal habitat distribution. The results of landings data compared with bottom temperature data, showed clear relations between where the cod were caught and the ambient bottom temperature. High bottom temperatures during Q3 in the coastal waters of the Jammer Bay have occurred more frequently in recent years which may explain the increasing avoidance of larger cod in this area. Cod avoided waters higher than 14°C in accordance with temperature boundaries observed from the cod DST data (Dinesen et al. 2019).

Plaice, on the other hand, were caught in temperatures higher than 16°C and no avoidance seemed to occur for this species, despite the DST information on temperature boundaries for the species. The results imply that the temperature-regulated processes governing cod and plaice landings differ and may be due to differences in behavioural responses to unfavourable environmental conditions. For plaice, however, the recent steep population decline in adults may be due to overfishing, either by local fishers or exacerbate by an influx of a foreign fleet of beam trawlers. Information on the landings from these foreign fleets together with more detailed information on the temperature at the capture positions may provide a definite explanation for the local decline of adult plaice and directly improve the management for this species.

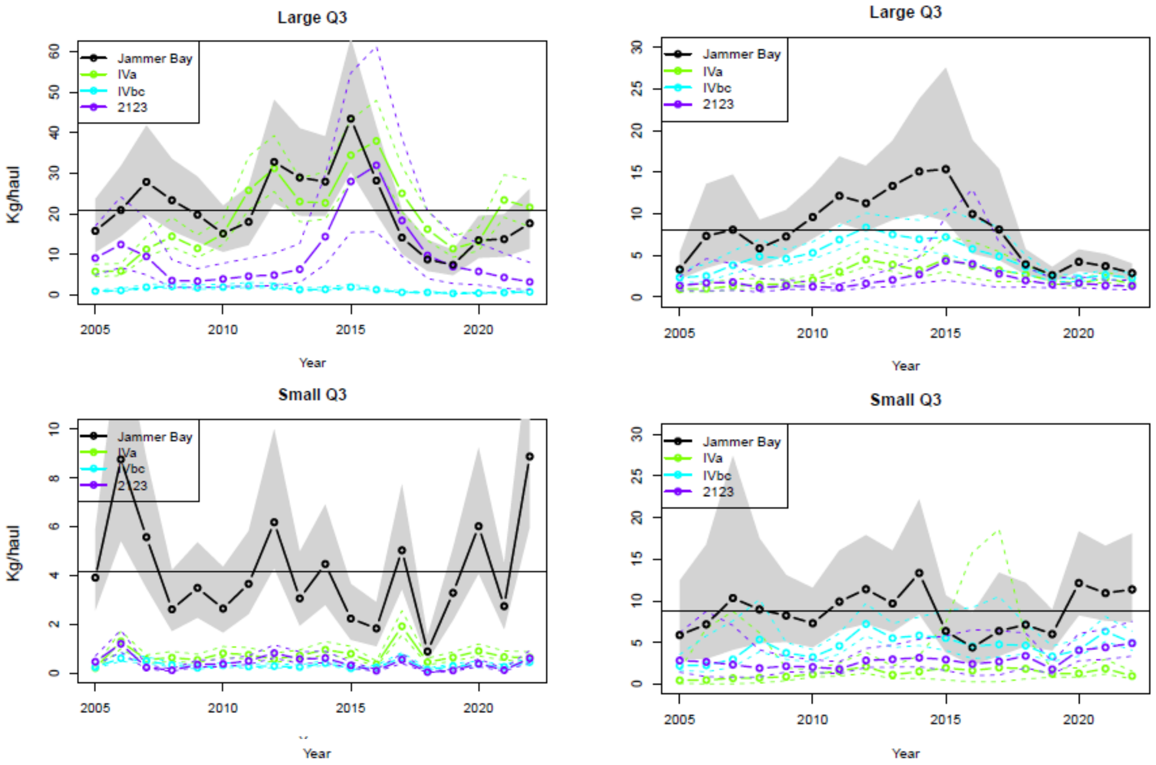


Figure 5.1. Densities of cod (left figures) and plaice (right figures) at different spatial scales covering the Jammer Bay area (ICES squares 43F8, 43F9, 44F8, 44F9), northern North Sea (ICES areas Iva) and mid and southern North Sea (ICES area IVbc), Kattegat and the Sound (ICES area 2123). The top figures are densities of allowable landing size of fish (cod >30 cm; plaice >27 cm) and the bottom figures show densities of the undersized cod and plaice.

5.3 Analyses of fishing cultures identified by core features pertaining to life modes, modes of operation, fishing gears, and economic value chains in the Jammer Bay area (Task 4.2)

Thomas Højrup, Kirsten Monrad Hansen, Søren Q. Eliasen

This Task identified the distinct types of fisheries in the Jammer Bay area using relevant features of each fishery, such as vessel lengths, engine sizes, gear types, profitability measures, crew sizes, quota, and ownership. They were categorised into four core features, which provided a new, operational framework of conceptual models, called “Fishing Cultures”. The conceptual models were applied to identify different connections between cultural life-modes and modes of production in the fisheries, their competition for ecosystem resources and their contributions to value chains and socio-cultural sustenance at the local, national, and international level. Further, a model for assessing the local economic effect of each Fishing Culture was developed.

Each Fishing Culture is a unity of four core features: i), life-mode; ii), mode of operation; iii), fishing methods and iv), fishing harbour affiliation. This framework can be further developed for other geographic areas by elaborating additional Fishing Culture concepts.

Seven Fishing Cultures identified: FC 1), Beach landing coastal fishery; FC 2), Dutch demersal beam-trawling; FC 3), Expansive harbour-based fishery; FC 4), Harbour based coastal fishery; FC 5), Specialised gillnet fishery; FC 6), Specialised anchor-seine fishery; FC 7), Profit-seeking large-scale fishery.

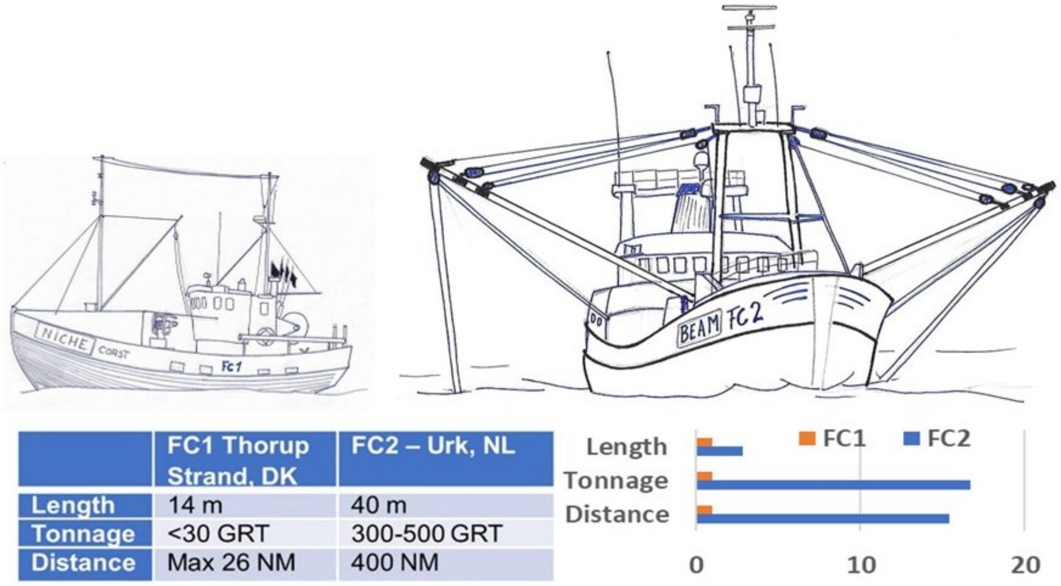
Two serious problematics are due to the structural contrast between i), different modes of operation and ii), between different fishing methods and gear. The study showed that:
i), Small and medium sized vessels realizing a broadly composed, versatile mode of operation all year round in the local Jammer Bay area (conducted mainly by Fishing Culture 1 and 4) may be vulnerable to larger vessels' unilateral specialized mode of operation (conducted by Fishing Culture 2, 3, 5, 6 and 7). The larger, more mobile and at times long-distance fishing vessels of the last categories can enter the local fishing grounds and displace the more local versatile vessels from their year-round areas and resources during high season. The conventional use of relatively small mesh sizes in the Norway lobster or brown shrimp fishery may (according to interviewed stakeholders of Fishing Cultures 1, 4, 5, 6) increase the risk of unwanted by-catch of juveniles and non-targeted species.
ii), Fishery using light gear to entangle or surround and herd the fish together with low impact on the seabed fauna is vulnerable to fishery using heavy, mobile bottom-contacting gear.

The problematic coexistence i), of opposite modes of operation and ii), of opposite fishing methods became aggravated when a foreign fleet of large beam-trawlers (FC 2) arrived in 2017 at the shallow grounds of the Jammer Bay searching for sole and plaice and subsequently returned to the Jammer Bay during the next 6 years because these target species were no longer available in their home waters of the Southern North Sea. Their presence in the area created conflicts with local fishers because of their inability to share common fishing grounds and fish stocks. According to local fishers, the impact on the seabed, marine food webs and juvenile fish by the beam trawlers negatively impacted their fishing opportunities in the shallow grounds of the Jammer Bay both during the time the beam trawlers were operating in the bay and for a considerable period after.

The interviewed stakeholders realizing Fishing Cultures 1, 4, 5, and 6 (local coastal fishing, gill-netting and anchor seining) find themselves caught in an antagonistic relationship to the large beam-trawlers' long-distance fishery in the Jammer Bay. The interviewed stakeholders experience that the large beam-trawlers owned by Dutch family companies (FC 2) introduce a high fishing pressure because they can operate independently of the weather and seabed impact. The local stakeholders viewed the long-distance beam trawlers as a threat to their livelihood because the local fleet of coastal vessels depend on the local resources in the Jammer Bay. The long-distance beam-trawling stakeholders conceive their fishery as a survival strategy, since the stocks of sole and plaice are absent from their own coastal waters and windfarms are allowed to expand in these areas prohibiting their spatial access to fishery.

Interviewed stakeholders from Fishing Culture 2 explained that by 'opening the ground' with their heavy beam trawls, bivalves living in the seabed are suspended and made available on the seabed as fish attracting bait. From the fishers' point of view, this could be advantageous for other fisheries as well, if they take the risk to fish where the ground has been opened by the large beam-trawler vessels. The interviewed stakeholders of the Jammer Bay realizing Fishing Cultures 1, 4, 5, 6 perceived this point of view as far too short-sighted and neglecting the long-term negative impact of heavy gears used by beam trawlers on habitats and fish stocks in the Jammer Bay. The interviewed stakeholders realizing Fishing Culture 2 suggested that the local fishers (FCs 1, 4, 5, 6) should adapt a similar long-range, mobile fishery, that allow local fishing grounds to alternately ‘recover’ after having been ‘opened up’. They contend that only increased fuel prices pose a barrier for such a development. The coastal fishers in the Jammer Bay respond that it is neither appropriate nor necessary to ‘damage’ the seabed and the ecosystem by utilising heavy gears with high fuel consumption.

The results showed that the beam trawlers of Fishing Culture 2 operate a downright long-distance fishery without any noticeable economic contribution to the local fishing communities in the Jammer Bay area. These Dutch beam trawlers (FC 2) had the lowest (almost zero) Local Economic Effect (LEE), in comparison to the other Fishing Cultures identified, which had a LEE ranging between 25% (F C7), 40% (FC 3 and 6) and 49%-56% (FC 1, 4, 5 and 6) of the landing value. Thus in comparison, the Fishing Cultures 1, 4, 5 and 6 contributed with the largest relative Local Economic Effect to the local fishing communities in the Jammer Bay area.



	FC1 Thorup Strand, DK	FC2 – Urk, NL
Length	14 m	40 m
Tonnage	<30 GRT	300-500 GRT
Distance	Max 26 NM	400 NM

Figure 5.2. Fishing Culture 1 and 2 have different modes of fishing and vessel capacities. No 1 depends fully on fishery in the Jammer Bay. No 2 conducts local as well as long-distance fishery. No 2 displaces No 1 in the Jammer Bay.

5.4 Habitat-related by-catch of non-target fish and protected, endangered, and threatened (PET) species (Task 4.3)

David Lusseau, Gildas Glemarec, Lotte Kindt-Larsen

The incidental capture of unwanted species (bycatch) like marine mammals, seabirds, or fish in set net fisheries is a long-known issue in European waters that is susceptible to negatively affect the population dynamics of protected, endangered, and threatened (PET) species. Bycatch stems from the concomitant presence of non-target, unwanted species and of fishing gears in an area. Nevertheless, spatiotemporal overlap between PET species and fisheries alone cannot explain observed levels of bycatch, and incidental captures also depend on a number of operational, ecological, and behavioural aspects that are often difficult to separate from one another.

In Denmark, considerable effort to monitor incidental captures of PET species in commercial fisheries has been made in the last 15 years, notably using semi-autonomous video-monitoring system, or electronic monitoring (EM) systems to associate high-resolution fishing effort and species-specific bycatch data. These EM data, collected on a sample of the commercial Danish fleet, have been used to highlight areas where bycatch risks are high and estimate PET species bycatch mortalities. In the southern part of the Jammer Bay, however, EM coverage has been historically relatively low. With the JAMBAY project, two new vessels joined the PET bycatch monitoring programme in 2023, and their EM data were analysed to refine our understanding of the bycatch variability in this important fishing area. Initially, we aimed to link high-resolution fishing effort and bycatch data from EM vessels to the high-resolution habitat maps from Work Package 1, but the data delivery was delayed so we exploited the Copernicus database instead (https://marine.copernicus.eu). The EU Copernicus Marine Service provides daily updates of important oceanographic variables such as sea surface and bottom temperature, indices of primary productivity, or bathymetry, which we could link to each fishing events in the EM fleet (since the latitude, longitude, date, and time were known for all monitored events) to explore the underlying factors influencing PET species bycatch. Bycatch registrations in the Jammer Bay involved several species of elasmobranchs (rays and sharks), of seabirds, and of marine mammals. Among the later, the harbour porpoise (*Phocoena phocoena*), is a common cetacean species highly susceptible to bycatch in gillnets, present in the Jammer Bay yearlong, and for which EM data series spans the longest, starting in the early 2010's. Porpoises constituted as such an ideal case study to explore the complex relationships between oceanographic features, habitat, and fishing effort distribution and intensity in the study area. Specifically, we trained a machine learning model (here, a classification tree model) using XGBoost to classify observed fishing operations (hauls) with and without harbour porpoise bycatch depending on fishing and oceanographic characteristics.

The results from our model shows that, although oceanographic features such as depth, salinity, bathymetric slope, or temperature (all of which could be used to define e.g., porpoise bycatch high-risk areas) are important contributors to porpoise bycatch in the Jammer Bay, the principal contributor to by-catch probability is by large fishing effort measured as the product of net fleet length and soak duration, while at the same time, and quite unexpectedly, gillnet mesh sizes was not found to be an important variable in our data. It is likely that mesh size effects on bycatch probability captures ecological features (e.g., via target species) increasing bycatch probability which are captured by the oceanographic variables considered in this machine learning model.

5.5 Spatial and density model for sensitive species (Task 4.4)

Casper W. Berg, Anna Rindorf, Tobias Mildenberger, Mikael van Deurs, Jasmin Thomassen

Spatial distribution maps and density time-series were estimated for four sensitive fish species that occur in the Jammer Bay area: Halibut (*Hippoglossus hippoglossus*), spurdog (*Squalus acanthias*), wolfish (*Anarhichas lupus*), and starry ray (*Amblyraja radiata*).

Data from five different trawl surveys (NS-IBTS, BITS, Cod, Sole, and Norwegian shrimp survey) were combined in a model that accounted for different catch efficiency in each survey due to different types of trawls for example. This combination of data from different surveys utilizes the sparse information available for these sensitive species in a better way than any of these surveys alone and allows standardized density maps for larger areas and longer time-series to be calculated. For halibut, and particularly spurdog, the overall trend in density from 1983-2023 is positive, whereas the overall trends for wolffish and starry ray are negative.

In addition, landings in the Jammer Bay from the period 1895-1910 were digitized and compared to those from the period 2005-2020. Due to potential non-reporting and species-misidentification it was not possible to compare landings of the sensitive species considered, only the most abundant species could be compared. Cod and haddock was by far the two most common landed species from 1895-1910, whereas plaice and herring were more common from 2005-2020.

5.6 Improving estimates of the relative importance of fishing and predation induced by cod and marine mammals on cod, plaice and other North Sea fish stocks (Task 4.5)

Morten Vinther, Vanessa Trijoulet, Nis Sand Jacobsen

The predation mortality of the commercially important fish stocks in the North Sea and Skagerrak has been estimated by the Stochastic Multi-Species model (SMS) developed and maintained by DTU Aqua. The model includes fisheries and diet data for 12 commercially important species (e.g., cod, saithe, herring, sandeel and sprat), additional 4 fish-eating species (e.g., grey gurnard and starry ray), 8 species of sea birds and marine mammals (harbour porpoise and grey seals). SMS has been updated to include stock assessment input data for 2020-2022, revised previous estimates of grey seal density and diet, and estimated uncertainties of fish diet estimates and used these in the model likelihood. This work was done in preparation for a week-long meeting in the ICES Working Group on Multispecies Assessment Methods (WGSAM) in October 2023. The output of the updated model quantifies the predator-prey interactions with respect to biomass eaten and predation mortalities and contributes as such to the understanding of the food web for the commercial species in the North Sea. Despite substantial changes in part of the input, the model output is consistent with the previous SMS run using data for 1974- 2019.

The changes in data and model made by DTU Aqua and additional changes in the density of seabirds made by other WGSAM members were quite comprehensive, such that the final run and result first were agreed on by WGSAM at the end of December. The final report from WGSAM 2024 provides a detailed description of the work done and the final model results. The results, mainly a new estimate of the natural mortalities, will be used by the ICES stock assessment working groups and catch advice for 2025.

5.7 Spatial catch data (discard and landings) from Skagerrak (Task 4.6)

Kirsten B. Håkansson, Marie Storr-Paulsen

Landings data were visualized in Danish waters in many other projects with the use of vessel monitoring systems (VMS) combined with information from the landing declarations and sale notes to get information on catch composition by location. In this Task (4.6), we combined the information on spatial distribution of the fisheries' (VMS and AIS) with the information from the landing declarations, sales slips, and data from the observer trips conducted by DTU Aqua to get a spatial distribution of both the landings and discards. This has been conducted for the period 2018 – 2022 for nine selected species in Skagerrak. Further, in this Task, we mapped the fishing effort and the observer coverage from the sampled fisheries in Skagerrak in the same period.

Another aim of this Task was to deliver a time series of catch data (discard and landings) from 2015-2022 on an online platform to give easy accessibility for further use of data. Catch data collected is mainly used in stock assessment in ICES (International Council for the Exploration of the Sea) and in fishery advice. The observer program covers a relatively small part of the total fishery (<1%) of all fishing trips and only some of the fleets are covered in the program.

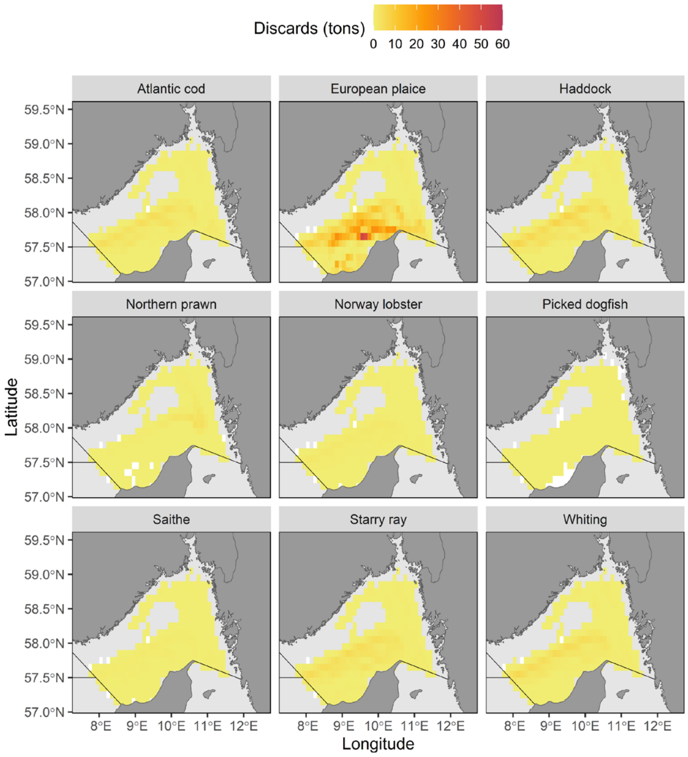


Figure 5.3. The distribution of the total estimated amount of discards per species for the sampled fisheries combined in 2022. The species are cod, plaice, haddock, Northern prawn, Norway lobsters, piked dogfish, saithe, starry ray and whiting.

6. Synthesis for ecosystem based spatial management (WP5.Task 5.1)

Grete E. Dinesen, Josefine Egekvist, Ole R. Eigaard, Josianne G. Støttrup

6.1 Introduction and aim

With this chapter, we aim to compile the newly generated information from the previous chapters into an example of how the results can be combined to inform ecosystem-based management towards environmentally sustainability, economic viability, and social equitability.

Managing the environment sustainably, requires information on benthic footprint of fisheries, the impact on fished population dynamics, and biodiversity to ensure that resources are maintained productive for the next generations. This entails that the fishery sector sustains a stable source of income and contributes to food provisioning. Here, information on how the fisheries are conducted and how management options can influence the different types of fisheries needs to be incorporated into the management process. Considering the different fisheries and how management can impact them, and the local economy derived from the fisheries is an important prerequisite to ensure social equity. Economic viability and social equity increase trust in governance and encourage compliance. Thus, ecosystem-based management essentially manages human activities and their causal imprints on ecosystems in a way that preserve healthy ecosystems and support long-term use of marine resources, while maintaining livelihood and well-being.

With the aim to demonstrate how the results of this project can be applied in scenario exploration, we implemented a pilot trial of trade-off modelling of fisheries spatial use of seabed habitats and landing values. More explicitly, we combined spatial use of different seabed habitat states (MSFD BBHTs) with economic revenues from the different commercial fisheries métiers. We were able to identify which seabed habitats provided the highest economic value, where fishing grounds are shared and where competition exists between fisheries.

The Marine Strategy Framework Directive (EU 2008/56) requires EU Member States to implement ecosystem-based management to restore and maintain healthy ecosystems and achieve sustainable use of marine resources. Towards this, several ecosystem Descriptors are applied for assessment of Good Environmental State (GES), including D6 “Seafloor integrity”. To achieve GES of D6, the extent of adverse effects on each BBHT must not exceed 25% (including a maximum of 2% loss of habitat). Moreover, the EU Biodiversity Strategy for 2030 requires Member States (MSs) to implement a 10% strict protection and an additional 20% high protection from human activities both on land and in the sea.

We estimated the trade-offs between benthic seabed closure indicators, including extent of each BBHT habitat and biological quality (RBS) as well as the Danish fisheries resource use. The pilot scenarios provide examples of how combining environmental and socio-economic data can be used to explore spatial-temporal linkages between ecosystem resource use, environmental impacts and protection requirements, and the potential loss of environmental state and fisheries landings value with different management options. The trade-off scenarios can also contribute to dialogue among stakeholders on how to achieve and maintain healthy ecosystems and improve sustainable use of fisheries resources and be implemented in management in the Danish seas.

6.2 Materials and methods

The geographic location of the four ICES statistical rectangles included in the Jammer Bay analysis is shown in a map below (Fig. 6.1). The ICES rectangle 43F8 is partly located in the Skagerrak and partly in the Central North Sea. The two ICES rectangles 44F8 and 44F9 are partly located in the Danish Exclusive Economic Zone (EEZ) and partly in the Norwegian EEZ. The analyses included only data from the areas located in the Danish EEZ.

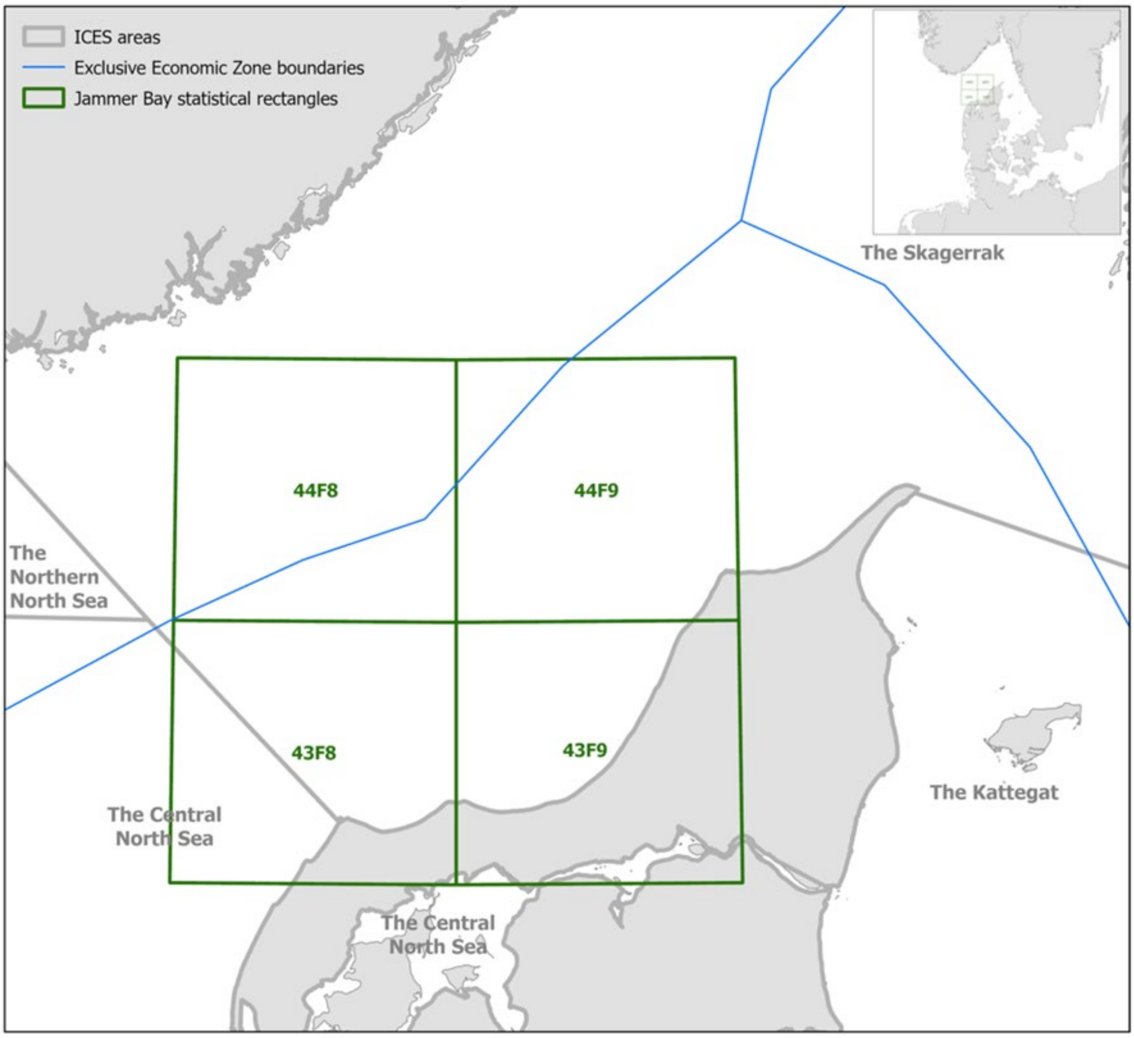
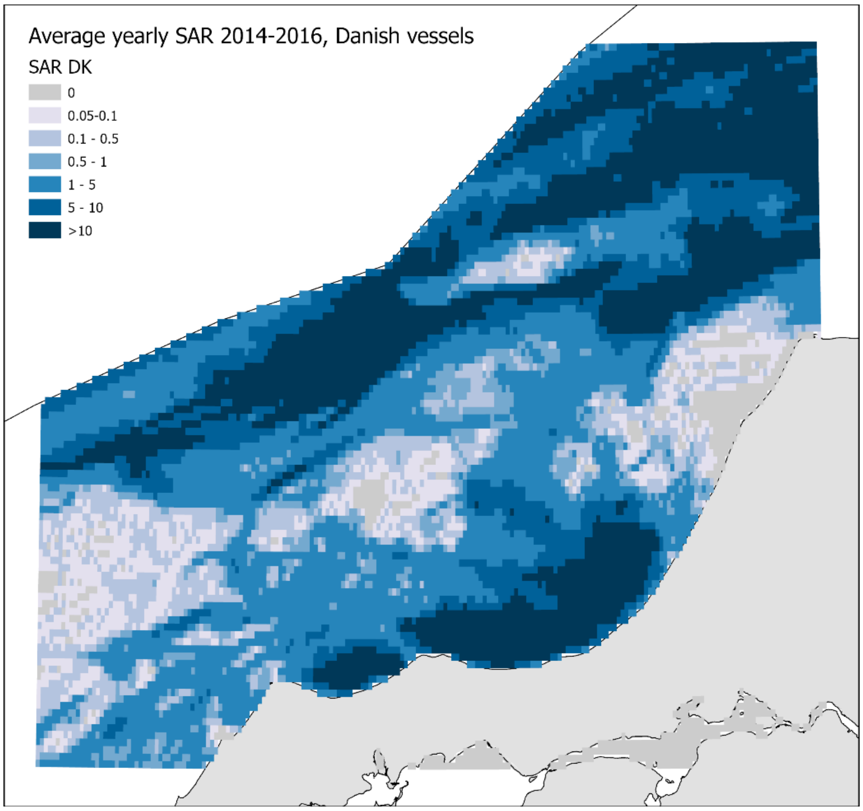
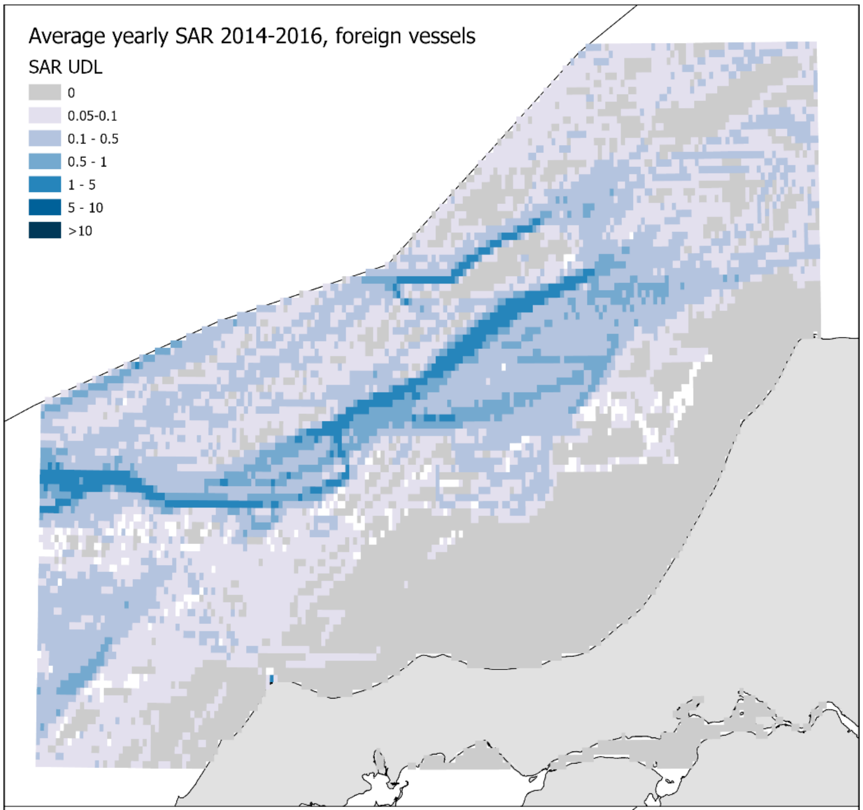


Figure 6.1. Map of the four ICES statistical rectangles included in the Jammer Bay analyses (green squares), and their location relative to the ICES areas (grey lines) and the Exclusive Economic Zone (EEZ) borders (blue line) between Denmark, Norway and Sweden.

The pilot scenarios for the Jammer Bay were based on new, medium-fine resolution data of fishing intensity, measured as swept area ratio (SAR) with a medium spatial resolution (grid cell size of 0.01° ~ 600 - 1000 m) (Fig. 6.2) (Eigaard et al. 2016, also see WP2, T2.1 for further details), and existing data from the EMODnet (EUSeaMap ver. 2021) of the spatial distribution of the Marine Strategy Framework Directive (MSFD) Benthic Broad Habitat Types (BBHTs) (Fig. 6.3), as well as calculations of the benthic indicator, Relative Benthic State (ICES 2017, ICES 2018). For details of the application in the Jammer Bay analyses, see Section 4.4 herein.

For the pilot trials of scenario trade-offs in the Jammer Bay, we applied the ICES WGFBIT assessment approach RBS & Trade-Offs, which is currently under development for large scale assessments of European waters (https://www.ices.dk/community/groups/Pages/WGFBIT.aspx) (ICES 2017, 2018, 2021).




Average yearly SAR 2014-2016, foreign vessels
SAR UDL
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0.05-0.1
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0.5 - 1
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5 - 10
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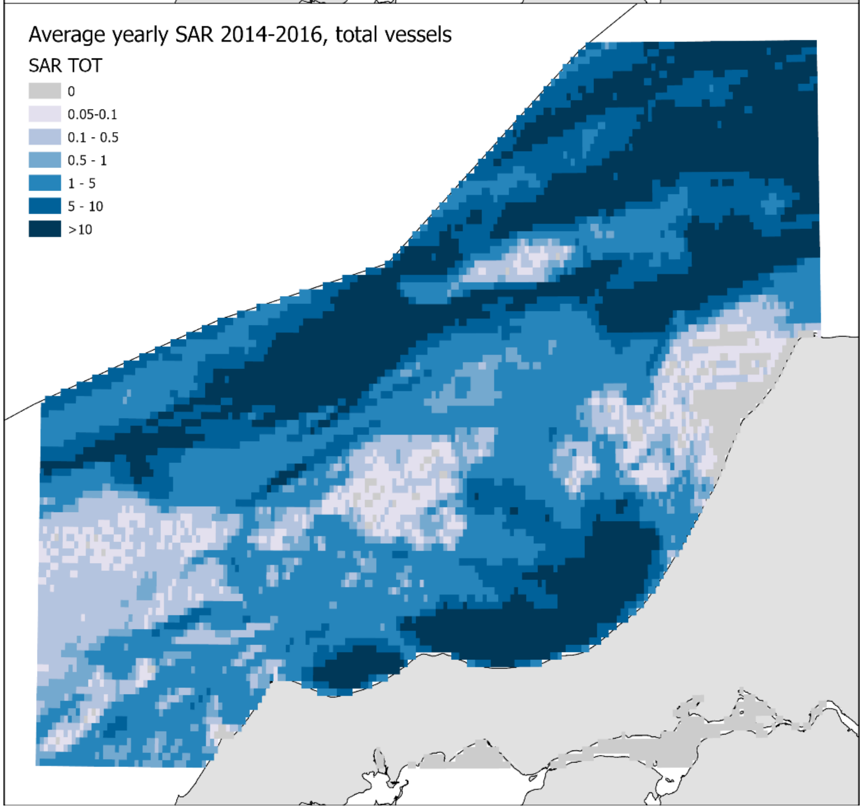
Average yearly SAR 2014-2016, total vessels
SAR TOT
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1 - 5
5 - 10
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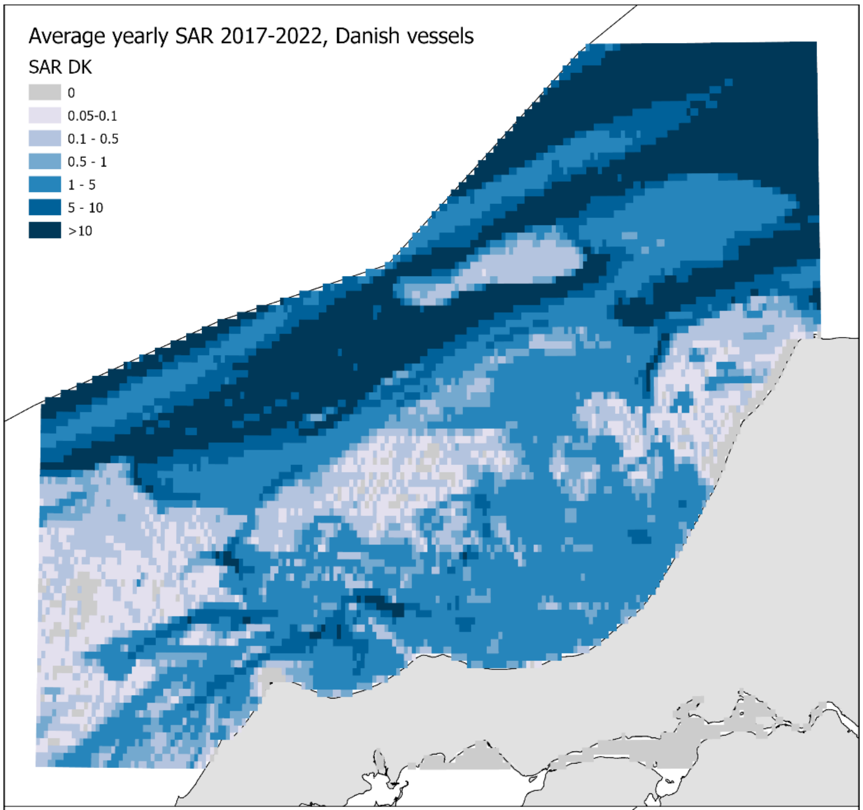
Average yearly SAR 2017-2022, Danish vessels
SAR DK
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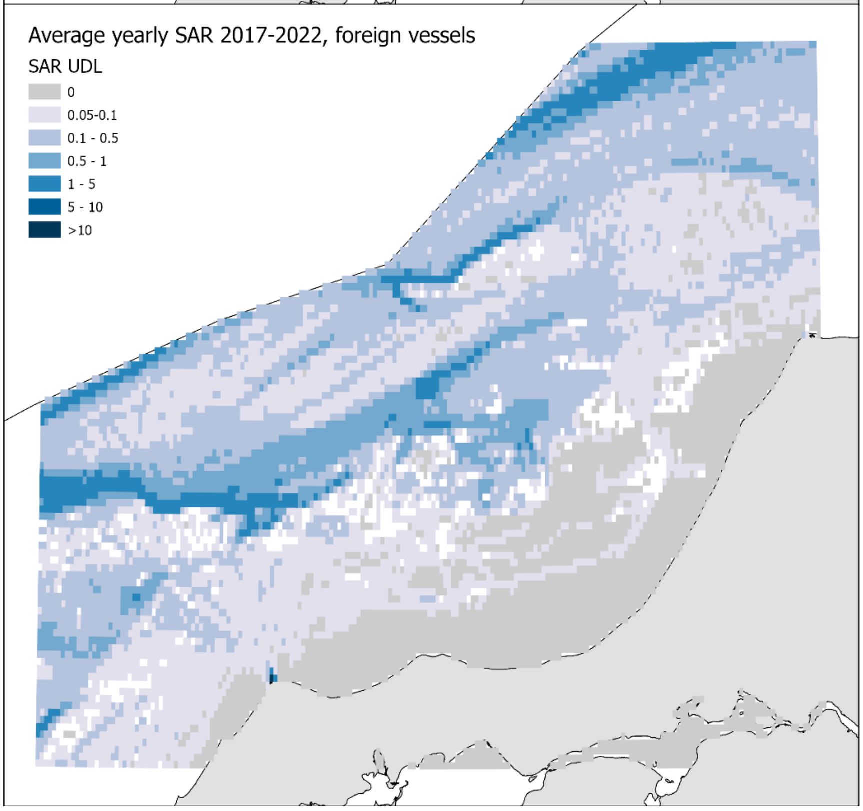
Average yearly SAR 2017-2022, foreign vessels
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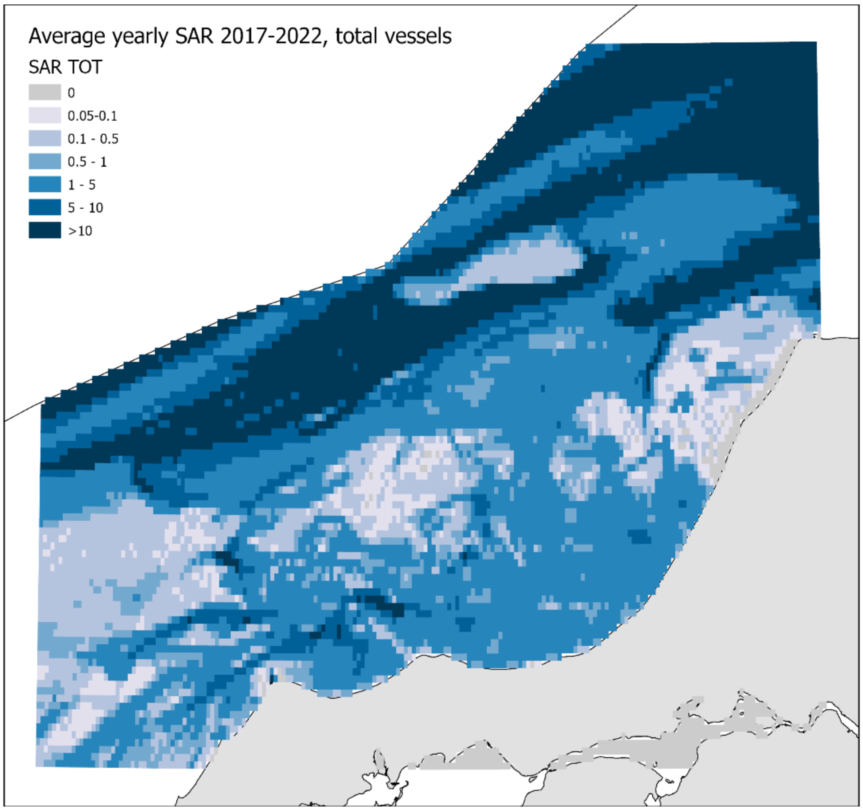


Figure 6.2. The Jammer Bay. Distribution of the average SAR for the Danish fleet, foreign fleets, and all fleets (Total) in the area in the two periods 2024-1016 and 2017-2022.

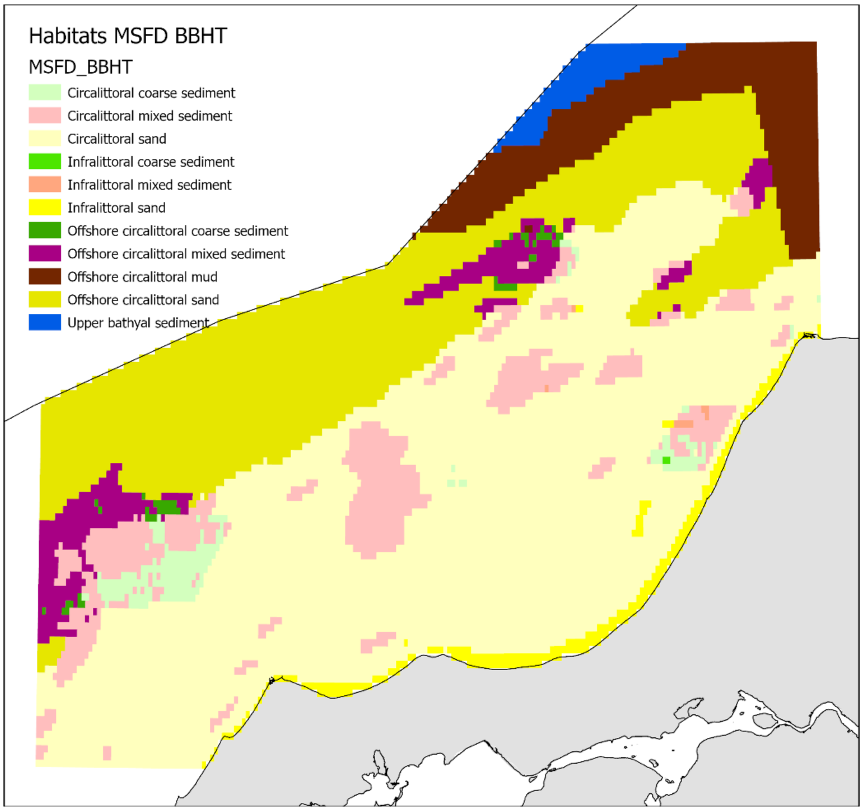


Figure 6.3. The Jammer Bay. Distribution of the MSFD BBHTs in the Jammer Bay area (data from EMODnet: EUSeaMap ver. 2021), mapped to the 0.01 degrees c-square resolution based on the habitat with the largest area within the c-square.

6.3 Results

6.3.1 Trade-offs between seabed habitat area and landing values

The Jammer Bay area is home to a large variety of different demersal fisheries and includes a number of vessels from the Danish fleet, as well as from several foreign fleets, especially the Dutch and Belgian. Since logbook and landings information of métiers, target species and landings, are only accessible for the native fleet of the individual EU Member State, we were only able to generate scenario models for the Danish fishing fleet.

The spatial distribution of the relative landing values in the Danish fishery using mobile bottom-contacting gears in the Jammer Bay area was concentrated towards the central and south-western areas in the period 2014-2016 (Fig. 6.4). In the subsequent period from 2017-2022, the relative landing values declined considerably in the central area of the bay, corresponding with the considerable increase in fishing intensity (SAR values) of foreign fleets (Fig. 6.2). Due to lack of logbook and landings information from the foreign fishing vessels, we could not estimate the landings values of these fleets and assign it to fishing grounds. Without this information it was not possible to investigate trade-offs with the loss of landings values for the Danish fleet.

Furthermore, between the two periods, the relative landings values slightly declined in the south-western area, as well as in a smaller northern area (on the deeper slope near the EEZ boundary) but increased in a western coastal area near Hirtshals (Fig. 6.2).

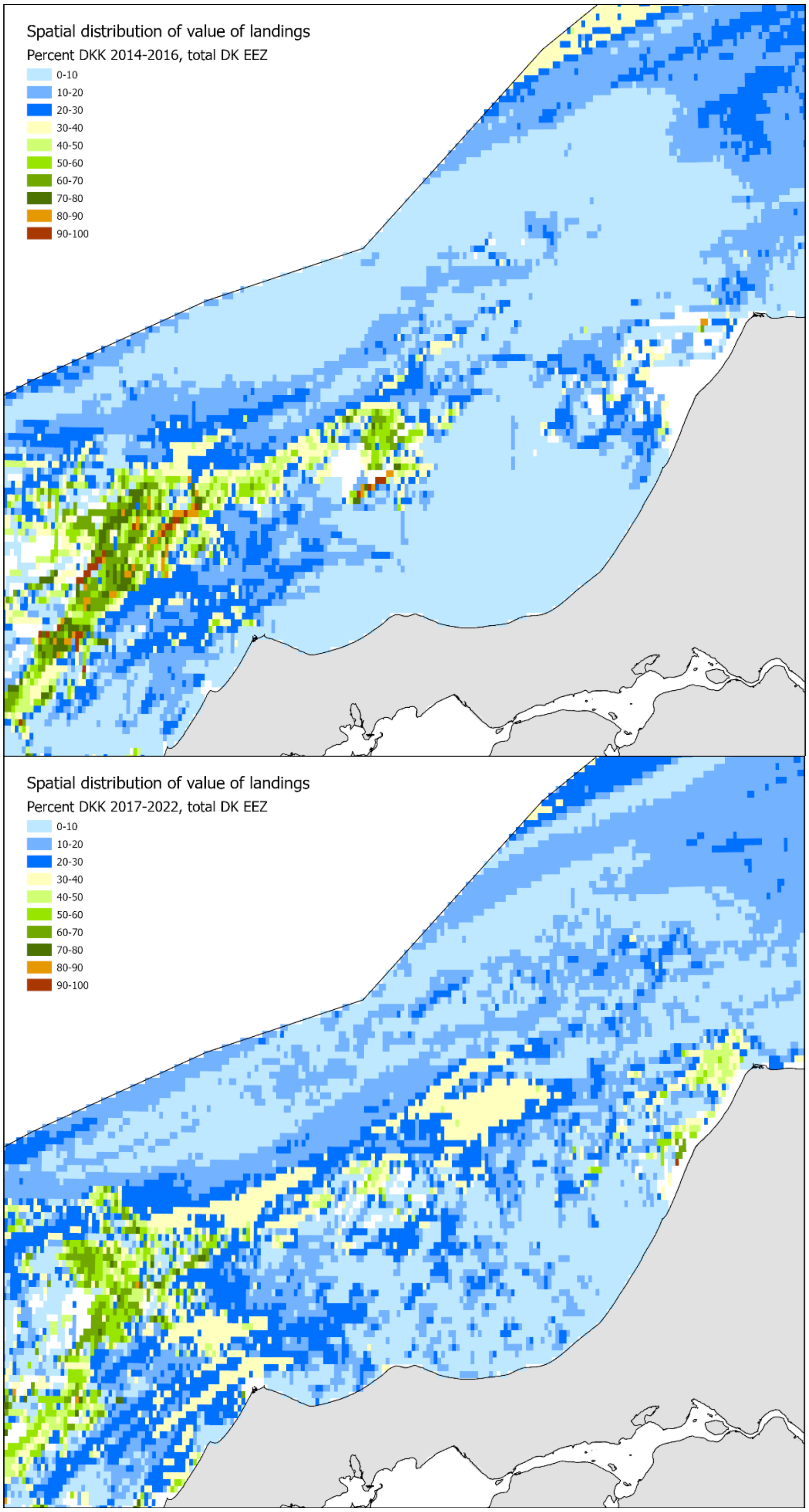


Figure 6.4. The Jammer Bay. Spatial distribution of the relative landing values of the Danish fisheries using mobile bottom-contacting gears in the two periods 2014-2016 (3 years) and 2017-2022 (6 years). The scale indicates the grid cell (area: ~ 600 x 1000 m) contribution to the total Danish landing value, where red marks the cells with the top 10% (90-100%) contribution, and pale blue marks the cells in the bottom 10% (0-10% of total) contribution.

Trade-off scenarios between potential habitat-specific spatial closures and their fisheries landings values (DKK) were assessed for each métier in the two periods 2014-2016 and 2017-2022. The first scenario explored a reduction in landings values related to the closure of cells from the highest to the lowest economic value of landings (Fig. 6.5). This approach to spatial fishing closure (High to Low, HL) of seabed habitat area would affect the most aggregated fisheries the hardest. A 30% closure from the high value end would terminate the income from Infralittoral mixed sediment and Offshore circalittoral mixed sediment. Furthermore, in most other BBHTs, it would reduce the fisheries income by more than 50%.

In comparison, the second scenario explored a reduction in landings values related to the closure of cells from the lowest to the highest economic value of landings (Fig. 6.6). This approach to spatial fishing closure (Low to High, LH) of seabed habitat would affect the peripheral fisheries the hardest. A 30% spatial closure from the lowest to the highest landings value would result in a limited reduction in fisheries income of the most spatially aggregated fisheries. The semi-aggregated fisheries would experience a smaller economic reduction related to Circalittoral coarse sediment, Offshore circalittoral sand and Offshore circalittoral mud.

Fisheries related to the deep Upper bathyal sediment is not aggregated spatially, and regardless of scenario (HL or LH), a 30% closure of this habitat would result in a ~30% percent reduction of income.

A third scenario explored a reduction in landings values related to the closure of cells from the highest to the lowest Relative Benthic State value (Fig. 6.7). This approach aims to protect the seabed habitat areas with the highest (i.e., best) scores of RBS (High to Low benthic state, HL RBS) by fishing closure. This resulted in a relatively low reduction of fisheries income, similar to the above scenario of closure of the areas with the lowest to the highest income (LH). This is likely a result of the benthic indicator RBS being at its highest (best) values in the seabed areas that are fished the least.

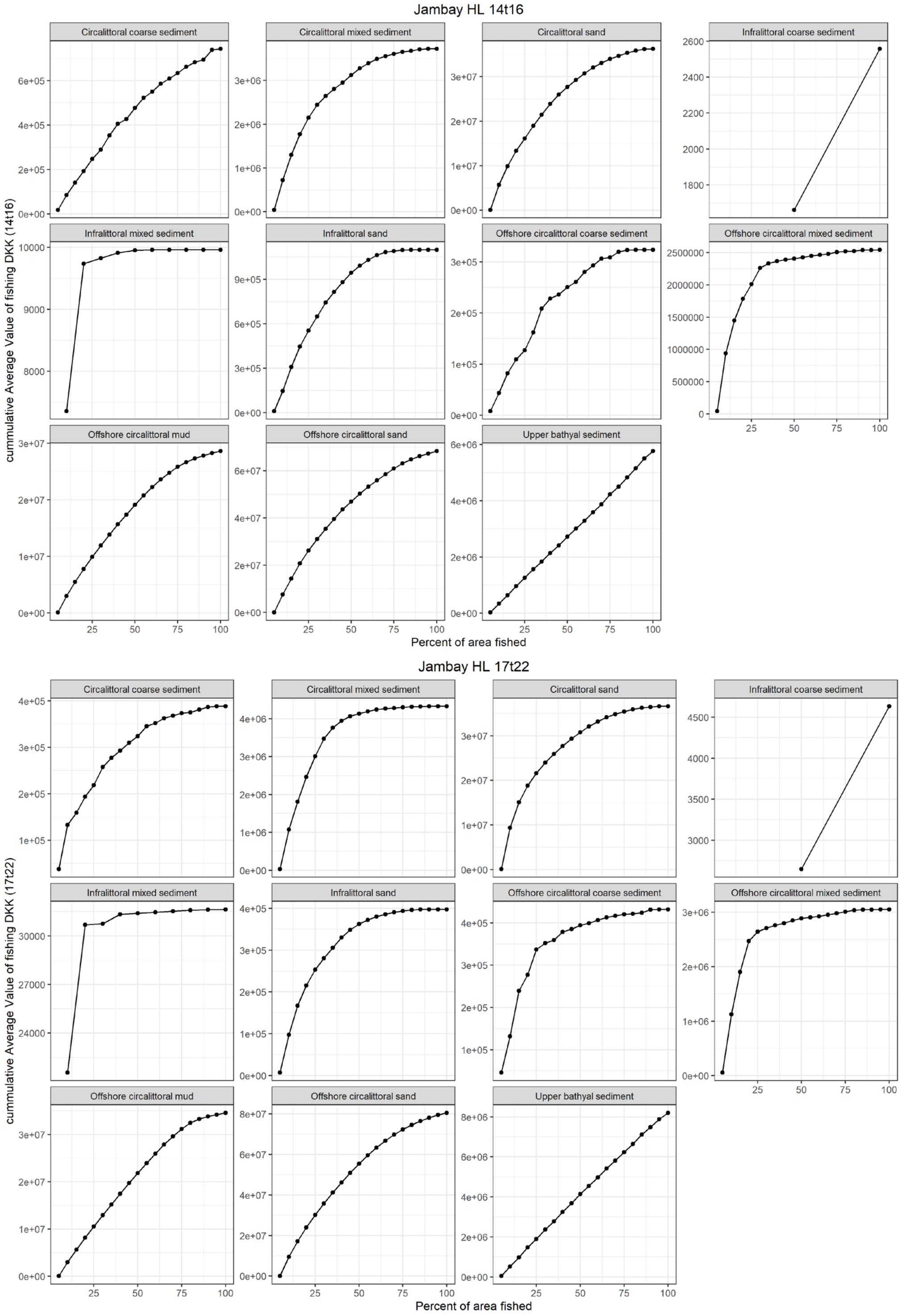


Figure 6.5. Percent of area fished and cumulative landing values from mobile bottom-contacting gears sorted from the highest to the lowest economic values (HL) by BBHT in each of the periods 2014-2016 and 2017-2022.

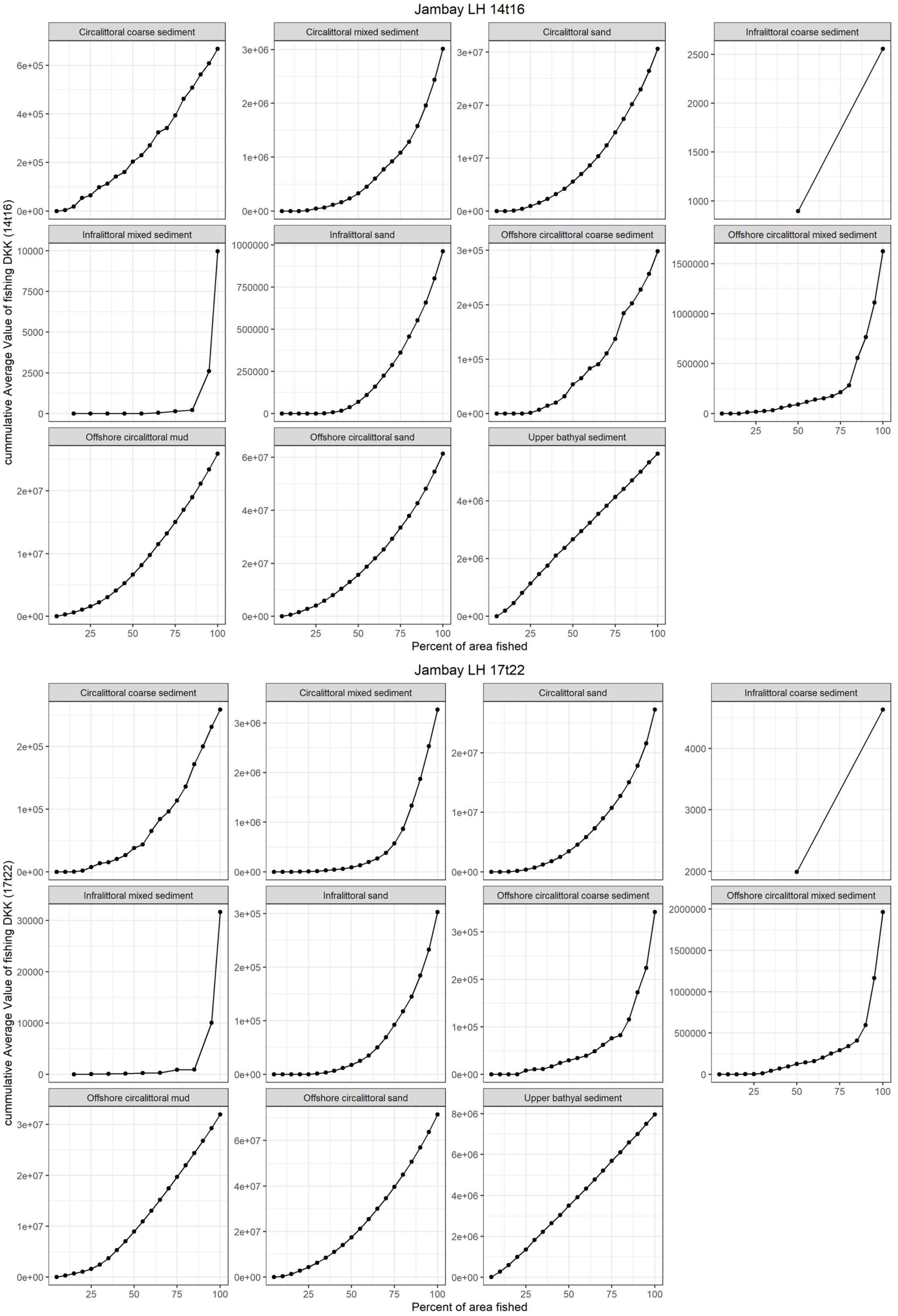


Figure 6.6. Percent of area fished and cumulative landing values from mobile bottom-contacting gears sorted from the lowest to the highest economic value (LH) by BBHT in each of the periods 2014-2016 and 2017-2022.

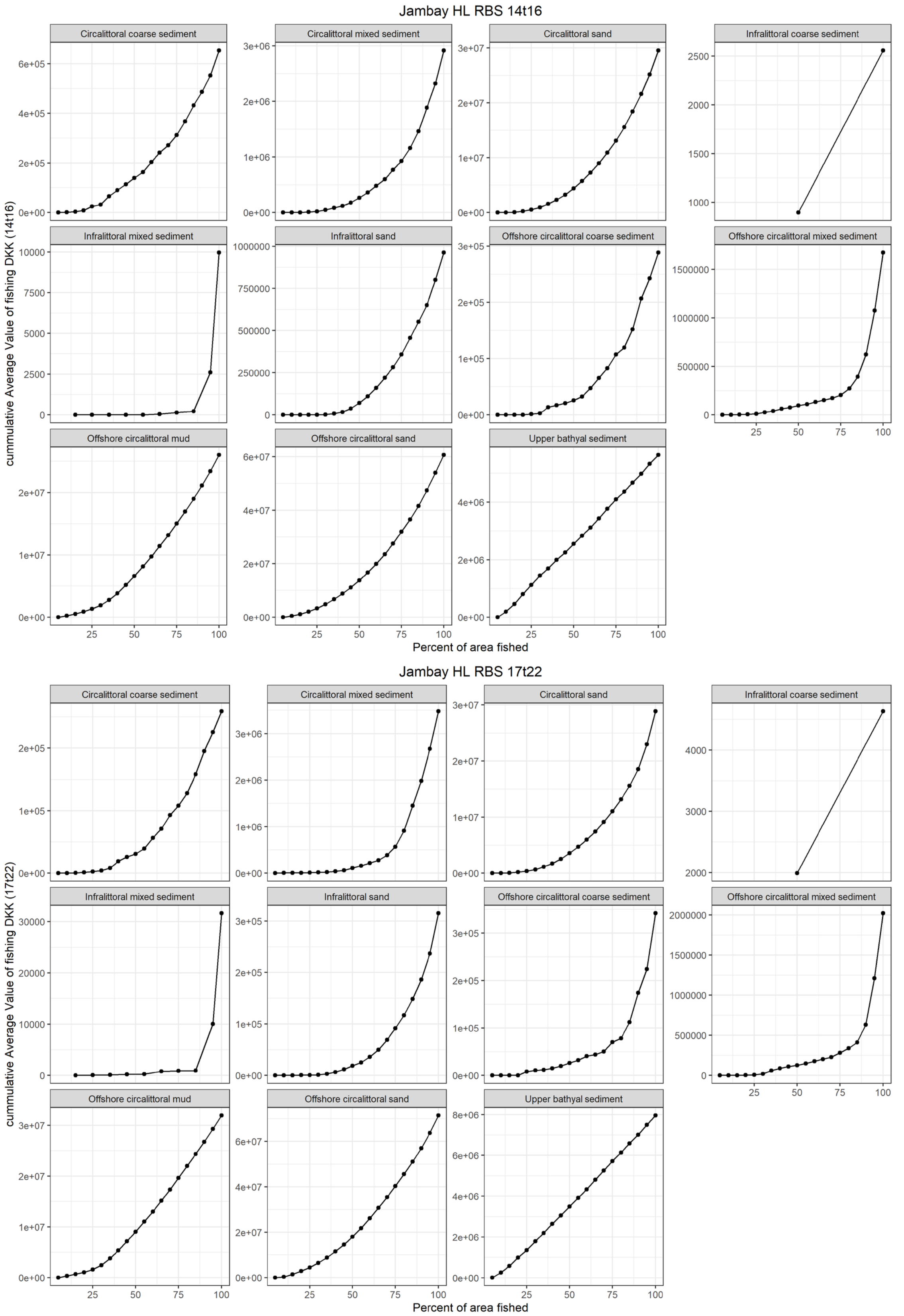


Figure 6.7. Percent of area fished and cumulative landing values from the mobile bottom-contacting gears sorted from the highest to the lowest Relative Benthic State indicator value (HL RBS) by BBHT in each of the periods 2014-2016 and 2017-2022.

To be environmentally effective, seabed closures require data-based consideration of environmental states and processes that are of importance to the entire ecosystem locally, and to other areas regionally. This also includes an assessment of the closed area functioning and its' potential to achieve and maintain good environmental state, as well as to contribute efficiently as a source area for recruitment to other areas.

The benthic indicator, Relative Benthic State (RBS), evaluates the environmental state of seabed habitats based on benthic faunal biomass longevity distribution. The RBS is based on a theory that the larger the proportion of faunal biomass that is long-lived, the more stable the state of that macrofaunal community. In the scenario analyses of seabed habitat closures, we sorted the individual cells (i.e., c-square size: 600 m x 1000 m) from the highest to the lowest RBS value, based on the estimated state under the conditions of the past periods from 2014-2016 and 2017-2022. Cells with RBS values ≥0.8 are considered in a good environmental state (GES); cells with RBS <0.8 to >0.6 are considered in a moderate not good state (subGES moderate), and cells with RBS ≤0.6 are considered in a not good state (subGES). The RBS indicator depends on benthic faunal data. The quantitative macrofaunal data (from the Danish monitoring programme NOVANA) used herein for estimation of the benthic indicator RBS comprise data from mud, sand and coarse sediments from shallow and deeper waters representing most of the BBHTs. However, due to the lack of quantitative benthic faunal NOVANA data from reef habitats, the RBS estimates included in Table 6.1 for the BBHTs Infralittoral mixed sediment, Circalittoral mixed sediment and Offshore circalittoral mixed sediment should be considered as a proxy and thus should be used with caution in management.

Considering the spatial distribution of fisheries with mobile bottom-contacting gears, three scenarios were explored using a 10%, 30%, and 75% spatial closure of the cells with the highest RBS values for each Benthic Broad Habitat Type (BBHT). The scenario results show what the state of benthic habitats would have been if the spatial closures were implemented at the end of the first period (2014-2016). In addition, we explored what the state would have been if the spatial closures were first implemented at the end of the second period (2017-2022). Therefore, a decline in average RBS between the two simulated times of closure indicates that delaying closure is detrimental to the habitat resulting in a poorer environmental state.

Scenario 1 explored a 10% strict spatial closure related to the Marine Strategy Framework Directive (MSFD) Descriptor 6 “Seafloor integrity”, Criteria 5 (D6C5) and the Biodiversity Strategy for 2030 (BDS2030). The 10% closure of cells with the highest RBS values for each Benthic Broad Habitat Type (BBHT) showed RBS average values ranged between 1-0.87 and thus are all in good environmental state (GES, RBS ≥0.8). The exception was Upper bathyal sediment with the RBS average of 0.69 in 2014-2016 and a lower average of 0.52 in 2017-2022 (Table 6.1). For the period 2017-2022, this scenario would have reduced fisheries income by ≤3.5% for each BBHT, equivalent to a total income loss of ~1 mill DKK, distributed relatively evenly across Offshore circalittoral sand, Offshore circalittoral mud and Upper bathyal sediment.

Scenario 2 explored a 30% spatial closure related to the BDS2030 (i.e., 10% strict closure and an additional 20% closure of total seabed). The results of the spatial closure of the cells with the highest RBS values for each BBHT showed most to be in GES (i.e., with an RBS average range between 0.99-0.87) (Table 6.1). However, a closure scenario of 30% of Offshore circalittoral sand showed that the RBS average was higher in the first period (0.86 in 2014-2016) than in the second period (0.75 in 2017-2022), with a change from GES to moderate subGES. A closure scenario of 30% of Offshore circalittoral mud showed a decline in RBS average from 0.75 in 2014-2016 to 0.54 in 2017-2022, corresponding to a deterioration from moderate subGES to subGES in the cells with the highest RBS. A closure scenario of 30% Upper bathyal sediment showed a decline in RBS average value from 0.53 in 2014-2016 to as low as 0.29 in 2017-2022, indicating a transition from a deteriorated to a deprived state of the cells with the highest RBS. For the period 2017-2022, this scenario would have reduced the fisheries income by ≤10% for most BBHTs, except for Upper bathyal sediment where the percent income loss was 22.5%. This illustrates that these habitats are primarily exploited by fisheries métiers that are not aggregated.

The total loss of fisheries income was estimated to 12 mill DKK. The scenarios results showed that most of the income loss was related to fisheries on Offshore circalittoral sand (6.5 mill DKK), whereas a smaller proportion of income loss of fisheries was derived from Upper bathyal sediment (1.8 mill DKK).

Scenario 3 considered a scenario, in which fishery with mobile bottom-contacting gears was potentially considered incompatible regardless of métier with the MSFD D6C5 ≥75% Extent Threshold for good environmental state (GES). This closure scenario of 75% of the area of each BBHT showed most BBHTs to be in GES (i.e., RBS average between 0.99-0.89) (Table 6.1). However, closure of 75% of Offshore circalittoral sand showed a decline of RBS average from 0.65 in 2014-2022 to 0.44 in 2017-2022. This translates to a decline from moderate subGES to subGES of the cells with the highest RBS values. Closure of 75% Offshore circalittoral mud showed a decline of RBS average from 0.37 in 2014-2016 to 0.22 in 2017-2022, indicating a further decline in the subGES level of this habitat. Closure of 75% Upper bathyal sediment showed a decline in the RBS average from 0.45 in 2014-2016 to as low as 0.17 in 2017-2022, reflecting the impoverishment of this habitat type.

For the period 2017-2022, this scenario would have reduced the overall fisheries income by 30-62% depending on the métier for most BBHTs. The percent income loss for Upper bathyal sediment was higher at 72%. However, considering the total loss of income of 79 mill DKK, Upper bathyal sediment only contributed to this loss with 6 mill DKK, whereas Offshore circalittoral sand contributed approximately half, approximately 40.5 mill DKK.

It is worth noting, that in all three scenarios of spatial closure, the highest relative percentage loss of fisheries income was derived from closure of the BBHT with the poorest environmental state. In terms of loss in monetary value, the highest fisheries economic loss was derived from BBHT with a better environmental state as measured by the RBS indicator.

Table. 6.1. Estimated economic costs for the Danish fishery related to spatial closure in the Jammer Bay of three different scenarios: 1), 10% closure; 2), 30% closure; and 3), 75% closure of the cells with the highest Relative Benthic State (RBS) for each seabed habitat proposed relevant to the Marine Strategy Framework Directive (MSFD) for each Benthic Broad Habitat Type (BBHT). The estimations are based on data for the two periods from 2014-2026 and 2017-2022. RBS values of ≥0.8 are considered in a good state; >0.8 to >0.6 are considered in a moderate not good state, and ≤0.6 in a deprived not good state. The percentage value of landings from fisheries by the métiers OTB_CRU, OTB_DEF, OTB_MCD, OTB_SPF, OTM_DEF, SDN_DEF, SSC_DEF and TBB_DEF are shown in the eight columns to the right. *Due to the lack of appropriate benthic faunal samples from reef habitats in the Danish monitoring programme NOVANA, the estimates included in this table for the BBHTs Infralittoral mixed sediment, Circalittoral mixed sediment and Offshore circalittoral mixed sediment should not yet be used for management purposes.

Years	MSFD_BBHT	Percent area, sorted from high to low RBS	Average RBS	Average impact	Percent DKK	Total cumulative DKK
14t16	Infralittoral sand	10	1.00	0.00	0.00	5
17t22	Infralittoral sand	10	1.00	0.00	0.01	24
14t16	Circalittoral sand	10	0.99	0.01	0.03	9,398
17t22	Circalittoral sand	10	0.99	0.01	0.07	19,022
14t16	Circalittoral coarse sediment	10	0.99	0.01	0.17	1,084
17t22	Circalittoral coarse sediment	10	0.99	0.01	0.08	219
14t16	*Circalittoral mixed sediment	10	0.99	0.01	0.02	670
17t22	*Circalittoral mixed sediment	10	0.99	0.01	0.14	4,821
14t16	Offshore circalittoral mud	10	0.92	0.08	0.85	222,084
17t22	Offshore circalittoral mud	10	0.87	0.13	1.01	322,685
14t16	Offshore circalittoral sand	10	0.94	0.06	0.69	419,210
17t22	Offshore circalittoral sand	10	0.92	0.08	0.51	363,093
14t16	Offshore circalittoral coarse sediment	10	0.99	0.01	0.00	9
17t22	Offshore circalittoral coarse sediment	10	0.99	0.01	0.00	10
14t16	*Offshore circalittoral mixed sediment	10	0.99	0.01	0.01	184
17t22	*Offshore circalittoral mixed sediment	10	0.99	0.01	0.00	10
14t16	Upper bathyal sediment	10	0.69	0.31	3.45	194,730
17t22	Upper bathyal sediment	10	0.52	0.48	3.29	261,783
14t16	Infralittoral sand	30	0.99	0.01	0.20	1,900
17t22	Infralittoral sand	30	0.99	0.01	0.24	741
14t16	Circalittoral sand	30	0.98	0.02	3.17	935,757
17t22	Circalittoral sand	30	0.98	0.02	2.29	661,806
14t16	Circalittoral coarse sediment	30	0.99	0.01	4.85	31,689
17t22	Circalittoral coarse sediment	30	0.99	0.01	1.56	4,045
14t16	*Circalittoral mixed sediment	30	0.99	0.01	1.52	44,348
17t22	*Circalittoral mixed sediment	30	0.99	0.01	0.43	14,800
14t16	Offshore circalittoral mud	30	0.76	0.24	7.40	1,926,750
17t22	Offshore circalittoral mud	30	0.55	0.45	7.70	2,458,091
14t16	Offshore circalittoral sand	30	0.87	0.13	8.01	4,855,578

17t22	Offshore circalittoral sand	30	0.76	0.24	9.03	6,451,539
14t16	Offshore circalittoral coarse sediment	30	0.98	0.02	1.01	2,917
17t22	Offshore circalittoral coarse sediment	30	0.98	0.02	3.17	10,814
14t16	*Offshore circalittoral mixed sediment	30	0.99	0.01	1.63	27,257
17t22	*Offshore circalittoral mixed sediment	30	0.99	0.01	0.87	17,668
14t16	Upper bathyal sediment	30	0.53	0.47	25.67	1,447,273
17t22	Upper bathyal sediment	30	0.29	0.71	22.44	1,784,847
14t16	Infralittoral sand	75	0.89	0.11	37.29	358,825
17t22	Infralittoral sand	75	0.98	0.02	29.16	91,820
14t16	*Infralittoral mixed sediment	75	0.99	0.01	1.33	133
17t22	*Infralittoral mixed sediment	75	0.99	0.01	2.76	873
14t16	Circalittoral sand	75	0.90	0.10	44.36	13,109,874
17t22	Circalittoral sand	75	0.92	0.08	38.30	11,066,272
14t16	Circalittoral coarse sediment	75	0.98	0.02	47.78	312,298
17t22	Circalittoral coarse sediment	75	0.98	0.02	41.65	107,941
14t16	*Circalittoral mixed sediment	75	0.95	0.05	31.83	928,647
17t22	*Circalittoral mixed sediment	75	0.95	0.05	16.34	569,016
14t16	Offshore circalittoral mud	75	0.37	0.63	57.72	15,025,773
17t22	Offshore circalittoral mud	75	0.23	0.77	61.53	19,641,923
14t16	Offshore circalittoral sand	75	0.66	0.34	52.71	31,970,849
17t22	Offshore circalittoral sand	75	0.45	0.55	56.54	40,391,185
14t16	Offshore circalittoral coarse sediment	75	0.93	0.07	37.25	107,353
17t22	Offshore circalittoral coarse sediment	75	0.91	0.09	20.45	69,884
14t16	*Offshore circalittoral mixed sediment	75	0.97	0.03	12.26	205,046
17t22	*Offshore circalittoral mixed sediment	75	0.97	0.03	13.97	282,599
14t16	Upper bathyal sediment	75	0.45	0.55	72.66	4,096,104
17t22	Upper bathyal sediment	75	0.17	0.83	71.89	5,718,269

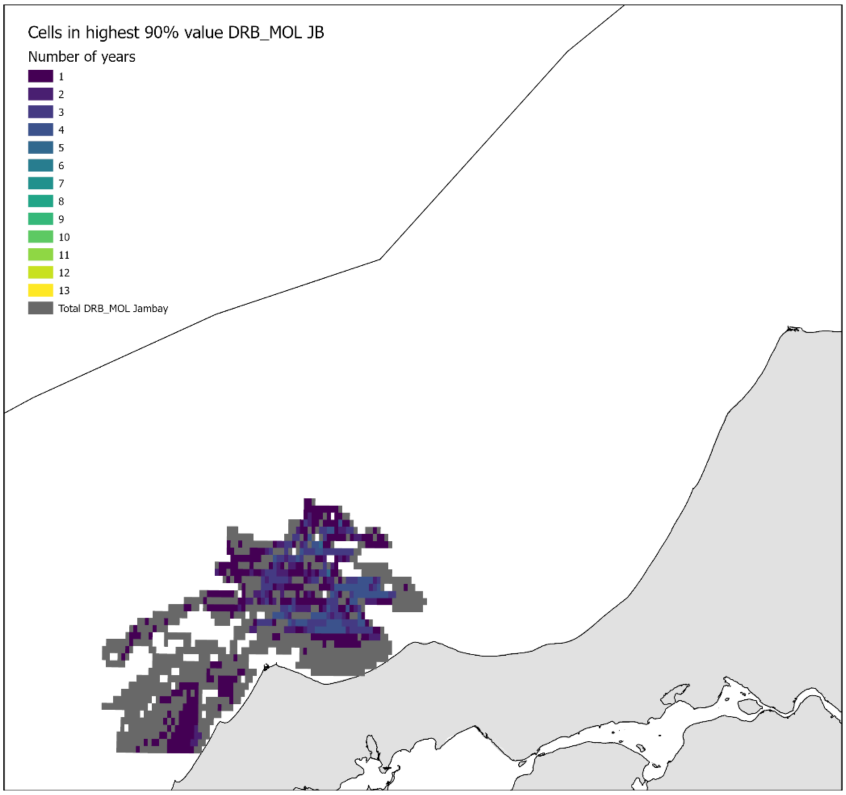
6.3.2 Core fishing grounds

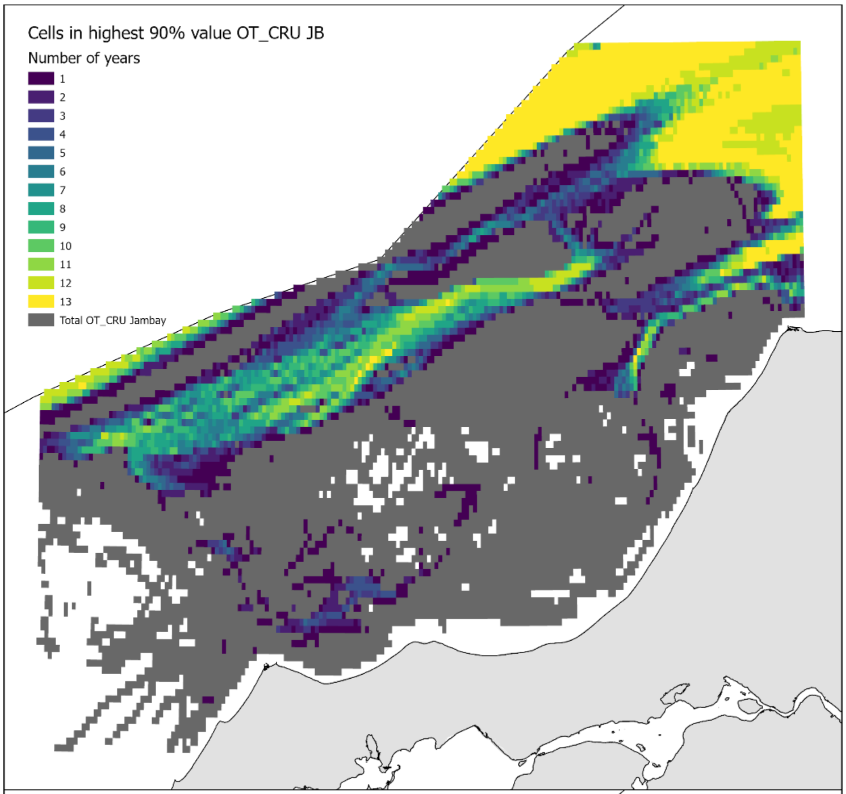
Core fishing grounds are considered as the areas from where the highest landing value can be obtained within the smallest area (and effort). Core fishing grounds were here defined as the areas where the grid cells cumulatively provided the highest 90% of the annual landing value per métier.

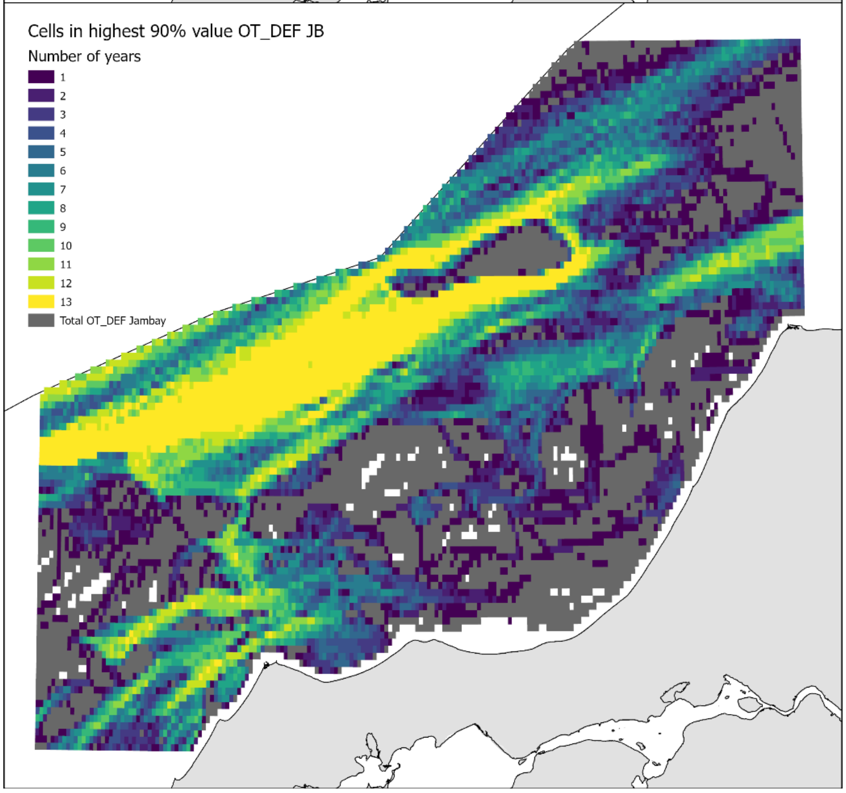
The Danish commercial fishing fleet operating in the area between 2014-2022 comprised the following metiers (based on VMS/AIS data and logbook information):

- DRB_MOL: Mussel dredges fishing molluscs (primarily bivalves);
- OT_CRU: Otter trawls fishing crustaceans, including Norway lobster (*Nephrops norvegicus*) and deep water shrimp (*Pandalus borealis*);
- OT_DEF: Otter trawls fishing demersal fish (e.g., flatfish, cod, sandeel);
- OT_SPF: Otter trawls fishing small pelagic fish (e.g., sprat);
- SDN: Danish seines fishing demersal fish (primarily flatfish);
- SSC: Scottish seines fishing demersal fish (primarily roundfish);
- TBB_CRU: Beam trawls fishing brown shrimp (*Crangon crangon*);
- TBB_DEF: Beam trawls fishing demersal fish (both flatfish and roundfish).

The core fishing grounds of the Danish fisheries are quite distinct. Each métier operates in a specific geographic location and level of aggregation (i.e., long-term constancy in spatial distribution). This also applies for the Jammer Bay area and was reflected in the assessment of the core fishing grounds where different seabed habitats were targeted by each métier (Fig. 6.8). Danish otter trawling for demersal fish and Norway lobster are concentrated in the deeper shelf areas with mud habitats along the border between the Danish and Norwegian EEZ's and towards the North with larger areas of aggregation on muddy sediments. The Danish and Scottish seining are located northerly along the EEZ border; whereas Danish beam trawling is located in the south-central part on mixed sediment (e.g., boulders, pebbles, gravel, sand).




Cells in highest 90% value OT_CRU JB
Number of years
1
2
3
4
5
6
7
8
9
10
11
12
13
Total OT_CRU Jambay


Cells in highest 90% value OT_DEF JB
Number of years
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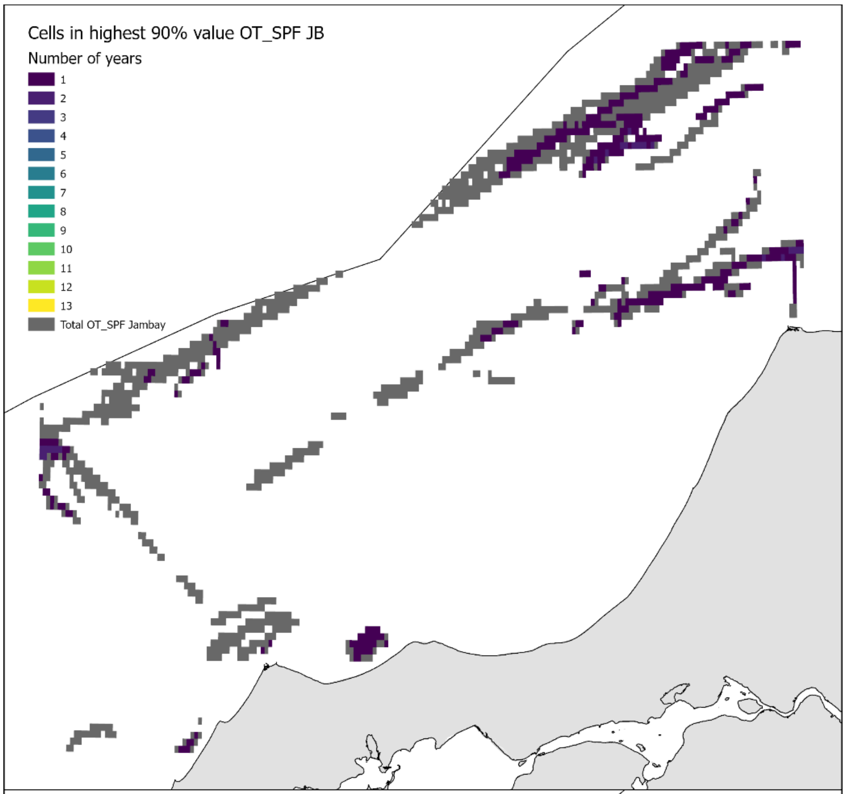
Total OT_DEF Jambay


Cells in highest 90% value OT_SPF JB
Number of years
1
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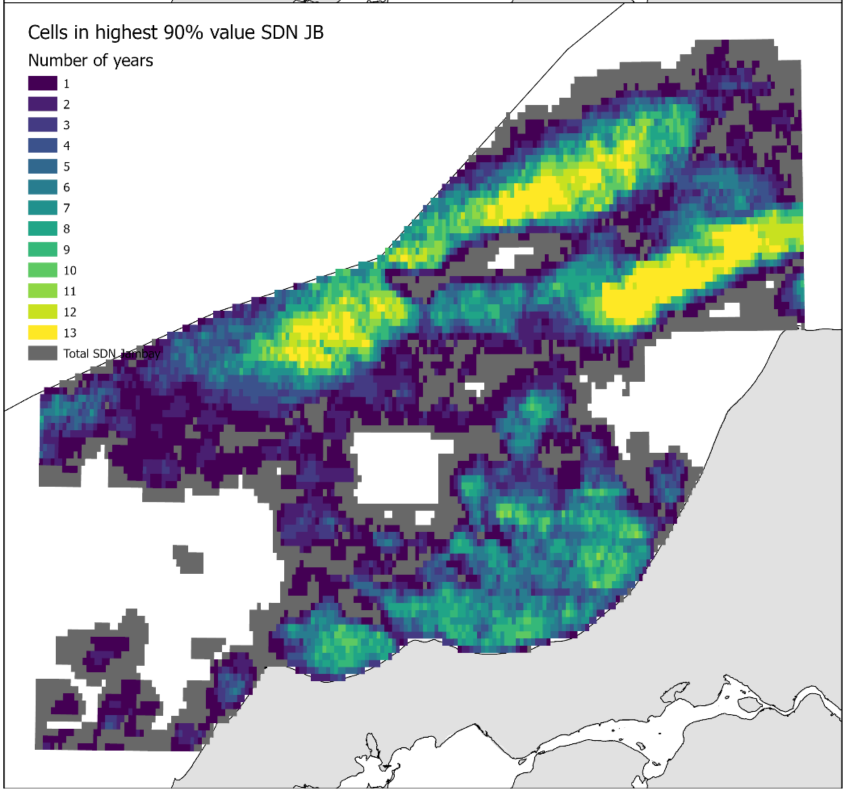
6
7
8
9
10
11
12
13
Total OT_SPF Jambay


Cells in highest 90% value SDN JB
Number of years
1
2
3
4
5
6
7
8
9
10
11
12
13
Total SDN Jambay

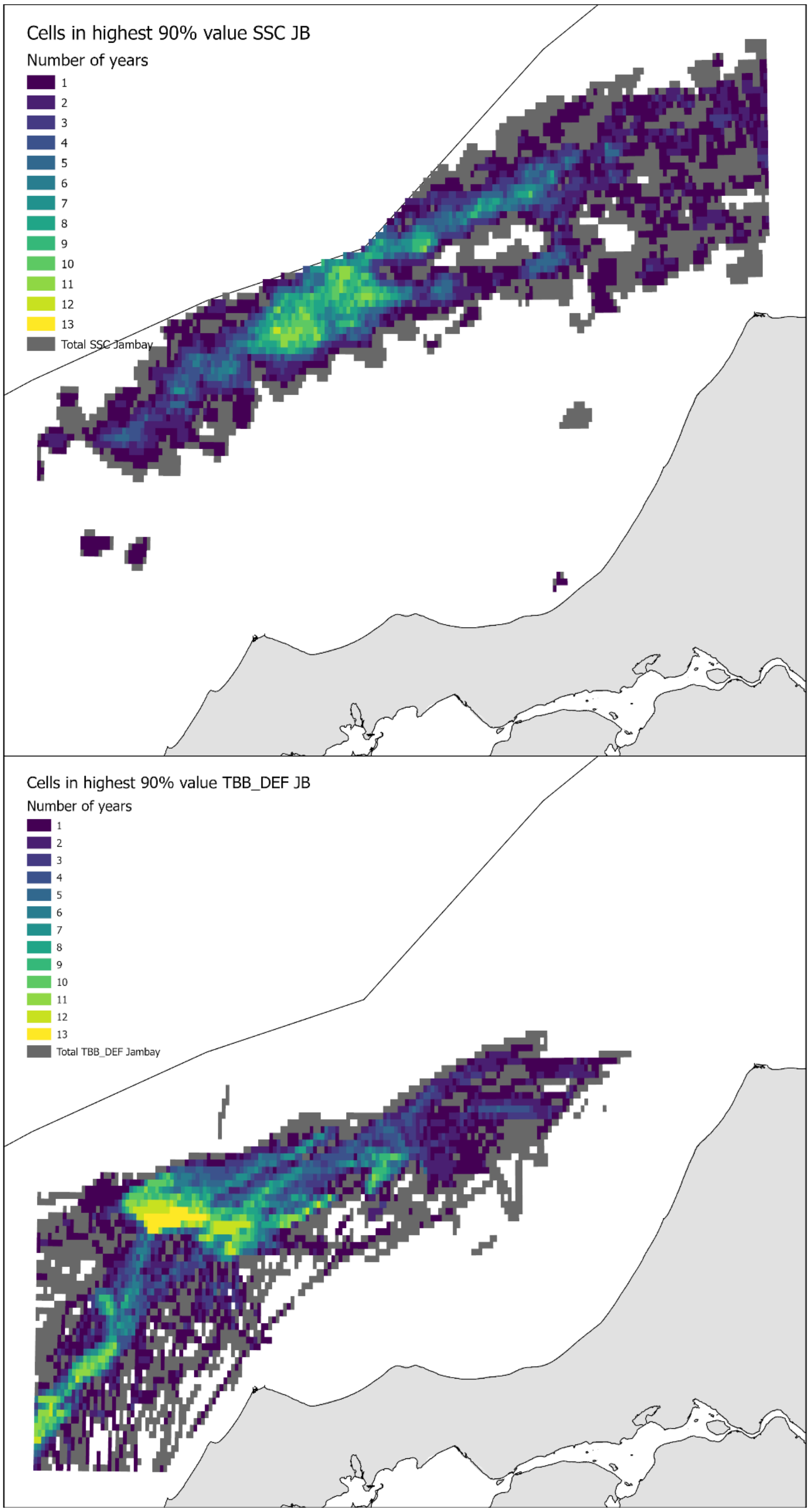
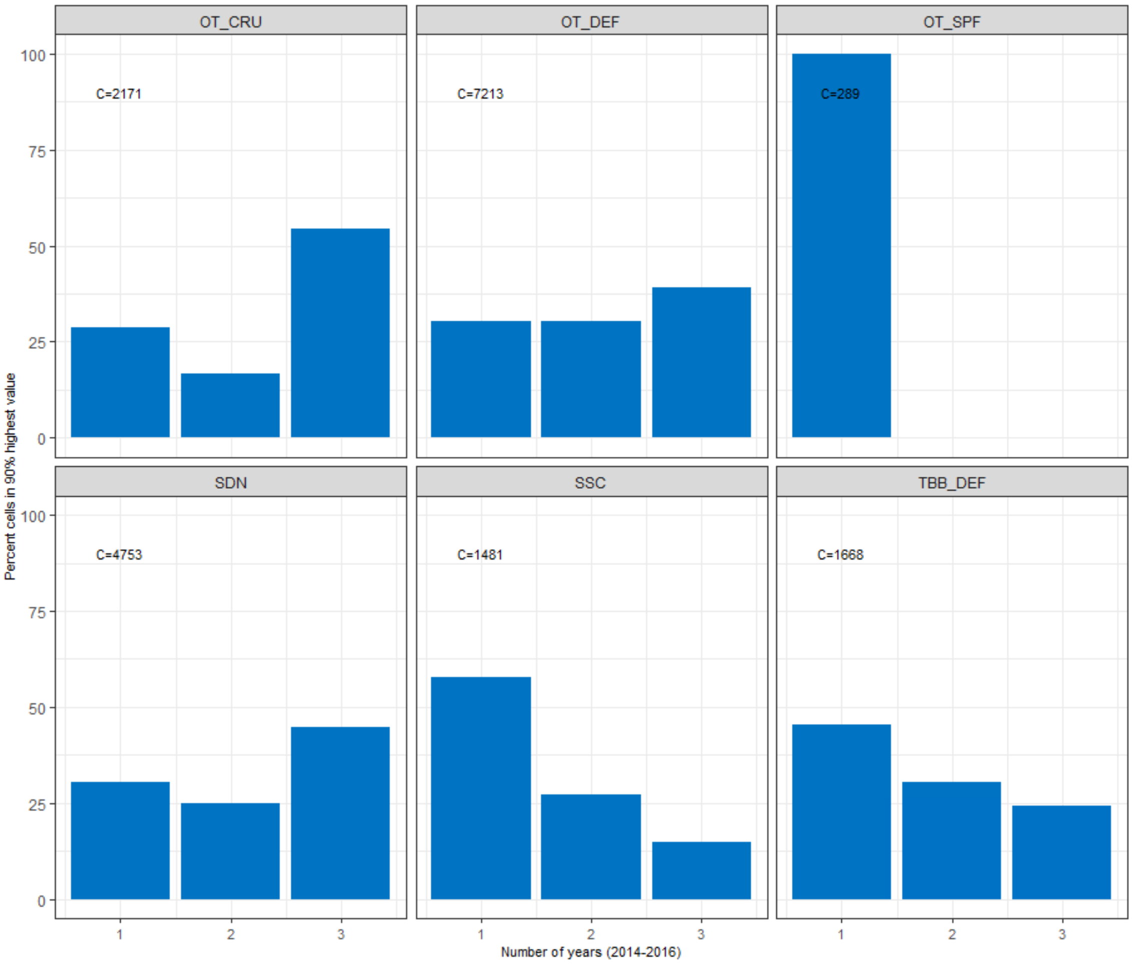


Figure 6.8. Distribution of core fishing grounds of the Danish fishing fleet in the Jammer Bay area. Number of years between 2014-2022 each grid cell was in the highest 90% landing value per fishing metier: DRB_MOL), mussel dredges for molluscs; OT_CRU), otter trawls for crustaceans (*Nephrops norvegicus*, *Pandalus borealis*); OT_DEP), otter trawls for demersal fish; OT_SPF), otter trawls for small pelagic fish (e.g., sprat); SDN), Danish seines for demersal fish; SSC), Scottish seines for demersal fish; TBB_DEF), beam trawls for demersal fish.

The figure below (Fig. 6.9) shows the number of years between 2014-2016 and 2017-2022 that a cell from a métier is within the 90% highest value of landings. Where fisheries are not aggregated, individual cells were only fished once, whereas fisheries are highly aggregated where the majority of cells are revisited in most years. For example, the otter trawling for sandeels (i.e., OT_SPF), the fishery is spatially highly variables between years. In comparison, the otter trawling for crustaceans (i.e., OT_CRU) exploits the same fishing grounds in multiple years.



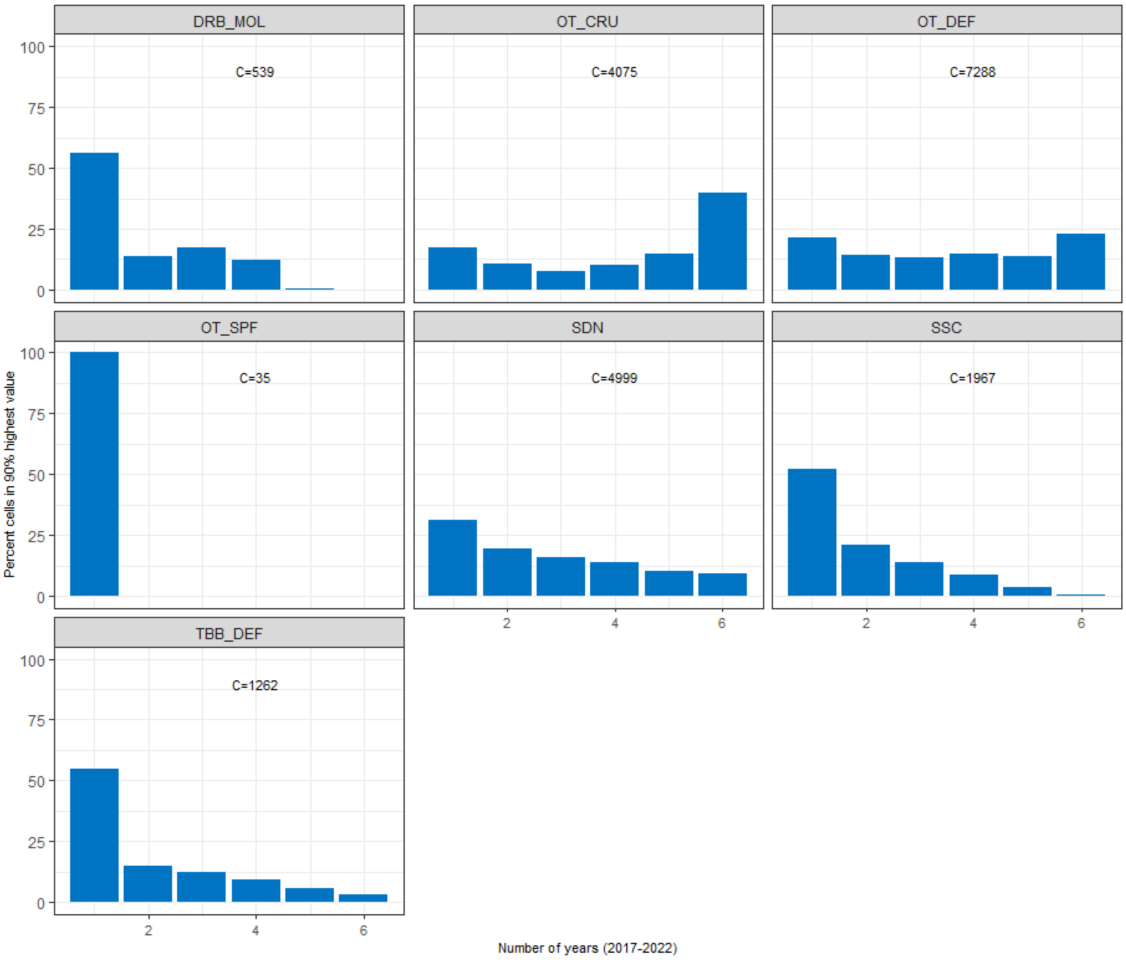


Figure 6.9. Number of years a cell is within the 90% highest value of landings by métier in the periods 2014-2026 and 2017-2022.

In both periods between 2014-2016 and 2017-2022, some Danish fisheries landings values were less aggregated than others (Fig. 6.8). Scottish seining for demersal fish (SSC), dredging for molluscs (i.e., DRB_MOL) and beam trawling for demersal fish (i.e., TBB_DEF) were not economically aggregated with the majority of the cells contributing to the 90% highest value of landings in only a single year. Thus, the income of these fisheries were spatially highly variable. Also, otter trawling for small pelagic fish (i.e., OT_SPF, e.g., sprat) was sporadic in both periods. Otter trawling for demersal fish (i.e., OT_DEF) and Danish seining for demersal fish (i.e., SDN) were economically partly aggregated. The core fishing grounds of the otter trawlers and larger Danish seiners were located in the outer parts of the area, whereas the smaller vessels fished coastally in the inner parts of the bay. The economically most aggregated métier was otter trawling for crustaceans (i.e., OT_CRU, *Nephrops norvegicus*, *Pandalus borealis*), which takes place on the outer deeper slopes of the Norwegian trench. In this fishery, a larger proportion of the fished cells contributed each year to the 90% highest value of landings. Thus, the income of this fishery is spatially constant over time.

The core fishing grounds of the métiers used by the Danish fleet are closely linked to the seabed habitat types. The outer part of the bay consisting of muddy sediments is primarily fished by Danish bottom trawlers for crustaceans (i.e., OT_CRU) and demersal fish (i.e., OT_DEF), as well as Scottish seiners and large Danish seiners targeting demersal fish (i.e., SSD and SDN). The coastal sandy and coarse habitats in the southern area are fished by small Danish trawlers for demersal fish and occasionally dredgers for collecting molluscs. Small Danish seiners targeting plaice dominate fisheries on the sandy and coarse sediments in the coastal areas of the inner Jammer Bay.

The central part of the bay is characterised by mosaic structures of sand, coarse and mixed sediments including multiple reefs with highly complex topography and hydrographic conditions. This large central area provides core fishing grounds on boulder reefs for small Danish gill netters (i.e., GNS) and small Danish seiners (i.e., SDN) on sand targeting demersal fish. Both fisheries are characterised by having relatively low impacts on these habitats. In the central and southern part of this area a few Danish beam trawlers (i.e., TBB) target demersal fish with a higher impact on the seabed (Rijnsdorp et al. 2020, Gislason et al. 2021, Pitcher et al. 2017; 2022).

Core fishing grounds of foreign fleets operating in the same area could not be economically or environmentally assessed individually in the Danish EEZ due to the generic lack of access to logbook and landings information from non-Danish vessels. Hence, it is not possible to conduct a full assessment of the total landings and discards in the Jammer Bay area. This pertains to the landing weights of different target species and their monetary values as well as the bycatch magnitude of prohibited and other unwanted species. Instead, AIS data was used to estimate the spatial fishing pressure as SAR values for the non-Danish vessels. Among the foreign fleet, beam trawlers and Scottish seiners impacted larger areas with high intensity (i.e., high SAR values) particularly in the central parts of the bay. Thus, it may be assumed that their seabed impacts, as well as their landings and discards, are of a magnitude that could negatively impact the ecosystem and the fisheries resources of the Jammer Bay.

Identification of core fishing grounds is an important aspect of ecosystem based fisheries management. This allows for spatial regulations that ensure maximum fisheries income and least negative impacts on seabed habitats. This knowledge is vital to mitigate larger seabed areas being unnecessarily impacted due to lower catch and landing value per unit effort and area. Furthermore, it is important to ensure that fisheries displacement to less disturbed seabed areas (and potentially in a better environmental state) does not occur.

An important consideration is unwanted bycatch in core fishing grounds. Unwanted bycatch of fish prey and predators including juveniles, as well as feeding or mating PETS and other sensitive species should be avoided. This adds further complexity to ecosystem based management. Depending on fishing gear type, period and intensity, core fishing grounds may, thus, be adversely affected with regards to ecosystem productivity (MSFD D4), biodiversity (MSFD D1) and seabed integrity (MSFD D6). Therefore, spatial fisheries regulations should be linked to trade-offs between resource use and impacts on ecosystem components in ecosystem-based management. This could be achieved by use of spatio-temporal scenario modelling of ecosystem and socioeconomic components in collaborations between stakeholders, scientists, and policy makers.

6.4 Discussion and perspectives

The overall aim of this project was accomplished by providing new high-resolution data and first generation results for a number of ecosystem elements, human activity impacts and socio-economic revenues pertaining to commercial fisheries.

Ecosystems are naturally highly dynamic in both space and time, and management thus requires temporal and spatial data at a resolution that reflects the complex structures and interacting processes and enable modelling that distinguish human impacts from natural variations. Towards this goal, we implemented a pilot trial of Trade-Off modelling for scenario exploration. We combined spatial use and impacts on different seabed habitats (BBHTs) with economic revenues from different commercial fisheries. We were able to identify which seabed habitats provided the highest value, where fishing grounds are shared, and where competition is highest.

The pilot scenarios showed how combining environmental and socio-economic data provided a good overview of linkages between ecosystem resource use and the potential loss in value with different management options. The pilot scenarios in this study were based on existing and new medium scale data. The new data generated in this study are at medium and high spatial (e.g., 600-1000 m, 60 x 100 m) and temporal (e.g., monthly, daily) resolution and make possible the inclusion of specific components in scenario modelling.

Thus, the perspectives of this kind of scenario modelling open up for development of ecosystem-based management by allowing the incorporation of trade-off between the socio-economic value and ecosystem impacts. On the one hand, socio-economic value can be further delineated into specific fisheries (métiers) and the accompanying fishing cultures and societal derived benefits. On the other hand, the ecosystem impacts can include a variety of components, such as fish population impacts, unwanted bycatch of juvenile fish and sensitive species (PETS), fisheries physical seabed disturbance, and seabed biodiversity indices.

As different fisheries impact the seabed to varying degrees, it is important to distinguish the activities of the metiers. In some cases, the fishing activity causes permanent loss of, or adverse effects on, seabed habitats and associated organisms. Also, unwanted bycatch differs between gears. This is why ecosystem-based management must include information on the impacts and values of the different fisheries in the specific areas where the activities take place to identify the trade-off where the ecosystem footprint is within sustainable boundaries and the economic output is viable.

In particular, the full-scale habitat mapping generated from this study showed for the first time the high complexity of the seabed structures (e.g., substrate, topography). The seabed maps help on the one hand to identify all habitat types and sensitive and vulnerable components. On the other hand, the maps enable direct links to impacts on these habitats, and thereby support a more accurate management of area use and protection. With the more detailed information on the distribution of seabed habitats and associated organisms, as well as hydrographic processes, it will be possible to optimise configuration and connectivity of habitats and populations. Changes in distribution are already evident and linked to climate changes. We expect this to accelerate natural process and thereby increase changes in distribution and productivity. Tools to incorporate these changes in management are essential to ensure future viability. Follow-up work is carried out in new projects (e.g., ECOSPACE, MARHAB).

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7. Project dissemination (WP5. Task 5.2)

Anja Gadgård Boye, Louise C. Flensborg

7.1 Introduction and aim

The overall aim of the task 'Project dissemination' is to share information about project methods and results among project participants and with the general public.

Thus, several initiatives have been carried out:

- 2 project workshops for all participants including all participants, relevant NGO's and other stakeholders
- 1 kick-off meeting
- 1 ICES report
- 1 DTU Aqua report
- Manuscripts in preparation for various journals etc.
- 5 oral presentations
- Launch of website
- Launch of online tool showing fishing pressure
- 3 short films to be launched at DTU Aqua's website Spring 2024.

The ICES report and presentations from conferences and workshops are available in the file "JAMBAY Dissemination Supplementary Material".

7.2 Materials and methods

DTU Aqua as project leader, has organized two workshops and one kick-off meeting. The workshops and the kick-off meeting included all participants, relevant NGO's and other stakeholders. The kick-off meeting (April 2023) and the first project workshop (September 2023) included all participants and was held online. The overall aim of the meeting and the workshop was to introduce the project to all participants, to present all work packages and tasks and to discuss dissemination among other project aspects. The second workshop will be held in Spring 2024 once all results have been analysed and reported by the various task leaders. This workshop will also be held as an online workshop due to the large number of participants. To this workshop other stakeholders will also be invited. Other activities such as reports, oral presentations, websites, short movies and online tools have been developed to ensure a broad dissemination. As several companies, organizations etc. have had the responsibility as 'task leaders', dissemination of project results has taken place from various platforms. As an example, at the Havforskermøde held at DTU 24-26 January 2024, several presentations were given on the mapping of the seabed of the Jammer Bay by GEUS, and on the development of benthic faunal indicators and 1st generation assessments of fisheries impacts on seabed habitats by DTU Aqua. DTU Aqua hosted the meeting (information is available at https://www.aqua.dtu.dk/nyheder/nyhed?id=be715258-9c9e-4d5a-ab08-1539726ec1f0).

7.3 Results

7.3.1 Workshops and kick-off activities

Results from the kick-off meeting and the first workshops are documented in the presentations given. All work packages and tasks were presented, methods described, and results were presented. The presentations given were shared with all the participants.

Project contribution to EU and ICES

Part of the results of the project were communicated at ICES in a workshop and in meetings, see reporting of WGSAM (October 23) (https://www.ices.dk/community/groups/pages/wgsam.aspx). In addition, we expect the project to provide valuable inputs and discussions to other stakeholders such as EU, OSPAR, and HELCOM as well as in other ICES work.

7.3.2 Project contribution to the Danish national assessment

The work conducted within the JAMBAY project provides valuable knowledge and insight for Danish national assessments. Results will be/have been presented through oral presentations at Dansk Havforskermøde 2024, DTU Aqua reports, online tools available from DTU Aqua's website, short films and future scientific manuscripts.

7.3.3 Manuscripts in preparation

The project results are under preparation for further dissemination as scientific manuscripts for subsequent submission to international peer-reviewed journals in continuation of this project.

7.3.4 Oral presentations/ powerpoint presentations

A total of five oral presentations have been given so far on project results:

1. ”En geologisk model for Jammerbugten baseret på multiprojekt data”, by Niels Nørgaard-Pedersen, Nicklas Christensen, Jørgen O. Leth, Sofie Kousted, Lars. Ø. Hansen, Mikkel S. Andersen, Isak. R. Larsen, Silas Clausen, Jacob R. Jørgensen, Lars-Georg Rödel, Sigurd B. Andersen, Peter Sandersen, Zyad Al-Hamdani & Verner B. Ernstsen

2. ”Havbundens morfologi og habitater i Jammerbugt: Diversitet og dynamik”, by Mikkel S. Andersen, Lars. Ø. Hansen, Isak. R. Larsen, Silas Clausen, Jacob R. Jørgensen, Niels Nørgaard-Pedersen, Nicklas Christensen, Jørgen O. Leth, Sofie Kousted, Lars-Georg Rödel, Sigurd B. Andersen, Peter Sandersen, Zyad Al-Hamdani & Verner B. Ernstsen

3. “Documenting how fishing gears interact with boulders”, by Nurul Huda and Barry O’Neill

4. **“***Modiolus modiolus* life cycle traits and behaviours principal for habitat formation, restoration and biodiversity**”** by Grete E. Dinesen

5. “Assessing the biological state of the seabed in relation to bottom trawling and hypoxia in Danish marine waters”, by Esther D. Beukhof, Josefine Egekvist, Jeppe Olsen, Jonathan Stounberg, Ole E. Eigaard, Asbjørn Christensen, Ciaran McLaverty, Anne-Mette Kroner, Anna H. Rindorf, Grete E. Dinesen

7.3.5 Public outreach

DTU Aqua has engaged with the company Travers Media[1] to produce small films about the JAMBAY project, on development of fishing gear and their impact on the seabed and data collection. The three films will be hosted at DTU Aqua's website and will be made public in Spring 2024. An online tool https://ono.dtuaqua.dk/DDFAM/ and a website https://sites.dtu.dk/jammerbugt is furthermore available for public use and communication.

7.4 Discussion and perspectives

DTU Aqua would like to thank all project participants for taking part in the dissemination task of project methods, results etc. A special thank you go to Travers Media for assisting in producing three short films about the JAMBAY project.

7.5 References.

https://ono.dtuaqua.dk/DDFAM/

https://sites.dtu.dk/jammerbugt

https://havforsker2024.dtu.dk/abstract-book

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[1] https://traversmedia.dk/home/omos

8. Project highlights

8.1 Geophysical mapping (WP1)

Highlights (Task 1.1)

- New geophysical data were acquired with side scan sonar (SSS), multibeam echosounder (MBES), and sub-bottom profiler (SBP).
- In total, 3,255 line-km of geophysical data were acquired, including instrument test and calibration lines, transit lines, turns, and revisited line-segments.
- The dataset provides information on substrate and morphology of the seabed surface and on the shallow subsurface geology.

Highlights (Task 1.2)

- Processing of geophysical data.
- Description of processing workflow in software packages.
- Preparation of data to be used in subsequent tasks.

Highlights (Task 1.3)

- Integration of new sub-bottom profiler (SBP) data with existing seismic data and sediment core data.
- Identification of five major stratigraphic units.
- Seismic interpretation of shallow seismic data, substantiated by vibrocore groundthruthing as the backbone for development of a unifying geological model for the entire Jammer Bay area.

Highlights (Task 1.4)

- Construction of thickness maps for the mobile sand unit and the late glacial unit.
- detailed thickness mapping of geological units with 200 m line spacing in the Focus area.
- The thickness distribution of the mobile sand unit in the Jammer Bay reveals large coherent areas of thick mobile sand layers and other areas almost devoid of mobile sand.

Highlights (Task 1.5)

- High resolution bathymetric mapping.
- Grid cell resolution determined from point density, along-track sounding spacing, and beam footprint size.
- Provides the basis, in combination with side scan imagery, for a detailed and continuous morphological mapping of the Focus area.

Highlights (Task 1.6)

- Seabed characterization from geomorphometric analysis.
- Morphological mapping using the semi-automated Geomorphon landform classification.
- The geomorphometric and morphological mapping provides potential for a morphodynamic interpretation.

Highlights (Task 1.7)

- Interpretation and mapping of seabed substrates using side scan sonar, sub-bottom profiler, and multibeam echosounder data.
- The mapped seabed substrates provide the spatial distribution of soft and hard substrate types throughout the survey areas.
- Mapping of trawl marks using side scan sonar data in combination with the multibeam bathymetry data.

Highlights (Task 1.8)

- Classification of Habitat Directive habitats using seabed substrate and morphology.
- Identification of sandbanks and stone reefs using semi-automated methods in GIS.
- Numerous stone reef habitats were observed in the Jammer Bay. In total, an area of 37 km^2 was mapped as stone reef.

Highlights (Task 1.9)

- New geophysical data were acquired with multibeam echosounder and sub-bottom profiler.
- 626 line-km were completed in the Screening area.
- The dataset provides information on substrate and morphology of the seabed surface and on the shallow subsurface geology.

Highlights (Task 1.11)

- Grain size distributions and carbon content analyses of 60 BACI area grab samples.
- 32 samples in the Focus area and 39 samples in the Screening area were analysed for grain size distribution and carbon content.
- ROV video provides substrate validation data for 2nd generation substrate map.

8.2 Physical fisheries impacts on seabed habitats (WP2)

Highlights (Task 2.1)

- The Jammer Bay fishing pressure data of swept area ratio (SAR), landed catch, fuel-use intensity, and sediment mobilisation were estimated and mapped for individual grid cells of 0.001 degrees longitude and latitude (approx. 60x100 meter).
- The development and application of state-of-the-art methodologies to Danish fisheries monitoring data enabled the estimation of fishing pressure data in a resolution, which is more than 1000 times higher than other publicly available pressure data and maps currently used for impact and trade off assessments.
- The Jammer Bay study area is intensively fished with bottom-towed gears and larger areas of the deeper, more offshore parts are fished more than 10 times annually.
- In the shallower fishing grounds, closer to shore, the fishing intensity is lower, but also here there are hot spot areas that are fished more than 10 times a year, and a large proportion of the seafloor is fished between 5 and 10 times a year.
- The Danish and the foreign fleet are largely complementary in their choice of fishing grounds in the Jammer Bay study area.
- The Danish fleet is responsible for the largest fishing pressure on the sandy sediments (Danish seines) and soft sediments (Otter trawlers), and for the coarser sediments it is mainly the foreign fleet (beam trawlers) that exerts the largest pressure.

Highlights (Task 2.2)

- Tickler chain beam trawls appear to be the gear most likely to snag when being fished on coarse sediments.
- Most gear types were generally able to pass the inward sloping boulders at the small and medium size, but not the largest boulders.
- The results suggest that high snagging risk in a seabed habitat does not per se prevent beam trawling as these vessel types generally have high engine power and likely can move and turn over boulders when snagging does occur.

Highlights (Task 2.3)

- A high-resolution hydrographic dataset for the Jammer Bay and surrounding basins was established.
- The connectivity for plaice habitats in the Jammer Bay and surrounding basins was assessed.
- The connectivity for representative habitat-forming invertebrates in the Jammer Bay and surrounding basins was assessed.
- Based on literature plaice post-larvae of 12-15 mm are most vulnerable to mobile bottom-contact fishing gear.
- An index for mobile bottom-gear disturbance of plaice recruitment was defined and assessed for the Jammer Bay.

Highlights (Task 2.4)

- Successful development and delivery of a protocol for measuring sandeel larvae using image processing tools.
- Deliverable of two valuable datasets: one for larvae densities and another for larvae lengths.
- Contribution to understanding the life cycle and recruitment patterns of sandeels, essential for marine ecosystem management and conservation.

8.3 Biological fisheries impacts (WP3)

Highlights (Task 3.1)

- We established comprehensive information on the distribution of >300 benthic macrofaunal taxa across a bottom trawling gradient based on new Van Veen samples (100 x 0.1 m^2 = 10 m^2) and new HAPS corer samples (200 x 0.0142 m^2 = 2.86 m^2) sampled on mud, sand and coarse sediment in the Jammer Bay.
- Following quality assurance of the new benthic macrofaunal data, the information on the density of species (S), density of individuals (N), wet weight (WW) and ash free dye weight (AFDW) the data will be integrated in the ongoing detailed analyses of fisheries impacts and environmental state of the benthic habitats and trade-offs in the Jammer Bay.
- The new data generated in this project will be highly valuable in upcoming analyses of fisheries impacts on benthic faunal biodiversity, functional traits and depletion ratios related to individual MSFD BBHTs, natural hydrographic and climate conditions, hypoxia, and fisheries footprints and fishing closure trade-offs, and can inform ecosystem-based management and associated areal designations in the implementation of the EU Marine Strategy Framework Directive (MSFD), Biodiversity Strategy for 2030 (BDS2030), the

Habitat Directive (HD) and Birds Directive (BD) of the NATURA 2000 network, and the Common Fisheries Policy (CFP).

Highlights (Task 3.2)

- In total, 20 fish and 13 benthic megafaunal invertebrates were caught by the beam trawls in the two BACI field experiments in the Jammer Bay.
- Fisheries impacts of a sumwing beam trawl with 3 tickler chains on Circalittoral sand showed plaice (*Platessa pleuronectes*), dominated the biomass in all 12 hauls but with not clear impact related trends, whereas the biomass of Dover sole (*Solea solea*), and dab (*Limnada limanda*), increased with the number of impacts.
- Fisheries impacts of a chain mat beam trawl on Circalittoral mixed sediment showed a biomass increase of cod (*Gadus morhua*), dab (*Limanda limanda*), and edible crab (*Cancer pagurus*), with increasing number of impacts likely due to site attraction by the seabed disturbance and suspension of damaged benthos and fish in the plume of the trawl tracks.
- Biomass of the attached (sessile) bryozoan colonies (*Flustra foliacea*), and large, mobile sea urchins (*Echinus esculentus*), showed a clear decline in biomass with increased trawling, and both are considered sensitive to bottom trawling.
- Most noticeable, the long-lived, slow growing octocoral (*Alcyonium digitatum*) that lives attached to boulders and other hard substrates was caught in all chain mat beam trawl hauls on Circalittoral mixed sediment, and with the highest biomasses (between 14-20 kg in 11 out of the 12 hauls with the chain mat beam trawl). Recovery of this habitat-forming species and its large colonies (of 10-20 cm height) are slow. Thus, the adverse effects on chain mat beam trawling on Circalittoral mixed sediments detrimental to structuring seabed fauna, with a high risk of habitat loss.

Highlights (Task 3.3A)

- Relative Margalef diversity index is an indicator of the state of biological seabed habitats in relation to bottom trawling and currently used by OSPAR to assess whether seabed habitats are in a Good Environmental State.
- The index was applied to the Danish part of the North Sea and Skagerrak using samples from the National Monitoring Programme for Water and Nature (NOVANA) from 2010-2022, revealing variations in Relative Margalef diversity across habitat types and periods.
- Overall, seabed habitats in the Danish part of the North Sea and Skagerrak were assessed to be having low or intermediate Relative Margalef diversity compared to unfished or low bottom trawling conditions.
- Limitations of the study include uneven sampling distribution across habitat types and periods, potential bias from sampling methods, and the need for further research to compare sampling methods and develop statistical models for predictive assessment.
- Future research, using benthos samples collected during the JAMBAY project, aims to address limitations and improve understanding of benthic seabed habitats and their response to fishing impacts.

Highlights (Task 3.3B)

- New fishing intensity model data enabled application of the ICES FBIT RBS indicator for GES assessment of Benthic Broad Habitat Types (BBHTs) in the Jammer Bay area.

- New hydrographic model data enabled estimation of the spatial contribution of hypoxia to the adverse effects on BBHTs.
- This 1st generation assessment using the RBS indicator showed that 3 of the 11 BHTS are in very low subGES, that is GES of RBS ≥0.8 respectively covered an area of 0% of the Upper bathyal sediment, ~17% of the Offshore circalittoral mud, and ~19% of the Offshore circalittoral sand.
- Further, 1 of the 11 BBHTs is in slight subGES, that is GES of RBS ≥0.8 covered an area of 73.5% of the Offshore circalittoral coarse sediment.

Highlights (Task 3.4)

- Environmental DNA (eDNA) was successfully extracted and stored for all sampled stations and their replicates.
- Quantitative PCR (qPCR) assays were developed for the bivalve *Modiolus modiolus* (Danish: hestemusling, English: Horse mussel) and the octocoral *Alcyonium digitatum* (Danish: dødningehånd, English: dead man's fingers) and tested on a subset of the collected samples.
- Metabarcoding analysis was performed on samples from six locations to analyse both fish and broad metazoan biodiversity.
- The metabarcoding analyses demonstrated that the approach can be applied to study broad biodiversity of fishes and invertebrates in the collected samples and showed meaningful differences in biodiversity across the analysed localities, sample types and habitats.
- The study supports that eDNA-based analysis holds promise as an effective tool for future biodiversity assessment in the Jammer Bay area.

8.4 Fisheries resources and socio-economy (WP4)

Highlights (Task 4.1)

- Survey data showed shifts in the relative densities of cod and plaice at both a regional and local scale.
- A sharp decline in the local adult populations of both cod and plaice in the Jammer Bay area was observed for recent years.
- A clear relationship between cod landings and suitable thermal habitat was observed, with adult cod avoiding bottom waters warmer than 14 °C, which is well within their thermal preferences (DST data).
- Plaice were caught in warmer waters than expected from the thermal tolerance levels of adults (DST data. Thus, the sharp decline in the adult plaice population in the Jammer Bay was not directly linked to thermal habitat preferences.
- The sharp decline of adult plaice in the Jammer Bay may be caused by local overfishing due to a sedentary behavioural response in warm waters rendering them more vulnerable to trawling. Local overfishing could have been exacerbated by influx of foreign demersal fleets.
- The high densities of juvenile cod and plaice indicated that the Jammer Bay area is an important nursery area for both species.

Highlights (Task 4.2)

- For the Jammer Bay area, 7 uniquely distinct Fishing Cultures are identified, which exploit and impact the marine environment and the sustainability of fishing communities differently.

- Problematic coexistence is at stake between Fishing Cultures with minor vessels of a local, versatile mode of operation and Fishing Cultures with larger mobile vessels of a unilateral specialized mode of operation.
- Antagonistic conflict between long distance operating beam trawlers of Fishing Culture 2 and Fishing Cultures 1, 4, 5, and 6 operating all year round in the Jammer Bay area.
- The local Economic Effects differ between Fishing Cultures. The high-value, labour-intensive Fishing Cultures contribute relatively most to the local economy. For the long distant vessels', the local Economic Effects is insignificant.
- The local, high-value, labour-intensive Fishing Cultures bear a debate with proponents of increasing mesh sizes in seine and trawl bags and full documented fishery with the aim to future-proof the fishery.
- ICES' recommendation of rising plaice TAC and quotas during several years, in spite of still decreasing landings in commercial fishery, makes fishers demand a decrease of the TAC.

Highlights (Task 4.3)

- Two vessels joined the PET (Protected, Endangered, and Threatened) species bycatch monitoring programme in 2023, and their electronic monitoring (EM) data are analysed to refine the understanding of the bycatch variability in the Jammer Bay area.
- Fishing activity, including bycatch events, from EM data and oceanographic variables information from the EU Copernicus Marine Service are associated to explore the operational and ecological factors that drive PET species bycatch probabilities in the Jammer Bay.
- A trained machine learning model using XGBoost shows that, although oceanographic features such as depth, salinity, bathymetric slope, or temperature are important, the main contributor to bycatch probability is fishing effort.
- Harbour porpoise, *Phocoena phocoena*, bycatch probabilities are mapped, highlighting that bycatch high-risk areas in the Jammer Bay vary in space and time during the year.

Highlights (Task 4.4)

- Spatial distribution maps and density time-series were estimated for four sensitive fish species that occur in the Jammer Bay area: Halibut, spurdog, wolffish, and starry ray.
- Data from five different trawl surveys (NS-IBTS, BITS, Cod, Sole, and Norwegian shrimp survey) were combined.
- For halibut and in particular spurdog the overall trend in densities from 1983-2023 is positive, whereas the overall trends for wolffish and starry ray are negative
- Landings in the Jammer Bay from the period 1895-1910 were digitized and compared to those from the period 2005-2020.

Highlights (Task 4.5)

- The Stochastic Multi-Species (SMS) model for fish stocks in the North Sea has been updated with new assessment data for 2020-2022, and with revised data for grey seal density and diet.
- The SMS method has been improved by including estimated uncertainties of diet data from a quarter of a million fish stomachs.
- The new data and enhanced model were presented at a week-long meeting in the ICES Working Group on Multispecies Assessment Methods (WGSAM) in October 2023.

- After two months of additional work, WGSAM finally approved the updates made by DTU Aqua and additional updates on sea bird density made by other international scientists.
- Data, methodology and results are presented in a 218-page ICES Scientific Reports published by ICES in January 2024.
- The results, mainly predation mortality at age by species, will be used in the ICES assessment of fish stock and the ICES catch advice for 2024.

Highlights (Task 4.6)

- Spatial map showing the discard of nine selected species from the sampled fisheries in Skagerrak.
- Spatial map showing the landings and sampling intensity by fishing fleet in Skagerrak.
- An updated discard report covering the period 2015-2022 including a two-page description for every fishery sampled with observers, showing the raised discard and landings as well as the discard ratio (DTU Aqua-report no 444-2024).
- An online appendix connected to the discard report to give open access for all sampled discard data by fleet segment and area and year for the period 2015-2022.

8.5 Synthesis for ecosystem-based spatial management (WP5)

Highlights (Task 5.1)

- A pilot trial of Trade-Off modelling for scenario exploration was implemented combining spatial use and impacts on different seabed habitats (BBHTs) with economic revenues from different commercial fisheries.
- With the Trade-off modelling we showed it was possible to identify which seabed habitats provided the highest value, where fishing grounds are shared, and where competition is highest.
- The pilot scenarios showed how combining environmental and socio-economic data provided a good overview of linkages between ecosystem resource use and the potential loss in value with different management options.

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