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

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Summary
We coupled empirical established relationships between fishing pressure and benthos functional groups with an individual-vessel based bio-economic modelling to test spatial scenarios for mitigating benthic fauna depletion caused by demersal fishing while evaluating likely effects on the economy of local fisheries. We first identified and mapped gradients of fishing pressure (FP, swept area, y^{-1}) and evaluated the sensitivity of functional fauna groups (deposit feeders (DF) and suspension feeders (SF)) related to different FP within pre-defined habitat types. Functional relationships were obtained from the coupling of vessel-based VMS data, logbooks and core sampling of benthic fauna in the Kattegat (ICES IIIas) over the period 2008-2012. We then applied the DISPLACE model (Bastardie et al., 2014) to evaluate the effect of two scenarios of spatial restrictions on fisheries, one aiming at protecting a particularly sensitive benthos community and the other scenario testing potential closed fishing areas for wind power production. The FP is displaced to different fishing grounds and thereby expected to impact other areas and habitats more. Both scenarios led to positive or adverse effects on vessel specific profit depending on the type of vessels and fishing activities. By considering our empirical study of benthic fauna the first displacement scenario is expected to improve the overall benthic fauna abundance particularly increasing the local abundance in muddy habitats, while the wind farm implementation planned in Kattegat will likely reduce the overall benthos abundance. Such dynamic and integrated modeling approach is required to predict potential adverse effects of fisheries and underlying habitats by effort displacement.

Introduction
Displaced fishing effort resulting from fisheries spatial restrictions can have unintended side effects on benthic habitats and communities. With the anticipated increased spatial restriction of fisheries activities in a "EU-blue growth perspective", policy makers are looking for means for integration of fishing sectors activities in broader marine spatial planning (MSP). It is necessary to conduct an environmental impact assessment for any new exploitation activity of the sea (EU, 2001). It is therefore essential for any MSP regime also to consider likely impacts on ecosystems caused by fishing activity displacement. Article 5 of the EU MSP Framework Directive (2014/89/EU) obliges member states to implement MSP with the objective of achieving a sustainable development of fisheries. By presenting two scenarios with two contrasting goals our approach is a showcase of how effects of fisheries spatial restriction can be anticipated on both major ecosystem components (such as fish stocks and benthic habitats/landscapes and associated organisms) and the fisheries economy, factors that all affect the policies and public demand when developing marine activities.

Materials and Methods
Observation data of benthic communities from 21 stations collected using haps core samples from the study area were obtained from the National Center of Energy and Environment Denmark (Aarhus University). In each sampling year, five samples were collected at each station and pooled representing a sampling surface area of 0.0715 m² and largely grouped to abundances of functional groups as either suspension feeders (SF) or deposit feeders (DF). We then identified and mapped

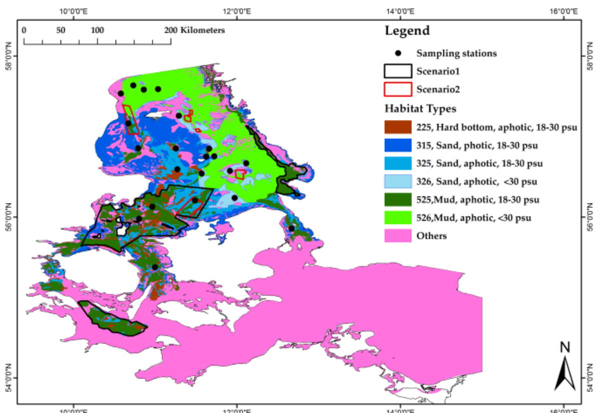

Figure 1: A map of the study area showing sampling stations, spatial distribution of sampled balance level 3 habitats type and spatial restriction scenarios

gradients of fishing pressure (FP) from vessel-based Danish VMS data combined with logbooks quantified in terms of swept area (y^{-1}) and evaluated the sensitivity of functional fauna groups (DF and SF) related to different FP within pre-defined habitat types. Functional relationships were obtained from the coupling of fishing pressure (FP) and the benthic fauna abundance data within the Kattegat (ICES IIIas, Figure 1) over the period 2008-2012. We then applied the DISPLACE model to evaluate effects of displaced fishing effort when suggesting a spatial restriction (Scenario 1) of what we found a sensitive habitat from our benthos emperical study (Figure 1 and 2, 525-Mud, aphotic, 18-30 psu) and (Scenario 2) a real case of proposed wind farms in Kattegat (http://www.ens.dk). DISPLACE provided aggregated bioeconomic indicators of the fisheries economy and fish stock dynamics that results from reallocation of fishing effort. Furthermore, we combined the modeled displaced fishing pressure to the results of the empirical etablished relations between the benthos and fishing pressureto predict expected change in benthic overall habitat specific abundance.

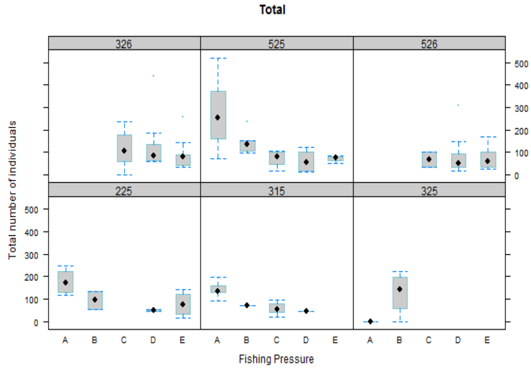

Figure 2: Response of benthos communities to a gradient of fishing pressure from A (Zero fishing pressure), B (low fishing pressure) to E (high fishing pressure) for DF+SF per habitat

Results and Discussion

The empirical study showed that the response to FP was more pronounced for benthos abundance associated with muddy substrate compared to harder substrates. Areas with lower fishing pressure had a significantly higher abundance of benthic fauna (Figure 2). Fleet modeling showed that Scenario 1 which was a FP restriction of about 60% in the most sensitive habitat resulted in 4% gain in overall profit (due to change in fuel costs, underlying stock developments, and landing composition) because 4% of the effort was displaced towards adjacent areas with different habitats. Offshore wind farm development in Kattegat (Scenario 2) also potentially increases the overall fishery profit by 5% due to FP pressure reallocation to adjacent habitats. The lack of clear changes in the distribution of fishing effort in Scenario 2 is because the spatial restriction was in areas with previously low fishing pressure (Figure 3). Interestingly, both scenarios led to positive or negative effects on individual profit depending on the type of vessels and fishing activities. Our empirical study of benthic fauna abundance indicated that displaced pressure by Scenario 1 could result in a 1% increase in overall benthic fauna abundance (but +3 % in the sensitive habitat), while the wind farm implementation in Kattegat would likely reduce the overall benthos abundance by 2%.

Ecosystem based management (EBM) is being prioritized in efforts to manage marine ecosystems, which implies a consideration of all the biological interactions within an ecosystem and the technical interactions with anthropogenic impacts including management. The role of MSP in an EBM context is also to empower marine managers or practitioners with assessment tools to evaluate possible impacts of marine spatial plans on the ecosystem and on the fisheries economic sector including an integrative impact assessment of the sustainability of the exploitation on alternative resources and components of the marine ecosystems.

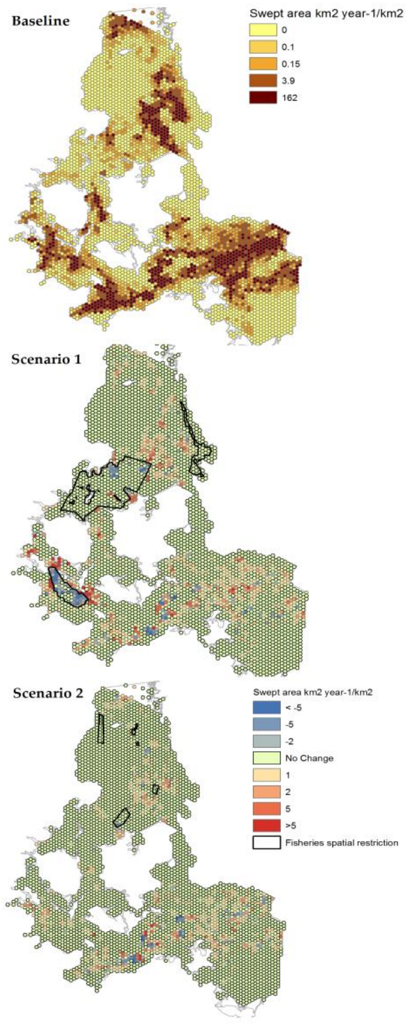

Figure 3: Spatial distribution of fishing effort per scenario; scenarios 1 and 2 expressed as gains/losses per cell relative to the baseline.

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