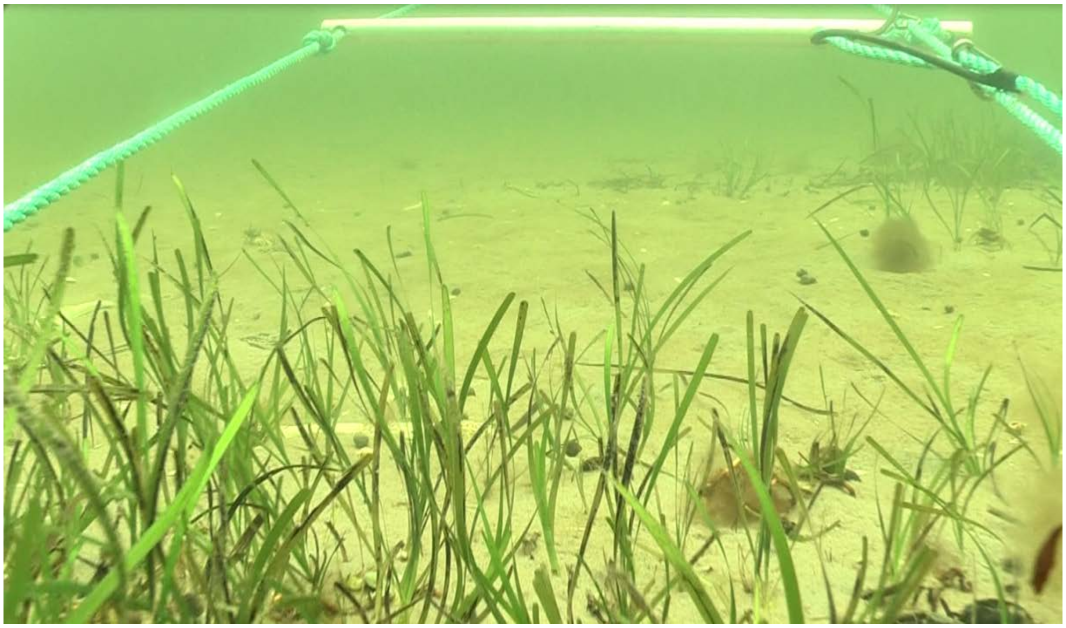
Reviewing the potential eelgrass impacts caused by mussel dredging

Danish Shellfish Centre, DTU Aqua

July 2014



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1.Introduction :

The following document is a short summary of a lengthy review on the potential negative effects of mussel dredging on eelgrass communities. The eelgrass populations in Denmark are subjected as well to a variety of natural stresses. Often it is difficult to separate the negative effects generated by natural and/or mussel dredging in the eelgrass beds. Therefore, the elongated version of this review gathers information about both sources of stress. However, in this short version we will focus just on the documented direct and indirect effects of dredgers, and other fishing arts in seagrasses.

2. Direct Impacts:

The direct impacts of dredging on eelgrass populations are those generated by the physical stress exerted by the dredging gear while moving along the sea bed. These impacts can be subdivided and quantified with relation to the stresses that the dredge generates into the seed bank, seedlings and mother beds.

2.1 Seed banks

To estimate the impacts generated from the dredges on seed banks and seedlings, the degree in which the dredging net penetrates the sediment has to be estimated. The light mussel dredging net excavates from 1 to 4 cm of sediment with a considerable horizontal forcing (Mayer et al.1991, Personal observations). The penetration depth into the sediment depends on the composition of the sediment, resulting in deeper penetration in muddy sites than in sandy areas. The maximal germination depth of seedlings is limited to about 5-6 cm (Greve et al 2005), so most surficial part of the seed bank, holding the most recent and viable seeds may be resuspended by dredging activities.

We performed a study in the Limfjorden where the seed bank of 3 transects from an eelgrass site were studied before and after dredging. The eelgrass bed was extended until 1 meter, being 2-2.5 composed of small eelgrass patches and bare sediments from 3 meters depth. The initial pool of seeds was located between 2 and 3 meters, and ranged between 1 - 4.17 seeds m^{-2} (Figure 1). After dredging no seeds was found in any transect at any depth. A combination of low initial seed densities and a heterogeneously distribution, lead to no statistical significance between seed bank before and after dredging.

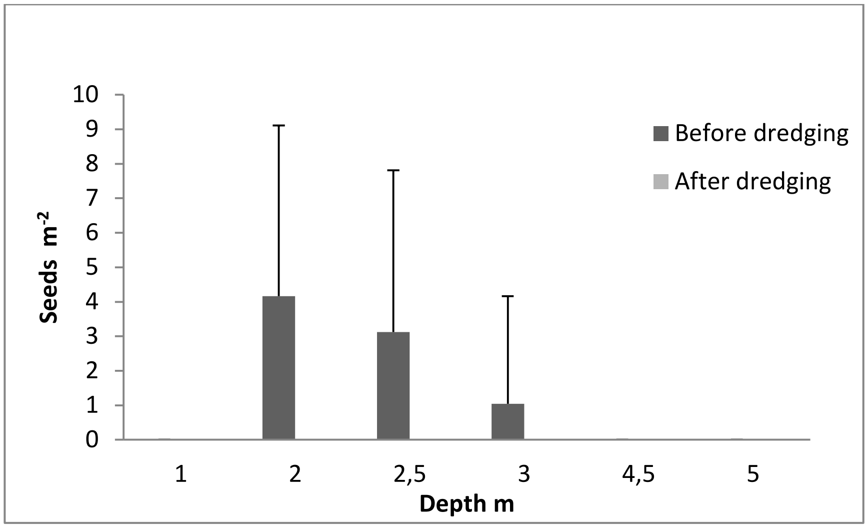


Figure 1: Seed distribution of eelgrass Zostera marina before and after mussel dredging in Salling, the Limfjorden.

2.2 Seedlings

Seedlings, have very weak and shallow roots on the first stages of development. In fact, 90 % of their roots are contained in the foremost 4 cm of sediment, therefore they will be uprooted by the horizontal drag force of the dredge. Hence they will have no chance for survival if dredging activities are performed in areas where they grow.

At the end of the growth season in September-October, successful seedlings can have developed up to 3-4 lateral shoots. The increment of below-ground mass (roots and rhizome) increases the anchoring ability (Personal observations). Nevertheless, these small eelgrass patches consisting of 3-4 shoots, will have little or no chance of survival after even a single dredge. However, further knowledge in this area is needed.

The survival rate of seedlings due to natural environmental stresses is estimated to be lower than 10% (Canal-Vergés et al 2010, Valdemarsen et al 2010)

2.3 Adult eelgrass beds

In general, seagrass recovery after small disturbances such as propeller scars or storms can be fast, a couple of weeks to some months (Williams 1988), while larger scale disturbances requires a recovery period of 2 to more than 5 years. As an example, scars (0,25 m^2) from anchors in *Zostera Capricorni* beds, recovered after a year, according to Rasheed (1999), whereas it took about 7 years recovery of Thalasia testudium (Dawes et al. 1997). The time for seagrass recovery, will depend on the seagrass species and the magnitude of the disturbance. In some cases, when the beds have been heavily disturbed, and the water quality is poor, and resuspension events have increased, the reestablishment of seagrass may take decades, or be permanently arrested (Ærtebjerg et al. 2003, Valdemarsen et al 2010).

There is lack of data on short and long term effects of fishing/dredging activities on adult seagrass beds (Stephan et al 2000). In a review by Boudouresque (2009) describing possible explanations for the regression of Mediterranean seagrass species, but here the trawling effects are only reported for *Possidonia oceanica*. In this case the trawling activities are known to be able to uproot 99000-363000 shoots h^{-1} (Martin et al 1997). Trawlling is also claimed to be the causes of between 12-80 % of the *Possidonia oceanica* losses in Tunisia, Spain and Corsica (Zaouali 1993, Martin et al 1997, Pasqualini et al 2000). Among the available data, there are some studies performed on eelgrass disturbances associated to oyster dredging (Wisehart 2007). In this study Oyster dredging was reported to increase the density of eelgrass. The causes behind this eelgrass areal increment were based on two parallel effects of the dredging activities. First there was observed an increment of reproductive plants (and therefore viable seeds). Secondarily, it was believed that dredging activities reduce seedling competition by decreasing the adult beds and oyster coverage, generating available space for seedling re-colonization. Nevertheless, it is to be taking in consideration that Danish eelgrass populations in the Limfjorden are patchy and not especially dense; therefore the lack of viable space is not a limiting factor. However mussel and oyster coverage might play a roll if sharing the shallow distribution with eelgrass in the Limfjorden. In the same study, oyster aquaculture method based on long lines, generated a reduction on the seedling density. The main reasons behind this regression were believed to be the alteration of the local hydrodynamics. Long line structures decreased current velocities in the water column, favoring the sedimentation generating burial of viable seeds under the critical depth of 5 cm. They also founded that the long line section had lower redox potential than dredge areas. This could be explained and supported by the absence of fine sediment on dredge areas. Dredging activities, suspend fine sediment (fraction in which the most organic material is accumulated), which depending on the hydrodynamics could generate a net export of the fine fraction of the sediment. On the contrary a study performed by Neckles 2005, found significant eelgrass decrease in dredge areas compared with the eelgrass density in non dredged areas. They estimated an recovery period of 9-20 years depending on the dredging history and intensity. Dredging effect has been measured as: reduced canopy, total biomass, shoot density, shoot height. Mussel dredging will completely uproot eelgrass shoots and remove living rhizomes and roots from muddy sediments. In our own study we performed dredging activities on eelgrass bed growing in sandy sediment. The dredging process was recorded in video with a High Definition camera. Analyzing these recordings the frequency of uprooting of apical shoots and rhizomes can be observed. However the used methodology did not allowed quantifying the proportion of uprooted *Zostera*. On the same topic, Orth et al 2006 reported a period of more than 3 years for adult eelgrass bed recovery after clam dredging (although results were variable).

Cabaco et al. (2005) studied the effects of clam harvesting on Ria Formosa (Portugal). In that case the clams were collected manually with a modified knife. Nevertheless, eelgrass population was significantly affected by this practice. In this same study, they focused on the development and survival of eelgrass ramets in which the total or part had been removed. The removal of the apical shoot reduced the survival of the eelgrass ramets by 80%. In accordance with this study, Boese et al. (2002) found detrimental effects of clam digging on eelgrass, lasting for a maximum of 10 months. In this study they observed as well the effect of clam raking; but they did not found measurable differences before and after raking. Manual clam harvesting is a technique too far from mussel dredging, however, mussel dredging on adult eelgrass beds, may particularly affects the border of the eelgrass bed, where the apical shoots are located. In this zone apical shoots are dominating and the recovery of the eelgrass patches may become affected.

3. Indirect effects:

Dredging generates sediment resuspension. The resuspension of the sediment reduces light availability at the seabed. When generating resuspension, reducing substances can as well be released to the water column, reducing the oxygen concentrations in the water column (Dolmer & Geitner 2004, Riemann and Hofmann 1991). Frequent resuspension triggered by dredgers will destroy the sediment stability and therefore reduce the critical share stress (increasing the potential for resuspension at lower current velocities). Finally, the transport and sedimentation of the sediment can cause eelgrass (both beds, seedlings and seeds) burial.

3.1 Resuspension

Dredging generates resuspension (Riemann and Hoffman 1991, Dayton et al. 1995; Dyekjær et al 1995; Johnson 2002: Morgan & Chuepagdee 2003; Rheault 2008; Mercaldo-Allen & Goldberg 2011), however the magnitude and duration of this resuspension vary dependent on the used dredging gear, the sediment characteristics, the locations, slope, the weather conditions and the hydrodynamics of the areas.

Most of the studies have been performed on hydraulic clam dredging gear, some of them are performed with the Dutch dredge, but to our knowledge, there are no studies (beside our own) performed with the Light Dutch dredge, which is referred to be the least damaging gear (Eigaard et al 2011). Therefore the following results are an indication rather than a completed assessment.

Dredging activities in Limfjorden affects sediment stability and induce resuspension by two main processes.

1. While the dredge is moving along the seabed.

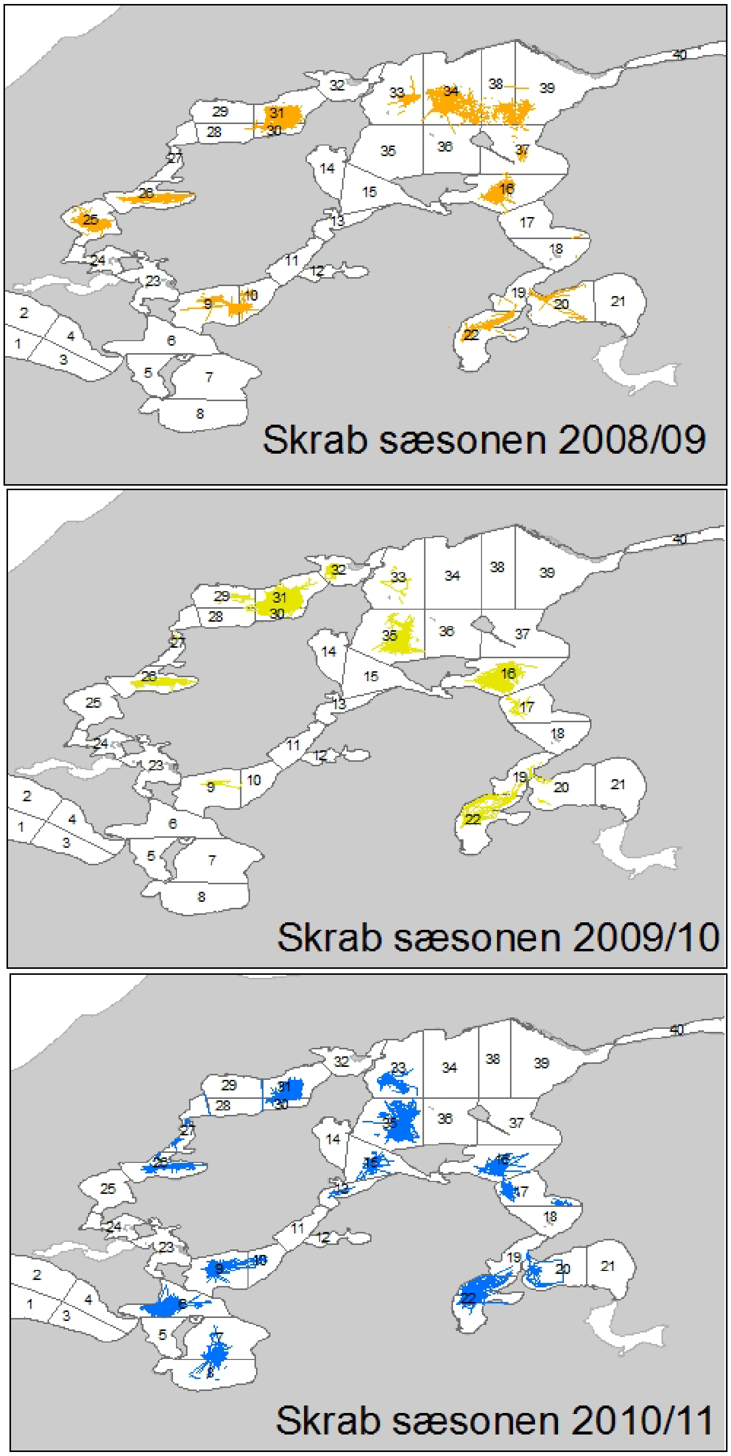
Here part of the sediment is caught in the dredge net together with the mussels while some sediment is sieved through the net's mesh. This sediment is resuspended because of the horizontal drag created by the moving net. The resuspended SPM is more concentrated near the sea bed, having a lower vertical mixing that the SPM generated by wave action (which is a turbulent movement). In addition, the horizontal transport generated by the dredge is quicker, than during natural wave induced reuspensions events. Therefore, the generated plum, may not be mixed into the entire water column, and remain much more concentrated at 0.2-1.0m above the bottom. The dispersion of the plume depends on current and wave action, and may travel over long distances, depending on the settling rate of the eroded SPM.

2. When the dredge net is taken to the water surface filled with mussels and sediment and flushed.

The sediment caught in the net is brought up with the mussels and wash out, by flushing movements, generating a sediment plume from the middle to the surface of the water column (due to the vertical movement of the net in the water column during this cleaning procedure).

How dense, how far it goes and how the sediment plum generated by dredgers affect the benthic light climate, will be discussed below.

Riemann & Hoffmann 1991 and Dyekjær et al 1995 performed in situ studies to quantify the plume of SPM generated by dredging activities, and the effects on the water quality. In the experiments, they tried to measure the sediment plume generated by the dredging. Sediment samples were taken at 3 depths and 9 locations surrounding the dredged area. The water samples were taken before dredging and immediately after, and 30 and 60 minutes after dredging (Riemann & Hoffmann 1991). The study showed maximal SPM values of ~1.5 kg m^{-2} (an increase of 1361 %) immediately after dredging decreasing at 30 min and disappearing after 60 min. However, they also found a significant increase in SPM, with strong winds (15 m s^{-1}) and no dredging activities. Dyekjær et al 1995 took samples before dredging and 10, 30, 60, 90 and 120 minutes after dredging and concluded, that mussel dredging and wind generated resuspension ranged within the same magnitude. In all studies, the plume had a relative short term influence in the vicinity of the dredged area, ranging from 1 to few hours (Riemann & Hoffmann 1991, Maier et al. 1998). In none of the studies could be measure a vertical concentration profile in the water column. This result is surprising, due to that heavier particles will settle relative quick while the lighter SPM fraction will move depending on the current and depth of the water column (Godcharles1971, Goodwin and Shaul 1980; Ruffin 1995, Tuck et al. 2000) either way moving out of the studied area. Substrate type can determine the amount of suspended solids in a plume and how long these particles persist. The distance and direction of the plume is primarily controlled by currents patterns generated by tidal action and meteorological conditions (Tarnowski 2006). For instance, non-cohesive sediment is able to settle within the first 30-60 min. Studies of sedimentation on the Limfjorden shows that mixed cohesive sediment can remain into suspension up to 2 days (personal observation from laboratory experiments). In the mentioned studies, the sampling interval was lengthy; and combined with the fact that they did not find vertical profiling in the WC (after dredging sediment concentration should be higher closer to the seabed), most possible the authors missed the plume. Dyekjær et al 1995 based their calculations assuming homogeneous conditions for sediment type, hydrodynamics … in the fjord, and therefore emphasized the limitations in their conclusions. They for instance estimated yearly budget of mussel dredging generated SPM assuming that the fishing effort was distributed to entire fjord area (1500 km^2). Nevertheless, 40 percent of the fjord's area is permanently closed to fishing activities, and it is the remaining 900 km^2 which remains potentially exposed to dredging generated resuspension. This will increase the load to a more localized but intense loading of 1.43 kg m^{-2} $year^{-1}$. Furthermore, if the fishing activities are restricted to the same areas repeatedly, this effect could be even higher at a local scale (Figure 9). For instance, for the fishing effort from 2008-2011, it can be observed that the areas 16, 22, 26, 30 and 31 have been worked yearly (Figure 2).



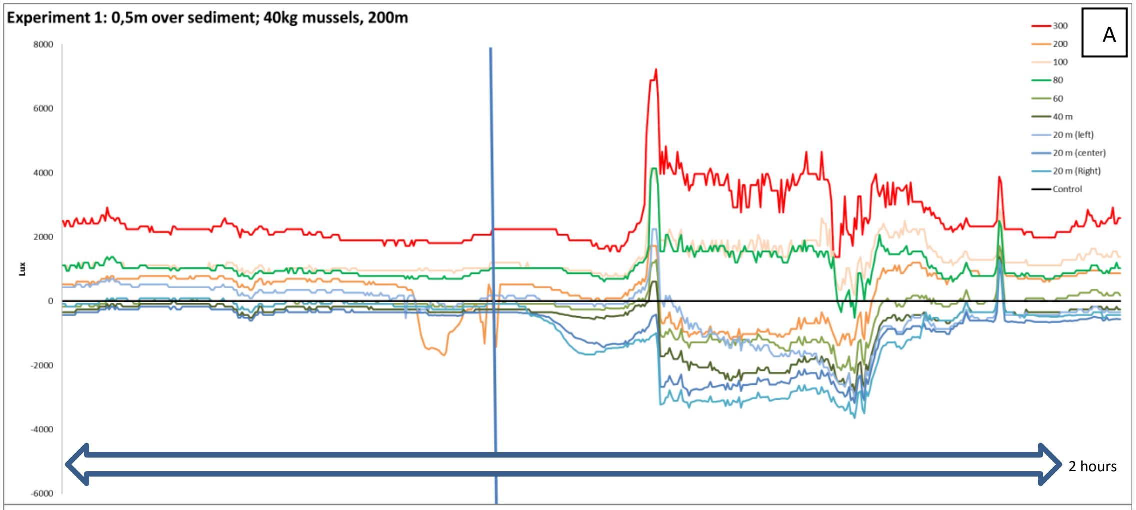
Skrab sæsonen 2008/09

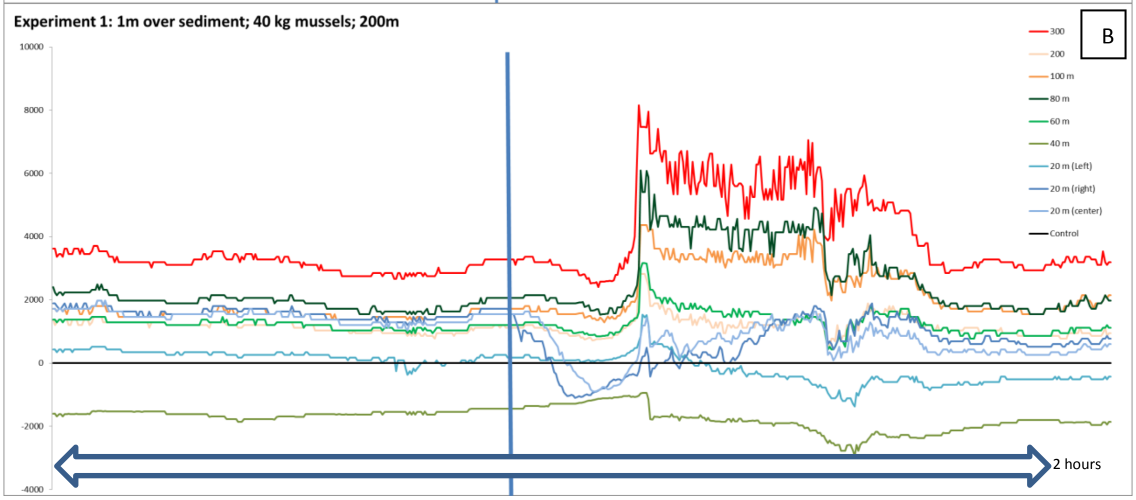
Skrab sæsonen 2009/10

Skrab sæsonen 2010/11

Figure 2: Reported mussel dredging activities in the Limfjorden for the seasons 2009-2011

The amplitude of the bed near horizontal transport of the SPM (20cm over the sediment) generated by dredging can be calculated under some assumptions. For cohesive sediments, assuming a maximum near bed current velocity of 0.1-0.15 m s^{-1} (Lund-Hansen et al. 1999) and a minimum of 2 hours for sedimentation of SPM; the SPM plume will move up to ~600 m. If the sediment is resuspended higher in the water column (for example while brought up with the net), the sedimentation time and the water current velocity will increase considerably. Lund-Hansen et al (1999) found that the resuspended SPM up to 2 m above the sediment, could travel ~3.3 km with an average current velocity of 0,06 m s^{-1}. However, other authors, found that clam dredgers generated a resuspended plume that was measurable (significantly higher than the control) in a range of just around 23-40 m from the dredge area (Manning 1957; Haven 1979; Manzi et al. 1985; Spencer 1997; Maier et al. 1998, Mercaldo-Allen & Goldberg 2011). In our own experiments, light reduction generated by resuspension, cause by a single dredge of 100 m could be measured up to ~100 m for a maximum of ~2 hours in a calm day (Figure 3). However, further experiments with increase dredged area are needed to reach further conclusions.


Experiment 1: 0,5m over sediment; 40kg mussels, 200m


Experiment 1: 1m over sediment; 40 kg mussels; 200m

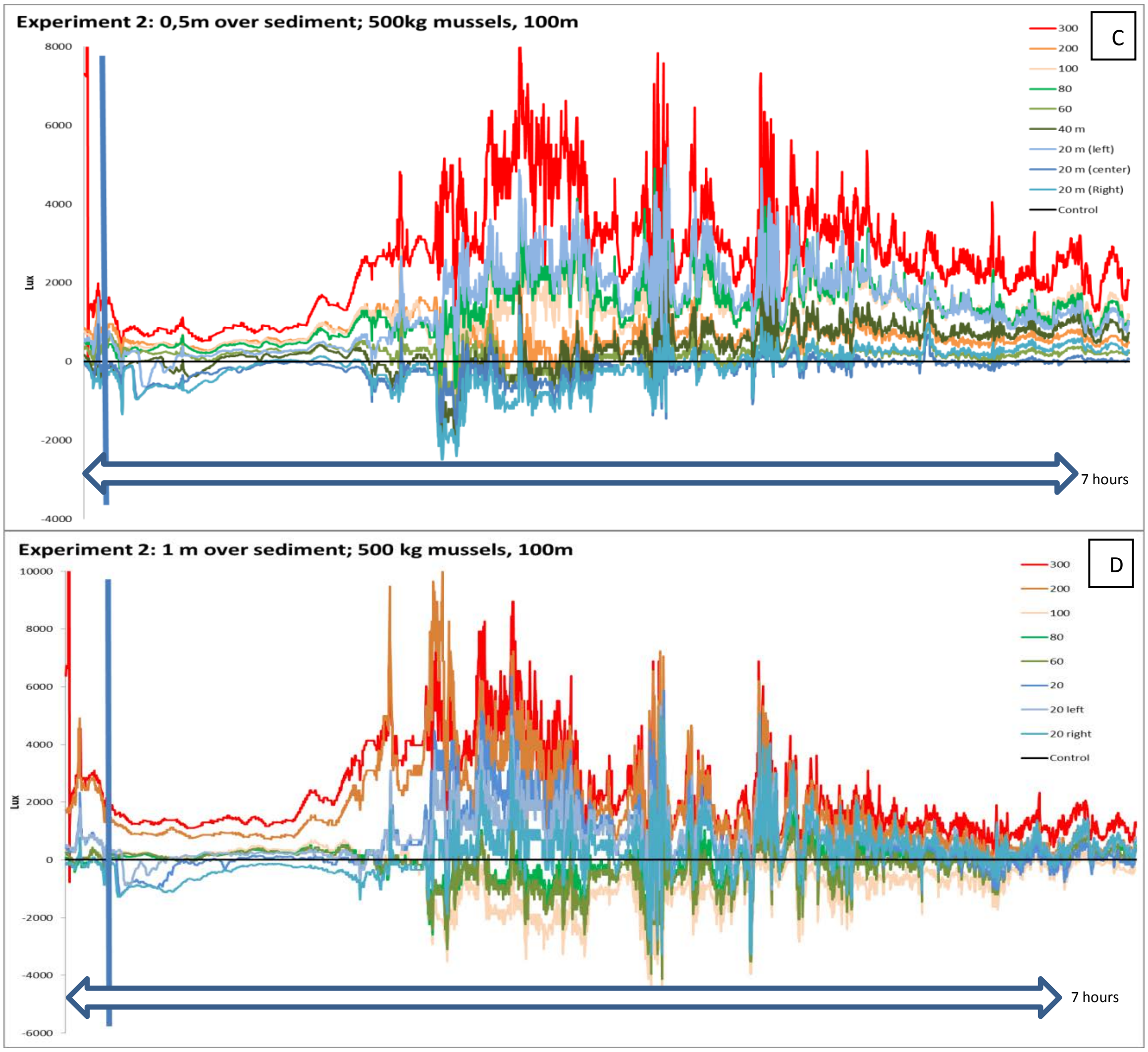


Figure 3: Light decrease over distance after mussel dredging. A) Light concentration at 0,5m from the sediment in Lux at 20, 40, 60, 80, 100, 200, 300 m distance from a 200 m dredge (40kg mussel catch) minus control light concentration (at 1000 m. B) Light concentration at 1mfrom the sediment in Lux at 20, 40, 60, 80, 100, 200, 300 m distance from a 200 m dredge (40kg mussel catch) minus control light concentration (at 1000 m). C) Light concentration at 0,5m from the sediment in Lux at 20, 40, 60, 80, 100, 200, 300 m distance from a 100 m dredge (500kg mussel catch) minus control light concentration (at 1000 m). D) Light concentration at 1m from the sediment in Lux at 20, 40, 60, 80, 100, 200, 300 m distance from a 100 m dredge (500kg mussel catch) minus control light concentration (at 1000 m).

The effect of suspended sediment on the benthic vegetation will depend on the distance from the dredged areas to the seagrass beds, depending the depth limit where the fisher boats are allowed to fish; but also both on the particle size (from 300 m to 3,3 km depending on particle size and current), and the fjord's bathymetry (for instance depth slope). Finally, it has to be considered that, frequent disturbances on the sediment, by dredging, will especially in cohesive sediments destroy the biostabilization. Sediment biostabilization in cohesive sediment takes up to 5 days to build up, with no disturbances and enough light availability (Frederiksen et al in preparation). Once the sediment biostability is lost, the sediment's critical erosion threshold is reduced, meaning that the sediment is more prompt to resuspend.

The consequence of an incremented SPM in the water column, affects negatively the light availability at the sea bed, reducing photosynthesis, and therefore reducing the eelgrass growth and restablishment potential. However, SPM is not the only light reducing material in the water column. Phytoplanktom blooms might cause even more light reduction at the sea bed. Although the nutrient levels in the Limfjorden have been reduced the studies performed by Carstensen (submitted) based on long term monitoring data (1989-2010) revealed that the levels of phytoplankton in the water column has not yet been reduced. For instance the yearly mean secchi depth for the Riisgaard broad, Skive fjord and Lovns broad 1989 was 2,5-4,5 m (for different locations), decreasing in 1994 to 2-2,5 m. The present secchi depth ranges between 1,5 m and 3 m for different locations. They also found increasing levels of particulate inorganic matter in the water column (indicating resuspension) over these years. This increase of SPM in the water column was suggested to be a response due to mussel removal and declining on eelgrass cover.

3.2 Upwelling of reducing substances

Limfjorden holds a history of euhrophication, and therefore the sediment has a high organic content. Organic rich sediments are generally exposed to slow oxygen diffusion from the water column and high microbial oxygen demand for mineralization processes. Anaerobic microbial remineralization promotes production of hydrogen sulphide in the sediment (Valiela 1984). Therefore, once sediment is resuspended it can bring reducing substances such as sulphides to the water column, reducing momentarily the oxygen concentration in the WC.

Oxygen limitations and sulphide substances plays an important role when considering eelgrass fitness and survival (Terrados et al 1999, Pedersen et al 2004).

Riemann & Hoffmann 1991 found a significant reduction in oxygen and increased but variable concentration of ammonium followed by induced sediment resuspension. In addition, it was observed a significant increment on total phosphorus with strong winds (15 m s-1). In hour studies we observed a small reduction of oxygen up to e 0,5 cm of the sediment, however the oxygen limitation was not critical, and it lasted ~30 min.

*It is to be considered that natural generated critical oxygen depletion is found in a wide range of broads from June to October.

Other dimension on sediment resuspension, includes the resuspension of hazardous substances fixed in the sediment. Filho et al. 2004 found bioaccumulation of cadmium, and zinc in the seagrass *Halodulie wrigthii*, caused by the release of heavy metals from polluted sediment due to dredging activities in Sepetiba Bay. Heavy metal pollution would typically affect seagrass biomass, but more importantly will introduce such pollutants in the trophic chain. Nevertheless this does not seem to be the case in the Limfjord.

3.3 Sedimentation

The generated resuspended materials will eventually sediment. SPM sedimentation rates and location will primarily depend on the hydrodynamical forcing, particle sizes and seabed roughness. Therefore the distance from the trawling activities to the seagrass beds, as well as the horizontal current velocity and direction in the water column, will influence significantly the fate of the generated SPM. Seagrass beds increase the bed roughness, and acts as a sediment trap (Duarte 2000, Larkum et al 2006). Furthermore, SPM sedimentation rates increase in seagrass beds with high cover of epiphytes (typical from eutrophic environments) due to the increase of exposed surface area. For instance, in the case of *Zostera marina*, epiphyted leaves often appears brown coated, with a layer of sediment and sink to the bottom (Erftemeijer & Robin Lewis 2006, personal observations).

In the field, it will be difficult to separate the effects of increased turbidity from the effects of SPM sedimentation, since both affects the photosynthetic capacities of the plants. Nevertheless, high sedimentation rates imply a certain percentage of plant burial. Mills and Fonseca 2003 studied the mortality of eelgrass *Zostera marina* exposed to varying burial in the field. Eelgrass plants were buried 25 and 75 % of their height, during 24 days, leading to mortalities of >50 and 100 % respectively.

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