Evaluation of the Effect of Sediment Spill from Offshore Wind Farm Construction on Marine Fish

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1 Introduction

The purpose of this memo is to evaluate the possible effects of sediment spill from construction of off-shore wind farms on fish.

As part of a plan to establish offshore wind turbines in Denmark, the Ministry of the Environment and Energy introduced a government order asking the electricity companies to set up five large-scale offshore wind farms with a total output of 750 MW. Rødsand in the Femer Belt was selected as the location for one demonstration project with an output of 150 MW.

The project was approved on the condition that an EIA (Environmental Impact Assessment) study was conducted in accordance with the guidelines of the Ministry of the Environment and Energy. Permission was also given to carry out the necessary preliminary studies.

The offshore wind farm at Rødsand may potentially affect the fish population in the area, during both construction and operation of the wind farm.

This paper attempts to estimate the effect of sediment spill from construction of the wind farm on the behaviour and physiology of the fish species known to be present in the area of the proposed wind farm (Bio/consult, 2000a, b).

Four types of construction have been proposed each with a different amount of estimated sediment spill (see Table 3). In the paper an evaluation of the effect of construction is made for all four construction types, although a spill scenario only exists for type 1 (DHI, 2000).

Different life stages of fish have different sensitivity to suspended sediment. Thus, in order to make a meaningful evaluation of the possible effects of suspended sediment on fish, it is essential to make an evaluation for each of the life stages. The paper evaluates the sensitivity of:

1. Eggs
2. Larvae
3. Juvenile fish
4. Adult fish

Different fish species are affected differently by suspended sediment. This may be due to for example size, physiological differences of the gills and behavioural differences.

The presence of the different life stages and species at Rødsand at the time of construction is included in the evaluation.

The first part of the paper reviews some of the scientific work on effects of suspended sediment on different fish species and different life stages. On the basis of the scientific knowledge gathered, the possible impact of suspended sediment and sediment sinking to the bottom on the fish species found at Rødsand is evaluated.

In the final section of the paper, an evaluation is made of all four construction types with regard to both the impact of the sediment spill and the noise level on the fish at Rødsand.

2 The effect of suspended sediment on different life stages of fish

The effects of suspended material on fish depends on: particle density, the size distribution of particles, the angularity of the particles, the mineral composition, the adsorption and absorption ability of the particles, oxygen and temperature conditions (Hygum, 1993).

It is generally so that the greater the concentration of suspended sediment, the greater is the impact on aquatic organisms. Newcombe & MacDonald (1991) showed, by using regression analysis, that concentration alone is a relatively poor indicator of suspended sediment effects on aquatic organisms. The product of sediment concentration (mg/l) and duration of exposure (hours) is a better indicator of effects.

Particle size and shape will influence the impact of sediment spill on fish. Generally speaking, the larger the particle (up to a point) and the more angular, the greater the impact (Hygum, 1993).

Any abiotic parameter that enlarges the metabolism of the fish will increase the sensitivity to suspended sediment. For example, the sensitivity depends on water temperature because a higher water temperature causes an increase in the metabolism and this requires an increase in the respiration rate. A higher respiration rate results in a greater flux of gasses across the gill lamella and in such situations suspended sediment will have a greater impact upon the fish.

Fish eggs and larvae are more sensitive to suspended sediment impacts than older life stages. The older the fish is, the smaller is the effect of suspended sediment on the mortality of the fish. Roughly speaking, concentrations of suspended material have to be on the scale of milligram per litre (mg/l) to be lethal to fish eggs and larvae. To be lethal to juvenile and adult fish, concentrations of suspended sediment have to be on the scale of grams per litre (g/l). This does not apply to clupeide fish, which are more sensitive to suspended sediment.

2.1 Effect on fish eggs

The impact of suspended sediment on fish eggs is first of all important with regard to pelagic eggs. The survival of pelagic eggs is dependent on their ability to remain in the upper parts of the water column where the abiotic parameters are ideal for the survival and development of the eggs. If fish eggs are exposed to settlement of sediment particles they will become heavier and sink down to a depth with sufficient salinity to keep them floating, or they will sink to the bottom. In both cases the risk of oxygen deficiency is larger than in the upper parts of the water column. If the fish egg sinks to the bottom a high mortality can be expected, primarily due to benthic predation or mechanical or physiological stress.

Rönnbäck & Westerberg (1996) found that increased concentrations of suspended sediment lead to an increase in the density of pelagic eggs such as cod (*Gadus morhua*) eggs in Øresund. The increased sinking rate was almost proportional to the accumulated amount of suspended sediment. The increased sinking would be proportional to both concentration of sediment and exposure time. This means, that even at the lowest concentration of sediment investigated, namely 5 mg/l, 11 hours of exposure was required to create an increased sinking rate equivalent to the increased sinking rate at a reduction of 1 psu.

At suspended sediment concentrations of 5 mg/l, cod eggs in the Øresund would sink to the bottom within 4 days.

Under turbulent conditions the sediment particles can fall of the eggs again, but the extent to which this will take place is unknown and highly dependent on a number of different factors, such as particle size and turbulence.

Rönnbäck & Westerberg (1996) found that at concentrations above 100 mg/l the mortality of cod eggs increased.

The impact of increased sediment concentrations is also important with regard to demersal eggs. In a review by Newcombe & MacDonald (1991) information is given that 100% mortality for Rainbow trout (*Oncorhynchus mykiss*) eggs was found after 6 days of exposure to suspended sediment concentrations of 1000-2500 mg/l. After long time of exposure (163 days) to 97-11 mg/l, the mortality of chum salmon eggs was 77-90%.

Auld & Schubel (1978) determined the effects of various suspended sediment concentrations on embryonic development of the eggs of several freshwater and estuarine fish species. Hatching success of the eggs of most species studied began to be reduced at concentrations of 500-1000 mg/l.

Messieh et al. (1981) reported that although burial of Atlantic herring (*Clupea harengus*) eggs under even a thin veneer of sediment caused substantial mortality, they were unable to detect any deleterious effect on hatching of suspended sediment concentrations as high as 7000 mg/l. However, they did find that the size at hatching tended to be higher at lower sediment concentrations.

Kiørboe et al. (1981) found that egg development of Atlantic herring (*Clupea harengus*) was not impaired by suspended sediment dosages of 300 and 500 mg/l for 1 day. They suggest that harmful effects of increased suspended sediment concentrations are most likely to occur when oxygen tension is reduced, which is often the case when organic matter and other reducing agents are released from the sea bed to the water.

Groot (1980) suggests that altering the structure of the spawning ground of herring may affect the stocks because herring in spawning condition may be unable to locate their customary spawning grounds and as a result shed their eggs on less optimal sites.

2.2 Fish larvae

Fish larvae are typically more sensitive to suspended sediment than are fish eggs of the same species. The effects can be both sub-lethal and lethal.

In many species of fish the larvae use sight for food searching. This is certainly the case for herring larvae (Batty, 1987). Larvae of species like anchovy, plaice, sole, turbot and cod sight their prey at a distance of only a few millimetres (usually less than one body length) (Bone et al., 1995). Fish larvae can not survive starvation for more than a few days before the y reach point of no return, where they are to weak to feed.

As the water becomes more turbid the vision of the larvae in their search for food is impeded. Furthermore, fine silt particles may adhere to the gills of the larvae and cause suffocation (Groot, 1980).

Johnston & Wildish (1982) investigated the effect of increased levels of suspended sediment on the feeding rate of larval herring (*Clupea harengus*) and on larvae of different ages. They found that at concentrations of 20 mg dry sediment/l the larval herring consumed significantly fewer food items. This is suggested to be due to a lower light intensity and visibility of prey as concentrations of suspended sediment increase. With regard to larvae of different ages they found that the smaller larvae were more affected by increased levels of suspended sediment than were larger larvae.

Direct lethal effects generally require higher concentrations of suspended sediment. In a review by Hansson (1995) it is suggested that reduced survival of larvae often requires concentrations above 100 mg/l.

Messieh et al. (1981) reported that Atlantic herring (*Clupea harengus*) larvae reared at concentrations above 540 mg/l tended to be small, and those exposed to 19.000 mg/l for 48 hours suffered 100% mortality.

In a review by Newcombe & MacDonald (1991) it was found that at low suspended sediment concentrations, e.g. 25 mg/l, minor lethal effects (6% mortality) was shown for sac fry of Arctic grayling (*Thymallus arcticus*, a salmonid fish) after 24 hours of exposure. At suspended sediment concentrations of 230 mg/l, 47 % of the sac fry had died after 4 days of exposure.

Rönnbäck & Westerberg (1996) found that yolk sac cod (*Gadus morhua*) larvae had a higher mortality than cod eggs, when exposed to suspended sediment and suggested that this could be due to blocking of the gills of the yolk sac larvae. They showed that the mortality of yolk sac cod larvae increased at concentrations above 10 mg suspended lime per litre. Prior to mortality a number of sublethal responses were observed. Among these was a quicker use of the yolk sac, resulting in a reduction of the time available for learning how to search for food. A lower level of activity was also observed and resulted in both a lower food intake and a higher risk of predation.

2.3 Effect on juvenile and adult fish

Response to suspended sediment might be avoidance or death. Roughly speaking, concentrations of suspended material have to be on the scale of milligram per litre (mg/l) to cause avoidance reactions from juvenile and adult fish. To be lethal concentrations of suspended sediment have to be on the scale of grams per litre (g/l). This does not apply to clupeide fish, which are more sensitive to suspended sediment.

The avoidance response and lethal response of juvenile and adult fish is to a great extent dependent on the species of fish. In general, bottom-dwelling species can be expected to be more tolerant of suspended sediment compared to pelagic species.

Sediment might have different impacts on juvenile and adult fish. The impact of suspended sediment could be either sub-lethal or lethal. Effects like clogging of gills, abrasion of the body surface, reduced sight, avoidance or death is mentioned below.

2.3.1 Clogging of gills

In water with suspended sediment, the fine particles can coat the respiratory epithelia of the fish and this will hinder gas exchange with the water. Larger sediment particles can be trapped by the gill lamellae and block the passage of water, leading to oxygen depletion (DOER, 2000).

Fish in the juvenile life stage are more sensitive to suspended solids than adult fish. As fish grow, gill dimensions increase resulting in an increase of the size of the openings in the gill filter. This means that as the fish grows, the gills may trap progressively fewer particles. Furthermore, small fish have a higher metabolic rate than large fish, i.e. they require more oxygen per unit body weight and, therefore, cannot tolerate the same relative intensity of gill-clogging (Moore, 1991).

Clupeide fish (herring-like fish) are plankton eaters and have gill bars, that are long and close together as compared to the gill bars of many carnivorous fish, that are small knots. Therefore, the gills of clupeide fish are easier clogged by sediment, and the clupeide fish are more sensitive to suspended sediment.

2.3.2 Abrasion of the body surface

Coarse particles in suspension may also harm fish by causing abrasion of the body surface, which may remove protective mucus and decrease the susceptibility to invasion by parasites or disease (Everhart & Duchrow 1970 as cited in Johnston 1981).

2.3.3 Reduced sight

The majority of fish uses the sight to search for prey. At increased concentrations of suspended sediment the visibility decrease, which makes feeding difficult. Slight shifts in the food habits of fishes captured within mud plumes suggest that reduced visibility and food availability may be of some local importance (Bouma 1976 as cited in Johnston 1981).

2.3.4 Avoidance response

Messieh et al. (1981) found that juvenile Atlantic herring (*Clupea harengus*) showed significant avoidance behaviour at concentrations above 12 mg/l and suggested that the same avoidance ability probably apply for adult herring.

Johnston & Wildish (1981) found that adult herring (*Clupea harengus*) would avoid suspended sediment at concentrations above 10 mg/l.

Adult salmonide fish (salmon and trout) show avoidance responses to suspended sediment at concentrations above app. 100mg/l and exposure for 1 hour (Newcombe & MacDonald, 1991).

Wildish & Power (1985) showed, that adult smelt (*Osmerus mordax*) would avoid suspended sediment at concentrations above 22 mg/l.

Westerberg et al. (1996) did a series of laboratory experiments on cod (*Gadus morhua*) and herring (*Clupea harengus*), and found a partly avoidance reaction of fish in contact with lime and clay suspension of app. 3 mg/l and a total avoidance reaction of fish in 6-8mg/l.

2.3.5 Lethal response

In a review by Newcombe & MacDonald (1991) it is documented that juvenile salmonide fish show lethal response to suspended sediment at concentrations from 1 g/L to 49 g/L and exposure for 4 days.

Plaice (*Pleuronected platessa*) is known to have survived immersion in a 3000 mg/l clay suspension for 14 days (Newton, 1973 as cited in Moore, 1991).

3 Fish species found at Rødsand

The most commonly occurring fish species at Rødsand were (Bio/consult, 2000a, 2000b):

Atlantic Cod (*Gadus morhua*)
Brisling (*Sprattus sprattus*) (sprat)
Dab (*Limanda limanda*)
Eelpout (*Zoarces viviparus*)
Flounder (*Platichthys flesus*)
Great sandeel (*Hyperoplus lanceolatus*)
Herring (*Clupea harengus*)
Lumpsucker (*Cyclopterus lumpus*)
Plaice (*Pleuronectes platessa*)
Sand goby (*Pomatoschistus minutus)*
Short-spined sea scorpion (*Myoxocephalus scorpius*)
Silver eel (*Anguilla anguilla*)
Small sandeel (*Ammodytes tobianus*)
Turbot (*Psetta maxima*)
Two-spotted goby (*Gobiusculus flavescens*)
Whiting (*Merlangius merlangus*)

Table 1 shows probable conditions of migration and spawning for selected species found at Rødsand.

The area of the proposed wind farm is possibly spawning area for small and great sandeel. It might also be spawning area for cod and flounder (Bioconsult, 2000a). The local fishermen also expect the area to be spawning area for turbot (Bioconsult, 2000b).

Species	Catch 1999		Migration		Probably spawning in the wind farm area	Probably spawning in the reference area
	Kg. Spring	Kg. Autumn	Statonary	Temporay		
Baltic herring	4	28		X		X
Brisling (sprat)	9	73		X		X
Fifteen-spined stickleback	0	116	X			
Atlantic cod	295	463		X	(X) 1)	(X) 1)
Whiting	0	428		X		
Small sandeel	308	115		X	X	X
Great sandeel	40	602		X	X	X
Two-spotted goby	17	12	X		Not investigated	Not investigated
Sand goby	0	99	X		Not investigated	Not investigated
Eelpout	4	129	X			
Short-spined sea scorpion	40	19	X			
Flounder	18	10		X	(X) 2)	

Table 1. List of selected species at Rødsand and the kilograms caught in, respectively, spring and autumn 1999. For each species it is indicated whether the Rødsand area is their stationary or temporary habitat. Furthermore, the probable use of the wind farm area and the reference area as a spawning area is suggested for each species (Bioconsult, 2000a).

The fish species which are most important to the income of the local fishermen, and which are present in the area of the proposed wind farm are cod, turbot and silver eel.

Table 2 shows approximation of the annual catch by local fishermen using nets in the wind farm area.

Estimate of fish catches with nets in the area of the wind farm	**Cod**	**Turbot**	**Flounder**	**Plaice**	**Dab**	**Silver eel**	**Lumpsucker**
In 1997	9.6 t	.23 t	.1 t	0 t	0 t	.33 t	0 t
In 1998	8.1 t	.16 t	0 t	0 t	0 t	.20 t	0 t
In 1999	11.1 t	.41 t	0 t	0 t	0 t	.68 t	0 t

Table 2. Approximation of the total annual catch with nets in the wind farm site itself (Bioconsult, 2000b).

4 Evaluation of the possible effects of sediment spill caused by construction of the wind farm at Rødsand on fish

4.1 The four construction types

Dredging and drilling for the foundations and burying of the sea cables are planned to take place in the period 1 April 2002 to 1 October 2002 where the trial run of the whole wind farm is scheduled. The construction work will not take place over the whole area at the same time. As an example, it is estimated that erecting a single turbine will take one day in suitable weather conditions. The direct disturbance, destruction or removal for the turbine foundations and the spooling out of cables in the wind farm site itself, is calculated to involve 1.1% of the total area of the wind farm.

For the establishment of the wind mills, four construction types have been proposed by SEAS. Table 3 shows for each of the four types, the amount of sediment involved, the noise level and the time used to establish one wind mill.

72 wind mills	Type 1 Gravitation Low (EIA)	Type 2 Gravitation High	Type 3 Monopile Drilled/sluiced	Type 4 Monopile Pile-driving
Hydrographic effect	Low	Low + 25 %	Low – 25 %	Low – 25 %
Material removed (m^3) Total	106.000	40.000	28.000	16.000
Tipped materiale m^3 Total	102.000	38.000	21.000	15.000
Sedimentary spill m^3 Total	4.000	2.000	7.000	1.000
Time pr. fundament - Preparation - Montage - Scour-protection.	 7 days 6 hours 4 days	 5 days 6 hours 4 days	 2 days 12 hours 2 days	 2 days 4 hours 2 days
Noise	80 dB	80 dB	80 dB	150 dB
Material used per wind mill	500	500	100	100
Artificial reef effect	++	+++	+	+

Table 3. Data on the four different construction types proposed for establishing the wind farm at Rødsand provided by SEAS, Dec. 2000.

4.2 Sediment spill assuming a type 1 construction

A detailed simulation of the expected sedimentary spill and the concentration, duration and area affected when using construction type 1, has been undertaken by DHI (DHI, 2000).

The simulation includes two different scenarios: 1) with 12 hours of digging and dredging work per day, and 2) with 24 hours of digging and dredging work per day (Table 4).

	Scenario 1 Normal activity		**Scenario 2 Maximal activity**	
Working hours per day	12		24	
Removing rate (m^3/3. hour)	207		207	
Amount removed per 24 hours (m^3)	828		1.656	
Sediment density (kg/m^3)	2.300		2.300	
Amount removed per 24 hours (ton)	1.904		3.808	
Sediment type	clay	Sand	clay	sand
Spill percentage	2	5	2	5
Spill (ton/24 hours)	38	95	76	190

Table 4. Data on the two scenarios for the construction work at Rødsand (DHI, 2000).

Both scenarios states, that only in the vicinity of the digging areas will the concentration of suspended sediment be higher than 10 mg/l and 15mg/l. These concentrations will only be exceeded in 10% of the construction period.

4.3 Evaluation of the impact of sediment spill on the fish species at Rødsand assuming a type 1 construction

The excavation of material from the sea bed and the entrenching and spooling out of cables between the turbines and from the turbines to the shore may be expected to affect the fish fauna at Rødsand. The impact can happen through:

- reduced egg hatching and increased egg mortality
- increased larval mortality
- destruction or removal of benthic fauna, some of which would otherwise provide food for fish
- impact of churned sediment on juvenile and adult fish, due to gill clogging and abrasion of body surface
- reduced feeding due to reduced visibility in the water
- stress due to construction work

4.3.1 *Effect on fish eggs*

Table 5 shows the spawning period for the most important fish species found at Rødsand. The exact time of spawning at Rødsand is not known and will vary between years.

Fish species	Jan.		Feb.		Mar		Apr.		May		June		July		Aug.		Sep.		Oct.		Nov.		Dec.	
Atlantic cod	■	■	■	■	■	■	■	■	■	■	■	■												
Brisling /Sprat							■	■	■	■	■	■	■	■	■	■								
Dab	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■								
Eelpout [1]	■	■	■																					■
Flounder			■	■	■	■	■	■	■	■														
Great sandeel							■	■	■	■	■	■	■	■	■	■	■	■						
Herring	■	■	■	■	■	■	■	■	■	■											■	■	■	■
Lumpsucker				■	■	■	■	■																
Plaice	■	■	■	■	■	■	■																	
Sand goby									■	■	■	■	■	■	■	■								
Silver eel																								
Short-spined sea scorpion	■	■	■	■	■	■																	■	■
Smal sandeel			■	■	■	■	■	■									■	■	■	■	■	■		
Turbot							■	■	■	■	■	■	■	■	■	■								
Whiting					■	■	■	■	■	■														
Construction period							■	■	■	■	■	■	■	■	■	■	■	■	■	■				

Table 5. Showing the spawning period for the 16 most important fish species found at Rødsand and the period where construction will take place. Information about spawning time is provided by www.fishbase.org. [1]Eelpout: Release of larvae from January to mid-February, fertilisation in August/September, maturation takes 5 months.

Pelagic eggs

As stated in section 2.1 suspended sediment might have an effect on pelagic eggs at concentrations as low as 5 mg/l, either directly increasing the mortality rate or indirectly increasing the sinking rate. At the bottom the chance of survival is considerably lowered.

According to DHI (2000), assuming a type 1 construction, concentrations of suspended sediment higher than 10 mg/l and 15mg/l were exceeded in 10% of the period of construction period at the most (see section 4.2).

The most common species at Rødsand that have pelagic eggs are cod, flatfish (European flounder, turbot, plaice and dab) and sprat.

Plaice and cod have their main spawning period in the early spring, outside the construction period and is therefore not expected to be affected by the construction activity. Flounder, dab, turbot, whiting and sprat have their main spawning period in the construction period and is therefore expected to be affected by the increased sediment concentrations in the immediate vicinity of the construction activity.

Demersal eggs

As stated in section 3.1, suspended sediment might have an affect on demersal eggs too. As the construction work will take place from April to October, it will affect the spawning of demersal fish such as small and great sandeel, sand goby, lumpsucker and herring. The eggs of these fish have an adhesive surface, and material released through the construction work will be able to stick to the eggs and thus reduce the diffusion of oxygen into the eggs, thereby increasing mortality.

Eelpout does not release the already hatched larvae in the construction period and short-spined sea-scorpion also spawn outside the construction period. Therefore, these species are not expected to be affected by the construction activity.

Neither the sandeels nor the gobies have direct commercial importance in the area around Rødsand. However, the effect of the construction work on demersal spawning could have a secondary impact on fishing, as these fish are food especially for cod and turbot, which are important species in the area.

If the concentration of suspended sediment does not exceed the levels stated by the computer simulation model created for construction type 1, the impact on demersal eggs might be restricted to the very near vicinity of the mills, since the levels of suspended sediment have to be app. 25-100 mg/l to affect the survival rate of demersal eggs (see section 2.1).

In Lumpsucker (*Cyclopterus lumpus*) spawning takes place in early spring and the female abandon the eggs after spawning. The male stays with the eggs and protects them. At very high sedimentation rates the male can be forced to abandon the eggs whereby the mortality risk of the eggs is increased significantly (Øresund, 2000).

Herring in the western Baltic spawn in spring, and is dependent on a high-energy environment with clean water and a water velocity of app. 1 m/s (Groot, 1980). Also the herring, that have a well-developed hearing, might use the sound characteristics of the seabed to recognise their spawning site (Groot, 1980). But as the main spawning ground for this strain is thought to be in the Femer Belt, just north of the German coast (Krog, 1993), the construction work will probably only have a marginal effect on the spawning of herring.

4.3.2 Effect on fish larvae

Suspended sediment might have an effect on fish larvae at concentrations as low as 10 mg/l (see section 2.1). According to the computer simulation model for construction type 1, this level of might be exceeded in 10% of the time in the immediate vicinity of the construction site. Therefore, there might be some impact on the larvae of cod, whiting, flounder, plaice, dab, turbot, sandeels, gobies, lumpsucker and herring which could all be present in the construction period.

4.3.3 Effect on juvenile and adult fish

There might be an impact on juvenile and adult flounder, dab, plaice, turbot, cod, whiting, eelpout, silver eel, sandeels, lumpsucker, gobies, sprat and herring.

However, the concentrations of suspended sediment are most probably too low to create a lethal impact on juvenile and adult fish, since this would require sediment concentrations in the range of g/l.

Avoidance reactions can be expected in the immediate vicinity of the construction activity, since avoidance reactions by the juvenile and adult fish would be expected in sediment concentrations the range of mg/l.

4.3.4 Effect on food supply

The dredging of material from the sea bed, along with excavation and spooling out of cables between the turbines, will directly disturb the area and destroy or remove benthic fauna, some of which constitutes the food supply for benthic fish, in particular flat fish.

It will affect a benthic biomass of 4.04 tons dry weight, and 256 tons of mussels, wet weight (VKI, 2000).

However, a given reduction in the food supply will not necessarily create a corresponding decrease in the fish stock. This would only happen if the amount of food available prior to the impact had only just been sufficient for the stock in its former nutritional condition.

4.4 Evaluation of the impact of sediment spill on the fish population at Rødsand assuming a type 2, 3 and 4 construction.

The sediment spill caused by construction type 2 and 4 seems to be less than the sediment spill by type 1. This means that the effect on fish eggs, fish larvae, juveniles and adult fish will probably be less than the effect assuming a type 1 construction.

When evaluating the effect of suspended sediment on fish it important to consider, not only the concentration of suspended sediment, but also the duration of the exposure. By multiplying the concentration of suspended sediment with the duration of exposure, the dose is attained. In general, the higher the dose, the greater the impact (Newcombe & MacDonald, 1991).

With regard to construction type 3, the spill is expected to exceed the spill from construction type 1, but the time needed for construction is shorter (Table 3). Therefore, it is, without at computer simulated spill scenario, very difficult to evaluate the impact of construction type 3 on the fish found at Rødsand.

5 Conclusion

Overall, it is evaluated, on the basis of the estimated concentrations of suspended material for construction type 1, that some effects of increased sediment concentrations are expected on eggs and larvae of some fish species (flounder, dab, turbot, cod, whiting sandells, gobies, lumpsucker, herring and sprat) in immediate vicinity of the construction of the wind mills.

The suspended sediment concentrations resulting from the construction work are evaluated to be so small that they are unlikely to have a lethal impact upon juvenile and adult fish. It is likely, though, that the construction activities, including the sediment spill, will stress the fish to such an extent that juvenile and adult fish will exhibit avoidance reactions.

Based on the spill scenario for construction type 1, and its expected impact on the fish species at Rødsand, it is evaluated that construction type 2 and 4 might also have some impact on the eggs and larvae, but is not expected to have lethal effects on juvenile and adult fish.

With regard to construction type 3, the spill is expected to exceed the spill from construction type 1, but the time needed for construction is shorter. Therefore, it is, without a computer simulated spill scenario, very difficult to evaluate the impact of construction type 3 on the fish found at Rødsand.

A more precise assessment of the temporary effects of the excavation should be made for each of the four construction types. It should be based on more accurate calculations of the sedimentary spill and its extent.

6 Overall evaluation of the four types of construction

This section attempts to evaluate the impact of the 4 construction types using the information provided by the current paper on the effect of sediment spill from construction type 1, and a paper on the effect of noise from construction type 4 (Bioconsult, 2001).

The noise level is highest when using construction type 4 (Table 3). Therefore, construction 4 represents “worst case” with regard to noise. The conclusion drawn in Bio/consult (2001) is that the noise from construction type 4 (pile driving) creates an avoidance reaction from some species of fish, especially fishes with specialised hearing such as cod, whiting, silver eel, herring and sprat. When evaluating the harmful effects to the ears of the fish, only herring and sprat are expected to be affected by the noise from pile driving. No other physical injuries to the fish are expected to be caused by the noise from pile-driving.

Sediment spill from construction type 1 is expected to have some effect on the survival of the eggs and larvae of fish in near vicinity of the wind mills, but is not evaluated to have lethal effects on juvenile and adult fish. Some avoidance by juvenile and adult fish is expected from construction type 1.

Since the sediment spill from construction type 2 and 4 is expected to be less and of shorter duration than the spill from construction type 1, the impact on the fish population is expected to be of less importance, than the impact caused by construction type 1.

Since the sediment spill from construction type 3 is calculated to be larger than the sediment spill from construction type 1, it can be expected to have a larger impact on the fish at Rødsand. On the other hand, the construction period is of shorter duration, and it is thus very difficult to evaluate the impact of sediment spill from construction type 3 on the current basis. A detailed simulation of the sediment concentrations and their extent is needed.

When comparing the impact of noise with the impact of sediment on the different life stages and fish species found at Rødsand, it is evaluated that the impact of sediment spill from construction type 1 will be more detrimental to the fish, than the impact of noise caused by construction type 4.

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