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HOW TO MANAGE LIGHT EMISSIONS TO AVOID MIGRATORY SONGBIRD COLLISIONS AT AN OFFSHORE CONSTRUCTION SITE

U. Zeidler[1], G. Nehls[2], S. Bräger[3], V. Kosarev[4] and J. Flamme[5]

Abstract: Birds migrating across offshore areas at night under certain weather conditions become attracted by artificial light and approach and even collide with vessels. In order to mitigate these effects during the construction of an Immersed Tunnel across the Fehmarnbelt between the Danish island of Lolland and the German island of Fehmarn, the German Plan Approval decision requires light mitigation measures and monitoring of the bird collision risks during the migration periods. It requires an Environmental Construction Inspection (ECI) to oversee the following mandatory measures as outlined in an official light management concept. The Fehmarnbelt Tunnel is the first Project required to implement a light management for offshore construction works to protect nocturnal bird migration. As it proved to be a challenging task to coordinate this Project over several years with over 50 work vessels, a new approach was developed by ECI together with the Project Owner and the Contractors how these obligations can be fulfilled: The core of the approach is the self-monitoring of the construction vessels and the relevant vessel crews are trained to respond to events when birds approach the vessels at night. ECI monitors bird migration by two far-reaching weather-radar stations and it identifies conditions which might lead to an increased collision risk. Crews are then informed through evening warnings sent to all project vessels. This presentation shows how a supervised self-control of the Contractor can fulfil the requirements on light-management to protect bird migration and evaluate the approach based on first experiences of five months of migration.

Keywords: bird migration, collision risk, crew induction, light management, self-monitoring, offshore construction

[1]Rambøll A/S, Denmark, ulze@ramboll.dk
[2]Bioconsult SH, Germany, g.nehls@bioconsult-sh.de
[3]Bioconsult SH, Germany, s.braeger@bioconsult-sh.de
[4]Bioconsult SH, Germany, s.kosarevs@bioconsult-sh.de
[5]Femern A/S, Denmark, jfl@femern.dk

1 INTRODUCTION

1.1 Light management for the Fixed Link across Fehmarnbelt

The Fehmarnbelt Tunnel Project is not only an engineering challenge but also a challenge for the management of impacts on the marine environment. The Fehmarnbelt is of utmost importance for bird migration from Scandinavia to southern Europe and Africa and back. One of the main concerns during the approval process in Germany were potential impacts by light emissions during the marine construction period on migrating birds.

In order to reflect the importance of the Fehmarnbelt for bird migration and to minimise possible effects by the construction activities, the German Plan Approval contains several conditions that have to be fulfilled during the construction period. The requirements contain technical measures and management related measures (see section 2) aiming at the reduction of offshore bird collision risks, most of which are not standard for offshore projects. In order to fulfil these requirements, a light management concept was developed which was coordinated with and finally approved by the German authorities. The light management concept has two core management-related activities:

- Self-monitoring of the construction vessels and readiness for qualified response to events when birds approach the vessels at night, executed by trained vessel crews.
- Continuous evaluation of bird approach risks by monitoring of bird migration activities and weather situations as a specified task for the expert group within the owner´s environmental construction inspection (ECI aka. “Umweltbaubegleitung (UBB)” in German).

1.2 Nocturnal bird migration in the Fehmarnbelt

The Fehmarnbelt is a key area for migratory land and water birds. The area provides habitats for wintering and resting bird species and contains internationally important bird sites protected under the EU Birds Directive. In addition, the area forms part of the African-Eurasian flyway, through which land and water birds pass on their way to and from breeding grounds in Scandinavia and the Arctic. The majority of water birds crosses the Fehmarnbelt in an east-west direction or vice versa, whereas land birds cross this part of the Baltic Sea heading southwest in the autumn and northeast in springtime.

Bird migration in the area has been intensively studied during the planning phase of the Fixed Link across the Fehmarnbelt applying a variety of methods such as tracking radar, surveillance radar, acoustical and visual observations (FEBI 2011 a,b,c). In the following, parts of the results of these investigations concerning nocturnal migration are summarized. Species of land birds crossing the Fehmarnbelt at night can either belong to the category of obligatory night migrants (e.g. thrushes, warblers, pipits) or facultative night migrants such as skylarks, chaffinches or starlings. Data from 2009 and 2010 show a high degree of simultaneity in the night migration and that the night migration over the Baltic Sea is not concentrated around the alignment of the Fixed Link but proceeds as a broad front (Figure 1). Flight altitudes vary but are generally high, often above 1000 m (Figure 3). Nocturnal migration, in contrast to diurnal migration, is also characterised by a higher degree of homogeneity of the migration directions (Figure 2).

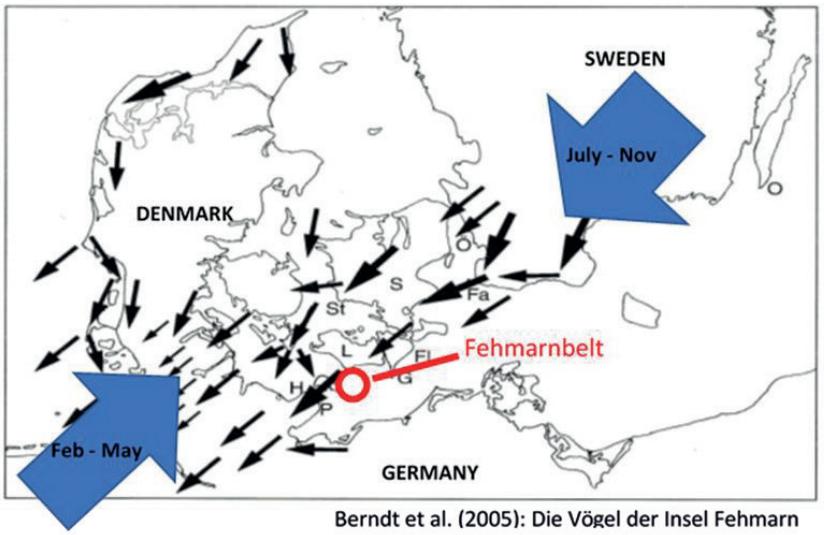

Figure 1. Location of the Fehmarnbelt at the southwestern entrance of the Baltic Sea together with the observed bird migration through the area in autumn and spring

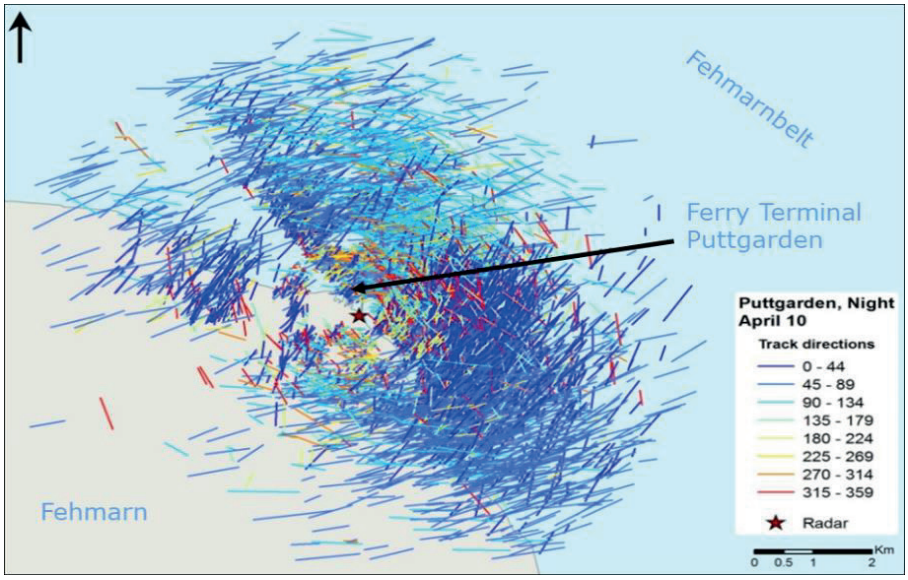

Figure 2. Radar tracks of nocturnal migrants at the landfall of the Fehmarnbælt Tunnel at Puttgarden (island of Fehmarn) April 2010. The line of the tracks indicates the migration direction (FEBI 2011c).

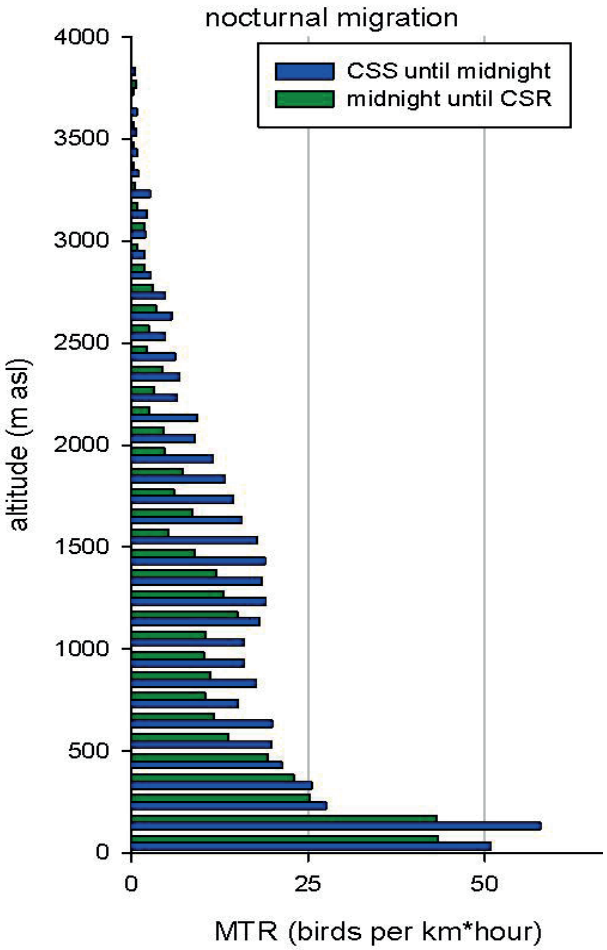

Figure 3. Flight altitude distributions of birds recorded with Pencil Beam Radar ('Superfledermaus') at Rødbyhavn in 2009. The figure shows nighttime migration intensity (birds per km per hour) distributed at altitudes between 0 km and 4 km (FEBI 2011c).

1.3 The impact of weather on bird migration

The migratory directions and intensities at a given point depend partly on local weather conditions, especially wind speed and direction. Furthermore, bird migration patterns may be determined by parameters reflecting the wider regional weather situation in the birds' original departure region (Alerstam 1990, Liechti 2006, Newton 2008, Hüppop et al. 2009). Radar data from the Fehmarnbelt show that flight altitudes above 1000 m often coincide with light winds or tailwinds without precipitation. In the case of headwinds or precipitation, radar data show a tendency for lower flight altitudes and lower bird migration intensities. Dealing with highly variable weather conditions is part of the natural migration biology, and each bird species has developed behavioural strategies to cope with shifting weather parameters. However, for passerines crossing marine areas, deteriorating weather conditions over the water may become challenging under certain conditions. When migrating birds encounter low visibility due to fog or precipitation, they may no longer be able to navigate celestially. Hence, they usually leave the original flight altitude, descend to navigate by landmarks and, if visibility continues to be poor, eventually come close to the water surface. In the Fehmarnbelt, birds can occasionally encounter dense fog under certain weather constellations, e.g. coastal fog or temperature inversion. These weather phenomena are usually linked to birds starting their migration under favorable conditions and then fly into zones with low visibility on their way.

1.4 What could be the problem, and what does light management have to do with it?

In the situations of deteriorating weather conditions described above, birds may become disoriented, and offshore working lights from vessels or other anthropogenic structures may become attractive. Birds will approach the lights and either land on the ship trying to find a roost to wait for more favorable conditions or circle the lights in disorientation, and by doing so become exhausted. There may also occur collisions with the vessel and its superstructures. Events of mass approaches of migrating birds on a vessel or other offshore structure are well known from navigation, fishery and the oil & gas industry and are readily described in the literature (Hüppop et al. 2016, Robert et al. 2015).

The fatal attraction of nocturnal migrants towards manmade light sources such as lighthouses during conditions of reduced visibility has been observed for centuries (e.g. Gätke 1891). At sea, the need of nocturnal migrants to find a place to land under extreme weather conditions has led to curious situations where the sheer number of roosting birds endangered even a vessel (Dick & Donaldson 1978). In recent years, this reaction to light, the influence of weather, and the resulting mortality among nocturnally migrating songbirds has been studied in much more detail (e.g., Desholm et al. 2006, Ellis et al. 2013, Gillings & Scott 2021, Manola et al. 2020, Ronconi et al. 2015, Snell & Thorup 2019, Van Doren et al. 2021, Winger et al. 2019).

1.5 Key role: the working light and its use

During offshore construction, a large number of working vessels are populating the Fehmarnbelt day and night. Besides obligatory navigational as well as safety lighting according to international maritime standards, different vessel types have specific requirements for working lights. While tugs, crew transfer vessels, supply vessels and guard vessels normally utilize strong spotlights occasionally for shorter periods, dredgers and barges have strong demands to illuminate their workspace continuously to enable safe operation. Large floodlights are normally installed on masts, on the bridge and other superstructures on the vessels. For the illumination of the barges` holds and hoppers, spotlights can only be installed towards bow or stern, since port side and starboard need to be kept free from structures not to interfere with loading and unloading. Therefore, spotlights on barges are mounted in an upright angle to be able to cover the entire length of the hold with the consequence that a pronounced fraction of the light cone is pointing towards or above the horizon. During the 5 years of offshore construction a permanent presence of vessels with strong working lights is expected and these are considered to play the dominant role for bird attraction.

2 THE GERMAN PLAN APPROVAL DECISION AND ITS CONDITIONS

Besides technical measures such as specifying light temperature and set up of lamps, the requirements also cover management measures aiming at reducing the risk of offshore bird collisions, most of which are not standard for offshore projects. Possible impacts on birds have been a major concern during the German Plan Approval process. Therefore, and to reflect the importance of the Fehmarnbelt for bird migration possible effects by the construction activities should be minimized. The German Plan Approval contains several conditions that have to be fulfilled during the construction period. For light management the following are the most relevant:

- Training of vessel crews.
- Mandatory procedures for handling of bird approach events (including criteria for light reduction and total operation stop).

- Definition of weather conditions that might lead to a higher risk of bird attraction and defining criteria for mass bird migration.
- Continuous monitoring of weather conditions.
- Continuous radar-based monitoring of bird migration intensity during migration season from February through May and July through November.
- Warning procedure for offshore vessels in case of conditions with high bird attraction risk.

These conditions define the frame for a light management that has been introduced to provide standards, procedures and regulations for lighting and to provide a management procedure for emergency situations. Consequently, the light management contains preventive and reactive components. In addition, the Project Owner is obliged to report weekly to the German authorities on the compliance of the light management.

3 IMPLEMENTED MEASURES OF LIGHT MANAGEMENT

In the following the preventive and reactive measures are described, which have been introduced to reduce the risk of bird approaches and to create readiness among the crews to cope with bird approach events.
The most important parts of the light management are

- The induction of the vessel crews to create awareness, and
- The assessment of actual bird approach risk based on weather and migration monitoring done by the owner's ECI team.

3.1 Crew inductions to create awareness

The light management relies largely on the involvement of the vessel crews. It is their responsibility to recognize critical situations when migrating birds should approach the vessel and follow the procedures set fourth for this situation. The decision to react needs to be taken on board of the vessel. Given the number of offshore vessels in operation it was deemed impossible to place an expert ornithologist on board of every vessel. To prepare the vessel crews for the procedure a Technical Induction has been prepared being obligatory for all crew members. Given the dimensions of the Project and the large number of involved seafarers, the induction has been integrated as module into the online induction on Health and Safety (HSE) issues, which each crew member must pass before receiving the Contractor´s offshore license.

In the induction, the crew members are informed about the general features of bird migration in the region and about the specific risks for migrating birds in relation to offshore structures. Videos of real bird approach events have proven to be an instructive tool to illustrate the need for light management and to justify the effort. Another important part of the induction is the official and mandatory procedure that must be followed in case of mass approach of birds. The procedure is summarised in the following three-step instruction:

- When 1-10 land birds are landing on the vessel or circling the lights: observe what happens, document the event.
- When > 10 birds are landing on the vessel or circling the lights: reduce working lights, observe what happens, document the event.
- When > 10 birds are landing on the vessel or circling the lights for more than 15 minutes: shut down working lights, wait until situation has cleared, document the event.

Because of extensive documentation requirements derived from the plan approval decision and by the German authorities, the vessel crews are required to submit a weekly report on bird observations, including a "nothing to report" statement, when no observations were made.

3.2 Assessment of actual bird approach risk based on weather and migration monitoring

A warning system has been established providing information about the actual migration activity and any derived risk of offshore bird approaches. The objective of the warning system is to support offshore light management and to maintain awareness of the vessel crews. The risk of mass bird approaches is deduced from a combination of weather forecast and actual observation of migration density taken from the online evaluation of weather radar data. The steps of the risk assessment are described in the following.

Figure 4. Location of weather radar stations from the German Weather Service (DWD). For the light management stations at Boostedt (Schleswig-Holstein) and Rostock (Mecklenburg-Vorpommern) have been evaluated

3.2.1 Monitoring of bird migration by DWD radar

Raw data from weather radar stations in Boostedt and Rostock (Figure 4) are obtained from the data portal of Deutscher Wetterdienst (DWD) . There are two methods available of filtering original data: – called polarimetric and simple – to estimate migration intensity. The polarimetric filter reduces clutter (e.g., due to hail), but also removes some bird-type signals as well, whereas the simple filter allows more clutter, but also more bird-type signals. Data from both filtering methods for each weather radar are analysed every 5 minutes.

As a first step, weather radar scans are merged together with the "wradlib" open-source Python library (https://docs.wradlib.org/en/stable/). The resulting combined file is used to extract bird type signals using the R package "bioRad" (https://cran.r-project.org/web/packages/bioRad/index.html). The output unit from "bioRad" is migration traffic rate (MTR) for each 5 minutes interval for each weather radar and for each filtering method within a 35 km radius around the radar. The MTR is a commonly used measure in radar ornithology indicating how many birds pass across a theoretical line of 1 km length in one hour, i.e., signals per hour and kilometer. The weather radar in Boostedt is the main reference point to get information about intensity of nocturnal bird migration in the area. First, it is located on the line where the majority of transit birds migrate from Scandinavia to Western Europe across Fehmarn Belt area. And second, it is located inland (not at the coastline as the weather radar in Rostock). This geographic location minimizes the clutter related to waves and low flying sea birds. MTR for each 5 minutes interval for Boosted are calculated for two altitude layers: 1. for the entire air column from 0 km to 5 km, and 2. for the lowest 600 m. Comparison between these two altitude profiles provide information about relative intensity of bird migration.

The weather radar in Rostock is the secondary reference point, it is located east of the main SW-NE line of nocturnal bird migration in the project area, and because of its coastal position data from this radar are more clutter infested. However, it serves as an additional information source giving an overview over the regional migration activity. The MTR for each 5 minutes interval for Rostock is calculated for three altitude layers: 1. for the entire air column from 0 km to 5 km, 2. for the lowest 600 m, and 3. for the lowest 200 m. Typically, nocturnal migration occurs above 200 m, and if most of migration for this radar is detected at the altitudes below 200 m it is the good reason to discard these data as clutter.

Each night between 20.00h and 22.00h, the expert ornithologist compares data from both radars at all altitudes and filtering methods and decides about the expected intensity of nocturnal bird migration above Fehmarnbelt during the night in question. Examples of the radar results are presented in Figure 5. Typically, nocturnal migration starts after dawn with a first peak in the early hours of the night. In some nights (Figure 5) the migration intensity shows several peaks and can continue until the morning hours. During other nights, migration activity just shows one peak or no activity. Migration intensity varies significantly and depends on many factors, whereof local weather conditions in the Fehmarnbelt are only one. Figure 4 shows examples of nights with low to very high migration intensity.

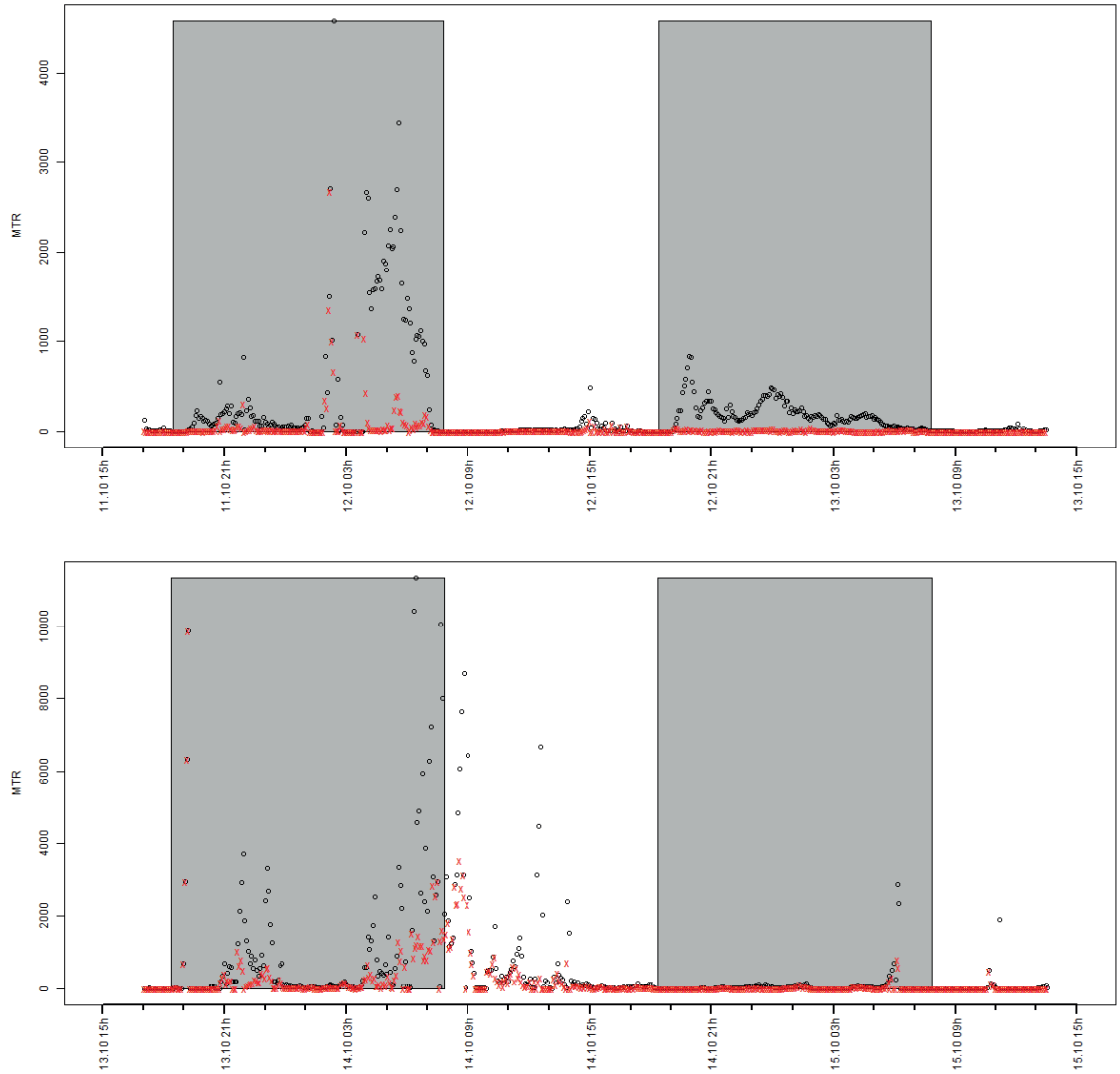

Figure 5. Mean traffic rates (MTR, i.e., the number of birds passing across a theoretical line of 1 km length in one hour) derived from the radar station at Boostedt in October 2021. Red crosses indicate signals below 600 m and circles represent all signals from ground to detection limit at about 5.000 m. Dark hours are shaded in grey.

3.2.2 Definition of bird approach risk from migration intensity and weather forecast

As described above, the output of the evaluation of weather radar data is expressed as "mean traffic rate" (MTR). From the two radar stations utilized for this project MTRs between 0 and 26.000 have been measured. To operationalize this wide range of values a logarithmical scale has been used to categorize the migration intensity (see table 1). Weather radars can detect birds in a distance of up to 35 km, which means that the two available stations from the German Weather Service did not cover the Fehmarnbelt. Furthermore, as indicated above (in section 1.2), nocturnal bird migration is observed to have a high degree of simultaneity, i.e., that a high migration activity in the Fehmarnbelt is most likely co-occurring with a high activity elsewhere in the region covered by the available radar. In this way, the radar data are used as proxy for the migration activity in the Fehmarnbelt.

Table 1. Categories of bird migration intensities from the output of the weather radars

MTR (signals/ km*h)	Categorized intensity
0-100	low
101-1000	medium
>1001	high

Weather forecasts were evaluated utilizing the online weather service www.windy.com. The main parameter of interest is the ground visibility. In addition, parameters such as precipitation and wind speed and direction have been evaluated to address adverse weather conditions for offshore bird migration. By combining actual migration intensity and the weather forecast, the risk of mass approaches of birds in the offshore area were categorized, and criteria for a warning were set up as shown in table 2.

Table 2. Criteria used for the warning of vessel crews

MTR (signals/ km*h)	weather risk factor (ground visibility)	bird migration intensity	warning to vessel crews
0-100 (low)	>5 km	low	no
	0-5 km	low	no
101-1000 (medium)	>5 km	low	no
	0-5 km	medium	**yes**
>1000 (high)	>5 km	low	no
	0-5 km	high	**yes**

A medium to high migration rate in combination with visibilities below 5 km has been considered to pose a medium and high risk for bird approaches, respectively, and consequently warnings were relayed to all vessel crews working offshore in a given night.

3.3 Ornithological hotline for crews to ask for advice all night

As a supplementary support to the vessels crews the ECI team has established a hotline, which is staffed by an ornithological specialist all night during migration season. For this a shared on-call duty has been organised among the ECI team specialists. The intention of the hotline is to provide technical advice in case of a mass approach of migrating birds on one or more vessels.

4 DISCUSSION

4.1 Recent examples of birds recorded on vessels

With commencement of offshore construction in July 2021, the project has now gone through the first bird migration season in the fall 2021. From the weekly reports received from the vessel crews, it can be concluded that no major bird approach events occurred. One Crew Transfer Vessel observed 12 and 50 small birds (passerines) passing the vessel without resting, and one barge reported landing of a single bird. All in all, it can be concluded that any impact on bird migration from offshore illumination was negligible.

4.2 Apparent effectiveness of measures thus far

One of the main objectives of the light management was to provide documentation of the impact on bird migration. With the implemented light management, it was possible to provide this documentation and to conclude on adaptive measures. Given the low impact on bird migration, it was concluded by the owner that no additional measures are needed. Another of the objectives was to establish a light management system that is largely self-managed by the contractor. This has been achieved by involvement and training of the vessel crews.

4.3 Lessons learnt

The progress of the Fehmarnbelt Tunnel Construction Works depends upon a complex and tight logistical planning and management. It is important to integrate measures of light management into other processes and procedures of the Construction Management. In the given case, the contractors' HSE management has been the entry point for the light management by the vessel crews. For instance, inductions of vessel crews have been integrated into the online HSE induction routine of the Contractor, inspections of vessel lighting have been combined with the Contractor´s self-inspections, and risk assessment for bird approaches has been provided by the ECI team as supportive action. With this approach, the impact on the construction progress appears to have been minimized.

The process of integrating light management into the Contractors' Health, Safety and Environment routines, however, has been slow, since these requirements have not been part of the contractual arrangements from the beginning, because Contracts were prepared and signed prior to consent in Germany, when authority requirements were not yet known.

4.4 Recommendations

Derived from the experience of the first season of light management the following recommendations can be forwarded:

- Light management should be tailored to the specific local risk factors (e.g. birds, and where relevant bats, insects, sea-turtles, fish) and be based upon a Risk Assessment for these factors.
- Basic features of light management should be stipulated in the contract beforehand and be integrated into the Contractor´s HSE management from the start of construction.
- Procedures must be clear and implementable.
- Light management should be executed by the crews offshore which requires good coordination between ECI team and the Contractor`s offshore management.
- Results of light management need to be documented thus forming the basis for adaptive management and reporting to the authorities, if required.

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