Chapter 23
Effects of Offshore Wind Farms on the Early Life Stages of *Dicentrarchus labrax*

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**Abstract** Anthropogenically generated underwater noise in the marine environment is ubiquitous, comprising both intense impulse and continuous noise. The installation of offshore wind farms across the North Sea has triggered a range of ecological questions regarding the impact of anthropogenically produced underwater noise on marine wildlife. Our interest is on the impact on the “passive drifters,” i.e., the early life stages of fish that form the basis of fish populations and are an important prey for pelagic predators. This study deals with the impact of pile driving and operational noise generated at offshore wind farms on *Dicentrarchus labrax* (sea bass) larvae.
1 Introduction

Offshore wind farms are being installed across the North Sea, including the Belgian part in which a concession zone is designed for the production of renewable energy and will host seven farms (Fig. 23.1). Three types of foundations have already been used, i.e., gravity-based foundations, monopiles, and jackets requiring four pin piles. The latter two are driven into the seabed and have a comparable single-strike sound exposure level (SEL$_{ss}$) that varies between 145 and 168 dB re 1 $\mu$Pa$^2\cdot$s at 750 m but have a different number of strikes and amount of piling time (Norro et al. 2013).

The construction phase of offshore wind farms raises questions about the possible impact it might have on the marine wildlife. Pile driving generates low- and midfrequency impulsive noise. At the moment, a growing group of scientists is conducting research on marine mammals and fishes looking for the possible effects on mortality, external and internal tissue damage, temporary and permanent hearing loss, physiological stress, and disturbance of natural behavior and distribution (Popper and Hastings 2009). The differences in species-specific hearing capabilities as well as vulnerability between fish species, fish sizes, and life stages complicate this bioacoustics research.

Research is moving toward defining the biological impact related to the SEL$_{ss}$, the cumulative SEL (SEL$_{cum}$), and the number of impulses (Halvorsen et al. 2012). A SEL$_{cum}$ of 210 dB re 1 $\mu$Pa$^2\cdot$s was defined as the threshold for the onset of injury for chinook salmon, but such levels only occur close to the piling source (Casper et al. 2012; Halvorsen et al. 2012). Practically no knowledge exists on the sound levels that cause mortality or injury to fish eggs, larvae, and fry. Given that their transport is mainly current based (Bolle et al. 2005), they are condemned to endure any underwater noise present in the water column. Accordingly, it is very important to determine the threshold sound levels causing any disturbance.

The ecological importance of fish eggs, larvae, and fry to maintain a healthy population size and their nutritional value in the pelagic food web only emphasizes the urgent need to establish these levels (Bos et al. 2009). Prins et al. (2009) made a first assumption about the impact of pile driving on fish eggs and larvae: “100% mortality of fish eggs and larvae in a radius of 1 km around the piling source.” This assumption was based on very little information (current patterns, dispersal, and ecological value). After the laboratory experiment in Bolle et al. (2012), a revision of this assumption was recommended. However, no field experiments have yet validated the laboratory experiments or the assumption, exposing a crucial gap in this research area that needs urgent attention.
Fig. 23.1
Belgian part of the North Sea with the offshore wind farm area. At the moment, C-power at the Thornton Bank, Belwind at the Bligh Bank, and Northwind at the Lodewijck Bank are installed or under construction. Reproduced from Vigin et al. (2013) with permission from the Management Unit of the North Sea Mathematical Models (MUMM)
The introduction of long-term continuous noise into the marine environment receives far less attention even though it is also a concern in aquaculture. The operational phase of the offshore wind farms will cause higher background sound pressure levels for the next 20 years (Norro et al. 2011). At the offshore wind farm on the Bligh Bank (Belgium), wind turbines on monopiles elevate the background underwater sound pressure level ~20 dB re 1 μPa (Norro et al. 2010). It is suggested that an increase in the background noise can interfere with the foraging behavior and communication of fish and induce stress in fish (Hastings and Popper 2005; Wahlberg and Westerberg 2005; Thomsen et al. 2006; Mueller-Blenkle et al. 2010). However, the impact on the early life stages of fish remains relatively unknown.

2 Objectives

A multidisciplinary study combining biology, acoustics, physiology, and biochemistry was designed to examine the impact of the construction and exploitation of offshore wind farms on the early life stages (eggs, larvae, and fry) of fish in Belgian waters. *Dicentrarchus labrax* (European sea bass) was chosen as the model species for round fish. The first work package (WP1) of the project dealt with the impact of pile-driving noise and tackled the impact assessment from different angles. (1) The worst-case scenario (close range) was analyzed onboard the piling platform Neptune (Northwind NV and its contractor GeoSea). (2) The impact at 500 m was examined onboard a research vessel. (3) In parallel, noise-exposure experiments were carried out under controlled conditions in the laboratory.

The second work package (WP2) of the project dealt with the chronic effects of operational noise on the development of fish eggs, larvae, and fry. These experiments were carried out under controlled conditions in the laboratory.

3 Target Species

*Dicentrarchus labrax* is a commercially important round fish species in fisheries as well as in the aquaculture industry. *Dicentrarchus labrax* is a well-studied species, in particular the larval growth, development, and skeletal formation (Zouiten et al. 2011). In addition, the year-round availability of the eggs, larvae, and fry in the Eclosérie Marine de Gravelines (France) is rather exceptional for a marine fish species. Consequently, *Dicentrarchus labrax* is frequently used in experiments and was used here as a model species for round physoclist fish (Pickett and Pawson 1994).
4 Work Packages

4.1 WP1

The general aim of the WP1 was to assess the impact of pile driving on eggs, larvae, and fry of *Dicentrarchus labrax*. (1) An experiment onboard the piling platform Neptune (Northwind NV and its contractor GeoSea) 43 m from the sound source analyzed the worst-case scenario (Fig. 23.2). *D. labrax* was exposed to pile-driving noise for a complete piling event of one monopile at 2.5 m depth in 500-ml vials, and the results were compared with a control group on land with no handling stress and a control group that underwent the same handling as the exposed group. Simultaneously, the sound pressure and particle velocity were measured. Immediate and delayed mortality were observed during and after the experiment. Physiological stress was determined by measuring whole body cortisol, analyzed with a cortisol

![Diagram of Piling Vessel](image)

**Fig. 23.2** Experimental setup to conduct the experiment on board the piling platform. The structure exists of one frame above the sea surface holding the sound equipment case with recorder and amplifier and a second frame 4 m in the sea containing the 500-ml vials of *Dicentrarchus labrax*. The hydrophone and 3-axis accelerometers are mounted just above the larval frame in the sea and are connected to the amplifier in the sound equipment case
radioimmunoassay kit, and calculating the respiration as determined by the difference in oxygen level in the vials at the start and end of the experiment. Ten percent of the surviving larvae were stored in 7% formaldehyde for histological analysis and the rest were transported back to the laboratory for further monitoring of their development.

(2) The impact at 500 m was examined onboard a research vessel and had the same experimental setup and approach as the experiment onboard the piling vessel.

(3) In parallel, noise-exposure experiments were carried out under controlled conditions in the laboratory and had the same experimental setup as the field experiments. A SIG Sparker Electrode submerged in a 400,00-l reservoir shot 3,000 V at 300 J/s and generated low-frequency impulsive noise, mimicking the sound pressure levels of pile-driving noise between 70 and 500 m from the piling source. The advantage of this experiment is the considerably reduced handling stress compared with the field experiments. The results were compared.

4.2 WP2

Chronic effects were examined during and after exposure of *D. labrax* eggs and larvae to the playback of the operational noise recordings for 1 month. The experimental design consisted of four groups: (1) a silent group; (2) a group only exposed during embryonic development; (3) a group only exposed during larval development; and (4) a group continuously exposed during both embryonic and larval development. Embryonic development, hatching percentage, time of hatching, and diameter of the yolk sac gave information about their viability and fitness. Larval development, yolk sac resorption, growth, symmetry, skeletal development, and chronic stress (Hsp70) were monitored.

5 Output

This paper presents the design of a doctoral thesis and no results are provided. Results that were obtained in WP1 and WP2 will serve several purposes. The US Fisheries Hydroacoustic Working Group formulated interim criteria for the maximum noise levels that fish could be exposed to without causing nonauditory tissue damage. The interim criterion for maximum $SE_{cum}$ for fish less than 2 g was set at 183 dB re 1 μPa²·s. The results of WP1 can contribute to the reexamination of these interim criteria. In addition, the experiment onboard the piling vessel in WP1 will allow validating the assumptions of Prins et al. (2009) and the results of Bolle et al. (2012; cf. supra). WP1 and WP2 deal with both underwater noise indicators: (1) low- and midfrequency impulsive noise and (2) ambient noise as
determined by the European Commission Directive 2008/56/EC in the Marine Strategy Framework Directive-Good Environmental Status (MSFD-GES; van der Graaf et al. 2012). These data are relevant to a scientifically based implementation of the MSFD-GES.

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References


