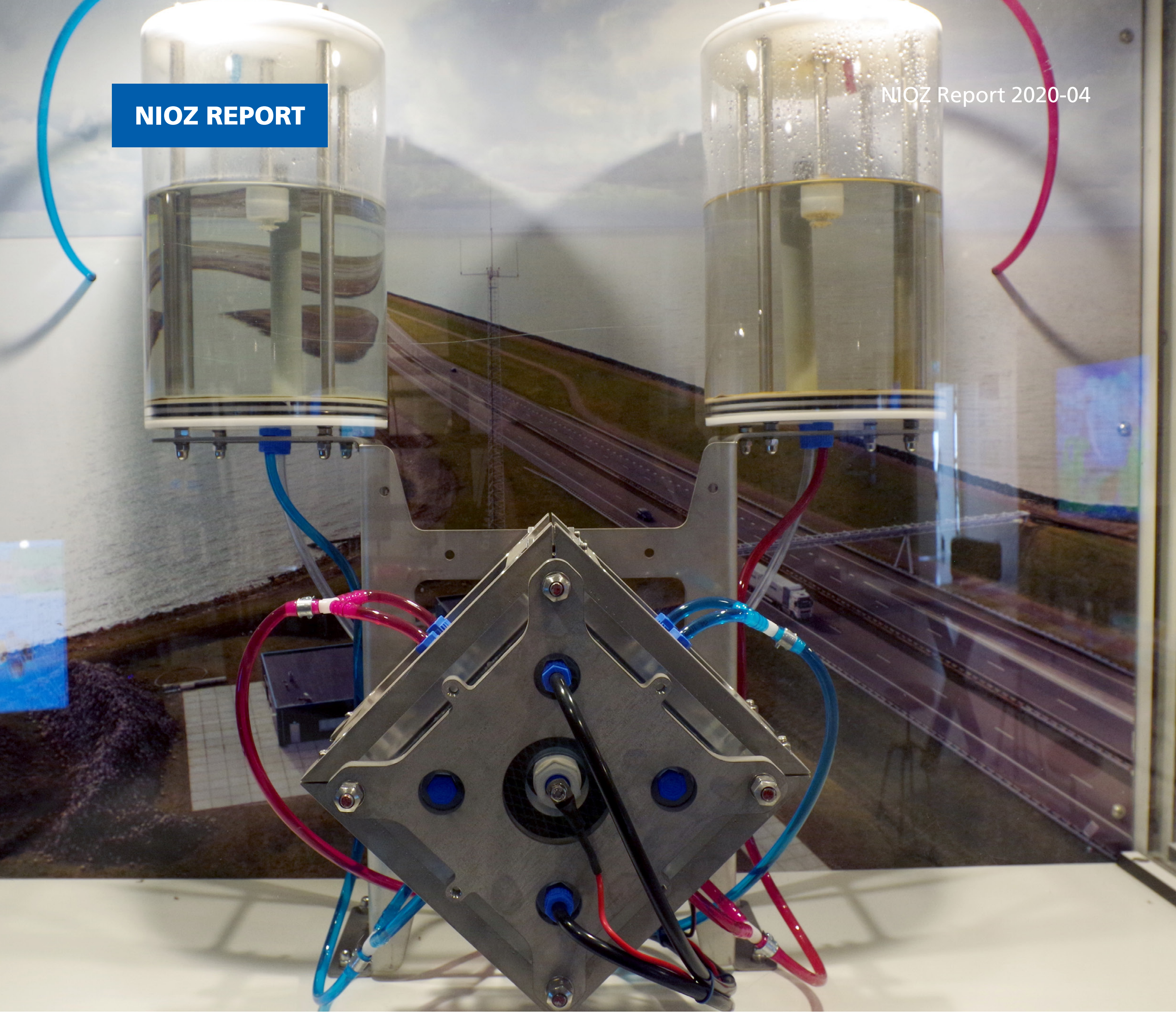

Review of the possible interactions between Blue Energy and aquatic organisms.

Deliverables 1.2 & 1.3 of project OOBE
(Onderzoek Omgevingseffecten Blue Energy).

Z. Jager & L. van Walraven

NIOZ Royal Netherlands Institute for Sea Research

Photo of a demonstration Reverse ElectroDialysis (RED) stack module displayed at Afsluitdijk Wadden Center. Photo: L. van Walraven

NIOZ REPORT

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Review of the impact of Blue Energy on organisms & impact of organisms on Blue Energy

Results of WP 1.2 & 1.3 of project OOBE (Onderzoek Omgevingseffecten Blue Energy - Effecten van organismen op innamesysteem en omgekeerd)

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Colophon

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Summary

In this review the possible impact of impingement and entrainment of aquatic organisms in Blue Energy is investigated, and possible impact mitigation strategies are presented. The possible impact of fouling by aquatic macro-organisms on Blue Energy is investigated as well. Impingement is the process in which organisms are filtered from the water intake by screens. The filter residue is subsequently returned to the environment. During impingement organisms can be exposed to mechanical damage, physical stress and possible suffocation. In the case of Blue Energy, additional osmotic stress can occur when fresh and marine water is combined. On return to the environment, there is an enlarged risk of predation by fish, birds or marine mammals. The survival after impingement is highly species-specific and is also determined by conditions such as the type of screens and the functioning of the return system, as well as environmental conditions and condition of the organism. It is recommended to apply mitigation in order to reduce the impingement and in this way secure a responsible water intake at the Blue Energy facility.

Entrainment is the process in which organisms are not removed from the water intake but pass through the installation. In this way, they can be exposed to several types of stress: mechanical damage, damage by pressure differences, chemical stress, stress by temperature or osmotic differences, suffocation or predation. In a survey of industrial cooling impact studies, entrainment survival up to 90% was found to be possible, depending on species and circumstances. The most significant mortality inducing factors in industrial cooling, temperature increase (ΔT) and chemical stress, are expected to have a lower impact in RED systems. The temperature increase caused by the RED process is less than 0.17 °C. The ΔT in RED will thus depend mainly on the difference in water temperatures of the fresh- and marine water source. Chemical treatment is not used in RED. In the RED-process, the exposure to osmotic changes and mechanical damage are expected to be the most relevant causes of damage and mortality. These aspects are investigated further in WP 2.2. and 2.5 of the Blue Energy environmental impact study. Impingement and entrainment are assessed quantitatively at a later stage in WP4.

Mitigation can be obtained by reducing the intake of organisms by applying physical barriers, such as wedgewire-screens of other ways of filtering the water, and by keeping the current velocity at the intake as low as possible (preferably below 0.15 m/s). Also the type of screening and the return system should be optimised to enhance the survival of the organisms that are taken. Other mitigation methods make use of behavioural influencing. These methods depend on the swimming capacities of the organisms themselves and are not effective for the small organisms that will be impinged and entrained at a Blue Energy installation. Finally mitigation efforts could be focused at minimizing the residence time of impinged organisms in the installation by placing the filtration step(s) closer to the intake point(s). The separate discharge of marine filter residue would prevent salinity stress of impinged marine organisms.

Fouling is caused by settling of organisms from the intake water on installation surfaces, including RED membranes. Fouling can influence the operation and proper functioning of the installation. Fouling organisms mostly belong to the meroplankton, living pelagically before settling on substrates or in sediments. Suitable settlement substrates can be found in the installation, in which case fouling is a fact. Fouling is dependent on the suitability of the substrate for settlement, the development stage of the organisms and suitable settlement conditions. Fouling can be prevented by keeping daylight out of the installation, which inhibit the growth conditions needed by algae and most cyanobacteria. Fouling can be reduced by applying prefiltration. Most of the fouling organisms are larger than 50 micron in size. Filtration of the Blue Energy process water by drum screens with mesh size of 50 micron (or less) should in theory be able to protect the stacks from fouling.

Other options include influencing the conditions and the suitability of the substrate for settlement using anti-fouling coatings or ultrasonic vibrations. Switching fresh- and marine feedwaters may also inhibit fouling. Furthermore, mechanical or chemical cleaning can be applied. These options should be evaluated for their energy efficiency or, in case of chemical treatments for their impact on the environment upon discharge.

1 Introduction

In Blue Energy, energy is generated from potential difference of water with different salinities. It is also known as SGP (salinity gradient power). One technology that can be used to harness Blue Energy is Reverse Electro Dialysis (RED). In RED, water from two water sources of different salinities is passed along either side of anion and cation exchange membranes whereby several sets of alternating anion and cation exchange membranes are stacked together. The salinity difference generates a potential difference, which is used to generate an electrical current using electrodes and a reversible redox reaction (Lacey, 1980; Vermaas et al., 2011).

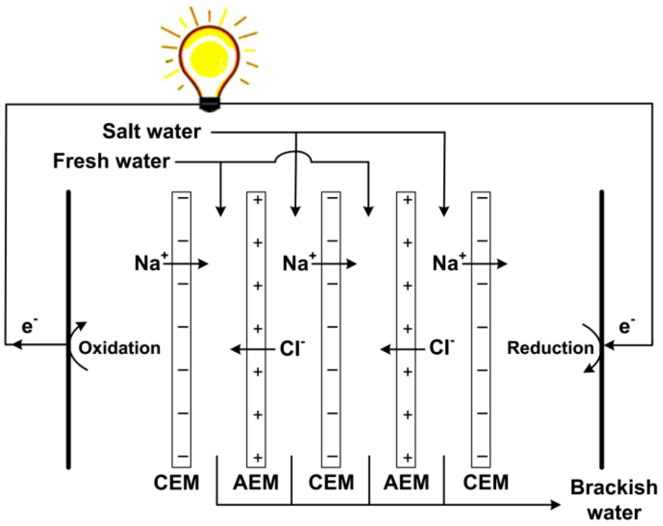


Figure 1 Principle of RED. The salt water and fresh water flow alternately along cation exchange membranes (CEM) and anion exchange membranes (AEM). A reversible redox reaction in a circulating electrolyte converts the ionic current into an electrical current (Vermaas et al., 2013).

In 2004 the research institute Wetsus started to study the RED technique. Following, the company REDstack was founded to further develop the RED technology into a commercially viable technique. To test the practical application of RED, first experiments were done at an experimental RED facility at the Wetsalt demo site in Harlingen. Following up, a Blue Energy pilot plant has been constructed on the Afsluitdijk in Breezanddijk, which is operational since May 2014. This installation uses fresh water from Lake IJssel and seawater from the Wadden Sea as feed water.

Feed water from surface sources can contain sediment and organisms, which can cause issues in a RED power plant such as fouling and clogging. Conversely, RED power plants can impact feed water sources during intake, processing, and discharge of water. The impingement (trapping of marine organisms against intake screens by the velocity and force of water flowing through them) and entrainment (passing through the installation of smaller organisms) of fish and other organisms will be an issue of increasing relevance with increasing volumes of water used, and it is of particular concern for the future full-scale installation with a very substantial water flow of 100 m^3/s.

Feed water pre-treatment in the experimental RED facility at the Wetsalt demo site in Harlingen, The Netherlands, consisted only of prefiltration using microfilters with a median diameter of 20 µm (Vermaas et al., 2013). In the REDstack pilot facility in Breezanddijk, feed water is drawn in through a tube with long vertical slits of 3 mm diameter, later changed to circular openings of 3.5 mm diameter. Within the facility the water is filtered using two rotating drumfilters, one for each feedwater source, which were covered with 20 µm diameter microfilters. In November 2016 the microfilters were changed to a diameter of ~50 µm.

RED stacks currently being tested at Breezanddijk are of the cross flow design with a cross section of $10x10cm^2$ and 5 – 10 membrane pairs (Vermaas et al. 2013, 2014; Moreno et al. 2016). On Sicily, the University of Palermo tested cross flow stacks with a cross section of $44x44cm^2$ and 500 membrane pairs (Tedesco 2016).

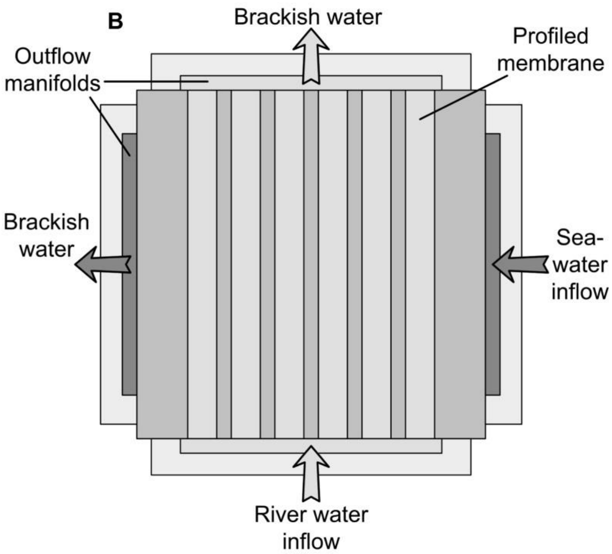


Figure 2 Schematic of a RED stack using the cross flow design as is currently used at Breezanddijk. Reproduced from Vermaas et al. 2014.

1. Objectives of the review

Using literature data on the impact of: i) cooling water intakes, ii) (screw)pumps and iii) pretreatment systems with low mechanical strain on entrained and impinged organisms, an inventory is made of the impact of the proposed systems (in workpackage 1.1) on aquatic organisms.

Research questions of this review are:

1. How does the water use in a RED power plant differ from that in conventional installations such as cooling water- and hydropower installations?
2. What organism impingement issues can be expected in a RED power plant and how can these be mitigated?
3. What organism entrainment issues can be expected in a RED power plant and how can these be mitigated?
4. What organism fouling issues can be expected in a RED power plant and how can these be treated?
5. Which organisms are present at the RED pilot site in Breezanddijk and how could these be affected by the pilot installation?

2. Reference to WP1.1 review of different techniques by Deltares

The review by Deltares (Goorden et al., 2017) concluded that conventional systems for the intake of industrial water, the application of artificial filtration, and the application of a wedgewire screen in combination with a fine-mesh drumscreen are feasible options within the energy criterium of 0.01 kW/m^3. Alternative filtration methods, using either filtration through the sea bed or using water from deep saline layers proved to be too costly in terms of energy at the Breezanddijk location. The use of a filtration basin with a permeable wall requires further research to determine its feasibility. Therefore our review puts the focus on conventional water intake installations and wedgewire/drumscreen combinations.

3. Reading guide

In Chapter 2 some background is given to the European and USA legislation on large-scale industrial (cooling) water intake. The Best Available Technology on different aspects of the water intake process, according to the EU-Directive, is described.

Chapter 3 describes several aspects of the use of large amounts of water: conventional installations for large scale (cooling) water intake, processes of impingement and entrainment and ways to mitigate those, issues of fouling and the impact of discharged water.

Chapter 4 describes the site specific situation of the Blue Energy pilot plant in Breezanddijk on the Afsluitdijk.

Chapter 5 identifies and characterizes the organisms susceptible to impingement and entrainment in the vicinity of the Breezanddijk Blue Energy pilot plant based on available studies and monitoring surveys.
Chapter 6 discusses the findings, draws conclusions and gives recommendations.

2 Legislation concerning large-scale water intake

Worldwide, different countries have different legislations concerning the large-scale intake of water from the surface waters. This chapter highlights the legislation of the EU and of the USA. The EU-legislation is translated into national laws. In the Netherlands, an assessment tool for industrial (cooling) water intake is being developed by RWS (ATKB 2016).

1. EU-legislation

The European Directive (96/61/EC) on Integrated Pollution Prevention and Control (IPPC) aims to achieve integrated prevention and control of pollution arising from the activities listed in Annex I of the Directive. The Directive lays down measures designed to prevent or, where that is not practicable, to reduce emissions in the air, water and land from the abovementioned activities, including measures concerning waste, in order to achieve a high level of protection of the environment taken as a whole.

According to Annex I, installations or parts of installations used for research, development and testing of new products and processes are not covered by Directive 96/61/EC. (Annex I). The Blue Energy installation, currently operating at the site Breezanddijk, is experimental and operates on a small scale and is not covered by Directive 96/61/EC. However, it may be applicable to the future upscaled installation, and therefore some aspects are highlighted.

The 'best reference' document (BREF) reflects the information exchange carried out according to Article 16 (2) of the 96/61/EC Directive on IPPC and describes the Best Available Techniques (BAT) or BAT-approach. Obliged by 96/61/EC, several BREF Documents were adopted, of which an overview can be found on the website of the Joint Research Centre of the EU (http://eippcb.jrc.ec.europa.eu/reference/).

Among those is the BREF on Industrial Cooling Systems in December 2001 (IPPC, 2001). The integrated BAT-approach for industrial cooling systems considers the environmental performance of the cooling system in the context of the overall environmental performance of an industrial process. It aims at minimising both the indirect and direct impacts of the operation of a cooling system. It is based on the experience that the environmental performance of cooling of a process largely depends on selection and design of the cooling system. The final BAT solution is mainly a site-specific matter.

The BREF on Industrial Cooling Systems is only partly applicable to the Blue Energy (BE) installation because in BE the water is used for energy generation instead of cooling. Nevertheless, the volumes of water are of comparable magnitude and aspects of water intake, such as entrainment and impingement, do also apply to BE. Of the applied cooling systems, mentioned in the BREF Industrial Cooling, only the once-through systems are of relevance to a Blue Energy installation, whereas cooling towers or closed circuit systems are not applicable.

In a Blue Energy installation, the type of water intake can be compared with a once-through water intake system such as in use for cooling water. The application of once-through water intakes involves several environmental aspects, that are listed below, based on the Best Reference document (BREF) for Large Industrial Cooling (IPPC, 2001):

a. the use of large amounts of water (including living organisms)
b. heat emission (in case the water is used for cooling purposes),
c. the risk of fish intake,
d. sensitivity to bio-fouling, scaling or corrosion
e. the use of additives and the resulting emissions to water,
f. energy consumption, mainly for pumps,
g. the risk of leakage from the process stream, and
h. the silting-up of sieves at water intake.

The final BAT solution will be site-specific, but for some aspects there are general BAT techniques identified. For new installations the approach focuses on prevention of emissions by selection of an adequate cooling configuration and by proper design and construction of the cooling system. Additionally, reduced emissions are achieved by optimization of daily operation.

Of the aspects that are listed in the BREF Industrial Cooling Systems (IPPC, 2001) the below are applicable to RED/Blue Energy:

- Process and site requirements. The intake of water ('once-through') is a prerequisite for the Blue Energy installation, hence the availability of sufficient volumes of water is important. Process and site requirements determine the water intake options, such as filtration of groundwater, pre-filtration via a filter-dike or shellfish beds. These alternatives were explored (Goorden et al., 2017; Wijsman & Smaal, 2017) but do at first glance not seem feasible at the site Breezanddijk. Pre-filtration by shellfish beds will be tested in WP 3 of the project. At Breezanddijk, the relatively low salinity of the seawater and the relatively high silt contents may pose restrictions on the applicable options for the Blue Energy installation (see next bullet).
- Reduction of energy consumption by the water intake system. The use of once-through systems is BAT, in particular for processes requiring large (cooling) capacities. In the case rivers and/or estuaries this method can only be acceptable if also the water intake is designed aiming at reduced (fish) entrainment. The energy consumption is taken into consideration by using an energy criterion of 0.01 kWh/m^3 in the BE-project. This criterion limits the application of energetic costly ground water filtration techniques at least at the Breezanddijk site (Goorden et al. 2017).
- Reduction of water requirements. In the case of RED-technology, the water use is dictated by the scale of the installation since energy is extracted from the mixing of the feed waters. A relative reduction of water consumption can only be achieved by maximising the efficiency of the process.
- Reduction of entrainment of organisms. No clear BAT have been identified in IPPC (2001); emphasis is put on an analysis of the biotope, as success and failure much depend on behavioural aspects of the species, and on proper design and positioning of the intake. Optimisation of the water intake is BAT, taking into account the water velocity, and watching for seasonal occurrence of macrofouling.
- Reduction of emissions of chemical substances to water. BAT-approach is the application of techniques to reduce emissions in this order (IPPC, 2001): 1. selection of cooling configurations with lower emission level to surface water 2. use of more corrosion resistant material 3. prevention and reduction of leakage of process substances into the cooling circuit 4. application of alternative (non-chemical) water treatment 5. wise selection of cooling water additives 6. optimized application (monitoring and dosage) of cooling water additives in once-through systems, proper design is to avoid stagnant zones and turbulence and to maintain a minimum water velocity in the system (to avoid settlement of larvae).
- Reduction of emissions by optimized cooling water treatment. It is considered BAT by IPPC (2001) to reduce the input of biocides by targeted dosing in combination with monitoring of the behaviour of macrofouling species and using the residence time of the water in the system.

BAT distinguishes between existing and new systems. All key BAT conclusions can be applied to new systems, such as the Blue Energy installation.

2. Implementation in The Netherlands

The relevant EU-Directives are implemented into national legislation. The legislation (water law, environmental law) is quite complex and furthermore changes from time to time; it is therefore not described in this report.

The activity of a Blue Energy installation may require an environmental impact assessment (EIA, EIA Decision, Besluit M.e.r in Dutch; the activity is 'M.e.r.-plichtig').

Frame 1. EIA Decision (Besluit M.e.r.), Annex C and Annex D. Annex C: activities, plans and decisions which require an EIA. Annex D: activities, plans and decisions for which the procedure described in articles 7.16 to 7.20 of the environmental law (Wet Milieubeheer) are applicable.

EIA Decision	*Activities*	*Cases*	*Plans*	*Decisions*
Annex C,	*De oprichting, wijziging*	*In gevallen waarin de*	*De structuurvisie,*	*De besluiten waarop*

C22.1	*of uitbreiding van thermische centrales en andere verbrandings-installaties.*	*activiteit betrekking heeft op een inrichting met een vermogen van 300 megawatt (thermisch) of meer.*	*bedoeld in de artikelen 2.1, 2.2 en 2.3 van de Wet ruimtelijke ordening, en het plan, bedoeld in de artikelen 3.1, eerste lid, 3.6, eerste lid, onderdelen a en b, van die wet.*	*afdeling 3.4 van de Algemene wet bestuursrecht en een of meer artikelen van afdeling 13.2 van de wet van toepassing zijn.*
Annex D, D22.1	*De oprichting, wijziging of uitbreiding van een industriële installatie bestemd voor de productie van elektriciteit, stoom en warm water.*	*In gevallen waarin de activiteit betrekking heeft op een elektriciteitscentrale met een vermogen van 200 megawatt (thermisch) of meer en, indien het een wijziging of uitbreiding betreft. 1°. het vermogen met 20% of meer toeneemt, of 2°. de inzet van een andere brandstof tot doel heeft*	*De structuurvisie, bedoeld in de artikelen 2.1, 2.2 en 2.3 van de Wet ruimtelijke ordening, en de plannen, bedoeld in de artikelen 3.1, eerste lid, 3.6, eerste lid, onderdelen a en b, van die wet.*	*De besluiten waarop afdeling 3.4 van de Algemene wet bestuursrecht en een of meer artikelen van afdeling 13.2 van de wet van toepassing zijn.*

C22.1 concerns the installation, modification of expansion of a thermic power station and other incineration installations, in cases where the capacity of the installation is 300 MWatt (thermic) or more. D22.1 concerns the installation, change or expansion of an industrial installation dedicated to the production of electricity, steam and warm water. Cases: in cases that the activity is related to a power station with a capacity of (more than) 200 MWatt (thermic) and, in case it is a change or expansion: 1. the capacity increase is 20% or more, or 2. the installation aims at using other fuel.

In the context of the Dutch Water Law, a tool is in development to assess the intake of cooling water by the industry. The Dutch approach to assess the impact of a cooling water intake structure (CWIS) is a multi-level approach (ATKB, 2016).

Level 0 is a BTA (best technology available) test, based on the volume of the intake, the current velocity and water flow. The criterium is calculated by the formula: ((1/0.15)*a-1)+((1/15)*b)), where a is current velocity (m/s) and b is water flow (m^3/s). A current velocity below 0.15 m/s is judged harmless, above 0.3 m/s it is judged potentially harmful. A water flow of 15 m^3/s or lower is arbitrarily assumed to be harmless, but it is based on expert judgement and not on data. If the outcome <1, the water intake is expected to be harmless. If the outcome ≥1, then the assessment proceeds to level 1.

Level 1 looks at technical aspects of the installation, using criteria such as the distance of the intake to the shore, the depth of the intake, the current velocity, the part of the water column that is taken, the presence of a trash rack, fine-meshed screens and a fish return system, and the shore-morphology. Each of the 8 criteria has a best score of 4 and a worst score of 1; the limit is a summed score of 24. If Level 1 scores insufficient (<24), a Level 2 assessment is required.

Level 2 assesses a worst case scenario, based on existing data on the fish population and taking into account the waterbody, the type and volume of the extraction, as well as the number of fish per volume. the ratio between fish (<15 cm) in the intake and surface water and the proportion between the fish population 0-group and older fish, both in spring and autumn. The extraction of fish from the population is quantified. Level 2 uses existing data and theoretical assumptions.

Level 3 assessment combines realistic data on fish impingement and fish presence at the site, to be monitored if no data are available. The realistic impact of impingement on the fish populations and on the EQR-score is determined. If the fish population decreases by 10%, or if the water body acquires a lower Ecological Quality Ratio (EQR) in the context of the EU Water Framework Directive, the water extraction is judged detrimental to the fish population and additional mitigation should be applied (ATKB, 2016).

Applying the above to Blue Energy/RED, the pilot installation at Breezanddijk has a low capacity (water intake volume 200 m^3 per h, or 0.05 m^3/s) and an intake velocity <0.1 m/s (personal communication S. Grasman, RED Stack). In this case, the level 0 assessment scores <1 and the water intake would be considered harmless.

However, for the upscaled situation assuming a water intake of 100 m^3/s and a current velocity of 0.1 m/s, the score would be >>1 and the assessment proceeds to Level 1. The design of the upscaled installation is not yet known. The criteria mentioned in the assessment tool Level 1 can be taken into account to design the installation according to the BTA/BAT (see also IPPC, 2001).

3. Outlook to legislation in the USA

In the USA, the Clean Water Act (2012) is relevant. Sections 316(a) and (b) of the Clean Water Act require the protection of fish and shellfish from discharge and withdrawal of surface water for power plant cooling. The U.S. Environmental Protection Agency (EPA) evaluated four regulatory options and selected a proposed EPA Rule in 2011. The Rule is part of the Clean Water Act §316(b) and it sets compliance standards for existing facilities. An Impingement Mortality and Entrainment (IM&E) Characterisation Study is required (Phase II rules of §316(b) of the Clean Water Act) as an integral part of a comprehensive demonstration study, including site-specific compliance to BTA (Best Technology Available) (EPRI, 2004). Such IM&E Characterisation Study should provide:

- Taxonomic identifications of all life stages of fish, shellfish, and protected species in the vicinity of the cooling water intake structure (CWIS) and susceptible to impingement and entrainment;
- A characterization of these species and life stages in terms of their abundance and their spatial and temporal distribution, sufficient to characterize the annual, seasonal and diel variations in impingement mortality and entrainment; and
- Documentation of current impingement mortality and entrainment of these species and life stages.

Usually, the IM&E monitoring aims at assessing the impingement abundance and impingement mortality, and entrainment abundance and entrainment mortality. (The monitoring carried out in WP2.4 and WP2.5 of the OOBE-project can be regarded as a form of IM&E monitoring.)

The Final 2014 Rule (of the Environmental Protection Agency, EPA) for Existing Electric Generating Plants and Factories applies to existing facilities that are designed to withdraw at least 2 million gallons per day of cooling water.

- The facilities are required to choose one of seven options to reduce mortality to fish and other aquatic organisms.
- Facilities that withdraw at least 125 million gallons per day must conduct studies to help their permitting authority determine whether and what site-specific controls, if any, would be required to further reduce mortality of aquatic organisms.
- New units added to an existing facility are required to reduce mortality of aquatic organisms that achieves one of two alternatives under national entrainment standards
- EPA consulted with the Fish and Wildlife Service and the National Marine Fisheries Service pursuant to the Endangered Species Act.

EPA produced supporting documents, such as the Final Biological Opinion and Appendices (May 19, 2014) annex to the Final 2014 Rule for Existing Electric Generation Plants and Factories. Furthermore, many underpinning studies were undertaken by the Electricty Power Research Industry (EPRI), for example cited in paragraph 3.3.

The description of further details of the regulations in the US is beyond the scope of this review.

3 The use of large amounts of water

1. Once-through

Large coastal power stations, either nuclear, gas-fueled (STEG), or coal-fueled, generally use once-through cooling systems. With a capacity of 435 MWe (gas) to 600 MWe (coal) or even 900-1300 MWe (nuclear), these modern power stations use 0.04-0.05 m^3/s cooling water per MWe generated; in practice the cooling water demand of a power station ranges between 30 and 65 m^3/s. This is lower than, but in a similar order of magnitude as, the required water flow for a future full-scale Blue Energy installation (100 m^3/s).

The water requirement for once-through cooling systems is on average 86 $m^3/h/MWth$ and the relative water use is 100% (IPPC, 2001). Based on our review, the average cooling water flow of European power stations is 0.04-1.07 m^3/s per MWe (Table 1, last column).

Variations in required cooling water flow occurs due to differences in warming of the water (ΔT, often in the range 8-11 °C) (Ehlin et al., 2009). Furthermore, modern installations seem to have a more efficient cooling water use than older ones.

With a water use of 1.0 m^3/s per MWe, the Blue Energy water demand ranks in the higher regions.

Table 1. Comparing the cooling water demand of different European power stations.

Source	Country	Station	type	Completion year	Turbine rating Mwe	Q dema m3/s	relative Q Mwe/1 m3/s	calculated Mwe/Q	calculated m3/s per Mwe
Turnpenny & Coughlan 2003	UK	Hams Hall A	conventional	1929	80	N/A			
Turnpenny & Coughlan 2003	UK	Fulham	conventional	1936	60	N/A			
Turnpenny & Coughlan 2003	UK	Hams Hall B	conventional	1942	50	N/A			
Turnpenny & Coughlan 2003	UK	Cliff Quay	conventional	1949	46	10.0	13.8	4.6	0.22
Turnpenny & Coughlan 2003	UK	Brighton B	conventional	1958	112.5	20.4	16.2	5.5	0.18
Turnpenny & Coughlan 2003	UK	Marchwood	conventional	1959	60	33.0	14.6	1.8	0.55
Turnpenny & Coughlan 2003	UK	Aberthaw A	conventional	1963	100	26.9	22.3	3.7	0.27
Turnpenny & Coughlan 2003	UK	Uskmouth B	conventional	1962	120	19.0	19	6.3	0.16
Turnpenny & Coughlan 2003	UK	Blyth A	conventional	1960	120	20.0	24	6.0	0.17
Turnpenny & Coughlan 2003	UK	Fawley	conventional	1971	500	64.0	31.25	7.8	0.13
Turnpenny & Coughlan 2003	UK	Littlebrook D	conventional	1984	660	58.0	33.9	11.4	0.09
Turnpenny & Coughlan 2003	UK	Peterhead	conventional	1982	660	28.0	47.8	23.6	0.04
Turnpenny & Coughlan 2003	UK	Calder Hall B	Magnox	1959	30	32.0	7.5	0.9	1.07
Turnpenny & Coughlan 2003	UK	Bradwell	Magnox	1962	52	26.0	12	2.0	0.50
Turnpenny & Coughlan 2003	UK	Wylfa	Magnox	1973	247	67.0	14.8	3.7	0.27
Turnpenny & Coughlan 2003	UK	Dungeness B	AGR	1970	660	40.0	33	16.5	0.06
Turnpenny & Coughlan 2003	UK	Hinkley Point B	AGR	1978	660	30.0	44	22.0	0.05
Turnpenny & Coughlan 2003	UK	Sizewell B	PWR	1995	660	52.0	25.4	12.7	0.08
Turnpenny & Coughlan 2003	UK	Great Yarmouth	CCGT	2002	140	8.8	16	15.9	0.06
Turnpenny & Coughlan 2003	UK	Shoreham	CCGT	2001	130	5.6	12.9	23.2	0.04
Ehlin 2009	SE	Forsmark 1	nuclear	1980	987	43.0		23.0	0.04
Ehlin 2009	SE	Forsmark 2	nuclear	1981	1000	43.0		23.3	0.04
Ehlin 2009	SE	Forsmark 3	nuclear	1985	1170	44.0		26.6	0.04
Ehlin 2009	SE	Oskarshamn 1	nuclear	1972	467	25.0		18.7	0.05
Ehlin 2009	SE	Oskarshamn 2	nuclear	1974	598	30.0		19.9	0.05
Ehlin 2009	SE	Oskarshamn 3	nuclear	1985	1150	50.0		23.0	0.04
Ehlin 2009	SE	Barsebäck 1	nuclear	1975	600	25.0		24.0	0.04
Ehlin 2009	SE	Barsebäck 2	nuclear	1977	600	25.0		24.0	0.04
Ehlin 2009	SE	Ringhals 1	nuclear	1976	850	44.0		19.3	0.05
Ehlin 2009	SE	Ringhals 2	nuclear	1975	870	35.0		24.9	0.04
Ehlin 2009	SE	Ringhals 3	nuclear	1981	920	43.0		21.4	0.05
Ehlin 2009	SE	Ringhals 4	nuclear	1983	915	43.0		21.3	0.05
EDF	FR	Gravelines	nuclear	1985	5400	240.0		22.5	0.04
EDF	FR	Penly	nuclear	1990, 1992	2600				
EDF	FR	Paluel	nuclear	1984, 1985,	5200				
EDF	FR	Le Havre	coal		1800				
EDF	FR	Flamanville	nuclear	1985, 1986	2600				
EDF	FR	Cordemais	coal, oil		2600				
EDF	FR	Blayais	nuclear	1981, 1982,	3600	160		22.5	0.04
Engie	NL	Eemscentrale	gas	1996	1750	55		31.8	0.03
RWE	NL	Eemshavencentrale	coal	2013	1600	65		24.6	0.04
NUON	NL	Magnumcentrale	gas	2012	1200	45		26.7	0.04
eon	D	Wilhelmshaven	coal	1976	747	33		22.6	0.04
Engie	D	Wilhelmshaven	coal	2012	830	30		27.7	0.04
EPZ	NL	Borsele	nuclear	1974	485				
Sloe-10	NL	Sloegebied	gas	2010	435				
Sloe-20	NL	Sloegebied	gas	2010	435				
MPP1	NL	Maasvlakte Eon	coal	1989	520	21			0.04
MPP2	NL	Maasvlakte Eon	coal	1988	520	21			0.04
Eneco	NL	Europoort EGEN-10	gas	2011	435	7			0.02
Eneco	NL	Europoort EGEN-20	gas	2011	435	7			0.02
Engie	NL	Maasvlakte Engie	coal	2015	800	28			0.04

2. Conventional installations

The general lay-out of a conventional once-through (cooling) water system includes a sequence of cleaning methods of the intake water to remove particles which might damage the interior construction of the installation (Figure 3). The water passes a trash-rack (typical bar-distance 10 cm), a fine-meshed screen (mesh size range 3-5 mm), either in the form of a drumscreen or vertical travelling screen and sometimes a microscreen (1 mm mesh) to remove fouling shellfish organisms. The fine-meshed screens are flushed with a (high-pressure) water spray to remove accumulated debris including fish, and wash it into a through or fish return system to a discharge (often to the surface water). This treatment causes damage and mortality of organisms. In addition, there is the need to apply anti-fouling treatment in cooling systems, such as thermal shock or chemical treatment (chlorination). The residues are discharged to the surface water (Jager, 2010).

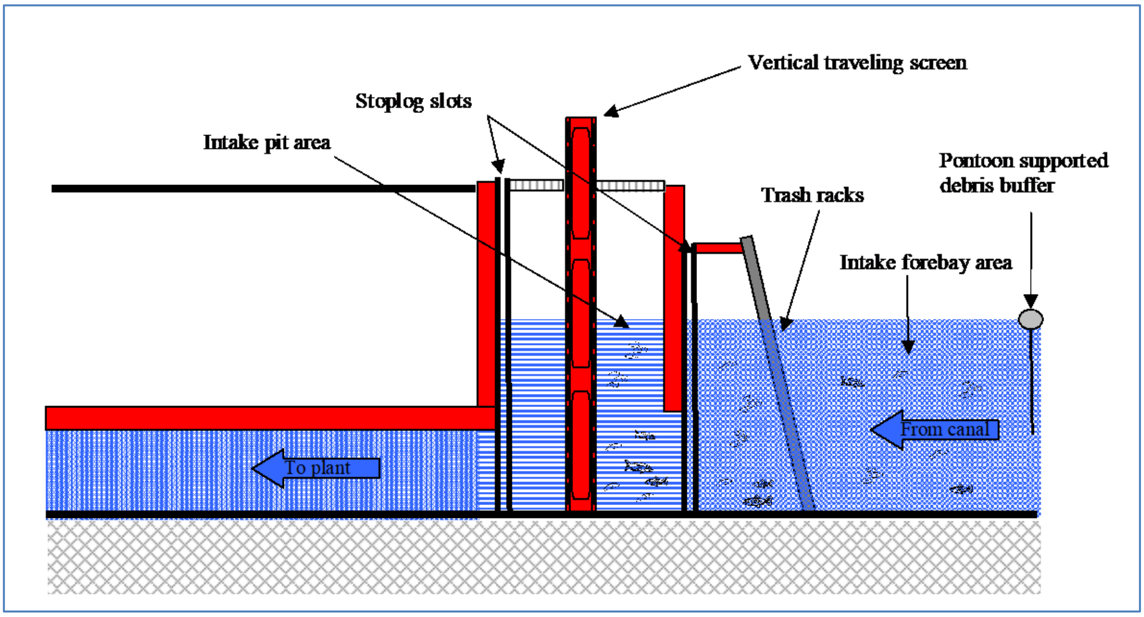


Figure 3. General schematic of the cooling water intake structures (CWISs) at Plant Barry. Source: EPRI report 1016807 (2010).

The organisms in the intake water can either be filtered (impingement) or be drawn through the entire installation (entrainment). The size of the finest sieve is determining which fraction is entrained or which is impinged. Impingement and entrainment are complementary. If the sieves are finer, more organisms are filtered out as impingement and less organisms are entrained, and the other way round.

During passage of the installation, entrained organisms are subjected to mechanical stress, and thermal shock. The impinged organisms may suffer from mechanical stress on the sieves or during transportation back to the environmental water. At return to the water, there is an enhanced risk of predation by mammals, birds or fish.

Pumps may provide a physical and behavioural barrier to fish; fish can be confused, damaged or killed by pumps. Current velocity and turbulence can cause damage by disorientation of the fish, leading to fish contact with the pumphouse with consequential descaling and superficial lesions (to gill structures or eyes), or enlarged predation risk. In a test in the USA with juvenile chinook salmon (93-128 mm in length, 8.1-23.5 g in mass), the type of injury depended on the current velocity (the onset of minor, major, and fatal injuries occurring at 12.2, 13.7, and 16.8 $m \cdot s^{-1}$ jet velocities, respectively), with acceleration showing the strongest predictive power for eye and opercle injuries and overall injury level (Deng et al., 2005). Salmonids (and many other fish species) are evolutionary adapted for swimming head-on into the flow, but they are poorly adapted to flow coming in from behind. Such reverse flows can lift and tear off scales, pry open the operculum, rupture or dislodge eyes, and damage gills (Deng et al., 2005).

Shear stress can also cause damage, such as descaling, damage to the protective slime on the skin, eye damage or eye loss, internal haemorrhages, bleeding gills. Clupeids (herring) are vulnerable to this type of stress and showed mortality at relatively low shear stress of 206 N/m^2 (Turnpenny et al., 1992 cited in Kunst et al., 2008).

Pressure changes are experienced by the fish throughout its passage through the turbine system. Rapid pressure changes cannot be accommodated by the fish, and may cause the swimbladder to distend or rupture. It is not so much the pressure increases that are damaging, but the pressure decreases that are of concern (Čada, 1997).

Between 2006-2011, the Foundation for Applied Water Research STOWA initiated investigations into different types of pumps and their effects on fish (Kunst et al., 2008). The study resulted in a tool that helps to select the least damaging pump in a specific situation ('gemalenwijzer'). The selection of pumps is dictated by the demands on the pumps, being the pump capacity in terms of volume of water per unit of time ('debiet' Q), and the difference in water level that has to be overcome ('opvoerhoogte' H).

In the review of Kunst et al. (2008), the highest percentage of damage were found at screw pumps (including the so-called axial pump). Less damaging pumps are the Paddle wheel, Archimedes screws, hidrostal pumps and faunapumps. Hidrostal pumps have not been investigated in the Netherlands, but there is some experience in other countries. The effectiveness of a Hidrostal pump and filtered mercury vapor light system for attracting, concentrating, and transporting fish commonly impinged on water intake structures of thermal electric generating stations on the Great Lakes was tested by Rodgers et al. (1985). Fish mortality rates were relatively low, but varied among fish species and increased at higher pumping speeds. Mortality also depended on the length of the transport loop.

Low-head turbines, that are used in tidal power installations, can have different types of impact on marine organisms (Dadswell & Rulifson (1994):

- mechanical damage: by contact with rotating runner blades, which leads to contusion, abrasion, lacerations
- shear: torn opercula and isthmus, decapitation, inverted and broken gill rakers
- pressure changes: popped eyes, haemorrhages in the eyes, at fin bases and internally and pinholed or burst swimbladders
- cavitation: pulping of body tissues and severe internal haemorrhages

Small and delicate fishes such as Clupeids are more prone to pressure-related injuries, whereas larger fish are more vulnerable to mechanical strike of the turbine blades.

In the Blue Energy installation, the intake water is filtered and the pump is protected from large organism to get trapped. The literature that was found was mainly about juvenile and adult fish. Those are not expected to interact with the pumps at Blue Energy, certainly not in the pilot plant. In the upscaled situation, a completely different pump capacity is needed and the future installation design is not known at this stage. However, it is to be expected that in the upscaled plant, comparable to conventional CWIS, the pumps will also be protected by screens or other devices, such that larger organisms and fish will not get in direct contact with the pumps.

The impact of pumps on larger organisms is therefore effectively mitigated by preventing direct contact.

4 Impingement

1. What is impingement?

Aquatic organisms (typically fish and larger invertebrates) can be trapped against the intake screens that are designed to prevent larger aquatic organisms and debris from entering a cooling water intake structure (CWIS). This process is known as impingement. It may occur if the intake velocity exceeds their ability to move away or if the organisms get entangled in debris that may be present in front of the CWIS.

2. Impact of impingement on organisms in installations

Impingement of juvenile and adult fish may result in immediate death due to mechanical abrasion and suffocation. Exposure to stress conditions which does not result in immediate death may lead to eventual mortality of the organism due to a lowered resistance to predation and disease or an inability to actively compete for food (Hanson et al., 1977). Impingement mortality is highly species- and size-specific and furthermore strongly dependent on the type of screens, the operation of the screens and on the environmental conditions (oxygen concentration in the water, temperature) and last but not least the condition of the fish. There are studies that suggest that fish are more susceptible to impingement if they are weakened (Bruijs, 2007).

3. Factors influencing impingement

To get impinged, the organisms must be in the waterbody from which the water is withdrawn and they must be entrapped against the intake screen by the extracted water flow. Impinged organisms are subject to physical stress and/or suffocation that can result in injury and the death of organisms (EPRI, 2004). The vulnerability and survival rate very much depend on the species.

Impingement is affected by biological, hydrological and water quality characteristics in interaction with the design and operation of each individual water intake structure (EPRI, 2004).

Relevant factors are (EPRI, 2004):

- the water body type: this determines the assemblages of fish and macroinvertebrate species
- the location of the WIS (water intake structure) in relation to the areas where species concentrate: this influences the species composition of the impingement
- seasonal concentrations of species in the vicinity of an intake, related with a. nursery areas, b. migratory pathways, c. seasonal movements associated with spawning, d. overwintering areas, e. behaviour such as schooling (e.g. of Clupeids), attraction to the intake for whatever reason (not thermal), or feeding opportunities on the intake screens.
- habitat preferences, leading to non-random distribution patterns of species or life-stages (onshore/offshore, water column benthic or pelagic orientation, habitat structure with or without vegetation and type of substratum)
- the ability to swim influences the susceptibility to impingement. Juveniles and fish <10 cm are prone to impingement. The ability to swim is composed of burst speed and sustained swimming speed (endurance), and both components tend to increase with size. The condition of the fish and water temperature may also influence impingement.

4. Estimates of impingement

Data on the amounts of fish taken in with the cooling water or caught at the entrance of a cooling system have not been widely reported. EPRI (2004) provided an overview, revealing that impingement rates can vary largely on a temporal (annual, monthly, daily, day-night, tidal state) and spatial basis. It is not uncommon that a limited number of species make up for 90% or more of the impinged numbers (Figure 4).

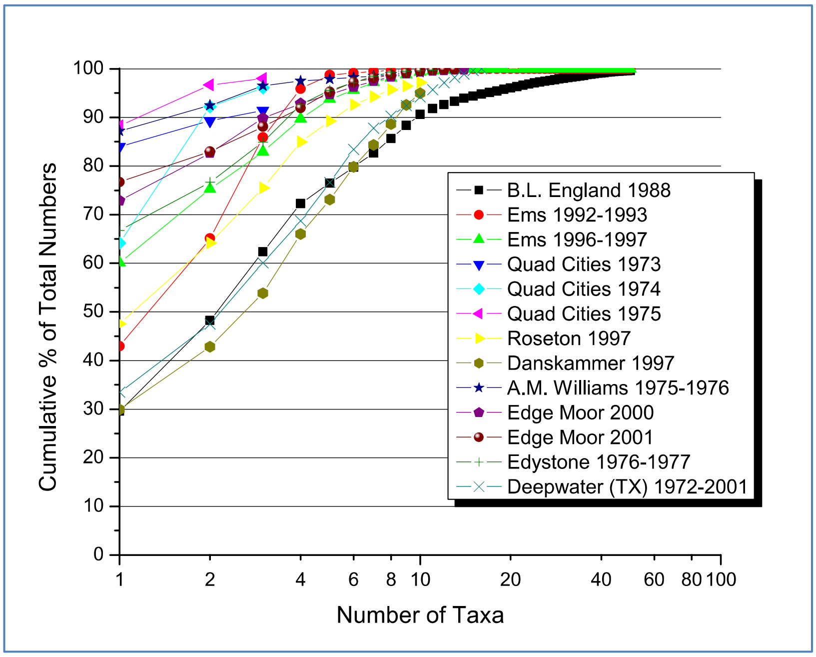
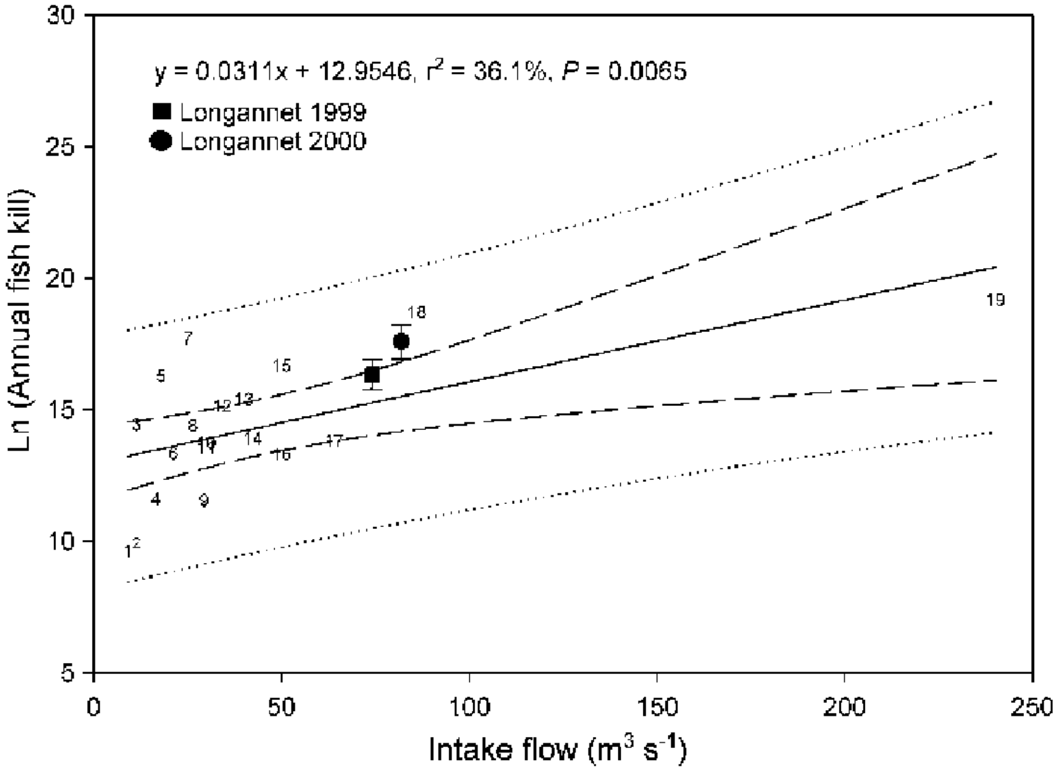


Figure 4. Number of taxa comprising total impingement in monitoring studies at various power stations. EPRI, 2004.

The impingement of fish is dependent on the configurations of the installation, the volume of water taken, the velocity of the water intake, the screening (mesh) and the presence and susceptibility of the fish in the environment. Sampling methods to quantify the impingement consist of collecting the flush water of the sieves and screens under different circumstances of tide, season and year to account for the main sources of variation that contribute to variability in fish impingement (Greenwood, 2008). The sampled numbers and weight are then converted to the numbers and weight per 10^6 m^3 cooling water filtered. Greenwood (2008) calculated these numbers by applying a Generalized Linear Model including quarter of sampling, number of pumps operationg, tidal height, phase (spring/neap), diel period (light/dark), and all the interactions between the latter three variables. In this way, the annual catch rate was estimated.

The estimated number of fish killed at the cooling-water intake is positively related to the intake flow (Kelso and Milburn, 1979, Henderson and Seaby, 2000). This relation is illustrated in Figure 9, in which Greenwood (2008) presents the number of annual fish kill versus intake flow (m^3/s) of 19 NW European power stations. From this, the order of magnitude of fish intake versus intake flow can be derived, but the figure also makes clear that at similar intake flow, different impingement occurs. Annual variations in impingement magnitude can be a factor 4 (Greenwood, 2008).

At an intake flow of 100 m^3/s, the natural log of the annual fish kill would be predicted roughly between 11 - 20 (Figure 5), which are an order of magnitude of 10 million impinged fish per year.



label	station name	source
1	Belfast West (UK)	Henderson and Seaby, 2000
2	Coolkeeragh (UK)	Henderson and Seaby, 2000
3	Kincardine (UK)	Sharman/DAFS, unpublished
4	Kilroot (UK)	Henderson and Seaby, 2000
5	Ems (Netherlands)	Hadderingh and Jager, 2002
6	Dunkerque (France)	Henderson and Seaby, 2000
7	Doel (Belgium)	Maes et al., 2004a
8	Oldbury (UK)	Henderson and Seaby, 2000
9	Ballylumford (UK)	Henderson and Seaby, 2000
10	Hinkley (UK)	Henderson and Seaby, 2000
11	Heysham (UK)	Henderson and Seaby, 2000
12	Sizewell A (UK)	Henderson and Seaby, 2000
13	Hartlepool (UK)	Henderson and Seaby, 2000
14	Dungeness B (UK)	Henderson and Seaby, 2000
15	West Thurrock (UK)	Henderson and Seaby, 2000
16	Fawley (UK)	Henderson and Seaby, 2000
17	Kingsnorth (UK)	Henderson and Seaby, 2000
18	Paluel (France)	Henderson and Seaby, 2000
19	Graveline (France)	Henderson and Seaby, 2000

Figure 5. Comparison of estimated fish killed at the cooling-water intake filter of Longannet Power Station in 1999 and 2000 with predictions from a regression of annual fish kill versus intake flow for 19 NW European power stations. Error bars represent the 95% c.i. for the Longannet estimates, dashed lines represent the 95% c.i. for the regression, and dotted lines represent the 95% prediction interval for the regression. Source: Greenwood, 2008.

The impingement at different Dutch power stations was studied (and summarized by Vriese et al., 2012). The study included the coastal power stations of E.ON Benelux (Maasvlakte) and 'Eemscentrale' (Ems estuary; Engie, formerly Electrabel/GDF Suez). The Eemscentrale (water flow 45 m^3/s) impinged an estimated number of $12.6*10^6$ (or 17.000 kg) fish during autumn (1 September - 31 December 2007), corresponding with 30 fish per 1.000 m^3. During spring (15

March - 31 July 2008) an estimated number of 275*10^6 fish (182.000 kg) were impinged, corresponding with 450 individuals per 1.000 m^3 cooling water intake.

Of these, 73% were 0- group fish (during their first year of life), and all of the impinged fish were <15 cm. The majority of the impingement during spring 2008 were herring (37%), Nilsson's pipefish (23%) and gobies (34%) (Van Giels, 2008). The current velocity of the water intake at Eemscentrale is 0.7 m/s. This relatively high current velocity is related to a comparatively high fish impingement.

5. What organism impingement issues can be expected in a RED power plant and how can these be mitigated

The above case-study shows that, depending on the location and site-specific characteristics of the water intake, large numbers of fish can be impinged with the water intake of a power station. In RED/Blue Energy, the impingment and entrainment of fish and other organisms will be an issue of increasing relevance with increasing volumes of water used, and it is a matter of concern for the full-scale installation with a very substantial water flow of 100 m^3/s. Based on the regression relation (Greenwood, 2008), the impingement (number of fish) was calculated for the three different intake scenario's in consideration for the Blue Energy installation (Table @). These numbers should be interpreted with caution, as they are only a rough indication of the order of magnitude to be expected.

Table @. Estimated fish impingement at three different intake volume scenario's for Blue Energy.

Impingement	Intake <0.1 m^3/s	Intake 10 m^3/s	Intake 100 m^3/s
Number ($x10^6$)	0.42	0.57	9.5

Application of the BAT (Best Available Technology) and mitigation where possible are required to operate such water intake from the Wadden Sea.

The available mitigation options are described in the next sections of the report.

6. Mitigation of impingement

The best way to reduce the impact of impingement is to avoid organisms being taken. Mitigation of impingement is possible by technology and operating measures, aiming at: 1. barriers and diversion systems that reduce involvement of organisms with the intake by excluding organisms from the intake; 2. flow reduction measures that reduce involvement with the water intake; 3. screening technologies or operating measures that improve survival of impinged organisms (EPRI, 2004).

1. Barriers and diversion systems

Barrier and diversion systems include physical measures (barrier nets, cylindrical wedgewire screens, aquatic filter barriers and louvers) as well as behavioural deterrents, such as sound and light systems.

The exclusion efficiency of physical barriers varies as a function of opening size and geometry of the barriers and swim speeds, sizes and body proportions of the organisms susceptible to impingement.

Fish diversion technologies (e.g., angled screens, louvers) bypass fish from the intake flow and return them to the source water body. Since fish are not collected or otherwise handled by these technologies, such systems are inherently less stressful. For diversion to occur, the organisms must have sufficient swimming capability to actively avoid contact with, or passage through, the diversion medium (Allen et al., 2012).

Barrier nets and aquatic filter barriers are still in an experimental stage and face fouling issues in the marine environment (Bruijs, 2007). It is less suitable in situations with high ambient current velocities and is therefore not recommended to apply at the Blue Energy test-site Breezanddijk.

The cylindrical wedgewire screen is a feasible option in new installations, depending on the available space and the water flow needed. The system is applicable at locations with high ambient current velocities (providing a 'sweeping flow') (Bruijs, 2007). The operation and efficacy of wedgewire screens will be discussed in more detail in the following section.

Behavioural devices act species-specific and are dependent on hydraulic and site-specific physiochemical water conditions, and they can work only for impingeable-sized organisms with reasonable swimming capacity.

Among behavioural devices are:

- sound devices, that are positive to divert (a shoal of) scale fish but not for eel;
- light systems with underwater lamps, positive to divert eel; less suitable in turbid waters;
- position, depth and design of the inlet; knowledge of local situation required to decide this;
- limits to speed of the water inflow (although the data from studies carried out in England indicate that the entrained fish allow themselves to be carried by the flow (i.e. deliberately drifting or dispersing) even when they are physically capable of escaping the flow by swimming);
- mesh size of the cooling water sieves (against damage to the cooling system). Observations have shown that, in the same power plant, a mesh size of 5 x 5 mm on average doubles the number of surviving entrained fish at the cooling water outlet compared with a mesh size of 2 x 2 mm, because impingement mortality of fish larvae is higher than entrainment mortality [KEMA, 1972] and [Hadderingh, 1978].

The effectiveness of behavioural deterrence systems has been found to be highly species-specific (EPRI 1999) and may be expected to vary with age. For eggs and fish larvae they will not work. These systems are not further discussed in the report.

2. Flow reduction measures

In principle, a low intake velocity would minimize entrapment, impingement, and likely mortality of organisms on intake screens because the fish could simply swim away from the screens (EPRI, 2000).

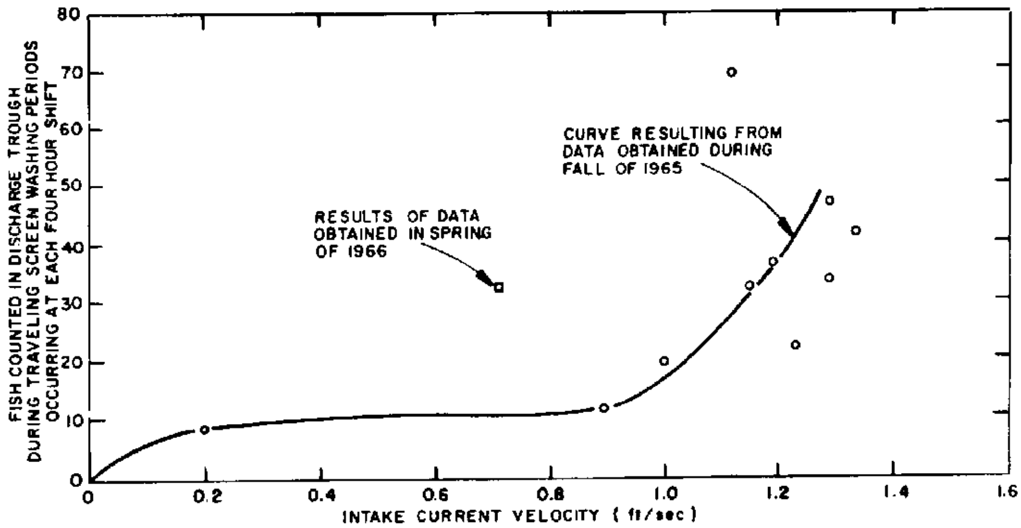


Figure 6. Environmental Impact Statements by the Atomic Energy Commission in the early 1970s used this figure of fish counts on intake screens at the Indian Point Plant on the Hudson River to illustrate increased impingement above about 1 f/s (30 cm/s). From: USAEC (1975), in EPRI (2000).

In the USA, a design intake current velocity criterium of 0.5 f/s (corresponding to 15 cm/s) is generally applied by the Environmental Protection Agency (EPA). The origin of the criterion is unclear, although often is being referred to Figure (8). Above 1 f/s (30 cm/s) the impingement quickly rises. The criterium of 0.5 f/s is therefore a conservative one, which can be used as a safe value. In the EU a (less precautionary) velocity of 30 cm/s (1 f/s) is taken as BAT (IPPC, 2001).

Flow reduction measures involve reducing the water intake flow rates by adapting pump operation or by adapting operation of (switch off) the facility at expected peaks of impingement. A technical measure is the application of a velocity cap in case of vertical offshore intakes. However, it does not protect fish eggs and larvae from impingement or entrainment.

Ad 3. Screening technologies include technologies, such as travelling screens with appropriate fish collection and return, and operation measures, such as continuously operating and washing the traveling screens. Mortality of impinged fish can be decreased by a good system to wash the fish from the sieves and to sluice them back to the surface water. Examples of screening technology are wedgewire screens (next section, 3.4.3) and traveling screens (section 3.4.4).

3. Wedgewire Screens

Wedgewire screens act by exclusion of organisms from the intake flow. They operate on the organism size in relation to slot width or mesh size and are influenced by the hydraulic conditions near and through the technology (Allen et al., 2012).

Wedgewire screens are high capacity passive intake screens, constructed by V-shaped wires that are welded on a frame (Figure 7). The opening between the wires can vary between 25 µm and 25 mm and the screen can be made of stainless steel or specific alloys to reduce fouling.

To be effective, the spacing between the wires needs to be sufficiently small (size 0.5-1 mm) to retain fish eggs and larvae, the flow-through velocity must be small (<0.15 m/s), and the current velocity along the screen must be sufficient to flush debris and settling organisms (Bruijs, 2007). The design of a wedgewire screen is such, that a nearly uniform low velocity flow (<0.15 m/s) is created through the entire screen surface.

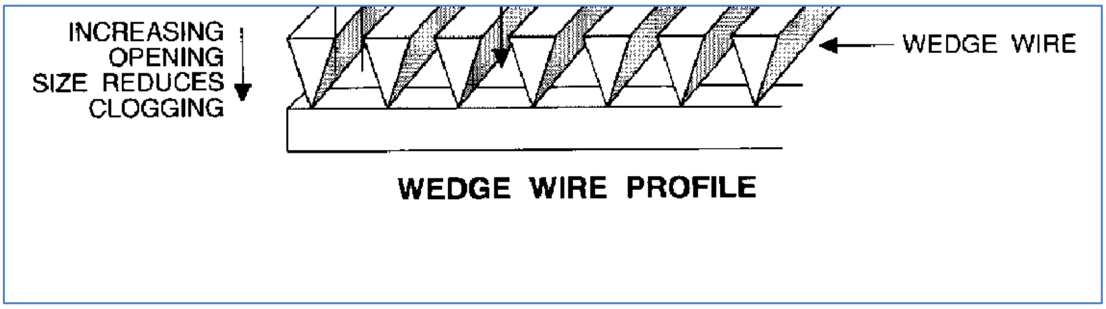


Figure 7. Wedgewire profile with V-shaped wires. Source: Department of Fisheries and Oceans, DFO/5080, 1995, ISBN 0-662-23168-6.

Wedgewire screens can have different forms, a.o. the cylindrical wedgewire screen (Figure 8). Wedgewire screens are placed at the entrance of the water intake and thus provide a first passive screening step.

Organisms that are impinged on a wedgewire screen are flushed off by the environmental currents and are expected to suffer little damage by this procedure.

Cylindrical wedgewire screens act via two distinct mechanisms (Weisberg et al., 1987):

- physical exclusion (predicted on the size of the organism > slot width) and
- hydrodynamic exclusion (facilitated by the rapid diffusion of the flow field immediately surrounding the wedgewire screen). Hydrodynamic exclusion is enhanced when ambient water velocity perpendicular to the sceen is larger than the velocity through the screen

Both exclusion mechanisms are related to fish size. Thus, larger larvae are not only more likely to be physically excluded (with head width of the larvae being important in determining physical exclusion), but they also will have greater swimming abilities to facilitate behavioural avoidance of an intake (EPRI 2003). Given these two mechanisms, the importance of an organism's life stage, morphology, overall size, and swimming abilities, which are all interrelated, become apparent.

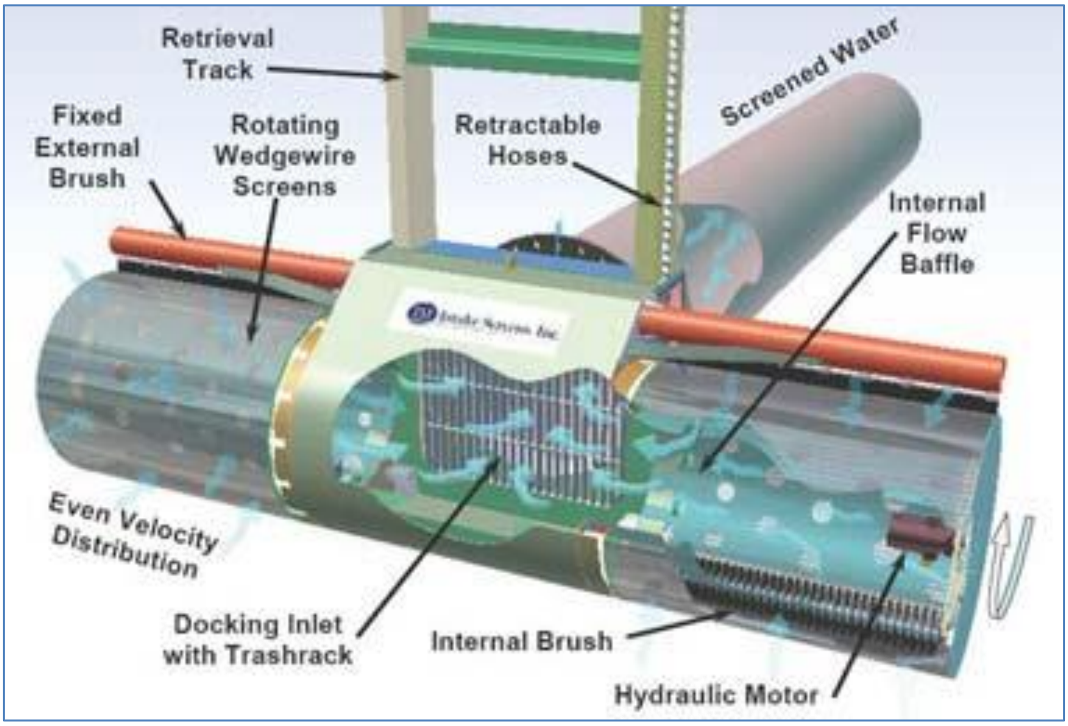


Figure 8. Cylindrical wedgewire screen. Source: http://intakescreensinc.com/brushed-cylinder/.

An example of the probability of screen entrainment of flatfish larvae based on head capsule allometric regressions on notochord lengths (to 25 mm) is given in Figure 9 for different screen slot dimensions and three type of fish species (based on Tenera Environmental, 2013).

Figure 9 illustrates that there are species specific differences: at a slot width of 1 mm, sea bass larvae are nearly all retained at a length of >6 mm, but flatfish larvae (>11 mm) and goby larvae (>10 mm) are retained at larger sizes.

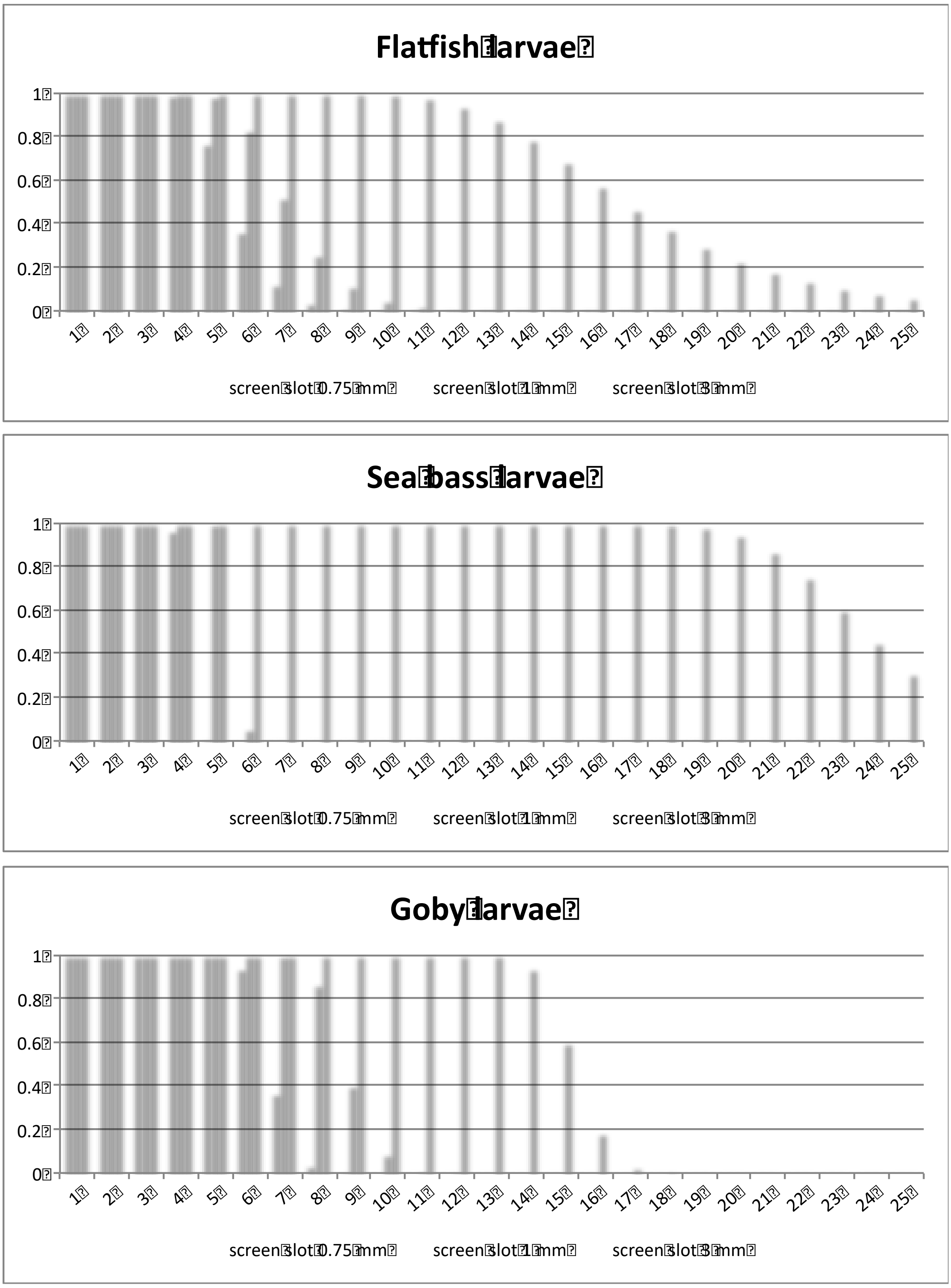


Figure 9. Probability of entrained larvae versus length, of flatfish (top), sea bass (middle) and goby (bottom) larvae at wedgewire screen slot width of 0.75, 1 or 3 mm. Tenera Environmental, 2013.

Wedgewire screens have been successfully employed in a 21 m^3/s once-through cooling (OTC) system (Great Lakes Research Division, 2982) and application to larger systems appears to be viable, according to Weisberg et al. (1987).

Following previous laboratory evaluations, field tests with wedgewire screens were performed in two water body types: the Portage River/Lake Erie, Ohio (freshwater) and Narragansett Bay, Rhode Island (estuarine) (reported by EPRI, 2005) and in a third water body, Chesapeake Bay (EPRI, 2006). In all three water bodies, screen slot widths were 0.5 or 1 mm and through-slot velocity 0.15 or 0.30 m/s. Ambient velocity was variable (0-1.1 m/s), depending on the tidal cycle and its magnitude. Slot velocities tested (0.15 or 0.3 m/s) did not have a significant effect on entrainment rates, but entrainment densities were lower with a smaller slot width. Larval entrainment densities increased (in both control and test samples) as ambient velocity increased, whereas egg entrainment densities were unaffected by ambient velocity. Impingement also increased with slot and ambient velocity, but decreased with slot size (EPRI, 2005).

The overall effectiveness of wedgewire screens varied, depending on biological (species, morphology, size) and engineering (slot width) parameters. For both slot widths, entrainment density decreased with larval length (EPRI, 2005). However, EPRI (2006) found that, despite variable effectivity for different species, the screens were generally more effective in reducing entrainment of eggs and larvae when the slot velocity was 0.15 m/s (by up to 30 percent) than when the slot velocity was 0.30 m/s. Entrainment decreased as ambient velocity (approaching the screen) increased. With the 0.5 mm screen, a significant species-specific reduction in entrainment was achieved. The 1.0 mm screen was less effective and gave reductions only for some species.

Entrainment reduction increased, therefore entrainment decreases, with increasing larval length. The entrainment of eggs was significantly reduced by the 0.5 mm screen, but not by the 1.0 mm screen. On the 1 mm screen, fish larvae >10 mm (head width >1 mm) were virtually absent (EPRI, 2005). Fish larger than 8-12 mm are generally not entrained through a 1 mm-screen (references to Dames and Moore 1979; Browne et al., 1981, Otto et al., 1981 in Weisberg et al., 1987).

According to EPRI (2005, 2006), testing with the 0.5 mm wedgewire screen demonstrated a significant reduction in entrainment of 72 % (at slot velocity 0.15 m/s) or 58% (at slot velocity 0.3 m/s) for all species and sizes of larvae combined. The reductions are species-specific and may be lower or higher than the overall reduction. The entrainment of eggs was significantly reduced by the 0.5 mm screen (≧92%), but not the 1.0 mm screen.

The evaluation of impingement rates was precluded by the difficulty of quantifying impingement in a field setting. However, it is unlikely that juvenile or adult fish will become impinged on wedgewire screens at such low slot velocities (EPRI, 2005).

Weisberg et al. (1987) had difficulty in discerning (statistically significant) differences in entrainment through screens of different slot sizes (1 vs. 2 mm). Apparently, a slot width of 3 mm is much less effective than slot width of 0.75 or 1 mm, therefore rectangular mesh or wedgewire screen slot openings larger than about 3 mm will result in very little entrainment reduction (EPRI, 2005).

Performance of screens will vary by location and also between years due to differences in the composition of entrained larvae and changes to their abundances and proportions over time. Fouling problems of wedgewire screens might be solved by toxic coatings or by back-flushing the screens with air (Weisberg et al. 1987). The application of toxic coatings may be restricted by regulations, therefore further investigation into the options for fouling prevention of wedgewire screens is needed.

Concluding, it seems that a wedgewire screen of 0.5 mm slot width and with slot velocity 0.15 m/s is more effective than wider slots and/or higher slot velocities. The entrainment reductions (both 0.5 and 1 mm slot width) increased with larval length (EPRI, 2006). Larvae less than 5 mm in length were not effectively excluded by any of the slot widths (Weisberg et al., 1987). Therefore, (eggs and) larvae <5 mm will not be kept out by applying wedgewire screens, regardless of the slot width. Proper maintenance and cleaning is important for keeping the effectiveness of the wedgewire screen. However, as pointed out above, for larger organisms significant reductions in entrainment can be achieved. Impingement seems not to be a major issue on wedgewire screens, as long as through-slot velocities are low and the organisms are swept off the screens by natural currents.

4. Traveling Screens

The efficacy of traveling screens depends on the ability to prevent organism passage and the survival upon handling. Handling causes stress to the organisms and may result in injuries, scale loss or mortality. The survival of impinged versus entrained eggs, larvae and early juveniles becomes important when finer mesh screens replace coarse grids. The fine-meshed screen is usually designed as a drum screen or a rotating bandscreen, which may be of large dimensions. Some examples of industrial suppliers are given below (Table 1):

Table 1. Examples of band- or drum-screens of large capacity.

Screen type	Passavant	Beaudrey	Hubert *travelling band screen*	7. Hubert *rotating drum screen*
Mesh size	0.1-1 mm	1-12 mm	1-10 mm	2-10 mm
Width	2.5-7 m	max. 7m	max. 4 m	max. 5 m
Depth	<20 m	?	<16 m	<20 m
Capacity (m^3/h)	100,000	70,000	60,000	120,000

Of these three examples, the Passavant screens seem to have the largest capacity in combination with the smallest mesh size. With a water demand of 100 m^3/s, circa 4 such units would be required. If applying a Hubert screen, the water demand of 100 m^3/s could be realised by applying 6 units of a travelling bandscreen, or 3 units of a rotating drum screen (mesh 2x2 mm at the smallest).

The fine-meshed screen is cleaned with spray-water and the fish are collected to be diverted back to the environment without further interference. Attention should be paid to provide shelter to the returned fish, which otherwise will risk being predated by large fish, seals or birds.

A study at the Plant Barry (Mobile River, Alabama) determined that a 24.5% reduction in fish impingement is possible with continuous traveling screen operation, however at the expense of a 100% increase of impingement of shellfish. Fish survival and fish health were evaluated and showed that in this case, most of the impinged (cat)fish were of compromised health prior to the impingement and they would not survive if returned to the river. Apparently, the compromised health makes the fish more susceptible to impingement (EPRI, 2010).

5 Entrainment

1. What is entrainment?

Organism entrainment is the process of ingress of organisms into water intakes after screening and/or filtration. These organisms travel further through the installation and can be retained actively or passively further on, or discharged.

2. Impact of entrainment of organisms in installations

Which- and how many - organisms are entrained depends firstly on the quantity and composition of organisms in the intake water and secondly on the level of screening and/or filtration, as discussed in the previous chapter. Most research on entrainment in conventional industrial installations has been focused on industrial cooling. Entrainment stress in industrial cooling can be mechanical, chemical, thermal or pressure related and is often a combination and interaction of these factors (e.g. Bamber and Seaby, 2004; Capuzzo, 1980; Choi et al., 2012; Hoffmeyer et al., 2005). A comprehensive review of entrainment issues in power plants is presented in (Mayhew et al., 2000). The review shows that in industrial cooling systems high entrainment survival of more than 90 % is attainable for many species.

Table 2 entrainment survival estimates in US power plants summarised in Mayhew et al. 2000.

Table 1
Entrainment survival of finfish and macroinvertebrates at selected power plants[a]

Power plant	Water body	Species	Year	Survival proportion	Reference
Pittsburg	San Joaquin Delta	Striped bass larvae	1978–1979	0.61	EA (1981b)
Roseton	Hudson River	Striped bass larvae	1975–1976	0.68	Cannon et al. (1978)
Bowline Point	Hudson River	Striped bass larvae	1975–1976	0.79	Cannon et al. (1978)
Indian Point	Hudson River	Striped bass larvae	1977–1980	0.59–0.74	Muessig et al. (1988)
Indian Point	Hudson River	White perch larvae	1978–1980	0.64–0.97	EA (1982)
Bowline Point	Hudson River	White perch larvae	1975–1976	0.97	Cannon et al. (1978)
Calvert Cliffs	Chesapeake Bay	Bay anchovy larvae	1979	0.05	EA (1981a)
Calvert Cliffs	Chesapeake Bay	Bay anchovy larvae	1980	0.03	EA (1981a)
Calvert Cliffs	Chesapeake Bay	Naked goby larvae	1979	0.88	EA (1981a)
Calvert Cliffs	Chesapeake Bay	Naked goby larvae	1980	0.98	EA (1981a)
Calvert Cliffs	Chesapeake Bay	Blenny larvae	1979	0.37	EA (1981a)
Calvert Cliffs	Chesapeake Bay	Blenny larvae	1980	0.79	EA (1981a)
Pittsburg	San Joaquin Delta	*Neomysis mercedis*	1978–1979	0.90	EA (1981b)
Pittsburg	San Joaquin Delta	Gammarid amphipods	1978–1979	0.96	EA (1981b)
Roseton	Hudson River	*Chaoborus punctipennis*	1975–1976	1.00	Cannon et al. (1978)
Danskammer Point	Hundson River	*Chaoborus punctipennis*	1975	0.71	Cannon et al. (1978)
Lovett	Hundson River	*Chaoborus punctipennis*	1976	1.00	Cannon et al. (1978)
Bowline Point	Hudson River	*Chaoborus punctipennis*	1975–1976	1.00	Cannon et al. (1978)
Roseton	Hudson Diver	*Gammarus daiberi*	1975–1976	0.76	Cannon et al. (1978)
Danskammer Point	Hudson River	*Gammarus daiberi*	1975	0.85	Cannon et al. (1978)
Lovett	Hudson River	*Gammarus daiberi*	1976	0.93	Cannon et al. (1978)
Bowline Point	Hudson River	*Gammarus daiberi*	1975–1976	0.86	Cannon et al. (1978)
Lovett	Hudson River	*Monoculodes edwardsi*	1976	0.16	Cannon et al. (1978)
Bowline Point	Hudson River	*Monoculodes edwardsi*	1975–1976	0.35	Cannon et al. (1978)
Bowline Point	Hudson River	*Neomysis americana*	1975–1976	0.50	Cannon et al. (1978)
Calvert Cliffs	Chesapeake Bay	*Neomysis americana*	1979–1980	0.85	EA (1981a)
Calvert Cliffs	Chesapeake Bay	*Corophium* sp.	1979–1980	0.73	EA (1981a)
Calvert Cliffs	Chesapeake Bay	*Neanthes succinea*	1979–1980	0.87	EA (1981a)
Calvert Cliffs	Chesapeake Bay	*Melita nitida*	1979–1980	0.75	EA (1981a)

[a] Pittsburg plant data for units 5 and 6 only at discharge temperatures < 30°C. Entrainment survival reported higher than 1.00 due to greater proportion of dead in intake samples were set to 1.00 in this table. Hudson River data (except Indian Pt.) are latent survival and do not incorporate the initial mortality component; all other data are total entrainment survival (initial + latent).

Table 3 Zooplankton entrainment review indicating principal stressors by Capuzzo et al. 1980.

Table 3. Summary of zooplankton entrainment studies at coastal power plants

Location	Power plant Generating capacity (Mw)	Water demand ($m^3 h^{-1}$)	Principal stress	Reference
Millstone Point Long Island Sound (USA)	650	95,000	mechanical	Carpenter et al. (1974a, b)
Chalk Point Patuxent River, MD (USA)	730	114,000	chlorine, slight thermal	Heinle (1976)
Vienna Nanticoke River, MD (USA)	240	12,600	no significant stress	Heinle (1976)
Morgantown Potomac River, MD (USA)	1140	222,000	chlorine, slight thermal	Heinle (1976)
Brayton Point Narragansett Bay (USA)	650	154,000	chlorine, thermal	Gentile et al. (1976)
Marshall Station Lake Norman, NC (USA)	2136	230,400	thermal	Davies & Jensen (1975)
Chesterfield James River, VA (USA)	1416	158,400	thermal, chlorine (>0.50 mgl^{-1})	Davies & Jensen (1975)
Indian River Indian River, DL (USA)	347	61,200	mechanical (?) chlorine (>1.00 mgl^{-1})	Davies & Jensen (1975)
Guayanilla Bay (Puerto Rico)	1073	138,000–234,000	—	Youngbluth (1976)
Martigues-Ponteau Mediterranean Sea (France)	—	—	thermal	Gaudy (1977)
Montaup Narragansett Bay (USA)	500	12,250	thermal, chlorine	this study
Cape Cod Canal Cape Cod Bay (USA)	1100	78,000	thermal, chlorine	this study

1. Mechanical stress

Mechanical stress includes factors such as abrasion and collision. Mechanical damage in a RED power plant can occur by shear, turbulence and contact with internal workings of the RED installation such as filters, pipes, stacks and pumps.

To achieve the highest possible efficiency, fluid resistance in the inner workings of a RED power plant should be minimised (Veerman 2010). Because of this, most of the pipes leading to- and away from- the stacks are overdimensioned. This overdimensioning will also serve to reduce shear stress.

Organisms that are not filtered out in the filtration step will pass through the stacks and could be subjected to considerable shear stress as stacks consist of membranes arranged in parallel, with inter-membrane distances of 100 – 500 micrometer. Membranes can be separated by spacers, or profiled membranes can be used (Veerman 2010, Vermaas et al. 2013). The magnitude of shear stress in the stack will be dependent on current velocity, intermembrane distance and boundary conditions at the membrane surface. Shear may be lower near hydrophilic membranes than near hydrophobic membranes as in the former the transition layer between the water and the membrane is thicker which means that local water velocity differences are smaller.

2. Pressure stress

Sudden pressure changes can be damaging to marine organisms. In the experiments performed at the WETSUS demo site in Harlingen, the pressure drop was max 1.5 bar (Vermaas et al. 2013). In the Afsluitdijk installation the pressure drop is < 1 bar (S. Grasman pers. comm.).

3. Chemical stress

Cooling water installations can employ biocidal chemicals to control fouling by organisms. The most commonly used chemical is sodium hypochlorite. Together with thermal stress this is often the main mortality causing factor (Capuzzo et al. 1980, Mayhew et al. 2000, Bamber and Seaby 2004).

4. Thermal stress

In conventional power plant cooling systems in temperate waters the cooling water temperature increase (ΔT) is in the order of 10 °C (Bamber and Seaby 2004). The effect of thermal stress in entrainment has been studied extensively and is, together with chemical stress, often the main factor causing mortality (Mayhew et al. 2000).

The available energy from the mixing of freshwater and seawater is 1.4 MJ per 2 m^3. The specific heat capacity *c* of water is 4.2 kJ kg^{-1} K^{-1}. 2 m^3 of water weighs 2000 kg so the heat capacity *C* of 2 m^3 of water is 8.4 MJ^{-1} K^{-1}. Without RED mixing of the water would result in an increase in water temperature of 1.4/8.4 = 0.17 K = 0.17 °C. With RED this increase in temperature would be less as part of the energy available from mining the water is converted into electricity.

Additional heating or cooling can occur when the air temperature is different from the water temperature or e.g. when transport structures such as tanks and pipes are heated by sunlight. At the relatively high flow rates necessary for RED power generation this might not an issue. In the Breezanddijk installation water temperature is only measured within the plant before the stacks. Measuring of heating or cooling in the pipes would require additional simultaneous temperature measurements at the intakes.

Lastly, when the two different water sources used in RED differ in temperature, sudden changes in temperature can occur when these two sources meet, at the same moments as described for salinity. This Δ T can be estimated by measuring the water temperatures of both incoming water flows, as is currently being done at the Breezanddijk installation.

5. Crowding

Concentration of organisms through filtration or other means can cause additional mortality as organisms can damage each other or predate on each other. Also oxygen content can become limiting when organism densities are elevated, especially at higher temperatures.

6. Osmotic stress

Osmotic stress happens when organisms experience sudden changes in ambient salinity of the water. Sudden salinity changes rarely happen to planktonic organisms as they drift along with currents and are not sessile (Muylaert et al., 2009). Tolerance for lower salinity levels is an important factor influencing the distribution of estuarine animals (Attrill, 2002; Kinne, 1970; Nielsen and Andersen, 2002). Salinity tolerance of plankton has received little attention (Calliari et al., 2008; Miller, 1983; Soetaert and Herman, 1994). Tolerance for sudden changes in salinity differs among taxa and between species within taxa. As an example, *Acartia clausi* mortality after a sudden halving of salinity from 32 to 14 was 31% while for the estuarine *Acartia tonsa* mortality after similar treatment was only 3% (Calliari et al., 2008). Larvae of the snail *lyanassa obsoleta* and the polychaete *Arenicola cristata* tolerated salinity reductions from 25 to 10 (Richmond and Woodin, 1996).

Studies in Norwegian fiords investigating the impact of freshwater discharge from hydropower plants on the fiord ecosystem found several impacts of freshwater discharge (Kaartvedt and Aksnes, 1992; Kaartvedt and Nordby, 1992). Zooplankton caught in the freshwater outflow died because of osmotic stress and large quantities of dead zooplankton were observed in the fiord.

Cooling systems of conventional power plants often draw and discharge water from the same source, making osmotic stress a non-issue in these types of installations. Consequently, we could not find cooling water entrainment studies where osmotic stress is considered. The limited number of studies presented above suggest that at least some estuarine planktonic organisms can survive a sudden reduction of salinity by 50% or more.

In contrast to conventional installations, salinity changes do occur in RED power generation; the RED technique is basically extracting energy from controlled mixing of two different water sources with differing salinity. Sudden changes in salinity can occur in the RED process water at several moments:

1. When backwashed filter residue from both fresh- and marine sources is combined prior to discharge
2. When backwashed filter residue from fresh- or marine sources is discharged directly to open water bodies with different salinity
3. Within the RED stacks as the water flows past the RED membranes
4. Within the bypass that is used to maintain flow rates when no- or little stacks are operational
5. When the used process water is discharged into an environment with different salinity.

To mitigate salinity-related mortality, several options can be considered. For backwashed filter residue, separating discharge of backwashed fresh and marine filter residue can prevent salinity changes entirely.

7. Predation

Filterfeeders attached to installation walls can cause plankton mortality of up to 50%, increasing with increased residence time (Karas, 1992). Mitigation of this predation can be achieved by either shortening the length of passage through the system by shortening pipes, regular cleaning of pipes or anti-fouling treatments. Enhanced predation can also occur when zooplankton densities are increased by filtration.

3. Measuring entrainment survival

Mayhem et al. (2000) stress the importance of proper sampling procedures when estimating entrainment survival. Early estimates using plankton nets for sampling often resulted in estimates of 100% mortality. They use a device called a "larval table" to minimise mortality due to sample collection. To summarise, measurements required to produce correct entrainment survival estimates are:

- Use a sampling technique that minimises sampling mortality,
- Simultaneous sampling at intake and outflow,
- Include measurements of extended survival over several days.

6 Fouling and clogging

This chapter discusses fouling by macrofauna. Fouling of RED membranes by microorganisms (biofilms) is investigated separately.

1. Categories of fouling organisms

Plankton can be divided into two different groups: holoplankton and meroplankton. Holoplankton are organisms that live in the water column their whole life, while meroplankton only live in the water column for part of their life.

Entrained holoplankton, which includes most phytoplankton and zooplankton such as copepods, cladocera (water fleas) and ctenophores will not settle on installation surfaces and, if not impinged, passes through the installation and is discharged. Holoplankton can however influence fouling by serving as food for fouling organisms.

Entrained meroplankton can cause fouling and clogging in the installation if the organisms manage to attach themselves to installation surfaces (e.g. barnacles, hydroids, mussels) or settle in sediment layers present in the installation (e.g. burrowing polychaetes and shellfish). For this to occur several criteria have to be met:

- Settlement surface is suitable for settlement: Fouling organisms can have different preferences for different artificial substrates
- The organism is -or can enter- the appropriate stage for settlement during entrainment: Organisms such as bivalves or barnacle larvae go through several stages over a period of days to months. Often only the final stage is able to settle on substrates.
- Other environmental conditions are suitable for settlement

Once an organism is settled, its growth and development will depend on factors such as current speed, food availability, predation, temperature and oxygen content.

2. Mitigation of fouling

Fouling by photosynthetic organisms (algae, most cyanobacteria) can be limited by keeping components in the dark as much as possible. Use of transparent materials should be limited as much as possible and additional shading of intake and discharge systems can limit fouling.

Fouling by filterfeeders can be limited by:

- Removal of larvae before settlement by filtration
- Removal of feed (plankton) in pretreatment,
- Applying anti-fouling coatings,
- Ultrasonic vibrations,
- Limit available surface area and “dead space” in installations,
- Mechanical cleaning,
- Chemical treatments,
- Salinity switching,
- Limit sedimentation within the installation, as organisms such as shellfish and worms can settle in sediments.

In the REDstack pilot plant current velocities within the stacks are between 0,1 and 2 cm/s, with membrane distances between 100 and 500 micron. Depending on the configuration the membranes are spaced using i) woven spacers, ii) extruded spacers or iii) profiles on the membranes themselves. Combinations of these options also occur and dynamic stack concepts with variable membrane spacing are also tested. Until now the fouling management of the stacks consists of the following methods:

- Flow switch: Periodically switching of fresh- and seawater supply of the stack with frequencies ranging from hourly to dayly.

- Back flush & forward flush: Flushing of stacks in both directions using higher than normal flow rates and using 1 micron filtered Lake IJssel water with 6g/L added salt.
- Air flush: incidental or periodical purging of RED stacks with pressurised air.
- Acid cleaning: In case of inorganic pollution (scaling) flushing of stacks with a pH 2 citric acid or hydrochloric acid solution.

The aim of the flow switch is to prevent organic fouling, but because the fresh water is relatively cleaner than the seawater silt is also flushed during the switch. Flow switch also reverses the polarity of the stack, causing less fouling of the electrodes.

Back flush & forward flush is used to flush out accumulated silt and other materials. On average this is being done biweekly. When back and forward flushing is not sufficient, air flush is applied. The air flush is also used as preventive measure with a frequency of once every two hours. Acid cleaning is only done when performance of the stacks necessitates its use. The frequency of acid cleaning is about once every month.

Flow switch as anti-fouling treatment

Effectiveness of switching salinity will depend on fouling organism types. Bivalves such as mussels can close their shell as a means to survive sudden salinity changes but many marine fouling organisms do not survive prolonged exposure to fresh water and this trait has been used as a treatment to kill possible invasive species in mussel transports (Gittenberger and Stegenga 2012).

Settlement limitations

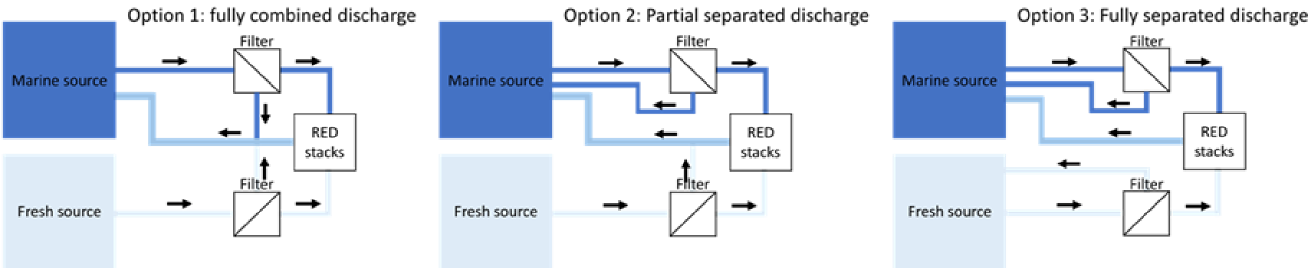
Barnacle settlement is inhibited at higher current speeds. De Wolf (1973) found redispersion into the water column occurred at current velocities of 35 to 67 cm/sec. Blue mussel settlement success increases at higher current velocities (Pulfrich 1996).

7 Impact of discharge

In the RED power plant there are several water flows that need to be discharged to the surface water:

1. The flushed filter residue from the marine side,
2. The flushed filter residue from the fresh side,
3. The brackish water that has either passed through the stacks or through a bypass.

These flows can be discharged either combined, or separate, in three different options, as shown below.



In option 1 the three flows are discharged together. In this option marine and freshwater organisms experience an osmotic shock if they pass through the stacks, but also if they are filtered out (impinged) in the filtration step.

In option 2 the marine filter residue flow is discharged separately to its source, and the organisms within do not experience an osmotic shock, which could contribute to increased survival. The organisms from the freshwater source still experience an osmotic shock. This option might be the one most similar to a situation where a fresh water source flows into the sea.

In option 3 both the marine and fresh filter residue flows are discharged separately to their respective sources, so the organisms within do not experience an osmotic shock. This could increase survival of organisms from the freshwater source. If however the RED power plant partly or wholly replaces an existing freshwater flow into the sea, this option will cause changes in the flow of carbon and sediment into the sea because organisms, but also particulate organic matter and sediment, are returned back to the freshwater source rather than discharged into the sea.

Survival in options 2 and 3 might be further increased by moving the filtration step as close as possible to the water source, thereby minimising the residence time of the organisms in the installation.

8 Site-specific situation Breezanddijk

1. The installation

The current Blue Energy pilot installation at Breezanddijk takes its feed water from two sources: fresh water (F) from Lake IJssel, salt water (S) from the Wadden Sea harbour of Breezanddijk. The pilot installation and the process steps are schematised in Figure 3. The items with red frame are the ones that may have an impact on organisms. Green frames indicate possible mitigation options to reduce the impact of those. Site-specific circumstances are relevant, and are to be taken into consideration as a given fact.

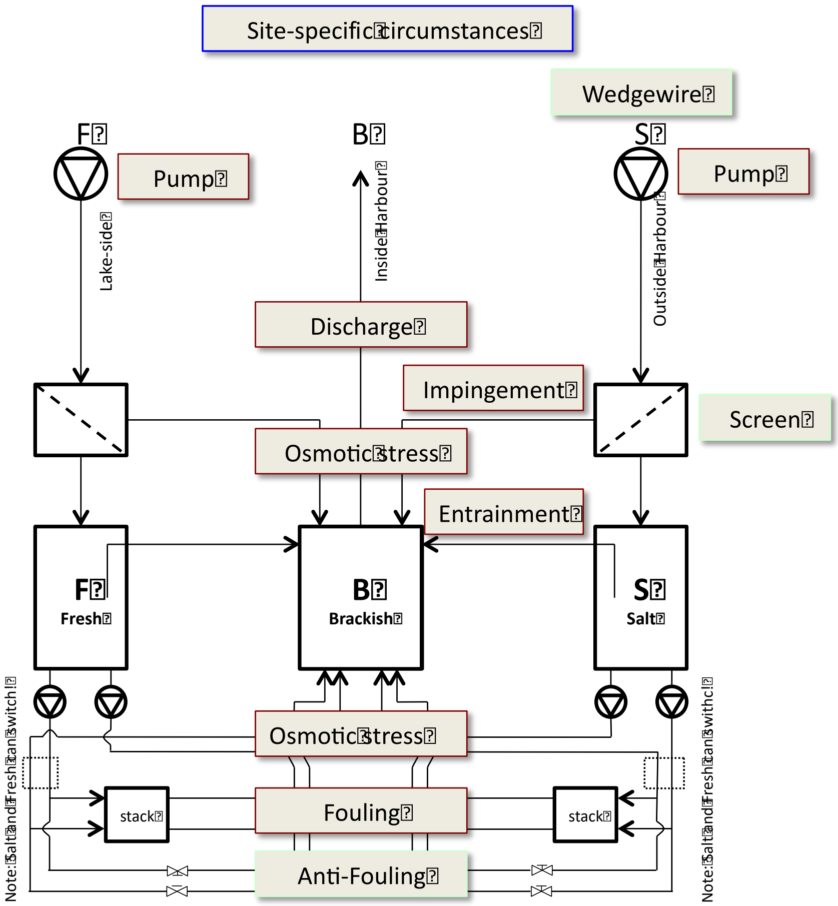


Figure 3. Schematic representation of the Blue Energy pilot-plant at Breezanddijk (NL). Main steps (black frames) and the effects of water intake (red framess): pumping with consequent impingement and entrainment, fouling, osmotic stress and discharge to the environment. Mitigation options (green frame): screens (wedgewire, bandscreen), anti-fouling.

1. Pump

In the pilot-plant water intake at Breezanddijk, currently a Melotte submersible pump is used, which is comparable to a centrifugal pump. The capacity is 200 m^3/h and the intake velocity is less than 0.1 m/s. The pump is protected by a tube with holes of 3-3.5 mm, that keep the larger organisms and debris out of the water intake system. The salt water is transported by tubes over several hundreds of meters to the installation prior to filtration.

2. Screen

In the pilot installation, fine meshed Hubert drum screens are used. At present the mesh size is around 50 µm, with 20 µm also tested. Tests with different screen types and screen materials are ongoing. In theory, organisms larger than the mesh size will be retained and flushed off the screens, being the impingement. Smaller organisms will pass through the mesh openings and are the entrained fraction. The drum screen is operated intermittently on the difference in water level before and after the screen.

3. Stacks

In the stacks, both water sources of different salinities are brought together. Organisms may experience osmotic stress. In the current configuration, osmotic stress may also occur at the point where the water flushed off the screens is recollected in (brackish) water tanks, to be returned to the Wadden Sea harbour.

4. Discharge

After passing the stacks, both water sources have become mixed with an intermediate salinity; this brackish water is collected and is discharged to the Wadden Sea harbour of Breezanddijk.

5. Site-specific circumstances

The description of the site-specific situation includes:

- Taxonomic identifications of all life stages of fish, shellfish, and protected species in the vicinity of the CWIS and susceptible to impingement and entrainment;
- A characterization of these species and life stages in terms of their abundance and their spatial and temporal distribution, sufficient to characterize the annual, seasonal and diel variations in impingement mortality and entrainment; and
- Documentation of current impingement mortality and entrainment of these species and life stages.

A first inventory was made, based on literature and existing monitoring, and is presented in the next sections. The project monitoring will provide supplementary information on the site-specific situation in a later stage.

2. The location

The Blue Energy pilot plant at Breezanddijk is located on the Frisian part of the Afsluitdijk barrier. The Wadden Sea part from which the pilot plant draws its seawater is part of the Marsdiep Tidal basin, which recieves seawater from the North Sea through the Marsdiep tidal inlet between Texel and Den Helder, but also through the Eierlandse gat inlet between Texel and Vlieland and the Terschelling watershed (Duran-Matute et al. 2014). Fresh water flows into the Marsdiep basin at Kornwerderzand to the northeast of Breezanddijk and Den Oever to the southwest of Breezanddijk. At Breezanddijk itself there is currently no other discharge of fresh water into the Wadden Sea.

Ridderinkhof et al. (1990) estimated that it takes on average 20 tidal periods for fresh water at Den Oever to be flushed to the North Sea, and 24 tidal periods for fresh water discharged at Kornwerderzand. More recent estimates of Duran-Matute et al. (2014) are much higher: 27.5 days for Den Oever and 38.6 days for Kornwerderzand. Breezanddijk lies in between these locations. So flushing times should lie between the estimates for the two locations. Flushing times can be very variable, and are highly influenced by wind forcing (Duran-Matute et al. 2014). The fresh water discharged near the Afsluitdijk does not all leave the Wadden Sea through the Marsdiep inlet but can be found throughout the western Wadden Sea (Fig. 10).

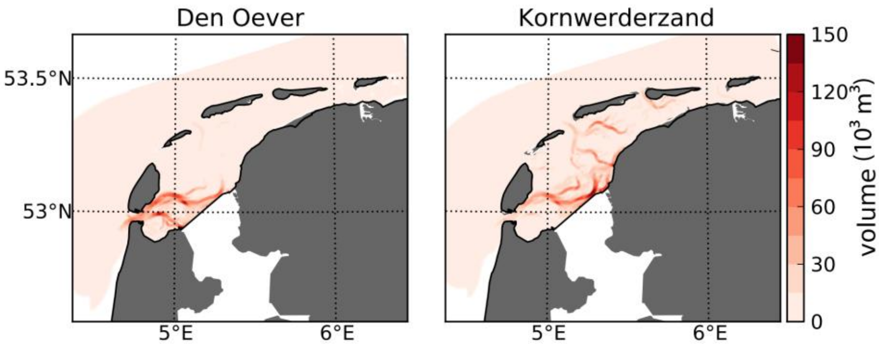


Figure 10 Average volume (103 m3) per horizontal model grid cell of the fresh water discharged at Den Oever and Kornwerderzand for the month of April 2009 from Duran-Matute et al. 2014.

3. Phytoplankton

Seasonal dynamics of the phytoplankton in the Wadden Sea are dominated by a spring bloom which lasts generally from April to June and is characterised by an early bloom dominated by diatoms, following by a *Phaeocystis* bloom. The timing of the spring bloom has remained largely unchanged (Cadée and Hegeman 2002; Philippart et al. 2010). In autumn a smaller phytoplankton bloom can occur, but this has decreased in magnitude in recent years (Philippart et al. 2010).

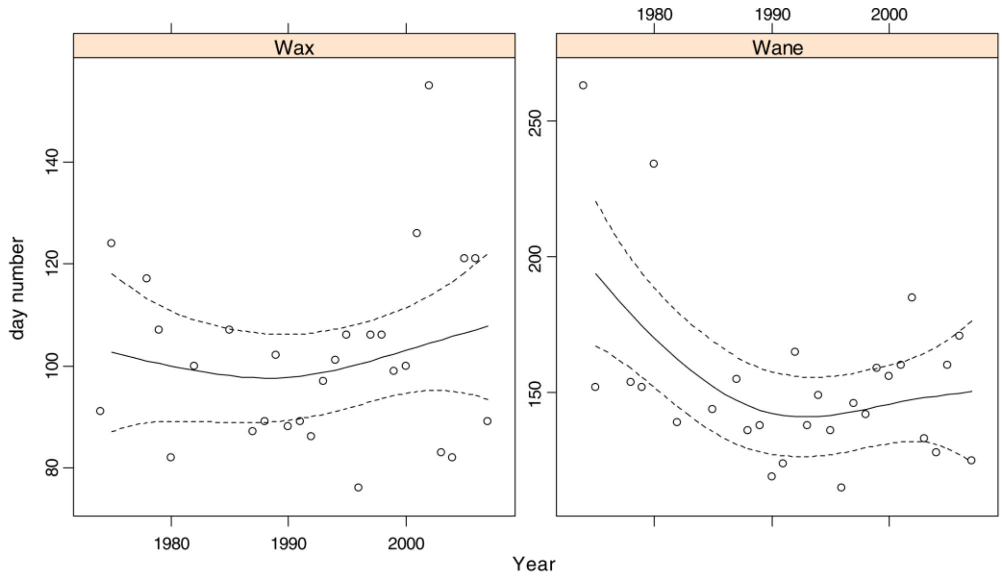


Figure 11 Timing of wax and wane of the spring phytoplankton bloom in the Wadden Sea (Philippart et al. 2010).

4. Zooplankton

1. Holoplankton

Little is known about composition and seasonal patterns of zooplankton in the western Wadden Sea. The zooplankton spring bloom appears to last mainly from March – June for most taxa (Fransz et al., 1992, 1991; Fransz and Arkel, 1983). Species composition is dominated by the copepods *Temora longicornis*, *Centropages hamatus*, *Acartia clausi* and *Pseudocalanus elongatus*. *Pseudocalanus* arrived first, followed by *Acartia* and *Centropages* and *Temora* (Fransz and van Arkel, 1983; Figure 12).

All of this data is 3-4 decades old, and many changes have happened since: The annual mean sea surface temperature in the western Wadden Sea has increased by an average of 1.5 °C in the last 25 years (Van Aken, 2008). A similar increase is oberved in the North Sea and the rest of the Wadden Sea area (Van Aken, 2010). From 1935 until 1988 riverine N and P influx increased gradually, after which nutrient levels decreased again, remaining at levels still higher than pre−1935 (van Raaphorst and de Jonge, 2004). In the 1970s primary production doubled quickly, but when eutrophication decreased primary production decreased more slowly (Cadée and Hegeman 1993). Abundance and egg production of the copepod Temora longicornis increased 4-8 times during the period of high eutrophication (Fransz et al. 1991), but whether zooplankton abundance decreased again after the eutrophication decreased is unknown.

Currently, zooplankton abundance, seasonal patterns and species composition is rarely included in the standard monitoring performed to comply with the Marine Strategy Framework Directive 2008/56/EC ("Monitoring Waterstaatkundige Toestand des Lands Milieumeetnet Rijkswateren" (MWTL, Anonymous 2014a) and Water Framework Directive 2000/60/EG. Only in inshore waters bucket samples or 1.5 m long tube samples are taken of surface water only (Anonymous 2014b).

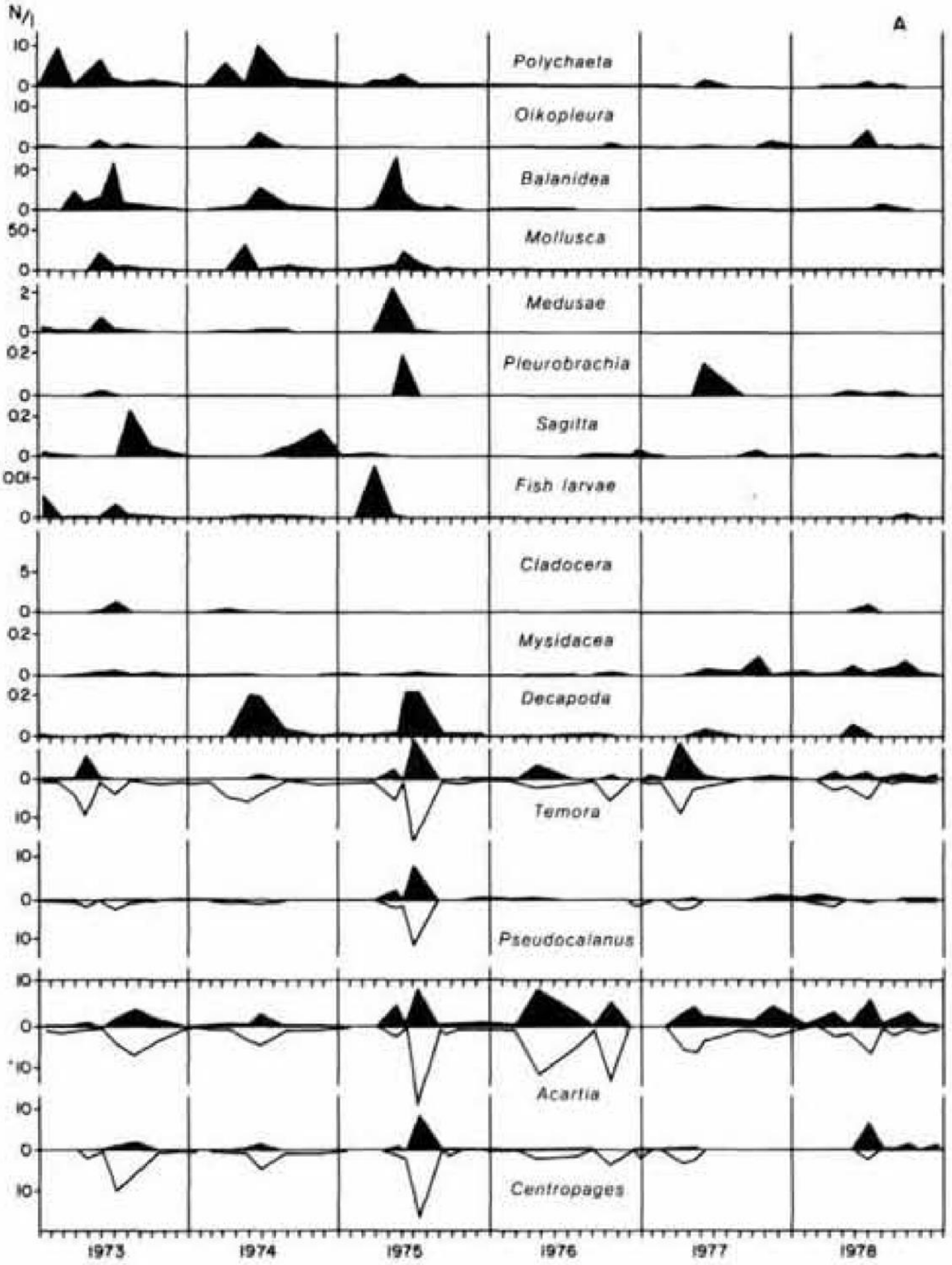


Figure 12 Seasonal patterns of common zooplankton taxa in the western Wadden Sea 1973-1978 in numbers per litre from (Fransz and Arkel, 1983).

Table 4 timing of presence of gelatinous zooplankton in the western Wadden Sea

Gelatinous predators/competitors present	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	
Gooseberry, *Pleurobrachia pileus*			?????								van der Veer 1984 and NIOZ fish fyke
Moon jellyfish, *Aurelia aurita*											van der Veer 1985 and NIOZ fish fyke
Stinging jellyfish, *Cyanea sp.*											NIOZ fish fyke
Sea nettle, *Chrysaora hysoscella*											NIOZ fish fyke
Blue jellyfish, *Rhizostoma octopus*											NIOZ fish fyke
Sea walnut, *Mnemiopsis leidyi*				only once							ZKO-fish cruises, NIOZ Balgzand monitoring, NIOZ fish fyke

5. Meroplankton

Meroplankton consists mainly of larvae of various organisms. Most species with meroplanktonic stages do not reproduce throughout the year but exhibit synchronous spawning in one or more seasonal spawning periods. Many species time their spawning spawning period such that it coincides with the phytoplankton spring bloom, which in the Wadden Sea occurs generally between April and June (Philippart et al. 2010).

This section gives an overview of meroplankton present in the Wadden Sea and gives an indication of which species and taxa can be fouling organisms.

1. Shellfish

Shellfish in the Wadden Sea exhibit seasonal spawning periods. Most bivalve species spawn in spring, summer and/or autumn. Two species can cause fouling by attaching themselves to hard substrates; the Pacific oyster *Crassostrea gigas* and the mussel *Mytilus edulis*. *C. gigas* spawns from June - September, while *M. edulis* spawns from April – September with a peak in May (Philippart et al. 2014).

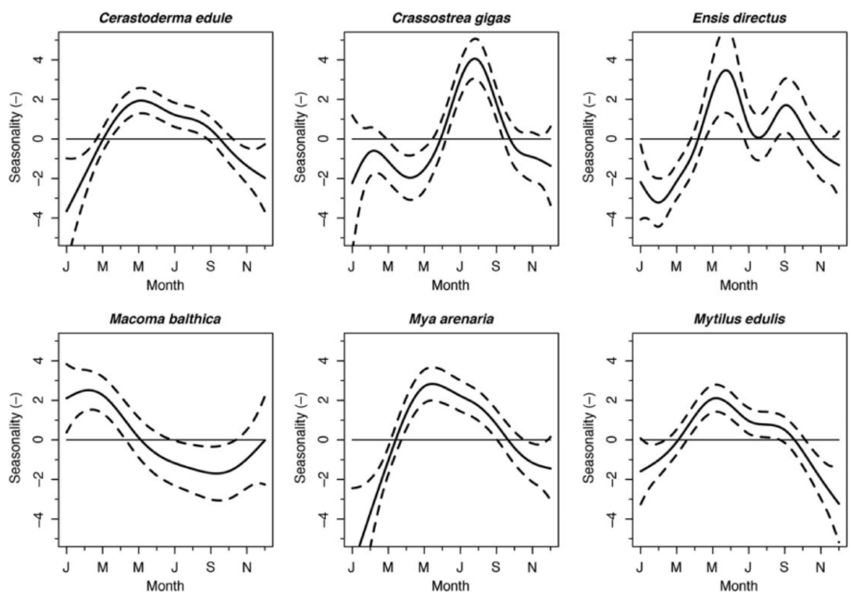
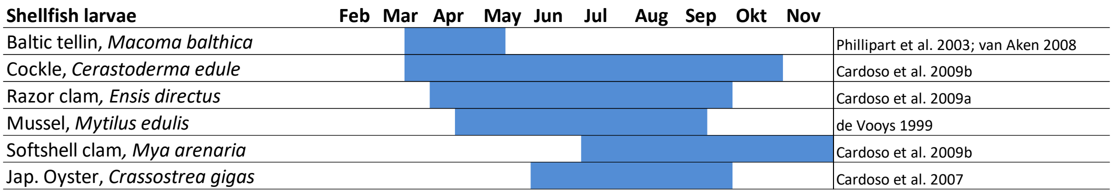


Figure 13 Reproductive phenology of bivalves in the western Wadden Sea based on presence of bivalve DNA in water samples from Philippart et al. (2014).

Table 5 Reproductive phenology of common Wadden Sea bivalves based on presence of larvae and gonadosomatic index.



2. Barnacles

Barnacles release their larvae to coincide with the phytoplankton spring bloom (White, 2007). Before settling barnacle larvae moult six times, of which the first five stages are Nauplius stages. The sixth stage, the Cyprid stage, is the stage that has to find a suitable substrate for settlement. Cyprid larvae do not feed and can live for several days. Cyprid larvae use different chemical and tactical cues to find a suitable settlement substrage. Several hours after settlement a cyprid larvae transforms into a juvenile barnacle (Larink and Westheide 2006). Because the low residence time of the water in the REDstack pilot plant it is likely that only the cyprid larvae are able to settle within the installation, and the Nauplius stages pass through the installation.

3. Polychaetes

Several species of Wadden Sea polychaetes have pelagic larvae. Polychaete larvae can be present throughout the year, although species tend to have distinct spawning periods. Polychaete larval stages last from a few days to weeks (Larink and Westheide 2006).

4. Sizes of fouling organisms

Retention of fouling organisms on the filtering system used in the RED pilot plant will depend on organism size and filter efficiency. The size ranges of different zooplankton taxa are shown in fig. 18, using data taken from a number of different sources (Larink & Westheide 2006, Conway 2012a,b,2015). This suggests that a mesh size of 20 to 50 will retain most if not all of the fouling zooplankton present in the Wadden Sea.

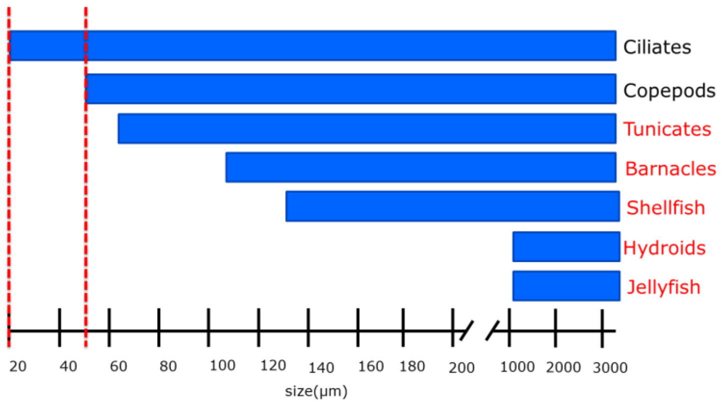


Figure 14 Size range of common zooplankton taxa with possible fouling taxa in red. Dashed vertical lines represent mesh size diameters of 20 and 50 micron respectively.

5. Fish eggs and larvae

Fish larvae are produced either in the Wadden Sea by fishes that spawn *'in situ'*, but a substantial number of fish species spawn in the North Sea and have their eggs and larvae carried by the residual current to the inshore waters that function as a nursery. Examples of the so-called nursery species are several flatfish species, herring and whiting. Species that spawn inside the Wadden Sea are the gobies, butterfish, pipefish (among others). Smelt (*Osmerus eperlanus*) is a diadromous species, of which the adults have a spawning run upstream rivers to deposit their eggs in freshwater. The larvae drift downstream during development, in which case the Wadden Sea again has the role as a nursery for juvenile smelt.

At arrival in the Wadden Sea, the larvae of flatfish go through a metamorphosis from a transparant, symmetric, pelagic form to a pigmented form with both eyes on one side of the postlarva, which then is adapted to a benthic lifestyle. Larvae of herring and sprat also undergo certain metamorphosis when becoming a postlarva, but they stay in the pelagic domain.

The fish species that spawn in the Wadden Sea often have a form of brood protection, either by forming a nest (stickleback, butterfish) or by glueing their eggs on hard substratum or vegetation (gobies, garfish) or by nursing the larvae in a brood pouch (pipefish) or even within the body cavity (eelpout, *Zoarces viviparus)*. As a consequence of this, free floating eggs of these fish will be more rarely found than fish larvae.

Based on the season in which spawning occurs, a distinction can be made in winter- and summer-spawners (Russell 1976, Munk and Nielsen 2005). The result is that eggs and larvae of different fish species can be encountered in the Wadden Sea year-round, however each with a species-specific seasonality (Table 6, Table 7).

Table 6 Occurrence of fish eggs of North Sea fish species that can occur in the Wadden Sea.

Fish species	Dutch name	Scientific name	Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Anchovy	Ansjovis	*Engraulis encrasicolus*	eggs						■	■	■				
Flounder	Bot	*Platichthys flesus*	eggs	■	■	■	■	■	■	■	■				
Gunnel	Botervis	*Pholis gunnellus*	eggs	■	■	■								■	■
Goby	Brakwatergrondel	*Pomatoschistus microps*	eggs				■	■	■	■	■	■			
Goby	Dikkopje	*Pomatoschistus minutus*	eggs			■	■	■	■	■	■				
Mullet	Diklipharder	*Chelon labrosus*	eggs												
Garfish	Geep	*Belone belone*	eggs				■	■							
Gurnard	Grauwe poon	*Eutrigla gurnardus*	eggs				■	■	■	■	■				
Pipefish	Grote zeenaald	*Syngnathus acus*	eggs					■	■	■					
Brill	Griet	*Scophthalmus rhombus*	eggs			■	■	■	■	■	■				
Herring	Haring	*Clupea harengus*	eggs			■	■					■	■	■	■
Pogge	Harnasman	*Agonus cataphractus*	eggs	■	■	■	■	■							
Horse mackerel	Horsmakreel	*Trachurus trachurus*	eggs					■	■	■	■	■			
Cod	Kabeljauw	*Gadus morhua*	eggs	■	■	■	■	■					■	■	
Viper	Kleine pieterman	*Echiichthys vipera*	eggs						■	■	■				
Nilsson's pipefish	Kleine zeenaald	*Syngnathus rostellatus*	eggs						■	■	■				
Mackerel	Makreel	*Scomber scomber*	eggs					■	■	■	■				
Pilchard	Pelser	*Sardina pilchardus*	eggs						■	■	■				
Dragonet	Pitvis	*Callionymus lyra*	eggs				■	■	■	■	■				
Gurnard	Rode poon	*Trigla lucerna*	eggs				■	■	■	■	■	■	■		
Dab	Schar	*Limanda limanda*	eggs			■	■	■	■						
Plaice	Schol	*Pleuronectes platessa*	eggs	■	■	■	■								
Scaldfish	Schurftvis	*Arnoglossus laterna*	eggs						■	■	■	■			
Sea snail	Slakdolf	*Liparis liparis*	eggs	■	■									■	■
Lumpsucker	Snotolf	*Cyclopterus lumpus*	eggs		■	■	■	■							
Sand lance	Smelt	*Hyperoplus lanceolatus*	eggs				■	■	■	■	■				
Smelt	Spiering	*Osmerus eperlanus*	eggs			■	■	■							
Sprat	Sprot	*Sprattus sprattus*	eggs	■	■	■	■	■	■						
Bib	Steenbolk	*Trisopterus luscus*	eggs	■	■	■	■	■	■	■	■				
Turbot	Tarbot	*Scophthalmus maximus*	eggs				■	■	■	■	■				
Sole	Tong	*Solea solea*	eggs				■	■	■	■	■				
Lemon sole	Tongschar	*Microstomus kitt*	eggs					■	■	■	■	■	■		
Five-bearded rockling	Vijfdradige meun	*Ciliata mustela*	eggs	■	■	■	■	■	■						
Whiting	Wijting	*Merlangius merlangus*	eggs			■	■	■	■						
Sea scorpion	Zeedonderpad	*Myoxocephalus scorpius*	eggs	■	■	■									■

Table 7 Occurrence of fish larvae in the pelagic western Wadden Sea

Flatfish larvae	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	
Plaice, *Pleuronectes platessa*		■	■								van der Veer 1985, 2001
Flounder, *Platichthys flesus*			■	■							van der Veer 1985, 2001
Sole, *Solea solea*				■	■						van der Veer 2001

Pelagic fish larvae	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	
Herring, *Clupea harengus*	?????	?????	■	■	■	■	■	■	■	?????	ZKO-fish cruises 2012
Sprat, *Sprattus sprattus*	?????	?????			■		■		■	?????	ZKO-fish cruises 2012
Pilchard, *Sardina pilchardus*	?????	?????			■	■			■	?????	ZKO-fish cruises 2012
Smelt, *Osmerus eperlanus*	?????	?????		■	■	■			■	?????	ZKO-fish cruises 2012
Anchovy, *Engraulis encrasicolus*	?????	?????				■	■		■	?????	ZKO-fish cruises 2012
Whiting, *Merlangius merlangius*	?????	?????	■	■	■					?????	ZKO-fish cruises 2012
Horse mackerel, *T. trachurus*	?????	?????				■	■	■		?????	ZKO-fish cruises 2012

6. Size of fish eggs and larvae

The size-spectrum of fish species that are expected in the vicinity of the Blue Energy site, ranges between 0.5-3.5 mm (eggs), 2-12 mm (larvae) or 5-70 mm (post-larvae). However, it has to be kept in mind that with fish larvae, the width of the head will be determining for the screening that discriminates between impingement and entrainment (see previous sections). Length-width ratios are known for some species, based on studies in the US, but not for most of the species that are encountered in the vicinity of Breezanddijk.

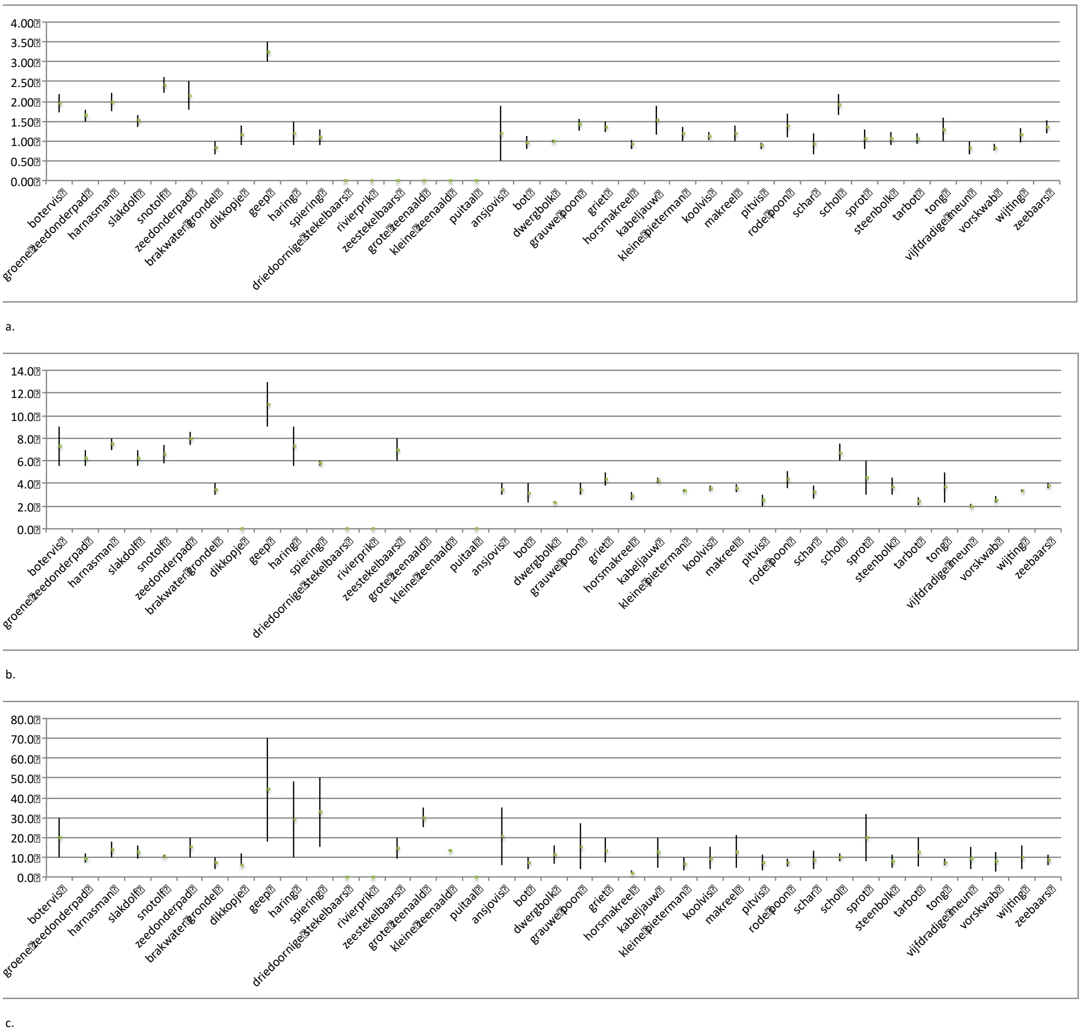


Figure 15. Length range (mm) of a. eggs, b. larvae and c. postlarvae of fish species that can be encountered in the vicinity of the Blue Energy site.

6. Fish

1. Presence of fish species

The presence of fish species was compiled from several relevant monitoring programs, such as:

- diadromous fish monitoring by Wageningen Marine Research near Kornwerderzand (fyke-monitoring) (Tulp et al., 2008, Griffioen, 2014); see fyke locations in Figure 16.
- the NIOZ fyke monitoring in the western Wadden Sea ('t Horntje; www.vismonitor.nl),
- WFD stownet monitoring Ems estuary (Jager, 2012)
- Demersal Fish Survey (DFS) (beam trawl survey), internationally coordinated by ICES

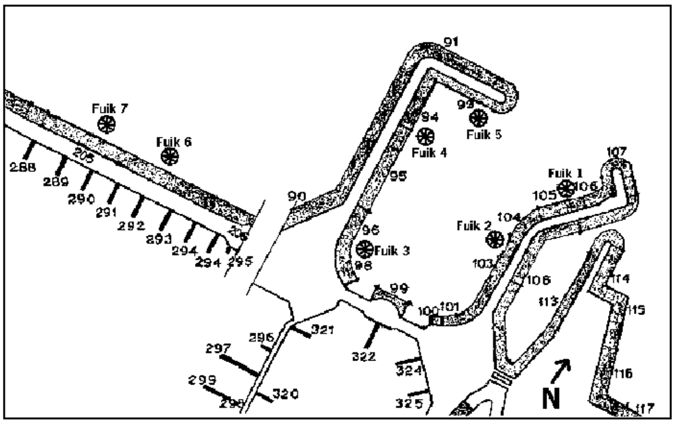


Figure 16. Overview of the fyke-locations in- and outside the discharge point of Kornwerderzand. The Blue Energy site is situated c.10 km to the west of this discharge location.

These monitoring surveys, with several gears and different seasonal timing, complement each other in giving an overview of the fish species that are likely to be present in the vicinity of the Blue Energy site.

The fish fauna consists of euryhaline or marine species and a number of freshwater species that are discharged from Lake IJssel through the sluices of Kornwerderzand or Den Oever (Table 8, Table 9).

Table 8. List of freshwater species, encountered in monitoring programs in the Wadden Sea (WWS=NIOZ fyke monitoring, KWZ=IMARES diadromous fish monitoring, Ems=WFD stow net monitoring).

Fish species (Dutch name)	Scientific name	WWS 1960-now	KWZ 2001-2007	KWZ 2013	Ems (2006-2011)
FRESH WATER					
brasem	*Abramis brama*	+	+	+	+
alver	*Alburnus alburnus*		+	+	
roofblei	*Aspius aspius*		+		
barbeel	*Barbus barbus*		+		+
kolblei	*Blicca bjoerkna*		+		+
giebel	*Carassius gibelio*		+		+
sneep	*Chondrostoma nasus*		+		
rivierdonderpad	*Cottus gobio*		+	+	
karper	*Cyprinus carpio*		+		+
snoek	*Esox lucius*		+	+	
pos	*Gymnocephalus cernuus*	+	+	+	+
winde	*Leuciscus idus*		+	+	+
serpeling	*Leuciscus leuciscus*		+	+	
regenboogforel	*Oncorhynchus mykiss*	+			
baars	*Perca fluviatilis*	+		+	+
marmergrondel	*Proterorhinus marmoratus*			+	
tiendoornige stekelbaars	*Pungitius pungitius*				+
blankvoorn	*Rutilus rutilus*		+	+	+
snoekbaars	*Sander lucioperca*	+	+	+	+
meerval	*Siluris glanis*				+
zeelt	*Tinca tinca*				+

Table 9. List of marine/estuarine species, encountered in monitoring programs in the Wadden Sea (abbreviations as in previous figure).

Fish species (Dutch name)	Scientific name	WWS 1960-now	KWZ 2001-2007	KWZ 2013	Ems (2006-2011)
MARINE/ESTUARINE					
harnasmannetje	*Agonus cataphractus*	+	+		+
fint	*Alosa fallax*	+	+	+	+
zandspiering	*Ammotdytes tobianus*	+	+		+
paling	*Anguilla anguilla*	+	+	+	+
glasgrondel	*Aphia minuta*	+	+		+
schurftvis	*Arnoglossus laterna*	+			
koornaarvis	*Atherina presbyter*	+	+	+	
geep	*Belone belone*	+	+		+
dwergtong	*Buglossidium luteum*	+			
pitvis	*Callionymus lyra*	+	+		
rode poon	*Chelidonichthys lucerna*	+	+		+
diklipharder	*Chelon labrosus*	+	+	+	+
vijfdradige meun	*Ciliata mustela*	+	+	+	+
haring	*Clupea harengus*	+		+	+
kommeraal	*Conger conger*	+			
grote marene	*Coregonus lavaretus*		+		
houting	*Coregonus oxyrinchus*		+	+	
snotolf	*Cyclopterus lumpus*	+	+		+
pijlstaartrog	*Dasyatis pastinaca*	+			
zeebaars	*Dicentrarchus labrax*	+	+	+	+
kleine pieterman	*Echiichthys vipera*	+	+	+	+
vierdradige meun	*Enchelíopus cimbrius*		+		
ansjovis	*Engraulis encrasicolus*	+	+		+
adderzeenaald	*Entelurus aequoreus*	+	+		+
grauwe poon	*Eutrigla gurnardus*	+	+		
kabeljauw	*Gadus morhua*	+	+	+	+
driedoornige stekelbaars	*Gasterosteus aculeatus*	+	+	+	+
smelt	*Hyperoplus lanceolatus*	+	+	+	+
gevlekte lipvis	*Labrus bergylta*	+			
rivierprik	*Lampetra fluviatilis*	+	+	+	+
schar	*Limanda limanda*	+	+	+	+
slakdolf	*Liparis liparis*	+	+	+	+
slijmvis	*Lipophrys pholis*	+			
goudharder	*Liza aurata*	+	+		
dunlipharder	*Liza ramada*	+			+
zeeduivel	*Lophius piscatorius*	+			
wijting	*Merlangius merlangus*	+	+	+	+
heek	*Merluccius merluccius*	+			
blauwe wijting	*Micromesistius poutassou*	+	+		
tongschar	*Microstomus kitt*	+	+		+
mul	*Mullus surmuletus*	+	+		+
gladde haai	*Mustelus mustelus*	+			
zeedonderpad	*Myoxocephalus scorpius*	+	+	+	+
spiering	*Osmerus eperlanus*	+	+	+	+
gehoornde slijmvis	*Parablennius gattorugine*		+		
zeeprik	*Petromyzon marinus*	+	+	+	+
botervis	*Pholis gunnellus*	+	+	+	+
bot	*Platichthys flesus*	+	+	+	+
schol	*Pleuronectes platessa*	+	+	+	+
pollak	*Pollachius pollachius*	+	+		
koolvis	*Pollachius virens*	+			
Lozano's grondel	*Pomatoschistus lozanoi*				+
brakwatergrondel	*Pomatoschistus microps*				+
dikkopje	*Pomatoschistus minutus*	+	+	+	+
vorskwab	*Raniceps raninus*	+	+		
zalm	*Salmo salar*	+	+	+	+
zeeforel	*Salmo trutta trutta*	+	+	+	+
pelser	*Sardina pilchardus*	+			
makreel	*Scomber scombrus*	+	+	+	
tarbot	*Scophthalmus maximus*	+	+		+
griet	*Scophthalmus rhombus*	+	+	+	+
hondshaai	*Scyliorhinus canicula*	+			
tong	*Solea solea*	+	+	+	+
goudbrasem	*Sparus aurata*	+			
zeestekelbaars	*Spinachia spinachia*	+	+		
zeekarper	*Spondyliosoma cantharus*	+			
sprot	*Sprattus sprattus*	+	+	+	+
doornhaai	*Squalus acanthias*	+			
zwartooglipvis	*Symphodus melops*	+	+		
grote zeenaald	*Syngnathus acus*	+			+
kleine zeenaald	*Syngnathus rostellatus*	+	+	+	+
groene zeedonderpad	*Taurulus bubalis*	+			
horsmakreel	*Trachurus trachurus*	+	+	+	+
steenbolk	*Trisopterus luscus*	+	+	+	+
dwergbolk	*Trisopterus minutus*	+			
puitaal	*Zoarces viviparus*	+	+	+	+

2. Seasonal occurrence

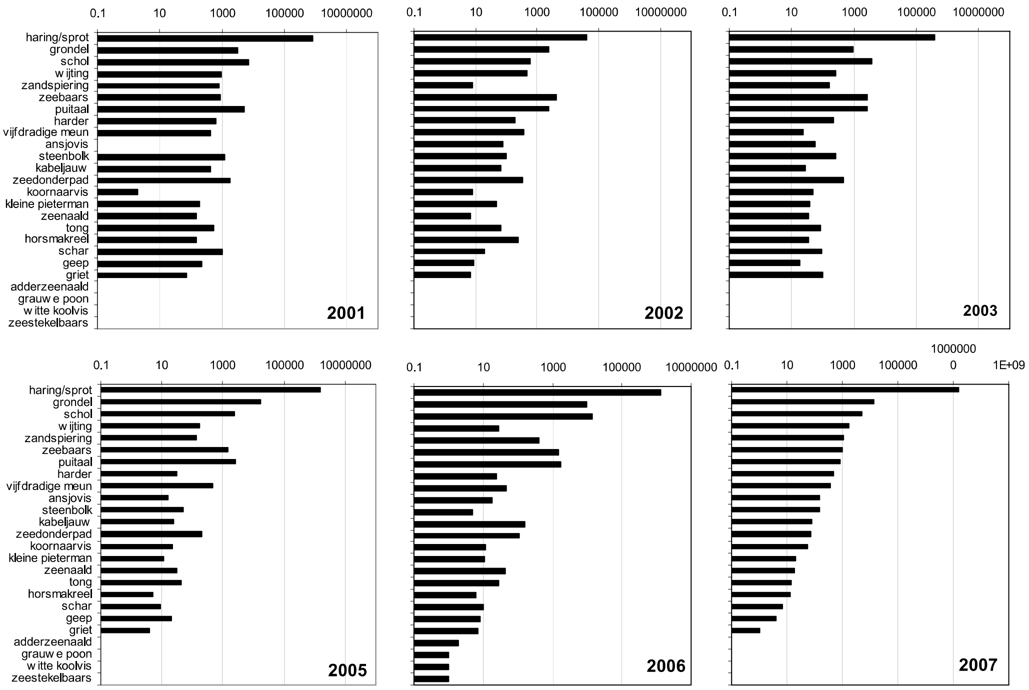
The seasonal occurrence of fish in the Wadden Sea was summarised based on the catches in the NIOZ fyke-monitoring in the Western Wadden Sea (Table 10). Many species have a year-round presence (flounder, herring, dab and plaice, among others), others are more time-restricted (anchovy, lemon sole, river lamprey and sea lamprey).

Table 10. Seasonal occurrence of fish species in the Wadden Sea (NIOZ www.waddenvismonitor.nl).

Fish species	Dutch name	Scientific name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Anchovy	Ansjovis	*Engraulis encrasicolus*				■	■	■	■	■			
Flounder	Bot	Platichthys flesus	■	■	■	■	■	■	■	■	■	■	■
Gunnel	Botervis	*Pholis gunnellus*			■	■	■	■	■	■	■	■	■
Goby	Brakwatergrondel	*Pomatoschistus microps*											
Goby	Dikkopje	*Pomatoschistus minutus*			■	■	■		■		■	■	■
Mullet	Dunlipharder	*Chelon labrosus*			■	■	■	■	■	■	■	■	■
Twaite shad	Fint	*Alosa fallax*	■	■	■	■	■	■	■	■	■	■	■
Garfish	Geep	*Belone belone*		■		■	■	■	■	■	■	■	
Gurnard	Grauwe poon	*Eutrigla gurnardus*											
Pipefish	Grote zeenaald	*Syngnathus acus*			■	■	■	■	■	■	■	■	■
Herring	Haring	*Clupea harengus*	■	■	■	■	■	■	■	■	■	■	■
Pogge	Harnasman	*Agonus cataphractus*			■	■	■	■	■	■	■	■	■
Horse mackerel	Horsmakreel	*Trachurus trachurus*		■			■	■	■	■	■	■	
Cod	Kabeljauw	*Gadus morhua*	■	■	■	■	■	■	■	■	■	■	■
Viper	Kleine pieterman	*Echiichthys vipera*				■	■	■	■	■	■	■	■
Nilsson's pipefish	Kleine zeenaald	*Syngnathus rostellatus*				■	■	■	■	■	■	■	
Sandsmelt	Koornaarvis	*Atherina presbyter*		■	■	■	■	■	■	■	■	■	■
Mackerel	Makreel	*Scomber scomber*				■	■	■	■	■	■	■	
Eel	Aal	*Anguilla anguilla*	■	■	■	■	■	■	■	■	■	■	■
Pilchard	Pelser	*Sardina pilchardus*		■		■	■	■	■	■	■	■	
Dragonet	Pitvis	*Callionymus lyra*			■	■	■	■	■	■	■	■	■
Eelpout	Puitaal	*Zoarces viviparus*	■	■	■	■	■	■	■	■	■	■	■
River lamprey	Rivierprik	*Lampetra fluviatilis*				■					■		■
Gurnard	Rode poon	*Trigla lucerna*				■	■	■	■	■	■	■	
Dab	Schar	*Limanda limanda*	■	■	■	■	■	■	■	■	■	■	■
Plaice	Schol	*Pleuronectes platessa*	■	■	■	■	■	■	■	■	■	■	■
Scaldfish	Schurftvis	*Arnoglossus laterna*				■	■	■			■	■	
Sea snail	Slakdolf	*Liparis liparis*			■	■			■	■	■	■	■
Lumpsucker	Snotolf	*Cyclopterus lumpus*	■		■	■	■		■	■	■	■	■
Sand lance	Smelt	*Hyperoplus lanceolatus*			■	■	■	■	■	■	■	■	■
Smelt	Spiering	*Osmerus eperlanus*	■	■	■	■	■		■		■	■	■
Sprat	Sprot	*Sprattus sprattus*	■			■	■	■	■	■	■	■	■
Bib	Steenbolk	*Trisopterus luscus*				■	■	■	■	■	■	■	■
Turbot	Tarbot	*Scophthalmus maximus*			■	■	■	■	■	■	■	■	■
Sole	Tong	*Solea solea*		■	■	■	■	■	■	■	■	■	■
Lemon sole	Tongschar	*Microstomus kitt*				■	■	■					
Five-bearded rockling	Vijfdradige meun	*Ciliata mustela*	■	■	■	■	■	■	■	■	■	■	■
Whiting	Wijting	*Merlangius merlangus*	■		■	■	■	■	■	■	■	■	■
Lesser sandeel	Zandspiering	*Ammodytes tobianus*			■	■						■	■
Lesser sandeel	Zandspiering	*Ammodytes tobianus*	■		■	■	■	■	■	■	■	■	■
Sea bass	Zeebaars	*Dicentrarchus labrax*	■		■	■	■	■	■	■	■	■	■
Sea scorpion	Zeedonderpad	*Myoxocephalus scorpius*	■	■	■	■	■	■	■	■	■	■	■
Sea lamprey	Zeeprik	*Petromyzon marinus*				■	■	■			■		■
Sea trout	Zeeforel	*Salmo trutta trutta*	■		■	■	■	■	■	■	■	■	■

3. Abundance of fish species

The most abundant fish species in the monitoring period (2001-2007) near Afsluitdijk at Kornwerderzand were herring/sprat (*Clupeidae*), gobies (*Pomatoschistus sp.*), plaice (*Pleuronectes platessa*), whiting (*Merlangius merlangus*) and sand smelt (*Ammodytes sp.*) (Tulp et al., 2008).



Figuur 12. Totaal aantal per zoutwater vissoort, geregistreerd in de verschillende jaren.

9 Discussion, conclusions and recommendations

In the preceding chapters we have reviewed available information that can be used to answer the five research questions that this review is based on. Here we will discuss and summarise our findings for each question separately.

1. How does the water use in a RED power plant differ from that in conventional installations?

Most of the information available was related to industrial cooling installations. In industrial cooling chemical stress, mechanical stress and thermal stress appear to be the main factors responsible for entrainment mortality. Chemical stress can be a result of chemical use, such as chlorine, to prevent fouling. The heating of the cooling water in the cooling process, often by several degrees Celsius, can cause thermal stress. In long transport systems predation of organisms by fouling filterfeeders can also contribute significantly to plankton mortality.

In a RED powerplant two water sources with two different salinity levels are mixed and the mixed water with a different, intermediate salinity is discharged to the marine water source. This differs from most conventional (cooling) installations as these extract water from a single source and return it to the same water source.

This results in an additional stressor occurring in RED: osmotic stress caused by the sudden decrease or increase in salinity ("salinity shock") for marine and fresh organisms, respectively.

2. What organism impingement issues can be expected in a RED power plant and how can these be mitigated?

The impingement issues in a RED power plant are largely comparable to the issues that have been described in industrial cooling installations. Thermal stress operates mainly on the organisms that are entrained, not on the impinged organisms, that are screened before being exposed to temperature differences. The impingement will largely be dependent on the type of mitigation and on the mesh sizes of applied screens. With fine meshed screens, juvenile and adult fish are not likely to be affected by impingement, however fish eggs and larvae are susceptible.

To decide on the application of BTA, site-specific circumstances have to be taken into account and candidate-systems are to be preselected. The efficacy of different options much depends on the local situation (Bruijs, 2007). The preselected systems are to be evaluated and reviewed. If sufficient knowledge is available from the review, further laboratory or field tests can be done.

3. What organism entrainment issues can be expected in a RED power plant and how can these be mitigated?

The main factors causing entrainment mortality of organisms in a RED power plant are likely different from those in industrial cooling plants. Chemical treatment using e.g. chlorine is not used in RED, making chemical stress unlikely. The temperature change ΔT is likely minimal or low in a RED plant , making this an unlikely contributor to plankton mortality as well.

Mechanical stress can occur in the RED plant during pump passage as well as during impingement on the initial filtration screen as well as on the drum sieve. Organisms passing through the stacks could possibly suffer from mechanical damage induced by high shear in the stacks, but it is unknown whether this occurs and if so, whether this stress is higher or lower than the stress organisms experience when they are filtered out in the drum sieve.

Also in RED water is transported in pipes with lengths of several hundred meters prior to filtration. In these pipes organisms will be subject to predation by the fouling organisms living on the pipes.

The main mortality causing factor in the RED power plant might be osmotic stress caused by the sudden decrease or increase in salinity ("salinity shock") for marine and fresh organisms, respectively. This salinity shock is currently experienced by organisms flushed off the drum sieve as well as organisms passing through the stacks as all effluent is combined and discharged to the harbour on the Wadden Sea side (option 1). To prevent salinity shocking of organisms that are impinged on the drum sieve, the option of separate discharge of the drum sieve backwash water could be considered for the Wadden Sea water only (option 2) and for the Lake IJssel water as well (option 3).

Whether option 2 or 3 should be considered depends first and foremost on whether it is necessary to reduce mortality of entrained organisms. High mortality of phytoplankton and zooplankton of both freshwater and marine origin is a naturally occurring phenomenon in estuaries, as shown by Soetaert and Herman (1994) for the western Scheldt. The relative importance of plankton mortality induced by REDstack compared to naturally occurring processes will be investigated in WP 1.4.

4. What organism fouling issues can be expected in a RED power plant and how can these be treated?

This review was restricted to fouling by macrofauna. Fouling by algae is not expected as there are no parts of the installation that are open or transparent to light. Organisms with a smallest size smaller than the hole or slit size at the water intake can be entrained and could settle on the installation surfaces (bivalves, gastropods, hydroids, bryozoans, barnacle larvae) or in sediment deposits in the installation (polychaetes and other worms, bivalves). Most meroplanktonic larvae of possible fouling organisms are larger than 50 µm and would thus be impinged on a drum sieve with a mesh size of 50 µm and smaller if this sieve is 100% efficient. This would prevent settlement of organisms in the part of the installation after the drum sieve: buffer tanks, pipes and stacks, up until the location where the stack effluent is mixed with the drum sieve backwash water. Placing the filtration step as close to the water inlet as possible would prevent most fouling organisms from settling in the pipes leading up to the installation.

Other options include influencing the conditions and the suitability of the substrate for settlement using anti-fouling coatings or ultrasonic vibrations. Switching fresh- and marine feedwaters may also inhibit fouling. Furthermore, mechanical or chemical cleaning can be applied. These options should be evaluated for their energy efficiency or, in case of chemical treatments for their impact on the environment upon discharge.

5. Which organisms are present at the RED pilot site in Breezanddijk and how could these be affected by the pilot installation?

The local situation was explored by reviewing the available data of the presence, size distribution and seasonal occurrence of different taxonomic groups of organisms in the vicinity of the Blue Energy installation at Breezanddijk. In the pilot plant, the pumps are covered with a tube with narrow holes (3.5 mm). It means that only smaller organisms can get through these holes.

Larger zooplankton and meroplankton organisms will be impinged on the drum screens if they have sizes between 20 micrometer and 3.5 mm diameter. This includes larger copepods, nematodes, polychaetes, larval stages of barnacles, shrimps and crabs and shellfish. Again, seasonal aspects will determine the abundance of the organisms present. Unfortunately information on zooplankton seasonal patterns, density and species composition is lacking in the western Wadden Sea and currently no monitoring of zooplankton is taking place in the area.

All fish eggs of fish species known to the area are between 0.5 and 3.5 mm in size and will be taken in and filtered on the drum screen, being part of the impingement. The eggs have a species-specific seasonal occurrence, some of them are produced locally and others are spawned in the North Sea and are transported by the water currents into the Wadden Sea.

The fish larvae and post-larvae of North Sea fish species range between 2 and 70 mm in size, and their presence also has a species-specific seasonal distribution. Larvae of flatfish (plaice, flounder, sole) and a number of pelagic fish larvae (a.o. Clupeids, smelt, anchovy, whiting and horse-mackerel) are impingement candidates at Breezanddijk. Juvenile and adult fish surpass the sizes that can be impinged with the current pump and are unlikely to enter the water intake.

2. Recommendations

1. Parameters needed for impact assessment

Currently water temperature and salinity are measured within the REDstack pilot plant before and after the filtration steps for both fresh water and seawater, and of the brackish effluent leaving the installation. These measurements will provide useful information for the estimation of the temperature change ΔT and salinity change ΔS in the installation. Additional measurements of temperature directly at the intakes and discharge location would be a useful addition.

No monitoring of zooplankton and pelagic fish is taking place in the western Wadden Sea. Seasonal patterns, abundance and species composition of zooplankton near Breezanddijk are unknown. This means that there is no baseline data available with which to compare abundance and species composition after construction of a large scale RED installation. Regular monitoring of western Wadden Sea zooplankton and pelagic fish over a period of multiple years is therefore urgently required.

2. Further research on impingement

The Blue Energy pilot at Breezanddijk provides opportunities for additional studies on impingement mortality. Tests with wedgewire screens under different assemblages of species and environmental conditions would be useful. Investigating the relationship between head width, body length, and entrainment rates of fish larvae in the laboratory would also be useful in developing a database of potential surrogate species for predicting the effectiveness of wedgewire screens (EPRI, 2006).

3. Further research on entrainment

In this review osmotic stress is identified as likely being an important factor contributing to mortality of organisms in RED power plant feed waters, both fresh as well as marine. As this issue is rarely studied in impact assessments of conventional (cooling) water installations, it is recommended to investigate survival of organisms after exposure to sudden changes in salinity using controlled experiments within the ΔS range observed at Breezanddijk as well as measure survival of organisms sampled from the discharge of the Breezanddijk power plant., using incubations.

4. Modelling of environmental impact.

In WP 1.4 the impact of a RED pilot plant at Breezanddijk on the aquatic environment will be modeled. As impingement and entrainment mortality of zooplankton and fish larvae in RED power plants is currently unknown, we recomment any modeling of the environmental impact to include a sensitivity analysis where mortality fractions ranging from 0 to 100% are included. For the estimation of the impact of the plant we recommend an approach similar to that used to investigate predation rates on zooplankton populations: estimating the clearance rate (Harris et al. 2000). In this way, the impact of the RED powerplant can be compared to natural zooplankton mortality caused by predation.

10 Literature

Anonymous, 2014a MWTL Meetplan 2014: Monitoring Waterstaatkundige Toestand des Lands Milieumeetnet Rijkswateren chemie en biologie. Tech. rep., Rijkswaterstaat, Ministerie van Infrastructuur en Milieu.

Anonymous, 2014b Richtlijn KRW Monitoring Oppervlaktewater en Protocol Toetsen & Beoordelen. Tech. rep., Rijkswaterstaat, Ministerie van Infrastructuur en Milieu.

ATKB, 2016. Ecologische beoordelingsmethodiek koelwateronttrekking. Rapport 20151079/01.

Allen, G., S. Amaral, J. Black, 2012. Chapter 17 Fish Protection Technologies: the US Experience. In: Rajagopal, S., H.A. Jenner & V.P. Venugopalan (eds.): Operational and Environmental Consequences of Large Industrial Cooling Water Systems. ISBN: 978-1-4614-1697-5.

Attrill, M.J., 2002. A testable linear model for diversity trends in estuaries. J. Anim. Ecol. 71, 262–269.

Bamber, R.N., Seaby, R.M.., 2004. The effects of power station entrainment passage on three species of marine planktonic crustacean, Acartia tonsa (Copepoda), Crangon crangon (Decapoda) and Homarus gammarus (Decapoda). Mar. Environ. Res. 57, 281–294. doi:10.1016/j.marenvres.2003.08.002

Čada, G.F., 1997. Shaken, not stirred: the recipe for a fish-friendly turbine. Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6036.

Cadée, G. C., & Hegeman, J., 1993. Persisting high levels of primary production at declining phosphate concentrations in the Dutch coastal area (Marsdiep). Netherlands Journal of Sea Research, 31(2), 147-152.

Cadée, G. C., & Hegeman, J., 2002. Phytoplankton in the Marsdiep at the end of the 20th century; 30 years monitoring biomass, primary production, and Phaeocystis blooms. Journal of Sea Research, 48(2), 97-110.

Calliari, D., Borg, M.C.A., Thor, P., Gorokhova, E., Tiselius, P., 2008. Instantaneous salinity reductions affect the survival and feeding rates of the co-occurring copepods Acartia tonsa Dana and A. clausi Giesbrecht differently. J Exp Mar Biol Ecol 362, 18–25.

Capuzzo, J.M., 1980. Impact of power-plant discharges on marine zooplankton: A review of thermal, mechanical and biocidal effects. Helgoländer Meeresunters. 33, 422–432.

Cardoso, J.F.M.., Witte, J.I., Van der Veer, H.W., 2009a. Reproductive investment of the American razor clam Ensis americanus in the Dutch Wadden Sea. J Sea Res 62, 295–298.

Cardoso, J.F.M.., Witte, J.I.J., Van der Veer, H.W., 2009b. Differential reproductive strategies of two bivalves in the Dutch Wadden Sea. Estuar. Coast. Shelf Sci. 84, 37–44.

Cardoso, J.F.M.F., Langlet, D., Loff, J.F., Martins, A.R., Witte, J.I.J., Santos, P.T., Van der Veer, H.W., 2007. Spatial variability in growth and reproduction of the Pacific oyster Crassostrea gigas (Thunberg, 1793) along the west European coast. J Sea Res 57, 303–315.

Choi, K.-H., Kim, Y.-O., Lee, J.-B., Wang, S.-Y., Lee, M.-W., Lee, P.-G., Ahn, D.-S., Hong, J.-S., Soh, H.-Y., 2012. Thermal impacts of a coal power plant on the plankton in an open coastal water environment. J. Mar. Sci. Technol. 20, 187–194.

Conway, D.V.P., 2012. Marine zooplankton of southern Britain. Part 1: Radiolaria, Heliozoa, Foraminifera, Ciliophora, Cnidaria, Ctenophora, Platyhelminthes, Nemertea, Rotifera and Mollusca. A.W.G. John (ed.). Occasional Publications. Marine Biological Association of the United Kingdom, No. 25, Plymouth, United Kingdom, 138 pp

Conway, D.V.P., 2012. Marine zooplankton of southern Britain. Part 2: Arachnida, Pycnogonida, Cladocera, Facetotecta, Cirripedia and Copepoda (ed. A.W.G. John). Occasional Publications. Marine Biological Association of the United Kingdom, No 26 Plymouth, United Kingdom 163 pp.

Conway, D.V.P., 2015. Marine zooplankton of southern Britain. Part 3: Ostracoda, Stomatopoda, Nebaliacea, Mysida, Amphipoda, Isopoda, Cumacea, Euphausiacea, Decapoda, Annelida, Tardigrada, Nematoda, Phoronida, Bryozoa, Entoprocta, Brachiopoda, Echinodermata, Chaetognatha, Hemichordata and Chordata. A.W.G. John (ed.). Occasional Publications. Marine Biological Association of the United Kingdom, No. 27, Plymouth, United Kingdom, 271 pp.

Dadswell, M.J. & R.A. Rulifson, 1994. Macrotidal estuaries: a region of collision between migratory marine animals and tidal power development. Biological Journal of the Linnean Society 51: 93-113.

De Wolf, P., 1973. Ecological observations on the mechanisms of dispersal of barnacle larvae during planktonic life and settling. Netherlands Journal of Sea Research, 6(1-2), 1-129.

Deng, Z., G.R. Guensch, C.A. McKinstry, R.P. Mueller, D.D. Dauble, M.C. Richmond, 2005. Evaluation of fish-injury mechanisms during exposure to turbulent shear flow. Can. J. Fish. Sci. Aquat. 62: 1513–1522. doi: 10.1139/F05-091.

Duran-Matute, M., Gerkema, T., De Boer, G. J., Nauw, J. J., & Gräwe, U., 2014. Residual circulation and freshwater transport in the Dutch Wadden Sea: a numerical modelling study. Ocean Science, 10(4), 611-632.

EPRI, 2000. Technical Evaluation of the Utility of Intake Approach Velocity as an Indicator of Potential Adverse Environmental Impact under Clean Water Act Section 316(b), EPRI, Palo Alto, CA, 2000. 1000731.

EPRI , 2004. Impingement Abundance Monitoring Technical Support Document. EPRI 1008470, Final Report December 2004.

EPRI, 2005. Field Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intakes. EPRI 1010112, Final Report May 2005.

EPRI, 2006. Field Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intake Structures. Chesapeake Bay Studies. EPRI 1012542, Final Report June 2006.

EPRI, 2010. Evaluation of Continuous Screen Rotation and Fish Survival. Studies at Plant Barry, Mobile River, AL. EPRI 1016807, Final Report Jan 2010. Cosponsor: Alabama Power Company.

Ehlin, U., S. Lindahl, E. Neuman, O. Sandström, J. Svensson, 2009. Miljöeffekter av stora kylvattenutsläpp. Erfarenheter från de svenska kärnkraftverken. Elforsk Rapport nr 09:79.

Fransz, H., Gonzalez, S., Cadée, G., Hansen, F., 1992. Long-term change of Temora longicornis (Copepoda, Calanoida) abundance in a Dutch tidal inlet (Marsdiep) in relation to eutrophication. Neth J Sea Res 30, 23–32.

Fransz, H.G., Colebrook, J.M., Gamble, J.C., Krause, M., 1991. The Zooplankton of the North-Sea. Neth J Sea Res 28, 1–52.

Fransz, H. G., & Arkel, W., 1983. Fluctuation and succession of common pelagic copepod species in the Dutch Wadden Sea. Oceanologica Acta, Special issue.

Gittenberger, A. and Stegenga, H., 2012. Risico analyse van uitheemse soorten in de exportgebieden voor Zuid - Noord transporten van de Oosterschelde naar de Waddenzee. GiMaRIS rapport 2012_27.

Goorden, N., S. Zwanenburg, L. van Duren, W. Borren, 2017. Inventarisatie mogelijkheden waterinnamesystemen t.b.v. Blue Energy. Resultaten werkpakket 1.1. Deltares Rapport 1210604-001.

Griffioen, A.B., 2014. Data rapportage najaar 2013 fuik monitoring Kornwerderzand t.b.v. de VismigratieRivier. IMARES Rapportnummer C034/14.

Hanson, C.H., J.R.White and H.W. Li, 1977. Entrapment and Impingement of fishes by power plant cooling water intakes: an overview. MRF Paper 1266, 17 p. From Marine Fisheries Review, Vol. 39, No. 10, October 1977.

Henderson, P. A. and Seaby, R. M. H. 2000. Technical evaluation of US Environmental Protection Agency proposed cooling water intake regulations for new facilities. Pisces Conservation Ltd., IRC House, The Square, Pennington, Lymington, England.

Hoffmeyer, M.S., Biancalana, F., Berasategui, A., 2005. Impact of a power plant cooling system on copepod and meroplankton survival (Bahía Blanca estuary, Argentina). Iheringia Sér. Zool. 95, 311–318.

Harris, R., Wiebe, P., Lenz, J., Skjoldal, H. R., & Huntley, M. (Eds.). (2000). ICES zooplankton methodology manual. Academic Press.

Jacobs P, Riegman R, van der Meer J, 2016 Impact of introduced juvenile mussel cultures on the pelagic ecosystem of the western Wadden Sea, The Netherlands. Aquacult Environ Interact 8:553-566.

Jager, Z., 2010. Position paper on the sustainable use of cooling water from the Wadden Sea. Wadden Academy.

Jager, Z., 2012. Technical evaluation of the Water Framework Directive Fish Index and Fish Monitoring of Transitional Waters. Report commisioned by RWS Centre for Water Management, Projectnr. 4500200516, 2012.

Kaartvedt, S., Aksnes, D.L., 1992. Does freshwater discharge cause mortality of fjord-living zooplankton? Estuar. Coast. Shelf Sci. 34, 305–313.

Kaartvedt, S., Nordby, E., 1992. Impact of a controlled freshwater discharge on zooplankton distribution in a Norwegian fjord. J. Exp. Mar. Biol. Ecol. 162, 279–293.

Karas, P., 1992. Zooplankton entrainment at Swedish nuclear power plants. Mar. Pollut. Bull. 24, 27–32.

Kelso, J.R.M. and G.S. Milburn, 1979. Entrainment and impingement of fish by power plants in the great lakes which use the once-through cooling process. J. Great Lakes Res. 5: 182-194.

Kinne, O., 1970. Marine ecology, V. 1: environmental factors, part 1. A comprehensive, integrated treatise on life in oceans and coastal waters. Wiley-Interscience, New York, New York.

Kunst, J.M., B. Spaargaren, T. Vriese, M. Kroes, C. Rutjes, E. van der Pouw Kraan, R.R. Jonker, 2008. Gemalen of vermalen worden. Onderzoek naar visvriendelijkheid van gemalen. I&M-99065369-MK, revisie D2.

Lacey, R.E., 1980. Energy by reverse electrodialysis. Ocean Eng. 7, 1–47.

Larink, O., & Westheide, W., 2006. Coastal plankton. Verlag Dr. Friedrich Pfeil, München.

Mayhew, D.A., Jensen, L.D., Hanson, D.F., Muessig, P.H., 2000. A comparative review of entrainment survival studies at power plants in estuarine environments. Environ. Sci. Policy 3, Supplement 1, 295–301. doi:10.1016/S1462-9011(00)00069-1

Miller, C.B., 1983. The zooplankton of estuaries., in: Estuaries and Enclosed Seas. Elsevier, Amsterdam.

Moreno, J., Slouwerhof, E., Vermaas, D. A., Saakes, M., & Nijmeijer, K. (2016). The breathing cell: cyclic intermembrane distance variation in reverse electrodialysis. Env. Sci. Technol, 50(20), 11386-11393.

Munk, P., & Nielsen, J. G., 2005. Eggs and larvae of North Sea fishes. Biofolia.

Muylaert, K., Sabbe, K., Vyverman, W., 2009. Changes in phytoplankton diversity and community composition along the salinity gradient of the Schelde estuary (Belgium/The Netherlands). Estuar. Coast. Shelf Sci. 82, 335–340.

Nielsen, T., Andersen, C., 2002. Plankton community structure and production along a freshwater-influenced Norwegian fjord system. Mar. Biol. 141, 707–724.

Pulfrich, A., 1996. Attachment and settlement of post-larval mussels (*Mytilus edulis* L.) in the Schleswig-Holstein Wadden Sea, Journal of Sea Research, Volume 36, Issue 3, 1996, Pages 239-250

Philippart, C. J. M., van Iperen, J. M., Cadée, G. C., & Zuur, A. F., 2010. Long-term field observations on seasonality in chlorophyll-a concentrations in a shallow coastal marine ecosystem, the Wadden Sea. Estuaries and Coasts, 33(2), 286-294.

Philippart, C. J., Van Bleijswijk, J. D., Kromkamp, J. C., Zuur, A. F., & Herman, P. M., 2014. Reproductive phenology of coastal marine bivalves in a seasonal environment. Journal of Plankton Research, fbu073.

Philippart, C.J.M., Lindeboom, H.J., van der Meer, J., Van der Veer, H.W., Witte, J.I.J., 1996. Long-term fluctuations in fish recruit abundance in the western Wadden Sea in relation to variation in the marine environment. ICES J Mar Sci 53, 1120–1129.

Philippart, C.J.M., Van Aken, H.M., Beukema, J.J., Bos, O.G., Cadee, G.C., Dekker, R., 2003. Climate-related changes in recruitment of the bivalve Macoma balthica. Limnol Ocean. 48, 2171–2185.

Richmond, C.E., Woodin, S.A., 1996. Short-term fluctuations in salinity: effects on planktonic invertebrate larvae. Mar. Ecol. Prog. Ser. 167–177.

Ridderinkhof, H., Zimmerman, J. T. F., & Philippart, M. E. 1990., Tidal exchange between the North Sea and Dutch Wadden Sea and mixing time scales of the tidal basins. Neth. J. Sea Res, 25(3), 331-350.

Rodgers, D.W., P.H. Patrick, 1985. Evaluation of a Hidrostal Pump Fish Return System. North American Journal of Fisheries Management, 5 (3A): 393-399.

Russel, F. S., 1976. The eggs and planktonic stages of British marine fishes. Academic Press, London

Soetaert, K., Herman, P.M., 1994. One foot in the grave: zooplankton drift into the Westerschelde estuary (The Netherlands). Mar. Ecol. Prog. Ser.

Tedesco, M., Cipollina, A., Tamburini, A., & Micale, G., 2017. Towards 1kW power production in a reverse electrodialysis pilot plant with saline waters and concentrated brines. J. of Membrane Sci, 522, 226-236.

Tenera Environmental, 2013. Length specific probabilities of screen entrainment of larval fishes based on head capsule measurements. Prepared for: Bechtel Power Corporation JUOTC Project. Report ESLO2013-17.0.

Tulp, I., I, de Boois, J. van Willigen, H.-J. Westerink, 2008. Diadrome vissen in de Waddenzee: Monitoring bij Kornwerderzand 2000-2007. Imares Rapport C048/08.

Tulp, I., van der Veer, H. W., van Walraven, L., Bolle, L. J. (in press) Can guild- or site-specific contrasts in trends or phenology explain the changed role of the Dutch Wadden Sea for fish? Journal of Sea Research.

Turnpenny, A.W.H. & J. Coughlan, 1992. Power generation on the british coast: thirty years of marine biological research. Hydroécol. Appl. Tome 4 Vol 1, pp. 1-11.

Van Aken, H. M., 2010a Meteorological forcing of long-term temperature variations of the Dutch coastal waters. J. Sea Res., 63, 143–151.

Van Aken, H. M., 2010b Meteorological forcing of long-term temperature variations of the Dutch coastal waters. J. Sea Res., 63, 143–151.

Van Giels, J., 2008. De effecten van onttrekking van koelwater op vis. Metingen voorjaar 2008. ATKB Project nummer 20080249.

Van der Veer, H.W., 1985. Impact of coelenterate predation on larval plaice Pleuronectes platessa and flounder *Platichthys flesus* stock in the western Wadden Sea. Mar Ecol Prog Ser 25, 229–238.

Van der Veer, H.W., Dapper, R., Witte, J.I., 2001. The nursery function of the intertidal areas in the western Wadden Sea for 0-group sole *Solea solea*(L.). J Sea Res 45, 271–279.

Van der Veer, H.W., Oorthuysen, W., 1985. Abundance, growth and food demand of the scyphomedusa *Aurelia aurita* in the western Wadden Sea. Neth J Sea Res 19, 38–44.

van Raaphorst, W., de Jonge, V. 2004 Reconstruction of the total N and P inputs from the IJsselmeer into the western Wadden Sea between 1935-1998. J. Sea Res., 51, 109–131.

Vermaas, D.A., Kunteng, D., Saakes, M., Nijmeijer, K., 2013. Fouling in reverse electrodialysis under natural conditions. Water Res. 47, 1289–1298. doi:10.1016/j.watres.2012.11.053

Vermaas, D.A., Saakes, M., Nijmeijer, K., 2011. Doubled power density from salinity gradients at reduced intermembrane distance. Environ. Sci. Technol. 45, 7089–7095.

Vermaas, D. A., Kunteng, D., Veerman, J., Saakes, M., & Nijmeijer, K., 2014. Periodic feedwater reversal and air sparging as antifouling strategies in reverse electrodialysis. Environ. Sci. Technol, 48(5), 3065-3073.

Vermaas, D. A., Saakes, M., & Nijmeijer, K., 2014. Early detection of preferential channeling in reverse electrodialysis. Electrochimica Acta, 117, 9-17.

Vooys, C.G.N. de, 1999. Numbers of larvae and primary plantigrades of the mussel Mytilus edulis in the western Dutch Wadden Sea. J Sea Res 41, 189–201.

Vriese, F.T., A.B. Griffioen & C. Deerenberg, 2012. Beoordelingssystematiek koelwateronttrekkingen - vervolg. IMARES Rapport C024/12.

Weisberg, S. B., W. H. Burton, F. Jacobs and E. A. Ross. 1987. Reductions in Ichthyoplankton Entrainment with Fine-Mesh, Wedge-Wire Screens. North American Journal of Fisheries Management 7: 386-393.

White, N., 2007. Semibalanus balanoides: an acorn barnacle. Marine Life Information Network: biology and sensitivity key information sub-programme. Marine Biological Association of the United Kingdom. Avaliable at: http://www.marlin.ac.uk/species/detail/1376 Accessed on 09-04-2017.

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