Fish Migration River Monitoring Plan

Monitoring program on the effectiveness of the FMR at Kornwerderzand

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Introduction

A large tidal barrier, the 32 km long Afsluitdijk, was constructed in 1932 in the Netherlands in the former estuary Zuiderzee connecting the Wadden Sea with the northern branch of the River Rhine (IJssel). This dam separated the former estuary from the Wadden Sea creating a large freshwater basin, Lake IJsselmeer. Excess freshwater is discharged through two sluice complexes in the Afsluitdijk dam; at Den Oever and at Kornwerderzand during low tide when water tables of Lake IJsselmeer are higher than those in de Wadden Sea. As a result estuarine habitats disappeared and fish migration from the Wadden Sea to Lake IJsselmeer and upstream located rivers was severely obstructed, given that fish could only pass by conquering the high water velocities in the discharge sluices during discharge events or pass through the adjacent ship lock.

As many small diadromous fish strongly rely on tidal currents for their migration towards freshwater water bodies by selectively using tidal currents during flood (incoming) tide, especially small diadromous fish have major difficulties in passing the discharge sluices. Because the current management protocol does not allow for salt water intrusion into IJsselmeer due to drinking water intake and agricultural use, passage by active upstream swimming is restricted to small temporal windows. As of 2015, a discharge sluice management aiming to aid passive drift with inflowing water during short time intervals in the ebb phase of part of the tidal cycles to Lake IJsselmeer has been implemented (so called ‘Fish Friendly Sluice Management’).

To restore fish migration between the Wadden Sea and Lake IJsselmeer at the discharge sluices of Kornwerderzand, and especially for small diadromous fish, a uniquely designed fish passage has been developed called the ‘Fish Migration River’ (FMR). This is an artificial river of several kilometres long providing long lasting migration windows (in principal continuous) with natural in and outgoing tidal flows, and with much lower water velocities during the ebb phase compared to the outgoing velocities in the discharge sluices.

Goal of this report

This report drafts a monitoring program aiming at determining and optimizing the effectiveness of restoring fish migration at Kornwerderzand with the FMR. For an adaptive management of the operation of the FMR, monitoring and evaluation are key aspects. The main research questions underlying the monitoring program will be outlined. The proposed research and monitoring approach describes which monitoring techniques can be applied, what set-up and schedule of different research components involved.

Target species

Target species of the monitoring program are especially diadromous fish: European sturgeon (*Acipenser sturio*), flounder (*Platichthys flesus*), allis shad (*Alosa alosa*), twaite shad (*Alosa fallax*), European eel (*Anguilla anguilla*), three-spined stickleback (*Gasterosteus aculeatus*), river lamprey (*Lampetra fluviatilis*), smelt (*Osmerus eperlanus*), sea lamprey (*Petromyzon marinus*), Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta*) and North Sea houting (*Coregonus oxyrinchus*).

Research questions

To determine the functioning and effectiveness of the FMR in restoring fish migration alongside the Afsluitdijk Dam between the Wadden Sea and Lake IJsselmeer, different research questions should be addressed. We categorised four research questions (Q1-Q4) into four overarching questions.

Question 1 mainly focusses on *measuring* passage success through the FMR and the other potential migratory pathways through the discharge sluices and shiplock.

Q1 What is the overall passage efficiency of the Kornwerderzand complex per target species?

Question 2 mainly focusses on *understanding* the factors and processes underlying the different passage efficiencies as determined within Q1 and if necessary how these might be improved by management options. E.g. when the results of the overall passage efficiency for a certain species or group of species are below target levels, then it needs to be determined whether the functioning of the FMR can be improved or optimised.

Q2 Is there a need for improving the functioning of the FMR ('optimizing') and how can this be achieved?

Question 3 focusses on the habitat role of the FMR for fish, the consequences of predation risk and how these relate to Q1 and Q2.

Q3 Is the FMR also used as a habitat by fish and its predators?

Question 4: Whereas Q1, Q2 and Q3 act on the local spatial scale of the Kornwerderzand sluice complex, Q4 takes a much *wider perspective* and determines the effects of increasing migratory opportunities on population levels in the marine and freshwater systems that are connected through the Kornwerderzand sluice complex.

Q4 What is the effectiveness of the FMR on fish population levels?

Monitoring techniques

To address the research questions Q1-Q4, different research and monitoring techniques are available to observe and follow individual fish or groups of fish. We give an overview of relevant and applicable techniques and make a distinction between *direct* and *indirect* measurements in answering the research questions. Direct techniques, e.g. tagging and telemetry techniques, allow us to follow and track individual fish and will yield direct measurement of percentages and rates (in time) of passage and attraction efficiency in combination with specific behavioural patterns. However, these techniques are not applicable to all fish species and sizes. For fish that cannot be investigated using direct techniques, other research approaches and techniques are needed to more 'indirectly' determine the total numbers of fish arriving at the complex and passing through the different routes and sections of the Kornwerderzand Complex comprising the FMR, discharge sluices and shiplock in time by measuring and estimating densities and fluxes of fish in the different connected sections of the complex. In addition to indirect techniques to assess total number and fluxes, mark recapture experiments can be used to determine underlying duration of passage, indicate passage behaviour and provide independent total number estimates.

Proposed monitoring set-up

- Determining passage and attraction (which includes approach or 'discovery' and entry) efficiency, rates per route and in time (Q1): a combination of telemetry methods (Vemco, NEDAP and PIT) with fixed and temporary detection station arrays that cover the entrances and exits of the FMR and other potential passage routes in the sluice complex to determine efficiency rates of the larger species and stages, with an extensive netting programme (drift nets, lift nets) to determine dynamics of densities and fluxes in time of the smaller species and stages to assess passage efficiency.
- Optimizing the functioning of FMR (Q2), is more flexible and dependant of the outcome of the Q1 results, where part of the 'hard-ware' (e.g. arrays and netting material) is used in a set-up focused to zoom in on potential bottlenecks that lower passage or attraction efficiency.
- Habitat use of the FMR in relation to fish (Q3), mainly in relation to migratory performance, additional sampling of fish and predators is proposed.
- Determining the effectiveness of the FMR on fish population levels (Q4) is very ambitious and requires large research efforts. In this monitoring program we focus on addressing other migratory bottlenecks that might occur on migration routes (e.g. upstream sections of the Rivers Vecht, IJssel and Rhine), the use of adjacent entrances to Lake IJsselmeer used by migratory fish that have visited Kornwerderzand, and relating trends in abundance of target species in existing and ongoing long-lasting monitoring programs, e.g. in Lake IJsselmeer, Wadden Sea, even though the ultimate goal is to restore fish populations

The monitoring plan covers 2 years before the construction of the FMR and 4 years after construction.

Knowledge acquirement within the monitoring program and scientific opportunities

Currently, knowledge on fish migration at large tidal barriers and underlying behaviour of migratory fish is still scarce. The proposed monitoring program will yield much data and insights that have scientific interest and applications for management of tidal barriers elsewhere. We suggest that performing the required fieldwork, labour, analysis and reporting within the monitoring program is best carried out by a staff of PhD-students with support of technicians and researchers. In addition, the FMR, research infrastructure and equipment needed for the monitoring program forms a good basis for expanding the monitoring program with focussed scientific studies for which additional funding can be sought. We advocate an integral scientific program that operates on different spatial scales from fine (fish' perspective in relation to cues) to large levels covering different water systems. An iterative approach with a combination of field data, modelling (e.g. hydrodynamics, fish behaviour, agent based population etc.) and controlled experiments e.g. in the proposed test facility and/or lab-experiments in our view give the best opportunities to gain both fundamental scientific knowledge as well as applied scientific knowledge that can be used to mitigate migratory issues both locally and internationally.

1 Introduction

1.1 General introduction

Worldwide much attention and efforts were put in rehabilitating fish migration along barriers in rivers,. For tidal barriers however, there are still many knowledge gaps on fish behaviour and migration success in relation to tidal dynamics, especially for small diadromous fish such as flounder larvae and glass eel (Winter et al. 2014). Moreover, behaviour and migration success are strongly site specific due to different local hydrodynamics, management protocols, migration opportunities and migration windows that allow fish to pass. In the last few years, following Water Framework Directive guidelines, many barriers are, or will be, equipped with fish migration management measures.

One of these barriers is the Afsluitdijk, a 32km long dam that closed off the former estuary Zuiderzee in 1931 and formed a large tidal barrier for migratory fish. Besides the disappearance of a natural estuary and creating a whole new freshwater ecosystem (Lake IJsselmeer), the Afsluitdijk dam has had a major impact on fish migration between fresh and salt water (Griffioen et al. 2014b, Winter et al. 2014). Some fish species adapted to the new situation and others disappeared (for review see Winter et al. 2014). The Afsluitdijk has two discharge sluice complexes (Den Oever and Kornwerderzand), where excess freshwater from Lake IJsselmeer is discharged into the Wadden Sea. According to the sluice management protocol, freshwater is only discharged at low tide to prevent salt water intrusion in the freshwater lake. Besides an abrupt transition from salt water to completely fresh water, upstream migrating fish will be confronted with high water velocities up to several meters per second (Kolvoort and Butijn 1990) resulting in only very short migration windows at the start and the end of the discharge event that can only be traversed by fish with sufficient swimming capacity.

At the Afsluitdijk, previous telemetry research has been conducted on passage success of some of the diadromous fish species, though numbers of test fish were small so far. Passage success of sea trout alongside the two sluice complexes in the Afsluitdijk was assessed using RFID inductive coupling telemetry (NEDAP system), where based on 70 tagged sea trout at least 47 % successfully entered Lake IJsselmeer in the current situation (De Vaate et al. 2003). Passage success of sea lamprey (*Petromyzon marinus*) was indicated to be 16-33% based on passage behaviour of 25 sea lampreys (Griffioen et al. 2014b). Griffioen et al. (2014) also tagged six houting (*Coregonus oxyrinchus*) of which four passed the sluices during the examined period. Passage success for other diadromous fish such as river lamprey (*Lampetra fluviatilis*), European (glass) eel (*Anguilla anguilla*), Flounder (*Platichthys flesus*), Twaite shad (*Alosa fallax*), three-spined stickleback (*Gasterosteus aculeatus*) and smelt (*Osmerus eperlanus*) at this location are still unknown. Other studies focussed more on migration strategies and life history along the coast of the Netherlands including the Afsluitdijk and the Wadden Sea (Deelder 1952, 1958, Dekker and vanWilligen 1997, Dekker 1998, Dekker 2000, Bult and Dekker 2007, Borcherding et al. 2008, Winter et al. 2008, Borcherding et al. 2013, Tulp et al. 2013, Phung et al. 2015).

As many small diadromous fish strongly rely on tidal currents for its migration towards freshwater water bodies by using Selective Tidal Transport (Jager 1998, Bos 1999, Jager 1999, 2001), it is assumed that especially small diadromous fish have major difficulties in finding and using migratory windows at the discharge sluices. The current management protocol does not allow for salt water intrusion into IJsselmeer due to drinking water intake and agricultural use. Migration strategies such as Selective Tidal Transport cannot successfully be used at this site since tidal currents towards the freshwater lake are largely lacking in the present situation. Eventual passage by active upstream swimming is restricted to small temporal windows that allow migration (Figure 1.1). As of 2015, a discharge sluice management aiming to aid passive drift with inflowing water during short time intervals in the ebb phase of part of the tidal cycles to Lake IJsselmeer has been implemented (so called ‘Fish Friendly Sluice Management).

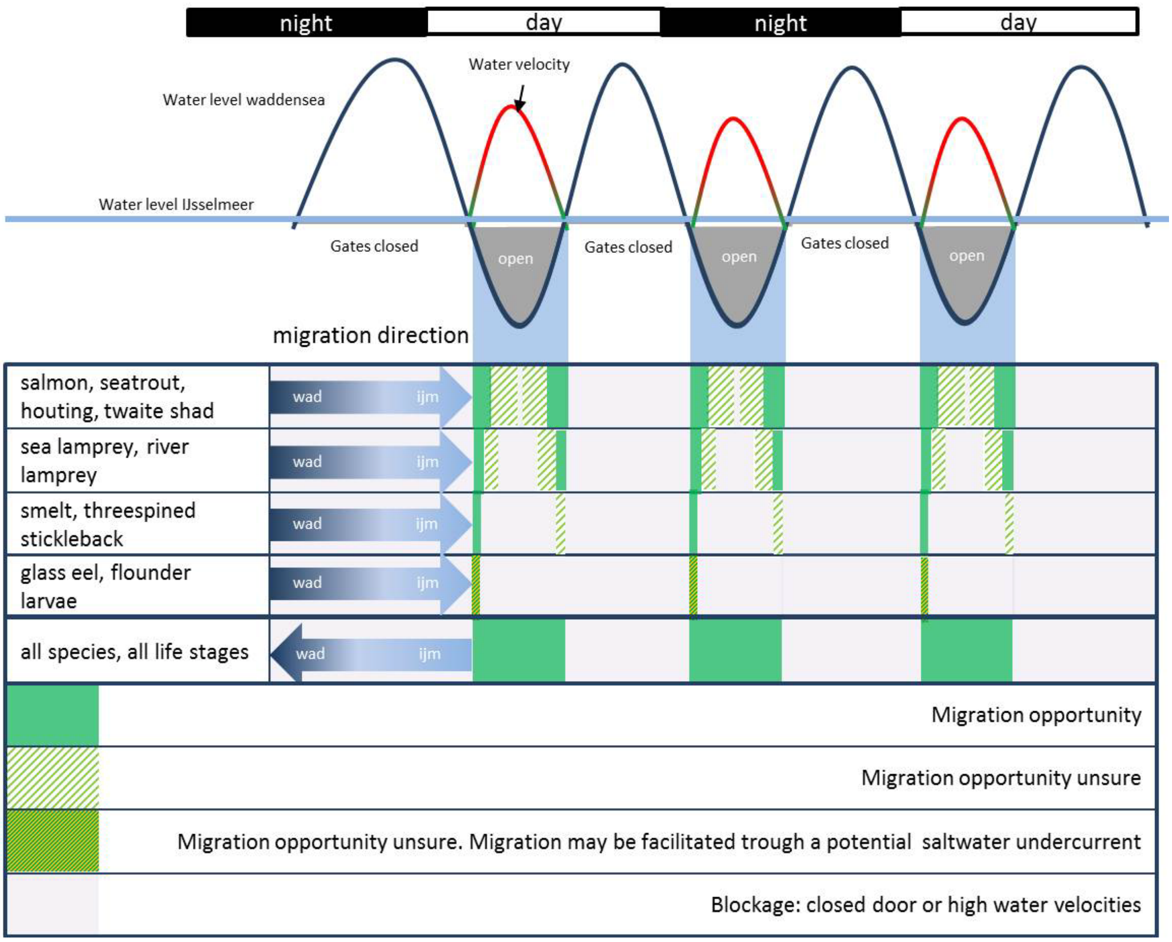

Figure 1.1 Potential migration opportunities for diadromous fish at the discharge sluices of Kornwerderzand in time in relation to the tidal cycle.

To restore fish migration between the Wadden Sea and Lake IJsselmeer, and especially also for small diadromous fish, a uniquely designed fish passage has been developed called the 'Fish Migration River' (FMR). This is an artificial river of several kilometres long providing long lasting migration windows with natural in- and outgoing tidal flows, and with much lower water velocities during flood phase than compared to the outgoing velocities in the discharge sluices.

Goal of this report

This report drafts a monitoring program aiming at determining and optimizing the effectiveness of restoring fish migration at Kornwerderzand with the FMR. This program is a follow up of an earlier proposed monitoring plan, written by the University of Karlstad and WAGENIGEN MARINE RESEARCH (Calles et al. 2014). The main research questions underlying the monitoring program will be outlined. The proposed research and monitoring approach will go into detail on which monitoring techniques can be applied, what set-up and schedule of different research components involved.

Target species

Target species of the monitoring program are especially diadromous fish: European sturgeon (*Acipenser sturio*), flounder (*Platichthys flesus*), allis shad (*Alosa alosa*), twaite shad (*Alosa fallax*), European eel (*Anguilla anguilla*), three-spined stickleback (*Gasterosteus aculeatus*), river lamprey (*Lampetra fluviatilis*), smelt (*Osmerus eperlanus*), sea lamprey (*Petromyzon marinus*), Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta*) and North Sea houting (*Coregonus oxyrinchus*).

Atlantic sturgeon and Allis shad (which are now being reintroduced in the Rhine) are target species, but became locally extinct in the River Rhine catchment and were never caught at Kornwerderzand so far, though reintroduction programs might change this in the future (Griffioen and Winter 2014a). In this report these species are not taken into account, but the proposed monitoring techniques (telemetry) applied on salmon and sea trout can also be used for sturgeon. The same applies to Allis shad when twaite shad. The FMR is designed in such a way that also large sturgeon should be physically able to pass (Winter et al. 2014).

1.2 Brief overview of the current knowledge on passage efficiency and behaviour of diadromous fish

To come up with advice on the design and management of the FMR in the pre phase, a literature study has been carried out to review relevant knowledge on the behaviour of diadromous fish species(i.e. those that migrate between marine and freshwater environments) during upstream migration towards freshwater (Winter et al. 2014). This literature study gives an overview of the population status in relation to the Afsluitdijk, timing of migration, migration and orientation behaviour, swimming capacity and passage strategies. After the literature study, several field research programs have been executed to fill in some relevant knowledge gaps (Griffioen 2014, Griffioen and Winter 2014a, b, Griffioen et al. 2014a, Griffioen et al. 2014b). In addition, several international expert meetings with specialists in diadromous fish ecology, hydrodynamics, technicians and others were organized to combine the available interdisciplinary knowledge and discuss and judge different design options of the FMR. Despite that a lot of knowledge has been collected in this process, there are still many knowledge gaps present, especially concerning passage success and behaviour of fish at tidal barriers (Griffioen et al. 2014b, Winter et al. 2014). A brief summary of the current state of knowledge is given in Table 1.

Table 1 *Overview of the current state of knowledge on the level of searching behaviour, swimming strategy and passage success. Each cell is marked with a coloured dot indicating: ● = conclusions based upon research ● = conclusions based upon speculation or by analogy with other, comparable, species. ● = unknown or best guess.*

Species	***Searching behaviour****	***Swimming behaviour***	***Passage succes*****
Atlantic Salmon	*● at discharge basin level at minimum*	*● Active*	*● >50% by analogy with sea trout*
Flounder Larvae	*● discharge basin level*	*● Passive drifting, selective tidal transport*	*● assumed to be low (Winter 2009)*
Three spined stickleback	*● discharge basin level, southern part*	*● Selective tidal transport and active swimming*	*● unknown. Best guess: low - moderate*
European eel (glass eel)	*● discharge basin level, southern part*	*● Selective tidal transport and active swimming*	*● unknown. Best guess: low - moderate*
Twaite shad	*● Unknown, most likely discharge basin level*	*● Active*	*● unknown.>50% by analogy with sea trout*
Houting	*● at discharge basin level at minimum*	*● Active*	*● >50% by analogy with sea trout and limited acoustic telemetry experiment results (Griffioen et al. 2014b)*
River lamprey	*● at discharge basin level and complex level at minimum*	*● Active*	*● < 33%, by analogy with sea lamprey (Griffioen and Winter 2014b, Griffioen et al. 2014b)*
Smelt	*● discharge basin level, southern part*	*● Active*	*● unknown: best guess: low-moderate (Tulp et al. 2013, Phung et al. 2015)*
Sea trout	*● at discharge basin level at minimum*	*● Active*	*● > 50% (De Vaate et al. 2003, Griffioen et al. 2014b)*
Sea lamprey	*● at discharge basin level at minimum*	*● Active*	*●16-33% (Griffioen et al. 2014b)[1]*

* The spatial scale 'discharge basin level' refers to the section of the sluice complex in between the piers on theWadden Sea side of the dischargge sluices, where the water is discharged into.

** Passage success does not only include passage percentage but also delay or extra energy losses, which are less often determined

[1] Corrected estimation of Griffioen et al. (2014b)

2 Design of FMR

The current most recent design of the FMR comprises six different sections, in the order of 1-6 going from sea to freshwater (Figure 2.1):

(1) two entrances which are approximately 16m wide, 3-5m deep depending on the tide, on the bottom there is habitat (e.g. riprap and sand) to facilitate local differences in water velocity for small diadromous fish. The entrances are always open and accessible.
(2) The inside section of the FMR at the marine side of the Afsluitdijk. This part has two separate channels and a more or less natural habitat type (e.g. sand, silt and rocks).
(3) The passage through the Afsluitdijk. This part can be closed or controlled with gates for safety issues and optimizing passage efficiency. The passage is 9m wide and has a separate 3m wide vertical slot pathway. The bottom is covered by riprap. The passage is 100m long and 3-5m deep depending on the tide.
(4) The more natural part on the freshwater side of the Afsluitdijk. This part can be completely flooded around high tide and there are no concrete walls or other technical parts, allowing a natural development in time with sloping shores. The bottom consists of sand.
(5) The more technical (artificial) part has walls to ensure that the FMR has sufficient total length to accommodate tidal movement of water within the FMR for the entire (or sometimes most of) tidal cycle. These walls are made of wooden poles and riprap.
(6) At the end of the FMR (at the freshwater inlet side of Lake IJsselmeer) there are sluices that can be closed. Four gates with wooden doors which are manageable through so called 'rinketten' to also provide migration opportunities when the doors are closed. In addition, also two vertical slots are present here.

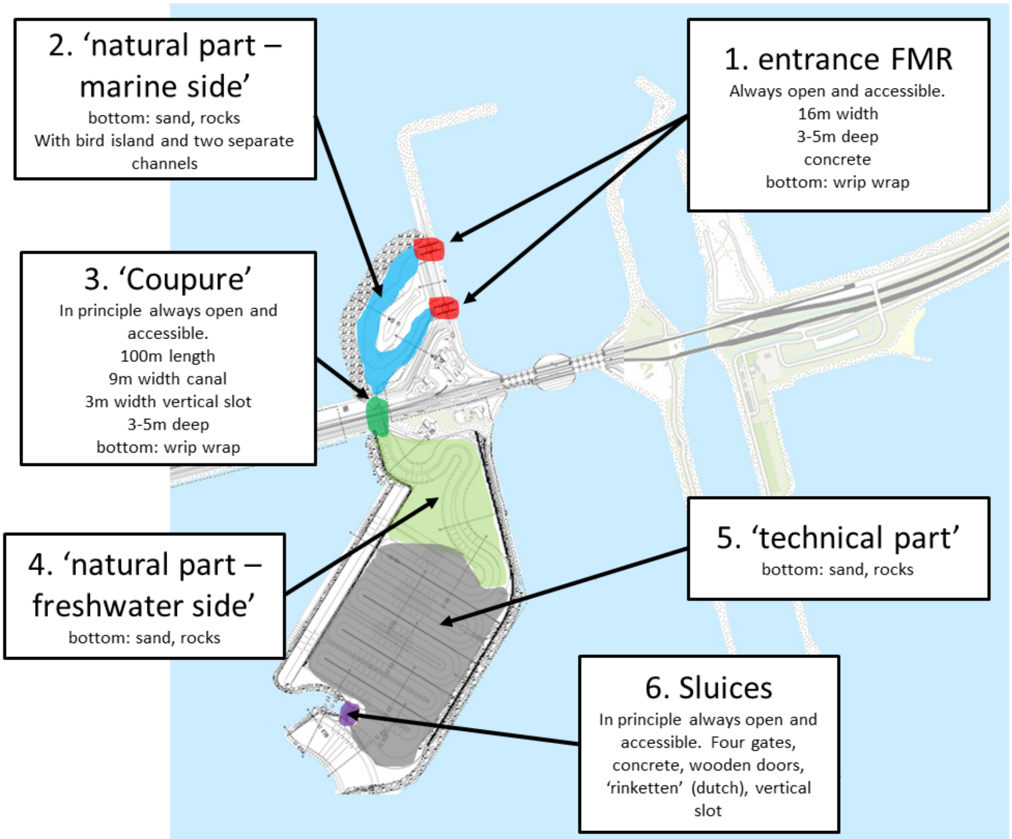

Figure 2.1 Design of the Fish Migration River (FMR), with two entrances, two separate channels, an open 'Coupure' through the dyke, a 'natural part', a 'technical part' with separation walls and a sluice complex (four gates, and vertical slots). In principle the FMR is always open and accessible depending on salinity levels and safety issues.

3 Research questions for monitoring the effectiveness of the FMR

To determine the functioning and effectiveness of the FMR in restoring fish migration alongside the Afsluitdijk Dam between the Wadden Sea and Lake IJsselmeer, different research questions should be addressed. We categorised four research questions (Q1-Q4) into four overarching questions.

Question 1 mainly focusses on *measuring* passage success through the FMR and the other potential migratory pathways through the discharge sluices and shiplock.
Q1 What is the overall passage efficiency of the Kornwerderzand complex per target species?

Question 2 mainly focusses on *understanding* the factors and processes underlying the different passage efficiencies as determined within Q1 and if necessary how these might be improved by management options (Bunt et al. 2012, Castro-Santos 2012). E.g. when the results of the overall passage efficiency for a certain species or group of species are below target levels, then it needs to be determined whether the functioning of the FMR can be improved or optimised.
Q2 Is there a need for improving the functioning of the FMR ('optimizing') and how can this be achieved?

Question 3 focusses on the habitat role of the FMR for fish, the consequences of predation risk and how these relate to Q1 and Q2.
Q3 Is the FMR also used as a habitat by fish and its predators?

Question 4: Whereas Q1, Q2 and Q3 act on the local spatial scale of the Kornwerderzand sluice complex, Q4 takes a much *wider perspective* and determines the effects of increasing migratory opportunities on population levels in the marine and freshwater systems that are connected through the Kornwerderzand sluice complex.
Q4 What is the effectiveness of the FMR on fish population levels?

In the following paragraphs these research question will be described in further detail.

3.1 Overall passage efficiency of Kornwerderzand (Q1)

The end goal of facilitating the discharge sluices and shiplock complex in the Afsluitdijk dam at Kornwerderzand with the FMR is to rehabilitate fish migration between the Wadden Sea to Lake IJsselmeer, where at present, migration into freshwater is most severely affected. Migration is restored when each migrant fish motivated to move to freshwater is able to successfully pass the Kornwerderzand Complex, with no or neglectable delay. The first goal of the monitoring program will be addressing to what extent fish can pass the different potential passage routes in the Kornwerderzand sluice complex: i.e. through the FMR, the discharge sluices and the shiplock (see Figure 3.1).

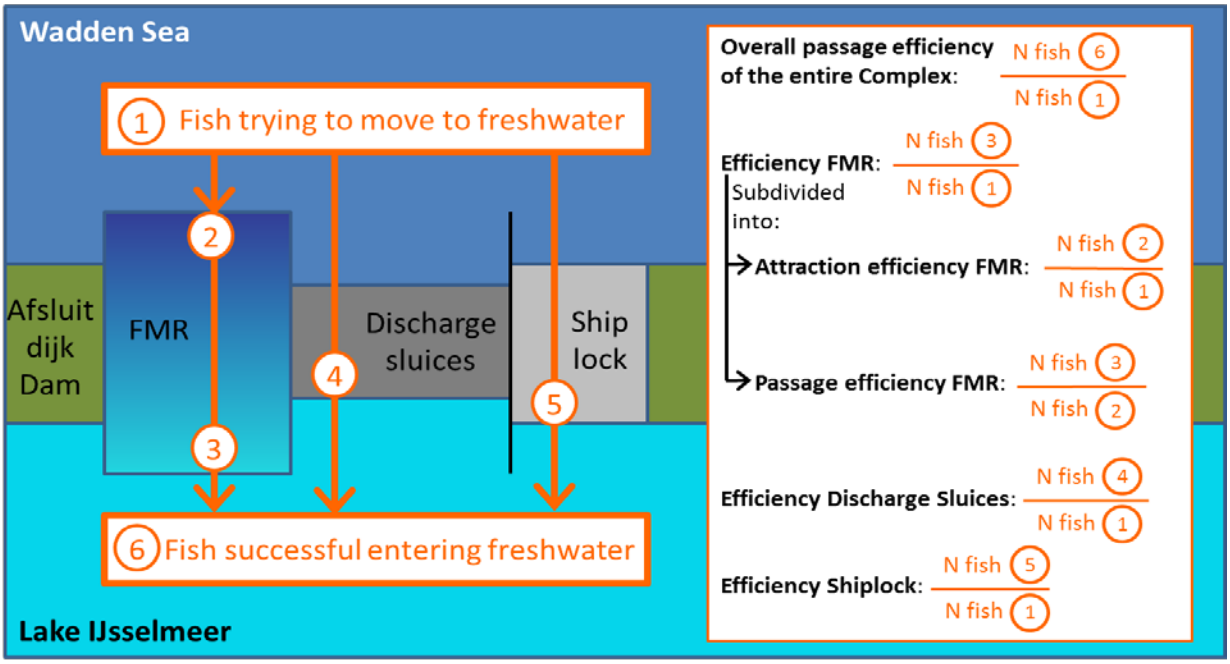

Figure 3.1 Schematic overview of determining passage efficiency through the different potential migratory routes FMR, discharge sluices and shiplock at the Kornwerderzand Complex. For each of the efficiencies along the different routes, it is given how these can be determined (see right hand panel). In addition to the % passage ('efficiency'), also delay and passage rates are important to consider within the evaluation of FMR performance.

The first overarching research question
"What is the overall passage efficiency of the Kornwerderzand complex per target species?"
can be determined when the following questions are addressed:

a. What is the attraction/passage efficiency of the FMR?
b. What is the attraction/passage efficiency of the Discharge Sluices?
c. What is the attraction/passage efficiency of the Shiplock?
d. What is the delay of successfully passing fish?

To answer *Q1 overall passage efficiency* of the entire Kornwerderzand sluice complex, the fraction of the number of fish that approaches the complex from the Wadden Sea side and is motivated to pass, (1) in Figure 3.1, that successfully passes one of the three routes; FMR, discharge sluices and/or shiplock, (6) in Figure 3.1, needs to be determined, i.e. the ratio between (6):(1). And further subdivided into determining the *attraction efficiency of the FMR*; which fraction of the fish motivated to pass the complex is attracted to the entrances of the FMR, ratio between (2):(1), and the *passage efficiency of the FMR*; which fraction of the fish entering the FMR will successfully pass to Lake IJsselmeer, ratio between (3):(2). The *passage efficiency of the discharge sluices*, is determined by the ratio between (4):(1), and *passage efficiency of the shiplock* by the ratio between (5):(1), (see Figure 3.1). Efficiency rates should be considered in relation to time (rates and migration windows (Castro-Santos and Haro 2003, Castro-Santos 2004, Castro-Santos 2012)).

3.2 Optimizing the functioning of the FMR (Q2)

When the results of the overall passage efficiency for a certain species or group of species are below target levels, then it needs to be determined whether the functioning of the FMR can be improved or optimised. This can be due to insufficient attraction of fish to the entrance of the FMR (bottleneck in attraction efficiency, e.g. in approach or entry of the fishway) or due to insufficient passage of fish within the FMR (bottleneck in passage efficiency) or both. Based on the data from monitoring research questions Q1, a further stepwise zooming into potential bottlenecks is needed to determine where attraction or passage is hampered, i.e. studying efficiencies in smaller sections of the FMR (see Figure

2.1). Determining where decreases in passage efficiency take place is important, but to be able to remove or mitigate the identified bottlenecks, also insight in the factors causing these reduced efficiencies and how these are related to options for altering management schemes or alterations for the FMR. Thus, the second research question is mainly focussing on gaining insight in the causes and exact pinpointing of eventual bottlenecks in overall passage efficiency, which is a result of passage through the different potential migratory routes.

Q2: "Is there a need for optimizing the functioning of the FMR and how can this be achieved?"

This includes the following research questions:

a. For which species is optimising of the functioning of the FMR needed, i.e. are passage efficiencies insufficient?
b. Are these related to attraction efficiency (approach or entry) or passage efficiency of the FMR or both?
c. Where does reduced efficiency take place, i.e. step-wise narrowing down the locations?
d. What factors and processes cause reduced efficiency, i.e. insight into behaviour and physical abilities of the species and life stages of concern is needed in relation to the local environmental conditions and dynamics in time (e.g. changes in sluice and water management needed)?
e. How can the identified species-specific bottlenecks in efficiency be mitigated or resolved, i.e. which alterations and/or adaptations in management schemes, options or constructions can be performed?

3.3 Habitat function of the FMR in relation to fish (Q3)

In addition to providing passage for migratory fish, the FMR can also serve as a habitat for (migratory) fishes and other taxa (Figure 3.2). Migratory fish might use the salinity gradients in the FMR for acclimatization from marine to freshwater conditions, when needed. This type of habitat use is then connected to Q1 and Q2 in that it affects passage efficiency and 'delay'. It can also provide food, making it potentially interesting for fish to use the FMR to forage. We have to be careful in our analysis here to be able to determine the difference between 'habitat use' and 'poor passage'. Relatively high densities of fish within the FMR can also attract top predators like predatory fish, birds or marine mammals and due to predation affect the efficiencies in Q1 and Q2 as well. Lastly, depending on the scale and dynamics in the salinity gradients it might also serve as a habitat for estuarine fish species.

"Does the FMR serve as habitat for fish and their predators?"

This can encompass the following research questions:

a. Do migratory fish use the FMR for acclimatization?
b. If so, what (species-specific) conditions are needed?
c. Do migratory fish use the FMR also for foraging?
d. Do other fish species use the FMR as habitat, e.g. estuarine species?
e. Is the FMR used by fish eating predators, e.g. piscivorous fish, birds and/or marine mammals?
f. What is the predation risk for migratory fish by these predators?
g. Can we differentiate between low passage rates caused by suboptimal functioning of the FMR and important transitional behaviours and physiological processes being served by the existing design?

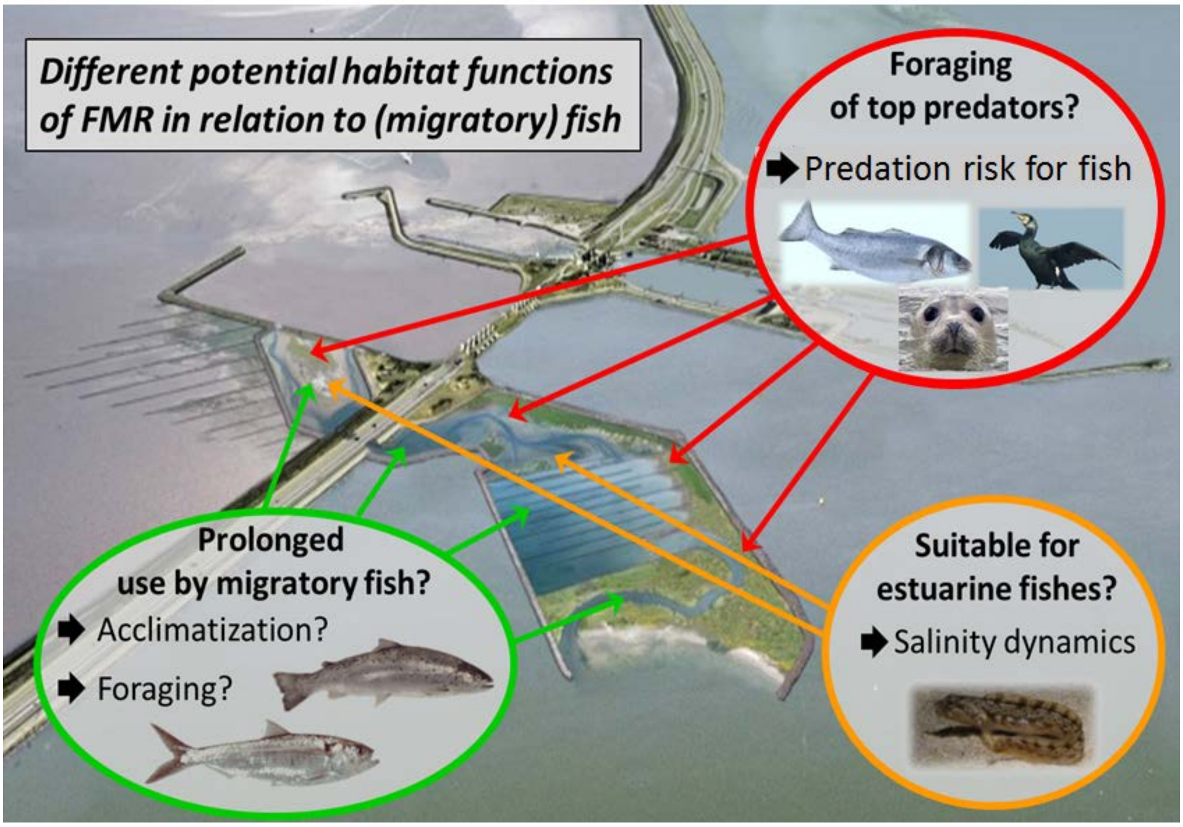

Figure 3.2 Overview of different types of habitat use in the FMR in relation to fish.

3.4 Effectiveness of the FMR on fish population levels (Q4)

The ultimate goal of improving fish migration at barriers and restore ecological connectivity is to restore populations of migratory fish. When providing the FMR at the Kornwerderzand Complex and altered sluice management to improve fish passage leads to increased fish migration opportunities, i.e. high overall passage efficiency (as determined within Q1 and Q2), this will not automatically imply that populations of migratory fish will increase in abundance. If obstruction of migration was the only (or most severe) limiting factor to population size of a given migratory fish population that passes the Kornwerderzand complex, then providing the FMR will lead to an increase in population size. When there are still other bottlenecks or limiting factors, e.g. other migratory barriers in upstream sections of the river system or a lack of critical habitats (e.g. for spawning), acting upon a migratory fish population during the completion of its lifecycle then next to improving migration opportunities at Kornwerderzand also additional management measures are needed to obtain an increase in population size.

When determining the effectiveness of management measures, e.g. providing the FMR, on a population level, then an important first step is to determine;

a. What can be defined as populations that use Kornwerderzand as a corridor between different critical habitats to complete their life cycle, in terms of population structure and/or links to other populations?
b. On what marine and freshwater spatial scales do these populations operate?

The spatial scale of habitat use is very different between species and can also differ between the marine phase and freshwater phase for a given species (Figure 3.3).

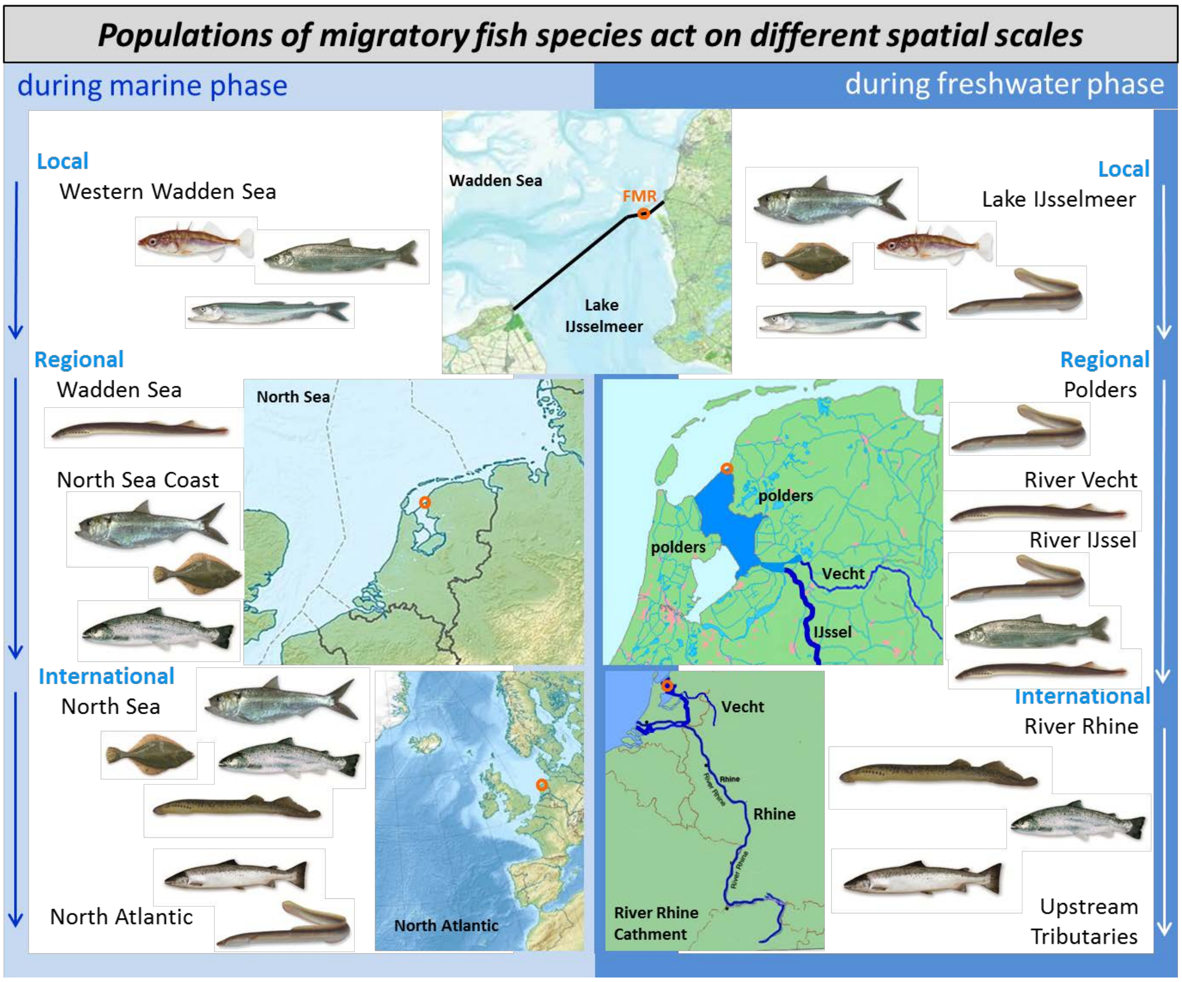

Figure 3.3 Overview of the different spatial scales (ranging from small local to large international scales) for the migratory fish species that use Kornwerderzand. A distinction is made for the marine phase (left panel) and the freshwater phase (right panel). The maps illustrate the matching scales.

Populations of migratory fish that mainly use local scales on both the marine side (e.g. restricted to the Western Wadden Sea) and freshwater side (e.g. restricted to Lake IJsselmeer) are three-spined stickleback and smelt. For both species applies that there are also non-migratory freshwater populations.

Other species, e.g. the Atlantic salmon, act on large scales on both the marine side (migrate to the open North Atlantic ocean for feeding) and the freshwater side (migrate upstream into the small tributaries of the Rhine in Germany, France and even Suisse). Populations that show intermediate scales, e.g. river lamprey migrating upstream River Vecht and River IJssel and their tributaries for spawning in freshwater, whereas the juveniles after metamorphosis from ammocoetes migrate downstream to marine coastal habitats in the Wadden Sea and adjacent areas of the North Sea.

Also, the spatial scale on which marine habitats are used might differ strongly from the spatial scale in which freshwater is used: e.g. adult European eel migrate > 6000 km to the Sargasso Sea in the North West Atlantic for spawning, whereas the vast majority of the glass eel entering freshwater systems will remain in the downstream parts.

When determining the effects of improving migration with the FMR at Kornwerderzand on a population level, not only the scale of the areas used by fish populations that pass Kornwerderzand is important, but also the population structure and rate of exchange between populations. For migratory populations that perform very local movements between the western Wadden Sea and Lake IJsselmeer, such as migratory smelt and three-spined stickleback a more direct link between improving migratory opportunities and response in population level can be expected than for instance for a panmictic migratory species as European eel, where there is one mixing world population. A response in population level for European eel can only be achieved with simultaneous measures taken Europe-wide. Thus, for local populations and populations that show strong homing to native rivers, such as Atlantic salmon, sea trout and houting, and form ‘river-basin specific populations, it is more likely that a response in population level can be observed due to mitigating migration barriers in a particular river basin. Be it that restoring fish passage at the Afsluitdijk might not drastically change overall population level of the European eel or flounder, local abundance in Lake IJsselmeer might however, strongly increased due improved migratory opportunities.

Thus, to address the overall effects of restoring fish passage by the FMR and adjusted sluice management at Kornwerderzand, the main question:

“What is the effectiveness of the FMR on fish population levels”
Can be further subdivided into:

a. What other marine and freshwater areas are used to complete the life cycle of the different of populations of migratory fish species that use Kornwerderzand?
b. What other migratory bottlenecks or alternative migratory pathways are present in the water systems used by these populations?
c. What are other limiting human-impacted factors that determine population size in each of these populations?
d. What trends in population abundance in marine and freshwater systems that are connected by the Afsluitdijk can be observed and how are these related to the improved migration opportunities?

Much of the basic knowledge on population dynamics and migratory behaviour of the target species in the different water systems they use is still lacking, and these questions are therefore not easily addressed for at least some of the target species. A complete coverage of this wider scope on population dynamics and population effects is very ambitious and requires a large research investment, beyond the scope of this monitoring program. We will explore what and for which target species is feasible to be included in our proposal.

4 Overview of monitoring techniques

4.1 Direct and indirect measurements on passage efficiency

There are many monitoring techniques available to observe and follow individual fish or groups of fish. In this chapter a brief overview of relevant and applicable techniques will be given in addition to, and based on, the overview given by Calles et al (2014). In this chapter a distinction will be made between *direct* and *indirect* measurements in answering the research questions. Direct techniques, e.g. tagging and telemetry techniques, allow to follow and track individual fish and will yield direct measurement of percentages of passage and attraction efficiency (e.g. in %/attempts, and attempts rate) in combination to specific behavioural patterns, e.g. searching behaviour or number of passage attempts, and duration of passage through different sections. However, these techniques are not always applicable to all fish species and sizes. Some fish are too small or too fragile for individual tagging techniques. For those fish, other research approaches and techniques are needed to more 'indirectly' determine the total numbers of fish arriving at the complex and passing through the different routes and sections of the Kornwerderzand Complex comprising the FMR, discharge sluices and shiplock as presented in Figure 3.1 by measuring densities and fluxes of fish in the different connected sections that make up the complex. In addition to these indirect techniques to assess total number and fluxes, mark recapture experiments can be used to determine underlying duration of passage, 'recurrence behaviour' (i.e. the degree to which back and forth movements in sections, or 'loop' movements within the complex occurs) and independent total number estimates. A schematic overview of the proposed approach of using direct techniques for species for which these are applicable in combination with indirect assessments based on total numbers, densities and flux measurements for fish species or life stages where tracking techniques are not available and where possible combined with mark-recapture experiments is given in Figure 4.1.

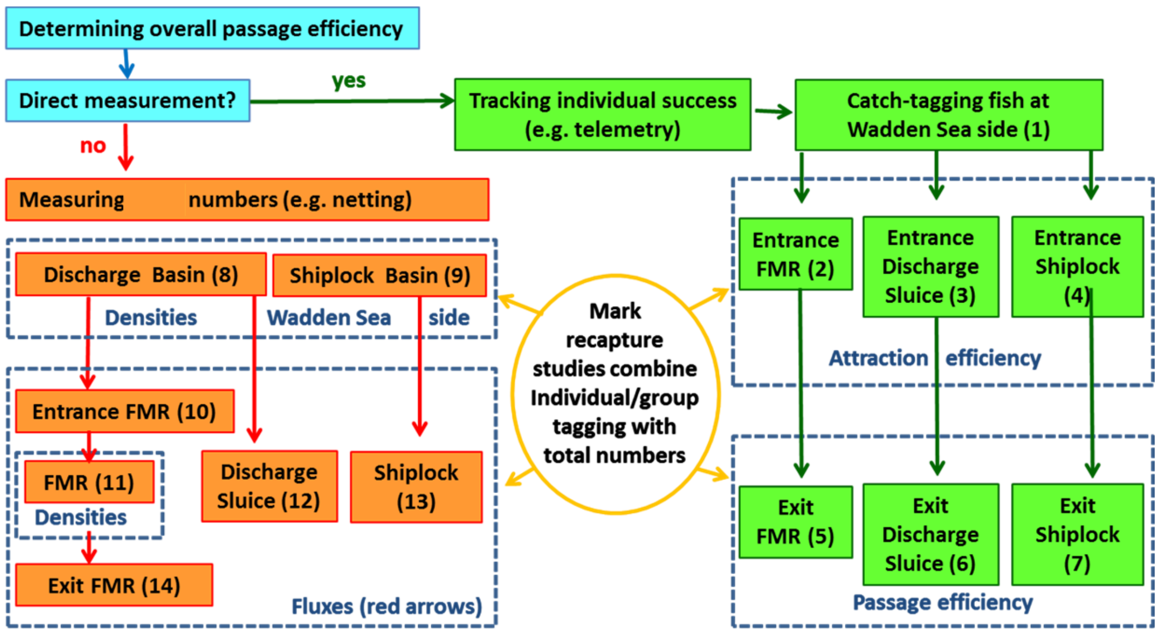

Figure 4.1. A schematic flow-chart of determining overall passage efficiency by using direct techniques for species for which these are applicable (green boxes and pathways) and with indirect assessments based on total numbers, densities and flux measurements for fish species or life stages where individual tracking techniques are not available (orange boxes and pathways) and where possible combined with mark-recapture experiments to determine duration, recurrence behaviour and provide independent estimates for total numbers.

4.2 Direct measurement monitoring techniques

Telemetry techniques give insight in individual searching behaviour, attraction and passage success of tagged fish as well as the duration of passage through different sections and indicate number of passage attempts and success and failure rates in time. These techniques yield *direct* measurements (%) of passage success and behavioural patterns as seen at Kornwerderzand (De Vaate et al. 2003, Griffioen et al. 2014b). There are several acoustic, transponder and radio-telemetry techniques available to track fish (as listed in Calles et al. 2015). Due to the larger water depths and salinity gradients in and around the sluice complex, radio-telemetry may not be feasible here, we will discuss the more sophisticated telemetry transponders: acoustic transmitters (e.g. VEMCO or JSATS), RFID transponders (NEDAP) and passive integrated transponders (PIT-tag) since these techniques can give answers to passage success. However, not all target species are physically suitable to implant tags.

With all of the following techniques, an approval of the animal ethical commission is needed since surgery to the fish is needed when implanting tags in the body cavity. E.g. fish needs to be anaesthetised (e.g. with 2-phenoxyethanol 0.2-1.0 ml/L depending on species and complexity of the surgery) to implant tags in the body cavity. Usually by a mid-ventral incision in the posterior quarter of the body cavity is made. The incision can be closed with resorbable sutures or glue. In many cases surgery last 3–5 min. After surgery fish need to be observed in a recovery tank until swimming behaviour is normal and released to continue migration. Preferably, translocation of fish should be as minimum as possible.

Acoustic telemetry: VEMCO Acoustic telemetry is a proven useful technique at the study site Kornwerderzand (Griffioen et al. 2014b). This techniques needs a transmitter (in the fish) and a receiver (Figure 4.2). The receivers are relatively small and can be placed at any location depending on the study (flexible). VEMCO can deliver client specific coded transmitters that operate at 69 kHz and 180 kHz and are available in different sizes: 180 kHz V4 and V5 (4mm and 5mm in diameter) and for 69 kHz (V7 – V16). Each tag sends an acoustic pulse train (8 pulses in approximately 3.2 seconds) at pre-set time intervals. These acoustic pulse trains are random about an average delay time to minimise collisions between different tag pulses. Each pulse train includes a specific ID number for each tag to track the individual fish and for the larger tags (V9-V16) there are also possibilities to log temperature and depth (pressure). Detection range and time of the transmitters is depending on the local circumstances (range), size (range and battery life) and pre-set time intervals (battery life).

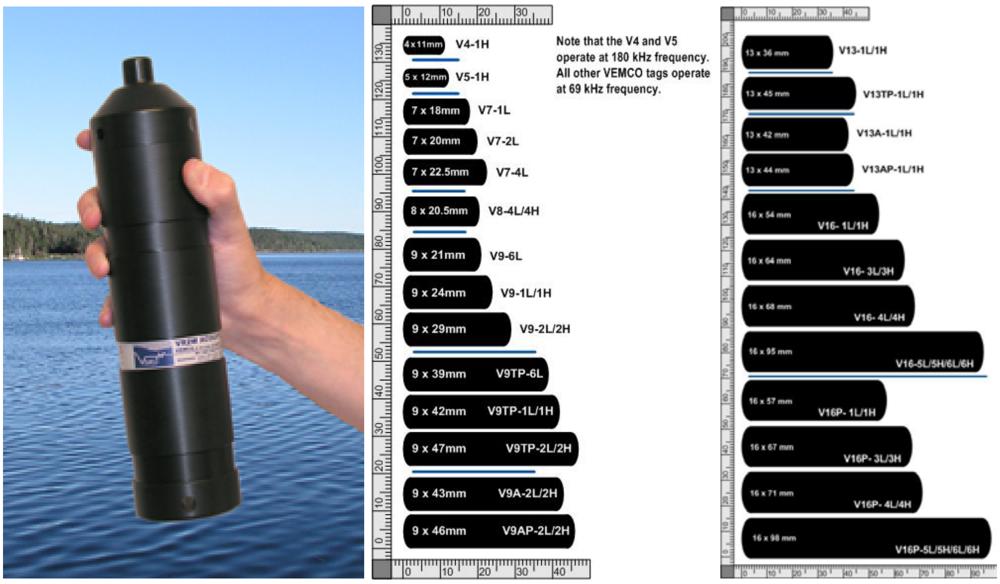

Figure 4.2 Vemco receiver (left) and different types of transmitters (right).

This technique can also be applied for a VEMCO Positioning System (VPS) that allows precise positioning of the fish in time and space e.g. (Winter et al. 2011) and is very useful for behavioural studies at both physical as for non-physical barriers. However not all sites, including the discharge basis at Kornwerderzand, allow to use such an experimental VPS setup.

The most commonly used VEMCO type in Belgium and the Netherlands is the VR2W, 69 kHz receiver type (V7-V16 transmitters). It can be very useful to use the same type of transmitters and receivers (69 kHz) for international purposes. E.g. in 2015 a tagged 'Dutch' eel was unexpected picked up in the Belgian receiver network (lifewatch.be).

Acoustic telemetry: JSATS

JSATS (Juvenile Salmon Acoustic Telemetry System) transmitters come in a variety of sizes (some even smaller than PIT-tags), weights, and pulse rate intervals (PRIs) to accommodate a range of fish sizes, study durations (few days – multiple years), and study objectives. JSATS is open source technique with free software. JSATS was developed specifically for fish passage applications, and offers rapid transmit rates with low collision probability (e.g. code transmissions occur in a few 10s of milliseconds. Tags may be cheaper in comparison to VEMCO, while receivers may be more expensive. In all, costs are comparable or at best even somewhat lower than the budget estimates for VEMCO equipment.

Radio Frequency Identification telemetry: NEDAP

This telemetry system is based on Radio Frequency Identification (RFID) technology and needs transmitters and fixed detection stations (Figure 4.3). Each of these stations contains three parallel antenna cables lay on the bottom of the site. The stations send out interrogation signals every 4 s, which activate each transponder that passes. The transponder then sends out a unique code, which is received by the stations. Lifetime of these transponders is guaranteed for 2 years, when the total number of detections does not exceed 1000 And the detection range is ca. 20 m above the three detection cables that fully cover the water width. The system has been tested in more saline waters where is also functions well (*Breukelaar, unpubl.*).

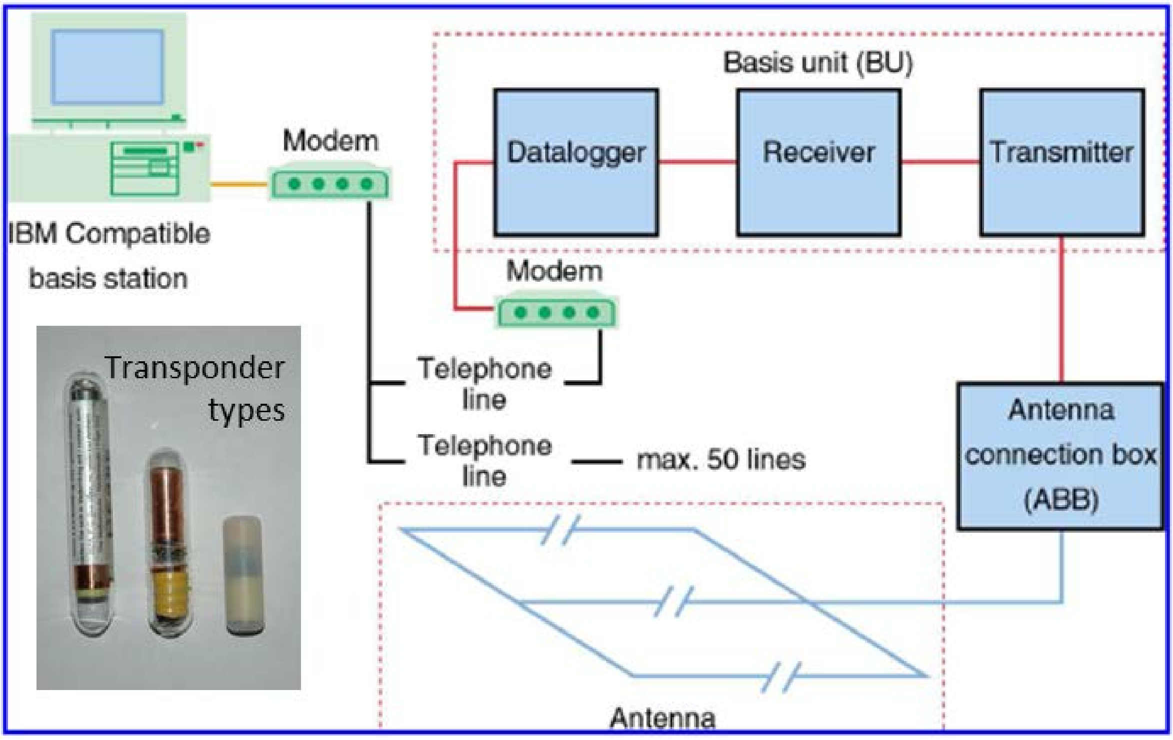

Figure 4.3 Schematic overview of NEDAP Trail-telemetry system, inset shows the 3 different types of transponders that are available.

At the moment there is one detection station covering the full inside of the complexes in the Afsluitdijk Dam at Kornwerderzand. In addition to these, there is an intensive array of 60 stations in the catchment areas of the Meuse and Rhine basin (De Vaate et al. 2003). It is preferred to install detection stations on the outside, i.e. to determine outside arrival and searching behaviour on the sea side. The transponders are suitable for larger fish (30 and 63 mm tag length).

Radio Frequency Identification telemetry: PIT-tag
This telemetry system is based on Radio Frequency Identification (RFID) technology and needs transmitters and fixed detection stations. Compared to the NEDAP technology these transponders do not have an internal power supply (passive), and tags are much smaller (12, 23 and 32mm in length). Another difference is that tags will operate indefinitely. The transponders are glass encapsulated electronic circuits powered by magnetic fields from a reader. In general there are two types of tags: half duplex (HDX) and full duplex (FDX). HDX is the most commonly used technique in the Netherlands and known as a more robust and reliable type for fish pass evaluation (Castro-Santos et al. 1996). The longer the tags the larger the detection range. The detection range will be smaller in salt water. With detection station design, at least three phases are distinguished:

1) design detection station
2) build a prototype to test loops and detection range
3) build final detection station

The alternating salinity inside the FMR will affect the performance of the antennas, but it should be possible to construct arrays of antennas that will detect most fish. Especially when auto-tuning electronics are applied. Fish have to be in the immediate vicinity of an antenna to be recorded and identified and it can be used on all tagged fish passing close enough to the antennas within the FMR. This technique can be used to tag a large number of individuals, considering the low price per tag, and fish can also be detected further inland when they enter rivers and creeks if detection station are installed over there. Contrary to NEDAP and VEMCO, duration of the tag is not a limitation and the study could last over a longer period of time compared to e.g. radio- and acoustic-telemetry described below.

4.3 Indirect measurement monitoring techniques

Visual: Video counting riverwatcher and fish counter
Video counting systems such as the VAKI riverwatcher has a scanner unit and a control unit. The system can provide automatic counts, reports and videos of all registered fish in Riverwatcher Daily. The system can estimate the size of each fish, capture videos (also IR) of each fish and PIT-tag identification is also possible once the system is equipped with a PIT-tag detection system. Fish need to be guided in the ‘tunnel’ in order to be detected, filmed and measured. Normally this guidance is done using trashracks as seen in Figure 4.4. *A standard tunnel is 160 x 105 x 63 cm (L x W x H) and is fitted with the underwater digital camera, lights and scanner unit. Standard opening between scanner plates is 40 cm, which might hamper some larger species like sturgeon or elusive species like shads. The tunnel ensures that the images are captured under controlled and constant lighting conditions, as well as the optimum position and distance of the fish to the camera.* [2] For the FMR a double or multiple stacked VAKI system is advised to cover the full water column (pers. comm. Magnus Thor Ásgeirsson).

[2] http://riverwatcher.is

Figure 4.4 VAKI riverwatcher examples (photos VAKI)

Resistive fish counter

The Logie fish counter (2100C) is used in conjunction with an electrode set to detect the upstream and downstream passage of fish in the body of water in which the electrode set is installed[3]. The counter is activated when a change in the resistance of the water is caused by the passage fish. When coupled to a video system, species determination is possible.

Acoustic: DIDSON / ARIS: detecting small scale behaviours and undisturbed counting of fish numbers

Acoustic camera's such as the DIDSON and the ARIS (www.soundmetrics.com) are very useful for behavioural and quantitative studies of fish. High resolution sonar images up to 128 beams and 3.0 MHz can observe fish without disturbance and are usable in turbid and dark waters e.g. (Doehring et al. 2011, Keeken et al. 2011, Griffioen et al. 2012). There are different types and models on the market. All models offer dual frequencies, dynamic focusing, multiple recording and output options, background subtraction and software: ARIS 3000 (128 beams 1.8/3.0 MHz 5-15m range), ARIS 1800 (96 beams 1.1/1.8 MHz 15-35m range), ARIS 1200 (48 beams 0.7/1.2 MHZ 35-80m range) and DIDSON-DH (96 beams 1.1/1.8 MHz 15-35m range). Images can be analysed using software. There are developments to analyse images automatically using Echoview for quantitative studies. This technique enables fish measurements under all light conditions, but species identification is difficult especially for the smaller fish, and the volume of the beam is relatively small.

Visual: Infrared camera

Infrared cameras in combination with LED infrared lightning are used to observe fish behaviour at small fish passages or other migration opportunities, with minor or no disturbance of the natural migration behaviour (e.g. (Foekema et al. 2015)).

Netting techniques: traps, seine, beam trawl, lift nets, driftnets, etc.

There are a lot of different netting techniques and types available that can be used or can be optimized for different purposes depending on the situation, research question or aim. Nets can be used both as passive (traps) or active (seine, trawl, liftnet etc). All nets have a species and site specific catch efficiency which should be taken into account. Traps are useful for trend monitoring and especially functional to apply during longer (migration) periods with relatively low effort. Especially for fish species with low abundance and short migration periods traps can increase the chance of a catch instead of an active fishing method. Traps are used since 2000 at Kornwerderzand for trend monitoring of diadromous fish (Sluis et al. 2014). These data is used in studies for the FMR pre studies (Griffioen 2014, Griffioen and Winter 2014a, b, Griffioen et al. 2014a, Griffioen et al. 2014b) and also in combination with mark recapture studies and (active) trawling for river lamprey to get knowledge on residence time and migratory delay near the sluices (Griffioen and Winter 2014b). Moreover, traps can be equipped with PIT-tag systems to asses retention efficiency of the traps, and also to gain estimates of population size.

[3] http://www.aquantic.com/

The upstream migration in tidal gates, of small diadromous fish can be determined using so-called tapered driftnets (ARCADIS 2015). It should be taken into account that these methods where only used during the adapted sluice management regime, which lasted for 15 minutes (ARCADIS 2015). Therefore, this technique has practical limitations for longer studies. These net can be installed in the tidal gates, but they do not fully cover the wet surface of a tidal gates. In previous studies, five nets where used: three nets on the bottom, one in the middle and one at the surface (ARCADIS 2015). All nets together, covered 7.5% of the full wet surface of one tidal gate. An alternative method is a large and long net ('atoomkuil') that fully covers the wet surface of a tidal gate, but mesh size (40mm – 8mm) must be wider compared to the tapered driftnets. Using the latter method, small and or elongated diadromous fish such as flounder larvae (5-7mm in length) and glass eel will probably be missed. In the shiplocks large fine meshed nets can be applied when there is no ship traffic (ARCADIS 2015).

Besides trend monitoring, traps are useful to catch test fish for telemetry experiments such as: three-spined stickleback, smelt, sea trout, salmon, houting, river lamprey and sea lamprey. In combination with other techniques (e.g. active trawling, mark recapture techniques), one can get insight in catch efficiency and the abundance of specific diadromous fish (Griffioen et al. 2014a).

Griffioen et al. (2014b) used an extensive liftnet program to get insight in the behaviour and abundance of small migratory fish: glass eel, flounder larvae, smelt and three spined stickleback. Foekema et al (*in press)* and Dekker used liftnets in combination with group dyeing to examine residence time of glass eel in the vicinity of tidal barriers (Dekker and vanWilligen 1997, 2000).

Marking: Group dyeing, tagging, colouring

Marking experiments are useful to have insight in residence time, behaviour and estimating abundance (Griffioen and Winter 2014b). Fish can be marked individually (e.g. PIT-tag) or as a group (e.g. using colours as Bismarck brown, visible implant elastomers (VIE), coded wire tags and tattoos). Such techniques can be applied to glass eels or any other fish for which group tagging is sufficient for the aim of the study. All species that are not able to be tagged with VEMCO, NEDAP are especially species of interest in mark recapture experiments to gain knowledge on behaviour, passage success etc. using indirect measurements. For this study these species are especially three-spined stickleback, smelt, flounder larvae and glass eel. Some species (stickleback and possibly smelt) can be tagged with PIT-tags, however considering the large numbers of fish and the species of interest, the number of marked fish should also be high for reliable results. Handling the fish for PIT-tagging should therefore be quick to ensure a sufficient number of fish that is tagged. Larger fish are relatively easy to tag (Griffioen and Winter 2014b), but species like a stickleback takes more time and other methods may seem better for mark recapture experiments. A pilot study for tagging issues is preferred to decide which species will be analysed based upon individual tracking or 'batch tracking'

The type of marking is therefore species specific and depends on the research question. The constraint of marking using colours or VIE is that each fish has to be marked individually and also checked individually (NMT 2008). This makes it labour intensive in comparison to batch mark colouring using Bismarck Brown. However, the constraint of colouring with Bismarck Brown is that the colours are only visible for a couple of days. Considering Batch marking using Bismarck brown seems therefore more suitable compared to VIE unless the timespan of the experiment is long. Not all species may not be suitable for batch colouring using Bismarck brown, this should be tested in a pilot study. If smelt seems not suitable for individual PIT-tag marking or VEMCO, VIE may be a useful method for this species (restricted to the less abundant and larger diadromous variant of the species). VIE colours (red, orange, green, yellow, pink and blue) are fluorescent under short-wavelength (far blue and UV) light and visibility can be enhanced by the use of suitable illumination (NMT 2008). This makes catch analysis with thousands of fish easier and more reliable. It is noteworthy, that all invasive methods could have influence on the fitness of the fish and results can therefore be distorted (Henrich et al. 2014). However, negative influences of the invasive methods will result in conservative conclusions, which is appropriate given the objective to produce good passage.

4.4 Abiotic measurements

Abiotic measurements are especially useful in the optimizing part of this monitoring program (Q2). Fish behaviour is often related to and influence by to local circumstances. Fish alternate their behaviour depending on hydrodynamics (e.g. Keefer et al. 2012). In literature, back and forth swimming is related to acclimatization to a newly salinity gradient, but could also be related to orientation or foraging (see review Winter et al. 2014). To evaluate (Q2) FMR passage efficiency, attraction flow and habitat use, it is important to relate behaviour to abiotic circumstances. Moreover, behavioural patterns should be quantified as precisely as possible using sophisticated telemetry techniques such as VEMCO at strategic location within the Kornwerderzand complex.

A network of fixed measuring devices on different water depths measuring: salinity, temperature, turbidity, velocity, flow direction and water level, is needed for fish behaviour interpretation. Abiotic data must be collected throughout the full length of the monitoring activities in great detail (e.g. per minute or per ten minute). The equipment should be installed in the FMR, lake IJssel and in the discharge basin. Additional computational fluid dynamics (CFD) modelling may be preferred since processes might occur in zones that are not monitored.

Since salt water intrusion into Lake IJsselmeer is a management prerequisite, managing saltwater dynamics is important. For the functioning of the FMR it is important to allow as much tidal movements as possible within the FMR. In relation to optimizing the functioning of the FMR (Q2), a combination and iterative approach of detailed modelling of the complex and FMR dynamics in e.g. salinity (salt water intrusion), and a detailed measuring program to validate the models are needed.

The netting program has included driftnets (anchored ‘plankton nets’ that alter fishing direction according to tidal currents) that move with tidal currents. Each driftnet should be equipped with flow meters to ensure precise water volume calculations. Additional CTD (conductivity, temperature and depth) meters could be used to related catches to abiotic circumstances. Liftnet, trawlnet and driftnet experiments should at least take into account CTD measurements during the activities. These meters must be attached to the nets to register the abiotic circumstances during netting activities.

Besides temporal measurements during netting programs, it is important for the telemetry experiments to have permanent registrations of abiotic parameters. These meters should at least include salinity, temperature, turbidity, velocity, flow direction and water level. Moreover, for hydrodynamic modelling studies, detailed bathymetry and other measurements are needed. This equipment (ADV, salinity meters, etc) is included in a separate Wadden Academy research proposal to use the FMR and complex at Kornwerderzand (Philippart 2016) and is not treated further in this report.

5 Proposed monitoring program

5.1 Program proposal based on four main research questions

The primary goals for the FMR are to provide and extend fish migration opportunities, especially for the heavily hampered small diadromous which are predominantly depended on tidal currents. The FMR will extend migratory windows and migratory opportunities for all migratory fish reaching Kornwerderzand. Moreover, the FMR will introduce a temporal brackish zone in the FMR providing a potential estuarine habitat and opportunities for acclimatization.

To evaluate these goals and characteristics, extensive surveys will be required. The proposed monitoring program primarily aims at evaluating the defined goals for the FMR and is divided into four main categories:

1. **Overall passage efficiency**
   What is the overall passage efficiency (rate) for the target species at the complex Kornwerderzand?
2. **Optimizing FMR**
   Are there bottlenecks present that hamper optimal attraction and passage efficiency of the FMR?
3. **Habitat use of the FMR in relation to fish**
   Will the FMR be used as a habitat for acclimatisation and or foraging?
4. **Effectiveness of the FMR on population levels**
   What other bottlenecks in the migration cycle are present?
   What are the effects of the FMR on population level?

When discussing the first research topic, all figures will indicate an extension of the program related to attraction efficiency, habitat use and bottleneck analysis. This monitoring program is designed and focussed on upstream migration.

5.2 Q1 Overall passage efficiency

Q1. What is the overall passage efficiency for the target species at the complex Kornwerderzand?
In general, overall passage efficiency is defined as the successful part of migrants (%) that was initially motivated to pass the complex of Kornwerderzand for continuation of migration. We consider the complex at Kornwerderzand as one complex with different migration opportunities including the FMR (Figure 5.1). The goal of the FMR is to increase the overall passage efficiency and to minimize delay of (motivated) migrants of the complex. To evaluate this goal a reference situation (T0) will be compared to a situation once the FMR is installed and in operation. For some species, sophisticated telemetry technique may be applied, while others need an extensive netting program in combination with mark-recapture experiments in order to get knowledge on the impact of the FMR (Table 2).

A successful overall passage is highly dependent on factors such as bottlenecks, optimal attraction efficiency and habitat use. Only if those topics are optimal, and no conflicting events occur elsewhere, effects on population level will be seen (Q4). Therefore, many techniques described and used to determine overall passage (Q1) are also (partially) applied for bottleneck analysis, attraction efficiency and habitat use. All of these factors are essential topics for an optimal passage efficiency. As seen in the passage in Geesthacht several PIT-tag loops are present e.g. halfway the passage. These loops are important to identify bottlenecks in the passage itself. Fish may enter a passage, but could be hampered by various reasons in the passage and decide to swim back again. This eventually will result in lower passage efficiency, while attraction efficiency will possibly be optimal. To examine such phenomena it is advised to equip the FMR with monitoring techniques not only at the entrance and the exit, but also in the passage itself. For that reason, fish equipped with relatively expensive transmitters or tags can simultaneously be used to identify potential bottlenecks in the FMR.

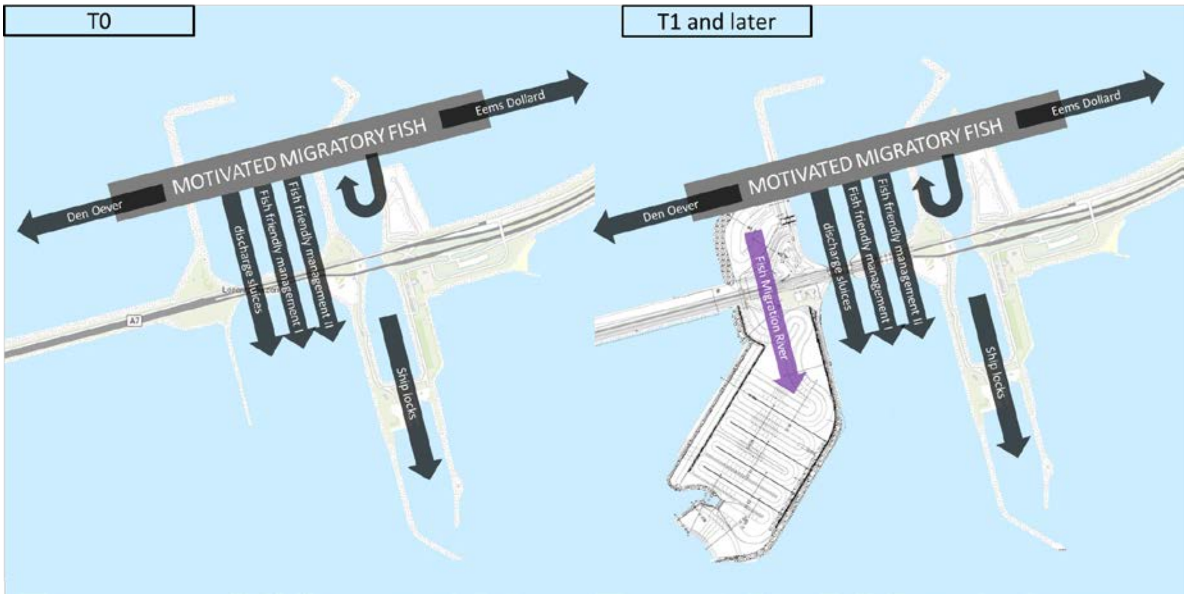

Figure 5.1 Reference situation (left) with two types of adapted discharge regimes (I & II) that facilitate fish migration (see Griffioen et al. 2014b). Right a future (T1 and later) situation, when the FMR is installed and in operation. Some of the motivated migrants will postpone their migration or die as a result of predation, fisheries or blockage. The direction to the other sluice complex in the Afsluitdijk (Den Oever) and adjacent river estuary of Eems-Dollard are indicated..

Table 2 Overview of different techniques, extensive background information and relevance per research question. The table gives an indication of usability per technique per species. The netting program includes different types of nets (traps, lifnet, drift net, trawlnets, etc). Of course, not all nets are applicable for all species. Alternative techniques such as JSAT should be taken into account, which can be applied for the same budgets as listed here for VEMCO.

Category	**NEDAP**	**VEMCO*** **	**PITtag**	**Netting program**
Technique	RFID	acoustic	RFID	nets
tracking fish	individual tracking	individual tracking	individual tracking	Indirect, batch tracking with mark recapture (colour, VIE) or individuals (PITtag, VIE)
Stations	fixed	fixed but flexible	fixed	flexible (active), fixed (passive)
Installation of stations	extensive	quick and easy	extensive	quick and easy
Related research questions	Q1, (Q2), Q4	Q1, Q2, (Q3), Q4	Q1 (partially)	Q1, Q2, Q3
Passage efficiency	yes, directly complex level	yes, directly complex level	yes, directly FMR level	indirect, density comparison
Attraction efficiency	yes, directly	yes, directly	yes, directly but limited to the FMR	indirect, density comparison
Fish behaviour (Q2)	marginal	yes	marginal	Not directly, but batch tracking with mark recapture (colour, VIE) or individuals (PITtag, VIE) is applicable
length of transmitters / tags cm	3.8 (small), 6.3 (large)	1.8-4.3cm (2.2cm) V7-V9	1.2-3.2	NA
diameter of transmitters / tags cm	1.3 (small), 1.6 (large)	0.7-0.9	0.2-0.4	NA
Applicable in hinterland (rivers)	yes	yes, extra costs	no	NA
Applicable at Northsea, Waddensea	no	yes, extra costs	no	NA
Applicable in hinterland (small tributaries)	yes, extra costs	yes, extra costs	yes, partially extra costs	NA
Surgery needed	yes	yes	no/yes, quick	NA
Power for stations	mains voltage	battery	mains voltage	NA
Power transmitters / tags	battery	battery	no, passive	NA
Battery life	6 months (small), 2 years (large)	flexible	eternal	NA
VPS study	no	yes	no	NA
vertical position of fish	no	yes	no	NA
Atlantic Salmon	yes	yes	yes	yes
Flounder Larvae	no	no	no	yes
Three spined stickleback	no	no	yes	yes
European eel (glass eel)	no	no	no	yes
Twaite shad	unsure*	unsure*	unsure*	yes
Houting	yes	yes	yes	yes
River lamprey	no	yes	yes	yes
Smelt	no	unsure*	unsure*	yes
Sea trout	yes	yes	yes	yes
Sea lamprey	yes	yes	yes	yes
Target species	4-5	5-7	6-8	10 (all)
Description and relevance technique	NEDAP will give insight in passage efficiency of the complex(Q1). Additional cables give insight in behavioural patterns. However system may be less flexible in comparison to acoustic telemetry techniques. This will give clues for acclimatization behaviour, bottleneck analysis etc. (Q2). It has a several detection stations in the hinterland, freshwater only (Q4).	VEMCO will give insight in de passage efficiency (Q1), additional receivers give isight in detailed behavioural patterns. This will give clues for acclimatization behaviour, bottleneck analysis etc. (Q2). Also habitat use will partially be clarified since receivers are installed in the FMR (Q3). With extra effort also receivers can be installed in the Waddensea, North Sea coast and the river (tributaries). The Belgian already have a network in coastal systems.	PITtag will give insight in passage efficiency of the FMR (Q1). The technique is not applicable for the discharge sluices or the shiplocks. PITtag stations are installed in small streams in the regional waters of water boards (partially Q4).	The netting program will give indirect passage efficiency (Q1) by comparison of densities and occurence of fish. In combination with mark recapture experiments, residence time and behaviour can be clarified to a certain degree of certainty (Q2). The netting program will also be used for question related to Q4.

*due to physical condition of fishspecies after catchment
**only FMR
*** JSAT might be a good alternative (see chapter 4)

5.2.1 Direct measurements using telemetry techniques

For the large (and not fragile) fish species, direct measurements, using sophisticated telemetry techniques (JSAT, VEMCO, NEDAP and PIT-tag), are a method to get detailed passage success per route (FMR, sluices and locks) within the complex. A representative group of fish per species will be tagged and released near or at the complex. Using telemetry techniques to follow these fish will give an estimate of the percentage of fish that tried to pass the complex in proportion to an actual passage success. As seen by Griffioen et al. (2014b), not all fish will be motivated to pass the barrier once released. Therefore, an estimate of the passage efficiency is always based on the number of tagged fish, the number of fish that made migration attempts after release and the fish that passed the complex. Preferable, the telemetry technique must be able to distinguish between an approach (attempt), an entry and passage of an individual. In general, overall fish passage efficiency of the following fish species can be evaluated using three different techniques: VEMCO (and/or JSAT), NEDAP and PIT-tag. Depending on the species a technique or a combination of techniques must be chosen. VEMCO is a flexible method giving high resolution data to gain insight in questions related to, behaviour, attempts and passage success. Whereas NEDAP has, at the moment, a better potential to gain knowledge on passage success in combination with success of the migration further upstream and will also give information on passage success. The construction of NEDAP stations to cover the complex of Kornwerderzand including the FMR is part of a cooperative action together with Rijkswaterstaat, is part of a larger existing network, and will be included in the construction process. PIT-tag is especially useful to use for smaller fish such as stickleback and smelt[4]. However, it is wise to tag all migratory fish that are physically able to tag with PIT-tags since tags are relatively cheap, the lifespan of the tags are 'eternal', and upstream tributaries may have also PIT-tags stations in the future. Mark recapture studies will also benefit from fish that are equipped with PIT-tags. Some fish will then be equipped with both a VEMCO or NEDAP transmitter and a PIT-tag.

VEMCO – reference situation T0

In the reference situation (T0) a total of 18 Vemco VR2W receivers are needed, both on the freshwater side, as at the marine side 12 receivers (Figure 5.2). To deploy a VR2W, the receivers are attached with tie-wraps to a wooden pole during low tide at the so that they were completely submersed during the complete tidal cycle at the marine side of the complex. Transmitters need to send a pulse train random between 30 to 50 seconds to prevent misdetection during high velocity rates and acoustic noise as a result of discharge events. At least two fixed reference transmitters are placed to determine how the detection range is influenced by discharge events and the large hydrodynamics in the discharge basin. Those transmitters are set to send a pulse train random between 460 to 500 seconds during the experiment. This experimental setup has been proven effective to evaluate searching behaviour and passage success of sea lamprey, houting and sea trout (Griffioen et al. 2014b). Larger fish can also be implanted with larger transmitters e.g. V9, but in general V7 transmitters are suitable enough for evaluation.

VEMCO – after construction

After the construction phase, a total of 19 Vemco VR2W receivers are needed to evaluate passage efficiency. Compared to the reference situation, an additional receiver is located at the exit of the FMR (fresh water side), and two are relocated at the entrance of the FMR (inside). It is noteworthy, that many larger fish species are expected to be caught in low numbers. Each individual is therefore very valuable. Therefore, an additional seven receivers can be installed to evaluate attraction efficiency and passage efficiency of the FMR, parallel when testing overall passage efficiency. And secondly, an additional 11 receivers can give knowledge on behaviour within the FMR. In the field it is needed to test whether there is an overlap in detection range of the receivers. Manual transmitters (low delay) or reference transmitters (long delay) can be used for this.

[4] Need to be tested in a pilot study whether larger smelt are suitable to implant PIT-tags

Program: overall passage efficiency (Q1)
Pre-construction (T0) 18 VR2W receivers
After construction (≥T1) 19 VR2W receivers
Program: attraction efficiency, passage efficiency FMR(Q2) and habitat use (Q3)
After construction (≥T1) 37 VR2W receivers.

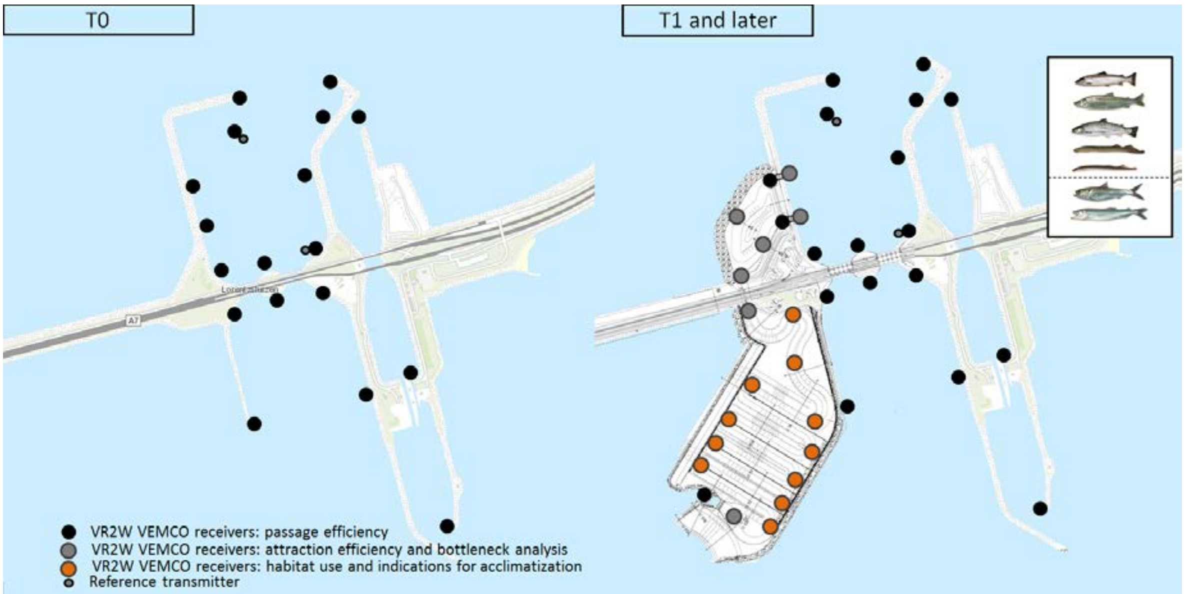

Figure 5.2 LEFT: Experimental setup with VEMCO VR2W receivers in reference situation. RIGHT a future (T1 and later) situation, with an extended VEMCO VR2W receiver setup.

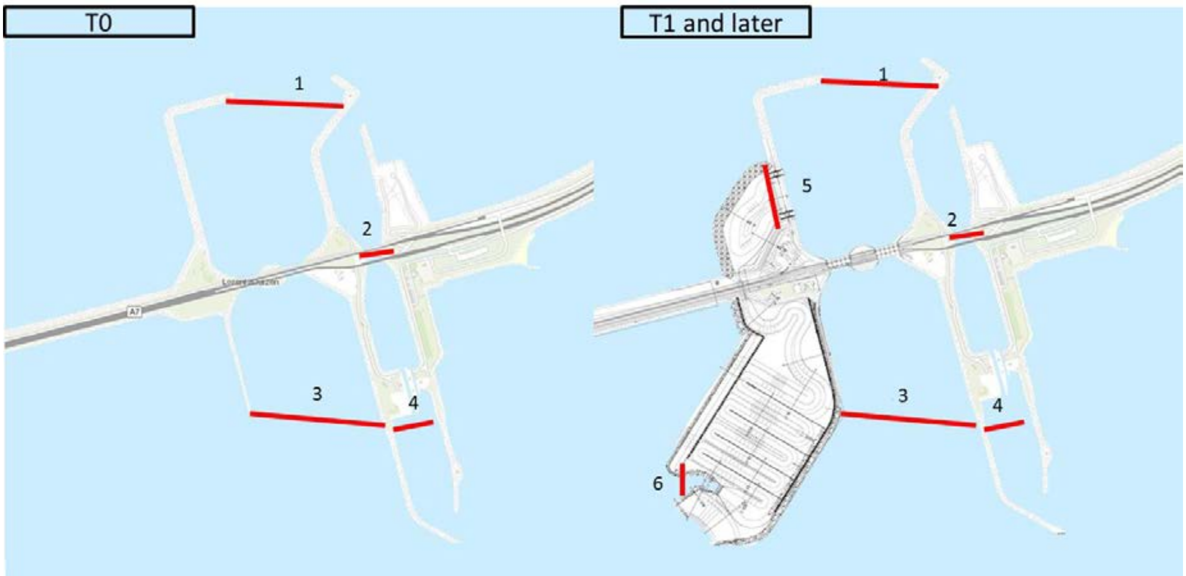

Figure 5.3 LEFT: Experimental setup with NEDAP detection stations in reference situation. RIGHT a future (T1 and later) situation, with an extended NEDAP detection station setup.

NEDAP - reference situation T0

In the reference situation four NEDAP detection stations are (or will be) placed: one covers the Wadden Sea entrance of the discharge basin (nr.1), one below the road (A7) at the seaside of the shiplock (nr.2), one at the inflow channel to the discharge sluices (nr.3) and one at the shiplock (nr.4) (IJsselmeer) (Figure 5.3).

NEDAP – after construction

In the 'after construction' situation two additional NEDAP detection stations will be placed (Figure 5.3): one at the entrances in the FMR (seaside, nr.5) and one at the IJsselmeer inlet/outlet of the FMR (IJsselmeer) to determine successful passage through the FMR (nr.6).

Target species

Larger migratory species that penetrate deep into the upstream river systems (to make optimal use of the existing netwerk of 60 detection stations in the Rhine and Meuse catchment area); i.e. Atlantic salmon, sea trout, sea lamprey are best suited for using NEDAP transponders.

To determine both detailed searching behaviour at the Kornwerderzand complex and use the existing network of NEDAP detection stations in the river systems, it is also possible to 'double tag' large fish with both NEDAP and Vemco transmitters. This will then also allow to determine misdetection rate for each system under the challenging conditions in and around the Kornwerderzand complex.

PIT-tag technique

Since not all diadromous fish can be equipped with sophisticated transmitters of VEMCO or NEDAP, other techniques are necessary to evaluate passage efficiency after construction. Moreover, PIT-tag transmitters are much cheaper and all relevant fish suitable for implantation can be equipped with PIT-tags to gain a larger sample size on top of VEMCO and NEDAP studies. However, the constraint of this technique is that it does not allow precise overall passage efficiency of the whole complex and detection range is small. Moreover, PIT-tags stations are difficult, if not impossible, to install at the discharge sluices (high water velocity and large wet surface) and the shiplocks (high intensity of ship traffic). Therefore, PIT-tag arrays will not give entirely direct measurements as VEMCO and NEDAP do with direct passage information at all possible migration routes at this location. PIT-tag telemetry is only used after construction and limited to the FMR. Additional measurement techniques (e.g. extensive netting program) need to be applied in order to complement on the insights on passage efficiency in the reference situation and the situation after construction. Target species of the PIT-tag monitoring program are especially three spined stickleback and smelt. Whether, this technique is applicable on smelt need to be tested. But, PIT-tags can be implanted in many other fish. All relevant other, larger, diadromous fish can be implanted with 12mm PIT-tag or larger (for better detection range) to increase sample size and for potential inland detection at river tributaries.

Program PIT-tag: passage efficiency FMR after construction

To evaluate the passage efficiency after construction, at least three locations need to be equipped with multiple PIT-tag stations allowing detections of the smallest, 12mm, tags (Figure 5.4). Preferable more locations are equipped with antennas to increase detection resolution. A detection range of ~30cm is assumed (pers. comm. J. Bolscher, Oregon), using the 12mm tags in salt water, and grid width of a PIT-tag loop should be 60cm at minimum. This range needs to be tested prior the construction and installation of a PIT-tag array. Larger fish can be tagged using larger tags, having a wider detection range. Considering the large dimensions of the system and the relatively small stickleback, the number of tagged fish must be high and fish probably need to be released at different locations at the complex depending on the first results. Additionally, the extensive netting program is simultaneously a mark recapture program. Fisherman in the area should ideally be equipped with a manual PIT-tag readers to scan their catch on tagged fish. Recaptures should be reported (size fish, date catch, trap information etc.).

PIT tag systems are only applied in the FMR. Therefore, additional techniques are necessary to (partially) cover other migration opportunities at the Kornwerderzand complex (sluices). The results of the passage efficiency of the FMR should be complemented with passage estimations of the discharge sluices and the shiplock (netting program and mark recapture) and a total abundance estimation in the discharge basin, using an extensive netting program (described elsewhere in this report).

Program PIT-tag: attraction efficiency, passage efficiency FMR and habitat use

To identify potential bottlenecks in the FMR, additional PIT-tag arrays need to be installed (Figure 5.4, green lines The arrays at the entrances (red lines), can be extended in the number of PIT-tag loops identifying the position of the fish in the water column, passing the entrance. An additional array (same design), at the marine side of the entrance, will give insight in potential swimming (or flushing) in and out the FMR. Also it will give information on how long fish, and when the fish will pass the ~17m wide entrance. Arrays at the 'marine side' of the Coupure and the 'freshwater side', will give information whether fish will reach the Coupure and how long they need in order to pass the Coupure. The same applies to the exit of the FMR.

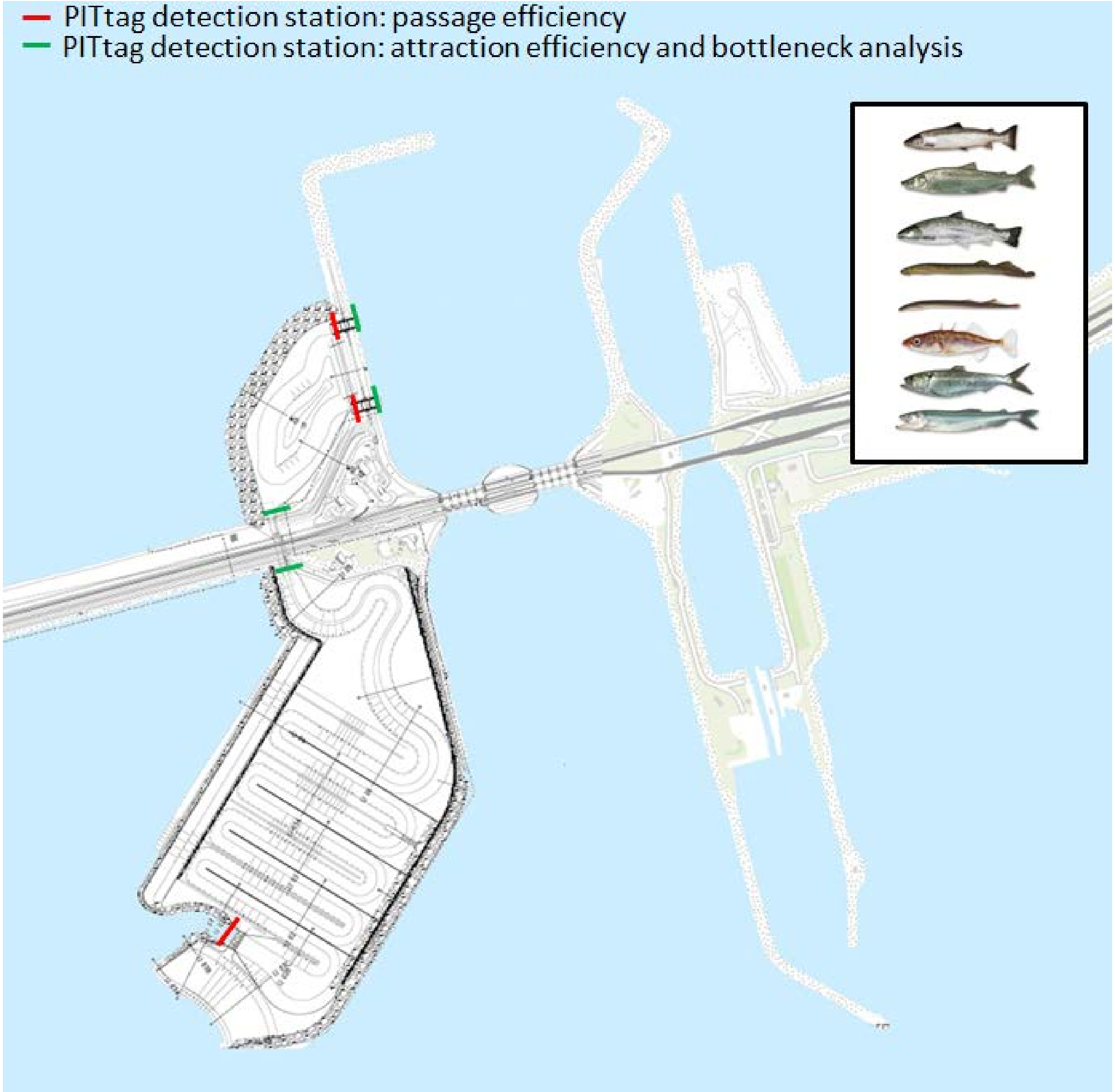

Figure 5.4 Location of PIT-tag arrays to evaluate passage efficiency, attraction efficiency and bottleneck analysis. Take into account that this is a minimum set up. Preferable, more (pairs of) antennas need to be installed to ensure good insight in possible delay or reluctance at different structures in the FMR (Q2).

Test fish for telemetry purposes

Salmon, sea trout, houting, sea lamprey and (larger, female) river lamprey all are suitable for to implant with VEMCO 69KHz transmitters (Winter et al. 2011, Winter et al. 2013, Griffioen et al. 2014b). For sensible species as diadromous smelt and twaite shad performing surgical procedure successfully is more challenging. Stickleback is too small and restricted to PIT-tagging.

For this study larger fish need to be caught with traps (fykes). Species like, sea lamprey, sea trout and salmon are low in abundance and difficult to catch. Additional traps (Figure 5.5) on top of the regular (WOT) monitoring program of Wageningen Marine Research will give a higher chance of catching these species including larger diadromous smelt. To prevent unnecessary mortality and damage to test fish, it is preferred to increase the number of lifting per week. To have a higher chance of catching houting, sea trout, salmon and twaite shad, on top of the trap program, beach seining is proposed (Griffioen et al. 2014a, Griffioen et al. 2014b). It has been proven effective to catch higher numbers of river lamprey with trawling in the deeper part (<25m) of the discharge basin (Griffioen and Winter 2014b).

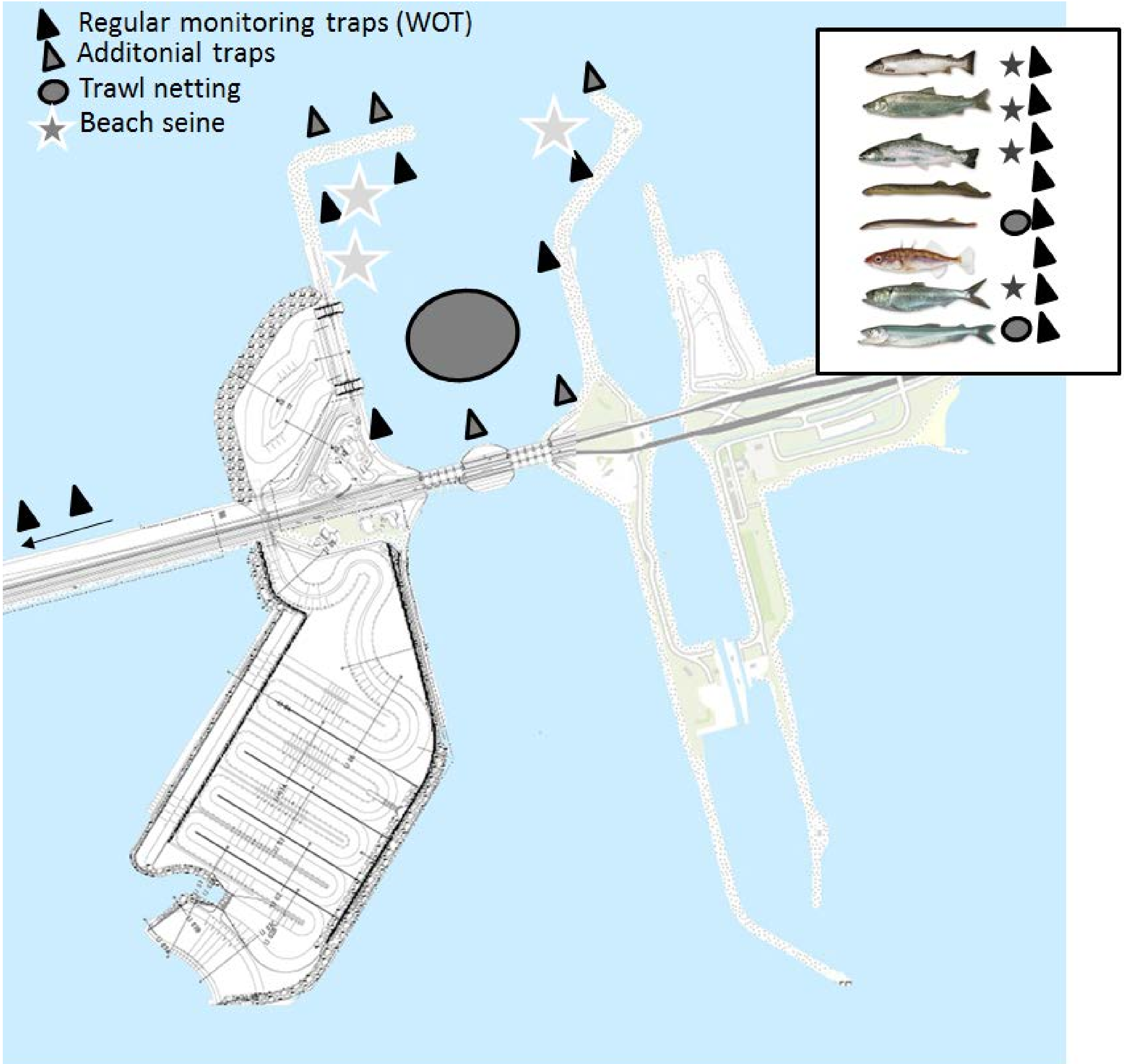

Figure 5.5 Species specific catching methods to catch test fish for telemetry studies such as VEMCO, NEDAP and PIT-tag techniques. Stickleback and smelt are only suitable for PIT-tag studies, however JSAT acoustic telemetry may be suitable for fish as small as 10 cm.

5.2.2 Indirect measurements using an extensive netting program

Determining passage efficiency of small diadromous fish is an interaction of, passage success, abundance and residence time (delay). All are crucial factors, but the combination of these three is a key factor to draw any conclusion on the functionality of management measures as the FMR but also other measures such as 'fish friendly sluice management'. Prior to all netting programs, power analysis must clarify the amount of effort required for each method to ensure a proper and solid monitoring set up.

Estimations of passage success for smaller fish, i.e. glass eel, stickleback, smelt and flounder larvae, is difficult and estimations of abundance and passage efficiency of smaller fish at the tidal barrier must be achieved by using lift nets and drift nets in combination with mark recapture experiments. This is scientifically a challenge and not fully developed mathematically. This is a big challenge for this study and, to our knowledge, quite new to fish migration studies. Additional video (visual or acoustic) techniques will be helpful for data interpretation and measuring rates of movement and density.

As lift nets have a fixed surface the abundance per area or volume can be calculated. In combination with mark recapture experiments (group dye marking for glass eel and individual PIT tag for stickleback and possibly smelt), density, delay and spatial dynamics and can be estimated. Further, by using drift nets in combination with flow meters estimations of the amount of fish per cubic meter entering the FMR (entrance, Wadden Sea), passing the FMR (exit, IJsselmeer), passing the discharge sluices and passing the ship locks can be achieved. Finally, a comparison between all catches (expressed as number of fish per 1000 m^3) in combination with mark recapture will give an indication of delay, spatial dynamics and passage success of the smaller fish.

Measuring passage success using driftnets

The first factor to be determined is the number of fish (density volume) that pass a sluice, the FMR or the shiplocks. To compare fluxes of the small diadromous fish, it is preferred to use identical nets (at least similar mesh size) at different locations within the complex (Figure 5.6). These nets will take a 'snapshot' of what the volume density of (small) fish is, during a particular time, event and at a specific location. The measurements have a high catchability for 'passive drifters' such as flounder larvae and to a lesser extent glass eel, but will be lower for more active swimmers such as stickleback and smelt. They either evade the nets or swim against currents missing the nets.

As seen by ARCADIS (2015), the wet surface of a discharge gate can be fully covered by nets or alternatively five small tapered traps covered a 7.5%. In general, the smaller surface covered by the nets the less accurate an extrapolation is. On the other hand, many small fish will die as a result of being caught in a net and there is a chance that the nets are too full to be lifted (ARCADIS, 2015). Therefore an optimum ratio between covered wet surface and total wet surface need to be explored during a pilot study to get optimum catchability and minor impact on population level. Lastly, these methods are labour intensive and restricted to short migration windows. Therefore, it should be taken into account that methods are practical and relatively easy to apply at different sites.

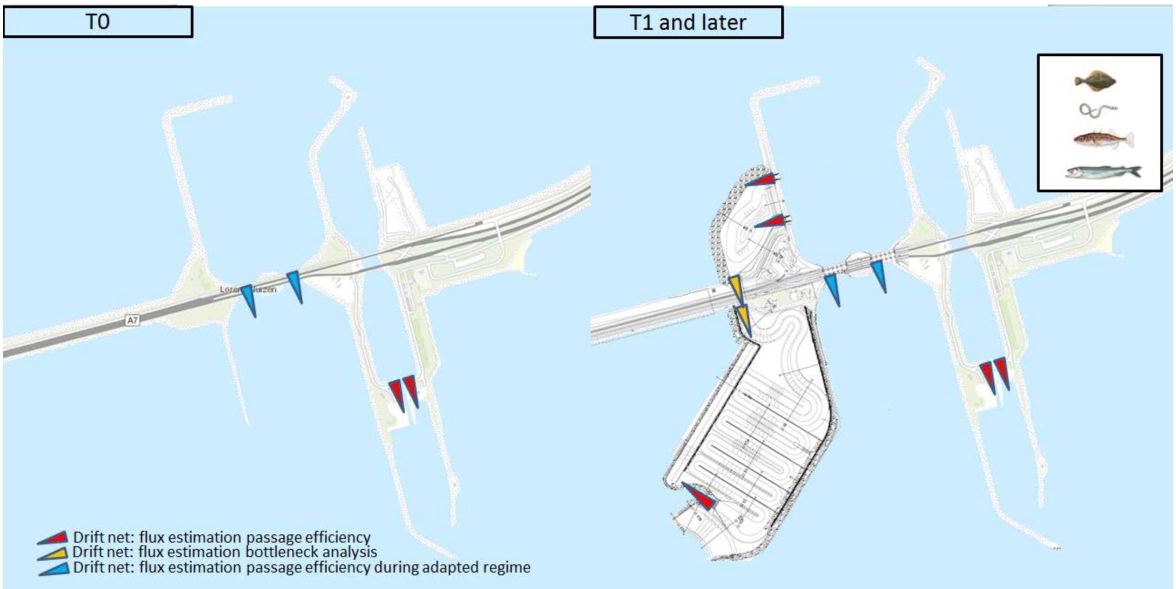

Figure 5.6 LEFT: Experimental setup with driftnets in reference situation (before T0). RIGHT during T1 and later to determine fluxes per water volume in time.

Measuring abundance and residence time using lift nets and trawl netting

The fluxes or volume density comparisons, need to be compared with abundance in the discharge basin (or shiplock basin), in order to get an idea of the impact on the migration success. In other words, a relation between abundance and migration success is needed to evaluate the effectiveness of a potential improved overall passage success. Therefore, a netting program in the discharge basin is needed to measure the abundance (volume density) and density fluctuations in time and space before and after construction (Figure 5.7). A similar method is previously used by (Dekker et al. 1998, Foekema et al. 2014 and Griffioen et al. 2015).

A second method is using a fine meshed glass eel trawl net at the water surface. This method is more effective in specifically catching higher numbers of glass eel and catches can be related to volume density numbers, but is specifically needed to use for group dye marking purposes. A mark recapture experiment using Bismarck brown is needed to evaluate residence time and a more accurate abundance estimate. Moreover, marked glass eel can be recaptured in other netting programs at different locations within the complex. Smelt and stickleback, tagged (PIT-tag) for passage efficiency also can be recaptured during these experiments and all catches should be analysed using a manual PIT-tag reader. All four species should be tested whether VIE is applicable. Contrary to Bismarck brown, VIE is a permanent mark. Some VIE marks can be checked using VI light, giving better chance of detecting recapture in large catches.

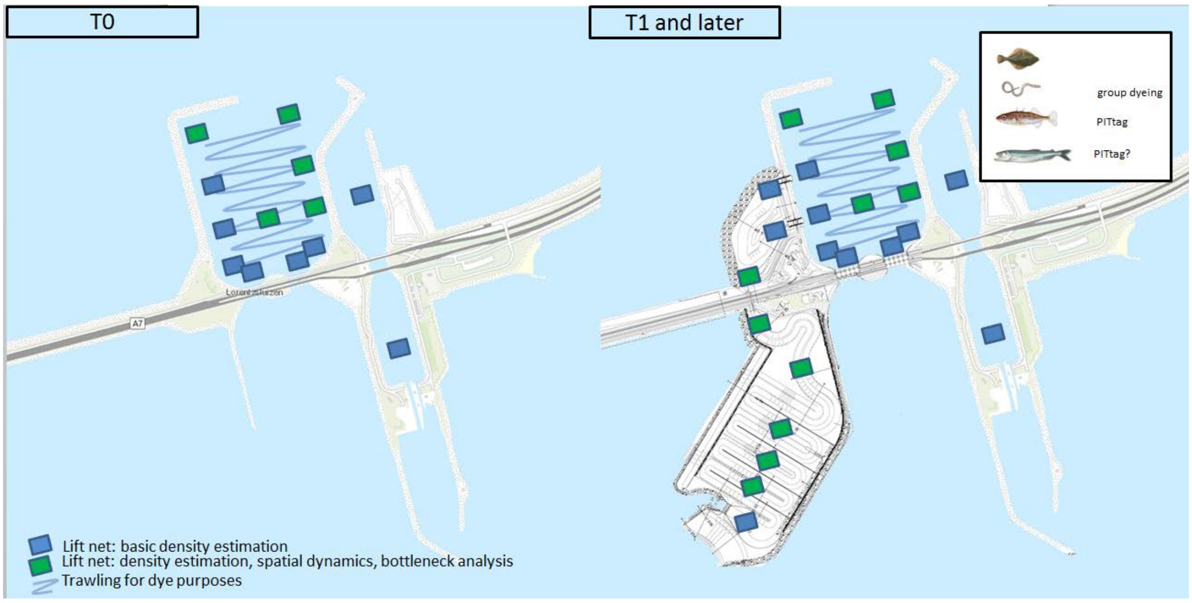

Figure 5.7 Lift net sampling set-up to determine spatial and temporal density dynamics of small fish in the different sections of the Kornwerderzand complex.

5.3 Q2 Optimizing the functioning of the FMR

Q2. Is there a need for improving the functioning of the FMR ('optimizing') and how can this be achieved?

Although much effort have been made to optimize the design and management of the FMR given the current state of knowledge, there are still many remaining knowledge gaps and uncertainties that might result in a suboptimal functioning of the FMR resulting in still too low passage efficiency for certain target species. Multiple scenarios are possible that needs further investigation. E.g. poor attraction efficiency, not optimal habitat type for resting or attaching, high(er) predation risk, unfavourable hydrodynamics (flush out risks), disturbance by human activities e.g. noise, etc. Hydrodynamic modelling can be used to explore different 'drift' and or 'selective tidal transport' behaviour scenarios of smaller migratory fish in the discharge basin in relation to attraction efficiency and in the FMR in relation to passage efficiency.

As described under Q1, many techniques, research infrastructure and effort to answer overall passage efficiency are already in place and can be used to address topics under Q2 such as attraction efficiency, potential bottlenecks and Q3 habitat use. However, in advance it is unclear where and which bottlenecks are present in the FMR that cause suboptimal efficiency of the FMR. Eventually, progressive insight must point out, if, what and where to monitor. The program described under Q1, will point out if the overall efficiency (at complex level) is too low for certain species (based on criteria for species-specific target efficiency). Monitoring equipment in the FMR described in Q1, will clarify potential bottlenecks to a certain level (e.g. attraction efficiency of the FMR).

If this is the case, a two-phased approach is proposed: 1) stepwise bottleneck identification and 2) formulation, implementation and testing of management options to decrease / remove bottlenecks. The following texts of this paragraph are hypothetically, initiating potential research questions and topics, but in the actual program this needs to be formulated based upon the results from research under Q1.

(1) stepwise bottleneck identification:

Entrance at the Wadden Sea side: attraction efficiency
The first potential bottleneck of the FMR are the two entrances. Finding the entrances is needed to have a successful passage efficiency of the FMR. It may occur that fish cannot find or cannot reach these entrances for different reasons. Fish can either find the entrance by active swimming as seen by many larger fish or by passive drifting ‘using’ inward tidal currents as seen by relative small diadromous fish. Active swimming fish can be attracted by a water flow (‘attraction flow’) originating from the FMR. Therefore, an attraction efficiency needs to be determined in order to see whether the attraction flow actually attracts fish. A second step is to see whether the fish actually uses the entrances. On the one hand they can find the entrance (‘approach’), but on the other hand they must be willing to successfully use the entrance (‘entry’).

Natural parts FMR marine side
If fish are able to find and will use the entrances, they end up in the ‘marine side’ of the FMR. Compared to the discharge basin, this part is relatively shallow allowing fish-eating birds to feed on fish. Large concentrations of fish can attract birds and piscivorous fish that can be hampering the passage efficiency of the FMR. A manual scanner of PIT-tags can be used to see whether PIT-tags are found on the island. The same applies for NEDAP and or VEMCO transmitters (both visual recapture). DIDSON/ARIS observations can identify large concentrations of fish and a potential predation risk. Moreover, habitat in this part of the FMR should be optimal for resting and or hiding.

Passage through the Afsluitdijk
Water currents in the ‘coupure’ may obviously be higher compared to the previous part of the FMR. The relatively narrow passage may cause an alteration in behaviour of the fish (Keefer et al. 2012).

Natural part FMR fresh water side
See comments on ‘*Natural parts FMR marine side*

Technical part of the FMR
This part of the FMR is the longest part. Fish must swim through a several kilometres long part. On the one hand they could use this part to swim back and forth for acclimatisation purposes. However, back and forth swimming could also be a result of disorientation for unknown reasons. It is recommended to perform physiological studies in a (field) laboratory, parallel to the field studies. This is not taken into account in this monitoring plan.

Sluices at the Lake IJsselmeer side of the FMR
The exit is a sluice complex with different migration opportunities. In principle it is always accessible, and the expectation is that fish will ‘go with the flow’ or swim undisturbed against the currents towards the freshwater lake depending on the direction of the tidal currents. However a sudden change in hydrodynamics could cause a change in behaviour.

(2) formulation, implementation and testing of management options to decrease / remove bottlenecks:

If bottlenecks are identified, the second step is to describe and test several management options to decrease or to remove bottlenecks. This may need a more fundamental research approach e.g. habitat use for resting or attaching or behavioural studies in relation to hydrodynamics. Obviously, many other issues may cause a potential bottleneck in the FMR or hamper optimal attraction efficiency. Progressive insight based on the research dealt with in Q1 will point out if further research is necessary.

In the monitoring plan a ‘flexible’ budget must be reserved to conduct research both to identify bottlenecks as for formulating, implementation and testing of management options to decrease/remove bottlenecks.

5.4 Q3 Habitat use of the FMR in relation to fish

Q3. Will the FMR be used as a habitat for acclimatisation and or foraging?

Foraging in the FMR
The FMR will create a habitat for piscivorous fish, birds and possibly marine mammals (e.g. seals) to forage as this is the case in the current situation in the discharge basin. However, if residence time of diadromous fish will be lowered as a result of the presence of the FMR, than predation may also be lowered. Predation of piscivorous fish or estuarine residents can be observed using acoustic equipment, stomach content analysis and presence absence analysis using traps in the FMR (Figure 5.8). But this may only be useful when predation seems to hamper passage efficiency.

Predation by birds, or abundance of fish-eating birds, can be observed by visual observations, perhaps with additional searching for PIT-tag or other transmitters on the bird island. Again, this is only useful when losses of fish entering the FMR are high and therefore lowering passage efficiency.

Traps in the FMR will give insight in the species composition (e.g. occurrence of diadromous fish, marine and freshwater visitors or estuarine residents) and the relative abundance of fish in the FMR at different locations. Some of the traps can also function as PIT-tag loops for ‘recapture purposes’. Fish are guided in the net, but are able to escape through a PIT-tag loop at the end of the trap. This may cause less mortality and damage to fish.

Promising new techniques like eDNA might be considered to be used as well to detect presence of different taxa using the FMR in time, and depending on the development of this novel method in the near future, perhaps even abundance estimates are feasible.

Acclimatization
Relatively little is known on the need for acclimatization per species and if needed what conditions for what duration is necessary to adjust to freshwater (Winter et al. 2014). In the current situation there is a sharp boundary between salt and freshwater. No acclimatization zone is present, except very temporal and dynamic gradients related to the discharge pulses of freshwater at the Wadden Sea side. In literature back and forth swimming behaviour is often related to acclimatization, but can be just as useful in orientation or saving energy using tidal currents (Winter et al. 2014). In the FMR several VEMCO receivers are proposed to identify back and forth swimming or prolonged presence (Figure 5.2, Q1). However, to relate this swimming behaviour to acclimatization ex situ experiments could be carried out(Leggett and Oboyle 1976, Wilson et al. 2004).

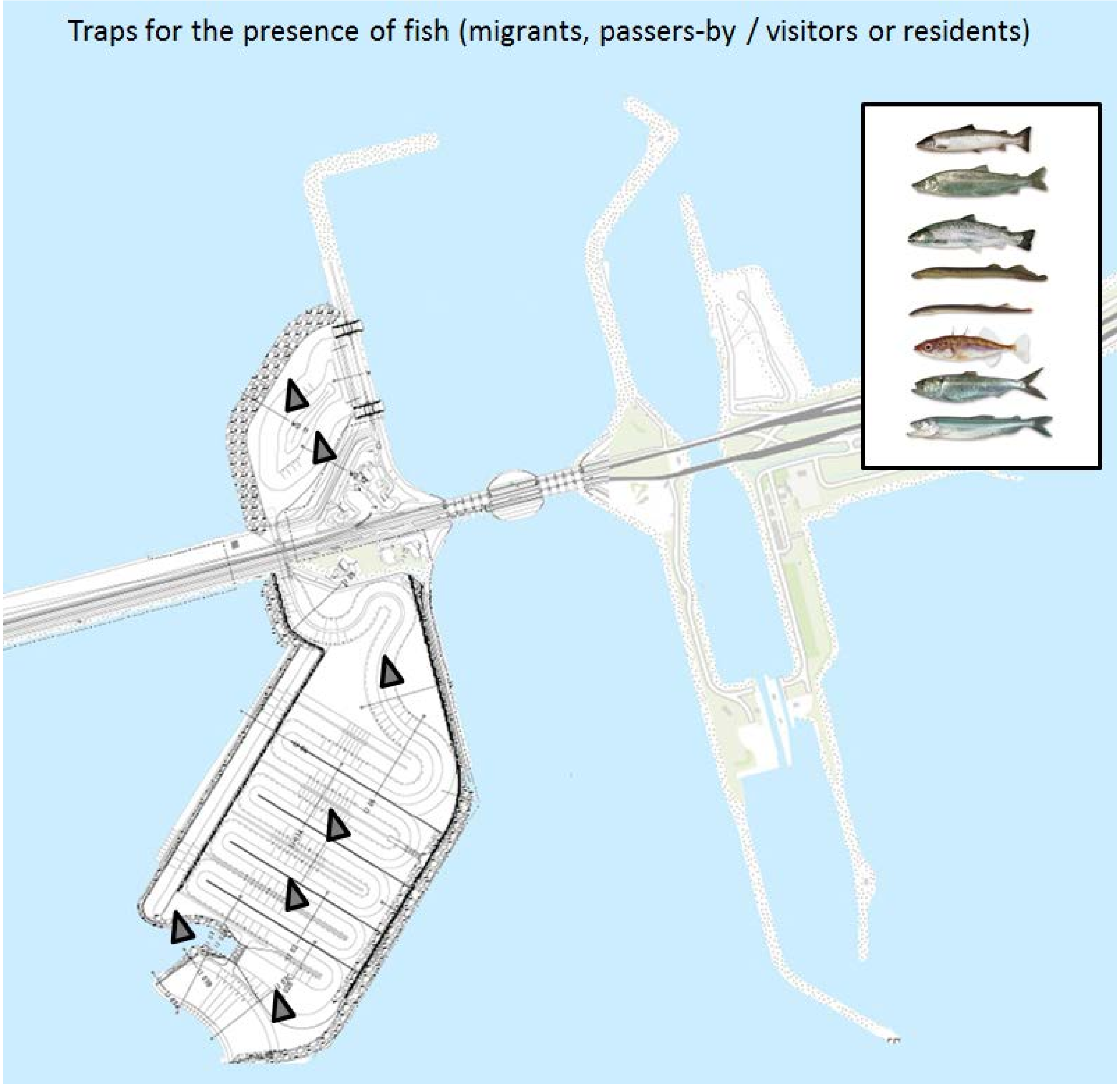

Figure 5.8 Indicative set-up of traps to monitor fish (all guilds) presence in the FMR.

5.5 Q4 Effectiveness of the FMR on population levels

As stated earlier, determining the effectiveness of the FMR on fish population levels is very ambitious and requires large research efforts. In this monitoring program we focus on addressing:

- Do other migratory bottlenecks occur on migration routes to habitats in upstream sections of the River Vecht, IJssel and Rhine?
- Are alternative entrances to freshwater systems used by migratory fish that have visited Kornwerderzand?
- Do trends in abundance of target species in existing and ongoing long-lasting monitoring programs correlate with increased migratory opportunities at Kornwerderzand?

By extending the local network of VEMCO receivers in and around the Kornwerderzand complex to other locations covering the upstream freshwater systems of the Afsluitdijk, migratory fish that were tagged within Q1 and Q2 studies can be tracked during their upstream movements as well (Figure 5.9). To determine larger scale movements in the Wadden Sea we propose to place a network of VEMCO receivers here as well. For this, an additional 31 receivers in river systems and an array of 30-40 in the Wadden Sea is proposed.

Figure 5.9 Proposed locations of Vemco receivers (see appendix 1 for further details on the different locations. In additional to the proposed placement of receivers, in the southern coastal area of the Rhine delta around the Haringvliet, arrays of Vemco receivers are foreseen in the near future. In Belgian coastal waters a network of Vemco receivers is already in place.

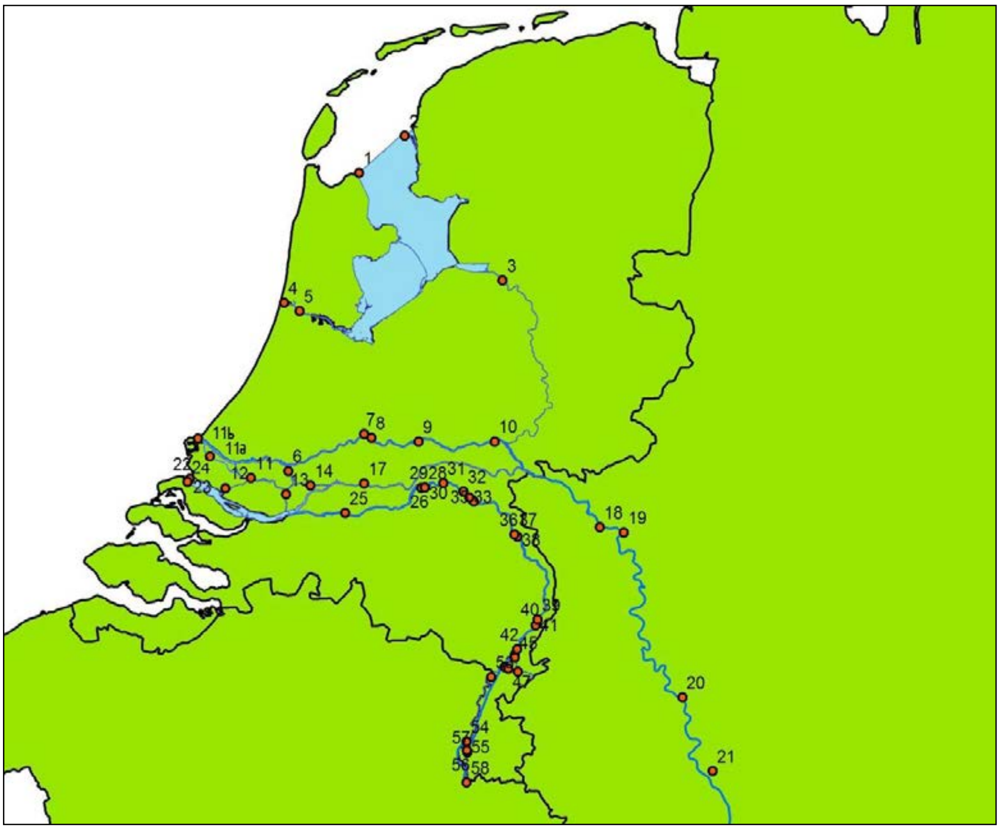

Figure 5.10 Map showing the current network of NEDAP trail detection station sin the Dutch river systems. More stations are available in upstream sections of the Rhine system.

The existing network of NEDAP detection stations in the River Rhine and Meuse catchment area (Figure 5.10) can be used to determine passage success into the upstream sections of the Rhine system as well as how other entrances to river systems might be used by Atlantic salmon, sea trout and sea lamprey.

Finally, already existing ongoing long-lasting monitoring programs can be used to analyse trends in abundance for the different target species and different water systems. Figure 5.11 gives an overview of monitoring programs that are already existing or ongoing around the Afsluitdijk and in the Wadden Sea and Lake IJsselmeer. These trend analyses can be to the increased migratory opportunities to pass the Kornwerderzand complex.

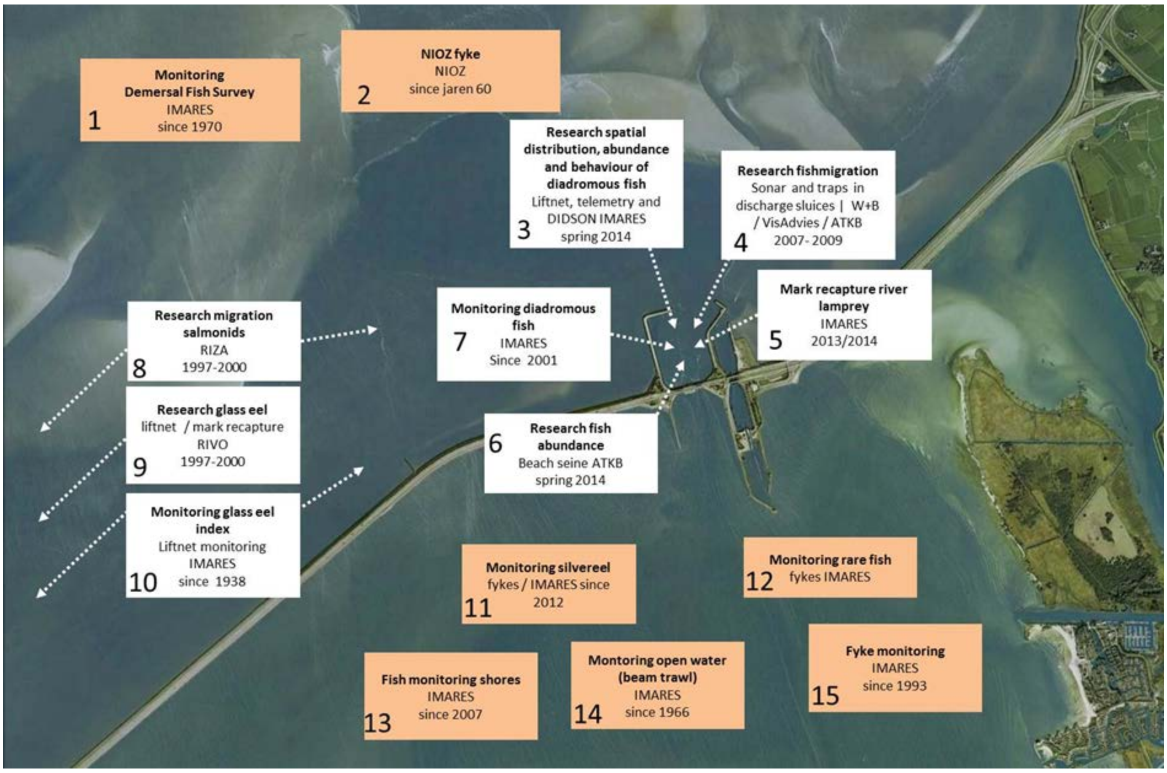

Figure 5.11. Overview of the Afsluitdijk at the Kornwerderzand sluice complex illustrating present and past monitoring and research in the area. Orange squares shows larger scale monitoring programs in the Wadden Sea and IJsselmeer and white squares shows monitoring programs along the Afsluitdijk on the saltwater side, mainly at the discharge sluice complexes.

6 Planning and communication of the program

6.1 General planning

Monitoring is applied during two phases: (1) pre-construction of the FMR, the so called ‘reference situation’ and (2) after the construction of the FMR. The first phase will take at least two years and the second four years of monitoring. As described in the introduction, there are still many knowledge gaps on passage efficiency in the current situation (Table 1). Therefore, the first phase, the pre-construction phase, should be used to fill in these knowledge gaps in order to have a good reference for evaluation studies after construction. Some techniques allow immediate application such as VEMCO or parts of the netting program (lift net). For other techniques, pilot studies, designing and construction phases are needed (e.g. PIT-tag arrays), before an extensive program can be implemented.

Eventually, many fieldwork activities are dependent on the abundance and catchability of relevant fish species. Especially in telemetry experiment it is highly preferred to have fish that are motivated to migrate towards the freshwater lake. Therefore, monitoring and fishery activities should be adapted to the migration season to have a higher chance of catching relevant fish and interpretability (Table 3). A general planning is given in Table 4.

Table 3 *Overview of the upstream migration season of the (relevant) target species.*

	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Atlantic Salmon												
Flounder Larvae												
Three spined stickleback												
European eel (glass eel)												
Twaite shad												
Houting												
River lamprey												
Smelt												
Sea trout												
Sea lamprey												

** At Haringvliet dam, Atlantic salmon and sea trout are present also in jan-apr.*

Pre-construction phase

In general, there are two main important monitoring issues during the pre-construction phase: direct measurements using VEMCO technique to have direct measurement of passage success. Secondly, an extensive netting program in combination with mark recapture experiments to monitor the abundance, residence time and passage success of small diadromous fish.

Before any monitoring activity can be applied, enquiries of different permits need to be successful (different Dutch permits: ‘waterwet vergunning’,’ invaarverbod ontheffing’ (“BPR”), ‘flora fauna wet’, ‘visserijwet’, ‘reguliere ontheffing’). Also regulations with fisherman (contract, protocols etc.) and writing a research proposal for the animal ethical committee for all surgical procedures and number of animals need to be finished and successful. Preferably, all future monitoring activities, after construction, should be taken into account as much as possible in all applications.

The pre-construction phase is also needed to have different kinds of pilot studies and testing of equipment. Especially concerning the design and tests of the large PIT-tag arrays, which should be working during the after-construction phase. Factors as, material for the arrays, determination of detection range in different salinity gradients and dealing with many loops within one array do need a testing phase and should be incorporated in the monitoring activities. Besides the PIT-tag arrays, driftnet constructions should be designed and tested in order to test for passage success. Also the catchability of these nets needs to be determined, possibly by using acoustic camera's or infrared cameras in or along the nets during the (pilot) experiments.

After construction phase
Immediately after a successful construction of the FMR, additional VEMCO receivers and NEDAP stations should be installed and the PIT-tag arrays should be installed and tested on the spot (as described under Q1 "overall passage efficiency"). Also the netting program should be continued and extended (as described under Q1 "overall passage efficiency").

Table 4 General planning of the different phases of the proposed monitoring program:

		pre construction phase			construction phase	T1 after construction			
		T-3	T-2	T-1	T0	T1	T2	T3	T4
Administration		Administration (e.g. fisheries permits, waterwet permit, animal commitee, etc)	Administration (e.g. permits)	Administration (e.g. permits)		Administration (e.g. permits)	Administration (e.g. permits)	Administration (e.g. permits)	Administration (e.g. permits)
Fisherman		Contracts fisherman	Contracts fisherman	Contracts fisherman		Contracts fisherman	Contracts fisherman	Contracts fisherman	Contracts fisherman
Communication		Contact and meetings with relevant parties (lockkeepers, RWS, Provinces), writing student proposals	Contact and meetings with relevant parties (lockkeepers, RWS, Provinces)	Contact and meetings with relevant parties (lockkeepers, RWS, Provinces)	Contact and meetings with relevant parties (lockkeepers, RWS, Provinces)	Contact and meetings with relevant parties (lockkeepers, RWS, Provinces)	Contact and meetings with relevant parties (lockkeepers, RWS, Provinces)	Contact and meetings with relevant parties (lockkeepers, RWS, Provinces)	Contact and meetings with relevant parties (lockkeepers, RWS, Provinces)
Fieldwork acitivities	pilot	Pilot netting program, testing application of the nets under different circumstances	Pilot handling fragile fish (smelt, twaite shad, etc) for different purposes (VIE, VEMCO PITtag)	PITtag arrays range testing (lab and field)	optional: pilot handling fragile fish (smelt, twaite shad, etc) for different purposes (VIE, PITtag)				
	PITtag		Developing and testing PITtag arrays	Developing and testing PITtag arrays	Installing PITtag array and testing on the spot.	PIT-tagging	PIT-tagging	PIT-tagging	optional PIT-tagging
	telemetry	Installing NEDAP cables	Installing VEMCO (JSAT) receivers, telemetry experiments	Telemetry experiments		Telemetry experiments	Telemetry experiments	Telemetry experiments	optional Telemetry experiments
	netting program		Extensive netting program	extensive netting program		extensive netting program	extensive netting program	extensive netting program	optional extensive netting program
	additional traps		yes	yes		yes	yes	yes	
	mark recapture		mark recapture experiments (colour, VIE)	mark recapture experiments (colour, VIE)		mark recapture experiments (colour, VIE, PITtag)	mark recapture experiments (colour, VIE, PITtag)	mark recapture experiments (colour, VIE, PITtag)	mark recapture experiments (colour, VIE, PITtag)
	Other				optional: acclimatization experiments (ex situ)				

Communication and sharing information
During all phases it is good to have informative presentations, (mini)symposia or informative meetings with relevant (third) parties. These meetings should be *internal* with detailed information and workshops on monitoring plans, safety issues, preliminary results, etc Informative meetings and workshops with lockkeepers, students, local fisherman or other parties are most relevant in terms of collaboration and safety issues. These meetings should be planned prior fieldwork activities during the research program. It is preferred to have an informative (internal) meeting prior to all fieldwork activities (T-3) to share research plans on headlines with lockkeepers, students, fisherman, third parties etc. *External* (open) with information on headlines for interested people may be just as important to get public awareness. The aim for these meetings could be primarily informative for interested people or relevant parties.

Publication of results, scientific output and progress reports
Besides (mini) symposia and presentations, results of research programs as well as relevant research procedures should be published to share information and knowledge about fish migration and monitoring / research. Moreover, short communications in semi scientific journals will probably make sharing information more efficient.

Official research results are preferably communicated in English and presented in scientific journals to ensure international sharing of the knowledge of this internationally worldwide unique fish passage. Yearly progress reports are needed to record the progress of the monitoring. The progress reports could function as evaluation during the monitoring program (especially concerning Q2). Moreover, these reports function as input for scientific papers.

6.2 Overview of prioritizing relevant techniques for the monitoring program

Overview activities and prioritizing activities monitoring FMR
Most of the monitoring activities are covered in answering Q1, the overall passage efficiency. However, not all of the monitoring activities are *essential* to answer the research questions. This report deals with more monitoring activities than is primarily necessary. However, due to many uncertainties in e.g. local environmental conditions or abundance of specific fish species, it is highly recommended to limit limit the degree of uncertainty in answering the research question.

For transparency, different activities are categorized in (1) **essential** (E): primarily needed to give answers to the research questions, (2) **relevant** (R): highly relevant activities and recommended to limit the degree of uncertainty of e.g. passage efficiency or behavioural patterns of fish, (3) **optional**: optional activities are useful to take into account since the local environment is very dynamic. Moreover, year class strength of certain (rare) fish species may influence monitoring results directly. Mostly, optional activities are related to an extra (back up) monitoring activity, when monitoring did not as expected during regular (essential) years. Or, there may be an overlap with other techniques.

In general the following techniques are categorized as follows to answer the research questions:

Technique	**Category**
VEMCO	Essential
PITtag	Relevant
NEDAP	Optional (Q1*), Essential (Q4)
Netting program (lift, driftnets)	Essential
mark recapture (PITtag, colour, VIE)	Essential
Additional traps	Essential
Beach seine	Essential
Trawling	Essential

*independent validation VEMCO study passage efficiency for some species (Q1)

The relevance of PIT-tag systems.
PITtag technology is a powerful tool. However, within this monitoring plan, PITtag systems are categorized as relevant (R), which means that PITtag detection technology is not essential (E) to answer the research questions[5]. Of course, mark recapture experiments with PITtag can be carried out independent of PITtag detection stations (manual readers are of course necessary).

Many fish can be equipped with the very small and relatively inexpensive PIT-tag transponders. Installing PIT-tag detection systems in the FMR which are strong enough to withstand the dynamic environmental conditions and dimensions of the FMR are expensive. However, there are alternatives to consider: (1) Research without PITtag systems, (2) temporal PITtag systems and (3) permanent PITtag systems. In the first two options it is important to consider whether there is still enough information present to answer the research questions. Per option this question will be discussed.

[5] Take into account: the target species which are relevant to PITtag telemetry studies are included in the netting program. Therefore, PITtag technology is ‘relevant’. However, once JSAT technology has been tested and fully developed within the project instead of or complementary to VEMCO, also small migratory fish may be followed individually.

1) *Research without PIT-tag detection stations*

When it is decided to execute the monitoring program without PIT-tag stations, will it still be possible to answer the research questions?

Larger fish (river lamprey and larger)

Yes, when no PITtag detection stations are present and VEMCO technology is applied, it is still possible to give passage efficiency of larger diadromous fish. Passage efficiency of larger diadromous fish will primarily be determined using VEMCO or JSAT (direct measurements of passage efficiency) and is independent of the use of PIT-tag telemetry studies. However, if VEMCO technology is lacking and passage efficiency is determined based upon NEDAP technology only, there will no data for e.g. river lamprey. Moreover, the degree of uncertainty of behavioural patterns and passage efficiency will be high(er).

Smaller fish (smaller than river lamprey)

Yes, but a large degree of uncertainty is present. The passage efficiency of small diadromous fish will be determined using an extensive netting program (indirect measurements of passage efficiency). Moreover, PIttag technology is not applicable to all small species. The netting program will give insight in differences of volume (fish) densities at different locations especially for stickleback, flounder larvae, glass eel and smelt. Additional mark recapture studies, using VIE, batch mark colouring or individual tags, will give more insight in behaviour and residence time. However, all of these methodologies do not allow individual tracking of small fish. Without PIT-tag systems, allowing individual tracking, a larger degree of uncertainty is present. For example number of fish that swim back and forth cannot be taken into account in data interpretation of the netting program. PIT-tag station will clarify behavioural patterns of tagged fish at locations covered by stations. However, as already mentioned, not all (small) fish are physically suitable for implantation of PIT-tags and uncertainties for still present for glass eel and flounder larvae.

2) *Research with temporal PIT-tag detection stations*

If it is decided to execute the monitoring program with temporal PIT-tag stations, will it still be possible to answer the research questions? Yes, it will be possible to answer the research question with temporal detection station. PIT-tag telemetry in the FMR, will largely increase the number of fish that can potentially be used to answer research questions for larger diadromous fish. Moreover, larger fish can be equipped with both VEMCO transmitters as PIT-tags or as the number of a fish species is high, fish can also be equipped with only a PIT-tag. The risk in this option is, that the stations need to be designed and constructed with relatively cheap, but good enough, material. Therefore, the effectiveness and success of the arrays cannot be guaranteed entirely. NOTE. The construction of the FMR need to be designed in such a way that PITtag arrays can be installed. Construction profiles in the walls of the FMR and in the water column are highly recommended to ensure effectiveness and success of PITtag arrays.

3) *Research with permanent PIT-tag stations*

Using permanent PIT-tag stations is obviously the best option from a monitoring point of view. The arrays will be designed, tested and installed by BIOMARK or another company. The stations will be fixed, permanent and useful for longer periods.

The relevance of telemetry systems: NEDAP and VEMCO
Telemetry is a useful method to track individual fish. In other words, it will give direct measurements of passage efficiency of the complex including the FMR. In this report two sophisticated systems are proposed that can either be used separately or complementary. Both systems have been proven to be effective at this study site (De Vaate et al. 2003, Griffioen et al. 2014b). Both systems can be used to answer Q1, passage efficiency. Both systems can potentially cover all routes within the complex. However, there are differences between the systems, both financially as technically.

NEDAP

NEDAP has the advantage that several existing detection stations are already installed in the rivers in the Netherlands and Germany. Moreover, detections of the transponders are not hampered by a heavily turbulent environment contrary to acoustic VEMCO transmitters. The cables are placed on the bottom and need electricity for functioning. Transponders are relatively large and not applicable for river lamprey and smaller fish. Moreover, NEDAP technique is less flexible. Therefore NEDAP is, compared to VEMCO, less efficient in giving insight in small scale patterns in behaviour (e.g. ratio between attempt and success, attempt rates, residence time, etc.).

VEMCO

VEMCO has several existing detection stations (receivers) at the coast of Belgium. Receivers can be installed, replaced, and maintained relatively easy. Also in rivers, Wadden Sea and other tributaries in regional water systems (e.g. Vechtstromen). Therefore, this technique has a stronger potential for the 'optimizing' part (Q2) of the monitoring program, since it is a more flexible system and has a complex approach, contrary to PITtag detection systems which are only applicable in the FMR. The system works with batteries which needs to be replaced yearly. The installation of several receivers, as proposed in this report, allows detailed behavioural interpretation of the fish. Transmitters are applicable for river lamprey and larger. A pilot study for implanting V7 transmitters in smelt and shads is proposed.

7 Knowledge acquirement within the monitoring program and scientific opportunities

Given the lack of current knowledge on fish migration at large tidal barriers and underlying behaviour of migratory fish the proposed monitoring program will yield much data and insights that have scientific interest, e.g. on behaviour and biology of migratory fish in relation to environmental dynamics, and applications for management of tidal barriers elsewhere. Because of this reason, we suggest that performing the required fieldwork, labour, analysis and reporting within the monitoring program is best carried out by a staff of PhD-students with support of technicians and researchers. Moreover, the FMR, research infrastructure and equipment needed for the monitoring program forms a good basis for expanding the monitoring program with focussed scientific studies for which additional funding can be sought, e.g. from scientific NWO programs (STW) or European subsidies.

Currently, the Wadden Academy is working on a proposal and design for a test facility in the FMR to make controlled in situ experiments on fish passage and behaviour in relation to environmental conditions and clues possible (Philippart 2016).

We advocate an integral scientific program that operates on different spatial scales from fine (fish' perspective in relation to cues) to large levels covering different water systems (Figure 7.1). An iterative approach with a combination of field data, modelling (e.g. hydrodynamics, fish behaviour, agent based population etc.) and controlled experiments e.g. in the proposed test facility and/or lab-experiments in our view give the best opportunities to gain both fundamental scientific knowledge as applied scientific knowledge that can be used to mitigate migratory issues internationally.

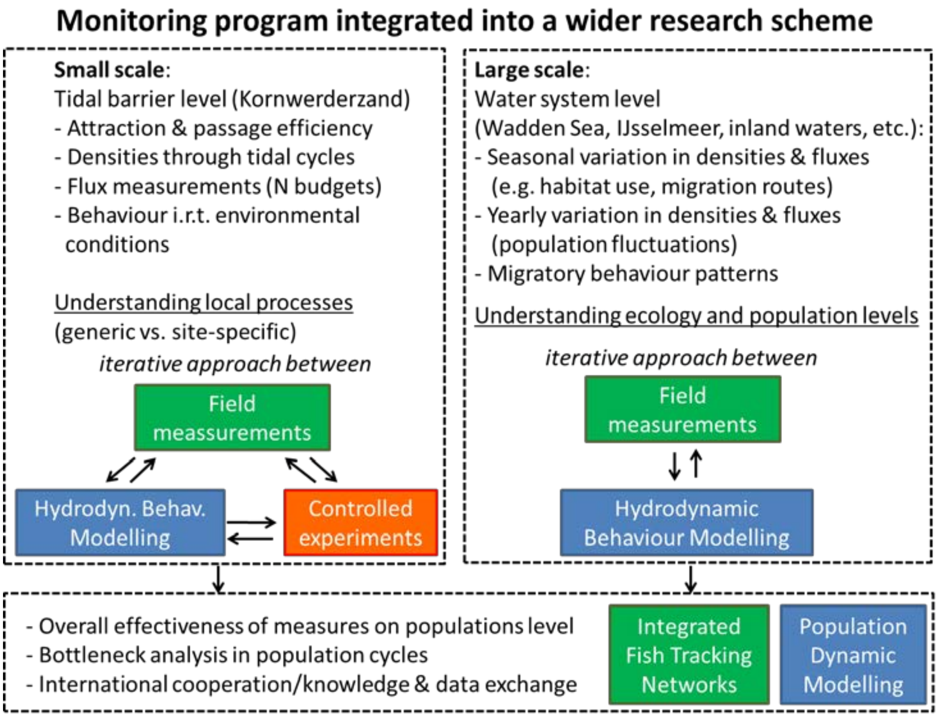

Figure 7.1 Framework example for how the research performed within this monitoring program can be the base for a wider integral scientific research program.

8 Quality Assurance

WAGENINGEN MARINE RESEARCH utilises an ISO 9001:2008 certified quality management system (certificate number: 187378-2015-AQ-NLD-RvA). This certificate is valid until 15 September 2018. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation. The scope can be found at the website of the Council for Accreditation (www.rva.nl).

On the basis of this accreditation, the quality characteristic Q is awarded to results of components which are incorporated in the scope, provided they comply with all quality requirements, as described in the applied Internal Standard Working procedure (ISW) of the relevant accredited test method.

The quality of the test methods is ensured in various ways. The accuracy of the analysis is regularly assessed by participation in inter-laboratory performance studies including those organized by QUASIMEME. If no inter-laboratory study is available, a second-level control is performed. In addition, a first-level control is performed for each series of measurements.
In addition to the line controls the following general quality controls are carried out:

- Blank research.
- Recovery.
- Internal standard
- Injection standard.
- Sensitivity.

The above controls are described in WAGENINGEN MARINE RESEARCH ISW 2.10.2.105.

If the quality cannot be guaranteed, appropriate measures are taken.

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Justification

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The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research.

Approved: Dr. I. Tulp
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