Bachelor Thesis

Research Report

The Fish Migration River- a fish-friendly solution?

Spatial distribution and abundance of 15 fish species at the discharge area at Kornwerderzand in relation to tidal regimes, discharge events, discharge volume and temperature

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Leeuwarden, July 2014

Final version

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A research on the spatial distribution and abundance of 15 fish species at the Kornwerderzand area in relation to tidal regimes, discharge events, discharge volume and temperature in the context of a projected Fish Migration River.

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Preface

Our grateful thank goes to Ben Griffioen from IMARES for his never-ending support, expertise, patience and positive vibes. Our further thank goes to the nice fish crew, Betty van Os, Marinus & Tjerk and Erwin Winter for going through whole nights on the boat with an amazing atmosphere, regardless storm and rain. Furthermore we want to thank Okka Bangma and David Goldsborough for their supervision, helping with words and deeds.

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Svenja Schönlau & Tomasz Zawadowski

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Summary

Fish have the natural behaviour to move across various aquatic ecosystems and for some species this is of vital importance. Migration is often a seasonal phenomenon which occurs in order to move between habitats, such as winter refuges-, foraging- and spawning or nursery habitats, also escaping unfavourable environmental conditions, expanding habitat, (re)populating new habitats and exchange between subpopulations. The Afsluitdijk in the Netherlands has been recognized as a bottleneck (obstacle) of major importance for fish migration, due to e.g. changes in natural salinity gradients and tidal regime as well as generated high water velocities, leading to short migration windows. Several ´fish friendly` management measures within the Afsluitdijk have been in operation, but most of them are not ideal. A large fish passage, the Fish Migration River (FMR) has been conceptualized at Kornwerderzand, which can provide opportunities for migratory fish to reach the IJsselmeer. In order to provide the FMR with the best possible design according to the ecology of occurring fish species, the Dienst Landelijk Gebied and the "De Nieuwe Afsluitdijk" (DNA) acquired a full assessment of the current situation at Kornwerderzand. This report provides insight in abundance and spatial distribution of 15 migratory fish species in fresh-salt transitions at the Kornwerderzand area in relation to tidal regimes, discharge events, discharge volume and temperature. Lift net sampling with the simultaneous application of the DIDSON (Dual frequency IDentification SONar; ultrasound underwater camera) camera was carried out to gain insight in the spatial and distribution of fish, combined with an enhanced fyke net sampling in and around the discharge basin at Kornwerderzand, carried out to evaluate the abundance. The results of the lift net sampling have shown, when focusing on four target species glass eel (*Anguilla anguilla* larvae), European smelt (*Osmerus eperlanus*), flounder larvae (*Platichthys flesus* larvae), three-spined stickleback (*Gasteroteus acculeatus*), that location 7 (in front of the west side discharge sluice) yielded the highest total catch number (n=2.431). The smallest number yielded location 11B (n=177) at the west side. When taking the spatial distribution throughout the discharge basin into account, sampling points in front of the sluices (location 3, 4, 6 and 7 recorded the highest average catch per location (n=1.934). No clear difference was found in spatial distribution between the other groups of locations (average n per sampling point: deepest point n= 1236; west side n= 1093; eastside n=941; most northward n=779). All sampling days had their starting point during flood tide and only half of them were finished after hide tide, thus the last run was taking place during the ebb tide only in 50% of the cases. Results have shown that most individuals were caught during run 1 (n=4.642) and thus during flood tide. Run 3, which generally took place during high tide and/or ebb tide, yielded 4.347 individuals. The least fish were caught during run 2 (n=3676), which was generally performed during high flood tide and/or high tide. The hypothesis that fish species, dependent on STST, are expected to have lower catch numbers with consecutive runs was correct only for glass eel and flounder. Results have shown no relation between spatial distribution of fish in relation to discharge events. Fish have a tendency to be distributed in front of the discharge sluices (location 3, 4, 6 and 7), regardless of previously occurred discharge events or particular consecutive runs. The hypothesis that weak swimmers (flounder, glass eel, stickleback) might be flushed away northwards after discharge events was incorrect. Additionally, results from DIDSON analysis have shown that the vertical distribution of fish in the water column differed per sampling day and per run. No clear pattern of distribution was recognizable in relation to runs and in terms of distribution preference. Results have shown differences in the fyke net sampling of autumn 2013 as well as in spring 2014 in the mean CPUE per species (autumn: mean CPUE 0-1227,1; spring mean CPUE 0-1871,7), as well as

per fyke (autumn: mean CPUE of 22,8 in fyke 6 to mean CPUE of 165,9 in fyke 1; spring: mean CPUE of 15,7 in fyke 7 to mean CPUE of 621,9 in fyke 3) and mean CPUE per species per fyke. For autumn 2013, results have shown a positive relation between mean CPUE per species of eel, flounder, houting and smelt and water surface temperature and a negative relation between mean CPUE per species of river lamprey, roach, ruffe, stickleback and zander and water surface temperature. For sea lamprey there was no clear relation found. Furthermore, there was a negative relation between mean CPUE of the diadromous species eel, flounder, houting and twait shad and discharge and a positive relation between the diadromous species river lamprey, smelt and stickleback as well as all the freshwater species (bream, perch roach, ruffe, and zander*)* and discharge. For spring 2014, results have shown a negative relation between mean CPUE of the species bream, houting, perch, river lamprey, smelt, twait shad and zander and water surface temperature and a positive relation between mean CPUE of the species eel, flounder and stickleback and water surface temperature. For sea lamprey there was no clear relation found. Results have shown a negative relation between the mean CPUE of the diadromous species eel, flounder and stickleback and discharge, and a positive relation between the diadromous species river lamprey and smelt as well as all the freshwater species and discharge. For twait shad only a very slight positive trend was recognizable and for sea lamprey no relation was found. The species caught the shipping locks in autumn were only freshwater species (besides flounder*)*, which were assumedly flushed out from the IJsselmeer. Consequently it can be stated that this location yielded only small numbers of diadromous fish and seems to be not used very much for migratory purposes. Fish is known to be flushed away or washed out with high discharge. The high numbers of caught freshwater fish species (n= 1,6 million) and the positive relation between mean CPUE of all freshwater fish species and increasing discharge volume in this study support this fact. Regarding lift net sampling it needs to be taken into account that spatial distribution of fish in relation to tidal regime did not had 100% rate of comparability per sampling day due to sampling at different tidal positions. Furthermore, it needs to be considered that the fyke net data was only representing a part of the situation at Kornwerzand because species richness and abundance is estimated much higher and abundance should be interpreted as a result of a combination of occurrence as well as behaviour of fish, which was not further investigated in this study. Additionally, fish migrating at a larvae stadium (e.g. flounder and glass eel), could have been actually present in the area but could not been caught due to a too large mesh size of the fyke net. In this study, only simple relations and interactions regarding the abundance of fish at the discharge area in relation to tidal regime and temperature over time were tested, which could have been led to biased results or results which are based on coincidence. Additionally, an analysis of delay scenarios, which are linked to the delay in response of fish to discharge, needed to be rejected. Also, it is to remark the warm winter of the year 2013/2014 could have led to a shift in migration period. A better understanding and therefore additional research is recommended to get better insight in the matters such as: species specific passage efficiency in the current situation, spatial searching behaviour of individual fish, capability of using short lasting migration windows, acclimatization requirements for fish to get used to changes in salinity, dimensions and salinity gradients that are needed to use the FMR as estuarine habitat and effectiveness of recovery measures for different populations. These are all themes which need further investigation.

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1. Introduction

Fish have the natural behaviour to move across various aquatic ecosystems and for some fish species this is of vital importance. For instance salmon and eel have to migrate between the sea and freshwater to fulfil their life cycle (Wanningen et al., 2008). Migration is often a seasonal phenomenon which occurs in order to move between habitats, such as winter refuges-, foraging- and spawning or nursery habitats, also escaping from unfavourable environmental conditions, expanding the habitat, (re)populating new habitats and exchange between subpopulations (Riemersma & Kroes, 2006). On their journey of thousands of kilometres migratory fish meet various artificial barriers. In the Netherlands and elsewhere, some of these barriers are made by man to keep the country safe, dry and accessible through the construction of dikes, dams, pumping stations, sluices and several hydro-electric power stations. These man-made objects can be insurmountable obstacles or even damage or kill fish during either upstream or downstream migration (Wanningen et al., 2008). The Afsluitdijk, a man-made dam in the Netherlands, located between Friesland and North Holland, has been recognized as such a bottleneck (obstacle) of major importance (Wanningen et al., 2012). During the past decades several -´fish friendly`- management measures within the Afsluitdijk were in operation, but most of them were not ideal as they facilitated only the strong swimmers like Atlantic salmon (*Salmo salar*) or sea trout (*Salmo trutta*) (Hertog, 2006). To mitigate migration problems for fish, a large fish passage, a Fish Migration River (further named FMR) has been conceptualized at Kornwerderzand, which can provide opportunities for migratory fish to reach the IJsselmeer (see picture on cover page and chapter 4). In order to provide the FMR with the best possible design according to the ecology of occurring fish species, various researches are already ongoing to evaluate the status quo.

Policy

In the European Union (EU), regulations for environmental threats and problems are of increasing importance and effectiveness. International and national legislations and policies have been created, purposed to deliver a good ecological status, which includes the restoration of fish populations and ensuring of the future well-being and stability of fish stocks (see fig. 1.2). Within the Netherlands, the governance is divided in Provincial as well as Municipal governance and The Dutch Water Boards, which play a key role in environmental management. Direct funding of facilities to achieve these has been made possible by the means of EU, national subsides and grants.

On EU level, the Water Framework Directive (WFD) (Directive 2000/60/EC) has the objectives to compile information and reporting on the effectiveness of undertaken actions, the improvement of fish passages and the removal of obsolete structures. In the framework of the WFD water managers have identified the mitigation of migration barriers for fish and the restoration of habitats as an important goal (Environment Agency, 2010). In addition, the Habitats Directive (Council Directive 92/43/EEC), which is proposed for protecting designated plant and animal species (e.g. twait shad (*Alosa fallax)* and river lamprey (*Lampetra fluviatilis)*) and the European Eel Regulation (European Commission, 2007), aiming for the recovery of the European eel stock, are ‘fish friendly’ working legislations. Subsequently, every Member State of the EU has the obligation to implement these policies through National legislation in order to fulfil the European requirements. Examples of National legislations and policies are the River Basin Management Plan (European Environment Agency, 2011), a requirement of the WFD, the Eel Management Plans (EMPs), targeted on the restoration of European eel stocks and the Natura 2000 Management Plans, which are protecting e.g. target species of migratory fish and their habitats, such as the Wadden Sea and IJsselmeer (European Commission, 2012). Following, Provincial Government is responsible for translating national policy on environment (Ministry) guidelines into the regional context. Simultaneously, enforcing national policy and strategy on environmental management is mostly decentralised to Municipal Government. These authorities develop local regulations and have both the legal and financial means to carry out and enforce decisions and regulations. Municipalities may also work together with public authorities such as Water Boards on water quality, wastewater treatment and other water-related matters (www.government.nl) (see chapter 2).

Situation of fish migration in the Netherlands

In the Netherlands, a national overview of migration problems was until recently not available. Therefore, it was agreed to draw up a list with migration bottlenecks that have the highest priority to be equipped with some sort of migration facility. The purpose was to enhance fish migration to ecologically important water bodies, nationally and internationally. By order of the Association of Water Boards and the Directorate General for Water such an overview, entitled ´Nederland leeft met vismigratie` (The Netherlands live with fish migration, 2012), was made by the Dutch Angling association, the Centre for Water Management, Deltares and the consultancy firms Visadvies and Wanningen Water Consult (Wanningen et al., 2008). In this overview, the first step of gathering information from all water managers in the Netherlands concerning the policy status and the strategy to handle fish migration problems was undertaken. Accordingly, detailed information has been gained about the bottlenecks and migration facilities for fish and was processed into a national standardized fish migration database. This fish migration database was analysed and combined with ecological information on important migration routes and living areas for fish. It was chosen to approach the migration problems from an ecological point of view. Fish species were selected by their migration needs. This was linked to the distribution of species specific water types needed during their life cycle (see table 1.1). This resulted in an overview of migration routes that are of national and international importance and represent revealing potential bottlenecks for migrating fish. Over 90% of the water boards have provided information for this project (Wanningen et al., 2012) regarding their policy and facts on migration barriers and facilities (Wanningen et al., 2008).

Table 1.1 Fish species with specific needs for migration in rivers, brooks, cannels, lakes and estuaries in the Netherlands (Wanningen et al., 2008) (research relevant species in bold).

Fish species	Type of migration
Atlantic Sturgeon (*Acipenser sturio*) **Atlantic Salmon (*Salmo salar*)** Allis Shad (*Alosa alosa*) **Sea Trout (*Salmo trutta*)** **Sea Lamprey (*Petromyzon marinus*)**	Type 1 Migration between sea, estuaries, large rivers, small rivers and brooks in Germany, Belgium and France.
Three-spined stickleback (*Gasterosteus aculeatus*) **Smelt (*Osmerus eperlanus*)**	Type 2 Migration between sea, estuaries and stagnant freshwater water bodies near the coast
River Lamprey (*Lampetra fluviatilis*) Ide *(Leuciscus idus)*	Type 3 Migration between sea, rivers, small rivers and brooks
European eel (*Anguilla anguilla*)	Type 4 Migration between sea, rivers, large lakes and canals
Barbel (*Barbus sp.)* Chub *(Squalius cephalus)* Burbot (*Lota lota)* Nase (*Chondrostoma nasus*) Dace *(Leuciscus leuciscus)*	Type 5 Migration between rivers, small rivers and brooks
Brook Lamprey *(Lampetra planeri)*	Type 6 Migration between small rivers and brooks

However, the completeness of the data is still a concern. Due to the large number of bottlenecks in the Netherlands, the overview differs per water board from fully complete to incomplete, but information on the most important sites is available for the whole country (Wanningen et al., 2012). One of the bottlenecks in the Netherlands, the Afsluitdijk, has been recognized as an obstacle of major importance (Hertog, 2006).

Problem description

Since 1932, the 30 km long Afsluitdijk separates the IJsselmeer (formally the Southern Sea) from the Wadden Sea. This dike is a barrier for fish that migrate to inland freshwater systems, situated behind the coast of the previous Southern Sea. The IJsselmeer changed into a freshwater lake and is now populated with different freshwater species as well as diadromous fish species during their freshwater stage (Hertog, 2006). Because the water of the IJsselmeer is still used for agricultural purposes and as a drinking water, salt water is not allowed to enter. For that reason, the discharge complexes of the Afsluitdijk (located at Kornwerderzand and Den Oever) are discharging surplus of fresh water only one-way into the Wadden Sea. This takes place during ebb current and at 10 cm difference in water height (Griffioen, 2014) (see chapter 3).

The Afsluitdijk changed the previous situation of having a natural gradient in salinity and tidal regimes, leading to e.g. problems for diadromous fish, which are migrating between fresh and salt water. Instead of a natural transition between fresh and salt water, the boundary is now much harder. With two discharge complexes and shipping locks at Den Oever and Kornwerderzand, the Afsluitdijk features only a small possibility for migration. Naturally, the difference between high tide and low tide is gradual in an estuary or transition water. Now, the dynamic of water exchange between Wadden Sea and IJsselmeer is strongly regulated, leading to unnatural high water velocities of several m/s at the discharge complexes. During the discharge of freshwater, fish have to swim against the current to the freshwater lake. They have to overtake water velocities up to 4,5 m/s, leading to short migration windows (at the begin of a discharge with low velocities) and an abrupt transition from saltwater to freshwater. These problems cause blockage, delay or an increased risk of predation, particularly regarding upward migrating fish which want to spawn or seek for nursery habitats in the freshwater lake or upstream rivers (Winter et al., 2014). Only salmonids are believed to have a reasonable chance of passing the barrier. Different studies with tagged sea trout (*Salmo trutta)* proved that some fish are able to cross the barrier; 65% and 49% of the tagged fish (Vaat & Breukelaar, 2001). The only possibility to overcome this barrier for fish with a low swimming capacity, like stickleback and smelt, is to use the very short period at the begin phase of discharge, in which the water velocity is 0.1 m/s (Hartgers et al., 2001). Fish that use Selective Tidal Stream Transport[1] (like glass eel and flounder) have basically no chance to pass the barrier through the discharge sluices. Only on rare occasions, when the sluices are not closed in time and some salt water passes through, the fish can enter the IJsselmeer (Dekker, 2004).

Currently, migratory fish species are facing big limitations during their migration, resulting in far ranging consequences for whole populations. Some fish species were able to adapt to the new situation while others disappeared. Thus, the Afsluitdijk had a major impact on fish migration between fresh and salt water (Hertog, 2006).

To diminish the migration problems, the FMR has been conceptualized, providing for better opportunities for migratory fish to reach the freshwater lake with longer migration windows, lower water velocities and an incoming flow from the Wadden Sea to IJsselmeer, which allows weak swimmers like flounder larvae to drift inside by the use of Selective Tidal Stream Transport.

Based on the available knowledge, the FMR seems to be best located at the west side of the discharge sluices of Kornwerderzand (Winter et al., 2014), but no research has been done until now regarding the reason for these concentrations or possible other concentrations at different locations.

Study area

The abundance of the different species is (mainly) estimated through a monitoring project (fyke net catches) in front of the sluices near Kornwerderzand (sea-side) since year 2000 (Tulp et al, 2003). Kornwerderzand has been chosen as a suitable location for the FMR, because this location appears to have the highest concentration of diadromous fish on the IJsselmeer side of the dike (Hertog, 2006). Kornwerderzand belongs to the municipality Southwest Frisia and is situated on a former artificial island which was created when the Afsluitdijk was built (see fig 1.1). At Kornwerderzand, the Afsluitdijk contains two discharge complexes, a combination of shipping locks and discharge sluices. These discharge complexes contain two groups of five drain tubes (spuikokers). The gates are opened during ebb, when the water level in the Wadden Sea is 10 cm lower than in the IJsselmeer. The IJsselmeer water is streaming with a downward slope into the Wadden Sea. To prevent any salt water entering the IJsselmeer, the water is discharged ongoing, until there is again a 10 cm higher water level in the IJsselmeer than in the Wadden Sea. Each drain tube contains two doors: one door northwards at the Wadden Sea site and one door southwards at the IJsselmeer site. At the beginning of a discharge event, these doors are opened consecutively. The outermost doors of the five groups of drain tubes can be used for adjusted sluice management for fish migration purposes (see fig 1.1) (Griffioen & Winter, 2014). In this context, the doors are opened a gap width which creates an access whereat the mean current velocity of the water is lower for stream upwards swimming fish. At this discharge ducts, fish need to be very quick ("burst swimming") in passing the distance of the doors in order to swim into the IJsselmeer (Griffioen & Winter, 2014).

[1] Selective Tidal Stream Transport (STST)- special, energy-efficient behaviour of fish using flood current energy to move them towards surface in seeking for passage into fresh water bodies.

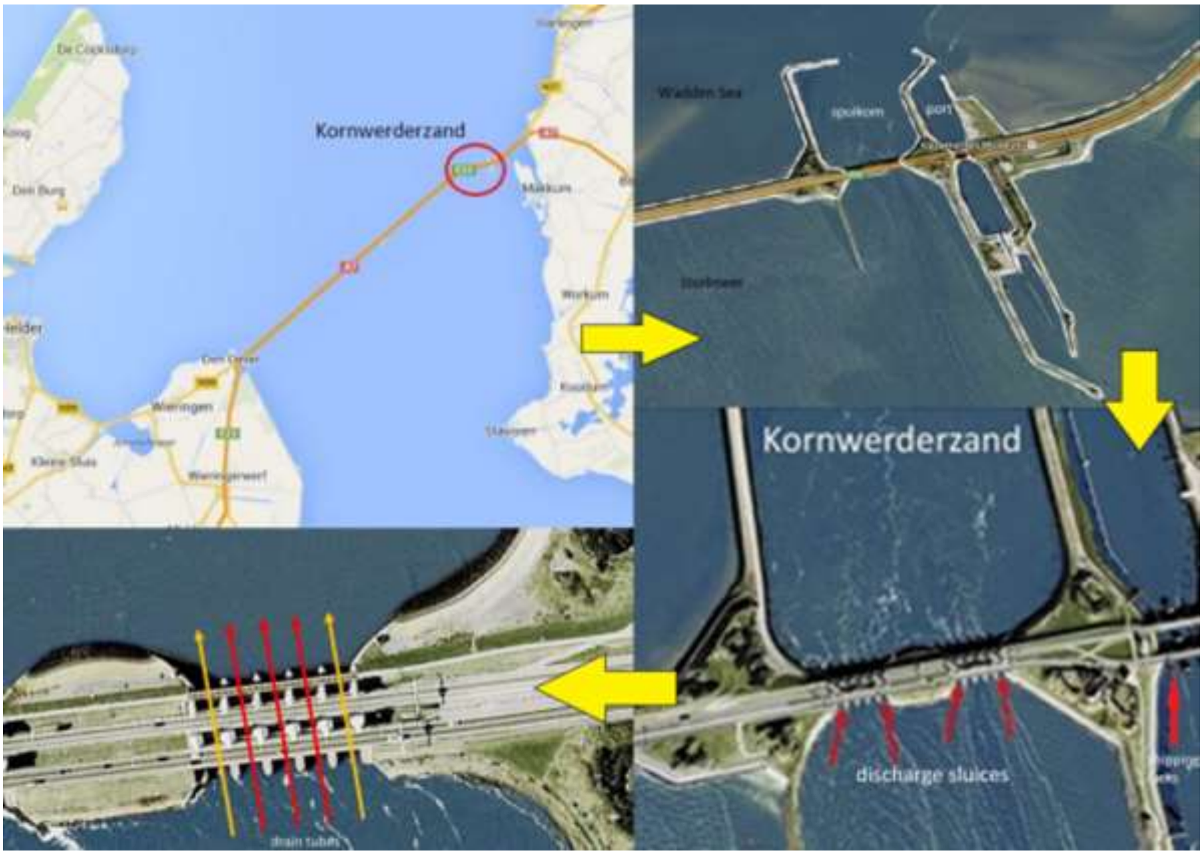

Figure 1.1 Research area at Kornwerderzand. From large to small scale: Location research area on a map (red circle); research area with discharge basin and port on IJsselmeer and Wadden Sea side; zoom-in of discharge sluices and shipping locks (red arrows); drain tubes with gates (red arrows normal discharge, yellow arrows fish friendly discharge). IMARES, 2014

Aim of research

There are still important knowledge gaps existing regarding the FMR topic. Species specific passage efficiency in the current situation, spatial searching behaviour of individual fish, capability of using short lasting migration windows, acclimatization requirements for fish to get used to changes in salinity, predation risk and losses, dimensions and salinity gradients that are needed to use the FMR as estuarine habitat, and effectiveness of recovery measures for different populations are all themes which need further investigation (Winter et al., 2014).

The problem owner, the Dienst Landelijk Gebied and the "De Nieuwe Afsluitdijk" (DNA) acquired a full assessment of the current situation at Kornwerderzand, in order to provide the FMR with the best possible design with the most efficiency, based on the ecology of fish. To gain the necessary scientific insight, the problem owners had assigned IMARES for the evaluation of the status quo. The overall goal of the ongoing projects was to enhance the scientific insight into the behaviour and abundance of fish species in relation to tidal regimes and discharge in order to obtain knowledge for the FMR.

As a sub project of IMARES research work (ongoing projects) concerning the FMR, this thesis was directed to gain scientific insight in the abundance and the spatial distribution of migratory fish in fresh-salt transitions at the Kornwerderzand area in relation to the tidal regimes, discharge events, discharge volume and temperature, in order to obtain knowledge for the design of the FMR. The outcome of this thesis can be regarded as one piece of the puzzle, aiming to fill a knowledge gap.

This thesis was a complementary research (sub project) with the aims:

- To get an indication of the relation between abundance and spatial distribution of diadromous fish species in relation to discharge events and thus in how far by attraction flow attracted fish stay in the discharge basin related to new discharge and tidal regime over time.
- To get an insight where high concentrations of fish species occur linked to the best potential entrance(s) of the FMR.
- To get insight into the spatial distribution of small fish (flounder larvae, glass eel, smelt, stickleback) around the discharge basin, their location and whether they are long term occurring or accumulating again between discharge events and tidal regime, linked to potential entrance(s) of the FMR.
- To investigate the behaviour of fish in terms of dispersal in the water column during tidal regimes as an additional value.

Ecology target species

This research was focussing on (the ecology of) 15 different diadromous and freshwater target species, which can occur at the discharge area of Kornwerderzand. The FMR has as one of its aims to be suitable for a broad group of diadromous fish. The species studied in this research were chosen according to the selection of target species for the FMR of PNRW (PNRW, 2013). The protection status of the migratory fish species according to Dutch law and legislation is given in table 1.2. An overview of their migration timing is given in table1. 3. The description of their ecology is given below and pointed out according to the importance of passing the Afsluitdijk, the timing of migration, migration and orientation behaviour, swimming capacity and passage strategies (for detailed information please see Appendix I).

Table 1.2 Protection status of diadromous target species within the Dutch law

English name	*Scientific name*	*Fisheries: closed season*	*FF-law*	*Reaching habitat*	*Red list*
Atlantic salmon	*Salmo salar*	Full year	-	II/V	
Flounder	*Platichthys flesus*	No	-		
Three-spined stickleback	*Gasterosteus aculeatus*	No	-		
European eel	*Anguilla anguilla*	Sep-Nov	X		
Twait shad	*Alosa fallax*	Full year	-	II/V	X
Houting	*Coregonus oxyrinchus*	-	X	II/IV	
River lamprey	*Lampetra fluviatilis*	Nov-April	-	II/V	
European smelt	*Osmerus eperlanus*	Fish dependant	-		
Sea (Brown) trout	*Salmo trutta*	Full year	-		
Sea lamprey	*Petromyzon marinus*	Full year	-	II	

Diadromous fish are fish species which are swimming back and forth between salt and fresh water, or vice versa, on their way to their mating and nursing grounds. All diadromous fish are passing the fresh-salt transition at least twice in their life, once as juvenile and once as adult (Winter et al., 2014). The freshwater fish species were included in the analysis because of their economic importance or due to their occurrence in high numbers in the IJsselmeer (Griffioen and Winter, 2014).

Investigated fish species were ten diadromous target fish species: Atlantic salmon (*Salmo salar*), flounder (*Platichthys flesus*), European eel (*Anguilla anguilla*), European river lamprey (*Lampetra fluviatilis*), European smelt (*Osmerus eperlanus*), North Sea houting (*Coregonus oxyrinchus),* sea lamprey (*Petromyzon marinus*), sea trout (*Salmo trutta*), three-spined stickleback (*Gasterosteus aculeatus*) and twait shad (*Alosa fallax*) and five fresh water target fish species: bream (*Abramis brama*), European Perch (*Perca fluviatilis*), roach (*Rutilus rutilus*), ruffe (*Gymnocephalus cernua*) and zander (*Sander lucioperca*) (see App. I).

Atlantic salmon, houting, river lamprey, sea lamprey, sea trout, smelt, stickleback and twait shad are anadromous species (Poulsen et al., 2012; Winter et al., 2014). Flounder and eel are catadromous (Morais et al., 2011; Winter et al., 2014) and migrating at a juvenile stadium. Houting, river lamprey, salmon, sea lamprey, sea trout, smelt, stickleback and twait shad are migrating as adults. Eel, sea lamprey, smelt, stickleback and twait shad are migrating in spring. Seat trout migrates from late spring until late autumn, salmon migrates in spring, summer and autumn, flounder only in the summer, houting only in autumn and river lamprey in autumn until early spring (Winter et al., 2014). Flounder and twait shad are migrating during the day (Trancart et al., 2012; Aprahamian et al., 2003), eel, river lamprey and smelt are nocturnal migrators (Kemp et al., 2011; Keefer et al., 2013) and salmon and sea trout do both (Potter, 1988; De Vaat, 2003; Kennedy et al., 2013) (see table 1.3).

Table 1.3 Timing of migration within the different target species, divided into stage of migration, season of migration, months of migration and day/night (○ = day; (●) = night) preference per species (Winter et al., 2014).

			winter		*spring*			*summer*			*autumn*				
English name	*Scientific name*	*Stage*	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*day/night preference*
Atlantic salmon	*Salmo salar*	*Adult*													○ (●)
Flounder	*Platichthys flesus*	*Juvenile*													○ (●)
Three-spined stickleback	*Gasterosteus aculeatus*	*Adult*													●
European eel	*Anguilla anguilla*	*Juvenile*													●
Twait shad	*Alosa fallax*	*Adult*													○ (●)
Houting	*Coregonus oxyrinchus*	*Adult*													?
River lamprey	*Lampetra fluviatilis*	*Adult*													(○) ●
European smelt	*Osmerus eperlanus*	*Adult*													●
Sea (Brown) trout	*Salmo trutta*	*Adult*													○ (●)
Sea lamprey	*Petromyzon marinus*	*Adult*													(○) ●

Flounder, young eel (glass eel) and stickleback make use of Selective Tidal Stream Transport (Bult & Dekker, 2007; Bos, 1999; Jager, 2001) and are regarded as weak swimmers. Smelt is a weak to moderate swimmer. Moderate to strong swimmers are river lamprey and sea lamprey. Houting, salmon, sea trout and twait shad are regarded as strong swimmers (Winter et al., 2014). A migration possibility is of high importance for all the species, except for flounder, where it is no requirement (Winter et al., 2014). It is indicated that acclimatization between fresh-salt transitions is important for twait shad (Winter et al., 2014), but unproblematic for eel (Wilson et al., 2004) and seems to be not of high importance for salmon (Potter, 1988). For the other species information is lacking (Winter et al., 2014).

Research questions

According to the aims of the research the following research questions have been designed:

"What is the spatial distribution and abundance of the 15 target fish species in and around the discharge area at Kornwerderzand in relation to tidal regimes, discharge events, discharge volume and temperature?"

Sub questions

1) "What is the spatial distribution of the four target species European smelt (*Osmerus eperlanus*), flounder larvae (*Platichthys flesus* larvae), glass eel (*Anguilla anguilla* larvae) and three-spined stickleback (*Gasterosteus aculeatus*) in the discharge basin and the port at Kornwerderzand in relation to tidal regimes and discharge events?"
2) "What is the vertical distribution of fish throughout the water column in fresh-salt water transitions of the discharge basin at Kornwerderzand?"
3) "What is the CPUE (Catch Per Unit Effort)[2] and the difference in species of the 15 target species between the different fykes at the Kornwerderzand area in relation to discharge volume and temperature in autumn 2013 and spring 2014?"

Reading instructions

In Chapter 2 detailed information is given about relevant policies, laws and legislations according to the topic, beginning with the international level, followed by the European, the national, provincial and municipal level. Chapter 3 features additional information about the Afsluitdijk, its development and subsequent consequences, as well as an overview of past, current and future adjusted sluice management for fish migration purposes. Chapter 4 provides detailed information about the FMR, including the description of the FMR project, the statement of the main goals and the identification of project requirements. Additionally, the design of the FMR is described and one possible function is explained. Following, involved stakeholders are introduced by mentioning their function in general and their role in the FMR project. In chapter 5 the used materials and methods applied for this study are elaborated, which includes the description of the study area, the method of data sampling, including the description of the function of used tools divided per sampling method/sub-research question. A summary of the type of collected data is given and the data preparation for the analysis is described, divided per sampling method/sub-research question. Subsequently, it is explained how the data has been analysed by defining steps and used software, divided per sampling method/sub-research question. Chapter 6 presents the results in tables, figures and text, divided per sampling method/sub-research question. In chapter 7 the results are discussed according to the ecology of the target fish species and linked to recent grey and scientific literature. Conclusions regarding the outcomes of chapter 6 and 7 are drawn in chapter 8. In chapter 9 we present our recommendations regarding fish migration in general and the FMR topic, resulting from the outcomes of chapter 6, 7 and 8. All required references used for this research are listed in chapter 10.

[2] CPUE- is an indirect measure of the abundance of a target species. Changes in the catch per unit effort are inferred to signify changes to the target species' true abundance (Puertas and Bodmer, 2004)

2. Policies

In the European Union (EU), regulations for environmental threats and problems are of increasing importance and effectiveness. International and national legislations and policies have been set, purposed to deliver a good ecological status, which includes the restoration of fish population, ensuring the future well-being and stability of fish stocks. Funding of facilities to achieve these has been made possible by the means of EU and national subsides. Figure 2.1 illustrates the policy framework for fish migration, starting at European Legislation, followed by the National Legislation and ending with Regional legislation.

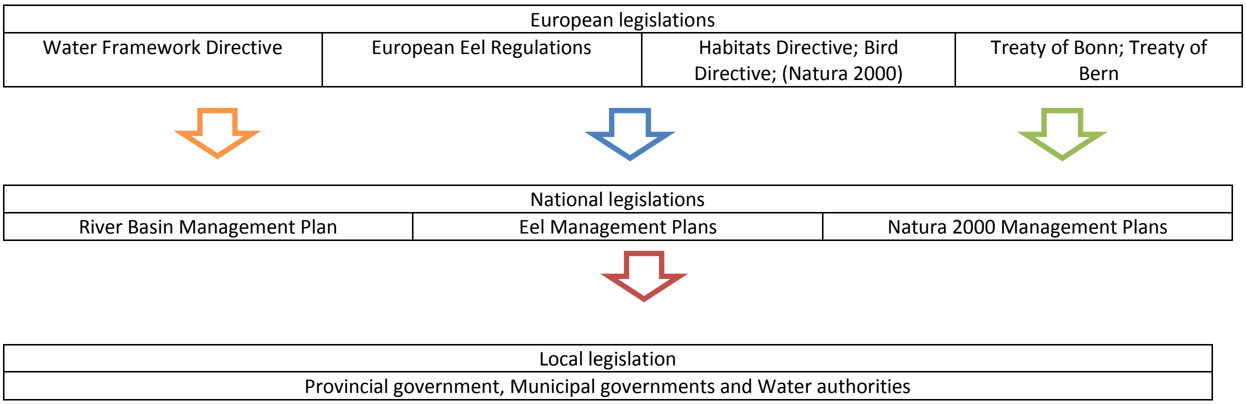

Figure 2.1 Policy frameworks for fish migration

2.1 European legislations

Water Framework Directive

Fish are one of the biological quality elements within the European Water Framework Directive (WFD) (Directive 2000/60/EC), which came into life in year 2000. In recent years the WFD was the main driving force for increased interest for improvement of fish stocks and fish migration. The WFD demands water managers to develop targets and measures for the fish stocks. Mitigating migration barriers (such as dams, hydro-electric power stations, pumping stations, sluices etc.) has been identified by water managers as an important measure to improve fish stocks apart from restoring habitats. Accessibility of spawning and nursery areas for fish has become part of the European (and national) water policies. The most important measures from the WFD regarding policy for fish migration are:
Collation of information and reporting on the effects of the measures in place, in order to protect migrating fish;

- Improvement of fish passage;
- Removal of obsolete structures (Environment Agency, 2010).

The WFD is the most important legislation relevant to ecological condition and to the well-being of migratory fish, however it is not the only legislation.

Treaty of Bonn

This treaty was created with regards to the protection of migrating wild animal species, Appendixes I and II, (dated 23rd June 1979). Section 2 of this treaty recognises the importance of migrating fish species and requires appropriate measures to be taken to insure the preservation of migrating species.

Treaty of Bern

This treaty was created with regards to the preservation of wild animal- and plant species and their natural habitat, Appendixes I, II, III, IV (dated 19 September 1979). This treaty aims for the preservation of wild plant and animal species and the habitats they depend on. The treaty is also designed for situations where co-operation is needed.

Habitats directive

The European Community proposed a directive for protecting exceptional natural areas in 1992: the Habitats Directive (Council Directive 92/43/EEC). This directive lists designated plant and animal species e.g. river lamprey and twait shad and natural communities that deserve extra protection.

"It promotes the maintenance of biodiversity by requiring the European Member States to take measures to maintain or restore natural habitats and wild species which are listed in the Annexes in the Directive to a favourable conservation status, introducing robust protection for those habitats and species of European importance. In applying these measures Member States are required to take into account the economic, socia and cultural requirements, as well as regional and local characteristics;

The most important measures from the Habitats Directive regarding fish migration:

- *Maintain or restore European protected habitats and species;*
- *Undertake surveillance of habitats and species (Article 11);*
- *Ensure strict protection of species listed on Annex IV (Article 12 for animals and Article 13 for plants)*

Member States shall also endeavour to encourage the management of features of the landscape that support the Natura 2000 network (Articles 3 and10);"

Figure 2.2 Role and measures of Habitats directive (Defra, 2012)

Birds directive

"This Directive as well as its amending acts seek to:

- *protect, manage and regulate all bird species naturally living in the wild within the European territory of the Member States, including the eggs of these birds, their nests and their habitats;*
- *regulate the exploitation of these species.*

The Member States must also conserve, maintain or restore the biotopes and habitats of these birds by:

- *creating protection zones;*
- *maintaining the habitats;*
- *restoring destroyed biotopes;*
- *creating biotopes."*

Figure 2.3 Summary of the Birds directive (EC, 2009)

European Eel Regulations

The European Eel Regulations gives a requirement to the Member States to produce a plan for the recovery of the European eel (*Anguilla anguilla*) stock. This was done by the Member States in 2008. It includes the current status, trends and the targets for the European eel stocks. Measures to reach the targets have also been set and monitoring programs to validate the targets have been included. One of the measures is that at least 40% of the European silver eel population (of the silver eel biomass) can escape to sea (Moria, 2008). Important criteria from the European Eel Regulations are:

- 40% of the European silver eel population (of the original silver eel biomass) should escape to sea ;
- 60% of glass eel caught in Europe (<12cm long) are to be used in restocking, for the purpose of increasing escapement of silver eel to the sea (start at 35%, reach 60% by 2013). However, there was no restocking of wild caught eels <12 cm, because no eels <12cm are caught in the Netherlands. The legal minimum size for eel fishery in the Netherlands is 28 cm. Therefore this percentage is zero (0%) (The Ministry of Agriculture, Nature and Food Quality, 2008).

European Eel Regulations reflect in the Dutch Eel Management plan with measures focused on enlargement of accessible natural habitats, optimizing migration of glass eel and adult fish and a larger quantitative and qualitative monitoring programme. As a result there should be:

- More eel reaching the adult stage
- More adults reaching the Atlantic Ocean
- More glass eel entering the inland waters (The Ministry of Agriculture, Nature and Food Quality, 2008).

2.2 National legislations

The European Union has set the above legislation regarding the protection of certain species and habitats and the restoration of fish migration. Every Member State has the obligation to develop national legislation in order to fulfil the European requirements. Relevant National legislations are:

River Basin Management Plan (RBMP)

"The WFD prescribes that management activities should aim to achieve the goals of the Directive within geographical areas or river basin districts (RBDs). These are based largely on surface water catchments, together with the boundaries of associated groundwater and coastal water bodies. For each river basin district, a river basin planning process must be developed" (European Environment Agency, 2011). The first milestone of this planning process is the first River Basin Management Plan (2009), second (2015) and further cycles (2021 and 2027)" (European Environment Agency, 2011). The Netherlands have 4 river basin districts, which all are international sharing water courses with Belgium, France, Luxemburg and Germany. The project had the following targets:

- To generate a national overview of migration bottlenecks and realised and planned fish migration facilities in WFD water bodies;
- To draw up a national line of thought to prioritise the need to mitigate migration bottlenecks in the Netherlands, in strong cooperation with the regional water managers;
- To make the information available in the public domain for a wide audience

“The RBMPs include a description of several water management plans at different levels: national, regional and provincial. The regional plans (waterschapsplannen) cover the sub-basins while the other plans (based on administrative boundaries) may overlap between the river basins. The issue of water management is clearly tackled in depth in the Netherlands.

However, there existence of a number of plans and strategies at different levels results in a complex matrix of plans and competences across the different authorities.

The RBMPs are very clearly structured and the different topics of the WFD implementation can be easily found in the setup of the plans.

A national approach has been followed in the implementation of the WFD. All RBMPs have the same structure. The 'Ministry of Infrastructure and the Environment' is the ultimate body responsible for the drafting of the RBMPs, and has a role of overall coordination.”

Figure 2.4 Quotation from “Implementation of Water Framework Directive (2000/60/EC), River Basin Management Plans “(EC, 2000)

Natura 2000 Management Plans

The EU is looking to ensure biodiversity by the preservation of natural habitats and wild fauna and flora in the territory of the Member States. The legal basis for Natura 2000 Management Plans is coming from other European legislation like the Birds Directive and the Habitats Directive, which form an important part of the EU's biodiversity policy. An ecological network of special protected areas, known as "Natura 2000" has been developed for this purpose. Nowadays 26.000 areas in all the Member States are a Natura 2000 protected area. These areas combined cover an area of more than 750.000 km2, which is 18% of the EU’s land area (European Commission 2012).

Migratory fish are within the target species of NATURA 2000, which were set for the Netherlands:

*“In the case of species, a recovery objective has been set at national level for more than half of the species. This relates in particular to butterflies, dragonflies and **migratory fish** as well as to the beaver (H1337) and root vole (H1340). The Natura 2000 landscapes North Sea, Wadden Sea and Delta, River Area, Brook Valleys and Lakes and Marshes in particular are required to make a contribution in this respect.”*

Figure 2.5 Species-wise objectives for Natura 2000 (EC, 2012)

2.3 Local legislation

The Netherlands has a long practice of dialogue and cooperation between government bodies, stakeholder organisations and citizens. Within this framework, policy on national and international issues is organized by central government and creates the basis for legislation approved by the Dutch Parliament.

The Ministry of Infrastructure and the Environment is responsible for developing policy in the national context and the provinces are responsible for translating these policies into the regional context. The municipalities have the power and financial means to promote and implement local policy on spatial planning and the environment (www.government.nl).

Local policy should be based on international and national policy adjusted to suit further specific (local) information. Some regional or local requirements, such as planning conditions, may not be enacted as legislation whilst others, for instance those made by provinces, municipalities or water board, might. Some Water Boards in the Netherlands have identified bottlenecks and formulated targets regarding fish migration in their water bodies, which reflect, for instance, ‘The Eel

Management Plan' or 'River Basin Management Plan' (Kroes & Wanningen, 2006). The Dutch Water Boards play a key role in environmental management in the Netherlands because they are responsible for managing and sustaining surface water quantity and quality throughout the country. One of the oldest public authorities in the Netherlands, the 26 Water Boards operate quite independently of national government in their primary task of safeguarding the country against flooding and rising sea level.

Moreover, the Water Boards are responsible for managing and maintaining flood defences along the coast, rivers and waterways. An integral part of this task is to manage and maintain sufficient quantity of surface water of adequate quality for many purposes – drinking water, domestic and industrial uses. This includes managing and operating municipal wastewater treatment plants and the discharge of treated water into surface waters. It comprises continuous monitoring of the chemical and biological quality of surface waters (www.government.nl).

3. The Afsluitdijk

The Afsluitdijk forms as a part of the Zuiderzeewerken an important water exchange between the Wadden Sea and the IJsselmeer area. The 32km long dike was built between 1927 and 1932 and separated the IJsselmeer (formally the Southern Sea) from the Wadden Sea (see fig 3.1). It`s completion in 1932 was accompanied by consequences for the migration of fish between the Zuiderzee and the bordering rivers. With the hence arising IJsselmeer a big freshwater basin was created with significant impacts on flora and fauna in this region.

Figure 3.1 The Afsluitdijk nowadays, Eagle shot of discharge sluices Kornwerderzand. Wim den Oever, 2007.

The Afsluitdijk is representing a barrier and changed the previous situation of having a natural gradient in salinity and tidal regimes, leading to e.g. problems for diadromous fish, which are migrating between fresh and salt water. Instead of a natural transition between fresh and salt water, the boundary is now much harder, with a water stream only directed to the Wadden Sea.

With two discharge complexes and shipping locks located at Den Oever and Kornwerder-zand, the Afsluitdijk features only a small possibility for migration. Naturally, the differences between high tide and low tide are going gradually in an estuary or transition water. Now, the dynamic of water exchange between Wadden Sea and IJsselmeer is strongly regulated, leading to unnatural high water velocities of several meters per second at the discharge complexes. Currently, migratory fish species are facing limitations during their migration, resulting in far ranging consequences for whole populations. Some fish species adapted to the new situation and others disappeared. Hence, the Afsluitdijk had a significant impact on fish migration between fresh and salt water (Hertog, 2006).

The Afsluitdijk contains in total five groups of discharge complexes, with each five discharge sluices, which are 12 meters wide and (on average) four meters deep. Three of these groups are situated near Den Oever (North-Holland) and two at Kornwerderzand (near the coast of Friesland). The sluices drain the excess water from the IJsselmeer. Each year between ten (in a dry year) and 20 (in a wet year) billion (10^9) cubic meters is discharged into the Wadden Sea. The discharge starts at a minimal height difference of 10 centimetres, with an average height difference of 50 centimetres (Rijkswaterstaat), resulting in a water velocity of respectively 1.4 and 3.1 m/s (Hertog, 2006). If the sluices are opened completely the water velocities are 4,5 m/s and are decreasing to around 2 m/s within the next half hour after the opening (Kolvoort, 1990).

Because the water of the Ijsselmeer is still used for agricultural purposes and as drinking water, salt water is not allowed to enter. For that reason, the discharge complexes of the Afsluitdijk are discharging surplus of fresh water only one-way into the Wadden Sea. This takes place during ebb current and at 10 cm difference in water (Griffioen, 2014). Depending on the need of discharge three different situations of discharge can occur: With a normal discharge level all sluice gates are completely opened (33333). At a lower discharge level, the three inner gates are completely opened and the two outer gates are opened for 50 cm (23332). At minimal discharge level, which is used as adjusted sluice management for fish migration purposes, only the two outer gates are opened for 50 cm (21112) (3=gate completely opened, 2=gate opened for 50cm, 1=gate closed; see fig. 3.2).

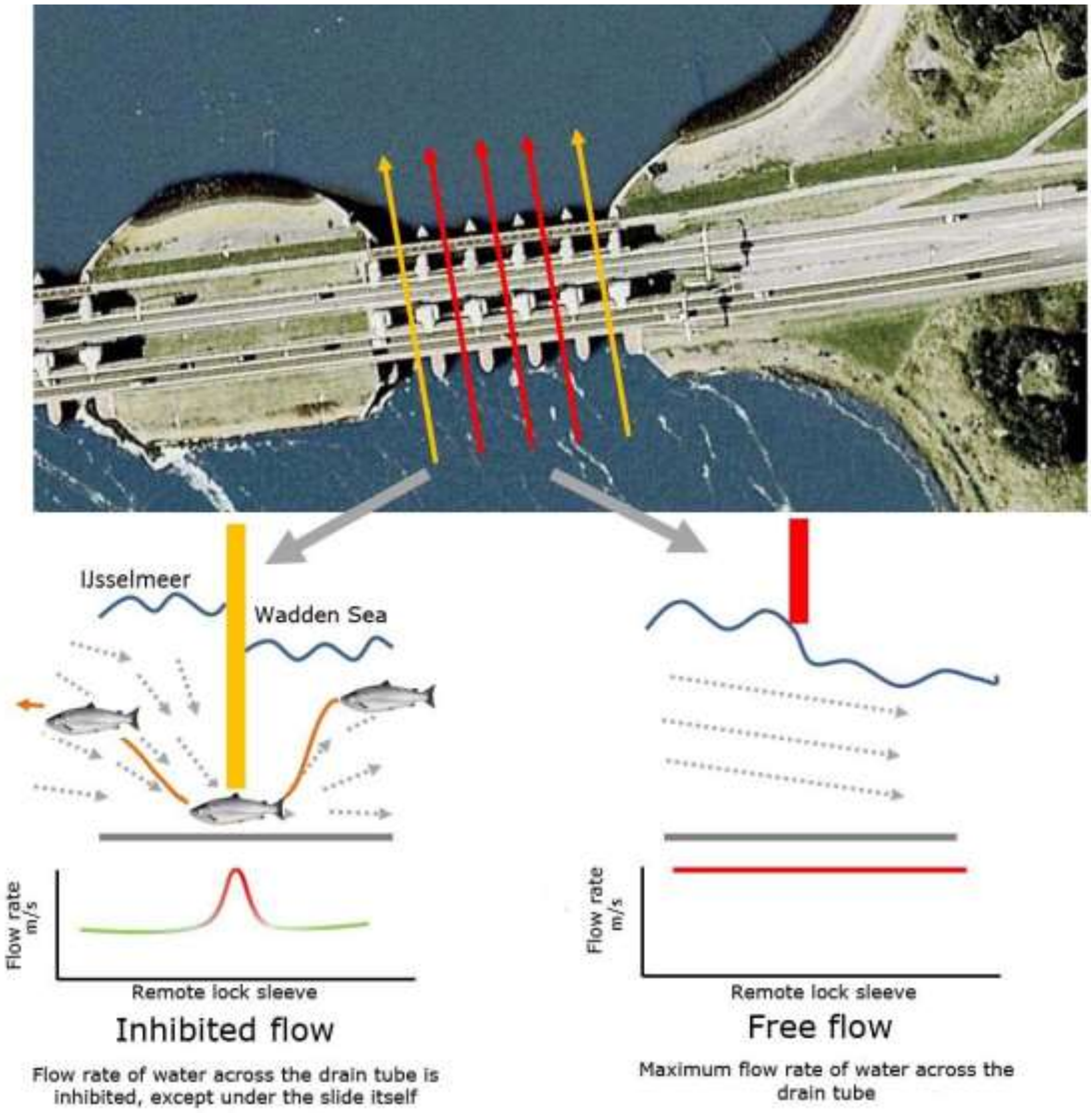

Figure 3.2 Current situation of the modified drainage management for fish migration facilitating strong swimmers (23332). In this situation, the outer gates of each group of discharge sluices (5) are put on a crack (orange line). The inner gates are opened (red line). This results in lower average flow in the drainage (only a short section under the gate where the flow rate is high) causing relatively strong swimmers as salmon and sea trout to have better passing opportunities (Source: Griffioen 2014).

During the discharge of freshwater, fish have to swim against the current to the freshwater lake. They have to overtake high water velocities up to 4,5 m/s during the discharge, resulting in short migration windows (at the start of the discharge when velocities are low) and an abrupt transition from saltwater to freshwater. These problems cause blockage, delay or a higher risk of predation, especially concerning upward migrating fish which want to spawn or seek for nursery habitats in the freshwater lake or upstream rivers (Griffioen, 2014).

3.1 Adjusted sluice management for fish migration

Because of the barrier Afsluitdijk, fish can only migrate from fresh to salt water and vice versa through the discharge sluices and the shipping locks. For that reason a sluice management for the optimization of fish migration was implemented by Rijkswaterstaat in the past (Winter et al., 2014). An overview of the previous, current and future management is given in table 3.1.

Management in the past

Before 1960, it was tried to create a passage for glass eel with opening the northern and the southern doors of the discharge sluices consecutively. After 1960 the management changed to a "glasaal-inlaten", in which context the discharge sluices were opened several centimetres during low tide, to enable young eel to pass the barrier (Dekker & van Willingen, 2000). In the begin of the 1990`s the measure was extended with open sluice gates until same water level in the months March until August. In 1991 the period was prolonged until September so that young flounder also got a chance to reach the IJsselmeer. After 1993, this measure was withdrawn because of too much salt inlet into the IJsselmeer. In the period 1992 until 1993 many fish were able to reach the IJsselmeer, including young flounder and eel (Vethaak et al, 2004; Winter et al., 2008). From 1993 until 2003 the management changed again. The gates of the sluices stayed open a gap width (50 cm) until 10 cm difference in water level from March until August, which led to decreased water velocities in the discharge duct.

Table 3.1 Development of sluice management for the optimization of fish migration between fresh-salt transitions at the discharge complexes of the Afsluitdijk. The table is giving information about the period, the measure, the effect of the measure and the expectable effect for fish (Dekker and van Willingen, 2000; Willet, 2004).

Period	Measure	Operation	Fish migration
Until 1960	*Fences with sluices*	*North and south gates are consecutively open, the south door opens while the north gate is closed again.*	*Fish swim actively in spaces between the gates and then towards the IJsselmeer with the opening of the south gate.*
After 1960	*Crack (space) from a few centimeters to 10 cm height difference*	*Ten edge gates are being open ajar. The flow rate in the vent tube of the water was significantly inhibited. How great the flow under the door was is unknown.*	*Fish swim actively through the gates during their opening.*
1991-1993	*Crack open until equalization of water levels*	*Slide limited opening (50 cm), so that flow into the drain tube is slowed down. March 1 to September 1.*	*Fish swim actively through during opening of the gates. In the lock the flow is lower than the flow rate when the gates are fully open. With equalized water levels passive or weaker swimmers can also pass and reach IJsselmeer.*
1993 - 2003	*Crack open until 10cm water level difference*	*Slide has limited opening (50 cm), so that the flow in the drain tube is slowed down. March until August.*	*Fish swim actively through the gates during the opening.*
2003 - now	*Crack open until 10cm water level difference (All year)*	*Slide has limited opening (50 cm), so that the flow in the drain tube is slowed down. Year round, if possible. Applied at two outer gates.*	*Fish swim actively through the gates during the opening.*
Nowadays	*Fences in shipping locks*	*Fences open at night when there are no shipping activities.*	*Fish can actively swim through fences inward.*
Future (2015)	*Fish passage at Den Oever*	*Siphon fish passage.*	*Fish can be passively 'transferred' inwards or actively swim.*
Future (2015)	*Early opening of the sluices*	*Salt water is being let in the IJsselmeer. The salt water is then washed away with the next lock and/or pumped through to build an equalized salt water return system.*	*Fish can swim actively or passively or drift with the tide in the IJsselmeer.*

Present and future management

From 2003 until today, this management was extended to gap width open sluice gates all year around (if possible). Depending on the need of discharge, three different situations can occur with the drainage method used since 2003: With a normal discharge level all sluice gates are completely opened. At a lower discharge level, the three inner gates are completely opened (see fig. 3.2, red arrows) and the two outer gates are opened for 50 cm (see fig. 3.2, orange arrows). This type of adjusted sluice management for fish migration purposes facilitates only the strong swimmers. At minimal discharge level, which is used as adjusted sluice management for fish migration purposes all year round-if possible-, the two outer gates are opened for 50 cm (see fig. 3.2, orange arrows) and the three inner gates are closed. This sluice management facilitates also the weak swimmers. It enhances the glass eel passage success and decreases the water velocities in the discharge ducts to 0,1m/s at the lowest water level, but still up to 2 m/s (Kolvoort, 1990). It was chosen for the two outermost gates because the currents are less hard at these locations and fish can enter more easily (Willet, 2004). This fish-friendly management can be adapted in the majority of cases. Nevertheless, in times of sparse or high river discharge, all gates and ducts need to be maximal closed or maximal opened. For small fish or weak swimmers, like glass eel, smelt, three-spined stickleback and flounder, these are unfavourable circumstances (RWS, 2013b). There are examples from Den Oever, where small and weak swimmers can enter the IJsselmeer via “loze schuttingen” (RWS, 2013a). Primarily, a fish passage was planned both for Den Oever and Kornwerderzand. In Den Oever this passage is going to be realized in 2015. The second passage at Kornwerderzand has been postponed in order to perform research in the context of the FMR.

4. Fish Migration River

The government is working on strengthening the Afsluitdijk and increasing the discharge capacity. Simultaneously, regional and national parties aim on the realization of a number of sustainable ambitions for the dam. One of the goals is the construction of a FMR near the area of Kornwerderzand. The “Fish Migration River Afsluitdijk” is a unique project to renew the Dutch icon Afsluitdijk (PNRW, 2013). With the construction of the FMR the ecological connection between the Wadden Sea and the IJsselmeer can be re-established, and hence migratory fish can once again reach their spawning grounds without hindrance caused by anthropogenic factors. The FMR has the goal to create migration opportunities into the IJsselmeer for migratory fish, fish in estuaries and freshwater fish which are flushed into the Sea during discharge. The main goal is the optimization of fish populations in the Wadden Sea, the IJsselmeer and the upstream river and beck systems. The core of the FMR project is the construction of a new water transit by the Afsluitdijk, embedded in a design that allows a gradual transition with a natural like fresh-salt water design (see fig. 4.1). The goals of the project are:

1. Realization of a concrete location in order to give advice about and to visualize the migration of diadromous fish and the importance of good fresh-salt transitions;

2. Strengthening and enriching the fish populations in the IJsselmeer and the Wadden Sea by the restoration of the migration route for the migratory fish;

3. Realization of a robust, high-quality natural connection between the two large natural areas IJsselmeer and Wadden Sea;

4. Realization of an economic boost for the sector recreation & tourism on the Afsluitdijk and thus for the provinces of Friesland and North Holland;

5. Contributing to the development of an economic future for the sport and commercial fishing in the IJsselmeer and the Wadden Sea (Winter et al., 2014).

Figure 4.1 Concept of the FMR at Kornwerderzand. Wageningen UR, 2014

The concept of the artificial FMR is a 6 km long passage, basically consisting of three parts: a 2 km long sea passage, a 100 m long 5 x 2 m tube through the dyke and a 4 km long freshwater/brackish passage (see fig 4.1). The lake-inlet of the river and the tubes through the dyke have doors to prevent salt water entering the freshwater lake. Accordingly, the last part of the river always needs to be passed by active swimming (Winter et al., 2014). The idea of the FMR is that it can be opened before and after the discharge sluices are opened, providing longer migration windows for fish to migrate into the IJsselmeer, with lower water velocities compared to the discharge sluices and temporarily even an incoming flow and tidal currents from the Wadden Sea to the IJsselmeer. This creates circumstances which allow weak swimmers like flounder larvae and glass eel to drift inside using Selective Tidal Stream Transport (Griffioen & Winter, 2014).

Although the definite design of the FMR is not clear yet, the following describes one of the design variants for a better understanding. Figure 4.2 shows a schematic view of the FMR, including the function of the fish passage during tidal regimes. The FMR consists of an estuary part on the Wadden Sea side, which can be closed by a double lockable sluice door from the Wadden Sea side. A rectangular, cement duct will be placed through the Afsluitdijk. A river system, also closable with a sluice, will be constructed at the IJsselmeer side. The functioning of the FMR can be explained as following: The discharge sluices of Kornwerderzand and the FMR are closed at high tide on the Wadden Sea side. In these circumstances, the FMR has a higher water level than the IJsselmeer and a brackish water milieu. Then, the FMR is opened before the discharge sluices. Also the IJsselmeer access is opened a bit later to prevent brackish water from entering. Subsequently, the discharge sluices are opened. Due to the discharge, the water currents in the FMR decrease and are eventually counter-rotating. Salt water enters the FMR, as a consequence of high tide in the Wadden Sea. The FMR will be closed at the outermost door of the IJsselmeer to prevent salt water to enter the IJsselmeer. Afterwards the discharge sluices will be closed, followed by the FMR. Now, the FMR contains a brackish water habitat. The functioning of the FMR can be divided into six phases (see fig 4.2):

Phase 1
Ebb current. Closed doors on the IJsselmeer side (nr. 1) and with duct (nr. 2). An “attraction flow” of fresh/brackish water is created. The discharge sluices are closed.

Phase 2
The same water levels in Wadden Sea and IJsselmeer, but the water level in the FMR is higher on the IJsselmeer side. The doors of duct are being opened, which creates an attraction flow through the Afsluitdijk. The discharge sluices are closed.

Phase 3
The water level on the Wadden Sea side is 10cm lower than on the IJsselmeer side. Normal discharge: the discharge sluices are being opened. Also door 1 is opened which creates two open water streams, one at the discharge sluices and one in the FMR.

Phase 4
Flood current. 10cm difference in water level of Wadden Sea and IJsselmeer. The doors of the discharge sluices are closed to prevent salt water entering the IJsselmeer. All the doors of the FMR stay open. This situation creates a free gradient of fresh water directed to the Wadden Sea.

Phase 5

Flood current. The water level in the Wadden Sea increases. To prevent salt water from entering, door nr. 1 on the IJsselmeer side is closed. This creates a water stream through the FMR directed to the IJsselmeer.

Phase 6

High tide. All doors are closed. Salt water can stream into the FMR with the tidal currents. (Winter et al., 2014)

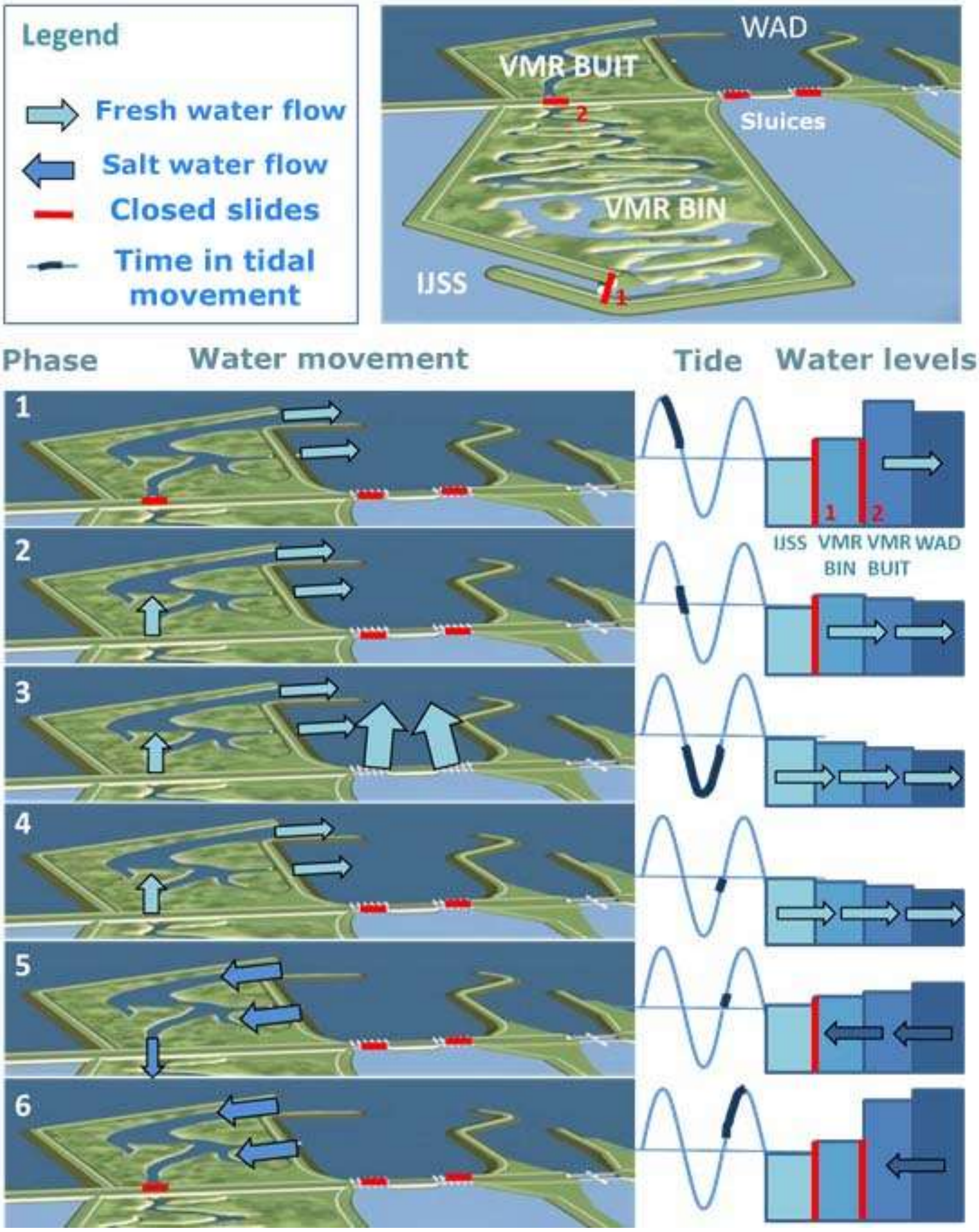

Figure 4.2 Schematic representation of a model of FMR. Note the final draft is still under discussion. At the top of the figure, the whole FMR seen from the Wadden Sea side (WAD) and IJsselmeer side (IJSS). Under the dam a sealable tube connects the two bodies of water. The tidal action and the associated water levels are represented in six phases in the figure. The direction of flow of the water is also drawn (dark blue = salt water, light blue = fresh water) (source: Griffioen, 2014).

The project is not only of importance for the nature. Part of the project will be the realization of a "Visitor Center FMR". Furthermore the project has ambitions to give the area a strong and qualitative impulse for recreation, tourism and professional fishing. In addition, the project can demonstrate a new form of eco-engineering with international recognition of the Dutch water engineering. In collaboration with other project partners, the province Friesland and the "Programma naar een Rijke Waddenzee" have set up a feasibility study in the FMR context, including a program of requirements (PNRW, 2013). These requirements include e.g. (PNRW, 2013):

- the FMR creates a robust ecological connection between Wadden Sea and IJsselmeer
- the FMR is suitable for a broad group of migratory fish;
- the FMR has a natural character;
- the FMR needs to be a day/night/all-year-round fish passage;
- the FMR features an optimal attraction flow (fresh water stream/attraction flow);
- the FMR includes brackish water habitat;
- the FMR features the possibility to return for freshwater fish;
- no salt water is allowed to enter the IJsselmeer;
- the adjustment of discharge regime on fish migration is necessary.

The FMR is an initiative of the Waddenvereniging, Stichting Het Blauwe Hart, Sportvisserij Nederland and the association Vaste Vistuigen Noord. The project is being elaborated by the program "Naar een Rijke Waddenzee"/ "Dienst Landelijk Gebied" in collaboration with the It Fryske Gea and the Rijkswaterstaat, with direction of the program "De Nieuwe Afsluitdijk" (DNA) (www.denieuweafsluitdijk.nl). The DNA is a partnership program between various stakeholders with the overall agreement on the renewal of the Afsluitdijk. The main goals are to keep the area safe for the coming years and to provide for a modernized experience for visitors (www.dienstlandelijkgebied.nl). The Government Service for Land and Water Management (further named DLG), an agency of the Ministry of Economic Affairs, is the client within the framework of the FMR and is dedicated to cooperate in finding solutions that meet the demands of local authorities and citizens, while also taking into account area's specific features. The DLG translates and implements abstract policy into projects, when it comes to the development of open spaces for recreation, nature, water management and agriculture. In order to achieve this, DLG acquires land, redevelops it and transfers it to administrative authorities and individuals (www.dienstlandelijkgebied.nl).

The design and also the factual implementation of the FMR are not defined yet. In 2012, a project plan was established, assigned by "Het Programma naar een Rijke Waddenzee". Following, according steps were made in in 2013. The civil-technical elaboration of the concept and it`s linkage to the plans for the improvement of the Afsluitdijk and follow-up studies, are important stands of the process.

5. Materials and Methods

Before a detailed management plan for the realization of the FMR at Kornwerderzand can be accomplished, a number of crucial fish migration processes need to be assessed. The location of the entrance needs to match with the behaviour of fish and the target species. Furthermore, as a key factor for the determination of success, the entrance(s) need(s) to be attractive for the fish, in order to make them find and use them. In this context the discharge over time (attraction flow) related to discharge volume over time is important, as well as the searching behaviour and the distribution of the different fish species at the location during tidal regimes. Passage success is dependent on occurring chances and behaviour. Timing and sprint capacity differ per species. In this context it is assumed that factors as tidal regimes, discharge volume over time and discharge over time (attraction flow) play a role. Additional research and enhanced monitoring provide for a (more) complete picture of the behaviour, the abundance and the spatial distribution of fish in and around the discharge basin at Kornwerderzand. In this research, a lift net sampling with the simultaneous application of the DIDSON (Dual frequency IDentification SONar) camera was carried out, together with an enhanced fyke net sampling in and around the discharge basin at Kornwerderzand. The outcomes of the fyke net sampling, which are nylon fishing nets with a float line attached to small plastic floats, provide the better insight in the abundance of fish close to the discharge complexes. Lift net and DIDSON are supplemental research. Lift net fishing is a further fishing method in which the nets are submerged, then raised or hauled upward out of the water to catch the fish. The DIDSON is an ultrasound underwater camera. Lift net sampling is giving insight in the spatial distribution of the smaller fish species (flounder larvae, glass eel, smelt and stickleback) and the DIDSON footages provide for more information of the vertical distribution of fish species in the water column in general. With this it can be evaluated, focused on the discharge basin between the fykes, how fish behave over time in relation to tide and after/before discharge (see fig 5.1).

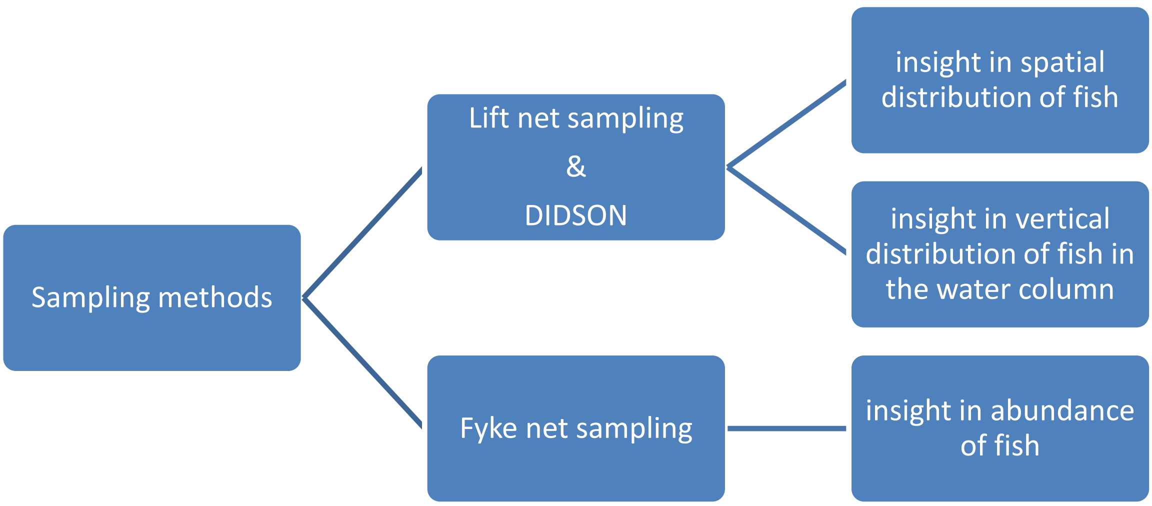

Figure 5.1 Overview of applied methods and purpose

5.1 Study area

The monitoring in this study took place at Kornwerderzand, at one of the two discharge complexes on the Wadden Sea site of the Afsluitdijk. Kornwerderzand is located in the North of the Netherlands, at 53° 4`21.6”N, 5° 20´16.49”E (Range 36212 m), approximately 4 km away from the Frisian coast (see fig 5.2) (Google Earth, 2014).

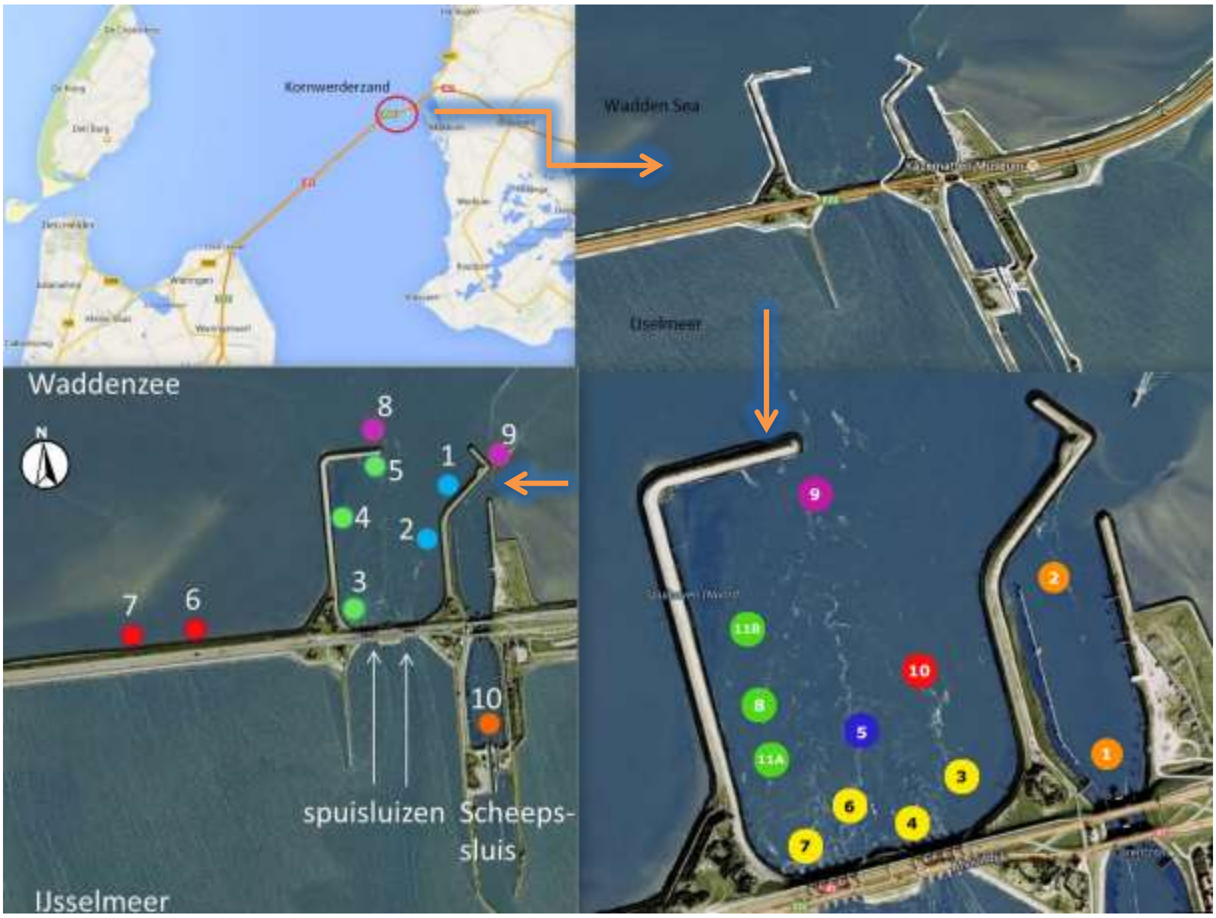

Figure 5.2 Study area at Kornwerderzand. From top-left corner: Location research area on a map (red circle); research area with discharge basin and port on IJsselmeer and Wadden Sea side; zoom-in on lift net sampling points at discharge basin and shipping locks; fyke net sampling points (IMARES, 2014).

The research area is exposed to tides, with high and low tide changing approximately every 6 hours and a maximum tidal range of 2,5 meters (Tide-forecast, 2011).

5.2 Data sampling

5.2.1 Cruise lift net sampling (Sub question 1)

Lift net sampling was performed at the research area at Kornwerderzand in order to answer the sub question number 1 “What is the spatial distribution of the four target species flounder larvae, glass eel, smelt and stickleback in the discharge basin and the port at Kornwerderzand in relation to tidal regimes and discharge events?”

Due to the preference of fish to migrate during the night and due to dependence on tidal regimes, evening/night measurements were carried out. Fieldwork was performed at two nights per month (March, April and May) and six nights in total (see fig. 5.3 for flowchart of data sampling process).

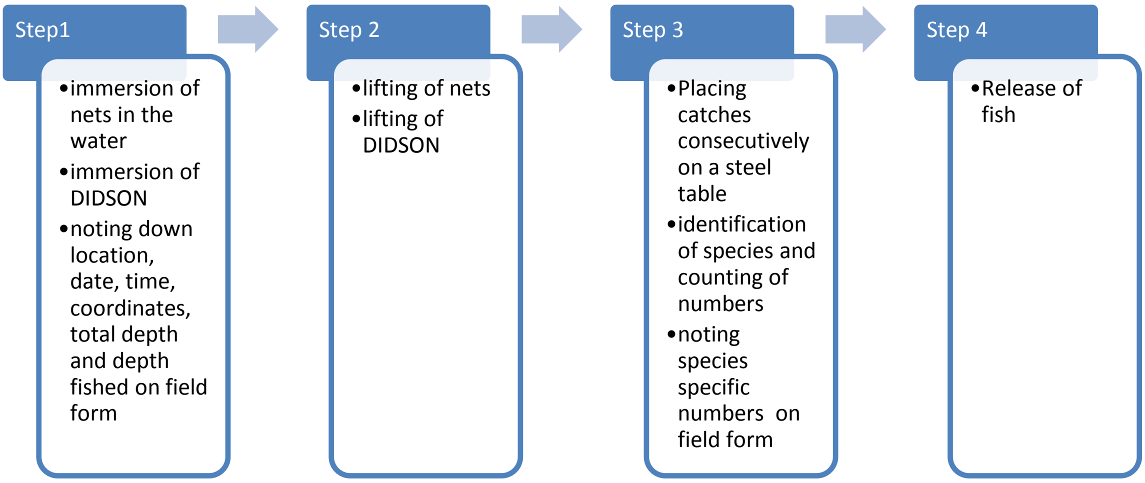

Figure 5.3 Flowchart of lift net sampling process

Each sampling night consisted of three runs in the discharge area, with one exception in April with only two runs due to the harsh weather conditions (sampling had to be stopped after the second run).

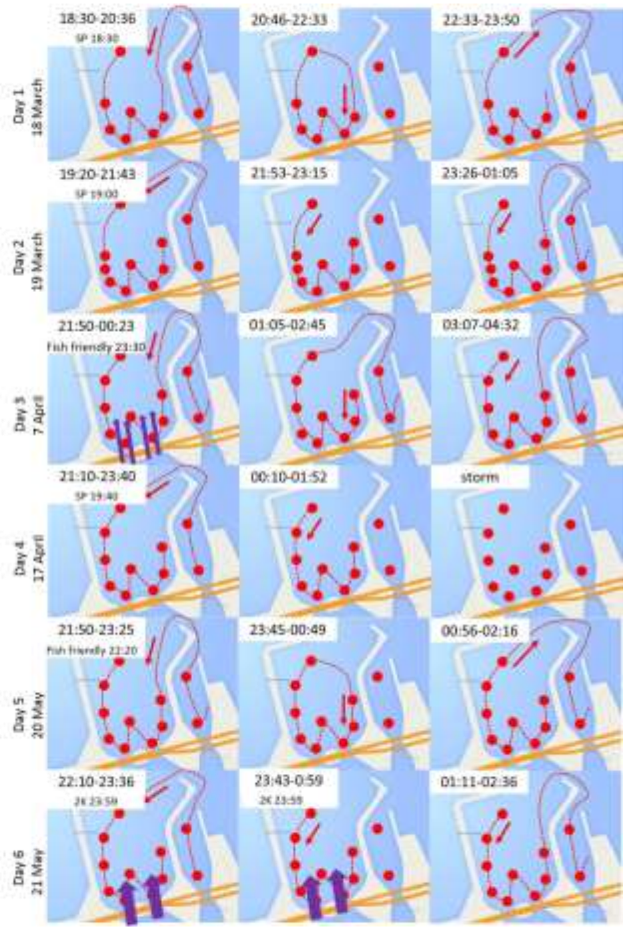

Figure 5.4 Overview of sampling strategy during lift net sampling with order of runs per day with starting time. SP= closure of gate; Fish friendly= management scenario with closure time; 2K= two gates open until given time

The data sampling started with two points (loc 1 and 2) in the "port" during flood current, just after low tide and just after discharge. Following, nine points in the discharge basin were sampled during upcoming tide (above equal water level) (Run 1). Afterwards the nine points in the discharge basin were sampled again during the end phase of the flood tide and at the peak of the high tide (Run 2) and repetitive during outgoing tide (until equal water level) (Run 3). Lastly, the two points in the "port" were sampled again (see fig. 5.4 and table 5.1). Lift net data sampling took place during six sampling days with different start and ending time as well as differing locations and order during the different runs. Every second sampling day, the order of sampling was done vice versa. Table 5.1 gives an overview of sampling order per sampling day and particular locations sampled.

Table 5.1 Overview of start and end time and sampling with sampling order of locations, divided per run per sampling day. Changes in location order are marked in bold

Sampling day	Run number	Time run start	Time run end	Locations in sampling order
Day 1, 18th March 2014	1	18:30	20:26	1 2 3 4 5 6 7 8 9
	2	20:46	22:33	x x 3 4 5 6 7 8 9
	3	22:33	23:34	x x 3 4 5 6 7 8 9 2 1
Day 2, 19th March 2014	1	19:20	21:43	1 2 9 8 **11A** 7 6 5 4 3 **10**
	2	21:53	23:15	x x 9 8 **11A** 7 6 5 4 3 **10**
	3	23:26	1:05	x x 9 8 **11A** 7 6 5 4 3 **10** 2 1
Day 3, 7th April 2014	1	21:50	0:23	1 2 10 3 4 5 6 7 8 **11B** 9
	2	1:05	2:45	x x 10 3 4 5 6 7 8 **11B** 9
	3	3:07	4:32	x x 10 3 4 5 6 7 8 **11B** 9 2 1
Day 4, 17th April 2014	1	21:10	23:40	1 2 9 11B 8 7 6 5 4 3 10
	2	0:10	1:52	x x 9 11B 8 7 6 5 4 3 10 **1**
	X	x	x	**x**
Day 5, 20th May 2014	1	21:50	23:25	1 2 10 3 4 5 6 7 8 11B 9
	2	23:45	0:49	x x 10 3 4 5 6 7 8 11B 9
	3	0:56	2:16	x x 10 3 4 5 6 7 8 11B 9 2 1
Day 6, 21st May 2014	1	22:10	23:36	1 2 9 11B 8 7 6 5 4 3 10
	2	23:43	0:59	x x 9 11B 8 7 6 5 4 3 10
	3	1:11	2:36	x x 9 11B 8 7 6 5 4 3 10 2 1

At every sampling point one big lift net (3x3m) and two smaller lift nets (1x1m) were simultaneously immersed in the water until a certain depth determined by the fisherman, ranging between 2 and 20 meter. Each time, one of the fishermen was giving a signal for the immersion and the lifting of the nets. The time of the nets in the water was (more or less) the same per location and lifting was done simultaneously. At the moment when the nets were immersed, date, time, location, run number, coordinates (GPS), total depth and fished depth were noted on the field form (see App III). Simultaneously, the DIDSON ultrasound camera was submerged into the water to record video footages in order to answer the second research sub question (see chapter 5.2.2). When the nets were lifted, the catch of the two 1x1m lift nets were determined first. Depending on the number of fish in the net, identification, sorting and counting was done in the net or on a sorting table. The number of fish per species was noted in the appropriate column and rows on the field form. Subsequently, the catch from the big net was placed on the steel table by means of a spoon net in order to identify and count the species. The numbers per species were noted on the field form analogous. If the number of particular species occurred to be greater than 50 (visual assessment), subsampling was carried out (divided by 2, 4, 8, 16, 32, 62, 128 or 256) (see table 5.2)

Table 5.2 Overview of subsampling carried out with numbers of fish and appropriate division of catch

Numbers of fish	*Subsampling(divided by x)*
< 50-100	2
101-200	4
201-500	8
501-1.000	16
1.001-2.000	32
2.001-5.000	62
5.001-10.000	128
10.001-30.000	256

Lastly, the fish were released into the water and the next sampling point was accessed (see fig. 5.3).

5.2.2 DIDSON (Sub question 2)

DIDSON products are Sound Metrics imaging sonars transmitting sound pulses and converting the returning echoes into digital images, much like a medical ultrasound sonogram. The advantage is that this technique provides for a good view/image even in dark or turbid (cloudy) water with otherwise zero visibility conditions, which are common in the research area (see fig. 5.5).

Figure 5.5 Example of DIDSON camera used during sampling.

To determine the vertical distribution of fish in the water column of the discharge basin, the DIDSON ultrasound camera was used during the lift net sampling (see chapter 5.2.1). The camera was fixed at the end of a three meter long steel pole and put at least 50 cm deep into the water (length of DIDSON camera itself) at each lift net sampling point. The moment of immersion and lifting was determined by one of the fishermen. Footages were made, which have visualized the vertical distribution of fish. Obtained images were analysed later on and linked to the lift net sampling.

5.2.3 Fyke net sampling (Sub question 3)

In order to answer sub question 3) "What is the CPUE and the difference in species of the 15 target species between the different fykes at the Kornwerderzand area in relation to discharge events, discharge volume and temperature in autumn 2013 and spring 2014?", fyke net sampling was performed.

The fyke net sampling research was carried out by IMARES in collaboration with the professional fishermen Van Malsen for the WOT-program [3] of the Ministry of Economic Affairs (EZ). Starting in 2001, annual data (with the exception of 2004) has been collected of three months in spring (April until June) and of four months in autumn (September-December) on the seven fyke net trap locations. Five out of the seven fyke net traps were located in the discharge basin (see fig. 5.6, points 1 to 5) and two along the dyke on the west side of the Afsluitdijk (see fig 5.6, points 6 and 7).

[3] WOT program (Wettelijke Onderzoek Taken) is a fishery research program, which is carrying out statutory research tasks related to the management of the fishery and aquaculture in the Netherlands. The programe is developed in coordination with the Ministry of Economic Affairs, Agriculture and Innovation (EL&I). (van Beek, 2012)

Figure 5.6 Map of research area at Kornwerderzand with fyke net sampling points (Imares, 2014).

The WOT-program specifically aims at diadromous fish species, but all species are registered. An exemption for the fyke net sampling was declared for the fyke net research, specifically for this research. In general, the fish traps have been lifted at least twice a week.

In order to get a more detailed link with the discharge volumes and a more detailed insight in the variety of the numbers of fish in the discharge basin and the relation to discharge events, the monitoring in the framework of the FMR was extended with three extra fish traps (two outside the discharge basin and one near the shipping locks, (see fig. 5.6, points 8, 9 and 10) and three liftings per week instead of only two.

The ten single fyke nets were lifted three times a week (Monday, Wednesday and Friday). The catch was sorted, species were identified and counted. Large catches were counted through sub sampling. Based on commercial sizes of fish (Table 5.3), a distinction to large and small fish was created.

The Catch Per Unit Effort (CPUE; Dutch: fuiketmaal) is the catch in the fyke net, per 24 hours that the fyke was placed under water. In order to obtain comparable data, the CPUE was calculated per lifting.

Table 5.3: Range of fish length for division between small and large fish, based on commercial sizes. (Griffioen, 2013, IMARES)

Species (Latin name)	Species (English name)	Boundary length (cm)	Species (Latin name)	Species (English name)	Boundary length (cm)
Diadromous fish species			Salt water fish species		
Alosa fallax	Twaite shad	40	*Agonus cataphractus*	Pogge	-
Anguilla anguilla	European eel	33	*Ammodytes tobianus*	Lesser sand eel	10
Chelon labrosus	Thicklip grey mullet	30	*Atherina presbyter*	Sand smelt	-
Coregonus lavaretus	Lavaret	20	*Belone belone*	Garfish	40
Coregonus oxyrhynchus	North Sea houting	20	*Ciliata mustela*	Fivebeard rockling	-
Dicentrarchus labrax	European seabass	40	*Clupea harengus*	Atlantic herring	15
Gasterosteus aculeatus	Three-spiked stickleback	-	*Cyclopterus lumpus*	Lumpfish	-
Lampetra fluviatilis	River lamprey	33	*Echiichthys vipera*	Lesser weever	-
Osmerus eperlanus	Smelt	13	*Gadus morhua*	Atlantic cos	40
Petromyzon marinus	Sea lamprey	50	*Gobiidae spec.*	Goby	-
Platichthys flesus	Flounder	21	*Hyperoplus lanceolatus*	Greater sand eel	10
Salmo salar	Atlantic salmon	40	*Limanda limanda*	Common dab	21
Salmo trutta	Sea trout	40	*Liparis liparis*	Common seasnail	-
Fresh water fish species			*Merlangius merlangus*	Whiting	30
Abramis brama	Common bream	15	*Microstomus kitt*	Lemon sole	-
Abramis bjoerkna	Silver bream	-	*Myoxocephalus scorpius*	Shorthorn sculpin	-
Esox lucius	Northern pike	-	*Pholis gunnellus*	Rock gunnel	-
Gymnocephalus cernuus	Ruffe	-	*Pleuronectes platessa*	European plaice	21
Perca fluviatilis	European perch	23	*Scomber scombrus*	Atlantic mackerel	25
Rutilus rutilus	Common roach	15	*Scophthalmus rhombus*	Brill	21
Stizostedion lucioperca	Zander	42	*Solea solea*	Common sole	30
			Syngnathus spec.	Seaweed pipefish	30
			Trachurus trachurus	Atlantic horse mackerel	25
			Trisopterus luscus	Bib	15
			Zoarces viviparus	Viviparous eelpout	-

5.3 Data collection

Collected data in this study are:

- Presence/Absence data of associated fish species (number of species)
- Abundance data of associated fish species (in numbers)
- Dispersal of associated fish species (in numbers per depth)
- Discharge volume (in cubic meter, via RWS)
- Discharge events (in time, via RWS)
- Depth (in meter)
- GPS Coordinates (hand GPS and logging system)

Additionally environmental details was requested

- Temperature (available via live.waterbase.nl)
- Tidal regime (via RWS)

5.4 Data preparation

5.4.1 Cruise lift net

During the lift net sampling, data was recorded on a field form (one field form per location/sampling point), consisting of the variables location, date, time, coordinates, depth (depth total and depth fished) (see App. II).

The field form was divided into four columns. The first column was showing the names of all the target species in the rows. The second column was to record the catch numbers of fish per species caught with the 1x1 lift net, the third column to note the numbers of fish caught with the other 1x1 lift net and the fourth column was to record the numbers fish caught with the 3x3 lift net. All numbers needed to be noted in the appropriate rows corresponding to the rows with the names of fish species of column one (see App. II). Afterwards the data was digitalised in Excel. For this purpose, an Excel template was created, containing 15 columns, with variables seen below.

- Date
- Time
- Location/sampling point
- Depth
- Depth fished
- Run number
- Species name in Dutch
- Species name in Latin
- Numbers fish 1x1 A
- Numbers fish 1x1 B
- Numbers fish 3x3
- Numbers fish total
- Comments
- Discharge volume (in million m3)
- Tidal regime

5.4.2 DIDSON

The DIDSON footages were saved on a laptop.

Additionally an Excel template was created. The file consisted of six different sheets, which represent the six different survey dates. Each sheet contained 14 columns. Per column, the following information was noted:

- location (lift net sampling point numbers from 1-11B)
- time of sample=file name
- frame rate (x/s)
- start frame of analysis
- end frame of analysis
- run number (of lift net sampling, run 1, 2, 3)
- average depth (in 0,5 meter steps; average of DIDSON movie; measured from foremost end of DIDSON camera until seafloor)
- Win start (depth from water surface until foremost end of DIDSON camera)
- estimation fish number total
- Occurrence of fish
- Distribution of fish
- Species lift net (n total)
- Number of smelt, stickleback and herring
- percentage of species smelt, stickleback and herring at this sampling point with lift net sampling(smelt/stickleback/herring)

The frequency of occurrence needed to be filled in the rows of the column “occurrence of fish” and the frequency of distribution needed to be filled in the rows of the column “distribution of fish” (see below).

In order to analyse the retrieved data with Excel, part of the variables were designed in categories or transformed in codes (see table 5.3).

Table 5.3 Overview of variable transformation in Excel for DIDSON analysis

Variable	Category/ code	Variable	Code	Definition
Estimation fish number total	categories	0		
		1-10		
		10-100		
		100-1.000		
		1.000-10.000		
		>10.000		
Occurrence of fish	categories	Single fish		
		aggregation		random distribution along the water column/ no clear schooling behaviour visible)
		school		a clear schooling behaviour of fish is visible
		other		
Frequency of fish occurrence	codes	no	0	
		one	1	
		few	2	
		many	3	
		all	4	
		other	5	
Distribution of fish	categories	Surface orientated		most of the fish are relatively in the upper part of the screen
		Pelagic orientated		most of the fish are relatively in the middle part of the screen
		Benthic orientated		most of the fish are relatively in the bottom part of the screen)
		Randomly distributed		no clear pattern visible
		Combination of orientation		
Frequency of distribution	codes	none	0	
		few	2	
		most	3	
		all	4	
		other	5	

5.4.3 Fyke net

The data of fyke net catches was collected by professional fishermen and gathered data was filled in a data base. The data forms were collected at the end of March and April and at mid-May. Data was imported by IMARES employers into Frisbe, the IMARES database, and retrieved with after data-check by the IMARES database manager. The established data base, which was also used as a template, consists of 27 columns with fyke net data with the following variables:

- Date (day)
- Year
- Month
- Week
- Code (fyke net number)
- Scientific name (Latin)
- Dutch name
- Number of large fish caught
- Number of small fish caught
- Number of total catches
- CPUE of small fish
- CPUE of large fish
- Mean CPUE (total)
- Days of fyke net being under water
- CPUE in log scale for small, large and all fish together respectively
- Discharged volume
- Discharged volume in million cubic meters (m^3) (daily)
- Starting and ending date of fyke net being placed
- Mean discharge in million cubic meters (m^3)
- Water surface temperature per day

Discharge data and temperature data was retrieved from the contact person Hans Miedema from Rijkswaterstaat.

5.5 Data analysis

5.5.1 Cruise lift net

The lift net data was analysed by using Microsoft Excel. Every sampling point consists of its geographical coordinates, time, date, number of run (1, 2, and 3), maximal depth and consequently immersion depth of the nets. Both depths differ due to intentionally left safe distance between nets and the actual bottom. Additionally, number of caught fish was being recorded with indication of used subsampling method when applicable.

All the mentioned data components were analysed with regard to the sub question number 1) aiming on getting an insight into the spatial distribution of four target species in relation to tidal regimes and discharge events (see fig. 5.7)

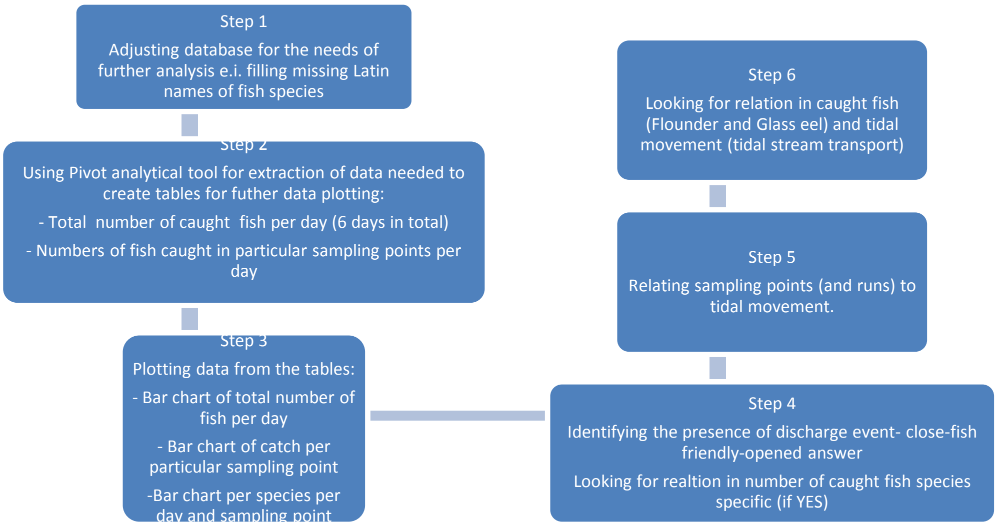

Figure 5.7 Flowchart of data analysis process with Excel of lift net sampling data

In order to see the spatial distribution of fish, the total catch number of all caught fish species was calculated separately per species per location per sampling day and of all days together. The total number of individuals and the depth fished per location was plotted with a bar chart. The four target species were selected and the total catch number of the four species was calculated analogous, separately per species, per location per sampling day and in total. Accordingly, the numbers of individuals per species were plotted per location per sampling day and per location for all days.

In order to see the relation between the spatial distribution of fish and the tidal regime, the sampling point at particular time was plotted against the water level. The different runs were highlighted in different colours. Additionally bubble charts were created for the four target species, showing their distribution in the discharge basin per sampling day, divided per run. These results (numbers per location per run) were linked to the tidal regime in order to test the hypothesis: More species which are using STST (flounder and glass eel) will be caught during high tide (mostly run 2 and partly run 3).

In order to see the relation between the spatial distribution of fish and the discharge events, data about the stands (1=close; 2=fish friendly (2 options); 3=open) of the discharge sluice before, during and after the sampling was gathered and an overview table was created, presenting the start and end time of the appropriate sluice management and its stand. Sampling time was highlighted. Subsequently, the table displaying discharge events was linked to the previously created bubble charts (in order to test the hypothesis: open= weak swimmers flushed away, strong swimmers attracted by attraction flow; fish friendly option 1 (23332): smaller numbers of strong swimmers in the discharge basin because they already passed the sluices; fish friendly option 2 (21112): smaller numbers of strong and weak swimmers because they already passed the sluices; close= fish is accumulating in front of the sluices).

5.5.2 DIDSON

The DIDSON footages were processed with specific DIDSON software (DIDSON V5.26). The analysis was done with regard to the questions i) What is the vertical distribution of fish throughout the water column? and ii) Are there differences in numbers of fish between locations based on the created categories? (see fig. 5.8).

Before the analysis of a footage started, the location (sampling point number), the run number (lift net sampling run 1, 2 or 3), the time of sample or respectively the file name, the frame rate and the Win start depth (depth from surface to foremost end of DIDSON camera in the water; automatically displayed with DIDSON software tool) were noted in the rows of the according columns in the according Excel sheets of the previously prepared Excel file.

Each DIDSON video footage was watched for 30 seconds, beginning at the second when the DIDSON camera was fully placed into the water and a clear image of good quality was visible. The start frame, the end frame and the number of frames per second were noted in the Excel file. While watching the footage section the number of fish occurring in these 30 seconds was roughly estimated following a LOG scale (0; 1-10; 10-100; 100-1000; 1000-10.000; >10.000) and noted as "estimation of fish number total" in the Excel file. Simultaneously an indication of fish occurrence was made by grouping the estimated number of fish in four categories (single fish; aggregation (random distribution along the water column/ no clear schooling behaviour visible); school (a clear schooling behaviour of fish is visible); other) and the frequency of each category was grouped as i) one, ii) few, or iii) many, noted in the Excel file. Notes were made on a separate sheet of paper. Per footage, two random points were selected to take a snap shot. At these two randomly chosen points, the movie was paused in order to measure the depth in meters with the measurement tool of the software. The two depths were noted in the Excel file (in 0,5m steps) and an average depth was calculated later on with Excel. When a DIDSON movie was shorter than 30 seconds or of bad quality, the movie was rejected.

Following, each footage was transformed into an echogram. With the echogram the vertical distribution of the fish in the water column was determined by dividing them in five categories i) surface oriented (most of the fish are relatively in the upper part of the screen), ii) pelagic oriented (most of the fish are relatively in the middle part of the screen), iii) benthic oriented (most of the fish are relatively in the bottom part of the screen, ix) randomly distributed (no clear pattern visible), and x) a combination of orientation. Subsequently, the amount of fish per category (surface; pelagic; benthic; random; combination) was evaluated by using groupings of i) all, ii) most, iii) few, ix) none, and noted in the Excel sheet. A snapshot was taken of each echogram and saved on laptop with the same file name as the footage.

The DIDSON footages were also linked to fish densities of lift net sampling. Therefore, the data of the lift net sampling was reviewed and the total catch number (n total) per sampling point was linked to the according DIDSON footage and noted in Excel. Subsequently three target species which are visible with the DIDSON (smelt, stickleback, and herring) were selected and the n per species per sampling point were noted in the Excel file and transformed in percentage. In this connection the total number (n total) represented always 100%.

The analysis of the retrieved data was done with Excel. The vertical distribution of fish in the research area was analysed by plotting the different created categories (surface; pelagic; bottom; randomly distributed; combination) against the frequency (all; most; few; none). For this purpose, one overview table was created for all the sampling days with a division per run and plotted accordingly. Secondly, overview tables were created per sampling day with a division per run and plotted accordingly. The results were than linked to the tidal movement during the lift net sampling.

In order to analyse the differences in numbers (in groups) of fish, the frequency of each group number was plotted per sampling day. The occurrence of fish (single fish; aggregation; school; other) was plotted against the frequency of each category (one; few; many) per sampling day. The percentage of the species smelt, stickleback and herring was plotted per location (sampling point) and in total (see fig. 5.8).

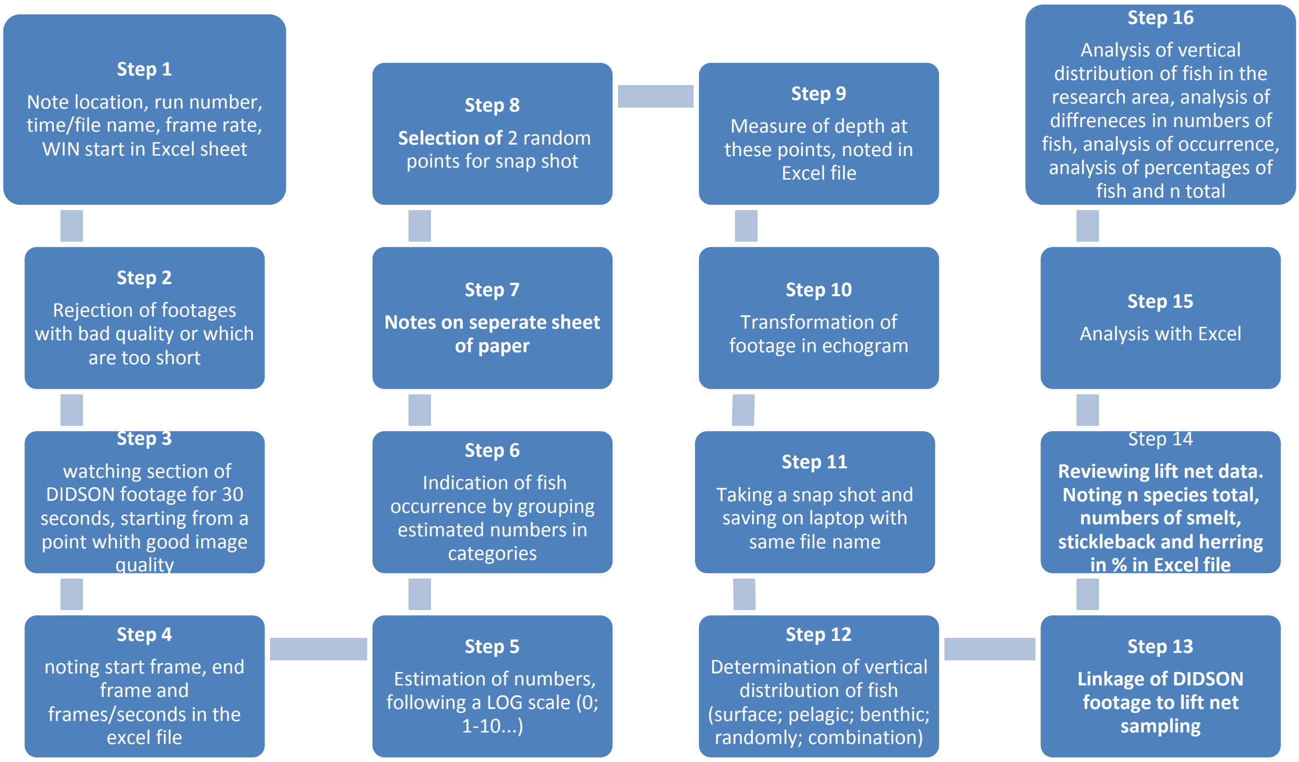

Fig 5.8 Flowchart of DIDSON analysis process

5.5.3 Fyke net

The fyke net database file, which was used for the analysis consisted of the following several components: 15 different fish species caught on particular days, the data for discharged volume, the CPUE per species and the daily water surface temperature. The CPUE is defined as the catch in the fyke net, per 24hours when the fyke was placed under water. The fykes were normally lifted in the morning between 06:00 – 14:00 o`clock, at set time intervals. Before the final fyke net database file was acquired it was firstly entered into the IMARES database FRISBE.

The data was processed and analysed using Microsoft Excel. Undertaken steps for data analysis are presented in the flowchart (see figure 5.9). Obtained fyke net data with according fish species was linked to discharge and temperature data, which was previously retrieved from RWS and formatted to daily discharge. Data of the surface temperature at Kornwerderzand was acquired via the waterbase (www.waterbase.nl) and also implemented in the main database file.

The fykes were lifted and the catch was sorted three times a week, meaning if a fyke trap was placed for three days under water, fish could have been caught on day 1, 2 or 3. In order to link the catch data directly with the discharge data, the mean discharge data of the days when the fyke net was placed under water was calculated. In this way a data set with mean discharge data over the same period that the fyke net was in the water was established. The same approach was set for the mean surface temperature.

Data analysis took place in two sets: starting from September (7 fykes), October, November and December (10 fykes each) in autumn 2013 and from the month March and April (10 fykes each) in spring 2014. The number of fish caught in total and the CPUE were calculated per species and represented in an overview table as well as the total catch number per fyke. The CPUE per species was calculated and plotted (divided in small and big fish) per species and per fyke. Mean weekly temperature and discharge were calculated and plotted in relation of number of fish per fyke and per species. Moreover, this outcome was compared with expected migration period based on literature study, which was essential for further discussion part. Subsequently, analysing whether the discharge of fresh water attracts more migratory fish into the discharge basin was performed ("na-ijl effect"/attraction flow effect).

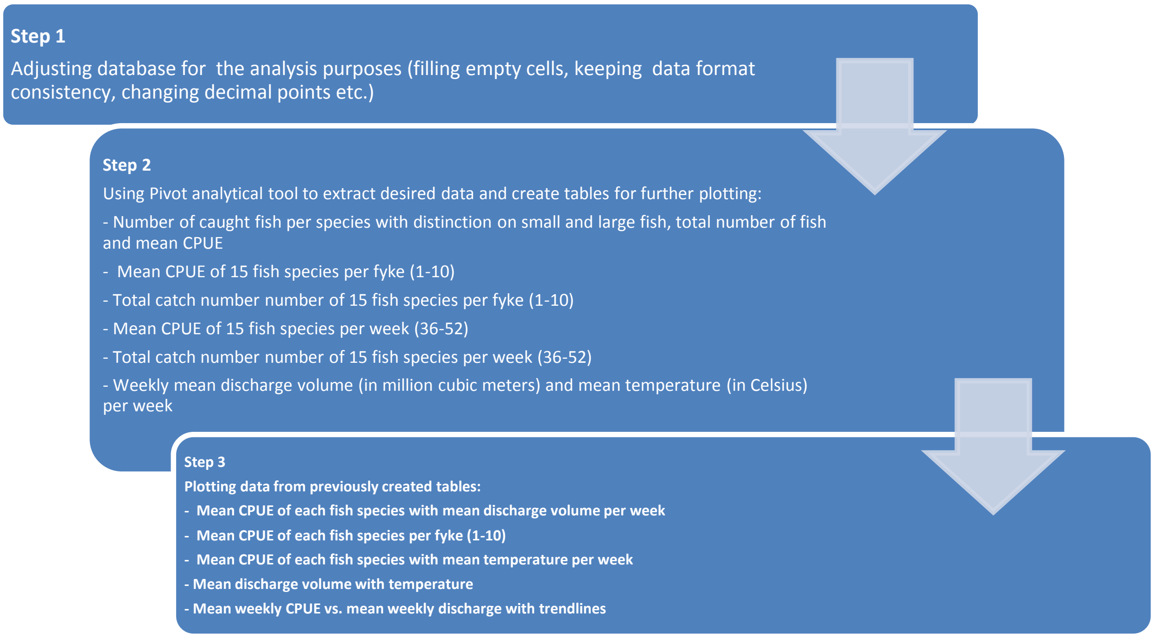

Figure 5.9 Flowchart of fyke net analysis process

6. Results

This chapter presents the results of the gathered data of the three applied sampling methods according the order of the sub questions.

6.1 Results lift nets

The results of gathered data of performed lift net sampling are presented according to spatial distribution of fish in the research area, the relation of spatial distribution to tidal regime and the relation of spatial distribution to discharge events.

6.1.1 Spatial distribution

The lift net sampling took place at different locations (loc) in the discharge basin as well as in the port. In order to evaluate the spatial distribution of fish in this area, the sampling points were grouped according to their geographic direction (see fig. 6.1.1).

Location 1 and 2 (orange points) represent the sampled points in the port. Location 10 and 3 (red point and yellow point) are located on the eastside of the discharge basin. The locations 3, 4, 6 and 7 (yellow points) were sampled in front of the discharge sluices. Location 7, 8, 11A and 11B represent the sampled points on the west side of the discharge basin (green points and yellow point). Location 5 (dark blue) is the deepest sampling point (25m) and location 9 (purple) the most northwards one (see fig. 6.1.1).

Figure 6.1.1 Research area with lift net sampling points, divided in groups. Orange= port, yellow= in front of sluices, red= eastside, green= west side, dark blue=deepest point, purple= most northward point.

During the lift net sampling in the months March, April and May 126.083 individuals of 29 different species were caught in total. The species caught in highest frequency was Atlantic herring (*Clupea harengus)* with *78.850* individuals.

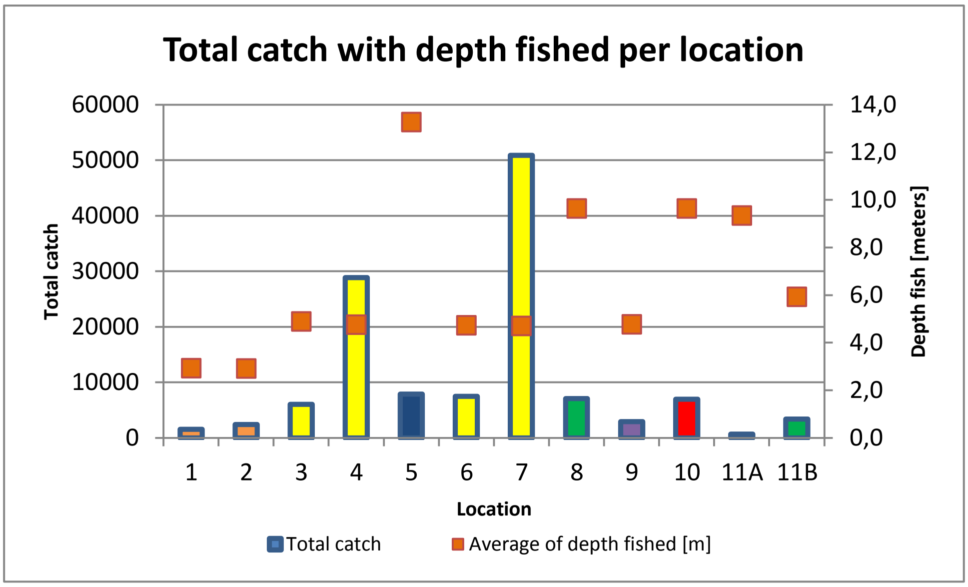

Figure 6.1.2 Total catch in numbers (n) of all caught species with average depth (y-as) per location (x-as) of all sampling days. The different locations are grouped with colours according to fig. 6.1.1

The results show that most individuals were caught at location 7 in front of the discharge sluices at the west side of the discharge basin (n=50.884) and least at the most northwards point (loc 9, n=2939). Fish is spatially distributed most at the locations in front of the discharge sluices in the discharge basin (loc 3, 4, 6 and 7; average n=23.166 per loc). The locations on the west side of the discharge basin (loc 7, 8, 11A and 11B) yielded the second highest catch with an average of n=15.000 per location, followed by the deepest point (loc 5) in the middle of the discharge basin (n=7.865) and the eastside of the discharge basin (loc 3 and 10; average catch of n=6.489 per loc). Besides, the locations sampled in the port (loc 1 and 2, n=1.971), the most northwards location (loc 9) yielded the smallest catch (n= 2.939) (see fig. 6.1.2).

The average of depth fished differs per location with the deepest fishing at location 5 (13,3m) and the shallowest at location 1 and 2 (2,9m) (see fig. 6.1.2).

When focussing on the four target species, the results show that location 7 yielded the highest total catch number (n=2.431). The smallest number yielded location 11B (n=177). When taking the spatial distribution throughout the discharge basin into account, the sampling points in front of the sluices (loc 3,4,6 and 7) recorded the highest average catch per location (n=1.934). There is no clear difference in spatial distribution between the other groups of locations identifiable (average n per sampling point: deepest point n= 1236; west side n= 1093; eastside n=941; most northward n=779) (see fig. 6.1.3).

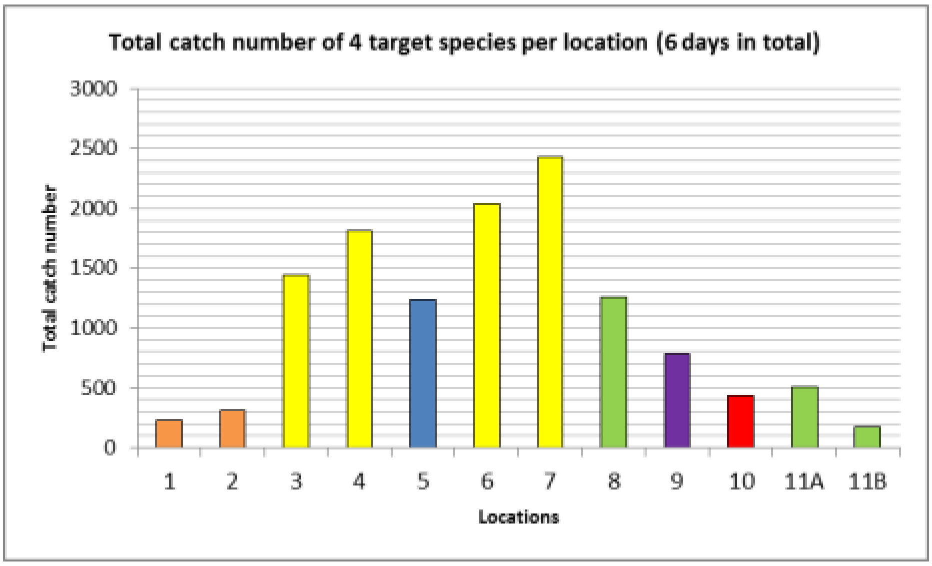

Figure 6.1.3 Total catch number n of four target species (y-as) per location (x-as) of all sampling days. The locations are grouped in colours according to fig. 6.1.1

Glass eel was caught most with 8.633 individuals. The species was caught mainly on day 1 and day 2, with highest numbers at location 4. Stickleback was caught 3367 times, especially on day 5 and 6, with highest numbers at location 7. Smelt was caught 440 times, mainly on day 1 and 2 with highest numbers at location 7 and flounder larvae was caught 225times, in particular on day 1 and 2, with highest numbers at location 8 (see App. III, I.).

6.1.2 Relation spatial distribution and tidal regime

Figure 6.1.4 illustrates that the consecutive runs of sampling took place at different phases of the tidal movement, with varying starting and end points. Summarized it can be said that all the sampling days had their starting point during the flood tide and only half of them were completed after high tide, thus the last run was taking place during the ebb tide only in 50% of the cases (see App. III, II.).

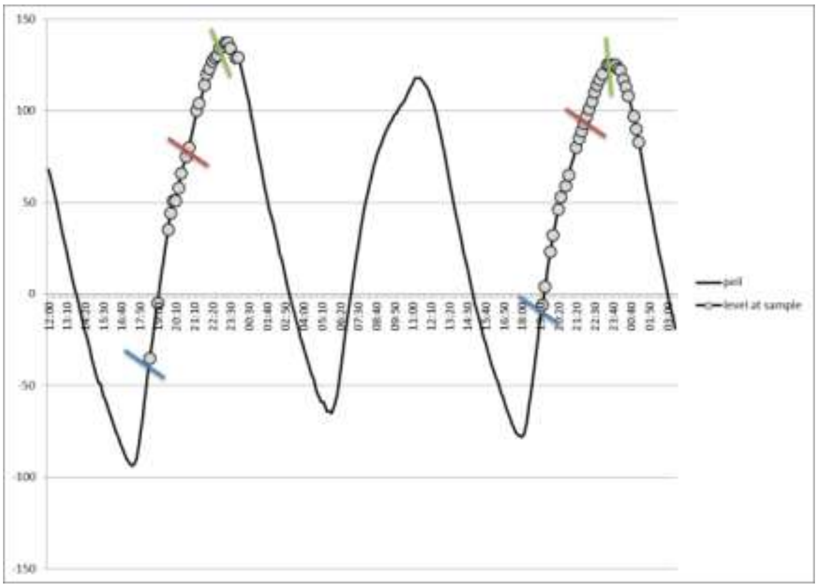

Figure 6.1.4 Water level (y-as) according to time during sampling on 18th and 19th March (x-as) with sampling points. The marking divides the three different runs per day.

The results show that the most individuals were caught during run 1 (n total=4.642) and thus during flood tide. Run 3 (high tide and/or ebb tide) yielded 4.347 individuals. The least fish were caught during run 2 (n=3676), which was performed during high flood tide and/or high tide.

A tendency of decrease in the number of catch during successive runs is recognisable for glass eel and flounder larvae (glass eel run 1 n=3.618, run 2 n=2.580, run 3 n=2.435; flounder larvae run 1 n=105, run 2 n=88, run 3 n=32). A tendency of increase in the number of catch during successive runs is notable for smelt and stickleback (smelt run 1 n=92, run 2 n= 139, run 3 n= 209; stickleback run 1 n=827, run 2 n=869, run 3 n=1671).

It is recognisable that fish tend to cumulate on the west side of the discharge basin during the first run, with a trend of steadily position shifting southwards with successive runs. When looking at the bubble charts, no clear indication that fish are flushed away after discharge events is observable (see fig. 6.1.5).

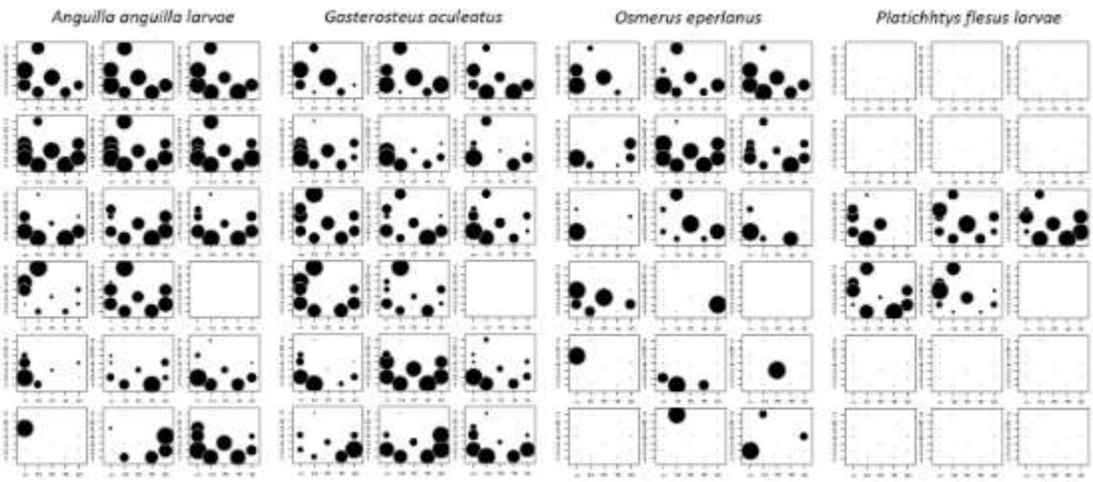

Figure 6.1.5 Spatial distribution of the four target species at different locations in the discharge basin, represented per day (from top to the bottom) and per run (from left to right). A square can be regarded as the discharge basin area. The different bubbles are representing the catch number (n) of the different species. The units (size of bubble) per day and per run are not visually comparable.

6.1.3 Relation spatial distribution and discharge events

As explained in chapter 3, three different situations of discharge can occur at the discharge sluices at Kornwerderzand. Besides the situation that all discharge gates are closed (11111), all gates can be fully opened (33333), fish friendly opened for strong swimmers (23332) or fish friendly opened, facilitating also weak swimmers (21112). The five different numbers are each representing the stand of one discharge gate, the first and the last number are representing the two outermost discharge gates of one discharge sluice. 1=discharge gate closed; 2= discharge gate opened a gap wide; 3= discharge gate fully opened.

Table 6.1.1 presents an overview of occurred discharge events with appropriate sluice management and duration before, during and after the data sampling.

Table 6.1.1 Discharge events with time and length before, during and after sampling. Close= all the discharge gates are closed (1); fish= adjusted sluice management for fish migration purposes with two options: the two outer gates are only opened a gap wide (2) and the three inner gates are fully opened (3) or the two outer gates are opened only a gap wide (2) and the three inner gates are completely closed (1); open= all the discharge gates are fully opened (3). Sampling period is marked in red with arrow.

Time start	Time end	Hours	Sampling start	close	fish	open
Day 1, 18th March 2014						
0:00	2:40	2:40		x		
2:40	6:30	3:50			X (23332)	
6:30	15:10	8:40		x		
15:10	18:10	2:40			X (23332)	
➔ **18:10**	5:00	9:20	18:30	x		
Day 2, 19th March 2014						
5:00	6:20	1:20			X (23332)	
6:20	16:00	9:50		x		
16:00	19:00	3:00			X (23332)	
➔ **19:00**	3:50	8:40	19:20	x		
3:50	7:20	3:30			X (23332)	
Day 3, 7th April 2014						
6:20	10:50	3:30			X 21112	
10:50	19:30	8:40		x		
➔ **19:30**	23:30	5:00	21:50		X 21112	
➔ **23:30**	7:50	8:20		x		
Day 4, 17th April 2014						
2:40	8:10	5:30			X 23332	
8:10	15:50	7:40		x		
15:50	19:50	4:00			X 23332	
➔ **19:50**	16:40	8:50	21:10	x		
Day 5, 20th May 2014						
5:21	10:28	5:20			X 21112	
➔ **10:50**	00:00	13:10	21:50	x		
Day 6, 21st May 2014						
6:10	11:15	5:10			X 21312; 21312	
11:15	18:54	7:44		x		
18:54	21:20	2:26		x	X 21312; 21311	
➔ **21:20**	23:59	2:39	22:10		X 11311; 11312	

The results show no relation between spatial distribution of fish in relation to discharge events. The fish tend to be spatially distributed in front of the discharge sluices (loc 3, 4, 6 and 7) regardless the previously occurred discharge events or consecutive runs.

At sampling day 1 (23332 discharge before sampling) fish were mainly distributed on the west side (loc 8) during run 1 and in front of the western sluices during run 2 (loc 7 and 5) and run 3 (loc 4, 6 and 7). The numbers of fish are decreasing from run 1 to run 2 and increasing slightly from run 2 to 3. At sampling day 2 (23332 discharge before sampling) fish were mainly distributed in front of the sluices (loc 4 and 5) during run 1, in front of the western sluices during run 2 (loc 7 and 6) and in front of the eastern and western sluices during run 3 (loc 3 and 7). The numbers of fish are decreasing from run 1 to run 2 and increasing slightly from run 2 to 3. At sampling day 4 (23332 discharge before sampling) all fish were primarily distributed northwards (loc 9) during both runs, with decreasing numbers of fish per run. At sampling day 5 (11111 before sampling) fish were distributed in front of the sluices during all runs, with increasing numbers per consequtive runs. At sampling day 3 (21112 discharge during sampling) fish were mostly distributed in front of the sluices during all runs, especially at location 4. The numbers of fish are increasing from run 1 to 2 and decreasing from run 2 to 3. At sampling day 6 (11311 and 11312 discharge during sampling) fish were mainly distributed in front of the sluices on the eastside during run 1 and 2 (loc 3) and on the west side during run 3 (loc 6), with increasing numbers per consecutive runs.

6.2 DIDSON

The number of footages made during the five sampling days differs per sampling day and per run. As higher numbers enhance the chance of variation, this should be taken into account when interpreting the results. In total, 113 DIDSON footages were analysed (see App. III, III.).

6.2.1 General pattern of fish distribution

The vertical distribution of fish in the water column differs per run. Of run 1 46 footages were analysed, 36 of run 2 and 31 of run 3. The results show that fish are mainly both randomly as well as most benthically distributed in the water column. At run 1, fish were randomly distributed in the majority of the cases (18 times), followed by a most pelagic distribution (14 times) and a most benthic distribution (8 times). A clear distinguishable distribution (category all fish surface, pelagic or benthic) occurred only once per category. At run 2, fish were mainly randomly distributed as well as most benthically distributed (10 times), followed by a most pelagic distribution (7 times). In return, there was a clear pattern visible where all the fish were pelagically distributed (5 times). At run 3, the fish were most benthically oriented, followed by a most pelagic distribution (12 times). On eight occasions fish were randomly distributed. In general, a surface distribution is assessed the least (see fig. 6.2.1).

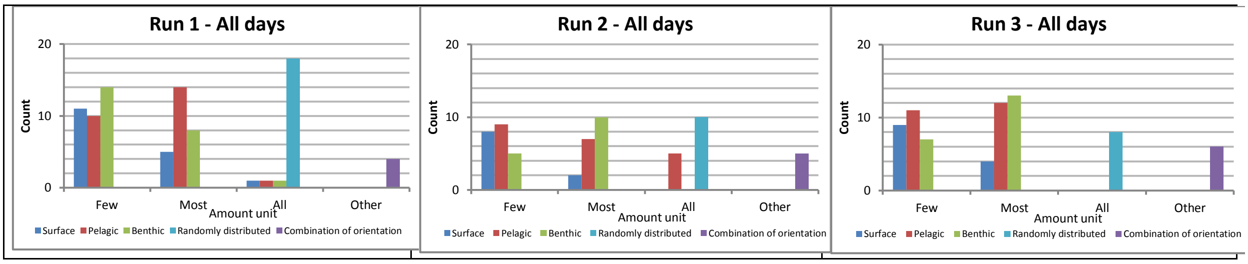

Figure 6.2.1 Vertical distribution of fish in the water column (x-as) with frequency per category (surface- dark blue, pelagic- orange, benthic- green, random- light blue, combination of orientations- purple) of all sampling days (y-as), divided per run.

6.2.2 Distribution pattern per sampling day

The vertical distribution of fish in the water column differs per sampling day (and per run). There is no clear pattern of distribution recognizable in relation to sampling days as well as runs and in terms of distribution preference (see App. III, IV.).

6.2.3 Numbers

Regarding all sampling days together, the numbers of fish observed in a footage is in particular between n=10-100 (44 times), followed by n=100-1.000 (35 times) and n=1.000-10.000 (24 times). The least numbers of fish observed is >10.000 (10 times).

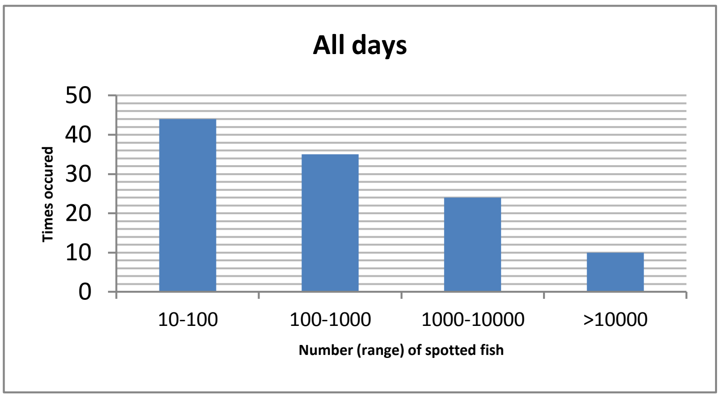

Figure 6.2.2. Grouping of numbers fish observed (x-as) in relation to their frequency (y-as) in total

At the sampling days 4 and 5 most of the fish numbers observed were n=10-100 (8 times out of 14, 11 times out of 15 and 12 times out of 29). At day 3 most of the fish observed were n=1.000-10.000 (12 times out of 29 footages), At day 6 fish were mostly observed as n=100-1.000 (10 times out of 26). Fish numbers >10.000 were observed most at day 3 (4 times out of 29), which was also the day with highest frequency of fish numbersobserved in general (12 times n=1.000-10.000) (see App. III, V.).

6.2.4 Occurrence

The results show that fish occurred mainly as a “few single fish” (63 times) during the sampling period. “Many single fish” were observed 46 times. “Many aggregations” of fish in the footage were observed 27 times and a “few aggregations” 22 times (see fig. 6.2.3).

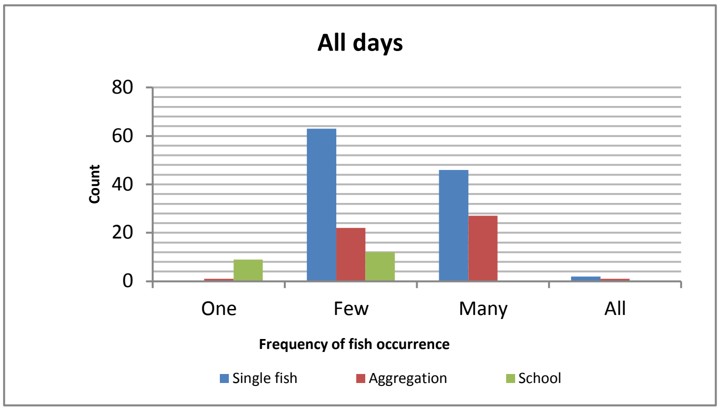

Figure 6.2.3 Occurrence of fish with frequency of occurrence (x-as) in relation to the frequency of counts (y-as) of all sampling days.

A “few schools” in a footage were observed 12 times and “one school” in a footages appeared 9 times. At sampling day 2 especially many single fish were observed (6 times). At sampling day 3 this was “few single fish” (14 times), at day 4 “many single fish” (8 times) and at day 5 and 6 especially “few single fish” were observed (18 and 16 times) (see App. III, VI.).

6.3 Results fyke nets autumn 2013

The results of gathered data gained during fyke net sampling in autumn 2013 are presented according to catch data (mean CPUE), spatial distribution of fish in the research area, relation of discharge volume and temperature, relation of mean CPUE per fyke and per species per fyke to temperature and relation of mean CPUE per fyke and per species per fyke to discharge volume.

6.3.1 Catch data

In autumn 2013, 1.735.017 individuals of the 15 target species were caught in total, with a mean CPUE of 112,8, whereof 1.281.079 individuals were large fish and 453.938 individuals small fish (see table 6.3.1).

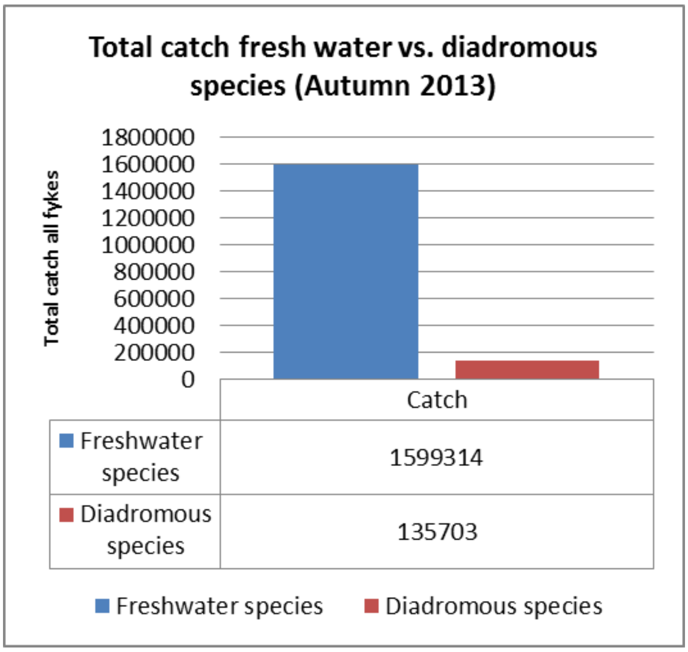

Figure 6.3.1 Total catch numbers of 15 target fish species divided by diadromous and freshwater species in autumn 2013.

Of the total catch, 1.599.314 individuals are freshwater fish species and 135.703 individuals are diadromous fish species (see fig. 6.3.1). The most caught species in general is ruffe, a freshwater fish, with 1.249.277 individuals and a mean CPUE of 1227,1. This was also the most frequently caught large fish. The most frequently caught small fish is perch, a freshwater fish, with 176.912 individuals. Out of the diadromous fish species smelt is caught most frequently in large, small and in total. Altlantic salmon and sea lamprey were not caught at all and sea trout only once (see table 6.3.1).

Table 6.3.1 Total catch number of 15 target fish species per species in autumn 2013 with distinction on large and small fish and mean CPUE per species. Highest numbers in bold, smallest numbers with *.

Scientific Name (Latin)	Large	Small	Total	Mean CPUE
Abramis brama	15	14513	14528	15,7
Alosa fallax	1	1357	1358	0,9
Anguilla anguilla	2005	1789	3794	2,6
Coregonus lavaretus oxyrinchus	0	101	101	0
Gasterosteus aculeatus	14134	0	14134	8,2
Gymnocephalus cernuus	**1249277**	0	**1249277**	1227,1
Lampetra fluviatilis	191	0	191	0,1
Osmerus eperlanus	13918	93188	**107106**	118,1
Perca fluviatilis	73	**176912**	176985	171,7
*Petromyzon marinus**	0	0	0	0
Platichthys flesus	170	8848	9018	8,2
Rutilus rutilus	216	84323	84539	65,6
*Salmo salar**	0	0	0	0
Salmo trutta trutta	1	0	1	0
Sander lucioperca	1078	72907	73985	73,6
TOTAL	1281079	453938	1735017	112,8

6.3.2 Spatial distribution

Figure 6.3.2 shows the spatial distribution of the fykes in and outside the discharge basin of the research area at Kornwerderzand. The different fykes are grouped and highlighted with colours as follows: Fyke 1 and 2 (light blue) are located on the eastside of the discharge basin. The fykes 3, 4 and 5 (green) are located on the west side of the discharge basin, fyke 6 and 7 (red) are located westward outside the discharge basin, fyke 8 and 9 (purple) are located northwards outside the discharge basin and fyke 10 (orange) is located at the shipping locks.

Figure 6.3.2 Map of the research area at Kornwerderzand with locations of fykes.

The numbers of fish caught differ per fyke and per species. According to the mean CPUE, fish were mainly caught at fyke 1 (mean CPUE of 165,9) and the least at fyke 6 (mean CPUE of 22,8). The fykes on the eastside of the discharge basin had both the biggest catch (fyke 1) and the fourth smallest catch (fyke 2, mean CPUE 109,4). Besides that, fish were mainly caught northwards outside the discharge basin (fyke 8 mean CPUE 161,3; fyke 9 mean CPUE 147,6), followed by a distribution throughout the shipping locks (fyke 10, mean CPUE 134,2). The fykes on the westside of the discharge basin (fyke 3, 4 and 5) had a similar fishing quota (mean CPUE 101,8; 126,5; 114,0). Fish were caught the least at the fykes outside discharge basin on the westside (fyke 6 and 7mean CPUE of 22,8 and 37,7)(App. III, VII.).

With regard to species specific distribution, the species bream, smelt and stickleback were mainly caught on the eastside of the discharge basin (fyke 1), roach (fyke 3), flounder, houting and zander (fyke 5) on the westside of the discharge basin, ruffe (fyke 8), perch, river lamprey and twait shad (fyke 9) northwards outside the discharge basin eel was mainly distributed at the shipping locks (fyke 10). Appendix IX gives a detailed overview about species specific distribution throughout the research area.

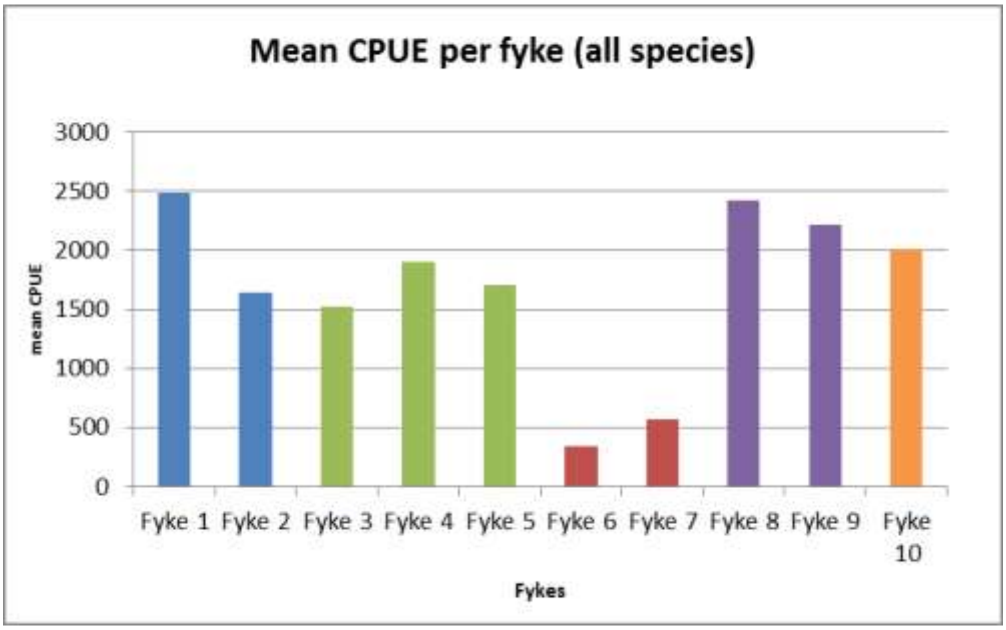

Figure 6.3.3 Total mean CPUE of all 15 target fish species (y-as) per fyke (x-as) in autumn 2013. Fyke 1 and 2 (blue) are located at the eastside of the discharge basin, fykes 3-5 (green) on the west side. Fyke 6 and 7 are placed on the west side outside the discharge basin and fyke 8 and 9 (purple) are placed towards the Wadden Sea outside the discharge basin. Fyke 10 (orange) is placed close to the shipping locks.

These results show a spatial distribution of weak swimmers at fyke 1 (smelt and stickleback), fyke 5 (flounder) and fyke 10 (eel).

Highest numbers of diadromous fish are recognisable on the eastside of the discharge basin (fyke 1 n=20.538, fyke 2 n= 20.254), on the westside at fyke 4 (n=19.865) and northwards at fyke 8 (n=17.388). The fykes 3, 5, 6 and 9 had a similar fishing quote with 11.000-13.000 individuals and the fyke westwards outside the discharge basin the second lowest (fyke 7, n=7.615). The least diadromous fish species are recognized at the shipping locks (fyke 10, n=2.687) (see App. III, VII.).

The results show the most species abundance in week 49 with a total number of 572.719 individuals. The least species were caught in week 36 with 480 individuals, which is also the smallest mean CPUE with 0,5. The highest mean CPUE is recognisable in week 47 (648,9).

According to the mean CPUE, houting and smelt were caught most in week 40, twait shad in week 41, eel and flounder in week 44, ruffe and zander in week 47, bream and roach in week 48, perch and river lamprey in week 49 and stickleback was caught most in week 52.

6.3.3 Discharge and water surface temperature

The total mean discharge (in million m³) in autumn 2013 was 28,7 million m³, with a minimum of 1 in week 36 and a maximum of 56,9 in week 47. The mean discharge of week 36, 38, 39, 40, 41, 43, 44, 45 is below the total mean discharge, and the weeks 37, 42, 46, 47, 48, 49, 50 and 52 have a mean discharge above the total mean.

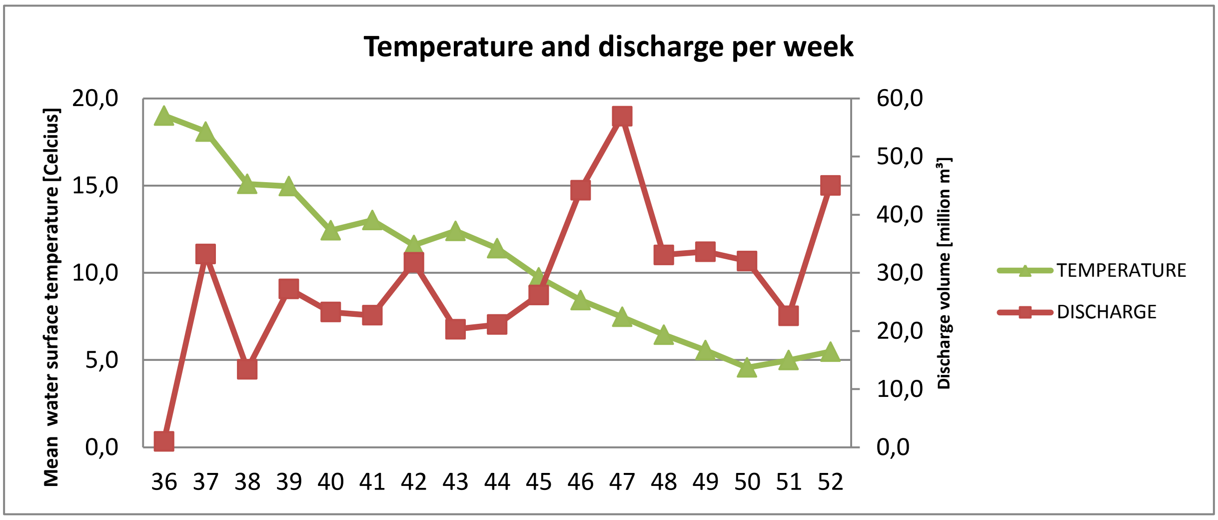

Figure 6.3.4 Mean water surface temperature in relation to mean discharge volume (in million m³) (y-as) per week (x-as) in autumn 2013.

The total mean water surface temperature in autumn 2013 was 10,6 °C, with a maximum mean temperature of 19 °C in week 36 and a minimum of 5 °C in week 51. Water surface temperature is decreasing per week. There is a relation between mean water surface temperature and mean discharge volume in million m³. The colder the mean water surface temperature, the more discharge in m³ (see fig. 6.3.4)

6.3.4 Relation catches and temperature

The results show no clear relation between total catch number (n total) and water surface temperature. It is indicated that the highest number of fish was caught at temperatures of 5 as well as 7 °C (see fig. 6.3.5).

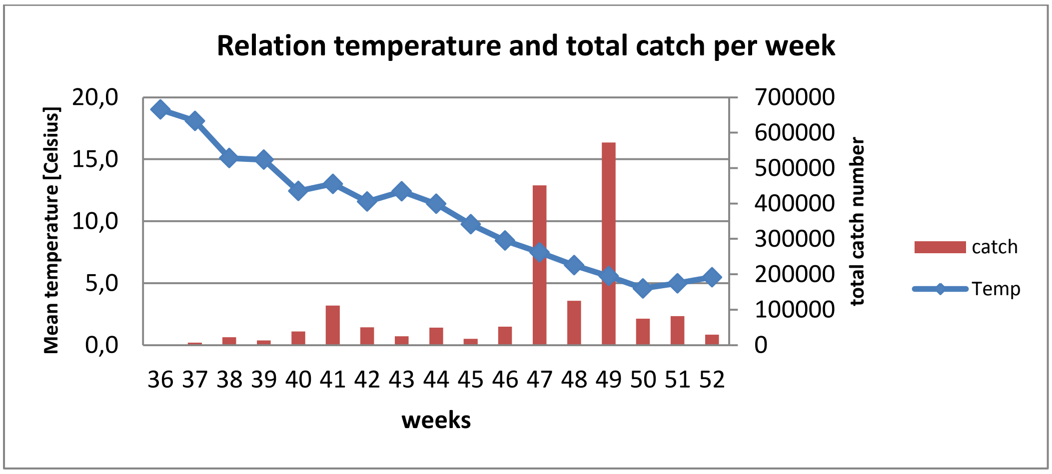

Figure 6.3.5 Total catch numbers of 15 target fish species in relation to temperature (y-as) over time (x-as) in autumn 2013.

However, there is a species specific relation between total catch per species and water surface temperature. Figure 6.3.6 shows the relation between timing of catch (weeks) mean CPUE per species and water surface temperature. The results show a positive relation between the mean CPUE per species of eel, flounder, houting and smelt and water surface temperature. The mean CPUE per species decreases with decreasing water surface temperature. A negative relation is recognisable between the mean CPUE per species of roach, river lamprey, stickleback and zander and water surface temperature. The mean CPUE per species increases with decreasing temperature. For perch there is no clear relation identifiable.

Bream was caught the whole research period, at warm as well as cold temperatures, but especially at temperatures around 7 °C. Eel was caught at high and low temperatures, with a peak at temperatures around 12 °C. Flounder was caught only with higher temperatures between 10 and 13 °C. Houting was caught only at temperatures around 13 °C. Perch was caught the whole research period, but with peaks at temperatures of 6 as well as 13 °C. River lamprey and ruffe were caught only at colder temperatures between 4 and 8 °C. Roach was caught the whole research period, but with a peak at 6 °C. Smelt was caught the whole research period at temperatures between 5 and 19 °C. Stickleback and zander were caught only at colder temperatures between 5 and 7 C. Twait shad was caught at high and low temperatures, with a peak at temperatures around 13 °C (see fig. 6.3.6).

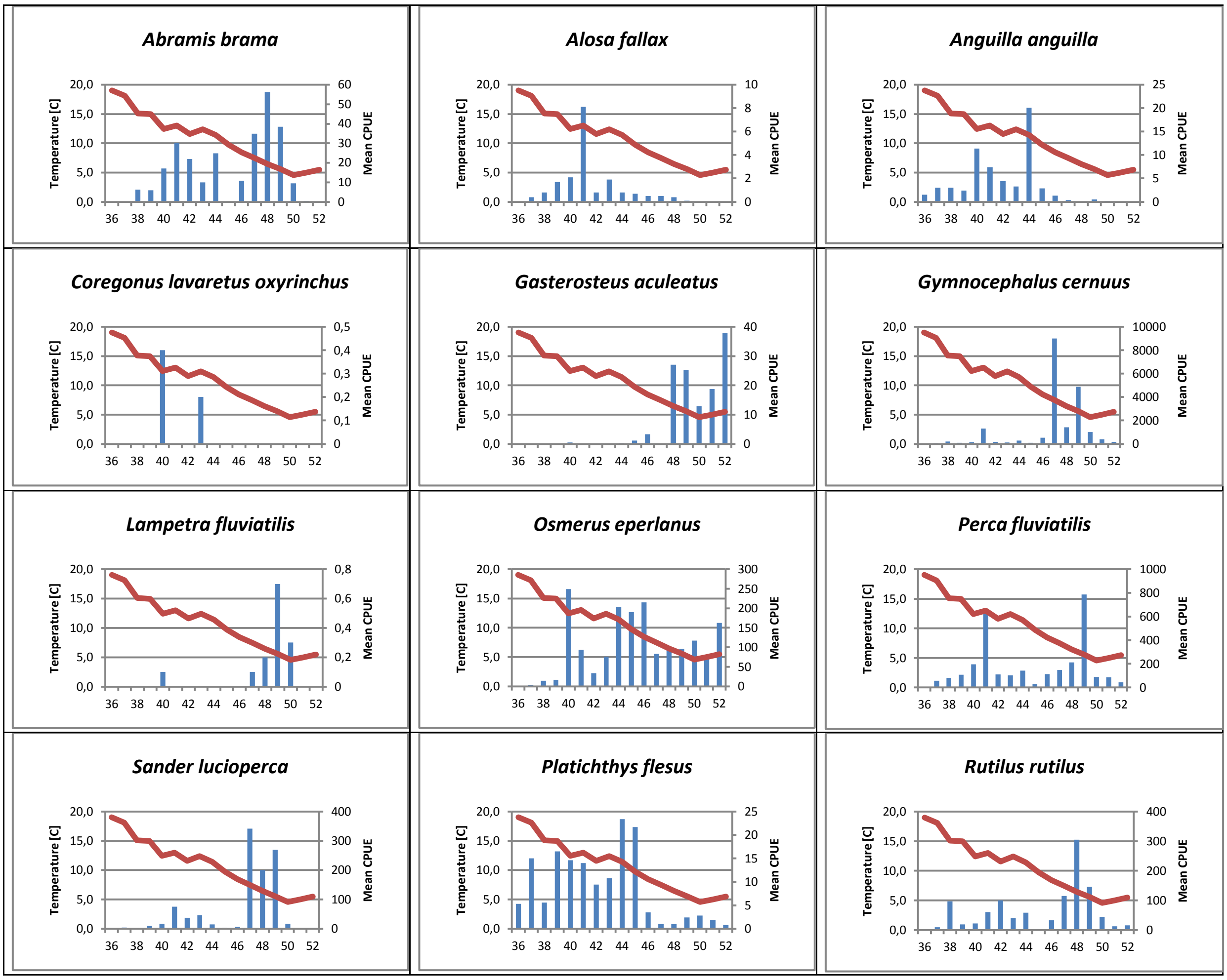

Figure 6.3.6 Mean CPUE per species of 15 target fish species in relation to mean water surface temperature (y-as) over time (x-as) in autumn 2013.

6.3.5 Relation catches and discharge

The results indicate a slight positive relation between total catch number (n total) and discharge volume. The total catch number (n total) seems to increase with increasing discharge volume. The highest number of fish was caught at a discharge volume of 35 and 58 million m³ (see fig.6.3.7).

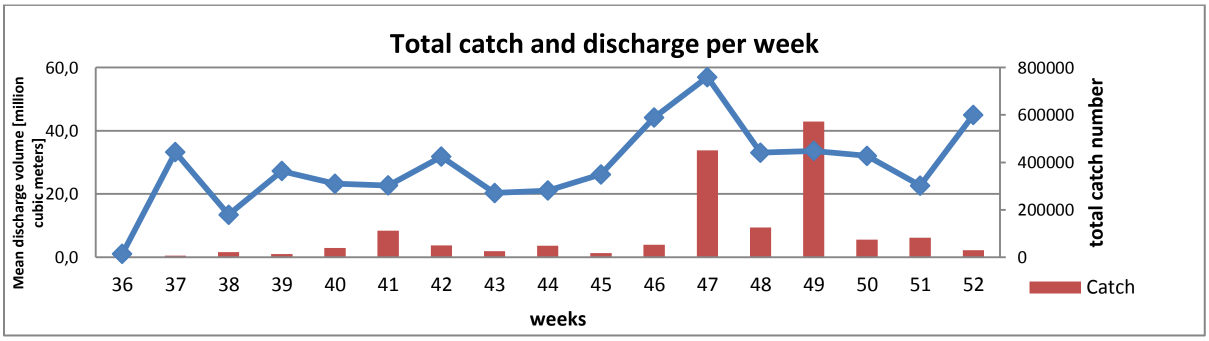

Figure 6.3.7 Total catch number in relation to discharge volume in million m³ (y-as) over time (x-as) in autumn 2013.

Figure 6.3.8 shows the relation between mean CPUE per species and discharge volume in million m³ over time (week 36-52). The results indicate a positive relation between the species bream, river lamprey, ruffe, stickleback, zander (and slight relation for roach) and discharge volume. The total catch numbers per species increases with increasing discharge volume. A negative relation is found between the total catch numbers of the species eel, flounder, houting and twait shad and discharge volume. The total catch number of these species decreases with increasing discharge volume. For perch and smelt no clear relation is recognisable.

Bream, perch, roach and smelt were caught at all discharge volumes. Eel and twait shad were caught at discharge volumes lower than the mean. Flounder was only caught at lower discharge volumes between 0 and 25 million m³. Houting was caught at discharge volumes lower than the mean, at around 20 million m³. River lamprey was caught at discharge volumes below the mean at around 20 to 25 million m³. Stickleback was caught at discharge volumes around 20 and 30 million m³. Ruffe and zander were caught only at very high discharge volumes of around 60 million m³ (see fig. 6.3.8).

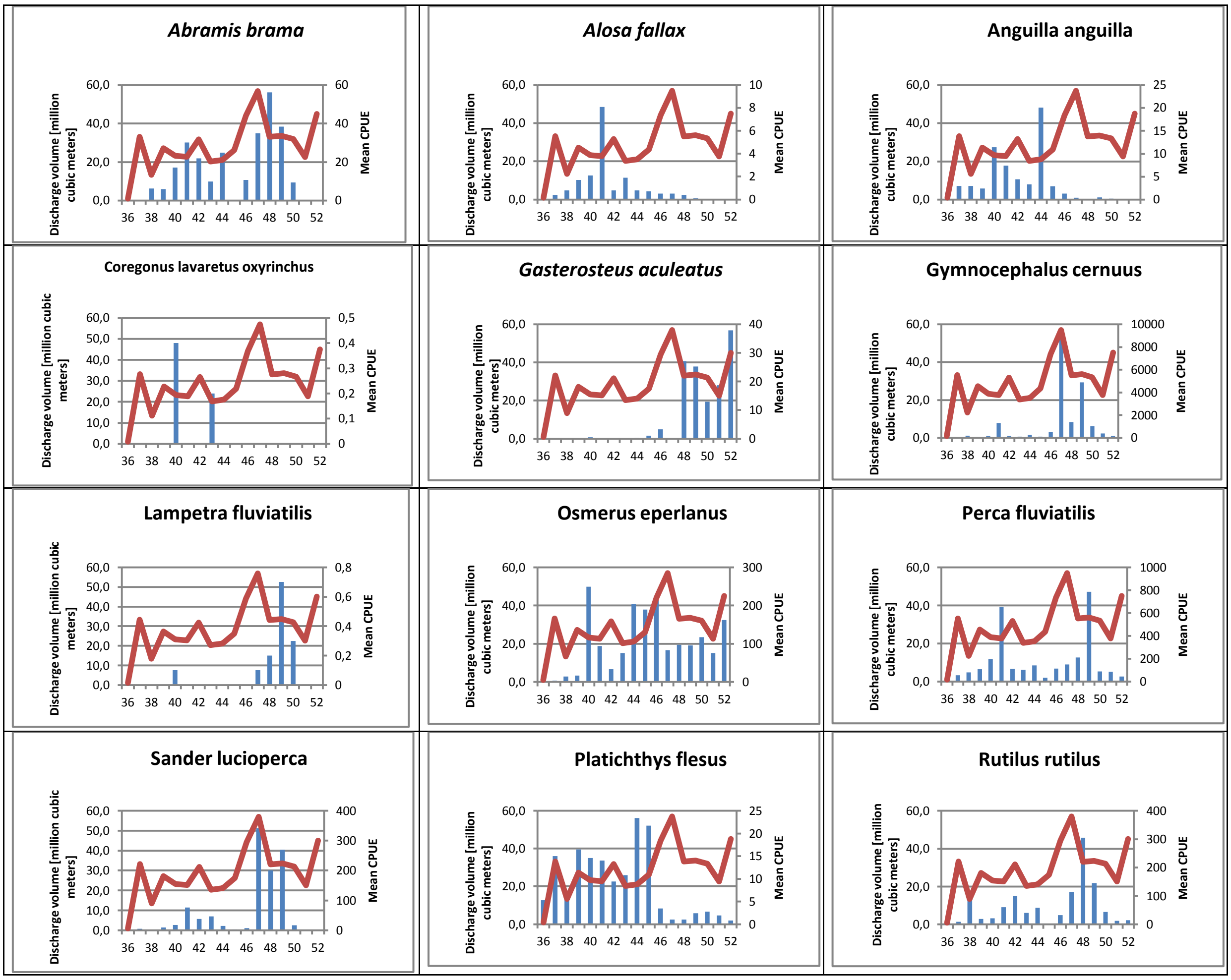

Figure 6.3.8 - Mean CPUE per species of 15 target fish species in relation to mean discharge volume in million m³ (y-as) over time (x-as) in autumn 2013.

In Appendix III, VIII-IX) figures show the relation between the weekly mean CPUE of the 15 target species, divided by diadromous and freshwater fish, and the discharge volume in million m³. There is a negative relation between the mean CPUE of the diadromous species eel, flounder, houting and twait shad and discharge and a positive relation between river lamprey, smelt and stickleback and discharge. For all the freshwater species (bream, perch, roach, ruffe, zander) a positive relation is found.

6.4 Results fyke nets spring 2014

The results of gathered data gained during fyke net sampling in spring 2014 are presented according to catch data (mean CPUE), spatial distribution of fish in the research area, relation of discharge volume and temperature, relation of mean CPUE per fyke and per species per fyke to temperature and relation of mean CPUE per fyke and per species per fyke to discharge volume.

6.4.1 Catch data

In spring 2014, 2.139.934 individuals of the 15 target species were caught with a mean CPUE of 291,8, whereof 1.459.165 individuals were large fish and 680.769 individuals small fish. Of the total catch, 1.148.666 individuals were diadromous fish species and 991.268 individuals were freshwater fish species (see fig. 6.4.1).

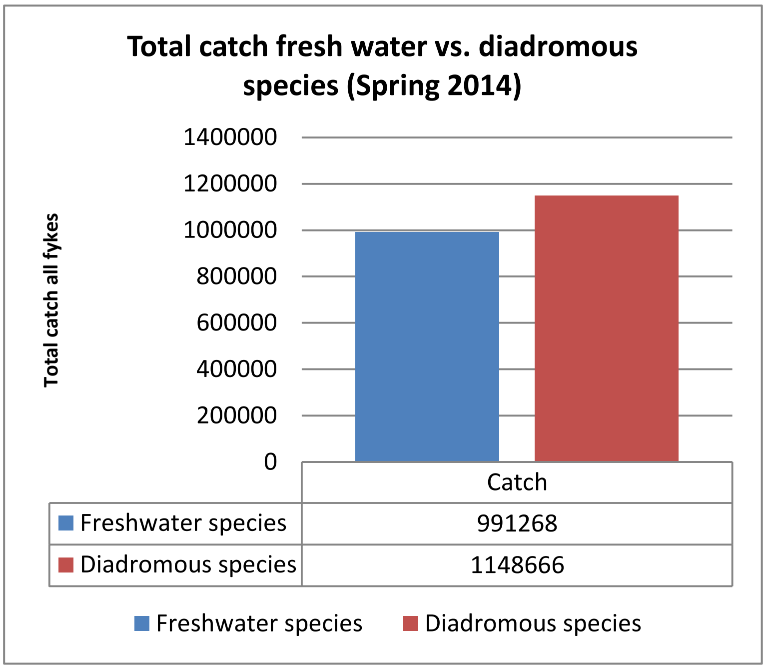

Figure 6.4.1Total catch numbers of 15 target fish species divided by diadromous and freshwater species in spring 2014.

The most caught species in general was ruffe, a freshwater fish, with 969.613 individuals and a mean CPUE of 1871,7. This was also the most frequently caught large fish. The most frequently caught small fish was smelt, a diadromous fish, with 647.643 individuals. . Out of the diadromous fish species smelt was also caught most frequently in large, small and in total. The least caught species were Atlantic salmon and sea trout with zero individuals (see fig. 6.4.1 and table 6.4.1).

Table 6.4.1 Total catch number of 15 target fish species per species in spring 2014 with distinction on large and small fish and mean CPUE per species. Highest numbers in bold, smallest numbers with *.

Scientific name (Latin)	Large	Small	Total	Mean CPUE
Abramis brama	5	4117	4122	7,8
Alosa fallax	1	42	43	0,1
Anguilla anguilla	228	201	429	0,8
Coregonus lavaretus oxyrinchus	0	0	0	0,0
Gasterosteus aculeatus	475772	0	475772	1001,9
Gymnocephalus cernuus	**969613**	0	**969613**	1871,7
Lampetra fluviatilis	22	0	22	0,0
Osmerus eperlanus	13375	**647643**	**661018**	1435,9
Perca fluviatilis	11	2212	2223	4,7
Petromyzon marinus	24	0	24	0,0
Platichthys flesus	105	11253	11358	22,2
Rutilus rutilus	9	14765	14774	30,2
*Salmo salar**	0	0	0	0,0
*Salmo trutta trutta**	0	0	0	0,0
Sander lucioperca	0	536	536	1,0
TOTAL	1.459.165	680.769	2.139.934	291,8

6.4.2 Spatial distribution

The numbers of fish caught differ per fyke and per species (see fig. 6.4.2, the distribution and the colouring of the fykes are according to fig. 6.3.2).

According to the mean CPUE, fish were caught most at the west side of the discharge basin (fyke 3 mean CPUE 621,9; fyke 5 mean CPUE 526,7) and the least westwards outside the discharge basin (fyke 7, mean CPUE 15,7). Besides that, fish were mainly caught on the eastside of the discharge basin (fyke 1 mean CPUE 475; fyke 2, mean CPUE 451,8), followed by fyke 4 (mean CPUE 335) and the northwards fykes (fyke 8 mean CPUE 124; fyke 9 mean CPUE 250,1). The fyke placed close to the shipping locks (fyke 10) had the third smallest catch with a mean CPUE of 61,4. Fish were least caught westwards outside discharge basin (fyke 6 CPUE 20,1; fyke 7 CPUE 15,7) (see App. III, X.).

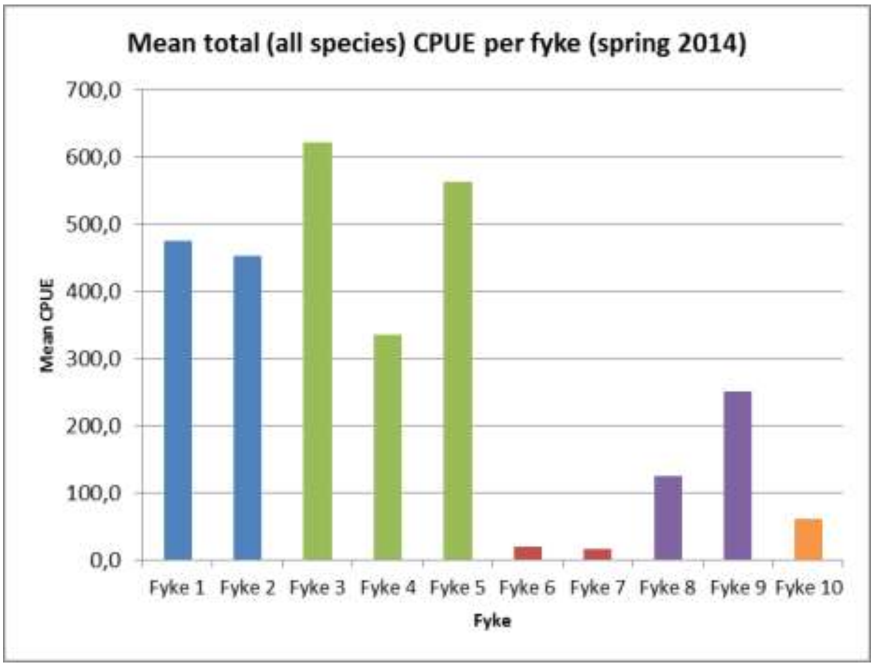

Figure 6.4.2 Total mean CPUE of all 15 target fish species (y-as) per fyke (x-as) in spring. Fyke 1 and 2 (blue) are located at the eastside of the discharge basin, fykes 3-5 (green) on the west side. Fyke 6 and 7 are placed on the west side outside the discharge basin and fyke 8 and 9 (purple) are placed towards the Wadden Sea outside the discharge basin. Fyke 10 (orange) is placed close to the shipping locks.

With regard to species specific distribution, bream, ruffe (fyke 1) and stickleback (fyke 2) were mainly caught on the eastside of the discharge basin, smelt (fyke 3), roach (fyke 4) and perch (fyke 5) on the westside of the discharge basin, sea lamprey (fyke 6) and eel (fyke 7) westwards outside the discharge area, flounder, river lamprey and twait shad northwards outside the discharge area (fyke 9) and river lamprey and zander were mainly caught at the shipping locks (fyke 10). App III, X) gives a detailed overview about species specific distribution throughout the research area.

These results show a spatial distribution of weak swimmers at fyke 1 (stickleback), fyke 2 (smelt) (both eastside), fyke 7 (westwards outside, eel) and fyke 9 (northwards outside, flounder).

Highest numbers of diadromous fish are recognisable on the westside of the discharge basin (fyke 3 n=297.551, fyke 5 n=198.426) and on the eastside at fyke 2 (n=185.207). The fykes 1, 4 and 6 had a similar fishing quote between 90.000-116.000 individuals, followed by fyke 8 with 71.352 individuals. The fykes westwards outside the discharge basin (fyke 6 and 7) had the second lowest fishing quote with around 11.000 individuals and the fyke at the shipping locks (fyke 10) caught the fewest individuals with n=8.209.

The results show the most species abundance in week 10 with a mean CPUE of 1.311,9. The least species were caught in week 14 with a mean CPUE of 22,3. According to the mean CPUE, bream, roach and ruffe were most abundant in week 10. River lamprey, perch, smelt and zander were most abundant in week 11, twait shad in week 12, eel in week 15, flounder in week 16 and stickleback had the highest abundance in week 17 (see App. III, X.).

6.4.3 Discharge and water temperature

The total mean discharge (in million m³) in spring 2014 was 9,7 million m³, with a minimum of 0,76 million m³ in week 14 and a maximum of 15,43 million m³ in week 11. The mean discharge of week 14, 15 and 16 is below the total mean discharge, and the weeks 10, 11, 12, 15 and 17 have a mean discharge above the total mean.

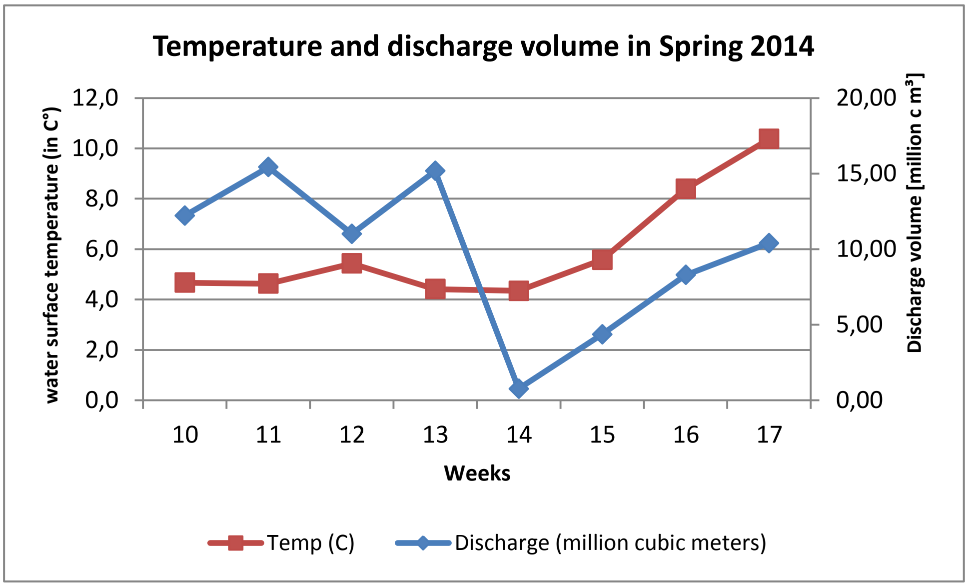

Figure 6.4.3 Mean water surface temperature in relation to mean discharge volume (in million m³) (y-as) per week (x-as) in spring 2014.

The total mean water surface temperature in autumn 2013 was 6 °C, with a minimum of 4,3 °C in week 14 and a maximum mean temperature of 10,4 °C in week 17. Water surface temperature is increasing per week (see fig. 6.4.3).

The results show a slight positive relation between water surface temperature and discharge. From week 14 onwards, the discharge increases with increasing temperature, or vice versa.

6.4.4 Relation catches and temperature

The results show no clear relation between total catch number (n total) and water surface temperature. In the beginning of the research period the catch number decreases with stable water surface temperature. From week 14 onwards there is a slight positive relation recognizable as the total mean CPUE increases with increasing water surface temperature. It is indicated that the highest number of fish was caught at temperatures of 5 °C (see fig. 6.4.4).

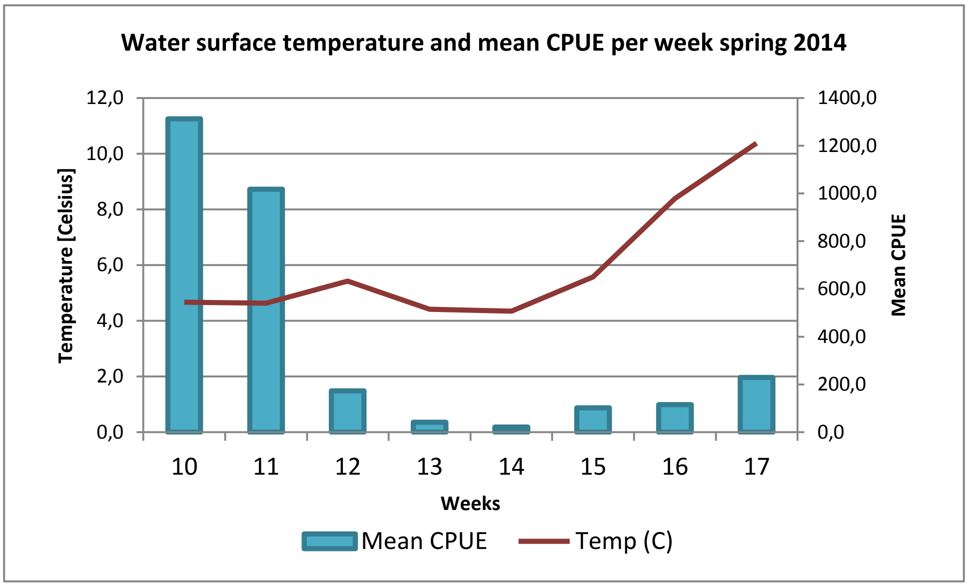

Figure 6.4.4 Total catch numbers of 15 target fish species in relation to temperature (y-as) over time (x-as) in spring 2014.

Figure 6.4.5 shows the relation between timing of catch (weeks), mean CPUE per species and water surface temperature. The results show a negative relation between mean CPUE of the species bream, perch, river lamprey, roach, ruffe, smelt, twait shad and zander and water surface temperature. The mean CPUE per species decreases with increasing water surface temperature. For the mean CPUE of the species eel, flounder and stickleback and water surface temperature a positive relation is recognizable. The mean CPUE per species increases with increasing water surface temperature. For sea lamprey there is no clear relation found.

Bream, perch, river lamprey, roach, ruffe, smelt, twait shad and zander were only caught at temperatures around 5 °C. Eel was caught increasingly with increasing temperature, but the highest numbers were caught at 5 °C. Flounder was caught the whole research period at temperatures between 5 and 10 °C and a peak at 8 °C. Sea lamprey was caught at temperatures from 5 to 10 °C. Stickleback was caught increasingly with increasing temperature, with highest numbers at highest temperatures of 10 °C (see fig. 6.4.5).

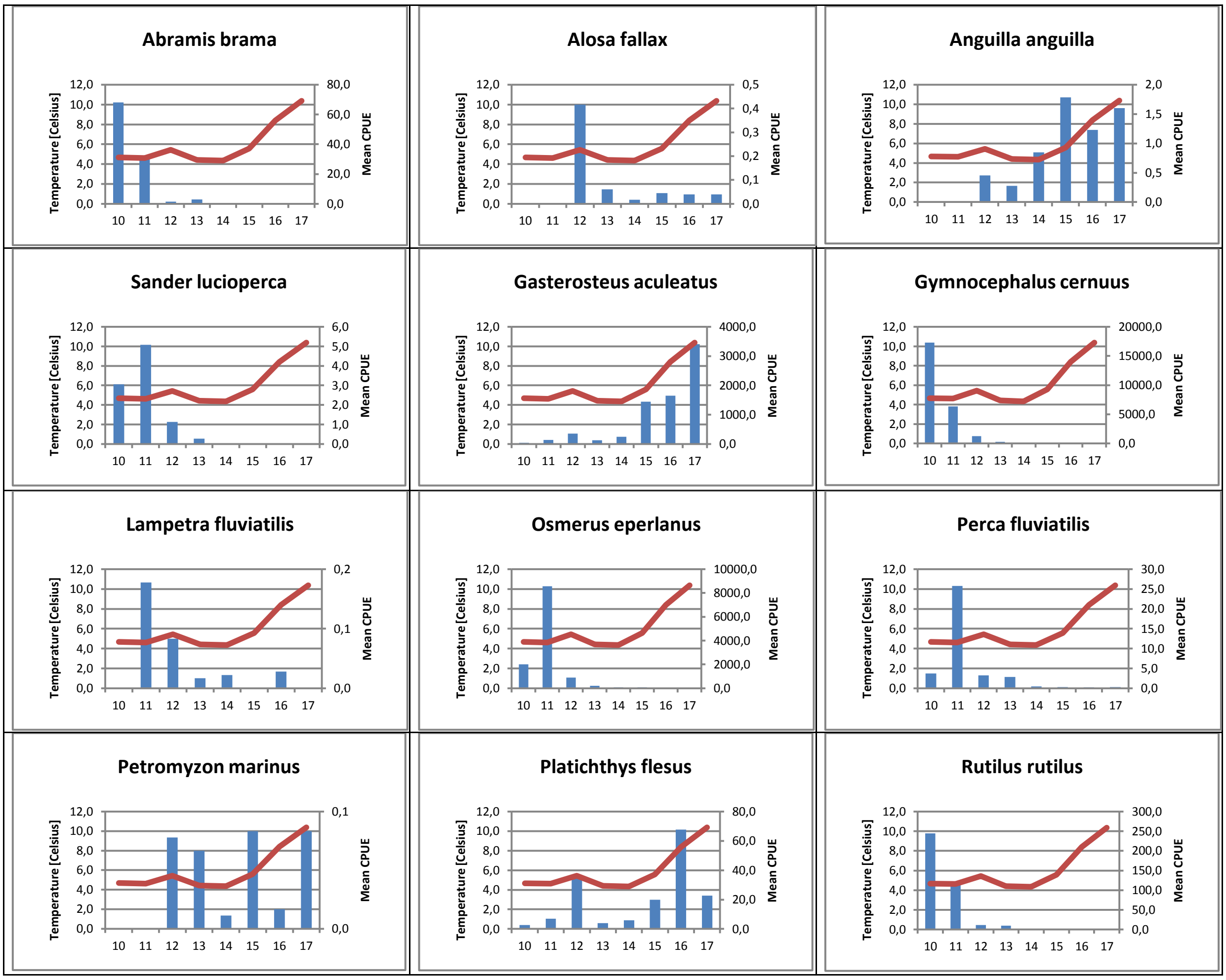

Figure 6.4.5 Mean CPUE per species of 15 target fish species in relation to mean water surface temperature (y-as) over time (x-as) in spring 2014

6.4.5 Relation catches and discharge

The results indicate a slight relation between discharge volume and total mean CPUE. From week 14 onwards, CPUE increases with increasing discharge volume. Figure 6.4.6 shows that the highest number of fish was caught at a discharge volume of 13 and 15 million m³ (week 10 and 11).

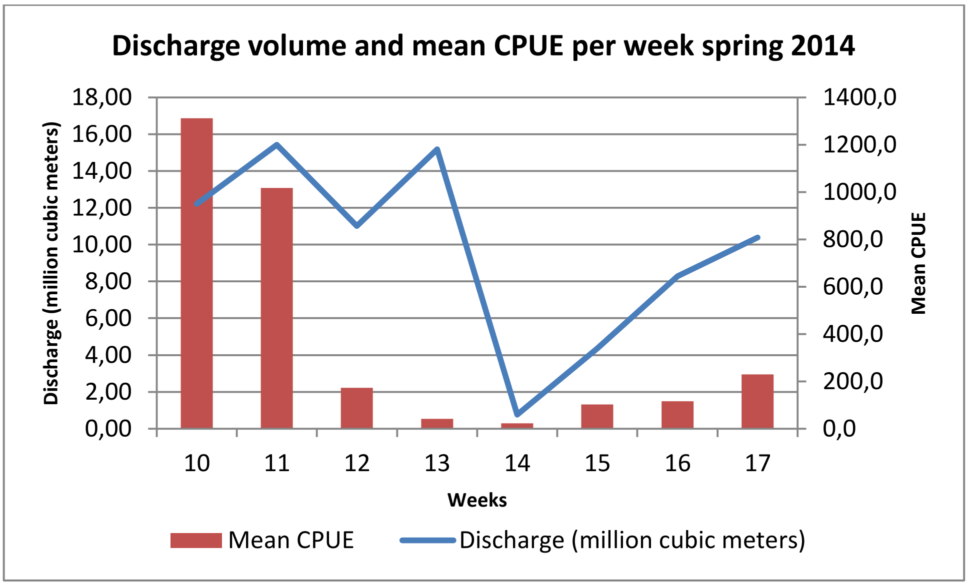

Figure 6.4.6 Total mean CPUE in relation to discharge volume in million m³ (y-as) over time (x-as) in spring 2014.

Figure 6.4.7 shows the relation between mean CPUE per species and discharge volume in million m³ over time (week10-17) in spring 2014. Bream, perch, river lamprey, roach, ruffe, smelt, twait shad and zander were caught at high discharge volumes between 13 and 15 million m³. Flounder and stickleback were caught at discharge volumes from 0 to 10 million m³ and eel from 0 to 15 million m³ (see fig. 6.4.7).

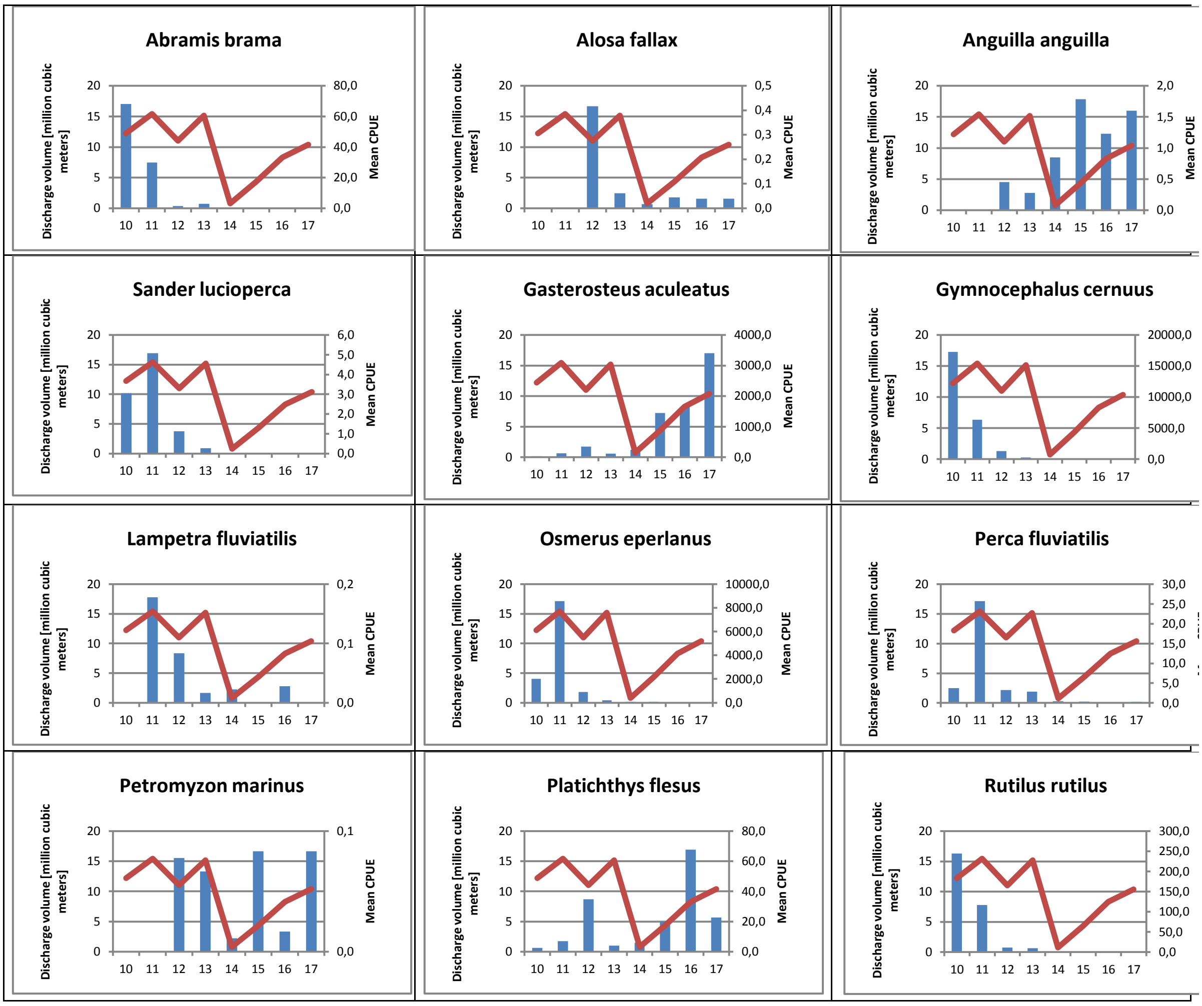

Figure 6.4.7- Mean CPUE per species of 15 target fish species in relation to mean discharge volume in million m³ (y-as) over time (x-as) in spring 2014.

Appendix III, XI-XII) shows the relation between the weekly mean CPUE of the 15 target species, divided by diadromous and freshwater fish, and the discharge volume in million m³. There is a negative relation between the mean CPUE of the diadromous species eel, flounder and stickleback and discharge volume. The mean CPUE per species decreases with increasing discharge. A positive relation is recognisable between the diadromous species river lamprey and smelt and discharge. The mean CPUE per species increases with increasing discharge. For twait shad only a very slight positive trend is seen and for sea lamprey no relation. For all the freshwater species (bream, perch, roach, ruffe, zander) a clear positive relation is found.

7. Discussion

In this chapter the findings of this research are interpreted and, where possible, compared with scientific and grey literature.

7.1 Lift net

7.1.1 Methodology

Lift net sampling was performed at the research area at Kornwerderzand in order to answer the sub question number 1 “What is the spatial distribution of the four target species European smelt (*Osmerus eperlanus*), flounder larvae (*Platichthys flesus* larvae*)*, glass eel (*Anguilla anguilla* larvae) and three-spined stickleback (*Gasteroteus aculeatus*) in the discharge basin and the port at Kornwerderzand in relation to tidal regimes and discharge events?” Due to the preference of fish to migrate during the night and due to dependency on tidal regimes, evening/night measurements were carried out. Sampling strategy was conceptualized before fieldwork, to start sampling at the same tidal position- starting at exactly low tide. This prerequisite was not met in reality due to various factors, e.g. longer than expected fishing gear preparation, having special guest on board who were interviewing fish crew and bad weather conditions. Therefore, spatial distribution of fish in relation to tidal regime does not have a 100% rate of comparability per sampling day. An additional difference in concept and practice was the cancellation of the third run during the fourth sampling day (17 April) due to unfavourable weather conditions and an approaching storm, whereas in theory each sampling day should have consisted of 3 runs. Moreover, location 11A was used only once during fieldwork as a sampling location, which reflects in the lowest total catch number from all the sampling locations. Additionally, locations in the port at Kornwerderzand (number 1 and 2) were used as sampling points only during runs 1 and 3, which reflects in lowest total catch.

7.1.2 Ecology

Generally speaking, when looking at the findings based on the performed fieldwork, a clear tendency of fish to accumulate in front of the discharge gates is visible. Especially during successive runs, four target (migratory) fish species became more numerous in front of the discharge sluices than anywhere else in the discharge basin. This positively corresponds to findings of Winter & Griffioen (2014). This can be explained using different theories. Firstly, according to Winter & Griffioen (2014) fish in general respond and follow the attraction flow created by mixing of salt water from the Wadden Sea side with discharged, fresh water from the IJsselmeer. Other literature indicates the same, namely it is assumed that the migratory fish need a micro attraction flow to find the entrance of the fish way (Dorst et al., 2012). This phenomenon of arising brackish water in the discharge basin is luring fish towards discharge gates and triggering their migratory behaviour (Hertog, 2006). Accumulation of fish in front of the discharge gates is more visible in successive runs, possibly because fish have had more time to come back from their hideouts or more northern position after discharge events. Secondly, according to Winter& Griffioen (2014) all the fish are able to use an energy efficient form of transportation called selective tidal stream transport (STST). However, some fish e.g. glass eel and flounder larvae are very dependent on this form of transportation, whereas two other target fish species (smelt and stickleback) may use it as an additional option to active swimming (Winter & Griffioen 2014). Before the fieldwork days started the hypothesis, that fish species dependant on STST were expected to have lower catch numbers with consecutive runs (only during the flood tide) up to the high tide point, was drawn. This hypothesis was correct only for glass eel and flounder larvae. Catch numbers for these species decreased with every run. This can be explained, because fish were behaving according to the STST scenario, when during the flood tide fish are carried up the water column with the flood current towards the surface, where they have more time to escape from being caught in the net dragged from the bottom (fisherman speculation). The hypothesis is not correct for two other fish species smelt and stickleback, where the total catch number increased with each consecutive run. Apparently, these fish are not strictly dependent on STST as their main form of transportation during migration (Griffioen, 2014).

Before performing fieldwork and analysing the findings the hypothesis ,that four target species of fish and especially the weakest swimmers e.g. glass eel and flounder larvae might be flushed away northwards after discharge events, was drawn. It appeared that the hypothesis was incorrect. This finding can by reasoned by several explanations. Firstly, fish could have been only partly flushed away, therefore not necessarily to be found in the farthest north sampling point, but possibly in the middle of discharge basin. Secondly, according to Winter & Griffioen (2014) fish have the tendency to hide at the bottom and along the shore of the discharge basin where the rocky bed surroundings can facilitate their sheltering. Findings in this research support that during the first run of sampling (after discharge events) fish is mainly caught on the west side of the discharge basin and in front of the discharge gates. Thirdly, fish are active swimmers and even weak swimmers reaching a speed of only 0,1 m/s can swim back after discharge events towards discharge gates in a matter of several minutes (Winter & Griffioen, 2014). Hence, even if flushed away, fish can easily change their spatial position in the discharge basin simultaneously to performed sampling runs.

In theory, management plans of the discharge sluices at Kornwerderzand imply two fish friendly scenarios, where one is facilitating weak (21112) and the other strong swimmers (23332) (see chapter 3). As appeared during lift net sampling days (see Table 6.1.1), there was always at least one discharge scenario or combination of scenarios prior to the sampling runs. The hypothesis that weak swimmers might be flushed away to the most northern parts of discharge basin during management facilitating strong swimmers was incorrect, because no relation to fish friendly management plan could have been noticed when scoping on location of caught fish. For the management plan facilitating weak swimmers, according to literature it is unknown if it is actually serving its purpose of giving higher success rate for weak swimmers to pass the sluices. Griffioen (2014) suggests that even with this management plan the current is still too strong for weak swimmers, especially glass eel and flounder larvae and it is uncertain for smelt and stickleback if and when can they pass. It is suggested by Griffioen (2014) that both management scenarios do not really matter for all the fish species. All in all, they have only a chance of passing the gates in the very beginning of the discharge event, when the current is still low. Nevertheless, it is also a very shot migration window. There is another uncertainty suggested by Griffioen (2014), whether the fish can remain in the IJsselmeer if they passed the gates successfully. Possibly, there can be a difference in the two types of management in the passage success of fish, since in the management plan facilitating weak swimmers, the average current is lower on the whole discharge basin complex. However, it should be kept in mind that this type of management might be only successful in situations where fish will pass over the bottom, which does not correspond to STST theory found to be correct in our study for the weak swimmers. When taking the general spatial distribution of the fish in the discharge basin during the different runs into consideration, especially during run 1(see fig 6.1.4) and the previously occurred discharge events into account, there is no clear relation recognizable.

Lastly, the relation between migration period and the number of caught fish was examined. Hypothesis drawn before the sampling days was predicting to catch more fish species during their migration period (see table 1.3). In general, three out of four target species start their migration window in March (glass eel, smelt and stickleback), while for flounder larvae it starts in April. For three target species the highest catch belongs to the month, which opens the migration window, excepting for stickleback with highest catch falling in May, which is out of the migration period for this species (according to table 1.3). Nevertheless, according to Hertog (2006), migration period for stickleback can last longer than in the table mentioned before. Theoretically, the expectation was to catch the most fish in the middle of their migration period and not in the beginning or end of it. This might have been caused by the warm winter (2013/2014), which could have shifted migration period for 3 target species in a way that migration windows started prior to the usual situation.

7.2 DIDSON

To determine the vertical distribution of fish in the water column of the discharge basin and two locations at the port of Kornwerderzand, the DIDSON ultrasound camera was used during the lift net sampling. This method was substantial for helping in answering second research sub question: "What is the vertical distribution of fish throughout the water column in fresh-salt water transitions of the discharge basin at Kornwerderzand?"

The theoretical approach was to put the camera at least 50 cm deep into the water (length of DIDSON camera itself) at each lift net sampling point. In practice not all the sampling points were accompanied with using DIDSON camera for taking video footages. During first sampling day (18th March) only several videos were made and all of them were rejected for analysis purposes due to their bad quality. Consequently, the 18th March could not be used for comparative purposes. The same applied with regard to particular video footages made during the other sampling days. Footages needed to be rejected because of their bad quality or short length. Furthermore, the number of footages at the locations at the port were 33,3% less due to less sampling at these locations. As a consequence, the total number of analysed videos per run and per location was not equal. Therefore, general count of occurred situations, applicable for describing the vertical distribution, occurrence and number of fish, was not unitary. Additionally a higher number of footages per run or per location could have enhanced the chance of variety.

The DIDSON camera was put at least 50cm in the water and was recording from there on downwards. Therefore, fish could have been missed on the surface, leading to a decreased surface oriented distribution in the analysis and thus falsified results. The DIDSON movies were watched for 30 seconds and fish was moving through the screen. This could have led to double counts, which could have falsified the results with regard to numbers.

DIDSON apparatus brings also some limitations, thus the species recognition is hardly possible. This was not applied in this study. The DIDSON can only receive signals of fish around 10 cm in length or bigger. Subsequently, not all the species caught with the lift net sampling were visible in video footages. Especially the two target species in larvae form (glass eel and flounder larvae) were not recorded. This has to be taken under consideration, when looking at results of this study. There could have been possibly many more other, not visible fish present in the water column. Therefore, the findings with regard to occurrence, vertical distribution as well as number of fish could have been misstated. The species identification was only based on estimations, with regard to occurring species in this area. Only the wide assumption of relation between spotted fish on the videos and actual catch per run/day can be drawn. Consequently, no conclusion and discussion drawing about species specific ecology was possible. Therefore, justification of fish vertical position preference cannot be made.

In general, as mentioned before in the ecological discussion part of the lift net sampling, according to (Winter & Griffioen, 2014) all the fish are able to use energy efficient form of transportation called selective tidal stream transport (STST). Apparently, based on the positioning of fish in the water column during consecutive runs, the fish spotted on DIDSON video footages did not show behaviour proving to use STST. Additionally, there is no strict positioning of the fish in the water column. In most of the cases fish are randomly distributed throughout the water column during the flood tide, at the high tide and during the ebb tide. This finding was expected, but another assumption that fish are hiding in the bottom in the very beginning of the flood current was also drawn. That seems not to be the case at the Kornwerderzand discharge basin area. In other words, the selective tidal stream transport is not that strict for the fish spotted on DIDSON video footages in this area. For the context of FMR project it seems that the height of the conceptualized entrance can be located between pelagic and water surface level, but only when taking into account the fish observed on DIDSON video footages.

7.3 Fyke net

This study was only a part of the situation at Kornwerderzand because of focussing only on 15 target species occurring in the area. In reality, the species richness and abundance in this area is much higher, as studies from IMARES suggest. More than 101 different species and almost 42 million individuals were observed over time and even here it is stated that this was only a part of the real situation (Griffioen & Winter, 2014). Additionally, the different fykes were located on the side of the discharge basin (fyke 1-5). Because the most of the discharge water, containing flushed out freshwater fish, passes the middle of the basin directed to the Wadden Sea, it is suggested that the freshwater fish, observed in this study, constitutes only a fraction of the real quantity. Vice versa, this also counts for diadromous fish, migrating from the Wadden Sea to the IJsselmeer, as they tend to migrate from the middle of the basin (personal comment local fisherman gebr. van Malsen).

Although the fyke catches represent a valuable image of the occurrence, species composition and migration period of fish, they only partly provide an insight in their abundance, because the fyke catches at Kornwerderzand can be interpreted as a result of a combination of occurrence as well as behaviour of fish. Different authors suggested that fish, which are confronted with barriers during their migration, show searching behaviour, which could have led to a broad distribution of fish throughout the fykes or double counts, waiting behaviour, leading to accumulation of fish at particular locations and an increased chance of trapping and recurrence behaviour, which could have led to double counts (Keefer et al., 2013; Jansen et al., 2007). The particular behavioural pattern of fish are not further analysed in this study. Consequently only assumptions can be made regarding ethological reasons when discussing the results. It is also not clear how large accumulations of fish can be interpreted because they can be either regarded as an evidence for limited migration possibilities but also as new aggregation of fish (Griffioen, 2014).

The fresh-salt transition at the Afsluitdijk is sharp. It is suggested that the discharged freshwater creates an attraction flow, which is stimulating migrating fish and enhances their chance of orientation. The more discharge the higher the attraction flow. The reaction of fish on a discharge event in particular and the consequences on their abundance is unknown (Winter & Griffioen, 2013; Winter et al., 2014). It is suggested by Griffioen (2014) that the discharge is creating a long term effect with regard to attraction of fish, recognizable when fish is still abundant in the discharge basin, even with less or no discharge. The reason could be that fish show either a type of waiting behaviour or that abundant fish is a result of new aggregations (Griffioen, 2014). In this study fish was highly abundant at the fyke located directly in front of the western sluice. Consequently, the assumption could be made that fish was attracted by the freshwater flow. Furthermore fish was also abundant during lower and no discharge (in some cases even with a negative relation to discharge), which could be an indication for the suggestion of Griffioen (2014). However, other factors, like earth magnetic fields, water currents (Rommel & McCleave, 1972), pheromones and odorants can play a role as well when it comes to the attraction of fish (Hansen et al., 1993; Jager, 1998, Winter et al., 2013). Especially smelt was distributed throughout all fykes in the discharge basin, which could indicate that the fish was showing a type of searching behavior. This was not clearly identifiable for other species when looking at the moderate to strong swimmers. In general, knowledge about the searching behaviour of fish is lacking (Winter et al., 2014).

It is also suggested that fish is flushed away to the Wadden Sea by discharge. This is supported by other findings, where it was observed that diadromous fish is most likely to migrate upstream at the beginning of a discharge event, when the water velocities are still low(er) (Witteveen & Bos, 2009). But assumedly, some fish are able to persist during discharge by staying on the bottom or seeking sheltered places. Nevertheless, especially weak swimmers, like flounder, are known to have a high risk of being flushed out due to weak swim capability. On the other hand, weak swimmers like eel, flounder, stickleback and partly also smelt (Winter at al., 2014) make use of STST (Potter, 1988). It is known that they stay at the bottom during ebb current to prevent being flushed away (Trancart et al., 2012) and coming up during flood current to save energy (Winter et al., 2014). Therefore, the fish can be expected at locations in high concentrations and, influenced by tide, also expected either in front of the sluices or in the back of the discharge basin. Furthermore, the fish which make use of STST are showing less searching behavior due to limitations in movement (Griffioen, 2014). High concentrations of fish at particular fykes could also be indices for acclimatization behavior, meaning that fish is waiting at a location in order to adapt their osmoregulation and adapt to the circumstances (Winter et al., 2014). However, knowledge about that is lacking. In this study especially flounder was caught most in the northward fyke (fyke 9) which could refer to a flush away. However, this cannot be applicable for the other species, regarded as weak swimmers and making (partly) use of STST (stickleback, smelt, eel). Also no clear high concentration at particular fykes was recognized.

In general, the fykes 6 and 7, westwards outside the discharge basin have caught the least individuals, measured in mean CPUE per species. In this area no discharge occurs. An assumption is that fish is thus less attracted by the attraction flow and therefore not that present. In contrast, both in autumn 2013 and in spring 2014, high numbers were caught at fyke 3, located directly in front of the western sluices. Here, it can be assumed that the fish was attracted by the attraction flow. The fykes which are located northwards outside the discharge area (fyke 8 and 9) yielded very high numbers in autumn 2013. This could be due to high discharge volume of the season, which possibly flushed the fish away. The same could also count for fyke 1, which yielded the highest numbers in autumn 2013. However, this is only applicable for the weak swimmers (e.g. flounder) which are caught in high numbers at this location. For stronger swimmers (e.g. river lamprey, twait shad and zander*)* which are also caught in high numbers, an explanation could be that the locations provide for a good connection to the gullies in the Wadden Sea, where a lot of fish is passing. Relative high numbers were caught in all the fykes on the west side of the discharge basin (fyke 3-5), especially in spring 2014. It is possible that these fykes are relatively sheltered locations and fish are seeking for shelter during or after discharge. This might be a combination of active or passive movement (e.g. fish is flushed out to fyke 5) (Griffioen, 2014). These results are in accordance with recent literature which suggest building the FMR on the west side of the discharge basin because of high concentrations of fish (Winter et al., 2014). According to the literature it is not known to what extent migratory fish is using the shipping locks for migratory purposes. The fyke located at the shipping locks yielded relative high numbers in autumn but low in spring. The species caught at this location in autumn were only freshwater species (besides eel*)*, which were assumedly flushed out from the IJsselmeer. Consequently it can be stated that this location yielded only small numbers of diadromous fish and seems to be not extensively used for migratory purposes.

The high positive relation between mean CPUE of all freshwater fish species and increasing discharge volume refers to the fact that freshwater fish species are flushed out of the IJsselmeer at high discharge volumes (Winter et al., 2014). The chance of the fish to travel back to the IJsselmeer is regarded at zero, due to the strong water velocities. Moreover, there is very little known about how long a freshwater fish can survive outside of the IJsselmeer. The peaks of flushed out freshwater fish differ per period (Winter et al., 2014). This was also the case in this study as in autumn over 1,5 million freshwater fish were monitored in the discharge basin, whereas the numbers in spring were around 100.000. The importance of this problem is not clearly stated and opinions about the dimension of the problem are diverged, from marginal to substantial. Comparative researches have shown numbers of flushed out freshwater fish between 65.000 and 1,4 million per year (Griffioen & Winter, 2014), whereas the numbers in this research were caught within three months. As stated before, the numbers of fish caught with the fyke nets represent only a part of the actual numbers. Fish is not recognized in the discharge basin shortly after the discharge but in other parts of the Wadden Sea in not a good state (per. comment gebr. van Maalsen), which might have even increased the chance of trapping with the fyke. Consequently, the washout of freshwater fish can be regarded as a greater problem.

However it needs to be taken into account that discharge is always higher during the winter months in the Netherlands, due to an increased amount of rainfall (www.geo.de). This could have influenced the results regarding the washout of freshwater species in autumn 2013 as well as the relations between diadromous fish species and discharge volume. When a positive relation was identified, discharge volume could have been in coincidence with high numbers of certain species, for instance due to migration period.

Temperature is an important factor for diadromous fish and can be linked to the species specific migration periods. Sprint capacity is highly dependent on size and water temperature (Winter et al, 2014). Each 10 degrees of temperature increase double the sprint capacity of fish species (Videler, 1993). Therefore, it was assumed that especially the weak swimmers migrate during higher temperatures in order to profit from a higher sprint capacity and decrease the chance of predation. This was applicable for eel, flounder and smelt in autumn and for eel, flounder and stickleback in spring.

Besides, it needs to be taken into account that fish, which is migrating at a larvae stadium (e.g. flounder and glass eel), could have been actually present in the area but could not be caught due to a too large mesh size of the fyke net. Additionally, species which are more unlikely to catch with fyke nets (e.g.sea trout and Atlantic salmon, pers. comment gebr. van Malsen) had a decreased chance of trapping.

As mentioned above, several factors play a role when it comes to the assessment of abundance of fish at the discharge area in relation to tidal regime and temperature over time. In this study, only the simple relations and interactions are tested, which could have led to biased results or results which are based on coincidence. For that reason it could have been more accurate to create a model (e.g. GLM), which takes all the influencing factors and interactions (i.e. migration period, temperature, discharge volume, discharge events, time of the year, season and rainfall) into account.

Furthermore, it was planned to create delay scenarios which are linked to the delay in response of fish to discharge. Due to a lack of time, this approach was rejected.

Below, the occurrence and abundance of diadromous fish in the research area during the monitoring period is discussed with regard to fish ecology, motivation and migration. Here, it is to remark the warm winter of the year 2013/2014 could have led to a shift in migration period (per. comment gebr. van Malsen).

7.3.1 Fyke net autumn 2013

European eel (*Anguilla anguilla)*

The individuals caught of eel were large as well as small. However, the larvae stadium (glass eel or glass eel) could not be caught with the fyke net due to too wide mesh size (Griffioen, 2014). As a catadromous species, the species is migrating as juvenile (Dekker & van Willingen, 2000) to the freshwater and coming back as adult to the Sea. Due to the fact that no glass eel could be caught, it is assumed that the large caught individuals were migrating downstream to the Sea (September until November), as this is in accordance with their migration period (Hartgers et al., 2001; Froese & Pauly, 2005). Because adult eel is around 50-100 cm (Hartgers et al., 2001), the caught small individuals might use the area as foraging grounds. The species was particularly caught at the shipping locks, possibly because the adult individuals used them to migrate from fresh to salt water. Eel was caught at high and low water temperatures to 7 degrees, which are in accordance with their migration time (Dekker, 1998). Because there was a negative relation between mean CPUE of the species and discharge volume recognized, it can be assumed that the species was not flushed out of the IJsselmeer.

European river lamprey *(Lampetra fluviatilis)*

All individuals caught of river lamprey were large individuals. Because the species is anadromous and migrating at adult stadium (Winter et al., 2014) it is assumable that the species was migrating to the mating grounds. Supportingly, river lamprey was observed at low temperatures and only in months November and December, which correlates to their preferred migration time in December (Griffioen & Kuijs, 2013) and according temperatures of 1,6 to 6 degrees (Winter et al., 2014). The species was in particular caught at the northwards fyke (loc 9), with small numbers at fyke 8 (northwards), fyke 3 and 10. The species has a tendency to attach on walls, for grip during currents resulting from discharge or tide (Griffioen, 2014). Furthermore, the individuals caught at fyke 9 could be passengers from/to the gullies (see above).

European smelt *(Osmerus eperlanus)*

Smelt was caught most frequently out of all species, as well in small and in large size. Because there are two populations existing, an anadromous and a freshwater one, the species was not clearly distinguishable (Tulp et al., 2003). However, the species was caught the whole research period, with a positive relation to decreasing temperature and a negative relation to increasing discharge, so it is assumed that the caught fish was not flushed out fish from the IJsselmeer. Since the anadromous population is migrating in spring (Winter et al., 2014) it can be assumed that the observed fish was anadromous foraging smelt. The species was caught most on the eastside of the discharge basin (fyke 1 and 2) and also northwards (fyke 8 and 9) and in medium to small numbers in the other fykes, so no clear location preference was identifiable. That the species is found northwards could be reasoned by the fact that it is regarded as weak/moderate swimmer (Winter et al., 2014) and flushed away by discharge or because it was foraging at this location.

Flounder *(Platichthys flesus)*

Flounder was caught especially at small size. However, the larvae stadium could not be caught due to too wide mesh size of the fyke net (Griffioen, 2014). Because flounder is a catadromous species

(Morais et al., 2011) and migrating upward at larvae stage (Winter et al., 2014) in April until June (Jager, 1999), it is assumed that the caught individuals were especially foraging in the area. The abundance of flounder was in positive relation to decreasing temperature and in negative relation to increasing discharge. This might be due to the fact that flounder is a weak swimmer (Winter et al., 2014) and can only partly swim against velocities with the consequence to be flushed away at high discharge (Griffioen, 2014). The species was found at fyke number 5 and 9 in highest numbers but in all other fykes as well. This is not in accordance with the expectation to find the species possibly most at fyke 4 and 1, as these are from discharge sheltered places (Griffioen et al., 2014), but it is in accordance with the expectation that the fish is flushed away.

North Sea houting *(Coregonus lavaretus oxyrinchus)*
Houting was caught not in big numbers and only caught in small size, which indicates that these were foraging individuals (Griffioen, 2014). This is also indicated by the fact that the species was caught only in two weeks out of the nine researched. Houting is caught in particular northwards (location 5) and was in general only oriented on the west side, possibly to search for shelter from discharge, even is this species is regarded as strong swimmer (Winter et al., 2014), to save energy. The species was caught decreasingly with decreasing temperatures which also supports that the species was no migrator as they are migrating at colder temperatures between 2 and 10 degrees (Winter et al, 2013). Because also a fresh water population of houting exists, caught individuals could also be flushed out individuals from the IJsselmeer (Winter et al., 2008) but there was no relation between houting and discharge.

Three-spined stickleback *(Gasterosteus aculeatus)*
Stickleback was caught only in large size. Because the species is anadromous and migrating in spring, caught individuals used the area as forage grounds. This is also supported by the fact that the species is migrating downwards in the month September and October (Winter et al., 2014) but was caught only at colder temperatures between 5 and 7 °C from mid-November to December. Furthermore this species was found in several locations in the discharge basin and showed no location preference. It is also suggested by Griffioen (2014) that high numbers of stickleback stay in and around the discharge basin, regardless their migration period. For stickleback there was no clear relation between mean CPUE and discharge recognizable, because the species was only caught at the end of the year where discharge is higher in general, so a relation could be based on coincidence.

Twait shad (*Alosa fallax*)
Almost all caught individuals of this species were juveniles. Twait shad is an anadromous species and an adult migrator and uses the area not as mating but as foraging grounds (Griffioen & Winter, 2014). The species was especially caught at water temperatures of 13 degrees which is in accordance with recent literature, which suggests that this species migrates between 19 and 9 degrees (Winter et al., 2014). The mean CPUE of twait shad decreased with decreasing water temperature. However this could be reasoned by the fact that the species is migrating decreasingly from June to November and water temperature is decreasing with time of the year as well (Winter et al., 2014). Twait shad was especially caught northwards, at the fykes 9, 8 and 5, but also at the other fykes. This distribution could be linked to the foraging behaviour of the species (thus not in front of the sluices) (Griffioen, 2014) but also it could be reasoned by the fact that the species has a lower swim capacity as a juvenile and could have been flushed away from the fore part of the discharge basin by the discharge (Winter et al., 2014). The species seems to avoid the location around the shipping locks,

possibly because of less food supply. Because there was a negative relation between mean CPUE of the species and discharge volume found, it can be assumed that the species was not flushed out of the IJsselmeer.

7.3.2 Fyke net spring 2014

European eel *(Anguilla anguilla)*

Eel was caught in small as well in large size. However the mesh size of the fyke net was too small to catch glass eel (or glass eel) which are migrating in spring. Assumedly, the occurring species were foraging in the research area. However it is remarked that adult eel can also migrate during other times of the year (Winter et al., 2008). A positive relation between the mean CPUE of the species and water temperature has been identified. According to Dekker (1998) young eel is migrating to freshwater when temperatures are above 7°C. The negative relation between the mean CPUE of eel and discharge can be explained by assuming that the species was avoiding the discharge basin during high discharge volumes, possibly to prevent them from being flushed away and to save energy when not swimming against high velocities. That is also supported by the fact that eel was especially distributed outside the spuikom (fyke 6 and 7, 9 and 10), possibly due to foraging or because the species want to escape the discharge currents.

European river lamprey *(Lampetra fluviatilis)*

The caught individuals of river lamprey were large individuals but in small numbers (n=22). Assumedly, the individuals were migrating adults, as they are migrating during winter and early spring at temperatures around 1,6 and 6 degrees (Winter et al., 2014) and the species was only caught at temperatures around 5 °C. There was a positive relation between the mean CPUE of river lamprey and discharge*,* which is explainable by the fact that either the species was mainly caught in the weeks with higher discharge or it was attracted by increasing attraction flow. The most individuals were caught northwards (fyke 9) and at the shipping locks. The individuals which are concentrated northwards could have been flushed out by the discharge, whereas the individuals caught at the shipping locks could have searched for grip, attached to the walls, either in order to save energy, to overcome currents, or to migrate via the shipping locks into the IJsselmeer.

European smelt *(Osmerus eperlanus)*

Smelt was caught at second highest numbers and in particular at small size (n=661.018). The species is migrating in spring at adult stadium. Therefore it is assumed that the individuals were young adults, on their way to upstream migration. Smelt was only caught at the beginning of the research period at temperatures around 5 °C. Due to a lack of comparative periods, it cannot be stated that there is a relation. The relation between the mean CPUE of the species and discharge volume was negative, possibly due to the fact that smelt is regarded as (moderate) weak swimmer (Winter et al., 2014) and was avoiding high discharge. The most individuals were caught on the west side, in the fykes 3-5. It is assumed that the fish caught at fyke 3 were waiting for their chance to pass the barrier. In general it can be an indication that the fish were seeking for shelter, as the west side of the discharge basin is regarded as a sheltered location (Griffioen, 2014).

Flounder *(Platichthys flesus)*

Flounder was caught especially in small size. The individuals were possibly, since migratory flounder larvae were not catchable with the fyke net, foraging juvenile or young adult individuals. The species was caught the whole research period at temperatures between 5 and 10 °C. Flounder was caught in all fykes but especially in the northern ones, which supports the theory that the species is flushed away by high discharge. Additionally, there was a negative relation between the mean CPUE of the species and discharge identifiable, which could indicate that flounder was avoiding the discharge basin during high discharge volumes in order to save energy and to prevent from being flushed away.

Sea lamprey *(Petromyzon marinus)*
Sea lamprey was only caught in small numbers (n=23) at large size. The caught individuals were possibly adults on their way to upward migration, since their migration period is in spring. The species was caught at temperatures from 5 to 10 °C. The relation between mean CPUE of sea lamprey and discharge might have been negative because the species could have passed the barrier, since it is regarded as moderate to strong swimmer (Winter et al., 2014). Sea lamprey was mainly caught at fyke 5 on the west side, possibly because it can attach or to walls in the surrounding (Griffioen, 2014).

Three-spined stickleback *(Gasterosteus aculeatus)*
Stickleback was caught only in large size and third highest numbers (n= 475.772). That could indicate that the caught individuals are belonging to the anadromous subpopulation since they are migrating as adults during spring (Hartgers et al., 2001). Stickleback was caught increasingly with increasing temperature which is in accordance with their migration period (Winter et al., 2014). The species seems to be less sensitive for discharge as only a slight negative relation between mean CPUE of stickleback and discharge was identified, which could be a reaction to the poor swim capacity of this species (Winter et al., 2014). Nevertheless, it was recognized by Griffioen (2014) that stickleback stays an increased time in the discharge basin with decreased discharge. It is suggested that either the species seems to stay waiting for migration possibilities on a location in the discharge basin or new individuals are accumulating continuously (Griffioen, 2014). Stickleback was caught especially in the fykes 1 and 2 on the eastside and fyke 3 on the west side, which is in accordance with other findings from Griffioen (2014). Fish seems to be attracted by the attraction flow and preserve in front of the sluices, waiting for a chance to pass.

Twait shad *(Alosa fallax)*
Twait shad was caught at small numbers but not in high numbers at all (n=43). Given the fact that the species is anadromous and juveniles are coming back to the Sea when temperatures are not lower than 9 °C (Winter et al., 2014), it can be assumed that the caught individuals were juveniles, using the area as forage grounds. The species was only found at temperatures of 9 °C, but it was also only found in week 12. So this might be coincidence. There was also no relation with discharge identifiable, since twait shad was only caught in a short time frame and no comparison was possible. The species was caught mainly northwards (fyke 8 and 9), possibly because it was flushed away by discharge or more likely because it was a passenger from the gullies.

8. Conclusions

The outcome of this report can be regarded as one piece of the puzzle, aiming on filling a knowledge gap in the broader context of the Fish Migration River project. In order to answer the main research question “What is the spatial distribution and abundance of the 15 target fish species in and around the discharge area at Kornwerderzand in relation to tidal regimes, discharge events, discharge volume and temperature?”, three sub questions were formulated.

8.1 Lift net

“What is the spatial distribution of the four target species European smelt (*Osmerus eperlanus*), and flounder larvae (*Platichthys flesus* larvae*)*, glass eel (*Anguilla anguilla* larvae) and three-spined stickleback (*Gasterosteus aculeatus*) in the discharge basin and the port at Kornwerderzand in relation to tidal regimes and discharge events?”

When focussing on the four target species, the results have shown that location 7 (in front of the west side discharge sluice) yielded the highest total catch number. The smallest number yielded location 11B. When taking the spatial distribution in the discharge basin into account, the sampling points in front of the sluices (yellow) recorded the highest average catch per location. There was no clear difference in spatial distribution between the other groups of locations identifiable.

Glass eel was caught the most, primarily on day 1 and day 2, and with highest numbers at location 4 (in front of the east side discharge sluice). Stickleback was the second biggest catch, especially on day 5 and 6, with highest numbers at location 7 (in front of the west side discharge sluice).Smelt was caught mainly on day 1 and 2 with highest numbers at location 7 and flounder was caught in particular on day 1 and 2, with highest numbers at location 8 (west side of discharge basin). The results are in accordance with the migration period of the species.

When taking into account the tidal regime, it can be said that all the sampling days had their starting point during the flood tide and only half of them were finished after hide tide, thus the last run was taking place during the ebb tide only in 50% of the cases. The results show that the most individuals were caught during run 1 and thus during flood tide. For two target species, flounder and glass eel there was a tendency of decrease in the number of catch during successive runs recognisable. For two other target species smelt and stickleback, a tendency of increase in the number of catch during successive runs was notable. Subsequently, STST was recognisable only for flounder and glass eel.

With regard to the spatial distribution of fish in relation to discharge events, the results have shown no relation. The fish have a tendency to be distributed in front of the discharge sluices (location 3, 4, 6 and 7) regardless the previously occurred discharge events or particular progressed runs. Consequently it can be said that fish is not flushed away by discharge.

Finally, with regard to suitable entrance(s) for the FMR, results arising from our study indicate the west side of the discharge basin as the best option (with the highest abundance of fish present just after discharge events).

8.2 DIDSON

"What is the vertical distribution of fish throughout the water column in fresh-salt water transitions of the discharge basin at Kornwerderzand?"

The results have shown that the vertical distribution of fish in the water column differed per sampling day and per run. There was no clear pattern of distribution recognizable in relation to runs and in terms of distribution preference.

When taking all the runs together, the results have shown that the fish were mostly randomly as well as benthically distributed in the water column. In general, a most surface oriented distribution was assessed the least.

8.3 Fyke net

What is the CPUE (Catch Per Unit Effort) and the difference in species of the 15 target species between the different fykes at the Kornwerderzand area in relation to discharge volume and temperature in autumn 2013 and spring 2014?"

8.3.1 Autumn 2013

During the monitoring period in autumn 2013, the mean CPUE differed per species, as well as per fyke and per species per fyke. According to the mean CPUE, fish were mainly distributed at fyke 1 and the least at fyke 6. The fykes on the eastside of the discharge basin had both the biggest catch (fyke 1) and the fourth smallest catch (fyke 2) Besides that, fish were mainly distributed northwards outside the discharge basin (fyke 8 and 9), followed by a distribution throughout the shipping locks (fyke 10). The fykes on the westside of the discharge basin (fyke 3, 4 and 5) had a similar fishing quota. Fish were the least distributed around the fykes outside discharge basin on the westside (fyke 6 and 7). Fyke 1 (eastside) caught the highest number of bream, smelt and stickleback, fyke 3 (west side in front of sluice) the highest number of roach, fyke 5 (west side) the highest numbers of flounder, houting and zander, the northward fykes the highest number of ruffe (fyke 8), perch, river lamprey and twait shad (fyke 9) and at the shipping locks (fyke 10) the highest number of eel was caught.

The results have shown a positive relation between the mean CPUE per species of eel, flounder, houting and smelt and water surface temperature and a negative relation between the mean CPUE per species of river lamprey and roach, ruffe, stickleback and zander and water surface temperature. For sea lamprey there was no clear relation identifiable. Furthermore, there was a negative relation between the mean CPUE of the diadromous species eel, flounder, houting and twait shad and discharge and a positive relation between the diadromous species river lamprey, smelt and stickleback and all the freshwater species (bream, perch roach, ruffe, and zander*)* and discharge.

8.3.2 Spring 2014

In the monitoring period in spring 2014, the mean CPUE differed per species, as well as per fyke and per species per fyke. According to the mean CPUE, fish were mostly distributed at the west side of the discharge basin (fyke 3 and 5) and the least distributed westwards outside the discharge basin (fyke 7). Besides that, fish were mainly distributed on the eastside of the discharge basin (fyke 1 and 2), followed by a distribution on the westside at fyke 4 and a northward distribution (fyke 8 and 9). The fyke placed close to the shipping locks (fyke 10) had the third smallest catch. Fish were least distributed westwards outside discharge basin (fyke 6 and 7). The fykes on the eastside caught the highest number of bream, ruffe (fyke 1) and stickleback (fyke 2), the fykes on the west side the highest number of smelt (fyke 3), roach (fyke 4) and perch (fyke 5), the fykes westwards outside the discharge basin the highest number of sea lamprey (fyke 6) and eel (fyke 7), fyke 9 (northwards outside) the highest numbers of flounder, river lamprey and twait shad and at the shipping locks (fyke 10) the highest number of river lamprey and zander were caught.

The results have shown a negative relation between mean CPUE of the species bream, houting, perch, river lamprey, smelt, twait shad and zander and water surface temperature and a positive relation between the mean CPUE of the species eel, flounder and stickleback and water surface temperature. For sea lamprey there was no clear relation identifiable. There was a negative relation between the CPUE of the diadromous species eel, flounder and stickleback and discharge, and a positive relation between the diadromous species river lamprey and smelt as well as all the freshwater species (bream, perch, roach, ruffe and zander) and discharge. For twait shad only a very slight positive trend was recognizable. For sea lamprey no relation was identifiable.

9. Recommendations

Regarding the experiences gained in this study and future perspectives, several recommendations can be made. The most important is filling still existing knowledge gaps with regards to the FMR project are:

- Species-specific passage efficiency in the current situation- The passage success rate of fish, especially for weak swimmers with present fish friendly management plans of the discharge sluices at Kornwerderzand, is still unknown.
- Spatial searching behaviour- how and to what extend is the attraction flow influencing fish to trigger their migratory behaviour and finding the source of the fresh water. The magnitude of this micro attraction flow can be varied during future monitoring programme(s) and in this way the most suitable attraction flow for the FMR can be determined in the future.
- Utilization of short-term migration windows- it is still unknown to what extent fish can use these short migration windows efficiently.
- Acclimatization requirements of fish in fresh-salt transitions- Information about species specific acclimatization requirements is lacking. Furthermore, it is not known how long acclimatization takes and what kind of fresh-salt gradients are preferred by certain fish species.
- Dimensions of FMR and fresh-salt dynamics needed for being a fish habitat- it is little known about the necessary dimensions, dynamics in fresh-salt water gradients, and diversity of habitats in relation to growth-or even spawning feature for the concept of FMR project.
- Mortality of fresh water fish in salt water-Information about how long a freshwater fish can survive outside of the IJsselmeer is lacking.

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Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling, Netherlands.

Appendix I Target species

Target fish species and their ecology

This chapter briefly describes the ecology of the various fish species that occur at the discharge basin of Kornwerderzand within the Afsluitdijk. The different target species were selected according to performed study and their description is focused on the importance of fish passing the Afsluitdijk during the migration from salt to fresh water. Fish selection for the lift net and DIDSON study is mostly based on the WFD and Natura 2000 framework.

Target species lift net sampling

European eel (*Anguilla anguilla*)

The European eel is a catadromous species. Although still unproven, the adult eel probably migrates to the Sargasso Sea, where spawning takes place. Downstream migration takes place from August to October. The leptocephali larvae are brought to the coasts of Europe by the Gulf Stream in 7 to 11 months of time. Glass eel, or elver, use Selective Tidal Stream Transport for migration (February – June) to fresh waters. After a period of 6-12 years for males and 9-20 years for females, the metamorphosis is complete. Adult eel is migrating back to the Sea between September and November. The length of an adult eel is 50 – 100 cm. (Hartgers et al., 2001 and Froese & Pauly, 2005). There is a great importance for this species of migration between fresh and salt water. The acclimatization between salt and fresh water seems to be unproblematic for this species (Wilson et al., 2004). There is no clear indication that acclimatization between fresh and salt water is of high importance for this species (Potter, 1988). Migration is happening during the night (Dekker and van Willingen, 2000) and at a sea temperature above 7 degrees (Dekker, 1998). The sprint capacity of this species in between 0,2 and 0,8 m/s. In the last decades the numbers of the European eel are declining (Dekker, 2004).

European smelt (*Osmerus eperlanus*)

There are two different populations of European smelt, a migratory (anadromous) population and a freshwater population. The populations differ in maturation age and length, 3- 4 years and 15-18 cm for migratory populations and 1-2 years and 8-10 cm for freshwater populations. The migratory fish are rarely seen far from shore, the essential part of its life spend in the estuary with short incursions in the literal zone. Rivers function as spawning sites (from March until April). When the eggs hatch after 3 – 5 weeks the larvae descend towards the estuarine zone, where they will mature and group together for reproduction (Froese & Pauly, 2005). Migration possibilities between fresh and salt water is of high importance for the migrating species. Migration is happening during the night, at temperatures between 1,5 and 11,5 degrees. According to the fishermen Van Malsen species occur in high concentrations in the deep waters at the discharge basin at the Wadden Sea side and the shipping locks in order to move towards the doors during ebb current. The sprint capacity of the species is between 0,7 and 2,2 m/s. The acclimatization ability between fresh and salt water is unknown for the anadromous species. It is suggested by Witteveen and Bos (2009) that they need to adapt to fresh water.

Flounder (Platychthys flesus)

Flounders are catadromous fish (Morais et al., 2011). Spawning of flounder, living in the Dutch coastal areas, takes place in the North Sea around February. The eggs and larvae move to the coast and arrive around April-May. The larvae and young flounder start to migrate towards fresh water from May until July. Fresh water is known to play an important role in the development of flounder. The migration to the North Sea for spawning takes place from September until November (Hartgers et al., 2001). Most (Dutch) flounder live in shallow coastal waters, estuaries and large fresh waters like the IJsselmeer, adult fish return to these waters every summer because of the feeding conditions (Vethaak et al., 2004). Migration is primarily happening during the day (Trancart et al., 2012). Flounders make use of Selective Tidal Stream Transport and are therefore highly dependent on water streams (Bos, 1999; Jager, 2001). A migration possibility from salt to fresh water is no requirement for this species but enhances the population growth. Also it cannot negate that flounders are actively oriented through fresh-salt gradients in which context lokstroom plays a role (Jager, 1998). It is assumed that the salt content in the water plays a crucial role for the dispersal of the flounder larvae (Jager, 1998; Bos & Thiel, 2006). Previous experiments indicated that also temperature can play a role in the dispersal (Bos & Thiel, 2006).

Three-spined stickleback (*Gasterosteus aculeatus)*

For the three-spined stickleback there are three different populations possible: fresh-water populations, living only in fresh water; brackish-water population, living in salt or brackish water; and the anadromous population, migrating between fresh and salt water. The migratory fish can grow up to 11 cm while the freshwater fish does not exceed 5 cm. The fact that there is more food available in marine environments explains the difference in size (Kemper, 2000). The short-living species is mature after one year and will migrate upstream from February till May, spawning takes place from April until August. The downstream migration starts in July. The temperature during migration is between 1,5 and 11,5 degrees (Hartgers et al., 2001). Stickleback partly uses Selective Tidal Stream Transport (Bult & Dekker, 2007). In general the swimming capacity of this species differs (Tudorache et al., 2007), with a sprint capacity between 0,2 and 0,9 m/s. Information about their acclimatization between fresh-salt transitions is lacking.

Target species fyke net sampling

The target species for the fyke net sampling are the above mentioned diadromous species flounder, eel, smelt and stickleback as well as the diadromous species houting, river lamprey, salmon, sea lamprey, sea trout and twait shad and the five freshwater species mentioned below.

Atlantic salmon (*Salmo salar*)

Salmon was once known to be extinct but with a reintroduction program from 1990 numbers are now stabilizing again (Wiegerinck et al., 2009). The life cycle of anadromous salmon starts upstream in the upper reaches of rivers, where the eggs are deposited in fast-flowing rivers and streams gravel. After a growth phase, mostly from one to three years young salmon (15-20 cm, so-called ' smolts ') travel to the sea. They live up to several years at sea. Then the adult salmon, particularly during the summer and autumn (June to November) takes a journey back to their birth river in order to spawn (Hertog, 2006). The temperature during migration is between 2 and 23 degrees. Salmon has a sprint capacity of 2,1 to 8,6 m/s. They are known to migrate during the day (Kennedy et al., 2013) as well as during the night (Potter, 1988). The migratory behaviour of salmon is driven by various stimuli (Hansen et al., 1993) but a clear statement on their way of orientation is missing. Barriers like dams can hold salmon back from migrating and they are known to wait in front of a barrier for a chance to pass (Russel et al., 1998). There is no clear evidence that acclimatization between fresh-salt transitions is of great importance (Potter, 1988). The importance of the migration between fresh and salt water for salmon population is great. Salmon situate itself in the upstream parts of the Rhine river area and it is crucial that they can go up the River to the spawning grounds. In order to reach the Rhine upstream areas, there can be three different possible routes that fish can undertake: via the Afsluitdijk and the IJssel, via the Haringvliet or via the Nieuwe waterweg. The latter is currently the only available route to the upstream part of the Rhine.

North Sea houting (*Coregonus oxyrinchus*)

Houting is an anadromous fish that became extinct in the first half of the twentieth century when looking at the spawning population in the Dutch rivers. Houting is an endemic species of the Wadden Sea and travel up the rivers to spawn. The roe of the freshwater houting is released into the water where eggs stick to gravel and vegetation (Poulsen et al., 2012). When fish cannot reach the upper parts of the river, for example, when facing barriers, they are forced to the more downstream parts of the river to spawn. The larvae come out in February to March of the egg and are not bigger than 10 mm in length (Borcherding et al., 2006). Time spend in the fresh water for the young houtings can vary, but they always pull out to the sea (Borcherding et al., 2008). In the past, houting became extinct because of the closing of the Zuiderzee, pollution, overfishing and the disappearance of spawning grounds (de Groot, 2002). It is well known that estuarine and coastal areas are important for the growth of the young fish to adult stages, but there is still a knowledge gap of to what extent it is important. Vakalalabure (1866) mentions that the houting during the autumn and the beginning of winter occurred in very widely in “de Zeeuwse stromen”, most of the Dutch rivers and the Zuiderzee (Hertog, 2006). In the remaining time of the year was the whitefish in ' more or less ' large number of along the Dutch coast. Houtings from 1987 to 1992, represented by small remains of the population were spotted in the Danish River Vidå, just off the Danish Wadden Sea area (Ejbye-Ernst & Nielsen, 1997). Moreover, houtings were massively turned off since the beginning of the nineties in the Rhine and the Lippe at theirs tributaries (Kranenbarg et al., 2002). The IJsselmeer is now an important habitat for the successfully introduced houting (Borcherding et al., 2008). Throughout the year, houtings of different age classes were found there, which could be a good indication of the population well-being. Research with Nedap-transponders shows that a substantial proportion of the adult population within IJsselmeer travels up the IJssel during the spawning period from November to December and returns to the IJsselmeer after the spawning (Borcherding et al., 2008). Only a very small part travels beyond the IJssel and pulls up to the German part of the Rhine river basin or the adjacent tidal rivers. The importance of the migration between fresh and salt water for houting is great, however some of the fish do not seem to migrate between the Wadden Sea and the IJsselmeer (Winter et al., 2008). The analyses of the ortholits showed that a part of the population from the IJsselmeer, use it as a foraging area and is not being attracted towards the sea (Winter et al., 2008). However, for houting remains important, that it can travel up the river to the spawning grounds. Also the river IJssel and its creek mouths seem to be important and possibly regarded as spawning areas for the fish (Borcherding et al., 2008). The sprint capacity of this species is between 1,5 to 2,9 m/s. Temperature during migration is between 2 and 10 degrees. Regarding migration behaviour, orientation ability and acclimatization ability information is lacking (Winter et al., 2013).

River lamprey (Lampetra fluviatilis)

European river lamprey is an anadromous fish species. After years in the Sea the species is swimming stream upwards to the mating grounds in autumn and the early spring, at temperatures between 1,6 and 6 degrees (Winter et al., 2014). Migration is happening primarily during the night (Kemp et al., 2011; Keefer et al., 2013). The species dies after mating. With a length of approximately 15 cm, the juveniles are migrating by parasitism on other fishes into the sea, until they are fully grown (30-40 cm). The migration between fresh-salt transitions is of high importance for this species (Winter et al., 2014). It is indicated that the river lamprey is not stable in hydraulically complex situations, but that they can make use of their mouth during the passaging of a barrier and tend to migrate close to the bottom and walls (Kemp et al., 2011). The sprint capacity of this species is between 0,7 and 1 m/s, and it seems like the species has a low passage success rate at barriers with velocities of 1,5 m/s or higher (Kemp et al., 2011). Information about the importance of acclimatization between fsh-salt transitions is lacking (Winter et al., 2014).

Sea lamprey (*Petromyzon marinus*)

Sea lamprey is a parasitic lamprey closely related to the European river lamprey and can reach a maximum length of 120 centimetres. The larval stage lasts 6 to 8 years and takes place in slurry riverbeds. At the end of this stage a length of approximately 15 centimetres is reached. In the larval stage the sea lamprey is very sensitive to poor water quality. The next phase takes place in the ocean as a parasitic life form, living on the blood of the host, this usually lasts three years. The period of migration towards sea is unknown. After the three years at sea the fish can reach a length of 60 – 80 cm. The migration of adults upstream takes place at night from March until June, after spawning the adult fish die. No spawning sites in the Netherlands are known for sea lamprey (Hartgers et al., 2001). Migration possibilities between fresh and salt water are of high importance for this species. The sprint capacity of adult sea lamprey is known between 1,2 to 2,9 m/s. The importance of fresh-salt transitions and the acclimatization ability of this species are unknown (Winter et al., 2014).

Sea trout/Brown trout (*Salmo trutta*)

Sea trout is a member of the salmonidae family which exhibits homing behaviour to reach their birth-river for spawning. Spawning starts at the end of autumn, the females are the first to arrive in November. It prefers well-oxygenated upland waters and large streams in mountainous areas. After one to five years in the fresh water, the sea trout starts migrating, at night from April until June, towards sea. The migration is triggered by day length, water temperature and velocity of the streams. After at least one winter in the ocean at sea, usually no more than a few hundred kilometres from the estuary of the birth river, adult trout will migrate towards the fresh waters from May until January. In the Netherlands trout usually migrates upstream in June/July and October. The length of an adult trout depends on the number of winters they spend at sea, 30-40 cm, 50-60 cm, 60-70 cm and 70-80 cm, after respectively one to 4 winters at sea (Vaat & Breukelaar, 2001). Migration possibilities between fresh and salt water are of high importance for this species but migration behaviour differs. Sea trout is migrating during the day and the night (De Vaat, 2003), at temperatures between 2 to 22 degrees. The sprint capacity is known between 2,0 and 8,1 m/s. The osmoregulation of sea trout is regulated hormonally (Lebel & Leloup, 1992), but information about a time frame in which the species is adapting to fresh water, as well as the role of fresh-salt transitions, is lacking.

Twait shad (*Alosa fallax*)

Twait shad is an anadromous species. Migration between fresh-salt transitions is of high importance for this species. The species migrates in April and May, primarily during the day (Aprahamian et al., 2003). After mating the adults are migrating back into the sea whereas the larva are driven stream downwards and are migrating into the sea from July until November, at water temperatures between 19 and 9 degrees (Winter et al., 2014). The sprint capacity of the twait shad is between 1,9 and 5,7 m/s. Migratory behaviour of this twait shad is unknown, but acclimatization between fresh-salt transitions seems to be of high importance for this species (Winter et al., 2014).

Source pictures: Griffioen (2014)

Freshwater target species

Common roach (*Rutilus rutilus*)

Common roach is a freshwater species. Roach is a shoaling fish and is not very migratory with the exception of the anadromous subspecies. In the cold season they migrate to deep waters where they form large and dense shoals (small inland harbours are a favourite) (Froese et al., 2006). The spawning season is in April and May. Most often spawning occurs on sunny days. Roach generally spawns at the same location each year. Large males form schools that females enter. Males trail the female and fertilize the eggs. When the pH of the water is below 5,5, roach cannot reproduce successfully (Froese et al., 2006).

Source picture: Agrino (2014)

Ruffe (*Gymnocephalus cernua*)

Ruffe is a freshwater species. The species has the capacity to reproduce at an extremely high rate. It usually matures in two to three years, but the population that lives in warmer waters has the ability to reproduce in the first year of life. A single female has the potential to lay 130.000 to 200.000 eggs annually. Ruffe will leave the deep dark water where they prefer and journey to warmer shallow water for spawning. The primary spawning season for the fish occurs from the middle of April through approximately June (Gangl, 1998).

Source picture: Farnham Angling Society (2014)

European perch (*Perca fluviatilis*)

Perch is a freswater species and spawns (in the Northern hemisphere) at the end of April or beginning of May, depositing the eggs upon water plants, or the branches of trees or shrubs that have become immersed in the water. Perch does not come into condition again until July. The eggs have been known to stick to the legs of wading birds and then transferred to other waters where the birds visit (Freyhof & Kottelat, 2008).

Source picture: Aquascope (2014)

Common bream (*Abramis brama*)

Bream is a freshwater species and spawns from April to June, when water temperatures are around 17 °C. At this time, males form territories in which the females lay 100.000 to 300.000 eggs on water plants. Bream generally lives in rivers (especially in the lower reaches) and in nutrient-rich lakes and ponds with muddy bottoms and plenty of algae. It can also be found in brackish sea waters (Freyhof & Kottelat, 2008).

Source picture: Farnham Angling Society (2014)

Zander (*Sander lucioperca*)

Zander is a species of freshwater and brackish habitats in western Eurasia. It is closely related to perch. Zander is often called pike-perch as they resemble the pike with their elongated body and head, and the perch with their spiny dorsal fin. Zander originates from larger lakes and rivers in Germany and Eastern Europe, from the Aral Sea to the Elbe. Today, zander can also be found in most of Western Europe and the USA. Zander tends to favour deeper bodies of flowing and still water, and requires a high oxygen content. In recent years, their number has declined in many places due to insufficient natural reproduction. Zander spawns from mid-February to May (Integrated Taxonomic Information System, 2006).

Source picture: SUB Göttingen (2014)

Appendix II Field form lift net sampling

location	
date	
time	
coordinates	
depth	

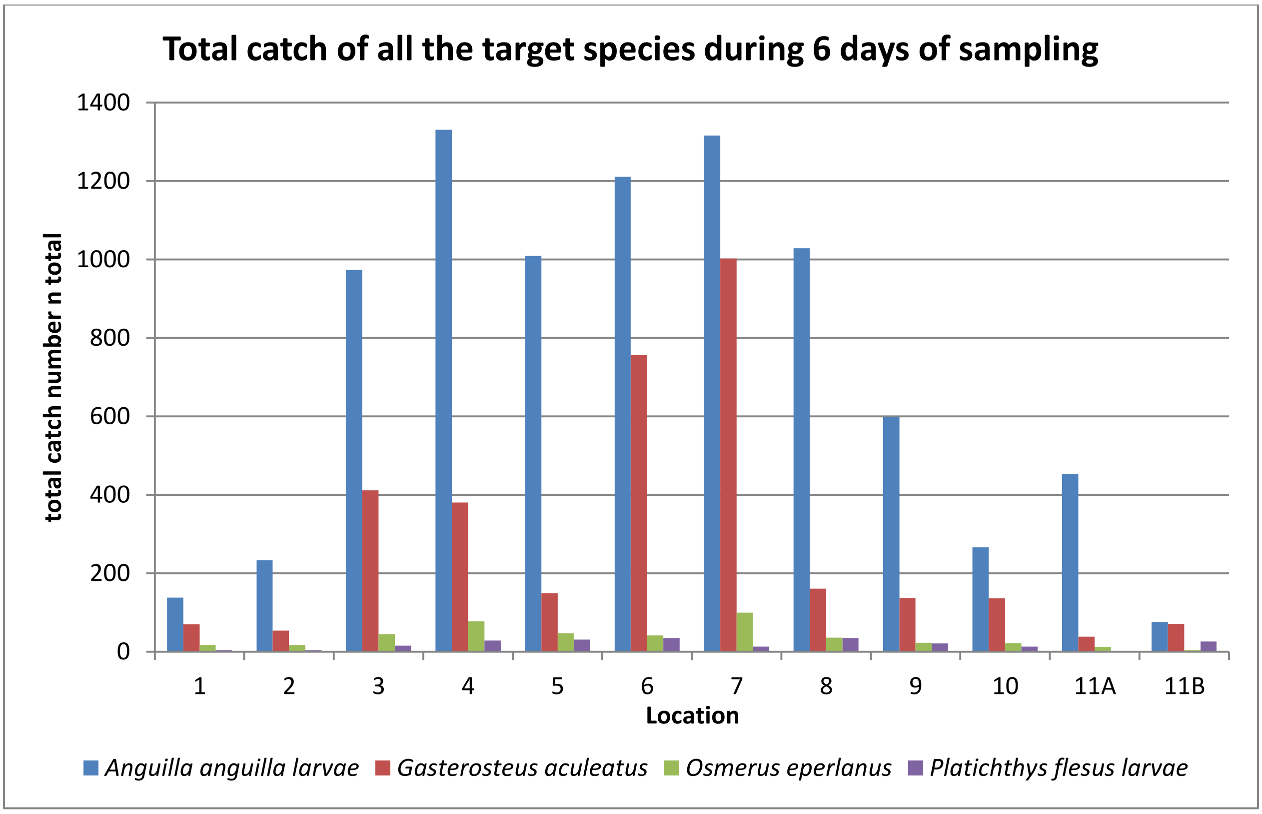
	1x1	1x1	3x3
driedoornige stekelbaars			
glasaal			
spiering			
grondel			
garnalen			
puitaal			
clupeide larve			
platvis larve groot (2-4cm)			
platvis larve klein			
pos			
grote zeenaald			
kwallen			
glasgrondel			
rivierprik			
botervis			
zandspiering			
zeedonderpad			
sprot			
haring			
krabben			
pos			

RUN 1
1 - 2 - 10 - 3 - 4 - 5 - 6 - 7 - 8 - 11B - 9
RUN 2
10 - 3 - 4 - 5 - 6 - 7 - 8 - 11B - 9
RUN 3
10 - 3 - 4 - 5 - 6 - 7 - 8 - 11B - 9 - 2 - 1

RUN 1
1 - 2 - 9 - 11B - 8 - 7 - 6 - 5 - 4 - 3 - 10
RUN 2
9 - 11B - 8 - 7 - 6 - 5 - 4 - 3 - 10
RUN 3
9 - 11B - 8 - 7 - 6 - 5 - 4 - 3 - 10 - 2 - 1

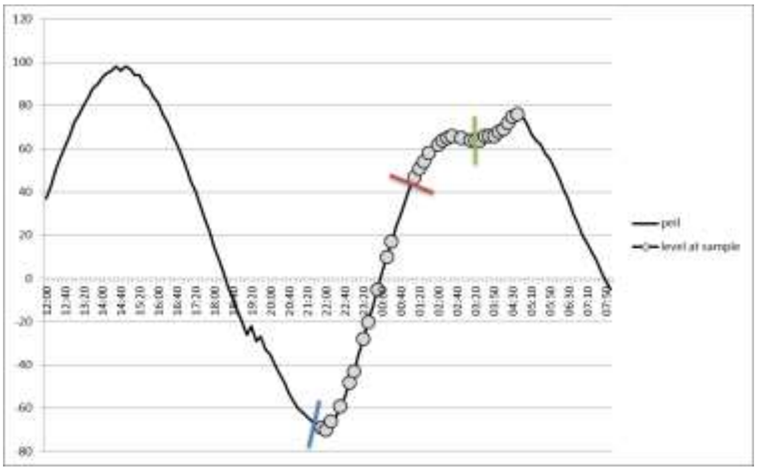
Appendix III Results

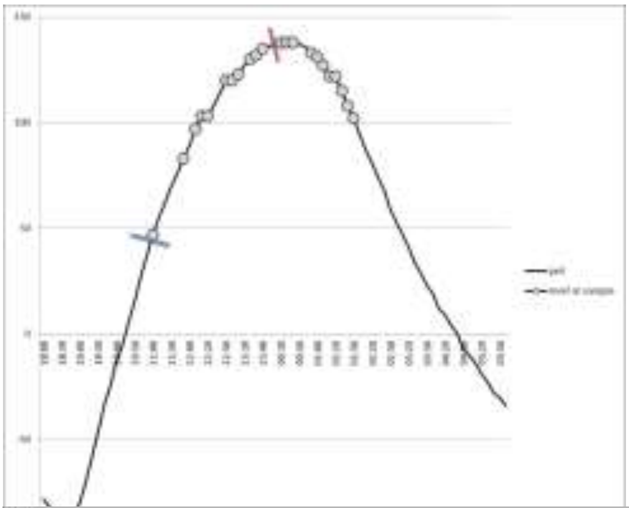
I) Total catch of all the target species during six days of sampling (lift net)

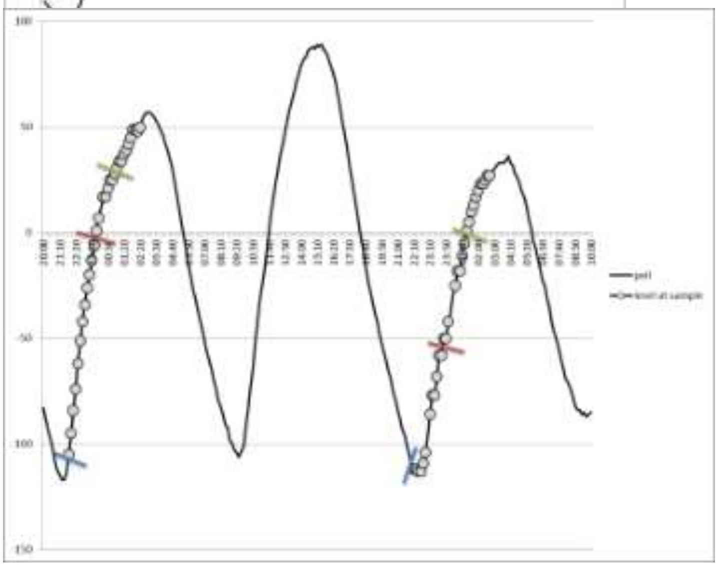


Scientific name	1	2	3	4	5	6	7	8	
Anguilla anguilla larvae	138	233	973	1331	1009	1211	1316	1029	5
Gasterosteus aculeatus	70	54	411	380	149	757	1003	161	1
Osmerus eperlanus	17	17	45	77	47	41	99	36	
Platichthys flesus larvae	4	4	15	28	31	35	13	35	
Total	229	308	1444	1816	1236	2044	2431	1261	7

II) Relation to tidal movement (7 April, 17 April and 20&21 May)







III) Number of analysed DIDSON video footages per sampling day and in total

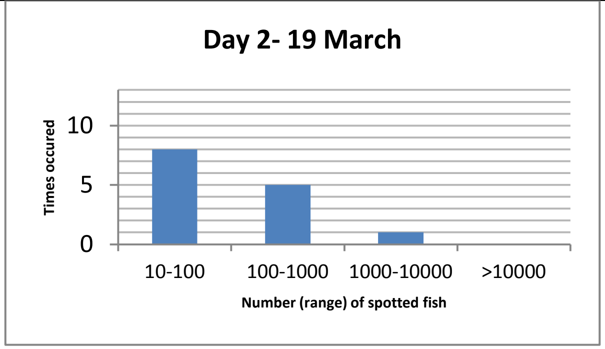
Run	Day 2- 19 March	Day 3- 7 April	Day 4- 17 April	Day 5- 20 May	Day 6-21May	Total
1	7	11	10	11	7	46
2	4	8	5	9	10	36
3	3	10	0	9	9	31
Total day	14	29	15	29	26	113

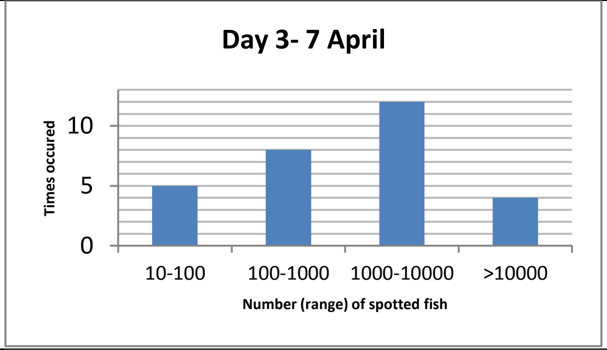
IV) Distribution pattern per sampling day (DIDSON analysis)

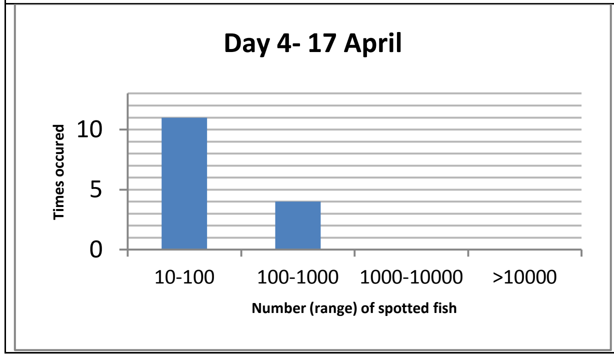
	All days together																			
	Surface				Pelagic				Benthic				Randomly distributed				Combination of orientation			
	Few	Most	All	Other	Few	Most	All	Other	Few	Most	All	Other	Few	Most	All	Other	Few	Most	All	Other
Run	2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5
1	11	5	1	0	10	14	1	0	14	8	1	0	0	0	18	0	0	0	0	4
2	8	2	0	0	9	7	5	0	5	10	0	0	0	0	10	0	0	0	0	5
3	9	4	0	0	11	12	0	0	7	13	0	0	0	0	8	0	0	0	0	6

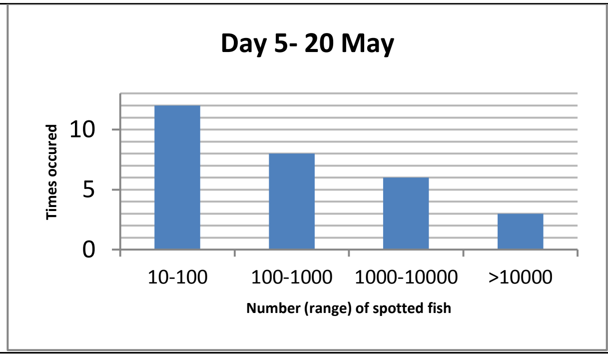
V) Grouping of fish number observed with frequency

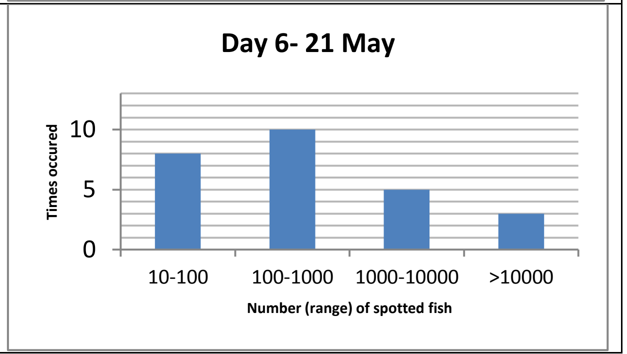
Date	10-100	100-1000	1000-10000	>10000	Number of analyzed footages per day
Day 2- 19 March	8	5	1	0	14
Day 3- 7 April	5	8	12	4	29
Day 4- 17 April	11	4	0	0	15
Day 5- 20 May	12	8	6	3	29
Day 6- 21 May	8	10	5	3	26
Total	**44**	**35**	**24**	**10**	**113**





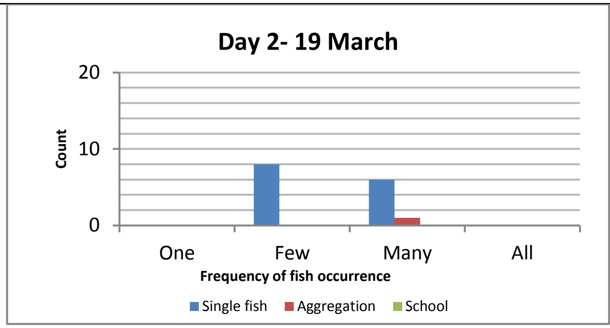


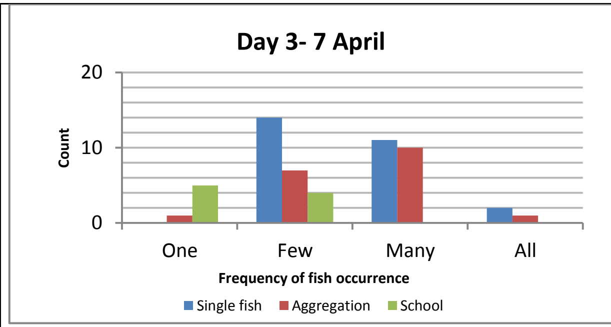


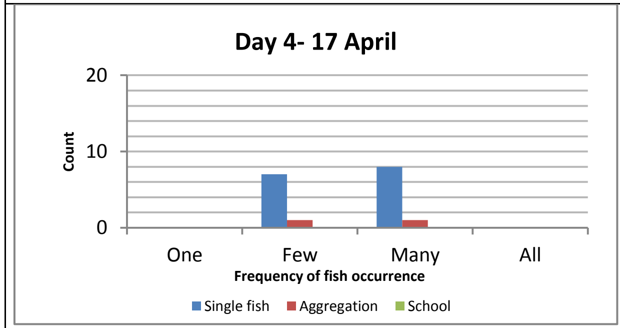


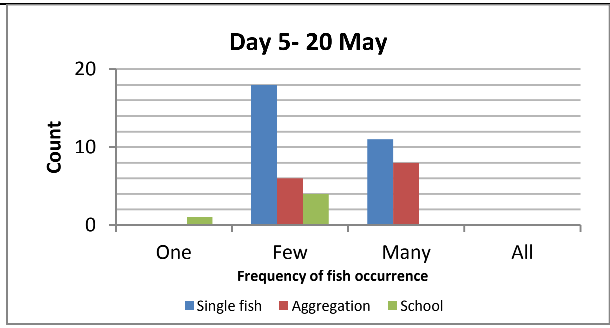
VI) Occurrence of fish with frequency, divided per sampling day and in total

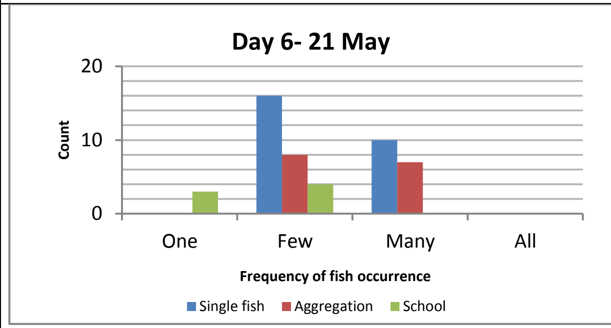
	Single fish				Aggregation				School			
	One	Few	Many	All	One	Few	Many	All	One	Few	Many	All
Date	1	2	3	4	1	2	3	4	1	2	3	4
Day 2- 19 March	0	8	6	0	0	0	1	0	0	0	0	0
Day 3- 7 April	0	14	11	2	1	7	10	1	5	4	0	0
Day 4- 17 April	0	7	8	0	0	1	1	0	0	0	0	0
Day 5- 20 May	0	18	11	0	0	6	8	0	1	4	0	0
Day 6- 21 May	0	16	10	0	0	8	7	0	3	4	0	0
Total	0	63	46	2	1	22	27	1	9	12	0	0









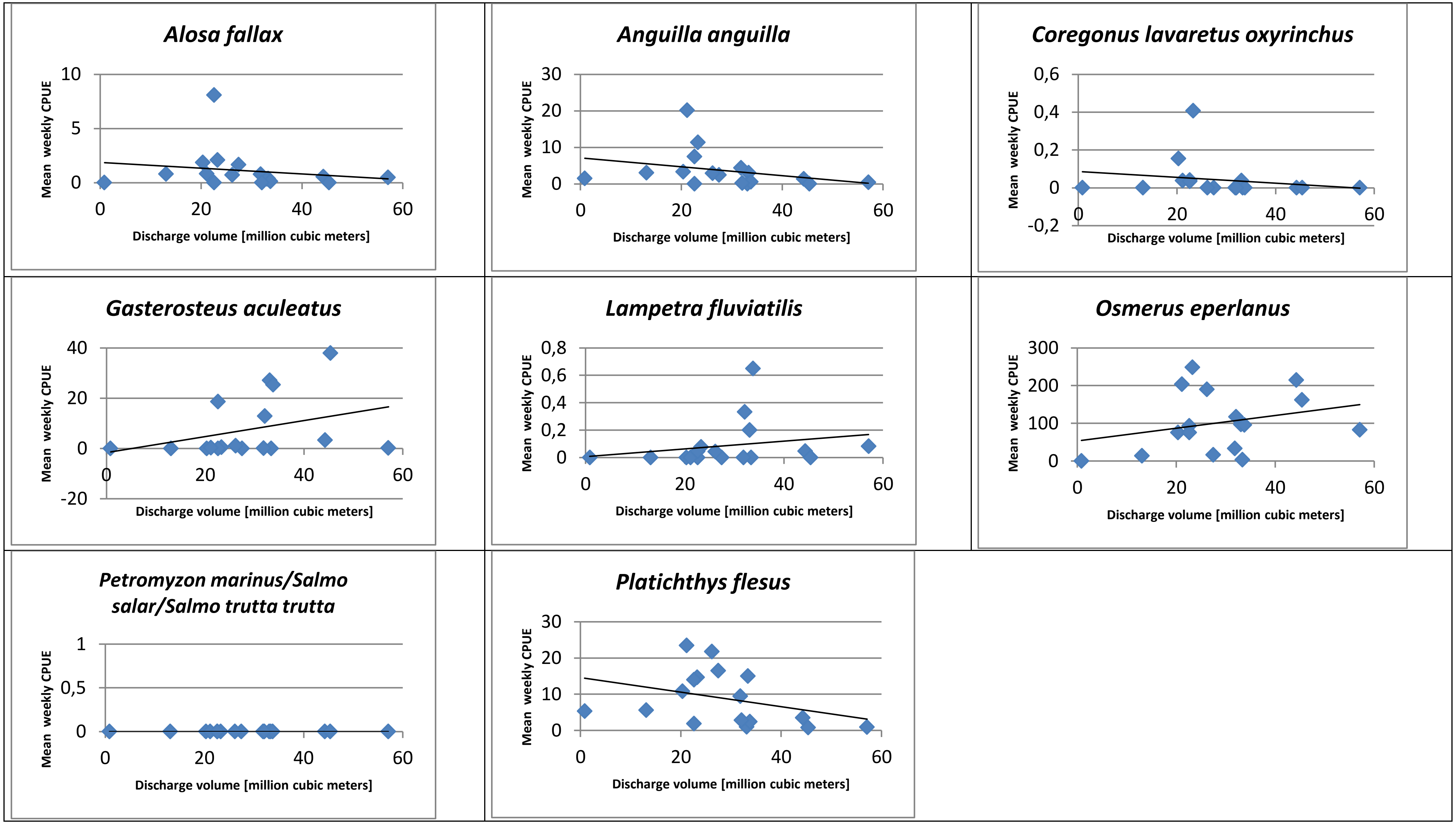


VII) Fyke net catches autumn 2013 in numbers and CPUE per species per fyke and per fyke total

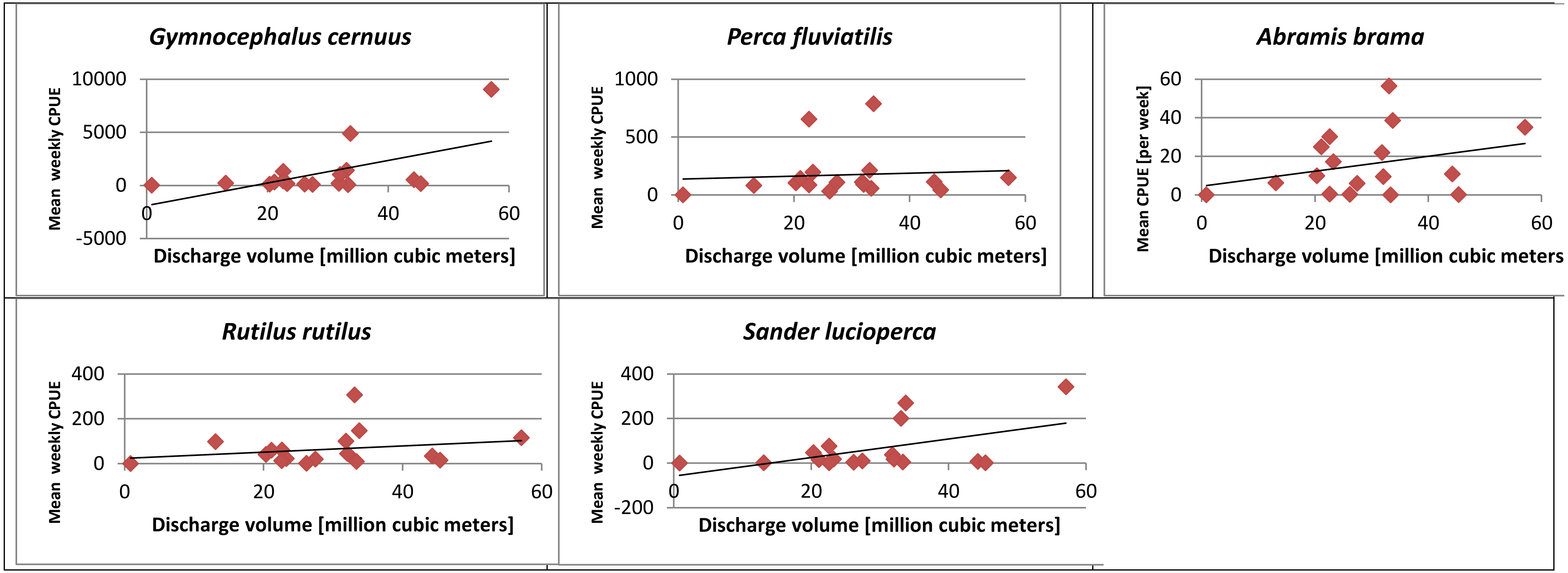
Scientific Name	Fyke 1	Fyke 2	Fyke 3	Fyke 4	Fyke 5	Fyke 6	Fyke 7	Fyke 8	Fyke 9	Fyke 10	Total
Alosa fallax	183	175	128	104	203	72	71	188	208	26	1358
Anguilla anguilla	230	344	552	220	411	399	326	181	281	850	3794
Coregonus lavaretus oxyrinchus	14	9	14	19	37	1	3	0	2	2	101
Gasterosteus aculeatus	2795	1388	414	3049	428	1902	1855	1151	841	311	14134
Lampetra fluviatilis	13	9	34	9	11	7	3	30	55	20	191
Osmerus eperlanus	16908	17221	8724	15146	9161	8712	5150	15240	9694	1150	107106
Petromyzon marinus	0	0	0	0	0	0	0	0	0	0	0
Platichthys flesus	395	1108	1254	1318	2697	183	207	598	931	327	9018
Salmo salar	0	0	0	0	0	0	0	0	0	0	0
Salmo trutta trutta	0	0	0	0	0	0	0	0	0	1	1
Total	20538	20254	11120	19865	12948	11276	7615	17388	12012	2687*	135703

Scientific Name	Fyke 1	Fyke 2	Fyke 3	Fyke 4	Fyke 5	Fyke 6	Fyke 7	Fyke 8	Fyke 9	Fyke 10
Abramis brama	24,3	12,3	48,2	31,0	39,3	0,1	1,2	5,5	4,5	2,1
Alosa fallax	1,0	1,3	0,7	0,2	1,6	0,4	0,4	1,5	2,0	0,0
Anguilla anguilla	0,7	2,0	3,0	1,0	1,8	2,2	2,4	1,5	1,7	10,5
Coregonus lavaretus oxyrinchus	0,0	0,0	0,1	0,1	0,3	0,0	0,0	0,0	0,0	0,0
Gasterosteus aculeatus	21,0	4,5	2,4	5,0	3,3	17,7	15,5	11,3	1,5	2,0
Gymnocephalus cernuus	1861,6	1125,5	940,7	1340,1	1031,5	193,5	423,1	1884,0	1539,2	1714,8
Lampetra fluviatilis	0,0	0,0	0,2	0,0	0,0	0,0	0,0	0,2	0,4	0,1
Osmerus eperlanus	232,2	187,5	80,0	127,7	87,0	79,7	28,9	219,0	151,1	3,2
Perca fluviatilis	175,6	199,3	182,9	144,1	192,0	27,9	45,9	178,9	352,7	201,0
Petromyzon marinus	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Platichthys flesus	3,9	9,6	12,4	7,5	26,7	1,3	2,0	7,9	8,1	3,4
Rutilus rutilus	71,9	53,9	192,1	150,3	182,3	4,6	3,2	18,1	20,5	12,1
*Salmo salar**	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
*Salmo trutta trutta**	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Sander lucioperca	96,6	44,7	64,4	92,5	144,4	14,8	43,4	91,2	132,2	63,7
TOTAL	165,9	109,4	101,8	126,6	114,0	22,8*	37,7	161,3	147,6	134,2

VIII) Relation between weekly mean CPUE of 10 diadromous target species and discharge volume in autumn 2013



IX) Relation between weekly mean CPUE of the 5 fresh water target species and discharge volume in autumn 2013

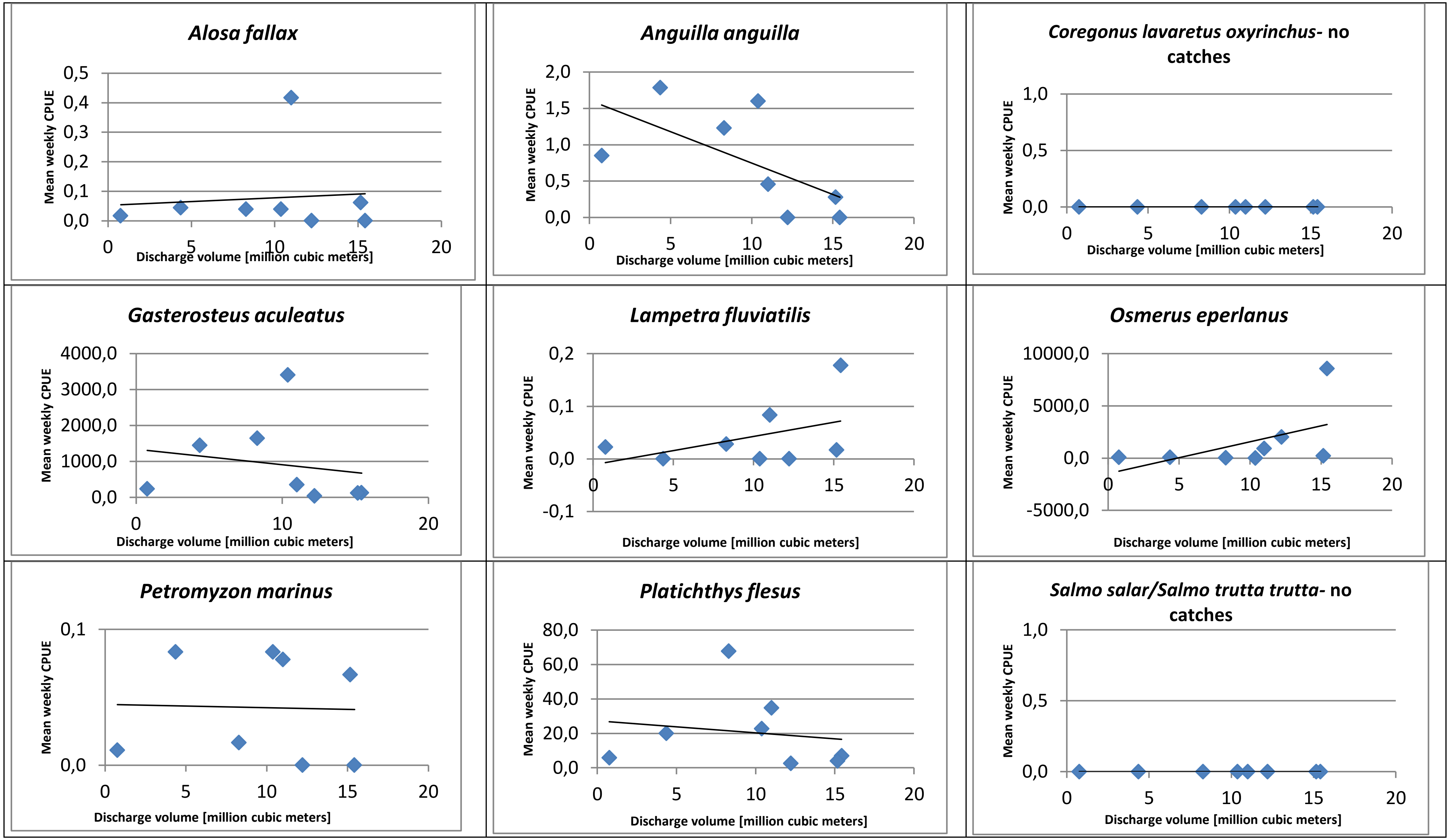


X) Fyke net catches spring 2014 in numbers and mean CPUE per species per fyke and per fyke total

Scientific Name	Fyke 1	Fyke 2	Fyke 3	Fyke 4	Fyke 5	Fyke 6	Fyke 7	Fyke 8	Fyke 9	Fyke 10	Total mean CPUE
Abramis brama	17,9	8,8	12,7	8,1	14,9	0,0	0,3	2,3	12,1	1,3	7,8
Alosa fallax	0,0	0,1	0,0	0,0	0,0	0,1	0,0	0,2	0,4	0,1	0,1
Anguilla anguilla	0,7	0,6	0,3	0,5	0,7	1,2	1,4	0,6	1,0	1,3	0,8
Coregonus lavaretus oxyrinchus	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Gasterosteus aculeatus	1518,5	2856,0	2602,4	140,7	814,8	189,8	185,8	312,7	1373,6	24,4	1001,9
Gymnocephalus cernuus	4553,5	2944,4	2899,0	2859,6	3978,6	56,6	20,4	266,3	420,1	718,5	1871,7
Lampetra fluviatilis	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,2	0,2	0,0
Osmerus eperlanus	952,8	931,5	3780,9	1938,4	3546,8	50,2	25,2	1202,4	1793,4	137,8	1435,9
Perca fluviatilis	2,3	3,0	1,2	2,5	14,9	0,2	0,1	7,4	6,3	8,8	4,7
Petromyzon marinus	0,0	0,0	0,0	0,0	0,3	0,0	0,0	0,0	0,0	0,0	0,0
Platichthys flesus	12,8	5,1	4,3	8,1	11,4	2,7	2,7	41,3	125,3	8,2	22,2
Rutilus rutilus	64,2	27,1	26,2	65,7	55,2	0,1	0,0	25,5	19,0	18,6	30,2
*Salmo salar**	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
*Salmo trutta trutta**	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Sander lucioperca	1,8	0,9	1,4	0,8	2,2	0,1	0,1	0,5	0,6	2,1	1,0
Total	475,0	451,8	621,9	335,0	562,7	20,1*	15,7	124,0	250,1	61,4	291,8

Scientific Name/Fyke	1	2	3	4	5	6	7	8	9	10	Total
Alosa fallax	1	3	1	1	0	4	1	8	19	5	43
Anguilla anguilla	33	31	16	28	35	58	76	33	51	68	429
Coregonus lavaretus oxyrinchus	0	0	0	0	0	0	0	0	0	0	0
Gasterosteus aculeatus	70393	135333	125315	6881	37773	9147	9608	14833	65136	1353	475772
Lampetra fluviatilis	1	0	0	3	0	0	0	2	8	8	22
Osmerus eperlanus	45669	49581	171997	86439	160063	2505	1191	54270	82968	6335	661.018
Petromyzon marinus	2	3	2	1	13	0	0	1	1	1	24
Platichthys flesus	648	256	220	410	542	132	130	2205	6376	439	11358
Salmo salar	0	0	0	0	0	0	0	0	0	0	0
Salmo trutta trutta	0	0	0	0	0	0	0	0	0	0	0
Total	116747	185207	297.551	93763	198426	11846	11006	71352	154559	8209*	1148666

XI) Relation between weekly mean CPUE of 10 diadromous target species and discharge volume in spring 2014



XII) Relation between weekly mean CPUE of 5 fresh water target species and discharge volume in spring 2014