Opening of the Haringvliet, a stream of possibilities

Comprehensive plan Delta21: Consequences and benefits of reintroducing tide and saltwater in the Haringvliet for nature restoration.

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Delta21 - opening the sluices of the Haringvliet is part of their project proposal concerning the realisation of Delta21. Members are: Huub Lavooij and Leen Berke.

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Executive summary

The project proposed by Delta21 aims to cover three aspects: energy transition, flood risk management and nature restoration. Our focus is on nature restoration. For almost 50 years now the Haringvliet has been closed off from the North Sea by the Haringvlietdam in the southwestern Delta of the Netherlands. For all these years the migration routes of species like European eel, Atlantic herring and Atlantic salmon have been blocked by this structure. By slightly opening the sluices, an attempt is made to help the restoration of these species. We offer an alternative solution for fish migration that keeps the freshwater provision sites in the Haringvliet safe from salt-intrusion. We discuss the scenario as it is presently managed, when the sluices are opened to create a 80 cm tidal change and when the sluices are managed as a storm surge barrier, including future climate change prospects. The current management will not be able to provide a stable brackish habitat and the other two scenarios do not ensure safe freshwater provisioning. Finally, we make a recommendation of a fish migration river with a brackish habitat that can house lost species like the flat oyster and seagrass. The system prevents that salt water reaches the freshwater supplies and allows migratory fish to safely complete their migration cycle. The fish migration river can be combined with the tidal lake proposed in the plans of the Delta21 project. Implementation of this river within the Delta21 project may result in a sustained clean water supply for farmers and drinking water companies and stimulates restoration of reduced fish stocks that originally inhabited the Haringvliet.

Samenvatting

Het door Delta21 voorgestelde project richt zich op drie aspecten: energietransitie, waterveiligheid en natuurherstel. Het Haringvliet is tegenwoordig al bijna 50 jaar afgesloten van de Noordzee door de Haringvlietdam in de zuidwestelijke Delta van Nederland. Gedurende deze jaren zijn de migratieroutes van soorten als de Europese aal, Atlantische haring en de Atlantische zalm geblokkeerd door het waterwerk. Door het gedeeltelijk openen van de sluizen is een poging gedaan tot het herstel van deze soorten. Wij bieden een alternatieve oplossing voor vismigratie die de locaties van zoetwatervoorziening in het Haringvliet beschermt tegen indringing van zout water. We bediscussiëren het huidige management scenario, het scenario met een sluisopening voor een getijde van 80 cm en het scenario waarin de sluizen worden gebruikt als stormvloedkering onder verwacht toekomstig klimaat. Het huidige management zal niet kunnen zorgen voor een stabiele brakke habitat en de andere twee scenario's waarborgen de zoetwatervoorziening niet. Tot slot doen we een aanbeveling voor de vismigratierivier met hierin een brakke habitat die verdwenen soorten als de platte oester en zeegras kan huisvesten. Het systeem voorkomt dat zout water de zoetwatervoorraden bereikt en zorgt ervoor dat trekvissen hun migratiecyclus veilig kunnen voltooien. De vismigratierivier kan gecombineerd worden met het getijde meer dat is voorgesteld in de plannen van Delta21. Implementatie van deze rivier in het Delta21 project kan resulteren in een duurzame schone watervoorziening voor boeren en drinkwaterbedrijven en stimuleert herstel van afgenomen visbestanden die oorspronkelijk in het Haringvliet leefden.

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1. Introduction

Efficient protection from flooding of rivers, the sea and lakes is an important and ongoing task in the Netherlands. The current coastal protection will not suffice in the future due to the changing environmental factors caused by climate change, including the rising sea levels, increased variability in rainfall and temperature. The Dutch government would like to expand its current flood risk management and has multiple requirements for this future approach, including water safety; availability of freshwater supply and a spatial design of the Dutch landscape that is climate-change resilient (Ministry of Infrastructure and Water Management et al., 2020). Several plans and projects have been proposed to include these requirements in a future approach in areas throughout the country.

Within the Delta-Programme of 2020 it is stated that the Ministry of Infrastructure and Water Management, the Ministry of Agriculture, Nature and Food Quality and the Ministry of the Interior and Kingdom Relations are striving to reach a climate-resilient, safe, ecologically resilient and economically vital South-Western Delta. Effective measures are needed in order to achieve such a delta and this demands exploration of alternatives for the long run that are aimed towards safety, freshwater availability, nature conservation/restoration and economy. In the next 5 years research is needed to find possible kinks and effects of continuation of the current preferential strategy (Ministry of Infrastructure and Water Management et al., 2020). Our commissioner is Delta21, which is one of the proposed projects for the South-Western Delta. They would like to propose their project to the government as the most ideal and “typical Dutch” solution. Their plan - designed to deal with this environmental issue - combines flood risk management, energy transition and nature restoration.

Delta21 proposes to use sections in the northern part of this area in a productive way to mitigate concerns in these three major fields, by creating an artificial lake for energy storage, or an energy storage basin (Figure 1). For flood risk management the plan aims to pump away excess water from behind the dykes, which is a cheaper alternative with less impact on the unique river landscape than reinforcing the dykes. Secondly, the large pump capacity of the artificial lake can store large amounts of energy. To illustrate: it can generate about 1860 MW of energy during 12 hours (Berke & Lavooij, 2019, 2020). Since most of the energy in the Netherlands should be won by renewable energy sources and the CO2-production should be down by 49% according to the National Climate Agreement by 2030 (Rijksoverheid, 2019), Delta21 would like to execute their project as soon as possible in order to contribute to this goal. Lastly, integration of the Delta21 concept with the Haringvliet insists on a permanent opening of the sluices. This would allow the return of salt water and tides in the estuary, creating a brackish habitat that enables fish to migrate land-inwards. This in turn would help populations of Atlantic herring (*Clupea harengus*), European eel (*Anguilla anguilla*) and European sturgeon (*Acipenser sturio*) among others to recover in the delta, but might have negative consequences on freshwater supplies and/or quality in the Haringvliet.

Figure 1: concept-art of the lake that will be created by the Delta21 project at the Haringvliet (Berke & Lavooij, 2019).

The area surrounding the Haringvliet is used by multiple stakeholders and the main parties are sectors involved with nature conservation, agriculture or potable water. A clear opposition in interest is characterised by groups wanting to introduce tidal flow and salt water to solve the undesirable state in the Haringvliet (based upon nature values/restoration) on the one hand and groups wanting to protect freshwater availability on the other hand. The agriculture sector and drinking water companies depend on a safe freshwater supply and are challenged by saltwater intrusion. Nature groups participate in the debate regarding the opening of the sluices as well since the wildlife and flora in the area will be affected and are generally in favour of compensating the loss of Natura2000 areas by boosting an estuarine ecosystem in the Haringvliet area. For some parties, such as WWF, it is desirable to realise this by opening the Haringvliet sluices and introducing tidal flow and salt water into the Haringvliet, since it is expected that this will promote biodiversity and resilience related to brackish ecosystems. However, there is not necessarily consensus within the discipline of ecology. Advisory group Borm & Huijgens for instance has its reservations about the beneficial effect of opening the Haringvliet sluice on a potential estuarine ecosystem.

The Ministry of Infrastructure and Water Management and the Ministry of Economic Affairs decide which project will be realized for the South-Western Delta and have a final say in the timeframe. The different needs and preferences for the area in combination with a knowledge gap surrounding the consequences of salinization on freshwater supplies and on the ecology of the Haringvliet hampers the finalization of any solution to the above-listed situation.

2. Integrative project purpose and research questions

We present a plan to create a healthy and stable brackish habitat within the Haringvliet estuary, where nature can be partly restored to its historic conditions, with an open connection to the North Sea that allows migratory fish to spawn land-inwards and return to the sea without obstacles. In addition, freshwater supply is maintained, mainly for agriculture and potable water. This plan is accompanied by three states of the Haringvliet that have been discussed in recent years. These include the current state of the front delta of the Haringvliet and two other possible scenarios where the sluices are partially opened (80% open) or completely opened (subjected to future climate prospects), resulting in different levels of salinization. We have taken a look at possible solutions and by using this information, this proposal with an alternative for brackish habitat restoration was constructed. This alternative was investigated the most as we saw a larger possibility in its realization than for the other three scenarios that have been around for a longer time already. The most important consequences for the main stakeholders (mainly those who are directly exposed to the changes and consequences of a permanently opened Haringvliet sluice opening) were taken into account.

In order to address the aforementioned knowledge gap, we will answer the following main research question:

What are possible solutions for creating a for migratory fish functional and stable brackish habitat within the Haringvliet, without impairing freshwater provisioning in the delta?

Sub questions supporting the main research question are as follows:

1) What are requirements for successful fish migration?
2) Which specific conditions are required in an alternative design in the Haringvliet?
    - What are requirements for a for migratory fish functional habitat?
    - What are requirements for creating a stable brackish habitat?
    - What are requirements for maintaining a safe freshwater supply?
3) What could be an alternative design for permanently opening 100% or part of the Haringvliet sluices in order to provide stable brackish water habitat while safeguarding fish migration and the desired freshwater supply?
4) What could be the profit for ecological functions for the adjacent river banks and the nearby region on the North Sea side of the sluice?
5) What could be the consequences of this design for salinization during periods of low river flows or very high river flows in the Haringvliet area?

3. Requirements for fish migration

Fish migration is a natural and globally occurring phenomenon which is influenced by many abiotic and biotic factors alike. Although fish species have unique qualities and needs when it comes to migration, several conditions are in general necessary in order for fish to pass certain barriers. For this study we focused on the fish movement between fresh and saltwater. Whether a fish passes a barrier depends on two main factors: is the fish physically able to pass this particular barrier, and is the fish willing to do so (Winter et al., 2020)? The physical ability of the fish to pass depends on the water conditions and current and therefore on the fish's stamina, swimming speed and swimming power. The willingness of the fish to pass depends on the attractiveness and the instinctive need to pass. Here we discuss several necessities for fish to migrate or simply pass barriers they encounter during migration.

3.1 To migrate or not to migrate?

There are multiple reasons that may drive a fish to migrate to a different area like food availability, reproduction possibilities and safe nursery habitats for larvae or juveniles. Some fish species need to move from a saltwater habitat to a freshwater habitat, or the other way around, in order to find a partner or because those conditions are necessary for the spawning (Crisp, 1996). However, the process is often costly due to the metabolic demand, increased risk of pathogen transmission, exposure to changing abiotic conditions and encounters with new predators (Alerstam et al., 2003). The benefits of migration therefore need to compensate for the costs. Migration requires genetic cues regarding timing and duration of the movement, physical adaptations in metabolism, behavioral adaptations for responding to fluctuating abiotic conditions such as currents and temperature during the journey, and lastly control of navigation and orientation (Berthold, 2001; Metcalfe et al., 1990; Pawloswki et al., 2000). Fish are able to navigate and orientate through environmental cues, like currents, salinity and stream odors or by picking up electro-magnetic cues (Northcote, 1984).

3.1.1 Behaviour of a fish - Does it want to pass?

If a fish faces a barrier it faces a dilemma: is it worth crossing this barrier and how much is it willing to risk? Some fish species depend on migration for food availability, safety or reproduction and might be willing to risk more than fish that inhabit the area (Jonsson, 1991; Northcote, 1984). A fish can either pass the barrier, turn around or wait for better circumstances. Attractiveness of the passing or migration influences this choice. The attractiveness is determined by: the difficulty, accessibility and alluring qualities of the passing that help the fish to locate the destination and by the internal need or urgency to pass (Winter et al., 2014).

3.1.2 Attractive and alluring qualities of a passing/barrier

Most diadromous fish use different cues to find migration routes in transition areas. Smell is used to orient themselves in transition areas from salt and freshwater. We will discuss two main olfactory cues: fish pheromones and the smell of organic compounds.

3.1.2.1 Fragrances (pheromones)

Many fish species use and focus on pheromones, excreted or secreted by other fish or juveniles in order to navigate (Winter et al., 2014). These chemical stimuli might indicate where spawning, nursery or feeding grounds are located, and are typically used by teleost fish (bony fish) like herring. Additionally jawless fish like the river lamprey (*Lampetra fluviatilis*) are also known to make use of pheromones during migration (Moser et al., 2015).

3.1.2.2 Fragrances (smell of freshwater/organic compounds)

Another factor that diadromous fish use for finding their migration routes to transitional or spawning areas is the use of smell of various (organic) compounds that are carried along by freshwater in rivers (Williams, et al., 2012; Winter et al., 2014). Studies show that many fish species primarily use their sense of smell to migrate to their spawning grounds. It is even suggested that many fish can smell their spawning grounds in order to find their way. Two examples of fish species that use this method to find their spawning grounds are salmonids and glass eels. The latter are thought to be able to smell organic compounds transported from the river much earlier than salt/freshwater gradients (Dittman & Quin, 1996; Winter et al., 2014). This means that olfactory cues help the eels navigate in the right direction long before salt/freshwater gradients can be detected (Winter et al., 2014).

3.1.3 Salt/freshwater gradient

A gradual transition from saltwater to freshwater is crucial for fish to migrate between the two habitat types. When rivers and seas meet, a natural gradient of fresh to saltwater including an area consisting of brackish water is formed (McLusky & Elliot, 2007). As previously stated, this gradient and the freshwater compounds it contains are used by fish to navigate and orientate. Additionally, the salinity gradient is crucial for the fish to adjust to the new environmental/physical conditions (Winter et al., 2014). Most fish cannot handle an immediate change from salt- to freshwater, since the change in water salinity requires alterations in the fish's osmoregulation. Osmoregulation is the regulation of the amount of water and electrolytes in the body. In saltwater, fish need to excrete salt from their body while maintaining water, whereas in freshwater this is the other way around (Laverty & Skadhauge, 2012).

3.1.4 Predation risk

Another factor influencing the attractiveness of a migration route is the predation risk. If a route is considered dangerous, fish might be less tempted to choose this path. Small passings lead to an increased density of fish. Some predator species have been found to be able to recognize and locate these 'prey hotspots', resulting in an increased predation risk for migrating fish (Dekker & Van Willigen, 1998, 2000; Lennox et al., 2019). Predatory fish, marine mammals and piscivorous birds are as a result often found in the surrounding areas of structures like fish ladders, dams, sluices and hydroelectric power stations (Agostinho et al., 2012). Some predator species can be avoided by swimming in a deeper water layer. However, other predator species including many piscivorous birds like cormorants (*Phalacrocorax carbo*) and great crested grebes (*Podiceps cristatus*), are able to dive to great depths for their prey. Therefore, a passage is considered more attractive when there is a less big barrier or no barrier at all.

Another factor influencing the predation risk is the water visibility. Some predator species can be avoided with quick manoeuvres, where great visibility is required, but other prey species rely on bad visibility in order to hide from predator species (Agostinho et al., 2012). Many fish therefore have been found to move in the dark hours of the day (Furey et al., 2016; Jonsson, 1991). Water turbulence, turbidity and (artificial) light therefore play a role in the predation risk and should be considered when analysing the predation risk of a passage.

The ability to hide and find shelter reduces the predation risk in an area, increasing the safety and thus attractiveness of a passage (Steele, 19999). Many naturally occurring organisms or structures could provide shelter for aquatic organisms, such as shellfish reefs (Schwartzbach et al., 2020), gravel and rock (Valdimarsson & Metcalfe, 1997) and macrophytes (Kotterba et al., 2017). Fish can use such structures and organisms to rest or hide from predator species, increasing their survival rates (Hylkema et al., 2020).

3.1.5 Anthropogenic disruptive factors

Other factors influencing the attractiveness of an area are anthropogenic disturbances. Some of which have been found to alter or even disrupt fish migration; reduce the chances of survival and reproduction in aquatic animals (Fay, 2009; Fay & Popper, 2000); cause temporary threshold shifts and change hormonal levels in some fish species (Radford et al., 2016). These disturbances include artificial lighting, electromagnetic fields, sound and polluting substrates in the environment (Neo et al., 2015; Shafiei Sabet et al., 2016; Winter et al., 2014).

Artificial light has been found to reduce the movement and speed of several fish species (Northcote, 1962). It can also directly affect fish behavior, as some fish species are attracted to light sources in dark conditions (Keefer et al., 2013), or show more hiding and lying down behavior (Jonsson, 1991). Changes in the local geomagnetic field can influence spatial patterns in fish, since geomagnetic fields play an important role in navigation and orientation of several fish species. Man made electronic constructions can interfere with the internal compass of fish. For instance, electromagnetic fields surrounding power cables have been found to cause delay during migration of silver eels (Öhman et al. 2007).

In addition to light and magnetic fields, sound can also be a disruptive factor and has been found to affect both the physiology and behavior of animals (Slabbekoorn et al., 2010). Some population assessment studies using catch rates for commercial fish stocks, reported an effect of vessel noise on the flight behaviour of fish (Slabbekoorn et al. 2010). Furthermore, there are some indications that pumping stations and hydropower plants can deter fish, as has been found by monitoring the behaviour of silver eels around the IJmuiden pumping station (van Keeken et al. 2010).

Lastly, man-made constructions can form migration barriers. Migratory fish such as eel, salmon, trout (*Salmo trutta trutta*), river lamprey and sea lamprey (*Petromyzon marinus*), are strongly influenced during upstream migration by barriers like dams, sluices and hydroelectric power plants (Jansen et al., 2007). When a barrier is present individuals remain at this barrier for a longer time than it would take them to swim into a river without a barrier (Baumgartner, 2006). This in turn can increase the predation risk, as mentioned before. In the downstream direction, the accumulation effect at barriers is smaller and duration of search behaviour is much shorter (Jansen et al., 2007).

3.2 Physical conditions - Is it able to pass?

3.2.1 Physical restrictions of the passageway

The ability of a fish to pass a certain barrier depends on the structural conditions of the passage and the physical constraints of the fish. Factors that influence the passability are the size, flow conditions, and the water quality of the passageway (Knapp et al. 2019). Timing of migration can play a major role in some of these factors, as the tides can alter the strength of the current and high water levels may form a larger entrance in situations where the entrance may otherwise be too shallow (Dodson, 1988). If the waterflow going through the entrance is uniform and has no obstacles or structures to break the current, then fish have no other choice but to swim through the passage in one go. This means that they will not be able to take a short rest behind an object (Knapp et al. 2019). Consequently, uniform flow forms an obstacle, only allowing fish that are able to swim against such a current for a sufficient amount of time to exit the passageway.

3.2.2 Physical restrictions of the fish

The ability for fish to “sprint” against the current is strongly dependent on the temperature of the water. For short bursts of swimming the white muscles use stored glycogen in an anaerobic biochemical process. With temperature increases of 10 degrees Celsius the maximum swimming speed of the fish during a short sprint doubles (Videler & Wardle 1991). Fish are therefore usually able to swim faster in short bursts during warmer periods like the summer and are thus depending on the timing of migration to increase their own capability to pass a barrier. This demonstrates the importance of physical constraints of the fish itself, as weak swimmers have a lower chance of successful passage when faced with a strong current. Since the maximum swimming speed of a fish is usually dependent on its size, where smaller fish generally are slower than larger fish, it is important to look at the requirements of the weakest species for migration. In the case that these weak swimmers are able to successfully overcome the current, so will the stronger swimmers.

Small fish can be affected in their swimming speed by the intensity of turbulence in the waterflow. Turbulence may destabilise small fish, causing them to lose against the current and cost them more energy to cross. A way for small swimmers to help them combat such a situation is using objects in the stream to rest behind in order to regain energy. This causes the fish to be able to anticipate the flow so that they only have to deliver high swimming speeds for short periods in between resting periods (Knapp et al. 2019). In order to mitigate their weak swimming performance, some fish make use of selective tidal stream transport (STST). These species, such as European eels, can distinguish between low-tide and high-tide. They use this in order to find their way but also to make it easier for them to enter an estuary. As juveniles they start entering the estuary during high-tide in order to be ‘drifting’ on the stream into the estuary (Verhelst et al., 2018).

3.2.3 Physical restrictions due to fisheries

Lastly, fisheries can form a significant physical barrier to migrating species. Commercial fisheries, as well as sport fishing, can result in additional fish mortality through catch and by-catch. As such, it is a hampering factor for migration success and population development. How great the impact is, depends on the fishing gear that is used, the fishing timing and effort, the after-catch handling, and the survival of the discarded fish (Brevé, 2007; Winter et al., 2020). Migrating fish are especially vulnerable to the influence of fisheries, due to the accumulation effect when encountering migration barriers or other narrow passages, as described before (Winter et al., 2014)

The impact of passive fishing gear such as fish traps is highly dependent on the activity of the fish itself as it has to actively swim into the gear (Griffioen & Winter, 2017). The catching probability is therefore determined by the abundance of fish in a particular location as well as its activity (Jansen et al., 2007). In the Netherlands there are strict regulations for catching fish. The catch of salmon and sea trout has been banned since 2000. For migratory fish species such as houting (*Coregonus oxyrinchus*), river lamprey, sea lamprey and twait shad (*Alosa fallax*) a regulation applies which states that they have to be released. In practice this is not always the case as migratory fish can still be caught unintentionally. Although they have to be released again, a portion of the bycatch fish will not survive (Winter et al., 2020).

4. Required conditions for an alternative design in the Haringvliet

Now that we have taken a look at fish migration and its important aspects, we can take a better look at what we require for our alternative. These aspects will fall underneath three different main subjects; requirements for creating a stable brackish water habitat, requirements for creating a habitat suitable for fish migration and requirements for freshwater provisioning. Due to similarities and overlap between a stable brackish habitat and fish migration we have grouped these subjects together under a larger ecology chapter. In this chapter we use the European eel and the hering as our target species. It is also important to mention that one of the main requirements for an alternative design is that there has to be a permanently open part in the haringvliet that allows for fish migration but doesn’t impact the freshwater provisioning in the Haringvliet.

4.1 Stable brackish habitat and fish migration

4.1.1 Navigational cues

In order for fish to find the destination of their migration multiple cues can be of help. Eels for example, use flow rate and flow orientation from water currents and the smell from compounds in river discharge to find their way (Dittman & Quin, 1996; Winter et al., 2014; Piper et al., 2012). For many fish, like herring and lamprey, pheromones are used to find the location of other individuals of their species upstream (Moser et al., 2015; Winter et al., 2014). These cues are thus of great importance for migrating fish and have to be detectable in order to ensure that migration takes place.

4.1.2 Possible barriers

Light from buoys, streetlights, construction lights or cars can illuminate area’s that fish have to pass through. This can disrupt the migration pattern of the European eel, which only travels in the dark (Bruijs & Durif, 2009; Klein Breteler et al., 2006). Studies have even shown that too much light on juveniles can reduce their survival and embryonic development, further lowering their survival and success in completing their lifecycle (Politis et al., 2014). Ideally we want to reduce artificial light as much as possible in order to stimulate the return of the European eel. Another issue is sound from structures or traffic that can scare away fish with sensitive hearing. Our key species the herring is very sensitive to sounds, and uses sound to provide itself with information about direction and range during migration (Blaxter et al., 1981). Sound pollution may cause these fish to miss the sounds that they need in order to find their destination during migration, or may cause them to swim the wrong way by mistaking the artificial sounds for natural occurring cues. We want to reduce the effect of artificial sounds on the migration as much as possible so that optimal herring migration is achieved.

4.1.3 Waterflow

Depending on the species that will inhabit or pass through the area, certain water flow conditions must be met. Species that migrate upstream have to be strong enough to swim against the current in order to reach their destination. There are two species that have to do this as juveniles in the Netherlands; the Atlantic herring and the European eel. Since juveniles of these species are the weakest swimmers that need to travel upstream we will derive the maximum flow velocity needed from their swimming speed. For juvenile Atlantic herring a maximum swimming speed of 0.5 m/s can be achieved, and for the European eel an average speed of 0.072 m/s (Brevé, 2007; McCleave, 1980; Turnpenny & Williams, 1982). Thus we ideally want to achieve a flow velocity of maximum 0.072 m/s. This current will allow these weak swimmers to reach their destination upstream.

4.1.4 Oxygen availability

In order to assess what minimum oxygen availability should be in the habitat, we look at different migratory fish that may appear in a dutch brackish water habitat and their requirements. Prominent candidates are Atlantic herring, European eel, European sturgeon and the Atlantic salmon (*Salmo salar*). Of these species the European eel is the most vulnerable to low oxygen levels. Due to eels having a bottom-bound lifestyle, they are also more susceptible to stratification. If the water column would not mix properly then the eel, who spends most of its time on the oxygen depraved bottom, will be the first to be affected (van Ginneken et al., 2005). In order for the eel to forage optimally, the oxygen concentration in the water should be at least 5 mg/l (van Ginneken et al., 2005).

4.1.5 Salt/freshwater gradient

For a stable brackish habitat to form it is important that the saltwater and freshwater mix. This mixing occurs when a certain velocity is reached. To ensure that this velocity is met there should be a sufficient tidal change. Otherwise the saltwater and freshwater will just form layers on top of each other with the saltwater on the bottom and the freshwater on top. This is because saltwater is heavier than freshwater (NOAA, n.d.).

4.1.6 Predation risk

To prevent large accumulations of fish that can be preyed upon by for example birds due to bottlenecks, our alternative should provide ample shelter (like seagrass) to ensure reasonably safe passage for fish. It can be that due to barriers fish can pile up and be picked off by birds and other predators (Winter et al., 2020). Therefore, it is important to take shelter into account. There are many naturally occurring organisms or structures that could provide adequate shelter, such as shellfish reefs (Schwartzbach et al., 2020), gravel and rock (Valdimarsson & Metcalfe, 1997) and macrophytes (Kotterba et al., 2017). This ‘natural’ shelter will be created when the ecosystem has had time to develop. However, quickly providing adequate shelter for especially larger fish can be accomplished by deploying artificial structures or ‘fish hotels’. In a short amount of time such artificial structures will be overgrown by naturally occurring organisms like oysters and anemones. Artificial structures can increase the structural complexity of a habitat, which is beneficial since habitat complexity is known to affect the fish species richness and abundances (Gratwicke & Speight, 2005). Several designs have been used and tested worldwide and yielded different outcomes and the availability of small shelters seems to affect the fish community greatly (Hylkema et al., 2020). Besides the characteristics of the structures which are beneficial for the fish community, the production costs and deployment logistics should be taken into account for choosing a proper design as well. For a for migratory fish functional habitat adequate shelter should be provided.

4.1.7 Food availability

For migratory fish that make use of a brackish habitat there has to be plenty of food available. Most of the migratory fish in the Netherlands forage in the brackish delta during migration (de Laak, 2007). For herring this means that there should be an abundance of zooplankton like copepods or water fleas. Young herring themselves and shrimp may fall prey to juvenile salmon that return from the river to the sea. The adult salmons do not feed during their migration land-inwards (van Emmerik, 2016). The same can be said about eels, who stop foraging when they reach maturity at the age of 5 to 18 years old. At this point the adult eels return towards the sea to reproduce. During maturation the eels' diet consists of molluscs, fish, crustaceans, insects and plant material (Bruijs & Durif, 2009; van Ginneken & Maes, 2005). Defining the amount of food that needs to be available is beyond the scope of this project, therefore we deem this need fulfilled when the created ecosystem is considered healthy, since it is assumed that a healthy ecosystem corresponds with a fully functioning food web (Murk, 2017).

4.1.8 Seagrass and shellfish reefs

Seagrass can provide shelter, food, clear water, oxygen and may even house bacteria that emit a smell that makes it easier for fish to find the brackish habitat (Boström & Bonsdorff, 2000; Jackson et al., 2001; Unsworth & Cullen-Unsworth, 2014). Because of these functions we aim to implement seagrass in the brackish habitat. The two seagrass species that originally occur in the Dutch coastal waters are common eelgrass (*Zostera Marina L.*) and dwarf eelgrass (*Zostera Noltii Hornem*) (de Brouwer et al., 2001). These two seagrasses need certain conditions to perform well. Therefore the conditions we pose for our alternative design should adhere to the following;

- The water depth, for common eelgrass and dwarf eelgrass, should be between 5 and 15 m.
- The salinity of the water should be between 18 to 40 ppt/psu for dwarf eelgrass with an optimal range of 30 to 40 ppt/psu (MarLin, n.d.). The values required for common eelgrass have a range between 18 to 40 ppt/psu (MarLin, n.d.).
- Flow velocity should not be higher than 1.5 m/sec for dwarf eelgrass and for common eelgrass not higher than 0.5 m/sec (MarLin, n.d.).
- They prefer substrates of mud, sandy mud, muddy sand and sand (MarLin, n.d.)
- They need reasonably high water clarity (therefore good to combine with shellfish reefs because they filter the water and thus make it less turbid) (MarLin, n.d.)
- The flowering period can be influenced by changes in water, temperature and tidal flows. Furthermore light availability, which is influenced by turbidity, can also play a role in this. Therefore, the less turbidity there is the more light would be available for the growth of seagrasses (MarLin, n.d.).

Next to these requirements, the seagrasses need to be kick started by planting them (van Katwijk, 2003). In order to help with water clarity and sedimentation, it is recommended that seagrasses are placed at locations where oyster reefs are present (Tan et al., 2020). Therefore, we insist on the placement of oyster reefs before seagrass growth is initiated.

As mentioned, shellfish reefs built by mussels and oysters can greatly contribute to a healthy seagrass habitat. They do this by offering shelter to small benthic species, filtering water to increase visibility and light availability, and breaking waves and slowing flow rate by forming big clustered reefs (Dame & Patten, 1981; Harding & Mann, 2001; Piazza et al., 2005; Stunz et al., 2010). Because of these functions we aim to implement shellfish reefs in the brackish habitat. There are three species of shellfish that can create these reefs; the European flat oyster (*Ostrea edulis*), the Pacific oyster (*Crassostrea gigas*) and the blue mussel (*Mytilus edulis*). In order for these species to settle there has to be suitable hard substrate for the spats to attach to. This can be in the form of rocks, wreckage, or bivalve shells. Once a reef is formed, there is no need for creating additional substrate space for new recruitment, as oysters and mussels can use the already settled bivalves as solid substrate to settle on (O'Beirn et al., 2000). Combination of all three species is possible, and have been found before in 2015 in the Dutch North Sea in the voordelta at depths of 2 to 5 m (Christianen et al. 2018). However, the flat oyster can even be found at depths of 80 metres (Helmer et al., 2019). Since we want to stimulate high biodiversity we would like to have all 3 bivalve species in the river, but the one of most interest is the flat oyster.

The flat oyster is now slowly making its comeback in Dutch waters after being gone for half a century and is regarded as a key eco-engineer. One of the main causes of its local extinction was the parasitic algae *Bonamia Ostreae* (Laing et al., 2006). This parasite can cause lethal damage to different shellfish species, but is mostly known for its devastating effect on European flat oysters. Since it is prohibited to place diseased oysters in an existing habitat where the disease does not occur yet, this can pose a threat to our plan of introducing the species in the fish migration river. Luckily, research is being done to the effect of Bonamia on oyster restoration, and development of populations that are resistant and free of Bonamia seems very plausible in the near future (Sas et al., 2020). We expect to be able to use these lineages of flat oysters for the migration river once it has been proven that they are Bonamia free, so there is little to no risk of this disease spreading through the Haringvliet to other shellfish populations.

Other projects that have been reïntroducing flat oysters in Dutch waters have shown to be fruitful and have the potential of creating entire new flat oyster reefs (Christianen et al., 2018). As an example, a bottom culture of flat oysters on cultivation plots in the Grevelingenmeer has been constructed. However, it should be noted that depth is a restricting factor in this system because of the limited mixing and the associated risk of food and oxygen depletion. Therefore, the water movement is an important parameter in shellfish culture. This is especially true for cultivation on the soil, where the supply of food and oxygen, as well as the removal of excess excrement products, are necessary conditions. This applies to cultivation in the water column, although these can also thrive in slow flowing water (Smaal & Wijsman, 2014). These limitations should be taken into account when aiming for successful introduction of shellfish banks in parts of the river.

4.2 Freshwater use in the Haringvliet area

As management decisions for the Haringvliet sluices will impact the hydrological system in the area, it is important to define the requirements necessary for the safeguarding of freshwater. The next section will firstly elaborate on important aspects related to the use and risks related to freshwater. After that, specific requirements for the Haringvliet will be described.

4.2.1 Haringvliet sluice management

In order to indicate the preconditions for freshwater protection around the Haringvliet, it is important to determine the area of influence. This area of influence illustrates the main spatial extent to which management decisions for the operation of the Haringvliet sluices will impact freshwater supply. According to Rijkswaterstaat (1998) this area consists of the estuary at the sea side of the Haringvliet and the following water bodies related to the northern delta basins: Haringvliet, Hollandsch Diep, Biesbosch (in Dordrecht, Sliedrecht and Brabant), Nieuwe Merwede, Amer, Nieuwe Waterweg, Nieuwe Maas, Hollandsche IJssel and the Lek up till the weir at Hagestein. The extraction of surface water in these water bodies for agricultural use is supervised by the water boards Brielse Dijkring, Goeree-Overflakkee, Delfland, Rijnland and Schieland. In the management areas of Brielse Dijk and Goeree-Overflakkee the water is mainly used for irrigation and the flushing of saline seepage. The other water boards manage more urbanized areas containing mostly grassland and greenhouse horticulture. Here, water is used to maintain groundwater levels in the peatlands in order to prevent land subsidence. In addition, when pointing out the area of influence of the sluice management of the Haringvliet, it is important to take into account the role of the sluices in the national management of freshwater flow in the Netherlands. Besides affecting the province of South Holland itself, the sluice is used to steer water flow in the Netherlands in order to prevent salinisation in the provinces of North Holland, Friesland and Groningen when there is a shortage of freshwater (Rijkswaterstaat, 1998). This steering is based on a distribution model that uses the Verdringingsreeks (de Boer & Radersma, 2011). Figure 2 gives an overview of the Rhine-Meuse river mouth in which the Haringvliet sluices are an important steering mechanism (Huismans et al., 2018).

Figure 2: Overview of Rhine-Meuse river mouth

General requirements for current and future sluice management of the Haringvliet aim at maintaining a low salinisation frequency of the Hollandsche IJssel near Gouda and Spui near Bernisse. Besides that, it is desired that no other compensatory measures other than changing the location of the drinking water extraction point of Delta Nuts and some agricultural water extraction points are necessary (Rijkswaterstaat, 1998).

4.2.2 Current water extraction for drinking water

Drinking water company Evides has been extracting water in the area of the Haringvliet since 1930. At first the water extraction took place near Haamstede and from 1935 until 2018 the extraction took place at Ouddorp. The water extraction point near Ouddorp is called Scheelhoek and just like Haamstede provided pre-filtered water from the Haringvliet (Arcadis, 2019). As a precaution for the Kierbesluit, the place of water extraction was changed from Scheelhoek to Haringvliet extraction point 15 kilometers further east (KWR, 2017). When the water is extracted at Haringvliet it is pumped to either Haamstede or Scheelhoek for the extensive filtration process. Evides delivers to 2.5 million customers as well as industry in the province of Zeeland. For the water balance it is important to strive for a continuous extraction of water. This means that restriction or stops of water extraction should be minimized. Salinization of the water has been a cause of short stops in water extraction at Scheelhoek. For the Haringvliet extraction point so far, the only stops that have taken place were due to high turbidity of the water and technical malfunctions. Salinization however, seems to be a concern in the future, especially with regards to future plans of opening the Haringvliet sluices more permanently (Arcadis, 2019).

When estuaries are described there are multiple zones defined and these are classified based on the mg Cl-/l or salinity (ppt). Table 1 shows the zone description in an estuary, the classification of the water type, mg Cl-/l and salinity (ppt). (Wijsman et al., 2018)

Table 1: Description of water types based on salinity

Zone	Mg Cl-/l	Salinity (ppt)	Classification
Freshwater	< 300	< 0.5	Fresh
Oligohaline	300 - 3000	0.5 - 5.4	Slightly brackish
Mesohaline	3000 - 10000	5.4 - 18	Brackish
Polyhaline	10000 - 17000	18 - 30.6	Salt
Euryhaline	> 17000	> 30.6	Salt

The conditions that drinking water needs to adhere to are based on the Dutch drinking water act. Using chloride concentration as a measure of salinity, this drinking water act states a maximum allowed yearly average of 150 mg Cl^- / l (0.27 ppt). A daily average is not stated but drinking water companies like Evides have a boundary of 250 mg Cl^- / l (0.45 ppt) daily. This is based on conditions set by the European union and WHO. The surface water at the extraction points should not exceed the yearly average of 150 mg Cl^- / l (0.27 ppt) as well. This means that the water must remain below a yearly average of 150 mg Cl^- / l (0,27 ppt). The Drinkwaterwet states that the drinking water companies are responsible for the protection of the extraction points (Helpdesk Water, 2019).

4.2.3 Effect of salinization on agriculture

For agriculture, freshwater is of utmost importance. The extraction points in the area are mostly west of the imaginary line placed between Middelharnis and Spui, which is seen as the barrier to where saltwater may intrude when the Kierbesluit was established (Arcadis, 2019; Rijkswaterstaat, 1998). This means that water for agriculture should be extracted from water further eastwards. The target value of chloride content of surface water for agriculture and greenhouse horticulture is 200 mg Cl^- / l (0.36 ppt). This value is included in the integrated water management plan of Zuid-Holland Zuid (Rijkswaterstaat, 1998). That is if the agricultural sector does not grow crops that are tolerable to salt. It has been shown that the threshold values for crops are diverse (Stowa, 2009). Threshold values for different types of crops are given in Table 2 (de Boer & Radersma, 2011).

Table 2: Salinity threshold values for different types of crops.

Crop type	Threshold value for chloride (mg Cl^- / l) / salinty (ppt)
Bulbs Cutflowers	< 200 / <0.36
Greenhouse crops(vegetables) Field vegetables Fruit Arboriculture	400 - 600 / 0.72 - 1.08
Arable crops Potatoes Corn	700 – 800 / 1.26 - 1.4
Grass	3600 / 6.50
Arable cereals Sugar beets	4850 / 8.76
Rapeseed	8700 / 15.72

4.2.4 External salinization

When the Haringvliet sluices are opened, salinization of the freshwater supply can take place. At the moment certain processes of salinization are already an issue without the opening of the Haringvliet sluices. Processes such as salt water intrusions along the coast (Stuyfzand & Louw, 2007), shallow drinking water winning (Stuurman et al., 2006) and influence of ground water levels (Oude Essink, 2007) are examples of such processes. In order to maintain a freshwater supply, focus is placed on what processes influence salinization and thus threaten the freshwater supply in the area. The key term here is external salinization. This is salt water that intrudes through the surface water (Helpdesk Water, 2019), which will be the case when the Haringvliet sluices will be (partially) opened.

With the opening of the Haringvliet sluices the North Sea would again have a direct connection to the river delta. This would make it possible for salt water to intrude into the river. A phenomenon that will likely take place is the formation of a salt wedge. The causes of such a salt wedge can be described as follows (de Boer & Radersma, 2011);

- River discharge: Due to climate change, decreased river discharge occurs more often than before. When river discharge becomes too low salt water may intrude from the North Sea and travel up river as the river no longer delivers enough freshwater to block out the sea.

- Sea level: Combined with low river discharge a high sea level may cause salt water intrusions to occur further up river. This is the case as the sea level now is in line with a part of the river that is further upwards.

- River depth: As salt water sinks below freshwater, deeper rivers may retain and accommodate more salt water. This increases the magnitude of the intrusion.

- Wind direction: If the prevailing wind direction is in line with the river delta, winds may push waves up in the direction of the delta and thus increase the amount of salt water that enters the rivers.

Even without the opening of the Haringvliet sluices, salinization of the Haringvliet could already take place through a process called backwards salinization. This process describes a salt water intrusion through primarily low discharge (1500 m3/s at Lobith) finding its way through the Nieuwe Waterweg, Oude Maas and Spui or Dordtse kil due to low river discharge. The salt water intrusion could then make its way into the Haringvliet. Due to climate change this phenomenon will occur more frequently possibly worsening the effects of potentially opening of the Haringvliet (Arcadis, 2019).

4.2.5 Requirements for safeguarding freshwater in the Haringvliet

One of the conditions we set for our alternative design is that the freshwater situation in the Haringvliet area remains. We therefore pose that our design should adhere to the following freshwater provisioning needs:

- Prevent salinity in the Haringvliet: no salt water is allowed in the Eastern Haringvliet (see figure 5 for imaginary line between Middelharnis and Spui) (Arcadis, 2019).
- The maximum surface water chloride concentration should not exceed the yearly average of 150 mg Cl^- / l (0.27 ppt) as posed by the Dutch drinking water act (Helpdesk water, 2019).
- Salinization of groundwater should be prevented according to the Kaderrichtlijn Water (KRW)/ Grondwaterrichtlijn (GWR).
- A saltwater wedge should be prevented.
- To prevent salinisation at the Nieuwe Waterweg, the Haringvliet sluices must be closed at a river discharge lower than 1,100 m^3/s at Lobith.

If a saltwater wedge forms it is important that it does not reach further than 12 kilometers inland, as that is the line that is put forward by Arcadis (2019) where saltwater is not allowed in the Haringvliet. As previously mentioned the occurrence of a saltwater wedge is dependent on River discharge, Sea level, river depth and wind direction. When providing an alternative situation, the river discharge has the potential to be too low to ensure this 12 kilometers. A way to combat this problem is creating steps in the riverbed as saltwater intrudes via the bottom of the water column (de Boer & Radersma, 2011).

Conceptual models for groundwater flow in the surrounding area of the Haringvliet show the presence of three types of groundwater bodies (figure 3; figure 4). An overview of how they are denoted by Rijkswaterstaat is given in table 3. The groundwater bodies give an indication of groundwater flow in the area. The groundwater body containing saline groundwater can generally be found at a depth ranging from 50 to 5 m, but is subject to spatio-temporal variation. It is important to note that the depth of the interface between fresh and saline groundwater depends on the current sluice management, the amount of underground freshwater storage and flushing of saline water in the hydrological system with freshwater coming from the inland side of the system. Prevention of saline seepage water is most important for protection of freshwater bodies, flow of freshwater from the dunes to the polders and infiltration of precipitation. The latter is important to prevent evaporation of saline water at ground level, which can damage vegetation and crops (KvK, 2009).

Table 3: Overview of groundwater bodies as denoted by Rijkswaterstaat

Groundwater body	Code	Dutch description	English translation
1	NLGW0016	Duin	Dune
2	NLGW0012	Zand met deklaag	Sand with cover layer
3	NLGW0011	Zout	Saline

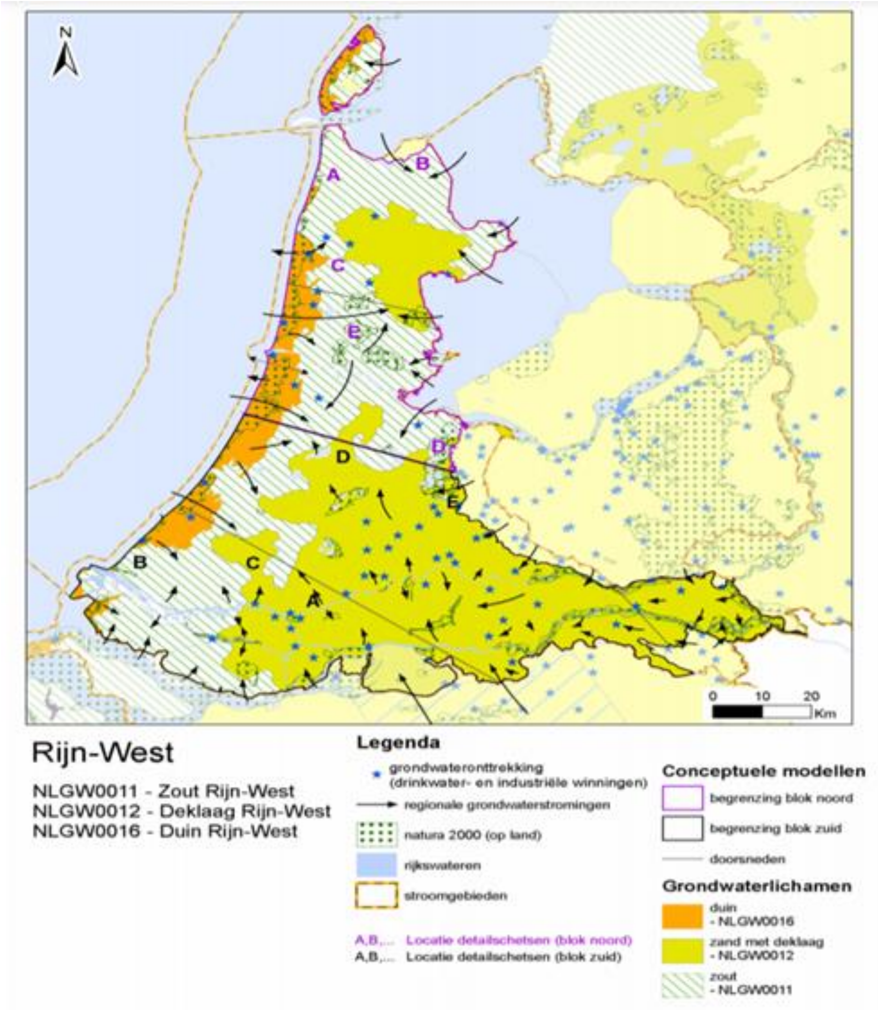

Figure 3: Conceptual model for groundwater flow 1 (Helpdesk Water, 2019)

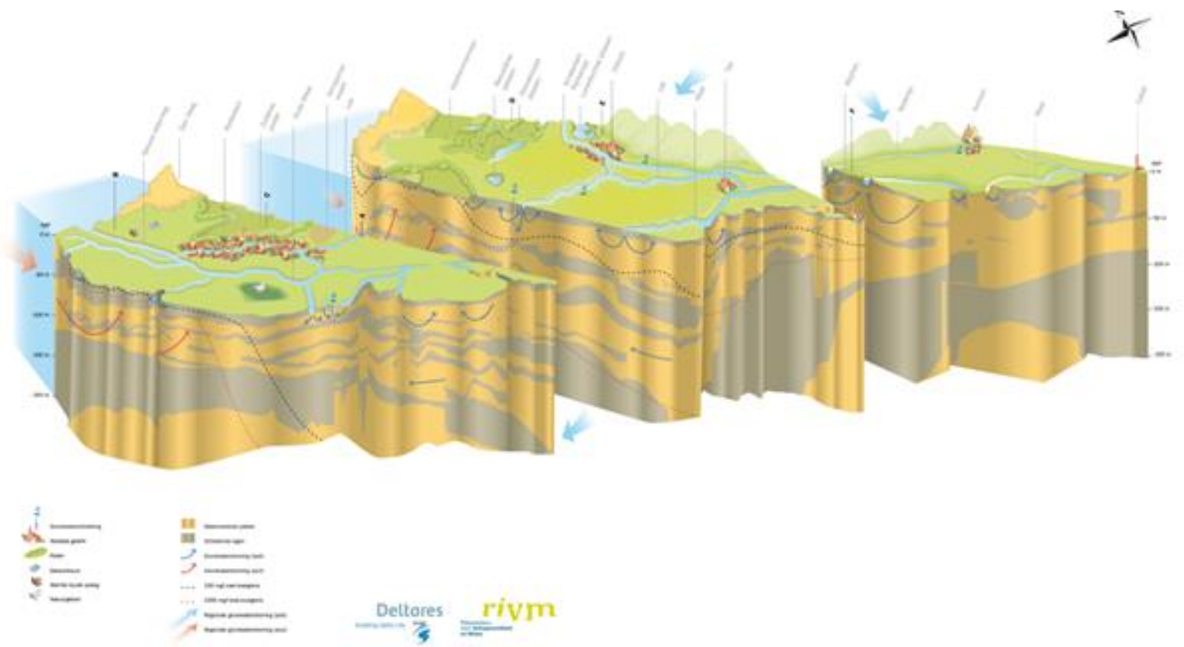

Figure 4: Conceptual model for groundwater flow 2 (Helpdesk Water, 2019)

5. Discussing alternative designs for the Haringvliet area

Currently the Kierbesluit is in place which means that the sluices can open during both high tide and low tide. The extent to which the sluices are opened is however kept at a minimum. This chapter will highlight how the Kierbesluit fits within the prerequisites that we have set. Then, we will discuss two more scenarios, 80 cm tide scenario and complete opening, which have been put forward as promising, to see how they fit within the prerequisites.

5.1 Scenario 1: Kierbesluit Haringvliet (current situation)

5.1.1 General description

Before, the sluices were opened based on the river discharge of the upper-Rhine and the slope of the water level in the Haringvliet. The degree to which the sluices were opened was dependent on the discharge at Lobith. At a discharge of 9,500 m3 the sluices were opened entirely, while at a discharge of 1,100 m3 the sluices were only slightly opened. In practice the sluices were mostly opened during low tide. In the Kierbesluit scenario the sluices are also partially opened during high tide. The aim is to maintain a water level of at least 0 meter +NAP at Moerdijk which is just east of the Haringvliet. The Kierbesluit allows for saltwater intrusion into the western part, meaning west from the line between Middelharnis and Spui (Wijsman et al., 2018).

5.1.2 Ability for fish to migrate

In the current situation fish are able to migrate from and to the Haringvliet when the sluices are opened. However, since the sluices are not constantly opened fish migration is not optimal. This is mostly due to the fact that fish cannot always migrate when they want to due to the non-permanent opening. Even when the sluices are open this does not necessarily mean all fish can migrate, since some species use the incoming tide to swim upstream of the river. If the sluices are not open during the incoming tide some fish will be unable to migrate (Winter et al., 2014). Additionally, there is a salt wedge in the Haringvliet when the sluices are opened. This means that there is barely any mixing between salt and freshwater. As such, saltwater fish barely have any time to acclimatise to freshwater or vice versa and might die trying to migrate (Nolte et al., 2014). Altogether these conditions mean that fish migration is still not optimized in the Haringvliet in its current state.

5.1.3 Ability for brackish habitat to form

As mentioned before, a tidal change is needed in order to form a brackish habitat. In the Kierbesluit scenario the tidal change, the difference between the water level at low and high tide, remains very small at only 30 - 40 cm. Also, the sluices will not always be open at both low and high tide so a flow back and forth between the Haringvliet and the North sea will not be permanent. When this flow will be present there is a chance that the velocity is not high enough to ensure that brackish water will form. The chance for a stable brackish habitat to form during this scenario is therefore low. The flow velocity will be low enough for seagrass to grow in the Haringvliet (MarLin, n.d., n.d.). However, the salinity may be a problem because a minimum of 18 ppt is needed and the influence of the river discharge will be too big to achieve this.

5.1.4 Impact on freshwater provisioning

The saltwater intrusion in the Kierbesluit is relatively low. In the Kierbesluit it has been proposed that the chloride level of the water west of the line between Middelharnis and Spui should not exceed 300 mg Cl-/l (0.54 ppt) at any time (Wijsman et al., 2018). The Kierbesluit takes notice of this number and the sluices will close when there is a potential risk of exceeding this value. Since the threshold value for surface water at the intake point is 150 mg Cl-/l (0.27 ppt) (Arcadis, 2019) there is a possibility that at days when river discharge is low and tide is high that intake should be halted. In Figure 5 the line between Middelharnis and Spui is shown to be the threshold for the 300 mg Cl-/l (0.54 ppt) line.

Figure 5: The line of 300 mg Cl-/l (or 0.54 ppt) is shown to imply to which point the brackish water will reach. West of the line the salinity might be higher, east of the line the salinity should be lower. Figure taken from Wijsman et al., (2018)

5.2 Scenario 2: Sluices management to create a 80 centimeter tidal change

5.2.1 General description

In the Kierbesluit scenario there is a tidal change of approximately 40 cm. This second scenario aims to have a tidal change of 80 cm. This will be achieved by never fully closing the sluices except during a storm. At the lowest discharge the sluices will remain opened to form a gap of 1.75 m. This means that over the whole dam with all the sluices at least 1600 m2 will be opened at any time. When the discharge is high enough the sluices will open more just like the situation Kierbesluit (Wijsman et al., 2018).

5.2.2 Ability for fish to migrate

In this scenario there is a lot more opportunity for fish to migrate. Here, the sluices are constantly opened which in turn makes it able for fish to notice the attraction stream from the estuary. This constantly open situation also helps with creating tidal fluctuation and therefore would likely help with the mixing of salt and freshwater. This will help with the acclimatization of fish when they migrate from salt to freshwater and vice versa and therefore reduce the mortality during migration (Wijsman et al., 2018). It is likely that in this scenario it is still difficult for weak swimmers to migrate since the sluices are further open during high discharge and during low discharge are less far open.

5.2.3 Ability for brackish habitat to form

In this scenario the sluices will be opened even at low discharges albeit only slightly. This means that together with the higher tidal change of approximately 80 cm there is greater potential for saltwater and freshwater to mix (NOAA, n.d.). When this mixing takes place a stable brackish habitat will be created. There is a chance that the flow velocity will be too high for seagrass to grow at times during the tidal changes (MarLin, n.d., n.d.). The salinity in the Haringvliet is not expected to reach a minimum of 18 ppt so the potential for seagrass to grow is low.

5.2.4 Impact on freshwater provisioning

The impact of saltwater intrusion in this scenario is uncertain. It is however certain that even at an average river discharge at high tide the line of 300 mg Cl-/l (0.54 ppt) is east of the surface water intake point (Figure 6) (Wijsman et al., 2018). This has as a consequence that the freshwater intake point has to be moved or efforts have to be made to desalinate the water. At a low river discharge at high tide it is not expected that the water in the Biesbosch would become slightly brackish (>0.5 ppt) (Wijsman et al., 2018).

Figure 6: The line of 300 mg Cl-/l (0.54 ppt) is shown to imply to which point the brackish water will reach. At normal river discharge and high tide ("Normale afvoer, Hoogtij") the purple line is given. At low river discharge and high tide ("Lage afvoer, Hoogtij") the red line is given. The gradient given next to the lines shows the uncertainty in the model. Figure taken from Wijsman et al., (2018)

5.3 Scenario 3: Complete opening of the sluices subject to future climate change prospects

5.3.1 General description

The third scenario is a complete opening of the sluices. In this scenario the Haringvliet sluices will be used as a storm surge barrier similar to the Oosterscheldekering. In this scenario the sluices will remain completely opened all the time. Only when the water level on the seaside reaches 2 m +NAP the sluices will be closed as a safety measure. In this scenario the tidal change is at its maximum and the saltwater intrusion will reach furthest. The tidal change will be more than 1.3 m. Also, the slope will change as the median waterlevel west of the Haringvliet will drop 10 to 20 cm (Wijsman et al., 2018).

5.3.2 Ability for fish to migrate

In this scenario fish migration will be easiest, in comparison to the other scenarios. This is because when the sluices are fully opened there will be a larger tidal fluctuation and this means that weaker swimmers can use the high tide to migrate upstream. Next to this, due to the sluices being completely opened and the flowrate being the highest, it is likely that salt and freshwater will mix well. This will create a brackish zone because the salt water is allowed to intrude, further creating a large area where fish can acclimatize before completely switching to salt or freshwater (Wijsman et al., 2018). Fish migration in this scenario is only limited by natural conditions like lower tides during the summer and during a storm when the sluices are closed. This scenario is likely the best for fish migration in comparison to the Kierbesluit and 80 cm tide scenario. While this scenario greatly improves the fish migration in the Haringvliet, the dam will still have some effect. The structure creates a prey hotspot of fish, as they tend to spend more time under the cover of a structure than in the obstacle free water column. This accumulation of fish increases predation pressure on migrating populations around the sluices, even if they are permanently opened (Baumgartner, 2006).

5.3.3 Ability for brackish habitat to form

In this scenario the sluices are opened fully all the time. With a tidal change of 1.3 m and constant flows going in the direction of the tide, the chance of saltwater and freshwater mixing is highest (NOAA, n.d.). In this scenario the chance of a stable brackish habitat to form is therefore the highest and it will reach furthest eastwards. It is possible that the flow velocities may be too high for seagrass patches to grow in the Haringvliet (MarLin, n.d., n.d.). There is a chance that for a small part in the west of the Haringvliet the salinity can reach at least 18 ppt, however combined with the high flow velocity this will create a scenario where the water may be brackish but there is no stable brackish habitat.

5.3.4 Impact on freshwater provisioning

The impact of complete opening of the sluices on freshwater provisioning will be high, especially when the future climate consequences are taken into account. First the situation when climate change is not taken into account will be discussed. The line of 300 mg Cl-/l (0.54 ppt) at a normal river discharge at high tide will be east of the surface water intake point (Wijsman et al., 2018). It will be close to Willemstad. The line of 300 mg Cl-/l (0.5 ppt) at low river discharge at high tide will be very close to, or even reach the Biesbosch (Figure 7), which means that during the summer months the Biesbosch could see freshwater and saltwater mixing, creating brackish water in the area.

Figure 7: The line of 300 mg Cl-/l (0.54 ppt) is shown to imply to which point the brackish water will reach. At normal river discharge and high tide ("Normale afvoer, Hoogtij") the purple line is given. At low river discharge and high tide ("Lage afvoer, Hoogtij") the red line is given. The gradient given next to the lines shows the uncertainty in the model. Figure taken from Wijsman et al., (2018)

When looking at the future climate change consequences there is much uncertainty. This is because the effects of climate change as well as the model cannot be predicted with 100% certainty. The line at normal discharge and high tide in the worst case scenario, the 300 mg Cl-/l (0.54 ppt), could almost reach the Biesbosch (Figure 8). At a low river discharge and high tide the whole Biesbosch could potentially become brackish (Wijsman et al., 2018).

Figure 8: The line of 300 mg Cl-/l (0.54 ppt) is shown to imply to which point the brackish water will reach. At normal river discharge and high tide ("Normale afvoer, Hoogtij") the purple line is given. At low river discharge and high tide ("Lage afvoer, Hoogtij") the red line is given. The gradient given next to the lines shows the uncertainty in the model. Figure taken from Wijsman et al., (2018)

5.4 Conclusion of three proposed scenarios

In order to determine how the three scenarios would fit to the prerequisites set we created a summarizing table 4. The scenarios were assessed to see if they provided the possibility for migratory fish to reach the barrier and if they could pass it. If there is an opportunity for a brackish habitat to form. And, if there is no disastrous impact on the freshwater provisioning in the area. None of the scenarios seem to sufficiently meet both the criteria for fish migration and the protection of freshwater simultaneously.

Table 4: Short overview of the scenarios and their impact on the ability of fish to migrate, ability to form a brackish habitat and the impact on freshwater provisioning.

	Scenario 1: Kierbesluit	**Scenario 2: 80 cm tidal change.**	**Scenario 3: fully opened**
When are the sluices open, and how far open are they?	Sluices are opened during high tide, but not permanently. How far they are opened is dependent on river discharge. Fully at 9,500 m3, only slightly at 1,100 m3	Sluices are opened at all times except during storms. How far they are opened is dependent on river discharge. At least a gap of 1.75 meters will be there.	Sluices are opened fully at all times, except for during storms.
Ability for fish to migrate	Possible, but limited and difficult for especially weak swimmers	Possible and improved due to the constant opening of the Haringvliet sluices	Possible due to constant opening of the Haringvliet sluices
Ability for a brackish habitat to form	Currently not a lot due to little mixing of salt and freshwater	Possible due to the allowance of saltwater intrusion being allowed further in the Haringvliet	Highly possible due to the sluices alway being completely open and therefore allow the most opportunity for salt and freshwater to mix
Impact on freshwater provisioning	Hardly any impact, saltwater intrusion is well regulated	Uncertain however it is likely that the saltwater intrusion will go past freshwater provisioning stations and thus impact it	Likely has a large impact on freshwater provisioning since saltwater is completely allowed to intrude and therefore would go past intake stations

6. Scenario 4: Alternative design ‘Fish migration river’

From the previous chapter, we concluded that scenarios 1 to 3 do not sufficiently meet all of the criteria for fish migration, a stable brackish habitat and the safeguarding of freshwater provisioning. This chapter will describe the Fish Migration River (FMR), which we propose as a fourth scenario and as an alternative to the Kierbesluit. After describing relevant characteristics of our proposed design, its consequences in terms of ecological profits and salinization during extreme river discharges are discussed in chapter 7 and 8.

6.1 Description fish migration river

Since the completion of the Haringvliet dam in 1970, the North sea has been closed off from the Haringvliet. This had severe consequences for the ecosystem and migratory fish, as they could no longer reach their spawning, nursery and feeding grounds. In 2018 a start was made to restore some of the natural tides and original estuarine characteristics with the Kierbesluit. Dynamics and continuous long and short term changes are the hallmark of an estuary. It is an area with many natural transitions, like varying salt concentrations and channel pattern (Wijsman et al., 2018).

A similar situation occurred in the IJsselmeer, which was closed off from the Wadden Sea by the Afsluitdijk in 1932. The initiatives for restoring the Wadden Sea- IJsselmeer-IJssel-Rhine connection has similarities with the initiatives of the Haringvliet, in that it aims at restoring fish migration. The IJsselmeer is fed by the river IJssel, which forms the upper part of the river Rhine, and the river Vecht flowing from Overijssel. The prevention of salt intrusion is of utmost importance, as the freshwater in the lake is essential for drinking water provision and agriculture. For migratory fish however, the afsluitdijk forms a major unnatural obstacle between the transition from salt to freshwater, which prevents them from reaching their spawning areas. The ‘Fish Migration River Afsluitdijk’ is a unique project with the goal of eliminating the ecological barrier the Afsluitdijk represents. The FMR ensures that migratory fish can enter their spawning, nursery and foraging areas again (Winter et al., 2014). For the realisation of the fish passage a number of requirements has been set: the freshwater supply must be safeguarded, it must be suitable for a wide range of migratory fish and have no significant restrictions on water storage. The Haringvliet faces similar challenges and a lot of time and money has been invested in improving fish migration possibilities in the upstream parts of the Rhine and Maas. Therefore a FMR could be a potential additional approach in restoring the fish migration.

6.2 Location

For the implementation of a FMR in the Haringvliet area, we have chosen the location indicated in figure 9 below. In order to prevent disruption of activities associated with the port near Stellendam, the FMR will be located at the north side of the Haringvlietdam. Traffic on the waters of the Haringvliet will therefore remain to be mainly at the south side of the Haringvliet and the FMR will have a minimal impact on the channel. Likewise, on the north side of the Haringvliet the wind farm and Haringvlietdam will be bypassed. The top view in figure 9&10

shows how the FMR can be included in the Haringvliet without intervening with the Delta21 project.

Figure 9: Map with the marked location of the proposed Fish Migration River in the red circle (Berke & Lavooij, 2019).

Figure 10: Close-up view of the location where the proposed Fish Migration River would enter the Haringvliet within the current design (WindenergieGoereeoverflakkee, n.d.).

6.3 Components

The dimensions, substrate type, heterogeneity in depth and flow conditions and dynamics in salt-fresh gradients determine whether the FMR will act as a suitable habitat for fish species (Winter et al., 2014). Some species could potentially utilize this FMR as a foraging and spawning area, while others will only use it as a passage opportunity. It is a difficult task how the FMR should be modelled in terms of length, width and depth. In the case of the FMR Afsluitdijk, all dimensions have been accurately determined in a feasibility study which looked into population status, migration timing, swimming capacity and passage possibilities for different target species (Winter et al., 2014).

This feasibility study also addresses a number of questions that are relevant in the field of hydrology, morphology, water management, finance and permits among others (Winter et al., 2014). In case of water management and ecology for example, salt concentration and passage efficiency will be important steering parameters in shaping a FMR. Components that could be taken into consideration when shaping a FMR (Figure 11) are for example; a freshwater attraction stream, an outside dyke part, a closable opening, a controlled brackish water environment and so on, taking inspiration from the Wadden sea river design.

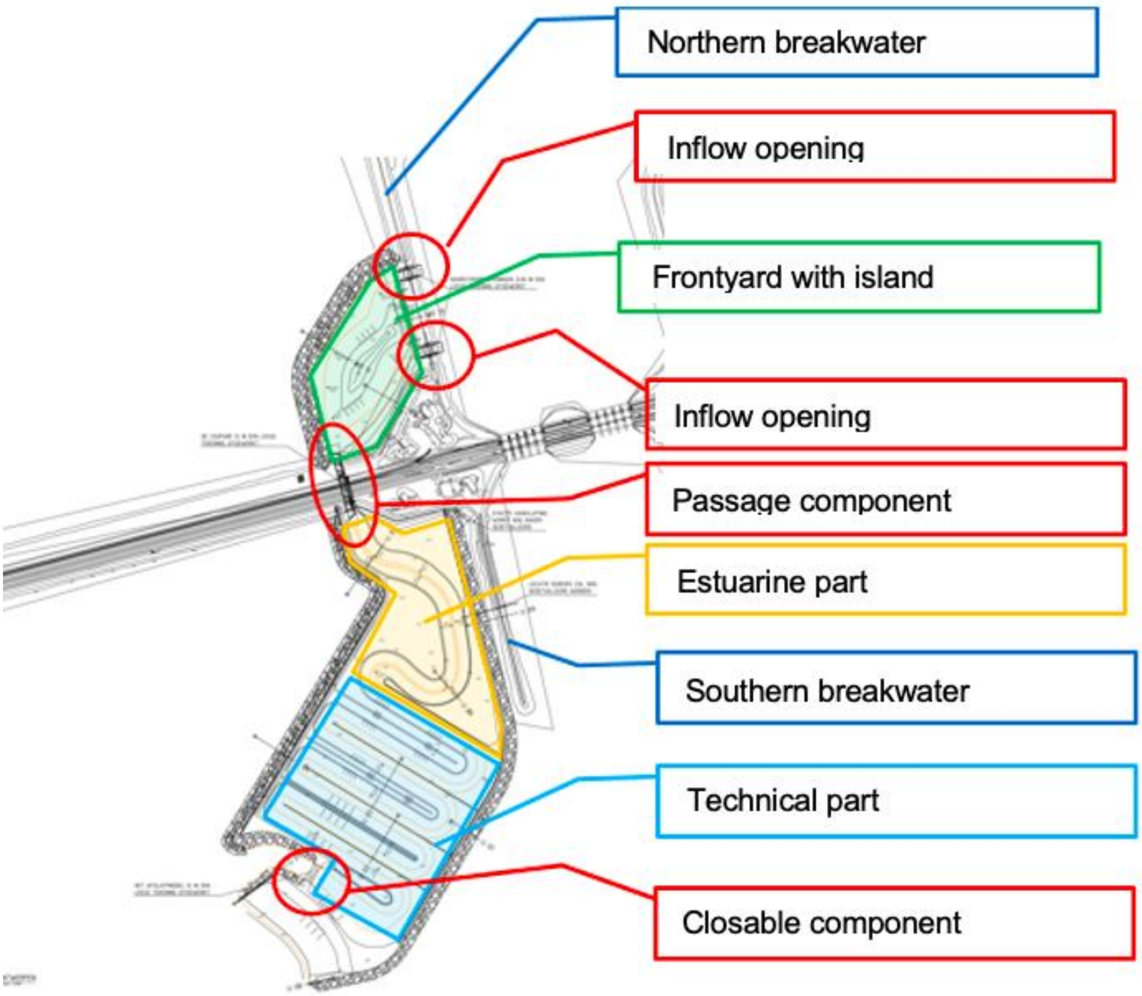

Figure 11: Showing a schematic drawing of the Fish Migration River design at the Afsluitdijk and its main components (adapted from: Planviewer.nl)

6.4 Factors that ensure passage

Fish passages have been established along barriers in flowing waters worldwide, whereby the flow conditions in the fish passage typically remain relatively stable. The ability of a fish to actively swim through these passages is an essential factor to pass successfully. The Kierbesluit deviates from this, since there is a phase of water flowing out to the front delta as well as water flowing in from the front delta. Fish can either hitch a ride on the current to the Haringvliet or they have to actively swim against it (H. V. Winter et al., 2020).

Diadromous fish must also have the opportunity to adapt to the shift from salt to freshwater. This brackish zone should therefore be a region of substantial surface area. It is particularly important to the fish larvae and young fish (PNRW, 2013). In principal, a brackish transition region in the current Rhine-Meuse delta is a rare habitat which can have a beneficial impact on the occurrence of organisms that use these ecosystems to complete (part of) their life cycle (H. V. Winter et al., 2020). The length of the FMR will be largely determined by the set boundary conditions, for example the desired creation of a stable brackish transitional zone with resting places and the limitation of saltwater intrusion in the Haringvliet. Hydrologic modelling will be needed in order to take multiple factors into account. Lastly, when assessing the number of fish that actually manage to enter the Haringvliet, 'total passage efficiency' can be described as the percentage of the number of fish that arrive at the sluice complex and are encouraged to migrate to the Haringvliet (H. V. Winter et al., 2020). Factors influencing the passability will be further discussed in the sections below.

6.4.1 Waterflow

Compared to scenario 1, waterflow will become more beneficial for fish migration in the FMR. Firstly, the FMR is expected to have a high efficiency in the attraction of fish. This expectation is based on the assumption that attraction stream will be the main outflow from the river. Attraction stream is an essential factor in the passage efficiency of the migration of fish, which contributes to migrating fish being able to find the entrance of the FMR (Winter et al., 2014). Consequently, fish will be better able to find their way into the Haringvliet. Secondly, flow velocity is dependent on the difference in water level between the Haringvliet and the North Sea. The meandering of the FMR will decrease flow velocity and therefore make it easier for migrating fish to pass (Nolte et al., 2014). In addition, a longer migration window will occur as the effects of tidal flow direction are dampened. Consequently, the migration of fish through the passage is less dependent on tide. Lastly, a more constant and natural transition from fresh to saline conditions occurs. This is enabled by the elongated transition zone created by the FMR (Winter et al., 2014).

In order to establish the aforementioned benefits, an optimization of the dimensions of the FMR should be made. For instance, by using 3D water flow modelling. In this process, a trade-off will be made because of conflicting demands on the FMR dimensions by the different benefits. To prevent stratification of fresh and saline water in the FMR for instance, depth of the river plays a larger role in the prevention of stratification than width thus a more shallow depth decreases the risk of stratification. However, a more shallow FMR will have higher flow velocities than a deep FMR. In addition, the attraction stream requires a large cross section. (Nolte et al., 2014) Thus a Pareto efficiënt outcome should be looked for in the process of designing the FMR.

6.4.2 Salinity

Most information from the FMR is based on the ongoing project at the Afsluitdijk. Therefore, some insights can be given but precise measurements would require more intricate research which we cannot perform ourselves. Salinity in the FMR seems to be dependent on the cross section of the river (Nolte et al., 2014). A smaller cross section would result in a larger salt intrusion length. This salt intrusion length is important to keep in mind as the length of the river can dictate to where this intrusion would take place, and thus if salt water would reach the Haringvliet. Another aspect that dictates salt intrusion length is the depth of the FMR, with a more shallow river causing less salt intrusion (Nolte et al., 2014). Stratification of salt and freshwater can also become an issue in the FMR as 1D models suggest that mixing will not take place and salt water will not reach the surface. This however is not confirmed by other models and the authors advise to definitely study a 3D model to see if it behaves the same (Nolte et al., 2014).

6.4.3 Oxygen availability

There is very little literature available for the oxygen conditions in the FMR. The report by Winter et al. (2014) insinuates that oxygen conditions can become critical issues during stagnation of the water column when mixing does no longer occur. This can especially be an issue when layering due to salt concentrations, increases in temperature or large amounts of sediments are present within the FMR. The report states that these issues can be overcome by flushing the system during warmer and dryer times.

6.4.4 Predation risk

Although predation is a natural process, the FMR does pose some extra risks for predation. These risks are primarily caused by the size and depth of the FMR as this is a bottleneck for migrating fish. Due to this bottleneck large amounts of fish may accumulate in one place. Therefore, they will be more vulnerable to predation by a variety of predators (Baumgartner, 2006; Dekker & Van Willigen, 1998). The report by Winter et al. (2014) states that it is very hard to assess possible predation in the FMR. For the project at the Afsluitdijk they made an initial assessment of the area by talking to local fishermen. These talks turned out to be fruitful and could therefore also be conducted in the case of the Haringvliet. If migration possibilities within the FMR are enhanced the predation risk can be reduced (Winter et al., 2014).

Another way to mitigate predation risk is the addition of shelter in the FMR. There are multiple types of shelter that work for different fish species. Three types of shelter that show good potential are; reef balls (A), layered cake (B) and piles of basaltic rock (C) (Figure 12). All of these shelter types have shown to result in an increase in abundance of fish, biomass and number of species in comparison to bare sand plots (Hylkema et al., 2020). It has been shown that the abundance of fish is closely related to the amount of sufficiently large shelter spaces that are present in the structures. This means that the layered cake has the potential to attract a large abundance of fish and fish biomass as compared to, for example, the reef balls. The piles of basaltic rocks have shown intermediate numbers in both fish abundance and fish biomass it attracts. The species richness does not seem to depend on the type of structure that is placed. Layered cakes are the most expensive structure to place with €8950,54 per 10 plots as compared to €8189,13 per 10 plots and €2165,45 per 10 plots for reef balls and the piles of basaltic rock respectively (Hylkema et al., 2020).

Figure 12: Three proposed shelter types. (A) reef balls, (B) layered cake, (C) Piles of basaltic rock

6.4.5 Food availability

Although the main function of a FMR is to allow passage, the brackish habitat that can be created within the river allows for a perfect foraging spot. Herring and eel can use this habitat to refuel before traveling up- or downstream, giving them more energy and thus higher chance of reaching their destination (Laak de, 2007). The FMR can be used to provide a feeding ground for passing herring. Small crustaceans like copepods and water fleas form the main food source for juvenile herrings. Abundance of these crustaceans is mostly dependent on light, oxygen availability and presence of algae. Alternatively, cultivation of water fleas is very cheap and they can be produced at high numbers (Pauw et al., 1981). These can be released in the migration river to create a stable population or feed the migrating species temporarily. Juvenile herrings in turn form the food source of other species including young salmon migrating towards the sea (van Emmerik, 2006). Eels may also feed on the herring in the river, but most of their foraging takes place in freshwater bodies (Bruijs, Maarten C.M. & Durif, 2009 ;Klein Breteler et al., 2006). In order to provide our key species with enough food, we should therefore provide a sufficient amount of small crustaceans, or ideal growing conditions for small crustaceans, so that a stable herring stock can be achieved.

6.4.6 Possible barriers

We have identified two possible barriers for the FMR, sound and light. In the current situation a road is going over the Haringvliet sluices which causes sound disturbances because of the traffic and light disturbance from the streetlights. This will not be different in the scenario for the FMR since it passes the Haringvlietdam, but the main part where the brackish habitat will be formed will not be influenced by this as it is at an appropriate distance from the road. A factor of sound disturbance in the current situation is the sluices itself, this will not be a disturbance anymore for the FMR.

6.4.7 Seagrass and shellfish

The main substrate top layer at our proposed location for the FMR is sea clay (Dinoloket, n.d.). However, sea clay is not the most suitable substrate for a functioning FMR. The best substrate would consist of sand and riprap (Figure 13) and therefore we propose this for our FMR (Griffioen & Winter, 2017). The sandy bottom provides the highest potential for the FMR to act as an estuarine system, improving the acclimatization and migration of fish. Because of the riprap, shelter and different flow velocities in the river can be created, enhancing the chance of acclimatization for migratory fish in the FMR. The riprap is a comparable structure to the pile of basaltic rocks that was described in chapter 6.4.4. We aim for healthy seagrass patches to grow in the FMR. Therefore there should be patches where sand is the top layer and no riprap is present. The best places to place these sandy, riprap less, patches have to be determined after more research is done on the flow velocities in the FMR.

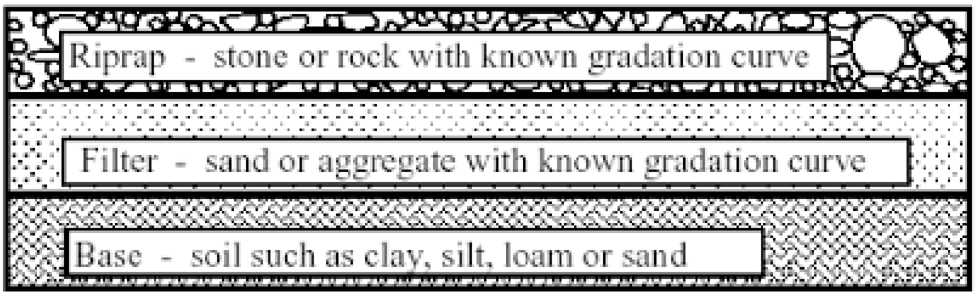

Figure 13: Proposed substrate layers in the fish migration river

When the substrate is up to the required standard, the next step to creating a stable brackish habitat is succession. In the ecological sense, succession is the process that describes the structural change of a biological community over time. Since we are starting from scratch, ecological succession is a key concept that is necessary to achieve a complete and functional brackish habitat. Nutrients will be available in the migration river due to the current welling up the bottom and bringing nutrients along (figure 14: 1). This will stimulate growth of algae in the river (Wieters, 2005). With algae present, a basic form of food is available (figure 14: 2). The algae can be predated on by zooplankton or shellfish (figure 14: 3), these will then form the next step in succession (Mitra & Flynn, 2006; Wieters, 2005). In order for the shellfish to settle however, there needs to be substrate available that they can bind to, this can be in the form of rocks, artificial reefs or other shellfish (figure 14: 4)(Christianen et al., 2018; O'Beirn et al., 2000). As soon as shellfish reefs have formed, turbidity in the river will decrease as the bivalves filter the water (figure 14: 5)(Harding & Mann, 2001; Stunz et al., 2010; Dame et al. 1981; Piazza et al., 2005). This allows sunlight to reach the bottom of the river and makes the third step in succession possible. Now that sunlight is available, resuspension is decreased and algae undergo predation pressure, it is possible for seagrass to grow in patches on the river bottom (figure 14: 6)(Young et al., 2018; MarLin, n.d., n.d.,Davis & Fourqurean, 2001). The seagrass patches form a hiding place, food source, navigational cue and nesting ground for an abundance of different species (figure 14: 7)(Jackson et al., 2001; Bostrom & Bonsdorff, 2000; Unsworth, 2014). At this point a stable brackish habitat has been formed that provides food, foraging grounds, hiding places, and passage for key species that can migrate through the FMR.

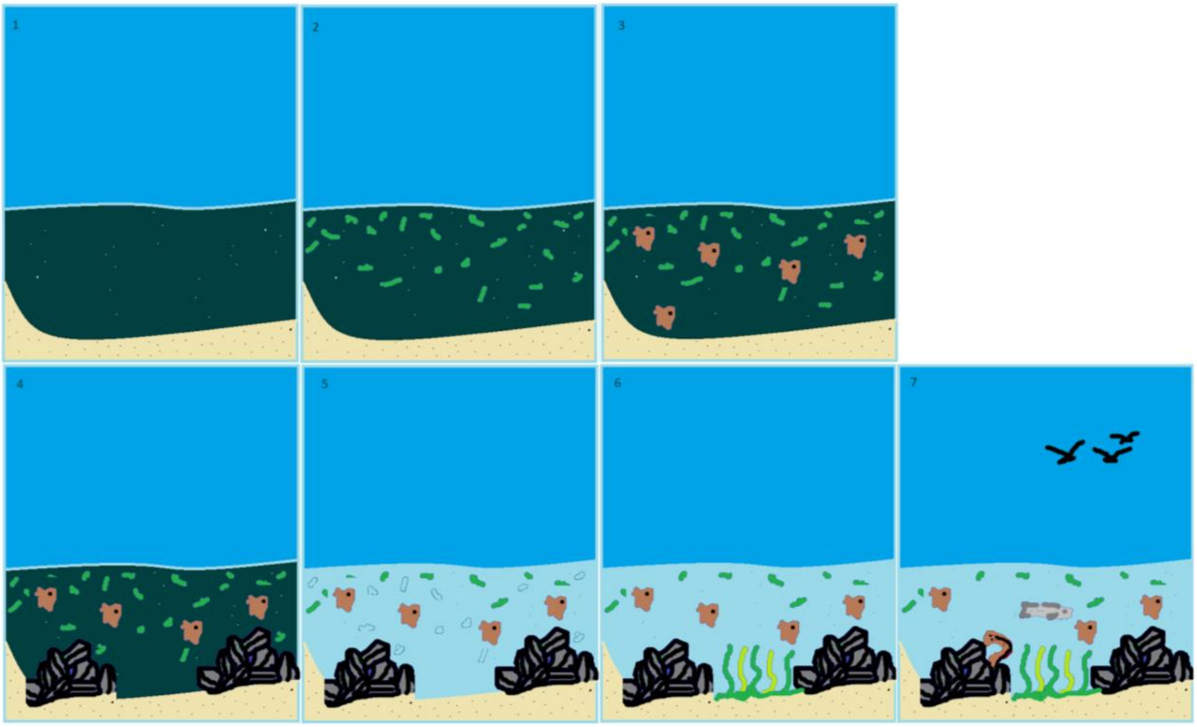

Figure 14: Ecological succession of the fish migration river in 7 steps

7. What could be the profit for ecological functions for the area surrounding the Haringvliet?

Now that the alternative design in the form of a FMR has been described we will take a look at the profits of building such a structure in terms of ecological functions. Not only the ecological value inside the river may be enhanced, but also the surrounding area of the FMR could profit from it. In this chapter we will therefore take a look at the ecological possibilities and profits of constructing the FMR.

7.1 Banks of the Fish Migration River

The banks that would be created with this design could contribute to the Natura2000 goals set for the area and the country. The abrupt change caused by the closed sluices on the Haringvliet caused the disappearance of salt marshes in the area. Allowing the exchange of water in the Haringvliet again could therefore be beneficial to these habitats (Troost et al., 2012). The management plan of Natura2000 for the coming years includes increasing the area of rivers with muddy banks, hydrophilous tall herb fringe communities of plains and alluvial forests, corresponding to the Natura2000 habitats codes H3270, H6430B and H91E0A (Natura2000, 2013). These habitats are decreasing throughout Europe which resulted in their inclusion on the Red List of Habitats, with either the status ‘vulnerable’ or ‘endangered’ (European Union, 2016a, 2016b). These habitats are the home to many different animals and plants, including rare and unique species (Natura2000, 2006;Natura2000, 2008a, 2008b).

Our alternative design offers opportunities for these unique tidal habitats, which were once part of the Dutch delta landscape (van der Pluijm & de Jong, 1998). It is difficult to predict how the environment will develop exactly, but similar areas can be used as a possible outcome and therefore reference, like the Westerschelde (van der Wal et al., 2008). By working together with other disciplines, including landscape architects, could help in forming the FMR area into a thriving, unique Dutch delta landscape with a great array of animal and plant species, as it once was.

7.2 Benthic organisms

The brackish water zone is by nature often species poor. Only a few species can survive in this dynamic environment, where freshwater transitions into saltwater and salinity levels usually vary greatly (Wijsman et al., 2018). There is a wide range of habitats in these systems since estuaries are typically very dynamic fresh, brackish and saltwater areas with many gradual changes. This is why, despite the small number of species that can survive there, a natural estuary can still host a diverse ecosystem with species unique to these habitats (Leeuw & Backx, 2001).

Tidal dynamics, sediment composition, salinity, temperature, water movement and biotic factors play a major role in estuarine systems whether benthic species can live there or not. Most benthic species prefer sand or silt to reside in. Silt can have effects on the productivity of the system. Mainly by affecting the development of the algae and secondary affecting the animals who live off those algae. Therefore, productivity partially determines the number of animal and plant species that can live in an estuary. However, too much silt in combination with relatively few edible particles is unfavorable (Duren et al., 2005).

The front delta of the Haringvliet is characterized by tidal flats and channels. The shape of these plates is the result of a complicated interplay between waves, tides and human interactions. These are important for many benthic species as well as seals and birds (Lodder & Wang, 2019).

The composition of sediments in the seabed and the silt content in the water undoubtedly influences the habitat of benthos, however demonstrating an actual causal relationship between these two factors and the occurence of certain benthic species is very difficult (Duren et al., 2005).

7.3 Seals

Located on the North Sea side of the Haringvlietdam there are sandbanks that are used by seals to rest on. The seals in question are the harbor seal (*Phoca vitulina*) and the grey seal (*Halichoerus grypus*). These species need sandbanks or sandy shores in order to nurture their young, give birth and rest (Ecomare, n.d.). The sandbanks that are used for this however are susceptible to erosion, especially if a strong current from open Haringvliet sluices hit the banks (Jessica Schop et al., 2016). Seals are often seen behind ajared barriers such as in Lake Grevelingen and the Eastern Scheld, in these cases the general rule applies; the bigger the opening to the area, the bigger the chance for seals to travel land-inward. Once a seal has entered a freshwater area, its biggest concern is not the salinity of the water, but the availability of a suitable food source. The problem that these seals face is then that it is often hard to return to their usual foraging grounds in the North Sea (Schop et al., 2016).

With a permanent opening to the Haringvliet, seals are likely to swim in and out of the estuary without being trapped. Our FMR will allow this migration of the seal without severely eroding the sandbanks in front of the Haringvlietdam. It is expected that the increased presence of seals in the Haringvliet might increase the predation pressure on our key (fish) species. However, seals already hunt our key species, the only difference is the location. Seals are currently able to easily feed on the fish that are stuck in front of the dam. Allowing a passage through the FMR will decrease their density and make it harder for seals to predate on the migrating fish. So even though the implementation of the FMR can help local seal populations prosper, it also reduces predation pressure on precious migrating fish species by those seals due to the removal of a prey hotspot. Seals fill the key role of top predator in the ecosystem, and thus cannot miss in a healthy habitat.

7.4 Birds

The delta area in the Netherlands is used as a roosting, foraging and breeding area by a lot of migratory bird species and also native bird species. The Haringvliet is used among other things to roost, forage and breed by these bird species and is therefore crucial in their life cycle (Ministry of Infrastructure and Water Management, 2016). When the Haringvliet was closed off in 1971, most bird species diminished in numbers due to the loss of brackish habitats and the benthos that could be found in these brackish habitats. The species that have been hit the hardest by the removal of this habitat are the wading birds like the dunlin (*Calidris alpine*) and the pied avocet (*Recurvirostra avosetta*). This is because their prey largely disappeared due to the loss of the brackish habitat (Vergeer et al., 2016). Another bird group that has decreased over the years is piscivorous birds like the great cormorant and the sandwich tern (*Thalasseus sandvicensis*). This population has likely also diminished due to a decrease of fish species as well as overall biomass in the Haringvliet. Restoring the fish migration routes and thus allowing fish to migrate is beneficial for these piscivorous birds and would likely increase their populations (Vergeer et al., 2016; Wijsman et al., 2018). The FMR would also allow for a lower residence time of migratory fish in the area in comparison to the Kierbesluit. Due to the lower residence time in the FMR, fish would be less easily preyed upon by birds. However, it should be noted that the depth and width of the river also play a role in this. If the river is too shallow and too narrow, fish will still be accumulating in a small spot where they can be more easily preyed upon as mentioned in predation risk (Winter et al., 2014).

While the FMR would not bring back substrates where the necessary prey species for some birds live in, the banks of the FMR can provide birds with additional foraging and roosting areas. Implementation of the FMR will likely reduce erosion of existing and forming sand banks. These provide crucial feeding grounds for key bird species. Similar to the seals, the birds will likely gain more suitable habitat that will increase their survival and population size (Schop et al., 2016).

Due to the integration of shellfish reefs in the FMR other birds species that previously did not occur in the Haringvliet could become more abundant. This is due to the fact that shellfish were not very common in the Haringvliet in comparison to the other delta areas and thus did not attract as much shellfish-eating birds (Vergeer et al., 2016). Examples of shellfish-eating birds that would be attracted to shellfish would be the common eider (*Somateria mollissima*) and the long-tailed duck (*Clangula hyemalis*).

7.5 Ecotourism

Next to all the ecological benefits that the FMR brings, it also brings a lot of opportunities for (eco)tourism as well. Some examples of these possibilities are a diving spot where tourists can dive in one of the few brackish water habitats in Europe or creating cycling routes and bird watching houses next to the FMR. Since brackish water habitats are relatively rare in Europe these will attract many species that are relatively rare and thus more desired to be viewed by birdwatchers and divers. Next to this, charismatic marine mammals like seals will likely be attracted to the area as well. This potentially provides opportunities for tourism focussed on these animals. With all the opportunities and benefits that the fish migration offers for (eco)tourism, it must be kept in mind that not the whole area becomes a touristic area and that this area is primarily made with ecological goals. Therefore specific spaces need to be defined where this (eco)tourism can flourish without impacting the main ecology.

8. What could be the consequences of the fish migration river for salinization during periods of extreme river discharge in the Haringvliet area?

Now that an alternative design has been proposed and described, we will focus more specifically on the impacts of this design and its adherence to our set conditions. This will encompass a smaller section about the salinization effects in the normal situation and two larger parts in the more unusual circumstances low and high river discharge.

Under normal circumstances with neither pushed up sea levels, low river discharge or high river discharge the FMR should not allow for salt water to reach the Haringvliet. Groundwater levels are not under threat from salinization more than usual due to flushing of the systems with freshwater (Pieter Beeldman interview). Salinity intrusions through the surface water should not be an issue either as various elements in the FMR like the cross-section and river distance can be calculated and modeled to determine the right numbers (Nolte et al., 2014). This can ensure that salt water will not intrude into the Haringvliet. Under normal circumstances the FMR thus should not pose any threats to salinization of the Haringvliet. However, it is interesting to look at more extreme circumstances and see if the fish migration could still adhere to our conditions in these situations.

8.1 Effects on salinization during low river discharge with the fish migration river design

An important factor to consider during the design of the FMR is the availability of freshwater. It is essential that freshwater can flow into the river to make sure that the saltwater does not intrude into the Haringvliet. Research on what the minimum amount of freshwater needed for the FMR is to function properly should be performed. It is expected that in the future more extreme situations in low and high river discharge will be present and this means that there is a potential risk concerning the proper functioning of the FMR. Stratification can take place, where salt water will be the lower layer and freshwater will be the toplayer. It is possible to create a slope in the FMR where the inlet on the Haringvliet side is higher so that even at a low discharge these stratification layers will ensure that the salt water does not reach into the Haringvliet. The extent to where the salt intrusion takes place into the FMR and potentially also the Haringvliet is dependent on the balance between inflow and outflow. This extent can therefore be minimised by decreasing the water inflow at high tide, so that the low tide has a relatively larger effect on salt intrusion.

The effect of the stratification can also be seen in saltwater wells that are known to be present in the Haringvliet. When saltwater enters the Haringvliet there is high potential that it is stored in one of these wells (De Goederen et al., 2006). At a low river discharge the saltwater could be released from these wells and form a potential risk for the salinity of the Haringvliet (Rijkswaterstaat, 1998). It is important to monitor these wells and make sure that they are flushed with freshwater in high tide situations to guarantee the water quality.

8.2 Effects on salinization during high river discharge with the fish migration river design

An indication of the salinity levels under abnormally high river flow conditions would be important information with a view to the brackish habitat in the FMR. The extent to which abnormally high river discharge would flush the brackish water is important, because it points out the stability of the brackish habitat. If the river discharge would be too high, the saline water could be pushed back, which would not be in favour of a stable brackish habitat.

The report by Nolte et al. (2014) on the implementation of a FMR in the Afsluitdijk shows that extensive research is needed to be able to describe the conditions that would occur in this situation. Another, more predictable element in this situation is the sluice management. Winter et al. (2014) mention that in times of abnormally high river discharge, the sluice management would be to fully open the sluices in the Afsluitdijk, causing a situation that is not fish friendly. We expect that similar sluice management would be required for the Haringvliet in order to prevent floodings. In order to prevent the flushing of the FMR, follow-up research could investigate the possibilities of closing the FMR during abnormally high river flow conditions.

9. Discussion

There are conflicting opinions and interests surrounding the current state of (the habitat and ecosystem in) the Haringvliet and the consequences of the suggested solution of permanently opening the sluices further remain limited to theory. This impedes the realisation of (and decision making process regarding) projects in the South-Western Delta, such as Delta21. In this report we proposed and investigated the potential of a FMR as an alternative to three chosen scenarios: The current Kierbesluit where the Haringvlietsluices are partially opened to stimulate fish migration from the North Sea into the river system of Europe. The 80 cm tidal change scenario, where the sluices are always opened, but not completely. And the scenario where the sluices are permanently completely opened. In the section below we will discuss the findings of this report. The aim of this report is to find a fitting solution for fish migration by creating a stable brackish habitat while minimizing effects on freshwater provisioning.

9.1 Feasibility Scenarios

Despite being offered as possible scenarios in our report, some scenarios are less likely to be executed. The open or 80 cm tidal change scenarios will very likely be heavily opposed, since they have larger implications on the freshwater supply than in the current situation. With the completely open scenario making the Haringvliet a brackish area again, various stakeholders will want to prevent this from happening and therefore the feasibility of both these scenarios is questionable.

We have conducted several interviews with experts and stakeholders, asking them about our idea for a FMR in the Haringvliet. Four out of five interviews granted us permission to use the interview content in our report. One of these experts was Reindert Nijland (researcher at WUR, focusing on which fish species would return after opening the Haringvliet sluices). He thought the FMR would be a great idea as there would be a permanent opening for fish to migrate. He did mention some challenges like the amount of water coming through the river. He therefore advised constructing the FMR as a branch of the Haringvliet. Pieter Beeldman from Rijkswaterstaat also thought the idea of a FMR could work in theory; if it works for the Afsluitdijk it could work for the Haringvliet as well. He thinks there would be challenges in the civil technical aspects, because of how the Haringvliet sluices and dams are built. Meike Coonen from Hydrologic, which handles the “lerend implementeren” approach at the Haringvliet said that she is not well known with the concept of the FMR, but does see some good points like migration options for fish and the FMR being apart from the sluices. Furthermore, she thinks that salt concentrations could be more manageable than is currently the case for the Kierbesluit. Wouter van der Heij from the FMR project at the Afsluitdijk thought larger tidal influence could be beneficial for the Haringvliet and therefore has his doubts about a FMR in the Haringvliet.

All in all the majority of these experts/stakeholders seem to like the idea of a FMR or at least the exploration of its possibilities. One thing that does become clear from these talks though, is that there are multiple challenges laid out for the undertaking of such a project and that it will take time to accurately assess and solve these uncertainties.

9.2 Design aspects fish migration river

Although the FMR has the potential to be a good solution, there are also some aspects that could be potential issues. One of these issues is the amount of time required for the calculations and technical aspects of creating a FMR. As the FMR requires very specific dimensions, the calculations for various aspects (including river length, width, depth and cross section) will take quite some time. Although this will not impede the solution as a whole, it should not be forgotten that there is a significant amount of work connected to this project that we were unable to fit in our tight schedule for making this consultancy report. It is therefore suggested that future researchers with more experience in landscaping and spatial design take a look at the costs and feasibility of placing the FMR.

Another aspect that deserves mentioning is the ecology that surrounds the FMR. Although estimations of ecological development can be made for the FMR, it is never certain if this will be exactly followed. This is the case, because ecology is a fickle thing and it is very hard to determine how life will exactly develop in the FMR and if fish will use the river to its full extent (T. Murk, personal communication, 4 november, 2020). Furthermore, it should also be stressed that this solution is a middle road. The FMR can be a solution beneficial to all parties. However the FMR cannot provide the same large scale ecological development of an opened Haringvliet. It will be on a smaller scale. Therefore there is a trade-off for the FMR against the opening of the sluices in terms of ecological advancements.

The last aspect that needs to be mentioned is the cost. The construction of a FMR and all its required labour is expensive. Although we cannot say anything about the exact costs of such a project, it is good to mention the probability of high costs for definitive advice. The FMR at the Afsluitdijk is supposed to cost around 55 million euros.

9.3 Opportunities of the Fish Migration River in a broader context

Although the design of the FMR is aimed at the area of the Haringvliet, we expect that the benefits will be noticeable in a broader context within the Netherlands and Europe. This section will address this context by elaborating three topics that have been important themes throughout the report, starting with fish migration. As the FMR creates an open connection between the North Sea and the Haringvliet, it facilitates the migration of several fish species from the North Sea land-inwards and vice versa. In the context of fish population the FMR will therefore contribute to a healthier fish stock.

The second element of the FMR that is beneficial on a scale larger than the Haringvliet is the creation of a brackish habitat and therefore housing of species such as benthic fauna, birds and other estuarine inhabitants. This would be an ecological improvement compared to the conditions of the present Haringvliet and makes that the area can possibly compensate for the loss of Natura2000 area in the Delta21 project.

Lastly, in terms of freshwater resources the FMR provides the opportunity for the Haringvliet sluices to remain active in terms of measures against salinization of Dutch lands and waters. The opening and closing of the Haringvliet sluices is currently actively used in the division of water between the Nieuwe Waterweg and the Haringvliet. The function of this is to flush part of the hydrological system in the Rijn Maas delta (M. Coonen, personal communication, 3 december, 2020). The sluices can continue to be used in this way if a FMR would be constructed in the Haringvliet area.

9.4 Summary of recommendations

Both the scope of our intended research and the time available to us have created some aspects that we recommend should be investigated further for the FMR. One of these aspects is the dimensions of the FMR. We advise that these dimensions are carefully calculated and modelled to obtain the right dimensions to prevent issues with both salinization and the dynamics within the FMR itself. Within this process it is also advised to investigate the climate robustness of the FMR. Furthermore we advise that the potential construction of the FMR in the Haringvliet is studied so that it can become possible to construct a FMR specifically for the Haringvliet sluices. Lastly, we recommend that the potential costs of the FMR are studied to get an estimated value of the project.

9.5 The bigger picture

It is good to indicate how we see our advice fit within the plans of Delta21. As ecological advancements are a requirement by Delta21 for their own project, we want to create a possibility to make a brackish habitat and safe passage for migrating fish. However, the feasibility of a completely open Haringvliet, without too many opposing stakeholders, is very small. Therefore we propose the idea of a FMR. This would provide Delta21 with an idea to create ecological value within their project, but at the same not influence the freshwater supply in the Haringvliet. We view this as crucial as a lot of stakeholders are involved and a solution that does not negatively influence one side might make way for renewed conversations between the different stakeholders and Delta21.

10. Consult

In this part of our report we will answer our main research question: "*What are possible solutions for creating a for migratory fish functional and stable brackish habitat within the Haringvliet, without impairing freshwater provisioning in the delta?"* and give our advice to Delta21.
We have listed various ways to manage the Haringvliet Sluices along with the opportunities and threats they bring. These different management strategies or designs are referred to as 'scenarios' and have been evaluated against the following criteria: the benefits for fish migration, the creation of a stable brackish habitat and the safeguarding of freshwater provisioning.

We believe that there is an alternative to opening the Haringvliet sluices. This is the FMR, which is expected to be the most beneficial option in terms of nature restoration without impairing freshwater provisioning. In table 5 we have summarized which scenario best meets our requirements according to our research.

Table 5: Summary of postives and negatives for the prerequisites we described per scenario

	Scenario 1 (Kierbesluit)	Scenario 2 (80 cm tidal change)	Scenario 3 (Fully opened)	Scenario 4 (Fish Migration River)
Migratory fish	+	++	+++	++
Stable brackish habitat	-	++	+++	++
Freshwater provisioning	+	--	---	+++

10.1 Migratory fish

The best scenario for creating a migration route for migratory fish is scenario 3. This is because the sluices will be opened permanently. The tidal fluctuation will ensure that even the weak swimmers will find their way into the Haringvliet. Because of the width of the Haringvlietsluices it is apparent that the attraction stream will be detectable for the migrating fish and there is enough room to pass. Scenario 2 is closely related to scenario 3 as the dynamics are fairly similar. However, the opening of the sluices will have less surface area, so there may be less attraction stream and space for the fish to pass. Also the tidal fluctuation will be less, which will have a negative effect on the fish that use the tide to migrate. Scenario 4 has a less wide opening when compared to the scenarios with the sluices. Therefore, the attraction stream will be less pronounced and the migratory fish may have more trouble finding the river. The habitat in the river will be conditioned in such a way that all fish that do enter will have the ability to safely reach the Haringvliet and migrate further upstream. Scenario 1 is where the sluices are not opened permanently but only at certain times. This has as a consequence that the fish at times still encounter a physical barrier. Also, the tidal fluctuation is relatively low and that impedes weak swimmers in their migratory pathway.

10.2 Stable brackish habitat

In scenario 3 it is very likely that a stable brackish habitat will form in the Haringvliet as there will always be an in- or outflow of salt- or freshwater. The tidal fluctuations will cause the water to mix well and therefore a stable brackish habitat has the potential to form. In scenario 2 the in- and outflow will be less prominent and thus there is a reduced potential of a stable brackish habitat to form when compared to scenario 3. In scenario 4 the stable brackish habitat will not form in the Haringvliet itself but in the FMR. The potential of a stable brackish habitat to form in the FMR is high because of the intertidal dynamics that will be present in the river. The ability to create the structure and substrate in the optimal way has the effect that the formation of a stable brackish habitat can be assured in the river. In scenario 1 only the west of the Haringvliet has the potential to form a stable brackish habitat. However, the low tidal fluctuation, especially at times of low river discharge, may cause stratification instead of brackish water.

10.3 Freshwater provisioning

The optimal scenario for freshwater provisioning is scenario 4. Because of the ability to design the FMR there is a potential that no saltwater ever reaches into the Haringvliet. This is the ideal scenario as freshwater provisioning is not endangered and even old freshwater intake points could be put to use again. Scenario 1 fits within the rules for current freshwater provisioning since the intakes were moved to the east of the Haringvliet. Scenario 2 has large consequences for the freshwater provisioning. The line for acceptable water intakes will move far east and water intake points for drinking water and agricultural use should be moved further east. In scenario 3 the line for acceptable salinities will be even further east than in scenario 2. This could even mean that the Biesbosch could become brackish during months with low river discharge.

10.4 Final advice

In this project, our aim is to make a recommendation for Delta21 on the best way to include ecological value in their plans. Evaluation of the criteria mentioned above shows that scenarios 1 to 3 have a negative score for either one of the 3 criteria. The ability for fish to migrate and a stable brackish habitat to develop is highest in the third scenario. In this scenario, the Haringvliet sluices would be completely opened. However, in the third scenario severe problems will affect the freshwater provisioning. In order to combat this, high costs have to be made. Therefore, we advise Delta21 to go with scenario 4; to create a for migratory fish functional and stable brackish habitat without impairing freshwater provisioning in the delta.

In scenario 4 there is a good potential for fish to successfully migrate and for a stable brackish habitat to form. No threats for freshwater provisioning are expected and controlling salt water intrusion will be easier than for scenario 1 to 3. The FMR offers many advantages against relatively few disadvantages. It would bring back many species that are unique for the Netherlands, providing opportunities for many tourist activities and not interfering with the freshwater activities within the Haringvliet. Consequently, implementing a Fish Migration River in the Haringvliet is our advised strategy to add ecological value to the Delta21 project, as it would pose benefits for both stakeholders with an interest in fish migration and stakeholders with an interest in the protection of freshwater supply.

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Appendices

Notulen interview Wouter van der Heij

Datum: 26-11-2020
Aanwezigen: Jelle, Valesca

Vraag	**Antwoord**
Wij vroegen ons af of de lengte van de vismigratierivier ergens op gebaseerd is? (bij ons is het geval dat we de haringvliet niet te zout mag worden na een bepaald punt).	In het ijsselmeer gelden ook randvoorwaarden, er mocht geen druppel zout water in het ijsselmeer komen. Dimensies rivier zo ontworpen dat het zoutwater wel in loopt maar nooit aan het einde van de rivier mag komen. Rivier is 4 km lang met veel kronkels. Stroomsnelheden mogen ook niet te hoog worden voor het indringen van het zout en bevordering van vismigratie. Het is wel een natuurproject maar gaan ook natuurwaarde verloren.
Is er rekening genomen met de breedte van de vismigratierivier? (wij hebben stukken gelezen dat een bredere rivier minder kans is op predatie van vogels etc)	Doorgerekend in hydrologische modellen en ander rekenwerk. Evenveel als achter het bepalen van de ecologische waarden. Zandige rivier is het uitgangspunt. Heeft wel gevolgen voor hoe het ontworpen is en welke materialen gebruikt worden.
Is er een reden voor een bepaalde diepte in de vismigratierivier?	Ja alles is tot in de puntjes uitgewerkt. Berekeningen hebben ongeveer 3 jaar gekost.
is er voldoende ruimte voor een permanent brak habitat mogelijk in een VMR?	Binnen het vmr is een zoet-zout overgang wel gelukt, maar heel klein schalig. Het is lastig stabiel te houden (zoutwaardes 10-25 ppm)
Wij vroegen ons af of er automatisch een zoet/zout gradiënt ontstaat en dat het zoete en zoute water met elkaar mixt of dat dit mix process “geholpen” moet worden? (door bijvoorbeeld stenen/rotsen te plaatsen).	VMR hebben er niet veel over gehad. er is op een 3d manier gekeken hoe zout inmenging in de rivier plaatsvindt. Door het aantal bochten zou het geen probleem moeten zijn (niet veel over gehoord, mogelijk geen probleem) tot stand gekomen tussen biologen en technici.

Is er in de vismigratierivier rekening gehouden met sterke en zwakke zwemmers? En zo ja wat is hiermee gedaan?	Ja, zwakke zwemmers gebruiken getijde golf, getijslag aan de binnenkant. Glasaalen gebruiken dit bijvoorbeeld. Qua lengte is uitgegaan van max. sprintsnelheden van vissoorten. Mag nooit hoger worden dan dat.
Wat was de grootste (sociale) weerstand/knelpunt?	Beroepsvisserij, mensen die hun fuikplekken moesten opgeven. In algemenere zin die twijfelde over de projectkosten. Verder weinig tot geen weerstand gehad. Voornamelijk voor fuikstek aan de binnenkant.
Is er een bepaald scenario waarin een VMR niet werkt? en wat zijn de belangrijkste voorwaarde voor het functioneren van de VMR?	Werkt niet onder storm omstandigheden. In geval van grotere droogtes, niet voldoende zoetwater voor de lokstroom. Weinig sprake van visintrek sowieso als er lage waterstanden zijn.
Hoe monitoren jullie de vismigratierivier?	-
We hebben gezien dat de vismigratie rivier afgesloten kon worden voor ik neem aan een storm(vloed). Hoe wordt dit gedaan?	In de afsluitdijk zitten 2 deuren die dicht kunnen, en bij het binnendijkse gedeelte zit ook een deur die dicht kan mocht het zoutgehalte te hoog worden. Indien tijdelijk gesloten een bypass nodig die vissen kunnen gebruiken.

Verdere notities

in hoeverre belemmerd dit de vismigratie ansich, ze zullen ook verplicht zijn tot compensatie in het gebied. het genereert mogelijk natuurschade en hoe daar een positieve draai aangeven. gedachte bij het meer: meer kan bijdragen leveren aan schelpdierkwekerij.

haringvliet grotere getijslag en dus grotere dimensies voor een VMR. waarschijnlijk kier vele mate beter dan een VMR. getij meer acclimaties milieu maken evt een optie of ander stabiel brakke omgeving

turbines wegpompen van water en tegelijkertijd energie opwekking (lauwersmeer niet rendabel, door getijden bij haringvliet mogelijk wel)

meer waarde zou kunnen zijn in de overgangszone tussen zoet en zout.

Notulen interview Reindert Nijland

Datum: 01-12-2020
Aanwezigen: Valesca, Jeroen, Erwin

Vraag	**Antwoord**
Heeft u een idee tot welke mate de vissen die nu in het haringvliet voorkomen migreren? En of er op dit moment sprake van migrerende vissen in het Haringvliet is	Vissen nu in het Haringvliet zijn zoetwatervissen en migreren niet expres. Zijn wel soorten die kunnen migreren. Er is met netten getest welke vissen er door de sluizen heen migreren. Migratie gebeurt wel naar de haringvliet maar soorten als een haring die meteen in zoet water komt gaat dood.
Hoe wordt bijgehouden welke vissoorten terugkomen? en in welke hoeveelheden?	Netto, kan miljoenen zijn maar er wordt niet gecontroleerd of die vissen overleven.
Welke soorten worden nog niet teruggevonden die wel gewenst of verwacht waren voor het creëren van een gezond ecosysteem?	Denk bijvoorbeeld aan trekvissen als fint, elft, houting, brown trout, zalm, steur. Er moeten eerst meer vissen komen maar al die soorten hebben wel de potentie om terug te keren. Vooral de niet eerder uitgestorven soorten. Fint bijvoorbeeld gebruikt zo'n getijdengebied als voortplantingsgebied.
Wat denk je van (pal)(har)ing als indicator species of een design efficiënt biedt / een gezond habitat creëert	Paling is een trekvis die zich goed kan aanpassen aan gradiënten, is hele handige indicator of er een fysieke barrière is die een barrière vormt. Een haring heeft een ander barrière aangezien het niet tegen een sterke gradiënt kan. Daardoor mixen we fysieke en chemische barrières met onze indicatorsoorten. Haring is een goede indicator wanneer het zijn hele levenscyclus kan doorlopen.
Wat is de grootste barrière m.b.t vismigratie, de fysiek barrière of chemische barrière? En is de Haringvlietdam de grootste barrière of zijn er verderop nog onneembare barrières die barrières vormen?	De afwezigheid van de zoet zout water gradient is heel belangrijk. Niet perse voor trekvissen. Die aanpassing vindt al deels plaats voor de sluis. Geen brak water is moeilijke barrière voor bijvoorbeeld haring.

Zou een vismigratierivier ervoor kunnen zorgen dat vissen beter herstellen dan met kier?	Reindert gelooft dat het een geweldig idee is. Vooral in het symposium vorige week zijn veel goede dingen verteld over de stromingen en dergelijke. Het grote voordeel is dat het permanent open is en zo een estuarium veroorzaakt. Er is mogelijkheid dat in het getijdenmeer met de afvoer van het haringvliet dat je qua waterhoeveelheid niet uitkomt. De vismigratierivier zou een zijtak moeten zijn maar niet in serie.
Wat zou u aanraden voor toekomstige monitoring van de vismigratie in het Haringvliet?	Meest efficiënte manier is een net ophangen, maar een idee als een kijkraam is ook mogelijk wanneer water helder genoeg zou zijn. Het best is regelmatig monsteren door bevissen of DNA analyse. In DNA zijn aantallen en levensstadium lastig.
Hoe lang zou het duren voordat teruggekeerde soorten commercieel bevist kunnen worden? of is dit helemaal niet het doel?	Paling is een moeilijk verhaal omdat hij bedreigd is. Als een haring er gebruik van kan maken kan je meteen commercieel bevissen, want er is veel jonge haring aanwezig.
Kunt u meer vertellen over het vishotel bij het Haringvliet?	Afstudeerproject voor kunst. Zijn buizen waaruit je een hele rifstructuur kunt maken. De rifjes die gemaakt zijn zijn 10 buizen (best klein) en daarna is onderzocht wat er een beetje omheen gebeurt. Zwartbekgrondels worden aangetrokken en het is leuk om te zien dat zon structuur wel wat vissen trekt. Als er een brak habitat vormt is het een heel goed idee om structuren aan te passen. Op grote schaal zou een vishotel te duur zijn dus is het beter om op een goedkope manier grote structuren aan te brengen

Verdere notities
Zou graag het eindrapport ontvangen als het mag van Huub en Leen.

Notulen interview Pieter Beeldman

Datum: 30-11-2020
Aanwezigen: Nuan Clabbers, Emiel Schuurke

Vraag	**Antwoord**
Kunt u kort een beetje vertellen wat uw rol is binnen het kierbesluit en het Haringvliet?	Doel op ecologie gebied en randvoorwaarden als zoetwatervoorziening en voorkomen zoutverspreiding. In team bezig met zoutverspreiding en ecologische monitoring (weghalen harde barrière).
Hoe kijkt u tegen het huidige beleid rondom het haringvliet aan?	Druk bezig met bekijken hoeveel opening we kunnen creëren. We hebben gewoon randvoorwaarden en daaraan moeten we voldoen (zoetwatervoorziening). Hierbinnen zijn we aan het zoeken in hoeverre we het project kunnen uitvoeren. We werken hierin samen met verschillende stakeholders en werken in dialoog om te kijken wat de mogelijkheden zijn.
Hoe kijkt u tegen een compleet geopend haringvliet aan?	Het hangt van je oplossing af wat je kan realiseren. Volledig openen zoals in de jaren 60 of ook stormvloedkering volledig open houden? Voordelen worden best benadrukt terwijl er veel risico's zijn. In natte jaren is het vaak geen probleem, maar in droge situatie kan zout dat nog in systeem zit omhoog komen. Dit zit erg ingewikkeld in elkaar. Door onderzoeken die we hebben gedaan weten we dat de oplossing niet makkelijk is.
Wat zijn de risico's van het Kierbesluit (momenteel en in de toekomst)?	Ecologisch risico, ecologische verbetering → op sommige momenten kunnen we niet open en dan kunnen vissen ook niet naar binnen. Risico wat betreft zoutverspreiding: zout zakt in putten/geulen en onvoldoende kracht om zout hieruit te krijgen. Als het volledig open is dan is er veel kracht van getijdewerking. (in putten kan 9000 mg/l) Zout in systemen kan voor onvoorziene situaties zorgen.

Waar ligt het grootste risico op verzilting? En waar zou dit meer problematisch zijn (grondwater, oppervlaktewater)?	Risico's zitten niet in grondwater. Voorne putten en Goeree hebben hoge zoutconcentraties in grondwater zitten. De kier speelt hier geen significante rol in. Eilanden zijn al ingericht om het zout door te spoelen (in sloten bijv). Water uit haringvliet kan hiervoor gebruikt worden. Maximale waarde is 150mg cl/l. Die waarde staat ook voor industriewater. Ooit was gedempt getij het einddoel. In 2010 is deze er uit gehaald. Het grondwater zit zeker wel goed, maar er is wel veel zoet water voor nodig (daardoor zijn innamepunten van groot belang).
Is het kierbesluit wel klimaatbestendig? Er vindt namelijk ook al verzilting plaats.	Er zullen lagere rivierafvoeren zijn waardoor de sluizen minder vaak open zullen kunnen. Dit zal echter geen grote effecten met zich meebrengen.
Waarom is er niet voor een alternatief gekozen?	In 2010 stond dat het kierbesluit zou stoppen, andere landen waren hierop tegen dus zijn andere alternatieven bekeken om de huidige belangen te behartigen. Verder openen van de sluizen was geen optie, omdat de belangen dan niet behartigd zouden worden.
Wij kijken op het moment naar een vismigratie rivier, hoe kijkt u hier tegenaan?	Vraag kan beter gesteld worden aan mensen van de afsluitdijk. Theoretisch gezien: als het daar kan zou het bij ons ook moeten kunnen. Civiel technisch zou het lastiger kunnen zijn door hoe de sluizen in elkaar zitten en de opvolging van dammen. In principe toch onvoldoende verstand van. Sommige beesten zouden meer baat hebben bij grotere openingen waar veel water doorheen gaat. Maar hier weet ik minder van af. Er zouden voordelen en nadelen zijn die niet benoemd worden.
Bent u bekend met delta21 en het ontstaan van een getijdemeer in de voordelta van het haringvliet? Hoe staat u hier tegenover.	De primaire vraag die ik hen stel is: hoe zorg je dat vissen passeren, maar zout niet. Met name in de allerdroogste jaren. Daar heb ik niet altijd het antwoord op gevonden. Tot hoe ver zullen de oude putten worden gevuld met zout. Hoe zorgen ze ervoor dat dat zout gestopt wordt. En als je daar voor

	zorgt hoe zorg je dat die vissen daar nog wel overheen kunnen. Hoe zorgen ze ervoor dat het zout niet bij de innamepunten komt voor zoetwater winning. Crux: zout moet er niet doorheen, maar al die vissen wel.

Verdere notities

vismigratierivier lijkt te managen voor het haringvliet met onze randvoorwaarden. Het punt gaat zijn hoe het civiel technisch in elkaar gaat steken. Hoe gaat het samenwerken met de dam en de sluizen. Afsluitdijk werd opnieuw ingericht haringvliet niet. Een van de sluizen dichtleggen kan niet zo maar. Baten kunnen afgezet worden tegen de kier.

Notulen interview - Meike Coonen -

Datum: 03-12-2020
Aanwezigen: Nuan Clabbers, Erwin Termaat, Emiel Schuurke

Vraag	Antwoord
Hoe bent u betrokken bij het Kierbesluit en de Haringvlietsluizen?	Werkt bij een adviesbureau (hydrologic). Er zijn meerdere trajecten gedaan voor rijkswaterstaat. Betrokken bij lerend implementeren voor het kierbesluit.
Wat is de rol van het Lerend Implementeren binnen het Kierbesluit?	Idee is om het op een kier te gaan zetten, zodat het ook bij vloed open is. Hoeveel, hoe lang etc wordt nog onderzocht. Drink innamepunten zijn dus al verlegd. Nu is de vraag hoe je het zoute water dat binnenkomt aan de westkant behoudt. Dynamiek is nog weinig over bekend. gegevens voor modellen zijn nodig. Dit wordt bekeken door mondjesmaat zout in te laten. Zo wordt bepaald hoe lang het open kan blijven etc. Dit is dus het lerend implementeren.
In welk stadium is het lerend	Er wordt onderzocht hoe je de natuur zo veel mogelijk tegemoet komt zonder de

implementeren?	randvoorwaarden die er zijn te overtreden. Verschillende mensen (rijkswaterstaat bijv) beoordelen data tot dusver en geven aan hoe snel een volgende stap kan worden gezet. Uit het project moet blijken hoe je de ruimte kunt vinden en hoe veel ruimte er is voor het openen van de sluizen.
Hoe ziet het operationeel management dat is gebaseerd op het Lerend Implementeren eruit?	-
Hoe is de terugkoppeling naar Rijkswaterstaat?	Op verschillende manieren: expert groep krijgt als eerste resultaten te zien. In die groep zitten mensen van rijkswaterstaat maar ook consultancy groepen. Dat wordt besproken met de klankbordgroep bestaande uit belanghebbenden in de omgeving. Die partijen worden dus nauw betrokken bij dit proces.
Zijn er uit de monitoring inzichten opgedaan op het gebied van risico's binnen hydrologie en ecologie? Wat zijn hiervan de gevolgen voor vervolgstappen in het Kierbesluit?	Er zijn zeker wel interessante bevindingen gedaan. Het is echt nog in een conceptfase. Relatief kort geleden van start gegaan. Perioden van lage rivierafvoer werd gezien als het grootste risico. Dit zou worden opgelost met het spoelen van het Haringvliet. Daar waren veel vragen omheen (getijdengeulen en putten). Zoetspoelen is wel echt een uitdaging. Zo zie je dus wel ontwikkelingen in hoe de doelen gehaald kunnen worden. Er wordt echter nog niks vastgelegd omdat het nog in zo'n vroeg stadium zit.
Zijn er huidige klimaatbestendige plannen en hoe past het kierbesluit hier in?	-
Wat zijn voorwaarden voor een juiste mixing van brak water en hoe wordt stratificatie voorkomen?	Heeft met de diepte en dynamiek te maken. Haringvliet is sneller stilstaand water, dan krijg je meer gelaagdheid. Meer dynamiek is meer menging. Getijslag en rivierafvoer spelen een belangrijke rol. Als het tegen elkaar instroomt heb je meer dynamiek. Voor de vmr zou je meer op micro niveau moeten kijken. Er zou voor menging gezorgd moeten worden. Bellen scherm wordt daar al voor gebruikt. In de vmr heb je

	ook al wel wat dynamiek, dus ik kan er niet heel specifiek iets over zeggen.
Om aan de randvoorwaarden binnen ecologie en zoetwatervoorziening te voldoen bekijken wij een alternatief: VMR. Vanuit perspectief hydroloog, zou u dit in het Haringvliet vinden passen?	Weet er niet heel veel van af. Aan de ene kant goed voor vismigratie en los van de sluizen. Vanuit natuurorganisaties gaat het niet alleen over vis, maar ook over de brakke habitat. Hydrologisch gezien zou het zout beheer een stuk makkelijker worden.

Verdere notities

Ze zijn bezig met verschillende expertgroepen, zowel hydrologisch als met natuur. Ze houden veel rekening met alle stakeholders

Er is ook een effect op de nieuwe waterweg wanneer er bij lage afvoer de sluizen dicht gingen

Er wordt veel onderzoek gedaan naar verschillende factoren en of die een rol spelen in het sluisbeheer

ooit bordspel gemaakt om mensen in de klankbordgroep met elkaar te laten praten

Haringvliet is belangrijke stuurknop in de hele rijn maasmonding, daarom ook overleg met betrokkenen uit noordelijke deel.

Bureau stroming adviseert veel natuurorganisaties. Veel betrokken geweest dus. Ze gaat voor ons wat mailen voor die mensen.