Living North Sea

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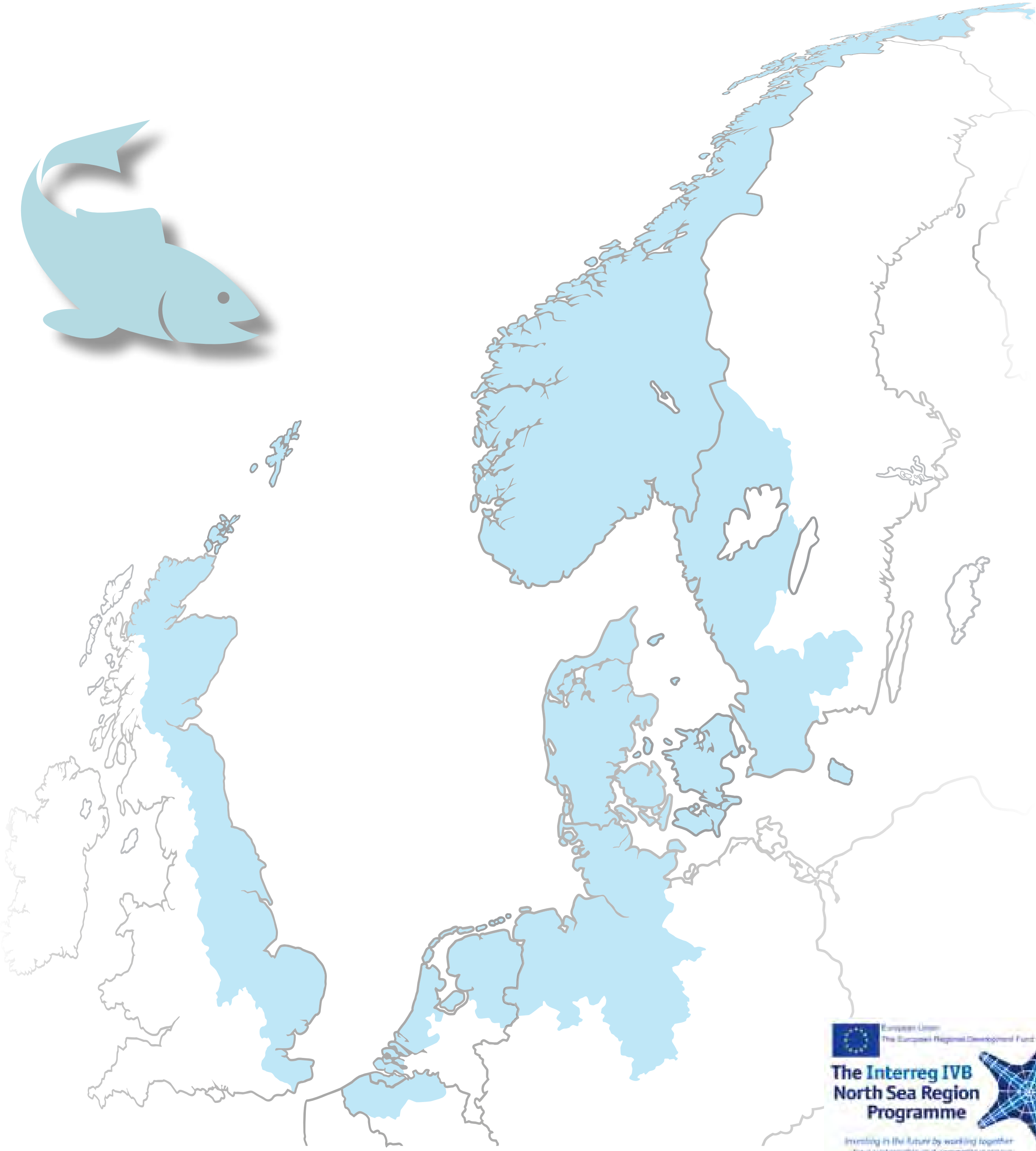
Reconnecting the North Sea

Innovative solutions for fish migration



The Interreg IVB North Sea Region Programme

Living North Sea

Preface

This document is the main written output from the Innovative Solutions work package of the Living North Sea project, which was presented at the Towards a Living North Sea conference in Gateshead, UK from the 13th - 15th November 2012.

This document links to a series of technical factsheets, which describe examples of fish migration solutions. In some cases, there are links to local contacts who may be able to provide assistance with fish migration problems, in other cases please refer to www.livingnorthsea.eu for assistance.

The scale of river fragmentation across the NSR of Europe is thought to be amongst the highest anywhere in the world. The impact of this may be understood in local terms, and even on a catchment or national basis. The European community-level consequences are much harder to elucidate, and will of course vary from species to species. The Innovative Solutions part of the LNS project has been quantifying the scale of man-made fish migration problems across the NSR. Data that has been much harder to accumulate than initially thought. A vast amount of knowledge has been shared between organisations and countries on best practice solutions to the key fish migration problems in the region. This has been highly beneficial in areas where established problems in one country, are just becoming recognised in another (e.g. pumping stations). In this case, years of trial and error, and assessment have been circumvented. A number of new solutions to fish migration barriers are currently being trialled and assessed as a part of the project, but there is still much work to be done, particularly in raising public awareness for the problem, and the necessity for solutions.

The aim of this document is to give an easy to understand overview of the key issues, with specific policy recommendations which could be adopted at local, national or an EU community level, whilst also linking to technical documents which give more detailed information required by the professional implementing solutions. The intention is that this resource will be of practical use to those working on fish migration issues at every level.

The Living North Sea project (LNS) brings together 15 beneficiaries from all seven countries in the North Sea Region of Europe (NSR), in a €6.4M project funded by the European Regional Development Fund (ERDF) through the North Sea Region IVB Interreg Programme. Interreg is a European Community initiative, which aims to stimulate interregional co-operation in the European Union. Strand B promotes transnational co-operation over pre-defined geographic regions of Europe, such as in this case, the countries that border the North Sea. One of the key themes for the NSR is promoting the sustainable management of the environment, and there are few issues more relevant to transnational co-operation than the management of commercially important natural resources that migrate across political boundaries. The risk of one country implementing policy and works that impact migratory fish stocks in other countries is high, and the LNS project aims to bring professionals working on this problem in the NSR together in a long-lasting partnership to collaborate and share resources for community benefit.

Alistair Maltby
Director North, The Rivers Trust

THE RIVERS TRUST
where there's water there's life

European Union
The European Regional Development Fund
The Interreg IVB North Sea Region Programme
Investing in the future by working together for a sustainable and competitive region

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1 - Approach of the project

SECTION SUMMARY

- Why are fish important to the North Sea Region
- Why fish migrate
- Why fish stocks have to be managed as one across the North Sea Region

1.1 Objective of the Living North Sea Project

1.1.1 Why focus on fish?

The project has focussed on fish migrating between fresh and salt water for four reasons:

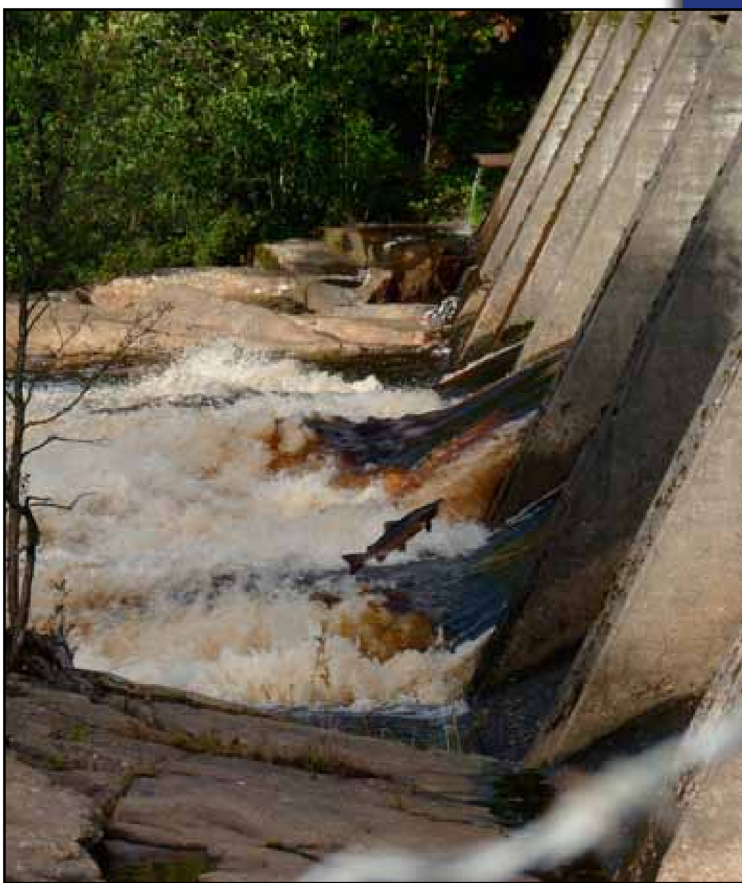
(1) Migratory fish have a long history and have been important sources of proteins since historical times in the region. Archeological remains at ancient settlements and latterly historic painting provide the oldest references to the occurrence of our migratory fish species in the North Sea region. These confirm the historical presence of sustainable populations of Atlantic salmon (*Salmo salar* L.) twaite shad (*Alosa falax* L.) three-spined stickleback (*Gasterosteus aculeatus* L.) European sturgeon (*Acipenser sturio* L.) Atlantic sturgeon (*Acipenser oxyrinchus* L.) European eel (*Anguilla anguilla* L.) sea trout (*Salmo trutta* L.) river lamprey (*Lampetra fluviatilis* L.) and European smelt (*Osmerus eperlanus* L.) in the North Sea region.

(2) Fish are important indicators and renowned symbols of ecosystem health. They are oxygen demanding and very susceptible to chemical pollution. Furthermore, most of the species are top predators dependent on organisms lower in the trophic chains.

(3) Several migratory fish species are important sporting species such as Atlantic salmon and European trout sustaining recreational fisheries. Some species are even harvested for commercial reasons such as coregonids in the Baltic.

(4) Some of the species are threatened by habitat destruction and some are in hazardous decline (e.g. European eel). Some of these migratory fish populations have even disappeared in the last few centuries in the North Sea region (e.g. blue fin tuna and sturgeon) while others have undergone significantly constrictions to their range (e.g. shad, smelt).

Various causes have been reported for this decline: poor chemical water quality, deteriorated physical habitat conditions, predation, fishing, migration barriers, parasites, oceanic change and climate change. Many migratory fish species have been intensively consumed by man for centuries, while industrial and agricultural activities combined with increasing population density polluted our rivers and destroyed crucial habitats for spawning, nursery and growth of migratory fish. The anthropogenic creation of fish migration barriers has been reported as one of the key issues explaining the decline of these species. Specifically, numerous pumping stations, weirs, sluices and flap gates have been built in the last century for flood protection, water level control, water diversion, the maintenance of polder areas and for use as water power.



The dramatic decline of eels recently turned this issue into a hot topic throughout the European Union. The increasing pressure on water resources and flood protection, e.g. due to climate change, will boost the need for flood protection barriers and controlled water evacuation in future decades. Consequently, the relevance of dealing with our migration barriers is growing, and knowledge exchange is crucial to allow others to learn from our mistakes. Specifically, although only 2 % of the world's land area is less than 10 m above sea level, about 10 % of the world's population is located in this area and thus flood protection and water evacuation issues, linked with the minimization of their ecological impacts on migratory fish populations, are of worldwide relevance. Countless studies report the impacts of migration barriers on migratory fish populations by increased predation, habitat loss due to impoundment, changes in the water quality and fish damage.

Most barriers block upstream migration of fish to their spawning sites (anadromous fish species like salmon, river lamprey and sea trout) or to their growing habitat (catadromous species like eel). Some barriers like pumping stations and hydropower plants may also limit downstream migration of anadromous and catadromous fish species to the sea, which is their respective growing and spawning habitat. By blocking access to habitats crucial to fulfil their life cycle, barriers may severely impact the sustainability of migratory fish populations. Further, barriers partition habitats within a catchment by breaking up connectivity preventing migration of all fish species and thus obstruct valuable spawning, forage and cover habitats. For resident fish species , the reduced availability of habitats will rarely put the fish species at risk of extinction. However, the reduced availability of suitable habitats may limit a species' population size. Further, freshwater fish may get flushed out when tidal barriers are opened at low tide to allow gravity discharge of freshwater.

The relatively slow reaction time of fish populations to the cumulative and synergetic effects of these impacts are difficult to study, but cannot be ignored. Due to the vast habitat area that are used by migratory fish species during their life cycle, migration barriers may also affect fish populations in the marine environment. Many coastal fisheries have suffered from substantial reduction in fish populations making them economically unviable. It should be recognized that many sea fisheries are dependent on the nursery areas provided by our estuaries and transitional waters for their sustainability (e.g. bass, sole, flounder). The knock-on impact can also be realized throughout the food web on other marine species that predating or are predated on by fish. Although the severity of the impact of any individual barrier may be related to their location in a river catchment, migration barriers create a continuous threat for migratory fish species particularly when taken in accumulation in the North Sea region.

Concern for migratory fish species is reflected in national, European and worldwide legislation which aims to reverse this trend, such as the Water Framework Directive, the Habitats and Eel Directives, and the International Convention on Biodiversity. Finally, we all have the responsibility to look after our local environment for now and future generations.

1.1.2 Why do fish migrate? [1]

Fish migrate because alternative habitats better suffice their needs for reproduction, for survival during critical seasons with e.g. too high or low temperature, or for growth. The distance of migration varies between species, within populations of the same species or even within one population of a species. There are also different types of fish migration that can be classified on a spatial and a temporal scale. On a spatial scale, some long-distance migrations involve movement of fish between freshwater and the marine environment and can involve distances of thousands of kilometres and prolonged residence in both habitat types. More typical is the 'seasonal movement' of fish in order to move between necessary habitats, for example between winter refuges and spawning or nursery habitats. Sometimes fish swim large distances when looking for food, depending on the food demand of the species, the population size, the availability of food and the schooling behaviour of the species. Other migrations are on a smaller scale, for example 'daily movements'. These occur in all habitats as fish move between refuges and feeding areas.

On a temporal scale, daily migrations between day and night refuges are also common, often involving small distances from open water to the riparian zone. Seasonal migration of fish is sometimes extensive but can be manifested in an irregular way. The exact migration period can vary each year, as it is stimulated by internal and/or external physiological change and by external factors such as changes in light level, hydrology, water quality or temperature. Other fish movements that do not necessary occur on a daily or seasonal basis could be classified as 'dispersion'. Dispersion defines migration undertaken to escape threatening environments such as water pollution, high water temperatures, low oxygen concentrations, high- and low river discharges, drying out of river sections, high population densities, low food availability or the presence of predators. Free interchange between small populations or sub-stocks is necessary to avoid inbreeding. Small isolated populations are vulnerable to local extinction, even when the environment is appropriate. Dispersion makes it possible to enlarge the habitat and to colonize new waters. As such, dispersion is driven by all circumstances that affect the survival of fish populations directly. In contrast to daily and seasonal migration, however, dispersion is a local population-scale phenomenon rather than a reference to migrations of individual fish. Consequently, dispersion does not necessarily occur at a daily or seasonal basis, but is more related to the temporal resolution of the circumstances that drive dispersion.

During its life cycle, a fish may undertake various daily, seasonal and dispersional migrations at different spatial scales. The interaction between internal and external factors determines whether a fish will migrate or not. For most fish species peak migration occurs in the period shortly before spawning. Subsequent horizontal dispersion of freshwater fish larvae occurs mainly in late spring and early summer. Other dispersal movement depends on external factors and can occur at any time during the year. Downstream migration as part of juvenile dispersion mainly takes place during the night, partly as a predator-avoidance response but also because juvenile fish have not yet fully developed their mechanism for orientation. In this report the term 'fish migration' is used for seasonal movements, daily movements and dispersion. Under this definition all fish migrate.

Based on migration behaviour, fish can be divided into potamodromous and diadromous groups. Potamodroumous species live in fresh water and migrate over local to regional distances. Migration can be lateral, from river to floodplain, or longitudinal from river mouth to small running waters upstream. Diadromous species migrate during their lifecycle between saltwater- and freshwater habitats. They can be divided into anadromous, catadromous and aphidromous species. Anadromous species like Atlantic salmon, sea lamprey, Atlantic sturgeon and the shads reproduce in fresh water and migrate to the sea where they grow to the adult stage. As an adult they migrate for spawning back to fresh water, often homing very specifically to their birthplace. The catadromous eel enter freshwater as juveniles where they grow to maturity prior to their return migration to salt water for spawning. Amphidromous species like flounder, herring and mullet are marine species that can also stay in fresh water, their migration occurring for refuge or feeding.

1. Gough, P., P. Philipsen, P.P. Schollema & H. Wanningen, 2012. From sea to source; International guidance for the restoration of fish migration highways.

1.1.3 Need for international cooperation

The North Sea region as defined by INTERREG funding consists of 7 countries, each country facing similar migration problems for fish species that rely on moving between the North Sea and freshwater systems. Further, many fish species use waters of multiple member states during their life. Consequently, working on a transnational scale could make the difference between success and failure but may also save money through efficiency and avoiding unnecessary work. For example: sea trout, a species of great economic and social importance to most North Sea countries, may uses coastal habitats of many countries. We know that fish tagged in Scotland are caught in nets in Denmark. It is therefore impossible to manage the populations of Scotland, without the co-operation of authorities in Denmark. This may be the case for many rivers and countries, and thus we need to understand these relationships before we can tackle the correct issue.

A second problem relates to the continued threat for migratory fish in freshwater ecosystems. This includes artificial barriers, pollution and habitat loss. These problems will be worsened by the anticipated increasing pressures from flood management, renewable energy generation and agriculture. These pressures are essential for European development and will go ahead, therefore we need to address how best to restore our migratory fish around these pressures, on a North Sea regional scale. Despite knowing some of the possible solutions to these problems, implementation is not straightforward and not widespread, particularly due to the perceived ‘disproportionate cost’ of the work required by other sectors. By looking at this problem in a transnational way, we will be able to prioritize important areas for key species, and make recommendations for local solutions. Therefore, strong cooperation and knowledge exchange on fish migration matters is key for achieving sustainable integrated water management.

1.2 Goal of the project

The Living North Sea project has been constructed to solve the problems surrounding the management of migratory fish species in the North Sea region. The aim of this project is therefore to use Sustainable Coastal Zone Management techniques for key migratory species of the North Sea countries, share existing knowledge between countries and sectors on populations and migratory routes, to identify the essential gaps in knowledge that we must answer. Collaboration to implement work efficiently will answer these essential questions. Living North Sea assessed the status of migratory fish species in the North Sea region, identified the main pressures that will need to be addressed in coastal and inland zones and made recommendations for solving them.

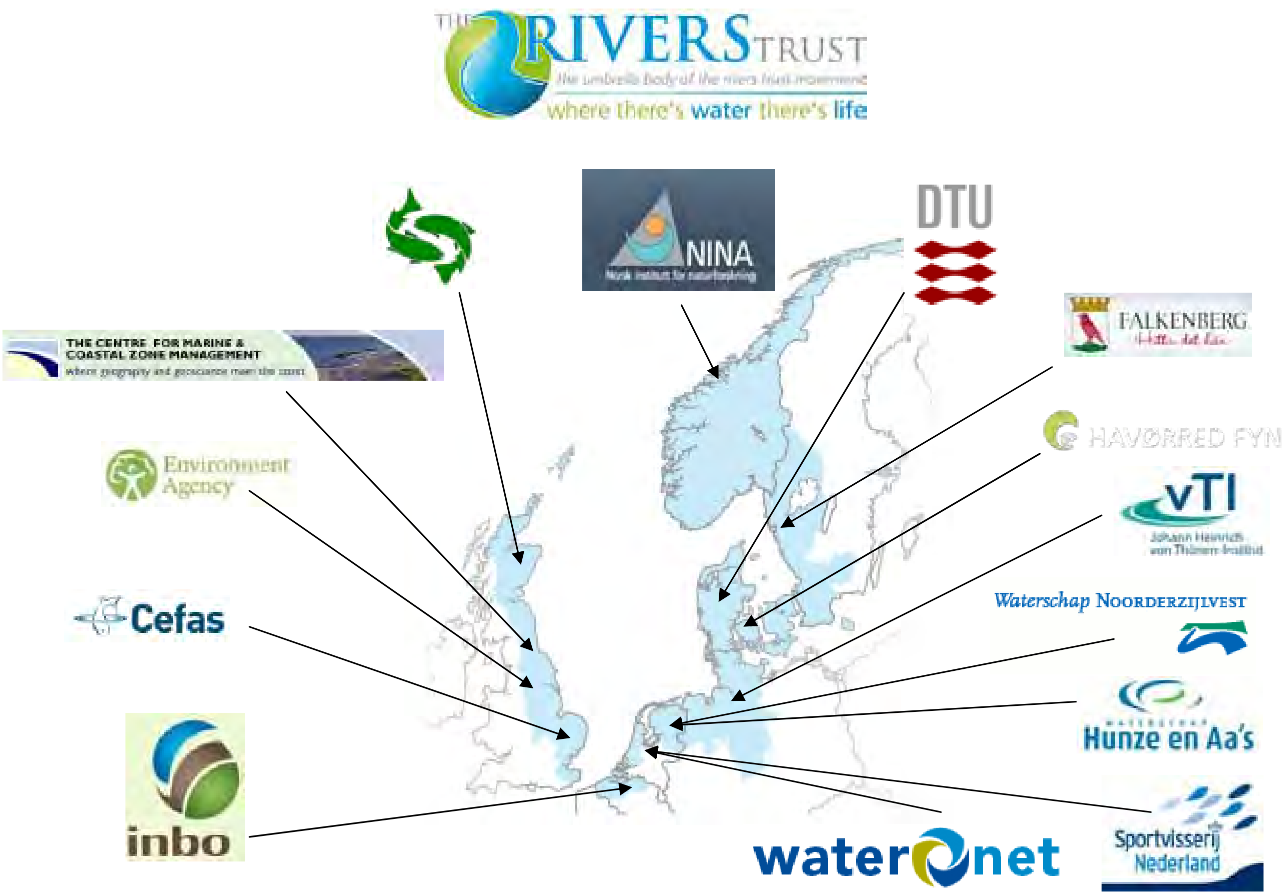
Living North Sea stimulated and facilitated data and knowledge exchange between partners and countries within the North Sea region. The project also included several large-scale communication actions on fish migration problems and innovative solutions, such as Fish Migration Day, hence stimulating public awareness of the problem. Finally, policy recommendations on the restoration of migratory fish populations have been defined to ensure that the results of the Living North Sea project will be firmly integrated into future national and European policies.

Actual opening of tidal sluice on River Nene as part of LNS “Fish Migration Day” the first time ever the barrier had been opened to allow fish migration

1.3 Organizations involved

Living North Sea consists of 15 partners from the 7 countries in the North Sea region:

- The Rivers Trust (lead partner, UK)
- Environment Agency (UK)
- The Tweed Foundation (UK)
- The Centre for Marine and Coastal Zone Management (UK)
- Centre for Environment, Fisheries and Aquaculture Science (CEFAS, UK)
- Regional Water Authority Hunze en Aa's (RWA H&A, NL)
- Regional Water Authority Noorderzijlvest (RWA NZV, NL)
- Regional Water Authority Waternet (NL)
- Dutch Angling Association (NL)
- Research Institute for Nature and Forest (INBO, B)
- Johan Heinrich von Thünen Institut (D)
- DTU Aqua National Institute of Aquatic Resources (DK)
- Seatrout Fyn (DK)
- Falkenberg Municipality (S)
- The Norwegian Institute for Nature research (NINA, N)



Distribution of the 15 Living North Sea partners over the 7 countries of the North Sea region.

1.4 Set up work package ‘Innovative solutions to fish migration problems’

This report describes the results of the work package “Innovative solutions to fish migration problems” within the Living North Sea project. The objectives of this work package were: 1) to identify the important challenges and bioregions for Sustainable Coastal and Inland Zone Management for migratory fish, 2) to develop best practice solutions to fish migration and 3) to make recommendations for the integration of best practice solutions in EU, national and regional policies and across multiple sectors.

Although the threats for migratory fish species are multiple, Living North Sea focused on three critical issues: tidal barriers and pumping stations, hydropower and habitat quality. Tidal barriers and pumping stations have been identified as major migration barriers in the North Sea region, especially in lowland areas. Despite a long tradition of hydropower in the North Sea region, many questions regarding the impact and adequate mitigation measure of these hydropower schemes on migratory fish remain unanswered.

Recently small-scale hydropower plants are increasingly being built in lowland areas of the North Sea region in response to European Union targets on low carbon energy production and in response to government incentives to facilitate this. Local security of energy production is also a factor. Consequently, it is crucial to assess the impacts of these small-scale hydropower plants on migratory fish species so licensing authorities can be confident of complying with European environmental legislation and therefore to make sure long term negative impacts on ecosystems are prevented. Finally, even in a river without migration barriers, poor habitat conditions may limit migratory fish populations. Therefore, several best practice projects demonstrating habitat restoration for migratory fish species are included in this report.

In summary, this report includes best practice examples of various innovative solutions to fish migration problems, with a particular focus on tidal barriers and pumping stations, hydropower and habitat restoration. Although these solutions are all located in the North Sea region, they may be relevant for fish migration problems and rivers worldwide and thus of interest to a wide range of river managers, stakeholders and policy makers.


Tagging of a River Lamprey as part of the telemetry study in NE-Netherlands (RWA Hunze en Aa’s)”

2 - Tidal barriers and pumping stations

SECTION SUMMARY

- The history of tidal barriers in the North Sea region
- Types of tidal barriers, impact on fish and the scale of the problem in the North Sea region
- Potential solutions
- Policy recommendations

2.1 Why do we have tidal barriers and pumping stations?

2.1.1 Historical development of tidal barriers and pumping stations

As soon as man started adapting their environment, rivers have been modified. Modification would likely have had little or no impact during the switch from hunter/gatherers to farming because of the limited population. It was not until the middle ages that river engineering really started to change the riverine habitat on a large scale. Straightening and dredging had only limited impact, but by the 17th century land drainage was increasingly practiced to increase crop yields and to make more flat land available for agriculture. Land reclamation was first practiced in the low countries and by the 1730's Dutch engineers were exporting their skills to other countries, notable England with the reclamation of the Wash and the East Anglian coast. The process usually involved some or all of the following techniques: straightening, dredging, creation of flood banks and techniques to discharge water to control water level.

This facilitated the drainage of land throughout the year but it also had an unforeseen consequence. As the land became drier the underlying peat layer dried out leading to shrinkage, which lowered the land. Flooding and siltation of the drains once more became a problem. As the technologies did not exist to dredge or straighten anymore, engineers sought other solutions like increased height of flood banks and closure of side tributaries with wooden flap gates to prevent tidal inundation.

The following pictures show examples of rivers with a water level that is higher than the surrounding land in different countries of the North Sea region. After centuries of intensive draining and building of flood banks, the floodplains are lower than the normal river levels. The surrounding land started to sink as the peat dried out.

The River Westerwoldsche Aa in the North-eastern part of The Netherlands

The River Hunze in the North-eastern part of The Netherlands

Flood bank on River Trent, UK showing how much higher the river is in relation to the surrounding land

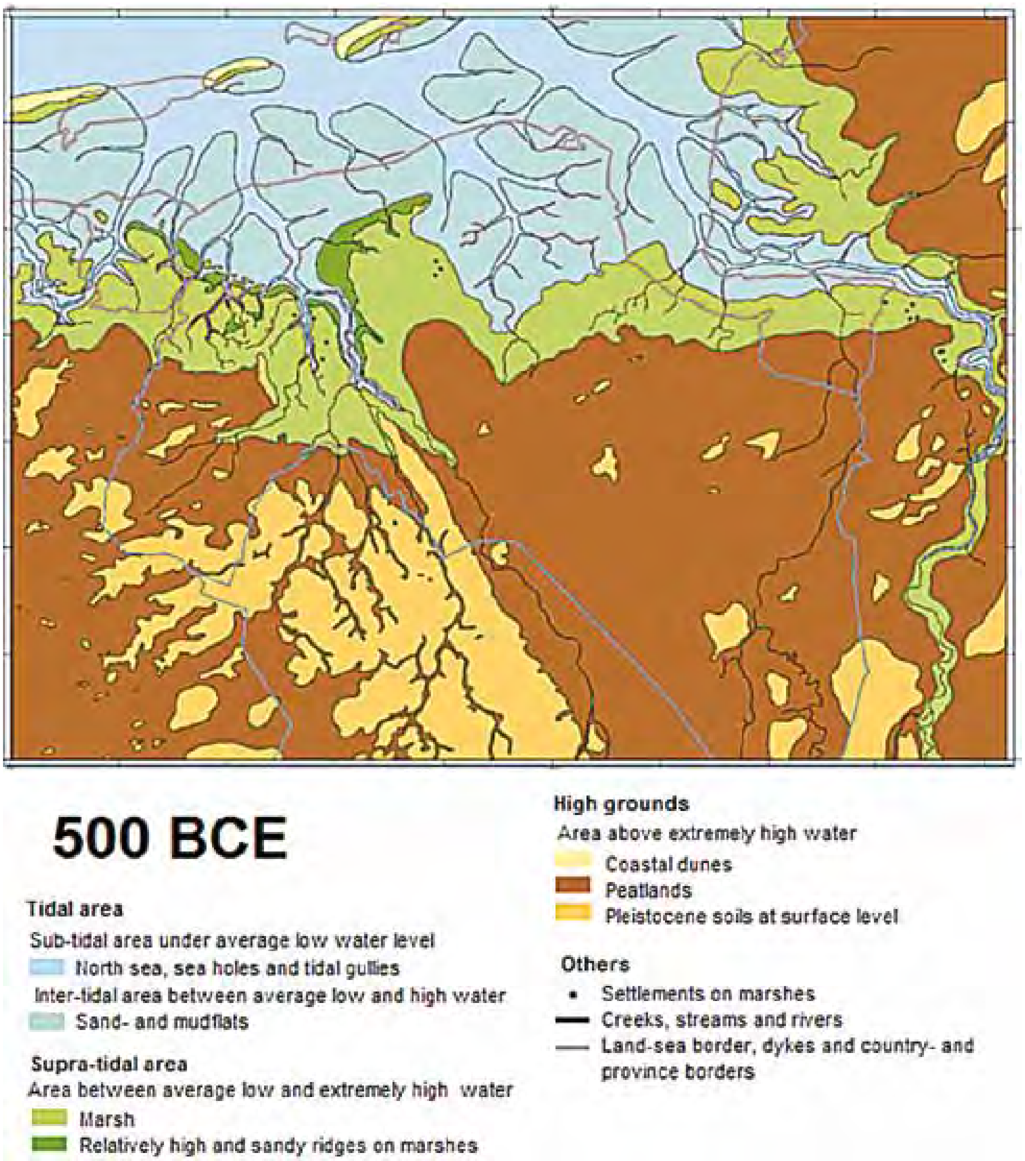
Fleet Outfall, River Trent UK, in flood conditions showing how tidal defences disconnect the river from its floodplain

The River Yser in Flanders, Belgium

For a long period gravity discharge was used to continue draining the land and flushing (allowing water into the drainage channels) to provide water for irrigation. The by-product of flushing was free fish passage at certain periods of the year, meaning that despite drainage, fish stocks remained relatively healthy. Despite all this the shrinkage process continued and gravity discharge became more and more inadequate. Consequently, further solutions were developed to accelerate water discharge. These solutions included wind (windmills) or horse driven pumps that operated infrequently and rotated at low revolutions so fish that entered them often passed through unharmed.

This situation continued until the industrial revolution when the technology for massive improvements in the efficiency of pumps were possible in the form of steam driven pumps. This allowed a fundamental change in agricultural intensification and productivity and the expansion of urban development into low lying areas that previously would not have been accessible because of seasonal or occasional flooding. By the 20th Century diesel pumps had replaced steam pumps and following the World Wars populations were growing. The need for increased agricultural productivity was nationally supported by governments and better and more efficient pumps further accelerated land drainage. This is probably the period when most migratory fish species that use both salt and freshwater habitats would have started to decline because of connectivity issues and mortality through the pumps.

Historical map[1] of the province of Groningen (NL) The difference between the original and current coastline (grey line in the map) is clearly visible. Many of the originally open connections have been closed down. (Vissenatlas Groningen Drenthe, 2008).



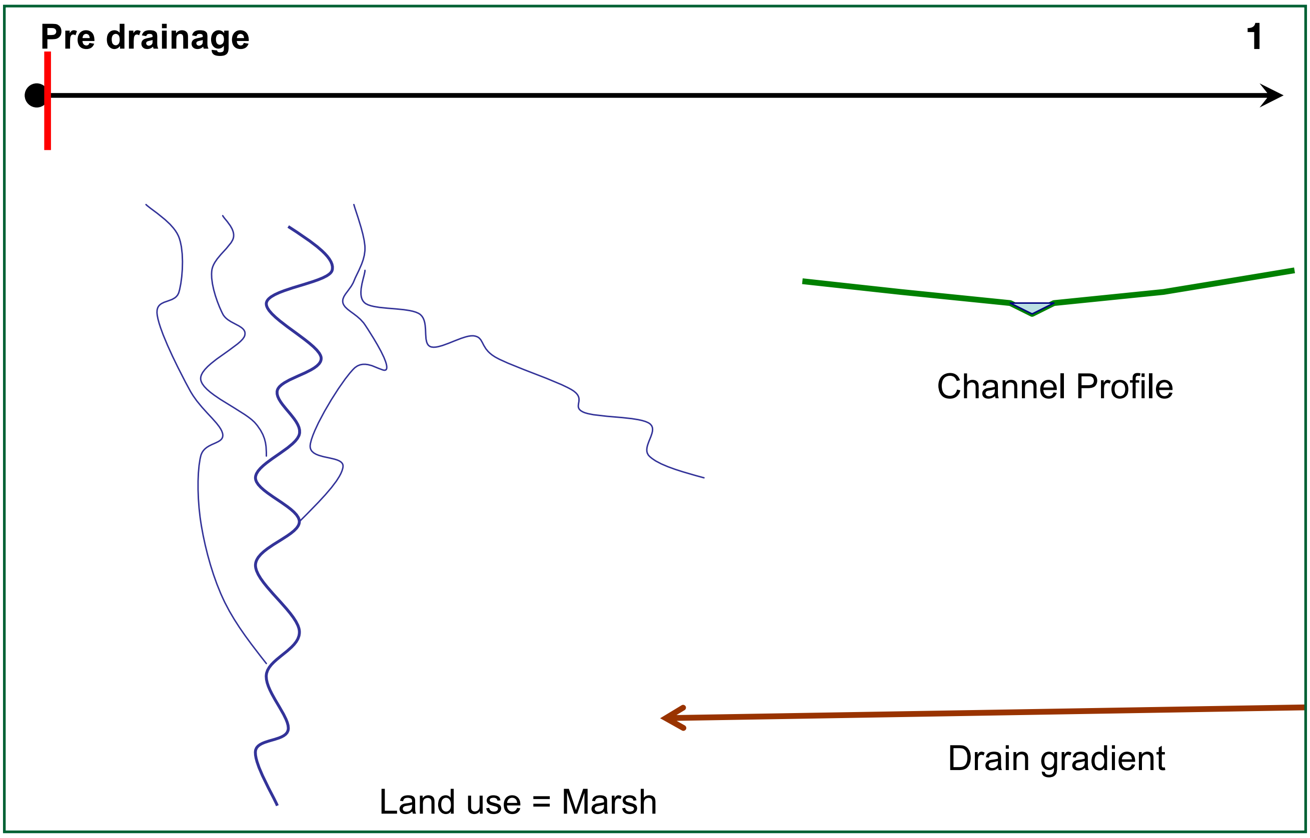
1. Brouwer, T. B. Crombaghs, A. Dijkstra, A.J. Scheper en P.P. Schollema, 2008. Vissenatlas Groningen Drenthe. Uitgeverij Profiel Bedum.

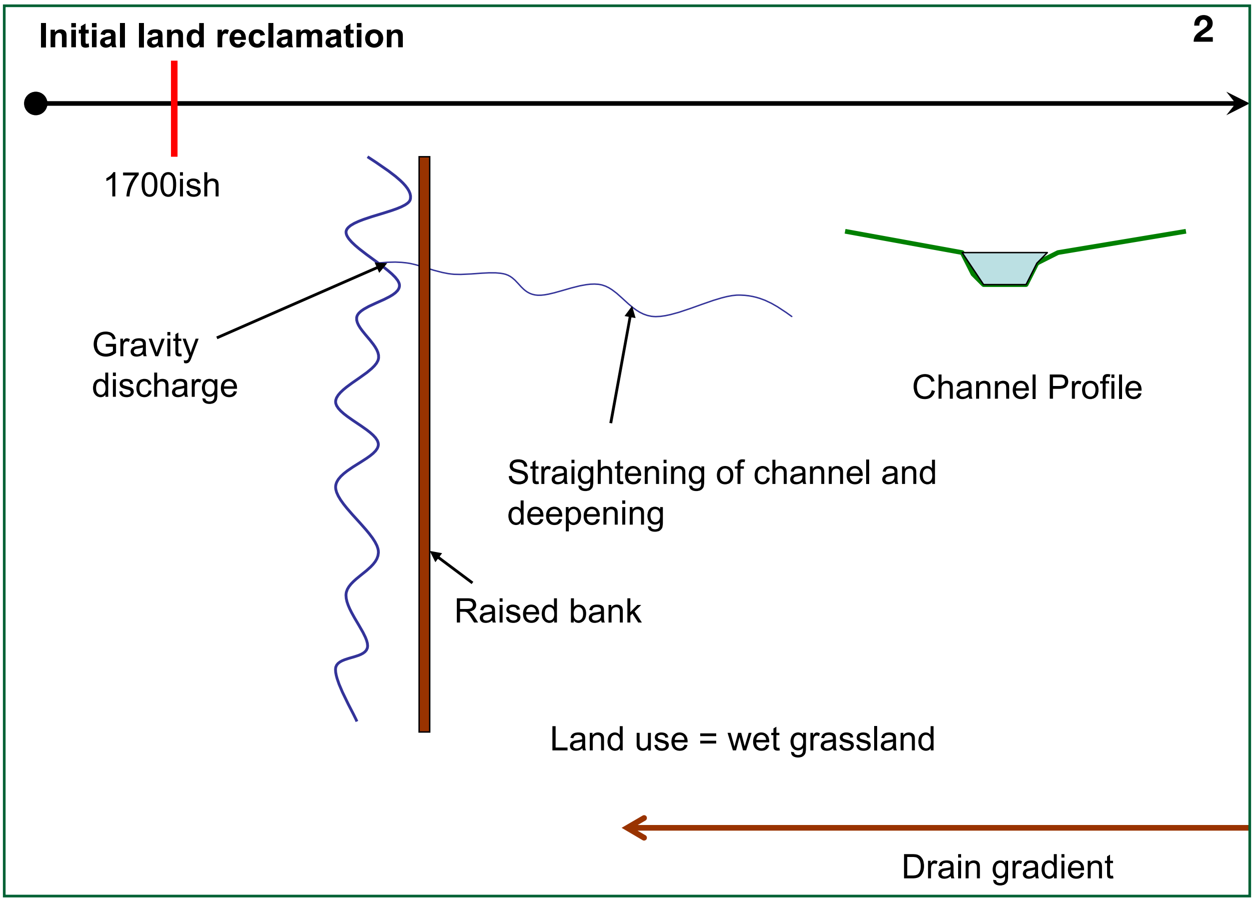
Laughton High Drain, River Trent UK, Showing river Trent significantly higher than surrounding floodplain

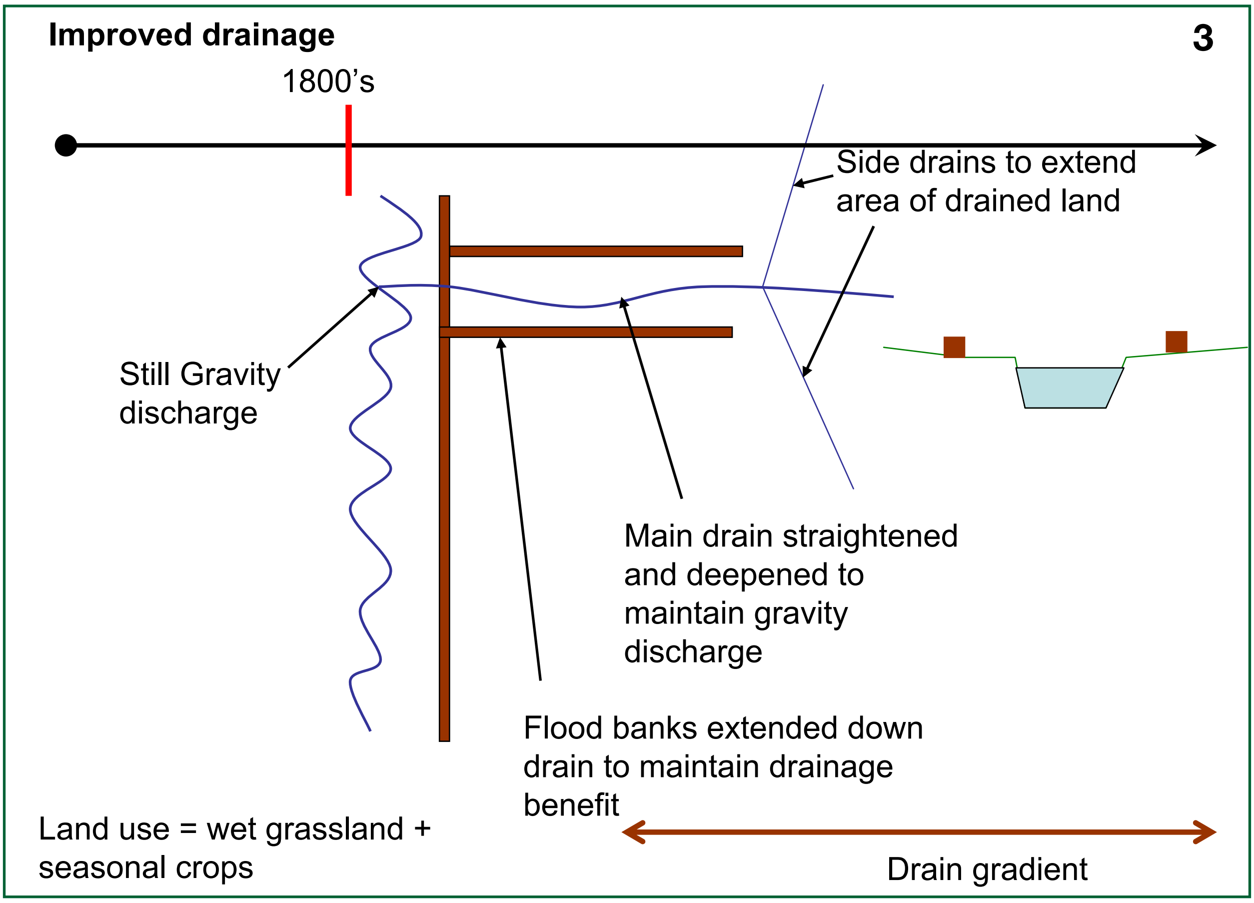
By the 1950s electricity was being adopted as the power source and this led to the automation of pumping stations and in many cases the final loss of fish connectivity with the main river. Flushing was lost and replaced by pumped bore holes or pumped irrigation techniques which resulted in significant reduction in the manpower employed to operate the pumps and drainage structures. Migratory fish species were effectively doomed.

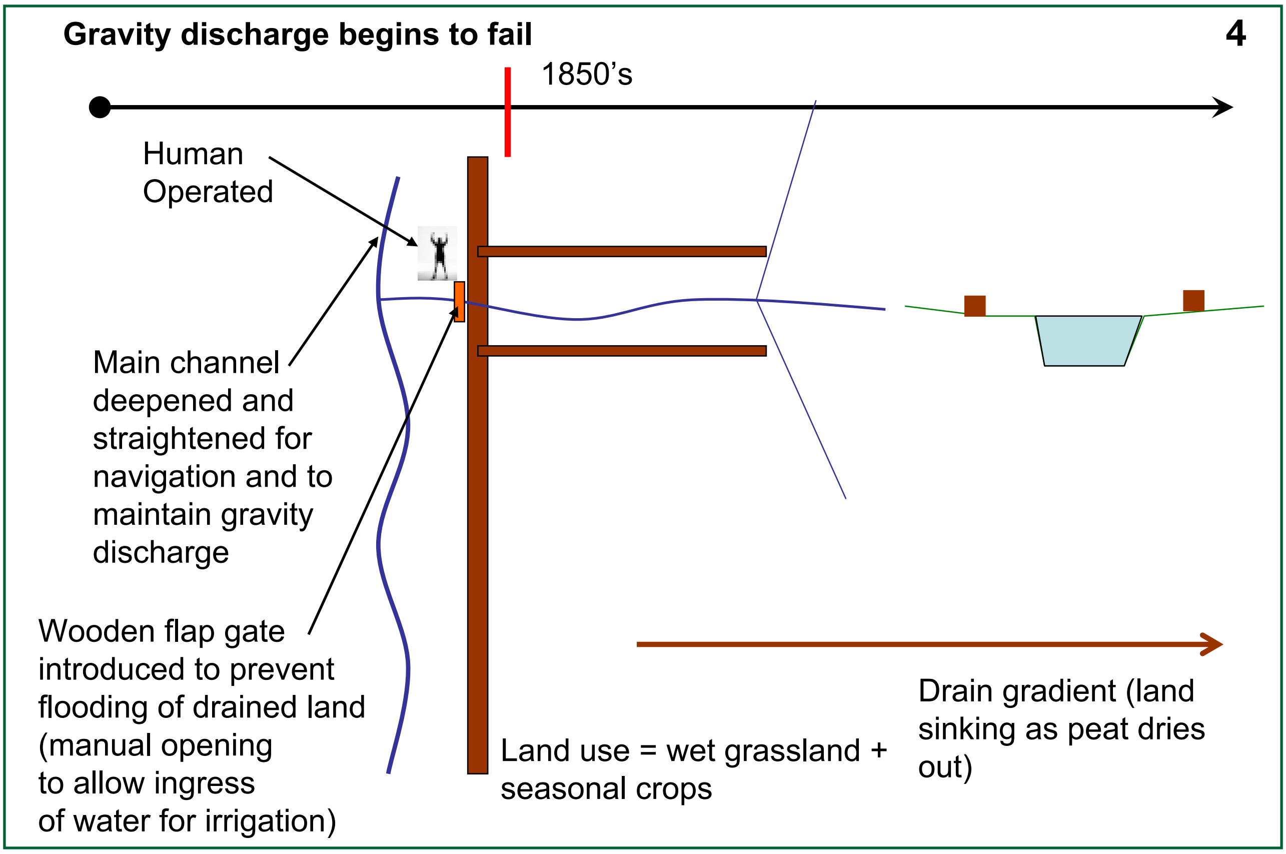
After many centuries of land drainage, shrinkage and subsequent dredging, the main rivers stems were often many meters above the surrounding land. This land could only be kept drained by separating the agricultural zone from the original river and kept dry by automated pumps. This resulted in practically all the tributaries being completely sealed off from their natal rivers, finally cutting off many hectares of productive fish habitat. The resident fish that remained in these sealed systems were then further endangered by lack of diversity in the habitat, inappropriate water level management, pollutions and mortality if they come into contact with the pumps. In many cases diadromous fish stocks practically disappeared from these drainage structures. The whole process is illustrated in the following diagrams:

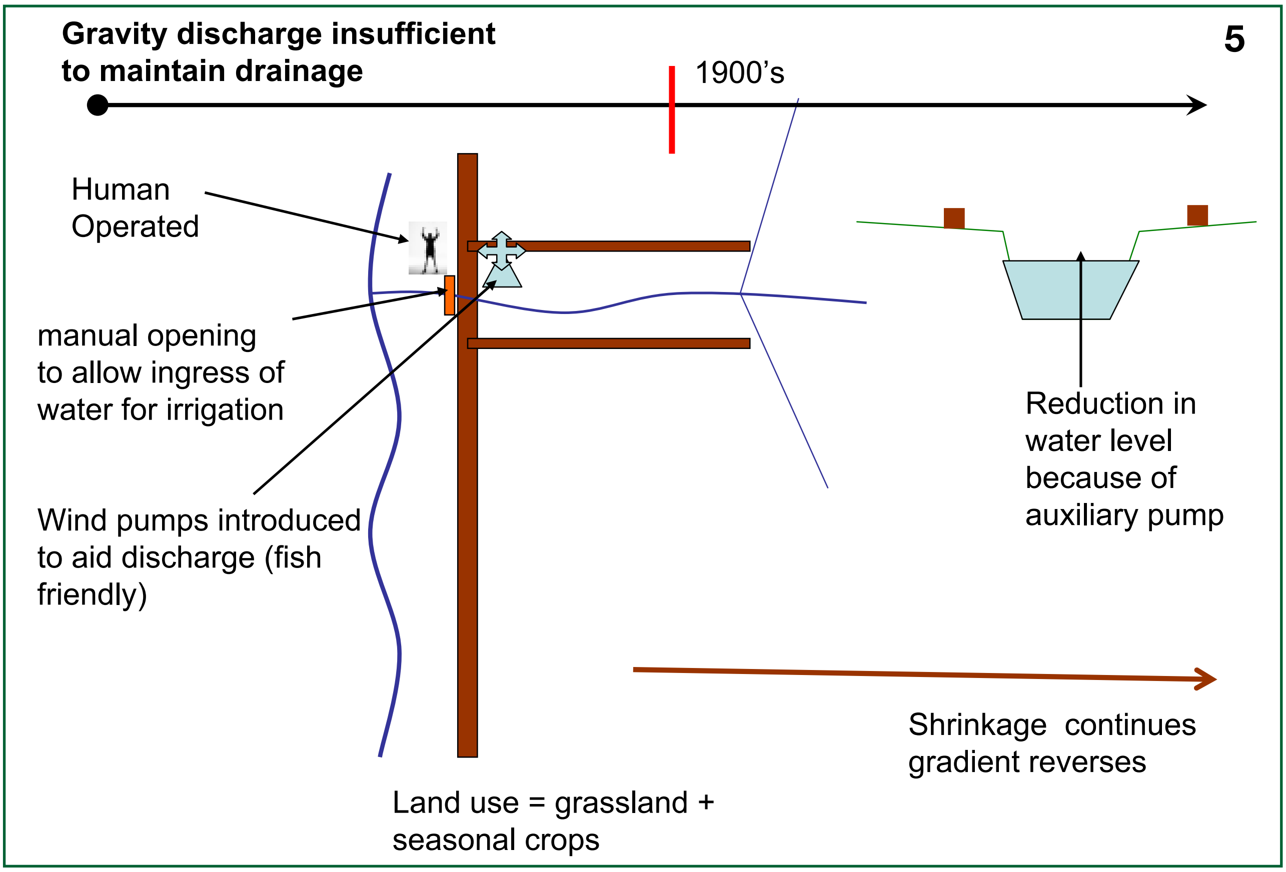
The evolution of free rivers to one totally disconnected from its floodplain

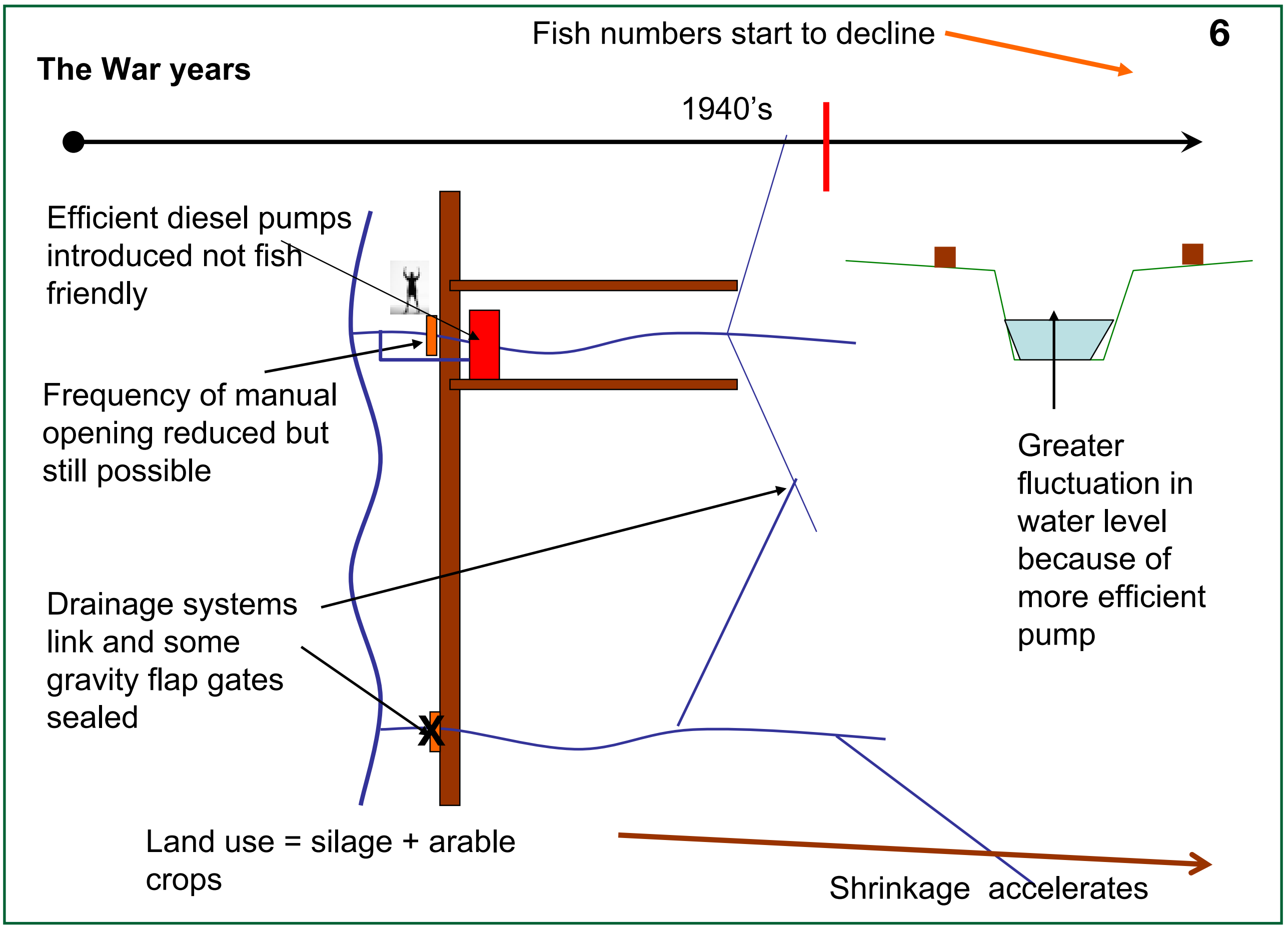


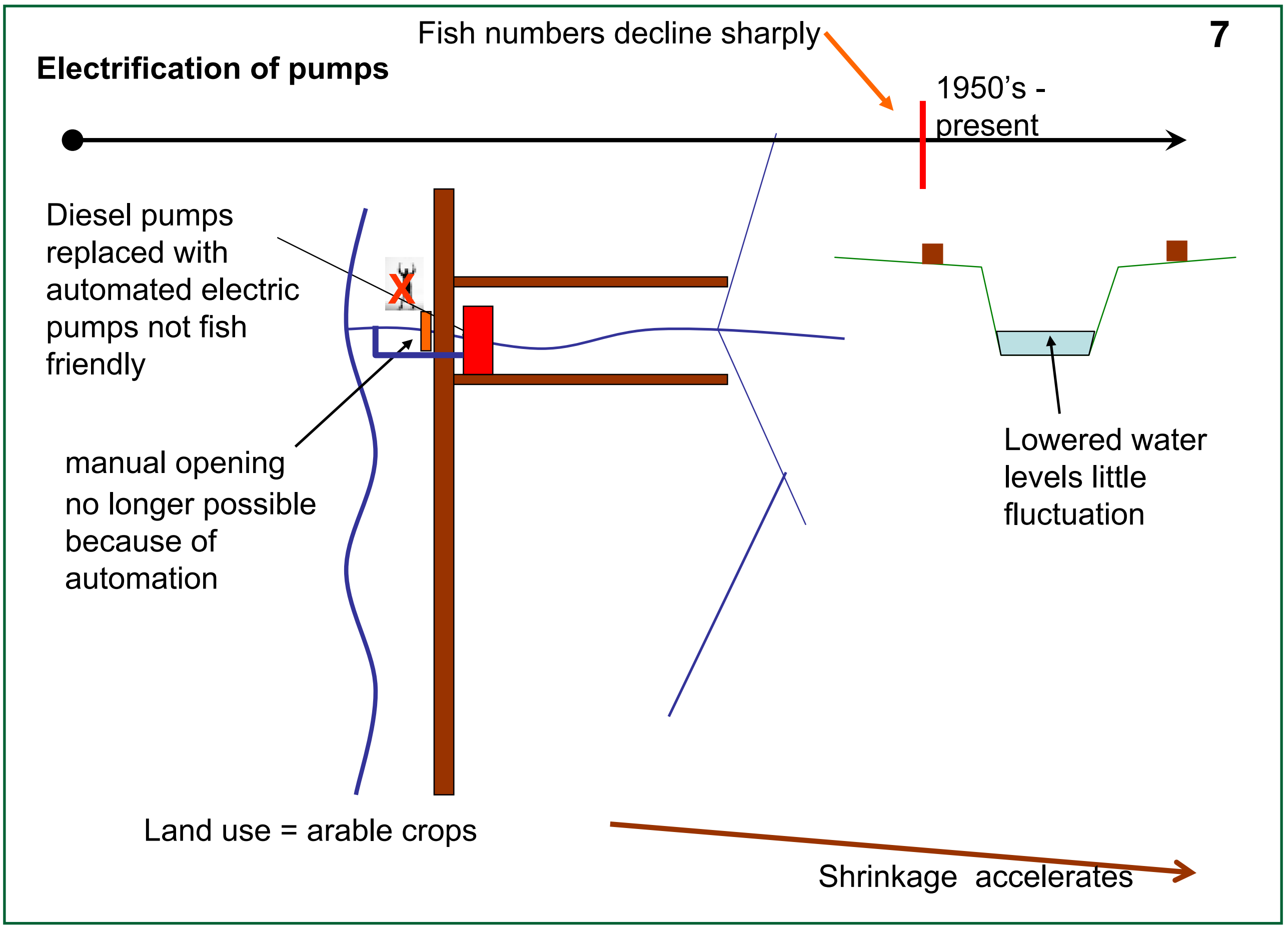

Initial land reclamation
2
1700ish
Gravity
discharge
Straightening of channel and
deepening
Channel Profile
Raised bank
Land use = wet grassland
Drain gradient


Improved drainage
3
1800's
Side drains to extend
area of drained land
Still Gravity
discharge
Main drain straightened
and deepened to
maintain gravity
discharge
Flood banks extended down
drain to maintain drainage
benefit
Land use = wet grassland +
seasonal crops
Drain gradient


Gravity discharge begins to fail
4
1850's
Human Operated
Main channel deepened and straightened for navigation and to maintain gravity discharge
Wooden flap gate introduced to prevent flooding of drained land (manual opening to allow ingress of water for irrigation)
Land use = wet grassland + seasonal crops
Drain gradient (land sinking as peat dries out)


Gravity discharge insufficient to maintain drainage
5
1900's
Human Operated
manual opening to allow ingress of water for irrigation
Wind pumps introduced to aid discharge (fish friendly)
Reduction in water level because of auxiliary pump
Shrinkage continues gradient reverses
Land use = grassland + seasonal crops


6
The War years
Fish numbers start to decline
1940's
Efficient diesel pumps introduced not fish friendly
Frequency of manual opening reduced but still possible
Drainage systems link and some gravity flap gates sealed
X
Greater fluctuation in water level because of more efficient pump
Land use = silage + arable crops
Shrinkage accelerates


7
Electrification of pumps
Fish numbers decline sharply
1950's - present
Diesel pumps replaced with automated electric pumps not fish friendly
X
manual opening no longer possible because of automation
Lowered water levels little fluctuation
Land use = arable crops
Shrinkage accelerates

2.1.2 Types of tidal barriers and pumping stations

The loss of gravity discharge not only entailed the need for drainage pumping stations but also for tidal barriers defending the land against the sea. Tidal barriers have taken many forms over the years but generally fall into one of the 3 basic operating criteria: weirs, tidal defences and / or pumping stations.

Tidal barrier "weir Herbrum" in the River Ems, Germany

(1) Weirs

Weirs are at the head of tide ending the zone between transitional brackish water and fresh water. Often these barriers do not provide hindrance to fish passage for many species as the water backs up over the structure and in some cases even reverses the flow. However some fish species like shad can be greatly impeded by such structures because of the way they wish to migrate in shoals and will only pass through laminar flows. Fish pass design is well understood for weirs and this is well described in the literature, but evaluation of passage efficiency is still poorly studied.

Eels migrating up a tidal weir on the River Severn. Picture courtesy of Peter Woods, UK Glass Eels

Cromwell Weir at head of tide on the River Trent, UK.
This weir forms the first barrier to fish migration unless inundated by spring tides

(2) Tidal defences

(Flapped outfalls, tilting weirs, tidal sluices, lifting weirs or tidal locks)

These are vertical structures that physically separate the freshwater and brackish environment. Water can pass through the structure by gravity when downstream conditions allow but when tide (tide lock) or fluvial discharge (during floods) will keep the structure shut to prevent inundation of the land, all connectivity is lost with the receiving watercourse. Depending on their position in the catchment, these structures can completely remove the intertidal habitat. Other tidal defences can be many miles inland such as the one found on the River Scheldt in Belgium, located 160 km from the river mouth. They are generally installed to prevent tidal flooding, allow land drainage or provide navigation routes. Depending on their design and operation, fish connectivity is not necessarily totally blocked but in most cases their presence significantly alters the habitat upstream. This can have advantages and disadvantages for certain fish species depending on their habitat requirements. In some cases the freshwater created upstream can become so important for certain species that it receives special legal protection for the communities it supports.

Wooden tidal flap gates, River Trent UK, passive operation

Tidal barrier, Noordzeekanaal IJmuide, Netherlands. Includes locks, siphons for gravity discharge and the largest pumping station in the Netherlands (max. 750 m³.s-1)

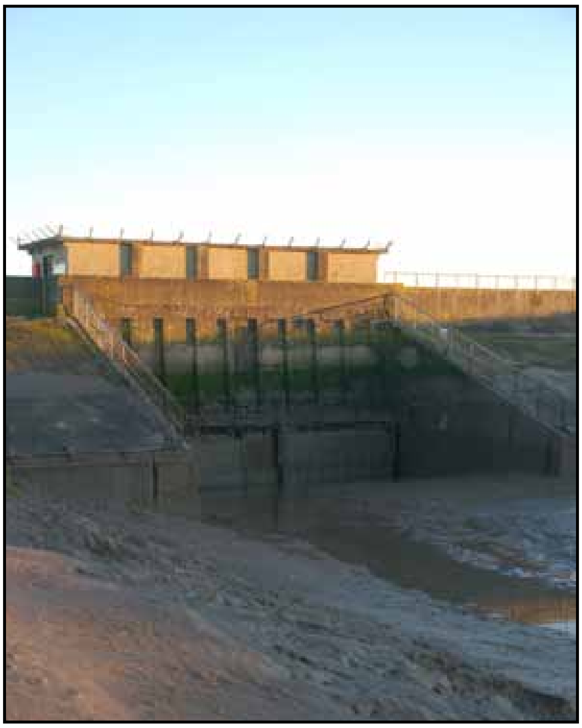
Tidal gate on the River Nene, Cambridgeshire, UK. This can be lowered to isolate tributary during tidal surges or fluvial flood event, mechanical operation

Tidal flap gate made from modern HDPE plastic, offers a light gate with better sealing over a wooden gate, light weight materials can be beneficial for fish passage as less water pressure is need to open them, but HDPE gates also seal better and have less opportunity for leakage that can make fish passage harder. Huntspill River, Somerset, UK

Round cast iron flap gates, Addlingfllet drain, River Trent, UK, passive operation

Even if fish can pass through the tidal flap gate, the culvert through the flood bank may act as a further migration barrier, example Burton on Staither, River Trent, UK

Pointing doors, tidal Trent, UK, passive operation



Large gravity controlled tidal flap gates, Huntspill Outfall, Somerset, UK, passive operation

Metal fluvial flap gates on the end of the River Chelt, UK, Passive Operation

Tilting weir, Somerset Level, UK, mechanically operated

(3) Pumping stations

(electric pumps, diesel pumps, windmills)

Pumps are often used in combination with the physical barriers described above. The pumps have generally been installed to improve land drainage (in response to land shrinkage caused by drying out of the underlying peat or underground gas removal) or to improve the level of protection from flooding associated with development. Depending on the situation the pumps can either be operated only occasionally or on an almost constant basis. Pumping stations at tidal defences for instance may only be operated in response to severe rain events or when gravity discharge through the defence (in 2) is insufficient or not possible. Most pumping stations in the low lying countries such as The Netherlands however are vital to drain areas where gravity discharge is not possible. They are operated on a regular basis and often discharge water in canalized rivers or artificial watercourses (sometimes km in length) to transport it to a central location for final removal over coastal defences.

Pumping stations may be equipped with different types of pumps. Traditionally windmills with water wheels were very common. In more recent pumping stations the pump types are often: Archimedes screw pumps, vertical screw pumps, centrifugal pumps or mixed flow pumps. The degree of damage to fish only partly depends on the type of pump (see section 2.2.3).

Pumping Station Naardermeer NL.
A traditional windmill with water wheel is still being used to control the water level

Barriers are present throughout Europe and are known under different names.
The table below shows the common names of several European Countries for these barriers.

English	Dutch	German	Danish	Norsk	Swedish
Tidal sluices	Spuisluizen	Sielbauwerk	Tidevandssluse	Tidevannssluse	Tidvattenslussar
Tidal locks	Zeesluizen	Seeschleuse	Sluseporte	Tidevannsport	Tidvattenportar
Tidal exclusion gate	Stormvloedkering	Sperrwerk	N/A	Reaktive tidevannsbarrierer	Tidvattenspärr
Pumping stations	Gemalen	Schöpfwerk	Pumpe stationer	Pumpestasjon	Pumpstationer
Tidal flap gates	Terugslagkleppen	Stauklappe	Højvandsklapper	Tidevannsklaffedører	Tidvattenklaffdörrar
Tidal Weir	Getijdenstuw	Tidewehr, Gezeitenwehr	Højvandssluse	Tidevannsdemning	Tidvattenfördämning

Isabella pumping station on the Leopoldkanaal in Boekhoute, Flanders, Belgium

Pumping station Hongerige Wolf in the North-eastern part of The Netherlands

Spiedam pumping station on the Averijevaart in Flanders, Belgium

Pumping station Ennemaborgh (The Netherlands), fitted with two specially adapted fish friendly Archimedes screws

2.2 Why are tidal barriers a problem? Why should we care?

2.2.1 General impacts [2]

Human development over the centuries has put a huge pressure on natural ecosystems. During the industrial revolution the impacts of this development were either not known because of poor understanding of fish biology or fish species loss was seen as an acceptable price to pay for the benefits and profits of such development. There are numerous examples of fish that have been made locally extinct by man's hand either from the creation of physical barriers or declining water quality. These include the loss of salmon from many of the rivers in the low lying countries around the North Sea region, such as the River Rhine and its tributaries, River Trent and many of the rivers that flow into the Humber estuary. Sea trout are believed to have been lost from Norfolk, the rivers that flow into the Wash and throughout Belgium and The Netherlands. Species loss or significant decline has not just occurred for salmonids. Historic fisheries for shad, smelt, lamprey and sturgeon have also been lost. Today we are particularly worried about the state of the European eel stock which has led to a species-specific EU directive for their protection throughout Europe.

The common thread in all this is that all fish species migrate (not just the iconic species that perform long distance migrations e.g. salmon & eels) at some point to complete their life cycle. We are learning all the time about fish biology and discovering many previously unknown fish migration strategies. However, often the impact of anthropogenic influences only becomes clear until the species has declined or become extinct. If at any point these migrations are disrupted, a life cycle "pinch-point or bottleneck" occurs that will ultimately result in suppressed or unsustainable fish populations.

With greater understanding has come public engagement, political intervention and now a host of pan European legislation and directives (e.g. Water Framework Directive, Habitats Directive) aimed at protecting our valuable ecosystems. The drivers for this protection are rarely just ecological considerations. We now recognize the importance of ecosystem management and the economic benefits it can derive both locally, regionally and for whole countries. Within the LNS project the economic importance and benefits from fish migration have been an important driver for some partners (such as the Municipality of Falkenberg (S), Seatrout Fyn (DK) or the Tweed foundation(UK)) to join the LNS project. Economic research has shown that communities value their environment and that it contributes to people's sense of wellbeing as well as financial rewards. Economists have shown that you can put a financial value on the environment through Willingness to Pay experiments and this has provided the evidence for more sustainable development that benefits the whole not the few. A socio-economic valuation of European eel, Atlantic salmon and Sea trout in four pilot areas around the North Sea Region was conducted as a Living North Sea project (Marchal, 2012). Economics can also have the power to accelerate habitat loss through the distorting the balance between financial and ecological considerations. These incentives could take the form of agricultural subsidies for particularly crop production (e.g. biofuels) or by the payment of tariffs to encourage "green" energy sources such as hydropower. Often different government policies and incentives are not compatible with each other and a balance has to be struck through informed debate. However, the goal must be for sustainable development that does not impact on the rights of future generations through the overuse of precious resources today.

In most cases the loss of a fish population is not just caused by one factor, but multiple causes, many outside the control of any particularly member state. However, in practically all cases the loss of access to important habitat or habitat destruction plays a significant part. More importantly these are the factors that member states can address if the following are available: political will, public engagement and a technological solution. The LNS project aim was to influence all three of these in regard to habitat access and restoration.

2. Marchal, J., 2012. Socio-economic valuation of European eel (Anguilla Anguilla) Atlantic salmon (Salmo salar) and sea trout (Salmo trutta trutta) in four pilot areas around the North Sea Region. Final Thesis Environmental Science. Van Hall Larenstein, Groningen.

2.2.2 Impacts of tidal barriers on fish

During their lifecycle fish need to face many different types of barriers that block their migration possibilities. Although there are dozens of different types it is still possible to distinguish 5 main types that are described in the table below. These types can be categorized under the aforementioned three categories of tidal barriers: tidal weirs (either reactive or not), tidal defences (tidal sluices, tilting or lifting weirs, tidal locks, tidal flap gates) and pumping stations.

Despite numerous studies on fish passage, this topic is still poorly demonstrated in many types of barriers, incl. tidal weirs and pumping stations. Specifically, a lot of the literature is grey and also in national languages. Further efforts should lead to standardised and widely accepted monitoring protocols to carry out fish passage studies properly, which could result in reliable peer reviewed studies. Finally, the effects and benefits of solutions to fish passage are often poorly demonstrated to a wider audience. As shown in the LNS project, international knowledge exchange may help to overcome this problem.

Type	Description	Fish passage opportunity	Why were they installed historically?
Tidal exclusion gates	Either a barrier that rises from the river bed or is lowered from and up and over gantry to seal of river during tidal surge. Normally also excludes vessel movement: once tidal flood risk has passed barrier is removed and normal intertidal conditions return.	**NORMALLY FREE FISH PASSAGE** as barrier only operates on extreme events.	modern structures as not technically feasible until modern hydraulics.
Tidal sluices and tilting / lifting weirs	Concrete structures with movable doors/flaps made out of wood or steel. Now more likely to be constructed of steel or HDPE which forms a tight seal preventing fish passage. Water is discharged by gravity underneath or over the structure (tilting weir) by raising and lowering, depending on tidal conditions	**VARIABLE OPPORTUNITIES** There is limited hindrance for many species in situations where water regularly backs up over the structure and in some cases even reverses the flow. At other locations water is only discharged by tidal sluices or tilting/lifting weirs and fish passage will then be excluded by tight seal, water velocity at interface and timing of operation	flood protection, agricultural drainage
Tidal locks	To facilitate vessel movement from sea to freshwater for transport of goods, often associated with ports, harbours or inland waterways.	**LIMITED OPPORTUNITY** Fish passage limited to accidental movement during vessel movement. Water velocities at times suitable but length of opportunity may limit certain species	Existed for centuries to allow movement of vessels between freshwater/saltwater while also providing sufficient depth to allow onward movement.
Tidal flap gates	Historically constructed in wood but now more likely to be metal or HDPE. These gates are either top or side hung and are normally in a partially closed position because of gravity. Seal totally on increased water pressure as the tide rises.	**LIMITED OPPORTUNITY**	Flood protection, agricultural drainage
Pumping stations	Pumping station used as the only method of removing water or in association with gravity discharge. They can also be used for either discharge excessive fluvial flow or to allow land drainage for agricultural or urban of low lying land even at levels below sea level e.g. polders NL/B or The Wash or tidal Trent in the UK.	**NO FREE PASSAGE + FISH DAMAGE**	Flood protection and land use

2.2.3 Specific attention to the impact of pumping stations on fish [3]

In recent years several studies have been done in the North Sea region on the effect of pumping stations on fish migration. These studies show that the damage and fish mortality rate caused by pumps and can vary greatly between different (kinds) of pumps. Even within one type of pump large differences in fish damage were found in different tests. Nevertheless there are some general conclusions and lessons learned from recent studies as described below.

In many pumps there is a significant positive relation between the length of fish and the amount of damage. The larger the fish the more damage. Large fish however do not readily enter a pump. They have greater swimming capacity and orientation capabilities than small fish and use these to avoid being drawn into pumps. But diadromous fish like eel for instance will enter pumps following their natural urge to migrate and do enter pumps, often with dramatic results. Small fish are easily sucked into pumps. A study in The Netherlands (STOWA, 2012) has shown that there is a positive relation between flow rate at the water intake and the number of small fish passing.

There are different causes for fish damage in pumps, such as shear and pressure changes, but most damage occurs from direct collisions of fish with propellers or guide-vanes in the pump. Large pumps in general are less harmful (for individual fish) than small pumps. And slow pumps in general are less harmful than pumps that operate at high speed. Conventional screw pumps are usually the most damaging for fish, while 3 blade Archimedes screw type pumps are relatively fish friendly.

The recent interest in fish migration and the mortality of fish at pumping stations has stimulated the development of new pumps as well as solutions to bypass pumps, So, the possibilities to solve problems caused by pumps are growing. Some manufactures claim that some of their pumps cause little or no damage to fish passing through. Independent tests with good results have been shown for adapted Archimedes screw pumps (e.g. Fishflow Innovations, De Wit), adapted mixed flow pumps (e.g. Hidrostal, Amarex KRT) and adapted axial flow pump (Pentair Nijhuis).

Examples of diesel powered pumps typical of those installed in tidal pumping station throughout the NSR in a period 1930-60s. Many of these pumping stations use centrifugal or screw pumps, which cause significant mortality to fish if attempting passage. East Stockwith Pumping station River Idle, UK

Inside Keadby Pumping Station on the River Trent, UK. Showing the amount of pumps needed to prevent flooding during storm events

3. *STOWA 2012. Gemalen of vermalen worden; onderzoek naar de visvriendelijkheid van 26 opvoerwerktuigen. STOWA 2012-04*

LNS acknowledges the fact that other manufactures also claim to produce fish friendly pumps and advises to use a standard protocol to test newly developed pumps. In The Netherlands a standard protocol is being developed to ensure better comparison between test results. In the coming few years new solutions will necessarily be implemented at many more sites. It is important that water authorities continue to test the effects in practice and share their results.

There are many issues to consider when building or retrofitting pumping stations (it is not simply a matter of installing a fish friendly pump). It is our experience over the last couple of years – also from LNS pilots - that the best solutions for fish migration at pumping stations are found when technicians and ecologists work together from the start of a project. This is also emphasized in the guidance on the realization of solutions for fish migration at pumping stations (chapter 2.4).

Pumping Station 'De Ruiter' Lakes Vinkeveen-NL (interior and exterior). Failure of the centrifugal pumps caused by large silver eel regularly occurs

Evidence of the damage that pump impellers can have on fish

Pumping station 't Hemeltje, Kortenhoef, The Netherlands. Example of screw pump that caused serious damage to silver eel and will be replaced by Archimedes screw pumps

Pumping Station Hoekpolder, Regional Water Authority Delfland, The Netherlands. Fish friendly pumping station, visited by LNS partners in January 2012

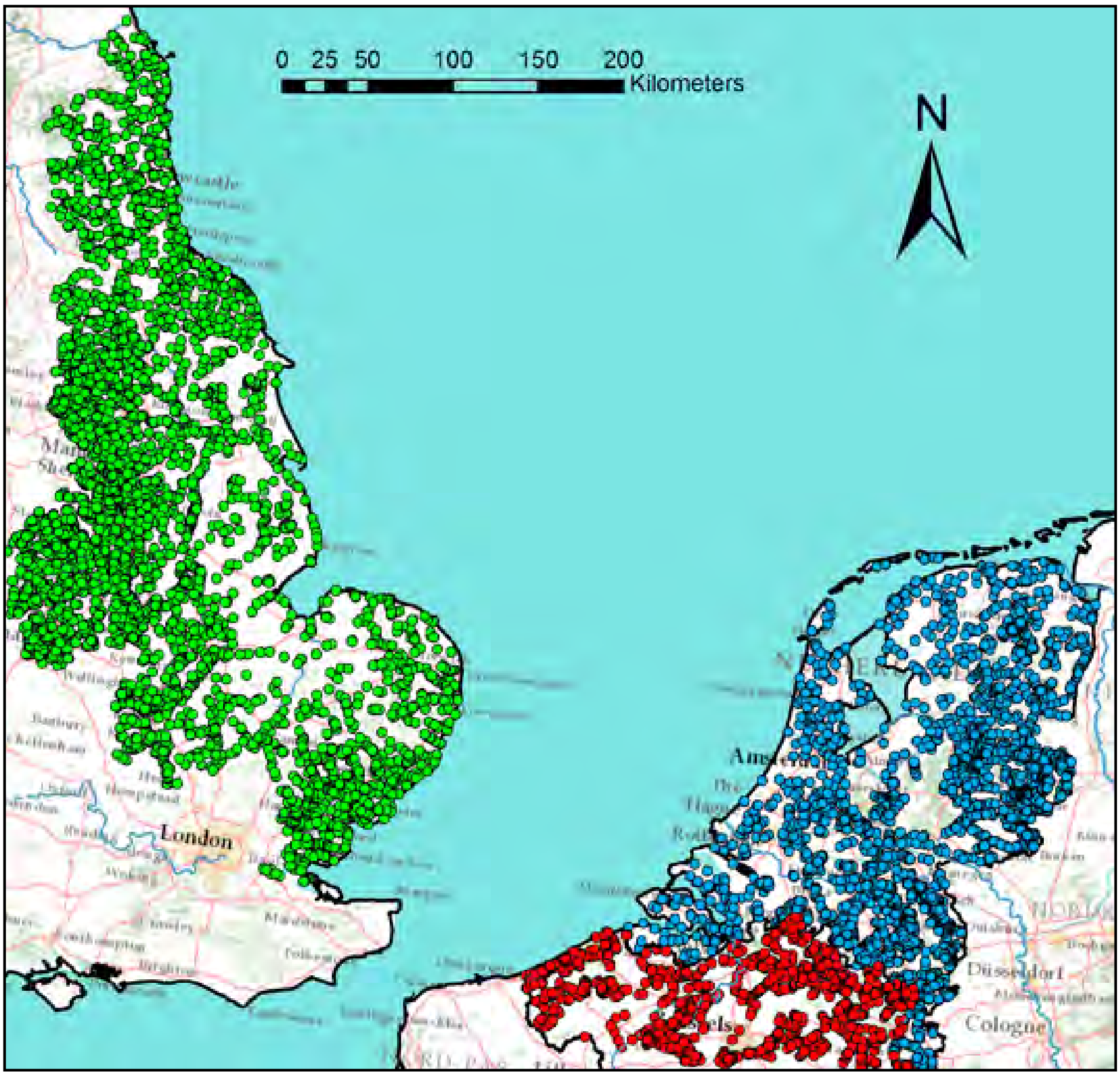
2.3 Scale of the problem in the North Sea region

2.3.1 Fish migration barriers across the North Sea region

Throughout the centuries, gravity discharge of water to the sea in low lying regions has declined significantly and in some river systems disappeared completely. An example of this is the Three Rivers site on the River Trent. Initially the rivers were straightened, then wood tide gates installed and finally a total exclusion pumping station was constructed, breaking the migratory connectivity with the tidal Trent. Other examples can be derived from comparison of the historical European coast line with our current coast line. Land has been extended by reclamation, necessitating the need to seal of river discharging to the North Sea to prevent tidal flooding of the new land. These changes took place slowly and with depopulation of rural communities the public awareness of the importance of free fish migration faded or was not considered. To date, most rivers in the North Sea region have been blocked by at least one migration barrier.

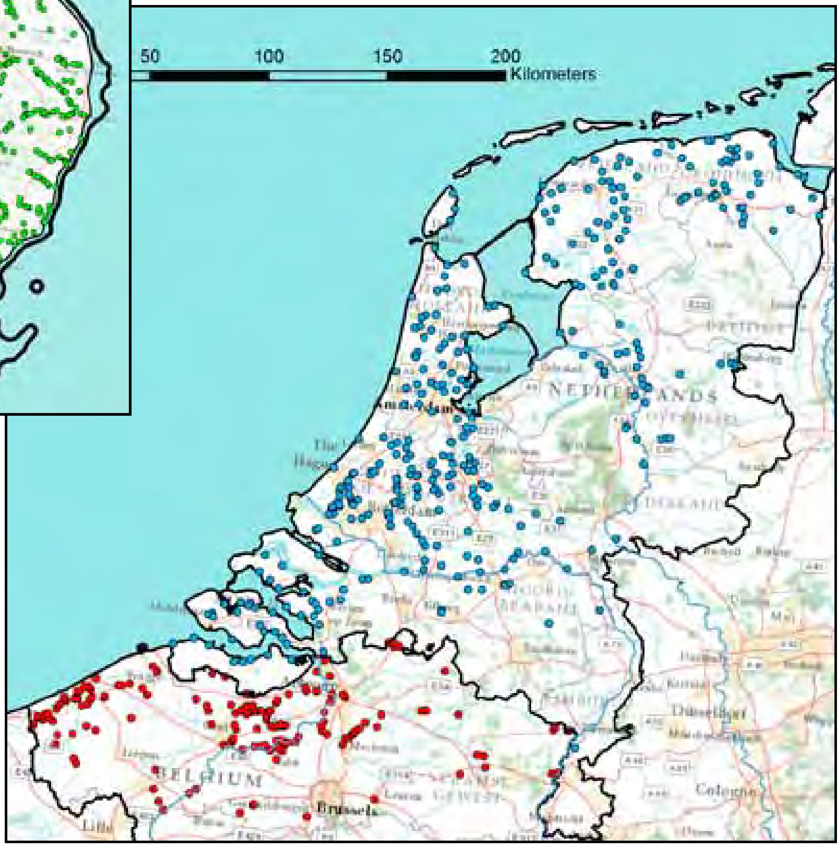
The dramatic decline of our migratory fish populations recently turned this problem into a hot topic. The increasing pressure on water resources and flood protection, e.g. due to climate change, will boost the need for flood protection barriers and controlled water evacuation in future decades. The planned Lauwersoog pumping station (Groningen area, NL) is a good example of how river managers aim to anticipate these future changes.

Tidal defence Lauwersoog in The Netherlands, where currently only gravity discharge is applied



Map showing the distribution of fish migration barriers in Belgium (red dots), The Netherlands (blue dots) and the East coast of the United Kingdom (green dots)

Map showing the fish migration barriers in Anglian Region of the UK



Map showing the distribution of pumping stations in Belgium (red dots) and The Netherlands (blue dots). The pumping stations in The Netherlands are only the priority locations that should be solved based on Water Framework Directive plans. These locations are only a small fraction (< 5%) of the total number of pumping stations in The Netherlands

The Three Rivers in the 1930s, showing gravity discharge with no barrier to fish

Three Rivers today with large pumping station (inset) now acting as a total barrier to fish migration

2.3.2 Public awareness and knowledge exchange

Increased knowledge exchange, an aim of the living North sea project, may lead to sustainable solutions for these migration problems in the North Sea region. Specifically, the optimal solution or mitigation of these barriers is often a matter of knowledge, perception and willingness to balance both environmental and operational considerations of all interested parties. Exchange of experiences may lead to win-win situations for ecology and river managers. The impact of tidal barriers, for instance, can be reduced by either restoring the natural estuary, by allowing a partial salinity inlet or by creating a more technical brackish basin that is situated between a marine and a freshwater system. Although river managers often avoid the inlet of salt water in their freshwater system, previous research has reported that this may not be such an issue and may have positive effects, e.g. controlling macrophytes. Further, knowledge exchange may help river managers to focus on the most effective solution. For instance, restoring fish migration at one bigger pumping station may be more effective than halfway measures on several small pumping stations.

The Living North Sea project demonstrated the impact of good knowledge exchange between river managers across the North Sea region. At the start of the project for instance, in the UK there was little awareness of the impact of pumping stations on fish populations, even though there are numerous pumping stations in the UK lowland areas. In Belgium and The Netherlands, the impact of pumping stations had been assessed by that time, and even some less damaging pumping systems were developed. In this case, knowledge exchange led to increased awareness of the problem and stimulated the implementation of fish migration solutions in the UK[1]. Knowledge exchange can also increase acceptance of a fish migration solution by stakeholders. For instance, several LNS partners conducted research on the adjusted management of tidal defences. This management demonstrated that controlled inlet of salt water did not necessarily lead to salt intrusion, which convinced water managers in the North Sea region to apply this adjusted defence management as well.

1. Wanningen Water Consult, 2011. A safe journey for eel in Wales and England. Quick scan on solutions for safe eel passage at pumping stations and tidal structures in the Somerset region and the tidal Trent region. Study assigned by Environment Agency, UK. Wanningen Water Consult, NL, 69 p.

2.4 Innovative solutions to tidal barriers and pumping stations

2.4.1 Remove, rebuild or renovate

It is obvious that the best way to restore fish migration is to remove the barrier. Some examples within the LNS partnership show that this is achievable. But it is also clear that removal is not always an option. Especially on locations where tidal defences or pumping stations are vital for land use and safety. In this case, rebuilding a barrier is the next best option to improve fish migration, because it gives maximum freedom in the design. The third option is to renovate the structure, changing only parts of the design. Even just changing the way a barrier is operated may significantly improve the situation for fish migration, often at relatively low costs. This chapter focuses on technical solutions for fish migration. In order to make a good decision about the proper fish migration solution for your tidal barrier or pumping station it is necessary to carry out a good specific location study. This designing process can be quite complicated and be influenced by many factors. The process can be divided in two separate parts: the design process and the technical possibilities. Both of these actions will be discussed in the following paragraphs. As an example, paragraph 2.4.2. presents a guidance for the design process of a pumping station. In paragraph 2.4.3. we will discuss some of the possible technical solutions for tidal barriers and pumping stations.

Knowledge exchange in practice during a LNS meeting, March 2011

2.4.2 Guidance for the designing process of tidal defences and pumping stations [1]

As part of the Living North Sea project a special guidance for the designing process of fish friendly pumping stations was developed. The text below shows an extraction of the executive summary of this study.

Executive summary of the report "Guidance on the Realisation of Fish Migration at Pumping stations" (Heemstra & Veneberg, 2012)

To make current knowledge accessible and to bring together different disciplines, this guidance aims to act as a tool in helping water managers (civil engineers, ecologists, hydrologists and managers of pumping stations) through the process of realizing fish migration at pumping stations. This is done with the help of the following 7 project phases which need to be followed in order.

1. Policy for Fish Migration

This project phase summarizes international, national and regional legislation and policy regarding fish and the restoration of fish migration in Europe. Policy frameworks are necessary for organizations when wanting to restore fish migration. The organization itself should play an important role to ensure the quality of these frameworks. Information sharing should therefore not be merely top-down, but the organization itself should also take its responsibility in sharing regional knowledge to the national level.

2. Regional Fish Migration Action Plan [2,3]

A regional fish migration action plan helps you to define your level of ambition. In this step objectives for fish migration in your management area are specified and you prioritize which water systems and barriers are most important based on certain criteria. The behaviour of fish should be placed centrally when producing such a structured plan. Several regional prioritization methodologies for migration barriers exist within North Sea region countries.

3. Pre-research

From the pre-research onwards your work will be site specific. The pre-research is basically an assessment of all aspects that might be relevant to the upcoming project phases to define, design and realise the optimal solution for a specific barrier at a specific location. To carry out such an assessment all relevant questions have been listed in this step.

4. Definition

In the definition phase all relevant aspects that have emerged during the pre-research will be translated into more specific and technical design criteria. To guide you through this step, relevant questions have been listed that are of importance in reaching an optimal solution.

5. Design

In the design phase you select a solution that meets the design criteria developed in the previous definition phase. A decision-structure in the form of a flow chart, and a computer tool[4] "Pumping Station Guidance to Solutions" will help you in the selection of possible solutions. The necessary steps to take into account in the design are described in this phase.

6. Realisation

This project phase describes the necessary considerations for the realisation of the fish migration facility in the field.

7. Follow-up

In this phase technical and ecological monitoring will have to be carried out in order to evaluate the efficiency and functioning of the migration facility. It is therefore important to learn through evaluation whether the solution has any potential shortcomings that need to be solved. Checklists of important criteria to keep into account are shown.

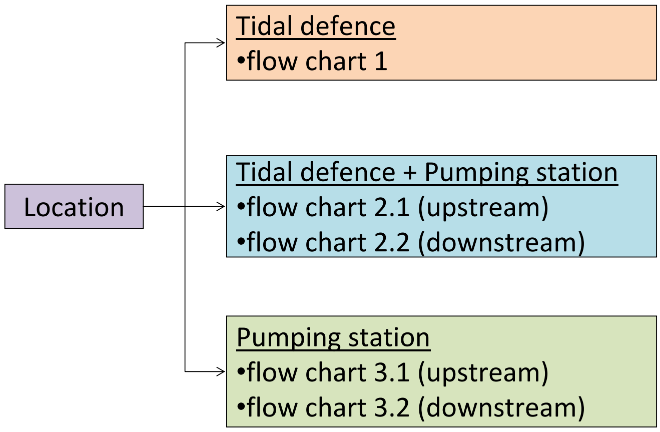
1. Heemstra, M and J. Veneberg, 2012. Guidance on the Realisation of Fish Migration at Pumping Stations, From idea to realisation and evaluation. Thesis report for Regional Water Authority Hunze en Aa's as part of the Living North Sea Project.
2. Solomon, D., Wright, R. 2012. Prioritising pumping stations for facilities for the passage of eels and other fish. Environment Agency Anglian region, 53 pp.
3. Stevens, M., Coeck, J. 2010. Wetenschappelijke onderbouwing van een strategische prioriteitenkaart vismigratie voor Vlaanderen. Research Institute for Nature and Forest INBO.R.2010.33, 44 pp.

4. STOWA afwegingskader 2012; a decision supporting computer tool as part of the STOWA "fish friendly pumping stations" project

2.4.3 Examples of technical solutions for tidal defences and pumping stations

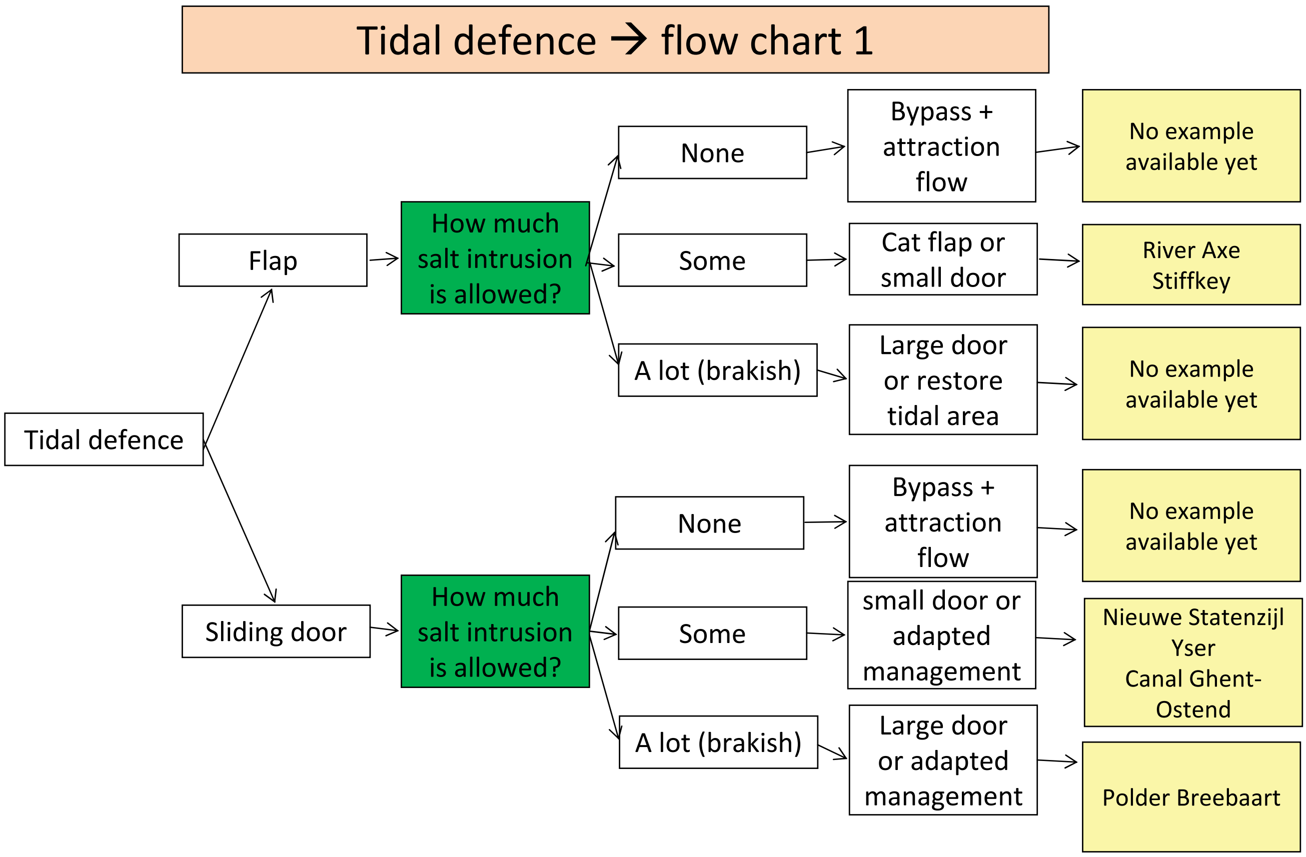
To help the reader find (examples of) solutions a tool using a series of flowcharts has been developed for the Living North Sea project. The flow charts will guide you in a few steps to the solutions that are possible for a specific type of barrier. This will also lead you to the LNS pilot project where examples of solutions have been implemented and studied.

The first step differentiates between situations where gravity discharge is possible (tidal defences with or without pumping stations) and situations where pumping is the only possible way to discharge water. The following charts specify the different kinds of solutions and examples for upstream or downstream migration separately.



Tidal defences

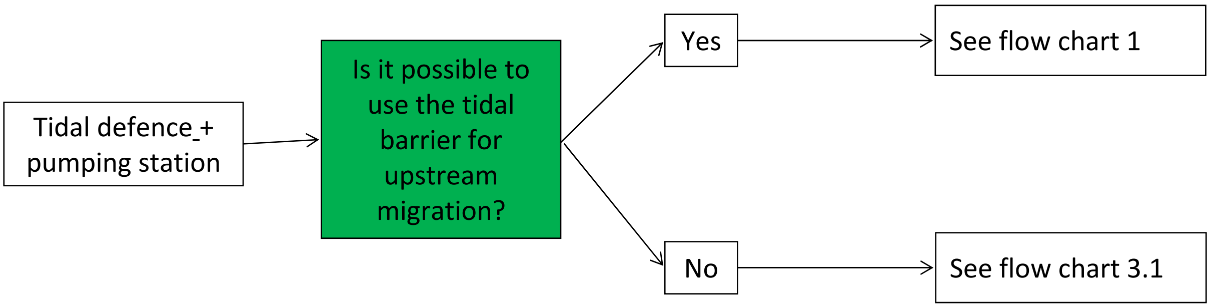
Tidal defences (weirs or tidal locks) can be made passable with flaps or doors. The possibility to implement a solution greatly depends on the salt intrusion that is allowed upstream of the tidal barrier.



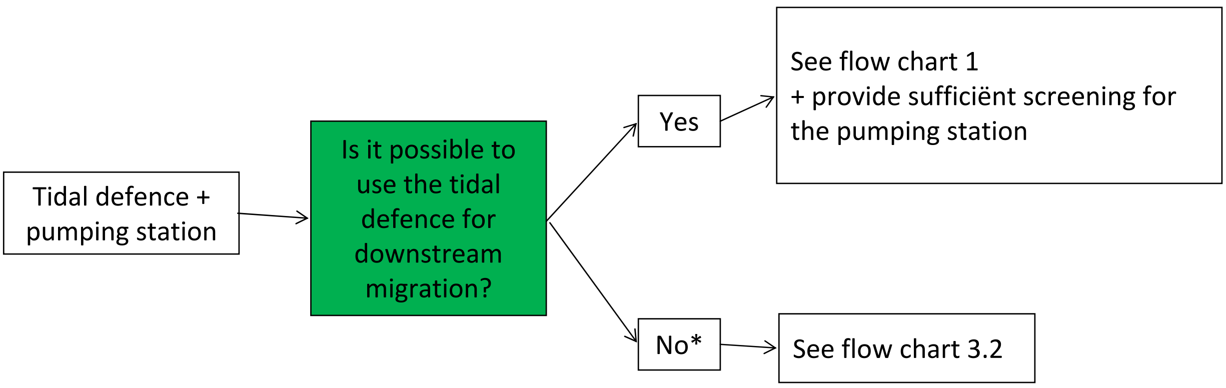
Combination of a tidal defence and a pumping station

Tidal defences are sometimes combined with pumping stations. The pumps are used in situations where gravity discharge alone is not sufficient (high tide or storm situations). Solutions for fish migration at these sites can either be found in adapted management of the tidal defence (weir or tidal lock) or in solutions that are possible to bypass pumping stations. Adapted management of the tidal defence is usually the easiest way. In situations where pumping and gravity discharge are both regularly used, one should consider solutions for both. For instance screening of pumps in combination with adapted management of the tidal defence.

Tidal defence + Pumping station → flow chart 2.1 (upstream)



Tidal defence + Pumping station → flow chart 2.2 (downstream)



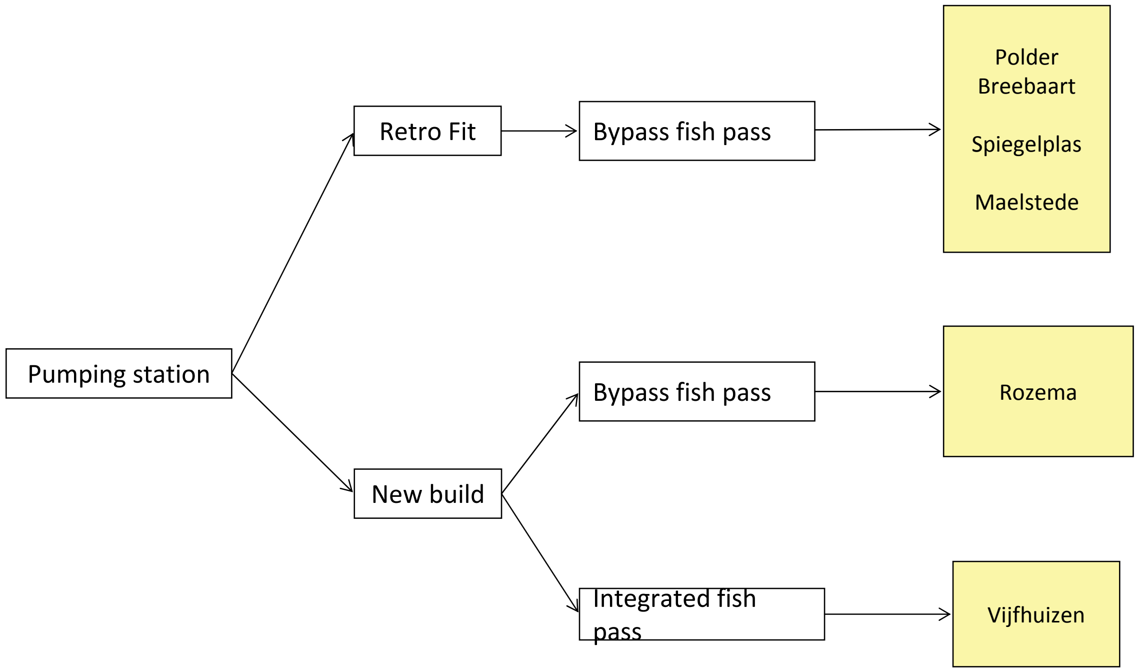
* In certain situations it is possible that the tidal barrier is out of use for long periods of time because of high water water levels at the sea/main river side. Under these circumstances it is difficult to block fish for a long period of time by using screening methods. In these cases an aditional fish pass is an option.

Pumping Stations

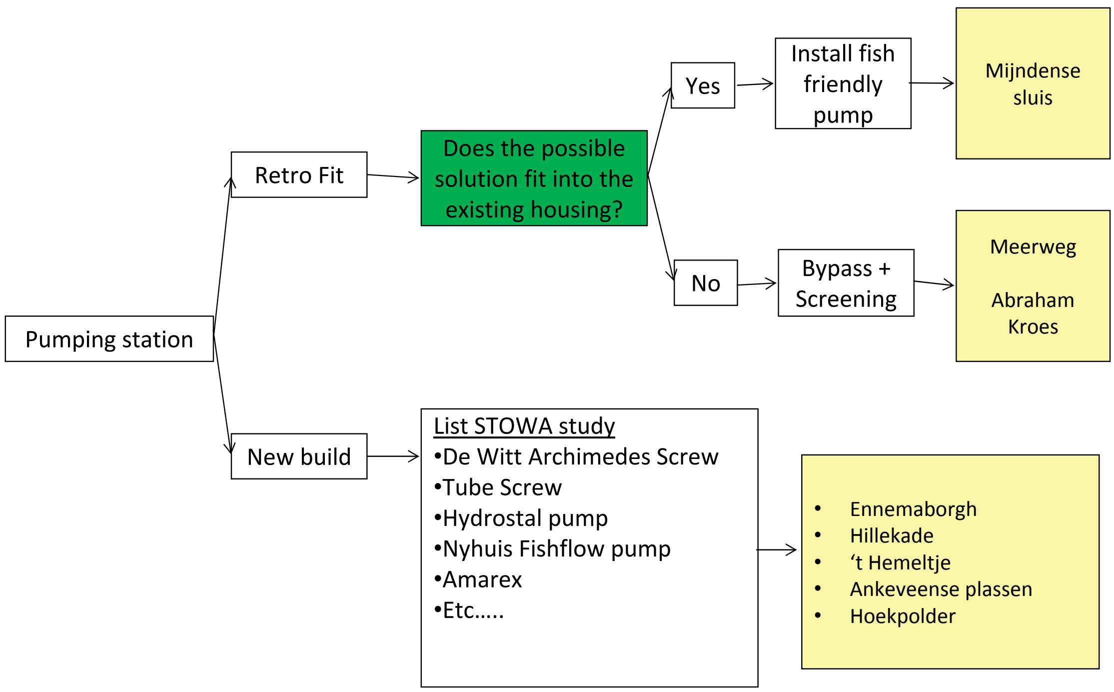
These flow charts will guide you to different solutions that have been implemented at sites where pumping stations have to be passed for fish migration. Upstream migration always needs a solution to bypass the pump itself. Solutions for downstream migration may be realized via fish friendly pumps or by screening and bypass.

This flow chart suggests that installing a fish friendly pump is always better than screening with a bypass. In some situations screening and bypassing may be the preferred solution, for instance to avoid coarse fish to be pumped out. A recent study in The Netherlands however showed that different possibilities for screening and bypassing where far from effective (Kroes, 2012)[1].

Pumping station → flow chart 3.1 (upstream)



Pumping station → flow chart 3.2 (downstream)



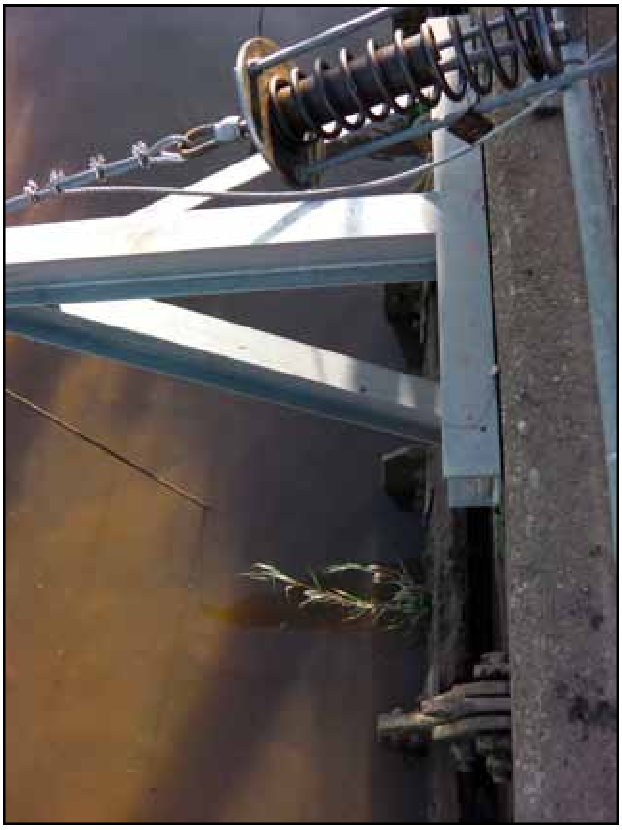
1. *Kroes, M.J., Bruijs, M.C.M. and Winter, H.V., 2012. Viswering en visgeleiding bij gemalen in Nederland. Tauw rapport, project 4745184*

Other LNS studies on solutions for fish migration

In the preceeding flow charts only the LNS pilot sites have been mentioned where specific solutions have been implemented. There is another group of LNS pilot projects where solutions for fish migration are still under study, or where the focus has been on other issues. These LNS pilots are listed here. More information is given in the factsheets in the appendix.

Three pet door devices, operated by a float to allow some opportunity for fish passage through a tidal flap gate

New HDPE tidal flap incorporating a "pet door" device awaiting installation on the Adlingfleet Drain, Tidal Trent, UK



Retarder spring attached to winch cable of wooden flap gate on the River Trent, UK. The spring compression extends the period of the gate remaining open on an incoming tide to increase opportunity for glass eel migration from tidal to freshwater habitats

Various types of pet doors installed on tidal flaps in the UK

Tidal door being lifted open on incoming tide as part of LNS Fish Migration Day, River Nene, UK

Hydro-acoustic images of a shoals of fish (roach?) passing upstream when tidal door was lifted

The different case studies that were not referred to in this report but that are included as well in the appendix.
Visited = case study was visited by LNS partners.
Research conducted by partner = a LNS partner conducted research on fish migration at this case study.
Research claimed for LNS = (part of) the research at this site was funded by the LNS project.
Category = Tidal barriers/defences (TB), pumping stations (PS), habitat restoration (HA), tracking and distribution / telemetry study (TD).
LNS partner = LNS partner that manages/studies the case study.

Country	River / Label	Visited	Research conducted by partner?	Research claimed for LNS?	Category	Fact sheet available?	LNS Partner	Description
B	Scheldt	yes	yes	yes	TB	TD8	INBO	Lamprey telemetry in the Scheldt river
B	Scheldt	yes	yes	yes	HA	HA1	INBO	Bypass Asper Oudenaarde in the Scheld river
B	Leopoldskanaal	yes	yes	yes	TB	TD9	INBO	Eel telemetry
B	Averijevaart	yes	yes	yes	PS	PS11	INBO	Evaluating the impact of a propeller pumping station
B	Scheldt	yes	yes	yes	TB	TB3	INBO	Study on the migration and behaviour of lamprey and eel in the Scheldt river, Belgium
DK	Syltemade	no	yes	yes	TD	TD6	Seatrout Fyn	Study on migration and survival of stocked fish in River Syltemade Å and River Storå, Fyn, Denmark
NL	Meuse	no	yes	yes	TD	TD5	Dutch Royal Angling Assoc	Study on migration and survival of stocked salmon smolts in the River Meuse
NL	Drentsche Aa	yes	yes	yes	TD	TD1	RWA H&A	Study on fish migration on the River Drentsche Aa and River Hunze, Provinces of Groningen and Drenthe
NL	Eemskanaal	no	yes	yes	TB	TB15	RWA H&A	Study the effectivity of fish friendly lock management at the Eemskanaal tidal barrier
NL	Various	yes	no	no	TB	TB13	RWA NZV	Designing best possible fishpassageas at three pumping and a few weirs stations
NL	Drentsche Aa	no	yes	yes	TB	TD1	RWA H&A	Fishpassage Loonerdiep 2
NL	Drentsche Aa	no	yes	yes	TB	TD1	RWA H&A	Fishpassage de Hemmen
NL	Drentsche Aa	no	yes	yes	TB	TD1	RWA H&A	Fishpassage/culvert Loonerdiep
NL	Drentsche Aa	no	yes	yes	TB	TD1	RWA H&A	Fishpassage/culvert Deurzerdiep
NL	Hunze	no	yes	yes	TB	TD1	RWA H&A	Fishpassage Hunze H1
NL	Drentsche Aa	no	yes	yes	TB	TD1	RWA H&A	Fishpassage Anreperdiep
NL	Hunze	no	yes	yes	TB	TD1	RWA H&A	Fishpassage Hunze H1
NL	Hunze	no	yes	yes	TB	TD1	RWA H&A	Fishpassage Achterste Diep
NL	Peizerdiep	no	yes	yes	HA	TD4	RWA NZV	Study on fish migration within the Noorderzijlvest river system, are fish able to find their spawningareas, Peizerdiep, The Netherlands
NL	Ijmuiden	yes	no	no	TB	TB10	Waternet	Program for fish migration in North Sea Canal and surrouding areas
NL	Vinkeveense plassen	yes	yes	yes	PS	PS4	Waternet	Study to improve the situation for fish migration at pumping station 'De Ruiter' Lake vinkeveen
NL	Vecht - Ijmeer	yes	yes	yes	TB	TB9	Waternet	Solution for fish migration at sluices (former sea locks) Muiden
S	Atran	yes	yes	yes	HA	HA7	Falkenberg	Project Herting, removal of dam at hydropower station
UK	Various	no	yes	yes	HA	HA3	CEFAS/EA/RT	PhD Study on gravel enrichment of rivers
UK	Judas Gap	yes	yes	yes	TB	TB7	EA	Upstream elver migration
UK	Stiffkey	yes	yes	yes	TB	TB4	EA	PhD study on fish migration through a tidal flap on the River Stiffkey, North Norfolk, UK
UK	Eau (Trent)	no	yes	yes	TB	TB12	EA	Installation of fish friendly flap gate on the River Eau (SE8376503293) on the tidal River Trent, England, UK
UK	River Glaven	yes	yes	yes	HA	HA5	EA	River Glaven
UK	Flatford Mill	yes	yes	yes	HP	PS2/PS3	EA	Flatford Mill (Archimedes screw, Larinier, Eel pass)
UK/DK	River Tees	yes	yes	yes	HA	TD7	CEFAS/DTU	Effect of diffuse pollutants on silver eel - Mitigation of water supply reservoirs on the River Tees
UK	Doublet	no	yes	yes	TB	TB6	EA	Dog in the Doublet
UK	Judas Gap	yes	yes	yes	TB	TB8	EA	Downstream silver eel migration
NL	Vecht	no	yes	yes	PS	PS6	Waternet	Study to improve fish migration at pumping station Naardermeer-NL
NL	Vecht	no	yes	yes	TB	TB11	Waternet	Study to improve fish migration at sluice Uitermeer-NL
DK	Various	no	NA	NA	TD	TD2	DTU	Improve knowledge of sea trout ecology in the North Sea
UK	Tweed	no	yes	yes	TD	TD3	Tweed Foundation	PhD study on Sea-trout & Salmon smolt migration downriver, adult movement upriver & angling exploitation rate
UK	Trent	no	yes	yes	TB	TB17	EA	Implications for water quality and sedimentation of provision of fish access at water-level management structures
NL	Vecht-Loosdrechtse Plassen	no	yes	yes	TB	PS5	Waternet	Study to improve the situation for fish migration between Loosdrecht lakes and river Vecht - NL
NL	Texel	no	yes	yes	HA	HA11	Waternet	Indispensable salt-fresh fish bypass through siphon over a dyke
NL	Westerwoldse Aa	no	yes	yes	TB	TB14	RWA H&A	Weir Veelerveen
NL	Westerwoldse Aa	no	yes	yes	TB	TB14	RWA H&A	Fishpassage Renneborg
NL	Westerwoldse Aa	no	yes	yes	TB	TB14	RWA H&A	Fishpassage Vlagtwedde
NL	Westerwoldse Aa	no	yes	yes	TB	TB14	RWA H&A	Weir Wedde
NL	Westerwoldse Aa	no	yes	yes	PS	TB14	RWA H&A	Pumping station Hongerige Wolf
NL	Westerwoldse Aa	no	yes	yes	TB	TB14	RWA H&A	Weir de Bult
NL	Westerwoldse Aa	no	yes	yes	TB	TB14	RWA H&A	Pumping station Sans Souci
NL	River Rhine	no	yes	yes	TD	TD10	Dutch Royal Angling Assoc	Telemetric study Rhine and North Sea: "Research on the migratory behaviour and habitat use of the European sturgeon (Acipencer Sturio)
NL	All Dutch rivers	no	yes	yes	TB	TB18	Dutch Royal Angling Assoc	National update 2012 of migration barriers and fish passages in The Netherlands, within WFD designated waterways

2.5 Summary of key messages

- Most river systems in the NSR used to be populated by fish species that migrate between sea and fresh inland waters. This situation has changed radically in the last century as a consequence of river modifications (building dams, tidal barriers, hydropower stations, cutting off meanders, gravel excavation), pollution and fisheries. In large areas the migratory fish species such as salmon, sturgeon, twaite and allis shad, houting and sea trout have disappeared.

- The LNS Project has shown that tidal barriers are a huge issue in the NSR disconnecting important coastal zones from the salt and fresh water. Especially for the rivers in the low lying coastal zones of the NSR.

- Pumping stations are a specific, and major problem for fish migration in several parts of the NSR. They can completely block upstream migration and seriously obstruct downstream migration, killing many fish that actually attempt to pass through the pumps. In The Netherlands there are more than 3000 larger pumping stations. But also in parts of Belgium, England and Germany pumping stations are important barriers for fish migration.

- LNS and other recent studies show that the damage and fish mortality rates can vary greatly between different (types of) pumps. Although the amount of available information is growing there are still many knowledge gaps to fill.

- Policy and projects to restore a good situation for fish migration should preferably follow the principle of Remove, Rebuild or Retrofit (in that order).

- Tidal barriers are not only physical barriers, but also introduce chemical barriers with a sudden transition between salt and fresh water. Their removal (or adapted management) restores or increases the inter-tidal coastal habitat. This is vital for fish to adapt to the changing environmental conditions."

- Because of the large number of barriers, prioritisation is necessary. The priority process recognises the need to tackle downstream barriers before upstream.

- Projects to improve the situation for fish migration at tidal barriers often have to deal with opposition because of the inlet of saline water (e.g. opening of sluices on incoming tide). The LNS project has shown that through modelling of salinity it is possible to allow significant back washing without impacting on the primary purpose of the barrier.

- The use of 'fish unfriendly pumps' (the types of pumps that are known to cause damage) should be avoided and existing "fish unfriendly pumps" should initially be adequately screened and replaced when possible. "Fish friendly" alternatives are available. However, improving fish migration at pumping stations involves more than just choosing a "fish friendly" pump. All aspects of fish migration at the specific site need to be considered. The LNS project has provided a working method (tool/guidance) that guides water managers, developers and contractors through the necessary steps to find the best possible solution for the specific situation.

- LNS advises to use a standard protocols to test newly developed pumps. As a result of recent legislation (e.g. European Water Framework Directive and European Eel Directive) there is an increasing interest and drive to remove fish migration problems. As a result also manufacturers of pumps are taking the initiative to develop "fish friendly" pumps.

2.6 LNS policy recommendations

Policy recommendations will be presented and discussed at the LNS end meeting in Newcastle (November 2012). The result will be included in the final version of this report.

- No new tidal barriers on “free rivers”.
- All barriers must undergo a fish passage priority assessment based on legal drivers to prioritise fish passage improvement works.
- 1. Remove: Where possible barriers should be removed (as a first priority)
- 2. Rebuild: Existing tidal barriers that cannot be removed in the short term should be rebuild and/or retrofitted with appropriate fish passage facilities and screening and comply with all legislative drivers. Rebuilding maximises the opportunities to install these facilities.
- 3. Retrofit: Where a fish barrier cannot be removed or rebuilt the operation procedure must be modified to increase the opportunity for successful fish migration.
- Engineers need to incorporate fish passage measures and screening (as agreed with ecologist) in all new designs where removal is not possible prior to infrastructure changes. New installations need to be monitored and meet independent success criteria.
- All new barriers with measures for fish migration should be studied and monitored and the facility should be changed if it does not work.
- Monitoring of the success of fish migration measures must be an on-going process to allow continuous improvement to designs into the future and dissemination of best practice and knowledge. There is a strong need for standardized monitoring protocols.
- All monitoring and fish passage standards should be made available to improve knowledge on fish passage and to inform future guidance.
- Policy for spatial planners must focus on improving the current situation by setting back of coastal flood banks, providing more space for water, reducing flood risk and re-establishing natural coastal morphological conditions.
- Industry (and government organisations) must be required to make their pumps and tidal infrastructure friendly to fish migration and this needs to be independently accredited.
- Government or national organisations should stimulate and facilitate the (international) exchange of knowledge and information. Special attention should be given to the fact that most literature is grey or in the national language.

3 - Hydropower in the North Sea region

SECTION SUMMARY

- Renewable energy legislation across the North Sea region
- Incentives payments schemes in the North Sea region
- Importance of hydro-electric power (HEP) and targets per country
- Potential impact of hydropower on fish and mitigation, case studies
- Policy recommendations

"Hydropower stations were extended about 100 years ago, which was important to the development of the town [Falkenberg, Sweden] at the time. We have now seen the consequences of this, and have through various measures tried to save both salmon and eel as well as other migratory fish, however with marginal results. So in order to save our unique stock of salmon and the endangered eel we will open the old river bed and shut down part of the hydropower station. We are grateful to nature for having lent the river bed to us, however, knowing better now, we will return it in order for it to recover. Our children and grandchildren should also be able to fish for salmon and eel in Ätran River. Our generation has no right to live beyond our means and eradicate these resources"

Open address given by Mari-Louise Wernersson of Falkenberg Municipality at the beginning of the LNS Full Partner Meeting October 2011.

3.1 Background

The Living North Sea (LNS) Project was set up to look at the impacts on fish and fisheries by loss of connectivity due to man-made barriers, including those associated with hydro-electric power (HEP). Examples are given where impacts have been reported and some of the mitigation measures that have been put in place to improve connectivity at these sites. This section also outlines the legislation which prevails on member states to provide incentives for renewable energy.

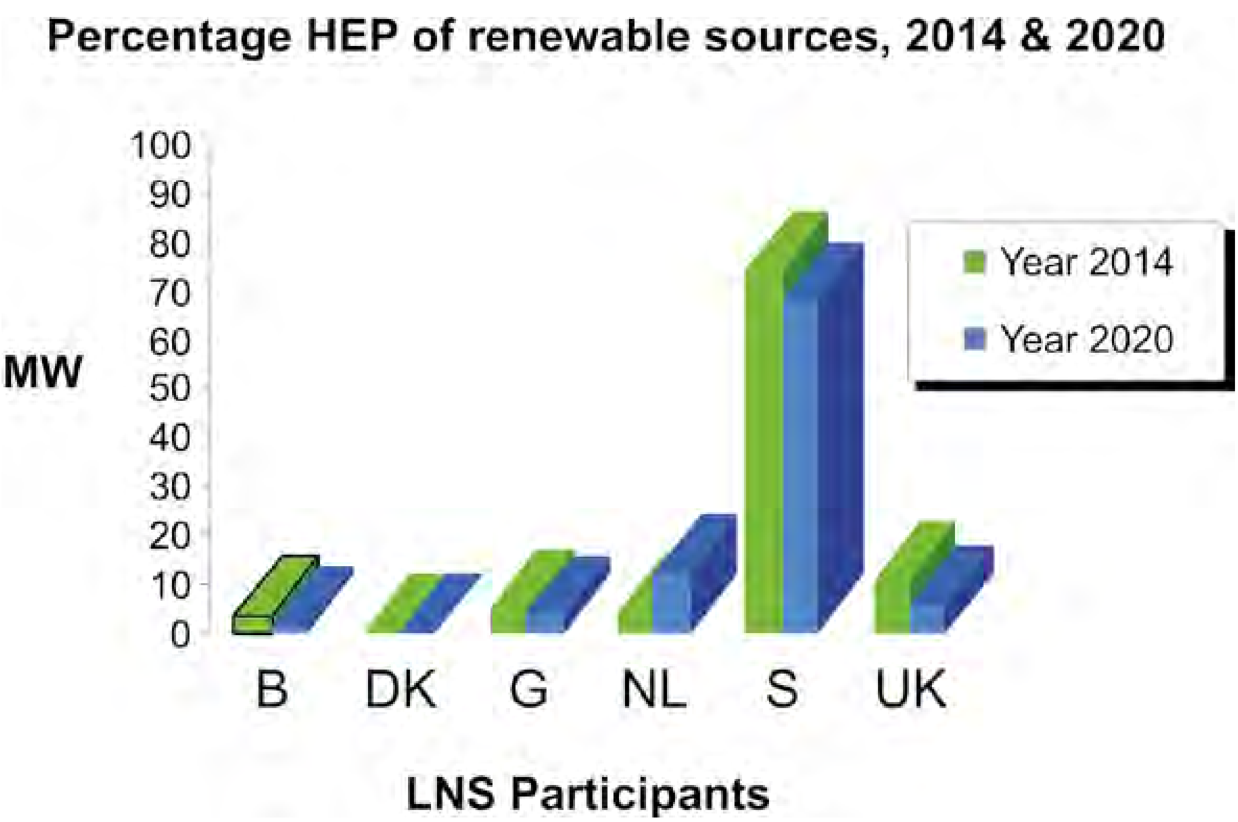
3.1.1 Renewable energy legislation

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (1998) set out to ensure that man-made emissions of greenhouse gases did not exceed their assigned amounts. The aim was to reduce the emissions of such gases by at least 5 % below 1990 levels during the period 2008 to 2012. To secure continued commitment to reducing greenhouse gases beyond 2012, the European Renewable Energy Directive (RED, 2009) set out mandatory targets for member states (27) of an EU share of 20 % of total energy consumption from renewable sources (solar/wind/biogas/HEP/tidal) by 2020.

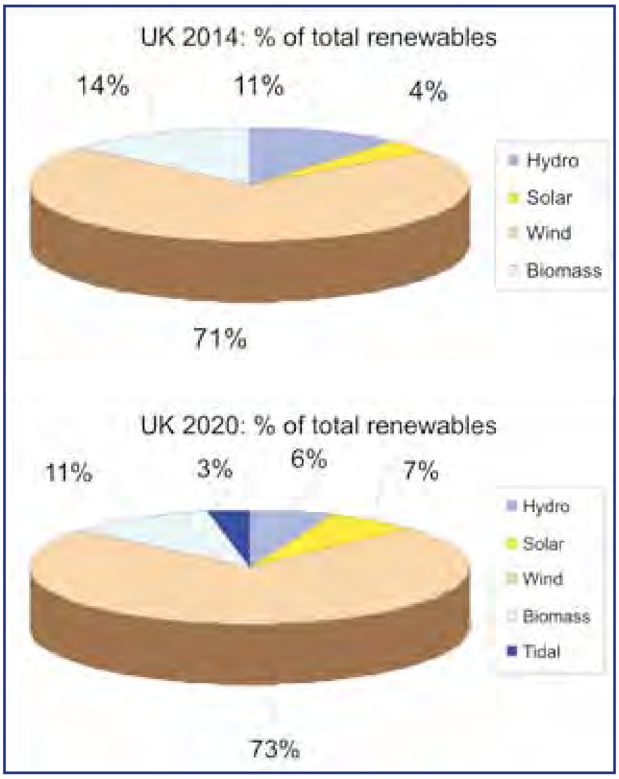
3.1.2 National Renewable Energy Action Plans 2010

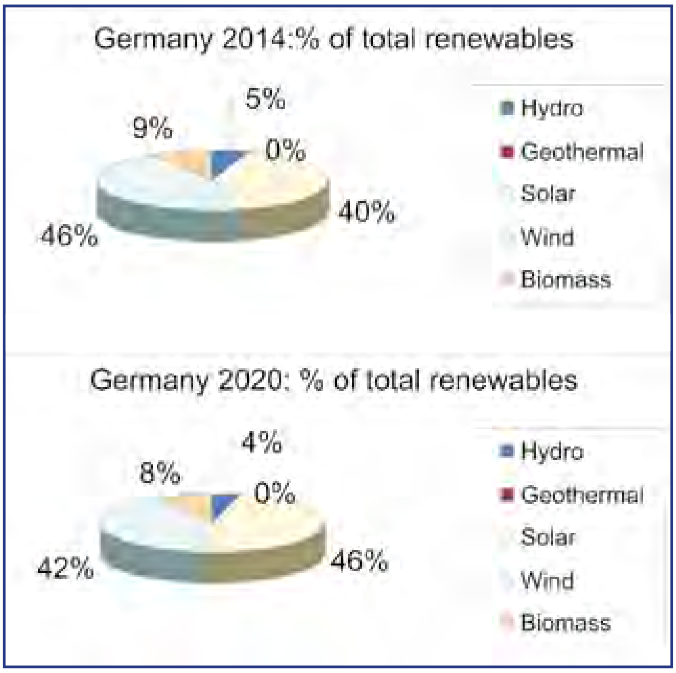
The Renewable Energy Directive (RED) also required each member state to produce a National Renewable Energy Action Plan (NREAP) by 2010 showing an increase in production of energy from renewable sources. Reduced reliance on fossil fuels and resource exhaustion constraints and a move towards decentralised energy production, promotes security of energy supply. Each country has set a percentage target of the total of electricity production which is generated from renewable sources.

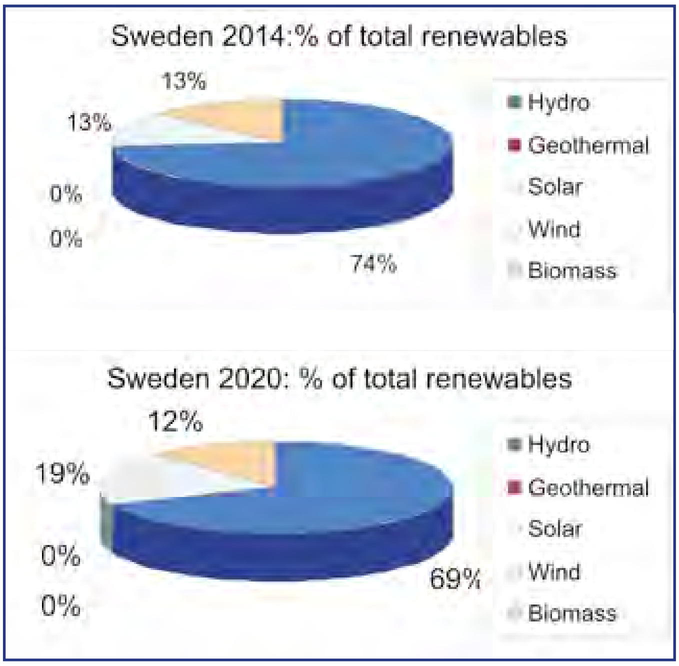
The RED also advocates measures to support small renewable schemes through direct price initiatives such as feed in tariffs (FiTs). The availability of these and other initiatives has led to an increase in applications for renewable energy schemes, including small hydropower schemes. In most EU member states electricity utilities now buy electricity generated from renewable sources produced by individuals and companies.

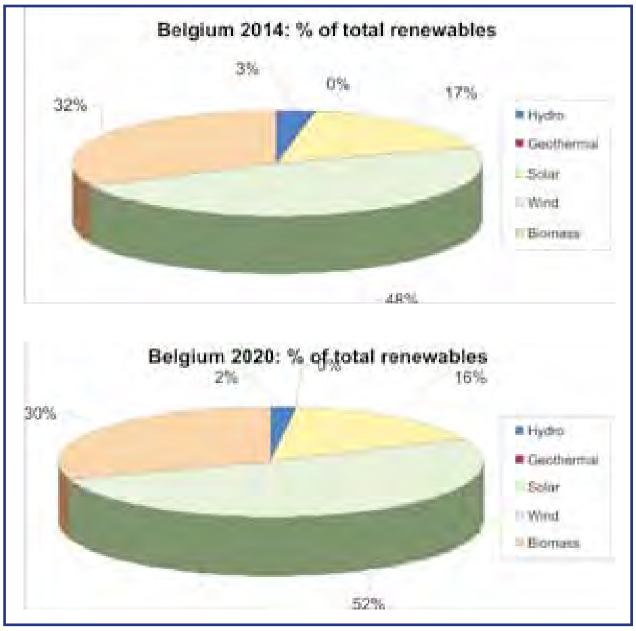


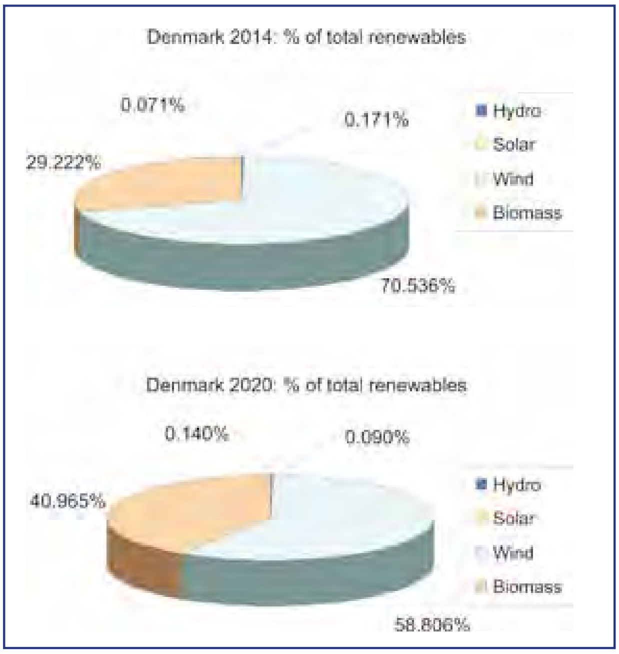
The predicted percentage production of renewable energy by member states for 2014 and 2020











The incentives for hydropower of the seven Living North Sea Project partner countries are shown in *table 1*. Prices are in euros per kilowatt-hour (€/Wh).

A summary of percentage renewable energy from hydropower in 2014 and 2020 is given in *table 2* for each LNS country. Figures are taken from tables 10a/b of NREAPs.

LNS Partner country	Feed-in-Tariffs €/kWh	€/kWh Green Certificates	Renewable target 2014 (%)	Renewable target 2020 (%)	% increased/ decreased
Belgium	n/a	0.0050	3.5	1.7	↓
Denmark	n/a		0.165	0.148 %	↓
Germany	0.034 - 0.13		5.4	3.9	↓
The Netherlands	0.073 - 0.125		4.2	12	
Norway	n/a	Variable	Demand dependent	Demand dependent	
Sweden	n/a	Variable	74.1	68.7	↓
United Kingdom	0.23		11.1	5.6	↓

Table 1. Incentives for hydropower generation in different member states.

*'0.29-0.46' is a price range from 0.29 €/kWh (Euros/kilowatt hour) to 0.46 €/kWh, depending on the amount produced. Prices valid for April 1st, 2012. *Taken from National Renewable Energy Action Plans, tables 10a/b*

Atrafors Hydropower Dam, Sweden and entrained bream on intake screen to hydropower plant

3.1.3 Member State targets for consumption from renewable sources by 2020

Belgium [1]

The generation of electricity from renewable sources in Belgium is predicted to rise from 2.2 % in 2005 to 13 % in 2020. This increase will largely be due to an increase in wind farms on the Belgian Continental Shelf. Tax deduction is available for companies that have hydropower schemes with maximum 1 MW capacity. Electricity suppliers have to show that they have supplied an amount of renewable electricity. Green Certificates represent the environmental value of renewable energy generated. The certificates can be traded separately from the energy produced.

Denmark

The long term aim within Denmark is that it will eventually become independent of the need for fossil fuels. To this end the target for generation of electricity from renewable sources by 2020 is 30 %. Denmark is not expecting hydropower to raise the contribution to the renewable percentage, the increase will be due to wind power and biomass. The tariffs are paid in accord with the Promotion of Renewable Energy Act (Fremme af vedvarende energi (VE-Lov) Act 2008) which came into force on January 1st 2011. Payment is made to schemes up to 10 MW capacity for 20 yrs and the cost is borne by the consumer who pays a surcharge which is determined four times a year by Energinet.dk.

Germany

In 1990 91 % of electricity from renewable sources was from hydropower. By 2009 this had dropped to 20 % and by 2020 this is proposed to be 9 % of an overall renewable target of 35 %. Most of the target will be met by biomass and wind power. Under the Renewable Energy Law (Erneuerbare-Energien-Gesetz (EEG) 2012) the plant operator receives the feed-in tariff from the grid operator, whose network he supplies. Through a nationwide allocation scheme, compensation payments are distributed equally to all operators and passed on to electricity customers, this ensures the FiTs are not budget restrained. FiTs are granted for 20 yrs, 15 yrs for large schemes (< 1 MW) for which there is a 1 % annual degression. It is thought that the capacity for schemes > 1 MW is fully exploited and that small schemes will not make any significant contribution to the overall renewable target for 2020.

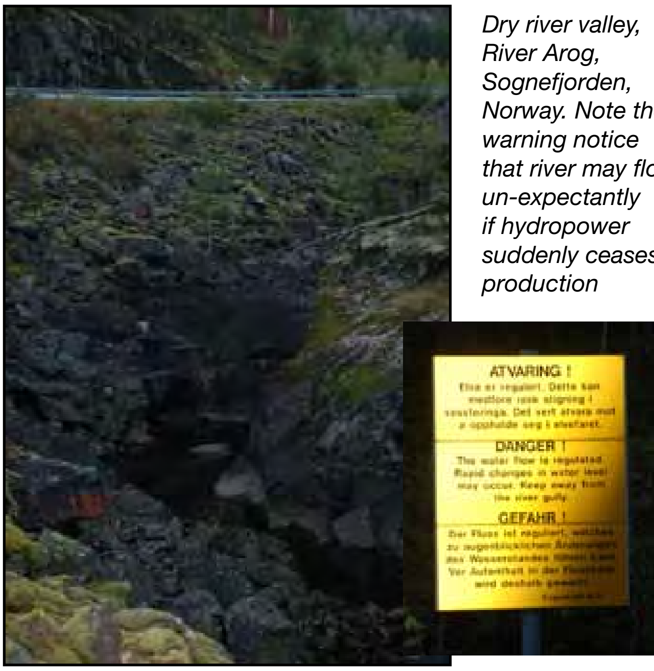
1. See *GREEN CERTIFICATES MECHANISMS IN BELGIUM: A USEFUL INSTRUMENT TO MITIGATE GHG EMISSIONS 2011 F. Van Stappen 1, D. Marchal 1, Y. Ryckmans 2, R. Crehay 1, Y. Schenkel Walloon Agricultural Research Centre (CRA-W) Agricultural Engineering Department, Laborelec / Electrabel*

The Netherlands

The target for generation of electricity from renewable sources in The Netherlands is 14 % by 2020. Incentives take the form of Feed in Tariffs. In order to be eligible, hydropower schemes should have a drop height of at least 50 cm. Plants whose drop height is 50 cm to 5 m are eligible for subsidies for 3800 full load hours/year. There are 4 stages of subsidies. Applicants are not always guaranteed the later subsidies as funds may run out. Schemes with a drop height of < 5 m are eligible for subsidies for up to 4800 full load hours/year, subsidy received for all 4 stages are the same. The mechanism for FiT payment is decreed in Stimulering Duurzame Energieproductie (Stimulering Duurzame Energieproductic 2012 SDE+).

Sweden

The renewables target for Sweden is 50 %, supported by investment in research of 1 billion SEK per year. A large part of this will be for PV and biogas as electrical sources research. The Electricity Certificate Act (Lagen om elcertifikat 2011) allows for schemes commissioned after 1 May 2003 to have an electricity certificate for 15 yrs (scheme ends 2035). The certificates correspond to a quota of their sales/consumption which must be increased each year. The electricity certificate scheme is not financed from the national budget. The additional income to producers that generate electricity from renewable energy sources is paid by the electricity consumers and is channelled to the producer via the electricity suppliers. In the 2020 forecast there is no expectation of an increase in hydropower schemes of < 10 MW and only 0.01 % increase in schemes of > 10 MW. Since Jan 1 2012 Sweden has entered into a communal green certificate market with Norway.



Dry river valley, River Arog, Sognefjorden, Norway. Note the warning notice that river may flow un-expectantly if hydropower suddenly ceases production

Norway

Although not part of the EU, Norway is part of the Europe Economic Agreement (EEA, 1994). As such Norway has also set a target for renewable energy production as a percentage of total energy production. The target is 96 % of the electricity produced is from hydropower of which 60 % is consumed within the country. For every unit of renewable energy (1 MWh) produced the state issues a ‘green’ certificate to the producer. The electricity suppliers and intensive users are obliged to meet a quota set by the state. Producers sell these certificates and thereby gain additional monies to the selling of electricity. An agreement has been signed between Norway and Sweden for a common market in green certificates that was established January 1st 2012. It’s hoped that green certificates will lead to a reduction in the producer price of electricity from renewable sources and the production of other electricity will be reduced. Production of renewable energy will be more cost effective and so the percentage of renewable energy as part of overall national production will rise.

UK

The U.K. has set a target of 15 % electricity generation from renewables by 2020. In 2014, 11 % of renewable electricity is predicted to come from hydropower, this figures drops to 6 % by 2020, the bulk of renewable electricity set to come mainly from off-shore wind power. There are two financial incentives in UK: the Renewables Obligation (RO; from Electricity Act 1989 and Energy (Northern Ireland) Order 2003) and Feed in Tariffs (Energy Act 2008). Since its introduction the RO has tripled the level of eligible renewable electricity generation (from 1.8 % of total UK supply to 5.4 % in 2008).

The RO works by obliging licensed electricity suppliers to source a specified and annually increasing proportion of their annual sales to customers from renewable sources, or pay a penalty. Generators are issued with Renewables Obligation Certificates, ROCs, for every megawatt hour (MWh) of eligible renewable electricity they produce. Generators can sell their ROCs to suppliers or traders to receive a premium on top of the wholesale price of their electricity. ROCs can be sold with or without the electricity they represent. The scheme is available until 2037 in UK, 2033 in NI. The Feed-in Tariff (FITs) scheme is intended to encourage deployment of additional small scale low carbon electricity generation. Applications for FiTs will be accepted until 2021 and be eligible for support for 20 yrs.

A summary of expected percentage contribution to total renewable energy production from 2005-2020 for each member state is given in *table 2* below.

Table 2. A summary of percentage renewable energy from hydropower in 2014 and 2020

	2005		2010		2011		2012		2013		2014		Total energy from renewable sources 2014		% hydropower energy from renewable sources 2014	
LNS MS	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh
Belgium	108.15	350.4	112.3	362.2	114.5	388.3	116.1	372.8	117.7	377.3	125.7	384	3618.4	11462.4	3.473911	3.350084
Denmark	10	23	10	31	10	31	10	31	10	31	10	31	6028	17078	0.165893	0.18152
Finland	3040	13190	3050	14210	3050	14210	3050	14210	3050	14210	3050	14210	5780	25150	52.76817	56.50099
Germany	4329	19687	4052	18000	4068	18000	4088	19000	4111	19000	4137	19000	77251	146490	5.35527	12.97017
Luxembourg	34	98.1	38	107	38	107	38	107	38	107	38	107	347	780	10.95101	13.71795
Netherland	37	89	47	128	56	159	67	195	68	200	68	200	1632.918	425.116	4.164324	47.04596
Norway																
Sweden	16345	72874	16350	71240	16351	70924	16352	70600	16353	70275	16354	69950	22079	90908	74.07038	76.94592
United Kingdom	1501	4921	1648	4790	1760	5230	1800	5360	1840	5480	1880	5610	16880	53280	11.13744	10.52928

	2015		2016		2017		2018		2019		2020		Total energy from renewable sources 2020		% hydropower energy from renewable sources 2020	
LNS MS	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh
Belgium	122.5	390.7	125.7	399.7	128.7	408.6	132.6	419.1	136.3	429.5	140	440	6255	23120	1.695942	1.903114
Denmark	10	31	10	31	10	31	10	31	10	31	10	31	6754	20595	0.14806	0.150522
Finland	3050	14210	3060	14250	3070	14290	3080	14330	3090	14370	3100	14410	8540	33320	36.29977	43.2473
Germany	4165	19000	4196	19000	4228	19000	4258	19000	4286	20000	4309	20000	110934	216935	3.884292	9.219351
Luxembourg	38	107	38	107	38	107	40	113	42	119	44	124	347	780	12.68012	15.89744
Netherland	68	200	95	303	122	406	149	508	176	611	203	714	1577.431	1333.047	12.88903	53.5615
Norway																
Sweden	16355	69625	16356	69300	16357	68975	16358	68650	16359	68325	16360	68000	23829	97258	68.65584	69.91713
United Kingdom	1920	5730	1960	5860	2000	5990	2040	6110	2080	6240	2130	6360	38210	116970	5.574457	5.437292

3.2 Impact of European Directives

3.2.1 Apparent conflict of EU directives

The potential impact assessments for hydropower schemes has been left to member states, but the RED does insist 'The coherence between the objectives of this (RE) Directive and the Community's other environmental legislation should be ensured.' The 'other environmental legislation' referred to includes the Habitats Directive (1992) and the Water Framework Directive (2000). Both of these ideally seek to restore habitats to a near natural state. In the case of hydropower, the infrastructure required could potentially exert a hydromorphological pressure and impacts which may prevent the water body from achieving Good Ecological Status.

The Common Implementation Strategy WFD and Hydromorphological Pressures Policy paper (European Commission, 2007) advocates the development of clear guidance on authorisation procedures for hydropower in relation to the WFD. Specifically it recommends modernisation and upgrading of existing infrastructures rather than to create new obstructions. It also calls on member states to identify "no-go" areas where hydropower schemes would not be allowed. The introduction of barriers to impound water for hydropower generation may appear to conflict with this aim but provision is made within Article 4 of WFD to designate a water body as artificial or heavily modified for the purposes of power generation which accepts that the water body cannot revert to its natural state but will achieve the best potential it can.

In Art. 4(3)-4(7) the WFD deals with hydro-morphology pressures. For new developments, there is a need to prevent deterioration of 'status' in a water body. Where this is not possible, mitigation measures should be applied. Where a physical modification has already taken place, restoration should be considered with a view to aiming to achieve 'good ecological status'. Where restoration is not possible, mitigation measures should be investigated with the aim to meet 'good ecological potential' (GEP). River Basin Management Plans should include measures for mitigation of existing HEPs which are causing impacts.

A Commission Communication (COM (2005) 627) recommends that member states should 'establish pre-planning mechanisms in which regions and municipalities are required to assign locations for different renewable energies, and to create lighter administrative procedures for small renewable projects'. In response the UK produced Hydropower: Mapping opportunities and environmental sensitivities (February 2010). The report identified almost 26,000 potential sites for small-scale HEP based on gross head across natural and existing man-made barriers and the potential generating capacity for each calculated from the gross head and flow statistics. This approach did not take into account Habitat Directive designated sites, protected species, existing abstractors rights or water availability. A review of the original data set reduced the number of potential sites by 20,000. If any of the remaining 6,000 are presented as potential hydropower schemes they will still need to meet the Water Framework Directive criteria of not derogating the water body in which they sit below Good Ecological Status. This illustrates that not all existing barriers have the potential to support a HEP scheme and meet EU obligations.

General view of HEP scheme on River Arog, Norway, clearly showing original river bed now completely dry. Many high head schemes are completely hidden within a mountain with only the electricity cables giving away their presence

3.3 Impacts of hydropower schemes on fish migration

Fisheries in the North Sea have been reduced by overfishing and a reduction in the connectivity of rivers from headwaters to the sea. Hydropower schemes are usually associated with barriers with the added potential hazard of turbines.

3.3.1 Potential impacts of renewable energy to fish.

The incentives introduced as a result of the Renewable Energy Directive have encouraged a range of renewable energy sources to be exploited. Diversity of resources allows energy security. The table below summarises the potential impacts of a range of renewable energies on fish.

Many studies have now shown that hydropower schemes can impact heavily on fish migration and production. This is not solely due to impassable barriers and a loss of connectivity from sea to headwaters but also by causing migration ‘breaks’, leaving fish vulnerable to predation and disease. Inadequate screening has also lead to entrainment into turbines causing injury and death. Fig. 3.4 shows the main potential impacts of dams and weirs on the riverine habitat.

Fig. 3.4. Impacts of hydropower obstructions

Renewable type	Potential Impacts	Potential impact on fish
HEP Low head	Turbine mortality Barrier/connectivity Change in water temperature	H
HEP High head	Depleted reach Turbine mortality/injury Barrier/connectivity Change in water temperature	H
Tidal	Turbine mortality Barrier/connectivity	M
Wind	No contact	n/a
Photovoltaic	No contact	n/a
Biomass	Impacts of loading due to agricultural production	L
Geothermal	No contact	n/a

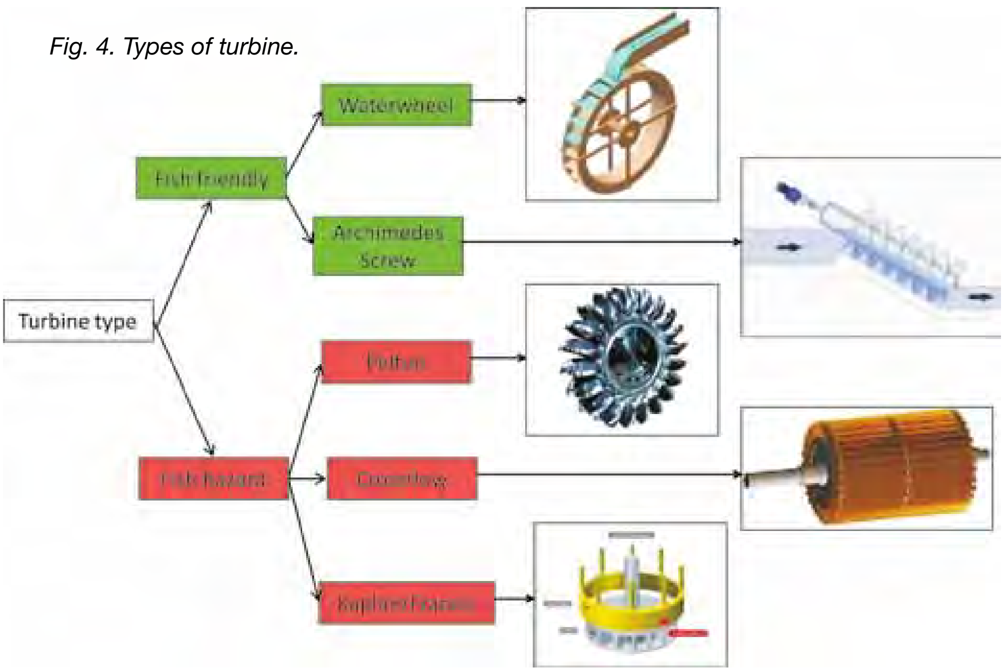


Fig. 4. Types of turbine.

3.3.2 Impacts of turbine type

Whereas barriers have the most impact on upstream migratory fish, turbines have the greatest impact on fish migrating downstream. The degree of impact of hydropower depends on several criteria:

- Turbine type
- Rotation speed of the turbine
- Distance between the blades
- Operating conditions
- Cavitation zones (vibration caused by bubbles formed as water passes through turbine)
- Fish size
- Fish species

3.3.3 Entrainment prevention

Turbines can broadly be split into two groups (Fig. 4). Those that are 'fish friendly' such as waterwheels and 3 blade Archimedes screws are most likely to be found at low head hydropower schemes where the gross head is less than 4 m but the volume of water is high. Those turbines that pose a potential hazard to fish, propeller turbines, Kaplan/Francis, Crossflow and Pelton turbines, are most likely to be found on high head schemes where the volume of water is relatively less but the gross head maybe > 100 m. These turbines are smaller, faster and have blades that are closer together which can cause serious injury or death to fish. To prevent entrainment several design criteria can be employed:

- Flow attraction to a bypass
- Protection mechanism e.g. screening and guidance device
- Approach of flow to turbine intake
- Conveyance mechanism e.g. fish pass
- Tailrace characteristics such as plunge pools

Herting HEP scheme Falkenberg Sweden showing in-take (a), turbine (b) and barrier (c)

3.3.4 Effects of high head hydropower installations on downstream salmonid populations

Certain studies have shown that hydropower can influence fish populations, Jonsson & Jonsson (2011)[1] gives detailed explanation of the mechanisms.

Damming a river allows for a reduction in extreme flooding and more even flows throughout the year. Water can be retained in the wet season and used for hydropower production all year round. In parts of Europe where the air temperature is below 0oC in the winter, high head river regulation can influence downstream flow and temperature which in turn affect fish production. The hydropower scheme can lead to both lower summer water temperature and flows and to higher winter water temperature and flow. The reasons for this are that water for hydropower is taken from deep behind the dam and not from the surface (as in natural lakes) and more energy (and water) is used during the cold part of the year.

Juvenile fish growth can be reduced in rivers where the temperature during the growth season decreases to below the optimal temperature for growth (15oC for trout and 18-20oC for salmon). Higher winter temperatures stimulates earlier hatching of the fry and earlier seaward migration in spring of juvenile anadromous salmonids produced in downstream areas. The migrating juveniles are often younger and smaller. On the other hand, adult return migration can be delayed because of lower summer flows. This is particularly the case in small rivers where flooding initiates the river ascent of fish. These changes may negatively influence survival and growth in sea water and subsequently, reproductive success in the river.

Production can decrease in relatively cold rivers where the ice covered area during winter limits juvenile abundance. In rivers where the water temperature in winter is relatively lower, the ice covered area decreases and juveniles living in the new ice-free areas cannot meet the required energy consumption leading to a loss in productivity.

Jonsson B, Jonsson N (2011) *Ecology of Atlantic salmon and brown trout: Habitat as a template for life histories. Fish and Fisheries Series 33, Springer, Dordrecht, 708 pp.*

3.4 Case studies

Studies throughout the LNS region have shown that hydropower schemes can impact on the riverine ecology including fish migration. This section includes several case studies of hydropower schemes where mitigation measures have be deployed to aid migration. More information is given in the fact sheets accompanying this report. Measures include:

- **Barrier reconstruction for fish passage:** Hertings dam, River Atran, Sweden.
- **Barrier removal and full fauna passage:** Fyllsted Mill, River Storå, Denmark.
- **Consideration of potential cumulative impacts:** River Trent, England.
- **Turbine type:** Howsham Weir, River Derwent, England.
- **Change to operational regime:** Bratteset, Smorkvo and Garna HEP stations, Norway.
- **Opening a culverted stream:** The Copper Stream, Denmark.
- **Weir reconstruction:** River Odense, Denmark.

Illustrating the height of a low head HEP scheme in Denmark prior to total removal

3.5 Key messages

"While water is a renewable resource, rivers are not" – Ronald Campbell, Tweed Foundation

The EU is committed to reducing greenhouse gas emissions to 80-95 % below 1990 levels by 2050 in the context of necessary reductions by developed countries as a group (Energy Roadmap 2050 COM(2011) 885/2). The most important contribution is expected from wind power (40.7% of which onshore wind power contributes 28.9%). The second largest technology is expected to be hydropower, 30.4 % of all RES-E in 2020, of which large hydropower takes 25.4%). In the 2050 Road Map micro hydropower is not considered. In general, the following key messages were put forward during the Living North Sea project:

- Not all renewable energy is environmentally benign. The whole environment cost of a hydropower proposal needs to be accessed.
- Each member state should identify "no go areas" for any hydropower development. These restriction zones should take into account European designations such as Nature 2000 sites, protected species, water resource availability, WFD classifications and locally important habitats.
- Hydropower developments should be considered at both catchment and site level, so that cumulative impacts with other HEP schemes or artificial influences (abstractions, discharges) can be assessed.
- All member states should develop a robust environmental assessment methodology to ensure there is no deterioration of WFD standards.
- Hydropower developments, where possible, should not involve the creation of a new obstruction but utilise existing structures.
- If a hydropower installation is considered beneficial then it must include appropriate mitigation measures e.g. facilities for the up- and downstream migration of all fish species.
- The legacy cost of a hydropower installation should be considered as part of development plans. Decommissioning hydropower facilities should be the financial responsibility of the licence holder/operator.
- Hydropower licences need to be time limited, to allow for changes to, mitigation or revocation of permits if the site is found to be environmentally damaging. Agreed funded environmental monitoring plans need to be in place before construction or operation of scheme.
- Subsidies for hydropower development needs to be proportionate to requirement. Receipt of subsidies should be dependent on approval of appropriate mitigation measures when required.
- Utilisation of waste water discharges for HEP generation should be investigated.
- Water transfer between catchments should be discouraged or a full environmental impact assessment should be completed if such transfers are proposed.
- Associated infrastructure such as roads and stream crossings need to be ecologically assessed as part of the scheme to the cost of the developer.

Partner organisations of the LNS project who have regulatory responsibilities are not bound by any of the projects findings but may wish to review their current procedures and incorporate any recommendations as appropriate in future revision.

3.6 LNS Policy recommendations

Policy recommendations will be presented and discussed at the LNS end meeting in Newcastle (November 2012). The result will be included in the final version of this report.

- The whole environmental cost of a hydropower proposal should be considered. Assessment should include plans for potential future decommissioning which will be carried out at the expense of the licence holder/operator.

- Each member state should identify hydropower ‘no-go’ areas taking into account European Directive classifications, protected species and habitats and water resource availability.

- Hydropower development should be considered as part of a wider strategic catchment plan so that the cumulative impacts of all artificial influences (abstractions, discharges, other HEP schemes) can be assessed at a local and catchment level.

- Where possible hydropower development should utilise existing structures and avoid creating new river obstructions or consider alternative renewable energy sources such as solar, wind or biogas.

4 - Habitat restoration for migratory fish in the North Sea region

SECTION SUMMARY

- Importance of habitat restoration when improving river connectivity
- Case studies of habitat restoration in the North Sea region
- Policy recommendations

4.1 Background

The previous sections already discussed the impact of barriers to migratory fish when attempting to reach suitable habitat. However, measures to restore connectivity will not repay themselves unless the habitat upstream is suitable to sustain the fish. There is probably not a single river or watercourse that has been left un-touched by man's influence in the North Sea region.

As described previously there is now a range of Directives and legislative initiatives aimed at protecting vulnerable habitats and at reversing damage done (Water Framework Directive (2000), The Marine Strategy Directive (2008) and Natura 2000 (1992)). Two of the biggest long-term impacts on fish populations are problems associated with habitat (for instance declining chemical water quality and physical habitat degradation) and continuity (for instance hydropower dams, weirs and pumping stations). The subject area is huge and there is a mass of literature documenting various studies and impacts.

If the habitat restricts any part of the fishes' life cycle there will be a production "pinch point" in the population. For a resident species this may lead to a reduction in productivity, but for a migratory species this may mean the difference between a sustainable population and one that is heading for extinction. The effects of a hydropower dam on diadromous fish might be instant, but it may take years for habitat degradation leading to extinction or suppression of the population to manifest itself. This is particularly true for long-lived fish species with a slow generation time, such as the European eel and sturgeon, while short-lived species like smelt or houting can be rapidly effected.

The fecundity of a species can also play a role: species that produce a lot of eggs can often persist for longer in marginal habitat over species that depend on high survival of relatively few eggs. The impacts of habitat degradation can be further masked by subtle changes in local life strategy influenced by density dependent factors. For example, a fish population may change from a high number of short-lived individuals to only a few larger, longer living specimens. Many of these changes may go unnoticed as the population drop is so slow that the lower level is just assumed as the norm and the lack of accurate catch records prevent the trend being recognized. In some cases the change from large numbers of small fish to fewer larger specimens is welcomed by recreation and commercial fisherman until the population suddenly crashes.

The one thing that is clear that the effectiveness of restoration of habitats is very difficult, poorly understood and evaluated. Therefore the LNS project also targeted its research on habitat and the dissipation of knowledge on habitat restoration efforts.

4.2 Habitat of rivers in the North Sea region

The river ecosystem includes the hydrology, diversity of habitats, sediments and biota. Rivers and streams tend to be a dynamic equilibrium driven by the dynamics of water discharge and sediment discharge and deposition. The resulting fluctuations are influenced by the slope and the substrate erodibility. River morphology and river basin land use is crucial for river biodiversity and ecosystem functioning. Human activities as river regulation, urbanization and clearing of forests for agriculture increasingly change the natural drivers of channel morphology on a global scale. The most important factor that provides variation in habitats is the amount of flow and the differences in flow. Differences in substrate (clay, sand, rocks) also are an important factor for variation in habitats within river ecosystems.

In rivers there are different habitats that are used by fish. Solid substrates likes rocks, gravel beds and wood can be important spawning grounds for fish species like river lamprey or sea trout. Sandy substrates form in relatively slow flowing parts of the rivers and provide important feeding grounds. Sandy substrates with detritus or a small layer of silt form places where river lamprey larvae reside and feed on algae and detritus that is swept away with the current. In the parts of the river that are stagnant silty areas occur. In the more dynamical parts of the river, for example the outer corners of river bends, heavy materials are deposited like gravel and rocks. Dead trees and wood that fall into the river can create local habitat diversity.

The LNS-project aims at identifying knowledge gaps and at the exchange of knowledge of species distribution and habitat use. It is clear that within the project multiple partners of different governmental levels and the non-profit sector are trying to solve different habitat problems. The Dutch, Belgian, English, German and to some extent the Danish partners are dealing with altered rivers and lakes in terms of nutrients and flow regime. Norway and especially Sweden are dealing with the altered chemical state of rivers and lakes due to acidification that took place in the last half of the century.

4.3 Examples of habitat projects in the North Sea region

4.3.1 Remeandering the Oostervoortse diep brook (NL)

The Oostervoortse diep is small stream to the south of Groningen and forms the beginning of a river system called Reitdiep-Peizerdiep. The Regional Water Authority Noorderzijlvest aims to investigate the change in fish stocks and the change in morphology (sediment, vegetation, flow etc.) after remeandering 4 km of brook. Within this system, because of canalisation, fish like lamprey, dace and other fish species that would be expected in this habitat have disappeared. The Regional Water Authority is also investigating if and how this stream should be cleared of weeds and plants. A study has shown that there was a massive change in the fish stock before and after remeandering. However riverine fish species that had disappeared from the system have not yet returned. This may be due to the relatively small size of the project area and the fact that it takes time for riverine fish species to find this new suitable habitats.

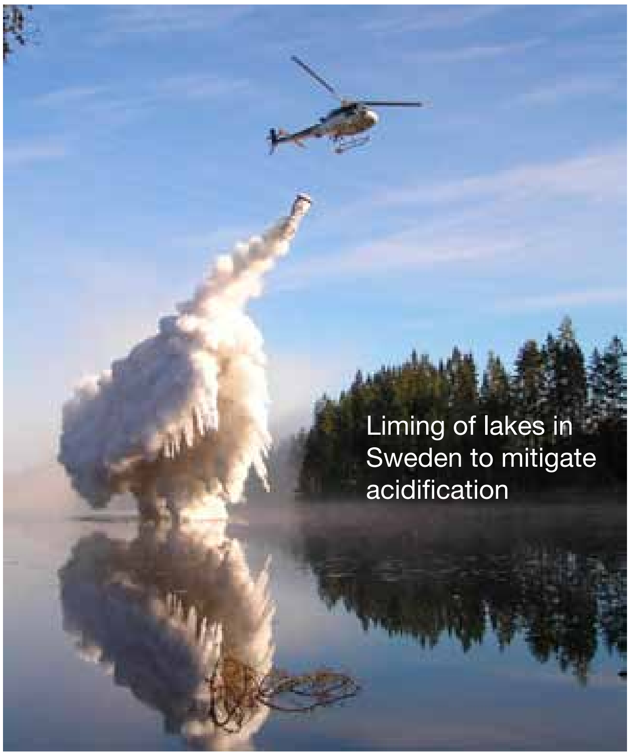
The re-meandering project in the Oostervoortse diep (The Netherlands)

4.3.2 Mitigate a modified flow-regime in the River Tees (UK)

The River Tees (managed by the Tees Rivers Trust) is a highly modified river that is surrounded by other rivers of high importance to migratory salmonids and eel. One of the issues that needs to be addressed is the large proportion of the river that is cut off by the creation of water storage reservoirs. These not only restrict the amount of habitat, but also cause problems downstream of the dams. The Tees Rivers Trust aims to mitigate a modified flow regime in the river Tees, the loss of natural hydro-geomorphological processes, and the subsequent loss of salmonid spawning streams. The trust has examined opportunities for replacing, and recreating spawning areas for migratory fish by modifying reservoir water release and opportunities for getting fish around the reservoir dams.

4.3.3 Liming of lakes to mitigate acidification (S)

When natural resources are lacking, helicopter liming with new liming products and techniques can mitigate acidification in areas that have been difficult to restore with previously used methods. Thousands of lakes in western Sweden (some of them being managed by the Municipality of Falkenberg) have been acidified due to long distance transport of acid precipitation mainly from other European countries. Restoration of these heavily acidified areas and lakes in western Sweden is a prerequisite to allow migratory fish species to return to former spawning and nursery areas. This restoration is crucial for migratory fish to move freely without chemical barriers and to complete their life cycles. Otherwise many migratory fish populations will be threatened, endangered or extinct.


Liming of lakes in Sweden to mitigate acidification

4.3.4 Installation of riffles as spawning habitat in the River Stiffkey (UK)

Ten spawning gravel habitats were introduced (by the Environment Agency and the Wild Trout Trust) into the River Stiffkey, north Norfolk, in 2009 as part of the Living North Sea restoration strategy to address reproductive limitations in the freshwater stage of anadromous brown trout that enter the river, and facilitate genetic diversity within the resident brown trout population. There are limited areas of natural riffles within this river because of previous management practices and these new spawning gravels will add to those installed in 2003.

The functioning of these spawning gravels has been monitored over two years as part of a PhD study to study the effects of hydrogeomorphology on the biological function of the introduced restoration spawning gravels within the River Stiffkey, north Norfolk. Outcomes will provide a greater scientific understanding of the catchment-sensitive functioning of the restoration gravel structures, contribute towards their continued management, as well as propose recommendations for future restoration designs. This project is part of a catchment approach to restoration, with opening up of the tidal flap (see fact sheet TB5), improved connectivity and habitat restoration (spawning habitat, channel narrowing, river maintenance procedures, fencing and land management to reduce sedimentation), all designed to provide a whole catchment approach to habitat restoration.

4.3.5 The effectiveness of stones in soft banks for smelt and eel (NL)

In the management area of Waterboard Rijnland (NL) there is an important seawater-freshwater connection in Katwijk, where fresh water is pumped out to sea. A two-way fish-passage is present at this location. Inland, the area is characterized by a connected system/network of small rivers (boezem) and polders with lots of ditches. For smelt (both for landlocked and migratory populations) a good measure could be the creation of banks with stones as spawning area. Also eel and perhaps other species could benefit from stone banks.

Smelt cannot reproduce optimally if its preferred spawning habitat is not present. Smelt needs large water, preferably a passable connection to sea and a presence of stone or sand banks in the fresh water habitat. A desk study made clear that smelt would benefit from a 5 % bank share of stone or a combination of sand/stone, especially at the banks of bigger lakes/larger waters. Also eel will strongly benefit from stone banks. This is because eel can hide in between the stones at daytime. As a side effect stone banks will prevent fishermen from placing eel fykes.

Stone banks are classified as non-natural in The Netherlands. This is why projects to restore "natural" banks are not widely carried out with stone as protection against waves. On the other hand stones have very good characteristics from an engineering point of view. And as it appears from this study, it is a good measure for smelt at appropriate (big) lakes, since only 5 % of the bank has to be 'stone' or stone/sand as basic material.

4.3.6 The twaite shad bay near Den Helder (NL)

Twaite shad, and other diadromous species as allis shad and herring need transitional waters to spawn. Especially in The Netherlands lots of connections to transitional (brackish) waters are cut off by dikes and dams. At some locations suitable spawning areas (habitat) are still available, just not reachable. In this case the waterboard Hollands Noorderkwartier executed a project near the city of Den Helder where habitat improvement was combined with measures to restore connectivity.

An existing connection between fresh and saltwater, was made passable for twaite shad (and some other species) in both directions. This connection is a tidal lock which was adapted for twaite shad to enter (fish is let in like a ship in a lock) and a pumping station was adapted to allow the fish to go out to sea again. Besides this a spawning bay for twaite shad was created 2 km inland by creating shallow parts.

4.3.7 Restoration of spawning grounds of seatrout in Bogense Bybæk (DK)

The Municipality of northern Fyn manages the streams in the Municipality and is responsible for achieving the environmental targets required for individual streams. In this area, and many others in Denmark, streams have been channelized and have poor physical conditions due to excessive maintenance. In addition to this, weirs and mill ponds have prevented the migration of various fish species like the sea trout. To complete its lifecycle, sea trout need streams with good physical conditions, high water quality and free passage. An important factor is the occurrence of suitable spawning grounds consisting of the right gravel beds. As gravel often has been removed in streams, an important element of habitat restoration is the creation of spawning grounds.

Other species such as lampreys and macroinvertebrates also could benefit from gravel beds. A study was carried out before and after the creation of free passage and establishment of gravel beds. This study made clear that the number of sea trout spawning nests downstream the weir at the mill increased between 2008 and 2010 from 31 to 52 as a result of more available spawning grounds (established in the project). Upstream Lower Mill the number of nests was doubled and the fraction of medium-sized and large nest greatly increased in 2009 and 2010. This suggests that spawning was performed by the larger sea trout compared to the stream dwelling brown trout.

4.3.8 The return of the European sturgeon?

European sturgeon has impressive physics, it can reach lengths of 3,5 meters, weights of 300 kilo and high age up to 70 years. Despite all their apparent strength, sturgeons turned out to be very vulnerable. It was the first migratory species to disappear from the North Sea and its connected rivers (and therefore likely the last to return).

Around 1900 our growth towards modern society took its toll. Fisheries developed from sail to steam (longer fishing trips, higher capacities), spawning habitat in our main rivers declined due to channelization, and there were problems with severe water pollution. That was then. In our modern times the water of the river Rhine is again quite clean. Celebrating the 50th anniversary of WWF, on May 9th 2012, the Dutch princess Laurentien, released the first 3 sturgeons in the Rhine. On the same spot where many sturgeons were sold at the historic fish market 'Kralingse Veer' in the port of Rotterdam. The rest was released at historical spawning sites near the German border.

These very rare specimens were received from the Irstea breeding program in France, being delivered to the Netherlands. This is seen as a first step in the reintroduction program initiated by WWF the Netherlands and ARK Nature in close cooperation with the Royal Dutch Angling Association (Sportvisserij Nederland - SNL) and Irstea.

The LNS budget was put to good use by SNL, organising the tagging and tracking, enabling us to follow fish downstream the river Rhine. Together, we found out that sturgeons could escape into the North Sea, all be it not through the estuary of the Rhine, but through the Port of Rotterdam. This is the effect of the estuary being disconnected from the North Sea due to sea lock Haringvliet-dam. In the harbour sturgeons apparently needed a few weeks to acclimatise to the salt water, swimming below bulk carrier ships. Next, the sturgeons reached their feeding grounds, all along the Dutch coast, where some were recaptured by commercial trawlers (shrimp fisheries). The survival rates of these strong fish were actually quite high: 4 out of 5 fish could be released unharmed. According to these first results, our hopes are up for rehabilitating the species, starting a new reintroduction program with sturgeons in the Rhine. Focussing on main issues, such as opening up the sea lock Haringvliet-dam and stressing the need for a good cooperation with commercial fisherman, working towards sustainable fisheries.

4.4 LNS Policy recommendations

- Obstacles should be removed complety in rivers and other watercourses to secure full fauna passage. While water is a renewable resource, rivers are not.

- For many migratory fish species there are important knowledge gaps that hamper efforts to protect these species and makes it difficult to assess effectiveness of measures. For future measures or policies to be effective we need more projects that research the effectiveness of measures on a large scale or at least on the river basin level. The effectiveness of measures to improve ecology should be assessed from a species level with an international perspective. Further, the whole life cycle should be considered when restoring or protecting migratory fish species.

- The problems stated in this report are not unique to the North Sea. However, considering the size of the North Sea, the number of countries involved and the number of people living in the North Sea region, this report could act as an example of how to deal with human impacts, how to improve the ecosystem and how to explore the boundaries of policies, legislation and more important ecological status and quality.

5 - Reports of the activities in the Living North Sea project

Studies / Reports		Country	Partner	Date
1.	Results of liming bottom fauna	Sweden	Falkenberg	2012
2.	Fish migration tagging at hydro power station Atran	Sweden	Falkenberg	2012
3.	Glass and Silver eel migration	Sweden	Falkenberg	2012
4.	Water quality results of liming	Sweden	Falkenberg	2012
5.	Migration and survival of stocked st smolts	Denmark	Seatrout Fyn	2012
6.	Pilot project report for full fauna passage at Fyllested Mill	Denmark	Seatrout Fyn	2012
7.	Where is the glass eel?	NL	Waternet	2012
8.	Effects of adapted sluice management on fish migration	NL	Waternet	2012
9.	Fish migration on the NZ-channel	NL	Waternet	2012
10.	Results monitoring fish migration at pumping stations	NL	Waternet	2012
11.	Monitoring results pumping stations and weirs	NL	Hunze en Aa's	2012
12.	Guidance Fish Friendly pumping stations	NL	Hunze en Aa's	2012
13.	River Lamprey /Eel telemetry	NL	Hunze en Aa's	2012
14.	Paper on downstream migration of Salmon Smolts on river Meuse	NL	SNL	2012
15.	Report on start of re-introduction of Atlantic Sturgeon in river Rhine	NL	SNL	2012
16.	Report knowledge document trout	NL	SNL	2012
17.	Prioritizing of pumping stations	UK	EA	2012
18.	Effectiveness of XXXX of pumping schemes?	UK	EA	2012
19.	PhD Paper st smolts migration river Tweed	UK	Tweed Foundation	2012
20.	Eel habitat priorities	UK	ART (The Rivers Trust)	2012
21.	PhD studies: - Coastal Engineering - Hydromogen sessions (?) - Eels/barriers	UK	EA	2012
22.	Glass eel migration 1 – 2 – 3	Belgium	INBO	2012
23.	Results monitoring pumping stations	Belgium	INBO	2012
24.	Restoration of migratory fish species river Scheldt	Belgium	INBO	2012
25.	River Lamprey telemetry	Belgium	INBO	2012
26.	Eel satellite tracking in the North sea area	Germany	vTI	2012
27.	Monitoring of eel swim bladder parasite in northern Germany	Germany	vTI	2012
28.	From North sea canal to Vecht; exploring the possibilities for improvement	NL	Waternet	2011
29.	North Sea Canal, a highway for migratory fish	NL	Waternet	2012
30.	Socio-economic valuation of eel, salmon and sea trout	NL	Noorderzijlvest	2012
31.	Sea trout in the Wadden Sea	NL	Noorderzijlvest	2012

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