
FROM SEA TO SOURCE

International guidance for the restoration of
fish migration highways



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Young boy with fish on the banks of
the Tonle Sap River in Cambodia
(© Zeb Hogan / WWF-Canon).

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Preferred citation

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

Photography

We gratefully acknowledge all of the contributors,
authors and WWF who gave us permission to use their
photographic material.

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Cartography

WWF HydroSHEDS

Lay out and cover design

Shapeshifter visual design
www.shapeshifter.nl

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MAJOR RIVERS OF THE



1 Yukon

2 Mackenzie

3 Nelson

4 Columbia

5 Colorado

6 Rio Grande

7 Mississippi

8 Orinoco

9 Amazon

10 Tocantins

11 Sao Francisco

12 Parana

13 Rhine

14 Danube

15 Dnieper

16 Nile

17 Niger

18 Congo

19 Zambezi

20 Orange

21 Ob

WORLD



22 Yenisei

23 Lena

24 Kolyma

25 Volga

26 Don

27 Tigris

28 Euphrates

29 Syr Darya

30 Amu Darya

31 Indus

32 Ganges

33 Brahmaputra

34 Irrawaddy

35 Salween

36 Mekong

37 Yellow

38 Yangtze

39 Amur

40 Murray Darling

PREFACE

WWF

Fish and people have a strong and intense relationship. Take the Mekong for example. Each year, a large and diverse migration of fish to their spawning grounds takes place along the lower Mekong River. Up to 70% of the commercial fish of this great river are long distance migratory species. If the migration is blocked by structures such as hydropower dams, the fish will not be able to reach spawning grounds. If this happens, fish populations will fail to sustain themselves and some species may vanish. The regional fishery industry, integral to the livelihoods of 60 million people, may collapse with devastating effects.

Managing rivers wisely, from Hilltop to Ocean (H₂O) is what the World Wide Fund for Nature (WWF) has been encouraging for decades. WWF works literally from the top of the world to the seas. From sources of rivers (e.g. the Tibetan Plateau) to rich floodplains (Zambezi); to productive estuarine systems, where rivers meet the sea (Mekong Delta). Each part of those river systems provides people with significant products and services.

The high altitude wetlands of the Andes function as a sponge, absorbing water and protecting cities downstream. The catchments of the Nile and the Euphrates provide fertile agricultural and fish production grounds and reed for housing. Estuarine systems with mangrove forests protect the land from storms and surges.

Valuing each part of the river and knowing that poor management in one part of the river can adversely affect other parts of that system, sometimes thousands of kilometers away, is of utmost importance for a sound and integrated management of the system. And in the case of fish, these relations are not only upstream to downstream, but also the other way around.

The Netherlands is a good example of this. After the floods of 1953, the Rhine-Meuse delta was

closed by dams for safety, disconnecting the rivers from the sea.

While great effort was made inland in the last decades to restore and reconnect river habitats, and the reintroduction of fish species such as salmon took place, the key to success for migratory fish all still depends on re-establishing that life-line between the sea and the river. We must open 'arms' in the delta and embrace our rare and sometimes unique fish species: from Sea to Source.

Let us appreciate what we have. In many places in the world, there are still some natural rivers that flow freely and where fish migrate freely without substantial obstacles. These rivers are ecological treasures. Because of the rich functions and services these rivers provide, they are also in many cases of high economic value.

People are often directly dependent on the protein provided by the fish that thrive in these free flowing rivers, supported by the capacity to migrate freely to maintain their life cycles and to prosper. This guidance 'From Sea to Source' gives examples of such rivers that deserve conservation and wise management.

Most other rivers are much more affected and damaged by human activity, but here, even in the most damaged rivers, the potential to restore fish migration demonstrably exists. The challenges for these rivers are here formulated as restoring more than conserving. This can be as drastic as 'dam removal', as explained in this guidance. Other less drastic solutions presented are fish habitat restoration.

This kind of restoration serves more than one purpose. The Living Rivers Program in The Netherlands, adopted by the government and many other parties in other countries has resulted in clear win-win situations. Nature is restored,

including access for fish to spawning grounds, safety is increased through the management of water levels, clay is harvested in a sustainable and profitable way, and tourism and recreation are increased substantially.

In rivers with man-made barriers to fish migration, measures such as fish ladders may mitigate the effects of infrastructure. These often expensive solutions work well for some fish species. These and other solutions will never truly replace the force of living, naturally connected rivers but are, in cases, the best we can reach.

Using examples of modern and inspirational solutions to restore fish migration, this guidance 'From Sea to Source' seeks to inform, educate, and - most of all - inspire those tasked to protect and restore our precious fish populations.

Johan van de Gronden
Director World Wide Fund for Nature
The Netherlands (WWF)

Free flowing river in the Altai Sayan Ecoregion

Russia (© Gernant Magnin).





Launch event Living North Sea Project, 2010.
Glass eels before release in a polder system in
Flanders, Belgium (© Herman Wannigen).

PREFACE

LIVING NORTH SEA PROJECT

The Living North Sea project (LNS) is proud to support this worldwide guidance on fish migration. Many of the project partners have contributed to the guidance, and many more will benefit from its advice.

LNS is a 6.4 M Euro project funded by the European Regional Development Fund through the Interreg IVB North Sea Region Programme. It involves 15 partners from seven countries with expertise and interest in fish migration issues ranging from non-government organisations to local government authorities, national or federal agencies, and universities.

Rivers in countries of the North Sea region are amongst some of the most fragmented by human development in the world. This makes the area useful for learning about impacts and solutions to fish migration problems, but still leaves a lot of complicated problems for which solutions must be learnt from other countries, in particular the confidence to actually remove barriers completely.

Modern river restoration recognises the importance of restoring natural processes, because the impact of man-made barriers is much more than just a physical impasse that can be solved by a technical fish pass. Habitat loss, habitat changes, upstream and downstream river channel & geomorphology changes, flow dynamics and so on, means that technical fish pass solutions will always be mitigation for a structure rather than a solution.

Part of the solution therefore lies in educating those responsible for designing and maintaining man-made structures, not only about engineering solutions to fish passage, but also about the outstanding issues that still compromise the sustainability of our rivers so that these are considered from the very earliest design stages.

This guidance will play an important role in demonstrating what has been achieved throughout the world.

Alistair Maltby

**Project Manager, Living North Sea
Director North, The Rivers Trust
(United Kingdom)**

EXECUTIVE SUMMARY

Since man first started to manipulate rivers, harnessing them for our own use whilst believing that in some way they were resilient to everything we did, the fauna and flora that flourished within them started to decline. Around the world the once abundant runs of fish, salmon, eel, shad, sturgeon, catfish, ayu and many more, declined so much that their new scarcity was an unexpected and growing problem for humans that depended on them for food and income. This loss continues today, in Africa, Asia and South America.

As our societies developed and understanding fish biology developed, countries started to react to environmental degradation and species loss with a new culture of care. The challenge of river restoration, including the rehabilitation of our fish stocks, was launched.

Much work has been carried out to improve fish stocks in the past few decades but the dissemination of this knowledge and emerging best practices has been limited. We believe that biologists, managers and engineers across the globe can learn a lot from each other! This guidance is intended to contribute to this learning process.

We have called this book 'guidance' for a very good reason. We hope that people will read it, or just browse it, and be inspired and guided by the collective global efforts to protect and to restore free migration for fish populations everywhere around the world.

We have worked with many fish migration experts who have generously given their time, effort, and the benefits of their thoughts and experience so that we may share these with our audience around the world. Through our contributors we are able to present inspiring examples of success from every continent. We have increasingly realized that the challenges we face in our own countries are, in fact, much the same around the world. We thank our contributors, most of whom

you may contact for more detail through the addresses at the back of this guidance, and with the benefit of their learning we distil the following key points:

- All rivers function as ecological highways for fish. We must recreate free and unconstrained migration routes to fish habitats between the **Sea and the Source** so that fish populations may survive, recover and flourish;
- There are very few truly natural, free flowing rivers left in the world. We strongly agree with WWF that these are **unique rivers that should be preserved**;
- International funding should be channelled to fisheries protection schemes and the maintenance of free-flowing rivers, especially in areas where people rely on fish for protein and income;
- To overcome the challenges to effective management of our rivers we promote the development of **restoration visions for rivers**, addressing the issues that constrain our environment and limit the free migration of all fish. **A river basin approach**;
- We have learned that it is always better to remove barriers because in this way we can **re-vitalize our rivers**. It is almost always cheaper than building a fish pass, and removal has multiple benefits for river naturalization - all aquatic and riparian flora and fauna will benefit! Such solutions can address a range of problems, of which fish migration may be just one;
- We conclude that it is very difficult to build a fishway that can pass all life history stages of every species of fish present. A fishway is a compromise on a system that has already been modified. **Natural is better!**;
- If we cannot remove obstructions, we must build fish passage solutions that will work for **all riverine fish species**. For example we believe it is no longer good enough to build passes that only work well for salmonids;
- In so many countries, in many continents, fishways have been built as they were origi-

nally conceived in Europe and North America. Unfortunately this has often resulted in expensive failure. Until **the biology of your local fish is understood**, you cannot design an optimal fishway!;

- Fishways only work well when ecologists, river managers and engineers work closely together, understand each other and share their best practices. **Call it Ecohydraulics!**;
- Hydropower planning should balance the economics of 'green energy' generation with the risk of ecological harm to guarantee the protection of migratory fish populations. It is only 'green' if it does not damage nature! In future **nature and energy policies should be more closely integrated**. Safe passage of fish through hydropower units must be considered during the construction phase, not as an afterthought;
- **Sustainable hydropower planning** should include socio-economic considerations that contribute to a fundamental planning process. We support the global protection of the remaining **free flowing rivers**. Other rivers may be identified as priorities for hydropower, but most will sustain careful co-existence of hydropower where free fish migration is assured through fish passage techniques;
- Fish migrate across political borders and that's why we believe that countries, and states within countries, should work together closely on fish migration matters, **exchanging knowledge and building capacity** and expertise for mutual benefit and healthy fish stocks;
- We have found that **community involvement and environmental education** is an essential part of the process to achieve effective ecological restoration of rivers;
- We support the approach exemplified in the USA where an **international course on fish passage engineering** has been set up by the University of Massachusetts. We encourage other universities and research institutions worldwide to follow this example by

integrating fish passage engineering in river restoration courses.

This guidance and its inspiring case examples seeks to be an important step forward. But we also direct you to:

- The Fish Migration Platform (www.fromseatosource.com) - an important step towards better knowledge dissemination worldwide;
- The Fish Migration Network, the Fish Ecology Network and the Dam Removal & Fish Passage Network on LINKEDin - wonderful venues for colleagues around the world to share their best practices and news.

Our acknowledgements

This project would not have been possible without examples from experts from all over the world. Thank you all for your contributions over the last two years. The production of this guidance has been financially supported by a broad group of 34 sponsors worldwide. We are delighted that they could see how valuable the guidance could be, and that they saw the need for knowledge exchange and inspiration of the fish migration theme worldwide. Without their help and financial support this would not have been possible.

Finally we gratefully acknowledge our good colleagues Martin Kroes, Marc Ordeix and David Vesely who contributed to the first European Guidance 'From Sea to Source'. Your work and inspiration in 2006 made it possible to develop this new worldwide version of the guidance. We hope you like it!

Peter Gough
Peter Philipsen
Peter Paul Schollema
Herman Wanningsen

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Hydro Investment Projects BV

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www.mitmanlleu.org/cerm



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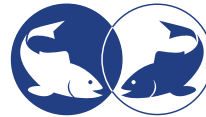


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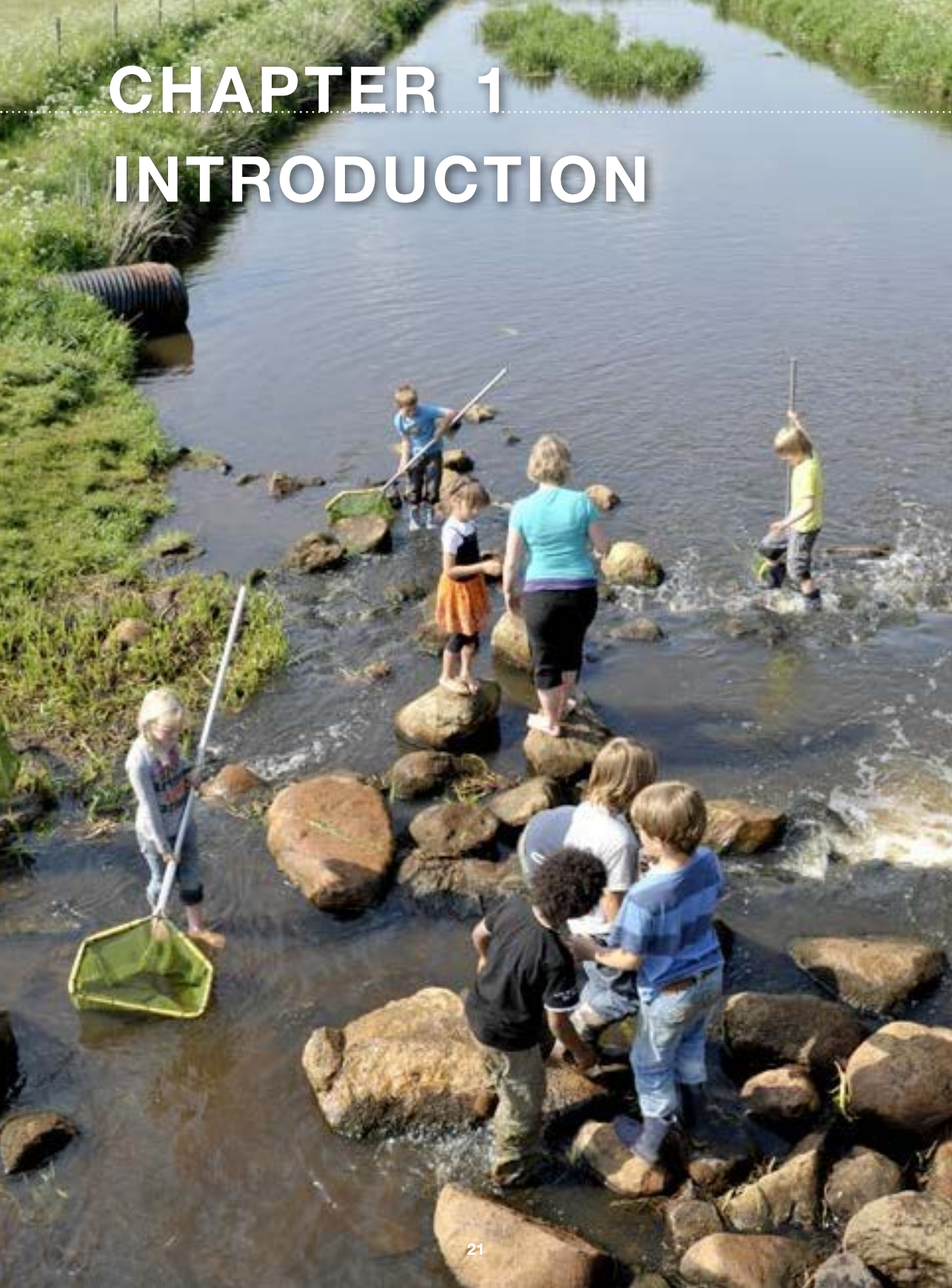
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CHAPTER 1

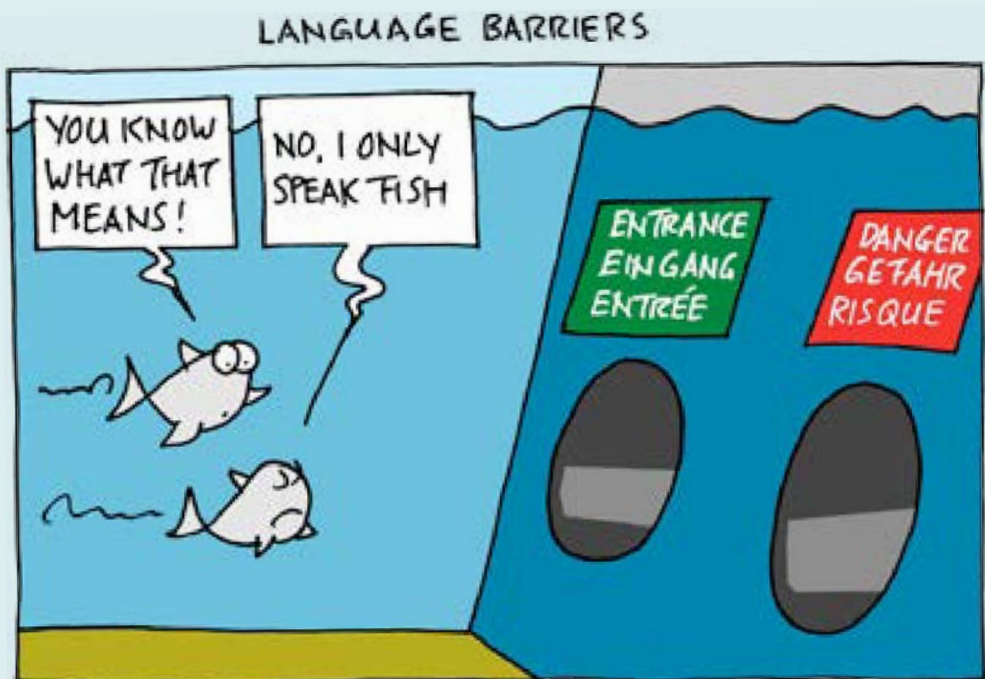
INTRODUCTION



INTRO

This is the first - global - guidance for the restoration of fish migration in rivers. We have written this to inspire not only scientists, water managers and policymakers who are working to reverse the global trend of rapidly declining stocks of migratory fish species in fresh waters, but also the many others with an interest in the well-being of our environment. Diadromous fish totally depend on free migration 'From-Sea-To-Source' to complete their life cycle.

This Global guidance is a follow-up to the first European Guidance on Fish Migration in Europe (Kroes *et al.*, 2006). The first project was initiated by a European partnership lead by the Dutch Regional Water Authority Hunze and Aa's. This guidance and its holistic approach has not only inspired river managers in Europe, but professionals all over the world, even being translated into Chinese in 2011.



1.1 WHY A WORLDWIDE GUIDANCE?

Migratory fish species endangered

During the last century man has profoundly influenced rivers all over the world. Rivers have been regulated by the building of dams, weirs and locks for a wide range of uses, and water is abstracted to support the needs of our populations and industries. River embankments are constructed for flood control and many river courses are straightened to improve discharge capacity. In addition, hydropower dams are increasingly being constructed to support the drive for renewable energy supplies.

All of these actions have greatly influenced our rivers, and also the wide range of organisms that live in them. Habitats of many river fish have disappeared or have become isolated by dams and weirs. Consequently iconic migrating fish species including salmon, sturgeon and eel have increasingly become unable to reach their spawning grounds, but additionally the migrations of many other fish have also been disrupted. This has caused substantial declines in the populations of many migrating fish species all over the world. Many of these species are now endangered or nearly extinct (IUCN Red List, 2010).

Why is this significant?

All fish migrate during their life cycle. Some of these migrations are particularly well known; however other fish that spend their whole lives within freshwater must also migrate - daily for feeding and seasonally to reproduce.

This guidance focuses on the large scale migrations undertaken by fish that must move from sea to source and vice versa. However it is important to consider the riverine environment as a whole because of the many interdependencies between freely migrating fish of all species and their natural environment.

Fish stocks, including riverine stocks, are vital to the wellbeing of human populations around the world. They are a critical food resource, a vital

component of the ecosystem, and also a potent indicator of the nature and health of our environment. They also represent a major recreational resource - for example in the USA the US Fish and Wildlife Service estimate the economic value of the National Fisheries Program at US \$3.6 billion annually, supporting 68,000 jobs (USFWS, 2011).

The challenge of communication

The challenge to restore functional fish migration is rarely easy, but nearly always possible. Effective measures require the synthesis of ecological, technical and socio-economic matters together with the very important, but often overlooked, challenge of effective communication. If those charged with delivering solutions for migration are unable to communicate problems and solutions in a persuasive way, then political and financial support might not become available and consequently resolution of fish migration problems may not be achieved.

Communicating the nature of problems effectively to a diverse audience can be challenging and that is why the use of case studies that visualize problems and solutions often proves to be so valuable. Many of these examples are already available around the world but this information, and much more, is often not easily accessible, perhaps because they are not published or are unavailable due to language barriers.

Inspiring cases

This guidance provides a number of cases from each continent that demonstrate fish migration solutions! The authors have drawn upon the experience and observations of fish migration specialists from all over the world and, through examples, show how fish populations can be improved through the restoration of river connectivity. For example we show that in many countries dams and weirs that have reached the end of their useful life are increasingly considered for removal (see www.americanrivers.org), and give inspiring examples of how this is done in practice throughout the world.

Positive trends in policy

Global policy clearly recognises the stress placed upon our freshwater and marine habitats and the implications of this for biodiversity and economic sustainability. There is increasing evidence of success in reversing the failed policies and practices from the past that have endangered our migratory fish populations globally. Very recently a number of diadromous fish species, such as the European eel, have been added to the **IUCN Red List of endangered species** (IUCN Red List, 2010) and in Europe this has led to River Basin Action Plans for eel that will ensure free migration, recruitment and improved stocks in the future.

The membership of the intergovernmental **Conservation of Migratory Species Treaty** has grown to include 116 countries from all over the world, as of 1 June 2012. This Treaty (also known as the Bonn Convention) aims to conserve terrestrial, marine and avian migratory species through concerted action and was concluded under the United Nations Environment Programme in 1974.

In 1995 the **UN Convention Law of the Sea** was concluded (UN CLOS, 1995). This treaty on the management of straddling and highly migratory fish stocks defines the rights and responsibilities of nations in their use of the world's oceans and establishes guidelines for the management of marine natural resources. The European Union and 162 additional countries have ratified the UN CLOS Treaty.

Following the 1992 Convention on Biological Diversity in Rio de Janeiro (CBD), 168 countries have ratified the CBD, with several developing substantive Biodiversity Action Plans (BAPs). A BAP is an internationally recognized program addressing threatened species and habitats which is designed to protect and restore biological systems.

The **Convention on Wetlands** (Ramsar, Iran, 1971) is an intergovernmental treaty aiming for

'the conservation and wise use of all wetlands (such as rivers and floodplains) to achieve sustainable development throughout the world'. A series of handbooks has been prepared following meetings of the Conference of the Contracting Parties, the latest of which was held in Romania in July 2012. The handbooks assist those responsible for implementation of the Convention at various governmental levels (www.ramsar.org).

Several are relevant to the management and protection of fish migration, including the handbooks on Wetland Policy, River Basin Management, and International Cooperation (Ramsar Convention Secretariat, 2006 and 2007). As of June 2012, 161 nations had joined the Convention as Contracting Parties and more than 2,100 wetlands around the world, covering over 193 million hectares, have been designated for inclusion in the Ramsar List of Wetlands of International Importance.

The Food and Agriculture Organization of the United Nations (FAO) is working with the entire international community for achievement of the **Millennium Development Goals** signed by world leaders in September 2000 (FAO, 2000). The FAO provides technical and policy advice to address main threats such as over-exploitation of marine resources and loss of biological diversity. It carries out significant work on the links between food security and bioenergy development and consequently river connectivity and the free migration of diadromous fish is high on the FAO agenda.

Hydropower, an environmentally friendly energy solution?

In recent years climate change has become an important issue on the global political agenda. The State of the Union of the USA (The White House, 2011) states that: *"We'll invest in biomedical research, information technology, and especially clean energy technology - an investment that will strengthen our security, protect our planet, and create countless new jobs for our people."* Inevitably therefore hydropower is be-

ing targeted as one of the most environmentally friendly energy solutions in the world.

However, the negative impacts of hydropower dams and stations on ecosystems, particularly on fish migration, have often not been fully accounted for and adequate protection measures can be difficult to achieve. In some countries

these have been ignored, or attempts at solutions have been ineffective.

Significant damage to fish populations has occurred in many cases, and cumulative impacts of multiple impounding structures have remained a major challenge. In the right circumstances and with due care fish stocks can be protected.

Migratory fish are an important food source

Top left: Keta salmon (Oncorhynchus keta) from the Amur River (Russian Federation) for sale at a fish market (© Hartmut Jungius / WWF-Canon). Top right: In The Netherlands fish is often sold in mobile fish shops (© Albert Jan Scheper). Bottom: Artisanal fisherman casts net fishing on the Niger River at sunset near Mopti, Mali (© Tanya Petersen / WWF-Canon).



However recent dam removals and heavy reliance on environmental mitigation or compensation measures are potent indications of the risks. Clearly a careful balancing of risk and benefit, on a societal scale, is required and we believe that can only be achieved within a comprehensive River Basin Management planning process.

River Basin Approach going worldwide

In this guidance we emphasise the need for prioritizing fish migration measures in the context of an Integrated River Basin Management plan or strategy. As a result of the Wetland Convention, and in many countries with the benefit of further domestic policies, the River Basin Approach has increasingly become an important and fundamental part of integrated water management. We are rapidly approaching a consistent position in which river basins are assessed and action plans identify and prioritize barriers to fish migration, including those that cross national boundaries.

The EU Water Framework Directive is a good example of this in practice. Every EU member state implemented River Basin Management Plans in 2009 and has described and implemented a set of measures in order to reach good ecological status by 2015.

1.2 GOALS OF THIS GUIDANCE

This guidance seeks to be inspirational, easy to read, attractive, but above all - effective. Our target audience is the wide range of people who are professionally involved in solving fish migration problems, but also those who are just interested in the subject. It is written in such a way that only

basic knowledge of fish migratory behaviour is needed for it to be a helpful guidance.

After reading through the guidance policymakers, water managers, ecologists and environmental engineers from all over the world should *feel inspired* to consider, address and prioritize fish migration measures within a river basin perspective.

It covers the challenges and their solutions around the world because we feel that we can always learn from other people's experience and that we can be motivated by learning of the substantial energies devoted to resolving fish migration in every continent of the world and the success stories that are increasingly emerging.

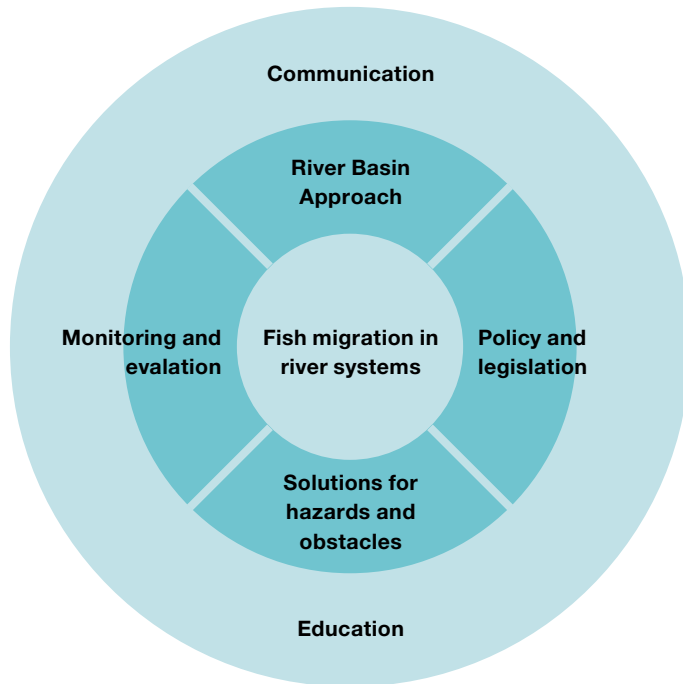
Although the guidance is written to give an up-to-date overview of fish migration issues worldwide, it cannot of course aspire to be exhaustive. Instead we try to highlight the growing importance of fish migration in environmental planning and, drawing on reference to existing policy (and perhaps inferring the need for new) and considering economic drivers related to fish migration, it provides examples and experiences from around the world.

The main aim is to learn from examples of best practice projects from all over the world. Although precise circumstances clearly vary, and the species in question are very diverse, the main challenges and solutions are often familiar. The many case studies are included to help in a very practical way, but mostly to inform and inspire.

WWW.FROMSEATOSOURCE.COM

This internet site was developed during the production of this Guidance 'From sea to source'. It provides an overview of important handbooks, technical manuals and networks. The digital version of the guidance can be downloaded here and additional information is given about how to access and disseminate knowledge regarding fish migration issues. This internet site will be hosted and updated by the authors of this guidance.

Figure 1.1 Schematic overview of relevant fish migration issues



1.3 HOW TO USE THE GUIDANCE

This guidance brings together the knowledge and experience of experts on fish migration from around the world. It gives an overview of fish migration issues worldwide and provides advice for restoration of upstream and downstream migration in the river systems of each continent. The approach comprises a total methodology that gives guidelines on the principles of fish migration in river systems and the implementation of measures and policies for protection and restoration.

It adopts the now firmly established concept of the river basin approach, setting appropriate solutions for resolution of hazards and obstacles to fish migration in a whole-river context. It also considers the associated issues of maintenance,

monitoring and evaluation of fishway facilities and, by communicating outcomes, education. This concept can be visualised as a planning and delivery circle, as shown in figure 1.1.

Fish migration in river systems

The principles of fish migration (figure 1.1) form the basis of a statement of need for a river basin management plan for fish migration. We consider the range of fishway options to provide access to habitat, but we do not cover matters of water quality or the quality of habitats that might, in many cases, be equally or even more significant factors suppressing fish populations.

River Basin Approach

As we have observed, the best outcomes are obtained when action plans for restoration of fish

migration are set out within a framework for the river basin as a whole (the ecosystem approach). A plan should comprise ambition, objectives and targets for watercourses that are identified as priorities, based on local and national criteria. Solutions for obstacles in a river basin should be collated and an action plan devised covering a defined timescale. The river basin approach is described in chapter 3.

Policy and legislation

It is often necessary to use, but also to seek to influence existing planning and policy procedures. It is important that the problem of damaged fish migration, and the means to resolve this, are recognised, agreed and then incorporated into appropriate policy and management plans. This is because the costs of solutions can be high, and so political agreement on financing is important. This will be more difficult in some countries than others, but generally influential policy support is essential if solutions, and the financial resource required to deliver them, are to be given sufficient priority. Chapter 4 enlarges upon policies with regards to fish migration.

Solutions for hazards and obstacles

The solutions for restoring fish migration are almost invariably specific to each site because of a unique combination of local features. The identified solutions should take into account all relevant factors including the nature of the obstructions, target fish species, hydrological and hydraulic conditions, any local practical constraints, and also longer term factors such as future water management strategy and climate change. The range of fishway options available is quite diverse and general design guidelines should be used to generate an optimal solution, e.g. dam removal, or the installation of bypasses or fishways. The construction programme itself should be a process in which biologists work closely with hydraulic engineers, water managers, structural designers and construction companies to deliver the best solution. Technical information and guidance on solutions can be found in chapter 5 and the reference list.

Monitoring and evaluation

The monitoring of new fishways should always be included within a project. This is because it is important to demonstrate, after construction, whether the new structure is delivering the required benefits. If it is not, then improvements may be required if the structure is to be made efficient and play its part in delivering the river basin plan. Technical information and guidance on monitoring can be found in chapter 6 and the reference list.

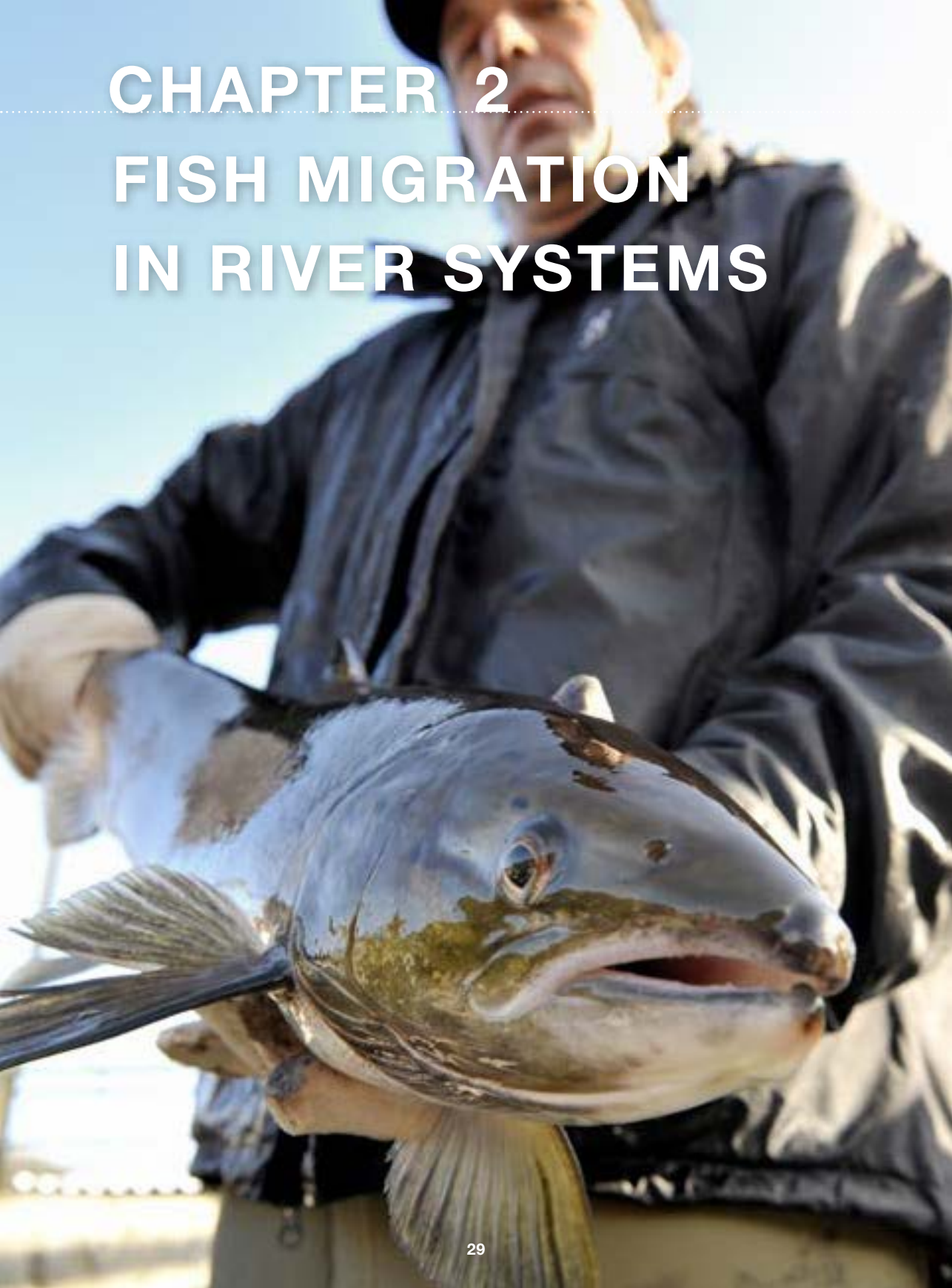
Communication and education

The outer layer of the circle (figure 1.1) represents communication and education. This is often overlooked but it is important and should always be incorporated into the process. Improvements to the environment, including the restoration of free fish migration, deliver benefit for society as a whole and particularly, in many instances, to local interest groups. These groups, or stakeholders, are often local people who will benefit most from the improvements, e.g. land owners, ecologists and fishermen. Good communication between experts who deliver the projects, stakeholders and the general public who have an interest in seeing the work delivered is important to convey a sense of ownership. It also ensures exchange of best practice between delivery groups and a raised profile of the work.

Communication also supports education of the public, from children up to experts. It explains the need for effective facilities to restore their rivers through promotion of restored fish migration, and the need to maintain the structures into the future. More details can be found in chapter 7.

CHAPTER 2

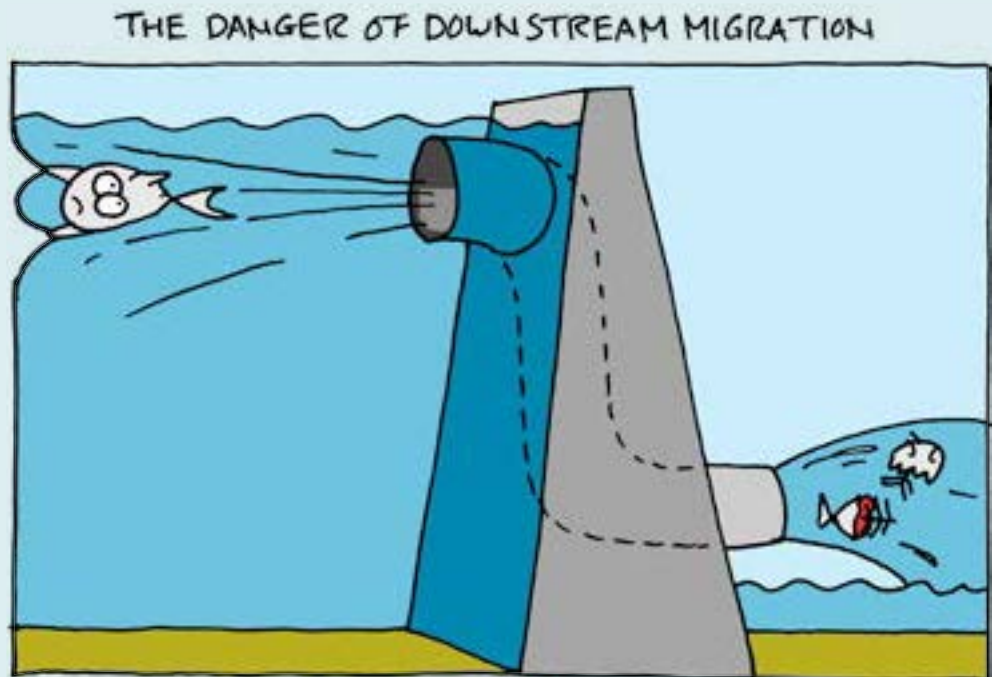
FISH MIGRATION IN RIVER SYSTEMS



INTRO

Comprehensive understanding of fish biology and migration is an important basis to make the right decisions for the future of fish migration in our rivers. The knowledge required covers the species that undertake migrations, their biology, the timing of their seasonal migrations, the habitats required and their extent and location.

We need to consider the characteristics of rivers, the anthropogenic impacts and other existing constraints to free migration. In this chapter we discuss the characteristics of natural river systems worldwide and consider the major differences. We also describe human impacts on rivers and the consequences of these for fish biodiversity.



2.1 GENERAL CHARACTERISTICS OF RIVER SYSTEMS AROUND THE WORLD

This review of the river basins and systems worldwide is necessarily very brief, and draws on literature published elsewhere (e.g. Welcomme, 1985). It is intended simply to reveal the great variability that exists and with which those involved with the management and improvement of fish migration around the world must contend.

North America

Much of the river network of the most northerly part of the continent consists of rivers that connect the large numbers of lakes and wetlands. Throughout much of Canada the landscape is mainly flat with substantial swampy areas that freeze for as much as half of the year, and then seasonally flood in the springtime when the landscape thaws. Large rivers, including the Nelson, the Saskatchewan Rivers and the Churchill River drain to the north east into the Hudson Bay, James Bay and Ungava Bay region whilst in the north the second largest river in the continent, the Mackenzie, Peace and Finlay River system drain to the Arctic Ocean. On the east coast a large number of rivers, the biggest being the St Lawrence River, drain to the Atlantic Ocean whilst several of the largest rivers in the continent, including the Yukon, Skeena, Columbia and Fraser drain much of the west coast of the continent into the Pacific Ocean.

Throughout much of the rest of the USA, rivers have been significantly modified by flood management works and the rivers are also heavily used for agricultural abstraction and for hydro-electric power. Most of the southern region is drained by the Mississippi catchment, the largest in the continent and the fourth largest in the world, together with the Arkansas River and the cross-border Rio Grande and Colorado Rivers.

The rivers of Central America are much shorter, and with steep gradients. The rapidly flowing streams are associated with the mountainous nature of the region where precipitation is high.

South America

In South America the rivers draining the Andes to the west are short and torrential. Rivers flowing to the Atlantic Ocean to the east include the Amazon. This is by far the largest river in the world with a catchment area of about 6.9 million square kilometres and an average discharge greater than the next thirteen longest rivers combined. Most of the continent is drained by the three largest rivers: the Amazon, the Orinoco and the Paraná. To the west upland rivers are associated with the mountain range however most other rivers are of the lowland type with extensive seasonally flooded jungle and plains.

The rivers around the Caribbean are shorter and are characterised by large coastal deltas and seasonal lakes. Some areas are very flat and consequently there are shallow and extensive inundated areas with many channels interconnecting relatively small temporary lagoons.

Europe

In comparison with other continents, Western Europe is drained by a number of shorter rivers and only one, the Danube, is amongst the fifty longest rivers in the world. Europe has two major drainage areas, firstly one draining towards the North West and descending to the Atlantic Ocean with its connecting seas, and secondly one draining towards the South-East, descending to the Mediterranean, Black and Caspian seas.

The river systems of Eastern Europe are characterised by relatively large slow flowing waters and in contrast the rivers of Western Europe typically originate in higher altitude areas and their hydrology is characterised by seasonally high water levels in spring and autumn. Some of the rivers of southern European are small with low discharge and some completely dry up in the summer months.

Asia

The river systems of Asia, including Russia, display great geographical diversity. The continent

has five of the ten longest rivers in the world, and nearly half of the fifty longest. The rivers of the Soviet Union in the north, including the Yenisei, Ob and Amur, are very large and, in common with other rivers of the Boreal Forest region in North America, are characterised by seasonal freezing and areas of permafrost. In the winter, freezing results in a damming effect after which the melting ice and snow inland cause high flows and extensive flooding.

Wharekiri Stream

From sea to source in New Zealand (© Marq Re-deker).



To the south the Euphrates-Tigris system is isolated from the rest of Asia. The upper courses of these rivers are relatively small in size and torrential, but the lower reaches have vast floodplains.

Many of the eastern and south eastern Asian river systems rise in the central mountain massif of the Himalayas and the Tibetan plateau. Large rivers of China, including the Yangtze, Yellow, Amur and Mekong, flow to the east and drain into the Pacific. Those of India and Pakistan, including the Indus, Brahmaputra and Ganges, flow out into coastal plains where, swollen by the seasonal monsoon, they often cause substantial flooding.

Many of the large river systems, notably the Yangtze, have large impounding reservoirs and are increasingly extensively managed for hydropower. As a consequence the natural inundation patterns are now much less frequent. The larger islands such as Japan, the Philippines and Indonesia have relatively small rivers and in their natural condition these flowed through marshy flood areas on the flat coastal alluvial plains.

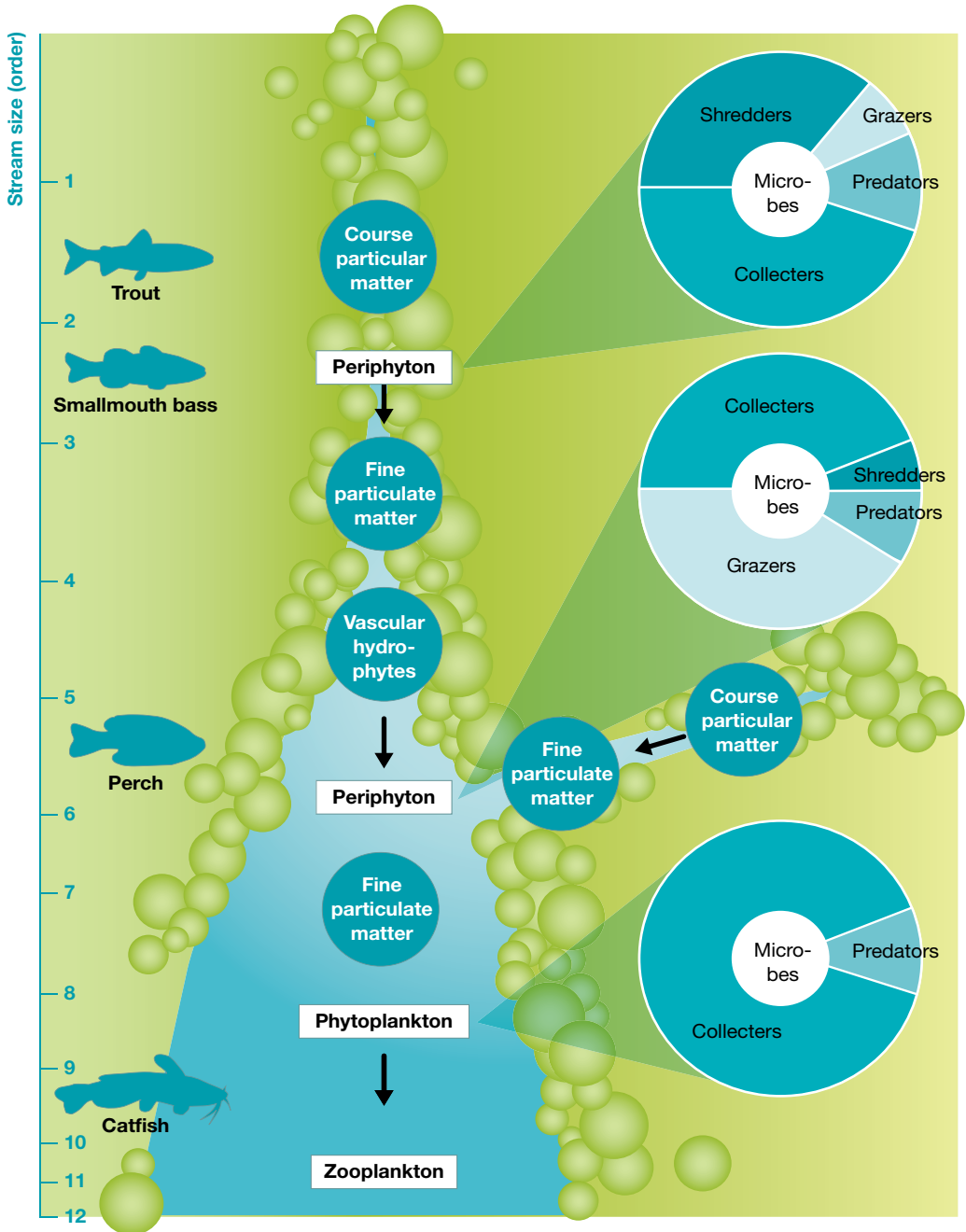
Africa

The Nile, with a length of over 6,600 km making it the longest river in the world with a catchment area of over 3 million km², and the Congo, Zaire, Zambezi and Niger are the largest rivers of Africa. Upland and torrential rivers are predominant in Africa, with most rivers rising in highland regions, and flowing to well-developed floodplains in the lower areas and approaching the coast. Inland deltas such as that of the Niger are common in Africa.

Vast wetlands are also present, such as the Sudd in South Sudan which is a part of the Nile River system. Forested floodplains and seasonally flooded jungle similar to that found in the Amazonian region are present in the Congo basin, and many smaller river basins such as those of Cameroon and Gabon.

Figure 2.1 River continuum concept

Conceptual relationship between stream size and the progressive shift in structural and functional attributes of lotic communities. (After Vannote et al., 1980).



Australia and New Zealand

River systems in southern Australia are predominantly arid. For example, the Murray Darling system drains the majority of South-Eastern Australia and is the fifteenth longest river in the world. It has a catchment area of over 1 million km², but a total annual discharge amounting to only 6% of the total continental discharge. Long periods of low flow occur, occasionally interspersed with massive floods.

The rivers of the north, notably those in the tropical region, have greater discharges carrying about 40% of the total flow of all Australian rivers. They drain the humid tropical areas of Northern Australia and Queensland and are characterised by annual floods inundating the lowland floodplains. The rivers of New Zealand are comparatively short and torrential and the mountainous terrain is characterised on the South Island by deep but small glacial lakes. The Waikato River is the longest river in New Zealand, running for 425 km through the North Island.

2.2 ECOLOGY OF RIVERS AND STREAMS

2.2.1 Hydrology

Rivers typically originate in upland areas from springs and drainage from wetlands that combine to form fast flowing shallow streams. These in turn combine with other tributaries to form larger, more smoothly flowing and deeper rivers that meander through lowlands towards the sea. The discharge of rivers depends on the size of the catchment and amount of rainfall that finds its way into streams and then leaves the catchments as stream flow. In mountainous areas precipitation can fall as snow and will only lead to discharge in spring during thaw. This varies with geography and latitude. Seasonal influences on discharge lead to characteristic patterns of flows in different parts of the river system. Some rivers show great fluctuations in flow whilst others, some fed by groundwater, have an almost constant flow throughout the year. Some streams show seasonally predictable flows, whilst others have an irregular flow pattern.

The structure and function of rivers varies widely between and within continents. In more arid climates many rivers and streams dry up, sometimes for a period of several months and consequently the fish fauna is often limited and dominated by species that are adapted to protective migration strategies, and seasonal colonisation. These and other dry river channels usually have relatively unvegetated banks due to the limited opportunity for establishment of riparian plants. In contrast, large and permanent rivers often support high riparian and aquatic species diversity.

As a consequence of rainfall or snow melt many rivers have lateral floodplains that are formed outside the normal riverbed and are supplied by seasonal floods. These floodplains are characterised by a high degree of lateral processes and the organisms of floodplains are adapted to the changes in discharge and flooding. Fish use inundated areas for foraging, spawning and as nursery areas and free movement between these habitats is an important requirement. Floodplains differ substantially in size and today their extent has been profoundly influenced by management. For example the largest natural floodplains in Europe were in the River Danube catchment, however only fragments of these now remain.

2.2.2 Biological zoning

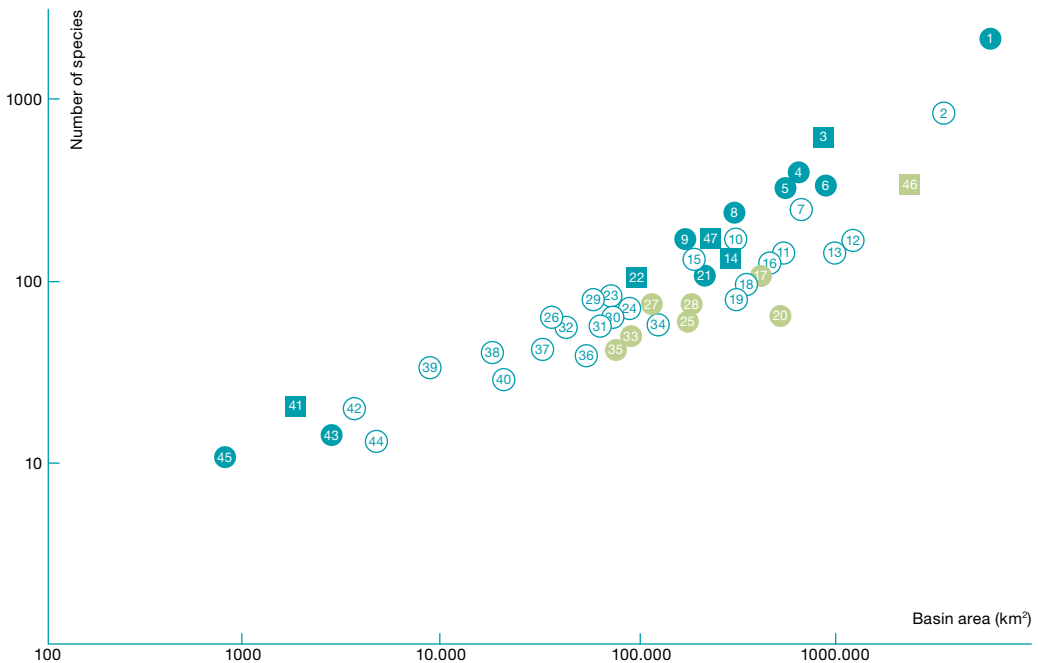
The distribution of fish species in any river varies according to the physical properties of the watercourse. Some fish species are bound to particular river stretches where the characteristics suit their biology, and the taxa of these species have been used to provide names for typical reaches of the streams. For example in Europe Huet (1949) describes the distribution of Northern European species on the basis of the slope and width of any particular reach of the river and named them 'trout', 'grayling', 'barbel' and 'bream' zones. Based on the physical parameter of slope, but also width and water temperature, stream sections can be further defined by the different species that live in them.

Illies (1961) suggested a classification that fits all aquatic fauna and is based on the physical structures of the river bed and the water temperature that prevails during the year. The running waters are divided into brooks (rhitron) and rivers (potamon) and can be further divided into upper, middle and lower reaches. Vannote *et al.* (1980)

suggested the river continuum concept which posits an orderly downstream progression of organisms (see figure 2.1). The diversity of species increases with the basin area at all latitudes, and research by Welcomme (1985) indicated that it does so faster as one approaches the tropics (see figure 2.2).

Figure 2.2 Number of species of fish present in major river systems

Plotted according to their basin areas: (●) South America; (○) Africa; (■) Asia; (●) Europe; (■) North America (Source: Welcomme, 1985).



- | | | | |
|------------------------------|----------------|--------------|---------------------|
| 1 Amazon | 12 Zambezi | 24 Bandama | 36 Shire |
| 2 Zaire (now known as Congo) | 13 Niger | 25 Dneiper | 37 Sokoto |
| 3 Mekong | 14 Brahmaputra | 26 Don | 38 Ruaha |
| 4 Madeira | 15 Benue | 27 Dneister | 39 Bia |
| 5 Paraná | 16 White Nile | 28 Dneimé | 40 Cavally |
| 6 Orinoco | 17 Danube | 29 Tana | 41 Paz |
| 7 Ubangi | 18 Volta | 30 Sassandra | 42 Me |
| 8 Negro | 19 Senegal | 31 Comoé | 43 Grande S. Tiguél |
| 9 Paraguay | 20 Volga | 32 Kafue | 44 Boubo |
| 10 Kasai | 21 Uruguay | 33 Vistula | 45 Sucio |
| 11 Chari | 22 Kapuas | 34 Cunene | 46 Mississippi |
| | 23 Gambia | 35 Dvina | 47 Amur |

2.2.3 Behaviour of migratory fish in freshwater systems

The migration of fish within freshwater is a well-known phenomenon and occurs worldwide. All species of fish migrate at some time in order to successfully complete their life cycles. Migration is typically a seasonal event most often associ-

ated with, and as a prelude to, reproduction.

Other behaviour of fish includes short term movements for other purposes, and dispersion. In this guidance the term 'fish migration' is used for seasonal movements, daily movements and dispersion.

Migratory fishes worldwide

Top left: Phanara from the Department of Fisheries releasing 15 kg tagged pra or river catfish (Pangasianodon hypophthalmus) in the Tonle Sap River, Cambodia (© Zeb Hogan / WWF-Canon). Top right: Brown trout (Salmo trutta) in shallow water migrating upstream, Bornholm, Denmark (©Wild Wonders of Europe /Martin Falklind / WWF). Bottom: Sockeye salmon (Oncorhynchus nerka), adults migrating up the Adams River (Canada) to spawn (© Michel Roggo / WWF-Canon).



Fish invariably migrate for the purpose of reproduction, and this is a fundamental part of their life cycle strategy. Migration is usually triggered by seasonal cues associated with maturation, and often by correlated environmental factors including flooding (Carolsfeld *et al.*, 2003). The simultaneous response of all individuals can result in spectacular migratory events as the population assembles at spawning locations or at migratory bottlenecks such as waterfalls. This emphasizes the need for fishways at man-made obstacles to have the capacity for the whole migrating population of fish.

Upstream spawning migration is a critical strategy to maintain optimum distribution of a species in a flowing water environment. The distance of migration varies between species, within populations of the same species, and sometimes within one population of a species that may demonstrate fidelity to one specific location within a river.

A general model of fish behaviour in which fish move between necessary habitats, for example between winter refuges and spawning or nursery habitats, is illustrated in Figure 2.4. Some of these behaviours are small scale 'daily movements', perhaps without a clear need or aim as fish move between refuges and feeding areas or to avoid predators. Sometimes fish can swim large distances when looking for food, depending on the food demand of the species, the population size, and the availability of food. Behaviours in which fish move between day and night refuges are also common, often involving small distances from open water to the riparian zone.

Fish also undertake movements that could be classified as migration to escape threatening environments, often seasonal in nature, including low river flow and seasonal drying of river sections, high water temperatures, and low oxygen concentrations. They may also occur as a result of the actions of man, such as the pollution of a river. These circumstances affect the survival of

fish populations and are perhaps more correctly classified as 'dispersion'. Dispersion is more a local phenomenon than a fundamental population-scale migration.

In the tropics the general pattern for reproductive migration is an upstream spawning migration, followed by a downstream dispersion of eggs, larvae and adults into floodplain areas where growth and maturation occur (Carolsfeld *et al.*, 2003).

Some migrations of fish involve distances of thousands of miles and can entail prolonged residence in different habitat types. For example, the anadromous sockeye salmon (*Onchorynchus nerka*) makes an extensive migration of more than 3,000 km up the River Yukon (USA and Canada) whilst on the other end of the scale the freshwater crucian carp (*Carassius carassius*) of Lake Kerkinis (Greece) migrates less than 1 km up the Kerkinitis River to spawn.

Based on the nature of their migration behaviour, fish can be divided into potamodromous and diadromous groups. Potamodromous species live in freshwater throughout their lives and migrate locally and regionally. Their migrations can be lateral from river to floodplain, or longitudinal from lower river reaches to small running waters upstream. However they do not enter the marine environment. Diadromous species migrate during their life cycle between saltwater and freshwater habitats.

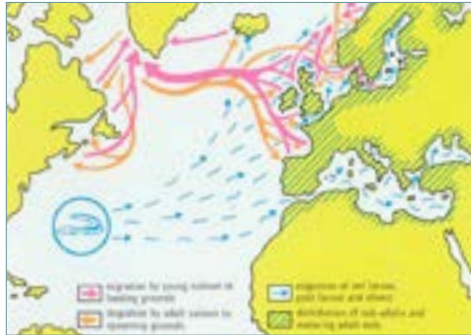
Migration between freshwater and the sea

Many species of fish migrate between river systems and the sea, either for breeding or feeding purposes or both. These species are often used as indicator species for good environmental and ecological status of river systems because as obligate migrants they experience a wide range of conditions and habitats, from upland stream to lowland rivers, estuary and coastal waters.

Diadromous fish are classified as anadromous, catadromous and amphidromous species. Ana-

Figure 2.3 Migration patterns

Migration patterns of European eel and Atlantic salmon (figure left) and American eel (figure right), www.ec.gc.ca



dromous species, including the salmon and shads, reproduce in freshwater before migrating to the sea where they grow to the adult stage. As maturing adults they migrate back to freshwater to reproduce, often homing with great specificity to the rivers of their birth.

The category includes several estuarine species of marine origin, such as the clay goby of the Indo-Pacific (*Batanga lebrotonis*), which undertake limited migrations upstream, as well as coastal marine species such as some clupeids which sometimes migrate over long distances in the river. In the temperate flood rivers of Europe the sturgeons (*Acipenseridae*), lampreys, shads and salmonids are the main anadromous fishes.

The catadromous eel enters freshwater as juveniles where they grow to maturity prior to their return migration to saltwater for spawning. Catadromous species are somewhat rarer in large tropical rivers, although eel are present in river systems around the world, including the mottled eel (*Anguilla nebulosa*) in the Zambezi and its tributaries, the long-finned eel of New Zealand (*Anguilla dieffenbachia*) and the European Eel (*Anguilla anguilla*).

Many species of marine origin migrate into the lower reaches of rivers to feed during the dry season and return to the sea during the rains

(Welcomme, 1985) or as some other seasonal response. Amphidromous species such as flounder (*Platichthys flesus*) in European waters, herring (*Clupea* spp.) and the ubiquitous mullet (family Mugilidae) are marine species that often enter freshwater, their migration occurring for refuge or feeding but not for reproduction.

Figure 2.3 demonstrates the anadromous life cycle of salmon and catadromous life cycle of eel in the Atlantic Ocean. Some anadromous or catadromous species contain populations which migrate within a restricted local or regional area, generally because the vital connections between saltwater and freshwater are blocked. These so-called landlocked populations can resume the anadromous or diadromous life cycle once more if these connections are restored.

Ecological role of freshwater fish migration

Much of the ecological role of freshwater fish migration remains unknown. That fish persist in undertaking migrations away from feeding areas to return to their historic reproductive grounds is perhaps indicative of the geographical origin of the stock or even the species. This seemingly programmed behaviour can result in extreme fidelity, such as that displayed by many salmonid populations, resulting in genetic divergence. In this way fish populations may become

functionally isolated, although in extreme cases the interchange of genetic material between populations or sub-stocks is necessary to avoid inbreeding.

Small isolated populations are vulnerable to local extinction, even when the environment is appropriate, and then straying or dispersion can maintain population health. Dispersion also makes it possible to enlarge the habitat for a species through the colonisation of new rivers and the habitats they offer.

Despite their relative insignificance in terms of area (less than 0.5% of the world's water), fresh inland waters contain 40% of all aquatic species and biodiversity. Because of the 'captive' geographic nature of inland waters, their close proximity to mankind, and the influence they impose on their environment, freshwater fish species outnumber marine ones on the current IUCN Red List by 84% (Carolsfeld *et al.*, 2003). Consequently, the role of freshwater fish migration in terms of biodiversity is significant.

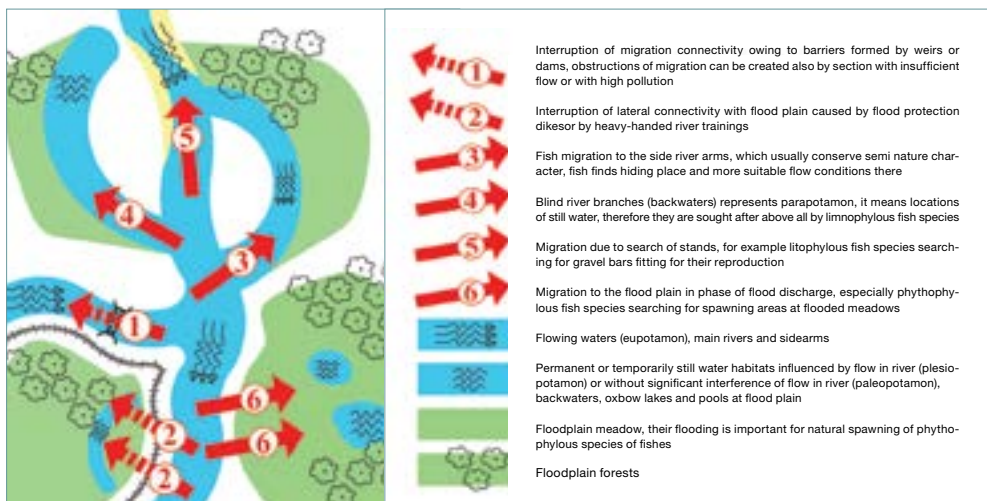
Migrating salmon return nutrients from sea to river ecosystems

Only recently ecological studies revealed that Pacific salmon provide substantial supporting and regulating services to coastal, freshwater and terrestrial ecosystems in the form of nutrient subsidies and ecosystem engineering (e.g. Hocking, M.D. and Reynolds, J.D., 2011). Nutrients tend to flow from the land to the sea, but these studies have shown how migrating salmon return nutrients from the open Pacific Ocean to coastal rivers and terrestrial habitats and the organisms that depend on these environments.

The study shows that salmon influence nutrient loading to plants, shifting plant communities toward nutrient-rich species, which in turn decreases plant diversity. These effects are mediated by interactions between salmon density and the physical characteristics of watersheds. Predicting how salmon affect terrestrial ecosystems is central to conservation plans that aim to better integrate ecosystem values into resource management.

Figure 2.4 lateral and longitudinal migration

Schematic illustration of lateral and longitudinal migration between refuge, feeding and spawning habitats of fish.



EXAMPLE

River-lake reconnection in the central and lower Yangtze

Authors: Zhang Cheng and Lei Gang
Organisation: WWF
Country: China



INTRODUCTION

There are hundreds of sluice gates built in the middle 20th century in the central and lower Yangtze area, primarily in order to control floods. Most of these gates were only rarely opened so they cut off the connectivity of these lakes with the Yangtze River, leading to fragmentation, eutrophication and degradation of the lake ecosystem and biodiversity, and a reduction in aquaculture potential. WWF's floodplain restoration and river-lake reconnection strategy brings extra value and options to the existing river-lake management approach.

WHAT DID WE DO?

In 2002, WWF (the Worldwide Fund for Nature) commenced a programme to lobby Hubei Province to reconnect floodplain lakes to the Yangtze River through seasonally opening the sluice gates, and sustainable gate management. The programme focused on three pilots: Zhangdu Lake (area 40 km²), Hong Lake (area 348 km²), and Tian'ezhou Oxbow (the ex-situ protection site for the threatened Père David's deer and finless porpoise, area 20 km²).

In conjunction with this work, WWF formed partnerships with government agencies and community partners to explore options for more sustainable river basin management and for alternative livelihoods for local people.

In 2005, through relevant governmental agencies agreement, the sluice gates in Zhangdu Lake, Hong Lake, and Tian'ezhou Oxbow have been seasonally re-opened, whilst illegal aquaculture facilities were removed. The success of these pilots was replicated by the neighboring Anhui Provincial Government at Baidang Lake (area 40 km²) in 2006.

WWF continued to scale up the programme, not only by increasing the number of lakes reconnected, but also by promoting the integration of such measures into national regulation or sectoral standards. WWF supported basic scientific research and stakeholder engagement, helped drafting the technical specification of 'adoption of fries by filling with river flows and sluice gate ecological regulation'.

The provincial government agencies have already adopted the new lake management regimes into their standard operating procedures and are allocating funding for ongoing implementation. To strengthen the effectiveness of wetland conservation efforts in the Yangtze River basin, WWF also supported the establishment of the Protected Area Network to link more than 100 nature reserves covering 2 million hectares along the Yangtze River, and many of the reserves have benefited from river-lake reconnection.

HOW DID IT WORK OUT?

The habitat enlargement and restoration has increased wildlife diversity and populations, for example fish species have been increased in terms of both diversity and population size. Within six months of reconnection, twelve migratory fish species returned to the Hong Lake. It supported only 100 herons and egrets when polluted, but after the reconnection, 45,000 wintering water birds including 20,000 breeding birds returned, one of which was the endangered Oriental White Stork. In 2008, the Hong Lake wetland was selected as Ramsar site.

In Zhangdu Lake the fish catch increased by 17.3% and nine fish species returned to the lake. Similarly the catch increased by 15% in Baidang Lake. Development of certified eco-fish farming by 412 households increased the income of fishers by 20-30% on average.

Cessations of unsustainable aquaculture, better agricultural practices, and reconnection to the Yangtze River have helped to reduce pollution in these lakes. The pollution level fell at Hong Lake from IV (fit for agricultural use only) to II (drinkable) according to China's national surface

water quality classification. As a result, 50 lakes have now been seasonally reconnected with the Yangtze in the central and lower Yangtze area up to the end of 2011. Relevant sectoral standards are expected to be released soon to establish a guarantee mechanism for the future.

LESSONS LEARNED

Altering flood control measures is critical in a floodplain area. To gain support to reconnect the floodplain lakes, demonstration work 'in the field' was vital to gain experience and to secure external support for wider application at provincial and national scales. Adaptation to the needs of government and other stakeholders was essential for gaining support and ownership.

The case again indicated that conservation and sustainable human activities can benefit each other. By reconnecting river and lakes, segmented lake ecosystem was restored, more fish species migrated into these lakes, sustainable aquaculture and fisheries were improved, and livelihoods and the environment of the local community were enhanced. A virtuous cycle has been formed and is now safeguarded by itself.

INTENSIVE NAVIGATION ON THE RIVER YANGTZE AT NANJING



Triggers for migration

Seasonal migrations of fish are sometimes extensive but can be short: both can be manifested in irregular ways. For example the striped bass (*Morone saxatilis*) migrates along the east coast of the USA (see fig 2.5), but the exact migration period can vary each year as it is stimulated by internal and external physiological change and by external factors such as changes in light level, hydrology, water quality or temperature. Similarly the spawning migration of Atlantic salmon can be interrupted by low river flows, and may not resume either until the flows recover or at the onset of imminent maturation.

Dispersion and displacement, predator avoidance, prey availability and seasonal factors also trigger migrations. The interaction between internal and external factors determines whether a fish will migrate or not, but for most fish species

their peak migration occurs in the period shortly before spawning. Subsequent larval dispersion of most species of fish commences immediately after hatch which in Europe 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 in juvenile fish the mechanism for orientation is not immediately in place (Pavlov *et al.*, 2002).

2.2.4 Migratory fish around the world

Carlsfeld *et al.* (2003) extensively reviewed the current status of migratory fish around the world. The following review draws partly on this material.

Figure 2.5 Seasonal migration

Seasonal migration of striped bass (*Morone saxatilis*) off the east coast of the USA.



Striped bass

Caught on Nantucket Island (USA).



SECRETS OF THE EEL'S MIGRATION REVEALED

The European eel has a mysterious life cycle. It spends many years in our rivers before heading out to sea and across the Atlantic to the Sargasso Sea in the western Atlantic near the Bahamas. Here, it is assumed they spawn and lay eggs; however, this has never been witnessed. The eggs hatch into transparent larvae called leptocephalus and they make the return journey to Europe floating on oceanic currents. By the time they reach our shores, they have developed into tiny glass eels that swim against the current into Europe's rivers. What makes them return to the Sargasso Sea and which direction do they take?

Unexpected direction and depth explained

Research suggests they are not simply travelling the shortest distance. Instead they travel in a more efficient way, using the ocean currents that begin to the west of Africa which help to propel them toward the Sargasso Sea. During the night eels swim in shallow warm water, and then at dawn they make steep dives to depths of 1,000 m or more where they remain for the day before ascending again. Because eels do not feed on their migration this behaviour cannot relate to foraging. The researchers believe that the shallow warm water may help the eels maintain a high metabolism, while the cooler water at depth delays the sexual development of the eels helping them maintain their streamline form.

(Aarestrup, K. *et al.*, 2009)

North America

This continent probably has more species of anadromous fish than any other continent. The most important, and the best known of the migratory fish species of North America, is the salmon. They are found on both coasts, but the genus of fish in the Pacific and the Atlantic are different.

On the Pacific coast, and extending all around the north Pacific Rim are no less than six species of salmon belonging to the single genus *Oncorhynchus*. They range from California in the south along the whole of the western coast of the continent, around the coastline of Alaska and the north of Canada.

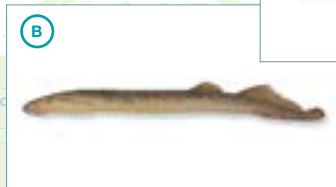
The Atlantic salmon (*Salmo salar*) is a single species, and this is now mainly located in the rivers of the Canadian Atlantic coast in New Brunswick, Quebec and Labrador. In the USA, there are some residual stocks, many increasing as a result of restoration programmes in the area between the states of Maine and Massachusetts.

Both genera of salmon migrate from the sea to spawn in freshwater rivers where they bury their eggs in gravel. Other anadromous salmonid species of the north are the charr (*Salvelinus alpinus*) and the Dolly Varden (*Salvelinus malma malma*), found in the coastal waters and cold freshwater rivers of the north, and the cutthroat trout (*Oncorhynchus clarkii*). The Arctic cisco (*Coregonus autumnalis*), a whitefish, feeds in the summer in the Arctic regions of Siberia, Canada and Alaska, and ascends rivers, such as Canada's Mackenzie River to spawn, remaining there during the winter.

On the west coast, other anadromous species are found such as the eulachon (a species of smelt, *Thaleichthys pacificus*), the green and white sturgeons (*Acipenser medirostris* and *A. transmontanus*) and the Pacific lamprey (*Lam-petra tridentata*). Smelt are found from Northern California to the eastern Bering Sea. Green sturgeon, which grow slowly and are highly migratory, exist in the range from Ensenada in Mexico,

MIGRATORY FISH

EXAMPLES OF MIGRATORY FISH WORLDWIDE



North America

- A** Pacific salmon (*Onchorynchus* spp.) © U.S. Fish and Wildlife Service
- B** Sea lamprey (*Petromyzon marinus*) © Sportvisserij Nederland
- C** Alewife (*Alosa pseudoharengus*) © U.S. Fish and Wildlife Service
- D** Atlantic salmon (*Salmo salar*) © Sportvisserij Nederland
- E** Shortnose sturgeon (*Acipenser brevirostrum*) © U.S. Fish and Wildlife Service

Europe

- F** European eel (*Anguilla anguilla*) © Sportvisserij Nederland
- G** Houting (*Coregonus (lavaretus) oxyrinchus*) © Sportvisserij Nederland
- H** Sea trout (*Salmo trutta trutta*) © Sportvisserij Nederland
- I** Atlantic sturgeon (*Acipenser sturio*) © Sportvisserij Nederland

Asia

- J** Mekon Giant catfish (*Panghasianodon gigas*) © Eric Baran

South America

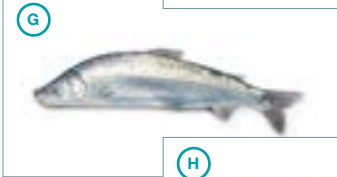
- K** Curimatá (*Prochilodus lineatus*) © Oscar Akio Shibatta
- L** Dourado (*Salminus brasiliensis*) © Oscar Akio Shibatta
- M** Pintado (*Pseudoplatystoma corruscans*) © Oscar Akio Shibatta

Africa

- N** Redeye Labeo (*Labeo cylindricus*) © Rashid Tamatah
- O** Allis shad (*Alosa alosa*) © Sportvisserij Nederland

Australia

- P** Golden perch (*Macquaria ambigua*) © Pat Tully, NSW Government
- Q** Australian bass (*Macquaria novemaculeata*) © Pat Tully, NSW Government
- R** Shortfin eel (*Anguilla australis*) © Pat Tully, NSW Government



to Southeast Alaska. White sturgeon, or Pacific sturgeon, is the largest fish found in freshwater in North America and weigh up to 1,500 pounds. They can grow up to 6 metres in length and can live to an age of more than 100 years, migrating to spawn in the lower reaches of large rivers including the Columbia and Fraser. The Pacific sea lamprey is found from the Gulf of California California to the Bering Sea. They migrate from the river to the ocean to feed, returning to freshwater a few years later to spawn.

The East Coast of North America shows different migratory fish species like e.g. the shads: alewife (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*) and American shad (*Alosa sapidissima*). These fish, which enter rivers to spawn in the spring and early summer, are unusual as they are iteroparous, demonstrating a spawning strategy in which they survive and return to spawn in several consecutive years. Other diadromous species are the striped bass (*Morone saxatilis*), the shortnose sturgeon (*Acipenser brevirostrum*) and the Atlantic sturgeons (*Acipenser oxyrinchus*). The only catadromous species found on this coast is the American eel (*Anguilla rostrata*), which spawns in the Sargasso Sea, possibly in the same locations as the European eel.

South America

According to Carolsfeld (2003) there is a staggering variety of migratory species in South America, with a highly diverse range of life histories. The migrations of salmon and eel in Europe and North America are very well known, however few outside South America will have heard of the *surubim* (*Pseudoplatystoma corruscans*), the *curimba* (*Prochilodus lineatus*), or the salmon-like *dourado* (*Salminus basiliensis*) species. These iconic fish of South America are every bit as charismatic as their northern hemisphere salmon and eel.

Other well-known species are the big catfish or the pimelodids, smooth-skinned fish particularly prized for their flesh. The spawning migrations of these and other species begin when the rainy

season starts. Some species migrate upstream to spawn, while others migrate downstream. Some spawn in headwaters above the flooded areas of the Pantanal, the world's largest wetland, while others release their eggs into the river's mainstem. The *pacu* and *tambaqui* are generic names for groups of species within the multiple genera of characin. Several dozen large species of characin have life impressive life cycles, with some of them migrating more than a thousand kilometres to spawn and, unlike the salmon, they do this in many consecutive years.

Interestingly, the first stage of the reproductive migration of larger and economically important species such as *piracema*, is often triggered by small forage species leaving the flood-plain lagoons and 'migrating' into the main river channel. This interaction is well known locally as the 'lufada' and is exploited by seasonal fishermen.

Europe

Europe knows several significant migratory species of which the Atlantic salmon (*Salmo salar*) is the absolute king of the rivers with original habitat that ranged all along the North-West European coast. The species is under severe pressure and has vanished from over 300 rivers and is about to disappear from many more. The principle reasons for this include the obstruction of their migratory pathways into and within rivers, pollution of the rivers, and in some cases over-exploitation. Most of the remaining healthy salmon populations are nowadays found in the less densely populated Northern European countries like Norway and Scotland.

Other significant migratory species are the lampreys, of which there are two anadromous species (*Petromyzon marinus* and *Lampetra fluviatilis*) and two species of shad (*Alosa alosa* and *A. fallax*). All of these species migrate to spawn in rivers after leaving the sea where they grow towards maturity. In some parts of Europe, like Wales, Denmark, Sweden, Scotland and Ireland, an anadromous form of the trout (*Salmo trutta*

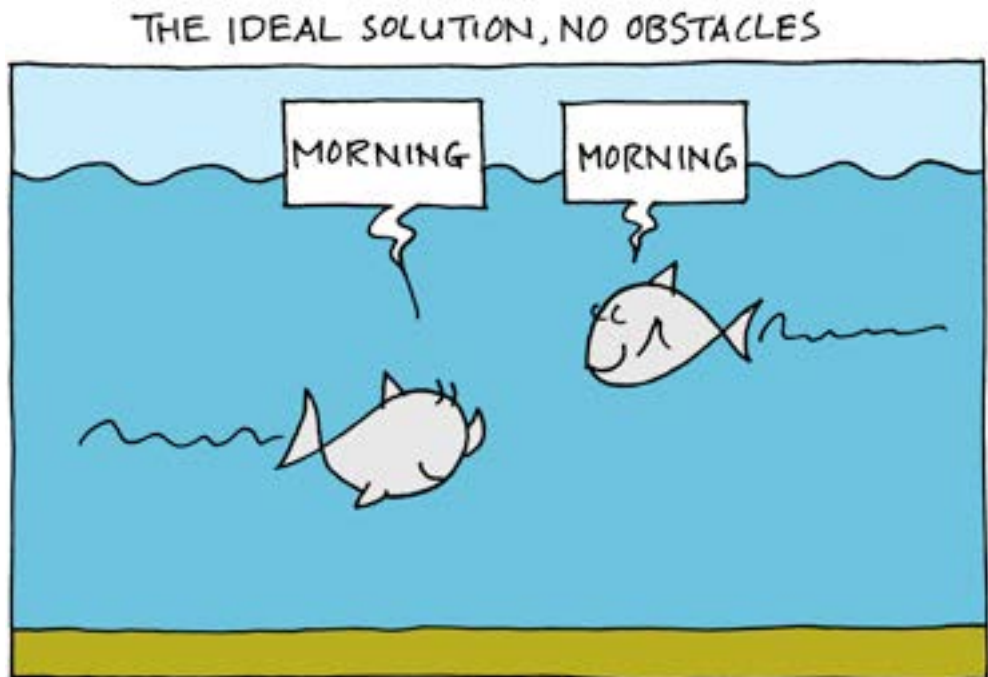
trutta), the sea trout, is locally highly significant for the sport fisheries it supports. For example on the Danish Island Fyn, where sea trout has been released in the rivers in the past 20 years in combination with a habitat restoration and weir removal program. As a result the Island Fyn has seen an increase in touristic visits and is now one of the top locations in Europe for sea trout sport fishery.

The European eel (*Anguilla Anguilla*) is a catadromous species spawning in the Sargasso Sea. Other anadromous fish migrate from the sea into many European coastal rivers. Mullet (*Mugil* spp., *Liza* spp.), bass (*Dicentrarchus labrax*) and flounder (*Platichthys flesus*) all make variable progress into rivers as juveniles or adults to take advantage of feeding habitats there.

The once abundant Atlantic sturgeon (*Acipenser sturio*) is now almost extinct, because of pollution, fishery and man-made barriers. The last

population in Europe is located in the Garonne River in France. Recently re-introduction programs have been started in the Elbe and Rhine River. In May 2012 WWF and the Dutch Angling Association released young Atlantic sturgeons in the Rhine River.

In Eastern Europe, the beluga (*Huso huso*), and other sturgeons (Russian sturgeon, *Acipenser guldenstaedti*, sevryuga, *Acipenser stellatus*, and the sterlet, *Acipenser ruthenus*) have all been heavily fished for their roe (caviar). In Poland, the Warta River was dammed contributing to the disappearance of the anadromous Vimba bream (*Vimba vimba*). In the Mediterranean, diadromous fish were present in the past however most are extinct and the population numbers of most others have greatly decreased. In France and in Spain dams such as those on the Rhone and Ter Rivers have reduced access to spawning grounds of shad (*Alosa alosa*) and lamprey (*P. marinus*).



EXAMPLE

Assessing the impact of barriers on connectivity of endangered native fishes in the face of salmonid invasions in Southern Chile

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Country: Chile



INTRODUCTION

With 44 native freshwater fishes (Habit *et al.*, 2006) and 15 exotic species (Campos *et al.*, 1998), the freshwater fish biodiversity of Chile is relatively low, although it maintains high levels of endemism. Three factors account for its unique freshwater fauna: (1) the country represents a biogeographic island isolated by the Atacama desert in the north, the Antarctic glaciers in the south, and the Andes in the east, (2) the steep gradient of Andean rivers imposes a high degree of ecological specialisation, and (3) the history of tectonic activity and glaciations have further increased the degree of geographical isolation (Campos *et al.*, 1998). An estimated 66% of the native freshwater fishes are of conservation concern (CONAMA, 2010; www.mma.gob.cl), mainly due to habitat degradation, the introduction of exotic species (Gajardo & Laikre, 2002; Habit *et al.*, 2010) and, more recently, also due to hydroelectric developments that constrain dispersal and connectivity (CERM, 2009).

Eighty nine large hydroelectric projects are currently in operation or undergoing the Environmental Impact Assessment required by law in Chile (SEA, 2010). Fifteen of these develop-

ments will be located in the *Los Ríos* region (The Rivers region) and nineteen in *Los Lagos* (X) region (The Lake region), whose names highlight the relevance of watercourses and lakes to a number of endangered native fishes including *Cheirodon australe*, *Cheirodon killani*, *Diplomystes camposensis*, *Trichomycterus areolatus*, *Galaxias globiceps*, *Odontesthes brevianalis*, *Odontesthes mauleanum*, *Aplochiton zebra*, *Aplochiton taeniatus*, and *Percillia gillisi*. In addition to these high profile hydroelectric developments, there are many more smaller barriers that can also block upstream fish passage, including weirs that divert water to salmonid hatcheries, concrete ramps under bridges to prevent erosion, and flood defenses and similar works that change the flow and may impact on upstream fish passage.

WHAT ARE WE DOING?

In collaboration with stakeholders who seek protection of local aquatic resources, we began a baseline evaluation of fish populations in five rivers of the *Río Bueno* basin, where hydroelectric power plants are scheduled. Our focus, in line with the Convention of Biological Diversity (CBD) signed by Chile, is to have an inventory of na-

tive fishes throughout the basin. We then plan to use a range of ecological tools including stable isotope analysis (Shröder & Garcia de Leaniz, 2011) and a suite of recently developed molecular markers (Vanhaecke *et al.*, 2011) to monitor the spatio-temporal distribution and connectivity of fish populations, both in impacted and control rivers (without artificial barriers). By taking a multidisciplinary approach, we are hoping to have good pre- and post-intervention data that will help to establish sound guidelines for the protection of endangered fish fauna.

LESSONS LEARNED

Through a DEFRA (UK) funded Darwin Initiative (www.biodiversity.cl) we are meeting with government and stakeholders to discuss threats to

native fish fauna, alerting them about the potential synergistic effect posed by the interaction of barriers and invasive salmonids (Garcia de Leaniz *et al.*, 2010), and the need to have good scientific data and a monitoring programme in place. Our study has already served to disseminate the need to conserve critical freshwater habitats, and our approach will help us estimate the extent of population fragmentation. This is critical for native diadromous species that migrate to coastal-estuarine areas to spawn, and which use different parts of the basin to complete their life cycles. Clearly, the life cycle of such species could be significantly altered by barriers, but whether this will augment, or perhaps mitigate, the impact of invasive salmonids is not clear and requires careful study.

PULLINQUE HYDROELECTRIC STATION IN THE LOS RÍOS REGION (VALDIVIA, CHILE)

A 4.6 km canal diverts water from Lake Pullinque to the power house to produce 51.4 MW of electricity via 3 vertical Francis turbines. The plant was built in 1962 with no specific provisions for the passage of fish.



Asian Rivers

There is an enormous diversity of rivers in Asia, with five of the ten longest rivers in the world and habitats of every type represented. Rivers range from northern temperate in Russia, northern China and Japan to the great rivers of south east Asia. In the north the same Pacific salmon (*Oncorhynchus* spp) found in North America occur alongside a further salmonid, the cherry salmon (*Oncorhynchus masou*), which occurs only in Asia. In the south there is an enormous number of species demonstrating a wide range of life history strategies. Most of the southern floodplain rivers support artisan fisheries upon which many millions of people depend for their welfare, however the productivity of many has been damaged by intense pressure from the human population including the construction of dams and other impounding structures.

For much of their northern range the salmonids are relatively unaffected by the pressures of development, however to the south there is much greater impact. In excess of 98% of the salmon producing rivers of Japan have been impacted by dams and other modifications and most fisheries are now dependent on hatchery and ranching operations to maintain productivity.

More to the south, mighty river systems like the Yangtze and Mekong Rivers provide important habitat to a large number of migratory species. With over 1200 different fish species the Mekong River is one of the most diverse river systems in the world. Due to large scale damming projects the existence of many migratory fish species, like e.g. the Mekong giant catfish (*Pangasianodon gigas*), are under threat. In the Yangtze River projects like the Three Gorges Project will block important migratory routes which might have a significant effect on migratory species like black carp (*Mylopharyngodon piceus*) and bighead carp (*Aristichthys nobilis*).

In India the Ganges River or Ganga is the most heavily populated river basin in the world with over 400 million people in the catchment, many

of whom are dependent on the services of the river. Two major dams – the Haridwar in the upper catchment built for irrigation and the Farakka hydroelectric dam downstream have profoundly affected the fauna of 140 fish species and the indigenous Ganges river dolphin (*Platanista gangetica gangetica*). The widely distributed species of mahseer (*Tor tor*, but also used as a generic name for *Neolissochilus* spp and *Nazirithor* spp) migrate to the upper reaches and tributaries of the rivers where they occur, their migrations being triggered by flooding following the monsoon. Many of the larger mahseer species are in severe decline due to pollution, over-fishing and habitat loss. The ilish, or hilsa shad (*Tenulosa ilisha*) which, unusually for the tropics is anadromous, and which supported important fisheries is seriously affected by dams. For example in the Indus, upstream impoundments affect flow and access and the species is now nearly eliminated.

Africa

Two of the largest rivers in the world are in Africa, the Nile which is also the longest river in the world, and the Congo. Many other large rivers drain the continent and together they provide vital resources for the human population. There is now an unprecedented pace of proposals for dams that marks a significant conflict between economic development on the one hand, and sustainable development for ecosystem services on the other. This has led to formation of the African Rivers Network which is seeking a new appreciation of the need for equitable and sustainable development.

It is estimated that many billions of dollars are currently available for massive projects in most countries in the continent: for example the world's single largest hydropower project (the Inga Rapids on the Congo River, with a projected output of 44,000 MW) is proposed in the Democratic Republic of Congo as part of an overall \$80 billion African electricity infrastructure project. The building of dams also disrupted the migration patterns of several species in the River Zambezi.

The Markala Dam built in 1943 and the Selengue hydroelectric dam built in 1984 (and renovated in 1996-2001) in the River Niger (Mali) appear to be rare examples of dams that do not affect reproduction of many fishes, as spawning areas are located downstream.

Many species of great significance for local communities must migrate to complete their life-cycle and maintain the population levels required to sustain exploitation. These include the African knife-fish (*Gymnarchus niloticus*), Senegal bichir (*Polypterus senegalus*) and Peters' elephantnose fish (*Gnathonemus niger*), the reproduction of which is linked to access to the floodplain. The threats to migration of these, and other species, represents a significant pressure on sustainability of the artisan fisheries.

TIPS

- Identify the key indicator fish species for restoration or conservation;
- Include economic drivers for migratory fish, such as a food supply for human populations, tourism, or recreational values in your river basin plans.

2.3 IMPACTS OF BARRIERS ON FISH MIGRATION

2.3.1 Introduction

Barriers to fish migration can have profound consequences for hydrology and habitats, riverine fisheries and the upstream and downstream migration of fish. Worldwide the main barriers to fish migration are dams and weirs, but other structures also cause problems in some regions. The lowland area of The Netherlands for example is well known for the high number of pumping stations and sluices that profoundly affect the free migration of fish.

The degree to which river systems are impacted worldwide (Figure 2.6) is demonstrated by fragmentation analyses such as that carried out by Nilsson *et al.* (2000). Of the 227 large river basins

they assessed, 37% were strongly affected by fragmentation and altered flows, 23% were moderately affected, while 40% were unaffected. Unaffected rivers were defined as those without dams in the main channel of the river and, if tributaries of the river had been dammed, river discharge had declined or been contained within reservoirs by no more than 2%.

2.3.2 Obstacles for fish migration

Different types of obstacles to fish migration exist worldwide: most represent problems for longitudinal and/or lateral migrations through obstruction of fish movement, and some also represent a great risk for survival of fish. Barriers in the longitudinal direction present problems for both upstream and downstream migrations. Barrages, flood-control dams, tidal barrages and sluices, pumping- and hydropower stations are all examples of potential barriers to upstream migration. Pumping and hydropower stations can cause severe damage to those downstream migrating fish that pass through pumps and turbines.

For other types of barriers, such as shipping locks and culverts, the impact on fish migration is not always immediately clear. Taken together in a river catchment, the cumulative impact of such structures is often severe and this must be taken into account as part of any river basin plan.

For a better understanding of the problems of barriers for longitudinal migrations, we need improved detailed knowledge of the behaviour of many fish species at barriers. The number of barriers in many rivers is a concern because of their combined impact, and in some cases even high quality design and construction of fish passes cannot adequately protect fish populations.

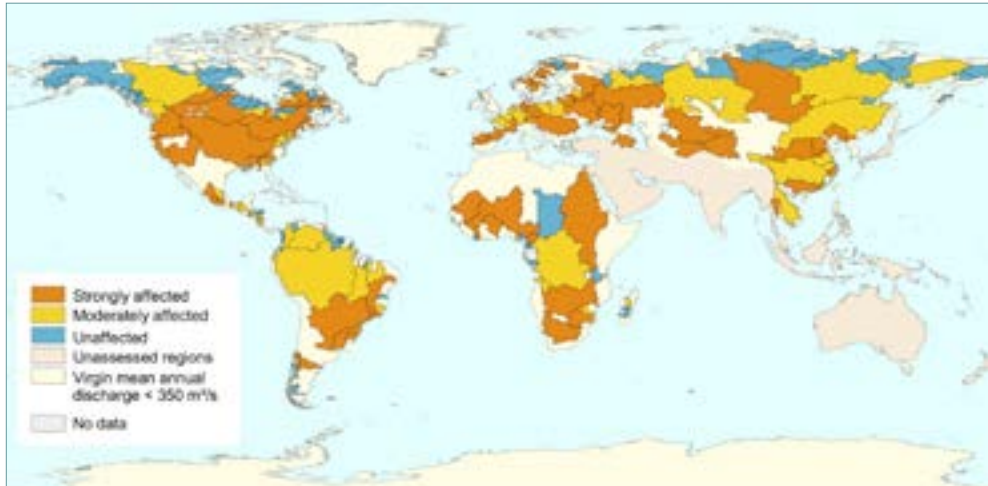
Upstream migration

The mechanism of impact of barriers on fish includes, in order of priority:

- The physical presence of a structure creating a difference in water level. Some fish, notably salmon, may be able to leap small obstruc-

Figure 2.6 River fragmentation worldwide

(www.earthtrends.wri.org).



tions (probably no higher than 3m, depending on the precise hydraulic conditions) and other fish such as eel may be able to ascend a structure by crawling in lower flow areas. However passage of the majority of species is prevented by quite small head differences;

- If a fish pass is present the entrances may be small with inadequate and weak attraction flow. Migrating fish generally follow the main flow lines towards barriers, and it is important that these emanate from fish pass entrances wherever possible, or that the fish pass flow is located very close to the main flow;
- Deep ponded sections of river upstream. These may not represent functional habitat for the migrating species;
- Strong and turbulent flow downstream. In extreme conditions this may prevent or deter fish from approaching sufficiently close to the barrier to detect or enter a fish pass;
- Reduced and attenuated flow below the obstruction. Storage of water in a reservoir may change the seasonal discharge patterns of the river and interrupt the natural cycle of migration.

The mechanisms of impact of barriers on fish migration depend on the swimming ability and behaviour of migrating fish. These characteristics are often specific to the species, life stage, condition and size of the fish, and to flow and water temperature during their critical migration time.

In many countries the most common problems relate to the upstream migration of fish at low head weirs (0.5 m - 4.0 m). Weirs have been constructed in a variety of ways, with local preferences in construction styles often evident. Most have a fixed and level crest together with water control structures such as sluices and abstraction systems, and unfortunately many were built with no apparent concern for their impact on fish migrations. Most were originally built for the purposes of water power, generally milling, and may have been re-built or modified many times in the past. Today some are used for abstraction (mainly potable and industrial use but also for irrigation), navigation and hydropower but many have been developed and retained in a relict form for historical and aesthetic purposes. Most countries have many thousands of such structures in their watercourses.

Lateral migration

A main obstacle for lateral fish migration in some rivers is that of dykes and flood banks. These can isolate rivers from potential wetlands in the valley so that seasonal inundation of the floodplains may no longer occur. Other potential barriers are structures built to reduce or prevent erosion of banks, which also can often lead to isolation of the river from riparian habitats.

Downstream migration

In all weir or dam-regulated rivers, notably those that contain water intake facilities, damage to downstream migratory fish, and therefore impact on fish stocks, can be expected. The nature and degree of damage can vary strongly, dependent on the type of water intake and the presence of effective bypasses and protective screens. Large scale mortality of downstream migrating fish can have severe ecological consequences for the fish stock as these losses may operate after density-dependent factors have concluded. For species such as salmon, compensation through restocking is feasible although perhaps not always desirable because of genetic risk to the recipient population, however for some other species such as eel it is not generally possible to compensate for damage by restocking. If species are important for commercial fisheries a high mortality also has economic consequences due to the loss of fishing opportunity and reduced commercial harvest.

Downstream migrating fish can encounter serious damage as a consequence of:

- **Hydroelectric power plants**

At hydroelectric power plants some damage is almost inevitable, even when protection through screening combined with bypasses and guidance systems is in use. Damage by passage through turbines often varies from 5 to 40%, but can in some circumstances be much higher and up to 100%;

- **Pumping stations**

Pumping stations are often used in lowland areas throughout the world for the purpose of wa-

ter management to maintain water levels and reduce the risk of flooding. Damage to fish during passage through pumping stations is comparable with that in hydroelectric power plants;

- **Industrial and potable water intake**

In many river systems water is used for industrial purposes, including cooling and potable supply. In some cases these abstractions may not require impoundment through a weir or dam, however in all cases fish entrainment is a risk. In the vicinity of a water intake, flow velocities increase and these can be interpreted as a guiding or attraction flow by downstream migrating fish. Fish are usually orientated to the principle flow line in order to continue their migration and can therefore be led into an intake, where they are exposed to the risk of injury and mortality and from which, even if motivated to do so, they may be unable or unwilling to return to the river;

- **Mechanical barriers**

Racks or screens are used to prevent trash or debris entering into water intake facilities used for industrial water supply, for turbines and pumping stations. Most damage occurs due to impingement of fish as a consequence of high and sustained flow velocities towards the rack or screen. According to Beamish (1978) most fish can overcome flow velocities of 0,5 m/s if they are motivated to do so;

- **Large drops over the weir or spillway**

Injury or mortality can occur when fish pass over a spillway and fall into the pool downstream. Significant damage including injuries to gills, eyes and internal organs, can occur when the impact velocity exceeds 15-16 m/s. This critical velocity is reached after a free fall of around 30-40 m for fish of 15-16 cm and 13 m for fish longer than 60 cm (Larinier *et al.*, 2002). Fish may also prove reluctant to pass over such structures leading to delay, predation and failed passage;

- **Chemical/ temperature barriers**

Chemical barriers can be pollution plumes,

acid sulphate soil discharges, thermal discharges and areas of low dissolved oxygen. Weirs, in particular large dams, can create cold water issues through the practice of releasing water from the bottom of a dam which can alter temperature regimes downstream. This can have an adverse impact on migration and breeding patterns of some fish species. Combustion power stations often require river water for cooling, although increasingly the best practice of atmospheric cooling is more protective of aquatic environments. The alternative of direct cooling leads to thermal pollution contributing to aquatic environmental impacts including eutrophication and adverse impacts on fish migration.

2.3.3 Hydrology and habitats

Free flowing rivers

Of the 177 rivers in the world that are longer than 1,000 km only 64 (less than 40%) remain free-flowing and many are currently threatened by proposals for new dams. Most of these rivers are actually tributaries of even larger rivers, for example 20% of the free-flowing rivers are tributaries of the Amazon, whilst another 20% are rivers of the far east of Russia. Only one large river in

Europe (the Pechora, rising in the Ural Mountains and flowing to the Barents Sea) remains largely un-modified. The threats to these few remaining rivers led to a call to governments to safeguard them (WWF, 2006), and it is clear that the position should be urgently reviewed if these great rivers are to be preserved for the future.

“Wild rivers are earth’s renegades, defying gravity, dancing to their own tunes, resisting the authority of humans, always chipping away, and eventually always winning.”

(Richard Bangs - River Gods, as cited in WWF, 2006).

Regulated rivers

Many structures, including barrages, weirs, dams and sluices, are built for water conservation during dry periods, for navigation, hydropower, irrigation, or for water supply. Others are built to protect against flooding, causing hydrological change, interruption of the stream flow and river continuum.

Larger structures such as big barrages, weirs and flood-control dams lead to structural channel changes through their impact upon flows,

DEVELOPMENT OF DAMS WORLDWIDE

In Europe the requirements for river impoundment included hydropower in the north, irrigation in the south and abstraction for potable supply and industry in most places. This led to the majority of dam construction from the 18th century onwards. Asia is now the most active region in the world for dam development. Historically this was also done for irrigation, for example in India and Turkey, but now many more are built for hydroelectric power generation. China is currently leading the way with at least 22,000 dams (some estimates indicate over 30,000) and hundreds more under construction, again mainly for flood control and irrigation but with some for hydropower.

In the Americas, 80% of the region’s dams are in the USA, but in South America hydropower is now a key driver for dam construction with Brazil being most active. In Africa irrigation and hydropower have once again been the main drivers for dam building, and many more projects are now being promoted. In Australia about half of the dams were built for water supply. The tables on the right give an overview of statistics for large dams in each continent and the top twenty countries in terms of number of dams. >>

Overview large dams per continent

(UNEP, 2001).

	World (incl. China)	Europe	Asia	North and Central America	South America	Africa	Austral- Asia
Total number of large dams	47655 ^a	5480	5480	8010	979	1269	577
Average height (m)	31 ^b	33	33	28	37	28	33
Average reservoir area (km ²)	23 ^b	7	44	13	30	43	17
Avg. reservoir capacity (million m ³)	269 ^b	70	268	998	1011	883	205

^a The primary source of data is ICOLD World Register of Dams (1998, 2000) and estimates by the World Commission of Dams (WCD, 2001).

^b The ICOLD 1998 database was used to calculate the average dam height, reservoir capacity and surface area by region.

Top 20 countries by number of dams

(UNEP, 2001).

	Country	Icold 1998 and WCD estimates	Percentage of total dams	Dams under construction
1	China	22000	46.2	280
2	United States	6575	13.8	-
3	India	4291	9.0	960
4	Japan	2675	5.6	463
5	Spain	1196	2.5	-
6	Canada	793	1.7	-
7	South Korea	765	1.6	132
8	Turkey	625	1.3	193
9	Brazil	594	1.2	-
10	France	569	1.2	-
11	South Africa	539	1.1	-
12	Mexico	537	1.1	-
13	Italy	524	1.1	-
14	United Kingdom	517	1.1	-
15	Australia	486	1.0	-
16	Norway	335	0.7	-
17	Germany	311	0.7	-
18	Albania	306	0.6	-
19	Romania	246	0.5	-
20	Zimbabwe	213	0.4	-
	Others	3558	7.0	48 (Iran)
	Total	47655	100.0	2076

River Vecht (The Netherlands)

This river was regulated during the 20th century. Plans are developed to restore this river by reconstruction of the river and the floodplains (© Groene Zoden Fotografie).



with diversity in flow patterns decreasing from source to sea. Downstream of every construction there is a short zone with relatively high velocities and turbulence, but both subsequently decrease further downstream and a more natural regime is re-established. The building of barrages and dams in areas with low summer flow can, subject to details of the operating regime, increase the duration of the dry period for downstream habitats.

Furthermore, structures can block the flow of nutrients through the river system towards the sea through storage within deposited sediments, depending on local stream hydraulics. Flood-control and navigation requirements lead to relatively constant water levels that might prevent inundation of floodplains during seasonal floods. The hydrology and characteristics of any remaining free flowing stretches within a dammed river depend strongly on the number of structures and the degree of impoundment.

These habitat modifications can profoundly af-

fect the ecology of the system, for example specialist invertebrates adapted to flowing stretches (rheophilic fauna) are replaced by more generalist species or in some cases by opportunistic species that would not otherwise be found. Impoundment to create reservoirs can transform faunal composition into communities of species characteristic to that of a lake.

The natural mouth of a river and its estuary are important as transition zones. A gradual transition of salt concentration and temperature give fish the opportunity to adapt their physiology prior to migration between river and sea. However flood control sluices and tidal barrages can impose a distinct and rapid change between salt and freshwater. This can directly or indirectly cause physiological damage to migrating fish that might be poorly prepared for rapid transition between environments.

In some circumstances these structures and their management can lead to the flushing out and loss of freshwater species. Loss of brackish

and freshwater tidal areas, which also serve as important nursery habitat for marine, estuarine and diadromous species, is a clear loss to local biodiversity.

2.3.4 Consequences of river fragmentation for riverine fisheries

Dams have generally resulted in negative impacts on riverine fisheries throughout the world (Jackson & Marmulla, 2001). The loss in fishery yield is sometimes partly compensated by new fisheries in some large reservoirs, however this does not generally maintain biodiversity value.

Fish yield in floodplain river ecosystems is directly related to the height and duration of floods and therefore dams that reduce downstream inundation of floodplains have an impact on overall fisheries production. Fisheries depending on migratory fish are often severely impacted because movement of these fish along rivers is readily blocked by dams. In many cases a series of dams has been constructed, and the combined impacts are particularly damaging to migratory fish stocks, even if each dam is equipped with a fish pass.

Barriers to fish migration lead to the fragmentation of rivers, resulting in a decline of habitat quality for fish and the isolation of sub-populations of the fish stock. For species that are not able to fulfil their life cycle, for instance diadromous species, this can have major consequences for stock survival. Decline of habitat quality

can also detrimentally affect non-anadromous populations, causing a bottleneck for dispersion to larger habitats. Fragmentation can result in ecological and behavioural changes, physiological problems, genetic degradation and deterioration of habitat structure of rivers.

2.4 ECONOMIC VALUE OF MIGRATING FISH

Although diadromous fish comprise only a small percentage of the total catch in riverine fish (table 2.1), they frequently have high economic value. Often interceptory fisheries have developed where and when fish migrate and have refined their methods to maximise their effectiveness. Consequently such fisheries interrupt migration through the removal of large quantities of fish.

This has been very significant in some cases, for example the glass eel fisheries within the estuaries of Spain, Portugal, France and the UK and estuarine fisheries for sturgeon have all severely depleted the respective stocks. Similar local levels of exploitation for many other species, notably salmon, have also had serious local implications for stock viability.

Economic drivers

Riverine fisheries are an important source of money and food (high-quality protein), particularly in poorer countries where their products are readily available to the population. Ninety percent of riverine fishery production comes from developing countries where the fisheries provide employment for some 60 million people

Table 2.1 Breakdown of global riverine catches (FAO, 2010).

	Weight (in million tonnes)	Percentage
Freshwater fish	28.8	54.7
Molluscs	13.1	24.9
Crustaceans	5.0	9.5
Diadromous fish	3.3	6.3
Marine fish	1.8	3.3
Aquatic animals	0.6	1.2
Total	52.6	100

EXAMPLE

Assessing the impact of culverts on population connectivity of endangered galaxiid fishes in the Falkland Islands

Authors: Dan Fowler¹ and Carlos Garcia de Leaniz²
Organisation: Falkland Islands Fisheries¹ and Swansea University (UK)²
Country: Falkland Islands



INTRODUCTION

There are an estimated 786 km of road tracks in the Falkland Islands crisscrossing a dense network of streams, lakes and ponds. Most of these tracks have been built over the last two decades and use culverts, rather than bridges, to negotiate stream crossing. The actual number of culverts is not known, but a conservative estimate would be in the hundreds. In a pilot survey, Ross reported finding culverts in 22 of 38 sampling locations (58%) in both West and East Falkland, but this is almost certainly an underestimate (Ross, 2009).

Concerns have been raised about the potential impacts of culverts on the connectivity of the two native galaxiid fishes, *Galaxias maculatus* (Falklands minnow) and the endangered *Aplocheilichthys* sp. (confusingly named 'zebra trout'), which rely on a marine larval phase for completing their life cycle, as well as on the introduced sea trout (*Salmo trutta trutta*) which forms the basis of a valuable sport fishery.

Costs, and not fish passage, has been the overriding criterion for designing such culverts, and assessing their impact has been flagged as a high conservation priority, particularly for the endangered *Aplocheilichthys*.

WHAT ARE WE DOING?

That culverts hinder, or even impede, fish passage is implicitly recognised in local fishing regulations which forbid angling within 100 m on either side of such structures on government land. Yet, there is no information on the effects of culverts on Falkland fish populations, and no guidelines to help mitigate their impacts. As part of a DEFRA (UK)-funded Darwin Initiative designed to protect native galaxiid fishes (www.biodiversity.cl) we are compiling information on the number, characteristics, and location of culverts (and other potential barriers) in Falkland Islands waterways. We are also developing a field assessment of their likely impact based on culvert dimensions, location within the waterways, and data on water velocity and depth profiles. Culvert maintenance tends to be carried out on an ad-hoc basis, and it is hoped that our study can at least influence the replacement of older culverts across the Islands.

WHAT DID WE FIND?

This is an ongoing study and our data are hence preliminary, but our first surveys indicate that culverts in the Falklands are widespread and vary widely in size, from 30 to 200 m in diameter, and can be over 15 m long. They are now being favoured over bridges to create causeways over

all types of waterways, from head streams as small as 1.5 m wide, to stream mouths under tidal influence 155 m wide. Small culverts are made of PVC, but large ones tend to be made of corrugated iron. Average bottom water velocities (at 5 cm from the bottom) were 60 cm/s (range 0-125 cm/s) and 55 cm/s (range 0-113 cm/s) at the upstream and downstream ends of nine culverts, respectively. Similar values for water depth were 34.6 cm at the upstream end and 35.2 cm at the downstream end. We found instances where culverts were dry because water was infiltrating under rock gabions, as well as perched culverts that made fish passage impossible.

LESSONS LEARNED

Culverts are widespread in the Falklands, and yet their impacts on native fauna have not been addressed. As old culverts need replacement and new tracks are being planned, it is essential to develop a sound system for assessing their impacts, and for suggesting mitigation or alternative measures. We are using a simple field

inventory to identify potential barriers for fish migration, and will make use of genetic data to estimate levels of gene flow to infer connectivity between populations. No information is available on the swimming stamina of native galaxiids (and was not, therefore, a factor that could have been taken into account in their design), but studies on 7 fish species indicate that water velocities in culverts should not exceed 92 cm/s for any species, and should not exceed 45 cm/s for brown trout (Tudorache *et al.*, 2008), the species that most closely resembles the native *Aplochiton* sp.

On this basis, it would thus appear that many of the culverts in the Falklands constitute a significant barrier for fish migration. We also encountered, just like Ross, dry and perched culverts that were impossible for fish to ascend under all conditions (Ross, 2009). Data are still very limited, but we suspect that culverts may pose one of the biggest threats to the conservation of native galaxiid fishes in the Falkland Islands.

FIELD ASSESSMENT OF CULVERTS ON THE FALKLAND ISLANDS



EXAMPLE

Brokopondo reservoir. Long term effects of (Afobaka dam) hydropower damming without fish migration measures

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Organisation: University of Suriname, Center for Agricultural Research in Suriname (CELOS)¹, Institut de Recherche pour le Développement IRD, Laboratoire d'Écologie des Hydrosystèmes Fluviaux, France² and University of Suriname, National Zoological Collection Suriname³

Country: Suriname



INTRODUCTION

In this study the long-term changes in the fish fauna of Brokopondo Reservoir in Suriname have been assessed. This large reservoir (1,560 km²) was the first created within tropical rainforest. The 54 m high dam at Afobaka, 194 km from the estuary, was constructed in 1964 without fish ladders or other artificial devices to lessen the impact of the dam on fish migrations.

The assessment was done by comparing pre- and post-impoundment faunas based on (size-selective) gill net samples in the main river channel and reservoir (e.g. Vieira, 1982; Novoa *et al.*, 1991; Leite, 1993; Santos, 1995; Mérona *et al.*, 2003). This probably resulted in under sampling small-sized species and species from specific riverine (tributaries, rapids and floodplain lakes) and reservoir (shore) habitats.

WHY IS THIS RELEVANT?

Although studies of short-term changes in Neotropical fish faunas exist (e.g. Vieira, 1982; Leite, 1993; Santos, 1995; Ponton *et al.*, 2000; Méro-

na *et al.*, 2001, 2003; Mérona, 2002), few studies have addressed long-term impacts of dams on fish communities (Agostinho *et al.*, 1999). Because different methods were being used to catch fish (including smaller fish), this study gives a trustworthy representation of changes in the fish community as a whole. Other studies have used nets only and collected the bigger specimen only.

The middle reach of a river may be viewed as a zone with high habitat heterogeneity where headwater and coastal plain species overlap, resulting in high fish diversity. The serial discontinuity concept (Ward & Stanford, 1983, 1995) predicts that a dam in the middle reaches, as here with the Brokopondo reservoir, can have a large impact on riverine fish diversity.

IMPORTANT FINDINGS

Before closure, the fish fauna of the Suriname River consisted of 172 species, representing high diversity and a generally even distribution. The riverine fauna was dominated by small-sized

species, but no single species was numerically dominant. There were 4 large migratory species, among which large catfishes (*Brachyplatystoma filamentosum*, *Hemisorubim platyrhynchos* and *Pseudoplatystoma fasciatum*) that dominated the biomass. Species were evenly distributed between riverine habitats: rapids, tributaries and the main channel.

Four years after closure of the dam, only 62 fish species were collected from the Brokopondo Reservoir, but the composition of the fish fauna was still in the process of change. The reservoir fauna in 1978 was very similar to the reservoir fauna in 2005, indicating that a stable equilibrium had been reached 14 years after closure of the dam.

By this time the reservoir fauna consisted of 41 species, with low diversity and low abundance. Low evenness indicates that the abundance of a species not distributed equally within the ecosystem. This is comparable to other Amazonian reservoirs, where the number of fish species was reduced dramatically compared to pre-impoundment.

After closure no large migratory fishes of the Suriname River were collected in Brokopondo

AFOBAKA DAM

This dam created the Brokopondo reservoir.



Reservoir, either in 1978 nor in 2002-2005. Many large-sized migratory catfishes are mainstays of Neotropical subsistence and commercial river fisheries, but they are vulnerable to damming because of their wide-ranging habits (Barthem *et al.*, 1991; Araujo-Lima *et al.*, 1995; Agostinho *et al.*, 1999; Carolsfeld *et al.*, 2003). However, different species react to damming differently and some are able to survive in the smaller sections of river that are available to them after a dam is erected. This is the case in the Tucuruí reservoir (Ribeiro *et al.*, 1995) and Itaipu reservoir (Agostinho *et al.*, 1999). After initial increases (in comparison to populations upstream of the reservoir) large migratory catfishes became rare.

However, *Pterodoras granulosus* was able to extend its distribution from the Lower and Middle Paraná to the Upper Paraná and Itaipu Reservoir after the reservoir inundated the natural barrier of Sete Quedas Falls (Agostinho *et al.*, 1999). Potamodromous detritivorous characoids were more successful in Amazonian reservoirs than piscivorous migratory catfishes.

LESSONS LEARNED

Before closure of the dam, there were 4 large migratory fish species in the Suriname River. After closure, no large migratory fishes of the Suriname River were collected in Brokopondo Reservoir. This indicates that large migratory catfishes are vulnerable to damming because of their wide-ranging habits.

Hydropower can be a partial solution for the energy demand of some countries; however small catchments and flat topography result in large reservoirs that generate little power (low MW/km²) such as the Balbina (Brazil) and Brokopondo reservoirs.

A rational approach to long-term sustainable use of natural resources in a watershed should include ecological zoning and integration of all ecological and socio-economic implications into an overall River Basin Plan (Ribeiro *et al.*, 1995).

in both developed and developing countries. Evidently the riverine fishery sector involves a tremendous workforce, producing food where it is greatly needed. However many riverine fisheries are located in areas of increasing local economic development, and often industrialization, both of which compete for water resources and can negatively affect inland waters and the living aquatic resources and fisheries they support (FAO, 2010).

Agriculture is responsible in many areas for draining wetlands, abstracting a tremendous amount of water through irrigation and disrupting connectivity between rivers and floodplains. Floodplains are some of the most productive riverine fishery habitats, especially in tropical areas. For example, more than 40% of the floodplains of Bangladesh have been modified and impoldered for rice growing, and more than 60% of the water flow of the Ganges Basin is abstracted for irrigation and other purposes.

Recreation is a major contributor to the local economy. For example, recreational fishing is worth approximately £300 million annually to the UK economy, 700 million to the Dutch economy, more than US \$980 million to the Alaskan economy and a staggering US \$3.6 billion total annual economic impact in the USA. The shift in emphasis in some countries away from fisheries as a food source to provide recreation may be followed in developing countries as their economies develop further.

2.5 CLIMATE CHANGE

The effects of climate change are hard to predict but rising sea levels and increased temperatures will change the distribution and composition of fish stocks, notably those of diadromous fish. The impact of global warming on water resources will be profound, and for most migratory fish whose biology is adapted to seasonal hydrology, the implications are enormous (Carolsfeld *et al.*, 2003). Increased temperatures and eutrophica-

Saloum Delta (Senegal)

Fisheries provide an important source of income (© Gernant Magnin).



tion may initially increase production of some species, but beyond some (currently undefined) set of thresholds production will decline. The timing of many fish migrations will be affected. For example, the freshwater lakes and streams in Connecticut (USA) may become much more productive due to warming and eutrophication, however there will be less opportunity for anadromous salmon and shad as flows decline or become more sporadic. Similarly, if the trend of lower productivity of the Atlantic Ocean extends northwards towards higher latitudes and diminishes the productivity of the north Atlantic and arctic regions, there will be less advantage to anadromy, potentially threatening the highly valuable stocks of salmon. Todd *et al.*, (2008) and Friedland *et al.* (2009) present evidence of recent climate-driven decline in productivity of the north Atlantic pelagic ecosystem and the implications of this for salmon.

There are also specific concerns in some regions about potential changes in timing, intensity and duration of floods, to which many fish species are accustomed in terms of migration, spawning and transport of spawning products, as a result of climate change (FAO, 2010). For example, a young salmon can migrate to sea only during a brief spring time window when it has become physiologically adapted to saltwater by the influence of water temperature and day length. If it arrives too early or too late, it is less likely to survive the transfer to saltwater.

Climate change is expected to drive many species ranges towards the poles by mid-century, leading to numerous local extinctions. This will have a strong influence on species distributions and diadromous species will be affected most. Climate change may already have impacted the presumed breeding grounds for eel in the Sargasso Sea (IUCN, 2010).

The tropical ichthyofauna is more diverse and probably less resilient to climate change than temperate ones because of the greater predictability of, and hence adaptation to, environmental

conditions in tropical regions. This has equipped fish there with little capacity to cope with environmental changes, and particularly to modifications of longitudinal connectivity (Marmulla *et al.*, 2004).

Because of their great importance fisheries must be included in global climate policy dialogue. The reason for this is clear and is exemplified by the work of Allison *et al.* (2009) who claim that around 520 million people around the world are fisheries-dependent. One-third of the world relies on aquatic products from fisheries and aquaculture for at least one-fifth of their protein intake, and 98% of these people are in the developing world. This underlines the strong link between society and fish as an economic driver.

2.6 GENERAL CONCLUSIONS

River systems must be considered as a network of surface waters, groundwater and coastal waters within a river basin that, together, function as a total ecosystem. A good understanding of the hydrological and ecological nature of the river system, including fish migration, is vital for good river basin management. Restoration of fish migration is only part of the solution when working on ecological restoration of river systems.

Migratory fish species are often used as 'key indicator species' that highlight 'good ecological status' of river systems. They can be divided into potamodromous species that live entirely in freshwater and migrate within the river, and diadromous species that must migrate during their life cycle between sea and river. Diadromous species comprise anadromous, catadromous and amphidromous species. Anadromous species such as the salmon reproduce in freshwater and migrate to the sea where they grow to the adult stage. The catadromous eel enters freshwater as juveniles where they grow to maturity prior to their return migration to saltwater for spawning. Amphidromous species such as herring and mullet are marine species which often enter freshwater to find refuge or food, but not for reproduction purposes.

EXAMPLE

Westslope cutthroat trout conservation program

Author: Matt Boyer
Organisation: Montana Fish, Wildlife and Parks
Country: USA



INTRODUCTION

Westslope cutthroat trout (*Oncorhynchus clarkii lewisii*) were historically the most abundant and widely distributed of the cutthroat trout subspecies (Behnke, 1992). Today, this species occupies less than 10% of its range and is threatened with genomic extinction due to widespread introgressive hybridization with introduced trout species (Allendorf *et al.*, 2004; Shepard *et al.*, 2005). Conservation management plans for westslope cutthroat trout (WSC trout) aim to maintain and expand the remaining genetically pure populations.

The South Fork Flathead River drainage (2,705 km²) comprises over half of the remaining interconnected habitat for WSC trout and provides an exceptional fishery in a pristine wilderness setting. Although wilderness designation has largely protected this watershed from anthropogenic habitat degradation, historic stocking of non-native rainbow trout (*O. mykiss*) and Yellowstone cutthroat trout (*O. c. bouvieri*) in headwater lakes and their outlet streams poses a significant threat to the persistence of genetically pure WSC trout in the South Fork Flathead drainage.

WESTSLOPE CUTTHROAT TROUT



WHAT DID WE DO?

In 2007, Montana Fish, Wildlife, and Parks, United States Forest Service, and Bonneville Power Administration implemented a watershed scale conservation program aimed at removing sources of non-native trout from 21 headwater lakes and outlet streams and re-establishing populations of WSC trout. Removal of non-native trout is accomplished through the use of the piscicide rotenone or by genetic swamping.

This latter tactic involves annual stocking and subsequent successful reproduction of WSC trout to eliminate non-native genes from the population over a period of years. To date, populations of WSC trout have been restored to approximately half of the headwater lakes in the

South Fork Flathead River drainage and completion of this project is expected to occur by 2018.

HOW DID IT WORK OUT?

Large scale conservation projects must incorporate adaptive considerations to ensure the maintenance of ecological processes that sustain native fisheries. WSC trout exhibit substantial genetic divergence between populations, even over small geographic scales (Allendorf and Leary, 1988).

Conservation of genetic variation is crucial for long-term persistence of a species and, in the case of WSC trout, requires ensuring the continued existence of many populations throughout

its range. To achieve this goal, multiple broodstocks from genetically unique populations are being used to stock headwater lakes once non-native trout have been removed. This effort represents a substantial advancement in the conservation of genetic variation in native fishes with a high degree of interpopulation divergence.

LESSONS LEARNED

Lastly, conservation programs must effectively incorporate the human dimension. That is the recognition that humans are part of ecological systems and must be included in conservation planning. Ultimately, the extensive public involvement and review process has greatly contributed to the success of this project by balancing social and biological goals.

FLATHEAD RIVER



The current status of the European Eel (*Anguilla anguilla*)

Author: Kim Aarestrup
Organisation: Technical University of Denmark
Country: Denmark



INTRODUCTION

Life cycle

The European eel is a catadromous species which spawns in the Sargasso Sea, south of Bermuda (overlapping with the spawning area of American eel, *Anguilla rostrata*). It is believed that they spawn at 100-250 m depth and that their eggs hatch within a few days. The young larvae (leptocephali) are carried by the ocean current across the Atlantic Ocean to the western approaches to Africa and Europe. Upon reaching the coast they transform into elvers and ascend accessible brackish and freshwater areas, although it is known that some remain in estuaries or at sea. The eels feed for a period of between 5 to over 30 years before partially maturing and commencing the migration back to the Sargasso Sea to spawn and die (figure 1).

There are still many unknown aspects of the eel's life cycle. For example, no one has ever caught a mature eel in the spawning area and only the initial part of this migration is known (Aarestrup *et al.*, 2009). The complicated life cycle has hitherto rendered it impossible to breed eels artificially and consequently all traded eels are of wild origin (including eels raised in aquaculture).

Geographical distribution

The European eel is probably the only true pan-European fish species being distributed from Northern Africa to Northern Norway and from the Azores to the Black Sea. Historically, it was present in all accessible waters in Europe and North Africa. It is also present in Iceland, where there are significant numbers of hybrids (with the American eel) (Avisé *et al.*, 1990). Recent studies have confirmed that eel throughout the entire distribution range belong to the same population (Als *et al.*, 2011).

EUROPEAN EEL ON THE EDGE?



Human impacts

European eel has been heavily exploited for centuries. They have been targeted both through commercial and recreational fisheries and also for use in aquaculture. Other causes of loss include blockage of up-river migration, destruction of habitat, pollution and introduction of parasites. Furthermore, a potential change in ocean currents, possibly as a consequence of the onset of global warming, has also been considered a possible factor.

As a consequence the population has plummeted in the last decades and the species is now listed as critically endangered by the International Union for Conservation of Nature. The recent population decrease has led EU to take action and member nations have been directed to draw up national management plans to restore the population.

POSSIBLE SOLUTIONS

Strong determinate political decisions are needed to save the population. The long life cycle will require strong intervention for several decades and maybe longer if the population is to be restored. Furthermore, the species nature in the form of a single population calls for an international approach as poor management of eels in one nation may have negative effects in the entire distribution range. The basic management problem is the lack of detailed information about behaviour and survival at critical life stages.

However, increasing survival of eel within Europe leading to larger numbers migrating to the spawning grounds is essential. This necessitates reductions in fishery and hydropower related mortalities. Stocking is also listed as a possible management option for increasing the spawning population. However, there is insufficient evidence to support this solution and it should not be selected as the only management option. Completion of the freshwater growth phase in hatcheries may reduce the impact of aquaculture on wild eels and maintain a supply for eels to markets, but it will not save the eel population.

KEY DRIVERS

The high economic value of eels may suppress adequate measure towards stock protection. The fishery is not expected to increase, but illegal fishing may thrive even if legislative restrictions are implemented. There will therefore be a need for strong enforcement of the measures introduced. The continued international demand for carbon dioxide neutral energy production from non-fossil sources such as hydropower will increase blockage of migration, as well as

increase the current risk of entrainment and impingement mortality, and compromise current initiatives to reduce the overall mortality.

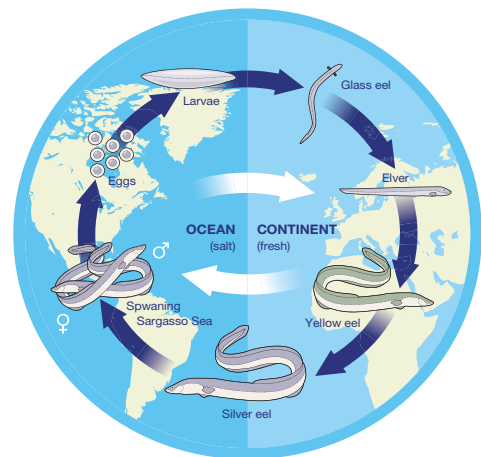
FUTURE DIRECTIONS

Reducing mortality during the life cycle is essential. The long life cycle means that restoration of the eel population is a long term project extending over several decades if not centuries. Possible measures include:

- 1 Increasing our knowledge on differential survival to optimise and predict management outcomes;
- 2 Closing of fisheries;
- 3 Removing hydropower stations (or at least closure during critical migration periods);
- 4 Reducing pollution, especially heavy metals and xenobiotics in rivers and coastal areas.

FIGURE 1

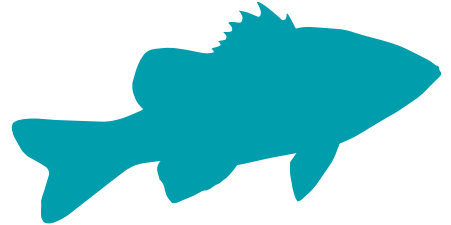
Life cycle of European eel (www.waternet.nl).



SPECIES EXAMPLE

Fish passage issues for Australian bass (*Macquaria novemaculeata*)

Authors: Lee Baumgartner¹ and John Harris²
Organisation: NSW Department of Primary Industries¹ and Harris Research²
Country: Australia



INTRODUCTION

Australian bass are a catadromous percichthyid endemic to southeastern Australia. They support popular recreational fisheries. Bass live in fresh-water, migrating to spawn in estuaries but may make many repeat movements between fresh-water and the estuary during their lifetime. Bass are long lived (over 20 years), highly fecund, high level predators that can grow up to 600 mm and weigh over 3 kg (Harris, 1988). The species' range in New South Wales, Queensland and Victoria encompasses many highly regulated rivers (Harris, 1988).

Dams and weirs impact bass distribution and abundance by obstructing spawning and recruitment migrations. Half of the total potential habitat is affected (Harris 1984). Dams exclude bass from upstream reaches resulting in local extinctions (Harris 1988; Gehrke *et al.*, 2001), except when stocked. For example, the construction of Tallowa Dam on the Shoalhaven River resulted in extirpation from upstream reaches in less than 25 years (Gehrke *et al.*, 2001). Low-head barriers (culverts, road crossings, etc.) also obstruct migrations, especially upstream-migrating juveniles near tidal limits.

High flows stimulate bass spawning migrations (Harris, 1988) and water storage and altered flow regimes reduce recruitment. Flow diversions out of the Snowy River (Victoria) have prevented nat-

ural recruitment for over 19 years. A large-scale stocking program is now required to rehabilitate the population in this catchment. Mitigation of human impacts for Australian bass therefore requires a complex combination of improved upstream passage to facilitate recolonisation, and also provision of environmental flows for spawning and recruitment.

SOLUTIONS

New South Wales Fisheries Management legislation (*New South Wales Government, Fisheries Management Act, 1994*) explicitly seeks to ensure fish passage is either maintained or enhanced by any water development activities. Specifically, any new migration barrier or modification to an existing barrier requires the provision of fish passage to maintain migration pathways for native fish. This created a legislative requirement

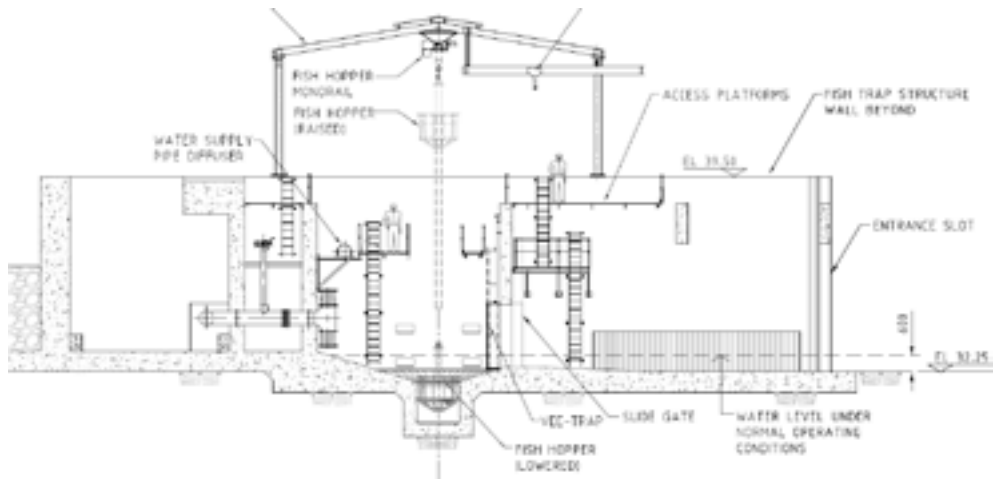
AUSTRALIAN BASS

(© Pat Tully, NSW Government).



FIGURE 1

Nerang River trap-and-haul fishway.



to progress fish passage options in New South Wales, Queensland and Victoria.

Development of effective fishways began with laboratory trials (Mallen-Cooper, 1992), using a vertical-slot fishway model. Optimal criteria (slot width, floor slope, cell size) for passing sub-adult fish were established, and now guide design for various fishway types (rock ramp, Denil, bypass). The biggest fish passage rehabilitation program has been on the Hawkesbury-Nepean River (Sydney) where 13 migration barriers were retrofitted with vertical slot fishways and environmental flow release valves. Larger barriers in New South Wales and Queensland, Tallowa Dam (Shoalhaven River) and Paradise Dam (Burnett River) have automated fish lifts and Hinze Dam (Nerang River) has a trap-and-haul fishway.

Catch and size restrictions control fishery exploitation and Australian bass are protected from commercial use in all rivers throughout their range.

WHAT ARE THE KEY DRIVERS?

Preservation of biodiversity and declining fish-

eries drive fish passage rehabilitation and the development of supporting legislation. Fishway construction is subject to economic priorities and the size, location and ownership of barriers are criteria influencing mitigation approaches. Vertical slot fishways commonly serve larger barriers (< 6 m), but smaller barriers (1 - 2 m) are often suited to nature-like bypass or rock ramp fishways. Setting priorities among sites considers location within the river system, barrier type and size, hydrology and target species. Constructing authorities work with fish biologists to assess solutions.

FUTURE DIRECTIONS

Australian bass rehabilitation adopts an adaptive management framework. Conservation managers and researchers work together to address knowledge gaps in fishway design and species biology. Research knowledge and fishway performance data are applied at new works and constructing authorities apply design criteria from scientific research. Future priorities for bass center on rehabilitating wild stocks and this will require further development of effective fishway criteria for designs that have lower capital costs.

Bassano Dam

This dam is part of the Eastern Irrigation District, a large irrigation network in southern Alberta (Canada), that provides water to farms, towns, and recreation areas (© Patricia Buckley / WWF-Canada).



Barriers in rivers have profound consequences for hydrology and habitats, riverine fisheries and especially the upstream and downstream migrations of fish. The nature of the problems are similar around the world with fish being excluded from vital reproductive and recruitment areas upstream and in floodplains and the impact of impounding structures on natural habitats.

Migratory fish species are by nature highly sensitive to changes in their environment. With human populations expanding, dam developments proliferating, imminent climate change and an increasing economic reliance on fish resources worldwide, addressing fish migration issues to sustain fish populations is increasingly a vital challenge.

Worldwide the main barriers to fish migration are dams and weirs. Large parts of the river systems in Europe, North America and South-East Asia are heavily fragmented (with China leading at more than 22,000 dams). The main purpose of these dams is flood control and hydropower. The remaining free-flowing rivers in the world are mainly found in the tundra regions of Canada and Russia, and in the river basins of South America and Africa.

An aerial photograph showing a dark, winding river that meanders through a lush green landscape. The river flows from the top right towards the bottom left, curving around several large, dense forested islands. The surrounding land is a mix of vibrant green fields and some brownish, possibly harvested or fallow, areas. In the upper left corner, a small cluster of buildings is visible. The overall scene is a typical rural river basin.

CHAPTER 3

RIVER BASIN

APPROACH

INTRO

Rivers throughout the world have been heavily modified by humans causing a large decrease in ecological quality. On many rivers work is being carried out in order to restore habitat and fish migration but in many cases this is limited by financial resources or social and technical constraints.

Targets for restoration of fish migration should be considered carefully, within the context of the entire river basin, taking into account a comprehensive plan that considers available habitat and potential scope for upstream and downstream migration within the river continuum.

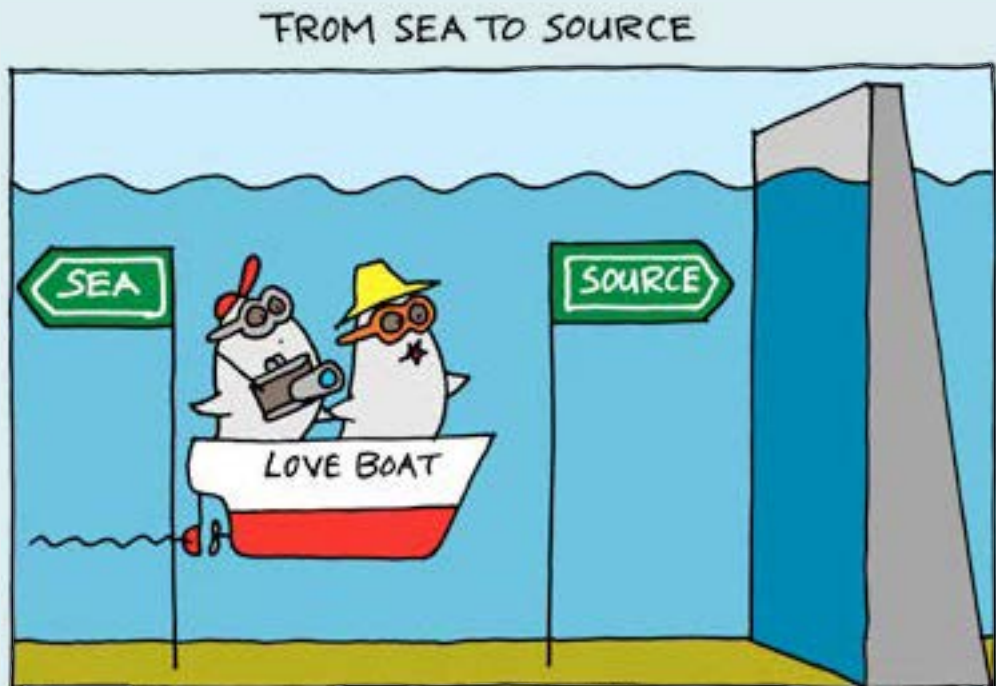
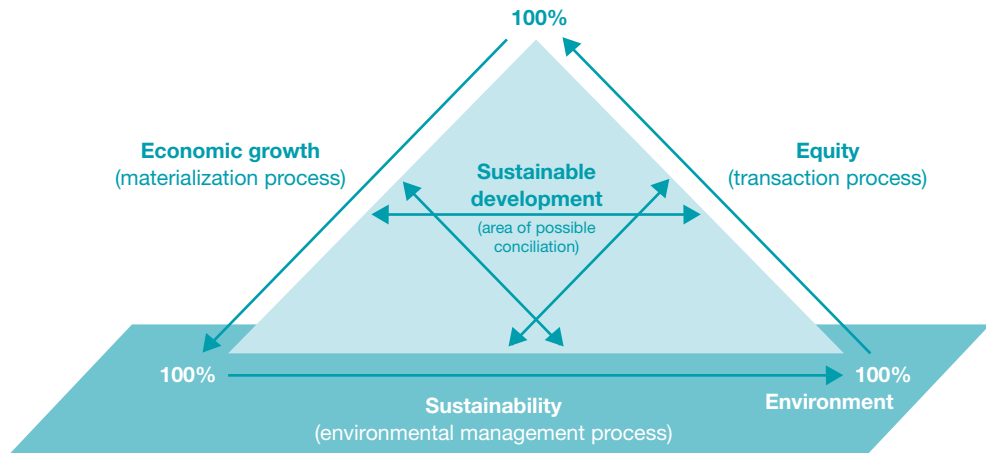


Figure 3.1

Interrelationships between economic growth, equity and sustainability (UNEP, 2002).



3.1 SCIENTIFIC BASIS FOR SUSTAINABLE DEVELOPMENT OF RIVERS

The river basin approach forms the scientific and social basis for sustainable management of rivers worldwide. A key element in achieving sustainable development is to ensure that the carrying capacity of ecosystems is achieved and that they are able to assimilate natural and anthropogenic stress (UNEP, 2002). Understanding of the natural biota should be integrated with that of hydrological processes and water quality pressures within the river catchment area to provide a scientific background for maintaining ecological quality. In this way, ecosystem properties and services become the management tool in which the watershed is a primary planning unit.

By incorporating ecosystem resilience into this management tool, a preventive, holistic, and global approach to the watershed is created – in contrast to the reactive, sectorial, and site specific approach typical of present practices in water resources management. However, environmental management is only one of the three key considerations on which the concept of sustainable development has been built (Figure 3.1).

To achieve sustainable development, other issues need to be addressed as well. Policy, institutional, economic, social, environmental and legal issues need to be integrated in a sound management system: this is The River Basin Approach. It is an example of a social incentive-based participatory mechanism for solving conflicts and allocating water between competing users, including natural ecosystems.

The River Basin Approach is a result of the Vision for Water and Nature (IUCN, 2000) which aimed to 'adopt an ecosystem-based approach within river basins for sustainable water resources management'. A handbook specifically on the subject of River Basin Management and International Cooperation has been prepared by the Ramsar Convention Secretariat (2007) recently.

A report by the US Environmental Protection Agency (1995), which seems appropriate still, states that organizing around major watersheds or basins can improve the scientific basis for management decision-making. Focusing on basins and watersheds encourages agencies to seek information on all significant stressors, including those that tend to be overlooked by tra-

EXAMPLE

Free Flowing Rivers 'The river wild'

Authors: Esther Blom, Jian-hua Meng,
Zhang Cheng and Bart Geenen
Organisation: WWF
Country: China, Russia and The Netherlands



INTRODUCTION

Free flowing rivers are defined by WWF as rivers that flow undisturbed without encountering large dams, weirs or barrages and without being significantly restricted by dykes or levees. Free flowing rivers are increasingly rare. A study by WWF revealed that of 164 rivers longer than 1,000 km, only 64 (40%) can still be considered to remain free flowing and on 17 of these dams are planned (WWF, 2006).

Only 21 of the 64 free flowing rivers longer than 1,000 km are un-dammed from source to sea. Most of the remaining free flowing rivers are large tributaries of the world's major river systems. In Europe for example, there is only one river left that remains free flowing from source to sea, the Pechora in Russia flowing from the Ural to the Arctic sea.

Modifications to rivers influence one or more spatial and temporal parameters of the river, such as the seasonal runoff and flooding patterns and variations in river depths. Rivers, especially free flowing rivers, provide important functions and services to humans. The fish, water fowl and mussels living in rivers are important sources of food to people. Regulating services such as water purification and flood mitigation are very valuable services to people dependent on the river, and will become even more valuable with ongoing climate change.

Despite all the services free flowing rivers provide, people have sought to tame and control them by building dams and dykes. Ecologically, fragmentation of rivers due to river modifications is a huge problem as maintaining connectivity on all levels is essential to conserve freshwater biodiversity. This includes connectivity between and within aquatic habitats, connectivity with the riparian zone and floodplains, connectivity between freshwater and saltwater habitats and connectivity with subterranean systems.

CASES BY WWF ON FREE FLOWING RIVERS

The water security team of the WWF freshwater programme set a goal to protect and restore the environmental flows necessary to sustain freshwater and estuarine ecosystems and the freshwater species and human livelihoods that depend on these ecosystems. Specifically, it is striving to preserve the remaining free flowing rivers from harmful infrastructure and to prevent over-abstraction from rivers and ecosystems. Priority rivers identified by WWF for freshwater biodiversity conservation are the Amur, Yangtze, Mekong, Ganga, Indus, Zambezi, Danube and Western Balkans, East African freshwater systems, Amazon, Pantanal, and Chihuahuan desert.

Two examples of rivers where WWF is working to maintain them as free flowing are:

Chishui River

This 440 km long river in Southwest China has a very high biodiversity and is the only tributary of the Yangtze that remains without dams, making it unique and a priority for conservation. It is recognized by the government as a fish sanctuary; 108 species of fish still migrate between the source in the Yunnan province and the mouth where the Chishui joins the Yangtze River, including the endemic Fat fish (*Sinocrossocheilus labiatus*).

Mainly since construction of the Three Gorges Dam on the main stem of the Yangtze further downstream, this river is considered a priority area for fish conservation by many stakeholders.

There is currently no immediate confirmed threat of dam development in the main stem of this river. However, only one of the three provinces through which the river runs, Guizhou Province, has committed to maintain the river without dams in its provincial legislation. Sichuan Province appears open to adopting comparable legislation; however the biggest threat originates from Yunnan province. The source area of the river is officially recognized as a 'famous poor country' and therefore receives significant national investment for development, including infrastructural development. An increasing demand for energy throughout China, and this area in particular, means that there is a risk of dam development in the longer term.

CHISHUI RIVER

(© Wei Baoyu, WWF China).



THE HARINGVLIET DAM

In 2011 it was decided that the locks in the Haringvliet dam will be opened to restore the tidal influence in the former estuary (© Gerard Litjens Meinerswijk).



WWF works together with various partners to safeguard the free flowing character of the river and maintain a healthy river. In Guizhou, it is cooperating with the National People's Congress and Guizhou Provincial Government to develop a river management plan based on sound integrated river basin management principles. Recently a Joint Meeting Mechanism within the province has been established to deal with the daily management and conflicts among lower level governments in the River Basin. With the Guizhou Provincial Developing and Reforming Commission (which is one of the decision making bodies for economic development) and Guizhou Provincial Environmental Department, WWF is now working on the Chishui River Integrated Development and Conservation Plan. Also, WWF is facilitating cooperation between the three provinces by introducing PES (Payment for Environmental Services), Water Stewardship and other tools. These were developed by WWF in other catchments with national and international resources to achieve a long term commitment to keep rivers free flowing.

In Yunnan, WWF developed sustainable livelihood projects that provide an alternative poverty reduction strategy to the large scale investments. In Guizhou, it cooperates with famous distillery companies that also depend on good water

quality and quantity. Recently, and as proposed by WWF, an Environmental Promoting Committee has been established with 142 enterprises participating within the River Basin. Within this sector, WWF has joined the lobby against the spilling of unpurified waste water from the paper factories in the river and joined forces to spread the message on the value of a free flowing river.

Amur/Heilong

Another practical example of WWF's work on the most important free flowing rivers is that on the Amur/Heilong River. The Amur/Heilong is, at 4,510 km long, one of the ten largest rivers in the world and contains 120 species of fish. It is also one of the last major rivers with no dams on the main stem.

The river is shared by three countries - Mongolia, China and Russia - each of which has rapidly developing national economies, and the river is therefore exposed to very strong pressures. Industry, forestry, agriculture, mining and infrastructure development pose great threats. However the majority of the Amur-Heilong River's watersheds, including the main stem and some of its tributaries, retain their free-flowing character. WWF is working with each of the countries bordering the river to study the unique characteristics of this free flowing river. In a study (to be finalised) WWF has selected the most important ecological services to illustrate the threat of unsustainable hydropower, mining, agriculture and infrastructure development to the basin's integrity and to the national objectives of the riverside countries. The study describes the range of political issues and visions that currently influence the Amur/Heilong basin's development, and endeavors to foster constructive dialogue among ecologists, landscape planners and decision-makers that will result in the sustainable use of water resources.

HARINGVLIET, SOUTHWEST DELTA OF THE NETHERLANDS

After a major flood in 1953, the river arms of the southwest delta of The Netherlands (Rhine-

Meuse, Scheldt) has been closed by means of huge dams and barrages on the river as well as the sea side. For reasons of improving safety for people that depend on this delta, and in light of expected climate change, WWF has advised the complete re-opening of the most northern river arm, the Haringvliet.

Based on a study by Wageningen University it also appears that from an economic point of view, it is sensible to open this specific river arm, and turn it into a more free flowing system (albeit it still heavily influenced by infrastructure such as local climate dykes and other infrastructure further upstream).

This pilot study suggests that opening of the Haringvliet will lead to an increase in the total economic value of the Haringvliet area by hundreds of millions Euro/y, which is a substantial increase compared to the closed arms scenario. WWF is discussing the outcomes of this study with government, stakeholders and experts to ensure that this proposed natural solution is taken into account when the future of the Rhine-Meuse-Scheldt delta is decided.

LESSONS LEARNED

The importance of rivers to people is undeniable, supplying numerous services upon which people depend on a daily basis, and that should also be preserved for future generations. With increasing infrastructure the capacity of rivers to provide regulating and supporting services is seriously degrading. The value of free flowing rivers is now increasingly recognized by society and a number of awareness and protection mechanisms are being applied in different countries, including economic and ecological evaluations of free flowing rivers and specific protected areas and river projects. It appears important to attach economic value to the regulating and supporting services of free flowing rivers in discussions on river infrastructure development.

Keeping our rivers free flowing requires governments to recognize the values of free flowing rivers. Countries should work across political boundaries with other countries sharing river basins. In each river basin, one or more tributaries at least should be kept free flowing, and the remaining intact main stems should also be protected.

AMUR/HEILONG

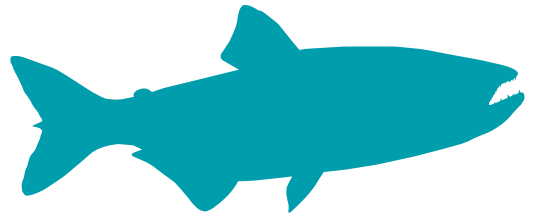
Onon River is part of the Amur/Heilong River catchment area (© Gernant Magnin).



SPECIES EXAMPLE

Current status of: dourado (*Salminus brasiliensis*), surubim (*Pseudoplatystoma corruscans*) and curimba (*Prochilodus lineatus*)

Authors: Sergio Makrakis and Maristela Cavicchioli Makrakis
Organisation: GETECH, Universidade Estadual do Oeste do Paraná
Country: Brazil



INTRODUCTION

South American rivers have a very high diversity of fish species estimated at more than 5,000 species (Reis *et al.*, 2003). There is a staggering variety of migratory species with great life cycle diversity, and some fish migrate more than 1,000 km to spawn year after year. More importantly, the South American migratory fish species feed people, and provide them with recreation (Carolsfeld *et al.*, 2003). Most of them are targeted by artisanal and sport fishing. A good example is the dourado *Salminus* (a salmon look-alike), one of the largest characins that grows up to 116 cm long (Godoy, 1975), is piscivorous and the most valuable sport fish in Brazil.

Large piscivorous catfishes including surubim or pintado, *Pseudoplatystoma corruscans*, a pimelodidae, are very popular in the marketplace, particularly for restaurants (Agostinho *et al.*, 2003). This species is the largest catfish in the Paraná River basin, with individuals up to 152 cm in length (Agostinho *et al.*, 2003). In the São Francisco River, it grows to 120 kg (Sato *et al.*, 2003) and is one of the most important fisheries resources (Menezes, 1956; Godinho *et al.*, 1997; Godinho and Godinho, 2003). Surubim is a major

trophy for recreational anglers in the São Francisco River due to its large size and it is the most valuable fish for commercial fisheries because of its outstanding taste (Godinho *et al.*, 2007). However, there are also migratory species of less economic value such as *Prochilodus*, a Prochilodontidae known as curimba or curimbatá in Portuguese, and sábalo in Spanish, the biology and behaviour of which has been much studied. The species is a medium-sized characin that grows up to 72 cm in length (Castro & Vari, 2003).

GEOGRAPHICAL DISTRIBUTION

Salminus species, dorado or dourado, are restricted to South America. They are potamodromous and distributed in Argentina, Bolivia, Brazil, Colombia, Paraguay, and Uruguay. *Salminus affinis* is found in the Magdalena River basin, and *Salminus brasiliensis* occurs in Paraná, Paraguay and Uruguay River basins; Laguna dos Patos drainage, upper Chaparé and Mamoré River basin in Bolivia, but its occurrence in the remaining Amazon River basin is highly doubtful (Reis *et al.*, 2003). The occurrence of *Salminus franciscanus* is limited to the São Francisco River basin in Brazil (Lima & Britski, 2007). They inhabit lotic environments of large rivers and tributaries with

moderate abundance in relation to other migratory species.

Pseudoplatystoma corruscans is found in South American Rivers including the São Francisco (Brazil) and Paraná (Argentina, Brazil, Paraguay, and Uruguay) River basins. This species lives in large rivers and tributaries, and features in the sport and artisanal fisheries in the dam-free stretches of the Paraná basin, but also enters the riverine zone of reservoirs to feed (Agostinho *et al.*, 2003).

Prochilodus species are widely distributed in many countries of South America occurring in the Orinoco, Amazon, Tocantins, São Francisco, La Plata, Apicá, Pardo, Jequitinhonha, Parnaíba, Mearim, Paraíba do Sul, Atrato, Sinú, Cauca-Magdalena, Lake Maracaibo, Branco, Marauí, Caroni River basins, and others. *Prochilodus lineatus* is one of the most studied of the prochilodontids. It is a potamodromous species widely distributed in the Paraná-Paraguay and Paraíba do Sul River basins including rivers, lagoons and reservoirs. It is an important species for commercial and recreational fishing and its abundance in reservoirs is correlated with the presence of free stretches upstream and in large lateral tributaries (Agostinho *et al.*, 2003).

SALMINUS BRASILIENSIS

Dourado, caught downstream of the Itaipu dam, Paraná River.



PSEUDOPLATYSTOMA CORRUSCANS

Surubim migrate over long distances, up to 400 km, to spawn.



LIFE CYCLE

Salminus brasiliensis as with other *Salminus* species are migratory, moving long distances (up to 1,000 km) to reach spawning sites in the rainy season. Sverlij & Espinach-Ros documented movements of up to 1,440 km between the La Plara River estuary and Posadas, Argentina (Sverlij & Espinach-Ros, 1986). These fish spawn in running waters (Godoy, 1975) after the water level has begun to rise. The spawning areas are in the upper stretches of the large tributaries (in running waters) and fish spawn during the rainy season, especially from October to January. The eggs and larvae drift into lower parts of tributaries to develop, and juveniles migrate into marginal lagoons to find feed and shelter. This species is able to ascend fish ladders and other fish passage systems, including the Canal da Piracema-Itaipu Binacional in Brazil (Makrakis *et al.*, 2007a, b).

Pseudoplatystoma corruscans, or surubim, is a potamodromous species that also migrates long distances (more than 400 km) to spawn (Makrakis *et al.*, submitted). Spawning occurs from November to March in the main river channel or in large tributaries, and flooded areas and lagoons are used as nursery grounds. Studies have shown that the species has ability to ascend fish passes (Makrakis *et al.*, 2007a, b).

PROCHILODUS LINEATUS

Curimba is a frequently used fish specie for stocking in the Paraná River (© Oscar Akio Shibata).



Prochilodus species show migratory behaviour and stratified distribution in distinct environments of South American river basins. The spawning strategies are similar to *Salminus*. As the flood-water recedes, the fish remains in the lagoons for up to two years, or until their first maturation is complete (Agostinho *et al.*, 1993). Adult *P. lineatus* prefer lotic environments whereas juveniles are most frequently found in marginal lagoons of the main river channel. Recruitment is extremely variable according to the annual flood regime that is controlled by dams (Gomes & Agostinho, 1997). *Prochilodus lineatus* migrates upstream long distances for spawning and migrations can reach distances of greater than 1,000 km (Godoy, 1975). This species also migrates large distances downstream, and the return migration after spawning is more irregular, and can include entry to the floodplains to feed and recover the energy spent during reproduction (Agostinho *et al.*, 2003). Recent studies of fish passage systems at the Canal da Piracema-Itaipu Binacional (Makrakis *et al.*, 2007a, b) using PIT-tags indicate that downstream movement involves passage through turbines.

HUMAN IMPACTS

Like many other migrant species, dourado, surubim and curimatá populations have been suffering serious declines in several watersheds. The most important reasons for this are the ob-

structions of migration routes by hydroelectric power plants, alterations of the natural flow regime governed by the economic demands of the power plants, habitat destruction, pollution, and heavy fishing pressure (Pesoa & Schultz, 2010; Agostinho *et al.*, 2003).

FUTURE DIRECTIONS

Management actions taken to minimize impacts of dams to migratory species in Brazil have historically consisted of the construction of fish passes, fishery controls and stocking (Agostinho *et al.*, 2008). Stocking has been the most conspicuous strategy used by hydropower companies over the last decades to mitigate impacts on migratory fish in the Paraná River basin, and *P. lineatus* was the most stocked species (Agostinho *et al.*, 2003). Conservation efforts should also focus on the preservation of the remaining wetlands, which play a key ecological function as nursery, refuge and forage habitat, and the control of fishery activity which, at present, may cause more serious impact than industrial and domestic sewage (Pesoa & Schultz, 2010).

ditional programs (e.g., ecosystem effects due to habitat loss).

River Basin Organizations Worldwide

Some river basin organizations have been in place since as early as the 1930's. From a historical perspective, development-oriented basin organizations probably reached their zenith in the 1940's-1970's dam building era, when emphasis was on resource development for hydroelectric power, irrigation, flood control and the provision of potable water supplies (Jaspers, 2003).

Today new and reformed basin organizations, such as the Mekong River Basin Commission, the Murray-Darling Basin Commission and the Delaware River Basin Commission have emerged, motivated by sustainable development imperatives. These 'new' entities often originated from former basin organizations or national water agencies and international water organizations, and the more proactive continually 'retool' their business towards a broader mandate of social and ecological sustainability (Hooper, 2006).

In many cases river basin organizations have been designed to bring help about integrated water resources management and improve water governance in trans-boundary water basins. All evidence suggests these organizations are becoming increasingly significant in every region of the world. Throughout history, internationally shared rivers were managed through treaties.

The International Network of Basin Organizations currently has 134 member organizations in 51 countries, not including the river basin organizations at the local and state levels. These fora enable governments that share rivers to come together to coordinate activities, share information, and develop integrated management approaches. For an overview of river basin organizations around the world see: www.trans-boundarywaters.orst.edu.

Institutional framework

A key issue for the River Basin Approach is how the management responsibilities for one river basin are divided between different administrative authorities. According to the Ramsar Handbook on River Basin Management (2007), it is important to realise that water resource planning and management is a multidisciplinary process and therefore has to be promoted as a collaborative framework among all the relevant agencies operating nationally, and those involved within the river basin itself as well as local communities.

The development of administrative units in water resource management has to coincide with river basin boundaries instead of political boundaries. It also requires the support of policy and economic instruments such as water pricing (e.g. 'user pays'). The lack, of efficient water legislation and policies is a potential bottleneck to successful river basin management.

Until recently there was little consultation with the public on river basin management issues in many countries. But a shift has been observed with a greater role being provided for various stakeholder groups. Experience shows that effective collaboration between agencies and active members of the general public increases the chances of success.

Decentralization of river basin management

Decentralization and increased stakeholder involvement are widely being promoted worldwide as ways to successful river basin management. Dinar *et al.* (2006) used an analytical framework for relating decentralization and stakeholder involvement to compare 83 river basins worldwide. The results suggest that water scarcity can be used to reform and unite stakeholders in the basin and can lead to better performance of river basin management cycle.

EU Legal Framework for River Basin Organizations

On a regional or continental level, the European

THE THREE BASIC STEPS OF THE RIVER BASIN APPROACH

STEP 1

Objectives for
fish migration
in the whole
river basin

Upstream:

- Identify target species;
- Identify and characterise the constraints to free migration;
- Identify and quantify the upstream habitats required for each species to achieve the required ecological status.

Downstream:

- Identify target species;
- Identify and characterise the constraints to free migration;
- Quantify the required survival rate of species migrating to marine waters.

Other ecological targets:

- Identify the minimum and maximum flows required by each life stage;
- Identify and quantify the suitable habitats within the river stretches that are connected;
- Estimate the connectivity improvements required to achieve Good Ecological Status.

STEP 2

Prioritise waters
within the river basin

Biologists, engineers, specialists on hydrology/water management and planning bodies should agree priority waters based on:

- Ecological need and technical potential;
- Opportunities to link with other projects;
- Production of a GIS-map and database providing quantitative estimates of habitats.

STEP 3

Priorities
of measures

For both upstream and downstream migration:

- Agree the criteria for planning (financial, ecological or other);
- Prioritize the candidate sites (high, medium or low);
- Assess resources and costs.

Union has adopted a *unified legal framework* and the development of a scientific and technological base according to the principles of sustainable development. This has culminated in the European Water Framework Directive (EC, 2000) which is an example of a good institutional framework for the River Basin Approach. The Directive has the following key aims:

- Expanding the scope of water protection to all

waters, surface waters and groundwater;

- Achieving 'good ecological status' for all waters by a set deadline;
- Water management based on river basin management;
- 'Combined approach' of emission limit values and quality standards;
- Getting the prices right;
- Getting citizens involved more closely;
- Streamlining legislation.

The need for a river basin approach (a holistic view with a focus on the ecosystem) is being recognized by scientists and policymakers worldwide, as the basis for sustainable water management. Consequently, the EU Water Framework Directive is regarded as an example of an institutional framework for good governance and policy-making on a regional or continental level.

The basic steps in the River Basin Approach, in practice, consist of setting strategic objectives (including target fish species and ecological targets), and prioritizing rivers and measures. Other examples of effective individual River Basin Management can be seen on the Murray-Darling River Commission Website www.mdba.gov.au and the Mekong River Commission Website www.mrcmekong.org.

3.2 BASIC STEPS

Under the River Basin Approach, fish species that are characteristic for the type of water body, together with their requirements for habitat and migration within the river system and constraints to improvement, should be determined. The important questions are how rivers must be prioritised for restoration of fish migration, and whether it is necessary to achieve full connectivity from sea to source in order to maintain or restore these species. Pragmatically it is often necessary to focus ambition on priority waters and to set targets for certain species or a group of species.

3.2.1 Strategic objectives

For each river within the river basin, objectives for fish migration should be defined. An objective might be, for example, to achieve free migration (up- and downstream) of target species from sea to source. Where this is not possible, for example due to over-riding imperatives of socio-economic factors, then for some rivers the objective might be simply to ensure no further degradation of fish migration potential (a 'no detriment' principle). A whole basin plan should seek to protect and enhance the migra-

tion potential for all of the fish species present. The objectives should complement and support the total ecological objectives for the river basin and they should therefore preferably be integrated with the local or regional plans of appropriate partner organisations.

Criteria for selection of target species include:

- That they have access to their full original distribution in the river basin;
- That there is a realistic chance for restoration of a sustainable population;
- That they have a high requirement for connectivity of habitats and habitat quality;
- That they are part of national or international policy;
- That they are of relevance for different stakeholders.

It is important that objectives are quantified, for example by defining the abundance and distribution of a species in a river system that is necessary for a sustainable population. Quantification is also relevant for habitat features such as the occurrence of freely flowing river stretches that are not modified by weirs.

It is likely that target species, those which are characteristic for the type of water body, will already be well known. Targets for fish migration will be an intrinsic part of overall targets for fisheries and fish stock management, and for natural and ecological targets, and should hopefully gain broad social acceptance.

Objectives must at least achieve 'no detriment' for fish passage and this should ensure no further decline in the species due to habitat fragmentation and blockage of migration routes.

Some rivers will be so modified as a result of urbanisation and industrialisation that full realisation of potential is currently economically unrealistic. However it should be a clear objective or aspiration to achieve much more through the restoration of fish migration routes wherever appropriate.

RIVERS

EXAMPLES OF RIVERS WORLDWIDE



- A** Rogue River (USA) © Kavita Heyn
- B** Mississippi River (USA) © National Park Service
- C** Ythan (Scotland) © Groene Zoden Fotografie
- D** Åtran (Sweden) © Groene Zoden Fotografie
- E** Ramganga River in Corbett National Park (India) © Gerald S. Cubitt / WWF-Canon
- F** River in the Altai Sayan Ecoregion (Russia) © Gernant Magnin
- G** Iguazu National Park. Iguazu Falls Atlantic Rainforest Paraná River (Brazil) © Michel Gunther / WWF-Canon
- H** São João River at the river mouth as it exits into the Atlantic Ocean at Cabo Frio and casimiro de Abreu (Brazil). © Edward Parker / WWF-Canon
- I** Fishermen returning after fishing on the Kafue River (Zambia) © Martin Harvey / WWF-Canon
- J** Stream Drakensberge (South Africa) © Marq Redeker
- K** Derwent River in Tasmania (Australia) © Marq Redeker
- L** Mueller River (New Zealand) © Marq Redeker





The restoration of upstream fish migration within most river basins will present a substantial challenge. In Europe for example, river basin plans were produced in 2009 by all EU member states, as required by the European Water Framework Directive (EC, 2000). These plans describe the future objective for the state of all river basins and their water bodies so that they may support healthy and sustainable stocks of the prescribed target species.

3.2.2 Prioritizing rivers

Once strategic objectives are established it is important to prioritise waters within the river basin for action. For example, most modified rivers in Europe contain many weirs, small dams, hydroelectric power stations and a range of other migratory obstructions that have been built over the past few centuries.

In some of the largest river systems the total number of obstacles can exceed 1,000, several of which may be complete obstructions to fish passage but many of which might only be partial barriers. A recent assessment in England and Wales (UK) identified an excess of 25,000 such obstructions.

It is not necessarily the case that all obstacles should be made passable for fish to achieve the relevant objectives and it might not be affordable. It may be important to prioritise rivers, for example by selecting 'natural waters' as priority waters, followed by the 'heavily modified waters' and then the 'artificial water bodies'. Each might be important for sustainable existence of some target species. Alternatively selection of waters can be on the basis of known achievable distribution of target species and by expert judgement.

For diadromous and potamodromous species migratory routes can be identified on the obvious basis of drainage direction of the rivers in the river basin. In opening migration routes it is important to secure passage progressively, working upstream for anadromous species, but it is

also important to maximise uptake of opportunities as and where they arise, working towards the strategic objective and vision.

Prioritisation should be undertaken by a multi-disciplinary team consisting of biologists, engineers, hydrologists and water managers, supplemented by planning specialists. It is important to recognise opportunities to enter partnerships with other projects (e.g. land use planning, water management, ecological restoration etc.) that might give rise to more cost-effective solutions. The outcome of prioritisation should preferably be a GIS (Geographic Information System) based action plan that clearly sets out the priority waters and the relevant migratory obstructions that they contain.

The approach should be similar for downstream migration with a comprehensive plan to resolve all potentially damaging barriers and intakes in a river system. The cumulative impact of barriers must also be considered in producing an action plan. In some rivers cumulative damage can be so great that it may be questionable whether populations of some fish can be sustained.

Even if fish passage and survival at some sites is as high as 95%, the cumulative impact of a succession of similar sites can be very damaging. It is again important to prioritise rivers and river reaches for action where improved protection will deliver the objectives. Examples of priority rivers and waters are:

- Those that are part of national or regional policy or agreed action plans, for instance in Germany (the region Nordrhein-Westfalen) rivers that are included within a migratory fish program are prioritised;
- Where important stocks of anadromous and catadromous fish exist, or where there is potential to restore them.

3.2.3 Prioritizing measures

Once priority waters have been confirmed potential solutions to the obstructions to migration

TIPS

- Identify partners and establish river basin committees to work with a shared vision;
- Prioritize waters within a river basin and work towards practical and achievable goals;
- Ensure that hydropower and dam removal planning and development take full account of fish stocks and fisheries and the economies that depend on them;
- Work with local people, including subsistence fishermen, community based organisations and recreational anglers. They are dedicated people!

can be identified. Full restoration of fish migration routes in river systems may be a very difficult and expensive goal, especially when a chain of many obstacles needs to be addressed. In most cases it is simply not possible to resolve all of these at once and for this reason a phased approach is often required. Prioritisation for action should be on the basis of criteria agreed at the outset.

It may be the case that more than one solution might be identified to resolve an obstruction. Depending on an assessment of individual costs and benefits and ecological outcome, it is preferable to select the most natural solution (see chapter 5). The final prioritisation plan must provide an indication of resources and finance that will be required within each phase of action.

The protection of downstream migrants can be more difficult than for upstream migrants. In most significant surface water abstractions, it is highly likely that construction of appropriate mechanical barriers would be required. Depending on the site these might be very large and expensive. In the UK passive wedge-wire screening is regarded as the best available technology, but it is not always appropriate to use when taking

into account the high costs compared to benefits. Fixed grids and gratings and, increasingly, behavioural screens are also used and generally the principle of Best Available Technology Not Entailing Excessive Cost (BAT/BATNEEC) is applied. In some circumstances it is claimed, and may be feasible, to use 'fish friendly' turbines or dam bypasses.

However, it is important to demonstrate beforehand that the required standards for fish survival rate can be attained. In some circumstances it may be considered economically unviable to use the best practice screen spacing required, or a screen may not be technically feasible. In these cases protection of fish should be achieved by other measures such as fish friendly management of the turbines (for example seasonal restrictions on abstraction), although this may not be as effective and compensation may still be required.

A full evaluation of potential technical solutions and their respective benefits for the fish species concerned is required. Technology to protect fish at water intakes is an area where further research is required to identify best practice. In this respect it would be helpful to develop robust pilot programmes, where damage is known to occur, to explore more acceptable solutions with the support of appropriate industrial sectors.

EXAMPLE

How to protect downstream migrating fish: a multiscale approach

Authors: D.S. Pavlov & V.N. Mikheev
Organisation: A.N. Severtsov Institute of Ecology & Evolution, Russian Academy of Sciences
Country: Russia



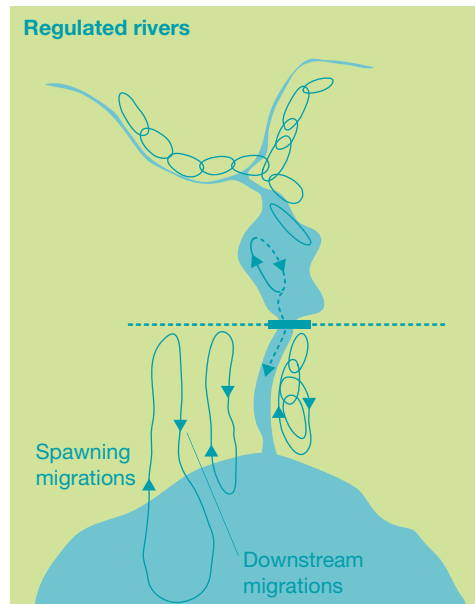
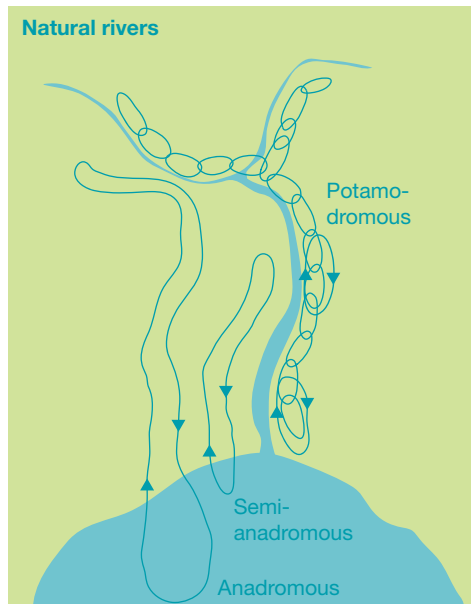
INTRODUCTION

Downstream migration is one of the most important phases of the migration cycle of both diadromous and potamodromous fish. Migration is strongly influenced by anthropogenic

impacts in both natural and regulated rivers. Various intake structures ranging from small pumps to huge turbines cause mass mortality of fish, especially juveniles. To minimize the risk of mortality and damage to migrating fish, local

MIGRATORY CYCLES

Schematic overview of migratory cycles of potamodromous and diadromous fishes.



operational management and structures in the vicinity of water intakes should be taken into account. This also applies on operating processes on a larger scale.

WHAT DID WE DO?

Experimental and field studies on fish behavior and ecology have been carried out by the Institute of Ecology & Evolution, in collaboration with other institutions in Russia. These have resulted in basic knowledge of fish migration cycles and behavior that determine interactions of migrating fish with water flow, biological and physical objects in the regulated rivers.

A multi-scale approach is suggested, based on fundamental knowledge of fish ecology and behavior and aimed at minimization of fish contacts with water abstraction systems. At different levels of a hierarchy: river basins, rivers and reservoirs, ecological zones within a water body, and hydraulically modified water bodies adjacent to water intakes all have to be considered. When fish enter a zone of critical velocity they can be protected either by diverting them from turbine intakes or by using fish friendly turbines. The ability of fish to escape critical velocities is related to swimming capacity and orientation skills which decrease with increased turbulence.

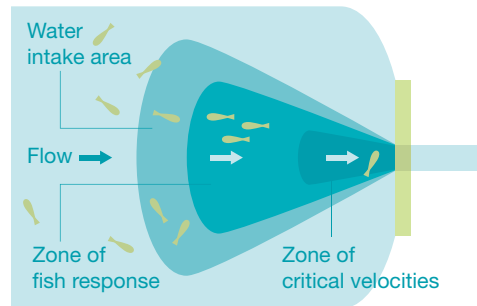
HOW DID IT WORK OUT?

Various structures preventing entrapment by power plant turbines and other water intakes were developed on the basis of fish behavior (Pavlov, 1989). Within the zone of behavioral response, fish behavior can be influenced in order to slow down their drift or divert the fish from the zone of critical velocity. Diurnal drift rhythms, changes in buoyancy and different reactions of fish to visual and mechanical structures are important in this respect. The structures built might help to influence spatial patterns of downstream migrations long before fish have approached a water intake.

Migration activity both in diadromous and potamodromous fish can be strongly influenced by

HYDRAULIC STRUCTURE

Hydraulic structure of the water intake area near the dam in water reservoirs.



food availability. A case study on pike-perch showed that shortage of prey fish caused intensive downstream migration from a reservoir. Increase in population density of small pelagic prey fish, *Clupeonella cultriventris*, substantially reduced downstream migration of pike-perch from one of the reservoirs on the River Don.

LESSONS LEARNED

Based on the work that has been described above we recommended the following approaches:

- Downstream migration of fish in regulated rivers can be influenced through ecological and behavioral impacts at different stages of the migration. These impacts modify fish behavior and distribution at different spatial and temporal scales. Fish rheoreaction, cohesiveness, and hormonal state together with habitat heterogeneity, hydraulic structure of the water flow, and trophic conditions are the major factors modifying downstream migration;
- Diadromous and potamodromous fish need different approaches for their protection during downstream migration in regulated rivers;
- Migration of short-distance potamodromous migrants can be prevented or slowed by ecological/behavioral measures including improvement of habitats, trophic situation, and conditions for orientation and locomotion.

Restoring fish migration in Flanders (Belgium)

Authors: Maarten Stevens, Ans Mouton, David Buysse, Tom van den Neucker & Johan Coeck

Organisation: Research Institute for Nature and Forest (INBO)

Country: Belgium



FISH MIGRATION, POLICY AND LEGISLATION

Flanders is one of the most urbanized regions of Europe. The main rivers in the catchment are typical rain-fed lowland rivers with low gradients and wide flat floodplains. The main cities are situated in the floodplains that are densely populated and cultivated for agriculture. Streams and rivers are used for navigation, irrigation, drinking water supply, and power generation, and most of them are hydrologically isolated from their former inundation areas by dikes.

This multifunctionality of the hydrological system poses threats to the ecological integrity of the river ecosystem. In particular, the destruction of habitat and the construction of migration barriers have a major impact on fish populations in rivers. Most fish species require different habitats for the main phases of their life cycle, e.g. spawning, nursery and feeding (Lucas & Baras, 2001).

Fish passage barriers block or delay fish migration and thus contribute to the decline and even the extinction of species that depend on longitudinal or lateral movements during certain phases of their life cycle (Cowx, 2002). The impact of an obstacle on fish depends on the type of barrier, river hydrology and species (Northcote, 1998).

The clear adverse effects of barriers on the health and sustainability of fish populations requires an integrated approach to tackle the problem of fish migration. Therefore several pieces of national and international legislation have been adopted to restore free fish migration in and between river catchments.

Restoration of fish migration is an explicit goal of the Benelux Decision on free fish migration (M (2009) 1), which states that the countries of the Benelux Economic Union should guarantee free fish migration in all hydrographic basins. This Decision also incorporates the goals set in associated European legislations (Water Framework Directive (WFD), Habitats Directive (HD) and eel regulation). The Benelux Decision on free fish migration has been implemented in Flemish legislation through the Integrated Water Management Decree.

PRIORITY NETWORK FOR FREE FISH MIGRATION

In order to meet the requirements of the Benelux Decision, each member state needs to draw up a map indicating the most important watercourses for fish migration. The network of watercourses where free fish migration has to be restored should include at least the watercourses that are important for fishes that are protected under

the EU Habitat Directive and eel. In addition, the Benelux Decision allows account to be taken of regionally important fishes. Therefore, the Flemish priority map also takes into account the distribution of rheophilic species for which a restoration program has been developed in Flanders, i.e. dace (*Leuciscus leuciscus*), chub (*Squalius cephalus*) and burbot (*Lota lota*).

The timing for the restoration of free fish migration in the new Benelux Decision has been made consistent with the timing of the Water Framework Directive (2015/2021/2027). The following sections explain, step by step, how the network of priority watercourses is constructed (Figure 1).

Step 1 - HD species

In the first step, rivers and streams were selected in which the HD species occur or which are part of special areas of conservation (SAC's) that were designated for the protection of the HD species.

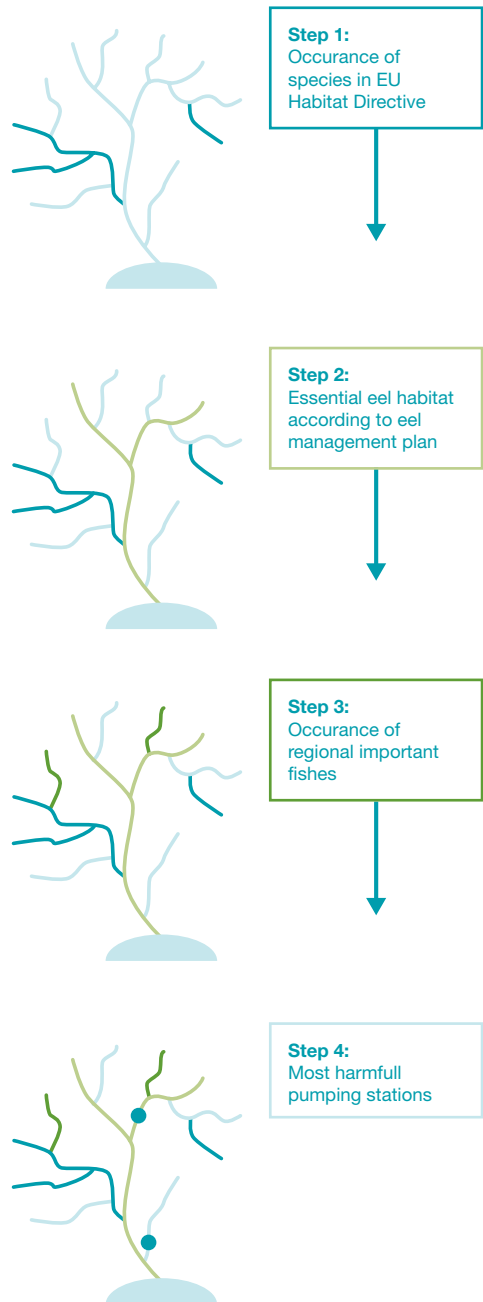
The list of protected HD species includes six fish species (bitterling, *Rhodeus sericeus amarus*; weatherfish, *Misgurnus fossilis*; spined loach, *Cobitis taenia*; bullhead, *Cottus gobio*; twaite shad, *Alosa fallax* and Atlantic salmon, *Salmo salar*) and two lamprey species (river lamprey, *Lampetra fluviatilis* and brook lamprey, *Lampetra planeri*). The distribution of bitterling was not taken into account because its conservation status in Flanders is already favorable and no measures for migration are required for the robust conservation of this species.

Step 2 - Eels

In the second step, the most important water courses of the Eel Management Plan were added. These include the major rivers in Flanders and the largest watercourses in the polder. The major rivers form the backbone of the migration network. They represent a large habitat area and allow eels to colonize inland waters. Special attention is paid to the major saltwater to freshwater transitions at the coast, where man-made

FIGURE 1

Procedure for the selection of watercourses in the Flemish network of free fish migration.



>>EXAMPLE

KLEINE NETE

Fish pass in the River Kleine Nete at the weir of Herentals (Belgium).



.....
barriers impede the access for eels from the sea to the inland rivers. Polder waters are important habitat for eel because:

- 1 They are close to the sea and therefore easily colonized by eels;
- 2 They are highly productive aquatic ecosystems;
- 3 They have a relatively high structural quality.

In order to enable the colonization of the polder waters by eel, the navigable and largest unnavigable waterways (first category) were added to the migration network.

Step 3 - Rheophilic species

Some rheophilic species have been locally ex-

tinct in rivers in Flanders. The main causes for their disappearance are usually the inaccessibility of typical spawning grounds and the deterioration of water and habitat quality. In recent years however, species restoration plans have been developed for chub, dace and burbot. In order to support these restoration efforts, rivers and streams were selected for the migration network based on catch data of the rheophilic species and the location of their reintroduction sites.

Step 4 - Pumping stations

Polders are frequently drained by pumping stations. Pumping stations and hydroturbines are the main sources of mortality during seaward migration of silver eels (Anonymous, 2009; Brujls & Durif, 2009). As part of the implementation of the Eel Management Plan, an inventory of all pumping stations in Flanders was made. Some of these pumping stations are located on watercourses outside the priority map for fish migration, although they still have a considerable impact on the amount of silver eels that can reach the sea. Therefore, a list of the most damaging pumping stations was added to the priority map. This only involves the individual pumping stations, not the watercourses on which they are located.

Extent of the prioritization map

The total length of the migration network in the prioritization map is 3,274 km or 15% of the total length of the hydrographic network in Flanders (Table 1). 679 obstacles have already been

.....
TABLE 1

Length (km) of the network of watercourses in the prioritization map for fish migration in Flanders.

Type of watercourse	Total hydrographic network (km)	Prioritization map Benelux Decree (km)	To be inventoried (km)
Navigable	1582	908	66
Unnavigable, cat 1	1285	878	171
Unnavigable, cat 2	6474	1369	599
Unnavigable, cat 3	6682	108	36
Unclassified	6302	11	5
Total	22325	3274	877

inventoried on the watercourses of the priority network, but 877 km watercourses still have to be inventoried for the first time.

PRIORITIZATION OF BARRIER REMOVAL

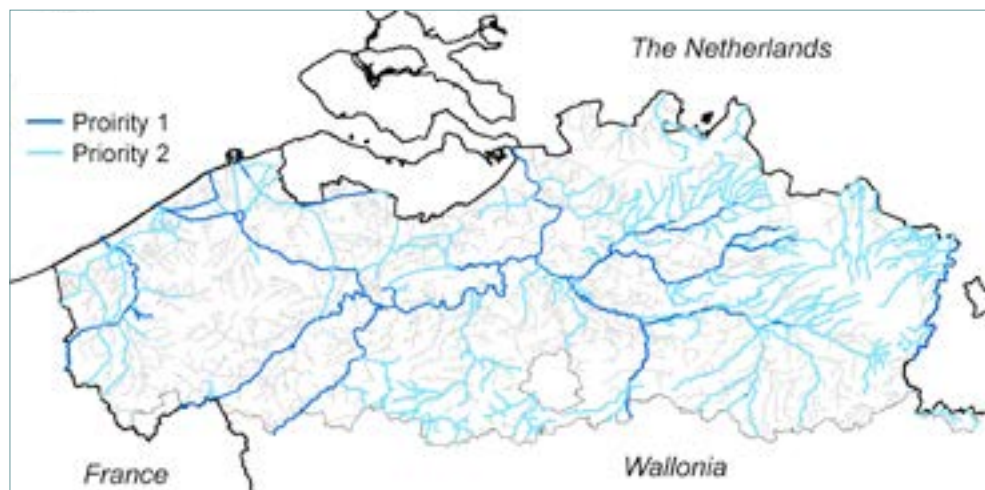
According to the Benelux Decision, a prioritization is given for the removal or mitigation of the obstacles on the watercourses that were selected in the fish migration network (Figure 2). A distinction is made between obstacles of the first and second priorities. The obstacles of first priority are those that are located on the main rivers of the river basin districts (River Scheldt and River Meuse).

The most ecologically important tributaries were

added to this category. All the obstacles on the remaining watercourses of the priority map have second priority. 90% of the obstacles of first priority should be eliminated by 2015, and the remaining 10% by 2021. The vast majority of the migration barriers of highest priority are located on the most important watercourses of the eel management plan (Step 2). These include the salt-freshwater transitions, the obstacles on the main rivers and the access to the polders waters. The obstacles of second priority are divided into three groups: 50% should be eliminated before 31 December 2015, 75% by 31 December 2021 and, by 31 December 2027, all of the remaining obstacles should be made passable to fish.

FIGURE 2

Prioritization network of watercourses in Flanders as determined under the Benelux Decision on free fish migration (M(2009)1).



Fish connectivity in the rivers of Catalonia

Authors: Marc Ordeix¹, Quim Pou-Rovira¹, Núria Sellarès¹, Antoni Munné² & Anna Casamitjana²

Organisation: Center for the Study of Mediterranean Rivers (CERM)¹ and Catalan Water Agency²

Country: Catalonia (Spain)



INTRODUCTION

The presence of 886 large obstacles, mostly weirs and dams, has seriously affected migratory fish species in Catalan rivers, including the European eel, shad, sturgeon (now locally extinct) and sea lamprey populations. Other non-diadromous fish, some of them endemic to the Iberian peninsula, have had their migration routes damaged and are consequently now endangered. Between 2006 and 2010, river connectivity and fish pass facilities had been evaluated in order to generate information to improve the design, construction, management and assessment of fish passes in Catalan rivers according to international best practices (Marmulla & Welcomme, 2002; Armstrong *et al.*, 2004). This has been done under an agreement between the Catalan Water Agency and the CERM.

WHAT DID WE DO?

The evaluation was carried out in two phases:

- 1 During 2006, a preliminary evaluation of fish pass facilities in Catalonia was carried out through direct inspection of 78 fishways. In 2010, this was updated after visits to 16 new fish passes built between 2006 and 2010. A database of the 94 obstacles and their associated fishways was compiled and the ICF index, which evaluates the degree of impediment for fish passage (Solà *et al.*, 2011),

was calculated;

- 2 During the period 2006 to 2010, an analysis of the effectiveness of 9 representative fish passes was carried out, for a range of different types of river stretches, fish species and fish passes. These were located in weirs associated with hydropower plants (5) and gauging stations (4) (Ordeix *et al.*, 2011a; Ordeix *et al.*, 2011b).

Several methodologies were used to check effectiveness, and this was complemented by collection of environmental data:

- a Direct estimation techniques involved the installation of fish traps upstream of the facility, at the exit of the fish pass, and visual counts;
- b Indirect estimation techniques using electric fishing or trapping systems, group mark-recapture methods (injecting an acrylic paint in the caudal fin of the fish) and individual mark-recapture methods (inserting Passive Induction Transmitters, PIT tags, in the peritoneal cavity of fishes). These were used to compare fish population structure on each side of the obstacle in river sections with equivalent hydrology and habitat characteristics.

HOW DID IT WORK OUT?

Sixteen fish passes (17%) were classified as res-

toration solutions (partial weir removals) while only seven obstacles (7%) were close-to-nature fish passes (ramps). Forty six (49%) were rehabilitation solutions that basically used pool and vertical slot fishways. Ten (11%) solutions used deflectors and baffle fish passes. Only six (6%) smooth ramps and two fish lifts (2%) were observed (Ordeix *et al.*, 2011b).

Using the ICF index, twenty of the obstacles (21%) were classified as 'very good quality' and sixteen (17%) as having 'good' connectivity, being partial barriers, small scale structures, or close-to-nature fish facilities. Sixteen of the obstacles (17%) were considered in the 'moderate' quality class, fourteen (15%), 'poor' and twenty eight (30%), 'bad' (Figure 1).

The *in situ* assessment of 9 fish passes agreed with the results of the ICF index with only small differences observed.

LESSONS LEARNED

The results have shown that:

- 1 Ecological connectivity for fish in Catalan

rivers is generally bad. There are fishways in 11% of the obstacles but often they do not adequately address the requirements of native fish species;

- 2 Most of the fish passes are poorly maintained;
- 3 Fish passage crossing rates are, with few exceptions, too low and in a lot of cases only the upstream movements of larger fish, often predominantly female cyprinids, are facilitated;
- 4 Due to the high variability in jumping and swimming capabilities of native fish species, and the great diversity of river types in our river basins, it is essential in all cases to carefully assess each new passage solution that is implemented, at least during the spawning periods of native fish species;
- 5 Although the results of implementing the ICF index and *in situ* assessments at the 9 fish passes are consistent, it is necessary to apply the methods to more fish passes to validate them. If necessary, both methodologies and the different types of solutions to improve fish migration and native species conservation should be improved.

FIGURE 1

Fishways and categories of fish connectivity in the rivers of Catalonia (NE Iberian Peninsula) in 2010 (Ordeix *et al.*, 2011a).



EXAMPLE

Free migration for fish! Communal approach for restoration of the continuum of the Rivers Rhine and Meuse

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and E.H.H.R. Lammens²
Organisation: TAUW consult¹ and Ministry of
Infrastructure and the Environment²
Country: The Netherlands



INTRODUCTION

The Atlantic salmon (*Salmo salar*) has a special and complex life cycle in which the species migrates between freshwater and saltwater stages and lives in a variety of habitats. The River Rhine basin was, approximately 100 years ago, one of the largest salmon producing rivers in Western Europe. The salmon's habitat extended from the mouth of the Rhine to its upper reaches below Schaffhausen, Switzerland, and into several tributaries including the Aare, Moezel, Main, Neckar, Ruhr and Sieg (De Groot, 1986). The salmon also inhabited the River Meuse basin

up to Monthermé, near the mouth of the River Semoy in France, and spawned in most of the Meuse's tributaries.

The Rivers Rhine and Meuse have changed radically in the last century as a consequence of river modifications e.g. the building of dams and closure works in estuaries, cutting of meanders, dredging of shallow sections and excavation of gravel beds, the construction of hydroelectric power stations and a decline in water quality. In addition the commercial fishing of salmon contributed to the decline of the population. All

FIGURE 1

Cross section of the V-shaped weir with vertical slot in de Rhine fishways ($Q=4 \text{ m}^3/\text{s}$, h (head difference) =16 cm).

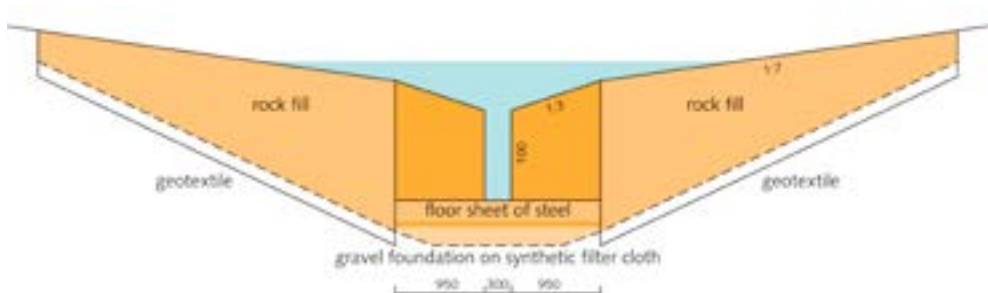
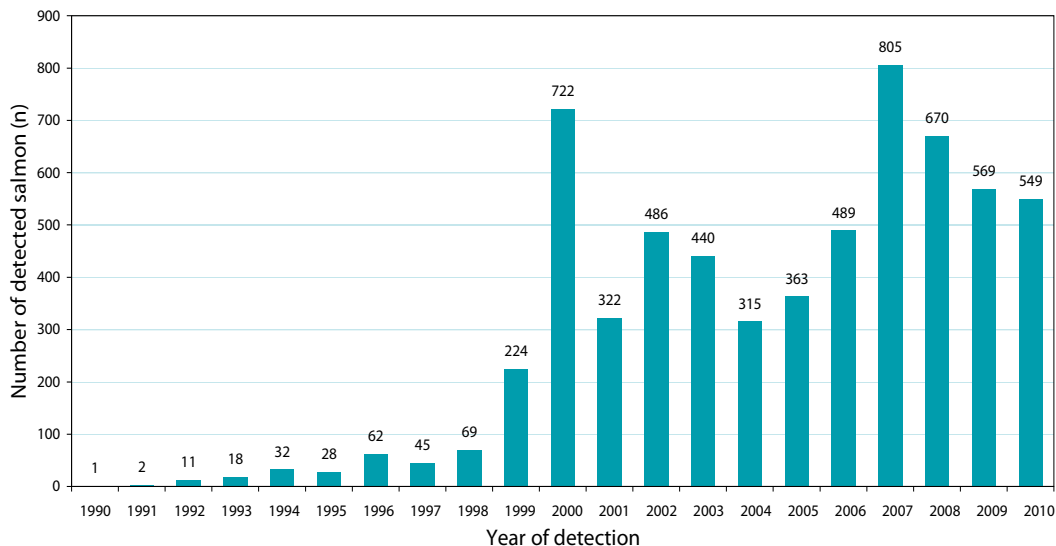


FIGURE 2

Salmon (N = 6.222) counted in the Rhine since 1990. The control stations in Iffezheim and Gamsbheim are operational since, respectively 2000 and 2006 (Graph prepared by Daniel Fey, LANUV NRW).



these factors led to the extinction of large migratory fish such as the Atlantic salmon but also houting (*Coregonus oxyrinhus*), the Atlantic sturgeon (*Acipenser sturio*), twaite shad (*Alosa fallax*) and allis shad (*Alosa alosa*). These issues must all be addressed if the recovery of the large migratory fish populations is to occur.

WHAT WAS DONE?

In 1950 the International Commission for the Protection of the Rhine (ICPR) was set up and the Rhine Action Programme was started shortly after the Sandoz disaster in 1986. The following objective was set for 2000: “to bring back the Rhine ecosystem into a condition in which formerly indigenous, higher species (including the indicator species, the salmon) can again establish themselves in the great European river the Rhine”. Shortly after this the International Meuse Commission (IMC, with similar objectives) was also set up and in the mid 1980’s the first steps towards the reintroduction of salmon into the

Meuse were taken.

The recovery plan for the Rhine has four objectives:

- Inventory and restoration of spawning areas and nursery grounds;
- Identifying and removing obstacles to fish migration;
- Releasing salmon, combined with marking where appropriate;
- Construction of monitoring (catch) stations.

The results of the Rhine Action Plan were a stimulus to start the 'Salmon 2020' programme as part of the Master Plan 'Migratory Fish Rhine'. The target is to enable salmon to reach Basel and to spawn in the upper reaches of the Rhine in Germany and France before 2020. Other migratory fish such as sea trout, allis shad and European eel will also benefit from the measures. Upstream of the waterfall of Schaffhausen at Lake Constance, in the Alpine Rhine and its tributaries, lake trout is the target species.

>>EXAMPLE

Measures for reintroduction and restoration of migratory fish in the Belgium Ardennes and the German Eifel in Nordrhein-Westfalen are important for the River Meuse. A 'Master Plan Migratory Fish Meuse' has been produced, in which salmon and eel are the target species. The Master Plan combines all initiatives of each party in the IMC to work towards sustainable populations of diadromous fish species. The Rivers Ourthe and Ruhr are located closest to the sea and have the best potential for recovery of a salmon population in the Meuse River basin.

The highest priority measures for achievement of a stable salmon population in the Rivers Rhine and Meuse are the restoration of migration routes (up- and downstream), reduction in fishery mortality and improvement of the quality and quantity of spawning and nursery areas. The Rhine and Meuse master plans include time-scales and costs for delivery and are integrated within the Water Framework Directive River Basin Plans for the international districts Rhine and Meuse. Most measures are carried out as part of national plans.

HOW DID IT WORK OUT?

Migratory fish can enter the River Rhine via the Nieuwe Waterweg. The most important route for onward migration in the Rhine system is the Waal as it has no weirs and provides the largest attraction flow (Bij de Vaate & Breukelaar, 2001; Breukelaar *et al.*, 2009). The discharge of the Waal is two-thirds that of the total Rhine discharge. In comparison, the discharge of the IJssel is one-ninth of the Rhine. In addition, the sluices of the dam in Lake IJsselmeer are a difficult barrier for upstream migration. Since 2005 upstream migration has been possible at all three dams in the River Nederrijn/Lek.

The most important route to enter the Meuse system is the Haringvliet; however, the Haringvlietdam is still a significant barrier for upstream migration (figure 3). The potential for fish-friendly management of the sluices is now being explored. Since 2008 the dams in the River Meuse

and the downstream area of the River Ruhr to Eifel-Ruhr and the River Geul to Belgium have fishways. All fishways in the Dutch part of the Rhine and Meuse have a special combination of V-shaped weirs with a vertical slot in the center (figure 1) (Dorst & Kok, 2005).

LESSONS LEARNED

In the past 10 years the number of fish species has increased in the Rhine basin and this indicates a recovery of riverine species. With the improving water quality and connectivity, the availability of suitable habitat now appears to be an important bottleneck (Aarts *et al.*, 2004). Other important bottlenecks are the fishery and hydro-electric power stations (ICPR, 2011; IMC, 2011).

Since the start of the Rhine Action Programme approximately 6,222 salmon have been counted on their way to the spawning areas in the period 1992-2010 (figure 2). Major spawning areas are situated in the Rivers Wupper and Dühnn, Sieg, Ahr, Saynbach, Bruche (Illsystem) and Wisper. There is a correlation between the improved scope for fish migration and the level of natural recruitment (ICPR, 2009). The numbers of returning fish are however, currently too low for a sustainable population. Since 2008 salmon have also returned to the River Meuse at the fishway in Lixhe and in the Ruhr at Roermond.

FIGURE 3

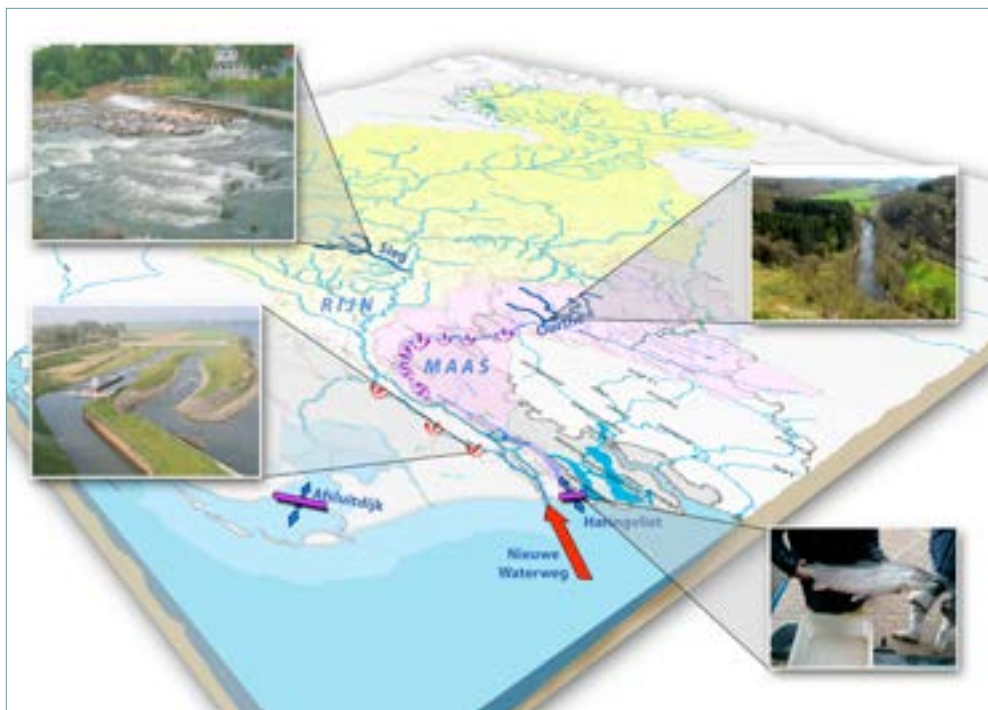
Map of the river basin of the Rivers Rhine and Meuse and the position of weirs and sluices in The Netherlands. (© J. de Putter).

Top right: The River Ourthe has good potential for the restoration of a salmon population in the Meuse River basin. (© Martin Kroes)

Top left: Fishway in the River Sieg near Buisdorf contains a control station for counting salmon. (© Gerard de Laak)

Below right: A salmon caught near the Haringvlietsluices is implanted with a transponder. (© Gerard de Laak)

Below left: Fish passage in the River Lek, near Hagestein. All three weirs in the Lek/Nederrijn have fish passes. (© Tom Buijse)



How new hydropower schemes should be managed

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Organisation: Angling Trust
Country: United Kingdom



INTRODUCTION

Run-of-river hydropower in England and Wales had mostly become redundant by the middle of the 20th century due to the national electricity grid and cheap electricity. However, in recent years there has been resurgence in interest in the development of new schemes, driven by Government targets for renewable energy, subsidies and grants, and the guarantee for 20 years of a premium price for 'green' electricity. The regulation of hydropower in England and Wales is by the Environment Agency (EA) in the form of licences to impound rivers, licences to abstract, and consent for works in and near rivers to ensure that there is no increased risk of flooding.

WHAT HAS BEEN DONE?

The EA has recently produced an opportunity mapping study which identifies over 26,000 existing obstructions that could be suitable for hydropower. However, the paucity of this resource is evident when considering that development of all of those to their maximum potential would only produce 1% of the current electricity demand. A more realistic estimate would be less than 0.5%, and a recent report for the UK Government was even less optimistic.

The EA has also produced a 'Good Practice Guide' in conjunction with the British Hydropower Association, which provides a 'tick-box' approach to assessing the possible issues sur-

rounding each hydropower application. However fishery and angling organisations and representative bodies consider it to be inadequate to protect fish populations, and the guide is now being re-considered.

HOW IS THIS WORKING OUT?

Where water is diverted through a turbine, there is obviously a stretch of river depleted of flow, which may be just a few metres or up to several kilometres in length. Traditional hydropower practice is to allow a minimal residual flow and then take all the remaining water, up to the mean flow or more, for electricity generation. This is easiest to engineer and maximises the economic return of each scheme.

This is no longer timescale considered to be good practice, as such a regime fails to protect natural variability of flows, and has been shown to reduce the biomass of fish and alter the structure of fish populations. Migrating fish are generally attracted to the greater flow from the turbine channel which, if it has no fish passage facility, will result in delay or prevention of migration. Even where a turbine is situated on, or next to, the impoundment, the reduction of flow over the weir may prevent fish passing directly over it or attract fish away from a fish pass, as well as affecting the ecology and morphology of the weir pool.

Downstream migration issues include those as-

sociated with passage through a turbine, and include immediate and delayed mortality, adequate levels of screening, inability of fish to locate and use a safe passage route, and increased predation.

LESSONS LEARNED

It is the contention of angling representative bodies that a Government-driven initiative of this potential scale of development should have required a Strategic Environmental Assessment (SEA-Directive 2001/42/EC). This would ensure that potential environmental consequences of the strategy were identified and assessed during planning. This should have included assessments of river continuity, rather than the current generic approach, and the compatibility of the strategy with the EU Water Framework Directive (WFD). A SEA should also identify catchments where new schemes should not be developed for eco-

logical reasons, clearly assess the maximum number of schemes that might be allowed on a river system before unacceptable environmental impact occurs, and identify existing redundant impoundments which should be removed to deliver WFD obligations. It is still not too late to undertake this task.

If hydropower in the UK is to continue in its current haphazard manner, more robust guidelines and policy must address best practice, take account of current and new research, and consider actual and potential cumulative impacts.

Hydropower installations often have a lifespan in excess of 50 years. Therefore it is essential not only that they do not impact excessively on fisheries and ecology, but also that they do not compromise future WFD programmes. Only then could they be considered 'green' and sustainable.

RIVER SKAWA (POLAND)

Hydropower plant in the River Skawa (Poland) which was installed in 2006.



SPECIES EXAMPLE

The current status of New Zealand longfin eel (*Anguilla dieffenbachii*)

Author: Don Jellyman
Organisation: NIWA
Country: New Zealand



INTRODUCTION

Biology and distribution

The longfin eel, *Anguilla dieffenbachii*, is endemic to New Zealand. It is the most commonly encountered native freshwater fish being found from estuaries to headwaters of rivers, although it has a preference for stony and flowing water habitats. It is generally slow growing, typically 2-3 cm/year, but females can achieve a very large size, sometimes > 15 kg and 1.5 m long.

EEL SMOKERY

Female shortfin (Anguilla australis) migratory eels, another eel species in New Zealand, being air-dried prior to smoking at Lake Forsyth (Waikarewa). This is a traditional fishing site for Maori, who only harvest the silver eels.



The mean age at migration is usually 30-40 years, but can be more than 90 years in extreme cases (Jellyman, 1995). While the freshwater life cycle is reasonably well understood, the marine life history is poorly known as no larvae (leptocephali) have been recorded to date. Ascension locations of pop-up tags indicate a likely spawning area in the South Fiji Basin (Jellyman and Tsukamoto, 2010), a result consistent with results from larval drift modeling studies (Jellyman and Bowen, 2009). Fishing for glass eels is not allowed, but there are important customary (Maori) and commercial fisheries. Although there are no long term databases of recruitment, there is concern for the level of recruitment of longfins (Jellyman, 2009).

Human impacts

Research has emphasized the longevity and vulnerability of the species to overfishing and highlighted the need for protected areas (Hoyle & Jellyman, 2002; Graynoth *et al.*, 2008). The commercial fishery is managed through a quota system, and there have been recent reductions in longfin quota in recognition that the species is vulnerable to over-exploitation. Historically, many hydro dams have not had passage facilities for upstream moving juveniles (December - February) or downstream moving silver eels (April-June), although steps are underway to rectify this.

LONGFIN EEL



There are no commercial fisheries for silver eels. Any longfin eel > 4 kg must be returned unharmed to the water, a law designed to protect potential migratory eels. Unfortunately, by itself this regulation is relatively ineffective as it can take eels 20-30 years to achieve this size, and the likelihood of avoiding capture for this period is low. Recent management has focused on increasing the extent of areas where commercial fishing is not allowed.

KEY DRIVERS

Longfins are New Zealand's largest freshwater fish - they frequently comprise > 90% of fish biomass in streams (Hicks and McCaughan, 1997). They are important apex predators and their removal leads to an increase of prey spe-

cies (Burnet, 1968). Present commercial harvest levels are approximately 150 ton per annum, and CPUE (catch-per-unit-effort) appears to be relatively stable in most regions over recent years. However, there are ongoing concerns about the well-being of stocks as present recruitment is significantly less than historic levels. In recognition of these criteria and the vulnerability of the species to over-exploitation, longfins are listed as 'declining' (Allibone *et al.*, 2009), the lowest threatened species classification.

FUTURE DIRECTIONS

Future management will focus on improved access for juveniles and adults alike. Should there be reductions in key fishery indicators like recruitment indices and CPUE, then consideration would be given to reductions in quota and possibly extending reserve areas. Although the Japanese eel has been spawned and reared in captivity (Tanaka *et al.*, 2001), production of hatchery-raised juveniles (glass eels) of *Anguilla* spp. in significant quantities is still many years away.



CHAPTER 4 POLICY AND LEGISLATION



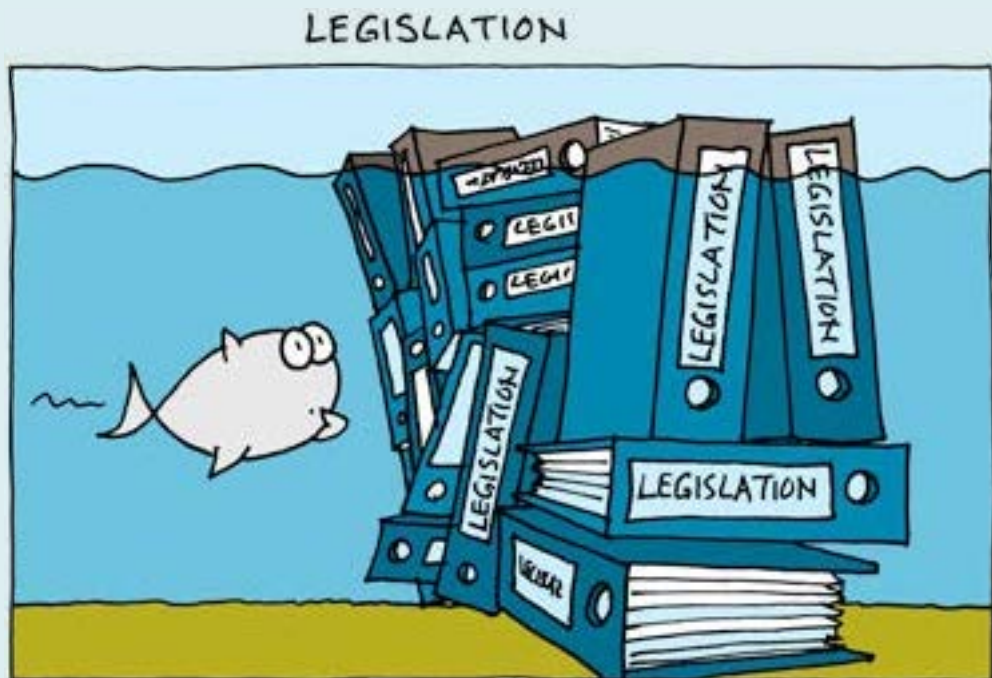
INTRO

Effective legislation and policy are essential in order to protect fish species and their natural habitats. In some countries legislation for the protection of riverine fisheries has been in place for many years. For example in 1889, the US Congress enacted the first federal law intended to ensure the safe passage of salmon upstream. In Germany the building of fish passes was incorporated in a former version of the Prussian Fishery Law of 1874 whilst in the UK legislation requiring the removal of obstructions to migrating fish was enacted as early as the 16th century!

In Brazil fish migration policies go back as early as 1927 when a São Paulo State Law mandated the installation of fish ladders on dams. Such regulations addressed many

local problems; however the number of obstacles that remain in these countries and throughout the world demonstrate the need for ongoing refined legislation and policy. We believe that a comprehensive river basin approach for fish migration demands collective policy on an international and national level. In this chapter we describe the most relevant policies relating to fish migration for each continent. We present an overview of the main global policies and then, for each continent, we highlight specific fish migration policies.

Finally, for each continent we give one or two examples of countries that are at the forefront of fish migration measures and River Basin Management.



4.1 GLOBAL POLICIES

There are several major global and UN policies of relevance to fish migration.

IUCN (the International Union for Conservation of Nature) Red list (concerning preservation of endangered species, 2009). The IUCN, founded in 1948, was the world's first global conservation network. It is government-funded and has an official observer status at the United Nations General Assembly. It sets definitive international standards for species extinction risk and recently a number of diadromous fish species, such as the European eel, have been added to the Red List.

This has resulted in Action Plans produced by European River Basin Committees to ensure free migration, recruitment and the improvement of stocks. For more information see: www.iucn-redlist.org

The Bonn Convention (The Convention on Conservation of Migratory Species of Wild Animals) which was signed in 1979 and came into force in 1983, is a global Convention with over 110 contracting member states. The Convention concerns the protection of migrating wild animal species, defined in appendices I and II. Section 2 of the treaty recognises the importance of migrating fish species and requires appropriate measures to be taken to ensure the preservation of migrating species.

UNCLOS III (the United Nations Convention on the Law of the Sea), which replaced earlier such treaties, concerns the management of straddling and highly migratory fish stocks, and came into force in 1994. The Convention defines the rights and responsibilities of nations in their use of the world's oceans and establishes guidelines for the management of marine natural resources. To date 162 countries and the European Union have ratified the UNCLOS Treaty.

OSPAR (The Convention for the Protection of the Marine Environment of the North East Atlantic).

The convention sets a framework for contracting parties to devise (Annex V) and implement (Article 2) necessary measures to conserve ecosystems and biological diversity and where possible to restore those that might already be damaged.

The Rio Convention (The Convention on Biological Diversity, UN, 1992) arose from the Earth Summit held in Rio de Janeiro in 1992. This Convention concerns the conservation of all species and ecosystems and is intended to protect biodiversity.

Many countries have ratified the Convention, and consequently have developed substantive Biodiversity Action Plans (BAPs). A BAP is an internationally recognized program addressing threatened species and habitats and is designed to protect and restore biological systems.

The Millennium Development Goals (one of which seeks to ensure environmental sustainability) are goals to which all 193 United Nation member states and at least 23 international organisations have agreed to achieve by 2015. The Food and Agriculture Organization of the United Nations (FAO) is working with the international community for achievement of the goals signed by world leaders in September 2000 (FAO, 2000).

Ramsar Convention (The Convention on Wetlands of International Importance 1971) is an intergovernmental treaty signed in Ramsar, Iran, in 1971. The Convention sets a framework that requires member countries to maintain the ecological character of their Wetlands of International Importance and to achieve sustainable development of wetlands throughout the world.

Wetlands achieving certain criteria are included in the List of Wetlands of International Importance. This is of direct relevance to fish migration through the resulting handbooks on Wetland Policy (Ramsar Convention Secretariat, 2006), River Basin Management (2007) and International Cooperation (2007).

THE FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO) AND FISH MIGRATION ISSUES

Gerd Marmulla

FAO provides technical and policy advice to address *inter alia* the main threats on fisheries such as over exploitation of fishery resources and loss of biological diversity. FAO carries out significant work linking food security, livelihood issues and sustainable use of natural resources. Consequently river connectivity and the free migration of diadromous fish are high on the agenda of the Fisheries and Aquaculture Department of FAO. Through its *Marine and Inland Fisheries Service, the Fisheries and Aquaculture Department* is reviewing the inland water restoration activities on a world-wide scale to give advice to Member States through the appropriate instruments and bodies. The overall objective of the programme is to contribute, through improved management, to the sustainability of fisheries in inland waters for food as well as to deliver social and economic benefit in the member countries.

FAO promotes the work of Regional Fishery Bodies (RFB) - a group of States or organizations that are parties to an international fishery arrangement - to work together towards the conservation and sustainable management of fish stocks. The RFB can play a critical role in promoting long-term sustainable fisheries where international cooperation is required regarding conservation and fish migration issues. The European Inland Fisheries and Aquaculture Advisory Commission (EIFAAC) is such a body, dealing with fisheries and aquaculture in inland waters in Europe. EIFAAC provides advice on fish passage issues.

FAO/EIFAAC Fish Passage Working Group

Working visit at the Vistula River (Poland).



4.2. NORTH AMERICA

The countries of North America - Canada, the USA and Mexico - have important trans-boundary river basins, and the successful management of natural resources and water resources has been of major importance. Congenial relationships across political boundaries are essential and this has been achieved by the USA and Canada through an International Joint Commission and important bi-national agreements including the Great Lakes Water Quality Agreement and the Boundary Waters Treaty of 1909.

To the south similar initiatives, including the Integrated Border Environmental Programme have been ongoing to address water resource management issues. The importance with which these issues have been addressed are an example of the critical need to address and resolve trans-boundary matters relating to cross-border rivers and their management.

USA

On a national level there are two federal agencies in the USA that deal with fish migration issues:

- The U.S. Fish and Wildlife Service (FWS), division of fisheries and habitat conservation (FHC), is responsible for conserving, protecting, and enhancing fish and wildlife and their habitat. It implements Habitat Conservation Plans (HCP) for specific species;
- National Oceanic and Atmospheric Administration - Fisheries (NOAA Fisheries, formerly National Marine Fisheries Service or NMFS), is responsible for the stewardship of the nation's living marine resources and their habitat.

Endangered Species Act, 1973

The most important policy regarding fish migration in the USA is the Endangered Species Act of 1973 (ESA, 1973). It provides for the conservation of species that are endangered or threatened throughout all, or a significant portion of, their range and conservation of the ecosystems on which they depend. The ESA, which has been amended several times, is administered by the two federal agencies (FWS and NOAA).

A good example of the positive effect of the ESA in practice is the reoccupation in 2009 of historic habitat for endangered river fishes in the Colorado and Yampa Rivers. NOAA has produced conservation programs under the Endangered Species Act in relation to anadromous fish such as Atlantic salmon (*Salmo salar*), Chinook salmon (*Oncorhynchus tshawytscha*) and Atlantic sturgeon (*Acipenser oxyrinchus*).

Anadromous Fish Conservation Act

The Anadromous Fish Conservation Act (1965, but regularly amended and extended) authorizes the US Government Secretaries of Commerce and the Interior to enter into cooperative agreements with states to protect the nation's anadromous and Great Lakes fishery resources. Implementation occurs through the NOAA within the Department of Commerce, and through the FWS within the U.S. Department of the Interior.

The intent is to conserve, and improve a range of fisheries including anadromous fisheries which the USA agreed to conserve through international agreements. Under these agreements the US Government carries out activities such as biological research, construction of fishways and fish protection devices, to facilitate free migration of fish resources.

FWS Salmon of the West program

This implements more than 30 on-the-ground habitat restoration programs protecting and conserving aquatic, estuarine, wetland and associated terrestrial habitats, through measures including in-stream flow conservation, fish passage improvement and fish screening programs for important river systems such as the Columbia, Snake, Yakima, Sacramento, Trinity, and others.

FWS National Fish Passage Program (NFPP)

An estimated 2.5 million barriers still exist in the USA, many of which no longer serve their original purpose and were abandoned years ago. Launched by the FWS in 1999, the NFPP is a voluntary, non-regulatory initiative that provides

BARRIERS

EXAMPLES OF FISH MIGRATION BARRIERS WORLDWIDE



- A** Savage Rapids Dam on the Rogue River, Oregon (USA). This was the first dam the fish strike from the sea and is located 172 km upstream of the ocean. This dam has been removed in 2009 and 640 km of upstream river is attainable for fish again since then. © Jamie Pittock / WWF-Canon
- B** Weir Somerset (UK). This weir in the Somerset region is an obstacle for coarse fish and eel. A special facility has been constructed for eel.
- C** Cal Rosal weir in the Llobregat River (Spain) © Marc Ordeix
- D** Pumping station Stroink is one of the biggest pumping stations in The Netherlands © Groene Zoden Fotografie
- E** The Tehri dam on the Ganges River, in the state of Uttarakhand, India. The dam became operational in 2005, and is the 5th largest in the world. © Joerg Hartmann / WWF-Germany
- F** Construction the Three Gorges dam on the Yangtze River. The Three Gorges Dam on the Yangtze is the largest hydroelectric dam in the world. The controversial dam stretches 2 km across the Yangtze River, creating a reservoir more than 600 km long (Hubei Province, China) © Michel Gunther / WWF-Canon
- G** The Serra da Mesa dam near Minacu (Brazil) © Edward Parker / WWF-Canon
- H** Agricultural dam on the Qued Sebou River (Morocco) © Michel Gunther / WWF-Canon
- I** The Neelam Sanjeeva Reddy Sagar (Srisaillam) Hydro Electric Project, which lies across the Krishna River 200 km south of Hyderabad (Andhra Pradesh, India). © Brian Thomson / WWF-Canon
- J** Pumping station in the lowland region of New Zealand © Jacques Boubee



financial and technical assistance to remove or bypass these artificial barriers that impede the movement of fish and contribute to their further decline. Since 1999 the NFPP has brought about the removal or bypass of more than 749 barriers across the country, work that has supported nearly 15,000 jobs in local communities. It has re-opened 11,249 miles of river, and 80,556 acres for fish access and reproduction (www.fws.gov).

National Fish Habitat Action Plan (NFHAP)

The aim of the NFHAP (Association of Fish and Wildlife Agencies, 2006) is to protect, restore and enhance the nation's fish and aquatic communities through partnerships that foster fish habitat conservation. NFHAP is a national investment strategy to maximize the impact of conservation dollars on the ground.

Under NFHAP, Federal, State, Tribal, and privately-raised funds are leveraged through regional partnerships to address the nation's biggest fish habitat challenges. Under the NFHAP the condition of all fish habitats in the U.S. has been assessed and a *Status of Fish Habitats in the U.S.* report will be released in 2012. Furthermore over 12 Fish Habitat Partnerships in priority areas have been established and projects to protect, restore, and enhance priority habitats are funded.

Canada

Fisheries Act, 1985

The Fisheries Act is the most important piece of legislation for fish migration management. The fish habitat provisions of this Act enable the federal government to protect marine and freshwater habitats that support certain species by fish migration measures. Under the Act, the policy for the Management of Fish Habitat (Canada, 1986) provides strategies that together support the concepts of sustainable development and the ecosystem approach. Several sections, some introduced as early as 1868, refer to obstructions and the need to maintain free migration for diadromous fish.

Species at Risk Act, 2004

The Species at Risk Act was created to prevent Canadian native species from becoming threatened or extinct. It also provides for the recovery and effective management of these wildlife species of special concern.

Canadian and US Lakewide Management Plans

The US and Canadian governments jointly implement the Remedial Action Plans, or Lakewide Management Plans (International Joint Commission USA and Canada, 1987), which included ecological indicators of birds and fish. The plans also mapped out the key measures for restoring the ecosystem of the Great Lakes Region including fish migration in rivers.

4.3 SOUTH AMERICA

In South America there is no single sub-continental policy regarding river basin management and fish migration. However on the national level, some countries including Brazil have put in place significant fish migration policies. Most of the available information on fish migration in South America is of a taxonomic and systematic nature. A recent report on fish and aquatic habitat conservation in South America (Barletta *et al.*, 2010), highlighted a lack of appropriate information about ecology, biology and taxonomy (especially in the remote Amazon basins) for each biome and river basin within the continent.

Brazil

The first fish migration policies in Brazil date back to 1927. In that year, the São Paulo State Law Number 2250 (dated December 28) mandated the installation of fish ladders on dams. This law was so controversial at the time that a specialist from the US (J. H. Brunson) was consulted to analyse the need for fish ladders. In 1934 a new federal law was introduced (Decree number 24,643; July 1934; Article 143, named the Water Code), which stated that all dams producing electricity should have mechanisms to allow the preservation and movement of fish. In 1938 another new law (Decree Law number 794; October 19, 1938; Article 68) stated that dams must

THE SITUATION AFTER WEIR REMOVAL ON THE ISLAND FYN (DENMARK)

On this island all weirs are removed for free migration of fish.



have mechanisms that allow the preservation of ichthyofauna, either by the construction of fish ladders or by construction of fish hatcheries. In 1967, Decree Law 221 (28/02/67) delegated to SUDEPE (Federal Agency for the Development of Fisheries) the task of determining the best mechanism for the protection of the aquatic fauna. This agency, whose main purpose was fish culture development made it mandatory to have a fish hatchery in each sub-basin where dams were built.

In 1983 it became mandatory (Consideration of Environmental Impact Studies, Law number 6938, August 31, 1981) to submit a report detailing the environmental impacts of any development. This would include a survey of the area, a description of the proposed action and alternatives, and identification, analysis and prediction of the major positive and negative impacts.

The substantial importance of the last unimpounded stretch of the Upper Paraná to the maintenance of biodiversity, including the conservation of migratory fishes, was recently recognised by the federal and state governments through the creation of three conservation units:

- 1 Environmental Protection Area of the Island and Varzea of the Paraná (10,031 km²);
- 2 Ilha Grande National Park, occupying the lower half of the Ilha Grande Island;
- 3 Ivinheima State Park, including the main nursery area at Mato Grosso do Sul State (700 km²).

Elsewhere in South America some migratory species have been studied but there is little clarity on the status of the fish fauna. Carolsfeld *et al.* consider that some species in the Paraná system will be at risk due to damming and overfish-

Fish Passages Turkey

Discussion between engineers about a fish passage facility constructed at a new dam.



ing (Carolsfeld *et al.*, 2003). Baigún *et al.* (2012) assessed the risk of extinction of some species in the lower La Plata basin using IUCN regional criteria. They consider *Brycon orbignyanus*, *Geniden barbuis*, *Salminus hilarii* and *Zungaro jahu* to be vulnerable and these were proposed for inclusion in Appendix 1 (CMS 2010).

4.4 EUROPE

Modern regulation of environmental threats and problems is increasingly effective within the EC and in some other continents. EC law such as the Water Framework Directive (EC, 2000) seeks to deliver Good Ecological Status in all river basins and this includes restoration of populations of migrating fish such as salmon, eel and trout. The EC directives are transposed into national legislation and supplement existing national legislation to serve national interest concerning the management of flora and fauna together with their linkages to socio-economic interests of the country.

In many cases direct funding of facilities to achieve this is made possible through EC funding awards and grants such as the ERDF (European Regional Development Funds). Law and policy on a local level are increasingly focused on the implementation of international obligations as well as national laws by national or regional regulation. This is leading to increased targeting of

national funds to address local need for environmental management including that for migratory fish. The more significant European legislation that is directly relevant to the restoration of fish migration in river systems is discussed below. More information can be obtained from the EC website: www.ec.europa.eu

Water Framework Directive (Directive 2000/60/EC).

The Water Framework Directive (WFD) provides a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater. The WFD is valid for all member states of the European Union, although the member states have some freedom to determine how the WFD is integrated within their own national legislation. The WFD is in place to ensure that:

- Aquatic ecosystems and areas directly dependent on these ecosystems are preserved from further deterioration;
- The aquatic environment is improved, e.g. through substantial reduction in discharges and emissions;
- The sustainable use of water is promoted on the basis of long-term protection of available water resources;
- Groundwater pollution is reduced considerably.

WFD demands that member states ecologically optimise the use of rivers at acceptable cost, and this extends to targets for fish stocks and migrations. Ecological monitoring programs have been refined and inter-calibrated to be consistent and were implemented in 2006. In 2009 the first of three cycles of River Basin Management Plans (RBMP) and associated Programmes of Measures for each of the river basins was implemented. Targets for each basin for the first six-year cycle of WFD should be attained by 22 December 2015 when the results of ecological monitoring will be compared with the relevant targets. The WFD is the most substantial legislation relevant to ecological condition, including the well-being of migratory fish.

Regulation 92/43/EEC of the European Council (concerning the preservation of natural habitats of wild flora and fauna dated 21 May 1992). This directive, widely known as the 'Habitats Directive' (EC, 1992) aims to establish a 'favourable conservation status' for habitat types and species that have been selected as being of EC interest. A European ecological network known as 'Natura 2000' has been established.

The Bern Convention (The Convention on the Conservation of European Wildlife and Natural Habitats) was adopted in Bern, Switzerland, in 1979. This treaty aims for the preservation of wild plant and animal species and the habitats they depend on (which are listed in appendixes I, II, III, and IV of the Convention). The treaty increases cooperation between contracting parties where this is needed between different countries (Lelek, 1980; Lelek, 1996). The Convention was implemented in Europe in 1979

through Council Directive 79/409/EEC (on the Conservation of Wild Birds, known as the EC Birds Directive) and in 1992 through Council Directive 92/43/EEC (on the Conservation of Natural Habitats and of Wild Flora and Fauna, known as the EC Habitats Directive). Under both directives, 'Natura 2000' sites have been established to address and reverse the loss of biodiversity in Europe.

Treaty of the Committee of ministers of the Benelux Economical Union (concerning the free migration of fish species in the hydrographical basins of the Benelux countries Belgium, Netherlands, Luxembourg, dated 2009. Section 2 of this treaty requires the governments of the Benelux countries to ensure the free migration of fish species in all river basins. Priority is given to the migration of the larger anadromous and catadromous fish species to and from the spawning and nursery areas.

HYDROPOWER AND FISH PASSAGE IN FRANCE

Dam in the River Gave d'Oloron at the hydropower station of Sorde l' Abbeye. The new owner of the hydropower plant 'International Hydro' is installing a new fish pass system based on the latest French design criteria.



EU EEL REGULATION

Christos Theophilou

Directorate General for Maritime Affairs and Fisheries

European Commission

Council Regulation (EC) 1100/2007 establishing measures for the recovery of the stock of European eel, was adopted by the Council of Ministers on 11 June 2007. The key element of this Regulation is that it requires Member States to prepare and implement Eel Management Plans (EMP's) in order to achieve a common recovery target. The Commission, taking into account the evaluation carried out by ICES (The International Council for the Exploration of the Seas) has adopted these plans, which entered the implementation phase over the past 2 years.

The eel regulation was drafted taking into account the fact that the European eel is a single stock, and that various natural and anthropogenic factors affect the stock throughout its range of distribution. Therefore, rather than imposing uniform measures throughout the EU, a common escapement target was set, leaving it mostly up to Member States to select which measures they needed to implement. The target of the plans is to allow at least 40% of adult eel to escape from inland waters towards the sea to spawn.

The 40% escapement target is defined as '40% of the escapement which would have existed under pristine conditions'. To this end, Member States have proposed various measures within their plans, e.g. limitation of fisheries, improving river continuity by demolishing migration obstacles or constructing fish passes, reducing pollution, controlling predators, restocking inland waters, controlling the spread of parasites, etc.

In addition, the Regulation obliges Member States where there are glass eel (juvenile eel less than 12 cm long) fisheries to reserve 35% of the catch for restocking within the EU. This figure will increase by at least 5% per annum to reach at least 60% by 2013.

The Member States are to present reports to the Commission, outlining the progress achieved via the implementation of their plans, every three years. The first progress report is due by 1 July 2012.

By 31 December 2013 the Commission will draft a global progress report and present it to the European Parliament and the Council. In light of this report the Commission could propose additional or alternative measures to ensure that the recovery target will be achieved.

The European eel is listed on Annex II of CITES (Convention on International Trade of Endangered Species). This listing came into

Eel fishery in the Ebro delta



Restocking with eelers

In the past large areas in The Netherlands were restocked with eelers. Nowadays the focus is more on restoring migration routes at hydro-power station, pumping stations and sluices.



effect on 13 March 2009. In order for international trade to occur, special permits must be issued by the relevant authority of each Member State.

The CITES Scientific Review Group (SRG), comprising representatives from EU national authorities, meets on a regular basis in order to assess the status of the stock. Based on the available data, the SRG has decided that no extra-EU trade of eels should take place in 2011 and 2012. This decision will continue to be reviewed in the coming years.

Incorporation of the WFD and other directives in national and local policies

Further to EC directives and treaties, legislation and policy vary considerably between each country. It is clearly important that those working on fish migration issues are familiar with the relevant legislation on fish migration and the available mechanisms to solve fish migration problems. This is an important local basis for action on fish migration issues. Local policy should be based on national and international policy adjusted to suit further specific (local) information. Some regional or local requirements, such as planning conditions, may not be enacted as legislation whilst others, such as those made by federal states, municipalities or Regional Water Authorities, might.

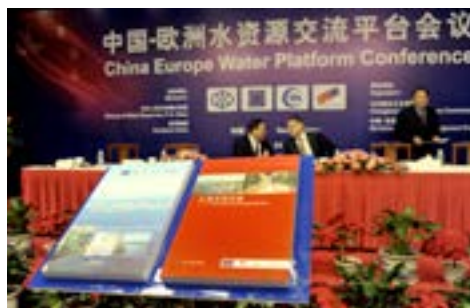
4.5 ASIA

In Asia, despite the presence of thousands of dams, there appear to be no specific fish migration policies. The River Basin Approach is generally adopted from the models developed in the USA, Europe and Australia, although it is clear that more work is required.

However, in China there is now much interest in ecological restoration, river basin management

Chinese version

The Chinese version of the first Guidance 'From sea to source' was officially presented at the Yangtze Forum (2011).



and fish migration issues, as demonstrated by the recent translation of the European Fish Migration Guidance (Kroes, *et al.*, 2006) into a Chinese version (funded by the EU China River Basin Management Program).

China

According to Yang and Griffiths (2007) the legal framework supporting water management in China is centred on the Water Law (NPC 2002a).

EXAMPLE

Establishing the river continuum concept: Ecological restoration of confluences of rivers and their tributaries

Authors: Matthijs de Vos¹ and Jasper Arntz²
Organisation: Regional Water Authority Rijn & IJssel¹ and TAUW Consult²
Country: The Netherlands



INTRODUCTION

Improving the opportunity for migration from major rivers to regional and local streams is an important measure for many fish species in The Netherlands, where major rivers such as the River IJssel are separated from their tributaries (figure 1). For diadromous species such as the European eel (*Anguilla anguilla*) and potadromous species including ide (*Leuciscus idus*), burbot (*Lota lota*) and European chub (*Leuciscus cephalus*) connection of rivers and streams is essential for successful completion of life cycles. The potadromous species are reliant on the streams for spawning and nursery habitats.

FIGURE 1 RIVER IJSSEL AND TRIBUTARIES



WATER MANAGEMENT AND FISH MIGRATION

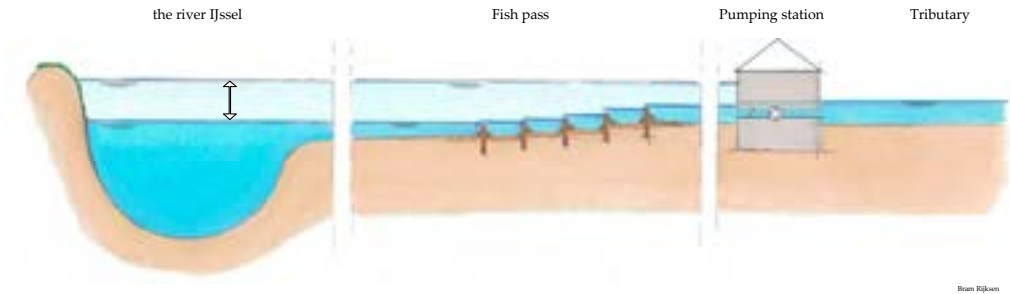
For safety and for agricultural purposes, most tributaries are managed at a constant water level. Discharge by gravity is only possible in periods when the River IJssel carries relatively small amounts of water, as the main river level must be lower than the tributary levels. However even in this situation natural migration between the river and tributaries is not possible because of the weirs that have been constructed to maintain the constant water level.

At high river levels a pumping station is necessary to regulate and guarantee discharge of tributary flow to the main river, and flap gates are used to prevent inland flooding. At low river levels, downstream migration is secure through natural tributary flow. However, in such a 'natural' situation, the weir and valves provide a continuous drop in water level, which represents a problem for upstream migration.

ECOLOGICAL RESTORATION

In order to establish the river continuum concept in the eastern part of The Netherlands, Regional Water Authority Rijn & IJssel has selected 5 of the tributaries of the River IJssel with the greatest ecological potential for study. The feasibility study was carried out to assess potential restoration of fish migration at each of the 5 conflu-

FIGURE 2 PUMPING STATION AND FISH PASS



ences (Tauw, 2010). The purpose of the restoration is to facilitate upstream migration into the tributary and to provide fish habitat. Designs for restoration of natural morphology of the confluence within the river bed, included a pool and weir (V-shaped) fish pass. The fish passes are calibrated to the typical water levels of the River IJssel during the period from February to June, and the designs improve migration potential during periods of natural drainage (figure 2). The fish passes are located at an appropriate distance to ensure that the pumping station can function without any problems.

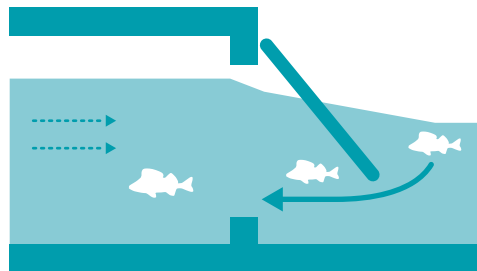
The design of the flap gates in the pumping station was of particular importance. Modeling the behavior of the valves with computational fluid dynamics showed that under normal circumstances the valves were not passable in the upstream direction due to high current velocities. Also the size of the opening (caused by water pressure) proved to be much too small to allow fish to pass. It was clear from the modeling that design of the water management structures needs to be adjusted. The weir should be removed and the valves need to be replaced.

CONCLUSION

Depending on the hydrological situations, upstream migration from the main river to the tributaries can be improved by creating a fish pass within the river bed. When this fish pass is located at some distance from the pumping station, it will not constrain the flows generated during pumping. Valves used for natural drainage are

not passable for fish under normal circumstances. To create an opening the valves need to be replaced by a more balanced and/or light, but very solid material (figure 3). Also the valves can be placed perpendicular to the flow direction. The implementation of the measures to improve the migration routes are scheduled for 2013.

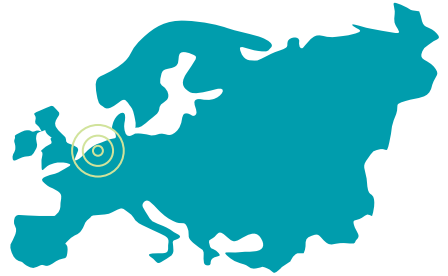
FIGURE 3 THE FISH FRIENDLY GATE



EXAMPLE

From sea to source. Targets for fish migration highways in the North of The Netherlands

Authors: Peter Paul Schollema¹, Herman Wanningen² and Albert Jan Scheper³
Organisations: Regional Water Authority Hunze en Aa's¹, Wanningen Water Consult² and Regional Angling Federation Groningen Drenthe³
Country: The Netherlands



VISION 'FROM SEA TO SOURCE'

One of the most important policies for fish migration created by the Regional Water Authority Hunze en Aa's is the vision 'Van Wad tot Aa' Groningen Northern-Drenthe 2005-2015. This shared vision was created in cooperation with the Regional Water Authority Noorderzijlvest and the Regional Angling Federation Groningen Drenthe (Riemersma & Kroes, 2006) by a team of representatives working in partnership.

A key principle for the partners was the need for a structured approach to prevent further decline of the potential for fish migration in the area. The vision differentiates between coastal constructions, obstructions within rivers and brooks and structures preventing lateral migrations to floodplains. This was done because each type of landscape needs a different approach and the vision sets objectives for representative fish species in each of these different areas. The vision has two themes:

- Prevention of further deterioration of fish migration potential (the 'stand-still' or 'no detriment' principle) whilst seeking as many opportunities as possible for improvement through, for example, major repairs to struc-

tures or by proposing new standards for fish passage within new developments and renovations. This approach is applicable to all surface water bodies within the management area and to all artificial constructions, and is supported with a number of decision models;

- Solutions for migration bottlenecks identified in the vision. The vision prioritizes the bottlenecks by creating a so-called fish migration map that identifies all bottlenecks within the management area. The advantage of such a map is that the bottlenecks are clearly visible and it is straightforward to see which bottlenecks have priority. The vision seeks to remove the migration bottlenecks for fish situated within these watercourses within 10 years. The objectives must be reached by 2015. This systematic approach identifies the relevant bottlenecks, and then prioritizes and identifies measures to resolve the problems. It also seeks to identify opportunity to deliver solutions in partnership with others to maximize the value of possible subsidies. Furthermore, the vision stresses the importance of using natural solutions to improve fish migration first and, only when that is not possible, identifies the technical fish pass solutions that are required.

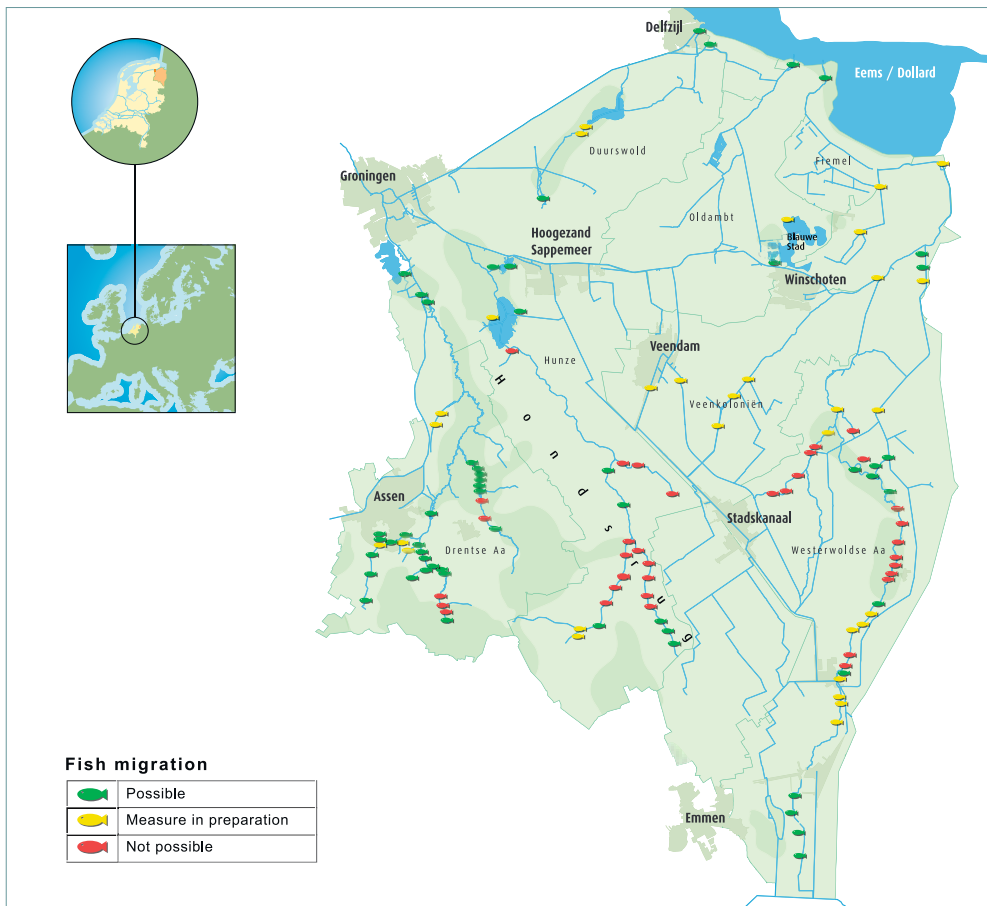
An important instrument which is used to make regional policy is the so-called ecological connection zones. These are zones that connect ecologically important areas with each other and seek to ensure that fauna as well as flora can freely interchange between these areas.

Rivers and brooks are often used as ecological connection zones ('Fish Migration Highways'), because they effectively link geographically distinct areas. Key target species are used to measure the quality of these zones, one of these being the river lamprey.

STEP BY STEP - WORKING TOWARDS FREE FISH MIGRATION

In 2005 the vision had shown a total number of 130 fish migration barriers in the management area of the Regional Water Authority Hunze and Aa's. By early 2012 more than 60 of these barriers had been removed or fitted with an appropriate fish migration facility. By 2015 another 40 barriers will be resolved. Cooperation between the different partner organisations in the region has shown to be a powerful instrument to gain the financial and technical support required to achieve the required solutions.

FISH MIGRATION MAP; PRIORITY WATERS, BOTTLENECKS AND SOLUTIONS



RARE AND ENDEMIC FISH NATURE RESERVE IN THE UPPER REACHES OF THE YANGTZE RIVER

The Upper Yangtze is home to 230 species of fish, almost 100 of which have never been found anywhere else. This makes it one of the most important regions for unique fish species in the world. It is also home to protected fish that are only found in China, such as the Chinese sturgeon, the Chinese paddlefish, the Yangtze sturgeon, the Chinese high fin banded shark and the Sichuan taimen.

The Three Gorges Dam development has had a negative impact on about 40 different species of fish – some 40% of the fish species unique to the Upper Yangtze. Therefore, in 1996, nature reserves were established to address ecological impact of the dams including protection of rare fish, and in 1997 the Sichuan government combined these into the Hejiang-Leibo Rare Fish Provincial Nature Reserve. In April 2000, the State Council upgraded this to a National Reserve. However as the requirement for hydropower development has accelerated, spawning grounds have been lost, habitats degraded and consequently populations of many species have sharply reduced. The reserve is the last refuge for most of the threatened fish species.

Yangtze River

Tourists' site on the Yangtze River, home to some of China's most spectacular natural scenery: a series of canyons the Qutang Gorge, Wuxia Gorge and Xiling Gorge, collectively known as the Sanxia, or Three Gorges which is now partly flooded after the Three Gorges dam was finished. Coursing over a distance of 6,380 km, the mighty Yangtze is the longest river in China and the third longest in the world after the Amazon in South America and the Nile in Africa. It is also a cradle of ancient Chinese civilization (© Michel Gunther / WWF-Canon).



In November 2010, the Ministry of Environmental Protection (MEP) of China confirmed that the commission responsible for China's national nature reserves had approved changes to the reserve. These included plans to shrink the reserve by 14.6 square kilometres in an area within the boundaries of Chongqing, a municipality in south-west China. More than 22 kilometres of river are to be removed from the protected area and 73.3 kilometres, currently classified as a buffer zone, re-designated as an 'experimental zone'.

It includes water related laws on Environmental Impact Assessment (NPC, 2002b) and secondary legislation concerning regulation and related provisions. To date in China the emphasis of water policy has been on water quantity, flood defence and hydropower. Economic growth has been the overriding factor in applying and enforcing the water laws. The Yellow River and Yangtze River commissions operate river basin planning, and provide strategic direction to the provincial and local level. However, action is not yet truly integrated and implementation by the provinces is variable (Yang and Griffiths, 2007). More recently the Chinese interest in the EU Water Framework Directive has increased (e.g. Griffiths and Torenbeek, 2011) and China is working now on a River Health Assessment System.

China Biodiversity Protection Strategy and Action Plan (2011 to 2030)

The Chinese government has recently published the China Biodiversity Protection and Action Plan that demands "stronger protection of rare and unique fish species and their habitats on the Upper Yangtze" (NPC, 2010). However, environmental groups point out that fragmentation of upstream parts of rivers with more and more dams, and reduction in the size of the only fish reserve at the national level, runs contrary to this undertaking. According to Liu (2011), current development may well destroy the last remaining habitat for many rare fish species on the Upper Yangtze and cause their extinction.

USA-China Environment Clean Water Action Plan

In 2006, under the China-US Strategic Economic Dialogue (SED), the two countries agreed a Ten Year Framework for Cooperation on Energy and

Environment. They agreed to establish a cooperative partnership in the field of environmental protection (EPA, 2007). The partnership adheres to a strategy of 'rest and recuperation' for the waters of China. The resulting Clean Water Action Plan draws upon USA expert knowledge to develop concrete river basin management plans, including fish migration measures. Possible programs include the Jiangsu, Jiangxi Ningxia, Sichuan, Shaanxi, Tianjin and Zhejiang.

EU-China River Basin Management Programme

In 2006 the EU and China initiated a programme to establish integrated river basin management practices in the Yellow and Yangtze River basins drawing on European expertise. The projects are environmentally sustainable and address global environmental concerns, as well as those of local populations, with a goal to replicate them in other regions of China. The program draws on the principles of the EC Water Framework Directive and encourages exchange of ideas on policy and management of major river basins and water resources, including fish migration measures.

The EU-China Biodiversity Program (ECBP) is the EU's largest overseas biodiversity programme, encompassing the use of 52 million euro funding including field project partnership contributions.

Russian Federation

The Federal Law on Fisheries and Conservation of Aquatic Biological Resources (Russian Federation, adopted on 20 December 2004) prioritises the conservation of aquatic biological resources and their exploitation. Exploited species such as salmon have the status of federal property, and various bodies have executive powers to enforce

Mekong River

Proposed dam site near Pak Ou caves on the Mekong River not far from Luang Prabang. After much protest, the government relocated construction elsewhere. Laos or Lao People's Democratic Republic (© Elizabeth Kemf / WWF-Canon).



regulations (including federal laws on environment and environmental impact assessment, the water code, and various local regulations) to maintain the natural resource. There have been substantial changes to the regulatory system, and in 2007 the bodies responsible for management of the diadromous fish resource included the State Committee for Fisheries, the Ministry of Nature Management, Territorial Directorates for Fisheries and, significantly, Basin Directorates for conservation and enhancement of aquatic biological resources and fisheries management.

The regulations and associated initiatives include projects ranging from management of the impact of aquaculture (including issues relating to salmon farm escapes and transgenics), hydropower and navigation, to requirements to

maintain rivers and mitigate the effects of logging by removing debris after loose log drifting. The restoration of spawning and nursery habitat, and development and implementation of habitat restoration programmes is carried out under the 'Polluter Pays' principle. All economic activity planned on salmon rivers or close to them, must be approved by relevant authorities and conducted to cause no damage to salmon habitat.

Recommendations for habitat restoration must be prepared in accordance with the special order of the Federal Agency for Fishery # 501 (Russian Federation, 2009). Detailed plans for salmon habitat protection, conservation and restoration for specific rivers are under development.

Significant recent initiatives to manage and conserve salmon resources include the Russian

Salmon Fund which seeks to preserve the diversity of salmon for sustainable exploitation, and the Russian Salmon Fishery Improvement Project which, amongst other goals, seeks to achieve marine stewardship council certification for the Russian far east Pacific salmon fisheries.

4.6 AFRICA

In Africa, there appear to be no specific fish migration policies on a continental level. However, in South Africa, river basin management and fish migration issues are being actively addressed.

African Water Resource Database (AWRD)

The FAO has developed the African Water Resource Database (AWRD) which is a set of data and custom-designed tools, combined in a GIS analytical framework. It aims at facilitating data gathering and management with a specific focus on inland fisheries and aquaculture. This database could also be used as a basis for river basin management and to plan fish migration measures.

South Africa

South Africa appears to be the foremost African country in terms of the implementation of fish migration measures and river basin management. The Department of Water Affairs and Forestry (DWAF) is the lead agency in implementing policy and environmental legislation seeking to protect riverine ecosystems and to address fish migration issues. The relevant legislation for this includes:

- The Environment Conservation Act, 1989 (No. 73 of 1989);
- The National Environmental Management Act (Act 107 of 1998);
- The National Water Act, 1998 (Act No. 36 of 1998);
- The National Environmental Management: Biodiversity Act, 2004 (Act 10 of 2004).

Under the National Water Act (South Africa, 1998) the Government is responsible for overall water resources management as public trustee, and

the Act provides powers for licensing of water uses. An important element of the Act is replacement of the previous system of centralized water management by DWAF with decentralized water management at the river basin level. For this purpose DWAF has divided South Africa into 19 water management areas, defined as large river basins, or several adjacent smaller basins to be managed by bodies comparable to the river basin committees in the EU.

The Water Research Commission (WRC) was established under the Water Research Act (Act No 34 of 1971) and it has compiled comprehensive guidelines for the planning, design and operation of fishways in South Africa. Fish migration is also an integral part of the River Health Program developed by DWAF under which status reports have been compiled for each river.

4.7 AUSTRALIA AND NEW ZEALAND

The Threatened Species Conservation Act, 1995

This Act, introduced by the New South Wales Government in 1995, is the main piece of legislation to protect migratory fish species. The Act sets out a number of specific objectives relating to the conservation of biological diversity and the promotion of ecologically sustainable development. Under the Act a scientific committee is set up, the functions of which include identification and classification of threatened species and key threatening processes.

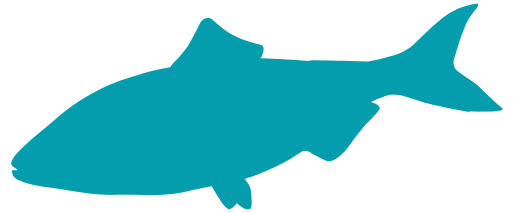
The National Water Initiative

The National Water Initiative (NWI) established by the National Water Commission (Australia, 2004) is Australia's enduring blueprint for water reform. It builds on the 1994 strategic framework for the efficient and sustainable reform of the Australian water industry and, through it, governments across Australia have agreed on actions to achieve a more cohesive national approach to the way Australia manages, measures, plans for, prices, and trades water. Each state and territory government is required to prepare a NWI implementation plan.

SPECIES EXAMPLE

Where have all the allis gone? The decline of *Alosa alosa* from Morocco and in particular the Oued Sebou

Author: Miran Aprahamian
Organisation: Environment Agency
Country: United Kingdom



INTRODUCTION

Allis shad historically occurred along the Atlantic coast from Norway to Morocco, extending along the British Isles, the coasts of Germany, Holland, Belgium, and France, and then down to Spain and Portugal. The original latitudinal distribution of allis shad in the eastern Atlantic was between 28°N and 60°N latitude (Baglinière *et al.*, 2003).

At the start of the 20th century, shad were an important commercial fish with the total annual catch of shad from Moroccan waters (including the Oued Moulouya, which drains into the Mediterranean Sea) being in the region of 1000 tonnes (Watier, 1918).

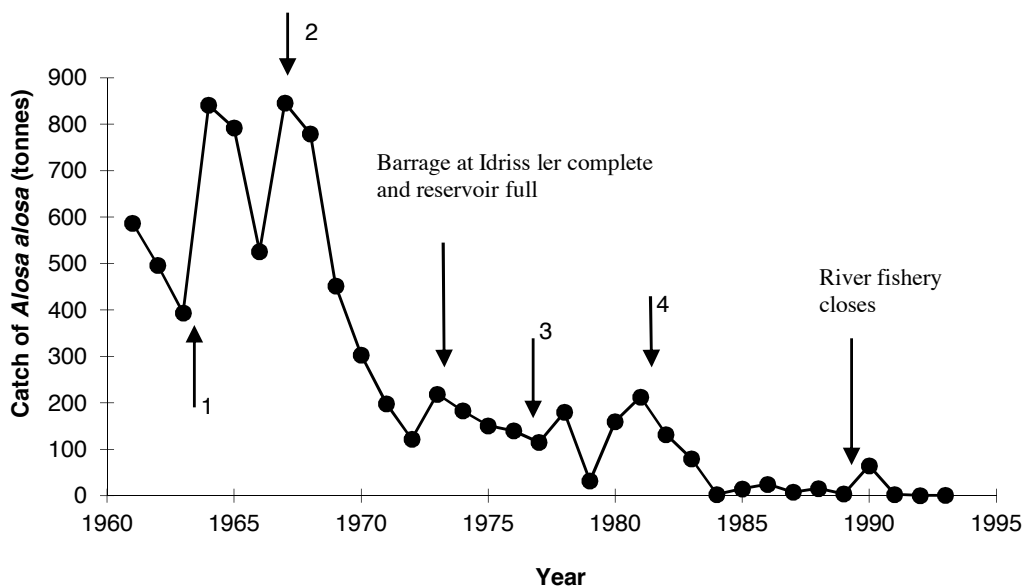
However, during the 1970's the construction of barrages resulted in a number of populations

ALLIS SHAD



FIGURE 1

The combined marine and river catch of *Alosa alosa* from the Oued Sebou (Morocco) between 1961 and 1993. Numbers refer to when different sugar refineries were constructed (Sabatié, 1993).



becoming extinct with the southern limit of their spawning distribution moving 500 km north from the Oued Massa to the Oued Sebou.

The most important population was in the Oued Sebou, however the construction of the barrage at Idriss ler in the early 1970's drowned out a number of spawning areas in the Oued In-aouen with the resulting decline in the population, and the catch declining to approximately 10 tonnes/year from 700-800 tonnes/year (Figure 1). A fish pass was incorporated into the barrage; however it was ineffective.

In the 1980's the situation for the shad in the Oued Sebou was further compounded by pollution from sugar factories, paper mills, yeast factories and from urban and agricultural sources

which, together with high fishing pressure and in the 1990's a new dam being built at Lalla Aïcha 40 km from the mouth of the estuary, resulted in the species becoming extinct in the Oued Sebou. The Portuguese populations now represent the southern limit of their distribution (Baglinière *et al.*, 2003).

POSSIBLE SOLUTIONS

At present the only measure being taken to preserve shad in the Sebou is the prohibition of fishing. Other solutions are:

- 1 Cleaning up the industrial and household wastewater before discharging it into the Sebou and controlling the use of fertilizers and pesticides in agriculture;
- 2 Equipping Lalla Aïcha, Idriss The First and Al Wahda dams with fish passes.

SPECIES EXAMPLE

Current status of the native catadromous eel species *Anguilla bengalensis labiata* and *Anguilla mossambica* in Tanzania

Author: Rashid Tamatamah
Organisation: Department of Aquatic Sciences
and Fisheries, University of Dar es Salaam
Country: Tanzania



INTRODUCTION

Five or possibly six freshwater eel species are known from African rivers (Skelton, 1994). Two species of eels are native in Tanzanian rivers entering the Indian Ocean (Matthes, 1967, Bailey 1969, Skelton, 1993), the African mottled eel (*Anguilla bengalensis labiata*) and the African longfin eel (*Anguilla mossambica*). *A. bengalensis labiata* reaches a length of up to 175 cm and weighs up to 20 kg while *A. mossambica* attains a maximum length and weight of 150 cm and 5 kg, respectively (www.fishbase.org).

LIFE CYCLE

African mottled eel and African longfin eel have similar life histories. They are migratory species, which breed in the ocean. Between December and February each year, elvers enter the rivers at night and migrate hundreds of kilometers upstream, mainly during the rainy season when the river is flowing strongly. They feed actively on insects such as blackfly larvae (*Simulium* species) and other small aquatic invertebrates and cease to move upstream when they attain a length of 25 – 30 cm.

Adult eel are usually sedentary and are carnivorous, feeding on dead or living prey but especially fish and crabs. After feeding in fresh water for 15 – 20 years, adults return to sea to breed.

GEOGRAPHICAL DISTRIBUTION

Western Indian Ocean: east coast rivers of Africa from Kenya south to Cape Agulhas, also in Madagascar and other western Indian Ocean islands. Moves well inland and is also reported from New Caledonia (Skelton, 1993).

HUMAN IMPACTS

Fortunately, eels are not target species in riverine fisheries because they have insignificant market value in Tanzania. The decline of the native eel species in Tanzania started in the 1980's after the construction of large dams across several eastward flowing rivers (Studio Pietrangeli, 2011).

Compared to pre-impoundment fish studies for proposed and constructed dams along the major rivers: Pangani (Bailey, 1965 and 1969), Great Ruaha (Petr, 1974) and Lower Rufiji (Hopson, 1979), only a few individual eels have been caught in fishing trials carried out over the past decade. Habitat loss or alteration, discharge modifications, prevention of free upstream migration, as well as delays in migration caused by dams are the major threats.

WHAT NEEDS TO BE DONE?

To address these threats Tanzania has developed policy strategies that seek to minimize the impacts of drastic environmental changes, in-

cluding those associated with dams. The current environmental legislations such as the Environmental Management Act, 2004 and the Environmental Impact Assessment and Audit Regulations, 2005 require all development projects that have significant adverse environmental impacts to pass through a mandatory Environmental and

Social Impact Assessment (ESIA). Also, although fish passes were not considered in the design of dams constructed in the past, this option has been included as a strategy to overcome fish passage problems for the new Kidunda Dam soon to be constructed across the Ruvu River (Studio Pietrangeli, 2011).

KIHANSI RIVER

A dam on the Kihansi River, a tributary of Rufiji River in Tanzania showing desiccation of the old river channel and a release flow of 1.5 - 1.6 m³/s (max. 2 m³/s) after impoundment in 1999. The minimum pre-impoundment discharge past this section was 7 m³/s (© P. Valimba).



Waikato River

With 425 km this is the longest river in New Zealand (© Marq Redeker).



The Natural Resources Commission New South Wales

The Natural Resources Commission (NRC) was established under the Natural Resources Commission Act (2003) to recommend state-wide standards and targets for natural resource management and to audit Catchment Action Plans (developed by Catchment Management Authorities) in achieving these standards and targets. The Water Quality and River Flow environmental objectives are used as the basis for the NRC's water resource condition targets. Catchment Action Plans will be assessed against the outcome of planned actions in contributing to achieving the targets.

The New South Wales State Weirs Policy

In September 1995, the Minister for Land and Water Conservation of the New South Wales Government initiated the State Weirs Policy (Australia, 1995). The goal of the State Weirs Policy is to halt and, where possible, reduce and remediate the environmental impact of weirs by means of fish passages.

Native Fish Strategy

The Native Fish Strategy (NFS) is intended to

ensure that viable fish communities and populations are sustained throughout the rivers of the Murray–Darling Basin. The goal of the strategy is to rehabilitate native fish communities in the basin back to 60% of their estimated pre-European-settlement levels, within 50 years of implementation. The NFS has been in place since 2004 when experts estimated that levels were about 10% of those that existed pre-European-settlement (www.mdba.gov.au).

Water and the Resource Management Act 1991, New Zealand

This, together with the Fisheries Act (1997) is New Zealand's main piece of legislation that sets out how to manage the environment, including fish migration issues. It sets a framework for the identification and management of the impact of human activities on the environment and for the management of indigenous biodiversity. An example of the use of the Act is the response to potential issues arising from dam developments. River flow and fish migration requirements are dealt with by regional councils, and most consents for construction require residual flows to be maintained to protect the environment, and the construction of fish passes to preserve free

migration of fish. Regulatory authority for fish passage issues is the responsibility of the Department of Conservation. Most dams in New Zealand are operated by The Electricity Corporation of New Zealand, and they have promoted research into the provision of fish passage facilities through its dams.

4.8 ECONOMIC DRIVERS AND FISH MIGRATION

The economic cost and evaluations of remediation options for fish migration issues (such as those relating to habitat fragmentation) is generally a subject for environmental economists working to an ecological restoration plan. However, there are several important social drivers relating to fish migration as well, such as food, recreation, heritage, and natural history. Other economic drivers may also be important, particularly larger local hydropower schemes. Many

smaller schemes often have small, and often marginal, economic benefit at best.

The DPSIR Principle (Driving Forces - Pressures - State - Impacts - Responses) assumes that social, economic, and environmental systems are interrelated. The DPSIR principle has been adopted by the European Environmental Agency (EEA) and used to assess and manage environmental problems, and as part of this fish migration issues may be placed into a socio-economic context. This system analysis highlights the driving forces of - and relations between - the environmental system and the human system (Smeets & Weterings, 1999). According to this analytical approach, social and economic developments exert pressure on the environment and, as a consequence, the state of the environment changes, such as the availability of fish habitat and biodiversity.

Tonle Sap River

Small, migratory food fish on drying racks on the shores of the Tonle Sap River in Cambodia (© Zeb Hogan / WWF-Canon).



EXAMPLE

Developing a fish passage culture in New South Wales (Australia)

Authors: Cameron Lay & Craig Copeland
Organisation: NSW Department of Primary Industries
Country: Australia



INTRODUCTION

The arid nature of Australia's climate has necessitated significant levels of dam and weir construction to support industry, agriculture and social expansion. Combined with the cumulative impact of tens of thousands of road crossings, the movement of native fish within rivers and between adjacent habitats has been severely restricted.

These barriers have been a major contributor to a 90% decline in the abundance and diversity of native fish throughout Australia's largest river system, the Murray-Darling Basin (MDBC, 2003). In New South Wales (NSW) alone there are more than 4,000 licensed structures (generally large weirs) that act as barriers to fish passage, and

the number of unlicensed structures (smaller weirs and road crossings) is likely to be as great again (NSW DPI, 2006). While technical solutions were developed in the 1990's to overcome fish passage problems for Australian native fish (Mallen-Cooper, 1996), the challenge presenting itself has been to make meaningful improvements given the scale of the problem and limited financial resources.

WHAT DID WE DO?

To address this need within NSW, three specific strategies have been undertaken: policy development and implementation; structure prioritization; and the development of partnerships:

- Maximizing the effectiveness of existing legislation and government policy has been central to increasing fish passage investment. Emphasis was placed on opportunities to engage structure owners, varied industry sectors and stakeholders in an effort to increase compliance and understanding of fish passage issues. This has ensured that all new works are fish passage friendly;
- Identifying state and regional priorities for action has given clear direction for future investment, with the top 100 priority weirs being reviewed and fish passage options drafted for future consideration, while more than 7,000 road crossings have been individually assessed and prioritized for future remediation (NSW DPI, 2006);

INEFFECTIVE FISHWAY

Bird predation at weir with ineffective fishway.



- Fostering partnerships with structure owners and the vast network of potential advocates in the recreational and commercial fishing industries has raised the profile of the fish passage problem. Developing a Fish Habitat Network for recreational fishers, incorporating fish passage improvements in the asset management plans for water authorities and establishing strong guidelines with local authorities to ensure road and storm water assets meet best practice for fish migration have all contributed to a growing awareness of fish passage issues.

HOW DID IT WORK OUT?

Following the implementation of these three specific strategies, the total investment in fish passage in NSW alone during the period 2005-2010 exceeded 60 M AUD, up from approximately 5 M AUD in the preceding 5 years.

Fish passage can be elevated to a high order issue amongst both government and the wider community through targeted and sustained efforts. Ongoing research to improve fish passage

technology and design needed to be matched with a comparable effort in raising the prominence of fish passage as a priority tool for ecological restoration. Incorporating fish passage considerations into the decision making of governments, water management agencies and private industry was an essential part of this process.

LESSONS LEARNED

Understanding how to facilitate the movement of fish past dams and weirs is only half of the solution in delivering long-term improvements to both riverine connectivity and aquatic health.

The role of fish passage in restoring river health is not normally well understood within governments and the wider community. Therefore specific strategies needed to be developed to inform and engage these sectors. In particular, fostering relationships and improved understanding within the sectors that have the most to gain through improved river health (such as the commercial and recreational fishing sectors) should be central to future efforts.

FIGURE 1 SCHEMATIC OVERVIEW OF WEIRS IN NEW SOUTH WALES (AUSTRALIA).



Nationwide practices and regulation with regard to fish migration in China

Authors: Zhang Cheng and Lei Gang
Organisation: WWF
Country: China



INTRODUCTION

In 1958 the first fish ladder in China, with a maximum hydraulic head of 18 m, was built at the Qililong Hydropower Station on the Fuchun River in Zhejiang Province. Then in the 1960's and 1970's, more than 40 more fish pass facilities were built across the eastern Chinese provinces including Jiangsu, Anhui, Heilongjiang, etc. Most of these fishways were built on low water head (normally less than 10 m) gates.

Monitoring and analysis showed that they seldom worked well, and they were finally abandoned. The Yangtang Fishway, built in 1981 as part of a low water head hydropower station in Hunan Province, is reported as probably the most effective fishway in China; however it is now also out of service due to sedimentation.

In the 1980's, Chinese experts tried to design fish pass structures as part of the Gezhouba Project on the Yangtze for rare species such as Chinese Sturgeon. However due to the lack of experience and the high cost of fishways, these were abandoned and only artificial propagation and release measures were pursued. From 1981 to 1983, the first trial of Chinese Sturgeon fry stocking was conducted.

Efforts to construct fish passes in association with hydropower projects have therefore nearly

stopped in China in the two decades following Gezhouba's construction. However monitoring data reveals that fish still attempt to migrate upstream in the Yangtze, as the downstream ship lock area continues to see an accumulation of fish.

The Water Law of the People's Republic of China promulgated in January 1988, and the Environmental Protection Law of the People's Republic of China promulgated in December 1989 both require hydropower projects to "take measures to protect the aquatic environment and ecosystem; If a permanent gate or dam is constructed on a migration route, fish pass facilities should be built simultaneously".

In 2009, the Water Resources and Hydropower Planning and Design General Institute (GIWP) and Nanjing Hydraulic Research Institute (NHRI) started compiling the *Guideline for Fishway in Water Conservancy and Hydropower Project* as required by the Ministry of Water Resources (MWR).

A review meeting of the final draft guidelines was held in Beijing in November 2011, and it is expected that the official guidelines will be released in 2012 and act as a sectoral code listing the requirements for fishway design, construction, operation, and monitoring.

Despite the current lack of detailed guidelines, hydropower developers have already started to plan for fish migration for many reasons including political, social and economic pressure. It is reported that fish pass structures will be taken into account for the Xiaonanhai Hydropower project planned on the upper Yangtze in Chongqing Municipality (notably in the Upper Yangtze Fish Nature Reserve), the Lidi Hydropower project, and the Ganlanba Hydropower project on the Lancang River (Mekong River) in Yunnan Province.

THREATS TO FISH MIGRATION

The major threats to fish migration in China are:

1 Over fishing

Decreasing fish resources stimulated new techniques for fishing. Most of the techniques are illegal; however due to corruption in the fishery authorities, over fishing is more serious than before. Data shows the overall fishery catch prior to 2002 was 420,000 tons, but that this had decreased to less than 100,000 tons after 2002. This catch from the Yangtze in Hubei Province has a great impact on fish migration in the Yangtze River.

BAIJI

Lipotes vexillifer, the fish eating Yangtze River dolphin, also called Baiji. Right, the only captive Yangtze River dolphin, who died in the Centre in July 2002. Research Centre for Aquatic Biodiversity and Resource Conservation of the Chinese Academy of Sciences. Wuhan, Hubei Province, China (© Michel Gunther / WWF-Canon).



2 Water engineering and hydropower

Since the first large dam, the Gezhouba Dam was built in the 1970's, the TGD was built in the 1990's and more than 100 large hydropower stations are planned in the upper and Central Yangtze. None of these developments include fish ladders. The most damaged fish species are sturgeons which historically migrate from the sea to the upper mountain areas of the Yangtze.

WWF'S ACTION AND PROGRAMME:

The main objectives are:

- 1 Working closely with the Yangtze Fishery Resources Commission on increasing the natural production of fish fry;
- 2 Promote the Environmental Flows concept and practices in central and lower Yangtze, to establish stakeholder coordination platform and re-operate hydraulic infrastructures;
- 3 In partnership with scientific institutes, research possible new fish spawning grounds;
- 4 Promoting the opening of sluice gates to reconnect the river and lakes;
- 5 Organizing a campaign on conservation of key species, e.g. the river dolphin (*Lipotes vexillifer*), to awake the concerns of both public and government.

Recent comments from Chinese Premier Wen Jiabao, especially announcements on aquatic wild life conservation and dolphin conservation. This means that there will inevitably be great change in the implementation of fishery law in the central and lower Yangtze.

EXAMPLE

The importance of the fish resource in the Mekong River and examples of best practice

Authors: Eric Baran and Un Borin
Organisation: WorldFish Center
Country: Cambodia



INTRODUCTION

The Mekong is an exceptional river in many ways. In terms of fish biodiversity, it is the world's second richest river after the Amazon (www.fishbase.org). With 6 to 18% of the global freshwater fish catch, it is also home to the largest freshwater fisheries in the world.

Fish catch estimates vary between 755,000 tons (FAO FIGIS figures) and 2.6 million tons, with the most reliable assessment being 2.1 million tons per annum (Hortle 2007, ICEM 2010). This corresponds to about 18% of the global freshwater fish catch (range 6-22%), making the Mekong the largest inland fishery in the world.

The productive Mekong fisheries are essential to the food security of the 60 million people of the Lower Mekong Basin. According to FAO figures reflecting national statistics, freshwater fish consumption in Cambodia, Lao PDR, Thailand and Vietnam ranges between 9 and 19 kg/person/year, making them the top four countries in the world (world average = 2.3 kg/person/year).

However, a review of 20 food consumption surveys in 19,000 Mekong households indicates that fish consumption is even higher, ranging between 24.5 and 34.5 kg/person/year (Hortle, 2007). Fish contributes 81% of the population's protein intake in Cambodia and 48% in Laos.

ECONOMIC VALUE OF MEKONG FISHERIES

Estimates of the economic value of captured fish in the Mekong Basin range between US \$1.4 billion per year (Sverdrup-Jensen, 2002) and US \$2.2-3.9 billion (Hortle, 2009).

Although high dollar figures do not adequately reflect value in countries where fish is valuable because it is cheap and thus accessible to a large number of rural poor.

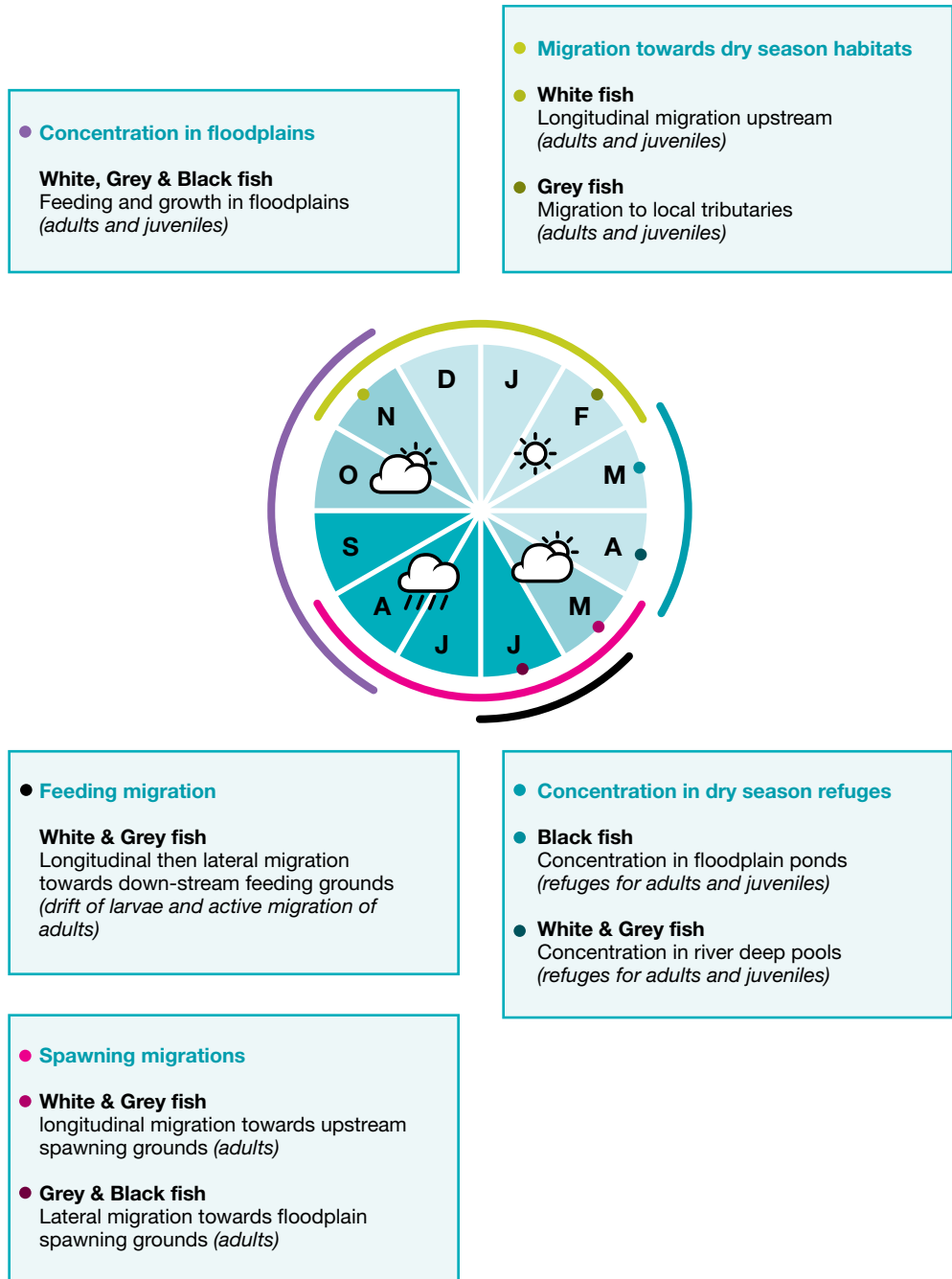
Mekong inland fisheries also provide employment to 1.6 of the 14 million Cambodians. In the Mekong Delta in Vietnam, 60% of the people are part-time fishers (An Giang province) and 88% of 'very poor' households depend on fisheries (Tay Ninh province; UNEP, 2010).

Fish migrations are an essential feature of the Mekong. Of the 189 migratory fish species known, 165 are long-distance migrants (Baran, 2006) and these species represent more than 37% of the total yield, i.e. more than 770,000 tons per year (ICEM, 2010).

The combination of high fish biodiversity, high productivity, high exploitation rate and long-distance migrations makes dam development a major concern in the Mekong Basin (Baran and Myschwoda, 2009).

FIGURE 1

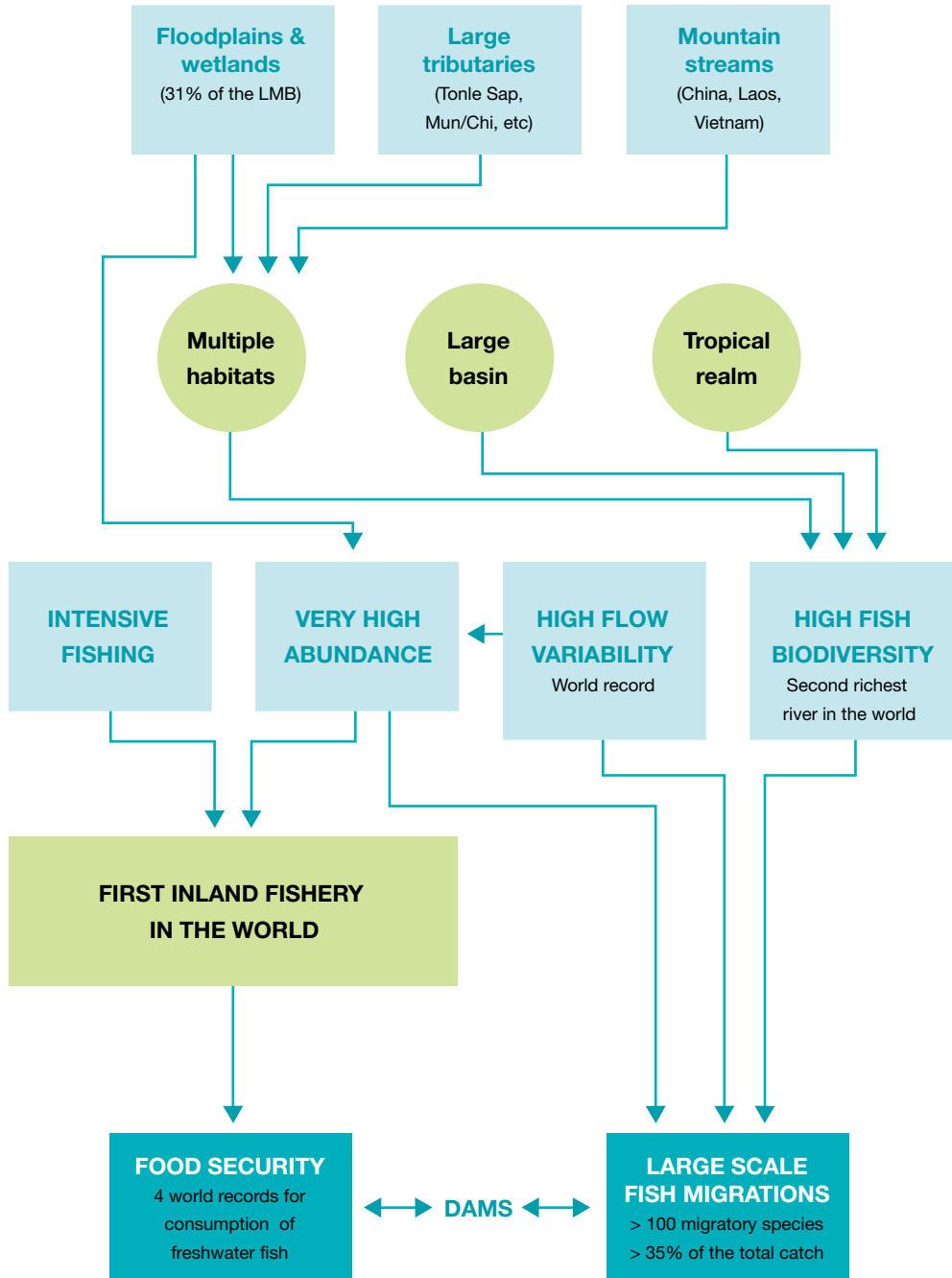
Migration patterns of fish in the Mekong River basin.



>>EXAMPLE

FIGURE 2

The role of migratory fish for the food security in the Mekong River basin.



BEST PRACTICES IN THE MEKONG RIVER BASIN

Although dam development in the Mekong is still taking place without regional planning (Grumbine and Jianchu Xu, 2011), several good practices can be highlighted:

- 1 The activities of the Mekong River Commission, a river basin organization revived in 1995. This institution focuses mainly on improving technical information (hydrological modeling, fisheries, environment, etc.) but is also trying to frame the development of the Mekong (including a Basin Development Plan, Integrated Water Resources Management strategy, Procedures for Notification, Prior Consultation and Agreement regarding mainstream dams). However, the development of numerous dams on tributaries does not fall within the MRC's jurisdiction;
- 2 The development by the MRC in 2009 of 'Preliminary Design Guidance for Proposed Mainstream Dams in the Lower Mekong Basin'. The guidance points are based on sustainability principles and cover navigation, fish passage, sediment transport, water quality and dam safety;

- 3 The implementation in 2010 of a Strategic Environmental Assessment of Mekong mainstream dams (ICEM, 2010), praised for its quality and influence. At a smaller scale, another SEA in Vietnam (Vu Gia – Thu Bon River Basin, ICEM, 2008) led to the creation of a corridor of free-flowing rivers for the sustainability of the migratory fish resource;

- 4 The large number of publications, easily accessible, about the Mekong Basin. Most of this literature is grey, yet this body of knowledge is exceptional for a tropical river. These documents can be accessed via:

www.mekonginfo.org
www.mrcmekong.org
www.mpowernetwork.org
www.mekong.waterandfood.org
www.worldfishcenter.org
www.laofab.org
www.wdrj.fi

In the coming years, the controversial Xayaburi mainstream dam proposed by Lao PDR (Vaidyanathan, 2011) will test the ability of the Mekong River Commission to keep a balance between the conflicting needs of its member countries.

TONLE SAP

Dai Fishery on the Tonle Sap River in Cambodia (© Eric Baran).



4.9 FUNDS FOR FISH

This section suggests various routes to help fish migration specialists to find funding for river restoration projects and fish migration measures. It cannot be an exhaustive overview, however it aims to inspire creative ways of thinking about how public, and perhaps private funds might be made available for river improvements.

In general the more developed countries in Europe, the USA and Australia have diverse funding mechanisms in place. But in developing countries fish migration issues are mainly addressed within the framework of hydropower development (EIA) and specific river basin projects mostly financed by development banks such as the UNDP/ World Bank.

For Europe, the 2006 European Fish Migration Guidance (Kroes, *et al.*, 2006) (www.hunzeenaas.nl) considered many public and private funding opportunities. These included state funding to restore ecological functionality to damaged rivers, and funding from key stakeholder groups including angling and biodiversity interests. In the USA, private investment strategies such as the National Fish Habitat Action Plan are more common, where the federal state (generally the Fish and Wildlife Service), and in some area tribal initiatives and privately-raised funds, are combined through regional partnerships to address fish migration issues and habitat protection and restoration.

In all countries stakeholders and governments should work together with developers, for example hydropower organisations and other water users, on strategic regional and national planning.

Free-flowing rivers are rare and these, together with relatively un-impacted rivers with few dams should be identified for protection and restoration. In Europe substantial amounts of money are being invested to restore ecological status under the WFD. For example the Westphalia region of Germany is planning to invest 60 million euro

every year until 2027 to achieve this, and other countries also plan investments costing millions of euros. The importance of legal drivers for ecological protection and restoration is clear.

Hydropower is a significant issue on many rivers around the world with schemes dating back many decades and, today, growing interest in new schemes. A strategic compromise deal with hydropower organisations could be a mechanism to protect some of the remaining natural unimpounded rivers in return for agreements for further developments in other less ecologically important rivers. Building on this concept, hydropower resources could be used to decommission dams, particularly older and less efficient hydropower dams, and in some areas to restore naturally functioning rivers. Funding allocated by governments for nature and water projects could be used as well. The Penobscot River Restoration Project in Maine is a good example of this kind of successful collaboration (www.penobscotrivers.org).

Stakeholders in fishery and agricultural initiatives should develop coalitions to address the potential impacts of hydropower dam development. However this may be difficult to achieve unless the true costs of impoundments are recognised more widely. In their natural state all rivers can support healthy fish stocks and in the larger rivers around the globe these usually support large and important artisanal and subsistence fisheries. However, many studies have demonstrated plummeting stocks directly after dam development (e.g. Mol, 2000 & Baran, *et al.*, 2011). In addition changes in sediment transport often lead to less fertile floodplains and agricultural land and ambitions to create fisheries within the newly impounded areas generally fail.

The Mekong River is a good example where a fish resource is a major driver for the economy. Dam development has had devastating impacts on fish stocks and people's livelihoods. These socio-economic issues have recently been driving the commission of the Mekong River Basin Committee, which is seeking to establish com-

mitment to a more integrated management of the catchment and its ecology for the benefit of the people living in the watershed. The concept of tribal and indigenous land and water rights is an important one and is increasingly used around the world to initiate funding for sustainable development projects.

A significant challenge that, happily, has been met in most continents is that of cross-border rivers in which more than one country has a role to play in protecting the natural functioning of rivers. The Mekong, Nile, Rhine, Niger and Danube are examples where political will has secured integrated thinking for trans-boundary rivers.

Within rivers, notably the larger ones, the global impact of habitat fragmentation because of the rapid expansion of so-called 'green' hydropower dam development has not been addressed comprehensively. Significant UN and EU funding is still channelled into potentially damaging dam developments in the third world and it would seem sensible if some of these funds could be addressed for fisheries protections scheme and to ensure that some rivers are kept free-flowing.

TIPS

- National and international representatives (UN/ FAO) should cooperate with stakeholders (such as hydropower companies) in developing fish migration policies and management plans within a river basin framework;
- Stakeholders and local water managers should initiate and provide bottom-up input to the planning process;
- UN and EU funding should in some cases be re-assessed. Funding proposals for potentially damaging dam development schemes should first address fish ecology and migration issues. These bodies and others should ensure that some rivers are kept free-flowing.

4.10 GENERAL CONCLUSIONS

Policies concerning the protection and restoration of fish migration are well developed in Europe and the USA, where the level of habitat degradation and fragmentation is highest. Australia has good policies in place, though the level of degradation there is currently relatively moderate. Africa appears to have no continental policies in place regarding fish migration, although some strategy exists, for example in South Africa. Overall the level of fragmentation is currently low but increasing. In South America, most countries have a low level of degradation and there are therefore many free flowing rivers, although once again this position is changing. In Asia the picture is much more diverse. While the level of fragmentation in China and India is high, they both have policies in place for national river basin management and fish habitat protection. However this appears to be largely aimed at limiting the impacts of damage done in the past related to poor water management.

In general there are few specific and effective fish migration policies outside the US and the EU. The regions with greatest risk of imminent habitat fragmentation, often because of large hydropower developments, are Asia, Africa and South America. Effective policy is clearly needed in these regions which are the major emerging economic powers. It is hoped that the challenges and the resource they stand to lose will be recognised before it is too late.

EXAMPLE

Cardiff Bay Barrage. Ensuring diadromous fish mitigation

Authors: Peter Gough
Organisation: Environment Agency Wales
Country: Wales, UK



INTRODUCTION

A tidal barrage impounding the Rivers Taff and Ely in Cardiff, South Wales, was promoted by the UK government in 1990 to catalyse economic rehabilitation of the local redundant commercial dockyards and waterfront. The 1 km long barrage totally excludes saline water, as an ecologically diverse freshwater impoundment was a specific requirement. The barrage was constructed and finally closed to tidal intrusion in 2000.

The structure includes three navigation locks, five 9 m-wide sluices and a large fish pass comprising of pool-and-overfall and denil fish pass components. The 550 hectare impoundment and the sluices are capable of storing and discharging 1 in 1,000 year combined fluvial discharge and tidal surge events, and therefore provide substantial tidal flood protection to Cardiff, the capital city of Wales.

The River Taff is one of several rivers in the area that are rapidly recovering from damage resulting from the industrial revolution when diadromous fish became locally extinct. The legacy of this era was very poor water quality due to the extensive coal mining, metal works and the associated large human population to service these industries, together with multiple impounding works that supplied water and power to industry.

WHAT DID WE DO?

During initial concept and feasibility stages we worked closely with the developer and their consultants to ensure robust mitigation for the diadromous fish populations the recovery of which, by 1990, was underway. Mitigation consists of:

- A large fish pass with an operational flow capacity capacity of about 5 m³ m/s, equivalent to about 25% of the average daily flow of the Taff;
- A secondary fish pass operating during periods of tidelock when tidal levels exceed the impounded level;
- A substantial fish monitoring programme consisting, pre- during and post-construction, of marked salmon smolt releases, adult salmonid trapping about 4 km upstream in the Taff, and telemetric tracking of salmon migrations from the estuary past the barrage and into the river;
- A mitigation guarantee based on the results of the monitoring programme.

The developer committed to the annual monitoring programme for a total period of 18 years, the out-turn cost of which was about £7 m, and the 12-year mitigation programme is scheduled to last until 2020 at a forecast cost of about £4 m.

HOW DID IT WORK OUT?

The fisheries programme demonstrated that, although there was a measured impact on the migratory success of salmon seeking to pass the barrage, this was not sufficient to prevent ongoing recovery of populations of salmon and sea trout. The migration of juvenile eel past the barrage has been maintained through their use of the main fish pass, but also through their use of the navigation locks.

The scale of recovery of the populations in the absence of the barrage can only be estimated, and would have been compromised for many decades without full access to the upper catchment.

Barrage mitigation resources have been used to construct major fish passes that would otherwise have excluded diadromous fish from almost all salmonid spawning habitats and vital eel recruitment areas.

CARDIFF BAY BARRAGE

(© Cardiff Harbour Authority)



Monitoring will continue until 2020, and current observations demonstrate that salmon stock recovery is ongoing with the geographical expansion of natural recruitment accelerating each year.

LESSONS LEARNED

The development of the barrage represented a substantial threat to the environmental well-being of the iconic capital city river of Wales. The cost of ensuring that the environmental recovery of the river was not compromised, and that the fundamental 'polluter pays' principle, now widely accepted as a basis for environmental protection, is inevitably high for a development of this size.

The total cost of the fisheries programme and other environmental protection measures has been very large. However it will still be less than 10% of the overall costs and should therefore be regarded as the necessary cost of sustainable development.

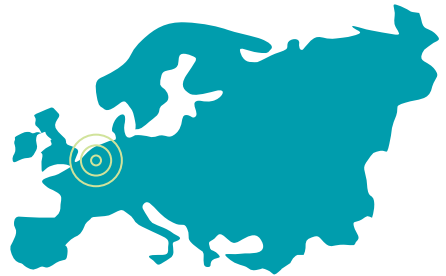
BLACKWEIR FISH PASS ON THE RIVER TAFF



EXAMPLE

Fish migration between Flanders and The Netherlands with EU funds

Authors: Marco Beers¹, Paul Naveau² & Bianca Veraart²
Organisation: Regional Water Authority Brabantse Delta¹ & Province of Antwerp²
Country: The Netherlands¹ & Belgium²



INTRODUCTION

The EU Interreg IIIa project IASM (Integrale Aanpak Stroomgebied Mark) was initiated because of problems with water quality and quantity in the small rivers Weerijs and Mark. The main objectives of the project were to improve water quality, aquatic ecology and water quantity of the rivers. Both streams have their source in Flanders (Belgium), and then flow into The Netherlands where they join the channels of Breda from where they flow through the Mark-Dintel system into Lake Volkerak. Within the Interreg project both Flanders and The Netherlands have established their

own measures, and to ensure mutual targets will be achieved a Dutch-Flanders committee was formed.

ACTIONS UNDERTAKEN

The main measures taken to improve aquatic ecology were construction of fish passes to establish upstream migration, and restoration of channel morphology. In The Netherlands vertical slot fish passes were built in the Weerijs, and in the Mark a pool fishway with overfall weirs (cascades) in a parallel stream was built.

In Flanders the province of Antwerp replaced a weir with a pool and weir fish ladder on the Weerijs, and within the Klein en Groot Schietveld Nature 2000 site and in association with 'Agentschap Natuur en Bos', a stream restoration project combined with a parallel fish migration channel was completed. Additionally 'Vlaamse Milieu Maatschappij' removed several weirs on the Rivers Weerijs and the Mark and installed several vertical slot fish passes.

RIVER WEERIJS

Vertical slot fishway next to weir in 'Weerijs'.



OUTCOME

Fish passes have been built at all weirs on the Weerijs and fish can now migrate upstream from Lake Volkerak into Flanders and the Nature 2000 site. In the Mark, two weirs are still without fish

passes and therefore remain as barriers for fish migration. Regional Water Authority Brabantse Delta will construct fish passes at these weirs soon. An important part of the project is the evaluation and research of fish passes. In 2005, 2006 and 2009 several fish passes in the Weerijds and the Mark in both Flanders and The Netherlands were evaluated for their ecological functioning. All of the fish passes investigated appear to be attractive to fish and have good passage efficiency. During the evaluations a lot of common species, such as roach, perch and gudgeon were caught. The evaluation showed that more critical species, such as chub and ide also use the fish passes and the populations of these species will hopefully recover in our systems.

LESSONS LEARNED

During the project both countries exchanged

data and knowledge about the two rivers. As a result of this process we learned a lot from each other, and the importance of international cooperation and funding in these types of restoration projects became evident. Therefore after the project we will continue to exchange evaluation results of fish passes and other ecological research in the rivers.

Furthermore we realize how important it is to be mutually aware of our goals for fish migration in trans-boundary streams and rivers and waterways that form a natural border between the two countries. In meetings, such as the steering group of the Flemish Waterschap Mark en Weerijds, we try to harmonise these goals and priorities for fish migration in rivers, e.g. for the Molenbeek and Pools Heining (Kleine Aa and Heerlese Loop in Flanders).

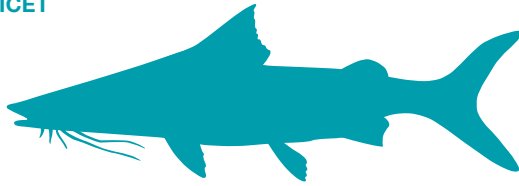
FIGURE 1

Fishways and barriers in 'Mark' and 'Weerijds'.



Management implications for Dourada (*Brachyplatystoma rousseauxii*)

Author: Claudio Baigún
Organisation: Instituto Tecnológico de Chascomús, CONICET
Country: Argentina



LIFE CYCLE

The dourada belongs to the Pimelodidae family and is one of the largest Neotropical catfish, reaching up to 1.90 m in length (Barthem and Goulding, 1997). The biological cycle comprises long migratory movements of up to 3,500 km along the Orinoco and the Solimões-Amazonas axis (Barthem and Goulding, 1997). In the Orinoco basin it is found from the delta to the Apure River and in main tributaries, whereas in the Amazon there are migrations from the estuary, where their larvae, juveniles and pre-adults grow and feed, to main tributaries in the upper basin at the Andean piedmont where adults reproduce (Alonso and Pirker, 2005).

Migratory movements start as fish are still pre-adults when they leave the nursery areas, mostly after one year, to feed and grow during their second year in the middle Amazon before moving upstream for spawning in the headwaters. This species can be considered to have a periodic strategy since it grows fast during the first two to three years reaching first sexual maturity in the third year, exhibits a high fecundity, long generation time, long life span and a breeding cycle that is synchronized with the hydrological regime. Growth parameters vary between stocks with asymptotic length ranging from 152 to 207 cm and a growth rate (K) from 0.08 to

0.32 m/year. Natural mortality rate has been estimated at 0.27 to 0.52 (García Vazquez *et al.*, 2009).

GEOGRAPHIC DISTRIBUTION

The species is spread along the Orinoco and Amazon basins, being found in Brazil, Bolivia, French Guyanas, Peru, Colombia and Venezuela (Lundberg and Littmann, 2003). The species range extends into major tributaries such as the Caqueta, Juruá, Purus, Madeira, Içá, Japurá and Apure Rivers.

FISHERY RELEVANCE

An industrial fishery has been established along the middle and lower Amazon, from which a large proportion of the catch is exported, promoting economic activity and a living resource for fishermen (Parente *et al.*, 2005). However, since almost 90% of the fish are purchased at low prices by the industry and the local intermediaries that transport fish to regional markets, revenues for fishermen are insufficient and this leads to heavier fishing pressure.

In the upper Amazon basin the species also represents one of the main targets for the artisanal fishery. Within the estuary, immature fish of only one year old are excessively exploited by artisanal and industrial fishing fleets (Barthem and

Petrere, 1995) whereas in the middle Amazon captures are concentrated mostly on fish of two years in age, and this fishing mortality is considered to be limiting (Alonso and Pirker, 2005). In the Orinoco the species is also one of the main fishery targets (Novoa, 2002).

HUMAN IMPACTS

Threats for species conservation come from different sources. Overfishing is considered a major factor close to urban areas (Petrere *et al.*, 2004; Alonso and Pirker, 2005) and by-catch effects also represent a major source of undesirable fishing mortality. In the upper basin at the Andean foothills threats comes from mining, damming, deforestation and agriculture as water quality and habitat are modified. Dams on the Apure subbasin of the Orinoco system and planned hydroelectric dams across the Amazon basin (Barthem *et al.*, 1991; Bayley and Petrere, 1989) are envisaged as the most serious threat for migratory species conservation as they could block upstream adult movements to spawning areas and reduce downstream larval drift to estuary nursery grounds.

FUTURE DIRECTIONS

Conservation of dourada represents a major challenge, partly because it is a trans boundary species that exhibits long distance migrations. Concerted conservation and management

measures over the entire distribution area and in each country are required to avoid overfishing, undertake critical habitat conservation and to avoid disrupting the species life cycle.

Although some biological knowledge has been gathered it is still necessary to assess how the population dynamics are related. Not only to the hydrological regime but also to increasing fishing impacts, and how both factors can be used to predict maximum sustainable exploitation level. Better management practices should be applied by recognizing different areas that are used for breeding, growth and reproduction, thus promoting specific regulations (Fabr e *et al.*, 2005).

In addition a community-based participatory framework for resource management should be encouraged. Improvements in fishermen socio-economic conditions directed to increase per-capita incomes and to develop aggregated value chains as alternative livelihoods and are recommended to reduce fishing pressure.

It is essential to consider river fragmentation as this can severely disrupt the species life cycle by isolating critical spawning and breeding areas. Based on past experience, fishways and stocking are unlikely to be suitable tools to mitigate dam impacts for this emblematic species.

THE DOURADA

(  Carlos Hoyos).



SPECIES EXAMPLE

Current protection of Chinese sturgeon (*Acipenser sinensis*)

Authors: Tian ZhiFu and Jiang GuZheng
Organisation: Changjiang Water Resources Protection Institute
Country: China



LIFE CYCLE

The Chinese sturgeon (*Acipenser sinensis*) is a large migratory fish which is unique to China. The male sturgeons mature when they are 12 to 15 year-old, while the female sturgeon mature at 17 to 25 years. The mature sturgeons migrate from the sea to the Upper Yangtze River from May to June each year, and after spawning during October to November they migrate back downstream to the sea. The juvenile sturgeon hatch and after about a year they migrate downstream, reaching the Yangtze River mouth between May and June. They remain there, feeding until the end of September and they then migrate to the open sea to grow.

STATUS

The Chinese sturgeon has always been the most important economic fish species in the Yangtze River with a high economic and academic value. The abundance of Chinese sturgeon has declined since the 1970's for the following reasons:

- 1 Blockage of migration by the hydropower stations: The Gezhouba dam has blocked migratory passage for spawning and recruitment, and has therefore affected the sturgeon species by:
 - A reduction of available spawning ground: the sturgeon cannot reach the spawning grounds because of the Gezhouba dam. Although similar grounds for spawning and

breeding exist downstream of the dam, the overall quantity is significantly reduced through human interference, water levels, current velocity and sedimentation all of which are affected by the release of water from the dam;

- A reduction in the size of the breeding community: changes in the environmental conditions result in breeding failure due to the degradation, and failed or delayed development of the gonads. A small number of sturgeon with normal gonads were unable to breed because of the lack of spawning grounds with favourable conditions for laying eggs;
 - Mortality in passing the dam: The sturgeons migrate upstream for breeding. Twenty years after the river was dammed at Gezhouba, approximately 3 to 5 sturgeon die each year from strike wounds.
- 2 Restriction of natural breeding: natural breeding of the sturgeon ended 2 to 3 years after the river was dammed at Gezhouba. Restoration of the species, after it has been largely eliminated, is severely constrained by the very long life cycle and the long time for fish to reach sexual maturity;
 - 3 The fishery: during the period 1972 to 1980 when the fishery was not regulated, the annual catch fluctuated between 394 to 636

sturgeons. The highest number recorded was 1,163 sturgeon (including 161 sturgeon found upstream of the dam) when the river was closed in 1981 and the sturgeon accumulated downstream of the dam. In 1983 and 1984, the catch of sturgeon reached 2,176 but reduced to approximately 500 fish each year from 1996 to 2000;

- 4 Wounds by ships: with the development of navigation in the Yangtze River, the number of ships and volume of navigation increased significantly. Chinese sturgeons are vulnerable to injury by boat propellers, with incidents occurring every year.

RESEARCH AND MANAGEMENT

The Chinese government wishes to protect sturgeon resources, and has invested significant financial and human resources in research. Since the 1970's, considerable research has

been undertaken on the fish passage facilities at Gezhouba, and campaigns to protect the sturgeon have been established.

Due to the large size of the fish and the small passage facility, it is very difficult for sturgeon to pass downstream over the dam after spawning. Some new spawning grounds downstream of the dam have been found.

Fish passage was not initially recommended for the protection of sturgeon, with other measures introduced such as artificial breeding and stocking, trapping and passing sturgeon over the dam, fishery prohibition, etc.

At the same time the dissemination of information promoting the protection of sturgeon was implemented throughout the river basin. A facility to receive and care for wounded and captured sturgeon was also launched.

RELEASE OF YOUNG CHINESE STURGEONS



>>SPECIES EXAMPLE

CHINESE STURGEON



The Chinese Sturgeon Research Institute was founded in 1982 with a mission to undertake research on artificial propagation. In 1983 they were successful in achieving propagation and that year the species was listed as a National Class I protected animal. Following this 6,1 million juvenile sturgeon were released into the Yangtze River by the Yangtze River Fisheries Research Institute and the Chinese Sturgeon Research Institute between 1983 and 2001.

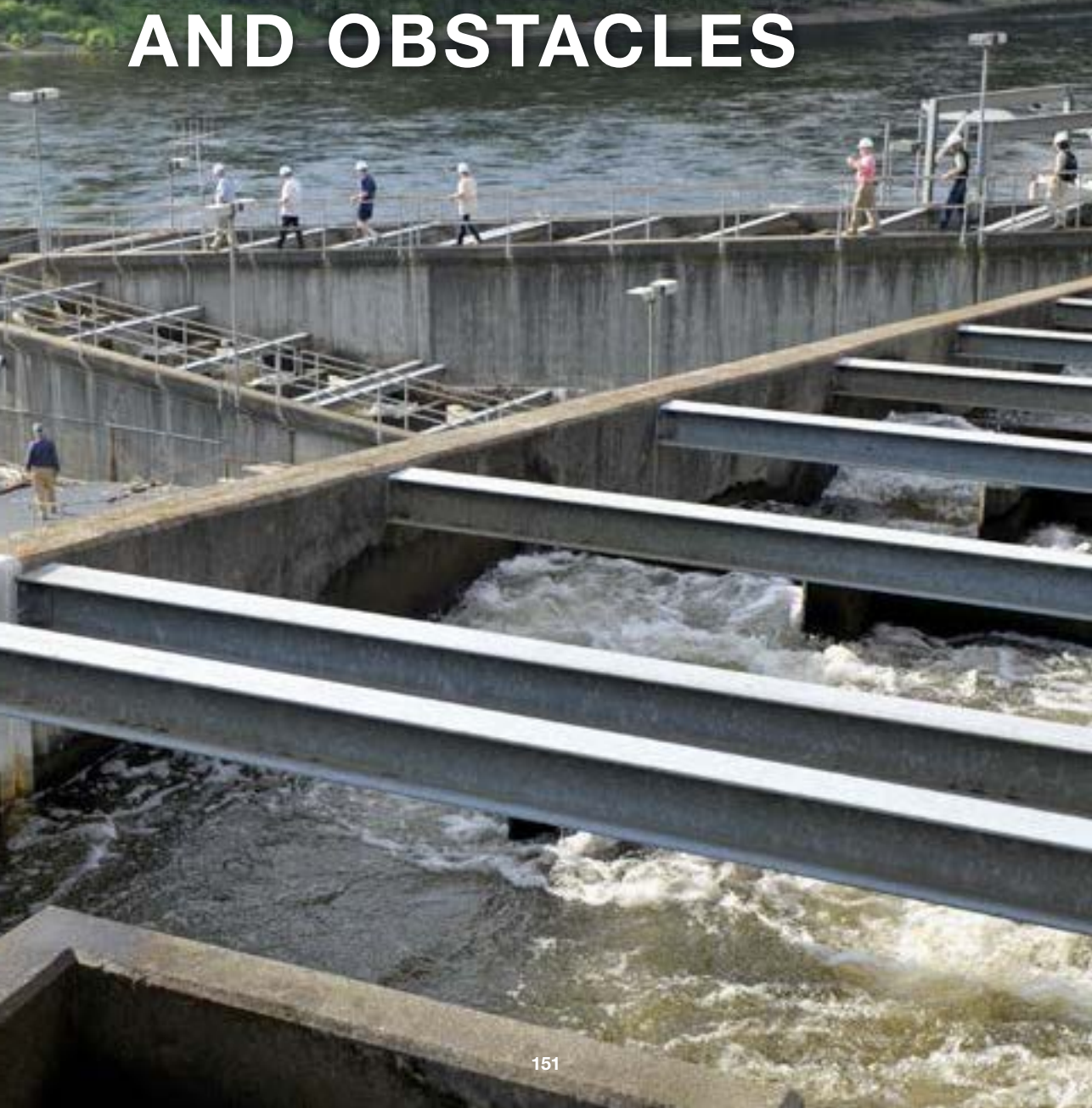
The Yichang Chinese Sturgeon Conservation Area was set up in 1996 to protect the spawning grounds downstream of the dam and in 2002 the Yangtze Estuary Chinese Sturgeon Conservation Area was established to protect

their habitats. In 2009 the first fully artificial reproduction of cultured Chinese sturgeon was achieved.

FUTURE DIRECTIONS

Modern biological technology should be applied to preserve the genetic material of Chinese sturgeon. The establishment of a captive artificial sturgeon community and allopathic speciation is a way to preserve the species. The natural community could be restored and multiplied through increased artificial propagation for the purpose of enhancing the preservation of their natural community. Protection should be strengthened to form an overall system for the conservation of Chinese sturgeon.

CHAPTER 5 SOLUTIONS FOR HAZARDS AND OBSTACLES



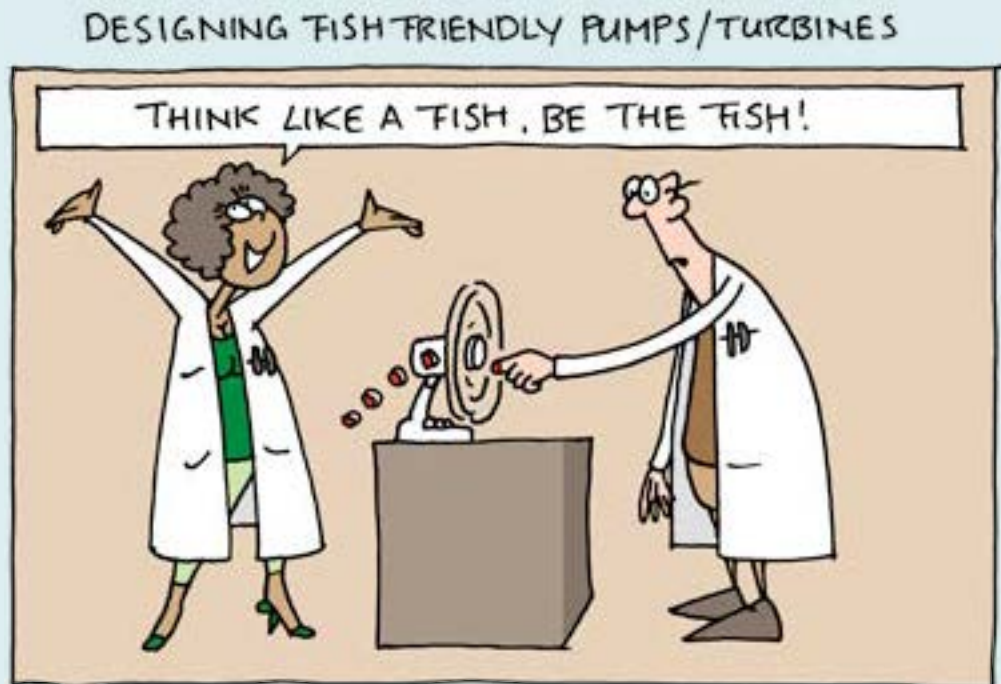
INTRO

Solutions for fish passage change over time as our knowledge, technology and most of all our experience evolve. Frequently, fishways may prove to be effective but not necessarily efficient. We must learn from failings and improvements to secure the most effective and efficient passes possible. Increasingly we are learning that international exchange and dissemination of fish passage information is supporting learning and knowledge transfer.

Throughout the world there are regular national and continental conferences on the subject of fish passage taking place. Each year these conferences play an important role in the exchange of knowledge on this topic and they attract significant numbers of professionals.

Examples of such events are the series of international fish passage conferences organised in the USA by the University of Massachusetts. Elsewhere the language barrier is an obstacle that needs resolution: there are many studies worldwide representing a substantial volume of information but they are not published in the English language and are therefore largely unavailable.

Many countries have their own Technical Guidance on fishway and fish migration solutions, but many of these are in languages that make them unavailable to a broader international public.



5.1 FISH MIGRATION FACILITIES: THE CURRENT PICTURE

Free migration of fish is essential if their life cycles are to be completed and the populations maintained at optimal levels. All species of fish migrate during their life cycle, not just the better known long-range migrants such as salmon, dorado and eel. The challenge of providing fish passes for fish to ascend man-made barriers is well known, however the lesser known issues around downstream migration are equally critical and are relatively unrecognised (Williams *et al.*, 2011).

5.1.1 Upstream facilities

Fish pass facilities to provide opportunity for the upstream migration of fish, principally salmon and sea trout, have existed since the 19th century in Europe and the USA. The first fish ladder in Brazil was built in 1911 at Itaipu. In some countries fish pass solutions date back to the 18th century or even earlier. Some of the earliest passes were probably quite ineffective, largely because of poor construction and insufficient maintenance of the facilities and incomplete understanding of the swimming capabilities of fish.

This occasionally resulted in a change of focus to financial compensation for damage to stocks, or to fish stocking in mitigation for damage and angling, and sometimes also because these species were protected by law. Protective legislation in the UK for salmon, for example, is known from the 15th century.

Most attention has been on the large and long distance migratory fish such as the Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta*), European eel (*Anguilla anguilla*) and, in some countries, the sturgeon (*Acipenser* spp., *Beluga* spp.). This was clearly due to the high economic value of these species to commercial fisheries and angling.

New requirements to provide free passage for fish to fulfil ecological targets and as part of

habitat restorations, together with an era of intensive fish pass research based on field testing and small scale fish pass models (Denil, 1909; Price-Tannat, 1937; Aitken *et al.*, 1966; Larinier *et al.*, 1992; Clay, 1995; Pavlov, 1989; Gebler, 1998; Boiten, 1989 & 2005) quickly lead to many variants of technical fish passes. Pool passes became commonly used in the early 20th century, and remain so in some regions. These were mostly pool and traverse (plunging flow) or some variant of vertical slot (streaming flow) passes. In the 1970's Denil passes became common and in the last 30 years super-active bottom baffle (Larinier, 2001) passes, vertical slot and nature like bypasses have also become commonly used.

Technical solutions such as these will, if correctly designed and built, enable efficient fish migration but they often cannot, in themselves, directly lead to full ecological restoration or protection. This is because the impact of the structure on which they are built remains. Neither can these technical fish passes represent, in anything other than a small way, additional habitat for fish.

Semi-natural solutions such as bypass channels, nature-like channels around obstacles, and in-river rock ramps are increasingly used instead of technical fish passes. These structures require more space, as they must generally be installed at low gradients, however their appearance can be attractive and therefore they are proving to be increasingly popular.

The most effective solution to achieve upstream migration of all fish species, including small fish that have no direct economic value, is of course to remove the barrier all together. Wherever this is feasible, when considered against hydraulic and flood risk changes, this option should be vigorously pursued.

The biggest problem in constructing upstream fish passage facilities or removing barriers is generally financial constraint. Effective solutions in highly populated areas or at high-head

Hydropower plant in the River Ebro

(Mequinenza, Spain).



hydroelectric dams represent significant technical challenges, however more often it is the decision whether to allocate public funds that is the constraint.

The large number of obstructions, occasionally in excess of a thousand in some rivers, means that much of the problem for restoring the free migration of fish lies with finding sufficient funding. Technical and semi-natural fish passes are expensive and this means that in many cases it may be possible to build only a small number each year. In the UK (England & Wales) about 50 fish passes have been built in the last five years, but this is relatively slow progress against the 25,000 known man-made barriers, approximately 5,000 of which are important to address WFD commitments. Slow progress such as this is common around the world, and partly in an attempt to resolve this many partnerships have been set up by user groups, such as rivers

trusts and anglers, to raise funds to make improvements, including the construction of fish passes. In the UK there is renewed ambition for fish migration improvement through these organisations, working either independently or in collaboration with the Environment Agency (the UK Government regulatory authority in England and Wales).

5.1.2 Downstream facilities

Problems for downstream migration are relevant mainly to juvenile phases although in some species to adults as well. Significant problems for safe and timely downstream migration of fish in Europe have only recently been widely acknowledged, and this will inevitably be the case around the world wherever the issue has been considered. The issues in securing downstream passage are different in that many obstructions are, in contrast to securing upstream migration, relatively easily passable in the downstream di-

rection. The exceptions to this are firstly when some aspect of fish behaviour makes them reluctant to pass over the obstruction or unable to readily find a safe migration route or, more frequently, when the obstructions support abstractions into which the migrants might be entrained. Both are significant constraints and more work is needed to understand how they may be effectively resolved. Downstream migrants generally take advantage of principle currents and fish may have little time to react to, even if they are physically capable and elect to do so, of avoiding areas of potential danger.

The increasing demand for hydropower, and especially now the great interest in low-head hydropower, is due to rapidly emerging demands for renewable energy. This is a major problem for fisheries around the world. The provision of effective screening and bypass facilities at hydropower developments is a legal requirement in some countries, such as the UK, but in many cases this can be sufficiently expensive to significantly erode the economic case for development. In other countries there is currently no such legal protection.

Effective fish protection facilities are often much more difficult and complex to achieve than the facilities for upstream fish migration. The problems for downstream migration when abstracting water for mills, navigation channels, hydropower, for commercial use or for potable supply are widely recognised in most European countries, however experience with resolving the problems appears to be largely restricted to Germany, France and the UK. In these countries and in North America problems for downstream migration have been thoroughly examined for anadromous species, in particular salmonids and eel (e.g. Larinier, 2001). However little information and experience is available for other species, because until recently there was little concern for them.

Today a large number of systems exist to prevent damage caused by water intake at hydroelectric power stations. These generally consist

of physical screens, either alone or together with behavioural exclusion systems. The most efficient techniques available appear to be physical barriers, but these can represent significant operational challenges. Behavioural solutions are therefore attractive but remain largely experimental due to the fundamental problem in influencing behaviours of a range of fish species and, consequently, their current low rate of reliability. It appears that a fully satisfactory solution has not been devised, and indeed might not exist. This is particularly the case for large power stations and hydropower plants (Larinier, 2001) where extremely high rates of fish entrainment may occur. Behavioural exclusion systems have varying degrees of success and are often critically dependent on the location and precise operation of the device.

In the USA studies to adapt turbine design for safe fish migration have been ongoing (e.g. Cada *et al.*, 1997) so that passage through hydropower turbines may be less damaging, whilst the emerging popularity of Archimedes screw turbines in Europe appears to offer a solution that is relatively benign to fish.

It remains the case that sufficiently effective and reliable facilities for downstream fish passage and intake protection measures are not yet available, and may not even be achievable, and that further research is needed.

5.2 FISH PASS DESIGN AND CONSTRUCTION: A THREE-STEP APPROACH

This section describes the approach to resolving upstream and downstream migration problems at a range of structures. It is partly based on existing manuals for restoration of upstream fish migration (Larinier *et al.*, 2002; Armstrong *et al.*, 2005; Kroes & Monden, 2005; Kapitzke, 2010, etc.) and for downstream migration (Turnpenny *et al.*, 1998a; DVKW, 2002; DVWK, 2004; Turnpenny & O'Keefe, 2005; DWA, 2005), on other published sources, and also on the experience of the authors. We refer the reader to these manuals for further technical and design information.

THE THREE BASIC STEPS

STEP 1

Definition

Management objectives

Features and conditions:

- The nature and operational protocol of the obstacle;
- Financial, ownership and legal requirements;
- Hydrological and hydraulic factors;
- Geology, geomorphology and hydro morphology;
- Section profiles, topography, substrate type and amount of debris.

Target species:

- River zone;
- Fish species present.

Choice of the specific solution

(what facility will achieve the objectives):

- Solution for combined up- and downstream functionality or;
- Upstream migration facility;
- Downstream migration facility.

STEP 2

Design

General design criteria:

- Biological criteria for target species;
- Hydrological information;
- Hydraulic criteria;
- Topography and structural condition of the structure;
- Topography of the local river bed.

Specific design criteria:

- See different technical manuals;
- Future monitoring requirements;
- Health and safety.

Licences and permits:

- Secure all permits and licences which are required for construction.

STEP 3

Construction and maintenance

Final detailed design:

- Biological and hydraulic criteria;
- Logistical issues for construction.

Coordination of construction:

- Project team including fish biologist and engineers;
- Procurement of contractors for construction and supervision;
- Supervision and resolution of issues as they arise during construction.

Protocols for ongoing maintenance:

- General description of operation of facility;
- Timing and frequency of inspections;
- Required methods and materials;
- Health and safety issues.

Each step is discussed in this chapter, including the identification of need, the starting points and the principles. It should be noted that some solutions for hazards and obstacles may apply to both upstream and downstream directions. There is often more than one option to deliver the objectives, and each should be studied and considered in an integrated way to identify the optimum solution for each site. Although a solution that works for migration in both directions is always preferred, in some cases discrete structures for upstream and downstream migrants may be required. Therefore each step described here deals with upstream and downstream migration separately.

5.3 STEP 1: DEFINITION

The definition phase comprises a study of the existing situation and constraining factors for migration, local features and conditions, target species and an outline choice of a specific solution. It is very important that the different disciplines of ecology, hydrology and engineering work closely together at this stage to achieve an optimal and deliverable solution.

5.3.1 Upstream fish migration

Solutions for hazards and obstacles are always site-specific but depend on basic criteria and

principles, the nature of the river, and the target fish species. Some types of migration barriers might be quite unique to certain areas or, more often, are characteristic for water types, for example: rivers and streams in highlands, rivers and streams in lowlands, coastal zones and flatlands. Each river type is characterised by the presence, sometimes temporal, of specific groups of fish species.

Features and conditions

For each site a description of the local features and conditions is required so that an optimal concept might be identified. The concept should be influenced by the long term plan or vision for the river basin, which is partly a reflection of local sociological need. The plan itself will be influenced by the characteristics of the surrounding area, and hydrological, biological, financial and legal factors. The critical environmental questions to be answered are:

- what are the target species, and at what time of the year and in what hydrological conditions do they need to migrate?
- what are the structure, function and projected life of the obstruction and how is it operated?
- what are the seasonal flow rates and what might limit the amount of flow that can be used for the fish pass?

Taimen (*Hucho taimen*)

Eg-Uur River, Mongolia (© Zeb Hogan).



Atlantic salmon (*Salmo salar*)

Estonia (© Saulius Stakenas).



Giant catfish (*Pangasianodon gigas*)

Chiang Khong, Thailand (© WWF / Suthep Kritsanavarin).



The vision for the river basin and specifically for the river in question should be central to the strategy to improve fish passage opportunity.

Target species

Target species can be identified on the basis of river typology studies, or zoning, or simply on the known assemblage of species which local fisheries staff and anglers will identify. The choice of target species will determine the design (e.g. type of solution, size, flow, head drops and minimum depth) and location of a fish pass.

Every fish species has its own characteristic swimming capacity and typical behaviour. The swimming capacity depends on morphology, condition and length of the species, and the water temperature during their migration. Behaviour of fish is variable between species, and will vary on a seasonal and daily basis in response to a wide range of factors. Behavioural issues of relevance include orientation of fish either as indi-

viduals or shoals within the river channel during migration, their residence time at barriers, the rate of onset of maturation, and responses to hydraulic parameters and light amongst others.

Choice of solution

Passage can always be secured by removal of the barrier! This should always be the preferred option and should be thoroughly considered first. Many impounding structures are relict industrial structures remaining from uses that have long-since ended. Since they were constructed many years ago substantial riverside development, such as bridges, embankments and houses may have been built that rely on the upstream water levels supported by weirs and dams. In such cases removal may therefore not be possible without accepting significant risk, but the option should always be fully explored.

Where removal is not possible, reducing the barrier height or construction of semi-natural solu-

tions such as nature-like bypasses or rock ramps should be considered next.

The installation of simple passage devices, such as flow detectors that help larger fish to migrate upstream, should also be considered. However many such structures do not provide passage opportunity for smaller species.

Technical solutions to secure the passage of fish past an obstruction are variously referred to as fishways, fish passes, fish passages and fish ladders. The principle is always to use migratory cues to attract migratory fish to a specified point downstream of the obstruction and to allow them to pass upstream by providing a route in which water velocity and turbulence is both attractive and within the fishes swimming abilities. Most fish passes that fail do so, because they are not sufficiently attractive to fish, or are not located where fish naturally assemble. The range of hydraulic preferences between species is a major challenge if a single passage structure is to function adequately for the whole fish assemblage.

In the past, focus has been on securing pas-

sage for principle species such as salmon, eel and shad. However this is changing in more and more countries where overall ecological status is the goal, and this requires free longitudinal and lateral migrations for all species of fish. The selection of a passage solution should therefore address the whole fish fauna wherever this is technically feasible, and where it is not an explicit management statement should be made so that river basin goals may be moderated.

Solutions for the free migration of fish can be categorised in order of preference:

- 1 Natural solutions (restoration of the natural situation, for example dam removal, partial breaching or lowering);
- 2 Semi-natural solutions (fish passes that provide a nature-like migration route for fish and, where possible, additional and new habitat);
- 3 Technical solutions (such as baffle or pool and weir fish passes, eel ladders or fish lifts);
- 4 Adapted management of the barrier (notably the flexible use of sluices and gates to sustain migration).

Taking all of these factors into account, together with other locally specific matters and condi-

Table 5.1 Safety issues driving Dam Removal in the USA
(*American rivers, 1999*).

Cause of failure	Details	Percentage
Overtopping.	<ul style="list-style-type: none"> • Inadequate spillway design; • Debris blockage of spillway; • Settlement of dam crest. 	34
Foundation defects.	<ul style="list-style-type: none"> • Differential settlement; • Sliding and slope instability; • High uplift pressures; • Uncontrolled foundation seepage. 	30
Piping and seepage.	<ul style="list-style-type: none"> • Internal erosion through dam caused by seepage (piping); • Seepage and erosion along hydraulic structures such as outlet; • Conduits or spillways, or leakage through animal burrows. 	20
Conduits and valves.	<ul style="list-style-type: none"> • Cracks in dam; • Piping of embankment material into conduit through joints or cracks. 	10
Other.		6

EXAMPLE

Removing unused weirs to restore salmon connectivity

Author: Carlos Garcia de Leaniz
Organisation: Swansea University (UK)
Country: Spain



INTRODUCTION

Obstacles are probably responsible for the extirpation of more migratory fish populations worldwide than any other stressor. Low-head dams and weirs can greatly limit the distribution and abundance of Atlantic salmon and other migratory salmonids in streams. Weirs can significantly increase the vulnerability of migratory fish to anglers, alter natural migration patterns, and exacerbate the effects of opportunistic predators.

Overcrowding of fish at downstream pools can also facilitate the spread of parasites and infectious diseases, magnify the impact of pollution incidents, and increase the risk of mass mortalities, particularly at low flows. Yet, the benefits of removing low head dams and small weirs (i.e. those that do not represent a permanent or insurmountable barrier to fish migration) are only recently beginning to be addressed.

WHAT DID WE DO?

At least 40 weirs and low head dams have been removed in 20 Spanish rivers for environmental reasons (chiefly to increase the area accessible to salmon and other migratory fish) during the last two decades, and many more are due to be removed within the next few years. These have ranged in height from 0.6 to 6.5 m (mean height = 2.4 m). Various benefits are sought from weir removal, including:

- 1 To facilitate upstream fish passage, particularly to the spawning and nursery grounds

(typically of higher quality and located in the headwaters and tributaries);

- 2 To ease downstream migration of smolts, particularly at low flows;
- 3 To reduce mortalities caused by stress, spread of infectious diseases, poaching, predation and increased vulnerability to angling.

HOW DID IT WORK OUT?

The first weir to be breached in Spain for environmental reasons was possibly the Sinde weir (2 m) in the River Ulla, which was breached with hand tools during 1993. A few years later, in 1999, five unused weirs were demolished or breached in the River Asón with the aid of a hydraulic backhoe digger fitted with a hammer/breaker. Work was carried out during the summer to minimize silt transportation and run off. In some cases, the largest slabs and rocks removed from the weirs were used to stabilize the river banks. In other cases, these were simply left in place and were carried away with the subsequent autumn flows. A few months after the demolition of some of these weirs, migratory salmonids were seen ascending and spawning in areas formerly of difficult or impossible access.

LESSONS LEARNED

Not all barriers can be removed easily, thus some form of prioritization strategy is required. We used a simple decision flow chart to demolish unused weirs in the salmon rivers of North Spain based on a field inventory. Abandoned weirs or

those without water abstraction rights are first targeted as these are legally easier to demolish. Although experience in removing weirs in Spain is still small and fragmentary we found the following advantages and disadvantages of weir removal over other solutions:

Advantages

- 1 Solves upstream and downstream fish passage;
- 2 Typically cheaper than any fish pass;
- 3 Achieves direct, integral stream restoration;
- 4 Addresses other problems (e.g. structural

safety);

- 5 Does not hinder future options.

Disadvantages

- 1 Not always practical or feasible;
- 2 Short-term mobilization of sediments, potentially toxic;
- 3 Limited experience in Europe (compared to fish passes);
- 4 Societal & cultural issues, historical value of some weirs;
- 5 Paperwork and red-tape: may take a long time to do it.

WEIR REMOVAL IN PRACTICE

The removal of the Trefilerias weir in the River Gandara which is a tributary of the River Ason (Cantabria).



Strategic-level assessment of weir removal opportunities

Authors: Alex Humphreys¹ and Peter Gough²
Organisation: Atkins Ltd¹ and Environment Agency Wales²
Country: United Kingdom



INTRODUCTION

In river catchments that contain multiple obstructions, it is sometimes impractical to undertake detailed assessments of the risks and opportunities for improving fish passage at every barrier and better to do so in an integrated way. There is a clear need to develop methodologies that can be implemented over many sites in a rapid, yet above all, consistent manner. There are many issues to consider when assessing the most appropriate course of action for addressing a migratory barrier. If a barrier has been present in a watercourse for a significant period of time, then the river will have adapted to its presence and removal may well give rise to significant changes. These changes could have an impact upon a diverse range of receptors, from human beings to flora and fauna and even the river itself.

REMOVAL OF THE KENTCHURCH WEIR



The potential impacts on human beings alone occupy a broad spectrum, incorporating features such as infrastructure (e.g. bridges, river walls, and service crossings), private properties, agricultural land, public rights of way, flood risk and abstractions. The risks are also likely to vary significantly from site to site.

The preferred outcome in all cases is to remove the barrier, delivering benefits to all fish, other fauna, and to river morphology as required by the EC Water Framework Directive (WFD). In practice this is not possible for all sites, and it is important to understand the constraints, and to identify other options to achieve the objective.

Clearly, the task of removing most barriers warrants detailed assessment by a multi-disciplinary team. A core team containing expertise in fisheries, geomorphology and river engineering is required and other disciplines to supplement this core team will vary in accordance with the specific needs of a particular site. For example, one site may warrant detailed appraisal by a heritage expert, whereas another site may lie alongside protected habitats in a designated location, which may require the advice of an ecologist.

A strategic level assessment of barriers within a river catchment will identify the nature of further work required for each site within the study area

REMOVAL OF THE KENTCHURCH WEIR

This old weir, probably 19th century, ended its functional life in about the early 20th century. Together with other weirs in the River Monnow catchment (part of the River Wye on the England-Wales border, UK) this weir blocked migrations of Atlantic salmon, lampreys, shads and eel to nearly 180 km of functional habitats. In 2002 one of just 3 remaining large weirs was naturally breached during a flood, and following this a large fish pass was built on the lowest weir. That left Kentchurch - a highly rural weir about 35 m wide and 2.7 m high, and with no role for water management.

Removal was considered to be the best option as the weir was showing signs of collapse and the benefits of removal for river morphology, flora and fauna development and full un-constrained access for all species of fish were considered to far-outweigh the costs of repair. Planning for removal took more than 1 year, but actual removal took just 2 days! Monitoring of river morphology and river bed changes, and comparison of these with pre-removal modelling predictions, together with fisheries and macroinvertebrate monitoring are now underway so that we may gain maximum learning from this, the largest weir removal yet undertaken in England and Wales (Photos A to F).



>>EXAMPLE

if they are to progress towards carrying out the removal. A more detailed assessment to tackle barrier issues at a specific location would probably require the appointment of the necessary experts in order to assess fully the risks and opportunities linked with removal. The overall assessment of the team is critical in order to draw conclusions on the options at each site and potential impacts that a barrier removal could have on issues such as river hydro morphology, heritage and ecology.

WHAT DID WE DO?

Kentchurch Weir on the River Monnow in South East Wales, UK, is an example of a large weir that has been through this process. The objective was to examine options to restore connectivity to the river and to remove a significant migratory barrier from an important tributary of the River Wye. This included a strategic-level assessment, which identified the need for further work to clarify options, and the production of a detailed document that incorporated the multi-disciplined assessments into a coherent study justifying the cost, risks and opportunities.

The first objective of the core team was to establish the scale of obstruction that the barrier presented for various species of fish, and the options to restore free migration. The next step was then to identify the receptors that could be affected by the anticipated changes to the structure. Once this was done, the appropriate course of action depends on the level at which the study is being implemented.

HOW DID IT WORK OUT?

The study confirmed the preferred option of weir removal was feasible. We proceeded to identify how the barrier could be removed, and then how the environment surrounding the barrier might change once the removal had taken place. The study was sufficient to inform regulatory authorities and land owners of the viability of the project, and the Environment Agency of the scope to achieve the WFD objectives in this river.

REMOVAL OF THE KENTCHURCH WEIR



LESSONS LEARNED

It is clear that the nature of barriers in river systems and their impact on the environment varies hugely. Consequently, there is no 'one size fits all', prescriptive methodology for assessing the risks and opportunities of resolving fish migration or of removing these barriers from our rivers. However, we developed a rapid strategic assessment approach including a robust appraisal of the fisheries, geomorphology and engineering risks and opportunities associated with removing barriers. Armed with this core assessment, it is then possible to specify the further work and supporting studies required to establish whether there is a favourable balance of risk and opportunity associated with demolishing an in-river barrier.

tions (e.g. the type of water body, target species, and the management of the structure) and the financial scope for action, the optimal passage solution for a migration barrier can be identified.

Ad 1

Natural solutions; e.g. dam and weir removal

The optimum ecological solution for maximum fish passage efficiency is clearly the complete removal of the structure. This is increasingly considered as the most cost-effective solution, and today is becoming more and more common. In the USA in 2012 for example, at least 100 dam removals are planned (www.americanrivers.org).

Weir or dam removal restores the natural situation at that location allowing natural dynamics and channel structural diversity to recover and a natural hydro morphological regime to be restored. This solution is preferred because not only is migration in both the longitudinal and lateral direction restored, but also local habitats generally recover to their pre-impoundment quality. A feasibility study is usually needed to identify any potential constraints such as increased flood risk downstream and

local bank erosion and bank stability matters. Particularly if there are any man-made river bank structures close to the proposed works. These often constrain objectives for weir removal projects.

When it is not possible to completely remove the barrier, the next preferred approach is to achieve a solution as close as possible to a natural regime, perhaps by lowering the crest height of the dam. It is often important to recognise that, in addition to clear environmental benefit, dam removal can often solve significant safety and ongoing economic commitments for maintenance as well.

Safety issues

These have proved to be a major driving force for dam removal in the USA (American Rivers, 1999). According to the Association of State Dam Safety Officials in the USA, the average life expectancy of a dam is 50 years. Approximately half of all dams in the USA are now more than 50 years old, and the American Society of Civil Engineers estimates that by the year 2020 that figure will reach 85 percent (ICOLD, 1998).

Table 5.2 Overview of natural solutions to restore upstream migrations

Natural solutions	Description	Principle Application
Removing dams and weirs.	Impounding structures that may be removed, subject to local river management review.	Small streams and rivers, and occasionally larger rivers (low and high head).
Removing weirs in combination with restoration of natural habitat (e.g. river restoration).	The removal of weirs or dams often needs to be combined with lengthening the stretch of the river, in order to manage flow velocities and restore natural meandering.	Small streams and rivers, and occasionally larger rivers (low and high head).
Removing dykes and restoration of floodplains.	When dykes are removed natural floodplains are re-connected with the rivers in periods of high water levels.	Polders, reservoirs, larger lowland rivers.
Restoration of estuaries.	Restoration of estuarine character can be achieved when tidal sluices are managed more sensitively, removed or permanently opened. Full hydrological, saline and sediment regimes can be restored.	Estuaries.

EXAMPLE

Removing dams in the United States

Authors: Brian Graber and Serena McClain
Organisation: American Rivers
Country: United States of America



INTRODUCTION

For more than a decade, American Rivers has led a national effort to restore rivers by removing dams in the United States. Removing a dam is the most long-term, self-sustaining way to provide fish passage for multiple native species and multiple life stages of species. Because dam removals restore more natural riverine conditions, they allow passage of a wider range of species, including weaker swimming fish that would not pass through technical fishways. Dam removals also provide additional ecological benefits beyond fish passage: the restored flowing condition often improves water quality by maintaining lower water temperature and consequently higher dissolved oxygen; dam removals restore stretches of riverine habitat for native river species from a previously impounded condition; and dam removals improve the sediment transport regime, allowing coarse material to once again mobilize, often improving downstream habitat.

DAM OWNERS AND DAM REMOVAL

More than 1,000 dams have been removed in the United States, most of them 'small' dams less than 8 meters in height. Between 50 and 60 dams are now removed each year nationally. While these projects have had tremendous ecological benefits, dam removals are frequently initiated for economic reasons rather than for fish passage. The majority of dams in the U.S. were built decades to centuries ago and more dam owners are reaching decision points on whether

to repair their aging structures. Especially in the northeastern part of the country where industrialization occurred first, many, perhaps most dams are no longer serving the purpose that they were built to provide. These dams were built to generate mechanical power for adjacent mills, most of which are no longer in operation. However, the dams remain and become maintenance burdens and safety liabilities for their current owners. Often facing pressure from state dam safety offices, many dam owners are electing to remove their dams rather than continue to maintain structures that are providing little economic benefit. As a result, most dams that are removed are former industrial dams and usually not dams that are actively providing flood control, hydro-power, or water supply. However, economically 'active' dams are also sometimes removed if their costs are exceeding their benefits.

AMERICAN RIVERS RESTORATION PROGRAM

American Rivers involvement with dam removals varies from individual project management to broad policy advocacy, based on the needs of individual states and local groups. American Rivers is a national non-profit organization dedicated to protecting and restoring rivers for the benefit of people, fish, and wildlife. The American Rivers Restoration Program recognized more than a decade ago that dam removal is among the most effective techniques for restoring river habitat and have been working since

to make dam removal a common practice. The Restoration Program is staffed with scientists and planners who provide a range of services and have cumulatively worked on hundreds of dam removal projects. They also work to expand funding available for dam removals; have trained hundreds of professionals to manage dam removal projects; and work with many state and federal agencies to clarify governing regulations and expand capacity to complete more dam removal projects.

PATAPSCO RIVER DAM REMOVALS

While some high-profile, large dams are being removed in the U.S., such as the 38 m high Condit Dam from the White Salmon River, or the 33 m and 64 m high Elwha River dams, the majority of dam removals are much smaller structures. Recent projects on the Patapsco River in the State of Maryland provide good examples of the more typical U.S. dam removals.

Nestled largely within the Patapsco Valley State Park, the Patapsco River flows for almost 56 km

through Elkridge, Ellicott City and other Maryland towns before it reaches Baltimore Harbor and the Chesapeake Bay. The Patapsco is one of the Baltimore area's hidden jewels, providing the people of Maryland with a favorite fishing hole, segments to canoe and kayak with class I and II rapids, trails to wander, and respite from the summer heat. As recently as two years ago, the Patapsco River was fragmented by four dams: Bloede, Simkins, Union, and Daniels. This outdated infrastructure blocked passage for migratory fish like American shad, alewife, blueback herring, and American eel. They also served as an attractive nuisance for area swimmers, resulting in several deaths at Bloede Dam over the years.

Over the past few years, American Rivers and its partners have been working to remove this suite of dams, providing access to more than 480 km of freely flowing mainstem and tributary habitat for diadromous species, restoring natural riverine function, and boosting recreational opportunities. The 7.3 m high Union Dam and the 3.6 m

SIMKINS DAM BEFORE REMOVAL



>>EXAMPLE

SITUATION AFTER THE SIMKINS DAM HAS BEEN REMOVED



high Simkins Dam were both removed in 2010, opening 68 kilometers of Patapsco River main-stem and tributaries. Both projects were united under one banner when American Recovery and Reinvestment Act funding intended to provide regional economic stimulus was awarded by a federal agency, the National Oceanic and Atmospheric Administration.

LESSONS LEARNED

The Union Dam project team faced seemingly insurmountable permitting hurdles that later led to an excessively invasive engineering approach to restoring the resource, as regulators sought to protect the river from short-term changes caused by the dam removal. Learning from this experience, the Simkins project team developed an effective permitting methodology that allowed for more of an adaptive management approach. The issues at stake were whether clean, coarse-grain sand and gravel could be released downstream during removal and whether equipment could be allowed to operate temporarily in-stream without a full water diversion. The adaptive management

approach taken at the Simkins site worked under the auspices that the long-term benefits of the project outweighed any temporary impacts experienced by allowing the river to transport sediment and restore its own habitat over time. The result of these divergent approaches presents a unique opportunity to do a side-by-side comparison and dissect why many of the pitfalls and obstacles encountered during the Union removal only served to strengthen the case for the restoration approach taken at Simkins. American Rivers is working with a team of scientists to monitor the geomorphic and ecological response of the river to the dam removals.

The lessons learned in comparing these two methods carries even greater weight in light of future dam removal efforts on the Patapsco River and throughout the Chesapeake Bay watershed. American Rivers is currently working with an engineering team to finalize the design of the 9.1 m high Bloede Dam removal, the first dam on the Patapsco River and linchpin to the river's restoration.

Economic issues

Economics is a significant factor in the decision to remove a dam. Dam operation and maintenance costs tend to increase as a dam gets older. For example, as a dam traps river sediments traveling downstream, the reservoir impounds less water and therefore decreases the effectiveness of the dam. In many cases, it is now clear that dam removal often costs less than repair costs for older dams, especially where the benefits of the dam are increasingly marginal or non-existent.

It is important to note that not all dam removals are success stories, as in some cases dams have been removed incorrectly without a thorough appraisal of the issues. Much experience with dam removal has been gained in the USA and, more recently and increasingly, in Europe. Some of the important lessons learned were listed by American Rivers (1999):

- Dams must be removed in an informed and responsible manner to minimize or eliminate negative impacts from the removal;
- Where historic records of upstream activities indicate possible presence of pollutants in the river, the accumulated sediment upstream of dam should be tested for potential contamination;
- The volume of sediment stored upstream of the dam, and potential impacts of sediment on downstream navigation, structures, and other river uses should be assessed beforehand;
- Potential hazards and blockages in the reservoir that will become exposed after dam removal should be investigated;
- Absolute clarity and unambiguous conditions in removal authorizations are required.

Ad 2

Semi-natural solutions; e.g. bypass channels and controlled flooding

If it is not possible to fully restore the natural regime, then a semi-natural solution should be pursued by creating an artificial, though nature-

like, channel around the dam or weir (see table 5.3).

These can partially resolve fish migration issues whilst also contributing extra habitat or holding areas for a range of fish species. The barrier remains partly in place and the risks of bank stability problems are therefore moderated and perhaps eliminated.

Ad 3

Technical solutions; e.g. fishways and fishlifts

If it is not possible to achieve the objectives of free passage for fish through a natural or semi-natural solution, then the next option to consider is a technical solution, or formal fish pass (see table 5.4).

Formal fish passes can contribute to securing longitudinal and lateral migration, but by their nature they do not contribute any extra habitat nor restore natural hydromorphology within the impounded reach of the river. Nevertheless they can effectively resolve fish passage issues where more natural alternatives cannot be used and they are probably the most frequently used solution for resolution of fish migration worldwide.

Ad 4

Adjusted management; e.g. opening sluices and locks

Some barriers can be managed differently to enable fish passage to occur. There are several potential areas in which management can be adjusted, and often all that is needed is a good understanding of the times that fish wish to migrate and the flow and velocity characteristics that are conducive to this, together with clarity on what can be delivered by management change (see table 5.5).

Adjusting management in this way can be an almost zero-cost solution and may even be superior to a formal fish pass as much larger attraction flows may be available.

Nature-like bypass channels for migration and reproduction

Author: Jukka Jormola
Organisation: Finnish Environment Institute
Country: Finland



INTRODUCTION

Construction of dams for purposes like power generation or water consumption threatens the natural life cycle of several fish stocks, which need rivers for reproduction or migration between habitats in lakes and the sea. Damming of river sections changes the character of rivers to more lacustrine habitats. If dams cannot be removed, fish passes can help migration. To address the problem of habitat change, clear requirements for environmental flow and the construction of new compensative habitats should be required. In Canada there is much experience of constructing spawning and rearing channels for Pacific salmon species. They have helped

to restore or even exceed original reproduction rates of salmon stocks. Compensative habitats can be combined in fish pass planning by constructing nature-like bypass channels. This should be considered in resolving problems associated with existing dams and in giving new permits for utilizing rivers.

DESIGN APPLICATIONS

Nature-like fish pass facilities resemble natural rapids or small streams. Generally the first option to be considered to enable migration and reproduction of fish is the removal or modification of existing obstacles to restore rapids or create rock ramps. If a dam must be preserved and space is available to the side of it, nature-like bypass channels can be constructed around the obstacle. To enable fish to find the channel for upstream migration, the entrance must be located near to the main current from a power plant or dam. The entrance can be constructed as a vertical slot fishway section or with a wall structure, if there are high fluctuations of the tail-water level.

THE RUPPOLDINGEN POWER PLANT

The reproduction channel of the Ruppoldingen power plant suits for several species.



Steep nature-like fish passes are constructed with a pool and weir structure. With one or more routes for migration between stones, fish can pass the weirs by swimming and without jumping. The maximum average gradient for such a structure is normally 5%. Channels with lower gradients, less than 1%, can be constructed with free flowing water and no weirs in which the cur-

THE RUPPOLDINGEN POWER PLANT

The fish pass of the Ruppoldingen power plant, entrance turning to the dam.



rent and vortices caused by perturbation stones keep the whole channel deep enough for swimming.

Nature-like fish passes support migration of all kinds of fish living in rivers. They serve as ecological corridors for invertebrates, such as crayfish, and mammals including otter, but also for other species moving along rivers and their banks. Also reproduction of fish is possible in nature-like bypass channels. Special sections of the channels can be designed to promote spawning for various species, perhaps to compensate the loss of reproduction areas in modified rivers. One possibility is to design a separate reproduction channel in connection with a nature-like fish pass, diverting the water into two arms with one water intake.

RUPPOLDINGEN REPRODUCTION CHANNEL, RIVER AARE, SWITZERLAND

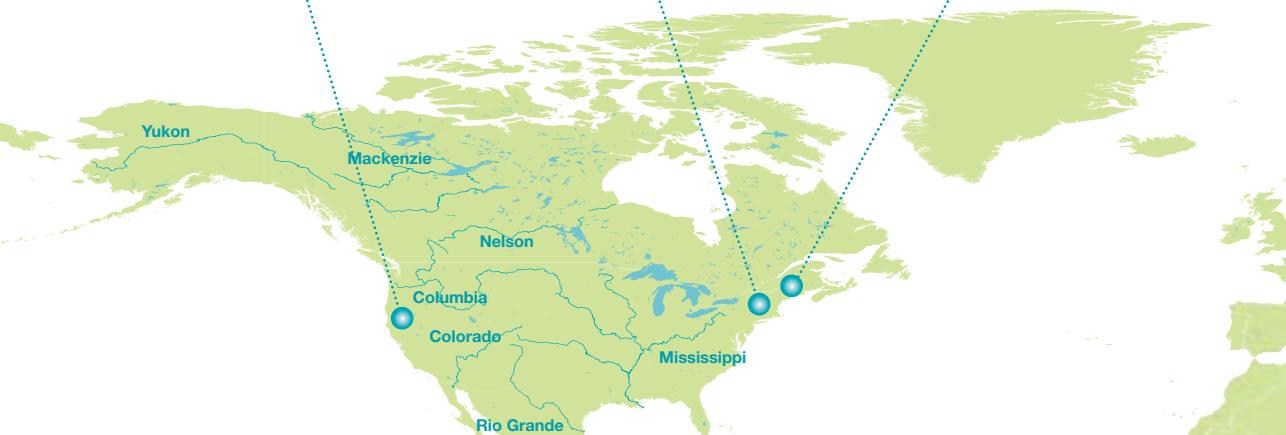
In Switzerland at the Ruppoldingen power plant which has a head difference of 6 m, a fish pass

with a discharge $0.4 \text{ m}^3/\text{s}$ enters the river close to the power plant. The bypass channel has discharges between $1.5\text{--}4.5 \text{ m}^3/\text{s}$, a gradient of 0.64% , and flows to the River Aare 1.2 km downstream. Large fish including pike (*Esox Lucius*), carp (*Cyprinus carpio*), barbel (*Barbus barbus*) and wels catfish (*Silurus glanis*) have been observed in the bypass channel. Juveniles of grayling (*Thymallus thymallus*) in the channel are a sign of natural reproduction.

The Ruppoldingen power plant fulfils the requirements of the branding of 'Naturemade Star', which is one of the most demanding renewable energy brands. The Ruppoldingen reproduction channel is used as an example for the Rheinfelden reproduction channel in the Rhine, above Basel, completed in spring 2012.

SOLUTIONS

FISH MIGRATION SOLUTIONS WORLDWIDE



- A** Fishway at the J.C. Boyle Dam in the Klamath River, built in 1958, 225 miles up the river from the sea. The John C. Boyle Dam is one of four on the Klamath River that would be removed under the Klamath Economic Restoration Act (USA). © Jamie Pittock / WWF-Canon
- B** The Fort Halifax Dam being removed from the Sebasticook River in Maine (USA). © Natural Resources Council of Maine
- C** Vertical slot fishway at Cabot power station, Connecticut River (USA). © Groene Zoden Fotografie
- D** Fishway on the Pecha River, a tributary of the Tuloma River, Murmansk region, the Kola Peninsular (Russia). © G.G. Filippov
- E** Cone design fishway under construction on Pak Peung flood regulator in Paksan, central Laos. This fishway is installed in 2012 to enhance the lateral migration between the Mekong River and a large floodplain wetland. The wetland decreased by 50% as estimated by local fishermen since the flood regulation was installed. © Douangkham Singhanouvong (LARReC)
- F** Pak Mun fishway at the confluence of the Mun and Mekong Rivers (Thailand). © Eric Baran
- G** A section of the almost 10 km long fishway at the Itaipu Dam on the Parana River (Brazil). © Itaipu Binacional
- H** Tidal locks Cleveringsluizen between Wadden Sea and lake Lauwersmeer are managed in a fish friendly way (The Netherlands). © Groene Zoden Fotografie
- I** The Geestacht vertical slot fishway in the Elbe River has a total length of 550 m (Germany). © Groene Zoden Fotografie
- J** Full-width rock ramp fishway at Bandon Grove on the Williams River (Australia). © Martin Mallen-Cooper



Fish lifts in South America

Authors: Sergio Makrakis and Maristela Cavicchioli Makrakis
Organisation: GETECH - Universidade Estadual do Oeste do Paraná
Country: Brazil



INTRODUCTION

A fish lift or fish elevator, as its name implies, can provide passage for fish over a barrier and is well suited for high barriers. Fish are attracted towards, and swim into a collection area at the base of the obstruction and when enough fish accumulate in the collection area, they are crowded into a hopper that carries them into a flume that empties into the river above the barrier. In South America, fish lifts are a relatively new measure to promote fish migration and at high dams they provide an alternative to fish ladders. The mechanics of two different fish lifts at the Funil dam and the Porto Primavera dam in Brazil are described. In addition, the efficiency of fish lifts at the Santa Clara dam (Brazil) and the Yacyretá Dam (Paraguay/Argentina) is discussed.

FISH LIFT AT PORTO PRIMAVERA DAM (CESP, PARANÁ RIVER, BRAZIL)

The fish lift at the Porto Primavera Dam (Engenheiro Sergio Motta Hydroelectric Power Plant, Paraná River) is installed on the power plant central generation structures and weirs. Four large centrifugal pumps generate a laminar flow inside a channel, attracting fish to a hopper that raises them to a height of 29 m. The fish are then poured into a laboratory hopper, where they can be identified, counted and weighed, and are then transferred by gravity to the reservoir. This lift came into operation in November 1999.

FISH LIFT AT FUNIL DAM (CEMIG, GRANDE RIVER)

The fish lift at Funil Dam (Funil Hydroelectric Power Plant, Grande River) came into operation in January 2004. The system is equipped with four main parts: the input channel, mechanical elevator, the tailrace and the auxiliary water system. The function of the auxiliary water system is to provide flow in the channel entrance which is located on the left bank of the tailrace and is approximately 26 m x 2.40 m, and this provides attraction for fish to the input channel of the system.

The auxiliary water system operates as an attraction flow and is restricted to a maximum flow of 6 m³/s. This provides a flow of water with velocity and turbulence characteristics that attract fish from the outflow channel to the interior of the system. The fish attracted by this mechanism approach and, via a waterfall provided by a gate installed inside the channel entry point, enter into the system.

After an appropriate time, the fish inside the channel are confined and driven by a crowder to the pusher region of the open shaft, where an 8 gallon bucket rises vertically to transport the fish to a height of 50 m. A mobile screen prevents the return of fish once they are confined in the channel, and remains in this position until the pusher car has returned to its operational position. The bucket, hoisted by a winch with a capacity of 12

tons, then starts the process of releasing the fish above the dam. Once it has reached a position just above the level of the reservoir, the fish are released directly into the output channel from which the fish are emptied toward the reservoir. Once complete the bucket returns to the lower position, the grating moves upward, and a new cycle of capture and transport begins.

EFFICIENCY MONITORING

Studies of the efficiency of fish lifts in Brazil are rare. Pompeu and Martinez evaluated the efficiency and selectivity of the first trap and truck fish passage system in Brazil, installed in the Santa Clara Dam on the Mucuri River (Pompeu and Martinez, 2007). The species composition in the lift was compared to the original composition of the Mucuri River fish fauna and with the populations that gather downstream of the dam during the reproductive season. The proportion of previously tagged individuals translocated by the lift was used to estimate its efficiency. During the 2003/2004 reproductive period, 67,841 individuals of 32 species passed through the lift, corresponding to 66% of the lower Mucuri River fish richness. Less than 0.5% of the fish died or was injured during the

passage. In comparison to the river's population, smaller individuals and marine species were under-represented. However, the composition and structure of the community passed by the lift was similar to that downstream of the dam during the reproductive season. The estimated efficiency of the fish lift ranged from 0.2% for *Pogonopoma wertheimeri* to 16.1% for *Leporinus conirostris* reaching an average of 7% for all migratory species.

The journal Neotropical Ichthyology published a special edition for studies of fish passage in June 2007. Oldani *et al.* found the efficiency of the fish elevators at Yacyretá Dam (Paraguay/Argentina) in transporting migratory species to be only 2%, with nearly all the fish that were successfully transported coming from only three non-migratory species (Oldani *et al.*, 2007). These studies show that the efficiency of fish lifts in Brazil is probably in the order of only a few percent for migratory species in the first years of instalment, and decreases annually afterwards. This is because the fish lifts function only for upstream migration - fish that need to migrate from the lentic environments are not attracted to the lift for downstream migration purposes.

FISH LIFT AT FUNIL DAM

(© Paulo dos Santos Pompeu).



DETAIL OF THE FISH LIFT AT FUNIL DAM

(© Paulo dos Santos Pompeu).



EXAMPLE

Tidal flaps and fish passage

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Organisation: Fisheries Consultant
Country: England



INTRODUCTION

Significant areas of England, and many other coastal European countries, lie below the high tide level, and are drained through freshwater flow via tidal flaps, tidal doors, and tidal sluices or by pumping. Tidal flaps are designed to allow river run-off to flow seawards when the landward water level is higher than the tide level, but to prevent the reverse landward flow of tidal water.

Being top-hinged they tend to close under their own weight, and the seating face may be sloped

THE AXE ESTUARY, DEVON, UK

Williams/Stoneman Self Regulating Tidal Flap on the Axe Estuary, Devon, UK. The flap is closed at low and high tide, but open at mid-tide to allow saline water (and fish!) into a salt marsh. (© Mike Williams, Environment Agency).



back towards the top to encourage positive seating. This means that the door closes while there is still a positive head on the landward side, and as the gate closes the flow around the gate is still of fairly high velocity, and beyond the swimming ability of many small fish such as elvers. Modern materials and rubber seals prevent minor leaks that small fish could exploit.

For the great majority of the time outfalls carry a small fraction of their maximum capacity, and the flap is only just 'cracked' open even at low tide, with the seaward flow 'squirting' sideways through a small gap. These features mean that tidal flaps represent a serious impediment to landward passage of fish, including elvers.

WHAT DID WE DO?

The issues for passage of eels and other fish, and ways of addressing them were investigated on behalf of the Environment Agency (UK), with reference to structures and solutions in the United Kingdom, Europe, North America and Australia. The report 'Eel passage at tidal structures and pumping stations' is available at www.ada.org.uk

Potential solutions identified and described include: replacement of flaps with tidal doors, which have side hinges; these remain open for some period after level equalisation, offering fish an opportunity to pass landwards. Fitting smaller, lightweight flaps or doors (similar to 'cat flaps') within the main flap, with or without some mechanism to delay closure until well after level equalisation. At least three designs have been

installed in the UK. Replacement of the flap with a 'Self Regulating Tidal (SRT) Flap', which allows a significant but controlled degree of tidal intrusion. These are generally used where recovery of the landward area as a controlled tidal habitat is desired, which is a rapidly increasing trend. At least two designs have been installed in the UK. Introduction of some arrangement to delay closure of the main flap, such as springs or coun-

terweights, or maintenance of a small gap at all times.

LESSONS LEARNED

Similar problems are being experienced, and solutions developed, around the world. Better communication, including free circulation of reports such as this guidance, will make a considerable contribution.

'CAT-FLAP' FITTED INTO A TIDAL FLAP

Manufactured by ACE (www.aquaticcontrol.co.uk). Opening of the smaller flap is controlled by a float attached to the outer edge.



Table 5.3 Overview of semi natural solutions to restore upstream migrations

Semi natural solutions	Description	Application
Nature like bypass channels.	A natural waterway that bypasses the river from upstream of the obstacle to downstream. The waterway is similar to the natural situation and therefore provides some potential habitat as well as restoration of fish migration.	Rivers and small rivers.
Pool-riffle fishways.	Higher gradient stretch with large stones or wooden structures placed to create a pool and riffle structure.	Rivers and small rivers.
Riprap; rock ramp fishways.	Relatively high gradient stretch with large stones randomly placed. This solution appears as a natural rapid.	Rivers and small rivers.
Step-pool; cascade fishways.	Relatively high gradient stretch with rows of stones placed over the whole width, forming cascades. It is also possible to use large wooden structures.	Rivers and small rivers.
Restoration of tidal exchange.	Through active management of tidal sluices it is possible to restore tidal exchange inland with resulting opportunity for fish passage. This is possible in the river and in areas adjacent to the river by means of a culvert. A permanent freshwater supply is needed.	Estuaries.
Restoration of temporal flooding areas/wetlands.	Temporary controlled flooding areas by pumping water onto the floodplain or by allowing floodwater to accumulate areas previously protected from tidal inundation (e.g. 'managed retreat' schemes).	Polders, floodplains and reservoirs.

5.3.2 Downstream fish migration

Weirs and dams have been built over the last two centuries to support higher impounded water levels for various purposes, including water abstraction and hydropower generation. Although downstream migrant fish can often safely pass over low weirs, the abstraction or generation processes, if present, can draw the fish into intakes and thereby cause loss and serious mortality. If the rates of abstraction are high then fish mortality can reach serious levels.

For the many redundant weirs where there are no longer any abstractions, passage may be

straightforward although with some species delay may result from reluctance of fish to pass over the weir.

Uncontrolled passage over high head dams, either as overflow or within water discharged through siphons or in sluicing, is inevitably highly damaging. This is due to the physical impacts of pressure changes, abrasion and shear forces, and the freefall of fish, either within the water plume or in some cases in air, to the water level below.

Passage past dams and weirs can expose fish

to predators that often accumulate downstream of such structures. In lowland countries pumping stations represent a unique challenge to fish migration in both directions. The risks during downstream passage are broadly the same as those for hydropower with exposure to rotating blades.

In all cases it is important to minimise the entrainment of fish and to maximise their passage through carefully designed and safe bypass systems.

Features and conditions

Solutions to provide safe downstream fish migration strongly depend on the local situation. In planning a facility for fish protection and guidance, information is required on the hydrological and technical features of the structure past which fish need to safely migrate, the way in which the site is managed, and the natural behaviour of the fish that are present.

Important hydrological features include the daily rate of flow during the migration period and the proportion of this which is routed through a turbine or is otherwise abstracted. Other features include channel morphology in the vicinity of the abstraction, as this can determine the route fish may take as they approach the structure and the location at which they assemble prior to passage.

Also important are the depth at which water is drawn-off, the flow rates and velocity patterns at that point, light and sound conditions underwater and the local occurrence and behaviour of floating or semi-buoyant sediment, debris and trash. Fish migration may occur at high flows and an understanding of local flow characteristics in extreme conditions is also required.

Relevant technical features of the water intake site include the precise design and lay-out, the management protocol under the full range of flows, and any technical and licensing conditions that constrain abstraction, including any environmental 'hands-off' flows.

The nature of the abstraction, including the type of any turbine, the hydraulic features including bywash flow and residual flow in the river, and the fish species present will together influence the extent of damage and the mortality rate. Although every site is unique, various formulae have been suggested to predict the mortality rate at Francis and Kaplan turbines in France (Larinier *et al.*, 2002) and similar approaches have been developed in the UK (Turnpenny *et al.*, 2000).

These give generalised estimates of mortality rates that can be used in a predictive way to identify whether installations cause significant damage. More reliable data on mortality rates can be derived from experimental field research (e.g. Berg, 1987; Hadderingh & Bakker, 1998; Pavlov *et al.*, 2002) that can also provide indications of the nature and extent of non-lethal physical damage to fish. Specific studies of this type can be very expensive.

In some situations it is possible that the spillway can function as a bypass and surface bypasses located close to the abstraction screens can also be effective. Indeed the provision of such facilities is usually a specific requirement of the licencing process that seeks to minimise environmental harm.

The distribution of water between the abstraction and the spillway will almost always directly influence the proportion of fish that pass over the spillway, and careful design of the structure and its management is required to maximise escapement.

Target species

General principles, but also local intelligence will determine which species should be protected at any abstraction point. This will guide selection of the best available facility for downstream fish migration and the management regime to minimise the risk of fish loss. Target species are usually well known and are generally determined based on biological information and fishery records.

Table 5.4 Overview of possible technical solutions to restore upstream migrations

Technical solutions	Description	Application
Pool fishway with overfall weirs.	Fishway with pools that are separated by overfalls. The weirs are usually notched to take low flows and can be designed to provide plunging or, more often, streaming flow (usually with adherent flow or 'nappe' of water to prevent excessive aeration and promote ascent by swimming rather than jumping) to suit the fish species present. Sometimes the overfalls have a v-shape in order to concentrate water.	Rivers and small rivers (relatively low range of water levels; usually relatively low head drop).
Pool fishway with vertical slots.	Fishway with pools that are separated by walls containing one or two deep vertical slots reaching to, or close to, the bed of the pass. Can be combined with pool and weir fishways or submerged orifice passes.	Rivers and small rivers (can cope well with low to relatively high range of water levels).
Pool fishway with submerged orifices.	Fishway with pools that are separated by walls containing submerged orifices.	Polder, rivers and small rivers (low head).
Tube and siphon fishway.	This type of fishway can provide fish migration from the sea to inland waters that are below sea level. A tube and siphon fishway uses a pump to create an attraction flow and a vacuum pump transports the fish to the inland water level.	Polder, estuaries.
Fish lock.	Fish locks have the same operating principle as shipping locks. One variant, the Borland Lift, operates on this principle by periodically filling a low diameter cylinder to raise the level to the crest of a dam, sometimes up to 50 m high.	Rivers (sometimes high head).
Fish lift.	The strategy of the lift is to attract fish to a water filled chamber at the downstream side of the obstruction (the tailrace area) and mechanically lift the whole chamber to the top of the dam for release.	Rivers and small rivers, hydroelectric dam (can be high head).
Baffle ('Denil' or 'Larinier') fishway.	Baffled fish passes are relatively narrow chutes or flumes, usually no more than 1 m wide for Denils but up to 5 m wide for Larinier passes, within which steel or wooden baffles of varying design are located. The internal roughness created by the baffles disperses energy and reduces velocity to enable fish passage.	Rivers and small rivers (relatively low head).

>>

<p>>> Fishways for eel and elvers.</p>	<p>Special passes for migration of young eel and elver. They can be combined with fishways for other fish species. These fishways are generally small channels filled with substrate that utilises the ability of eel and elver to climb and crawl when passing an obstacle. A low flow of water is required. Climbing substrates can consist of branches, reeds, artificial brush or grass. Other solutions consist of roughened surfaces or embossed features on weir surfaces to facilitate climbing.</p>	<p>Rivers and small rivers, polder, estuaries.</p>
<p>Screw jack (<i>Archimedes screw</i>) fishway.</p>	<p>The function of these is based on the same principle as the tube and siphon fishway. It uses a screw jack to pump up the water and create an attraction flow in the direction of the inland water below sea level (polders).</p>	<p>Polder, estuaries.</p>
<p>Fish friendly pumps.</p>	<p>Adjusted types of regular pumps. New designs of blades and lower rotation speeds insure a safer passage of the fish.</p>	<p>Polders</p>
<p>Fish friendly culverts.</p>	<p>A culvert is a connection between two water bodies, typically a pre-formed concrete tube located below roads or other constructions. In order to make a culvert passable for fish, the flow characteristics (velocity, water level and slope) are adjusted to facilitate fish passage and sometimes to mimic the natural river. It is possible to lower the culvert, in order to create sufficient depth for fish to swim, to place weirs or baffles in the culvert, or (preferably) by replacing the culvert with a clear-span bridge. Migration of land animals, notably otter, should be taken into account.</p>	<p>Rivers and small rivers (low head).</p>

Initial assessments may demonstrate that the requirements of some species may not be critical to intake and screen designs, for example if:

- the fish species is able to complete its life cycle in the available habitat and in connected side waters with no need to migrate;
- the magnitude of the impact of the abstractions on the population is negligible and can be absorbed, for example through density-dependent mechanisms elsewhere;
- a species is already extinct with little chance of returning in the future.

The remaining target species should be protected through combining sufficient ecological knowledge with best-practice technical solutions for bypasses, screens and for protected environmental flows. The justification for this expense is provided in some countries by domestic legislation but can also be supported by fishery economics and other social arguments.

Choice of solution

It should first be determined whether the objectives for secure migration can be met by mod-

Table 5.5 Overview of possible ways for adjusted management to restore upstream migration

Adjusted management	Description	Application
Estuarine constructions (e.g. discharge sluices).	Fish migration can be achieved by opening the sluices when the difference in water level between the sea and the inland water is low. The lower the velocity at this time, the more species are able to pass the structure. It is also preferable to allow sea water to intrude into the inland water during high tides.	Estuaries.
Adjusted sills.	Weirs that underflow can be passable when the water level difference is low. This option should be explored, even though the potential time for fish migration may not last for long. Flow velocities are low under these circumstances.	Small rivers and rivers (low head).
Shipping locks.	Fish passage can often occur when navigation locks operate. This can be an important migration route and the option of 'locking-through' for fish, not necessarily in association with ships, should be explored. This is especially suitable when all of the waterway discharge passes through the shipping lock. It is often less suitable when most water passes over adjacent weirs, because most of the attraction may come from the weir; however even then the lock might still be a significant migratory route.	Waterways with navigation/ or used to have navigation.

eration of the abstraction or pumping regime or by re-siting of the intakes and screens. If this is not possible then suitable facilities for protection of downstream migration should be selected to eliminate entrainment risk or reduce it to acceptable levels.

A solution to protect fish through guidance and screening should be determined first through a study of best practice (e.g. Turnpenny and O'Keefe, 2005) and the known effectiveness of certain facilities for the target species. The most suitable for the site may then be selected taking into account all relevant local factors.

The selected management regime and associated facilities for protection of downstream migrating fish should prevent entrainment into the abstraction channel (e.g. turbine intakes) whilst guiding them to a bypass that transports the fish downstream (Larinier *et al.*, 2002). The principle

is to guide fish towards a bypass taking advantage of, or through manipulation of, hydraulic flow patterns because most fish tend to move with the current during their downstream migrations.

Several different types of guiding and screening facilities exist and may be categorised into:

- 1 Mechanical barriers (that physically exclude fish from the water intake, e.g. wedge wire or bar screens);
- 2 Behavioural barriers or screening (that influence fish behaviour to guide them to a downstream route using some sort of stimulus e.g. sound, light);
- 3 Bypasses into which a sufficient flow passes to draw fish, or to trigger their movement towards a bypass route;
- 4 Adjusted or alternative management (e.g. daily closure) and other methods;
- 5 A combination of some or all of the above.

Based on the identity of the target species and their biology, and technical features of the abstraction, it is possible to identify a facility and management regime to protect downstream migrating fish at the site.

Ad 1

Mechanical barrier

Many different mechanical barriers have been developed for a wide range of scenarios of river size, abstraction type and fish fauna (Turnpenny *et al.*, 1998a; DWA, 2005; O' Keefe and Turnpenny, 2005). Passive wedge wire cylindrical screens, down to 3 mm gap size, are generally considered to be the best method for physical exclusion of fish, with up to 100% effectiveness.

The selection of appropriate screen bar spacing is important if protection of the target fish species and life stage is to be achieved whilst adverse impact on water abstraction is minimised. It is important to note that fast flows through any screen may kill fish through impingement and it is important to avoid this, for example by managing the intake orientation (angle) and surface area to restrict approach velocities below those from which fish can escape (see table 5.6).

Some European countries have regulations for screening. For example the French government has adopted 20 mm as an obliged gap size, whereas in Germany 15 mm is being used. Hence, there is a growing need for a more standard gap size that will prevent fish from being damaged.

V-screen with a 1.75 mm gap size on the White River

Washington State (USA). This screen is installed to protect and guide downstream migrating fry (Pacific salmon) © Olle Calles.



EXAMPLE

Improving downstream passage conditions for fish at hydro-electric facilities in Sweden

Authors: Olle Calles¹, Simon Karlsson¹ & Johan Tielman²
Organisation: Karlstad University¹ & E.ON Vattenkraft AB²
Country: Sweden



INTRODUCTION

Swedish rivers are heavily impacted by hydro-power plants, but during the last decade many fishways have been built to re-establish longitudinal connectivity. Nature-like fishways are becoming more common and many obstacles are now passable for many species of fish, not only the strong swimming salmonids.

Since all diadromous species are dependent on two-way connectivity, i.e. free passage both upstream and downstream past obstacles, there is

an urgent need to start testing measures to facilitate downstream passage (Calles & Greenberg, 2009). Here we describe the first two low-sloping racks with bypass facilities built and tested in Sweden.

WHAT DID WE DO?

At two hydroelectric plants in southern Sweden, low-sloping racks with bypass entrances were designed, built and tested for passage efficiency for different species. Fish were radio-tagged and released upstream of the plants, before and after the measures were implemented, and their passage success was documented by radio-telemetry and mark-recapture trials.

RIVER EMÅN

The low-sloping rack and surface oriented bypass entrances on the River Emån.



River Ätran

At the hydroelectric plant in Ätrafors on the River Ätran there were three parallel racks with 20 mm gaps and a vertical inclination of 63° which, in combination with severe turbine induced losses (Francis turbines and a 23 m head), resulted in downstream migrating European silver eels (*Anguilla anguilla*) suffering a 70% loss at this plant (Calles *et al.*, 2010).

The racks were subsequently replaced by three new racks with 18 mm gaps and a vertical inclination of 35°, and six submerged openings in the rack. The openings lead to traps situated behind the racks that were manually emptied.

River Emån

At the hydroelectric plant in Övre Finsjö on the River Emån there was a rack with 20 mm gaps and a vertical inclination of 80°, which caused losses of up to 68% among trout smolts passing through the rack and the small Francis turbines (Calles & Greenberg, 2009). The rack was subsequently replaced by a new rack with 18 mm gaps and a vertical inclination of 35°, and two surface oriented bypass entrances in the rack. The openings both enter a bypass system behind the rack that passes over the crest of the dam and rejoins the river channel downstream of the plant.

HOW DID IT WORK OUT?

River Åtran

After the racks were changed, the loss of downstream migrating silver eels was reduced to <10%. The increased surface area of the new racks resulted in a lowered risk of impingement for eels, and a decreased head loss at the racks (Calles & Bergdahl, 2009).

River Emån

After the rack was changed, no trout smolts passed through the turbines, and only 16% of the smolts were lost when passing the plant. In total more than 1,000 individuals from 17 fish species used the bypass system. Large fish seemed to be reluctant to enter the bypass, and ongoing studies are analysing the hydraulic conditions at the bypass entrances.

LESSONS LEARNED

These two examples show that low-sloping racks with bypass systems improve passage conditions at hydroelectric plants for several species and life-stages of fish. At the hydroelectric plant in the River Åtran, the new racks even resulted in a reduced head loss, in spite of a reduced rack gap size.

The principles of low-sloping fine-spaced racks with bypass systems could be implemented at small and medium sized hydroelectric plants, where there is a need for improved passage conditions for downstream migrating fish.

LOW-SLOPING RACKS

Overview of the low-sloping racks in Rivers Emån (top) and Åtran (second from top). Detailed view of the low-sloping racks with angles, approach velocities and resulting velocity vectors from River Emån (third from top) and Åtran (bottom). Figure modified from Calles & Bergdahl, 2009.

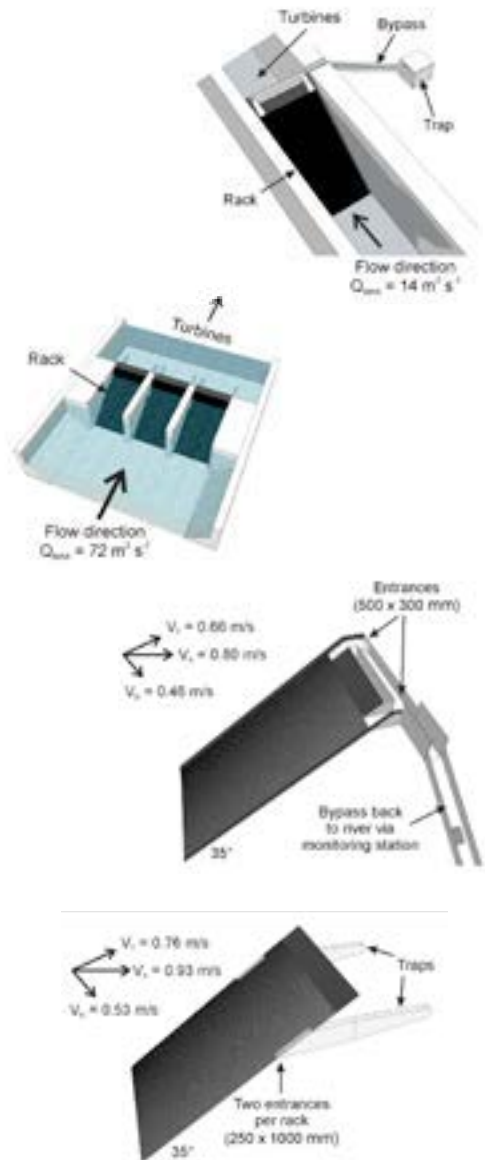


Table 5.6 Overview of mechanical barriers for downstream migration

Type of screen	Application	Species
Passive mesh screen.	Difficult at large abstractions.	Salmonids (smolts and parr) and larger fish.
Vertical/inclined bar racks.	All.	Salmonids (smolts and parr) and larger fish.
Rotary disc screen.	Rivers with a strong sweeping flow. Not suitable for large intakes due to the requirement for high surface area for desired flow velocities.	Salmonids (smolts and parr) and larger fish.
Coanda screen.	Spillway screen for small, typically upland hydro intakes (or replacement of existing spill way screens).	Salmonids (smolts and parr) and larger fish.
Smolt safe™ screen.	Spillway screen for new-build small upland hydro intakes (or replacement of existing spill way screens). Other types of application where sufficient head of water exists, e.g. fish farms on upland rivers.	Salmonids (smolts and parr) and other fish.
Band or drum screen.	Estuarine and coastal power stations, other large abstractions.	Robust epibenthic species (e.g. flatfishes). Less suitable for pelagic species and sensitive species including salmon smolts.
Passive wedge wire cylinder screen (PWWC).	Wide range of smaller abstractions in fresh and marine water. Not suitable for low head hydroelectric power stations.	All species and sizes of fish given suitable wire spacing.
Small aperture wedge wire panel screens.	Difficult at large abstractions.	All juvenile and adult salmonids, lampreys, eel and cyprinid species.
Sub gravel intakes and wells.	Relatively small abstractions in fast flowing, eroding substrate rivers, suitable for potable water or fish farm supply.	All species and sizes. May have a negative effect on the fish habitat.
Marine Life Exclusion System (MLES™).	Industrial and power plant abstractions where the flow rate is in the range of 0.04 - 0.1 m³/s. Maximum 50 mm head differential.	Provides protection of early stages of fish.
Barrier nets.	Mainly suited for large water bodies with low bio-fouling and debris levels and where fish risk is seasonal.	Salmonid smolts and adults of most species.
Modular inclined screen.	Application in upland areas. Generally of a large size and high costs relative to flow.	All juvenile and adult salmonids, lampreys, eel and cyprinid species.
Self cleaning belt screens.	Wide range of applications where a self cleaning fine mesh screen is required. The screen has been used widely in the USA for irrigation water intake.	All juveniles and adult salmonids, lampreys, eel and cyprinid species.
Labyrinth screen.	At large intakes or where space is premium and a compact screening arrangement is required.	All juvenile and adult salmonids, lampreys, eel and cyprinid species.

Ad 2

Behavioural barriers

The use of behavioural barriers such as acoustic barriers to exclude fish from abstraction channels or to guide fish to a bypass facility is an attractive option due to its simplicity, however it is usually only partially effective. This is because the avoidance behaviour they promote is often very variable between individual fish of each species and the precise point or onset of a startle or avoidance reaction may be critical to successful guidance. It is critical that target fish are ensonified at a location from which they have the swimming capacity to effectively respond and avoid entrainment and impingement. Behavioural barriers are very species-specific, with no known system for some species. It seems that a system for the protection of all fish species is therefore not possible (see table 5.7).

In Europe some promising results have been reported in certain applications from the application of louvre screens (Solomon, 1992), light arrays (Haddingh *et al.*, 1992; Bruijs *et al.*, 2003), acoustic deterrents (Turnpenny *et al.*, 1998b), bubble screens (Turnpenny, 1998) and the use of turbulent attraction flow (Solomon, 1992). Other behavioural technologies that are used in the USA consist of turbulent attraction flow (Coutant, 2001) and surface collectors (Lemon *et al.*, 2000).

Ad 3

Bypass systems

The use of mechanical or behavioural barriers can minimise or possibly in some cases even eliminate entrainment of fish, however an alternative migration route or bypass system (also known as a bywash) is clearly necessary if successful migration is to occur with no undue delay.

Table 5.7 Overview of behavioural barriers for downstream fish migration

Type of barrier	Application	Species
Louvre screen.	Canalized waterways with a uniform approach flow.	Most fish are deflected in appropriate situations. Good experience in some deployments for salmonid smolts and adults, adult shad and cyprinids.
Bubble screen.	Sites where high performance is not essential. Not fast flowing or deep water locations.	Some evidence of success for salmonids, some cyprinids and shad. Probably variable effectiveness depending on local circumstance.
Electric barrier.	Not suitable for marine or brackish waters.	Large fish, as relatively low and safe voltages are used.
Acoustic barrier.	High rate flow intakes (where low exclusion is acceptable). Need to ensure that sound is constrained so that migration of sensitive species is not unduly influenced.	Fish with moderate to high hearing sensitivity (e.g. shads, smelt, herring, cyprinids and bass). Not effective for others.
Light based systems.	Small hydropower intakes and pumping stations.	Adult eel are known to be deflected and, in some circumstances, salmonid smolts. Little evidence for other species.
Turbulent attraction flow.	Small hydropower intake.	Developed for salmonid smolts. Unknown effectiveness for other species.
Surface collector.	Large dams.	Developed for salmonid smolts. Unknown effectiveness for other species.

For fish that migrate near the water surface there are published criteria for the positioning and design of bypasses in small to middle sized rivers. However this is not the case for larger rivers where solutions can be highly expensive (such

as those on the Columbia River, USA) and further experimental work is required to design workable and effective solutions. For fish that migrate near the bottom, such as eel, several bypass systems are currently under development (see table 5.8).

Table 5.8 Overview of possible bypasses for downstream migration

Type of Bypass	Description	Species
Surface bypass.	Bypass situated at the most downstream point of the fish protection system, to which downstream migrating fish are guided (and gather). They are situated in the upper layer of the water column and can be integrated in existing structures, see below.	Developed for salmonid smolts but may also work for other surface-oriented species.
Bottom bypass.	Bypass situated at the most downstream point of the fish protection system, to which downstream migrating fish are guided (and gather). They are situated at the bottom of the water column and can be integrated in existing structures, see below.	Known to be effective for eel and other bottom orientated species.
Bottom gallery.	Once eel make contact with a physical barrier they are often startled and escape upstream instead of searching sideways for an alternative route. Therefore a structure placed on the bottom and upstream of the physical barrier could collect eel and guide them to a bypass. In Europe a patented version exists (Bottom gallery [®]).	Eel and bottom orientated species.
Venturi bypass.	Bypass system using the venturi principle. A flowing plume is created by the main flow (Manshanden [™]) from which fish are deflected by light. Very useful for pumping stations. Can be used as surface or bottom bypasses.	All.
Lock.	Locks that function as flow regulators of the turbine, next to the water intake, are possible bypass routes.	They can be suitable for smolts. Underflow structures can be used for eel and bottom orientated species.
Navigation lock.	It is known that some fish are able to use navigation locks for downstream migration, as well as upstream migration. However their location and attraction for downstream migrating fish is usually poor.	All.
Fish pass.	Fish also use fish passes for downstream migration. The main constraint is attraction, with their relatively low flows, for downstream migrating fish as well as the location of the entrance (upstream). It may be possible to connect a surface bypass into the fish pass, in which case the bypass flow would supplement the attraction flow for upstream migrants. Passage down baffled fish passes, especially denil passes, has been reported to damage salmonid smolts and probably other fragile fish species.	All.

An alternative is to catch fish and transport them around the abstraction or hydropower site, especially when multiple hazards need to be passed, although this is clearly very expensive, usually impractical, and may itself have unacceptable impact on fish survival.

Ad 4 Adjusted management regime and other methods

In some cases it is possible to adjust the management of the abstraction system in order to prevent or minimise damage to fish. This may consist of seasonal or daily adjustments to the amount of water abstracted, or to the setting of residual flows in the river that must be protected. There are also technical adaptations that might be considered at the design stage such as the type of turbine or pump, the precise design of the spillway (e.g. water depth), and the use of physical or behavioural screens. Careful management of water approach velocities towards a screen by maximising the surface area of the screen and using an appropriate bar spacing is also very important. At hydropower stations the use of more, rather than fewer, turbines to reduce the velocity of approach flows, and the use of turbines that cause least damage (for example with blunt leading vane edges) and adjusted turbine management can all help to reduce fish strike and mortality. Some designs of turbine, for example Archimedes screws, are far safer for fish passage than others, e.g. Kaplan turbines.

5.4 STEP 2: DESIGN

“An efficient fish pass is one that allows all fish that wish to pass a structure to do so safely and with minimal delay. The attraction of fish to a pass and the conditions encountered by fish within a pass are both of paramount importance.”

5.4.1 Upstream fish migration

An efficient fish pass must be both attractive for migrating fish and readily passable by them. To ensure that this is achieved, appropriate guidelines for design determined by the biological criteria appropriate for the target fish species

should be taken into account. Knowledge of the behaviour of target species, including the precise timing of their migration, their responses to flow and the location at which they assemble as they seek to pass a structure is crucial for the design of a fish pass. Similarly a clear understanding of the swimming and endurance capabilities of each species is required if the pass is to be negotiated with ease and no undue delay.

General guidelines for attraction and passability are discussed below. Guidelines for detailed design of a facility, and particularly structural design, are not a part of this guidance, however existing comprehensive technical manuals are identified in the list of references. A list of guidelines is also available on the website www.fromseatosource.com

Attraction

A facility for upstream migration may be concluded as effective when it has the ability to efficiently attract fish towards the entrance. Attraction would be maximised if the full flow of the river were available, but this is clearly not practical. When the proportion of the flow that passes through the fish pass or bypass is reduced then the attraction will depend on the location of the entrance, the apportionment of flow (e.g. Armstrong *et al.*, 2004) and certain fish behavioural characteristics. It is important to make sure that migration is readily possible at the key times of the year when migration is required.

Passability

Attracting fish into the fish pass is the most critical element for any fish pass. Thereafter passage should occur if the fish pass has been built to provide conditions that are within the swimming capabilities of the fish and, therefore, is passable.

A vital factor is the flow pattern within the fish pass. Waterways containing heterogeneous and therefore more natural flow patterns are generally easier for a wider range of migrating fish species to pass than technical fish passes. They

are constructed at lower gradients and therefore take up much more room than technical passes, which are more often used when room is restricting and the total head needs to be achieved within a relatively short distance. In technical fish passes the maximum drops, current velocities, turbulence and water depth need to be carefully managed at the design stage to guarantee effective passability for each of the target species.

Important design criteria are:

- The drops between pools;
- The nature of the flow between pools (plunging or streaming);
- Flow velocities;
- Turbulence (energy density);
- Water depth;
- The width of pools and slots.

For many species, notably cyprinids, it is best to have a diversity of flow velocities and micro-habitats along the width and length of the fish pass. These are best provided in a nature-like channel that also offers the opportunity for a pleasing

aesthetic appearance. In some circumstances there might be opportunities to link a natural passage channel through agricultural areas adjacent to the facility. Stones or woody structures roughen the bottom and promote the passage of fish and other fauna (invertebrates). Stones and boulders are also placed on the bed of technical pool passes for the same effect.

5.4.2 Downstream fish migration

Downstream passage over low head structures is believed to be straightforward, although fish may be reluctant to pass without delay and this may expose them to predators. The issues are much more significant on high head dams and wherever water abstractions are operating.

The realistic objective for fish protection at water intakes, in terms of the proportion of migrants that must be allowed to survive passage for stock maintenance or fishery support, should be determined first. This should then determine the solution required to protect downstream migrants, and define the related design and management

FISH FRIENDLY (MICRO) HYDROPOWER IN LOWLANDS

Guus Kruitwagen

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The Netherlands

The Netherlands is located in the delta of the Rivers Rhine, Scheldt, Meuse and Ems, and consequently the country is characterised by large numbers of waterways, both natural and man-made. Most of these waterways are regulated by the presence of numerous pumping stations, weirs, spill sluices and navigation locks each of which is a potential obstruction to the free migration of fish.

Over the last ten years many projects have been initiated to alleviate migration barriers by the construction of fish passes and the installation of fish friendly pumps. In a few cases the opportunity to combine these measures with hydropower has been explored. The relatively flat terrain and the absence of major elevations in the landscape make the country unsuitable for large scale hydropower schemes, but nonetheless there are some opportunities for power generation from its water resources.

To date only 0.4% of the renewable energy used in The Netherlands is hydropower energy

(CBS Statistics, 2012). The main contribution to hydropower production comes from 7 installations with an installed capacity just over 0.1 MW. The potential for the installation of hydropower schemes with capacity over 0.1 MW is limited not only by the absence of sufficient head, but also the importance of the waterways for navigation, and public concerns about the potential consequences for fish stocks.

The elaborate Dutch water system does however, provide opportunities for hydropower generation on a smaller scale. Micro hydropower schemes can be developed at locations with heads of only a few meters and even in the lowlands of The Netherlands potential locations can be found or created where they create no risk for navigation.

Opportunities are present at weirs and locks, but also at the countless inlet constructions used to feed water to low polder areas. However despite the presence of many suitable locations, few micro hydropower schemes have been installed to date, and part of the reason for this is concern for the potential implications for migrating fish.

The relatively new interest in fish migration over the last years has prompted the development of fish friendly pumps. The learning from research on fish friendly design of pumps has been directly applied to turbines, resulting in the improvement of existing turbines and development of new concepts. This has supported opportunities for the application of hydropower schemes with less risk for fish stocks and fish migration.

Examples are the development of several fish friendly Archimedean turbines and ongoing research on the application of a fish friendly axial pump as a turbine. The opportunities for application of these fish friendly turbines in the Dutch water system are illustrated by the turbine that was recently installed at the Hezenberg weir (near Hattem) in the management area of the Regional Water Authority Veluwe.

This weir, with a head of 2.5 m, was fitted with an Archimedean turbine with a capacity of 28 KWh. The weir and turbine feed a former brook with water from a navigation channel.

Fish friendly micro hydropower turbines can generate energy from existing heads, and thus contribute to the sustainability of the Dutch water management. However, hydropower planning should be based on environmental impact studies and implications before it is installed. These studies should include the ecological role (habitat, connectivity) of the river stretches in the river basin. Careful consideration of the specific features of proposed turbines is required to ensure that the development does not result in adverse effects on fish habitat and migration.

Archimedean turbine in The Netherlands
(© *Regional Water Authority Veluwe*).



Pumping stations; problems and solutions for fish migration

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Country: The Netherlands



INTRODUCTION

Pumping stations, like weirs, dams and sluices, are man made constructions that form barriers to fish migration. They are used to discharge water out of water systems where gravity discharge is not possible. This situation is very common in The Netherlands, where many polders have water levels below sea level and there are more than 3,000 large pumping stations to deal with this. However other countries, including Belgium, Germany and parts of England also require the use of pumping stations to drain low-lying land. In these areas pumping stations form a specific and major problem for fish migration.

If there is no passage system, then upstream migration (*directed from the sea towards freshwater or from reservoir canals towards polder areas*) is completely blocked. Downstream migration (*directed from freshwater to the sea or from polders to canals*) is influenced in different ways. Fish that pass through the pumps may be killed or damaged. Different forms of damage range from loss of a few scales to cuts, rupture of internal organs or complete decapitation. This is caused by collision of fish with rotating blades and other parts of the pump, rapid pressure changes, turbulence and water velocity (hydraulic shear) and cavitation (Kunst *et al.*, 2008).

Since about 2006 there has been growing inter-

est in The Netherlands and Belgium for improvements to the scope for fish migration at pumping stations. This is a result of the European Water Framework Directive (WFD) and the European Eel Regulation which have compelled member states to specify ecological goals for their water systems and to define the measures to reach those goals. There has also been increasing public interest and political response to publications and presentations that demonstrate the reality of macerated and chopped fish after their passage through pumps.

WHAT DID WE DO?

The necessity to deal with the challenge of improving fish migration (as well as the ethical aspect of the fish kill) is now widely adopted in policy documents of the water authorities. In their plans for the WFD water authorities have planned the measures to take for fish migration at pumping stations. But before expensive measures are taken, it is important to have sufficient understanding of the size and scope of the problem: what is the damage caused by different kinds of pumps, what are 'fish friendly' solutions and how effective are they?

In The Netherlands the Foundation for Applied Water Research, STOWA, started a large scale (national) research programme in 2007 on fish migration at pumping stations. A desk study in

2008 provided an overview of the different types of pumps that are commonly used, together with the scope and scale of the problems for fish migration and possible solutions.

The most common pumps used in The Netherlands are Archimedes screw pumps, centrifugal pumps, screw pumps and mixed flow pumps. It is clear that some of these are more harmful than other types, but results from studies on individual pumping stations show large differences in damage inflicted on fish. It is not only the kind of pump in a pumping station that defines the scope of the problem for fish migration. Capacity, size, speed and head-drop also influence the nature of the damage caused by a specific pump.

Additionally; sound, vibrations, flow-rate at The water intake and characteristics of the debris screens can also influence the behaviour of fish approaching a pumping station and their subsequent fate.

The desk study revealed many knowledge gaps. Information about fish mortality at pumping stations was scarce, sometimes difficult to compare and gave no real insight into the importance of the various influencing factors. Therefore a large field research was initiated in autumn 2009, testing 26 pumping stations in practice. Each location was sampled several times to collect fish that had passed through the pump and to determine the nature and level of damage. The fish populations on the upstream side of the pumping stations were also assessed in order to understand the nature of the fish stock on the 'supply' side.

HOW DID IT WORK OUT?

The overall results are summarized in the table below (STOWA, 2012).

Many small fish but few large fish

- Most fish passing the pumps were found to be small. 99% of all fish that passed the pumps during the study were smaller than 15 cm. Therefore the calculated damage profiles for different pumps are largely based on small fish;
- At all of the sites it was possible for larger fish to enter the pumps, but the results show that in practice many large fish do not readily enter a pump. They have greater swimming capacity and better orientation capabilities than small fish and they use these to avoid being drawn into the pump;
- Small fish on the other hand are easily sucked into the pumps. This may especially be the case at night when it is more difficult for fish to orientate themselves. The STOWA study has shown that there is a positive relation between flow rate at a water intake and the number of fish (smaller than 15 cm) passing. This leads to the conclusion that for most small fish 'migration' through the pumping station was unintended.

Overall fish mortality

- The overall damage rate (direct mortality, all pumping stations together) for small fish is 10.6%. For fish larger than 15 cm it is 22.9%. Although an even higher mortality rate for large fish was anticipated, it is notable that the 'large fish' in this study were mostly smaller than 30 cm;

POSSIBLE BYPASSES FOR DOWNSTREAM MIGRATION

Upstream (supply side) - sample

Size	Number	%-age
	11.852	
N<15 cm	10.003	84.4
N>15 cm	1.849	15.6

Caught after passage through pumps

Size	Number	%-age	Mortality (%-age)
	265.470		
N<15 cm	262.895	99.03	10.6
N>15 cm	2.575	0.97	22.9

>>EXAMPLE

- The study has shown that in many pumps there is a significant relationship between the length of the fish and the amount of damage. This confirms the hypothesis that ‘the larger the fish the more damage there is’;
- Delayed mortality is significant. The mortality rates above refer to immediate mortality. At a few sites fish were kept in enclosures to investigate if internal damage may cause delayed mortality. At some locations the delayed mortality was substantial, but numbers investigated were too low to distinguish between different kinds of pumps.

Mortality of eel

In these studies special attention was given to the level of damage on European Eel (*Anguilla anguilla*). In the Dutch polder areas this is the only (or at least most common) fish species that must migrate to the sea to fulfil its life cycle. It is generally believed (and also shown in research using Didson technology) that eel, like other large fish, may at first be alarmed by the sound, vibrations or by the construction itself. They may be reluctant to enter a pump, but in the end the biological drive to continue migration overcomes reluctance and the eel will follow the flow and enter the pumps. The mature silver eel are relatively large and therefore very vulnerable when

passing pumps. Unfortunately surprisingly few eel were caught during the STOWA research in 2009 (364 eel at 24 pumping stations, compared to 265,000 cyprinids and percids). The research period in the autumn of 2009 was very dry and most pumping stations were rarely operated. Consequently there was little migratory activity of silver eel. Studies by INBO (Institute for Nature and Forrest Research, Belgium) show that the numbers of silver eel passing through pumps may be very low for long periods but will suddenly peak in favourable conditions for migration (Bayens *et al.*, 2011)

Differences between pump types and other aspects

The STOWA research has combined the findings from the field research done in 2009 with results from other studies. This provides information about fish mortality at more than 75 pumps or pumping stations. There is a great variety in the amount of damage found, and it is not possible to clearly distinguish between different kinds of pumps on the basis of the level of fish damage. Even within one type of pump large differences were found in different tests. This means that other aspects such as capacity and speed (rpm) play an important role. Nevertheless, the research has shown that:

HOEKPOLDER

Pumping station Hoekpolder fitted with ‘fixed wall’ Archimedes screw pump.



ARCHIMEDES SCREW PUMP

Detail of the ‘fixed wall’ Archimedes screw pump.



FISH FRIENDLY AXIAL FLOW PUMP

Pentair Nijhuis and Fish Flow Innovations.



- Conventional screw pumps are usually the most damaging for fish;
- Archimedes screw type pumps are relatively fish friendly;
- There are alternatives that cause little or no damage to fish.

The STOWA research endeavoured to establish relationships between fish mortality and different aspects of pumps that might be relevant. A significant correlation was demonstrated between the speed of pumps and mortality of fish. This is unsurprising since a high speed increases the probability that fish will be hit by the blades. Other aspects are likely to be of significance, but the relationship with fish mortality could not be quantified. For instance capacity may influence speed (high speed means higher mortality), but also the size of the pump (large pump means lower mortality).

LESSONS LEARNED.

- 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;

- Fish friendly pumps - with little or no damage to fish passing through – are available. Tested examples with good results are 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);
- Solving the problems of downstream fish migration at pumping station is not simply a matter of installing another kind of pump. Larger fish are deterred by sound, vibrations and some other aspects of pumping station operations. Relatively few large fish actually seem to pass through pumping stations;
- The solution of upstream migration requires additional measures to bypass the pumping station;
- For eel the migration through pumping stations is a big problem. Therefore it is emphasized that water authorities need to install fish friendly pumps to minimize mortality of silver eel. Other fish species will also benefit from this;
- There are many issues to consider when building or retrofitting pumping stations (water management, ecology, costs). It is our experience over the last couple of years that the best solutions for fish migration at pumping stations are found when technicians and ecologists work together from the start of a project. STOWA has developed a spreadsheet based tool, which makes the results of the study easily available and stimulates the communication between technicians and ecologists;
- There is still little practical experience with newly developed fish friendly pumps. However 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. A protocol is being developed to ensure better comparison between test results.

criteria. The cumulative impact of multiple abstractions must be considered where relevant. The final design should protect target species from entrainment, perhaps by combining screens with bypass facilities, in order to fulfil the requirements of the river basin plan.

Screens

A wide range of physical barriers have been used for fish screening, some of which may also function as behavioural barriers. They can be divided into screening for salmonids and other larger fish, and for juvenile and smaller fish (Turnpenny and O' Keefe &, 2005). The most frequently used are mechanical barriers (e.g. trash racks or angled bar racks). Screening efficiency is related to fish length (or width), to bar spacing ratio, and to fish responses to hydraulic conditions at the front of the barrier and the bypass entrance (Lariniér, 2001). Screens should be situated at the point of diversion of water from a river and not within the abstraction channel itself as fish may prove reluctant or unable to return to the river.

Bypass systems

In addition to screening to prevent fish entrainment into abstraction channels, fish should be provided with an alternative safe route downstream that is readily found. This may of course be provided by the residual flow within the river channel itself, depending on the site layout.

Bypass systems vary in design and location, depending on the local situation and the target species (e.g. benthic or surface orientated migratory species). The effectiveness of bypass systems depends on the dimensions, shape and precise location of the water off-take, the proportion of flow within, precise location of the bypass, and local hydraulic conditions. A combination of one or more bypass routes (weirs, navigation locks or fish passes) are often present at most larger sites and all can be used effectively by fish in certain circumstances.

Other solutions for minimising fish damage

In many operations it may be more cost effective

to reduce or cease abstractions during the migration period of the target species, rather than to install screens. This might be driven by biological criteria combined in a predictive mathematical model that defines the likely timing of the downstream migration. This has been used for Pacific salmon smolts, based on increasing flow in spring time (DVWK, 2002), and for downstream migrating Atlantic salmon smolts similar correlations exist (Schwevers, 1999). This is likely to be river and latitude-specific. For adult eel a correlation is reported with a period of a few days around the new moon and an increase in river flow in the autumn (Brujij *et al.*, 2003; Vriese *et al.*, 2006). Since factors other than flow (e.g. water and air temperature, turbidity, flow velocity, oxygen levels etc.) can also determine migration activity the reliability of simple generic correlation models is doubtful and therefore it is wise to be cautious when using this approach.

Other possible technical warning systems consist of surveillance by underwater cameras, or fish detection by sonar. Some biological warning systems use the principle that captured fish have the same behaviour as the species in the wild, especially if they are held in tanks through which river water is passed. This principle is used in The Netherlands and Germany with captured eel, tagged with transponders, in a system known as Migromat[®] (Adam, 2000; Brujij *et al.*, 2003) when the onset of detected migratory symptoms is used to adjust abstraction practice.

Turbines claimed to be relatively friendly to fish, and which might reduce passage mortality at hydropower sites, have been developed and include designs with blunted leading edges to the turbine blades. Archimedes screw turbines are usually fitted with compressible bumpers on the leading edge of the blades to minimise the effect of strike. Further development to reduce damage to fish depends on improved knowledge of the mechanics of fish passage through the turbines and the factors that influence this, including flow velocities, and the fluid dynamics within the turbine. Clearly the most fish friendly turbines

should always be selected wherever feasible (DVWK, 2003).

In the few circumstances where downstream migration protection is not possible for some reason, programmes have been put in place to capture fish upstream, transport them via barges or by road, and then to release them downstream of the intake. This so-called 'trap and transport' method can be effective where there are multiple intakes in the river, although it is expensive and may itself be damaging to fish. These procedures have been used in the US since the 1960s for Pacific salmonid smolts in the Colombia River, where there are many large hydropower dams. However the success of this has remained the source of debate (National Research Council, 1996). Trials have also been undertaken in Germany (Atlantic smolts in the River Lahn) and in Luxembourg (eel in the River Moselle).

5.5 STEP 3: CONSTRUCTION AND MAINTENANCE

5.5.1 Construction Upstream facilities

Every design should be very carefully checked for the following biological, hydraulic and other criteria prior to construction:

- Has the possibility of removal of the obstruction been thoroughly considered?
- Has an ecological or 'nature-like' design been selected in preference to a technical design (as these are more effective for smaller fish with low swimming capabilities)?
- Is the entrance to the fish pass located where fish will naturally arrive at the obstacle?
- Is the entrance to the fish pass easy to locate?
- Will it contain enough water to attract fish at the critical times of the year?
- Is the entrance located as close as possible to the toe of the weir?

Louvre screen

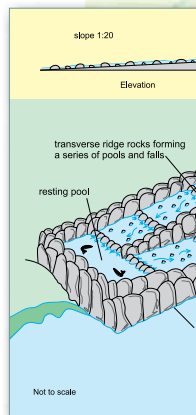
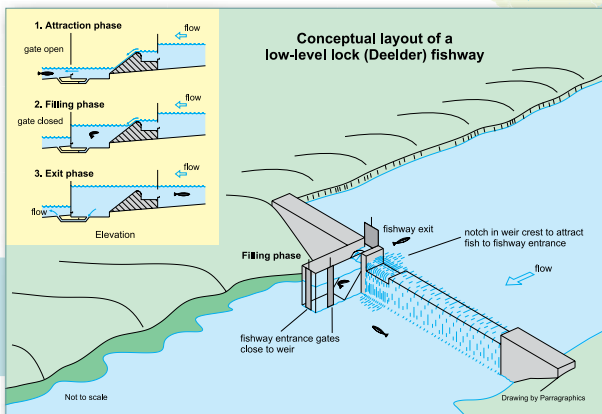
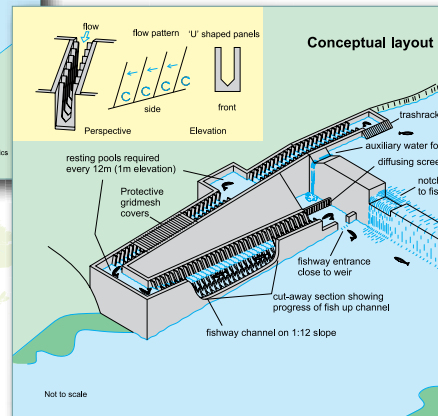
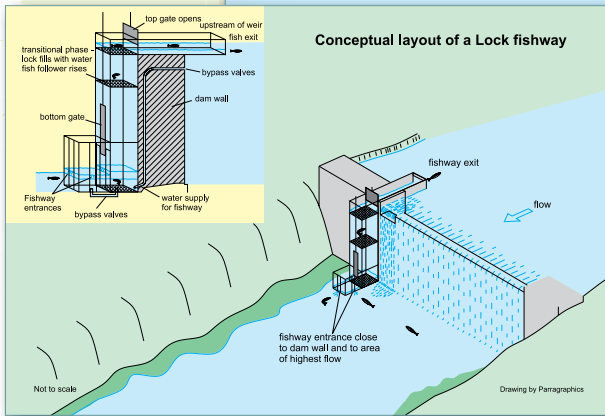
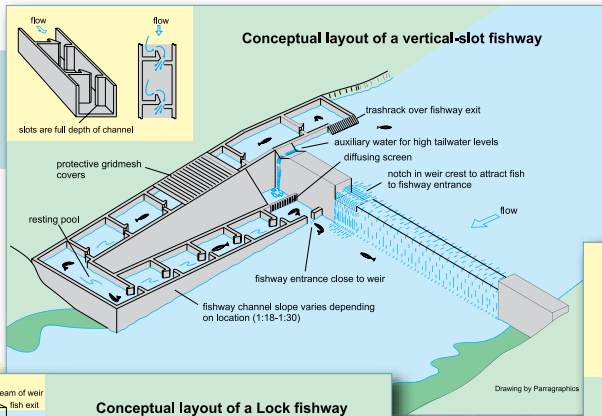
This screen at the Holyoke hydropower plant (USA) is installed to divert downstream migrating fish towards a tube that leads the fish safely past the turbines into the main river.

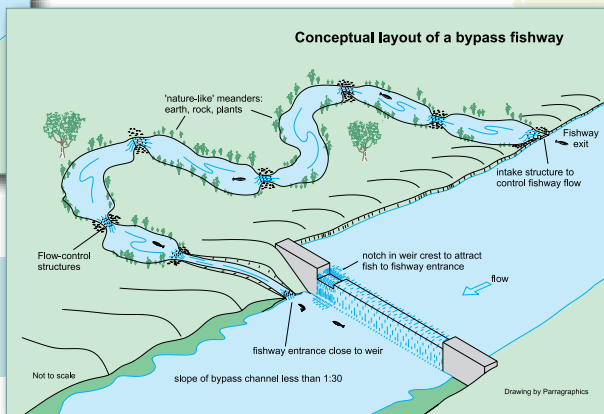
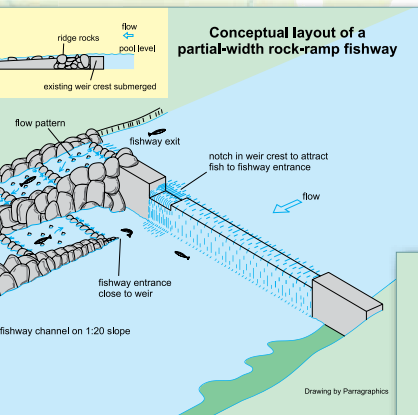
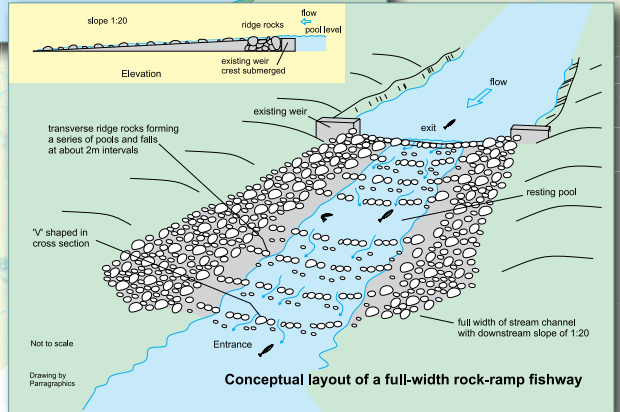
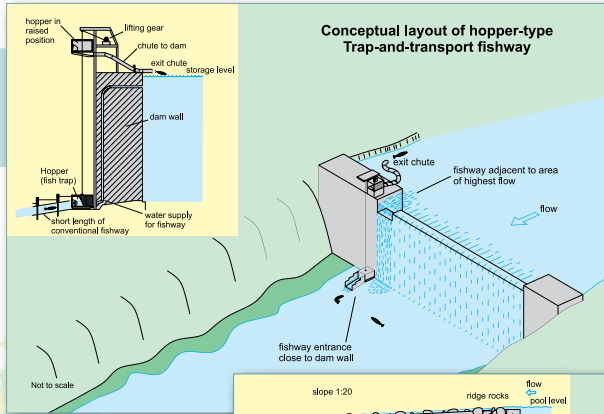
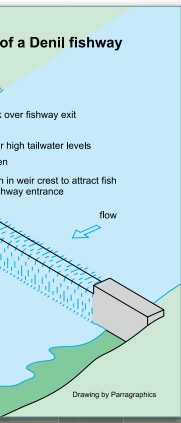


FISHWAYS

THORNCROFT AND HARRIS, 2000

SCHEMATIC OVERVIEW OF VARIOUS FISHWAYS





- Is the pass co-located with any other discharge (e.g. hydropower discharge) to maximise attraction?
- Is the turbulence in the pass within acceptable limits?
- Will the fish pass be passable for each of the target species?
- Is the fish pass large enough to accommodate peak migrations of the target species?
- Are there sufficient arrangements to exclude debris?
- Can the fish pass be negotiated by swimming (instead of jumping)?
- Is the diversity of stream flows in the fish pass maximised?
- Does the fish pass provide a route for fish migration throughout the whole year?
- Is the fish exit from the fish pass sufficiently far away from the weir, dam etc. in order to prevent migrating fish from being swept downstream?
- Can the fish pass be easily accessed for clearing of debris and maintenance?
- Have provisions for monitoring been included?

And finally,

- is the facility safe for all who visit it?

Downstream facilities

Similarly, the proposed design of a downstream facility should also be carefully checked prior to construction:

- Have passage structures, such as one or more lowered sections of the crest, been provided at the most obvious points where fish accumulate prior to passage?
- Has every opportunity been taken to reduce entrainment risk by setting an appropriate abstraction management regime?
- Will the facility function during the critical migration period of each target fish species and each relevant life stage?
- Are the screens designed with at least 20% over-capacity to allow for partial blockage or blinding?
- Are flow conditions in front of physical barriers arranged so that high velocity hot spots

do not occur?

- Are flow velocities in front of the physical barriers below the escape velocities of the target species and key life stages?
- Will the selected mesh spacing or behavioural guidance method exclude, protect or guide the target fish to a bypass (for onwards migration)?
- Is the amount of flow sufficient to attract fish to the bypass?
- Is the entrance to the bypass located at the point to which the fish are guided?
- Does the bypass entrance provide good hydraulic conditions that deter fish from escape once entered?
- Is the bypass not going to be a visible deterrent to fish?
- Is the outfall of the bypass located away from the turbulent zone, and is the fall not higher than 10 m?
- Is the downstream water depth sufficient so that the risk of predation by birds or fish is minimal?

5.5.2 Operational and structural maintenance

Owners and operators of fish passes often assume that their fish passage facilities continue to function well throughout the year, and therefore maintenance is often neglected. In many cases this neglect leads to the pass becoming blocked by debris including branches, leaves, algae, and sometimes gravels mobilised in floods, resulting in partial or total blockage of the fish pass. Consequently the flow through the fish pass can be severely reduced, or even stopped, with adverse implications for fish attraction and passage.

Facilities for downstream migration, such as physical screens, are only efficient if they are correctly operated, cleaned and maintained and they should therefore be carefully designed so that this can be safely done. Common problems with mesh panel and bar screens include structural damage, damaged screen seals, screens not fully seated, screens removed to avoid clogging problems and screens heavily clogged (Turnpenny *et al.*, 1998a; Turnpenny *et al.*, 2005).

In order to make sure that facilities function as they are designed, a clear inspection and maintenance plan should be prepared and carried out. In the UK it is a legal duty for fish passes for migratory salmonids to be maintained in an efficient state and it is an offence not to do so.

Maintenance is best done as part of a structured inspection programme or protocol that defines the times when the facility must work. For example in Finland fish passes are closed during the winter, or the amount of water is significantly reduced to prevent ice formation.

Maintenance needs to be carried out in the period prior to the migration period of the target species. The intensity of maintenance may differ per site, depending on local circumstances, and this will be readily identified following operational experience and an objective risk assessment (Armstrong *et al.*, 2005). In addition to structural maintenance, regular inspection is necessary to avoid malfunctioning due to blockage.

Maintenance of fish passes and screening facilities is inherently dangerous and it is essential for operator health and safety issues to be taken into account.

TIPS

- Use a checklist to ensure that all new fish migration facilities are appropriately designed, efficient and safe;
- Define the required period of operation of the facility;
- A working fish pass only stays working if a good maintenance plan is developed and implemented;
- Create protocols for inspection and maintenance of fish pass facilities;
- Maintenance officers need biological and hydrological background so that they may ensure optimal maintenance;
- Take health and safety very seriously.

5.6 Fish migration facilities around the world

FAO (2001) extensively reviewed the current status of fish passes around the world and identified successes but also failures. The following review draws partly on this material.

5.6.1 Introduction

The ambition to provide passage for fish, especially commercially important species, probably started when man first realised that waterfalls and other structures in rivers could block access of fish to traditional spawning and nursery grounds. Many fisheries in rivers started in response to the seasonal abundance of fish returning to their spawning grounds, and this migratory behavior was used to ensure that there were good catches in times of plenty. The sight of salmon leaping at waterfalls demonstrated that the fish had ambition to reach the uppermost spawning streams, and it was also realised that they could be prevented from doing so by the structures that man was building for purposes such as the powering of mills and for irrigation. Clearly there was scope to increase the abundance of fish if their access to upstream habitats could be improved.

Written records of the earliest attempts to ensure that fish could pass structures date back to 15th-century England when free gaps in weirs were specified, and to 17th-century France, where bundles of branches were used to create steps in steep channels for fish to bypass obstructions. With the industrial revolution came many thousands of weirs and dams to power industry, and as waterways in Europe became more damaged and polluted the once important stocks of migrating fish were destroyed and the importance of provision for migrating fish in many places was forgotten. In England the once great runs of salmon, sea trout and shad into the Thames, Trent and Humber were lost, as they were for the great European Rivers Rhine, Elbe and Meuse amongst others.

However in many other rivers the needs of fish were not forgotten and the urgency to build

EXAMPLE

Maintenance of fish passes

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Country: The Netherlands



INTRODUCTION

Over the past few years we have made a lot of progress in constructing fish passes. In The Netherlands most rivers do not flow naturally anymore because of the large number of weirs present. Implementation of fish passage solutions therefore provides an opportunity to recreate the connectivity and habitats that most species need. Rather than simply constructing technical solutions to facilitate migration past an obstacle we have started to consider solutions that also create new flowing water habitat. In this way our fish passes can also become refuges for fish.

The solution we have developed are long nature-like fish passes made from and containing a lot of natural materials. The longer the fish pass, the easier it is to dissipate the energy of the water

and the easier it is to create more natural habitat. These solutions do have the disadvantage that plants and trees can grow within the fish pass, and this example explains how we deal with this.

WHAT DID WE DO?

The challenge of planning, financing and constructing fish passes is substantial; however we have also realized that their maintenance is critical. We realized the importance of this, and our maintenance team was also not slow to point this out to us! Luckily, they were also willing and prepared to help us out.

We therefore agreed to formulate a maintenance plan for all of our fish passes. The plan starts with a brief description of fish passes in general; why we have them, what the maintenance team needed to know about them, and why they have to be maintained. After that each fish pass is specifically described: we describe the area it is in, its function, how we want it to work, how we want the pass and its surroundings to look, and how we think maintenance should be carried out.

The maintenance team uses the plan to develop specific work plans so that it is clear what must be done, and they then implement the plan. The team leader motivates the men to do a good job in maintaining the fish passes, and we found that it is also necessary to involve the person who is responsible for the area the fish pass is in. This person has a say in the construction of the fish

MANUAL MAINTENANCE OF FISHWAY



pass as well as in the maintenance plan. Working in this way we have ensured that our plan is important and is actually used and is not just left on a desk.

HOW DID IT WORK OUT?

In 2011 we started to work with this more structured way of maintaining the fish passes. The first result has been that we are all starting to discuss our fish passes and their maintenance more, which is clearly a good thing. Since the beginning of 2010 we have started to plan maintenance at an earlier stage, within the construc-

tion planning phase. Working this way we are ensuring that the people who are responsible for maintenance are not confronted with an unsolvable problem in the future. We think and hope that their closer involvement with fish pass work will provide benefit in future.

LESSONS LEARNED

We have learned that a working fish pass is not only the result of the skill of the designers and the craftsmanship of the constructor. A working fish pass only stays working if a good maintenance plan is developed and implemented.

MAINTENANCE

Optimizing the position of stones during field course for maintenance staff.



structures to protect and enhance fish access past the weirs and waterfalls led to improved understanding and better designs. A version of a fishway was patented in 1837 by Richard McFarlan of Bathurst, New Brunswick, who designed his fishway to bypass a dam at his water-powered lumber mill. Elsewhere in the USA, the first fish ladder was apparently built in Rhode Island, on the Pawtuxet Falls Dam in 1880, although it was removed in 1924, when the City of Providence replaced the wooden dam with a concrete one. Much earlier in England, an Act of Parliament ('An Act for the Reedifieing of Milles near the City of Hereforde') was passed in 1555 that required what we would now recognise as 'free gaps' of a specified size (16 inches high by 12 inches wide) to be left open in weirs for the 'convenient passage of salmon and other fish' (Anon, 1555). Buckland later described in 1867 how to resolve the multiple obstructions in the River Ellen in northern England by making pool passes. In 1868 (as described in Bompas, 1896) he considered 'the difficulty of dealing with weirs' for fish and concluded that the problem 'seems to resolve itself into a question of bread v salmon' as many of the mill weirs obstructing salmon had been built to mill corn. Shortly afterwards Francis (1870) also described pool passes.

Developments continued through the first baffled fish pass designs of Denil (Denil, 1909) which

were smaller and cheaper, and later through diagonal 'balk' passes and further developments of pool passes (Pryce-Tannatt, 1937). Ongoing refinements to design occurred in the USA where the vertical slot variant of pool passes was conceived and installed at Bonneville dam on the Colombia River (described in Clay, 1995), and in Europe where refined baffled fish passes were developed. The superactive baffle pass first described by Larinier led to designs that could cater for multiple species of fish and in a range of fish pass sizes and discharges through deployment of parallel fish pass units (Larinier, 2002).

Perhaps the final phases of basic development are those of the 'nature like' fishway, and rock ramps (see FAO/DVWK, 2002). The nature-like concept is simply based on bypass channels taking flows of water around obstacles within constructed channels that mimic the natural physical character of a river (Aarestrup *et al.*, 2003; Larinier *et al.*, 2006). The rock ramp uses a similar concept but within the river itself, creating a relatively steep gradient section of river leading up to the remaining weir crest. Both usually use large boulders embedded within a constructed channel (Gebler, 1998) to retain a new river bed.

Elsewhere fish passes and ladders followed the developments in Europe and the USA. The

Drentsche Aa

Cascade fishway in the small river Drentsche Aa (The Netherlands) (© Groene Zoden Fotografie).



first fish ladder in Brazil was built in 1911 at the Itaipu Dam (Agostinho *et al.*, 2008) although in common with other passes elsewhere it was replaced later by a more effective alternative (Fernandez *et al.*, 2007).

The following brief review for each continent is not exhaustive, but aims to explore the current use of fish passes throughout the world, the target species, the state of technology and the current philosophy. One of the most common issues appears to be the widespread application of European and North American fish pass designs, originally conceived for salmonids, for fish of entirely different biological characteristics. Experience is invariably that this approach is not effective for most species and that, in any case, future efforts should be targeted at an ecosystem level to provide passage for a broader range of fish species (Mallen-Cooper and Brand, 2007).

5.6.2 North America

The US has catalogued more than 75,000 dams greater than about 2 m high along its waterways, and tens of thousands of smaller dams exist in rivers across the country (American Rivers, 1999). Fish passage requirements are most commonly defined along the Pacific and Atlantic coasts which support the most important anadromous fisheries, and in the Rocky Mountains which have valuable recreational fisheries.

Some of the main advances in upstream passage technology, notably for large rivers, have come from the westcoast of North America. The basic pool pass designs have evolved over the years since the building of the first dam (Bonneville on the Columbia River) about 60 years ago (OTA, 1995) and today include variants of vertical slot fishways including the Ice Harbor design (named after the hydropower dam where it was deployed in 1955) which can accommodate high variation in upstream and downstream water level. Today several very large hydropower developments are in place on the Columbia River and its principal tributary, the Snake River. The management of upstream passage is sophisticated with multiple

entrances to collection galleries and, frequently, large fish passes on each bank of the river. The systems developed over the past 50 years are considered to work well for the main west coast anadromous salmonids (several strains of chinook salmon, based on run-timing characteristics, and sockeye salmon) (e.g. Roscoe *et al.*, 2011) and steelhead trout (*Onchoryhnchus* spp.). However the performance of these passes for American shad has been reported to be poor on both the west- and eastcoast fishways, so that nature-like channels are now being considered in some cases (Franklin, 2009). These may also offer better scope for striped bass and lamprey.

In Canada Thiem *et al.* (2012) have recently reported variable success (25-100% passage efficiency) of a vertical slot fishway in Quebec amongst the species that attempted to use it, and observed that better data on performance, including delay, could still lead to improved future designs.

Baffled fishways have not been widely used although one variant, the 'Alaskan-A' or the Alaskan steep-pass has been developed for use as a modular fishway. The pass can be installed at higher gradients than other denil-type baffled fish passes, but the main feature is that the modular nature means that they can be easily transported, even by helicopter, for assembly at remote sites (Clay, 1995).

On the Atlantic seaboard of the USA and Canada, fish restoration programmes on the main rivers where salmon and other species were extirpated by industrial developments are now common. In New England substantial investment on rivers including the Connecticut, Merrimack and Penobscot started in the 1960's and fish passes have been constructed at most of the large dams that excluded Atlantic salmon, alosids and lamprey from the upstream rivers. On the Connecticut River large pool fishways based on the Ice Harbor design have been constructed at Turners Falls, where there are 3 separate ladders, the largest with 68 pools. Further downstream the

Hadley Falls Fish Lift on the Holyoke Dam has been successfully used to pass large populations of shad and salmon amongst other species. Denil fish passes are not widely used (Washburn and Gillis, 1985), although one was built on the Presumpscot River in Maine to replace an earlier ineffective fishway that had been built principally for alewife.

On the east coast of Canada, Clay reported 240 fish passes, whilst in central Canada and the USA Clay lists 40 fish passes used by potamodromous species as well as salmonids (Clay, 1995). This number will inevitably have greatly increased, for example Kerr (2010) gives an inventory of 42 fishways in Ontario alone.

5.6.3 South America

The huge diversity of freshwater fish, including many long distance migrators, in South America has been noted by Northcote (1998) and more recently by Agostinho *et al.* (2008). Of the estimated 13,000 species of freshwater fish that have been described possibly as many as 31% of these are found in the neotropical regions of South America with probably more than 1,300 in the Amazon Basin and 310 in the Upper Paraná alone. With more than 700 major dams, and more planned, on the large rivers of Brazil it is inevitable that major impacts on this diverse fish fauna have occurred.

Fish passages were the first actions taken to mitigate damage to migrating fish stocks in the Parana, with the first fish pass built in the Pardo River at the Igarapava Dam. Perhaps 10 more were built prior to the 1960s and since then dozens more have been built with fish lifts at two locations (e.g. Porto Primavera Dam). The effectiveness of these fishways was generally not investigated but this has been rectified to some extent since (e.g. Agostinho *et al.*, 2007), although the results generally proved disappointing.

Fish communities in these large rivers include the potamodromous and highly important characins and siluroids which constitute a vital

food resource for artisan fisheries. Among the characins, prochilodids of the genera *Semaprochilodus* and *Prochilodus* and siluroids including *Pimelodus*, *Brachyplatystoma*, *Pseudoplatystoma* and *Plecostomus* are significant target species in the fisheries.

Some of the migratory species undertake very long migrations, from 200 km to as much as 1,000 km (Carolsfeld *et al.*, 2003) and some of them are able to use the fish passages built, although there are concerns about subsequent migration within the lentic environments of the impounded reaches. Agostinho (2008) concludes that current fishway construction practice is inadequate, and that insufficient consideration has been given to the nature of the dams and design of appropriate fishways. More recently it has been concluded that the dams and fishways may even act as 'ecological traps' as they entice fish to ascend to poor environments where predation risk is high and reproduction is poor leading to a failure to provide recruitment to downstream habitat (Switkes, 2008). This has led to a seemingly radical suggestion to de-commission some fishways, however the urgency for greater understanding of the biology and dynamics of the main species is clearly the way forward.

Perhaps the most impressive fish pass example is the new Itaipu fish ladder in Brazil. This 7.9 km long dam (14,000 MW installed capacity) on the Paraná River, one of the largest operating hydroelectric facilities in the world, was built on a series of natural cascades that were themselves barriers to upstream fish migration. The dam was originally built without a fish pass, except for an experimental model installed to obtain information on the biology of the migratory species attracted to the structure. The fish pass flow was clearly inadequate, at only 0.3 m³/s, to work as an effective pass as the average river flow during the experiment was 11,800 m³/s (Borghetti *et al.*, 1994). Subsequently a 27 m high, 155 m long experimental vertical slot fish ladder was constructed and it was reported (Borghetti *et al.*, 1998, taken from Carolsfeld,

Holyoke fishlift

The Holyoke power plant in the Connecticut River (USA) is equipped with a fishlift (16 m) which transports upstream migrating fish. The lift is situated on the right-hand side of the powerplant.



2003) that 40% of the 65 species found downstream were able to reach the upper part of the ladder. A second study looked at the use of the new fishway built in 2002, the 10 km long (and consequently the largest known fishway in the world) Canal da Piracema (Fernandez *et al.*, 2007). This showed that 116 species, of which 17 were long distance migratory fish including the streaked prochilod (*Prochilodus lineatus*) and piapara (*Leporinus elongates*), successfully used the ladder.

Hydroelectric impoundments are considered the most damaging human threat to Amazonian fish populations and fisheries. Dam construction in the upper reaches of rivers appears to have led to the disappearance of many migratory stocks and yet more recent dams are still being built with no adequate fish passage facilities.

The existence of some apparent success stories in the continent indicate what can be achieved. In Brazil the elevator installed in the Yacyreta Dam, in the Middle Paraná, seems to be working more

satisfactorily than others in the river system. In 1995, it was reported to have allowed passage of 44% of the species recorded in the tailrace (totalling 1.8 million individuals, weighing 252 tons!). These results have inspired recent installation of similar elevators in the Porto Primavera Dam on the Paraná River (Sao Paulo) as well, however the results of these installations are not yet known (Carolsfeld, 2003). Godinho *et al.* (1991) studied a fish pass in the region of the Salto do Morais dam on the Tijuco River, capturing within it 34 of the 41 species present. However, the fish pass seemed very selective with only a few individuals of most species present and only 2% of the fish reached the upper section of the fish pass. The same authors mentioned another fish pass at Emas Falls on a low dam which seemed to be more efficient.

There appears to be relatively little fish pass development in Argentina. Quiros (1989) mentioned 3 ineffective passes on hydropower dams in Argentina, one of which was the downstream dam (Cierre Sur or Chapetón) on the Paraná which

EXAMPLE

The Canal da Piracema at the Itaipu Dam

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Country: Brazil



INTRODUCTION

The Canal da Piracema at the Itaipu dam site is the longest (nearly 10 km) fish passage system in the world. It was built in 2002; 20 years after the formation of the reservoir. The words 'Canal da Piracema' originate from the indigenous words: *pira* = fish and *cema* = jump. The Itaipu reservoir was impounded in October 1982 and has an area of 1,350 km² at its normal operational level. This is a binational project because 57% of the Itaipu reservoir is located in Brazil and 43% in Paraguay.

THE PIRACEMA CANAL

The Piracema Canal connecting the Paraná River and Itaipu Reservoir. The study segments are numbered in black circles.



WHAT IS THE PROBLEM?

The Itaipu dam and other power plants along the Paraná River have contributed to habitat fragmentation by imposing a barrier to the rheophilic fishes. A decrease in the migratory fish population has been observed downstream of the dam due to factors such as the loss of spawning and nursery areas and the spillway impact that possibly compromise egg and larval survival.

THE PIRACEMA SIDE CHANNEL SOLUTION

One possible option to mitigate the impacts of dams was the use of side channels, which lead migratory fishes toward spawning areas (Borghetti *et al.*, 1994). This measure was applied at the Itaipu dam, with the construction of the Piracema side channel, this being the longest fish passage system in the world. The passage simulates diverse environments, and includes fish ladders, a natural fish passage channel and four artificial ponds. The channel was built with the hope of diminishing the impacts caused by the interruption of the river course by promoting the relocation of migratory fishes upstream and downstream of the dam. The construction of this fish passage was somewhat controversial. On the one hand, it connected two distinct ichthyofaunistic provinces; the Sete Quedas falls had constituted a natural barrier between these provinces, but the reservoir submerged this natural barrier and the fish passage contributes

ARIAL VIEW OF THE PIRACEMA CANAL

(© Itaipu Binacional).



to further mixing of species. On the other hand, the Canal da Piracema could contribute to the dispersion of some species that remained restricted downstream of dam (Júlio Júnior *et al.*, 2009), but would naturally occur throughout the river stretch.

EVALUATION

The Canal da Piracema has been described as a model for the fish passage proposed for the Santo Antônio and Jirau dams on the Madeira River in the Amazon, having one of the world's highest diversity of fish species. A study (Makrakis, 2007) evaluated the ichthyofauna present in the Canal da Piracema and the abundance and distribution of long-distance migratory fish

species along this fish pass system (evaluated possible selectivity).

The Canal da Piracema was shown to be difficult to sample due to its environmental heterogeneity: artificial ponds, ladders and nature-like fish passage. To solve this problem, several fishing methods were used, adequate for the several biotopes present (unstructured and structured littoral were sampled with seining nets and electrofishing; lentic areas were sampled with gillnets and longlines in deeper areas; and rapid water areas were sampled with cast nets).

The ichthyofauna of the Canal da Piracema followed the pattern for South America and the

>>EXAMPLE

Paraná River, with a predominance of Characiformes and Siluriformes. The most representative families were Characidae, Anostomidae, Pimelodidae and Loricariidae. Some 116 species were captured (17 of which were long-distance migrants) during the period studied. Small-sized species predominated in unstructured and structured littoral areas, especially *Bryconamericus exodon* and *Apareiodon affinis*. The most abundant species was *Hypostomus* spp. in lentic areas, followed by *Iheringichthys labrosus*. *Hoplias* aff. *Malabaricus* predominated in deeper lentic areas. Long-distance migratory species were abundant in rapid waters; they were *Prochilodus lineatus* and *Leporinus elongatus*.

The reduction in the number of species, including migrants, is an indication that the Canal da Piracema is selecting the species that ascend

it. Therefore, the search for information on the efficiency of the various fish passages present in the Canal da Piracema is fundamental, to facilitate the upstream movements of fishes. If this is attained, this polemic fish passage has the potential to contribute to the conservation of fish stocks in the Itaipu Reservoir and upstream stretches, due to the presence of spawning and development (nurseries) areas for migratory species.

The Canal has been monitored more recently by PIT-tag telemetry (since December 2009). This technology has allowed the assessment of the bottlenecks in the system and the planning of the improvements required. A main bottleneck, the Canal de Deságüe no Rio Bela Vista (CABV), was identified and improvements are being studied to make this segment more effective.

CANOEING IN THE PIRACEMA CANAL

Canoeing is a popular sport in the Piracema canal. This makes it a unique multifunctional fishway (© Itaipu Binacional).



was equipped in 1984 with 2 large Russian-design selective channel fish elevators, based on the Borland lock principle. It was believed that they would have to cater for more than 100,000 tonnes of fish each year. One of these operates in the upper water level for characids, which follow velocity gradients, and the other for bottom-dwelling siluroids. The passes were not considered to work well because of poor attraction of fish to their entrances and their behaviour within the locking system (Quiros, 1989).

Oldani *et al.* (1998) later reported 140 dams on the De La Plata River basin with another 280 planned at the time they wrote their paper! However they listed only a few pool and weir passes at the lower head dams, one Borland-type fish lift at the Salto Grande Dam with fish elevators at the Yacyreta Dam. All were reported to work with limited success.

5.6.4 Europe

In Western Europe fish passes have been built for Atlantic salmon and sea-run brown trout, for well over a hundred years. The recognition that all species need to migrate, together with the new ecosystem approach, has resulted in the increasing construction of multi species fish passes.

In England and Wales, a recent inventory suggests that there are approximately 500 fish passes, almost all of which were built for salmon and sea trout. Fish passes of approved design are a statutory requirement for all new obstacles, and in existing obstructions that are being substantially re-built, if the authorities indicate this is a requirement. The awareness of the need for the passage of potamodromous species and other non-salmonid diadromous species such as shad (*allis* and *twaite*) and eel is much more recent.

Proposed new legislation to extend the legal requirements for fish passes to all species of fish is currently being considered. The most commonly used fish pass has been the pool-type fish pass but more recently superactive bottom

baffle passes have become much more common (Armstrong, 1996).

In France, legislation requires that free passage must be assured through all obstructions situated on designated 'migratory fish' rivers. Consequently, several hundred fish passes have been built or retrofitted. Denil fish passes are only used for Atlantic salmon, sea trout and sea lamprey on small rivers. Fish lifts or large pool-type passes with large and deep vertical slots or deep notches are used for shad. When several species must be taken into account, the recommended fish pass is the pool type (Larinier, 1998). The Loire River is the one of the last free-flowing rivers in Europe. A dam removal program is being successfully executed to create even more room for this river.

In Italy the Zanchi project at the Steccaia Dam on the Ombrone River is Italy's first fishway and is designed to allow the upstream spawning migration of shad (*Alosa fallax nilotica*). Currently fishway design in Italy is intensively evaluated by the Politecnico di Torino (Land, Environment and Geo-Engineering Department) and the University of Florence.

In polder areas (low lying tracks of land, often lower than sea level and surrounded by embankments) in Belgium, England and The Netherlands pumping stations often block migration routes and fish are damaged by contact with the rotating blades of the pumps. The Dutch government has undertaken a national study to look at possible solutions for these problems, and throughout Europe these issues are to be addressed as a result of the EC Directive to ensure the future of the stock of eel.

The threats to migratory fish in Russia and the Baltic states are familiar. Lenhardt *et al.* (2007) report that the development of the Danube in modern-day Serbia, first for navigation in the late 19th century and then through dam construction in the second half of the 20th century, blocked sturgeon migrations. They reported a reduc-

tion in sturgeon catch from 1,144 tonnes in 1940 to just 8 tonnes in 1995. Lagutov and Lagutov (2007) stated that 100% of the spawning grounds of the beluga (*Huso huso*) in the Volga and Don Rivers were lost due to dam construction. Construction of the 44 m high Volga hydroelectric dam, opened in 1961, was reported to disrupt migrations of Caspian Sea fish fauna, including beluga, towards their spawning grounds.

They described a strategy for restoring migration routes by replacing the early inefficient fishways. Downstream migration has also been reported to be a significant factor at 45 Russian dams due to interruption of migration and diversion of fish into turbine intakes (Pavlov *et al.*, 2002).

5.6.5 Asia

Nakamura and Yotsukura (1987) reported approximately 10,000 fish passes on Japanese rivers, with the main target species being the amphidromous sweetfish, or ayu (*Plecoglossus altivelis*), anadromous salmonids and their landlocked form (*Oncorhynchus* spp.) and Japanese eel (*Anguilla japonica*). Over 95% of the fish passes were conventional pool and weir fish passes, the others being vertical slot and denil type and most were based on European concepts.

These did not always work well for local fish species, and Hara and Wada (1995) reported that denils did not work for ayu, for which low gradient pool and weir fishways with head-drops less than 10 cm were required. Iwashita and Hishikawa (1990) reported that a 280 m long fish ladder, close in form to a pool pass with natural rock substrate in the pools and with carefully controlled lighting, worked well for the ayu after the original notches in the weirs were in-filled to stop the flow perturbation they caused, and which delayed fish.

It has been reported that 98% of the salmon rivers of Japan are dammed, but that initiatives to remove dams where possible are now making significant progress. The removal of 31 of the 127 dams in 5 streams in the Shiretoko Penin-

sula (a world heritage site) to restore migration of 6 salmonids including masu salmon is taken as an indication of current ambition (www.wildsalmoncenter.org).

In Taiwan 5 hydropower sites (total output nearly 1 MW) were reported on the Tachia River and at one of these the first fish ladder in the country was built in 1998 (the Maan hydropower project and fish ladder project) for eel (*A. japonica*) and mullet (*Mugil sp.*).

As noted by Clay (1995), China has a large number of reservoirs (about 86,000) and the fisheries they support are intensively exploited for aquaculture, therefore largely negating the need to include provision for migration of wild fish. The target is largely the assemblage of potamodromous species, mainly various species of carp, and the catadromous Japanese eel. Most fish passes built are again of the pool-type, based on concepts developed for diadromous salmonids, and consequently it is reported that they do not work well.

The substantial economic and population growth over the past 50 years has resulted in major demands for new energy sources and consequently there has been a great increase in development of hydropower. The Yangtze River, which is the third longest river in the world and contains

Fishway Turkey

Vertical slot fishway under construction (© Groene Zoden Fotografie).



Fishway Russia

Fishway on the Tuloma River at the Lower Tuloma hydroelectric station, Murmansk region, the Kola Peninsular, (Russia). This fishway was designed to facilitate the passage of Atlantic salmon (© G.G. Filippov).



50% of all China's dams, supports a fish fauna comparable to that of the great South American rivers. It contains more than 360 species of fish, about half of which are endemic to the catchment.

The Mekong basin reportedly supports the largest inland fishery in the world (Ziv *et al.*, 2012) and 78 dams have been built on its tributaries, with many more planned, but without any strategic consideration of fishery matters. This appears to be improving greatly with the formation of the multinational Mekong River Commission in 1995, and as demonstrated by a recent fish migration assessment for the proposed Xayaburi Dam (Baran *et al.*, 2011). On the Hanjiang River, the Danjiangkou Dam was built without a fish pass, and yet it has been noted that although this may change the diversity of the population it might not have a calamitous effect on fish (mainly *Cyprinidae*) production (Liu and Yu, 2006).

Generally, since the onset of significant dam construction there have been significant declines in fish populations and catches and several local

fish species are considered threatened or endangered. These reductions are partly a result of habitat fragmentation caused by dam construction. The majority of dams in China do not have fish passage facilities and those that do exist are often poorly designed.

In Bangladesh three fish passes and a fish friendly water regulator have been constructed since 1990. The Sariakandi fish pass on the Jamuna to the Bangali River in Bogra (1999-2001) is the most recent one and modern fish pass of Bangladesh and was constructed by the Bangladesh Water Development Board (BWDB).

5.6.6 Africa

In Africa there are now many proposals for dams, marking a significant conflict between socio-economic development on the one hand, and sustainable development on the other hand. This has led to the formation of the African Rivers Network which is seeking a new appreciation of sustainable development. One of the world's largest hydropower projects (the Inga Rapids on the Congo River, with a projected output of

EXAMPLE

Fish ladders on the River Elbe near Geesthacht

Author: Beate Adam
Organisation: Vattenfall Europe Generation AG & Institute of Applied Ecology
Country: Germany



INTRODUCTION

The weir at Geesthacht is located 140 km upstream of the delta of the River Elbe where it drains into the North Sea. It is the only dam for 700 km of the Elbe that is within Germany, into which it flows from its source in the Czech Republic. In 1989 a nature-like bypass channel was

built on the southern bank of the weir, but due to construction and hydraulic defects, the migration of fish was not sufficiently improved.

Therefore an additional double-slotted fish pass was constructed on the northern bank of the river by the energy company Vattenfall in 2009.

THE OLD NATURAL LIKE BYPASS CHANNEL

On the southern bank of the weir at Geesthacht (© IfÖ).



WHAT DID WE DO?

The concept of the new fish pass was to provide passage opportunity for every local lamprey and fish species, so the swimming behaviour, morphometry and physical capacity of each species were considered. The aim in terms of functionality was to ensure that fish could locate and use the pass for 300 days/year, even when the river was influenced by varying discharges and tides:

- The entrance of the fish ladder is directly located at the foot of the weir, ensuring that upstream migrating fish do not get lost in a dead end;
- Additional discharge at the outlet of the fish pass provides further attraction at all times creating a guiding flow of at least 0.3 m/s. This makes operation of the fish ladder independent from tidal influence;
- Guidance towards the fish ladder is supported by five synclinal trenches that discharge a total of 10 m³/s at the dam threshold into the tail water next to the fish ladder;
- The double slot fish pass consists of 49 basins, each of which is 16 m wide and 9 m long. The total width of the two slots in each partition wall is 1.2 m. These dimensions are sufficient for the swimming manoeuvres of adult European sturgeon (*Acipenser sturio*);
- The hydraulics of the fish pass were calculated so that species with low swimming capabilities, such as smelt (*Osmerus eperlanus*) and bleak (*Alburnus alburnus*) can pass through the maximum flow velocity of 1.4 m/s in the slots;
- The basins provide sufficient resting areas for the fish because they have very low turbulence with a maximum power density of 50 watts.m³;
- A continuous flow path connects the slots in the 550 m long construction and the velocity of at least 0.3 m/s is maintained by five additional injections of water. This migration route is also attractive for high-performance species like salmon (*Salmo salar*) and sea trout (*Salmo trutta trutta*);
- Rounded river pebbles (maximum 15 cm di-

THE NEW DOUBLE SLOTTED FISH PASS

On the northern bank of the weir at Geesthacht (© IfÖ/Vattenvall).



- (meter) have been placed on the bed of the basins to create a reduced flow velocity and low turbulence microhabitat. This benefits species with low swimming-performance such as flounder (*Pleuronectes flesus*) and ruffe (*Gymnocephalus cernuus*);
- In addition 4 eel-ladders are installed at the entrance. These support the upstream migration of European eel (*Anguilla anguilla*), which are not able to pass the slots.

HOW DID IT WORK OUT?

Migration through the nature-like bypass channel and, since opening on the 1st August 2011, through the double slot fish pass is monitored daily. In 6 months since both passes were operational more than 150,000 individuals of 37

>>EXAMPLE

MONITORING STATION

At the exit of the double slot fish pass.



species have migrated through the double slot fish pass. Many of these species are listed on regional red lists, e.g. river lamprey (*Lampetra fluviatilis*), houting (*Coregonus* ssp.) and blue bream (*Ballerus ballerus*). In the same period around a tenth of this number, representing 25 species, have used the nature-like bypass channel (Schwevers *et al.*, 2011a, 2011b).

Migratory behaviour is included within the monitoring, and is studied using Half Duplex Transponder (HDX) Technology from the tail water of the weir and right through the two fish passes. Annually up to 10,000 fish of different species

are individually tagged with a HDX-transponder and released at defined locations within the tail water. If the tagged fish pass the HDX-antennas, which are installed within the fish ladders, their presence is automatically registered providing data on fish identity, time and location.

In this way information on the ability of fish to find the fish pass and the duration of passage is collected. To date 37 % of the tagged and released fish have been detected by the HDX-technology and, for example, 88 % of the river lampreys (*Lampetra fluviatilis*) were found to use the new double slot fish pass.

44,000 MW) is proposed in the Democratic Republic of Congo. The project is part of an US \$80 billion dollar infrastructural project in Africa.

Africa has over 2,000 known species of indigenous freshwater fishes. Many of them are threatened by the construction of dams in the continent which has multiplied greatly since the 1950's for both irrigation and hydroelectric power generation. However the construction of facilities for passage of fish has not matched this. In 1990 (Bok, 1990) and again in 2004 (Bok *et al.*, 2004) it was reported that of the large numbers of barriers built in South Africa there were only 35 fishways and that most of them were ineffective as they had been based on European designs that were inappropriate for the fish endemic to the region. This is a common problem it seems.

The need for good information on the biology of local species and improved designs of future fish passes has become apparent in recent years. South Africa has a relatively low diversity of freshwater fish and in the coastal streams there

are only 6 catadromous species, 2 mullets and 4 species of eel, whilst in the more inland rivers of the Transvaal, there are some potamodromous species, mainly cyprinids, with both juveniles and adult migrating upstream.

The absence of diadromous fish means that African dams are only likely to hinder potamodromous species such as large Labeo, Barbus, Allestes, Distichodus and Citharinus which migrate long distances up and down rivers to complete their breeding cycle in response to seasonal flooding (Daget *et al.*, 1988).

5.6.7 Australia

Mallen-Cooper (1996) reported that of the 86 species of freshwater fish in SE Australia, 36 were migratory and required free passage in rivers to complete their life cycles. However of the 1,500 dams in the region only 69 had fishways and these were, once again, based on northern hemisphere designs for salmonids. Consequently it was unlikely that they worked. This was one of the reasons identified for dramatic declines in native fish species over the past century.

Spawning channels

The spawning channel at the Aviemore Dam (New Zealand) provides spawning habitat for Lake Waitaki lake trout and rainbow trout. If free passage is not possible or not effective spawning channels can provide an alternative spawning ground for fish.



Fish migration and cultural history in the small river Rode Beek

Author: Ykeliën Damstra,
Organisation: Regional Water Authority Veluwe
Country: The Netherlands



INTRODUCTION

In the 17th century, on the eastern flank of the Veluwe ice-pushed ridge, many brooks were constructed to meet the demand for watermills, castle moats and fish breeding. These man-made brooks provide a constant supply of good quality water with a constant temperature. Over the years, typical fish and invertebrate species became established.

In addition to their ecological value, the cultural and historical importance of the man-made brooks was substantial. In the small River Rode Beek, the remnants of watermills, so-called wijerds (large lakes upriver of watermills), weirs and other structures to distribute the water, and revetments that prevent the banks from collapsing are still present.

The watermills, mill sites and weirs are migration barriers for the fish species and, to ensure the viability of the various populations, it is important that the barriers are made passable to fish without affecting their cultural history. The Rode Beek has a former mill site which represented a 'cultural-historical migration barrier'. Also, the river section upstream of the mill was leaking and had to be covered with loam.

Watercourses with different chemical qualities were separated in the past: the iron-rich water from the Rode Beek was suitable for driving a mill, but not for making paper. This water came

from the small River Hartense Molenbeek. From a cultural and historical point of view, it was important to maintain this division.

The various mill sites, wijerds and weirs represent migration barriers for rheophilic fish species. One of the most characteristic fish species in the Rode Beek is the brook lamprey (*Lampetra planeri*) and the closed-off sections currently contain viable populations. This is an indication of good water quality and the presence of suitable habitats, including spawning sites.

WHAT DID WE DO?

Firstly, the cultural-historical and natural values of the Rode Beek were identified. This was followed by an analysis of the bottlenecks to fish migration. In order to keep the former mill site visible whilst also ensuring that fish migration could occur, it was decided to construct a shortcut to an existing waterway that joins the Rode Beek downstream of the mill site. A basin fish pass had previously been built within this shortcut to enable movement over a fall of approximately 1.2 m.

Free migration in the entire Rode Beek and Nieuwe Beek is now possible, thanks to this adjustment (and the installation of a fish siphon downstream). Also, the controlled section upstream of the mill site has been covered with loam to prevent leakage to adjacent sites. On top of the loam layer, the original river substrate has been

returned to the brook and this will provide habitat for the larvae of the brook lamprey soon.

Trees have been retained as much as possible. They give the bank structure, and the branches and leaves that fall into the water provide food and a suitable habitat. Prior to this work, the fish in every section was caught and returned upriver, to the Rode Beek and Nieuwe Beek.

HOW DID IT WORK OUT?

The work described above was carried out in 2009 and 2010. A fish survey will be undertaken in the entire Rode Beek in 2012 after the work is finished and the fish and evertbrate commu-

nity has recovered. Hardly any habitat was destroyed, fish migration has been improved and brook lampreys can still be found both downstream and upstream. The brook lamprey population is not expected to have reduced.

LESSONS LEARNED

It is important to consider both cultural history and ecology, and we have demonstrated that this can be done. Work such as that described here is best carried out by sub-section of the watercourse (not the entire brook at once). The extensive maintenance described benefits ecology in these man-made brooks and also their high cultural-historical value.

BROOK LAMPREY

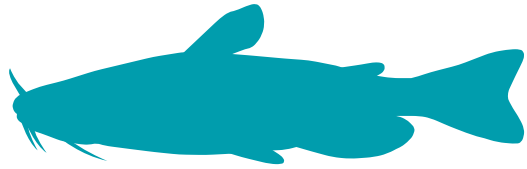
Brook lamprey (Lampetra planeri) in the River Rode Beek (© Jorrit Geerlinks www.jorritgeerlinks.nl).



SPECIES EXAMPLE

The current status of Bagre marino (*Genidens barbatus*)

Authors: Claudio Baigún¹ & Priscilla Minotti²
Organisation: Instituto Tecnológico de Chascomús, CONICET¹ and Instituto de Investigación e Ingeniería Ambiental, Universidad Nacional de San Martín²
Country: Argentina



LIFE CYCLE

Genidens barbatus, previously denominated *Neotuma barba*, belongs to the Ariidae family and is one of the few native anadromous species in South America. It is a long lived species, known to live up to 35 years, achieving maximum size of 1.2 m (Marceniuk and Menezes, 2007), an asymptotic length of 106 to 188 cm and a growth rate of 0.04 to 0.13 m/year, thus exhibiting slow grow and low mortality rate (Velasco *et al.*, 2007). The species inhabits bottom areas, feeding on a wide range of food items from the bottom up to 50 m depth, with preference for fish of the Sciaenidae family (Reis, 1986).

Adults move from coastal areas into freshwater for reproductive purposes, spawning in rivers, lagoons (albufers) and estuaries. In Brazil, where this species has an important population that moves between the ocean and the Los Patos lagoon estuary, adults enter at the end of winter, and gonad maturation occurs at the end of spring and early summer (Araújo, 1988). This catfish has very low fecundity, with a mouth brooding strategy.

Eggs and embryos are incubated in the buccal cavity of the males for two months (Gomes and Araújo, 2004) and the larvae are released in mixohaline waters where juveniles grow for at

least three to four years, after which they move to coastal waters, returning when they reach about eight years of age for first spawning. In the Rio de la Plata estuary, adults enter during spring and early summer for spawning (García *et al.*, 2010).

Migrations occur also in the lower Paraná River as far as Rosario city with fish returning to the estuary within two months (Minotti and Malvarez, 1992). Juveniles have been recorded close to the Rio de la Plata saline front, which is the freshwater-saltwater mixing area (Acha *et al.*, 2003).

GEOGRAPHIC DISTRIBUTION

The species inhabits the coasts and estuaries of South America from Guyana to Argentina, and is usually found in shallow, muddy coastal areas (Araújo, 1988).

FISHERY RELEVANCE

The species represents a major resource in estuaries. At Rio Grande port located within the Los Patos lagoon, marine catfish is considered a main target species representing 80% of the Ariidae species landed in southeast Brazilian ports (Marceniuk, 1995). In the De la Plata River Estuary and in the lower Paraná Delta, the species represents a valuable recreational fishery (Colautti *et al.*, 2009).

HUMAN IMPACTS

The species is considered vulnerable in the lower La Plata basin (Baigún *et al.*, 2012) where the main threats come from fishing activity which, in Argentina, is not specifically regulated. In both countries catches coincide with the seasonal reproductive migrations of adults into estuaries.

Records of the Los Patos lagoon fishery suggest a stock depletion produced by harmful fishing gears (Kalikowski and Vasconcellos, 2006). Adults inhabiting the continental shelf are captured by the trawler fleet in southern Brazil and adjacent regions (southeastern Brazil, Uruguay, and Argentina).

FUTURE DIRECTIONS

The conservation of *Genidens barbatus* will depend upon new fishery policies developed to regulate its exploitation. Since the species exhibits an extreme k-strategy, specific regulations are required to avoid capture during reproduction and incubation seasons, with a ban on fishing in the estuary nursery areas. It will also be necessary to implement marine protected areas at the estuary mouths where fish concentrate before entering their reproductive migration. Finally, bionomic characteristics such as low natural mortality, low growth rate and late maturity also mean that fishing pressure should be carefully monitored to achieve sustainable fisheries.

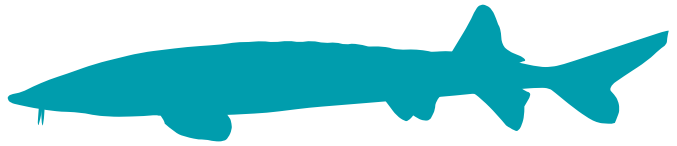
BAGRE MARINO

(© Priscilla Minotti).



Russian sturgeon (*Acipenser gueldenstaedtii*) in the Volga River

Authors: D.S. Pavlov¹ & V.N. Mikheev²
Organisation: A.N. Severtsov Institute of Ecology¹
& Evolution, Russian Academy of Sciences²
Country: Russia



BEFORE REGULATION OF THE RIVER

The Russian sturgeon (*Acipenser gueldenstaedtii*) was one of the most commercially important fishes in the Volga River basin until the river was regulated. This anadromous species has two migratory forms, vernal and hiemal. Vernal migrants start their upstream movement in March at a water temperature of 0.2-4°C, with migration intensity peaking in May (at temperatures of 6-9°C) and spawning starting as soon as the fish reach their spawning grounds. Migration

of the hiemal fish starts in May, peaking in mid-summer (at temperatures of 22-27°C), and continuing until late autumn. The number of hiemal sturgeons was usually about 4 times that of the vernal migrants. Before the construction of main dams (in the middle of the 20th century), Russian sturgeon migrated up to the most distant tributaries within the Volga basin, and it had the largest share in the sturgeon fishery.

MAIN DAMS IN THE VOLGA WATER SHED



FRAGMENTED MIGRATIONS, LOST SPAWNING GROUNDS

The amount of available spawning grounds dramatically decreased after more than 10 power plants were built on the Volga River and its main tributaries. The largest negative impact was caused by the dams near Saratov and Volgograd (about 800 km upstream of the delta). After construction of the Volgograd dam less than 20% of the spawning grounds remained available for Russian sturgeon but, after many years, a fish pass was constructed at the dam to allow spawners to migrate upstream to more than 500 km of habitat within the main river and some tributaries. However the Saratov dam severely deteriorated the spawning conditions upstream of the Volgograd dam and made the fish pass there effectively useless.

Today, the spawning grounds in the lower reach-

RUSSIAN STURGEON

Black Sea, Tendra, Ukraine (© Andrey Nekrasov / WWF-Canon).



es of the Volga River are used by both vernal and hiemal migratory forms. The mean age of adults entering the Volga River for spawning is now about 19 years (in the 1980s it was 21-23 years), the mean weight of the spawners decreased by 5.4 kg in the 1990s, and there is a sharp drop in the proportion of females in the population. Since regulation, the downstream migration time of juveniles has become shorter and consequently smaller fish enter the delta and the sea.

MAIN RISKS FOR MIGRANTS

The fishery was the main factor controlling the populations of sturgeon before regulation of the Volga. Now, the major negative impacts on the Russian sturgeon migrating within the accessible part of the Volga downstream from the Volgograd dam include impacts on ascending spawners and drifting juveniles. They are:

- More than 80% loss of spawning grounds due to dams, altered hydraulic regimes, eutrophication, sedimentation and pollution;
- Deterioration in the conditions for upstream migrations of adults (changed flow regime, pollution, turbidity);
- Deterioration in the conditions for downstream migrations of juveniles (water abstraction, pollution, changed hydraulic and trophic conditions);

- Poaching, representing one of the major risks for adults, both during migration and at the spawning grounds.

RESEARCH AND MANAGEMENT

Despite the loss of habitat within the majority of the Volga basin spawning grounds and nursery areas, the lower reaches of the river remain available for migrants. Their contribution to the stock of the Russian sturgeon of the Caspian Sea is substantial. Moreover, the area between the Saratov and Volgograd dams is potentially suitable for spawners and juveniles if some amelioration is undertaken. To facilitate spawning and recruitment to the natural population of the Russian sturgeon in the lower Volga, research and practical measures should include:

- Improvement of local conditions for spawning and migration in the Volgograd reservoir (between Saratov and Volgograd dams) and, associated with this;
- Restoration of the fish pass through the Volgograd dam;
- Efficient measures for reduction of poaching should be urgently undertaken;
- Understanding of the migrations of both adults and juveniles should be improved in order to transform the ecosystem of the regulated river.

Fishway Nepean River (Australia)

The entrance of this vertical slot fishway is situated directly next to the weir (© Lee Baumgartner).



In the Murray-Darling river system, the longest in Australia at about 3,700 km, most of the migrant fish are potamodromous with adults migrating upstream to spawn. Under the 'Sea to Hume' programme the Murray-Darling Basin Commission is seeking to address 13 priority barriers known to impede fish migration amongst the 4,000 barriers in the basin. An assessment of the first 3 vertical slot fishways built (Baumgartner *et al.*, 2010) showed that they successfully passed species of the target size, but that smaller individuals did not pass effectively.

Experience elsewhere also showed that earlier designs of fishways were inefficient. Melbourne Water reported survey work that showed an early rock fishway built in 1993 did not function and consequently it was replaced by a vertical slot fishway predicted to bring benefit to over 2,000 km of the Yarra River.

In the tropical and sub-tropical region of Australia in Queensland, 20 fish passes were built in 2008, apparently benefiting 70 native species of fish (www.dpi.qld.gov.au). The passes, including rock ramps and vertical slot fishways, benefited from the learning from about 22 earlier fish passes built prior to 1970, and almost all of them have been constructed on tidal dams (Barry, 1990). The new designs improve on the salmonid-nature of the earlier passes, which were considered to be ineffective for native fish. Most coastal streams in the northern part of the continent support populations of catadromous or amphidromous fish, with both juveniles and adults migrating upstream into rivers and creek habitats.

CHAPTER 6

MONITORING AND EVALUATION



INTRO

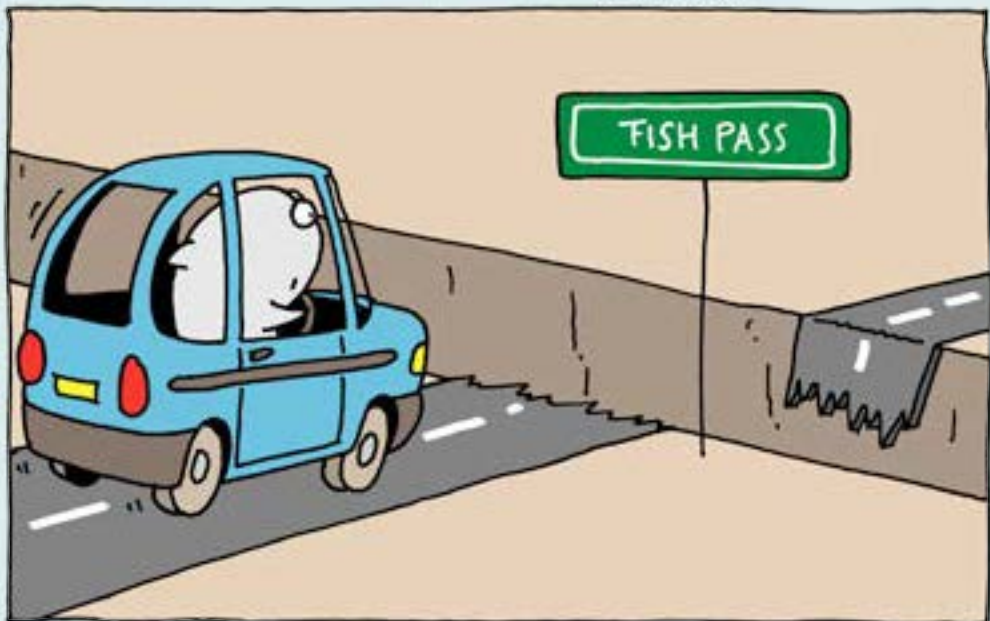
Many fish passes are constructed all over the world, but monitoring of their performance is still limited. This is because of the high cost for effective monitoring and the false perception by funders that this has little benefit. Nevertheless, fish passes are often very expensive and it is essential that their effectiveness is demonstrated so that environmental outcomes can be confirmed, and performance and learning may be optimised.

Any improvement to fish passage at an existing obstruction is beneficial. The importance of monitoring and evaluation is demonstrated by a study in Germany where it was discovered that 200 fish passes were not functioning properly (Schwevers *et al.*, 2005). Monitoring of fish passes is vital to evaluate the hydraulic functioning of the pass, to evaluate the efficiency with which fish use the pass and in some cases also to evaluate the consequences of the pass for a fish population or fish stock.

In general monitoring contributes to a learning process to improve future designs and to detect shortcomings of facilities. It is also important to learn how well fish passes function so that we may confirm that management systems are optimal and progressively improve our designs.

In this chapter we set out the relevant questions that should be considered as part of a monitoring and evaluation programme, the practical aspects of addressing these, and then we consider who might carry this out. The monitoring techniques that we discuss in this chapter should be considered in the context of an integrated river basin management approach. Monitoring should always be part of an evaluation programme.

THE NEED FOR MAINTENANCE



6.1 MONITORING & EVALUATION OF FISH MIGRATION

A recent study on fish pass effectiveness monitoring worldwide (Roscoe, 2010) concluded that mechanistic questions were studied much more often in North America than in Europe, South America or Australia. This type of information is essential to understand effectiveness, and necessary if facilities are to be improved to maximise fish passage. Despite the large body of literature concerning passage at fishways and other facilities, several important information gaps exist, such as mechanisms of passage failure and post-passage consequences.

Studies that focus on biological aspects of passage, such as fish behaviours in different hydraulic environments, are deemed necessary to expand the knowledge base of fishway science. In this context, Castro-Santos *et al.* (2009) suggest a framework for evaluating fishways, highlighting a set of biologically relevant performance parameters and hydraulic covariates.

A global review of hundreds of studies on the effectiveness of freshwater rehabilitation techniques by the FAO (2005) concluded that techniques that restore connectivity, such as dam removal and restoration of floods, are most effective. However, they may take years or decades before a change in fish or other biota is evident. In addition, the review concluded that, fundamentally, most rehabilitation projects lack a well-designed and funded evaluation program to monitor fish pass effectiveness. Insufficient monitoring and evaluation of passage facilities may partly explain why many fishways have failed to mitigate the effects of barriers on fish and why stock declines have continued in many places (Agostinho and Pelicice, 2008).

To understand the mechanisms of migrations and mitigate human impacts on fishes, interdisciplinary studies combining telemetry with disciplines including behaviour, physiology, functional genomics and experimental biology are

Fish Research Center

The Conte Anadromous Fish Research Center U.S. Geological Survey. Located adjacent to the Connecticut River in northwestern Massachusetts.



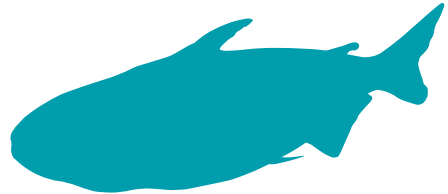
needed (Cooke *et al.*, 2008). An interdisciplinary approach would allow fish passage scientists to address new questions regarding the consequences and mechanisms of passage as well as better resolve old issues, such as attraction to fishway entrances.

Lastly basic research concerning migration cues, fish behaviour and swimming mechanics in complex flows (e.g. Liao, 2007) will greatly benefit fishway science. Studies of fundamental biology are particularly needed for fish in the tropics, where little is known regarding migration cues and swimming abilities.

SPECIES EXAMPLE

Current status of the Giant catfish (*Pangasianodon gigas*)

Authors: Eric Baran and Un Borin
Organisation: WorldFish Center
Country: Cambodia



GIANT CATFISH

2.5 m long giant catfish caught in Cambodia in the Tonle Sap River (© Eric Baran).



INTRODUCTION

With 781 fish species, including 135 migratory species, the Mekong River features the second highest fish biodiversity in the world (ICEM, 2010). Among its iconic species is the world's largest freshwater migratory fish, the giant catfish (*Pangasianodon gigas*), which reaches up to 270 cm long and weighs up to 293 kg (www.fishbase.org).

Life cycle

Between October and December each year, the giant catfish moves from the lower Mekong floodplains where it feeds (in particular in the Tonle Sap Basin) to upstream breeding sites located in Northern Cambodia, Thailand (Ubon Ratchathani, Chiang Saen) and Laos, often more than 2,000 km away (Hogan *et al.*, 2001). *P. gigas* feeds on detritus and algae and features one of the fastest fish growth rates in the world. However, it matures slowly and its age at first maturation is between 10 and 17 years old. Since 2001 this fish has been bred in captivity in Thailand from wild-caught parents.

Geographical distribution

P. gigas (Chevey, 1930) is endemic to the Mekong Basin. Its distribution seems to be limited to the Mekong mainstream and the Tonle Sap Basin. In the past, the species was also recorded in Vietnam and southern Yunnan province in China (Roberts and Vidthayanon, 1991). The species occurs over an area limited to

4,150 km² (Hogan, 2011) representing just 0.5% of the Mekong Basin. Its distribution and migrations make it extremely sensitive to mainstream dam development. Halls and Kshatriya estimate a 100% mortality rate for *P. gigas* passing through turbines, which implies that a single mainstream dam could decimate the species (Halls and Kshatriya, 2009).

HUMAN IMPACTS

This naturally rare species started to decline in the 1970's, and over the past decade only a few individuals have been caught each year in the whole Mekong River (Hogan, 2011). For these reasons *P. gigas* is classified on the IUCN Red List as critically endangered. The reasons given for this decline are overfishing (i.e. more fishers and more intensive fishing) and loss of habitat, impacts that apply to all Mekong giant fish species such as the giant carp (*Catlocarpio siamensis*), the giant salmon carp (*Aptosyax grypus*) and the seven-line barb (*Probarbus jullieni*).

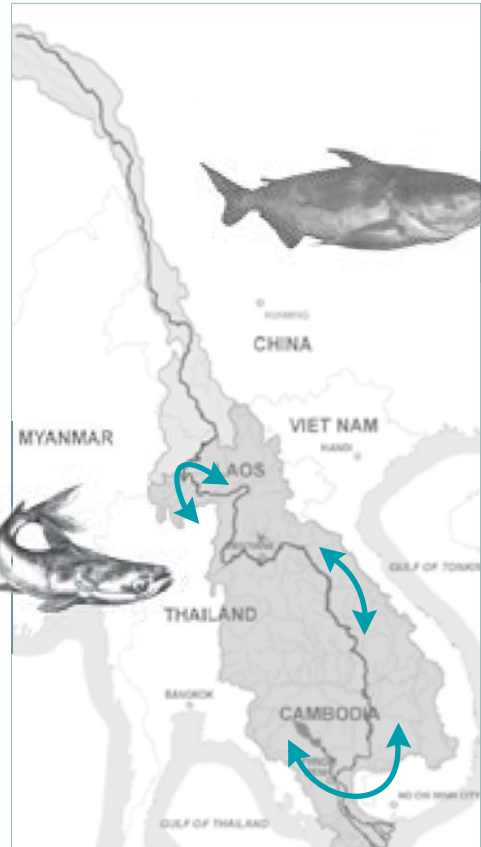
FUTURE DIRECTIONS

The small population of *P. gigas* is confined to a limited area and is highly sensitive to fishing due to the fish's large size and long distance migrations. In the context of an increasing human population, extensive changes in floodplain land use and intensive dam development, the future of this species looks quite bleak. Since it is impossible to enforce extremely limited fishing quotas or bans, the main hope for the survival of this species may lie in aquaculture production in captivity.

However, there is currently no evidence of self-sustaining aquaculture-based populations (Hogan, 2011), and clearly more research is needed in this field. Other main options for restoration include the protection of known spawning sites in Laos/Thailand, and the revival in Cambodia of a sufficiently funded protection program to buy at an attractive price live fish from Tonle Sap fishermen for release upstream of Phnom Penh in the Mekong mainstream.

MIGRATION ROUTE OF GIANT CATFISH

The Mekong River basin.



6.2 DEFINING EFFECTIVENESS AND EFFICIENCY

The key questions focus on the effectiveness, efficiency and hydraulic functioning of fish passes. These may differ for upstream and downstream facilities.

The *effectiveness* of a pass is a qualitative description of performance. Effectiveness depends on attractiveness to fish, passability for each target species, and the ecological outcomes of the level of passage achieved. General questions that must be addressed are:

- Which species use the facility?
- Do all target species (in all relevant life stages) use the facility?
- To what extent are any of the fish species delayed prior to passage, and is this ecologically significant?
- Does the facility have a habitat function for target species?
- What influence does the facility have on the fish stock?

The *efficiency* of a pass depends on the general criteria as set in the previous chapter. The efficiency of a fish pass refers to the proportion of a fish stock present downstream of the obstruction, that enters and successfully moves through the facility without undue delay (Larinier, 2002). Cumulative effects must be considered when several obstacles exist in a river.

Evaluation should assess quantitative goals set for effectiveness for each target species, set as the percentage of the population that should pass and the acceptable migration delay. For anadromous species like salmon, passage of the whole population should be the goal, and delay minimised when the obstacle is downstream of spawning grounds. If significant spawning grounds are located below the obstacle, then performance goals can be less stringent. This is also the case for potamodromous species, where effectiveness is also judged by the number or proportion of the stock that can safely pass.

In general 'effectiveness' demonstrates that some fish are able to use the pass. The numbers of fish recorded using the facility may be very high, but this cannot necessarily be taken as an indication of good performance of the fish pass, as there may also be many unsuccessful attempts at passage. Efficiency is a better descriptor of performance, as this is a measure of the proportion of the available fish that wished to ascend the obstacle that were able to do so. It is usually further defined in terms of the time delay that is observed.

6.3 CHOICE OF MONITORING METHODS

Methods for monitoring upstream and downstream migration can be divided into capture-dependent and capture-independent methods. Capture dependent techniques consist of the capture or recapture of fish, some of which may be marked as part of a mark and recapture experimental design. Capture independent techniques, which are generally more effective but also more expensive, consist of visual observations and remote sensing techniques.

6.3.1 Monitoring of upstream fish migration *Effectiveness*

The effectiveness of a fish pass is a qualitative judgement on performance and can be determined either directly or indirectly. Capture techniques (direct), for example trapping within or immediately upstream of the fish pass, are capture dependent methods that give indicative information on the timing of use of the pass, the species that use it and their sizes.

Trapping and tagging studies might use simple colour batch marks or tags applied to fish caught downstream that may subsequently be identified in trapping studies upstream, having used a fish pass. Recapture of fish is best achieved using a simple fish trap within the fish pass or, for some species, by using fyke nets upstream. Other fishery surveys, including electrofishing or trapping upstream and even rod catches and spawning observations can be used for the estimation of effectiveness.

Capture independent methods (indirect) such as simple visual inspections, video monitoring, automatic (resistance) counters, sonar-techniques and telemetric techniques such as radio or acoustic tracking systems can be used to assess effectiveness of a fish pass. It is very important to clearly identify the objectives of the monitoring programme, so that resources are used in the most effective way.

Fish counters can provide very good quantitative data on the numbers of fish ascending and descending a fish pass. They require relatively non-turbulent water for effective operation, and this is generally found at the exit of the fish pass, but may also be found in the laminar flows of orifices or slots. Different types of counters exist, and selection depends on factors including the size of the pass, the clarity of water during migration, scope for inclusion of a counter dur-

ing design and construction of the fish pass, and the financial resources available. The choice of counter type also depends on the behaviours of the target fish species and the required level of accuracy and species discrimination. Different counters offer differing levels of reliability and precision, the potential for species identification, and scope for individual fish measurement. Some systems are available 'off the shelf', for example the Icelandic Vaki system (www.vaki.is), whereas others use cheaper modular deployments of underwater cameras and lighting systems but are often less reliable and can be more labour-intensive.

Much more informative data may be obtained using more complex radio telemetric tracking programmes or PIT (Passive Integrated Transponder) tagging, from which far more valuable information on fish behaviour in the vicinity of the

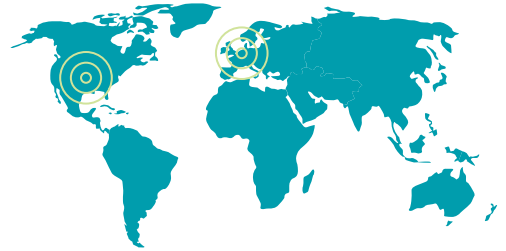
Tagging of river lamprey

The river lamprey is operated to insert an acoustic tag (© Marlous Heemstra).



Monitoring dam removal

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INTRODUCTION

Dam removal is widely regarded as one of the most effective ecological restoration tools for a river. According to Bednarek (2001), dam removal can enable the return of native species by resto-ring ecological conditions on which native species depend. It seems obvious - when the dam is removed, the river will have a better ability to restore itself. Free connectivity from-sea-to-source will enable key migratory species to re-colonize the river, and the river will return to its former ecological state. But does that always happen? It is important to know how things work out exactly. Uncertainties with regards to flood risk, flow modification, sediment transport, contaminants, species extirpation, infrastructure conflicts and channel/bank stability are often challenges in the decision making process for dam removals.

In cases where dam removal proceeds, adequate monitoring of the new physical environment and processes, notably the sedimentation process and ecological shifts, is important. This is because it may be necessary to demonstrate that the new environment created by the removal is not detrimental in any way, for example to riparian land owners. It is also relevant because removal creates new habitats and spawning areas for aquatic organisms and the outcome of this should be understood, not least to inform future removal proposals. The value of monitoring the restoration process is often overlooked, due to financial constraints and the fact that budgets for projects are mostly used for the

dam removal itself. Post dam removal monitoring has therefore been limited. However it is important to know if the goal of ecological uplift is attained: What species return? How quickly and in what succession? How much sediment will be mobilized and where did it redeposit? Were any species negatively impacted and how can we reduce impacts in the future? What lessons can be learned?

Below, the current status of monitoring dam removal is assessed for the USA and Europe, two continents in which the majority of dam removals occurs.

DAM REMOVAL IN THE USA

In the USA organisations like American Rivers and NOAA's Restoration Center take a leading role on dam removal. In addition, Pennsylvania stands out as a leader amongst the states removing dams. American Rivers keeps an annual list of dams removed in the USA and has chronicled a series of inspiring success stories (American Rivers, 1999).

These success stories indicate that when natural flow fluctuations are restored to a river and barriers are removed, biodiversity and population densities of native aquatic organisms increase (American Rivers, 2002). For example, when Florida's Dead Lake Dam on the Chipola River dam was removed, fluctuations in the natural flow of the river increased and quickly the diversity of species nearly doubled from 34 to 61 aquatic species.

The Edwards Dam Removal

One exciting and successful project was the removal of the Edwards Dam on the Kennebec River in Maine in 2000. Stone & Webster (1995) and Dadswell (1996) initially projected the effects on the restoration of anadromous fish to be very positive. The Midwest Biodiversity Institute then monitored the Kennebec River after the removal of the dam from 2002 to 2007. During low flow (late summer) monitoring data were gathered on the composition of the fish community by percentage, numerical abundance, relative biomass abundance (using boat electro fishing techniques), water quality and habitat quality.

The monitoring data showed a rapid recolonization by numerous diadromous fish species:

- Alewives returned with great abundance and a commercial fishery upstream of the site of former Edwards Dam was established. With a total number of 1.5 million and an estimated harvest of over 450,000, it is considered to represent the largest run of alewife in the country in 2010;
- Migratory fish appeared just weeks after the dam came down, having reoccupied most of the accessible river;
- A total of 12 migratory fish species have returned to old spawning grounds upstream of the dam. They include alewives, striped bass, Atlantic and shortnose sturgeon, smelt and American shad;
- Birds that depend on fish and aquatic insects also returned - bald eagles and swallows became common sights.

With regards to sediment transport, gravel and cobble upstream of the dam became re-exposed and the thin layer of impounded sediment was transported downstream. Approximately 25 km of riverine habitat were recovered. Dam removal quickly restored spawning habitat above the former dam for 10 species of sea-run fish. The restoration of natural sediment transport in a river and the uncovering of pre-dam riverbed substrate is regarded as vital to riparian and riverine habitats and species.

On the issue of sediment transport management the Aspen Institute's national dialogue on dam removal (2002) advised those removing dams:

- To assess the amount and characteristics (i.e., quality, organic content, moisture content and grain size) of the sediments before removal (impounded behind the dam and within the river);
- To assess the river system's natural ability to transport sediment (its carrying capacity). This can be done by comparing the projected sediment release to the effects of a natural storm event;
- Not to assume that full dredging of impounded sediment is the 'lowest risk option'. Natural erosion can be the least costly method with the least impact on the river system, provided the sediment is clean and the amount is within the carrying capacity of the river.

Currently the interagency Subcommittee on Sedimentation (SOS) is sponsoring the development of a decision framework for assessing sediment-related effects from dam removals. The decision framework provides guidance on the level of sediment data collection, analysis, and modelling needed for reservoir sediment management. The framework is based on criteria which scale the characteristics of the reservoir sediment to sediment characteristics of the river on which the reservoir is located. To assist with the framework development, workshops of invited technical experts from around the United States were convened in October 2008 in Portland, Oregon and October 2009 in State College, Pennsylvania. The decision framework developed at these workshops is currently being validated with actual damremoval case studies from across the United States including small, medium, and large reservoir sediment volumes (T. Randle, pers. comment, 2012).

The Stream Barrier Removal Monitoring Guide (2007) published by the Gulf of Maine Council, with cooperation from numerous federal, state and non-governmental organizations has become the primary guideline for dam removal

monitoring in the USA. The guide sets up an approach for systematic monitoring of barrier removal, including dams, culverts and other barriers. The approach is based on a 'skeletal' framework built by a series of cross sections along a longitudinal profile at which grain size distribution, photo stations, water quality and the riparian plant community are monitored. In addition methods are discussed by which macro-invertebrates and fish passage can be monitored.

Through the USA's experience removing hundreds of dams, some obvious patterns and similarities in responses between specific 'categories' of dam removals has become evident. Inappropriate overgeneralizations and mistakes can easily be made when using the monitoring results of one dam removal to assess the potential outcomes of another dam removal, unless the user has a solid understanding of the different categories of dam removals.

A Broad Level Classification System for Dam Removals developed in 2010 by Wildman and MacBroom is an initial endeavour to categorize dam removals based on past experience in order to better predict outcomes and potential impacts. Similarly, monitoring results should be grouped by dam removal categories to more appropriately apply the lessons learned on dam removal projects. Numerous dam removal projects have now been completed and monitored throughout the USA and there are many lessons to be learned, however funding still proves to be a limiting factor in the number of projects monitored.

DAM REMOVAL IN EUROPE

In Europe information on dam removal is more fragmented than in the USA. Dam removal projects have been undertaken throughout Europe, like Sweden, Denmark, Germany and France. However, monitoring data are scarce. The European Centre for River Restoration is an association of national centers promoting ecological restoration of rivers throughout Europe,

however no specific information on dam removal is reported.

The Maison-Rouges Dam

The removal of the Maison-Rouges dam was one of the first examples of major dam removal in France. It received extensive media coverage and is well-documented. The dam was situated in the River Vienne (Loire river basin in France) and was owned by EDF (a French electricity supply company) since 1948. The removal of the dam started in 1999 and was carried out in three phases:

- Installation of protective dykes and removal of the transversal dam;
- Gradual lowering of the impoundment and removal of the protective dykes on the right bank;
- Installation of protective dykes on the left bank in order to maintain dry conditions on the worksite for the demolition of the buildings. A concrete slab was laid on the bottom of the river in order to limit the effects of bed scouring and slow down the downstream migration of sediments.

The overall monitoring results are very positive. Habitats have diversified, key indicator species have returned quickly, and accumulated sediments have been removed by natural processes. Preliminary monitoring was carried out in 1995 and 1998, consisting of assessments of hydro-morphology and sedimentology, macroinvertebrates, large migratory fish, and riparian vegetation. Post monitoring operations were then conducted each year from 1999 to 2005, and again in 2009.

The monitoring of migratory fish was done by the Conseil Supérieur de la Pêche (CSP) and the Loire Grands Migrateurs Association (LOGRAMI). The results were inspiring and convincing in terms of the recolonization in 1999, findings confirmed in subsequent years.

Shad started recolonizing the 35 km stretch that had been made accessible and quickly used

the favourable sites for reproduction. Very positive results were also obtained for sea lamprey. Today, the Vienne basin is home to 80% of the sea lamprey stock present in the Loire basin. As for the Atlantic salmon: 9 adults were recorded there during the second half of 1999, the first such observations in 75 years since the building of the dam. In 2004, 57 large salmonid spawners were recorded, which is a record in recent times. The return of thick-lipped grey mullet has also been observed at two video-monitor stations.

In 1996, the volume of sediments accumulated behind the dam was estimated at 900,000 m³. Two years after removal, in 2001, the depletion involved 400,000 m³ of sediments which were then moving towards the Loire at an average speed of 2.8 km per year (Malavoi, 2005). In 2000, the mobilisation of sediments - formerly retained by the dam - led to siltation downstream causing a significant loss of habitats for invertebrates.

But by 2002 and 2005, following depletion of the previously stored sediments, the river recovered naturally. Habitats favourable to invertebrates reappeared and species which had been present before the arrival of the sediments have returned.

LESSONS LEARNED

The value of monitoring the restoration process is generally still underestimated worldwide, both from a socio-economic and environmental perspective. While finding funding for restoration projects is often challenging, finding funding to monitor the restoration post completion is even more challenging. Consequently, monitoring data are scarce and fragmented, especially within Europe. In contrast to Europe we have seen a recent rise in the number of USA dam removals that have been monitored after removal.

Too often, just the scientists doing the monitoring learn from the monitoring and not the greater dam removal community. It is critical that avenues are developed to distribute monitoring results effectively, if we are to learn from the lessons of past dam removals. Planners, designers and builders of dam removal projects need reliable monitoring data on critical issues such as recolonization and sediment transportation to help ensure the future of restoration offers. Overall, the inspiring success stories are good tools for communicating dam removals issues with stakeholders and members of the general public. Existing monitoring data show that restoration of a river often happens much more quickly than anticipated.

CONDIT DAM

The iconic Condit dam that was removed in 2011 from the White Salmon River in Washington (© Pacificorp).



pass and during passage itself can be derived. Commercially available radio tags (about 6 cm long and 1.5 cm diameter) can be implanted in fish or placed in the stomachs of larger salmon. They transmit a signal either continuously or at specified intervals, and carefully placed receivers can reveal when fish approach a fish pass, the locations where fish search for an entrance, or how fish use natural bypass channels as a new habitat. Advances in coding of these tags mean that large numbers of fish can simultaneously be tracked at any location. Acoustic tags can be used with networks of receivers to provide more detailed 3-dimensional information on fish location, although such systems are sensitive to aerated water.

PIT-tags have been developed as miniature tags (as little as 1 cm long and 0.3 cm in diameter) for fisheries studies. They emit a signal when the tag comes within range of a detector and is interrogated, for example when the tagged fish approaches a cable on the water bottom, a scanner at a fish pass entrance or exit, or come within range of a handheld antenna (Vaate & Breukeelaar, 2001).

This information can be used in many ways, for example to adapt management of the fish pass and for improvement of the design of natural bypass channels.

Sonar techniques, for example the DIDSON system, can detect fish in three dimensions and determine the swimming direction and depth of fish (Kemper, 2005). However they cannot usually be used in depths less than 2 m and are very sensitive to entrained air, which is of course common at many fish pass entrances. They cannot readily identify detected targets to species, although supplementary netting, for example, can be used to validate species composition.

In some cases temporary monitoring of effectiveness may be required to demonstrate that fish passes are functioning over the required range of flows. Additionally some of the more intensively studied sites might also form the basis for long-term stock assessments, for example a salmon counter within a pass in the lower reach of a main river may additionally provide escapement estimates for the whole stock.

Table 6.1 Monitoring techniques for upstream migration

System	Comments
Fish counters.	Systems such as the Icelandic Vaki system or resistivity counters fitted to a crump weir-type exit from a pass. Use of these systems is limited at high turbidity.
Sonar.	Good system for observing detailed fish behaviour at short range (e.g. DIDSON). Relatively expensive.
Acoustic tags.	Because of the greater detection range the use of these systems is preferred over PIT tags for more detailed behavioural assessments, but the tags are more expensive (e.g. Vemco and HTI).
PIT tags.	The use of PIT tags is fairly cheap but limited to the antenna range (which may actually answer management questions very well). Often used in shallow water or locations where fish need to pass through confined spaces like fish passes.
Radio tags.	Provide good information on fish behaviour, such as approaches to a fish pass, but with less precision of location than acoustic tags. Do not work in saline environments. Very user-friendly.
Fyke nets/fish trap (in combination with fish tagging).	Catches fish as they move through a pass. When combined with marking fish on the downstream side of the fish pass the efficiency of upstream passage may also be estimated.

Efficiency

An efficient fish pass is one that enables the passage of a high proportion of the migrating fish stock without undue delay (Larinier, 2002), exceeding a pre-determined management target. Determining the efficiency of a pass is more intensive and expensive than simply determining the effectiveness of a fish pass, and such assessments are therefore more common at strategically and ecologically important sites.

A count of the fish passing through a fish pass is not in itself a measure of efficiency. For that, the number of fish available to migrate through the pass must also be known, and that may come from an estimate of abundance from a fish counter downstream (Larinier & Travade, 1992). With care, some of the methods described above can also be used, however in all cases the study should provide the estimates of fish availability that are needed.

The efficiency of a fish pass is defined as the proportion of available fish that successfully use the pass. In its simplest form efficiency (E) is that proportion (n) of the available stock of fish (N) which succeeds in ascending or descending a fish pass.

$$E = n/N$$

Overall the preferred method for monitoring upstream migration is radio telemetry because of the amount and quality of data it yields. It is recognised that this is a relatively expensive technique, however radio-tagged fish can be tracked for many months, yielding information on the performance of more than one pass in a river, the identity and nature of other potential obstructions, and the spawning destinations of fish. Such data can be of considerable strategic value.

Hydraulic measurements

It is recommended that the results of hydraulic measurement programmes should contribute to an overall fish pass evaluation program that

should also include local hydrological conditions, the hydraulic conditions within the pass as well as the identity, numbers and sizes of each target species of fish that successfully uses the pass.

Measurement of the hydraulic conditions in a pass should preferably occur under a variety of flows. This is to ensure that the pass meets the original design criteria, for example peak turbulence, and thus is suitable for the particular target species. It also ensures that the facility operates effectively across the expected range of river discharge and levels and can help to optimise fish pass operation. Results from hydraulic measurements can serve for contractual approval purposes when a fish pass is commissioned.

6.3.2 Monitoring of downstream fish migration

There is good understanding of the requirement of most species to migrate upstream, however it is not yet as widely recognised that fish must also be allowed to migrate freely downstream. Many impounding structures are known to delay or even prevent downstream migration, usually because some behavioural aspect deters fish from approaching the structure and, in doing so, may cause exhaustion as fish attempt to avoid the structure. Better understanding of this and incorporation of downstream migration facilities, such as notches or bypasses, is an ongoing requirement.

Effectiveness and efficiency

The concepts of effectiveness and efficiency apply equally to downstream migration. This is because it is important to know firstly that fish are safely migrating downstream past a structure, and then that the management regime ensures that a high proportion of the population can safely do so.

It is generally believed that downstream passage over low-head weirs is safe for all species of fish, and that they pass with a high efficiency.

Monitoring the migration of the European eel (*Anguilla anguilla*): a non-intrusive sonar method

Authors: G. S. Bilotta¹, P. Sibley², J. Hateley² and A. Don²
Organisation: School of Environment and Technology (University of Brighton)¹ and Environment Agency²
Country: United Kingdom



INTRODUCTION

The European eel (*Anguilla anguilla*) is an important species both ecologically and economically (Moriarty & Dekker, 1997). However, the species has experienced a sharp population decline across its range over the last 30 years and is now classified as ‘critically endangered’ according to the International Union for Conservation of Nature (Freyhof & Kottelat, 2008).

In recognition of this issue, the European Commission has established legislation (Regulation No.1100/2007), which requires all member states with natural *A. anguilla* habitats to produce Eel Management Plans (EMPs) with a goal to permit the escapement to sea of at least 40% of the silver eel (adult life-stage) biomass that would have occurred prior to anthropogenic influences.

To demonstrate the level of compliance with this target figure and ensure the conservation of this species, it is necessary to collect accurate and reliable datasets of *A. anguilla* escapement. The aim of this study was to evaluate the potential of high-frequency multi-beam sonar for collecting such data and to examine the usefulness of this non-intrusive approach for the conservation of elusive aquatic species such as *A. anguilla*.

METHODS

The research was carried out in the period July–November 2009 on the River Huntspill (Somerset, UK), using a high-frequency multi-beam sonar (DIDSON 300 m, Soundmetrics Corp.; www.soundmetrics.com) firing across the complete channel cross-section (see figure).

The sonar recorded continuously throughout the monitoring period, and data processing time was reduced through the use of the ‘convolved samples over threshold’ (CSOT) function within the sonar software. This function reads in a recorded file and can write a much shorter CSOT file that comprises only the frames of footage in which targets with specified parameters (size range, motion and acoustic signal) are present.

A statistical procedure was used to develop a suitable set of variables that could be utilized by the CSOT function to consistently reduce file size and processing time while retaining accurate counts of *A. anguilla*-like targets. The mass of each escaping *A. anguilla* was quantified through a two-step process, described in more detail by Bilotta *et al.*, 2011 involving:

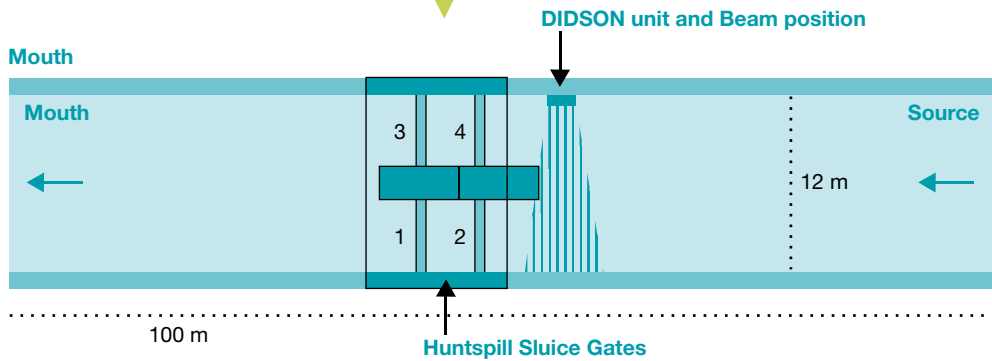
- 1 Measurements of total length (LT) made using the ‘Mark Fish’ function within the sonar software;

LOCATION

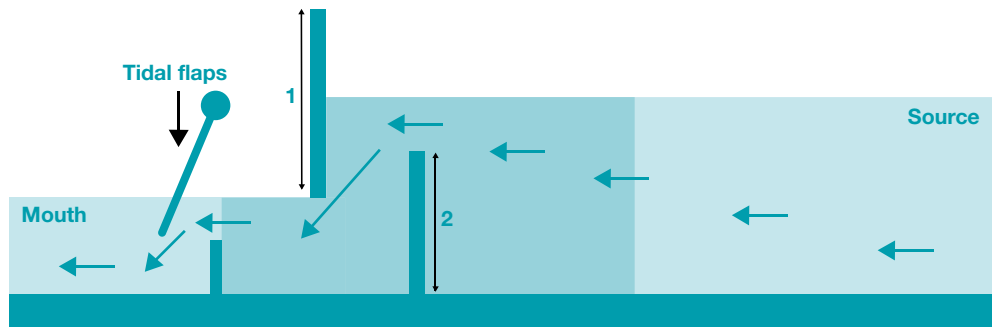
Location of the River Huntspill, Somerset (UK), with a plan view and cross-section view of the sluice gates and position of the Didson unit and beam position. Arrows in the cross-section and plan views denote the direction of flow. Adapted from Bilotta et al., (2011).



PLAN VIEW



CROSS-SECTION VIEW



>>EXAMPLE

HUNTSPILL SLUICE

Photo left: Front view of the sluice with tidal flap gates. Photo right: View from the sluice on the Severn Estuary.



2 These measurements were then applied to a regression equation based on the relationship between *A. anguilla* LT and mass (Bilotta et al., 2011). The estimated biomass of net escapement was calculated using the regression equations derived from the steps above (where the estimated net biomass of escapement is equal to the sum of downstream migrating fish biomass minus the sum of upstream migrating fish biomass).

RESULTS AND DISCUSSION

This study is the first to quantify the seasonal biomass of *A. anguilla* escapement using high-frequency multi-beam sonar. The estimated net biomass of escapement was 340 kg. This comprised 1,138 individual counts with the mean mass (\pm s.e.) of each escaping *A. anguilla* = 0.30 ± 0.01 kg. The assessment of compliance with the 40 % escapement target in this particular site is complicated by (a) the lack of historical reference-condition escapement estimates, and (b) the complexities of the Huntspill drainage network which, at times due to flood alleviation measures, receives water (possibly carrying *A. anguilla*), sourced from linked catchments with a total wetted area of 1,669 ha (i.e. much larger than the 60 ha estimated habitat area). Nevertheless, the data and information gained from

this type of research promise to advance the understanding of the behaviour and population dynamics of *A. anguilla*.

This study has demonstrated that high-frequency multi-beam sonar is capable of monitoring continuously and can capture, in a non-intrusive manner, the discrete events when *A. anguilla* migration occurs. This technology is capable of monitoring in turbid and relatively deep water (to 300 m depth) environments during nocturnal hours, the specific types of habitat through which *A. anguilla* typically migrate during escapement.

These capabilities provide multi-beam sonar with a real advantage over the existing *A. anguilla* monitoring techniques, which are either (1) not capable of quantifying escapement (e.g. fyke-net and electrofishing surveys), or (2) intrusive techniques that are carried out on a sub-sample of the population (e.g. mark and recapture or tagging and telemetry), both of which rely on an assumed relationship between the resident population, or a sub-sample of it, and the amount of escapement.

However it is acknowledged that this is presumptive, and that more work is needed to confirm this.

Most monitoring of the performance of facilities for downstream migration has focussed on estimation of mortality and damage to downstream migrating fish caused by entrainment of fish into water intakes, and the efficiency of facilities for fish protection and guidance.

Water intakes may be for consumptive use, with no return of water to the river and therefore entrained fish are lost, or for power generation where, although the water is returned, entrained fish are exposed to turbines. Damage or mortality rates at hydroelectric stations can differ greatly depending on several factors, including fish species and length, intake approach velocity, turbine type and the effectiveness of any by-wash.

The first step for any abstraction system is to determine whether a facility to maximise the effectiveness and efficiency of downstream migration is necessary. Questions that need to be answered are:

- What fish are present that need to migrate downstream?
- What is the predicted damage and mortality rate at the site?

In some cases downstream migration can continue without specific facilities through slight adaptations to abstraction management or turbine operation in order to improve conditions for safe migration. Ideally all of the possible migration routes e.g. turbine, spillway, sluices and any fish pass should be monitored at the same time, however this is often impractical or expensive.

The evaluation should consider:

- What is the entrainment rate into the water intake or turbine?
- What is the damage rate and mortality rate of

fish caused by turbines or other parts of the plant?

- What is the preferred safe migration route and can it be improved?
- What is the efficiency of the downstream migration facility, based on attractiveness and safe passage of fish through the facility?
- What amendments to the operating regime might be required to afford adequate protection to fish?

Monitoring effectiveness and efficiency

It is important to understand the mechanisms and success of downstream migration at all structures, especially when this is influenced by abstractions, including non-consumptive abstractions for hydropower schemes. Furthermore it is important to assess the performance of facilities to prevent or minimise damage.

The assessment techniques described for the monitoring of upstream migration are broadly applicable. Capture of fish downstream of the abstraction point or the bypass by various trapping methods can provide information on downstream passage effectiveness, especially if the fish are those marked upstream. The selection of a trapping technique is site and, most notably, flow dependent. Methods may vary from simple

Rotary screw Trap

In the River Dee in North Wales (© Ian Davidson).



EXAMPLE

Eel-friendly operation of hydro-power plants based on the early warning system MIGROMAT®

Author: Beate Adam
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Country: Germany



INTRODUCTION

To secure the downstream migration of silver eels by preventing them from entering hydro-power intakes, various mechanical and behavioural barriers have been developed. Unfortunately the effectiveness of these techniques is poor in comparison to investment and operating costs. In contrast to this, protection of eels can be achieved using the predictive early warning system MIGROMAT® (migrare = lat., hiking). With no further investment costs an eel-protective hydroelectric power plant operating regime can be

implemented. This is possible by reducing turbine speed or by opening alternative routes for downstream migration.

HOW DOES IT WORK?

The principle of the MIGROMAT®, which is patent-protected in Europe, is based on the handling and holding of wild eels in large tanks supplied with circulating water from the river at the respective location. Within the tanks are antennas that continuously register the behaviour of the PIT-tagged eels.

MIGROMAT®

Near Killaloe at the River Shannon (Ireland).



When behavioural change occurs, it is likely that a wild eel migration event will occur in the next few hours at that location. Such behavioural modifications are known as pre-migratory restlessness and, among other things, they are measurable by the significant increased activity of the captured eels, first described by Lowe (Lowe, 1952).

Use of this method was verified by two different independent research projects, one on the Dutch River Meuse promoted by the European Community (Bruijs *et al.*, 2003) and the other in France (Durif, 2003). The MIGROMAT® can automatically send an alarm, up to 6 hours before the beginning of a migration event, to notify the operator of a hydropower installation to initiate eel-protection arrangements.

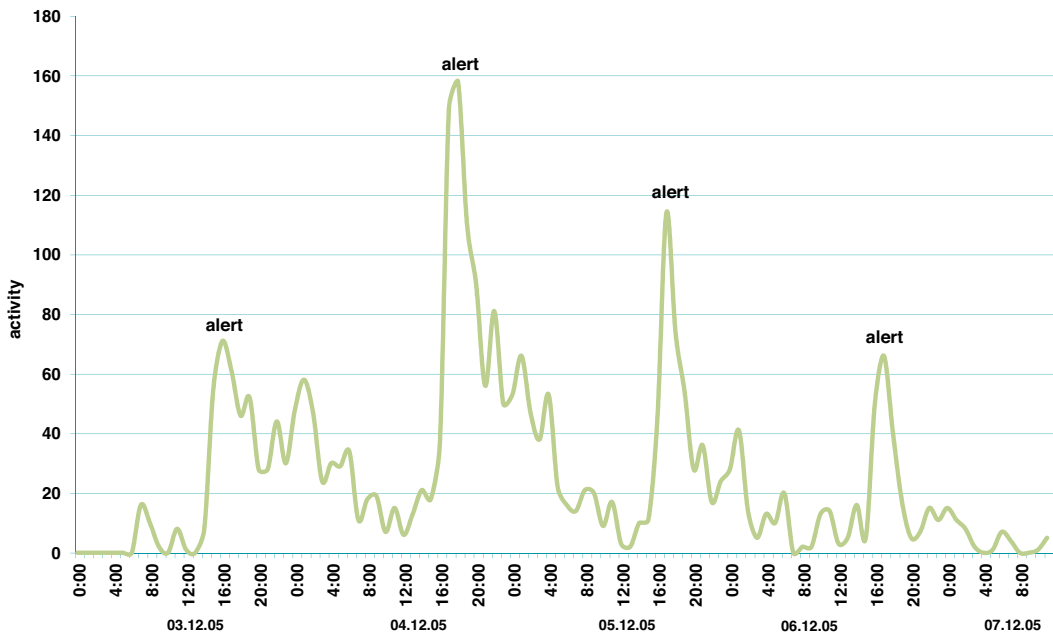
IMPLEMENTATION AND FUTURE USE

Since the invention of this early warning system, MIGROMAT® has been deployed on several different rivers: one on the River Lahn (Germany), two on the River Meuse (The Netherlands), one on the River Sauer (Luxembourg) and one on the River Shannon (Ireland). Another MIGROMAT® at

the Wahnhausen hydroelectric power plant on the River Fulda has been used for the protection of eel since 2002. From 2011 three further hydroelectric power plants (Statkraft on the River Weser and two more at sites on the River Main, Germany, by EON) will also be developed for eel-friendly operation.

FIGURE 1

Example of 4 days with pre-migratory restlessness, 3rd to 7th December 2005 in a MIGROMAT® at the Rosport hydropower plant, River Sauer (Luxembourg).



EXAMPLE

Implementation of a surface bypass for downstream migrating eels at a hydroelectric facility in New Zealand

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Country: New Zealand



INTRODUCTION

In New Zealand, longfinned (*Anguilla dieffenbachii*) and shortfinned (*A. australis*) freshwater eels not only have high cultural value but also form important customary, commercial and recreational fisheries. Adult eels must migrate to sea to spawn and complete their life cycle, and during their journey they encounter many anthropogenic barriers including hydroelectric dams. Hydroelectric dams can impact downstream migrants in a variety of ways including physical damage, delays in migration and increased susceptibility to predators. A review of eel passage through turbines in New Zealand concluded that survival of large migrant eels (silver eels) was likely to be nil (Mitchell & Boubée, 1992). Hydroelectric generating schemes in New Zealand are generally located some distance from the sea with the upstream habitat supporting low population densities of eels which typically produce large highly fecund female eels. Large migrant eels >1 m in length are now rare in New Zealand and populations need access to safe downstream passage and therefore to be protected from the impacts of hydroelectric dams.

WHAT DID WE DO?

Critical research continues to increase our un-

derstanding of the characteristics and behaviour of eels during their downstream migration. This knowledge has led to the development of a suite of techniques that are now either in place or are being considered at a number of hydroelectric facilities (e.g. Boubée & Williams, 2006). One approach that appears to have been particularly successful at small plants is the implementation of small diameter downstream bypasses.

WAIRERE FALLS POWER STATION

Bypass pipe feeding into a stainless steel chute downstream of Wairere Falls Power Station.



WAIRERE FALLS POWER STATION

Large migrant eel exits from bypass onto stainless steel chute at Wairere Falls Power Station. This photo is provided by the remote camera system that records the passage of migrant eels through the chute.



The effectiveness of this relatively low cost method of providing safe downstream passage for eel was tested at Wairere Falls Power Station (Mōkau River, North Island). Initially at this site, two 100 mm holes were drilled side by side in the dam wall, about 1 m below the water surface. The bypass position was based on observations that migrating eels travel close to the water surface but dive repeatedly whilst searching for an outlet near the dam face (Watene *et al.*, 2003). A 150 mm horizontal steel pipe carries fish from the bypass entrance to a stainless steel chute and over the natural rock falls to the river downstream (photo left). A counting gate and video camera monitor and record the passage of eels (photo top).

HOW DID IT WORK OUT?

The initial results showed that downstream migrant eels found and used the small diameter bypass to safely negotiate the dam (Boubée & Williams, 2006). Based on these findings, two additional bypasses with larger entrances were added in 2007. Since then, this relatively simple system has saved over 3,500 eels from certain

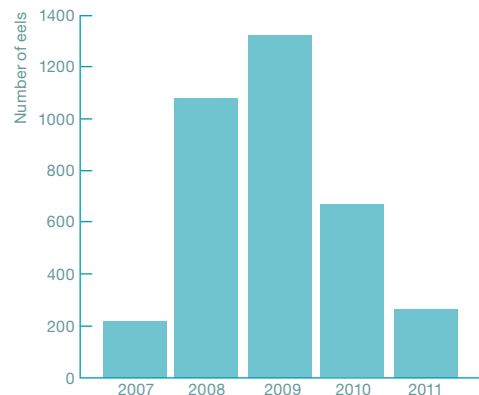
death (photo 3). Although the numbers observed in 2011 were lower than previous years (figure 1) it is likely that more migrant eels passed over the weirs during spilling events, a strategy that is also now being used to maximise downstream passage of eels at this power plant (Stevenson & Boubée, 2010; Martin, 2011). The implementation of this technology is now being considered at other sites around New Zealand.

LESSONS LEARNED

Until recently few hydroelectric facilities in New Zealand had measures in place to protect downstream migrant eels. However, the success obtained at the Wairere Falls Power Station has encouraged other generators to not only investigate, but in a number of cases implement, downstream passage facilities and operations. At one site, downstream bypasses have also been incorporated into the design of an upstream passage facility. Maintenance of these facilities is, as always, an integral part of their success. By their very nature, mitigation facilities and/or activities tend to be situated in areas that are relatively inaccessible and often dangerous. It is therefore essential that safe access and means of maintenance be included at the design stage of any mitigation that is proposed.

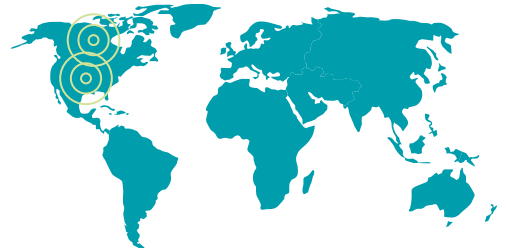
FIGURE 1

Estimated number of eels using the bypass at Wairere Falls Power Station between 2007 and 2011.



Fishway performance at upstream barriers to migration

Authors: Christopher Bunt¹, Ted Castro-Santos² and Alex Haro²
Organisation: Biotactic Incorporated¹ and USGS²
Country: Canada¹ and USA²



INTRODUCTION

Fishways at barriers that would otherwise block upstream fish passage structures are an important component of river restoration projects worldwide. Broad diversity exists among swimming abilities, migration windows and motivation of migratory fishes – all of which are reflected in fish guidance, fish attraction and successful or complete passage through fishways of various designs. In order to quantify efficiency of fish movement at areas of difficult passage we must first know how many fish of a particular species attempt to pass relative to the number of fish that succeed (Bunt *et al.*, 1999; Castro-Santos and Haro, 2010; Larinier *et al.*, 2005; Roscoe and Hinch, 2010). This is best accomplished using telemetry. Site-specific design variations in both technical and nature-like fishways related to slope, width, length, depth, configuration (i.e., shape, design and number of pools, traverses, orifices, baffles or roughness elements), entrance location and other factors influence the effectiveness of attraction, and passage for different fish species, but the relative contribution of these factors is difficult to separate and quantify, largely due to a lack of established and broadly applied methods (Castro-Santos *et al.*, 2009). Quantitative evaluation of the factors affecting fish attraction and passage (as well as guidance to a fishway entrance) is of paramount importance so that successful fishway design and construction decisions can be made.

WHAT DID WE DO?

We conducted a meta-analysis of existing fishway performance data to quantify, summarize, compare and review the upstream attraction and passage efficiencies for various species of anadromous and potamodromous fish through various fishways using data from studies with comparable attributes (Bunt *et al.*, 2011). To standardize values and minimize confounding variables, studies were considered appropriate for inclusion in the meta-analysis if they:

- 1 included data from fish that were individually monitored using radio, acoustic or PIT telemetry to measure fishway attraction efficiency and passage efficiency;
- 2 provided physical data from the fishways and data from anadromous and potamodromous fish actively migrating upstream in rivers (usually before the spawning period) from multi-year studies, multiple species, and studies from multiple sites and/or multiple fishways;
- 3 were based on evaluations of fish passage under natural conditions. Data were derived from peer-reviewed, published scientific studies and consultant reports and were then mathematically analyzed using principal components analysis (PCA) and multiple logistic regressions to determine what factors affected fish attraction and passage.

HOW DID IT WORK OUT?

From 116 available peer-reviewed scientific pa-

pers and consultant reports, only 19 satisfied the three standardized criteria for this analysis and described upstream passage performance at 35 distinct fishways at 28 locations. When separated by year and species, there were 101 records of data, from 26 species of fish in 6 countries (Canada, Denmark, Russia, Scotland, Sweden and the United States) and 4 categories of fishway structures including pool-and-weir, Denil, vertical-slot and nature-like.

Fish Attraction:

Attraction efficiency varied broadly across all fishway types (Figure 1a). Pool-and-weir (range = 29 - 100%, mean = 77%, median = 81%), vertical-slot (range = 0 - 100%, mean = 63%, median = 80%) and Denil (range = 21-100%, mean = 61%, median = 57%) type fishways were broadly comparable, but attraction into nature-like fishways (range = 0 - 100%, mean = 48%, median = 50%) was notably worse than in technical types. Based on the results of principal components analysis, patterns of attraction appear to be

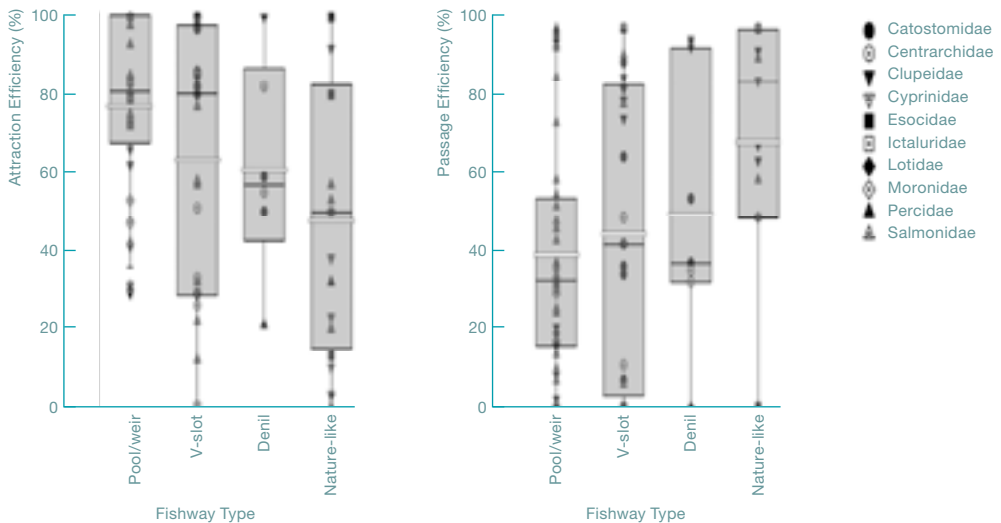
driven by the biological characteristics of the fish that were studied, suggesting that attraction to fishways may have more to do with fish behavior and biology rather than structure type or hydraulics. However, there was also some evidence that poorer attraction among nature-like fishways may be related to reduced or insufficient attraction flows compared with technical fishways.

Fish Passage:

Passage efficiency also varied broadly across all fishway types (Figure 1b). Ranges and mean values were 0 - 100% (mean = 40%, median = 34%) for pool-and-weir fishways, 0 - 100% (mean = 45%, median = 43%) for vertical-slot fishways, 0 - 97% (mean = 51%, median = 38%) for Denil fishways and 0 - 100% (mean = 70%, median = 86%) for nature-like fishways. In contrast to attraction, nature-like fishways performed better, generally passing more fish of more species than the technical types. Principal components analysis indicated that nature-like fishways (Figure 2a) and fishways with lower slopes (Figure 2b) had higher passage efficiencies.

FIGURE 1

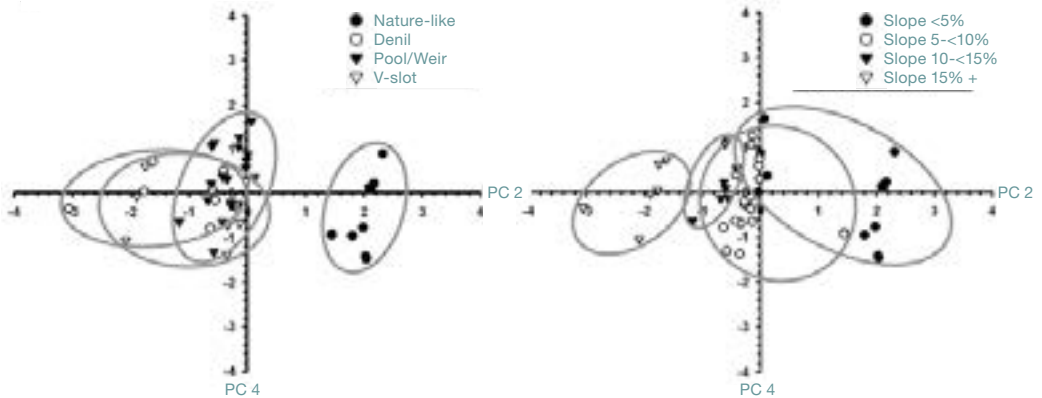
Box and whisker plots for each fishway type, arranged on the x-axis from greatest to least attraction efficiency (a) and least to greatest passage efficiency (b), summarizing maximum, minimum, median (black line) mean (white line) and outlier values for 10 families of potamodromous and anadromous fish.



>>EXAMPLE

FIGURE 2

Principal component 2 versus principal component 4 for passage coded by fishway type (a) and slope (b). Note the separation of nature-like fishways from technical designs in (a) and low slope and high slope fishways in (b). * indicates statistically significant plots.



LESSONS LEARNED

Available data do not clearly justify recommendations for any particular fishway type. Although there was some suggestion that nature-like fishways have better passage performance, it is important to recognize that nature-like fishways tend to be built with very low slope and it is possible that the superior passage performance of this fishway type was largely attributable to slope rather than to any other intrinsic design benefit. Nature-like fishways appear to function well for species with reduced swimming performance (Bunt, 2006; Calles and Greenberg, 2007) but there were many cases when flow was too low to effectively attract fish to the entrance location (Bunt, 2001; Larinier *et al.*, 2005; Moser *et al.*, 2000; Sprankle, 2005). There was some suggestion that pool-and-weir and vertical-slot fishways generally had better attraction than Denil and nature-like fishways. This relationship can again be attributed to differences in the amount of attraction flow provided by each fishway type (Naughton *et al.*, 2007; Pratt *et al.*, 2006).

Our analysis suggests that the most important biological factors that drive attraction efficiency are migratory characteristics (i.e., if the moni-

tored species was anadromous or potamodromous) and thermal tolerance (i.e., if the species was considered to be adapted to warm water or cool water conditions). These factors have metabolic (physiological) and behavioural or motivational components that require further investigation.

In addition to setting the framework for comparisons, this study clearly defines a standardized monitoring protocol that will yield refined taxon-specific fishway performance data required to improve fishway effectiveness and fish passage.

netting or electrofishing to estimate the numbers of fish that descend a bypass channel or by-wash, or pass an inlet screen, to various designs of traps including Canadian rotary screw traps which are increasingly used to sample salmon smolts during their migration.

However, once again the best results are obtained when using radio or acoustic tag telemetry, PIT tags or in some cases in larger rivers, hydroacoustic methods. These can be used to measure entrainment rates and the effectiveness of bypasses, but also to examine the behaviour of fish as they react to the various structures and abstractions.

Where there is more than one potential route for fish it can be important to know which is preferred so that it may be managed appropriately to maintain or increase its effectiveness. Studies of various kinds can provide this information, for example by trapping within each route. This may also include mark and recapture methods to provide evidence of fish passage and the relative importance of each route.

Fish can be marked in a number of ways, for example with dye marks or appropriately-sized plastic tags, and marked fish can be recaptured using fyke nets or some other nets or traps downstream. With this system the effectiveness of a bypass can be determined as well as the efficiency through the recapture and enumeration of marked fish.

The loss through entrainment into abstractions and the damage and mortality of fish at other facilities should be determined for each target species, in terms of numbers and, if relevant, biomass. Damage at the facility, and protection by screens, can differ considerably between species. Monitoring should distinguish between fish that are dead or lethally injured, those with sub-lethal damage and those fish with no damage. It may be necessary to retain fish from the monitoring programme for a short period of time (1 or 2 days or, rarely, longer) to assess delayed mortality.

The mortality rate (M) is the proportion of the total number of fish (n) that are dead (d).

$$M = d / n * 100$$

The damage rate includes the damaged fish (v):

$$M = d + v / n * 100$$

In the case of multiple sites (i) in the river system that cause damage, the total damage rate (Stot) can be calculated by:

$$Stot = (di + vi) / ni * 100$$

The rate of mortality or damage should be calculated for each species, and the management of the plant may need to be adapted according to the results.

Programmes for these assessments usually consist of capture dependent methods such as large nets, however these are strongly influenced by the discharge of the river or the volume of the sampled abstraction flow.

Fish, both alive and dead, can be captured from any fish return system associated with the abstraction, and dead or damaged fish can also be retrieved from the trash that is collected from the trash rack. Both can be checked on a routine basis, and both can be managed to provide quantitative monitoring data.

6.4 GENERAL CONCLUSIONS

Once the information requirements related to migration at obstacles and fish protection at abstractions have been clearly identified then an evaluation program can be designed. Important factors to consider include costs, in terms of the people who will be involved and the equipment required, time schedules and the required period of monitoring. A programme should aim to deliver the requisite information for each target species and may need, therefore, to operate only in specified months of the year. In Finland for example the salmon migration period usually starts in April-May in the southern areas,

EXAMPLE

Development of a juvenile salmonid bypass system evaluated using hydro-acoustic and acoustic telemetry techniques

Authors: Tracey W. Steig, Patrick A. Nealon, Kevin K. Kumagai, Colleen M. Sullivan and Samuel V. Johnston
Organisation: Hydroacoustic Technology Inc.
Country: USA



INTRODUCTION

The Columbia River Basin is the most hydro-electrically developed river system in the world with more than 400 dams. The Basin drains 259,000-square-miles, including regions of Oregon, Washington and British Columbia. The combined consequences of dams, changing

ocean conditions and loss of river habitat have contributed significantly to declines in historically strong anadromous fish runs (CCRH, 2011).

Significant efforts to improve salmon runs have been made by implementing ways to move juvenile salmonids safely around hydroelectric turbines as they migrate towards the ocean. At Rocky Reach Dam, years of juvenile salmonid migration studies led to the design and installation of surface bypass systems. Until 1982 there was very little information about downstream migration patterns of juvenile fish at the dams. Investigations commenced with single beam echosounders (Ransom and Steig, 1994), and as a result of substantial technological developments with split-beam echosounders and horizontally scanning split-beam systems the precise behaviour of downstream migrating salmon smolts became increasingly clear.

These investigations led to increasingly more difficult questions around behaviours of individual species of juvenile salmon, and route selection through hydroelectric projects. Attempts

FIGURE 1

Basic components of the HTI Acoustic Tag Tracking System used to track movements of fish implanted with acoustic tags.



TABLE 1

Survival results at Rocky Reach hydroelectric project. Steelhead results were over a three year period, for sockeye the results occurred three times during a 5 year period and for chinook results are currently in the evaluation phase, with predictions suggesting survival >0.930.

Species	Bypass Passage	Survival	Study
Steelhead (<i>Oncorhynchus mykiss</i>)	67%	0.958	3-year average
Sockeye salmon (<i>O. Nerka</i>)	56%	>0.930	3 studies in 5 years
Chinook salmon (<i>O. Tshawytscha</i>)	48%	>0.930	prediction

to answer these questions using radio tracking technology fell short due to the inability to sample at depths greater than 10 m and the general lack of positioning precision. We therefore investigated the suitability of advanced acoustic tags to answer these questions.

WHAT DID WE DO?

We developed a system using an acoustic tag receiver, hydrophones and a user interface/data storage computer (Figure 1). The system uses a fixed array of underwater hydrophones to track movements of fish implanted with acoustic tags. Each tag transmits an underwater sound signal that sends identification information about the tag to hydrophones. As tagged fish approach the study area, the tag signal is detected and the arrival time recorded at several hydrophones. For

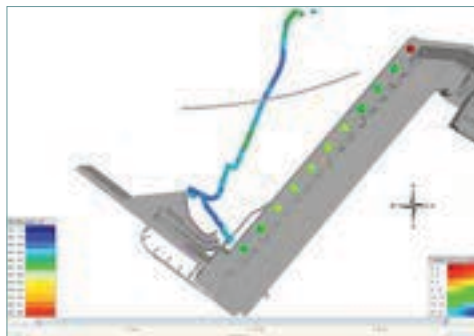
three-dimensional tracking, tag signals must be received on at least four hydrophones. The differences in tag signal arrival time at each hydrophone is used to calculate the three-dimensional position of each tagged fish (Ehrenberg and Steig, 2003). An example of a three-dimensional tag track is presented in Figure 2.

HOW DID IT WORK OUT?

Since the first study in 1998, acoustic tagging studies have been conducted each spring in the forebay at Rocky Reach. During bypass development, operation was modified based on these studies, including increasing flows and modifications to a second bypass entrance. In 2001, Chelan PUD, in coordination with the fisheries agencies and Native American Tribes determined that the configuration of the fish bypass system had been tested satisfactorily and that installation of a permanent system was warranted. Since then studies have been conducted to estimate species-specific survival, behavior and passage route preference. Estimates of bypass utilization and survival are encouraging, met expectations, and are in compliance with passage standards (Table 1). The acoustic telemetry evaluations have proven that the bypass is successful in safely bypassing juvenile salmonids around the dam.

FIGURE 2

Swimming path of fish moving through Rocky Reach forebay and entering the fish collection/ bypass facility.



LESSONS LEARNED

Subsequent evaluations have proven that the bypass is successful in safely bypassing juvenile salmonids around the dam. This demonstrates the potential to assess and improve fish passage at all hydropower dams.

but in June in the north, and ceases as water temperature drops in October. Information like this should be used to define the period of monitoring needed.

Fish passes and bypasses can provide a good opportunity for monitoring fish stocks in a river in addition to the requirement to monitor performance of the structure itself. It is important that the chosen method does not affect the migrating fish.

Programmes such as these may be a requirement of the national organisation charged with protecting fisheries, or they may choose to take advantage of the opportunity to initiate strategic monitoring themselves. It may also be a condition of licencing for the owner or operator of the structures that necessitated the fish pass in the first place to carry out monitoring, and in some cases this should be a condition of any consent given.

New projects to fit fish passes to old weirs and dams should also have appropriate monitoring built in to demonstrate that the required improvements to fish migration have been successfully achieved.

In some countries it may be necessary to obtain appropriate legal permissions and exemptions for monitoring, for example when handling protected fish for research purposes or using equipment such as radio transmitting tags that may be regulated by national legislation.

TIPS

- Monitor the hydraulic performance of the facility immediately after construction. The results can be used as approval and acceptance criteria for compliance with contractual requirements;
- Consider identifying fish passes at strategic locations in a river basin for monitoring of both the performance of the structure and the overall effect on fish populations (a quantitative approach). A scientific approach to monitoring is usually required and appropriate advice on this should be sought;
- Include plans for evaluation of the facility at an early stage, so that necessary facilities are included within the design process;
- The objective of evaluation is to quantify the effectiveness of the facility, but this should also demonstrate whether the facility adequately contributes to a target such as 'good ecological status' for national and international standards such as the Water Framework Directive in Europe;
- Evaluation can also help to improve future design criteria and should therefore be widely shared.

CHAPTER 7

COMMUNICATION AND EDUCATION



INTRO

The wellbeing of our fish populations is a potent indicator of the environmental health of our waterways. The large migrators such as salmon are truly iconic and have inspired mankind for millennia. Even Shakespeare referred to them:

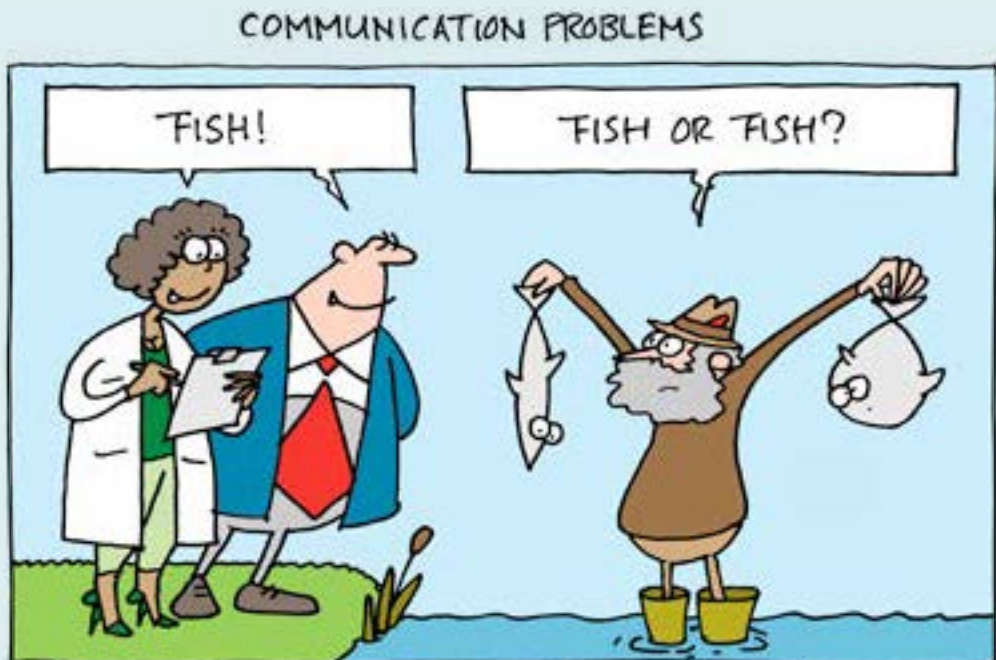
“There is a river in Macedon; and there is also moreover a river at Monmouth: it is called Wye at Monmouth; but it is out of my prains what is the name of the other river; but 'tis all one, 'tis alike as my fingers is to my fingers, and there is salmons in both.”

(Shakespeare, 1599. Henry V, Act IV, Scene 7)

Fish migration issues are receiving more public attention worldwide as awareness is rising. New media are being used to improve communication. For example, tribal communities in Brazil that depend heavily on fish for subsistence have organized themselves to protest against dam developments that

threaten fish stocks through disruption of migratory pathways. Together with rock star Sting, Chief Raoni of the Kayapo tribe toured many parts of the world in opposition to one hydroelectric project in 2009. That project is predicted to have significant negative impacts on fish stocks as fish are excluded from vital habitats and other habitats are lost (Fernside, P.M., 2006).

Fish are an emotive and valuable issue upon which communities can focus as they become involved in environmental and water projects. Important local insight can be gained from fishermen who often have very good knowledge of the status of rivers, whilst having their own firmly held views on what should be done! We believe that achieving fish migration is the ultimate goal, but that environmental education and the involvement of society are an essential part of the process to achieve it!



7.1 EXCHANGE OF INFORMATION

Effective communication of expert knowledge worldwide is important. If fish migration problems are not communicated persuasively, then political and financial support for fish migration solutions might not be achieved. In this context, independent national panels of experts on fish migration matters in many countries have provided an effective channel for the exchange of information and expertise.

These panels act as centres for expertise on all issues relating to fish migration and passage facilities. They provide advice on design criteria and standards and new developments in these areas, on the existence and implementation of appropriate local and regional regulations, and perhaps most importantly they provide advice and assistance to managers and local bodies.

Some panels might also be able to help and advice on the availability of grants and other funding sources for construction projects, project management, the funding of research and development and also the maintenance of area or national databases.

The exchange of information, including research reports, project records and scientific publications is very important if we are to gain from the experience of others. Special attention should be paid to making knowledge available in the English language, since many reports are written in local languages only!

Examples of expert knowledge panels and networks

The networks referred to above facilitate direct communication between regional agencies and authorities and non-governmental organisations, but there is no reason why international networks cannot also be used to great mutual advantage. In Europe, the expert group on fish migration matters is the European Inland Fisheries Advisory Committee of the FAO (EIFAC) which meets on a regular basis to discuss cross border fish migration issues. Communication between

countries in mainland Europe has also improved significantly since implementation of the Water Framework Directive.

Other examples of international communication between expert groups relates to countries that share a river basin, for example the International Association for Danube research (www.iad.gs) and the information and knowledge management program of the Mekong River Basin Committee (www.mrcmekong.org).

From 2009 fish migration experts from all over the world have begun to exchange information and ideas and to discuss matters of mutual interest through the 'World Fish Migration Network', 'Fish Ecology Network' and the 'Dam Removal and Fish Passage Network' on LinkedIn (www.linkedin.com). These networks have grown quickly since inception and are a valuable asset.

Symposia

In addition to the existing expert networks, international conferences and symposia provide valuable opportunities to exchange information on general topics such as the restoration of river basins and more specific technical issues such as the design and construction of passage facilities. Relevant recent international symposia have been held in 2011 and 2012, including an International Fish Passage Conference (USA), the Second International Symposium on Fish passages in South America (Brasil) and the International Conference on Ecohydraulics (Austria) which is organized once every two years. Information on such opportunities can be obtained through the LINKED-in network and www.fromseatosource.com

Internet

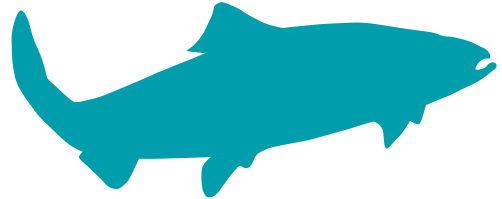
The internet is an important medium for sharing information. Interactive information systems, e.g. GIS mapping are also promising tools for information exchange. Examples include:

- ESIS: a prospective 'European Salmonid Information System' (Dijkers & bij de Vaate, 2002)';

SPECIES EXAMPLE

The current status of Atlantic salmon (*Salmo salar*)

Author: Bror Jonsson
Organisation: Norwegian institute for Nature Research (NINA)
Country: Norway



INTRODUCTION

Life cycle

Atlantic salmon spawn in the autumn in gravel and pebble-bedded rivers. After hatching and emergence, the young live in freshwater for between 1 and 4 years, occasionally longer, until smolting and migration to sea. Post-smolts feed in the ocean for 1-4 years before attaining maturity and returning to their home river for spawning. Surviving spent adults move back to sea where they remain for up to two years before rematuring and returning to freshwater. They can repeat this spawning process up to 4 times (Klemetsen *et al.*, 2003).

Geographical distribution

The Atlantic salmon is native to the North Atlantic basin, spawning in European and North-American rivers. In the eastern Atlantic, they occur from Petchorskaya in Russia to the River Lima and River Minho in Portugal and within the Baltic Sea. In the Atlantic Ocean, they are observed northwards to Svalbard (81° N). There are a few freshwater resident populations in Europe (Fennoscandia and Russia). In North-America, they spawn in rivers from Hudson Ungava Bay in Canada to the Connecticut River. Freshwater resident populations (called Sebago salmon), occur in many lakes westward to Lake Ontario. Over this wide distribution area, the species exhibits three main genetic groups: West Atlantic, East Atlantic and Baltic Atlantic salmon (Verspoor *et al.*, 2007). The

high degree of fidelity to their natal rivers means that there is a further genetic distinction between regions, rivers, and even within large rivers.

Human impacts

The Atlantic salmon is exploited through commercial and recreational fisheries and is extensively used for aquaculture and farming. These activities pose threats to wild populations, as do pollution including eutrophication and acidification of watercourses, abstraction of water, removal of spawning gravel, and construction of weirs (e.g. for abstraction, hydropower impoundments and navigation) that block the migratory route to the spawning grounds. Aquaculture represents a threat to wild salmon populations through the escape of fish that represents ecological competition, genetic introgression and the spread of contagious diseases.

Furthermore, due to a range of factors, now including climate change, the global abundance of wild Atlantic salmon has decreased radically over the past few decades. Management efforts are now being widely developed and applied to restore threatened populations (Jonsson and Jonsson, 2009a,b).

POSSIBLE SOLUTIONS

Bold political decisions are needed to save wild populations, and much is now being done. For example, marine fisheries are now heavily regu-

lated through quotas. Acidification of rivers is now less of a problem than a few years ago as industrial emissions have been more tightly regulated and intervention such as the application of crushed lime-stone has reduced surface water acidity. Through these measures and many others the species has returned to rivers where it was extinct.

Efforts have been made to stop farmed salmon from escaping, but this problem is unresolved. Sea lice multiply greatly in fish farms, and these threaten wild salmon at sea. When live Atlantic salmon were transferred to Pacific Canada for use in aquaculture, sea lice (*Lepeophtheirus salmonis*) were also transferred and has become a major threat to local pink salmon (*Oncorhynchus gorbuscha*) and Pacific eulachon (*Thaleichthys pacificus*).

KEY DRIVERS

The high economic value of farmed salmon is a constraint against further regulations and restrictions needed to conserve the species. Furthermore, there is increasing demand for more green energy, and hydropower schemes blocking rivers are expected to increase. Also, human influenced climate change is expected to influence salmon stocks negatively, and it is possible that this has already started. In some countries, freshwater fisheries are difficult to regulate because of the legal rights possessed by river and fishery owners.

FUTURE DIRECTIONS

For salmon farming, the obvious solution is better containment of the fish, for instance in land-based fish farms (Hindar and Jonsson, 1995). In this way it is possible to control and treat effluent

ATLANTIC SALMON

Young Atlantic salmon (called parr) grow up in rivers where they live for 1 to 8 years before smolting when they are between 10 and 30 cm long and weigh between 10 and 200 g in spring or early summer. They dwell mainly on gravel bottoms feeding on drifting invertebrates.



>> SPECIES EXAMPLE

FISH FARMS

Fish farms consist of a number of open sea pens where the immature fish are fed for 1-2 years from smolting to harvest.



waters. Other possible measures are:

- 1 Sterilization of farmed fish to avoid direct genetic effects;
- 2 Localizing salmon farms far away from areas with important wild populations to reduce gene flow between farmed and wild conspecifics, e.g. through development of fish-farm-free coastal parks;
- 3 Stronger restrictions on transport of live fish and eggs to reduce the spreading of exotic genes and diseases;
- 4 Establishment of gene banks to decrease the risk of losing valuable populations.

Furthermore, there should be continued emphasis on reducing global warming. Overfishing of small fishes and crustaceans, which are the marine resource base for wild salmon in the North Atlantic Ocean, should be avoided. The negative impacts of the continued damming of rivers for

hydroelectric purposes can be reduced by making proper upstream fishways past the installations. Also, seaward migrating salmon (smolts and post-spawners) should be led to alternative routes downstream to avoid being injured by the turbines of hydropower stations. The latter is a pressing research task. Towards the southern end of the distribution area, populations are most vulnerable and threatened by high summer temperatures, lack of water and poor spawning conditions. Thus, it is important that water is not channelled away from the rivers, spawning gravel is not removed from the river beds, and the water is not more heavily polluted by nutrients and toxic waste. Overharvesting of wild Atlantic salmon must be avoided, and the populations should be managed according to the precautionary principles as recommended by NASCO (The North Atlantic Salmon Conservation Organization).

- The 'IUCN Interactive river basin tool' (IUCN, 2003);
- The forthcoming Salmon Rivers Database (through NASCO, the North Atlantic Salmon Conservation Organisation);
- The 'Freshwater ecoregions of the world' (Abel *et al.*, 2008).

Other significant databases are being developed in Finland, Belgium and in The Netherlands (www.vismigratie.nl).

The websites of FAO, IUCN and The WorldFish Center (WorldFish) are also extremely good examples. Some portals are rather specific, e.g. the Global Ocean Ecosystem Dynamics project (GLOBEC) that concerns the impact of climate change on recruitment, abundance, diversity and productivity of marine populations. The Website of the FAO FishCode project (www.fao.org), aiming at supporting numerous bio ecological aspects as well as socio-economic areas, is more diverse.

Such portals are now routinely available, many that deal with marine resources and freshwater fishes. The UN Atlas of the Oceans is a more dynamic and interactive portal developed by FAO on behalf of its sister UN Agencies and concerns a range of oceanic matters. It is an excellent example of collaborative effort in coordinated information dissemination. Google Ocean is a unique publication platform in which large quantities of data can be made freely available to a large potential audience in the form of images, videos, sound files, and connection to specific sites, etc.

This is a rapidly developing field and is increasingly effective for information exchange (and, once again, LinkedIn is an effective way to maintain awareness).

7.2 COMMUNICATION WITH PARTNER AND PARTICIPATING ORGANISATIONS

There is a widespread and increasing focus today on the promotion of partnership working

to deliver environmental improvements. Closer co-operation between government agencies, water authorities and the public sector is essential if mutual interests and opportunities are to be identified and resources shared to address environmental needs. This is a relatively recent cultural shift and is clearly demonstrated in fisheries where interest groups including fishermen, private fishery owners, tribal communities and those interested in wildlife and biodiversity, who all frequently have strong views about the needs to improve fish stocks and fish habitats, have united in their efforts.

Bonneville fish ladder

This fish ladder on the Columbia River (USA) is equipped with a viewing window (© Olle Calles).



A good example is the Penobscot River partnership which is showing how everyone - tribal residents, companies and nature - wins when a river and the migration of fish within it are restored. For more information see: www.penobscotriver.org

Strong partnerships allow more to be achieved

than would otherwise be the case and usually ensures that the most cost effective decisions are taken. Identifying and engaging the range of public and private organisations and groups with an interest and a stake in planned management measures is important to encourage the sharing of views and values, to establish a common understanding of objectives and,

Monitoring with volunteers

Monitoring program on diadromous fish along the northern coastline of The Netherlands. More than 50 volunteers are involved in this program. The diadromous three spined stickleback (Gasterosteus aculeatus) is one of the most regularly caught fish species (© Groene Zoden Fotografie).



ultimately, to create a shared vision of what is to be done. Early engagement encourages the sharing of ideas and approaches and will identify the best means of delivering a project. In contrast there are clear risks in proceeding in any scheme without the necessary buy-in of all interest groups.

A good example of the use of knowledge held by participating organisations is the Native Fish Strategy of the Murray-Darling Basin (Murray-Darling River Authority, 2003). This strategy ensures that viable fish communities and populations are sustained within the river basin and encompasses specific community education and awareness programs. It is using the long-term knowledge of local fishermen to inform the current scientific understanding of fish species in the basin. The Native Fish Strategy (www.mdba.gov.au) has been recording the experiences of recreational fishers so that local, historical and cultural knowledge can be used in managing fish species in the Basin (Murray-Darling River Authority, 2011).

Before engaging partners a clear understanding of local issues and priorities is required together with clarity on potential areas for collaboration. It is important to set out what could actually be achieved and to agree this before commencing a project. If different groups have differing objectives then it may not be realistic to proceed in a partnership. The nature and extent of commitment from each partner should be identified, recognising that different partners can offer different levels and types of resource. For example, some may offer technical knowledge whereas others may offer practical guidance, local information, manpower for fieldwork, or offer the design and consultancy support that many fish pass schemes require.

It should be an objective to maximise capacity through combining the different capabilities of each partner. It is not possible to identify a general approach to partnerships as every situation is different due to local factors such as the range

TIPS

- Communication between ecologists, engineers and hydrologists is vital for the outcome of good fish migration solutions;
- Identify shared objectives and interests as a basis for co-operation between organisations;
- Organize events to inform the public about fish and fish migration, and provide practical demonstrations. In The Netherlands and the UK these days have proved to be very effective;
- Develop fish migration games so that children can learn while playing. Examples of these games are given in the guidance;
- Water managers, nature conservation organisations, fishery boards, etc. should work together on education and the development of educational programmes and material;
- Involving students in monitoring programmes can be an efficient way of conducting research. This is not only because of the cost efficiency aspects, but it also can prove to be a valuable training and development opportunity and an inspiring life-time experience for the students themselves.

of available partners, the scale and nature of the challenges to be resolved, local policy, and costs and available resources.

Essential requirements for a successful partnership are:

- Agreed objectives, set out clearly and fully described so that all partners have a clear understanding of them;
- Continued focus on the objective as a reference point during the project so that progress is tracked;
- Clear areas of responsibility, with accountability, for each of the partners.

7.3 COMMUNICATION WITH MEMBERS OF THE PUBLIC

Integrated water management does not relate only to the surface waters and banks of our rivers, channels and lakes but also to the whole catchment area. Although key interest groups can be readily identified, it is evident that the whole population of a river basin has a stake in projects to improve their own local environment. The human population within any river basin forms a diffuse and extensive group. The authors believe that people should ideally understand water management issues in general, and that specific measures to encourage fish migration should be publicised to improve public understanding of the issues.

Similarly, it is important that professionals involved in water management seek and listen to the opinion of the public, whether this is from organised stakeholder and lobby groups or from individuals. In Europe this has never been more important as fish migration measures resulting from the WFD are being recognised and solutions defined and implemented.

It is important to provide information to the public in a form that they can easily understand and which helps them to draw their own conclusions about priorities. If it is not adequately explained that free migration of fish is prevented if dams and weirs do not contain fish passes, then it is unlikely that the issue will feature strongly in the minds of politicians. The information provided should be appropriate for the part of society at which it is aimed. In the first instance it may be necessary to provide information about the water cycle, how water is used and why it is important to manage it carefully. For other groups, specific requirements for biodiversity or for navigation might be more important. A strategy to achieve this improved understanding is vital to gain a shared understanding of problems and future priorities for action.

By bringing the concept of the water cycle and its rational management to the citizens, an im-

proved understanding of the importance of water management may be achieved. Additionally, awareness of environmental management problems as well as the measures to address them may be communicated. Nowhere is this more apparent than in the concept of the river continuum for fish migration.

More and more, the potential of the internet is being used to inform the general public of fish migration issues. Increasingly, social media can be used effectively to communicate fish migration issues. For example, awareness was raised of diminishing fish stocks in the UK (mainly the heavily exploited marine stocks of the North East Atlantic Ocean) by a highly successful series of television programmes supported by an intensive online campaign called the 'Fishfight' in 2011. The campaign engaged celebrities and the general public to take on the politicians and supermarkets, and finally the EC itself during the negotiations for a new Common Fisheries Policy. For more information follow this link: www.fishfight.net

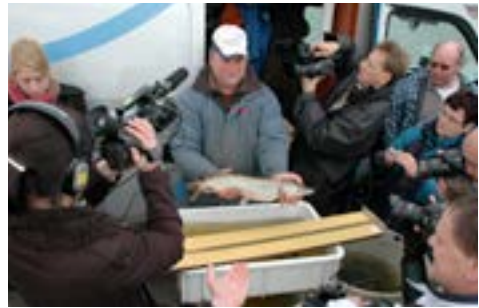
7.4 EDUCATION

Improved environmental awareness and care for our environments can result from appropriate education and can contribute to improved living standards of local and national societies. Personal commitment and motivation of those who deliver education is vital as enthusiasm is a good catalyst for success. Our approach to education provides basic knowledge, but this needs to be balanced by experience that can only come from an ongoing lifelong learning process. Both are relevant for students to be able to form their own opinions, to recognise connections between facts and to learn how to make choices for the benefit of society.

In relation to water management, public education should include information about the water cycle and the vital importance of water for the environment and for society. EIFAC has concluded (FAO, 2000) that in many parts of the world a system of education of commercial fishermen is necessary to ensure the future of

Raising awareness

Fish are popular for communication purposes and can raise high awareness for a more clean and healthy river environment. On the left a salmon caught in the River Åtran (Sweden) at a dam which will be removed in 2013. The pike, on the right, was the most famous pike of The Netherlands in 2007. 'The monster of Lake Oldambt' (© Groene Zoden Fotografie). Below a crowd of children with pra or river catfish (Pangasianodon hypophthalmus). River catfish are closely related to the Mekong giant catfish, Pangasiandon gigas, a critically endangered Mekong endemic. Fishers harvest both the river catfish and the Mekong giant catfish as they migrate from the Tonle Sap Lake (Cambodia) to the Mekong River at the end of the rainy season(© Zeb Hogan / WWF-Canon).



EXAMPLE

The Delaware River Experience Educational Program

Author: Mary Ellen Noonan
Organisation: Bucks County Conservation District
Country: USA



INTRODUCTION

Strangely enough, children from the USA know more about the African savannah than they do about their own backyard. Thanks to an innovative new program, that is about to change in the Delaware River Valley region.

WHAT DID WE DO?

Hundreds of school children living in the Delaware Valley of Pennsylvania and New Jersey are learning environmental principals by using the natural resources of their local community. Originally sponsored by the National Park Service as a collaborative effort of riverside Conservation Districts and the Bucks County Riverboat Co.,

RIVER OTTER PONTOON BOAT

Educational program for school children on the River Otter pontoon boat.



this unique program not only sends professional educators into schools to present information in the classroom; it brings the students to the Delaware River to experience all the river has to teach.

HOW DID IT WORK OUT?

Connecting classroom learning with real life studies of the local watershed fosters a sense of place and community, giving students an appreciation for how science concepts affect their environment. Students are introduced to watershed topics during an initial classroom visit from a conservation district educator. Engaging the students in a beach ball 'globe' toss helps them discover that even though our earth is covered by over 75% water, only a fraction (.001%) of that water is available for our use.

Students become an integral link in their own learning as they perform water quality assessments and investigate the macro-invertebrate life of the river. This information is used to determine the health of the watershed and students learn how actions on the land affect conditions in the water. Historical and cultural information is also blended with scientific information during the one-hour journey upriver aboard the River Otter pontoon boat. Students learn about American Eels that live in the river but migrate to the Sargasso Sea in the Atlantic Ocean to spawn. They learn about the American Shad which live

in the ocean but migrate up the Delaware and other east coast rivers to spawn. These fish, which were important to the early settlers as a constant source of food, were once close to extinction but are now abundant in the river.

Bald Eagles or other birds spotted while on the river might lead to a discussion of the use of the Delaware River as a navigational tool during bird migration. Passing under a bridge while aboard the River Otter, students learn about the ferry service which existed before the bridges. They learn about the canal, the floods and many other interesting facts about their river. Teachers and students have praised this program and additional funding has been made available. More information is available at www.bucksccd.org

LESSONS LEARNED

Students today are increasingly suffering from Nature Deficit Disorder, a phrase coined by Richard Louv in his book, 'Last Child in the Woods'. They often come to the classroom with very little prior knowledge of the environment. Programs

MACRO-INVERTEBRATE STUDY

'What do fish eat?'



.....
that bring students outdoors will continue to be important in linking scientific concepts learned in the classroom, and the students who are charged with learning these concepts, to the real, outside world.

DELAWARE RIVER



EXAMPLE

Fish Migration Day

Authors: Silvia Mosterd¹, Niels Breve² and Herman Wanningen³
Organisation: Regional Water Authority Noorderzijvest¹, Dutch Angling Association² and Wanningen Water Consult³
Country: The Netherlands



INTRODUCTION

Free migration of fish is necessary to achieve healthy fish stocks. Several species, including salmon, sea trout, sturgeon and eel, migrate between the sea and rivers. These species are particularly threatened by barriers such as weirs, dams and sluices, built for water management, hydropower and land drainage. Water and nature managers in Europe have been improving the position for these migratory species with fish passes and bypass channels around barriers, to help fish on their journey.

DRAWING COMPETITION

Competition with coloring pictures of a salmon
(© Harke Tjaden).



An essential aspect of the work on fish passage issues is raising awareness to gain the commitment of communities in the different river basins. By creating commitment at all levels of the communities and with all stakeholders, measures can be carried out more efficiently and financial opportunities can be maximised.

WHAT DID WE DO?

The Fish Migration Day is a new concept to achieve greater understanding and community involvement (including children and parents). The first Fish Migration Day was held on the 14th of May 2011 in the North Sea Region. The event was organized by the Living North Sea Project (www.livingnorthsea.eu), which is funded by the European Union.

At more than 25 locations in 7 countries in the North Sea Region, children and parents learned about a variety of topics, including: the different species of fish in their local rivers, fish passage solutions, water and nature management issues, fisheries, research, aquatic insects and they could also play the Eel Game (www.elyeel.eu). In Denmark the event was combined with activities at a sea aquarium. In Sweden the municipality of Falkenberg additionally raised awareness of dam removal and its role for migratory fish.

HOW DID IT WORK OUT?

The first Fish Migration Day was a big success

THE FISH MIGRATION DAY GOT THE ATTENTION OF REGIONAL TV STATIONS



and by the end of the day 5,000 people had visited the event. The day created publicity in regional and national press, internet, and also radio and TV stations such as the BBC in the United Kingdom. The National Geographic magazine (Dutch edition) also covered the event in an article on migratory fish. There is now an initiative to organize a worldwide follow-up in 2014 (www.wanningenwaterconsult.nl).

Communication expert Silvia Mosterd described her experiences:

"We worked together with the neighbouring Regional Water Authority Hunze en Aa's and the regional fishery board and organised a fun educational day at two fishways. We organised a wide range of activities for families with children, starting with a fish migration day at the fishway. Here children pushed two big colourful fish (divers dressed up) in the water in front of the fishway. They cheered to help the fish get through the fishway and reach their spawning areas and, I'm happy to say, they made it there!

In the centre of the village of Roden we set up three tents next to a historic manor. Each tent had a theme: the underwater world of fish, boundaries for fish, and travelling fish. Visitors

could explore the underwater world of fish by examining fish and water insects in tanks. They could look at schematic models of pumping stations and sluices which are barriers to fish. They could also see solutions to this problem in pictures, video and text, but also during the visits to the fishways. Children won a prize when they hung up their coloured picture of a travelling fish in the big fishnet. Adults who wanted to escape the busy activities were able to visit an exhibition of underwater pictures called 'Beeldschoon Water' (Ed: 'beautiful water').

Alongside the day full of activities we also had a regional fish migration campaign, not only to attract people to visit the fish migration day, but also to tell them the story of fish migration. In advertisements and free publicity, people were able to read about fish migration and the barriers that fish encounter while travelling through the waters of the northern part of The Netherlands. Between the campaign and the activity day we reached over 500,000 people in the Northern part of The Netherlands with the headline message that our work on fish migration is necessary. The event was a complete success!"

Information Centre 'Mosellum'

Authors: Bettina Thiel, Andreas Christ and Josef Groß
Organisation: Ministry of environment, agriculture, food, viniculture and forestry of Rhineland-Palatinate
Country: Germany



INTRODUCTION

From 1958 to 1964, the River Moselle in Germany was canalized (expanded and regulated via the installation of dams and locks) from the city of Metz in France to the confluence with the Rhine in Koblenz. The dams enable large cargo ships to navigate on the Moselle. They also provide opportunity for hydroelectric power. Unfortunately this has also changed the entire ecological system of the river.

In order to enable fish to migrate through the Moselle again, upstream to their spawning habitats, new fish passes are being built at each of the 10 German dams from Koblenz to Trier. Depending on the specific conditions at each dam techni-

cal designs will be chosen such as a vertical slot pass. For downstream migration a satisfactory solution has not yet been found, but research is continuing.

WHAT DID WE DO?

Next to the new fish pass in Koblenz an Information centre, the 'Mosellum' has been built. It gives visitors the opportunity to learn why it is important that fish are able to migrate between their spawning and feeding grounds and the sea. The Mosellum has 4 different exhibition areas, and the building is separated in split-levels so that it is possible to look from one area to the other.

The first exhibition area focuses on the region's geology and developmental history. This 'Shore' exhibit also reflects the diversity of the local habitats of the flora and fauna in and along the Moselle.

OUTSIDE VIEW

The Information centre Mosellum in Koblenz, Germany (© Thomas Müll).



The next exhibit area, the 'Ship', gives an overview of the changes to the Moselle over time exploring the tensions between economic and environmental interests, and presents some preliminary solutions to this multifaceted conflict. Visitors can assemble pieces of a Moselle puzzle in which the sections between the dams on the German part of the Moselle have to be lined up in the correct way so that a ship (a marble) is able to travel down the river. In another exhibit people can measure the power of their muscles in comparison to the hydroelectric power station.

Further downstairs the 'Underwater' exhibit focuses on fish and their habitats. Many species of fish migrate between different habitats, some of which are quite a great distance apart. The exhibit takes 2 examples of long-distance migratory fish - eel and salmon - and looks at their complex and sometimes perplexing life cycles. Photos, texts, and videos examine all aspects from the eel larvae's strange behavior to the salmon's sense of orientation. The Fish Species Display offers information on nearly all Moselle River fish. Perhaps the most spectacular part of this exhibition area is the possibility to spot fish 'live' in the fish pass through 3 large windows.

The final exhibit area is located on top of the building. Here information is presented about current possibilities and future prospects for fish that migrate up and down the Moselle. From here visitors can take a look at the Koblenz lock and dam or the fish pass - or simply enjoy the view of the Moselle from the roof terrace. For meetings and seminars the 'Ausonius-Studio' on this level has room for up to 30 participants.

HOW DID IT WORK OUT?

The education center (without the fish pass) costs around 2.5 million Euro. This includes the feasibility study and the marketing concept. The Mosellum was financed by the Ministry of envi-

UNDERWATER

Exhibition area 'Underwater' of the Mosellum (© Eva-Maria Finsterbusch).



LOOKOUT

Exhibition area 'Lookout' with a wonderful view over the Moselle (© Eva-Maria Finsterbusch).



ronment, agriculture, food, viticulture and forestry of Rhineland-Palatinate. It has opened in October 2011, and the great number of visitors in this short period is proof that the education center will be as popular as we hoped.

LESSONS LEARNED

Most people do not know why fish must migrate and how the 'Canalization' of the Moselle changed the whole ecosystem. They have little understanding why an expensive fish pass has to be built, financed by the government. This makes it very important to clearly explain the reason for this huge project. This can only be done through a transparent process.

Salmon homecoming project

Authors: Peter Gough and Richard Dearing
Organisation: Environment Agency Wales
Country: Wales (United Kingdom)



INTRODUCTION

The salmon homecoming project in Wales, UK, was initiated to inform and motivate children about the exciting return of the Atlantic salmon to many previously polluted rivers. The salmon is widely recognised as an icon of environmental quality, and this was used to celebrate the newfound health of many rivers. Originally intended to celebrate the success of new fish passes built on the relict weirs of the industrial revolution, the programme is now used to inspire children about many aspects of the work of the Environment Agency and rivers trusts in the UK.

Starting in the communities of the coal-field rivers of South Wales, where the return from extinction of local populations of salmon and sea trout has occurred, the homecoming project welcomed salmon back to their home rivers after an absence of 200 years. Now, similar projects have been launched in many schools throughout south and mid Wales to teach the children about the important of environmental quality in the rivers.

Two issues continue to restrict the recovery of salmon - old weirs built hundreds of years ago with little thought for fish migration, and diffuse pollution from agriculture. Work is well underway on the obstructions, but diffuse pollution is a less well known problem.

Diffuse pollution is caused by the combined effect of many scattered sources and sometimes by poor land use management. Some sources are small but together they can have an impact

on the environment. Farming, especially arable farming, forestry, roads and private sewage treatment are just a few examples of the sources of diffuse pollution.

WHAT DID WE DO?

Fisheries and environmental liaison staff from the Environment Agency worked with local people to select six catchments in rural mid-Wales. These were used as part of a special project to help raise awareness amongst the children of their local rivers, and to educate local people about the work still needed to encourage the development of strong salmon stocks.

To help celebrate success Atlantic salmon eggs were taken into the classroom of 7 to 10 year old children where, in carefully designed units, the children were able to see them hatch and develop. With the help of Arts Connection, a local initiative, children looked after the salmon fry and learned about the local environment and the fascinating salmon lifecycle. Later the salmon were released into the local rivers.

HOW DID IT WORK OUT?

Dewi Morris and Sian Walters from a local organization 'Arts Connection' said "We are delighted to be working on such a unique initiative and are planning a number of community arts projects throughout the spring and summer. These will help celebrate the salmon and the importance of the river environment. The salmon egg project captured the imagination of the children we work with here at the community centre".

Artists from 'Arts Connection' worked with the school children to help them with drawings and paintings of salmon. The children's life sized fish were carried triumphantly through Llanfyllin and other villages in procession down to the banks of the river where the fish were to be released.

For the Environment Agency, which is committed to working with the local community and businesses to create a healthier environment, the project was a big success. A lot was learned by the children, and their parents, and the spirit

of co-operation engendered between Arts Connection, the local community and ourselves was motivating for everyone.

LESSONS LEARNED

The project helped the children to understand the life cycle of the Atlantic salmon, but also how local rivers should be cared-for and treasured for their role in sustaining the young fish. In 2011, several hundred young salmon were released by the children, and they are all looking forward to seeing them return to complete their cycle of life.

CHILDREN ON THEIR WAY TO RELEASE YOUNG SALMON



inland fisheries. Furthermore, this should include provision of environmental and ecological information and, critically for us, this should include information on fish ecology and fish migration. Furthermore, information should be provided on the problems that are faced today in their specific area and the range of measures available to resolve these problems.

There is growing experience that demonstrates how effective the provision of educational information for children can be. The use of fish within their local rivers as an indicator of local environmental quality can be a very powerful tool to motivate and enthuse children and, in addition, to encourage them to learn more. Increasingly this can form part of the formal educational syllabus in many countries. A good example is the Wild Fish Conservancy in Duvall near Seattle in the USA. This organisation is devoted to educating members of the community about wild fish, their habitats, and the ways that humans impact native fish stocks. It provides a variety of education resources and opportunities to increase awareness, stimulate thinking, and encourage informed decision making (www.wildfishconservancy.org).

Another example is the Amoskeag Dam educational fishway center located in Manchester, New Hampshire where visitors can view live salmon in underwater viewing windows. These windows look into a 54-step fish ladder that allows migrating fish to swim around the Amoskeag Dam and continue on their way up the river to reproduce. In addition visitors can play a salmon migration game and explore the generation of electricity (www.amoskeagfishways.org).

Children should be involved directly through provision of information and perhaps by guiding them along rivers. Their enthusiasm is a highly effective mechanism to engage their parents in achieving improved ownership and care for their local environment. Seeing healthy fish is a more evocative method of education for children than simply providing lists of facts on water qual-

ity standards! To illustrate recognition of this, children's games for salmon and eel have been recently developed in the USA and in The Netherlands (www.elyeel.eu).

TIPS

- Identify or, if necessary, create a local or even a national group to assist in the delivery of fish pass projects;
- Become familiar with regional working groups on fish migration topics, and larger international fora, e.g. the World Fish Migration Network on LinkedIn;
- Learn from publications (scientific and popular) and newsletters on fish migration issues and consider producing your own;
- Exchange information via the internet, and look for internet orientated databases of issues and solutions;
- If you want to get people interested you have to involve children. When you engage children, you engage parents.

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Erdenbat with tagged Taimen (*Hucho taimen*)
from the Mongolian river Eg-Uur after surgery
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This guidance is sponsored by:

